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CRITICALITY ANALYSES FOR THE SPENT AND NEW FUEL STORAGE RACKS

D.C. Cook Units 1 and 2 Criticality Evaluation Using Framatome Fuel

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by

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Executive Summary

A reactivity equivalence analysis using Framatome ANP fuel was performed for the Spent Fuel Storage Racks (SFSR) and New Fuel Storage Vault (NFSV) for D.C. Cook Units 1 and 2. This analysis compares the proposed Framatome HTP 15x15 to be used in D.C. Cook Unit 1 and the Advanced Mk-BW 17x17 design to be used in D.C. Cook Unit 2 with the current Westinghouse design basis assembly in the context of the SFSR and NFSV. Both D. C. Cook Units 1 and 2 share a common SFSR and NFSV.

The evaluation indicated that the Framatome Advanced Mk-BW 17x17 is slightly more reactive than the Westinghouse design basis assembly in the SFSR due to the heavier assembly loading and larger diameter fuel pellet. For fully flooded conditions in the NFSV the Westinghouse OFA 17x17 design remained limiting and for interspersed moderator conditions in the NFSV the Framatome Advanced Mk-BW 17x17 was slightly more reactive.

All K-maximum (maximum K-effective) values remained less than 0.95 for the SFSR and K-maximum was less than 0.95 for fully flooded conditions with 100% dense water in the NFSV. For interspersed moderator conditions in the NFSV K-maximum was achieved at 3% water density and is less than the criticality limit for these conditions of 0.98. There were no changes to the Technical Specification enrichment versus burnup curves used with the SFSR and no change to the enrichment limits and ranges used with the NFSV. Since Framatome fuel uses Gadolinia for reactivity control rather than boron coated pellets in Westinghouse assembly designs, there is a Technical Specification amendment that addresses the use of Gadolinia in the NFSV for higher enriched fuel.

1.0 Introduction

American Electric Power (AEP) has assigned a fuel contract to Framatome ANP for D.C. Cook Units 1 and 2. Unit 1 currently uses a Westinghouse 15x15 fuel assembly design with 20 guide tubes and 1 instrument tube and Unit 2 uses a Westinghouse 17x17 design with 24 guide tubes and 1 instrument tube. Other assembly types have also been used at these units but those previously mentioned are most reactive and are used as the design basis for the Spent Fuel Storage Racks (SFSR) and New Fuel Storage Vault (NFSV). Framatome will provide the Framatome Mk-B HTP 15x15 design for Unit 1 and the Advanced Mk-BW 17x17 design for Unit 2. The Framatome assembly designs are very similar to the Westinghouse designs except for minor differences in assembly loading, pellet diameter, and use of Gadolinia fuel rods. This report demonstrates that the reactivity differences, calculated in the context of the SFSR and NFSR are minor, and do not result in violation of any criticality limits for fuel storage.

2.0 Analytical Methods

The analytical methods are discussed in Section 2.0. It briefly describes computer programs, licensing requirements, and computer models used for this analysis. This analysis is based on a reactivity comparison using nominal dimensions between design basis Westinghouse fuel and proposed Framatome fuel for Units 1 and 2. Since small reactivity deltas are computed between different assembly types it is not necessary to evaluate the full range of accidents, off-center fuel placement, tolerances, biases, and uncertainties. Rather, reactivity penalties are computed and added to the appropriate design basis k-maximum (which already includes penalties for accidents and tolerances) to demonstrate the racks remain critically safe for the minor assembly design differences involved. For the SFSR burnup credit was utilized in the previous criticality evaluation and credit for Integral Fuel Burnable Absorber (IFBA) was utilized for enrichments above a maximum enrichment of 4.55 wt% U^{235} for the NFSV. The differences between Framatome fuel and previous Westinghouse design basis fuel do not compromise or modify existing reactivity controls. The SFSRs at D.C. Cook Units 1 and 2 use Boral absorber plates and no credit for soluble boron is required to address issues such as Boraflex dissolution. Therefore, there is typically 20 $\%\Delta\rho$ conservatism available from the soluble boron that is not credited in these calculations.

2.1 Computer Programs and Standards

The reactivity deltas for the various storage rack configurations were determined with MCNP-4B (Monte Carlo) [1] and CASMO-3 (deterministic transport code) [2]. Both MCNP-4B and CASMO-3 have been routinely used in industry for criticality evaluations. The basic cross-sections used for MCNP-4B calculations is a smooth or continuous cross-section set that comes with MCNP-4B. CASMO-3 was used to determine some small reactivity effects and is desired because of its deterministic solution. Brief descriptions of these computer codes follow.

1. The MCNP-4B program treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and

some special fourth-degree surfaces. Point-wise continuous-energy cross-section data are used, although multigroup data may also be used. Fixed-source adjoint calculations may be made with the multigroup data option. For neutrons, all reactions in a particular cross-section evaluation are accounted for. Both free gas and S(alpha, beta) thermal treatments are used. Criticality sources as well as fixed and surface sources are available. For photons, the code takes account of incoherent and coherent scattering with and without electron binding effects, the possibility of florescent emission following photoelectric absorption, and absorption in pair production with local emission of annihilation radiation. A very general source and tally structure is available. The tallies have extensive statistical analysis of convergence. Rapid convergence is enabled by a wide variety of variance reduction methods. Energy ranges are 0-60 Mev for neutrons (data generally only available up to 20 Mev) and 1 kev – 1 Gev for photons and electrons.

2. CASMO-3 is a multigroup two-dimensional transport theory program for burnup calculations on LWR assemblies or simple pin geometries. The code handles a geometry consisting of cylindrical fuel rods of varying composition in a square pitch array. It is typically used by Framatome ANP to generate cross-sections for the fuel cycle codes. Typical fuel storage rack geometries can also be handled. The program is used for reactivity studies and to provide depletion data for burnup credit.

   The neutron data is provided from ENDF/B-4 although some data comes from other sources. Microscopic cross-sections are tabulated in 70 energy groups. The group structure was taken from the WIMS code with the addition that a boundary was put at 1.855 ev. The group structure consists of 14 fast groups, 13 resonance groups, and 43 thermal groups (below 4 ev which is the cut off for upscattering). Both P0 and P1 scattering cross-sections are considered when using the fundamental mode calculation. CASMO-3 also uses a 40 group library (used in this analysis) which is a condensation from the 70 group library using typical LWR spectra for the various nuclides. The 40 group library is recommended for both BWR and PWR analysis.

2.2 Analytical Requirements and Assumptions

ANSI/ANS-57.2 Section 6.4.2.1.3 [3] requires that consideration be given to credible abnormal occurrences. The following occurrences were considered in the 1990 Holtec [4] analysis of the SFSR and the 1996 Westinghouse [5] analysis of the NFSV when applicable.

1. The tipping and falling of a spent fuel assembly or consolidation canister is considered to be a secondary sequential accident; the deboration of the pool is the most severe accident.

2. Tipping of the storage rack or horizontal rack movement.

3. Misplacement of a fresh assembly with the rack.

4. Misplacement of a fuel assembly outside but adjacent to the rack.

5. A stuck fuel assembly with a crane providing an uplifting force.

6. The off-center tolerance analysis evaluates the horizontal movement of the assembly within the rack.

7. The "straight deep drop" or drop through accident.

8. Significant objects falling into the pool.

9. Threats to the storage racks from missiles generated by failure of rotating machinery or from natural phenomena are covered by the facility SAR, and are not dependent on fuel assembly design or enrichment.

The design basis for preventing criticality outside the reactor is that, including uncertainties, there is a 95 percent probability at a 95 percent confidence level that the effective neutron multiplication factor, k-effective, for a rack when flooded with full density water will be less than 0.95 as recommended by ANSI/ANS 57.3-1983 [8]. For the SFSR flooded with 100% dense moderator and no credit for soluble boron k-effective shall be maintained less than 0.95 (NUREG 0800; Reference [9], Section 9.1.2). Furthermore, k-effective of the NFSV under optimum moderation conditions shall be less than 0.98 and under fully flooded conditions less than 0.95 (Reference [9], Section 9.1.1).

NRC Regulatory Issue Summary 2001-12 [6] entitled "Non-conservatism In pressurized Water Reactor Spent Fuel Storage Pool Reactivity Equivalencing Calculations," dated May 18, 2001 indicates that reactivity equivalence calculations need to be performed in the context of the racks to correctly compute reactivity effects. All final reactivity penalties were calculated in the context of the SFSR or the NFSV are in compliance with this requirement. Application of a small reactivity penalty does not invalidate previous accident evaluations performed by Holtec [4] and Westinghouse [5].

Analysis assumptions include:

1. The tolerances on Framatome ANP assembly designs are similar to or the same as those of other vendor assemblies such that detailed additional tolerance studies are not required for computing small reactivity deltas between assemblies. Additionally, the Holtec [4] tolerance reactivity penalties are inherent in the computation of K-maximum in Section 5.0. The fuel enrichment tolerance is considered for the SFSR. The K-maximum calculations performed by Holtec [4] and Westinghouse [5] considered a 0.05 wt% U^{235} enrichment tolerance. The reactivity delta calculations between different fuel types for the SFSR were performed using the minimum required B^{10} areal density of 0.030 g-B^{10}/cm^2. Nominal Boral plate dimensions were utilized. All other assembly and rack dimensions used are nominal dimensions and are suitable for computing a reactivity delta between similar assembly types.

2. Because the reactivity differences are shown to be small between assemblies in this evaluation and in all cases the accidents evaluated in References [4] and [5] are not limiting compared to deboration of the pool, it was not necessary to reevaluate accident calculations.

2.3 Computational Models and Methods

Section 2.3 describes the basic models used to evaluate the SFSR and the NFSV. Results using these models are described in later sections.

2.3.1 SFSR Assembly Layout

The SFSR can contain fresh and burned fuel. Each rack has three regions (Regions 1, 2, and 3). A representation of a typical 12x14 array of storage cells is presented in Figure 2.3.1-1. Region 1 is designed to accommodate new fuel with a nominal enrichment of 4.95 wt% U^{235}, or spent fuel regardless of the discharge burnup. Region 2 is designed to accommodate fuel with a nominal enrichment up to 4.95 wt% U^{235} burned to at least 50 GWd/mtU, or fuel with other enrichment burnup combinations of equal reactivity. Region 3 is designed to accommodate fuel with a nominal enrichment up to 4.95 wt% U^{235} burned to at least 38 GWd/mtU, or fuel with other enrichment burnup combinations of equal reactivity. The equivalent reactivity criteria for Region 2 and 3 are defined by the following equations [4].

<u>Region 2 Storage</u>

Minimum Assembly Average Burnup in Mwd/MtU =

$$-22670 + 22220E - 2260E^2 + 149E^3$$

<u>Region 3 Storage</u>

Minimum Assembly Average Burnup in Mwd/MtU =

$$-26745 + 18746E - 1631E^2 + 98.4E^3$$

where

E = initial nominal peak fuel enrichment (without the enrichment tolerance) in wt% U^{235}.

Examining Figure 2.3.1-1 reveals that certain combinations of fuel within the rack are more reactive than others as far as modeling in CASMO-3 2x2 calculations are concerned. Since CASMO-3 calculations were run with a full assembly 2x2 array with periodic boundary conditions it is possible to evaluate reactivity deltas in different parts of the rack assuming cell types are infinite in all three spatial directions.

In addition to the loading of Region 3 fuel in the interior of the D.C. Cook Unit 1 and 2 SFSR, Technical Specifications [4] allow an interim loading of certain racks where the

Region 3 assemblies are replaced by a checkerboard of fresh fuel and water holes (no assemblies in alternating positions). Considering the normal loading of the racks with three regions and the interim loading pattern (for use during an emergency offload), potential limiting combinations possible for analysis with CASMO-3 are shown in Figure 2.3.1-2. Pattern 1 and Pattern 3 are most reactive. Pattern 2 is less reactive than Pattern 3 since Region 2 fuel is more highly burned than Region 1 fuel at the same enrichment. Therefore, Pattern 2 was not analyzed further. Pattern 4 could not be analyzed directly with CASMO-3 because some fuel must be put in the alternating regions that are water filled or CASMO-3 will not run. Therefore, water filled regions in Pattern 4 had Region 2 assemblies burned to 50 GWd/mtU substituted in their place and creates a more reactive configuration than allowed by the design. Therefore, Patterns 1, 3, and 4 were evaluated with Westinghouse fuel and subsequently with Framatome fuel to determine reactivity deltas. Note, that it is understood that the overall reactivity of a rack will be defined by the most reactive region in the rack with all respective patterns included. However, the rack can be analyzed piecemeal to determine which regions are most sensitive to different fuel types to define a reactivity delta. The resulting reactivity penalties are therefore bounding for application to the entire rack since CASMO-3 assumes an infinite array of the applicable cell pattern. Also, note that Pattern 1 is located on the edge of the rack only and by definition has greater radial leakage than other pattern types. Pattern 1 was found to have the greatest reactivity delta between assembly types and is likely conservative when considering that the effects of peripheral rack leakage were not considered.

Rack-to-rack spacing has been analyzed in the original Holtec [4] analysis and assures a minimum 1.75" spacing between modules [4]. This 1.75" spacing is far greater than that between assemblies within a rack and the rack-to-rack gap functions as a flux trap in the presence of Boral plates. Therefore, penalties associated with Framatome fuel in adjacent racks are not limiting because the peripheral rack regions are subject to a flux trap effect and there is less spectral coupling between assemblies in the different racks. The reactivity penalties between assembly types previously discussed included peripheral regions and were computed assuming an infinite array of cells and are therefore very conservative.

Figure 2.3.1-1 Typical 12x14 Assembly Rack

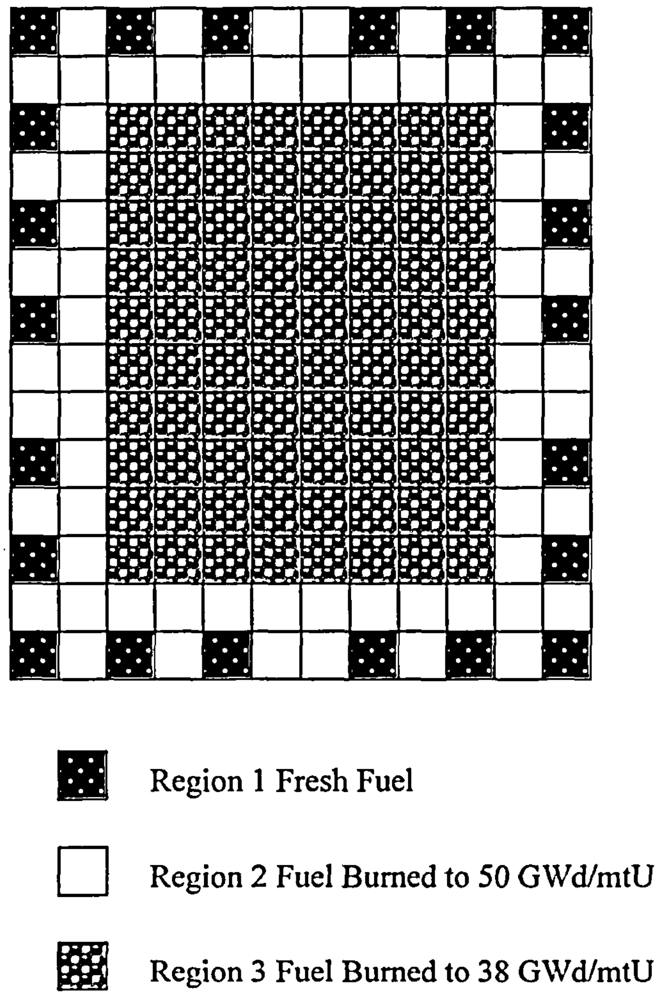
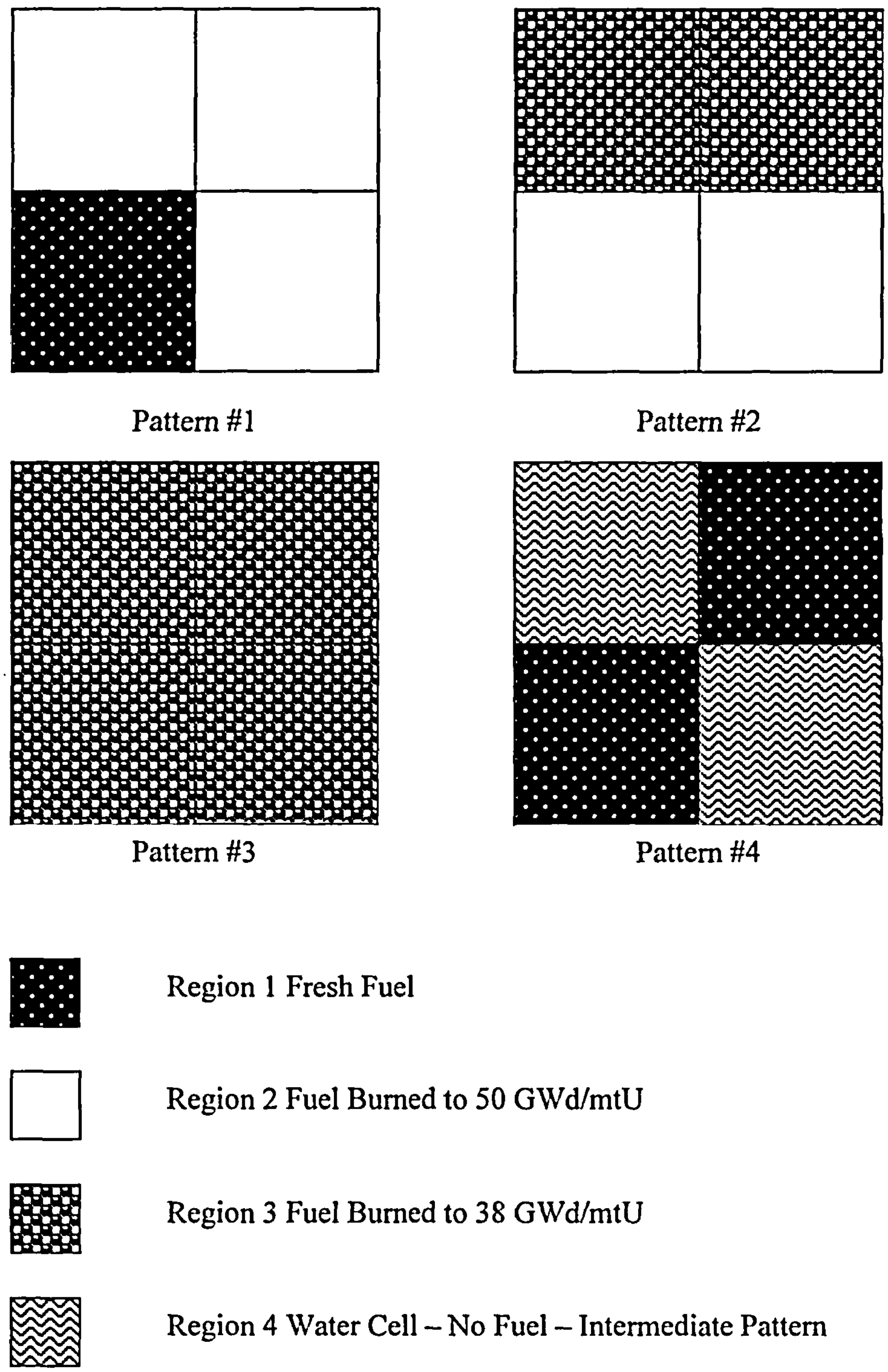


