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FRAMATOME ANP, INC. CRITICALITY EVALUATION
REPORT NO. 77-5069740-NP-00 DATED AUGUST 2005
(NON-PROPRIETARY VERSION)

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Shearon Harris Criticality Evaluation

77-5069740-NP-00

August 2005

Framatome ANP

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Executive Summary

The dry new fuel storage in the New Fuel Inspection Pit (dry storage pit) was evaluated and criticality criteria were met for both the fully flooded and interspersed moderator (misted or fog) cases. The design basis of the evaluation was the Framatome Advanced HTP-17 fuel assembly design with a maximum enrichment of 5.0 wt% and no Boraflex absorbers in the racks.

The Pool A and B PWR racks were evaluated using the Advanced HTP-17 assembly design assuming total Boraflex loss. Rack interaction effects were evaluated for fresh PWR, spent PWR, and spent BWR racks. A revised burnup versus enrichment curve was generated for Pool B PWR racks that are applicable to Pool A PWR racks in addition to soluble boron requirements. The burnup versus enrichment curve is provided in Section 3.1. Pool A and B requirements are:

1. The fresh fuel rack requires a checkerboarded loading pattern limited to two assemblies diagonally in any four rack cells, i.e., 2 of 4 checkerboard loading pattern for the assemblies in the rack.

2. The PWR spent fuel racks assemblies must demonstrate that they have an assembly average burnup greater than the BUC required minimum burnup for the assembly initial enrichment. Assemblies that meet this requirement may be stored unrestricted. Assemblies that fail this requirement may NOT be stored in the BUC rack and shall be treated as fresh fuel assemblies for the purposes of storage in Pools A and B.

    i. Plant measured assembly average burnup shall be decreased by the plant measured burnup uncertainty; typically [ ], specific value to be determined by plant procedures).

    ii. Assembly initial enrichment is to be the maximum planar average enrichment if the assembly enrichment varies by axial location.

    iii. Optionally, assembly initial enrichment may be conservatively increased by [ ] wt% U^{235} for enrichment uncertainty. Note that BUC loading curve already includes a [ ] wt% U^{235} enrichment uncertainty.

3. If fresh fuel and irradiated fuel are stored in the same rack module there must be an interface region between the two fuel regions. An interface between the fresh and irradiated fuel regions consists of either a single row containing a checkerboard of irradiated assemblies face adjacent with water holes in the fresh region, or a single row of water holes.

4. A minimum 500 ppm soluble boron concentration is required for fuel storage at normal conditions without fuel handling activity.

5. A minimum 1000 ppm soluble boron concentration is required for fuel storage with fuel handling activity with fresh fuel assemblies or spent fuel assemblies that do not meet the BUC requirements for storage in a BUC designated rack.

6. A minimum 500 ppm soluble boron concentration is required for fuel storage with fuel handling activity with BUC rack qualified spent fuel assemblies. This value is not applicable to handling fresh fuel assemblies or spent fuel assemblies that do not meet the BUC requirements for storage in a BUC designated rack being moved.

7. Irradiated BWR fuel must have a $K_{95/95} \leq$ [ ] to be placed in the BWR rack with 100% Boraflex degradation.

8. Irradiated PWR fuel that satisfies the irradiated fuel loading curve may be placed in any PWR spent rack cell or as a replacement for a fresh assembly in the fresh rack.

9. The Spent Fuel Pool water temperature shall not exceed 150 °F (65.56 °C) for normal operations.

10. New fuel assembly designs not bounded by the design basis assembly shall be demonstrated to be less reactive than the design basis assembly at all assembly average burnups in the SFP rack geometry in order to qualify for storage.

11. Non Fuel Bearing Containers (NFBC) may be placed in any spent PWR rack cell.

12. NFBC with non-fuel bearing components may be stored in the water holes in the fresh rack provided they are loaded with a loading pattern no greater than 1 NFBC in any 6 rack cells or as a replacement for fresh and irradiated fuel assemblies.

13. Framatome fuel assemblies may not be stored in spent fuel PWR racks if they were irradiated with a removable absorber component such as a WABA or Burnable Poison Rod Assembly (BPRA). Gadolinia bearing fuel is not restricted.

14. No restriction on placement of fresh PWR racks adjacent to either the spent PWR or BWR racks.

1.0 Introduction

The Shearon Harris Nuclear Power Plant (SHNPP, HNP, or Shearon Harris) requires a criticality analysis to address Boraflex dissolution in the PWR racks that are contained in Pools A and B. These pools can store both irradiated and fresh assemblies. Additionally, Pools A and B have BWR storage racks in close proximity to the Boraflex PWR racks that require evaluation of rack interaction effects. This study addresses the PWR racks in Pools A and B. Also evaluated are the dry racks external to the pool locations.

This study demonstrates that the assumption of total Boraflex degradation in Pools A and B requires credit for soluble boron to satisfy criticality criteria for both fresh and spent fuel racks. The dry racks have no Boraflex dissolution; however, at the direction of Progress Energy this analysis did not credit the Boraflex in the dry rack analyses. Additionally, the dry racks have certain locations that are locked out to prevent assembly insertion.

The fuel racks used for both pool and dry storage were manufactured with the same unit cell design by the same manufacturer. Three different rack module arrays are used (6 x 10, 7 x10 and 6 x 8). The individual PWR assembly rack cell model is applicable to all PWR Boraflex module arrays.

The pools contain irradiated fuel from HNP and another Progress Energy Facility, Robinson Nuclear Plant. HNP uses 17 x 17 fuel and the Robinson Nuclear Plant fuel is 15 x 15. The criticality analysis also addresses a new fuel assembly design: the Advanced HTP-17, marketed by Framatome ANP (FANP).

The analytical methods are discussed in Section 2.0. The results and administrative requirements for Pool A and B are provided in Section 3.0. The Dry New Fuel Storage Pit analysis is discussed in Section 4.0. Criticality results are summarized in Section 5.0. Design Requirements are discussed in Section 6.0 and licensing Requirements in Section 7.0.

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2.0 Analytical Methods

The analytical methods are discussed in this section. It briefly describes computer programs, licensing requirements, and computer models used for this analysis.

2.1 Computer Programs and Standards

1. The KENO-V.a computer code[1], a part of the SCALE 4.4a package, was used to calculate the k_{eff} of 100 critical systems (criticality benchmark experiments). The 44 group cross section set was used by the SCALE driver module CSAS25, which used modules BONAMI-2 and NITAWL to perform spatial and energy self-shielding of the cross sections for use in KENO-V.a.

   This calculation is performed according to the general methodology described in the Appendix Reference A.2 (NUREG/CR-6698 "Guide for Validation of Nuclear Criticality Safety Methodology") that is also briefly described in Appendix A. This appendix includes a discussion of the critical experiments selected to benchmark the computer code system, the results of the criticality calculations, the trending analysis, the basis for the statistical technique chosen, the bias, and the bias uncertainty.

   This code system is run on the Framatome ANP Linux-based scientific cluster. The hardware and software configurations are governed by Framatome ANP procedures to ensure calculational consistency in licensing applications. The code modules are installed on the system and the installation check cases are run to insure the results are consistent with the installation check cases that are provided with the code. The binary executables are put under configuration control so that any changes in the software will require re-certification. The hardware configuration of each machine in the cluster is documented so that any significant change in hardware or operating system that could result in a change in results is controlled. In the event of such a change in hardware or operating system, the hardware validation suite is re-run to confirm that the system still performs as it did when the code certification was performed.

2. CASMO-3 [2] 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 modeled. 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 the production library 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 analysis of the HNP wet and dry storage when applicable. Note that the design of the dry rack is the same as the racks used in the pools for new PWR assemblies; therefore, accident analyses performed for Pool A are applicable to dry storage. The calculations in this document augment those in References [4] and [5].

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 within 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 a rack cell.

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 [6]. For the racks flooded with 100% dense moderator and credit for soluble boron k-effective shall be maintained less than 0.95 (NUREG 0800; Reference [7], Section 9.1.2). Furthermore, k-effective of the dry rack storage under optimum moderation conditions shall be less than 0.98 and under fully flooded conditions less than 0.95 (Reference [7], Section 9.1.1).

NRC Regulatory Issue Summary 2001-12[8] 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 rack conditions and are in compliance with this requirement.

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. The fuel enrichment tolerance is considered for the burnup credit analysis of irradiated fuel. No tolerances on the Boraflex absorber panels or B^{10} content needs to be considered since this analysis assumes all Boraflex is dissolved and removed from any panels that contain Boraflex.

2. There are no definite fabrication tolerance values for the Advanced HTP assemblies. Values consistent with currently produced fuel assemblies at MAR are assumed for this assembly. Making this assumption is reasonable because these values are equal to, or bound, the tolerance values for the current HTP assembly.

3. The average temperature of the spent fuel pool is maintained by coolers at ~20°C (68 °F). It is assumed that under normal conditions the pool temperature will not exceed 66°C (150 °F) and that any temperature above 66°C (150 °F) is considered an abnormal occurrence covered by the double contingency principle.

4. The fuel and tolerance uncertainty Δk values for the PWR fuel assemblies and racks are applicable to the BWR fuel assemblies and racks for the calculation of $K_{95/95}$. Neither tolerance values nor tolerance uncertainties were provided for the BWR fuel or racks. Tolerance differences between the two fuel/rack types are considered to be small and covered by the ~1% Δk margin to the criticality safety margin discussed in section on the interaction effects with spent fuel racks.

5. For the dry storage calculations the Boraflex has been replaced by the interspersed moderation that is in the remainder of the storage rack for misted accident conditions. The stainless-steel wrapper that holds the Boraflex in place on the storage rack is assumed to remain for the calculations. The assumption is based on the work scope proposed by Progress Energy. Note that this is a very conservative assumption since there is no reason to expect Boraflex degradation in the dry racks that houses unirradiated fuel.

6. The design basis fresh fuel that is analyzed in dry storage is the advanced HTP-17 fuel assembly that has been proposed to Progress Energy for loading into the Shearon Harris reactor. The analyzed fuel assembly is loaded with 96% dense 4.95 wt% nominal (no enrichment tolerance) enriched fuel for the entire 144" active fuel length with no axial blankets and also contains no gadolinia bearing fuel rods. This assembly configuration is conservative relative to the actual future

fresh fuel that will be stored in the storage vault prior to being loaded into the reactor.

7. Calculations for PWR and BWR spent fuel racks performed for Pool A are also applicable to Pool B since the geometry and assembly types are the same between both pools. Although Pools A and B have different burnup versus enrichment curves, the points on those curves represent a locus of reactivity points that maintain $k_{95/95}$ for the rack less than 0.95. Therefore, interface effects for Pool B are acceptably bounded by the results from Pool A. Additionally, the misplaced assembly accident in Pool A requires soluble boron credit of >1000 ppm due to available spacing between pool walls and PWR racks and available empty water filled cells. This geometry is not available for Pool B and thus boron requirements for Pool B due to rack interaction effects or a misplaced assembly in Pool B are significantly bounded by the Pool A accident analysis.

8. The design basis fuel assembly that is analyzed in the Burnup Credit analysis for spent fuel racks in Pools A and B is the advanced HTP-17 fuel assembly that has been proposed to Progress Energy for loading into the Shearon Harris reactor. The analyzed fuel assembly for Harris Pool(s) is proposed to be loaded with 96% dense, nominal 4.95 wt% enriched fuel for the entire 144" active fuel length with no axial blanket and also contains no gadolinia bearing fuel rods. This assembly configuration is conservative relative to the actual future fresh fuel that will be stored in the spent fuel racks. This burnup credit analysis will use the Advanced HTP-17 assembly and apply a soluble boron ppm requirement in order to ensure that the current resident Westinghouse assemblies that used WABA inserts are bounded for spectral history effects.

9. Pools A and B spent fuel rack burnup credit calculations are performed in an infinite array with no leakage.

2.3 Computational Models and Methods

This section describes the basic models used to evaluate the storage rack in its use as a dry rack or in pool storage for unrestricted or restricted (2-of-4 region) storage. Results using these models are described in later sections.

2.3.1 Fuel Assembly Descriptions

Assembly dimensions are provided in this section to allow analysis of various PWR rack types using the limiting assembly type. The fuel assembly information for FANP 17x17 HTP fuel assemblies was taken from the original FANP rack calculation in Reference [4]. A review was made of assemblies fabricated since the original calculation and the dimensions provided in Table 2.3.1-1 remain valid for all FANP 17x17 HTP assemblies provided to HNP (Harris Nuclear Plant). This assembly was not used in the analysis, but dimensions are shown here as a comparison to the more reactive Advanced HTP-17 assembly shown in Table 2.3.1-2 that was used in the analysis.

Table 2.3.1-1 FANP 17x17 Fuel Dimensions

The Advanced HTP assembly design that has been proposed to Progress Energy for the Shearon Harris plant is the design basis fuel assembly used in the analysis. The dimensions for the proposed assembly are listed in Table 2.3.1-2 as extracted from the proposal. The tolerance and GT/IT values were not listed in that document. These values were extracted from a calculation performed to support criticality safety at the Lynchburg Fuel Fabrication Plant for the Advanced HTP assembly design.

Table 2.3.1-2 FANP Advanced HTP 17x17 Fuel Dimensions

2.3.2 Dry Storage, Pool A, and Pool B Rack Description

The dry rack used for unirradiated fuel is the same rack design used for PWR fuel in Pool A and B which may hold either new or irradiated fuel. Table 2.3.2-1 lists the nominal rack dimensions extracted from the original FANP evaluation (Reference [4]).

The dimensions from Tables 2.3.1-2 for the advanced HNP HTP-17 assembly and Table 2.3.2-1 for the storage rack were used to develop a rack cell model. Figure 2.3.2-1 shows the resulting model. The fuel assembly will be centered inside the module when fuel is present and will extend 144 inches in the vertical direction. Figure 2.3.2-2 shows a more descriptive picture of a rack cell with a fuel assembly present. The fuel model only includes the fuel rods with a 12" water reflector at top and bottom. Neglecting the grids, end-fittings, and plenum regions provides conservative results.

Table 2.3.2-1 Boraflex Storage Rack Information

Dimension	inches	cm	cm/2
Nominal Cell Dimensions			
Cell Pitch	10.5 ± 0.06	26.67± 0.1524	13.335
Cell Inner Dimension	8.75 +0.025/-0.050	22.225 +0.0635/0.127	11.1125
Wall Thickness	0.0747 ± 0.007	0.189738 ± 0.01778	0.094869
Cell OD (Calculated)	8.8994	22.60448	11.30224
Nominal Boraflex Panel			
Width [a]	~~7.46 ± 0.075~~	~~18.9484 ± 0.1905~~	~~9.4742~~
Thickness [a]	~~0.075 ± 0.010~~	~~0.1905± 0.0254~~	~~0.09525~~
Length(Shrinkage) [a]	~~144.25 ±0.25~~	~~366.4 ±0.635~~	~~183.2~~
Wrapper Thickness	0.035 ± 0.003	0.0889 ± 0.00762	0.04445
Gap wrapper/wall	0.1 ± 0.01	0.254 ± 0.0254	0.127
Cell OD w /Wrapper (Calculated value)	9.1694	23.29028	11.64514
B-10 density, g/cc [a]		~~0.121~~	

a) Complete degradation of Boraflex is assumed for this analysis. Note that the inner dimension of the wrapper length is assumed to be that of the Boraflex length to provide a conservative estimate of wrapper material. The wrapper material is assumed to be SS-304.