Figure 2.3.1-2 Sub-Regions of a Typical SFSR Evaluated With CASMO-3



2.3.2 SFSR Detailed Model

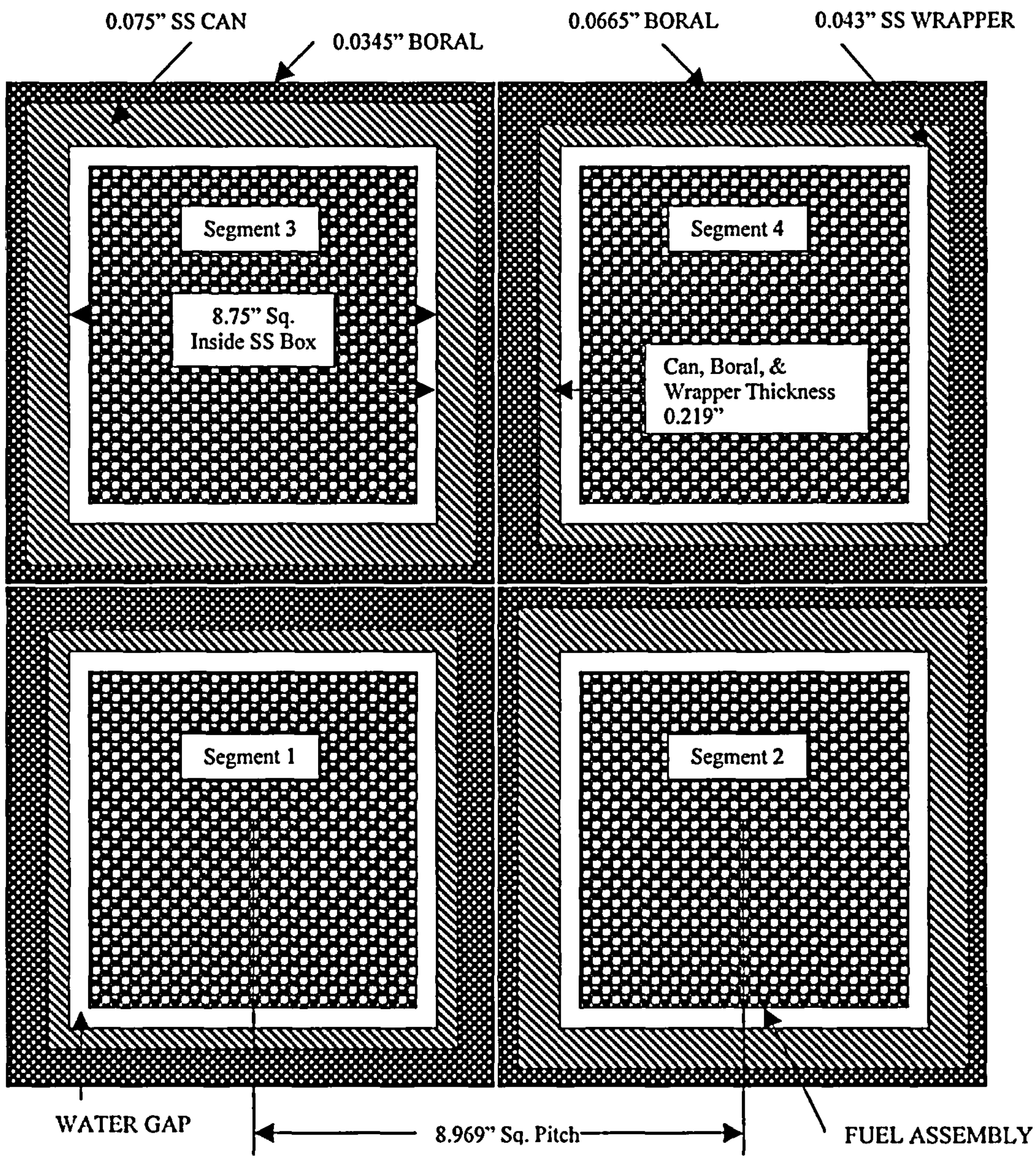
Reference [4] Attachment 4, page 4-31 provides a description of the SFSR cross-section. The model is a basic stainless-steel can with 7.50 inch wide, 0.101 inch thick Boral plates attached on four sides of the steel can. The Boral plates have been extended over the full width of the cell as a modeling simplification in Figure 2.3.2-1. This simplification added more absorber to the cell, however the amount is small and it is important not to adjust the areal density of the B^{10} loading in the Boral plate for transverse (perpendicular to the Boral plate) neutron interactions between assemblies. The CASMO-3 "FST" option allows the corner regions to be modeled as separate materials (water in this case) and this modification is not shown in Figure 2.3.2-1-1 but was incorporated into CASMO-3.

The Boral plates are covered with a 0.035 inch stainless-steel sheath. This sheath was extended in the model to make a square as shown in Figure 2.3.2-1. Note that the combined thickness of the can, Boral plate and wrapper has a nominal thickness of 0.219 inches and is 0.008 inches larger than the sum of the individual thicknesses. This is due to air or water that can occupy regions between the different materials and allows for tolerances on the Boral plate and other components. This 0.008 inch difference was modeled as stainless-steel and the wrapper thickness was increased from 0.035 inches to 0.043 inches to conserve the wall thickness dimension and not place too much water between the assembly and the wrapper. The reactivity delta calculations between different fuel types for the SFSR were performed using the minimum required B^{10} areal density of 0.030 g-B^{10}/cm^2. Nominal Boral plate dimensions were utilized. All other assembly and rack dimensions used are nominal dimensions and are suitable for computing a reactivity delta between similar assembly types.

Stainless-steel cans are located every other cell and are 0.075 inches thick. The center-to-center assembly pitch is 8.969 inches square. The inside dimension of the steel can is 8.75 inches square. Note that there is no water gap between cells as shown in Figure 2.3.2-1. With the previously described dimensions the distance from the center of the assembly to either the can edge or the wrapper edge is 4.375 inches. The water gap thickness will vary depending on the dimensions of the assembly evaluated.

Note that nominal dimensions are used throughout this analysis because it is only necessary to calculate the difference in reactivity between two assembly types in the context of the SFSR. Therefore, tolerance calculations are not required for a reactivity delta calculation and tolerances have been considered in the original Reference [4], Attachment 4 criticality analysis. Periodic boundary conditions are used in the CASMO-3 model to ensure proper repetition of assembly cell types.

Figure 2.3.2-1 SFSR Generalized Model (2x2 Array)
(Not to Scale)



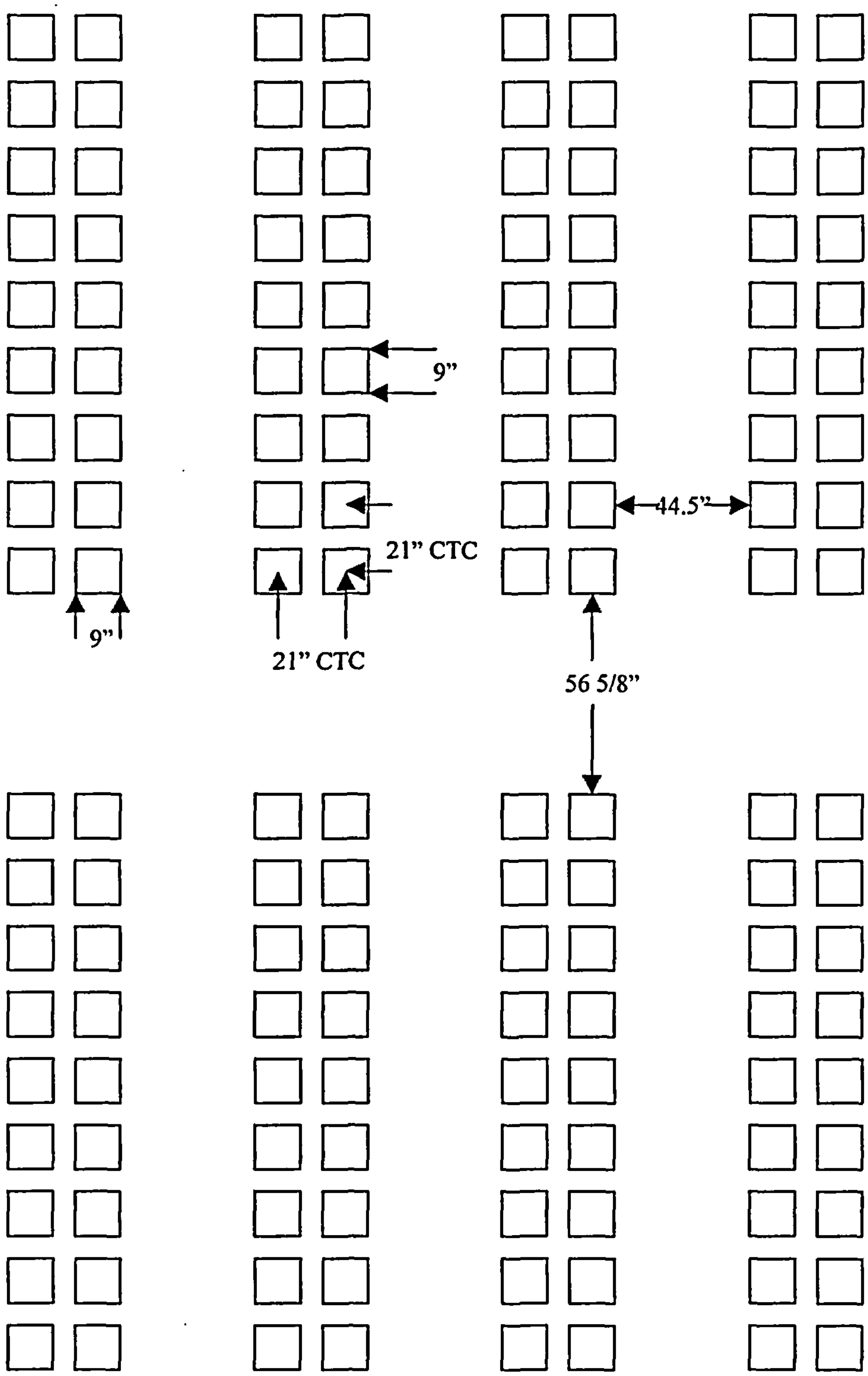
In the actual model there are small rectangular regions of water in the corner regions of each segment that displace Boral, however, these could not be drawn easily in the above figure. Note that the small lines between cells are not water gaps but are there to distinguish between cell types.

2.3.3 NFSV Assembly Layout

The NFSV layout consists of eight racks laid out in a 2x4 array. For interspersed moderator calculations using MCNP-4B, the array of racks are assumed infinitely reflected in all X and Y-radial directions. The 144" finite height of the active fuel is modeled in the Z-directions. The active fuel has 1000 cm (393.7 inches) of moderator above and below the active fuel column. This is an acceptable axial model because the center region of the NFSV rack has no assembly guides and there is no intervening structural material between assemblies in the rack making the axial center the most reactive axial region for fresh fuel. The upper and lower guides consist of an open structural cage. No intermediate spacer grids are modeled on the assemblies. Each rack consists of 18 assemblies in a 2x9 array on 21 inch centers. Other relevant dimensions are shown in Figure 2.3.3-1. Modeling of concrete walls, floors, and ceilings are not necessary for the computation of a small reactivity delta due to assembly types.

For fully flooded cases with 100% dense moderator a single assembly surrounded by water is modeled in MCNP-4B. The model can be limited to a single assembly since there is a minimum of at least 12" of water between adjacent assemblies in the NFSV. The 12" of water decouples the neutron spectrum between assemblies. Therefore, one assembly will not "see" the presence of another assembly in the NFSV with 100% dense moderator conditions.

Figure 2.3.3-1 NFSV Rack Layout



2.3.4 Fuel Assembly Descriptions

Assembly dimensions are provided in this section to allow analysis of the SFSR for the limiting assembly type. Reference [4] Attachment 4 mentions that the Westinghouse Standard 15x15 assembly is most reactive and is the design basis assembly for the SFSR criticality analysis. To ensure this is the case the Westinghouse OFA 17x17 assembly is also evaluated. Since D.C. Cook Units 1 and 2 share the same NFSV and SFSR both Westinghouse 15x15 and 17x17 designs can be present. Framatome assembly substitutes for these will be evaluated against these designs. Note that Zr-4, ZIRLO ™, and M5 ™ cladding are all neutronically similar for criticality calculations. For criticality calculations they are modeled as Zirconium. The upper guide tube dimension is used in all calculations.

Table 2.3.4-1 Westinghouse OFA 17x17 Assembly Dimensions

Description	Dimension/Parameter
Assembly ID	Westinghouse OFA
Assembly Type	17x17
Fuel Rods Per Assembly	264
Guide Tubes per Assembly	24
Instrument Tubes per Assembly	1
In-Core Assembly Pitch (cold conditions), in.	8.466
Fuel Rod Pitch (nom), in.	0.496
Pellet Diameter, in.	0.3088
Cladding OD, (nom), in.	0.360
Cladding ID, (nom), in.	0.315
Active Fuel Stack Length, in.	144.0
Upper Guide Tube OD, (nom), in.	0.474
Upper Guide Tube ID, (nom), in.	0.442
Lower Guide Tube OD, (nom), in.	0.429
Lower Guide Tube ID, (nom), in	0.397
Instrument Tube OD, (nom), in.	0.474
Instrument Tube ID, (nom), in.	0.442
Cladding Material	Zircaloy-4
GT Material	Zircaloy-4
IT Material	Zircaloy-4
Intermediate Grid Material	Zircaloy-4
Nom. Eff. Fuel Assm Loading, KgU	423.2

Table 2.3.4-2 Westinghouse 15x15 Assembly Dimensions

Description	Dimension/Parameter
Assembly ID	Westinghouse
Assembly Type	15x15
Fuel Rods Per Assembly	204
Guide Tubes per Assembly	20
Instrument Tubes per Assembly	1
In-Core Assembly Pitch (cold conditions), in.	8.466
Fuel Rod Pitch (nom), in.	0.5630
Pellet Diameter, in.	0.3659
Cladding OD, (nom), in.	0.422
Cladding ID, (nom), in.	0.3734
Active Fuel Stack Length, in.	144
Upper Guide Tube OD, (nom), in.	0.533
Upper Guide Tube ID, (nom), in.	0.499
Lower Guide Tube OD, (nom), in.	Unknown
Lower Guide Tube ID, (nom), in	Unknown
Instrument Tube OD, (nom), in.	0.533
Instrument Tube ID, (nom), in.	0.499
Cladding Material	Zircaloy-4
GT Material	Zircaloy-4
IT Material	Zircaloy-4
Intermediate Grid Material	Zircaloy-4
Nom. Eff. Fuel Assm Loading, KgU	463.84

Table 2.3.4-3 Framatome ANP 15x15 HTP Assembly Dimensions

Description	Dimension/Parameter
Assembly ID	Framatome HTP
Assembly Type	15x15
Fuel Rods Per Assembly	204
Guide Tubes per Assembly	20
Instrument Tubes per Assembly	1
In-Core Assembly Pitch (cold conditions), in.	8.466
Fuel Rod Pitch (nom), in.	0.5630
Pellet Diameter, in.	0.367
Cladding OD, (nom), in.	0.424
Cladding ID, (nom), in.	0.374
Active Fuel Stack Length, in.	144
Upper Guide Tube OD, (nom), in.	0.544
Upper Guide Tube ID, (nom), in.	0.511
Lower Guide Tube OD, (nom), in.	0.489
Lower Guide Tube ID, (nom), in	0.455
Instrument Tube OD, (nom), in.	0.544
Instrument Tube ID, (nom), in.	0.511
Cladding Material	M5
GT Material	Zircaloy-4
IT Material	Zircaloy-4
Intermediate Grid Material	Zircaloy-4
Nom. Eff Fuel Assm Loading, KgU	467

Table 2.3.4-4 Framatome ANP Built Advanced Mark-BW 17x17 Assembly Dimensions

Description	Dimension/Parameter
Assembly ID	Advanced Mk-BW
Assembly Type	17x17
Fuel Rods Per Assembly	264
Guide Tubes per Assembly	24
Instrument Tubes per Assembly	1
In-Core Assembly Pitch (cold conditions), in.	8.466
Fuel Rod Pitch (nom), in.	0.496
Pellet Diameter, in.	0.3225
Cladding OD, (nom), in.	0.374
Cladding ID, (nom), in.	0.329
Active Fuel Stack Length, in.	144
Upper Guide Tube OD, (nom), in.	0.482
Upper Guide Tube ID, (nom), in.	0.450
Lower Guide Tube OD, (nom), in.	0.429
Lower Guide Tube ID, (nom), in	0.397
Instrument Tube OD, (nom), in.	0.482
Instrument Tube ID, (nom), in.	0.450
Cladding Material	M5
GT Material	M5
IT Material	M5
Intermediate Grid Material	M5
Nom. Effective Fuel Assm Loading, KgU	466

2.4 Analytical Model Conservatisms

This section lists the major conservatisms associated with this evaluation.

1) Regions 1, 2, and 3 of the SFSR are evaluated assuming no radial or axial leakage. This will amplify the reactivity differences between fuel assembly types.

2) No credit is taken for the presence of poison clusters since these may be removed by mechanical means. A considerable number of these components are currently in the pool and provide a negative reactivity effect merely by water displacement in the assembly.

3) No credit was taken for xenon, peak samarium, and no credit was taken for the decay of Pu^{241} and other isotopes.

4) No credit is taken for intermediate spacer grids or end fittings.

5) It was assumed that every Westinghouse (non-Framatome) assembly had a full length equivalent BPRA at 3.0 wt% B_4C over the entire length of the active fuel region (including end regions) for the maximum burnup defined by the limiting end fuel segments. This was done because some very early component designs in Westinghouse fuel have had longer active absorber lengths. Furthermore, the spectral hardening reactivity penalty was shown to reach a maximum at approximately 65 GWd/mtU after the BPRA is removed for the range of the applicable inserted BPRA burnup history. The limiting 9" end fuel regions would have much less than 65 GWd/mtU and a conservative penalty based on the end segment burned to 40 GWd/mtU was applied. For the Westinghouse Standard 15x15 fuel the penalty was 0.728 %$\Delta\rho$ and for the Westinghouse 17x17 designs it was 0.688 %$\Delta\rho$. No penalty was defined for Framatome fuel since removable absorber components are not located in the most reactive limiting end regions and are not longer than 126".

6) The entire SFSR is assumed to have assemblies with burnups on the burnup versus enrichment curve.

7) No credit is taken for decay of burned fuel with an associated reduction in fissile products and buildup of fission product poisons.

8) All fuel is assumed to be at the maximum fuel enrichment tolerance.

9) All poison plates in the SFSR have the minimum B^{10} areal density.

The SFSR considers the previous conservatisms through the current analysis basis performed by Holtec [4] and the analyses performed by this evaluation. Because of the above conservatisms and the highly detailed criticality evaluation, the target K-maximum of 0.9480 is reasonable and larger values of retained margin are not needed. In addition to the above conservatisms, there still remains the very large credit (approximately 20% $\Delta\rho$) of soluble boron in the pool water.

The NFSV racks are evaluated with the following conservatisms.

1) All fuel includes the maximum enrichment tolerance.

2) No rack structural material is credited.

3) No intermediate spacer grids or end fittings are modeled.

4) The racks are assumed infinite in the radial X and Y-directions and finite in the axial or Z-direction.

5) The NFSV racks are assumed flooded by unborated water.

6) No removable control components are credited in the analysis.

The NFSV rack considers the previous conservatisms through the current analysis basis performed by Westinghouse [5] and the analyses performed by this evaluation. Because of the above conservatisms and the highly detailed criticality evaluation, the target K-maximum of 0.9495 is reasonable and larger values of retained margin are not needed.

2.5 Tolerances, Penalties, Uncertainties, and Bias

This section describes tolerances, penalties, uncertainties, and biases utilized in the analysis of the SFSR and NFSV. This section is divided into sub-sections that discuss each separately. The sub-section entitled "Fuel Enrichment and Density Tolerances" discusses two fuel assembly manufacturing tolerances that are considered in the current record of analysis performed by Holtec [4] for the SFSR and by Westinghouse [5] for the NFSV. These two tolerances are the most significant assembly tolerances for reactivity calculations and have been previously accepted by the NRC as the design basis for the current Holtec [4] rack analysis. The rest of the tolerance penalties pertain to the rack design and are discussed in the sub-section entitled "Rack Related Tolerances." Reactivity penalties associated with assembly burnup and axial burnup uncertainty are discussed in the sub-section entitled "Burnup Related Reactivity Penalties." Additionally, a bias with its associated uncertainty is discussed in a sub-section entitled "KENO-Va Model Bias and Uncertainty." Each of the tolerances, penalties, uncertainties, and bias is discussed below.

2.5.1 Method Discussion of Tolerances, Biases, and Uncertainties

Criticality analysis methodology involves the computation of a base k-effective for the SFSR or the NFSV using a code such as KENO-Va. As an example, a KENO-Va code bias plus uncertainty on the bias is determined based on comparison to measured critical fuel configurations (i.e., critical benchmarks) and is then applied to the base absolute k-effective. This was done in the original Holtec [4] and Westinghouse [5] analyses. The bias is not assembly specific but can be dependent on the type of fuel involved (UO_2 versus MOX for example) or on intervening absorber materials. Typically, a bias is determined using critical benchmark calculations that are appropriate for the type of rack and fuel being analyzed. There is an uncertainty component on the bias that is the result of both measured and calculated uncertainties associated with the critical configurations analyzed. The uncertainty on the bias may be statistically combined with other uncertainties as it is independent.