The Boraflex absorber has been removed (degraded) from the model but the SS-304 wrapper that holds the Boraflex is still modeled in the KENO V.a calculations. The same interspersed moderator used in the remainder of the module is placed where the Boraflex was located. Because of geometry limitations in CASMO-3, the wrapper material is combined with the cell wall and the resulting simplified CASMO-3 model is shown in Figure 2.3.2-3. The modified cell wall thickness is computed by the following using dimensions from Figure 2.3.2-1.

The CASMO-3 model has a fuel assembly located inside the cell wall. The cell wall and wrapper are modeled as Stainless Steel 304. The compositions for SS-304, fuel, cladding and moderator are taken from the standard composition library in the SCALE (Reference [1]) code package. The same compositions were also used in the CASMO-3 tolerance calculations.

Figure 2.3.2-1 Storage Rack Module with Boraflex Wrappers (KENO Model)

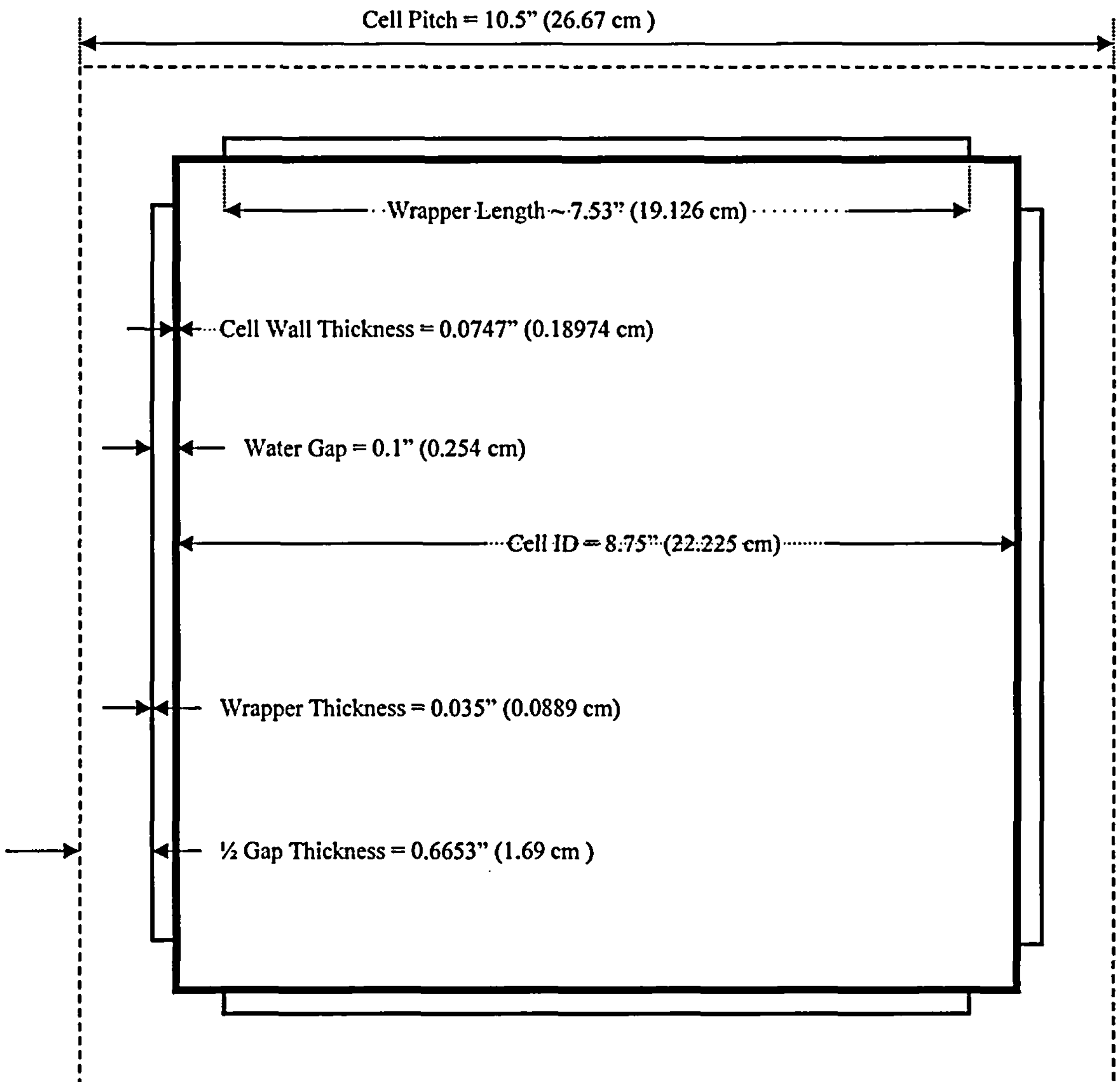


Figure 2.3.2-2 Rack Module with Fuel Assembly Inserted.

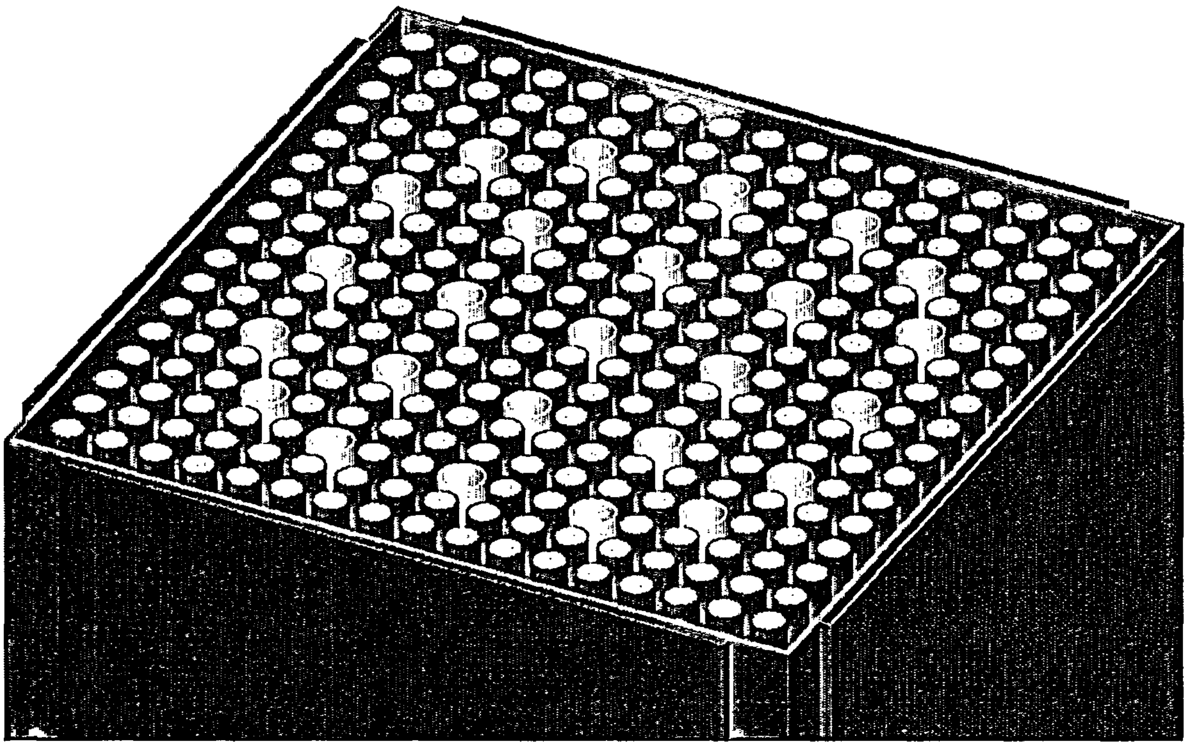


Figure 2.3.2-3 Rack Model for Casmo-3 Runs (Wrapper Combined with Cell Wall)

2.3.3 Dry Storage Rack Assembly Layout

The arrangement of the storage racks in the dry storage was obtained from documentation from Progress Energy. The positions of racks A1 through A4 and rack B1 are shown in the storage pit in Figure 2.3.3-1. The allowable fuel storage locations in the racks are shown on Figure 2.3.3-1. Non-shaded locations are the allowable fuel assembly storage positions that have not been sealed off to prevent fuel insertion. Each of the racks is a 6x10 array of storage cells. Fuel assemblies are loaded in a modified 1 in 9 pattern in the racks as shown on Figure 2.3.3-1 except for the north-western most location in the B1 rack where a fuel assembly was assumed to be inserted. Adding a fuel assembly in this location for this analysis is conservative.

All the KENO V.a calculations conservatively assumed that racks A1 through A4 are touching rather than having the 2.5" minimum spacing between them. For additional conservatism, the fuel and racks are assumed to be sitting on a 24" thick regular concrete slab. The dry storage inspection pit walls are also assumed to be made of 24" thick concrete. The dry storage inspection pit is assumed to be 20 feet deeper than the height of the 144" high fuel assemblies and racks. The right end of the storage pit was assumed to be the reverse of the left end of the dry storage inspection pit. These assumptions on pit dimensions are conservative.

The first set of interspersed calculations positioned the fuel in the checkerboard so that the fuel in racks A1-A4 and B1 are as shown on Figure 2.3.3-1 except for the one extra location in the B1 rack. The second set of calculations had the fuel located in the racks in the same locations but racks A1-A4 are positioned against the concrete wall with the 4" space removed as an upset condition. Figure 2.3.3-2 is a cut-away view showing the fuel arrangements for Case 1.

Figure 2.3.3-1 HNP Dry Storage Inspection Pit - Showing Fuel Assembly Layout

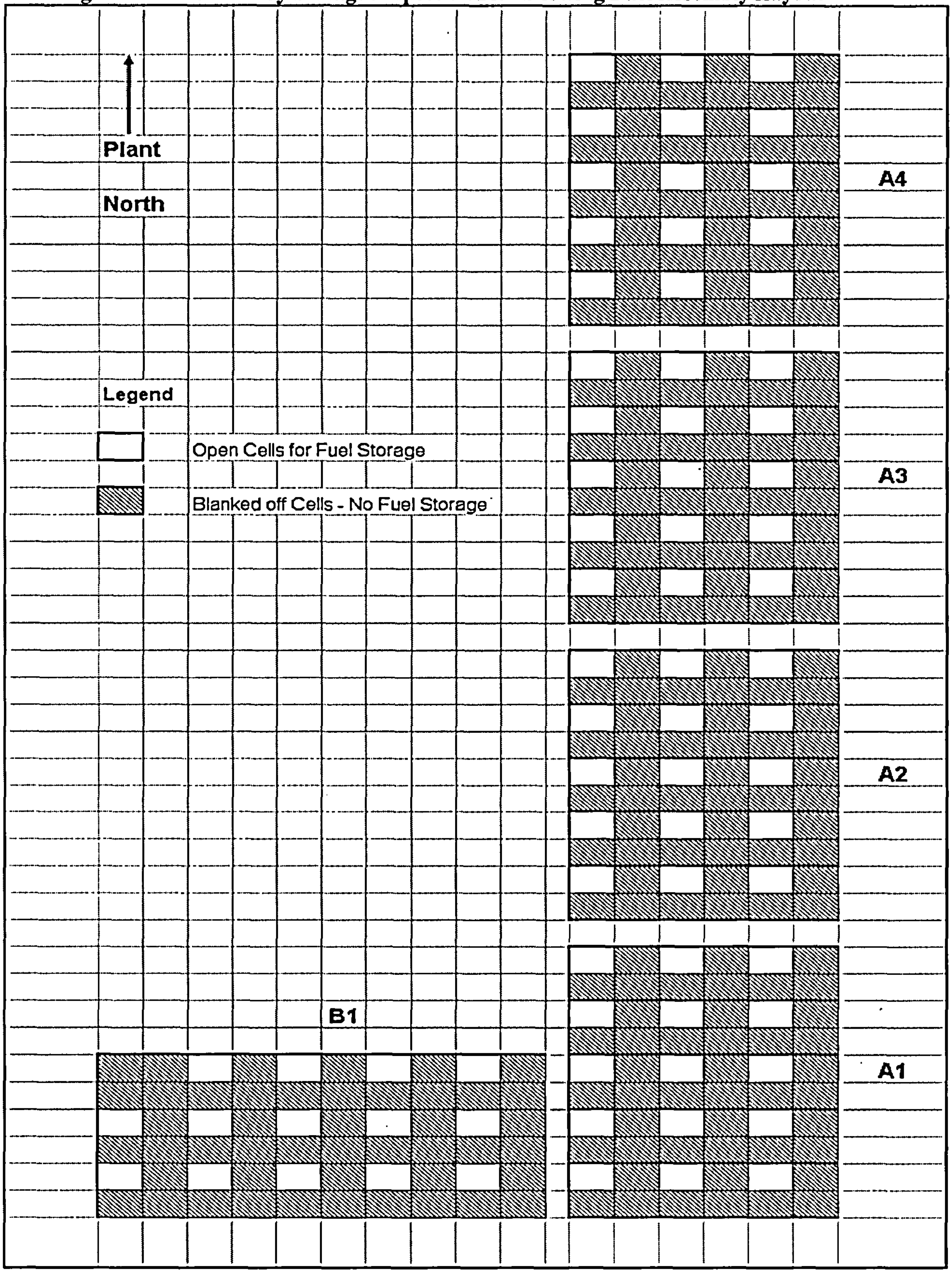
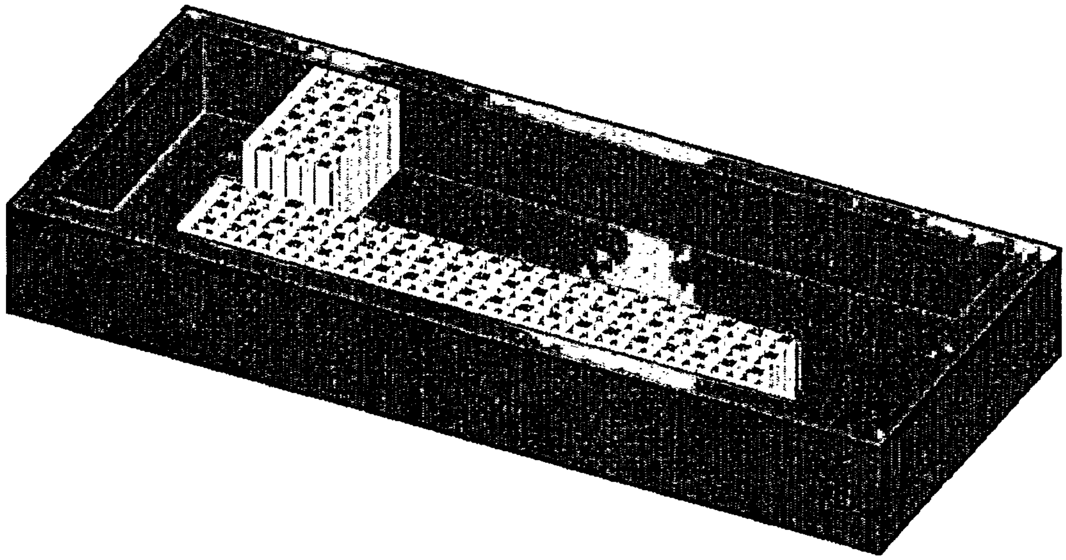