Reactivity penalties due to fuel and rack structural tolerances and other uncertainties are determined by difference calculations and applied to the base k-effective plus bias. Deterministic codes like, but not limited to, CASMO-3 are typically used for these applications because they allow depletion of fuel and because the associated code bias cancels when evaluating similar fuel types or conditions. When Monte-Carlo codes are used in difference calculations an answer is provided with an associated uncertainty and the uncertainty on the difference calculation must be considered at the 95/95 confidence level.

In the case of the D.C. Cook storage racks there are slightly different biases utilized in the SFSR and the NFSV. This occurs for several reasons. Westinghouse [5] used KENO-IV to evaluate the NFSV and Holtec [4] used KENO-Va for the SFSR. The following items contribute to the slightly different biases observed between the SFSR and the NFSV:

1. The use of KENO-Va versus KENO-IV.

2. There are several different cross-section sets that can be used with different KENO versions including the Cable 123 group library, 16 group Hansen Roach, as well as 27 and 44 group SCALE libraries, and others. All of which would contribute to slightly different biases.
3. The choice of critical benchmark configurations used to establish the bias.
4. The numerical technique used to obtain the bias.

Concerning Code Usage

A memorandum was issued by Laurence Kopp at the NRC to Timothy Collins/ Reactor Systems Division entitled, "Guidance on the Regulatory Requirements For Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," dated August 19, 1998. In this document the following is stated:

"Acceptable computer codes include but are not necessarily limited to, the following:

CASMO- a multigroup transport theory code in two dimensions.

NITAWL-KENO5a – a multigroup transport theory code in three dimensions, using the Monte-Carlo technique

PHOENIX-P – a multigroup transport theory code in two dimensions, using descrite ordinates

MONK6B – a multigroup transport theory code in three dimensions, using the Monte Carlo technique

DOT – a multigroup transport theory code in two dimensions, using descrete ordinates."

It is noted that Framatome is utilizing CASMO and is utilizing the MCNP-4B code that is a Monte-Carlo code similar to KENO5a and MONK6B. In addition, MCNP is directly mentioned in a NUREG as a suitable tool for dry storage criticality calculations

2.5.2 SFSR Discussion

In this sub-section fuel enrichment and density tolerances are discussed. This is followed by rack tolerances, burnup uncertainty, axial burnup effect, the KENO-Va Bias and the uncertainty on the bias, and the statistical combination of penalties. Each is discussed it turn.

Fuel Enrichment and Density Tolerances

a) Fuel Enrichment Tolerance

A review of the Holtec [4] document indicates that a +/-0.05 wt% U^{235} tolerance on enrichment was assumed and assigned a penalty of +/-0.0034 Δk (see pages 4-17, 4-23, and 4-24 of the 1991 Holtec [4] analysis). Framatome assumes the same fuel manufacturing enrichment tolerance. A tolerance penalty that reflects a +/-0.05 wt% U^{235}

fuel enrichment manufacturing variation was computed by Holtec [4] using CASMO-3 for burned fuel in the SFSR. The calculated Holtec [4] penalty was added to the KENO-Va design base k-effective. This enrichment tolerance calculated by Holtec [4] was applied to both the normal storage of fuel in the SFSR and also to the interim storage fuel configuration in the SFSR (fresh fuel checker boarded with empty cans or water holes). The enrichment tolerance is not sensitive to assembly type and this is suggested by Holtec [4] applying the same enrichment tolerance determined for a normal SFSR loading to the interim loading configuration. Therefore, the same reactivity penalty computed by Holtec [4] for Westinghouse fuel is applicable to Framatome fuel.

b) Fuel Pellet Density Tolerance

A review of the Holtec [4] document indicates that the nominal pellet density is 10.29 +/-0.20 g/cc UO_2. This leads to a tolerance on fuel density of +/-1.944% resulting in a penalty of +/-0.0035 Δk. Framatome specifies a tighter tolerance on fuel of +/-1.5%. Therefore, the use of the Holtec [4] calculated penalty of +/-0.0035 Δk is conservative for use with Framatome fuel. This tolerance, computed by Holtec [4] using CASMO-3 in the normal storage fuel configuration of the SFSR, was then added to the KENO-Va design base k-effective. The pellet density tolerance is not sensitive to assembly type and this is suggested by Holtec [4] applying the same pellet density tolerance determined for normal SFSR loading to the interim loading configuration. Therefore, the same reactivity penalty computed by Holtec [4] for Westinghouse fuel is applicable to Framatome fuel.

Rack Related Tolerances

a) Rack Manufacturing Tolerances

Table 4.1 and 4.2 in the Holtec [4] document lists an item called "Manufacturing Tolerances" and has a value of +/-0.0064 Δk. Table 4.5 on page 4-26 of the Holtec [4] document indicates how this uncertainty was determined. It consists of four items:

1.	Boron-10 loading (+/-0.00045 g/cm^2)	+/-0.0061 Δk	KENO-Va
2.	Boral Width (+/- 1/16")	+/-0.0009 Δk	CASMO-3
3.	Lattice Spacing (+/-0.04")	+/-0.0015 Δk	CASMO-3
4.	Stainless (Can) thickness (+/-0.005")	+/-0.0009 Δk	CASMO-3

The four previous uncertainties are statistically combined by Holtec [4] using the square root of the sum of the squares method and yield a rack manufacturing tolerance of +/-0.0064 Δk. Since the above four penalties pertain to the rack structure they are not dependent on the neutron source (fuel assembly). Similar and equivalent reactivity penalties would be calculated for any number of assembly types. Additionally, the minor reactivity difference represented by the rack structure is not necessarily maximized by using the most reactive assembly design. However, the present application is adequately conservative because these penalties are applied to every can in the entire rack. Additionally, these penalties are applied by Holtec [4] to the interim rack design which has an entirely different fuel loading scheme than that used to develop the penalties. There are a total of 10 different assembly designs currently stored by AEP. Therefore, application to two additional Framatome designs of like kind is also applicable.

b) Rack-to-Rack Water Gap Tolerance

A slightly larger water gap exists between racks in the spent fuel pool. The Holtec [4] document indicates the minimum rack-to-rack spacing is 1.75" with a ¼" spacing tolerance. Holtec [4] performed KENO-Va calculations and determined a tolerance penalty of +/-0.0045 Δk. Note that since a Monte-Carlo code was used for this calculation, most of the penalty is statistical uncertainty associated with each component of the difference calculation which has been lumped into the penalty. Framatome experience with flux traps of this magnitude in the presence of Boral plates yield a reactivity credit not a penalty, however, it is not possible to use a deterministic code like CASMO-3 because of the complex geometry. Therefore, Holtec [4] was likely forced to take a penalty where none was probably needed. The rack-to-rack penalty is not sensitive to assembly type and this is suggested by Holtec [4] applying the same rack-to-rack penalty determined for normal SFSR loading to the interim loading configuration. Therefore, the same reactivity penalty computed by Holtec [4] for Westinghouse fuel is applicable to Framatome fuel.

c) Off-Center or Eccentric Fuel Position

Off center fuel placement was modeled by Holtec [4] for the SFSR using KENO-Va with an infinite array of assemblies. Due to the infinite array nature of the rack geometry assumed and having all assemblies in the rack clustered into groups of 4 moved together, the calculated penalty for off-center movement of +/-0.0019 Δk is very conservative. Off-center fuel placement calculations performed by Framatome for poisoned racks usually indicate the most reactive placement of the assembly is centered in the can. The penalty is likely due entirely to the statistical uncertainty of the KENO-Va analysis. For example, the uncertainty on the base KENO-Va calculation is quoted by Holtec [4] to be +/-0.0012. Assuming a similar uncertainty for the centered and off-center cases would yield an uncertainty of $[(0.0012)^2 + (0.0012)^2]^{1/2} = 0.0017$ Δk and is very close to the quoted value of +/-0.0019 Δk. Therefore, the application of an off-center KENO-Va penalty is likely unnecessary.

The same eccentricity penalty is assumed for all current AEP assembly types including the Westinghouse standard 17x17 and 15x15 assembly designs, both of which are nearly identical to the two proposed relevant Framatome designs. The pellet eccentricity penalty is not sensitive to assembly type and this is suggested by Holtec [4] applying the eccentricity penalty determined for normal SFSR loading to the interim loading configuration. Therefore, the same reactivity penalty computed by Holtec [4] for Westinghouse fuel is applicable to Framatome fuel.

Burnup Related Reactivity Penalties

a) Burnup Uncertainty

The burnup uncertainty due to depletion of fuel was evaluated by Holtec [4] assuming a 5% uncertainty in burnup which is considered standard in the industry. This analysis was computed using CASMO-3 because KENO-Va cannot deplete fuel. Uncertainties were computed by Holtec [4] and applied to fuel at 50 GWd/mtU and at 38 GWd/mtU and have values of +/-0.0047 Δk and +/-0.0019 Δk, respectively. These penalties represent Regions 2 and 3 of the SFSR. For Region 1 Holtec [4] indicates that the fresh fuel dominates and no burnup uncertainty is applicable. It is interesting that Holtec [4] applies both of these reactivity penalties to their criticality analysis. In fact, it is only necessary to apply the Region 3 +/-0.0047 Δk penalty since the entire rack k-effective is determined by the most reactive sub-region of the rack. Therefore, the Region 3 penalty bounds the Region 2 penalty and both penalties are not required. Therefore, there is additional conservatism available from the Holtec [4] burnup uncertainty evaluation. Since the Framatome 15x15 and 17x17 designs are nearly identical to fuel that AEP already has, and since there is additional conservatism in the burnup evaluation, the burnup penalties are acceptable for use with Framatome fuel. No application of this penalty is made to the interim fuel storage configuration because it involves only fresh fuel.

b) Axial Burnup Effect

The axial burnup effect was computed by Holtec [4] to be +/-0.0037 Δk using KENO-Va using a typical axial burnup distribution at higher enrichment and burnup. Holtec [4] indicates that fuel of lower enrichment and burnup would have a smaller reactivity penalty. The axial burnup profile used by Holtec [4] is typical and also representative of the axial profiles in Framatome fuel. Therefore, the penalty is applicable to Framatome fuel as it is to other fuel vendor assembly designs in use by AEP.

KENO-Va Model Bias and Uncertainty

a) KENO-Va Model Bias

Since KENO-Va was used by Holtec [4] to perform the base k-effective calculation with nominal dimensions for the SFSR, any bias in calculations from the base code used must be considered. The bias is determined by comparison to applicable critical configurations and is not specific to any particular assembly design. The bias associated with KENO-Va using various cross-section sets is known to be approximately 0.01 Δk and the Holtec [4] quoted value of +0.0090 Δk is consistent with that knowledge. In addition to the bias there is an uncertainty on the bias, as a Monte-Carlo code was used, which Holtec [4] quotes as +/-0.0021 Δk. The uncertainty on the bias was treated as a "tolerance" penalty thus statistically combined with other tolerance and uncertainty penalties. Since a difference calculation is performed between Framatome and Westinghouse fuel for like assembly types and because the bias is not assembly specific, it is applicable to Framatome fuel.

b) KENO-Va Base Case Uncertainty

Since KENO-Va is used to perform a base calculation, and it is a Monte-Carlo code, the answer is statistical in nature. As a consequence all KENO-Va results have an associated uncertainty. The uncertainty is based on the number of generations run and the number of neutrons tracked per generation. The uncertainty is not assembly dependent for assemblies of similar design. Westinghouse and Framatome assemblies are of a similar design. Therefore, the base KENO-Va uncertainty is applicable to the Framatome fuel analysis. The Holtec [4] uncertainty used is +/-0.0012 Δk.

Combined Statistical Uncertainty

Whether the uncertainty is from the KENO-Va statistics on the base case or by a tolerance on a parameter, Holtec [4] statistically combined these uncertainties using the square root of the sum of the squares method as follows:

$$[(0.0021)^2 + (0.0012)^2 + (0.0064)^2 + (0.0045)^2 + (0.0034)^2 + (0.0035)^2 + (0.0019)^2 + (0.0047)^2 + (0.0019)^2]^{1/2} = 0.010963 = 0.0110$$

The value of k-maximum for the SFSR was computed by adding the bias and the axial burnup effect to the base k-effective as follows:

0.9160 + 0.0090 + 0.0037 = 0.9287 +/-0.0110 or k-maximum = 0.9397 = 0.94.

Framatome Example

Framatome computes a small difference between a Framatome fuel assembly and a limiting Westinghouse assembly and adds that to the base k-effective along with all the other differences previously computed with KENO-Va and CASMO-3. Framatome computed a limiting reactivity effect in terms of $\Delta\rho$ for the Advanced Mk-BW design to be +0.00901 $\Delta\rho$ using CASMO-3. Therefore, k-maximum now becomes (1/(1/0.94 – 0.00901) = 0.94802.

The above method utilized by Framatome for the SFSR calculation also reflects that the existing analysis does contain conservatisms. An additional +/-0.0019 Δk burnup uncertainty penalty was applied in addition to the limiting +/-0.0047 Δk burnup penalty and was unnecessary, a penalty was taken for off-center fuel movement and rack-to-rack water gaps that also may not be required.

2.5.3 NFSV Discussion

The NFSV is significantly different from the SFSR because it involves all fresh fuel and the limiting region of the rack is the axial center region where there is no rack structure. Additionally, no burnup uncertainty applies to this rack design. The fuel density and enrichment tolerances previously discussed for the SFSR are not rack dependent and thus applicable to the NFSV. The only tolerance remaining is the tolerance on assembly-to-assembly pitch in the rack and is not assembly dependent. When Framatome used MCNP-4B to calculate a difference between fuel assembly types for the NFSV, its associated MCNP-4B 2-sided 95/95 uncertainty was not statistically weighted with the other applicable uncertainties, as could have been done in the Holtec [4] method, but conservatively added directly to the base KENO-IV calculation. Therefore, the application of a MCNP-4B determined difference and uncertainty is conservative. Note that Westinghouse in their 1996 analysis [5] uses PHEONIX-P to evaluate the difference in reactivity between fuel with IFBA and fuel without it. These PHOENIX-P calculations have much larger reactivity differences when determining equivalent IFBA concentrations and patterns than the reactivity difference between a Westinghouse OFA 17x17 assembly and Framatome Advanced Mk-BW 17x17 assembly. Therefore, the NFSV analytical base (without IFBA) is completely applicable to Framatome fuel.

3.0 SFSR Analysis

This analysis is based on an approach that makes a comparison between rack k-effective values with different assembly types using CASMO-3. Since this analysis is based upon a relative comparison of k-effective values the absolute magnitude of k-effective is not the immediate concern. However, it is noted that k-effective values are all sufficiently less than the applicable criticality limit. A final summary of k-maximum values that reflect the calculated penalties from Sections 3.0 and 4.0 are included in Section 6.0. Nominal dimensions are used everywhere with the exception of the B^{10} areal density. The minimum B^{10} areal density was used. Additionally, the modeling of the SFSR has no leakage. The SFSR is modeled as infinite in X, Y, and Z-directions in CASMO-3. Therefore, k-effective equals k-infinity.

3.1 Segment Loading of Fresh Fuel

Examination of Figure 2.3.2-1 reveals that there are two different types of cells that define the 2x2 rack geometry. There are differing thicknesses of Boral and stainless steel used to define the two basic cell types in CASMO-3. It should be noted that there is only one nominal Boral plate thickness, however, CASMO-3 must have a uniform pitch for each cell type so the Boral plates are modeled partly in one cell and partly in another adjacent cell. This does not alter the nuclear calculations or results in any way since the actual geometry and total Boral plate thickness is preserved. To model the peripheral region of the SFSR only segment 1 contains fresh fuel while segments 2-4 contain burned fuel (See Figure 2.3.1-2, Pattern #1). The technical specifications call for Region 1 fresh fuel to be placed in an arrangement with Region 2 burned fuel according to equation on page 5-6 of the Technical Specifications [4,7]. The equation below defines minimum Region 2 burnup requirements as a function of initial nominal enrichment and is given as:

$$\text{Minimum Region 2 Burnup} = -22670 + 22220E - 2260E^2 + 149E^3$$

The above formula yields a required burnup of 50.015 GWd/mtU or rounding to 50 GWd/mtU if a nominal enrichment of 4.95 wt% is used (5.0 wt% U^{235} maximum). Therefore, CASMO-3 segment 1 has a fresh assembly at 5.0 wt% U^{235} while segments 2-4 have 5.0 wt% U^{235} fuel burned to 50 GWd/mtU. No IFBA or Gadolinia fuel is modeled for conservatism. The results are shown in Table 3.1-1. The Westinghouse 15x15 assembly is the current assembly design that yields the highest k-effective value. Therefore, the Westinghouse 15x15 is considered the base case with which other assemblies types will be compared for the SFSR.

Table 3.1-1 Reactivity Comparison of Different Fuel Types For One Region 1 Assembly With Three Region 2 Assemblies (2x2)

Assembly Type	Description	2x2 Average K-infinity	Reactivity Delta to Base Case ($\Delta\rho$)
Westinghouse 17x17 OFA	SFSR Calculation	0.88754	-0.00714
Westinghouse 15x15 Standard	SFSR Calculation	**0.89320 - Base**	0.0
Framatome ANP 17x17 Advanced Mk-BW	SFSR Calculation	0.90045	**0.00901**
Framatome ANP 15x15 20 GT Design	SFSR Calculation	0.89378	0.00073

Results from the previous table indicate that the Framatome Advanced Mk-BW is the most reactive assembly design in the context of the SFSR. This is due to the larger KgU assembly loading and larger pellet diameter coupled with the 17x17 pin configuration (wetter lattice).

The fuel racks in the Spent Fuel Pool allow more fuel combinations in a 2x2 array than just a single fresh Region 1 assembly with three neighboring Region 2 fuel types (See Figure 2.3.1-2, Patterns 2 through 4). It is also possible to have two Region 2 fuel assemblies next to two Region 3 assemblies (Pattern #2 – not limiting), one Region 3 assembly with three Region 2 assemblies (not limiting) or all Region 3 assemblies (Pattern #3). Since Region 3 assemblies are more reactive (have lower burnup requirements at a given enrichment) than Region 2 assemblies the only other limiting configuration that needs evaluation is a rack with all Region 3 assemblies (Pattern #3). The equation for the minimum allowed burnup for Region 3 fuel is given in Reference [4], Attachment 4, page 4-6 as:

$$\text{Minimum Region 3 Burnup} = -26745 + 18746E - 1631E^2 + 98.4E^3$$

With this equation a nominal 4.95 wt% fuel assembly (5.0 wt% maximum) has a minimum allowed burnup of 38019 Mwd/mtU or approximately 38 GWd/mtU. A comparison will be performed for different fuel types depleted to 38 GWd/mtU for a Region 3 SFSR configuration.

For this Region 3 configuration it is only necessary to evaluate the two limiting assembly types and they are the Westinghouse Standard 15x15 which is the previous design basis of the SFSR and the Framatome 17x17 Advanced Mk-BW design that was previously demonstrated to be most reactive.

Table 3.1-2 Reactivity Comparison of Different Fuel Types For Four Region 3 Assemblies (2x2)

Assembly Type	Description	2x2 Average K-infinity	Reactivity Delta to Base Case ($\Delta\rho$)
Westinghouse 15x15 Standard	SFSR Calculation	0.88131 - Base	0.0
Framatome ANP 17x17 Advanced Mk-BW	SFSR Calculation	0.88509	0.00485

Comparing the results of Table 3.1-1 and 3.1-2, the part of the 2x2 rack that contains the most reactive fuel is Region 1 surrounded by Region 2 assemblies (Pattern #1). The Framatome 17x17 Advanced Mk-BW is most reactive in this configuration as demonstrated by a 0.00901 $\Delta\rho$ increase over the Westinghouse Standard 15x15 design in Region 1 compared to 0.00485 $\Delta\rho$ increase in Region 3 (Pattern #3).

The D.C. Cook Technical Specifications also allow an interim storage pattern for a few racks that have fresh fuel checker-boarded with water holes (See Figure 2.3.1-2, Pattern #4). CASMO-3 does not allow the 2x2 rack option to be run with two water holes. There must be some amount of fuel present. Since we are interested in a reactivity delta it is bounding to model two fresh fuel assemblies checker-boarded with two Region 2 assemblies burned to 50 GWd/mtU to represent the interim loading scenario. Fuel is always more limiting than water.

The results of the interim SFSR analysis were also evaluated. The results indicate that the interim loading pattern in the SFSR is 0.00302 $\Delta\rho$ more reactive with the Framatome Advanced Mk-BW than with the design basis Westinghouse standard 15x15 assembly design.