Figure 2.3.3-2 Layout of the New Fuel Inspection Pit



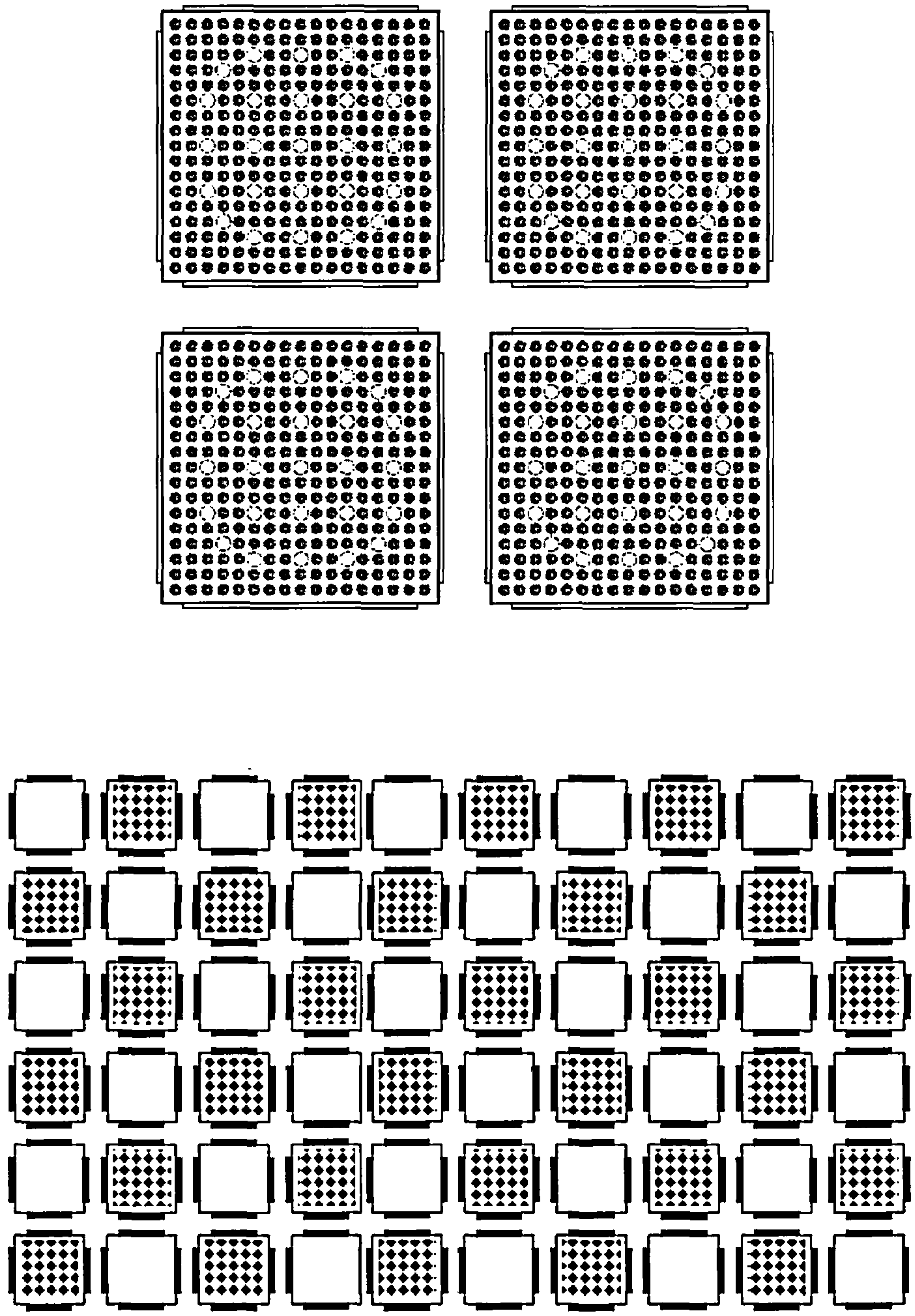
2.3.4 PWR Fuel Storage Rack Model

The base KENO V.a model of the rack has a 2 out of 4 loading pattern without Boraflex in the rack. The rack is explicitly modeled with the Boraflex regions completely replaced with water. The HTP and Advanced HTP assemblies generally have axial blankets, cut-back regions, and integral absorber rods in some axial planes. However, to allow flexibility for future changes in assembly and/or cycle designs, the model will conservatively assume a uniform maximum planar enrichment over the axial length and cross sectional area of the assembly. In addition, there will be no consideration of integral absorber rods in the assembly. Thus, the design base assembly model is a fresh assembly with a uniform, nominal enrichment of 4.95 wt% in each fuel pin. The [ ] wt% enrichment tolerance of Table 2.3.1.2 is included in the $K_{95/95}$ determination through a statistical combination of the manufacturing tolerance Δk. This is an acceptable alternative to use of a maximum enrichment of 5.0 wt% with no enrichment tolerance term.

The rack model is constructed with the assembly surrounded by the cell wall which is then merged with other components into arrays. The outer dimension of the cell is 8.8994" (half dimension = 11.30224 cm). Next, the horizontal wrapper cells are combined with the fuel cell in an array. The vertical panels are similarly formed and combined with the fuel cell/horizontal-panels in another array. Addition of ½ the water gap between the wrappers of each cell completes the individual cell model. The individual cell is then combined into the desired array to form an infinite rack model of a 2x2 array with periodic boundary conditions, an individual 6x10 rack module or a combination of modules. The overall geometry considers an x-y array of cells with 12" (30.48 cm) of water at the top and bottom of the active fuel length and with either reflective boundary conditions on all six sides of the array (infinite array) or a 12" water reflector exterior to the module(s) (finite modular array). Figure 2.3.4-1 illustrates the KENO V.a geometrical model for both the 2x2 and 6x10 array configurations. Note that both models represent an infinite array of fuel cells due to periodic boundary conditions at the edges of either array.

Shown in Figures 2.3.4-2 and 2.3.4-3 are the rack layout schemes for Pools A and B respectively. Note that these Pools have a mixture of PWR and BWR rack types. Also, all PWR racks are manufactured with the same design for both the dry new fuel storage racks and the racks in the pools. Therefore, the individual PWR assembly rack cell model is applicable to all PWR Boraflex rack module arrays. The BWR cell model is described in Appendix C.

Figure 2.3.4-1 Model of Central Region of PWR Racks and 6x10 Module Arrangement



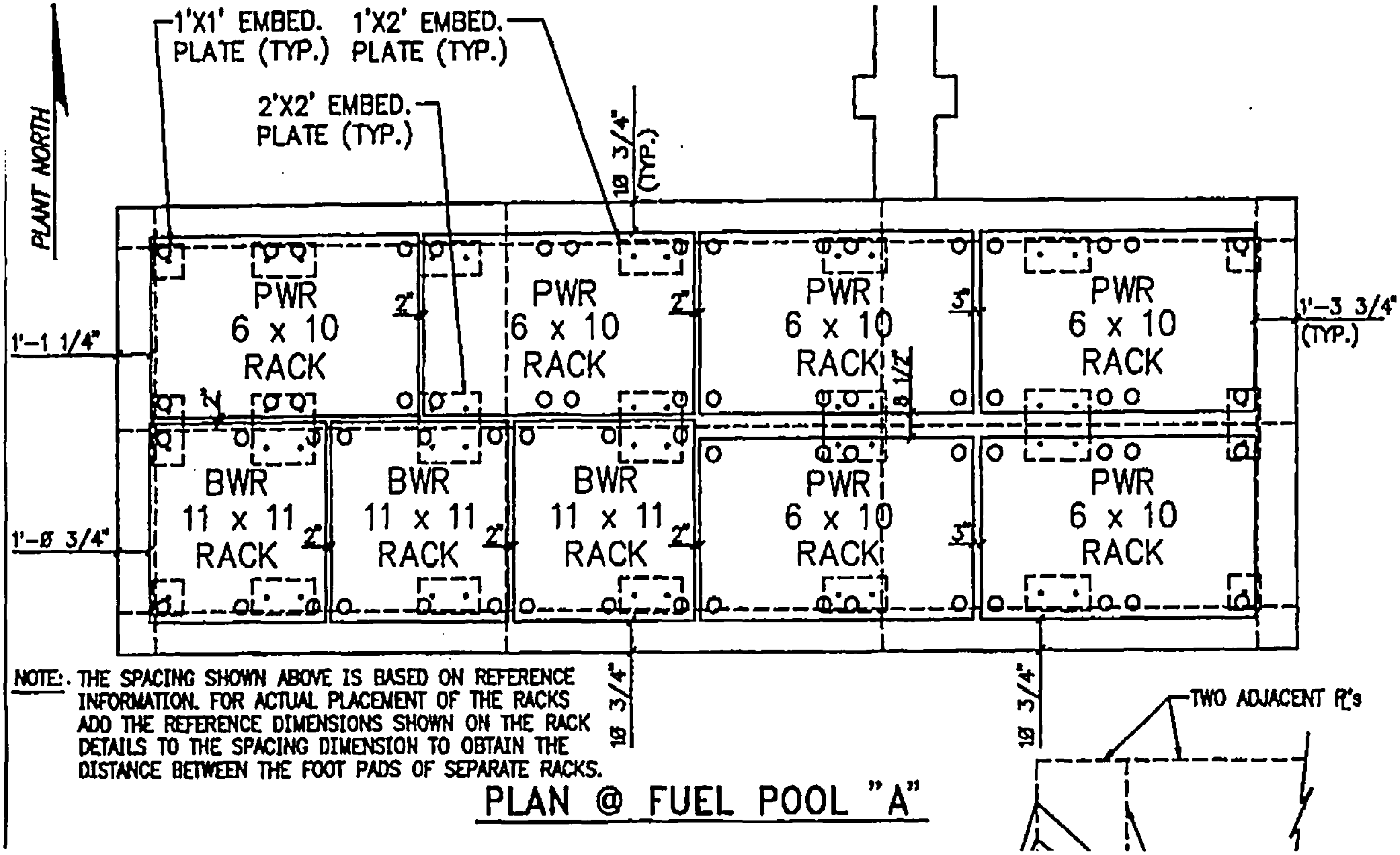


Figure 2.3.4-2 Pool A Rack Layout

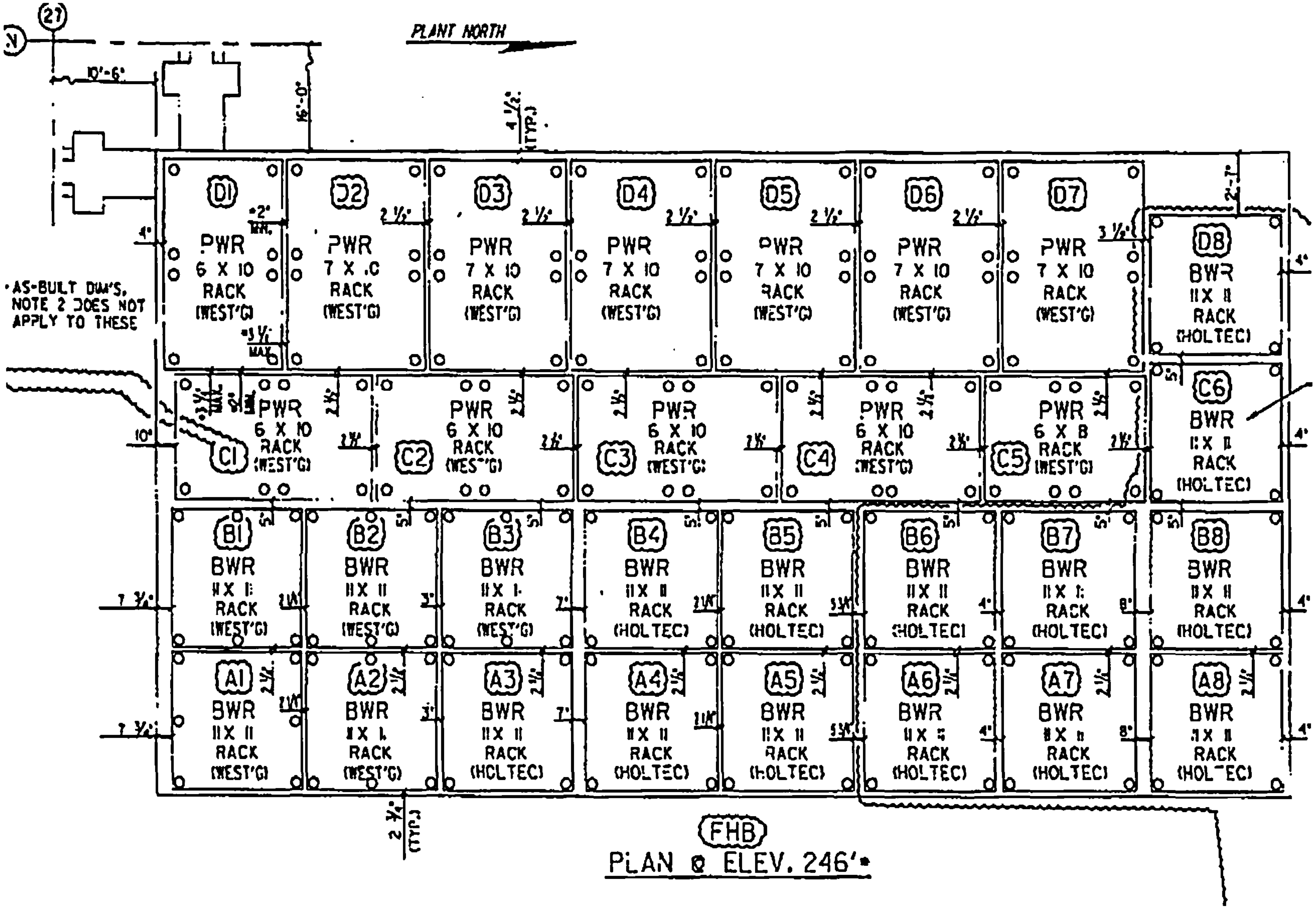


Figure 2.3.4-3 Pool B Rack Layout

2.3.5 Material Specification

The material specifications for the various components of the KENO V.a model use the standard compositions of the CSAS material processor of SCALE4.4a with appropriate material densities and/or isotopic weight percents.

2.4 Analytical Model Conservatisms

This section lists the major conservatisms associated with this evaluation.

1) No credit is taken for the presence of absorber clusters in fuel assemblies because they 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.

2) No credit was taken for xenon, peak samarium; neither was credit taken for the decay of Pu^{241}, other isotopes, or building of fission product absorbers.

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

4) No credit is taken for any remaining Boraflex panels.

5) A rack containing spent fuel is assumed to have assemblies with burnups on the burnup versus enrichment curve.

6) The maximum fuel enrichment tolerance of [ ] wt% is considered in the tolerance evaluation.

New fuel storage is evaluated with the following conservatisms.

1) All fuel includes the maximum enrichment tolerance via the tolerance evaluation.

2) No Boraflex material is credited.

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

4) The new fuel inspection pit is assumed flooded by unborated water.

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

2.5 Tolerances, Penalties, Uncertainties, and Bias

This section describes tolerances, penalties, uncertainties, and biases utilized in the analysis of the dry storage racks, Pool A PWR racks, and Pool B PWR racks. The tolerance penalties that pertain to the rack design are discussed in detail in Appendix B and summarized in Section 2.5.2. Reactivity penalties associated with system parameters are in Appendix B also and summarized in Section 2.5.3. Additionally, a bias with its associated uncertainty is discussed in Appendix A and summarized in Section 2.5.4. Accident penalties are summarized in Section 2.5.5.