3.2 Depletion of the Advanced Mk-BW with Gadolinia in the SFSR

The previous SFSR analyses were conducted without the consideration of Gadolinia fuel rods. Depletable absorbers can cause spectral hardening and subsequent buildup of plutonium isotopes that can increase reactivity at higher burnup conditions especially if the absorber components are removable (no negative reactivity credit can be taken for removable absorbers in criticality analyses). Although spectral hardening and plutonium production occur with integral fuel absorbers like Gadolinia, Gadolinia daughter products are also neutron absorbers and a residual reactivity penalty results that offsets any reactivity increase from spectral hardening. Additionally, in some designs the U^{235} carrier enrichment in a Gadolinia pin may be lower than that of a normal fuel rod per Framatome design requirements. These considerations act in a way to make Gadolinia fuel assemblies less limiting than the same assembly without Gadolinia. To demonstrate this, two Gadolinia fuel cases were run. The first is for a fuel assembly with 20 Gadolinia rods at 8 wt% Gadolinia depleted to 50 GWd/mtU and the second is for 8 Gadolinia fuel rods in an assembly at 2.0 wt% Gadolinia depleted to 50 GWd/mtU. A plot of the in-core normalized reactivity response with and without Gadolinia is shown in Figure 3.2-1. These results demonstrate that an assembly without Gadolinia fuel is most reactive for use in the SFSR with the normalized K-infinity converging at higher burnup conditions. Therefore, the results and penalties defined in Section 3.1 are bounding. Note that although these calculations are "in-core" and not in the context of the SFSR, they are only used to identify the limiting reactivity configuration (no Gadolinia) and not to draw conclusions on the absolute SFSR k-effective or to define specific reactivity penalties for the SFSR. Therefore, the reduced enrichment of the Gadolinia fuel rods, the presence of absorber Gadolinia daughter products from burnup, and water displacement effects remaining (Gadolinia fuel rods are non-removable) requires K-effective be reduced over the non-Gadolinia assembly at the same base enrichment.

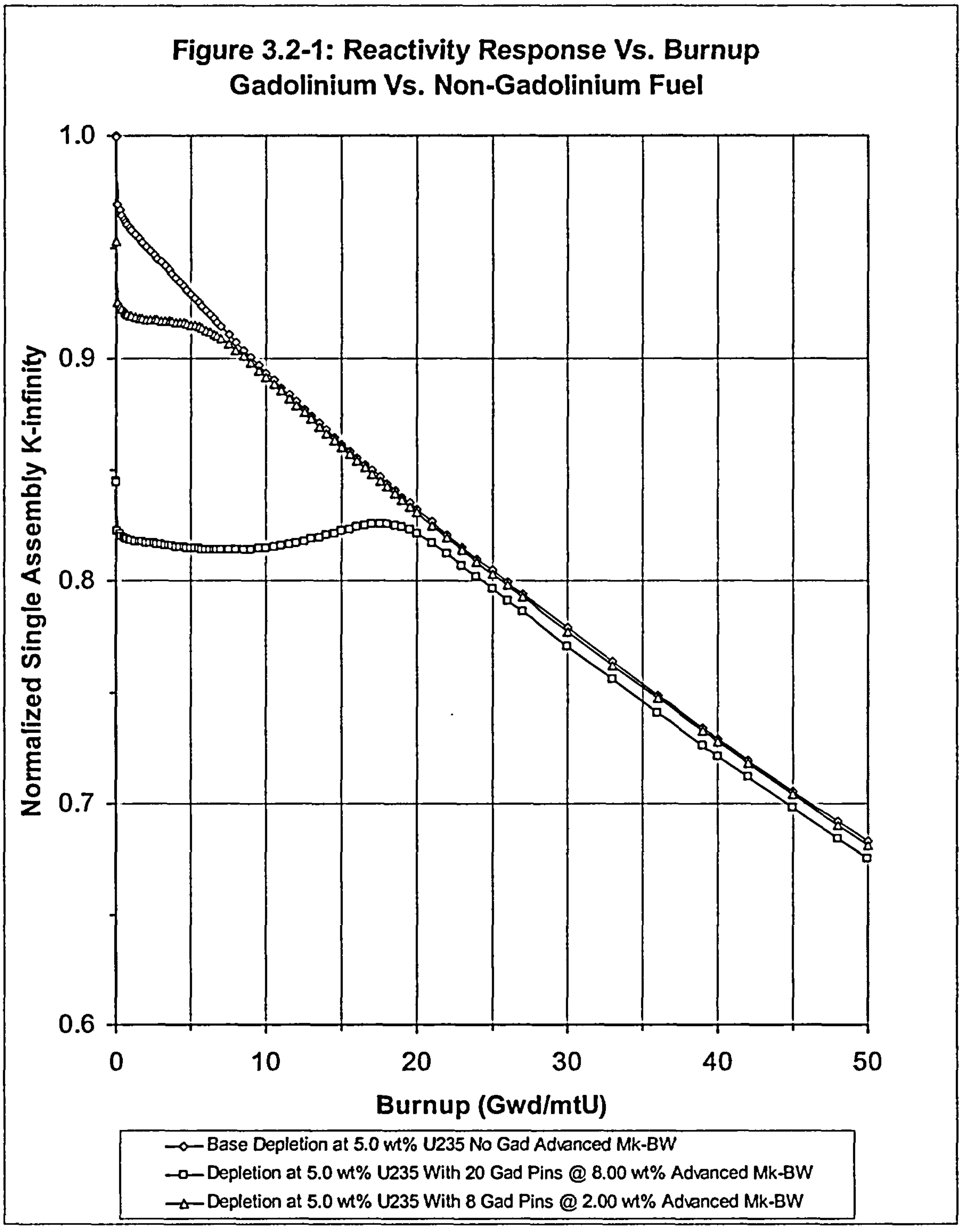


Figure 3.2-1: Reactivity Response Vs. Burnup
Gadolinium Vs. Non-Gadolinium Fuel
Normalized Single Assembly K-infinity
1.0
0.9
0.8
0.7
0.6
0
10
20
30
40
50
Burnup (Gwd/mtU)
Base Depletion at 5.0 wt% U235 No Gad Advanced Mk-BW
Depletion at 5.0 wt% U235 With 20 Gad Pins @ 8.00 wt% Advanced Mk-BW
Depletion at 5.0 wt% U235 With 8 Gad Pins @ 2.00 wt% Advanced Mk-BW

3.3 Reactivity Consequences of Removable Burnable Absorbers

The presence of a removable control component such as a Wet Annular Burnable Absorber (WABA) or a Burnable Poison Rod Assembly (BPRA) will harden the neutron spectrum during fuel depletion until the component is removed during refueling operations. The presence of the component breeds more Plutonium isotopes (particularly Pu^{239}) compared to what would have occurred at the same burnup with no component present. After the component is removed the assembly "prefers" to produce power from plutonium isotopes in preference to uranium resulting in a higher U^{235} concentration for a period of time after the absorber component has been removed compared to the non-component case at the same burnup. The result is an increase in reactivity after the component is removed that may continue to increase until it peaks about 20-30 GWd/mtU after component removal. The timing of the peak and the magnitude of the peak are also affected by the residence time of the control component. If the component is pulled at 10 GWd/mtU the peak may be more pronounced but small in total reactivity magnitude. If the component is pulled at 30 GWd/mtU the peak may not even exceed the increase immediately after the pull but the reactivity magnitude is larger.

For this analysis a 3.0 wt% B_4C in Al_2O_3 component was used. 3.0 wt% B_4C is about the limiting value that would ever be used in typical fuel cycle designs because it is desirable to burn out the boron by EOC. Both 17x17 and 15x15 Framatome designs are evaluated. The Mk-BW 17x17 and Mk-B HTP 15x15 designs are evaluated with the BPRA pulled at 10 and 20 GWd/mtU. The results are then evaluated in the SFSR context to determine the reactivity penalty associated with the BPRA at SFSR conditions.

The resulting penalties defined in this section are applied only to Westinghouse fuel since some Westinghouse assemblies had Pyrex rods of sufficient length to extend into the most reactive top and bottom 9" burned fuel regions. Fuel assembly types with active absorber length removable components that are not located in the end regions do not require penalties. This includes all Framatome fuel and most Westinghouse fuel. The analysis in this section used Framatome fuel only for the purposes of evaluation of a conservative penalty and is typical of other vendor fuel types. Note, that proposed Framatome fuel cycle designs involving Gadolinia fuel generally do not use removable burnable absorber components, however, their use is not prohibited by this analysis.

<u>BPRA Pull at 20 GWd/mtU</u>

The depleted Advanced Mk-BW 17x17 and Mk-B HTP 15x15 designs were evaluated in the SFSR at cold conditions with zero xenon at 20, 40, 60, and 80 GWd/mtU. The k-infinity results from the SFSR calculations at atmospheric pressure and cold conditions (water density = 1.0 g/cc) were used to compute the reactivity increase due to the control component (component now removed). The results for the Mk-BW and the Mk-B HTP assembly are shown in Figure 3.3-1. Note that for both assembly types the reactivity increase associated with control components is amplified when evaluated in the context of the SFSR. This is primarily the result of flux redistribution within the assembly with peaking shifting to the assembly interior, zero xenon conditions, and the denser moderator conditions at cold conditions.

Examination of the reactivity results indicates that the time of greatest reactivity penalty is not necessarily directly after the BPRA pull. These results indicate that the presence of the BPRA component breeds more Pu^{239} into the assembly due to the harder neutron spectrum. After the BPRA is pulled the Pu^{239} concentration increases for 20 GWd/mtU and then decreases. With burnup the Pu^{239} concentration begins to converge to the case that never had a BPRA. Similar behavior with burnup is observed for the other isotopes shown. The behavior of the Pu^{239} isotope by itself does not explain the continued reactivity increase after the BPRA is pulled.

Examination of the fission reaction rate ratio (BPRA out/no BPRA) indicates that fission rates converge between the two cases with burnup for Plutonium isotopes (results converge to 1.0 ratio). The exception is the behavior of U^{235}. The U^{235} fission rate ratio continues to increase with burnup indicating that it is the uranium response that is responsible for the continued reactivity increase after BPRA pull.

Since K-infinite (or K-effective) represents a balance between capture and fission rates, results indicate that the ratio of fission to capture increases and approaches a maximum at approximately 65-70 GWd/mtU when the BPRA is pulled at 20 GWd/mtU and corresponds to the peak reactivity delta also occurring at the same burnup condition (65-70 GWd/mtU). These results along with others imply that after the BPRA is pulled there is initially more Pu^{239} that continues to increase for a time with burnup (about 20 GWd/mtU). The Pu^{239} appears to fission in preference to the U^{235} and at the time of BPRA withdrawal there is also initially more U^{235} and Pu^{239} present compared to the no BPRA case. Eventually, the Pu^{239} burns sufficiently that the plutonium fission rate begins to decrease while the fission rate in U^{235} continues to increase. As the concentration of both fissionable isotopes eventually decreases the reactivity curve turns over and begins to decrease. Therefore, the reactivity response after BPRA pull is a balancing act between the initial buildup and depletion of U^{235} and Pu^{239} caused by the burnable component. A longer depletion time with the BPRA component present will reduce the magnitude of the burnup dependent peak after BPRA withdrawal but the magnitude of the reactivity difference at initial BPRA withdrawal will be greater than the same calculation with the BPRA in for a shorter time. These observations are valid in the range of 10 GWd/mtU to 50 GWd/mtU and are applicable to the SFSR.

The current D.C. Cook Unit 1 and 2 Technical Specifications define a burnup versus enrichment curve for the SFSR that is based on the assembly average burnup. The use of assembly average burnup is generally acceptable and conservative for burnups up to at least 40 GWd/mtU and is duly noted in the Holtec SFSR analysis [4] and accepted by the NRC. However, if a reactivity penalty is to be assigned to the SFSR result that represents the effects of spectral hardening from control components, some examination of the axial burnup should be considered as well as the active length of the absorber components.

For BPRAs used in Framatome fuel the active absorber length is 126" and is centered in the active fuel column. For WABAs the maximum length used in D.C. Cook unit 1 does not extend into the top or bottom 9" fuel regions. For D.C. Cook unit 2 a Pyrex BPRA length that does extend into the top and bottom 9" fuel regions was used in cycle 7 with the balance of assemblies using IFBA fuel in that and subsequent cycles. Note that IFBA fuel and Gadolinia have already been addressed in previous calculations [4,5] and Section

3.2 of this analysis. Note that the number of WABA rodlets can vary in an assembly and since WABAs are annular in nature, they are less limiting from a spectral hardening viewpoint than a solid BPRA or Pyrex rod.

A typical axial fuel burnup profile is a flattened cosine shape. The most reactive regions are in approximately the upper or lower 9" of the fuel column that are less burned assuming lower enriched axial blanket fuel is absent. Extensive burnup data from a previous criticality analysis indicates that for WABA type fuel at 5.11 wt% U^{235} the least burned end segment history with a WABA has a maximum burnup of 13.2 GWd/mtU. The total burnup on the limiting end segment is 27.845 GWd/mtU while the assembly average burnup is 50 GWd/mtU. Note that regions of the assembly that had a control component near the end segments are burned to a significantly greater degree and are not as limiting in terms of reactivity as at the average burnup of the end segments. The decreased reactivity associated with the increased burnup in other non-end segments offsets the increased reactivity penalty from spectral hardening for those segments that had a WABA or other control component. For example, there is a very large reactivity difference (at least 10% $\Delta\rho$) between fuel burned to 40 GWd/mtU in a segment near the end segment compared to fuel at the same enrichment at 27.845 GWd/mtU at the midpoint of the assembly end segment. The 10% $\Delta\rho$ decrease due to burnup offsets a maximum increase of approximately 0.73% $\Delta\rho$ due to spectral hardening effects. Therefore, it is appropriate to use the assembly end segment history to evaluate the reactivity penalty from spectral effects and not the average or maximum assembly exposure history.

In a previous criticality analysis the end segments were 9" long and contained no WABA rodlets. Even the Framatome 126" long BPRA would not be located in the end fuel regions. Therefore, assemblies that contain either WABAs or BPRAs do not require additional reactivity penalties due to spectral hardening since the absorber material is not located in the most reactive end fuel regions.

Therefore, the only limiting case results from the use of Pyrex rodlets. For this analysis the 3.0 wt% B_4C BPRA cluster was assumed since it is similar to Pyrex in composition and wt% B_4C and it will be assumed to be located in the end segment regions for conservatism. A conservative burnup history for the end segment regions is assumed.

BPRA Pull at 10 GWd/mtU

For this analysis calculations were performed for the Advanced Mk-BW 17x17 and Mk-B HTP 15x15 with the fuel burned to 10 GWd/mtU with a 3.0 wt% B_4C cluster present. The BPRA is pulled and the assembly is subsequently burned to 80 GWd/mtU. The results of the Mk-BW BPRA removal at HFP are shown in Figure 3.3-2. These results demonstrate that the reactivity increase due to Pu^{239} buildup is greater in the context of the SFSR as expected but not as large as observed for the case where the BPRA is left in the core for 20 GWd/mtU. The results of the Mk-B HTP 15x15 BPRA removal at HFP are shown in Figure 3.3-3. These results also demonstrate that the spectral hardening effect is slightly greater for the Framatome Mk-B HTP 15x15 assembly than for the Advanced Mk-BW 17x17 assembly.

Spectral Hardening Penalties

If the spectral hardening penalties for the Advanced Mk-BW 17x17 and the Framatome Mk-B HTP 15x15 designs are interpolated to 13.2 GWd/mtU the relevant end segment reactivity penalties can be determined. For the Framatome 15x15 Mk-B HTP design the penalty is 0.728 %$\Delta\rho$ for an assembly end segment conservatively burned to 40 GWd/mtU. For the Framatome 17x17 Advanced Mk-BW design the penalty is 0.688 %$\Delta\rho$ for the same conditions.

In this evaluation the 17x17 spectral hardening penalty was conservatively calculated using the Advanced Mk-BW fuel with a 3.0 wt% B_4C component and is typical of all 17x17 fuel types regardless of vendor. Therefore, a local increase in K-effective of 1.0 %$\Delta\rho$ from a maximum K-effective of 0.94 yields a maximum K-effective of 1/(1/0.94 – 0.00688) = **0.94612** and is less than the criticality limit of 0.95.

The 15x15 fuel types are represented by the spectral hardening penalty conservatively calculated using the Framatome Mk-B HTP 15x15 design with a 3.0 wt% B_4C component regardless of vendor. Therefore, a local increase in K-effective of 0.728 %$\Delta\rho$ from a maximum K-effective of 0.94 yields a maximum K-effective of 1/(1/0.94 – 0.00728) = **0.94648** and is less than the criticality limit of 0.95.

Therefore, if all non-Framatome 15x15 and 17x17 assembly types had the spectral hardening penalty applied to the end segments of the respective assembly types they represent and are at the allowed burnup and enrichment limits for the SFSR, the reactivity increase of the SFSR would be less than 0.73 %$\Delta\rho$ and the resulting criticality limit of 0.95 would not be exceeded.

For 15x15 and 17x17 assembly types that have maximum absorber lengths of 126" or less centered in the active fuel column, the spectral hardening effects are not limiting relative to the higher burnup conditions of the affected central axial segments. Also note that these results are very conservative because they assume an infinite array of assemblies (no axial or radial leakage) at the limiting conditions of burnup and enrichment and with the limiting spectral hardening penalties determined at 40 GWd/mtU applied to end segment regions that will never achieve such high values of burnup (i.e., 40 GWd/mtU).

Spectral Hardening From Rod Bite

It is possible to have spectral hardening effects in Framatome and Westinghouse fuel in the top end fuel region from the "rod bite" associated with Bank D insertion during operation. However an additional penalty was not assigned to any fuel type for control rod effects for the following reasons.

1. Usually only nine assemblies have partial Bank D insertion during any fuel cycle. Therefore, the frequency of having a large number of these assemblies grouped together in the rack sufficient to define k-maximum is very small. Assuming every assembly in the rack has partial rod bite effects is extreme. This is not the case for fuel with removable absorbers (WABAs, Pyrex, etc.) where larger numbers of components are typically employed in the core.

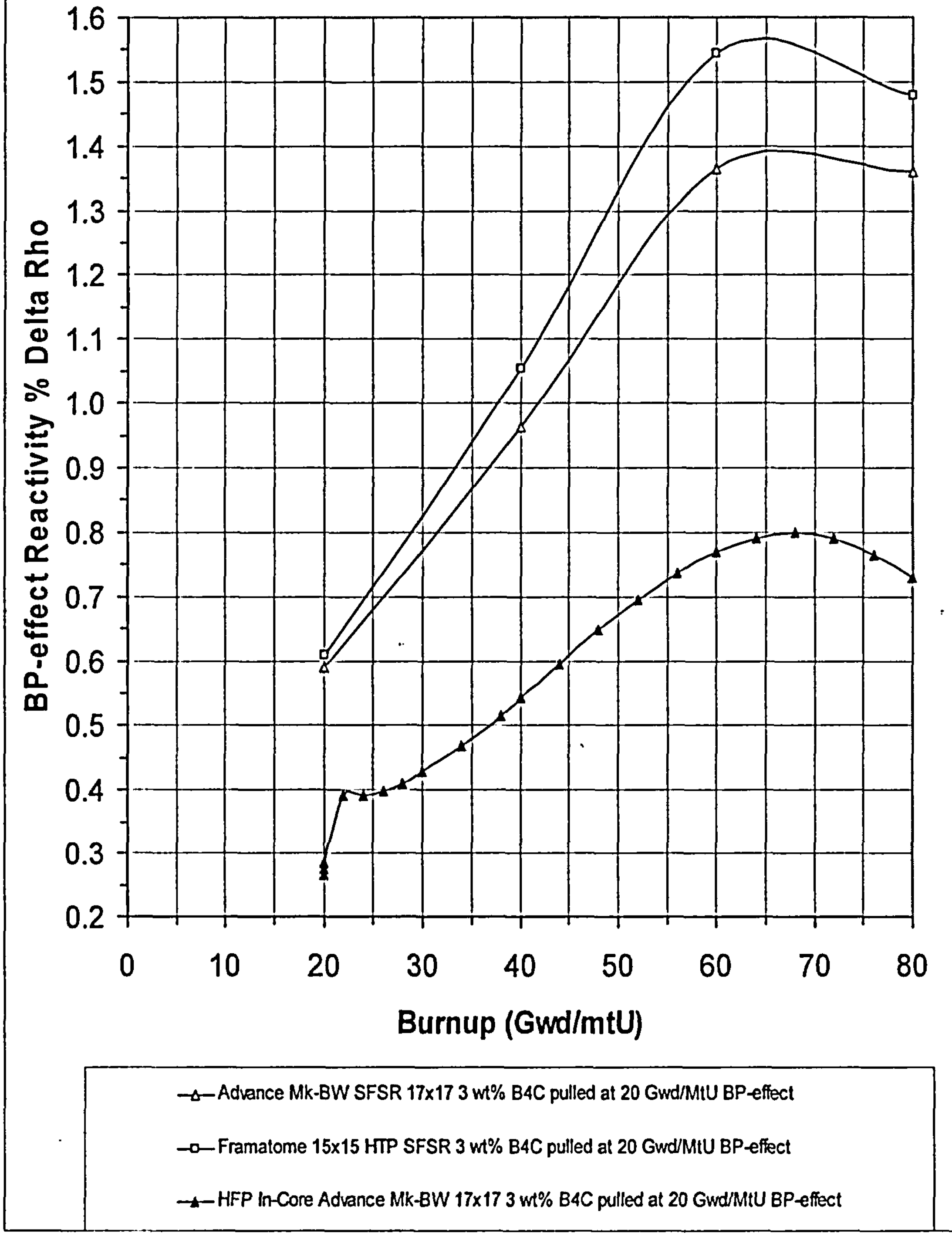
2. A burnup uncertainty is included in the Reference [4] tolerance penalty and is worth typically 0.2% to 0.5% Δk

3. The Holtec analysis [4] allows for axial burnup effects that are typically about 0.4% Δk.

4. The effect of the reflector region softens the neutron spectrum and causes the fuel to burn out more rapidly in the top region of the assembly than would be the case without the reflector. The fuel burnout from the softer spectrum partially offsets some of the Pu-239 buildup from partial rod insertion in the same top region over the lifetime of the fuel.