2.5.1 Method Discussion of Tolerances, Biases, and Uncertainties

Criticality analysis methodology involves the computation of a base k-effective using a code such as KENO V.a. As an example, a KENO V.a code bias plus uncertainty on the bias is determined based on comparison to measured critical fuel configurations (i.e., critical benchmarks; see Appendix A) and is then applied to the base absolute k-effective. 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 statistical component of the uncertainty of 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 (See Appendix B). 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.

The $K_{95/95}$ for the evaluation is calculated using the following formulation:

$$K_{95/95} = k_{eff} + bias_{method} + \Delta k_{sys} + [C^2(\sigma_k^2 + \sigma_{bias}^2 + \sigma_{sys}^2) + \Delta k_{tol}^2]^{1/2},$$

where,

k_{eff}	=	the KENO V.a calculated result;
$bias_{method}$	=	the bias associated with the calculation methodology;
Δk_{sys}	=	summation of Δk values associated with the variation of system and base case modeling parameters, e.g. moderator temperature and off-centered assembly in cell;
C	=	confidence multiplier based upon the number of benchmark cases;
σ_k, σ_{bias}, σ_{sys}	=	standard deviation of k_{eff}, methodology bias, and system Δk_{sys};
Δk_{tol}	=	statistical combination of statistically independent Δk values due to manufacturing tolerances, e.g. fuel enrichment, cell pitch, etc.

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-KENO V.a – a multigroup transport theory code in three dimensions, using the Monte-Carlo technique

PHOENIX-P – a multigroup transport theory code in two dimensions, using discrete 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 discrete ordinates."

It is noted that FANP is utilizing both CASMO-3 and the Monte Carlo code KENO V.a. All Monte-Carlo codes are directly mentioned in NUREG-1567 Section 8.4.4.1 and NUREG/CR-0200 as a suitable tool for criticality calculations. Note: No 'holes' were used in the geometry models, thus this analysis is not affected by NRC Information Notice 2005-13, "Potential Non-conservative Error in Modeling Geometric Regions in the KENO-V.A Criticality Code," May 17, 2005.

2.5.2 Rack Manufacturing and Assembly Tolerances

The CASMO-3 code is used to determine the reactivity effects of dimensional tolerances for the design basis fuel assembly and the PWR storage rack. The CASMO-3 model of the storage rack is not as explicit as the model used in KENO V.a because of geometry limitations; however, because of its deterministic solution methods the small reactivity changes can be determined more accurately.

The evaluation is based upon the dimensional tolerances listed in Table 2.3.2-1 for the racks and 2.3.1-2 for the design basis fuel assembly. The evaluation of the reactivity effects for manufacturing tolerances for the fuel and the racks are discussed in Appendix B. Table 2.5.2-1 summarizes the worst positive Δk values for the rack and assembly tolerances and are used in the determination of $K_{95/95}$. Since the fuel and rack tolerances are independent, they can be statistically combined.

Table 2.5.2-1 Manufacturing Tolerances

2.5.3 System Bias Effects

For the rack evaluations five system parameters are significant: moderator temperature effects, off-center placement of the assembly in the rack cell, rack interface effects, reactivity effects due to spectral hardening from removable absorber components (i.e., wet annular burnable absorber assemblies, WABA's etc.), and reactivity effects due to insertion of non-fuel bearing component containers (NFBC). Determination of the appropriate system Δk values are discussed below. The values are summarized in Table 2.5.3-1 for both the fresh and spent racks. Each effect is discussed in detail in Appendix Section B.2. Note that these effects do not apply to the dry fuel storage pit because of the rack loading arrangement, dry condition and lack of irradiated fuel.

Table 2.5.3-1 System Uncertainties ($\Delta k_{sys} \pm \sigma_{sys}$)

2.5.4 KENO V.a Methodology Bias and Uncertainty

The KENO V.a methodology bias is discussed in detail in Appendix A and applies to all rack types the use KENO V.a and the 44 group cross-section library. The bias and bias uncertainty were determined as:

$$\textit{Bias Uncertainty} = C_{95/95} * s_P = [\qquad\qquad\qquad\qquad]$$

The bias is obtained using the following formula that includes the weighted average of k_{eff}

$$\textbf{Bias} = \bar{k}_{eff} - 1 = [\qquad\qquad\qquad]$$

This bias will be applied as a positive penalty in the equation for computation of $K_{95/95}$ for the Shearon Harris storage pools.

2.5.5 Summary of Bias and Uncertainty Values

Table 2.5.5-1 summarizes the components of the $K_{95/95}$ formulations used for the evaluation of this document. The fresh rack basis are centered assemblies with a moderator temperature of 20°C. The basis for the spent fuel racks, both BWR and PWR, and a combination of fresh and spent racks, are assemblies centered in the rack with a moderator temperature of [ ]. $K_{95/95}$ is defined as:

$$K_{95/95} = k_{eff} + bias_{method} + \Delta k_{sys} + [C^2(\sigma_k^2 + \sigma_{bias}^2 + \sigma_{sys}^2) + \Delta k_{tol}^2]^{½}$$

Table 2.5.5-1 Summary of Bias and Δk Values

(Intentionally Left Blank)

3.0 Pool A and B Analysis

This analysis is performed to evaluate the fresh and spent fuel storage racks in the Shearon Harris Nuclear Power Plant (SHNPP, HNP, or Shearon Harris) storage pools to ensure criticality safety with Boraflex degradation. The storage racks were designed to be 'low density' racks with 'flux-traps' containing Boraflex panels to ensure criticality safety. However, irradiation induced damage to the panels has degraded Boraflex absorber plates. The evaluation assumes that the panels have disintegrated completely and are replaced with coolant. The 'fresh' fuel racks generally will contain fresh fuel or irradiated fuel with insufficient burnup to be stored in the spent fuel racks at SHNPP that rely on burnup to ensure criticality safety. Both racks require boron credit to satisfy the 0.95 criticality safety criterion. The evaluation uses the Advanced HTP fuel design as design basis assembly. To allow flexibility in fuel cycle designs, the evaluation will assume that the fuel assemblies contain only rods with a nominal, uniform axial and planar enrichment of 4.95 wt%. This assumption will bound assembly designs with integral absorber rods, axial cut-back regions, or axial blankets of varying enrichments that are typical of current assembly designs.

This section contains a summary of the major analyses performed for Pools A and B. Currently Pool A contains both fresh and spent PWR fuel racks as well as burned BWR fuel racks, while Pool B contains only spent fuel PWR and BWR racks. The rack designs for PWR fuel is the same in Pools A and B. Thus, this evaluation is not limited to the current rack arrangement in the pools.

3.1 Pool A and B Spent Fuel Burnup Loading Curve and Usage Requirements

Note that the Shearon Harris SFP storage rack criticality design basis is being changed to reflect a zero Boraflex credit and will become an unpoisoned storage rack system. This change represents a significant impact and the removal of the credit for the rack poison material needs to be counter balanced with the use of both burnup credit (BUC) and soluble boron credit in order to continue to fully load the storage racks. There are multiple combinations of BUC and soluble boron (PPM) credit possible to offset the reactivity increase associated with Boraflex removal. Upon evaluating the given configurations it is very clear that the soluble boron credit must be limited in order to avoid de-boration time requirements and for the SFP storage configurations $K_{95/95}$ value to remain below 1.00 for an unborated SFP. Similarly, the BUC loading curve should not be excessively demanding (i.e., require very high assembly burnup values) in order to remain useful and applicable to the expected fuel assembly discharge burnups. Therefore, the BUC rack analysis must be performed for a selected "Design Condition" as the first step in the analysis. Then, the BUC conditions will be evaluated relative to the regulatory $K_{95/95}$ acceptance criteria in order to set the soluble boron PPM requirements for both storage and fuel handing.

The target design criterion to be applied to the BUC analysis is defined by BUC K_{Design} with the following equation:

$$K_{Design} = k_{KENO} + \text{bias} + [C^2(\sigma_k^2 + \sigma_{bias}^2) + \Delta k_{tolerances}^2]^{1/2},$$

The BUC K_{Design} equation is the $K_{95/95}$ equation without the Δk_{sys} and σ_{sys} terms. The Δk_{sys} and σ_{sys} terms represent those parameters and conditions which require soluble boron PPM credit and will be handled separately after the BUC loading curve and requirements are determined. In most cases, the parameters and conditions represented by Δk_{sys} are represented as a delta reactivity relative to the BUC design basis configuration conditions. Hence, the following approximate relationship is developed:

$$K_{95/95} = \underset{\text{(BUC Credit)}}{K_{Design}} + \underset{\text{(Soluble Boron PPM Credit)}}{\Sigma \Delta k_{sys}}$$

Thus, in this manner a reasonable combination of BUC and PPM credit can be used to demonstrate that $K_{95/95} \leq 0.95$ to meet the regulatory requirements.

The BUC loading curve formulation is based upon a target K_{Design} that accounts for method bias and normal tolerances / uncertainties. These values are determined in order to develop a simple relationship for BUC analysis:

$$K_{Design} = k_{KENO} + \text{bias} + [C^2(\sigma_k^2 + \sigma_{bias}^2) + \Delta k_{tolerances}^2]^{1/2} = k_{KENO} + N$$

Where: $N = \text{bias} + [C^2(\sigma_k^2 + \sigma_{bias}^2) + \Delta k_{tolerances}^2]^{1/2}$ is a known numeric value.

Thus, the $K_{95/95}$ equation becomes from Appendix B:

$$K_{Design} = k_{KENO} + [\qquad\qquad\qquad\qquad\qquad\qquad]$$

A conservative estimate for σ_k can be used to complete the determination of the constant N. The BUC KENO V.a runs will need to check σ_k against the value to ensure that value for N remains applicable and conservative. Thus, for $\sigma_k \leq 0.0009$, the BUC target design criterion becomes:

$$K_{Design} = k_{KENO} + [\qquad\qquad]$$

This equation is used for the K_{Design} values provided in tables for the BUC fuel rack loading curve evaluation with K_{Design} [ ]. The soluble boron requirement is defined for this K_{Design} criteria to demonstrate that $K_{95/95}$ satisfies regulatory requirements.

The BUC model addresses the base set of conditions and modeling uncertainties that represent a symmetrically loaded storage cell with full density water in an infinite lattice. The following conditions are required to be evaluated as part of the normal operating conditions that will be expected to exist for the Shearon Harris SFP.

1) Moderator density variation up to the Technical Specification limit of 150.0 Deg. F (65.56 °C, 150 °F).
2) Asymmetric assembly position within a storage cell.
3) Fuel assembly spectral history effects for removable BP assemblies in assemblies currently residing in the pool (i.e., WABA inserts) but not for FANP 17x17 assemblies or PWR assemblies received from other plants.

4) BUC rack module interaction with other storage rack module types (i.e., BWR and Fresh PWR loaded racks).
5) Storage of non-fuel bearing material storage canisters (i.e., non-fuel bearing parts in a steel can).

The impact of any reactivity increase from these items will set the minimum soluble boron requirement for BUC storage rack configurations. Their reactivity impact (i.e., Δk_{sys} term) is summarized in Appendix B.2.6.

Therefore, similar to the BUC K_{design} formulation, a $K_{95/95}$ formulation can be created for KENO V.a soluble boron calculations:

$$K_{95/95} = k_{KENO} + \text{bias} + \Delta k_{sys} + [C^2(\sigma_k^2 + \sigma_{bias}^2 + \sigma_{sys}^2) + \Delta k_{tolerances}^2]^{1/2} =$$

$$k_{KENO} + M \leq 0.95$$

Where, $M = \text{bias} + \Delta k_{sys} + [C^2(\sigma_k^2 + \sigma_{bias}^2 + \sigma_{sys}^2) + \Delta k_{tolerances}^2]^{1/2}$

is a known numeric value.

Using the data provided in Appendix B.2.6, the $K_{95/95}$ equation becomes:

$K_{95/95} = k_{KENO}$ + [ ]

A conservative estimate for σ_k can be used to complete the determination of the constant M. The BUC KENO V.a runs will need to check σ_k against the value to ensure that value for M remains applicable and conservative. Thus, for $\sigma_k \leq$ [ ], the BUC acceptance criterion becomes (Table B.3-1):

$K_{95/95} = k_{KENO}$ + [ ] ≤ 0.95

The soluble boron in this evaluation will be varied until this equation is satisfied. This boron concentration defines the last component needed for the BUC fuel rack soluble boron requirement(s) evaluation.

Table 3.1-1 summarizes the BUC loading equation for K_{Design} [ ] generated from the assembly initial enrichment and assembly average burnup data pairs. This equation can be used to qualify assemblies for storage under the BUC requirements. Note that the curve fit provides conservative results when compared with the fit points. Thus, the equation form is acceptable for use. Appendix D discusses the details of how the burnup versus enrichment curve was generated for K_{Design} [ ] and for additional K_{Design} values.

Note that the burnup curve evaluation includes the allowances for uncertainties and variations by codes, methods, and manufacturing tolerances. The manufacturing tolerance allowance includes an explicit [ ] wt% tolerance for assembly initial enrichment variations. Therefore, an administrative adjustment for assembly initial enrichment is not required, but may be conservatively used to determine if an assembly qualifies for storage using the BUC requirements. However, the uncertainty associated with the reactor plant's ability to measure the assembly average burnup is not explicitly accounted for as part of the BUC loading curve analysis. Typically, a [ ] uncertainty can be used to bound the assembly average burnup measurement uncertainty. This burnup uncertainty factor <u>MUST</u> be addressed as part of the determination as to whether a specific assembly qualifies for storage using the BUC requirements.

Table 3.1-1 BUC Loading Curve Equation for K_{Design} [ ]

Least Square Coefficients for the following fit equation:

$$Y = C0 + C1 * X$$

[ ]

Note that X is the initial assembly enrichment in wt% U^{235} (e.g., 5.0 max) and Y is the required minimum assembly average burnup in GWd/mtU

BUC State Points for Equation Fit

Initial Enrichment wt% U235	Linear Fit MWd/mtU
1.53	0.00
1.76	2755
2.00	5690
2.50	11805
3.00	17920
3.50	24035
4.00	30150
4.50	36265
5.00	42380

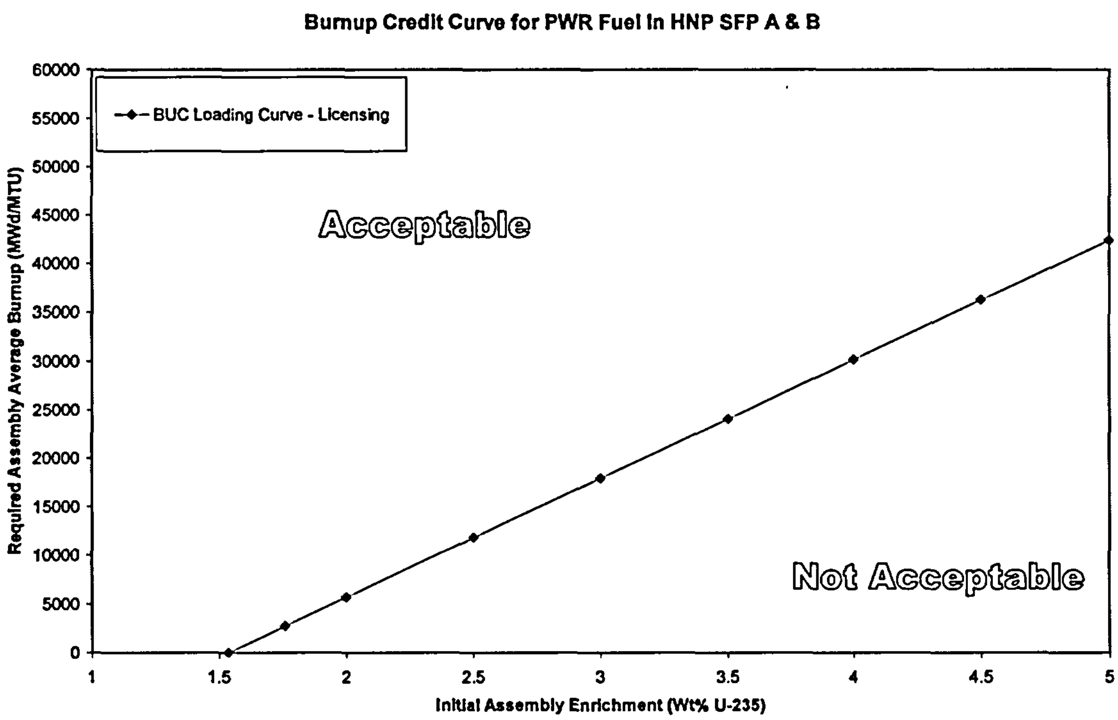
A typical procedural process to qualify assemblies for storage is as follows:

1) Obtain the assembly maximum planar initial enrichment [ ] and the plant measured assembly average burnup values.
2) Divide the measured assembly burnup by [ ] (i.e., decrease value by [ ] to obtain "MBu".
3) For additional conservatism 0.05 can be added to the assembly maximum planar initial enrichment from step 1 to get "PIE".
4) Use the PIE value with the BUC loading curve to obtain the required assembly average burnup "RBu".
5) Compare MBu to RBu

    a. IF MBu ≥ RBu then the assembly qualifies for storage using BUC requirements.
    b. IF MBu < RBu then the assembly does <u>not</u> qualify for storage.

The listed process was used to assess the current listed inventory of the Shearon Harris SFP storage.

Figure 3.1-1 BUC Loading Curve for K_{Design} [ ]



3.2 Pool Soluble Boron Requirements

The evaluation of Pools A and B were based on the current use of the pools and the situations that are unique to each pool. Specifically, Pool A is the location where new fuel is staged prior to loading in the SHNPP reactor and the location where core offload space is reserved. Pool A is the location where the 2-of-4, (non-BUC) region will be initially placed. Pool A contains both Boraflex PWR and Boraflex BWR racks. The layout of the pool permits dropping of a PWR assembly between a PWR rack and the pool wall. Analyses of these unique features are included in Section 3.2.2.

Pool B contains Boraflex PWR and two types of BWR racks. The BWR racks contain either Boraflex or Boral. Pool B is used primarily for fuel discharged from SHNPP and also stores fuel discharged from Progress Energy's Robinson Nuclear Plant. The majority of the space in Pool B will be dedicated to burnup credit (BUC) storage. ***However, conditions may arise where a section of Pool B is designated for non-BUC (2-of-4 storage).*** Unlike Pool A, Pool B does not have a location where an assembly could be located between the outside of a rack and have a concrete reflector on the opposite side.

Progress Energy is monitoring and assessing the degradation of Boraflex in the BWR racks. At this point in time, the BWR Boraflex racks can still perform their design function without credit for soluble boron. Thus, BWR Boraflex racks offer a boundary condition with a $K_{95/95}$ <0.95 without credit for soluble boron. The design basis BWR assembly is a GE-13 9x9 assembly uniformly loaded at 1.5 wt% enrichment without integral absorbers, axial blankets, or part length rods. Not withstanding the current integrity of the BWR Boraflex, the interface with the BWR racks has been analyzed with a proposed limiting fuel assembly design, enrichment, and no credit for Boraflex. The resulting $K_{95/95}$ for the BWR array is determined to be [ ] (from Appendix E). The interface criteria presented below become operative when Boraflex degradation in the BWR racks require credit for soluble boron to satisfy the $K_{95/95}$ < 0.95 regulatory requirement.

As described below, the specific conditions are analyzed and boron requirements determined. A summary of the most limiting conditions covering both Pools A and B are presented in Sections 3.4 and 5.0. As a practical matter, handling of a new or non- BUC fuel assembly may cross over both BUC and non-BUC regions so the highest value for fuel handling accidents must be used when fuel is being moved. Secondly, Pools A and B have the capability of being interconnected and therefore the highest individual boron requirement becomes the basis for soluble boron control of the combined pool and transfer canal volume.

3.2.1 Pool B Soluble Boron Requirements

The evaluation for BUC PWR storage racks will allow reasonable storage of the existing PWR assemblies in the Shearon Harris SFP. The regulatory requirement of $K_{95/95} \leq 0.95$ is met provided the following requirements for fuel racks designated as BUC PWR storage racks:

1. **An assembly must be demonstrated to have an assembly average burnup greater than the BUC required minimum burnup for the assembly initial enrichment. Assemblies that meet this requirement may be stored unrestricted. Assemblies that fail this requirement may NOT be stored in the BUC rack and shall be stored in the fresh fuel rack , or elsewhere.**

    i. **Plant measured assembly average burnup shall be decreased by the plant measured burnup uncertainty (Typically [ ], specific value to be determined by plant procedures).**

    ii. **Assembly initial enrichment is to be the maximum planar enrichment if the assembly enrichment varies by axial location.**

    iii. **Optionally, the assembly initial enrichment may be conservatively increased by [ ] wt% U^{235} for enrichment uncertainty. Note that BUC loading curve includes the [ ] wt% U^{235} enrichment uncertainty and the additional increase may be conservative, but is redundant.**

2. **A minimum SFP 500 ppm soluble boron concentration is required for fuel storage for normal conditions without fuel handling activity.**

3. **A minimum SFP 725 ppm soluble boron concentration is required for fuel storage with fuel handling activity with fresh fuel assemblies or spent fuel assemblies that do not meet the BUC requirements for storage in a BUC designated rack.**

4. **A minimum 500 ppm soluble boron concentration is required for fuel storage with fuel handling activity with BUC rack qualified spent fuel assemblies. This value is not applicable to handling fresh fuel assemblies or spent fuel assemblies being moved that do not meet the BUC requirements for storage in a BUC designated rack.**

5. **The Spent Fuel Pool water temperature shall not exceed 150 °F (65.56 °C) for normal operations.**

6. **Reload fuel assemblies shall be demonstrated to be less reactive than the SFP BUC rack Design Basis assembly at all assembly average burnups in the SFP rack geometry in order to qualify for storage.**

7. **FANP assemblies shall not be used with removable BP inserts during reactor operation. These assemblies do not generically qualify for storage in the BUC racks. They may be qualified with additional calculations.**

8. **The BWR storage rack must meet the assumptions/requirements described in this analysis.**

9. **Non-fuel bearing stainless steel containers may be stored in the BUC storage rack without restriction.**

The calculated results indicates that the limiting BUC rack multiplication factor is $K_{95/95}$ = [ ] with the SFP soluble boron requirements. Thus, the regulatory requirement of $K_{95/95} \leq 0.950$ for operating conditions is met.

The calculated result is that the limiting BUC rack multiplication factor is $K_{95/95}$ = [ ] in un-borated water. Thus, the regulatory requirement of $K_{95/95} \leq 1.000$ without soluble boron credit for the deboration accident condition is met.

The limiting accident condition is the misplacement/dropped fresh, high enrichment assembly between the SFP wall and a BUC rack module and requires a minimum SFP soluble boron concentration of [ ] for the BUC storage rack to meet regulatory requirements. Since normal storage requires a SFP soluble boron concentration of [ ] ppm, the maximum SFP soluble boron requirement is [ ] ppm for use of this BUC storage rack criticality analysis.

If a non-BUC region is established in Pool B, the limits described for Pool A apply to Pool B.

3.2.2 Pool A Soluble Boron Requirements

This fresh rack evaluation is based upon nominal dimensions for both the racks and fuel assemblies with manufacturing tolerances applied as Δk values in the $K_{95/95}$ determination. The design basis fresh PWR assembly is the FANP Advanced HTP assembly with a uniform nominal enrichment of 4.95 wt% with no integral absorbers or axial blankets. The design basis irradiated PWR assembly is an Advanced HTP assembly with a uniform enrichment of [ ] wt% without integral absorbers or axial blankets. This assembly represents the lower, zero burnup point on the BUC curve. For this evaluation it is assumed that all racks have experienced 100% Boraflex degradation. This may be slightly conservative for the PWR racks. The amount of degradation in the BWR racks is being investigated by Progress Energy and not considered severe. However, the PWR rack analyses for Pools A and B assumed 100% Boraflex degradation in the BWR racks. The PWR rack modules have a minimum separation of 2" between adjacent modules and the BWR modules a minimum of 1-7/8" between BWR modules. Arrangements of individual modules and arrays of modules were examined to determine the most reactive arrangement. This arrangement was the basis for the $K_{95/95}$ calculation. The evaluation shows that boron credit is required for the criticality safety of the storage pools. Further, the evaluation has shown that for appropriate limiting conditions the $K_{95/95}$ of the racks remain below 1.0 for the deboration accident and below 0.95 for normal conditions with the required amount of boron credit. Credible accident conditions require additional soluble boron to satisfy the 0.95 safety criterion.

This evaluation examined the PWR fresh fuel rack and interactions between the fresh and spent fuel racks. This included normal conditions for the racks and credible upset conditions such as a misplaced assembly, dropped assembly, and seismically induced rack movements.

The calculated results indicate that the limiting rack $K_{95/95}$ multiplication factors for the fresh PWR, spent PWR and BWR racks with the required boron credit are [ ], [ ], and [ ], respectively. Thus, the regulatory requirement of $K_{95/95} \leq$ 0.950 for operating conditions is met. The calculated results indicate that the limiting $K_{95/95}$ multiplication factors for the fresh PWR, spent PWR and BWR racks in un-borated water are [ ], [ ], and [ ] , respectively. Thus, the regulatory requirement of $K_{95/95} \leq 1.000$ for the deboration accident condition is met.

The results of the evaluation are summarized as follows:

Fresh PWR Fuel Rack:

1. **A required checker boarded loading pattern limited to two fresh, diagonally-adjacent assemblies in any four rack cells, i.e., 2 of 4 checkerboard loading pattern.**

2. **A minimum of 450 ppm soluble boron is required during operations without fuel movement, 1000 ppm soluble boron during movement of the design basis fresh fuel or irradiated fuel with burnup/enrichment combinations below the**

BUC curve, and 450 ppm soluble boron during movement of the design basis irradiated fuel assembly.

3. **Containers with non-fuel bearing components (NFBC) may be stored in the water holes in the fresh rack provided they are loaded in a pattern containing no more than 1 NFBC in any 6 rack cells, or in a fuel cell as a replacement for a fresh fuel assembly.**

4. **No restriction on placement of fresh PWR racks adjacent to either the spent PWR or BWR racks.**

The above fresh fuel boron requirements are based upon: a minimum of [ ] ppm boron credit for the normal condition; a minimum of [ ] ppm soluble boron for the bounding condition of a dropped design basis fresh assembly outside the rack; a minimum of 50 ppm noted for use of low enrichments in determination of the loading curve; and an additional minimum of [ ] ppm soluble boron required for seismically induced rack movement. Thus, the boron requirement for operations without fuel movement is [ ] ppm with seismic rack movement; with fresh fuel movement [ ] ppm; and with irradiated fuel movement [ ] ppm.

Mixture of Fresh and Irradiated Fuel in Same Rack Module:

1. **A required checker boarded loading pattern limited to two diagonally adjacent fresh assemblies in any four rack cells, i.e., 2 of 4 checkerboard loading pattern for the fresh assemblies in the fresh region of the rack.**

2. **Irradiated fuel satisfying the BUC curve may be placed in any rack cell in the irradiated fuel region of the rack.**

3. **An interface between the fresh and irradiated regions consisting of either a single row containing a pattern of alternating water holes and irradiated assemblies face adjacent to the water holes in fresh region, or a single row consisting only of water holes.**

4. **A minimum of 500 ppm soluble boron is required during operations without fuel movement, 1000 ppm soluble boron during movement of the design basis fresh fuel or irradiated fuel with burnup/enrichment combinations below the spent rack loading curve, and 500 ppm soluble boron during movement of the design basis irradiated fuel assembly.**

5. **NFBC in a 1 in 6 cell arrangement for the checkerboard fuel region or as a replacement for either fresh or irradiated assemblies.**

6. **No restriction on the placement of fresh PWR racks adjacent to either spent PWR rack or spent BWR racks.**

The [ ] ppm soluble boron requirement for the normal and spent fuel movement are those for the irradiated rack discussed below. The [ ] ppm boron requirement is that for fresh fuel movement previously discussed.

PWR Spent Fuel Rack:

1. **Irradiated fuel satisfying the BUC curve may be placed in any rack cell.**

2. **A minimum of 500 ppm soluble boron is required during operations without fuel movement, 725 ppm soluble boron during movement of the design basis fresh fuel, and 500 ppm soluble boron during movement of the design basis irradiated fuel assembly.**

3. **No restriction on the placement of spent PWR racks adjacent to either fresh PWR rack or spent BWR racks.**

4. **NFBC may be placed in any rack cell.**

The above boron requirements for the spent fuel racks are based upon: a minimum of [ ] ppm boron credit for the normal condition; a minimum of [ ] ppm soluble boron for the bounding condition of a dropped design basis fresh assembly outside the spent rack; a minimum of [ ] ppm noted for use of low enrichments in determination of the loading curve; and an additional minimum of [ ] ppm soluble boron is required for seismically induced rack movement. Thus, the boron requirement for operations without fuel movement is [ ] ppm with seismic rack movement; with fresh fuel movement [ ] ppm; and with irradiated fuel movement [ ] ppm. Note that these values supercede those in the burnup credit evaluation.

BWR Spent Fuel Racks – The following criteria apply to the BWR racks only when the BWR Boraflex analysis and Technical Specifications are modified to support credit for soluble boron:

1. **Irradiated design basis BWR fuel must have a $K_{95/95} \leq$ [ ] when placed in the BWR rack with 100% Boraflex degradation.**

2. **A minimum of 350 ppm soluble boron is required during operations without fuel movement, 475 ppm soluble boron during movement of the design basis fresh fuel, and 350 ppm soluble boron during movement of the design basis irradiated fuel assembly.**

3. **No restriction on placement of spent BWR racks adjacent to either PWR rack.**

The above boron requirements for the spent fuel racks are based upon: a minimum of [ ] ppm boron credit for the normal condition; a minimum of [ ] ppm soluble boron for the bounding condition of a dropped design basis fresh PWR assembly outside the spent rack; and an additional minimum of [ ] ppm soluble boron is required for seismically induced rack movement. Thus, the boron requirement for operations without fuel movement is [ ] ppm with seismic rack movement; with fresh fuel movement [ ] ppm; and with irradiated fuel movement [ ] ppm.