5. Holtec [4] argues in the current analysis of record that fresh fuel in Region 1, dominates the rack k-effective. Therefore, the small reactivity increase in an assembly possible from partial rod insertion will not influence the rack k-effective.

Figure 3.3-1 BP-Effect for Advanced Mk-BW and Framatome 15x15 HTP Design at 20 Gwd/mtU



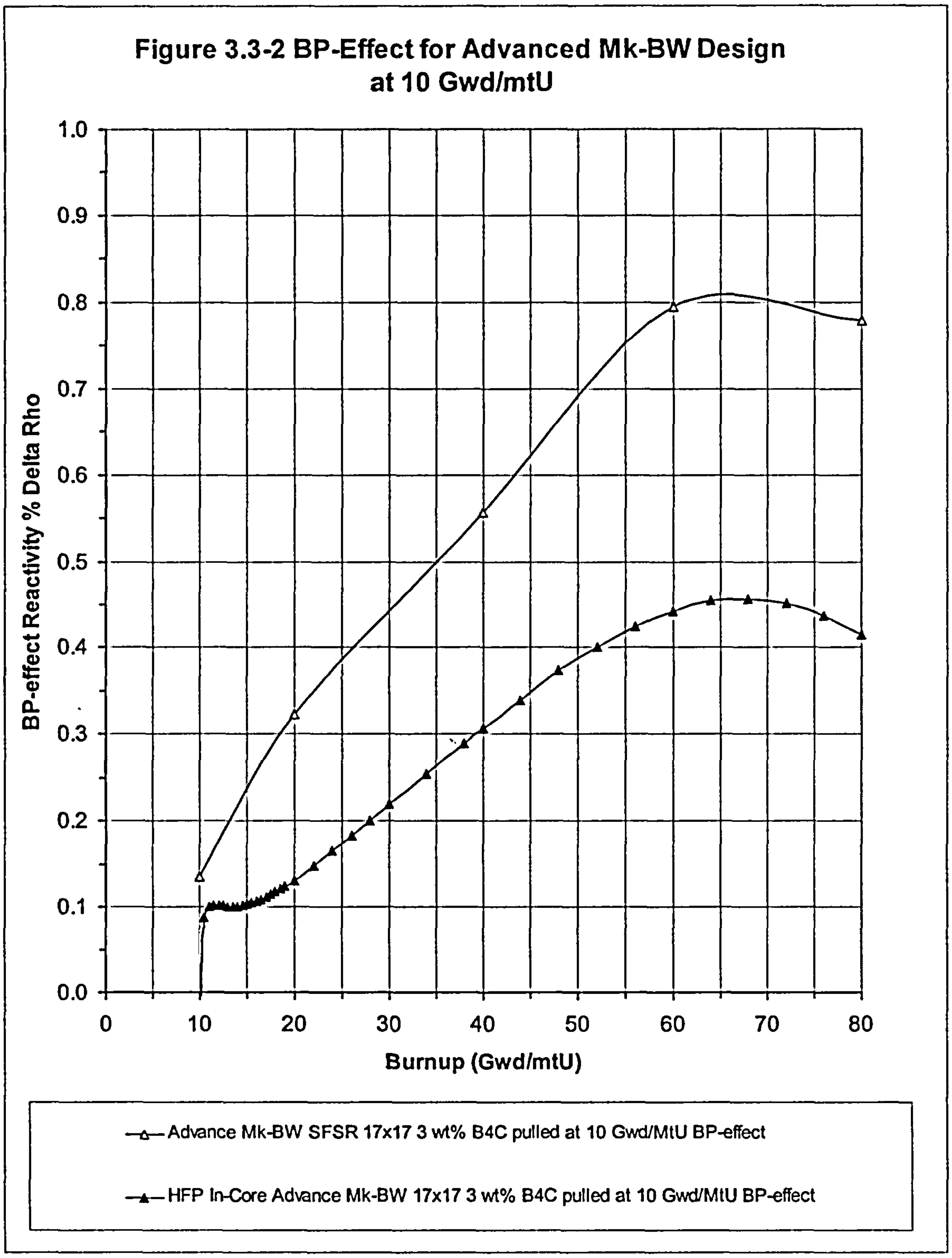
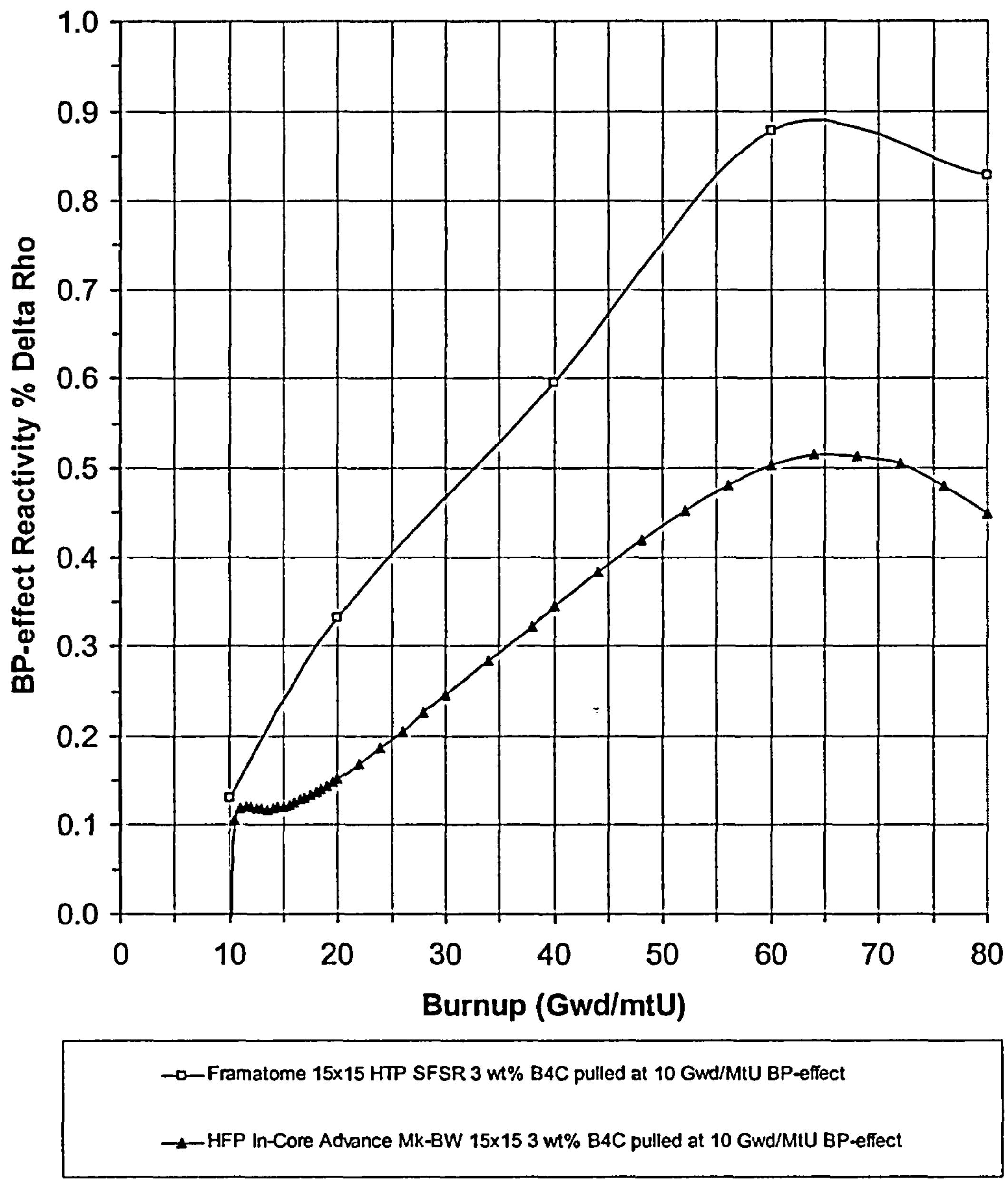


Figure 3.3-2 BP-Effect for Advanced Mk-BW Design
at 10 Gwd/mtU
BP-effect Reactivity % Delta Rho
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
70
80
Burnup (Gwd/mtU)
Advance Mk-BW SFSR 17x17 3 wt% B4C pulled at 10 Gwd/MtU BP-effect
HFP In-Core Advance Mk-BW 17x17 3 wt% B4C pulled at 10 Gwd/MtU BP-effect

Figure 3.3-3 BP-Effect for Framatome 15x15 HTP Design at 10 Gwd/mtU



3.4 Fuel-to-Boral Plate Orientation in the SFSR

A previous criticality analysis that used Westinghouse OFA fuel has three-dimensional KENOIV calculations that evaluated a "straight deep-drop" accident. This is an accident in which the assembly falls vertically into an open can in the rack and penetrates through the bottom of the rack. The model exposes 4" of uncovered fuel for every assembly in an infinite array (2x2 model) and is therefore very conservative. Fuel at 5.27 wt% U^{235} burned to 50 GWd/mtU was modeled and every assembly in the rack was displaced 4" below the absorber plates. The result was an increase in k-effective of 0.00193 $\Delta\rho$ +/- 0.00106 $\Delta\rho$. If it is assumed that only 0.5" of fuel will be allowed to extend above or below the SFSR absorber plate length and the 4" penalty is conservatively linearly interpolated, the resulting penalty is 0.00013 $\Delta\rho$ +/-0.00106 $\Delta\rho$. Clearly the penalty is within the uncertainty of the analysis and can be ignored. Furthermore, both the current and proposed fuel contains axial blankets at reduced enrichments that further reduce any axial penalties. Also, the stainless-steel cans extend above and below the assembly displacing the water moderator. Stainless-steel has a significant amount of nickel which is an absorber. For these reasons extension of the active new fuel less than or equal to 0.5" above or below the Boral plates in the SFSR is acceptable and has negligible consequences.

4.0 NFSV Analysis

The NFSV has a maximum enrichment limit of 4.55 wt% U^{235} with no IFBA or Gadolinia type fuel rods (Reference [4], Attachment 3 (Technical Specifications)). Reference [5], Attachment 4 also indicates that credit was taken for absorption in fuel assemblies from IFBA type fuel to justify a nominal enrichment of 4.95 wt% U^{235} by reactivity equivalency calculations. A similar approach is taken with regard to Gadolinia fuel.

For Gadolinia fuel different pin patterns exist for concentrations at 2, 4, 6, and 8 wt% Gadolinia. Therefore, a limiting minimum Gadolinia loading must be determined at a maximum enrichment of 5.0 wt% U^{235} for the flooded NFSV that maintains the limiting K-effective value at 4.55 wt% U^{235}.

4.1 Flooded NFSV Results

The flooded NFSV must be evaluated to determine the most reactive assembly type. MCNP-4B calculations were run with 20000 neutrons/generation and 2000 generations with the first 20 cycles skipped. This represents 39,960,000 neutron histories used to determine k-effective. The geometry assumes an infinite array of assemblies in the X-Y direction that are of infinite height using reflective boundary conditions so there is no leakage. The assemblies model 21 inch center-to-center spacing (See Figure 2.3.3-1) and have at least 12 inches of fully dense water between assemblies.

Four assembly types were evaluated in the fully flooded NFSV. The MCNP-4B results are shown in Table 4.1-1 below. Westinghouse states in Reference [5], Attachment 4 that the Westinghouse 17x17 OFA assembly is most limiting. The results of Table 4.1-1 confirm those conclusions and establish a target k-effective of 0.93085 +/-0.00012.

Table 4.1-1 Flooded NFSV Results for Assemblies at 4.55 wt% U^{235}

Assembly Type	Description	NFSV K-infinity +/- Sigma	Reactivity Delta to Base Case ($\Delta\rho$)
Westinghouse 15x15 Standard	Flooded NFSV	0.92705 +/- 0.00012	-0.00440 +/-0.00020
Framatome ANP 17x17 Advanced Mk-BW	Flooded NFSV	0.92356 +/- 0.00012	-0.00848 +/-0.00020
Westinghouse 17x17 OFA	Flooded NFSV	**0.93085 +/-0.00012**	0.0
Framatome ANP 15x15 w/ 20 GTs	Flooded NFSV	0.92593 +/-0.00012	-0.00571 +/-0.00020

The results above indicate that all Framatome assembly designs without Gadolinia are less reactive in the fresh fuel condition than the Westinghouse 17x17 OFA assembly.

4.2 Gadolinia Loading Patterns

The NFSV must be evaluated for the Framatome Mk-B HTP 15x15 and the Advanced Mk-BW 17x17 designs with Gadolinia at higher fuel enrichments. To accomplish this efficiently the CASMO-3 code was utilized to scope out different limiting fuel enrichments using in-core geometry and MCNP-4B was used to verify reactivity results in the context of the NFSV.

The base Westinghouse 17x17 OFA design was evaluated at an enrichment of 4.55 wt% U^{235}. Different Gadolinia patterns are modeled to determine any dependence of the pattern on k-infinity as shown in Figures 4.2-1 and 4.2-2 for the 17x17 pin configuration and Figures 4.2-3 and 4.2-4 for the 15x15 pin configuration. The results indicate that the Westinghouse OFA assembly is most limiting of the different assembly types and this is consistent with the MCNP-4B results in Section 4.1.

The minimum number of Gadolinia rods in an assembly that is to contain Gadolinia is 4 rods. The lowest Gadolinia concentration manufactured is currently 2 wt% Gadolinia. The presence of four 2 wt% Gadolinia rods in any symmetrical location in the assembly results in a K-infinity with 5.0 wt% U^{235} carrier fuel that is always less than K-infinity for an assembly with no Gadolinia at 4.55 wt% U^{235}. The use of more than 4 Gadolinia pins or pins at a higher Gadolinia concentration will only reduce K-infinity further from the cases shown in Table 4.2-1. **Therefore, the presence of Gadolinia rods under flooded conditions for the NFSV reduces K-infinity so that a maximum fuel enrichment including the enrichment tolerance of 5.0 wt% is acceptable.** The results in Table 4.2-1 are based on in-core geometry calculations and are further verified by subsequent MCNP-4B NFSV calculations in Table 4.2-2

Table 4.2-1 CASMO-3 Infinite Array Results For Framatome 17x17 and 15x15 Designs With Gadolinia Concentrations at Cold Conditions (In-Core)

Assembly Type	Description	K-infinity
West 17x17 OFA	4.55 wt% No IFBA – Base Case	1.49104
Framatome 17x17	4.55 wt% No Gad	1.48146
Framatome 17x17	5.0 wt%/4.25 wt% @ 2.0 wt% Gad; Pattern 1	1.46485
Framatome 17x17	5.0 wt%/4.25 wt% @ 2.0 wt% Gad; Pattern 2	1.46305
Framatome 15x15	4.55 wt% No Gad	1.48529
Framatome 15x15	5.0 wt%/4.25 wt% @ 2.0 wt% Gad; Pattern 3	1.46365
Framatome 15x15	5.0 wt%/4.25 wt% @ 2.0 wt% Gad; Pattern 4	1.45807

To further verify that Gadolinia assemblies at 5.0 wt% U^{235} are acceptable using the NFSV rack geometry MCNP-4B calculations are performed for the limiting Framatome Mk-B HTP 15x15 assembly design using 4 Gadolinia pins (pin pattern 4) at 2 wt% Gadolinia. The carrier enrichment is 5.0 wt% U^{235} for non-Gadolinia fuel rods and 4.25 wt% U^{235} for the Gadolinia rods. The result from this case can be compared to the non-Gadolinia case at 4.55 wt% U^{235} and is shown in Table 4.2-2.

Table 4.2-2 Flooded NFSV MCNP-4B Results for Framatome 15x15 Design

Assembly Type	Description	NFSV K-infinity +/- Sigma	Reactivity Delta to Base Case ($\Delta\rho$)
Framatome ANP 15x15 w/ 20 GTs no Gadolinia 4.55 wt% U^{235}	Flooded NFSV	0.92593 +/-0.00012	0.0
Framatome ANP 15x15 w/ 20 GTs w/ 4 Gd rods @ 2 wt% Gd @ 4.25 wt% U^{235} and all other rods at 5.0 wt% U^{235} w/no Gd	Flooded NFSV	0.91046 +/-0.00013	**-0.01835 +/-0.00021**

The results above indicate that all Framatome assemblies with a maximum carrier enrichment (including enrichment tolerance) from 4.55 wt% U^{235} to 5.0 wt% U^{235} must contain a minimum of 4 Gadolinia pins with a minimum of 2 wt% Gadolinia in the NFSV.