3.3 Summary of Pool A and B Requirements

Since Pool A and B are connected and the soluble boron requirements of both Pools are slightly different the most conservative requirements of each pool type from Section 3.1, 3.2, and 3.3 are selected. For Pools A and B the following limiting conditions apply:

1. **The fresh rack requires a checkerboarded loading pattern limited to two diagonally-adjacent fresh assemblies in any four rack cells, i.e., 2 of 4 checkerboard loading pattern for the assemblies in the rack.**

2. **For the PWR spent fuel rack, an assembly must have an assembly average burnup greater than the BUC minimum burnup required for the assembly initial enrichment. Assemblies that meet this requirement may be stored unrestricted. Assemblies that fail this requirement may NOT be stored in the BUC rack and shall be stored in the fresh fuel rack, or elsewhere.**

    i. **Plant measured assembly average burnup shall be decreased by the plant measured burnup uncertainty (Typically [ ] but a specific value is to be determined by plant procedures).**

    ii. **Assembly initial enrichment is to be the maximum planar enrichment if the assembly enrichment varies by axial location.**

    iii. **Optionally, an assembly initial enrichment may be conservatively increased by [ ] wt% U^{235} for enrichment uncertainty. Note that BUC loading curve includes a [ ] wt% U^{235} enrichment uncertainty and the additional increase may be conservative, but is redundant.**

3. **A rack containing both fresh and irradiated fuel requires an interface between the fresh and irradiated fuel regions consisting of either a single row of an alternating pattern of water holes and assemblies face adjacent to water holes in the fresh region, or a single row of water holes.**

4. **A minimum 500 ppm soluble boron concentration is required for fuel storage at normal conditions without fuel handling activity.**

5. **A minimum 1000 ppm soluble boron concentration is required for fuel storage for fuel handling activities with fresh fuel assemblies or spent fuel assemblies that do not meet the BUC requirements for storage in a BUC designated rack.**

6. A minimum 500 ppm soluble boron concentration is required for fuel storage for fuel handling activities with only BUC rack qualified spent fuel assemblies. Fresh fuel assemblies or spent fuel assemblies that do not meet the BUC requirements for storage in a BUC designated rack must not be moved.

7. The irradiated design basis BWR fuel must have a $K_{95/95} \leq$ [ ] when placed in the BWR rack with 100% Boraflex degradation.

8. Irradiated PWR fuel that satisfies that meet BUC requirements may be placed in any PWR spent rack cell, or as a replacement for a fresh assembly in the fresh rack.

9. The Spent Fuel Pool water temperature shall not exceed 150 °F (65.56 °C) for normal operations.

10. New fuel assembly designs not bounded by the design basis assembly shall be demonstrated to be less reactive than the design basis assembly at all assembly average burnups in the SFP rack geometry in order to qualify for storage.

11. Non Fuel Bearing Containers (NFBC) may be placed in any PWR spent rack cell.

12. NFBC may be stored in the water holes in the fresh rack provided the loading pattern contains no more than 1 NFBC in any 6 rack cells or in a cell as replacement for fresh and irradiated fuel assemblies.

13. Framatome fuel assemblies may not be stored in spent fuel PWR racks if they were irradiated with a removable absorber component such as a WABA or Burnable Poison Rod Assembly (BPRA). Gadolinia bearing fuel is not restricted.

14. No restriction on placement of PWR racks adjacent to either the other PWR, or BWR racks.

4.0 Dry New Fuel Storage Analysis

This section discusses the analysis of the storage racks in the New Fuel Inspection pit. The design basis fuel assembly for evaluation is a FANP Advanced HTP 17x17 assembly with a uniform planar maximum enrichment of 5.0 wt% U^{235} with no integral absorber fuel rods. The racks and the design basis model are the same design as those in the wet pools. The analysis considers normal dry conditions and credible upset conditions in the pit.

The normal condition for the New Fuel Inspection pit is dry with no substantial amount of moderation present. However, the analysis must determine the reactivity effect caused by the addition of various densities of moderation into the pit. It is possible for a secondary reactivity spike to occur at low-density moderator conditions that range from approximately 3% to 10% of fully dense water conditions. For example, such low-density water, fog, or mist conditions can occur when fire fighting equipment is used. Under interspersed moderator conditions the separate new fuel storage racks can be neutronically coupled. Therefore, modeling of rack interactions must be considered. Two sets of calculations were performed to determine reactivity at normal and upset conditions. Each set of calculations varied the interspersed moderation from dry (0%) to 100% density water at 20 °C (68 °F) both inside and outside the fuel assemblies to account for upset conditions.

Tables 4.1-1 and 4.1-2 give the results of the KENO V.a calculations. Figure 4.1-1 illustrates the results. The maximum calculated k-effective of [ ] occurred for the condition of fuel against the wall under fully flooded conditions. An additional upset condition was evaluated for a fuel assembly dropped outside the rack but adjacent to one in the rack. The calculated k-effective for this case was [ ] for the dry condition. This upset condition will never happen during a flooded condition because all fuel handling is suspended if there is water in the New Fuel Inspection Pit.

The $K_{95/95}$ formulation for this evaluation is slightly different than the wet racks. This is due to the removal of the system bias components (Table B.2.6-1) due to the sparse loading pattern, dry condition, and restriction to non-irradiated components. Due to the sparse loading pattern, the fresh rack manufacturing tolerances (Table B.1-5) are applicable. Thus, $K_{95/95}$ is determined from the following equation:

$$K_{95/95} = k_{KENO} + [\qquad]$$

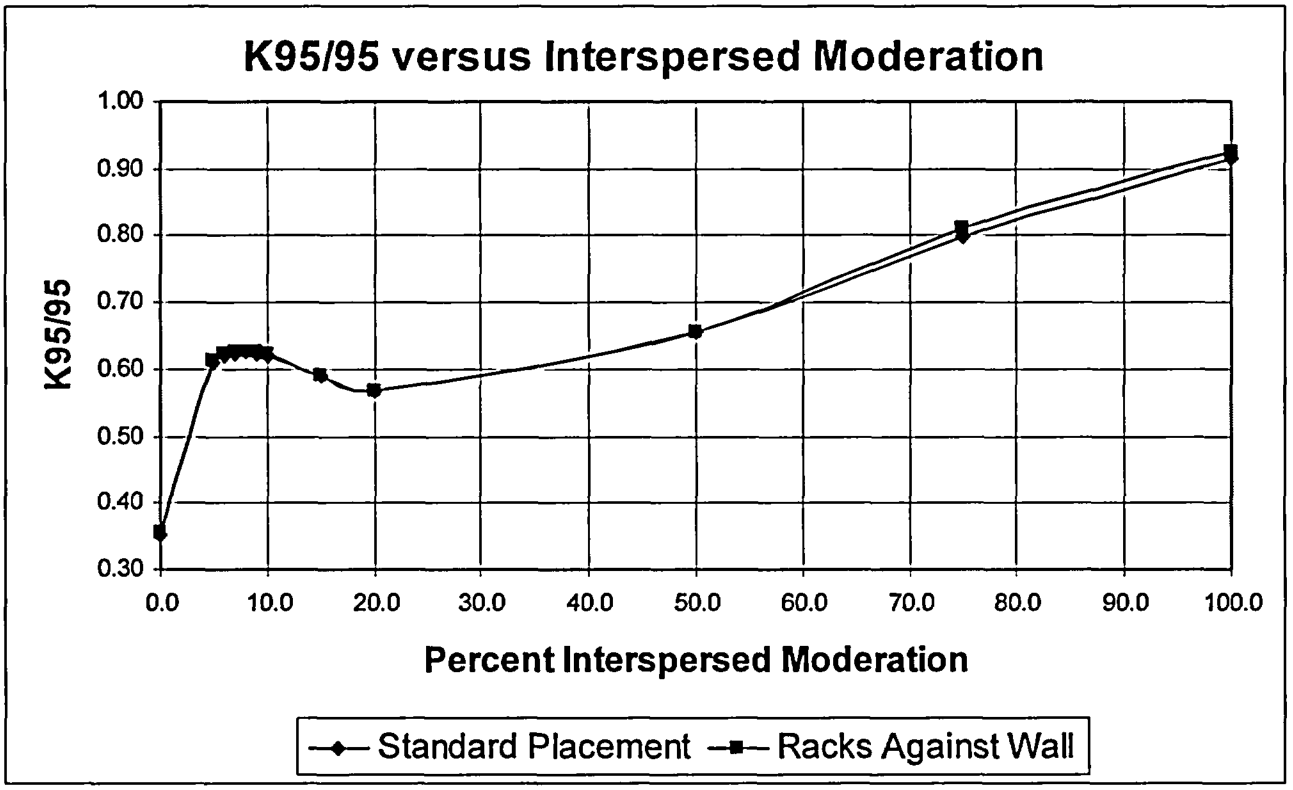
For the low interspersed moderation cases (<15% dense water) the EALF(ev) (Energy of the Average Lethargy Causing Fission) values in Tables 4.1-1 and 4.1-2 are seen to exceed the range of values analyzed in the validation analysis (Table A.7-1). Very few critical experiments at very low moderation conditions are readily available for the low enrichment (<5.00 wt%) range; therefore, the validation did not extend up to the EALF range seen in the low interspersed moderated storage vault. The reactivity is very low at the dry conditions with k-effective being well below the range of criticality concern.

Thus, exceeding the range of applicability for the EALF in the Dry New Fuel Storage Vault is not a criticality safety concern because of the low calculated k-effectives at low moderation levels.

Table 4.1-1 Results for Dry Storage Checker Board Fuel Array

Table 4.1-2 Results for Dry Storage Fuel Racks A1-A4 Against the Wall

Figure 4.1-1 Plot of Results from KENO V.a Calculations



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5.0 Summary and Conclusion for Dry New Fuel Storage, Pool A, and Pool B

The dry storage racks were evaluated with the Framatome Advanced HTP-17 fuel assembly design and criticality criteria were met for both the fully flooded and interspersed moderator (misted or fog) cases.

The Pool A and B PWR racks (both new and irradiated) were evaluated using the Advanced HTP-17 assembly design assuming total Boraflex loss. Rack interaction effects were evaluated for fresh PWR, spent PWR, and spent BWR racks. A burnup versus enrichment curve was generated for the PWR spent racks in addition to soluble boron requirements. The burnup versus enrichment curve is provided in Section 3.1. Pool A and B requirements are:

1. The PWR fresh rack requires a checkerboarded loading pattern limited to two diagonally-adjacent assemblies in any four rack cells, i.e., 2 of 4 checkerboard loading pattern for the assemblies in the rack.

2. The PWR spent fuel rack requires an assembly that has an assembly average burnup greater than the BUC minimum burnup required for the assembly initial enrichment. Assemblies that meet this requirement may be stored unrestricted. Assemblies that fail this requirement may NOT be stored in the BUC rack and shall be stored either in the fresh rack, or elsewhere.

    i. Plant measured assembly average burnup shall be decreased by the plant measured burnup uncertainty (Typically [ ] but the specific value is to be determined by plant procedures).

    ii. Assembly initial enrichment is to be the maximum planar enrichment if the assembly enrichment varies by axial location.

    iii. Assembly initial enrichment may optionally be conservatively increased by [ ] wt% U^{235} for enrichment uncertainty. Note that BUC loading curve includes a [ ] wt% U^{235} enrichment uncertainty and the additional increase may be conservative but is redundant.

3. An interface between the fresh and irradiated fuel regions consisting of either a single row of water holes alternating with irradiated assemblies face adjacent to water holes in the fresh region, or a single row of water holes.

4. A minimum 500 ppm soluble boron concentration is required for fuel storage at normal conditions without fuel handling activity.

5. A minimum 1000 ppm soluble boron concentration is required for fuel storage with fuel handling activity with fresh fuel assemblies or spent fuel assemblies that do not meet the BUC requirements for storage in a BUC designated rack.

6. A minimum 500 ppm soluble boron concentration is required for fuel storage with fuel handling activity with BUC rack qualified spent fuel assemblies. Movement of fresh fuel assemblies or spent fuel assemblies that do not meet the BUC requirements for storage in a BUC designated rack is not allowed.

7. Irradiated PWR fuel that satisfies the irradiated fuel loading curve may be placed in any PWR spent rack cell or as a replacement for a fresh assembly in the fresh rack.

8. The Spent Fuel Pool water temperature shall not exceed 150 ^{o}F (65.56 ^{o}C) for normal operations.

9. New fuel assembly designs not bounded by the design basis assembly shall be demonstrated to be less reactive than the design basis assembly at all assembly average burnups in the SFP rack geometry in order to qualify for storage.

10. Non Fuel Bearing Containers (NFBC) may be placed in any PWR spent rack cell.

11. NFBC with non-fuel bearing components may be stored in the water holes in the fresh rack provided the loading pattern contains no more than 1 NFBC in any 6 rack cells, or in a cell, as a replacement for fresh and irradiated fuel assemblies.

12. Framatome fuel assemblies may not be stored in spent fuel PWR racks if they were irradiated with a removable absorber component such as a WABA or Burnable Poison Rod Assembly (BPRA). Gadolinia bearing fuel is not restricted.

13. No restriction on placement of fresh PWR racks adjacent to either the spent PWR or BWR racks.

6.0 Design Requirements

The nominal dimensions of assemblies evaluated are listed in Tables 2.3.1-1 and 2.3.1-2 and include the new Framatome Advanced HTP-17.

The following parameters and requirements shall be controlled per Progress Energy plant design control process.

1. For Framatome fuel to be used in Shearon Harris the assembly design must be verified since the assembly design process is still underway for the Advanced HTP-17 design at the time of this analysis. Therefore, the fuel tolerance penalty from this analysis will remain applicable if the dimensional data in Tables 2.3.1-2 are maintained. Negative tolerances on these parameters are not of concern because they would reduce the delta reactivity penalty between assembly types.

2. Dimensional data used in Table 2.3.1-2 (Framatome Advanced HTP-17) must be verified as consistent with design values used for manufacturing. The primary data of interest contained in Table 2.3.1-2 is that specified by item 1) above, however, the balance of parameters in this table must be shown to be acceptable.

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7.0 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 fuel storage in Boraflex PWR racks be modified to accommodate fuel assuming complete Boraflex dissolution. The following requirements apply to Pool A and B.

1. The burnup versus enrichment curve discussed in Section 3.1 is applicable to PWR fuel in Pools A and B.

2. The soluble boron and other requirements discussed in Section 3.4 apply to Pools A and B in conjunction with the requirements of item 1).

No Technical Specification exists for dry storage of new fuel.

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

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8.0 References

1. SCALE4.4a, "A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation," NUREG/CR-0200, Revision 6, May 2000, Oak Ridge National Laboratory (ORNL).

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. Siemens Doc. EMF-93-139, "Criticality Safety Analysis: Shearon Harris Fuel Storage Racks with Siemens Power Corporation 17x17 Fuel Assemblies," C.D. Manning, Rev. 1, August 1993.

5. Siemens Doc. EMF-94-113, "H.B. Robinson New and Spent Fuel Criticality Analysis," C.D. Manning, July, 1994.

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

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

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

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Appendix A. Bias and Bias Uncertainty Evaluation

The purpose of the present analysis is to determine the bias of the k_{eff} calculated with SCALE 4.4a computer code for the Shearon Harris spent fuel pool criticality analysis. A statistical methodology is used to evaluate criticality benchmark experiments that are appropriate for the expected range of parameters. The scope of this report is limited to the validation of the KENO V.a module and CSAS25 driver in the SCALE 4.4a code package for use with the 44 energy group cross-section library 44GROUPNDF5 for Shearon Harris spent fuel criticality analyses.

This calculation is performed according to the general methodology described in Reference A.2 (NUREG/CR-6698 "Guide for Validation of Nuclear Criticality Safety Methodology") that is also briefly described in Section A.1. The critical experiments selected to benchmark the computer code system are discussed in Section A.4. The results of the criticality calculations, the trending analysis, the basis for the statistical technique chosen, the bias, and the bias uncertainty are presented in Section A.4. Final results are summarized in Section A.5.

A.1 Statistical Method for Determining the Code Bias

As presented in Reference A.2 (NUREG-6698), the validation of the criticality code must use a statistical analysis to determine the bias and bias uncertainty in the calculation of k_{eff}. The approach involves determining a weighted mean of k_{eff} that incorporates the uncertainty from both the measurement (σ_{exp}) and the calculation method (σ_{calc}). A combined uncertainty can be determined using the Equation 3 from Reference A.2, for each critical experiment:

$$\sigma_t = (\sigma_{calc}^2 + \sigma_{exp}^2)^{1/2}$$

The weighted mean of k_{eff} ($\bar{k}_{eff}$), the variance about mean (s), and the average total uncertainty of the benchmark experiments ($\bar{\sigma}^2$) can be calculated using the weighting factor $1/\sigma_t^2$ (see Eq. 4, 5, and 6 in Reference A.2). The final objective is to determine the square root of the pooled variance, defined as (Eq. 7 from Reference A.2):

$$s_P = \sqrt{s^2 + \bar{\sigma}^2}$$

The above value is used as the mean bias uncertainty, where bias is determined by the relation:

$Bias = \bar{k}_{eff} - 1$, if $\bar{k}_{eff}$ is less than 1, otherwise $Bias = 0$ (Eq.8 from Reference A.2)

The approach for determining the final statistical uncertainty in the calculational bias relies on the selection of an appropriate statistical treatment. Basically, the same steps and methods suggested in Reference A.2 for determining the upper safety limit (USL) can be applied also for determining the final bias uncertainty.

First, the possible trends in bias need to be investigated. Trends are identified through the use of regression fits to the calculated k_{eff} results. In many instances, a linear fit is sufficient to determine a trend in bias. Typical parameters used in these trending analyses are enrichment, H/X or a generic spectral parameter as the energy of the average lethargy causing fission (EALF).

Reference A.2 indicates that the use of both weighted or unweighted least squares techniques is an appropriate means for determining the fit of a function. For the present analysis linear regression was used on both weighted and unweighted k_{eff} values to determine the existence of a trend in bias. Typical numerical goodness of fit tests were applied afterwards to confirm the validity of the trend.

When a relationship between a calculated k_{eff} and an independent variable can be determined, a one-sided lower tolerance band may be used to express the bias and its uncertainty (Reference A.2). When no trend is identified, the pool of k_{eff} data is tested for normality. If the data is normally distributed, then a technique such as a one-sided tolerance limit is used to determine bias and its uncertainty. If the data is not normally distributed, then a non-parametric analysis method must be used to determine the bias and its uncertainty (Reference A.2). Similar examples of application of these techniques are included in References A.4 and A.5.

A.2 Area of Applicability Required for the Benchmark Experiments

The spent fuel pool at Shearon Harris will primarily contain commercial nuclear fuel in uranium oxide pins in a square array. This fuel is characterized by the typical parameter values provided in Table A.2-1. These typical values were used as primary tools in selecting the benchmark experiments appropriate for determining the code bias.

Benchmark calculations have been made on selected critical experiments, chosen, in so far as possible, to bound the range of variables in the spent fuel rack analyses. In rack designs, the most significant parameters affecting criticality are (1) the fuel enrichment, (2) the ^{10}B loading in the neutron absorber, and (3) the lattice spacing. Other parameters have a smaller effect but have been also included in the analyses.

One possible way of representing the data is through a spectral parameter that incorporates influences from the variations in other parameters. Such a parameter is computed by KENO V.a, which prints the "energy of the average lethargy causing fission" (EALF). The expected range for this parameter in the analyses was also included in Table A.2-1. Note that there are no critical experiments for low density (mist) moderator cases; however, interspersed moderator cases analyzed in subsequent sections demonstrate that the interspersed moderator cases were not limiting (had very low values of k_{eff}) compared to fully flooded (100% dense moderator) cases.

Table A.2-1. Range of Values of Key Parameters in Spent Fuel Pool

Parameter	Range of Values
Fissile material - Physical/Chemical Form	UO_2 rods
Enrichment	natural to 5.00 wt% U-235
Moderation/Moderator	Heterogeneous/Water
Lattice	Square
Pitch	1.2 to 1.45 cm
Clad	Zircaloy
Anticipated Absorber/Materials	Soluble Boron
	Stainless steel, Boron
H/X ratio	0 to 445
Reflection	Water, Stainless Steel
Neutron Energy Spectrum (Energy of the Average Lethargy Causing Fission)	0.25 to 2.5 eV

A.3 Description of the Criticality Experiments Selected

The set of criticality benchmark experiments has been constructed to accommodate large variations in the range of parameters of the rack configurations and also to provide adequate statistics for the evaluation of the code bias.

One hundred critical configurations were selected from various sources, such as the International Handbook of Evaluated Criticality Safety Benchmark Experiments (Reference A.1). These benchmarks include configurations performed with lattices of UO_2 fuel rods in water having various enrichments and moderating ratios (H/X). A set of MOX criticality benchmarks is also included in the present set. The area of applicability (AOA) is established within this range of benchmark experiment parameter values.

A brief description of the selected benchmark experiments, including the name of the SCALE 4.4a input files that have been constructed to model them, is presented in Table A.3-1. The table includes the references where detailed descriptions of the experiments are presented.

Table A.3-1 Descriptions of the Critical Benchmark Experiments

Experiment Case Name	Measured k_{eff}	σ exp	Brief Description	Neutron Absorber	Reflector
NUREG/CR-0073 PNL experiments (Reference A.3)					
c004	1.0000	0.0020	UO_2 pellets with 4.31 wt% ^{235}U Cluster of fuel rods on a 25.4 mm pitch. Moderator; water or borated water. Various separation distances used	None	Water and acrylic plates as well as a biological shield serve as primary reflector material.
c005b	1.0000	0.0018		0.625 cm Al plates	
c006b	1.0000	0.0019		0.625 cm Al plates	
c007a	1.0000	0.0021		0.302 cm SS-304L plates	
c008b	1.0000	0.0021			

Experiment Case Name	Measured k_{eff}	σ exp	Brief Description	Neutron Absorber	Reflector
c009b	1.0000	0.0021		0.298 cm SS-304L absorber plates with 1.05 wt % or 1.62 wt% B	
c010b	1.0000	0.0021			
c011b	1.0000	0.0021			
c012b	1.0000	0.0021		0.485 cm SS304L plates	
c013b	1.0000	0.0021			
c014b	1.0000	0.0021		Zircaloy-4 absorber plates	
c029b	1.0000	0.0021			
c030b	1.0000	0.0021			
c031b	1.0000	0.0021		Boral absorber	
BAW-1484-7 experiments (Reference A.4)					
aclp1	1.0002	0.0005	Enrichments of 2.459 wt% ^{235}U 3x3 array of fuel clusters. Various B_4C pins and stainless steel and boron-aluminum sheets were used as neutron absorbers. Cases so indicated also had dissolved boron in the water moderator.	None	Water and aluminum base plate are the primary reflective materials in the experiments. Minor contribution from the steel tank walls.
aclp2	1.0001	0.0005		1037 ppm boron	
aclp3	1.0000	0.0006		764 ppm boron	
aclp4	0.9999	0.0006		None	
aclp5	1.0000	0.0007		None	
aclp6	1.0097	0.0012		None	
aclp7	0.9998	0.0009		None	
aclp8	1.0083	0.0012		None	
aclp9	1.0030	0.0009		None	
aclp10	1.0001	0.0009		143 ppm boron	
aclp11a	1.0000	0.0006		510 ppm boron	
aclp11b	1.0007	0.0007		514 ppm boron	
aclp11c	1.0007	0.0006		501 ppm boron	
aclp11d	1.0007	0.0006		493 ppm boron	
aclp11e	1.0007	0.0006		474 ppm boron	
aclp11f	1.0007	0.0006		462 ppm boron	
aclp11g	1.0007	0.0006		432 ppm boron	
aclp12	1.0000	0.0007		217 ppm boron	
aclp13	1.0000	0.0010		15 ppm boron	
aclp13a	1.0000	0.0010		28 ppm boron	
aclp14	1.0001	0.0010		92 ppm boron	
aclp15	0.9998	0.0016		395 ppm boron	
aclp16	1.0001	0.0019		121 ppm boron	
aclp17	1.0000	0.0010		487 ppm boron	
aclp18	1.0002	0.0011		197 ppm boron	
aclp19	1.0002	0.0010		634 ppm boron	
aclp20	1.0003	0.0011		320 ppm boron	
aclp21	0.9997	0.0015		72 ppm boron	
BAW-1645-4 experiments (Reference A.5)					
rcon01	1.0007	0.0006	2.46 wt% ^{235}U 5x5 array of fuel cluster. Rod pitch between 1.2093 cm and 1.4097 cm. Cases so indicated also had dissolved boron in the water moderator.	435 ppm boron	Water and aluminum base plate are the primary reflective materials in the experiments. Minor contribution from the steel tank walls.
rcon02	1.0007	0.0006		426 ppm boron	
rcon03	1.0007	0.0006		406 ppm boron	
rcon04	1.0007	0.0006		383 ppm boron	
rcon05	1.0007	0.0006		354 ppm boron	
rcon06	1.0007	0.0006		335 ppm boron	
rcon07	1.0007	0.0006		361 ppm boron	
rcon08	1.0007	0.0006		121 ppm boron	
rcon09	1.0007	0.0006		886 ppm boron	

Experiment Case Name	Measured k_{eff}	σ exp	Brief Description	Neutron Absorber	Reflector
rcon10	1.0007	0.0006		871 ppm boron	
rcon11	1.0007	0.0006		852 ppm boron	
rcon12	1.0007	0.0006		834 ppm boron	
rcon13	1.0007	0.0006		815 ppm boron	
rcon14	1.0007	0.0006		781 ppm boron	
rcon15	1.0007	0.0006		746 ppm boton	
rcon16	1.0007	0.0006		1156 ppm boron	
rcon17	1.0007	0.0006		1141 ppm boron	
rcon18	1.0007	0.0006		1123 ppm boron	
rcon19	1.0007	0.0006		1107 ppm boron	
rcon20	1.0007	0.0006		1093 ppm boron	
rcon21	1.0007	0.0006		1068 ppm boron	
rcon28	1.0007	0.0006		121 ppm boron	
CEA Valduc Critical Mass Laboratory Experiments (Reference A.6)					
mdis01	1.0000	0.0014	4.738 wt% ^{235}U CEA Valduc Critical Mass Laboratory experiments. A key aspect of these experiments was to examine the reactivity effects of differing densities of hydrogenous materials within a cross shaped channel box placed between a two by two array of fuel rod assemblies. The assemblies each consisted of an 18 x 18 array of aluminum alloy clad fuel UO2 pellet columns. The reader is referred to Reference 3 for a description of the critical mass experiments and the computer models used for these validation cases.	None	The actual reflector boundaries vary from case to case.
mdis02	1.0000	0.0014			
mdis03	1.0000	0.0014			
mdis04	1.0000	0.0014			
mdis05	1.0000	0.0014			
mdis06	1.0000	0.0014			
mdis07	1.0000	0.0014			
mdis08	1.0000	0.0014			
mdis09	1.0000	0.0014			
mdis10	1.0000	0.0014			
mdis11	1.0000	0.0014			
mdis12	1.0000	0.0014			
mdis13	1.0000	0.0014			
mdis14	1.0000	0.0014			
mdis15	1.0000	0.0014			
mdis16	1.0000	0.0014			
mdis17	1.0000	0.0014			
mdis18	1.0000	0.0014			
mdis19	1.0000	0.0014			
LEU-COMP-THERM-022, -024, -025 Experiments (Reference A.1)					
leuct022-02	1.0000	0.0046	9.83 and 7.41 wt% enriched UO2 rods of varying numbers in hexagonal and square lattices in water.	None	Water is the primary reflector. Minor contribution from the steel tank walls.
leuct022-03	1.0000	0.0036			
leuct024-01	1.0000	0.0054			
leuct024-02	1.0000	0.0040			
leuct025-01	1.0000	0.0041			
leuct025-02	1.0000	0.0044			
Mixed Oxide (Reference A.1, Experiment MIX-COMP-THERM 002)					
epri70b (PNL-31)	1.0009	0.0047	Experiments with mixtures of natural UO2-2wt%PuO2 (8%240Pu). Square pitched lattices, with 1.778 cm, 2.2098 cm, and 2.5146 cm pitch in borated or pure water moderator.	687.9 ppm B	Reflected by water and Al.
epri70un (PNL-30)	1.0024	0.0060		1.7 ppm B	
epri87b (PNL-33)	1.0024	0.0024		1090.4 ppm B	
epri87un (PNL-32)	1.0042	0.0031		0.9 ppm B	

Experiment Case Name	Measured k_{eff}	σ exp	Brief Description	Neutron Absorber	Reflector
Epri99b (PNL-35)	1.0029	0.0027		767.2 ppm B	
Epri99un PNL-34)	1.0038	0.0025		1.6 ppm B	
Mixed Oxide (Reference A.1, Experiment MIX-COMP-THERM 003)					
saxtn104 (case 6)	1.0000	0.0023	Experiments with mixtures of natural UO2-6.6wt%PuO2 mixed-oxide (MOX), square-pitched, partial moderator height lattices. Moderator: borated or pure water moderator.	None	Reflected by water and Al.
saxtn56b (case 3)	1.0000	0.0054		337 ppm B	
saxtn792 (case 5)	1.0049	0.0027		None	
saxton52 (case 1)	1.0028	0.0072		None	
saxton56 (case 2) (PNL-35)	1.0019	0.0059		None	

A.4 Results of Calculations with SCALE 4.4.a

The critical experiments described in Section A.3 were modeled with the SCALE 4.4a computer system. The resulting k_{eff} and calculational uncertainty, along with the experimental k_{eff} and experimental uncertainty are tabulated in Table A.4-1. The parameters of interest in performing a trending analysis of the bias (Including EALF calculated by SCALE 4.4a) are also included in the table.