Figure 4.2-1 Gadolinia Fuel 17x17 – 4 Pins @ 2 wt% Gadolinia – Pattern 1

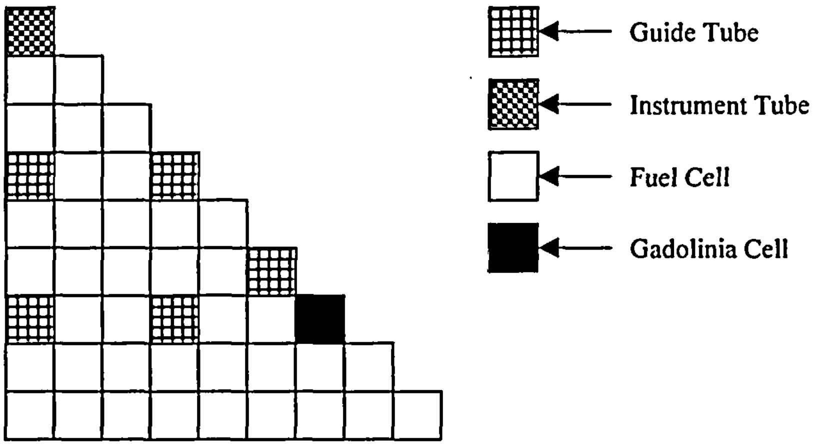


Figure 4.2-2 Gadolinia Fuel 17x17 – 4 Pins @ 2 wt% Gadolinia – Pattern 2

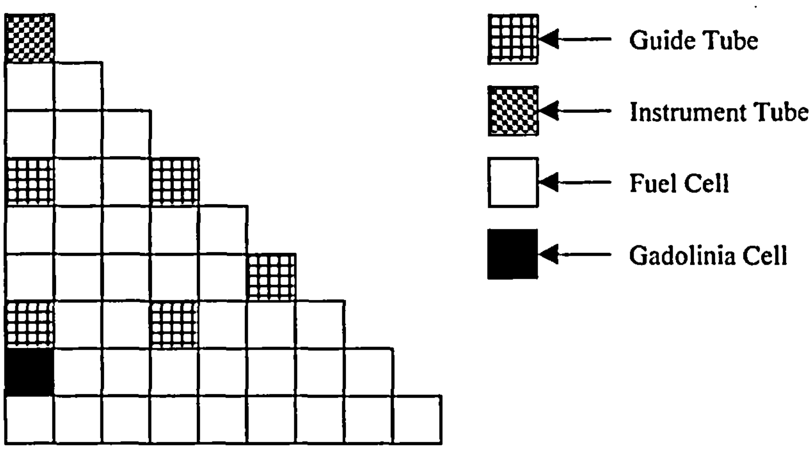


Figure 4.2-3 Gadolinia Fuel 15x15 – 4 Pins @ 2 wt% Gadolinia – Pattern 3

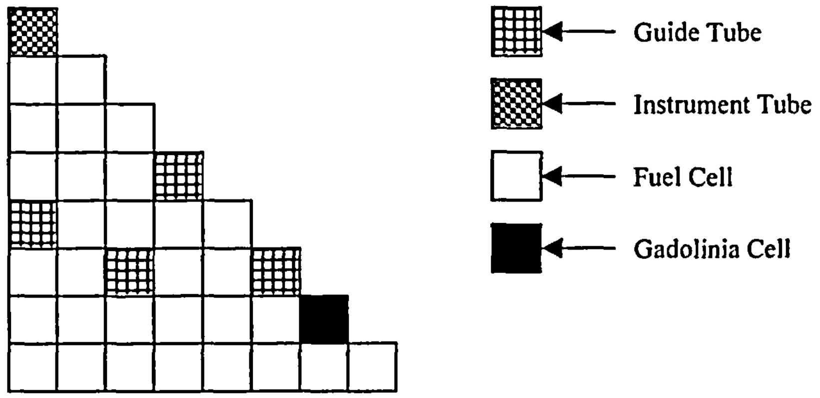
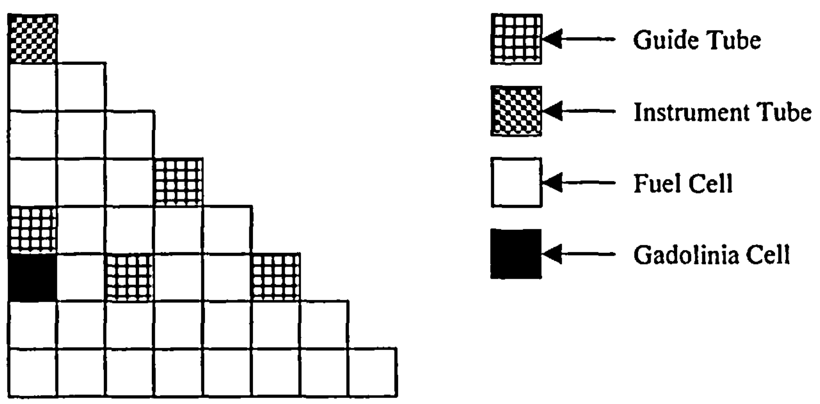


Figure 4.2-4 Gadolinia Fuel 15x15 – 4 Pins @ 2 wt% Gadolinia – Pattern 4



4.3 Interspersed Moderator Conditions

It is possible for a secondary reactivity spike to occur at low-density moderator conditions that range from approximately 3% to 10% fully dense water conditions. Such low-density water, fog, or mist conditions can occur when fire fighting equipment is used for example. Under interspersed moderator condition the separate new fuel storage racks are neutronically coupled. Therefore, modeling of racks relative to each other must be considered. Framatome ANP is interested in the reactivity difference between Framatome ANP fuel and the Westinghouse design basis fuel assembly in the context of the NFSV geometry under these misted conditions. Therefore, an infinite array of racks was modeled with fuel of finite height (144"). The pitch between fuel assemblies is 21" in the X-Y direction. Other pertinent dimensions are shown in Figure 2.3.3-1. The concrete floors and walls will not be modeled since we are interested in a reactivity delta and these materials will not affect that delta significantly. Using the scaled dimensions the NFSV was modeled and the results are shown in Table 4.3-1.

The results of Table 4.3-1 indicate the peak reactivity occurs for interspersed moderator conditions for the NFSV at 3% misted conditions regardless of assembly type. The Framatome 17x17 Advanced Mk-BW assembly is 0.00555 +/-0.00020 $\Delta\rho$ more reactive than the Westinghouse 17x17 OFA assembly. This reactivity delta is consistent in magnitude with that observed for the SFSR. The presence of a minimum of 4 Gadolinia fuel rods at 4.25 wt% U^{235} and 2 wt% Gadolinia in an assembly with the balance of rods at 5.0 wt% U^{235}, reduces the nominal k-effective to less than that for 4.55 wt% U^{235} fuel with no Gadolinia. Therefore, fuel with Gadolinia is not limiting in the NFSV.

These results indicate that the Technical Specifications for the NFSV do not need to be changed except to indicate that Framatome fuel above a maximum (including enrichment tolerance) enrichment of 4.55 wt% U^{235} must include a minimum of 4 symmetrically loaded Gadolinia fuel rods at a minimum of 2 wt% Gadolinia.

Note that the interspersed moderator k-effective calculations performed in Table 4.3-1 were performed using an infinite array of NFSV racks. Additionally 1000 cm of water was added below and above the assemblies in the rack rather than model concrete floors, walls, and ceiling. Therefore, there is no radial leakage and additional axial moderation. For misted cases this results in a much higher k-effective than the base case (k-effective = 0.8974) calculated in Reference [5]. This model is acceptable for calculating a reactivity delta between two assembly types. Also since this is a "misted" case the k-effective limit is 0.98 and the calculations do not violate that limit.

Table 4.3-1 Misted NFSV MCNP-4B Results

Assembly Type	Description	NFSV K-infinity +/- Sigma	Reactivity Delta to Base Case (Δρ)
Westinghouse OFA 17x17 design	1% Misted NFSV 4.55 wt% U-235	0.81991 +/- 0.00011	
Westinghouse OFA 17x17 design	2% Misted NFSV 4.55 wt% U-235	0.92981 +/- 0.00011	
Westinghouse OFA 17x17 design	3% Misted NFSV 4.55 wt% U-235	**0.96245 +/- 0.00011**	**0.0**
Westinghouse OFA 17x17 design	4% Misted NFSV 4.55 wt% U-235	0.95768 +/- 0.00011	
Westinghouse OFA 17x17 design	5% Misted NFSV 4.55 wt% U-235	0.93841 +/- 0.00011	
Framatome 17x17 Advanced Mk-BW	1% Misted NFSV 4.55 wt% U-235	0.82612 +/- 0.00011	
Framatome 17x17 Advanced Mk-BW	2% Misted NFSV 4.55 wt% U-235	0.93486 +/- 0.00011	
Framatome 17x17 Advanced Mk-BW	3% Misted NFSV 4.55 wt% U-235	**0.96762 +/- 0.00011**	**0.00555 +/- 0.00020**
Framatome 17x17 Advanced Mk-BW	4% Misted NFSV 4.55 wt% U-235	0.96356 +/- 0.00011	
Framatome 17x17 Advanced Mk-BW	5% Misted NFSV 4.55 wt% U-235	0.94449 +/- 0.00011	
Framatome 17x17 Advanced Mk-BW	1% Misted NFSV 5.0 wt% U-235 w/ 4 Gad pins @ 4.25 wt% U-235 and 2 wt% gad	0.81787 +/- 0.00011	
Framatome 17x17 Advanced Mk-BW	2% Misted NFSV 5.0 wt% U-235 w/ 4 Gad pins @ 4.25 wt% U-235 and 2 wt% gad	0.92235 +/- 0.00011	
Framatome 17x17 Advanced Mk-BW	3% Misted NFSV 5.0 wt% U-235 w/ 4 Gad pins @ 4.25 wt% U-235 and 2 wt% gad	**0.95325 +/- 0.00011**	**-0.01558 +/- 0.00021**
Framatome 17x17 Advanced Mk-BW	4% Misted NFSV 5.0 wt% U-235 w/ 4 Gad pins @ 4.25 wt% U-235 and 2 wt% gad	0.94855 +/- 0.00011	
Framatome 17x17 Advanced Mk-BW	5% Misted NFSV 5.0 wt% U-235 w/ 4 Gad pins @ 4.25 wt% U-235 and 2 wt% gad	0.93025 +/- 0.00011	

5.0 Summary of Results

Shown in Table 5.0-1 is a summary of the maximum K-effective values resulting from the analysis using Westinghouse K-maximum values as a starting basis. Note that no uncertainty applies to the CASMO-3 reactivity differences since these results were determined deterministically.

Table 5.0-1 Summary of K-maximum Results

Rack/Assembly Type	Description	Base Westinghouse K-maximum	Reactivity Delta added to Base Case ($\Delta\rho$)	Revised K-maximum
SFSR/Framatome Advanced Mk-BW 17x17	Region 1	0.94	0.00901	**0.94802**
SFSR/Framatome Mk-B HTP 15x15	Region 1	0.94	0.00073	0.94065
SFSR/Framatome Advanced Mk-BW 17x17	Region 2	0.94	Not Limiting Region	0.94
SFSR/Framatome Advanced Mk-BW 17x17	Region 3'	0.94	0.00485	0.94431
SFSR/Framatome Advanced Mk-BW 17x17	Interim Storage	0.94	0.00302	0.94268
SFSR/Framatome Advanced Mk-BW 17x17	All SFSR Regions w/ Gd	0.94	No Penalty	0.94
SFSR/Westinghouse 17x17 Only	Use of Pyrex Rods – Spectral Hardening	0.94	0.00688	0.94612
SFSR/Westinghouse 15x15 Only	Use of Pyrex Rods – Spectral Hardening	0.94	0.00728	0.94648
SFSR/Framatome Advanced Mk-BW 17x17	126" BPRA – Spectral Hardening	0.94	No Penalty	0.94
SFSR/Framatome Mk-BW 15x15	126" BPRA – Spectral Hardening	0.94	No Penalty	0.94
NFSV/Framatome Advanced Mk-BW 17x17	Fully Flooded Condition Fuel at 4.55 wt%	0.9495	Not Limiting, Set by Westinghouse Fuel	**0.9495**
NFSV/Framatome Mk-B HTP 15x15	Fully Flooded Condition Fuel at 4.55 wt%	0.9495	Not Limiting, Set by Westinghouse Fuel	**0.9495**
NFSV/Framatome Mk-B HTP 15x15	Fully Flooded Condition With 4 Gadolinia Rods at 2 wt% Gd Fuel at 5 wt%	0.9495	-0.01835 +/- 0.00021 [A]	0.93361

NFSV/Framatome Advanced Mk-BW 17x17	Fully Flooded Condition With 4 Gadolinia Rods at 2 wt% Gd Fuel at 5 wt%	0.9495	Not Evaluated Not Limiting	Not evaluated Not Limiting
NFSV/Framatome Advanced Mk-BW 17x17	3% Misted Condition Fuel at 4.55 wt%	0.8974	0.00555 +/- 0.00020 [A]	**0.90222**
NFSV/Framatome Mk-B HTP 15x15	3% Misted Condition Fuel at 4.55 wt%	0.8974	Not Evaluated Not Limiting	Not evaluated Not Limiting
NFSV/Framatome Advanced Mk-BW 17x17	3% Misted With 4 Gadolinia Rods at 2 wt% Gd Fuel at 5 wt%	0.8974	-0.01558 +/-0.00021 [A]	0.88536
NFSV/Framatome Mk-B HTP 15x15	3% Misted With 4 Gadolinia Rods at 2 wt% Gd Fuel at 5 wt%	0.8974	Not Evaluated Not Limiting	Not Evaluated Not Limiting

[A] One-sided upper tolerance factor conservatively assumed to be 2.0.

6.0 Conclusions

Framatome ANP fuel proposed for D.C. Cook Units 1 and 2 consists of two fuel assembly types. The first is the Advanced Mk-BW 17x17 fuel design and the second is a Standard Mk-B HTP 15x15 design. The assembly dimensions, used in the criticality analysis, are presented in an earlier section of this document. D.C. Cook Units 1 and 2 share a common NFSV and SFSR. Therefore, the analysis considered both assembly types in a common set of racks.

Spent Fuel Storage Rack Results

Comparison of the Framatome assembly designs with other designs used by D.C. Cook in the context of the SFSR at the maximum enrichment limit of 5.0 wt% U^{235} (including enrichment tolerance) indicated that the most reactive fuel design in the SFSR was the Framatome Advanced Mk-BW 17x17 design. The Advance Mk-BW 17x17 design is more reactive than earlier designs in the SFSR by 0.901 %$\Delta\rho$ when fresh fuel is loaded in Region 1 (one fresh Region 1 assembly with three burned Region 2 assemblies) locations of the SFSR. For the same configuration the Framatome Standard Mk-B HTP 15x15 design is only 0.073 %$\Delta\rho$ more reactive. When all burned fuel is loaded in Region 3 locations the reactivity increase from the Advanced Mk-BW 17x17 assembly is 0.485 %$\Delta\rho$. The Region 2 and 3 interface is not limiting. Since K-maximum is 0.94 there is adequate margin to the 0.95 criticality limit to absorb the reactivity increase from Framatome fuel in the SFSR.

Framatome Fuel With Gadolinia in the SFSR

Results indicate that the presence of at least 4 symmetric Gadolinia fuel rods with a minimum of 2 wt% Gd_2O_3 is sufficient to ensure that a Framatome assembly with Gadolinia is less reactive than an assembly without Gadolinia at the same enrichment for life. Therefore, no specific loading requirements are required for Gadolinia fuel except that there must be a minimum of four symmetric Gadolinia rods with a minimum of 2 wt% Gd_2O_3. Framatome ANP will not load less than four rods in an assembly (asymmetric loadings are not allowed) and Framatome does not manufacture Gadolinia fuel rods with less than 2 wt% Gd_2O_3.

Spectral Hardening Effects on Fuel in the SFSR

Calculations indicate the end segments of a burned assembly (approximately 9" in length) are the most reactive fuel regions (without axial blanket fuel) due to reduced burnup. The present of a WABA, BPRA, or Pyrex rod can increase reactivity with burnup due to spectral hardening. Spectral hardening results in increase Pu^{239} production and reduced U^{235} consumption with both acting to increase assembly reactivity even after the control component has been removed. Consideration of the axial burnup profile on an assembly demonstrates that although the interior segments have greater spectral hardening reactivity penalties, they are also at significantly higher burnup and the combination is less reactive than for the end segment regions. Therefore, the end segment regions of the assembly define the limiting reactivity response for a combination of spectral hardening with burnup.

Framatome ANP fuel absorber components are not present in end segment regions and therefore spectral hardening does not impose additional penalties. The same is true for WABA components used in Westinghouse fuel. The exception is Pyrex components that extend into the top and bottom 9" fuel regions. This analysis conservatively considered a 3 wt% B_4C component in the end segment region with an end segment burnup history of 13.2 GWd/mtU and defined a maximum reactivity penalty of 0.688 %$\Delta\rho$ using the Advanced Mk-BW 17x17 design and 0.728 %$\Delta\rho$ for the Framatome Mk-B HTP 15x15 design. These penalties are conservatively representative of other vendor fuel types of like kind except possibly some Combustion Engineering (CE) fuel which is not applicable to the D. C. Units. The analysis of record performed by Holtec [4] indicates that K-maximum is currently 0.94 for the SFSR. Therefore, application of these conservative penalties to all non-Framatome ANP fuel types results in a K-maximum for the SFSR of 0.94648 for Westinghouse fuel and is less than the 0.95 criticality requirement.

New Fuel Storage Rack – Flooded Condition

The NFSV was evaluated with Framatome fuel under fully flooded conditions with fully dense water (1 g/cc) at 39°F. The current maximum enrichment limit is 4.55 wt% U^{235} (including enrichment tolerance) for assemblies with no integral absorbers present such as IFBA rods or Gadolinia fuel. The design basis assembly for the NFSV is the Westinghouse OFA 17x17 fuel assembly. Evaluation of Framatome 15x15 and 17x17 fuel in the context of the NFSV at the enrichment limit reveals that Framatome fuel is less reactive than the Westinghouse design basis assembly under fully flooded conditions.

New Fuel Storage Rack with Gadolinia Fuel

For maximum enrichment limits in the NFSV above 4.55 wt% U^{235} and equal to or below 5.0 wt% U^{235} credit for IFBA or Gadolinia type absorber fuel rods must be considered. A Westinghouse analysis (Reference [5]) previously analyzed IFBA fuel rods and that analysis is not discussed here. The presence of Gadolinia fuel rods was evaluated for fresh Framatome fuel at 5.0 wt% U^{235} (both 15x15 and 17x17) both in the reactor context using CASMO-3 and the NFSV context using MCNP-4B. The CASMO-3 results indicate for both assembly types under flooded conditions that a minimum of 4 symmetrically loaded Gadolinia fuel rods at a minimum of 2 wt% Gd_2O_3 with a carrier enrichment of 5.0 wt% U^{235} are always less reactive than fuel with no Gadolinia at 4.55 wt% U^{235} regardless of the Gadolinia pattern chosen. These results were verified by evaluating the more limiting Framatome HTP 15x15 assembly in the NFSV with MCNP-4B. The results demonstrate that the presence of only 4 Gadolinia fuel rods with a minimum of 2 wt% Gd_2O_3 are required to maintain -1.835 +/- 0.021 %$\Delta\rho$ margin to K-effective for Framatome fuel at 4.55 wt% U^{235} with no Gadolinia. Therefore, assemblies with enrichments above 4.55 wt% and less than or equal to 5.0 wt% U^{235} must have at least 4 symmetrically loaded Gadolinia rods at a minimum of 2 wt% Gd_2O_3.

New Fuel Storage Rack – Interspersed Moderator Conditions

It is possible for a secondary reactivity spike to occur at low-density moderator conditions that range from approximately 3% to 10% fully dense water conditions. Such low-density water, fog, or mist conditions can occur when fire fighting equipment is used for example. Under interspersed moderator condition the separate new fuel storage racks are neutronically coupled. Therefore, modeling of racks relative to each other must be considered. Framatome ANP is interested in the reactivity difference between Framatome ANP fuel and the Westinghouse design basis fuel assembly in the context of the NFSV geometry under these misted conditions. Therefore, an infinite array of racks was modeled with fuel of finite height.

The results indicate the peak reactivity occurs for interspersed moderator conditions for the NFSV at 3% misted conditions regardless of assembly type. The Framatome 17x17 Advanced Mk-BW fuel assembly is +0.555 +/-0.020 %$\Delta\rho$ more reactive than the Westinghouse 17x17 OFA assembly. This reactivity delta is consistent in magnitude with that observed for the SFSR. The presence of a minimum of 4 Gadolinia fuel rods at 4.25 wt% U^{235} and 2 wt% Gadolinia in an assembly with the balance of rods at 5.0 wt% U^{235}, reduces the nominal k-effective to less than that for 4.55 wt% U^{235} fuel with no Gadolinia. Therefore, fuel with Gadolinia is not limiting in the NFSV. For all assembly types with or without Gadolinia for interspersed moderator conditions the k-maximum does not exceed 0.90222 (see Table 5.0-1) using MCNP-4B and is not limiting compared to fully flooded conditions with 100% dense water.

These results indicate that the Technical Specifications for the NFSV need to be changed to indicate that Framatome fuel above a maximum (including enrichment tolerance) enrichment of 4.55 wt% U^{235} must include a minimum of 4 symmetrically loaded Gadolinia fuel rods at a minimum of 2 wt% Gadolinia.

7.0 Design Requirements

The nominal dimensions of assemblies evaluated are listed in Tables 2.3.4-1 through 2.3.4-4. Westinghouse assembly tolerances are not known because this information is proprietary. However, the primary parameters that affect the tolerance penalty in the Holtec [4] and Westinghouse [5] evaluations are the design density of UO_2, fuel pellet diameter, and fuel stack height because these parameters affect assembly loading (KgU/assembly).

The following parameters and requirements shall be controlled per AEP's plant design control process.

1. For Framatome fuel to be used in D.C. Cook Units 1 and 2 the assembly design must be verified since the assembly design process is still underway for the Advanced Mk-BW 17x17 at the time of this analysis. Therefore, the Reference [4] and [5] tolerance penalty will remain applicable to this analysis of Framatome fuel if the dimensional data in Tables 2.3.4-3 and 2.3.4-4 are maintained with standard Framatome tolerances. Negative tolerances on these parameters are not of concern because they would reduce the delta reactivity penalty between assembly types.

2. For Framatome fuel absorber components must not extend into the top or bottom 9" fuel segments or further evaluation may be required.

3. Axial orientation of any fuel in the SFSR must be such that the active new fuel column does not extend above or below the Boral plate by more than 0.5".

4. Dimensional data used in Table 2.3.4-4 (Framatome Advanced Mk-BW 17x17) must be verified as consistent with design values used for manufacturing. The primary data of interest contained in Table 2.3.4-4 is that specified by item 1) above, however, the balance of parameters in this table must be shown to be acceptable.

5. Framatome fuel above a maximum enrichment (including enrichment tolerance) of 4.55 wt% U^{235} in the NFSV must include a minimum of 4 symmetrically loaded Gadolinia fuel rods at a minimum of 2 wt% Gadolinia.

8.0 Licensing Requirements

The licensing requirements in this section are viewed as a subset of the Design Requirements specified in Section 7.0. This analysis requires that the Technical Specification for the NFSV be modified to accommodate fuel with Gadolinia. The following requirement applies to the NFSV:

Framatome fuel above a maximum (including enrichment tolerance) enrichment of 4.55 wt% U^{235} in the NFSV must include a minimum of 4 symmetrically loaded Gadolinia fuel rods at a minimum of 2 wt% Gadolinia.

No changes are required to the SFSR Technical Specifications.

Final wording of the Technical Specification may differ from the wording presented here.

9.0 References

1. "MCNP-A General Monte Carlo N-Particle Transport Code, Version 4B," J.F. Briesmeister, Editor, LA-12625-M, Version 4B, Distributed by Radiation Safety Information Computational Center (RSICC) as code package CCC-660/DLC-189; MCNP4b2 distributed by RSICC as update C00660ALLCP02.

2. M. Edenius, et al., "CASMO-3 – A Fuel Assembly Burnup Program," STUDSVIK/NFA-89/3, Studsvik AB, Nykoping, Sweden, November 1989.

3. ANSI/ANS-57.2 – "Design requirements for Light Water Reactor Spent Fuel Storage Facilities at Nuclear Power Plants," American Nuclear Society, 1983.

4. Framatome Document 38-5038566-00, "AEP – D.C. Cook Unit 1 & 2 – Spent Fuel Pool Reracking Technical Specification Changes," Attachment 4, January 5, 2004. (Attachment 4 is the Holtec document)

5. Framatome Document 38-5038563-00, "AEP – D.C. Cook Unit 1 & 2 – Technical Specification 5.6.2 – Increase in Maximum Nominal Fuel Assembly Enrichment Limit, Taking Credit for Use of Integral Fuel Burnable Absorber Material," January 2, 2004. (Westinghouse document)

6. NRC Regulatory Issue Summary 2001-12 entitled "Non-conservatism In Pressurized Water Reactor Spent Fuel Storage Pool Reactivity Equivalencing Calculations, dated May 18, 2001.

7. Framatome Document 38-5038565-00, AEP – D.C. Cook Unit 1 – FSAR Pages 5-5 through 5-8A," from D.C. Cook FSAR, Amendment 243, 1/2/04.

8. ANSI/ANS-57.3 – "Design requirements for New Fuel Storage Facilities at Light Water Reactor Plants," American Nuclear Society, 1983.

9. NUREG-0800, "Rev 1, 2, and 3, "Standard Review Plan," Section 9, July 1987.

Enclosure 4 to AEP:NRC:4565

EXEMPTION REQUEST BASIS AND JUSTIFICATION FOR USE OF M5 ADVANCED ALLOY CLADDING

In accordance with 10 CFR 50.12, "Specific Exemptions," exemptions for Donald C. Cook Nuclear Plant (CNP) Unit 1 and Unit 2 are requested from the requirements specified in 10 CFR 50.44, "Standards for Combustible Gas Control System in Light-Water-Cooled Power Reactors," 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors," and 10 CFR 50 Appendix K, "ECCS Evaluation Models," paragraph I.A.5, regarding the use of zircaloy or ZIRLO as a fuel rod cladding material. The proposed exemptions will allow use of a different alloy for CNP Unit 1 and Unit 2 fuel rod cladding material.

BACKGROUND

10 CFR 50.44 and 10 CFR 50.46 provide various requirements for light water reactor system performance during and following a postulated loss-of-coolant accident (LOCA) for reactors containing uranium oxide fuel pellets clad with either zircaloy or ZIRLO. 10 CFR 50 Appendix K, Paragraph I.A.5, requires that the Baker-Just equation be used in emergency core cooling system (ECCS) evaluation models for determining the rate of energy release, hydrogen generation, and cladding oxidation for fuel rod cladding. All of these regulations, either explicitly or implicitly, state or assume that either zircaloy or ZIRLO is to be used as the fuel rod cladding material.

In order to accommodate the high fuel rod burnups that are required for current fuel management schemes and core designs, Framatome ANP, Inc. (FANP) uses a fuel rod cladding and fuel assembly structural material designated as M5. M5 is an alloy composed of primarily zirconium (approximately 99 percent) and niobium (approximately 1 percent) that has demonstrated superior corrosion resistance and reduced irradiation induced growth relative to both standard and low-tin zircaloy.

The FANP fuel assembly designs for CNP Unit 1 and Unit 2 include use of the M5 alloy as described below. The FANP fuel designs planned for use at CNP are supported by the general design criteria provided by EMF-92-116(P)(A), "Generic Mechanical Design Criteria for PWR Fuel Designs" (Reference 1). This topical report was approved by the Nuclear Regulatory Commission (NRC) by Safety Evaluation dated February 2, 1999 (Reference 2).

The M5 alloy would be used for fuel rod cladding, and may be used for fuel assembly spacer grids, fuel rod end plugs, and fuel assembly guide and instrument tubes. Such use of the M5 alloy at the CNP units will permit longer fuel residence times, higher fuel burnups, and reduced reload feed batch sizes, with corresponding improvements in fuel cycle economics. These improvements will be accompanied by increased performance margins with regard to fuel rod corrosion and fuel rod and fuel assembly growth. Reduced feed batch sizes will also help to reduce the spent fuel storage burden at CNP.

The chemical composition of the M5 alloy differs from the specifications for either zircaloy or ZIRLO. Therefore, in the absence of the requested exemption, use of the M5 alloy falls outside the language and intent of 10 CFR 50.44, 10 CFR 50.46, and 10 CFR 50 Appendix K, Paragraph I.A.5. Approval of this exemption request will allow the use of the M5 alloy as a fuel rod cladding material at CNP.

JUSTIFICATION

10 CFR 50.12 authorizes the NRC, upon application by any interested person, to grant exemptions from requirements of the regulators when special circumstances are present. Indiana Michigan Power Company (I&M) believes that such special circumstances are present in this instance to warrant exemption from the regulatory requirements of 10 CFR 50.44, 10 CFR 50.46, and 10 CFR 50 Appendix K, Paragraph I.A.5. Specifically, Section (ii) of 10 CFR 50.12(a)(2) states:

(ii) Application of the regulation in the particular circumstances would not serve the underlying purpose of the rule or is not necessary to achieve the underlying purpose of the rule.

I&M believes, for the reasons described below, that the use of the M5 advanced alloy as a fuel rod cladding material achieves the underlying purposes of 10 CFR 50.44, 10 CFR 50.46, and 10 CFR 50 Appendix K, Paragraph I.A.5.

The underlying purpose of 10 CFR 50.46 is to ensure that facilities have adequate acceptance criteria for the ECCS. FANP demonstrates in Topical Report BAW-10227P-A, "Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel," (Reference 3) that the effectiveness of the ECCS will not be affected by a change from zircaloy or ZIRLO fuel rod cladding to M5 fuel rod cladding. This topical report was approved by the NRC by Safety Evaluation dated February 4, 2000 (Reference 4). The analysis described in Reference 3 also demonstrates that the ECCS acceptance criteria applied to reactors fueled with zircaloy clad fuel are also applicable to reactors fueled with M5 fuel rod cladding.

Because the underlying purpose of 10 CFR 50.46 is achieved through the use of the M5 advanced alloy as a fuel rod cladding material, special circumstances are present under 10 CFR 50.12(a)(2)(ii) for granting an exemption to 10 CFR 50.46.

The underlying purposes of 10 CFR 50.44 and 10 CFR 50 Appendix K, Paragraph I.A.5, are to ensure that cladding oxidation and hydrogen generation are appropriately limited during a LOCA and conservatively accounted for in the ECCS evaluation model. Specifically, Appendix K requires that the Baker-Just equation be used in the ECCS evaluation model to determine the rate of energy release, cladding oxidation, and hydrogen generation. FANP demonstrates, in Appendix D of Reference 3 that the Baker-Just model is conservative in all post-LOCA scenarios with respect to the use of the M5 advanced alloy as a fuel rod cladding material. Appendix D of Reference 3 also shows that the amount of hydrogen generated in an M5-clad core during a LOCA will remain within the design bases of CNP Unit 1 and Unit 2.

Because the underlying purpose of 10 CFR 50.44 and 10 CFR 50 Appendix K, Paragraph I.A.5 is achieved through the use of the M5 advanced alloy as a fuel rod cladding material, special circumstances are present under 10 CFR 50.12(a)(2)(ii) for granting an exemption to 10 CFR 50.44 and 10 CFR 50 Appendix K, Paragraph I.A.5.

CONCLUSIONS

The underlying purpose of 10 CFR 50.44, 10 CFR 50.46, and 10 CFR 50 Appendix K, Paragraph I.A.5 is to provide adequate acceptance criteria for ECCS and to ensure that cladding oxidation and hydrogen generation are appropriately limited and accounted for during LOCA evaluation. Based upon the information presented above, the underlying purpose of 10 CFR 50.44, 10 CFR 50.46, and 10 CFR 50 Appendix K, Paragraph I.A.5 is accomplished through the use of the M5 advanced alloy as a fuel rod cladding material.

The granting of this exemption request would have no impact on plant radiological or non-radiological effluents and involves no radiological exposure.

Because these underlying purposes have been preserved, I&M concludes that the proposed exemption does not present an undue risk to the health and safety of the public and is consistent with the common defense and security.

REFERENCES

1. EMF-92-116(P)(A), "Generic Mechanical Design Criteria for PWR Fuel Designs," Siemans Power Corporation, Richland Washington, dated February 1999.

2. Letter from Frank Akstulewicz (NRC) to James A. Mallay (Siemens Power Corporation), "Acceptance for Referencing of Siemens Power Corporation Topical Report EMF-92-116(P): 'Generic Mechanical Design Criteria for PWR Fuel Designs,' (TAC NO. M84245)," dated February 2, 1999.

3. BAW-10227P-A, "Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel," Framatome Cogema Fuels (FCF), Lynchburg, Virginia, February 2000.

4. Letter from Stuart A. Richards (NRC) to T. A. Coleman (FCF), "Revised Safety Evaluation (SE) For Topical Report BAW-10227P: 'Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel,' (TAC NO. M99903)," dated February 4, 2000.

PRECEDENTS

1. Letter from Brenda Mozafari (NRC) to Dale E. Young (Florida Power Corporation), "Crystal River Unit 3 – Issuance of Exemption from 10 CFR 50.44, 10 CFR 50.46, and Appendix K to Part 50 of Title 10 for Framatome Cogema Fuels M5 Advanced Alloy for Fuel Rod Cladding (TAC NO. MB6590)," dated September 26, 2003.

2. Letter from Timothy G. Colburn (NRC) to Mark E. Warner (Amergen Energy Company), "Three Mile Island Nuclear Station Unit 1 (TMI-1), Exemption from the Requirements of 10 CFR Part 50, Sections 50.44, 50.46, and Appendix K for Framatome Cogema Fuels (FCF) M5 Advanced Alloy for Fuel Rod Cladding (TAC NO. MB0787)," dated May 8, 2001.

3. Letter from Ronald W. Hernan (NRC) to J. A. Scalice (Tennessee Valley Authority), "Sequoyah Nuclear Plant, Units 1 and 2 – Issuance of Exemption from the Requirements of 10 CFR 50.44, 50.46, and 10 CFR Part 50, Appendix K, to Allow the Use of the M5 Alloy for Fuel Cladding and Structural Material (TAC NOS. MA8223 and MA8224)," dated July 29, 2000.

4. Letter from David E. LaBarge (NRC) to W. R. McCollum, Jr. (Duke Energy Corporation), "Oconee Nuclear Station, Units 1, 2, and 3 Re: Exemption from Fuel Cladding Requirements (TAC NOS. MA6466, MA6467, and MA6468)," dated March 23, 2000.

5. Letter from Douglas V. Pickett (NRC) to Guy G. Campbell (FirstEnergy Nuclear Operating Company), "Issuance of Exemption from 10 CFR 50.44, 10 CFR 50.46, and Appendix K to Part 50 of Title 10 for Framatome Cogema Fuels M5 Advanced Alloy for Fuel Rod Cladding – Davis Besse Nuclear Power Station (TAC NO. MA3589)," dated March 15, 2000.

Enclosure 5 to AEP:NRC:4565

EXEMPTION REQUEST BASIS AND JUSTIFICATION FOR EXEMPTION FROM 10 CFR 70.24

In accordance with 10 CFR 70.17, "Specific Exemptions," Indiana Michigan Power Company (I&M) requests an exemption from the requirements of 10 CFR 70.24 for Donald C. Cook Nuclear Plant (CNP). The proposed exemption will provide continued relief from the requirements of 10 CFR 70.24(a)(1) and (2) regarding the detection, sensitivity, and coverage capabilities of the criticality monitors, and from (a)(3) regarding emergency procedures for each area in which licensed special nuclear material is handled, used, or stored.

BACKGROUND

10 CFR 70.24(a) states the requirements for a monitoring system that will energize clearly audible alarms if accidental criticality occurs in each area in which special nuclear material (SNM) is handled, used or stored. Also, 10 CFR 70.24(a) requires that emergency procedures be maintained for each area in which licensed SNM is handled, used, or stored to ensure that all personnel withdraw to an area of safety upon the sounding of the alarm. These procedures must include the conduct of drills to familiarize personnel with the evacuation plan, designation of responsible individuals for determining the cause of the alarm, and placement of radiation survey instruments in accessible locations for use in such an emergency.

An exemption from the requirements of 10 CFR 70.24(a)(1), (2), and (3) was previously granted to CNP on October 28, 1996 (Reference 1). Based on proposed changes to the new fuel storage rack reactivity requirements and methodology changes associated with the spent and new fuel storage rack criticality analyses in Enclosure 2 of this letter, Nuclear Regulatory Commission (NRC) is requested to approve an exemption to 10 CFR 70.24 which will provide continued relief for CNP.

JUSTIFICATION

The specific requirements for granting exemptions from Part 70 regulations are set forth in 10 CFR 70.17. Under Section 70.17(a), the Commission is authorized to grant an exemption as it determines is authorized by law and will not endanger life or property or the common defense and security, and is otherwise in the public interest.

As described in Section 9.7 of the Updated Final Safety Analysis Report, CNP has radiation monitors in the Auxiliary Building and Containment fuel handling areas, and there are procedures for responding to alarms from these monitors. However, CNP does not have a criticality accident monitoring system that meets the requirements of 10 CFR 70.24(a)(1) or (2), nor does CNP have emergency procedures to respond to the sounding of a criticality monitor alarm meeting the requirements of 10 CFR 70.24(a)(3). Therefore, I&M requests continued relief from these requirements. The basis for the previous exemption to 10 CFR 70.24 was that inadvertent or accidental criticality would be precluded through compliance with CNP Technical Specifications (TS), the geometric spacing of fuel assemblies in the spent and new fuel storage racks, and administrative controls imposed on fuel handling procedures. The justification provided below demonstrates that CNP TS, design, and administrative controls remain such that inadvertent criticality is precluded in SNM handling and storage areas at CNP.

Handling

Verbatim compliance with existing fuel handling procedures ensures safe subcritical conditions when handling fuel assemblies, even under adverse moderation conditions. CNP procedures allow movement of only one fuel assembly over the spent fuel storage racks at any one time and only allow the movement of one fuel assembly into the new fuel storage racks at one time during receipt and storage of fresh fuel assemblies. Procedures only allow movement of multiple fuel assemblies when the auxiliary building crane is being used to move fresh fuel assemblies from the new fuel storage racks to the pool elevator while the spent fuel bridge crane is moving fresh fuel assemblies from the elevator to its intended spent fuel storage location. No procedure allows simultaneous handling of more than one assembly with any particular handling device. Furthermore, procedures require that any fuel assembly placement in a storage location complies with TS. Therefore, procedures and design features prohibit handling of fuel assemblies that may result in unsafe or critical conditions.

Framatome ANP, Inc. (FANP) fuel assemblies are very similar in design, weight, and reactivity to the current design basis (Westinghouse) fuel assemblies. Therefore, receipt, inspection, and placement into the new fuel storage racks and handling in the spent fuel pool and reactor vessel will not require changes or alterations that would affect the administrative controls that prevent an inadvertent criticality.

Use and Storage

SNM, as nuclear fuel, is stored in the spent fuel pool and the new fuel storage rack. The spent fuel pool is used to store irradiated fuel under water after its discharge from the reactor, and new fuel prior to loading into the reactor. New fuel is stored dry (in air) in the new fuel storage rack. Spent and new fuel storage rack geometric spacing requirements have not changed since issuance of the October 28, 1996 exemption to 10 CFR 70.24.

SNM is also present in the form of fissile material incorporated into nuclear instrumentation. The small quantity of SNM present in these items precludes an inadvertent criticality.

CNP Unit 1 and Unit 2 share a common spent fuel storage rack and a common new fuel storage rack. At the time the 10 CFR 70.24 exemption was granted on October 28, 1996, the spent fuel pool was designed to store the fuel in a geometric array that precluded criticality. At that time, CNP Unit 1 and Unit 2 TS 5.6.1.1 required that the spent fuel racks be designed and maintained such that the effective neutron multiplication factor (K_{eff}) would remain less than 0.95. Analysis demonstrated that this requirement was met even in the event of a fuel handling accident. In addition, CNP Unit 1 and Unit 2 TS required the new fuel storage rack be designed and maintained to preclude criticality by maintaining a K_{eff} to not exceed 0.98 under optimum moderation conditions. At the time of the exemption to 10 CFR 70.24, the new fuel storage rack design precluded criticality by maintaining K_{eff} less than or equal to 0.95 when the racks are fully loaded and in the normal dry condition or fully flooded with unborated water. Since issuance of the October 28, 1996 exemption to 10 CFR 70.24, the above design requirements precluding criticality have changed only for the new fuel storage racks to add fuel burnable absorber requirements for fuel assembly maximum nominal enrichment between 4.55 and 4.95 weight percent U-235.

Enclosure 2 of this letter proposed changes to the new fuel storage rack reactivity requirements in the facility TS as a result of the change to the design basis fuel assembly. The proposed TS changes will allow the use of Gadolinia as a fuel burnable absorber versus the current TS requirement of Integral Fuel Burnable Absorber to ensure adequate reactivity margin in the new fuel storage racks. In addition, Enclosure 2 presents changes in the criticality analysis methodology to support the proposed TS changes. FANP performed criticality analyses (Enclosure 3) for the spent and new fuel storage racks to bound both the existing fuel assemblies and FANP fuel assemblies using the results of the licensing basis criticality analyses. The criticality analysis demonstrates that the TS requirements for K_{eff} in the spent and new fuel storage racks continue to be met at a 95 percent probability and a 95 percent confidence level with the proposed changes to the TS.

FANP fuel assemblies are very similar in design, weight, and reactivity to the current design basis fuel assemblies. The TS change allowing a FANP fuel burnable absorber, Gadolinia, to ensure adequate reactivity margin in the new fuel storage racks is supported by criticality analysis. Therefore, the storage of FANP fuel assemblies will remain within the TS limits for K_{eff}.

CONCLUSION

In accordance with 10 CFR 70.17(a), I&M requests exemption from the requirements of 10 CFR 70.24 and has demonstrated that there is reasonable assurance that inadvertent or accidental criticality with FANP fuel assemblies will be precluded during handling and storage through compliance with CNP TS, the present design configuration, and fuel handling procedures. I&M believes that the life, property or common defense, and security of the public will not be endangered. Compliance with the requirements of 10 CFR 70.24(a)(1), (2), and (3) would not increase the margin of safety, and, therefore, in accordance with the provisions in 10 CFR 70.17(a), I&M considers the requested exemption to be justified.

REFERENCE

1. Letter from John B. Hickman (NRC) to E. E. Fitzpatrick (I&M), "Exemption from 10 CFR 70.24 Criticality Monitoring Requirements – Donald C. Cook Nuclear Plant, Units 1 and 2 (TAC NOS. M95197 and M95198)," dated October 28, 1996.

PRECEDENTS

1. Letter from Robert E. Martin (NRC) to Dhiaa Jamil (Duke Energy Corporation), "McGuire Nuclear Station Re: Issuance of Exemption to 10 CFR 70.24, Criticality Accident Requirements (TAC NOS. M97863, M97864, MB5014 and MB5015)," dated January 31, 2003.

2. Letter from Robert J. Fritz (NRC) to Randall K. Edington (Entergy), "Exemption from Criticality Accident Requirements – River Bend Station, Unit 1 (TAC NOS. M98877)," dated December 2, 1998.

3. Letter from Gordon Edison (NRC) to J. P. O'Hanlon (Virginia Electric and Power Company), "Issuance of Revised Exemption from the Requirements of 10 CFR 70.24(a) - Surry Power Station (TAC NOS. MA0657 and MA0658)," dated July 15, 1998.

4. Letter from Monan C. Thadani (NRC) to Garrett D. Edwards (PECO Energy Company), "Issuance of Exemption from the Requirements of 10 CFR 70.24 Peach Bottom Atomic Power Station, Units 2 and 3 - (TAC NOS. MA1342 and MA1343)," dated June 22, 1998.

5. Letter from N. Kalyanam (NRC) to J. P. O'Hanlon (Virginia Electric and Power Company), "North Anna Electric Power Station, Units 1 and 2 - Exemption from 10 CFR 70.24(a), Criticality Accident Monitoring Requirements (TAC NOS. M97906 and M97907)," dated September 23, 1997.

Attachment 1A to AEP:NRC:4565

CNP UNIT 1 TECHNICAL SPECIFICATION PAGES
MARKED TO SHOW PROPOSED CHANGES

5-4

5-8

5-8a

5.2 CONTAINMENT (Continued)

DESIGN PRESSURE AND TEMPERATURE

5.2.2 The reactor containment building is designed and shall be maintained in accordance with the original design provisions contained in Section 5.2.2 of the FSAR.

PENETRATIONS

5.2.3 Penetrations through the reactor containment building are designed and shall be maintained in accordance with the original design provisions contained in Section 5.4 of the FSAR with allowance for normal degradation pursuant to the applicable Surveillance Requirements.

5.3 REACTOR CORE

FUEL ASSEMBLIES

5.3.1 The reactor core shall contain 193 fuel assemblies with each fuel assembly containing 204 fuel rods clad with Zircaloy-4, ~~or~~ ZIRLO, or M5, except that limited substitutions of zirconium alloy or stainless steel filler rods, in accordance with NRC-approved applications of fuel rod configurations, may be used. Fuel assemblies shall be limited to those fuel designs that have been analyzed with applicable NRC staff-approved codes and methods, and shown by tests or analysis to comply with all fuel safety design bases. A limited number of lead test assemblies that have not completed representative testing may be placed in non-limiting core regions. Each fuel rod shall have a nominal active fuel length of 144 inches. The initial core loading shall have a maximum enrichment of 3.35 weight percent U-235. Reload fuel shall be similar in physical design to the initial core loading and shall have a maximum nominal enrichment of 4.95 weight percent U-235.

CONTROL ROD ASSEMBLIES

5.3.2 The reactor core shall contain 53 full length and no part length control rod assemblies. The full length control rod assemblies shall contain a nominal 142 inches of absorber material. The nominal values of absorber material shall be 80 percent silver, 15 percent indium and 5 percent cadmium. All control rods shall be clad with stainless steel tubing.

5.6 FUEL STORAGE (Continued)

CRITICALITY - NEW FUEL

5.6.2 The new fuel storage racks are designed and shall be maintained with:

a. ~~Westinghouse f~~Fuel assemblies having either a maximum enrichment of 4.55 weight ~~%~~percent U-235, or an enrichment ~~between~~ greater than 4.55 and less than or equal to 4.95 weight ~~%~~percent U-235 with ~~greater than or equal to the minimum number of integral fuel burnable absorber pins as shown on Figure 5.6-4 (interpolation of the Boron-10 loading between 1.0X and 1.5X and between 1.5X and 2.0X is acceptable)~~a minimum of 4 symmetrically loaded Gadolinia fuel rods at a minimum of 2.0 weight percent Gadolinia;

b. $k_{eff} \leq 0.95$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 9.7 of the UFSAR;

c. $k_{eff} \leq 0.98$ if moderated by aqueous foam, which includes an allowance for uncertainties as described in Section 9.7 of the UFSAR; and

d. A nominal 21 inch center to center distance between fuel assemblies placed in the storage racks.

DRAINAGE

5.6.3 The spent fuel storage pool is designed and shall be maintained to prevent inadvertent draining of the pool below elevation 629'4".

~~Figure 5.6-4: New Fuel Storage Rack Integral Fuel Burnable Absorber (IFBA) Requirements~~

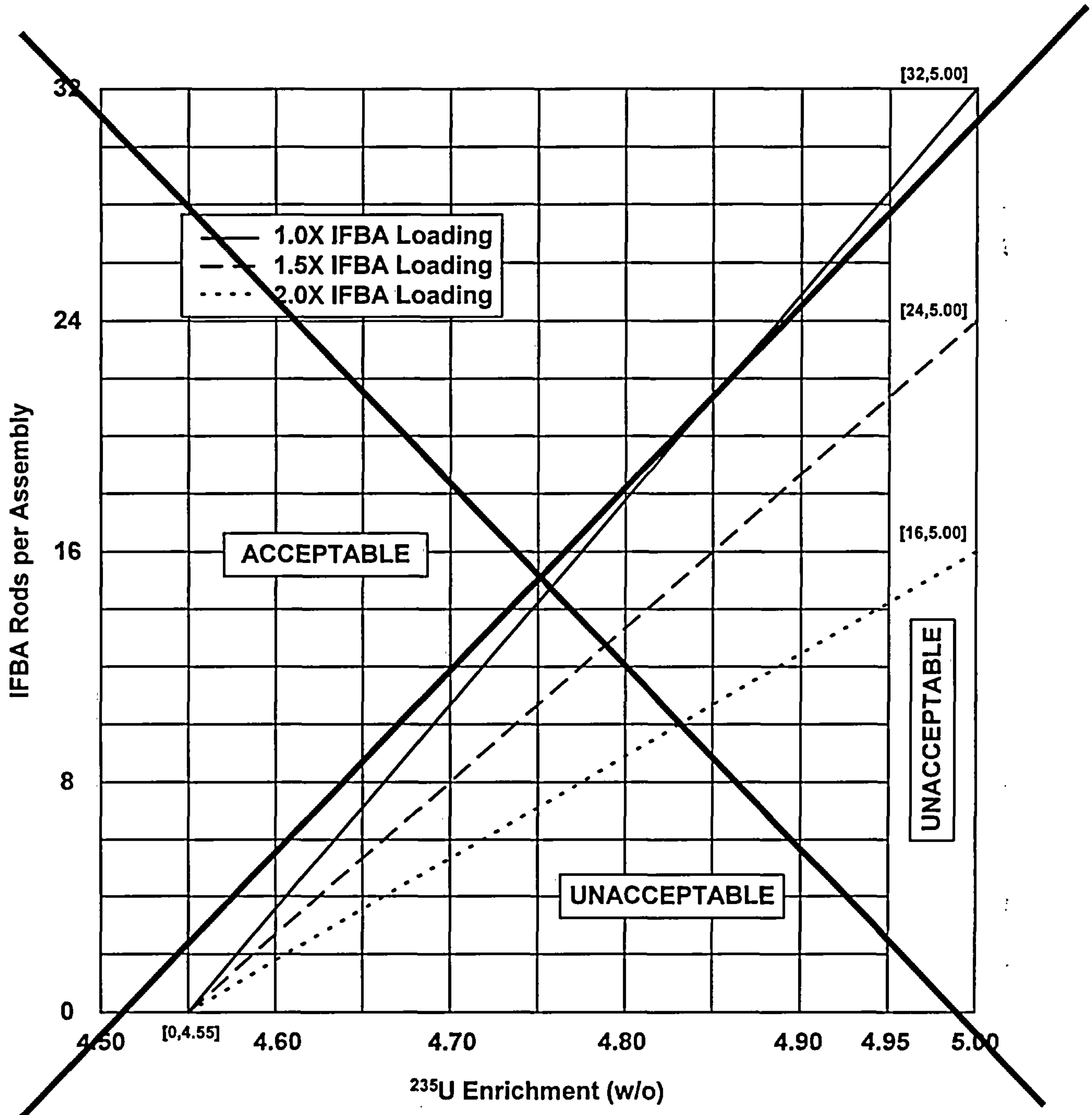


Figure 5.6-4 intentionally deleted.

Attachment 1B to AEP:NRC:4565

CNP UNIT 2 TECHNICAL SPECIFICATION PAGES
MARKED TO SHOW PROPOSED CHANGES

5-4

5-9

5-9a

5.3 REACTOR CORE

FUEL ASSEMBLIES

5.3.1 The reactor core shall contain 193 fuel assemblies with each fuel assembly containing 264 fuel rods clad with Zircaloy-4, ~~or~~ ZIRLO, or M5, except that limited substitutions of zirconium alloy or stainless steel filler rods, in accordance with NRC-approved applications of fuel rod configurations, may be used. Fuel assemblies shall be limited to those fuel designs that have been analyzed with applicable NRC staff-approved codes and methods, and shown by tests or analyses to comply with all fuel safety design bases. A limited number of lead test assemblies that have not completed representative testing may be placed in non-limiting core regions. Each fuel rod shall have a nominal active fuel length of 144 inches. The initial core loading shall have a maximum enrichment of 3.3 weight percent U-235. Reload fuel shall be similar in physical design to the initial core loading and may be nominally enriched up to 4.95 weight percent U-235.

CONTROL ROD ASSEMBLIES

5.3.2 The reactor core shall contain 53 full length and no part length control rod assemblies. The full length control rod assemblies shall contain a nominal 142 inches of absorber material. The nominal values of absorber material shall be 80 percent silver, 15 percent indium and 5 percent cadmium. All control rods shall be clad with stainless steel tubing.

5.4 REACTOR COOLANT SYSTEM

DESIGN PRESSURE AND TEMPERATURE

5.4.1 The reactor coolant system is designed and shall be maintained:

a. In accordance with the code requirements specified in Section 4.1.6 of the FSAR, with allowance for normal degradation pursuant to the applicable Surveillance Requirements.

b. For a pressure of 2485 psig, and

c. For a temperature of 650°F, except for the pressurizer which is 680°F.

5.6 FUEL STORAGE (Continued)

CRITICALITY - NEW FUEL

5.6.2 The new fuel storage racks are designed and shall be maintained with:

a. Fuel assemblies having either a maximum enrichment of 4.55 weight ~~%~~percent U-235, or an enrichment ~~between~~ greater than 4.55 and less than or equal to 4.95 weight ~~%~~percent U-235 with ~~the minimum number of integral fuel burnable absorber pins as shown on Figure 5.6-4 (interpolation of the Boron-10 loading between 1.0X and 1.5X and between 1.5X and 2.0X is acceptable)~~a minimum of 4 symmetrically loaded Gadolinia fuel rods at a minimum of 2.0 weight percent Gadolinia;

b. $k_{eff} \leq 0.95$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 9.7 of the UFSAR;

c. $k_{eff} \leq 0.98$ if moderated by aqueous foam, which includes an allowance for uncertainties as described in Section 9.7 of the UFSAR; and

d. A nominal 21 inch center to center distance between fuel assemblies placed in the storage racks.

DRAINAGE

5.6.3 The spent fuel storage pool is designed and shall be maintained to prevent inadvertent draining of the pool below elevation 629'4".

CAPACITY

5.6.4 The spent fuel storage pool is designed and shall be maintained with a storage capacity limited to no more than 3613 fuel assemblies.

~~Figure 5.6-4: New Fuel Storage Rack Integral Fuel Burnable Absorber (IFBA) Requirements~~

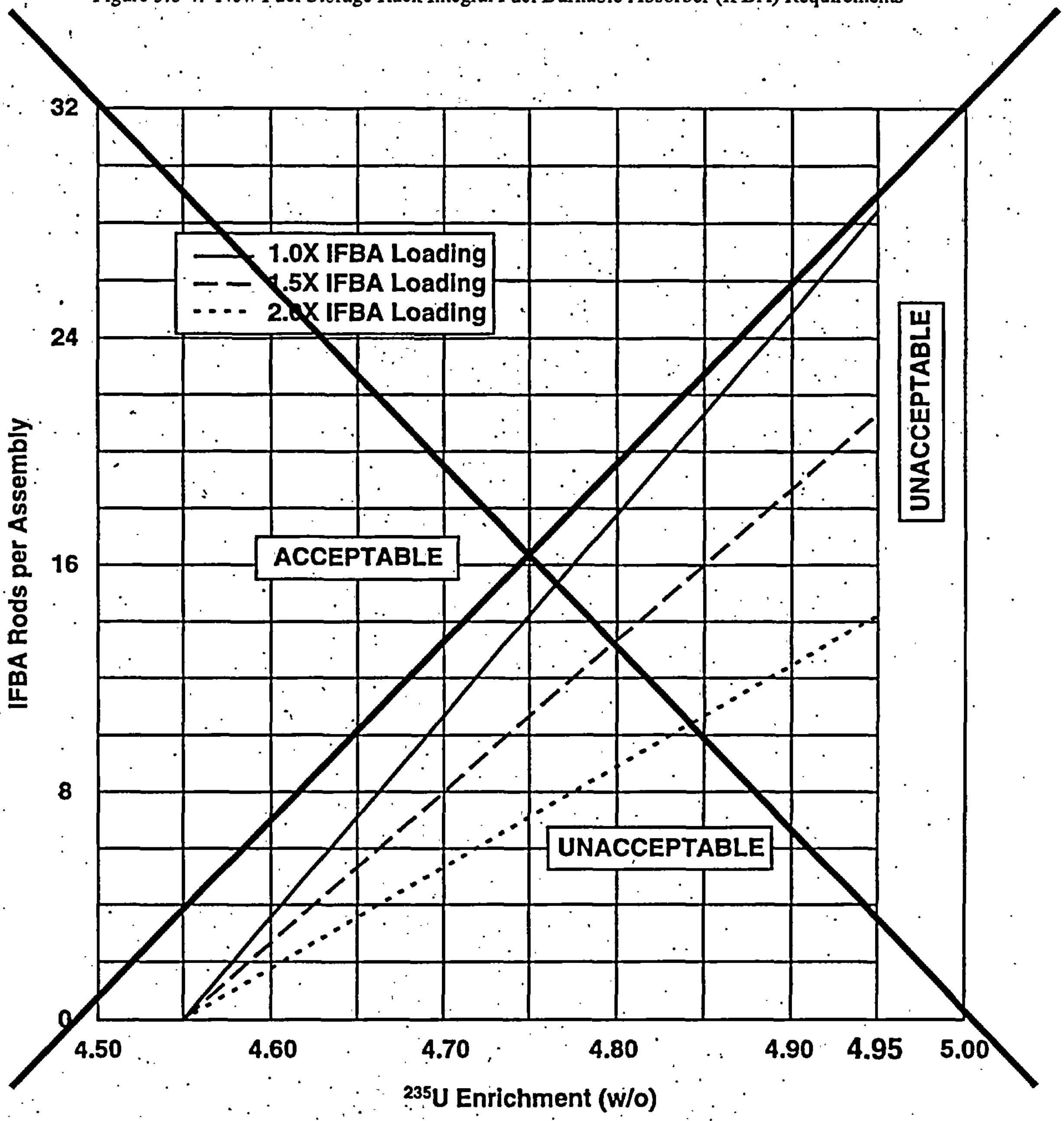


Figure 5.6-4 intentionally deleted.

Attachment 2A to AEP:NRC:4565

CNP UNIT 1 TECHNICAL SPECIFICATION PAGES
RETYPED WITH PROPOSED CHANGES INCORPORATED

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5.2 CONTAINMENT (Continued)

DESIGN PRESSURE AND TEMPERATURE

5.2.2 The reactor containment building is designed and shall be maintained in accordance with the original design provisions contained in Section 5.2.2 of the FSAR.

PENETRATIONS

5.2.3 Penetrations through the reactor containment building are designed and shall be maintained in accordance with the original design provisions contained in Section 5.4 of the FSAR with allowance for normal degradation pursuant to the applicable Surveillance Requirements.

5.3 REACTOR CORE

FUEL ASSEMBLIES

5.3.1 The reactor core shall contain 193 fuel assemblies with each fuel assembly containing 204 fuel rods clad with Zircaloy-4, ZIRLO, or M5, except that limited substitutions of zirconium alloy or stainless steel filler rods, in accordance with NRC-approved applications of fuel rod configurations, may be used. Fuel assemblies shall be limited to those fuel designs that have been analyzed with applicable NRC staff-approved codes and methods, and shown by tests or analysis to comply with all fuel safety design bases. A limited number of lead test assemblies that have not completed representative testing may be placed in non-limiting core regions. Each fuel rod shall have a nominal active fuel length of 144 inches. The initial core loading shall have a maximum enrichment of 3.35 weight percent U-235. Reload fuel shall be similar in physical design to the initial core loading and shall have a maximum nominal enrichment of 4.95 weight percent U-235.

CONTROL ROD ASSEMBLIES

5.3.2 The reactor core shall contain 53 full length and no part length control rod assemblies. The full length control rod assemblies shall contain a nominal 142 inches of absorber material. The nominal values of absorber material shall be 80 percent silver, 15 percent indium and 5 percent cadmium. All control rods shall be clad with stainless steel tubing.

5.6 FUEL STORAGE (Continued)

CRITICALITY - NEW FUEL

5.6.2 The new fuel storage racks are designed and shall be maintained with:

a. Fuel assemblies having either a maximum enrichment of 4.55 weight percent U-235, or an enrichment greater than 4.55 and less than or equal to 4.95 weight percent U-235 with a minimum of 4 symmetrically loaded Gadolinia fuel rods at a minimum of 2.0 weight percent Gadolinia;

b. $k_{eff} \leq 0.95$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 9.7 of the UFSAR;

c. $k_{eff} \leq 0.98$ if moderated by aqueous foam, which includes an allowance for uncertainties as described in Section 9.7 of the UFSAR; and

d. A nominal 21 inch center to center distance between fuel assemblies placed in the storage racks.

DRAINAGE

5.6.3 The spent fuel storage pool is designed and shall be maintained to prevent inadvertent draining of the pool below elevation 629'4".

Figure 5.6-4 intentionally deleted.

Attachment 2B to AEP:NRC:4565

CNP UNIT 2 TECHNICAL SPECIFICATION PAGES
RETYPED WITH PROPOSED CHANGES INCORPORATED

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5.3 REACTOR CORE

FUEL ASSEMBLIES

5.3.1 The reactor core shall contain 193 fuel assemblies with each fuel assembly containing 264 fuel rods clad with Zircaloy-4, ZIRLO, or M5 except that limited substitutions of zirconium alloy or stainless steel filler rods, in accordance with NRC-approved applications of fuel rod configurations, may be used. Fuel assemblies shall be limited to those fuel designs that have been analyzed with applicable NRC staff-approved codes and methods, and shown by tests or analyses to comply with all fuel safety design bases. A limited number of lead test assemblies that have not completed representative testing may be placed in non-limiting core regions. Each fuel rod shall have a nominal active fuel length of 144 inches. The initial core loading shall have a maximum enrichment of 3.3 weight percent U-235. Reload fuel shall be similar in physical design to the initial core loading and may be nominally enriched up to 4.95 weight percent U-235.

CONTROL ROD ASSEMBLIES

5.3.2 The reactor core shall contain 53 full length and no part length control rod assemblies. The full length control rod assemblies shall contain a nominal 142 inches of absorber material. The nominal values of absorber material shall be 80 percent silver, 15 percent indium and 5 percent cadmium. All control rods shall be clad with stainless steel tubing.

5.4 REACTOR COOLANT SYSTEM

DESIGN PRESSURE AND TEMPERATURE

5.4.1 The reactor coolant system is designed and shall be maintained:

a. In accordance with the code requirements specified in Section 4.1.6 of the FSAR, with allowance for normal degradation pursuant to the applicable Surveillance Requirements.

b. For a pressure of 2485 psig, and

c. For a temperature of 650°F, except for the pressurizer which is 680°F.

5.6 FUEL STORAGE (Continued)

CRITICALITY - NEW FUEL

5.6.2 The new fuel storage racks are designed and shall be maintained with:

a. Fuel assemblies having either a maximum enrichment of 4.55 weight percent U-235, or an enrichment greater than 4.55 and less than or equal to 4.95 weight percent U-235 with a minimum of 4 symmetrically loaded Gadolinia fuel rods at a minimum of 2.0 weight percent Gadolinia;

b. $k_{eff} \leq 0.95$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 9.7 of the UFSAR;

c. $k_{eff} \leq 0.98$ if moderated by aqueous foam, which includes an allowance for uncertainties as described in Section 9.7 of the UFSAR; and

d. A nominal 21 inch center to center distance between fuel assemblies placed in the storage racks.

DRAINAGE

5.6.3 The spent fuel storage pool is designed and shall be maintained to prevent inadvertent draining of the pool below elevation 629'4".

CAPACITY

5.6.4 The spent fuel storage pool is designed and shall be maintained with a storage capacity limited to no more than 3613 fuel assemblies.

Figure 5.6-4 intentionally deleted.