Table A.4-1 SCALE 4.4a Results for the Selected Benchmark Experiments

No	Case name	Benchmark values		SCALE 4.4a Calculated Values		EALF (eV)	Enrichment wt% ^{235}U	B (ppm)	H/X
		k_{eff}	σ_{exp}	k_{eff}	σ_{calc}				
1	c004	1.0000	0.0023	[ ]	[ ]	0.1126	4.31	0.0	255.92
2	c005b	1.0000	0.0054	[ ]	[ ]	0.1128	4.31	0.0	255.92
3	c006b	1.0049	0.0027	[ ]	[ ]	0.1130	4.31	0.0	255.92
4	c007a	1.0028	0.0072	[ ]	[ ]	0.1128	4.31	0.0	255.92
5	c008b	1.0019	0.0059	[ ]	[ ]	0.1135	4.31	0.0	255.92
6	c009b	1.0000	0.0023	[ ]	[ ]	0.1136	4.31	0.0	255.92
7	c010b	1.0000	0.0054	[ ]	[ ]	0.1142	4.31	0.0	255.92
8	c011b	1.0049	0.0027	[ ]	[ ]	0.1143	4.31	0.0	255.92
9	c012b	1.0028	0.0072	[ ]	[ ]	0.1148	4.31	0.0	255.92
10	c013b	1.0019	0.0059	[ ]	[ ]	0.1130	4.31	0.0	255.92
11	c014b	1.0000	0.0023	[ ]	[ ]	0.1133	4.31	0.0	255.92
12	c029b	1.0000	0.0054	[ ]	[ ]	0.1126	4.31	0.0	255.92
13	c030b	1.0049	0.0027	[ ]	[ ]	0.1132	4.31	0.0	255.92
14	c031b	1.0028	0.0072	[ ]	[ ]	0.1144	4.31	0.0	255.92
15	ACLP1	1.0019	0.0059	[ ]	[ ]	0.1725	2.46	0.0	215.57
16	ACLP2	1.0000	0.0023	[ ]	[ ]	0.2504	2.46	1037.0	215.79
17	ACLP3	1.0000	0.0054	[ ]	[ ]	0.1963	2.46	764.0	215.83
18	ACLP4	1.0049	0.0027	[ ]	[ ]	0.1912	2.46	0.0	215.91
19	ACLP5	1.0028	0.0072	[ ]	[ ]	0.1660	2.46	0.0	215.87
20	ACLP6	1.0019	0.0059	[ ]	[ ]	0.1712	2.46	0.0	215.87
21	ACLP7	1.0000	0.0023	[ ]	[ ]	0.1496	2.46	0.0	215.87
22	ACLP8	1.0000	0.0054	[ ]	[ ]	0.1537	2.46	0.0	215.87

No	Case name	Benchmark values		SCALE 4.4a Calculated Values		EALF (eV)	Enrichment wt% ^{235}U	B (ppm)	H/X
		k_{eff}	σ_{exp}	k_{eff}	σ_{calc}				
23	ACLP9	1.0049	0.0027	[ ]	[ ]	0.1409	2.46	0.0	215.87
24	ACLP10	1.0028	0.0072	[ ]	[ ]	0.1495	2.46	143.0	215.22
25	ACP11A	1.0019	0.0059	[ ]	[ ]	0.1996	2.46	510.0	215.32
26	ACP11B	1.0000	0.0023	[ ]	[ ]	0.1994	2.46	514.0	215.73
27	ACP11C	1.0000	0.0054	[ ]	[ ]	0.2019	2.46	501.0	215.32
28	ACP11D	1.0049	0.0027	[ ]	[ ]	0.2028	2.46	493.0	215.14
29	ACP11E	1.0028	0.0072	[ ]	[ ]	0.2037	2.46	474.0	214.70
30	ACP11F	1.0019	0.0059	[ ]	[ ]	0.2050	2.46	462.0	214.52
31	ACP11G	1.0000	0.0023	[ ]	[ ]	0.2045	2.46	432.0	215.97
32	ACLP12	1.0000	0.0054	[ ]	[ ]	0.1700	2.46	217.0	215.05
33	ACLP13	1.0049	0.0027	[ ]	[ ]	0.1965	2.46	15.0	215.67
34	ACP13A	1.0028	0.0072	[ ]	[ ]	0.1981	2.46	28.0	215.91
35	ACLP14	1.0019	0.0059	[ ]	[ ]	0.2011	2.46	92.0	215.83
36	ACLP15	1.0000	0.0023	[ ]	[ ]	0.2063	2.46	395.0	215.83
37	ACLP16	1.0000	0.0054	[ ]	[ ]	0.1730	2.46	121.0	215.83
38	ACLP17	1.0049	0.0027	[ ]	[ ]	0.2053	2.46	487.0	215.89
39	ACLP18	1.0028	0.0072	[ ]	[ ]	0.1725	2.46	197.0	215.89
40	ACLP19	1.0019	0.0059	[ ]	[ ]	0.2061	2.46	634.0	215.89
41	ACLP20	1.0000	0.0023	[ ]	[ ]	0.1730	2.46	320.0	215.89
42	ACLP21	1.0000	0.0054	[ ]	[ ]	0.1532	2.46	72.0	216.19
43	RCON01	1.0049	0.0027	[ ]	[ ]	2.4282	2.46	435.0	17.41
44	RCON02	1.0028	0.0072	[ ]	[ ]	2.4360	2.46	426.0	17.40
45	RCON03	1.0019	0.0059	[ ]	[ ]	2.4972	2.46	406.0	17.40
46	RCON04	1.0000	0.0023	[ ]	[ ]	2.4989	2.46	383.0	17.41
47	RCON05	1.0000	0.0054	[ ]	[ ]	2.4988	2.46	354.0	17.41
48	RCON06	1.0049	0.0027	[ ]	[ ]	2.5119	2.46	335.0	17.41
49	RCON07	1.0028	0.0072	[ ]	[ ]	1.6313	2.46	361.0	17.43
50	RCON08	1.0019	0.0059	[ ]	[ ]	1.1134	2.46	121.0	17.43
51	RCON09	1.0000	0.0023	[ ]	[ ]	1.4481	2.46	886.0	44.81
52	RCON10	1.0000	0.0054	[ ]	[ ]	1.4623	2.46	871.0	44.81
53	RCON11	1.0049	0.0027	[ ]	[ ]	1.5006	2.46	852.0	44.79
54	RCON12	1.0028	0.0072	[ ]	[ ]	1.4942	2.46	834.0	44.81
55	RCON13	1.0019	0.0059	[ ]	[ ]	1.4973	2.46	815.0	44.81
56	RCON14	1.0000	0.0023	[ ]	[ ]	1.5185	2.46	781.0	44.79
57	RCON15	1.0000	0.0054	[ ]	[ ]	1.5122	2.46	746.0	44.79
58	RCON16	1.0049	0.0027	[ ]	[ ]	0.4182	2.46	1156.0	118.47
59	RCON17	1.0028	0.0072	[ ]	[ ]	0.4293	2.46	1141.0	118.47
60	RCON18	1.0019	0.0059	[ ]	[ ]	0.4354	2.46	1123.0	118.44
61	RCON19	1.0000	0.0023	[ ]	[ ]	0.4371	2.46	1107.0	118.44
62	RCON20	1.0000	0.0054	[ ]	[ ]	0.4367	2.46	1093.0	118.44
63	RCON21	1.0049	0.0027	[ ]	[ ]	0.4404	2.46	1068.0	118.44
64	RCON28	1.0028	0.0072	[ ]	[ ]	0.9984	2.46	121.0	17.44
65	MDIS01	1.0019	0.0059	[ ]	[ ]	0.2822	4.74	0.0	137.61
66	MDIS02	1.0000	0.0023	[ ]	[ ]	0.2641	4.74	0.0	137.61
67	MDIS03	1.0000	0.0054	[ ]	[ ]	0.2636	4.74	0.0	137.61
68	MDIS04	1.0049	0.0027	[ ]	[ ]	0.2513	4.74	0.0	137.61
69	MDIS05	1.0028	0.0072	[ ]	[ ]	0.2411	4.74	0.0	137.61
70	MDIS06	1.0019	0.0059	[ ]	[ ]	0.2292	4.74	0.0	137.61
71	MDIS07	1.0000	0.0023	[ ]	[ ]	0.2250	4.74	0.0	137.61
72	MDIS08	1.0000	0.0054	[ ]	[ ]	0.2493	4.74	0.0	137.61
73	MDIS09	1.0049	0.0027	[ ]	[ ]	0.2483	4.74	0.0	137.61
74	MDIS10	1.0028	0.0072	[ ]	[ ]	0.2221	4.74	0.0	137.61
75	MDIS11	1.0019	0.0059	[ ]	[ ]	0.2043	4.74	0.0	137.61
76	MDIS12	1.0000	0.0023	[ ]	[ ]	0.1946	4.74	0.0	137.61

No	Case name	Benchmark values		SCALE 4.4a Calculated Values		EALF (eV)	Enrichment wt% ^{235}U	B (ppm)	H/X
		k_{eff}	σ_{exp}	k_{eff}	σ_{calc}				
77	MDIS13	1.0000	0.0054	[ ]	[ ]	0.1947	4.74	0.0	137.61
78	MDIS14	1.0049	0.0027	[ ]	[ ]	0.2299	4.74	0.0	137.61
79	MDIS15	1.0028	0.0072	[ ]	[ ]	0.2270	4.74	0.0	137.61
80	MDIS16	1.0019	0.0059	[ ]	[ ]	0.1905	4.74	0.0	137.61
81	MDIS17	1.0000	0.0023	[ ]	[ ]	0.1794	4.74	0.0	137.61
82	MDIS18	1.0000	0.0054	[ ]	[ ]	0.1747	4.74	0.0	137.61
83	MDIS19	1.0049	0.0027	[ ]	[ ]	0.1747	4.74	0.0	137.61
84	leuct022-02	1.0028	0.0072	[ ]	[ ]	0.2920	9.83	0.0	80.00
85	leuct022-03	1.0019	0.0059	[ ]	[ ]	0.1253	9.83	0.0	151.00
86	leuct024-01	1.0000	0.0023	[ ]	[ ]	1.0568	9.83	0.0	41.00
87	leuct024-02	1.0000	0.0054	[ ]	[ ]	0.1435	9.83	0.0	128.00
88	leuct025-01	1.0049	0.0027	[ ]	[ ]	0.4401	7.41	0.0	66.30
89	leuct025-02	1.0028	0.0072	[ ]	[ ]	0.2015	7.41	0.0	106.10
90	epri70b (PNL-31)	1.0019	0.0059	[ ]	[ ]	0.7631	-	688.0	146.15
91	epri70un (PNL-30)	1.0000	0.0023	[ ]	[ ]	0.5648	-	2.0	146.20
92	epri87b (PNL-33)	1.0000	0.0054	[ ]	[ ]	0.2780	-	1090.0	308.83
93	epri87un (PNL-32)	1.0049	0.0027	[ ]	[ ]	0.1894	-	1.0	308.99
94	epri99b (PNL-35)	1.0028	0.0072	[ ]	[ ]	0.1802	-	767.0	445.41
95	epri99un (PNL-34)	1.0019	0.0059	[ ]	[ ]	0.1353	-	2.0	445.57
96	saxtn104 (case 6)	1.0000	0.0023	[ ]	[ ]	0.1001	-	0.0	473.11
97	saxtn56b (case 3)	1.0000	0.0054	[ ]	[ ]	0.6523	-	337.0	95.24
98	saxtn792 (case 5)	1.0049	0.0027	[ ]	[ ]	0.1547	-	0.0	249.70
99	saxton52 (case 1)	1.0028	0.0072	[ ]	[ ]	0.8878	-	0.0	73.86
100	saxton56 (case 2)	1.0019	0.0059	[ ]	[ ]	0.5450	-	0.0	95.29

In order to address situations in which the critical experiment being modeled was at other than a critical state (i.e., slightly super or subcritical), the calculated k_{eff} is normalized to the experimental k_{exp}, using the following formula (Eq.9 from Reference A.2):

$$k_{norm} = k_{calc} / k_{exp}$$

In the following, the normalized values of the k_{eff} were used in the determination of the code bias and bias uncertainty.

A.5 Trending Analysis

The next step of the statistical methodology used to evaluate the code bias for the pool of experiments selected is to identify any trend in the bias. This is done by using the trending parameters presented in Table A.5-1.

Table A.5-1 Trending Parameters

Energy of the Average Lethargy causing Fission (EALF)
Fuel Enrichment (wt% ^{235}U)
Atom ratio of the moderator to fuel (H/X)
Soluble Boron Concentration

The first step in calculating the bias uncertainty limit is to apply regression–based methods to identify any trending of the calculated values of k_{eff} with the spectral and/or physical parameters. The trends show the results of systematic errors or bias inherent in the calculational method used to estimate criticality.

For the critical benchmark experiments that were slightly super or subcritical, an adjustment to the k_{eff} value calculated with SCALE 4.4a (k_{calc}) was done as suggested in Reference A.2. This adjustment is done by normalizing the calculated (k_{calc}) value to the experimental value (k_{exp}). This normalization does not affect the inherent bias in the calculation due to very small differences in k_{eff}. Unless otherwise mentioned, the normalized k_{eff} values (k_{norm}) have been used in all subsequent calculations.

Each subset of normalized k_{eff} values is first tested for trending against the spectral and/or physical parameters of interest (in this case, presented in Table A.5-1 above), using the build-in regression analysis tool from any general statistical software (e.g., Excel). Trending in this context is linear regression of unweighted calculated k_{eff} on the predictor variable(s) (spectral and/or physical parameters). In addition, the equations presented in Reference A.2 are also applied to check for a linear dependency in case of weighted k_{eff}, using as weight the factor $1/\sigma_i^2$ as previously discussed.

The linear regression fitted equation is in the form $y(x) = a + bx$, where y is the dependent variable (k_{eff}) and x is any of the predictor variables mentioned in Table A.5-1. The difference between the predicted y and actual value is known as the random error component (residuals).

The final validity of each linear trend is checked using well-established indicators or goodness-of-fit tests concerning the regression parameters. As a first indicator, the coefficient of determination (r^2) that is available as a result of using linear regression statistics, can be used to evaluate the linear trending. It represents the proportion of the sum of squares of deviations of the y values about their mean that can be attributed to a linear relation between y and x.

Another assessment of the adequacy of the linear model can be done by checking the goodness-of-fit against a null hypothesis on the slope (b) (Reference A.7, p. 371). The slope test requires calculating the test statistic "T" as in the following equation along with the corresponding statistical parameters (Reference A.7, p. p. 371).

$$T = \frac{\hat{\beta}_1}{s/\sqrt{S_{xx}}}$$

where, $\hat{\beta}_1$ is the estimated slope of the fitted linear regression equation,

$$S_{xx} = \sum_{i=1,n} (x_i - \bar{x})^2$$

and,

$$s=\frac{1}{(n-2)}\sum_{i=1,n}(y_i-\hat{y}_i)^2$$

where, $\hat{y}_i$ is the estimated value using the regression equation.

The test statistic is compared to the Student t-distribution ($t_{\alpha/2,n-2}$) with 95% confidence and *n-2* degrees of freedom (Reference A.8, p. p.T-5), where *n* is the initial number of points in the subset. Given a null hypothesis $H_0:\beta_1=0$, of "no statistically significant trend exists (slope is zero)", the hypothesis would be rejected if $|T| > t_{\alpha/2,n-2}$. By only accepting linear trends that the data supports with 95% confidence, trends due to the randomness of the data are eliminated. A good indicator of this statistical process is evaluation of the P-value probability (calculated by the regression tool in Excel) that gives a direct estimation of the probability of having linear trending due only to chance.

The last step of the regression analysis is determining whether or not the final requirements of the simple linear regression model are satisfied. The error components (residuals) need to be normally distributed with mean zero, and also the residuals need to show a random scatter about the center line (no pattern). These requirements were verified for the present calculation using the built-in statistical functions in Excel and by applying an omnibus normality test (Anderson-Darling [Reference A.8, p.372]) on the residuals.

The results of the trending parameter analysis for the criticality benchmark set (unweighted k_{eff}) are summarized in Table A.5-2.

Table A.5-2 Summary of Trending Analysis

[a] Benchmark experiments with MOX fuel excluded.

The results in Table A.5-2 show that there are no statistically significant or valid trends of k_{eff} with the trending parameters. An additional check was done by checking if there are any trends on the weighted data. The results of the regression analysis obtained using weighted k_{eff} (with the weight factor $1/\sigma_t^2$ as previously discussed) show that the determination coefficient (r^2) has similar low values as in the above table, indicating very weak and statistically insignificant trends.

Figures A.5-1 to A.5-4 show the distribution of the normalized k_{eff} values versus the trending parameters investigated.

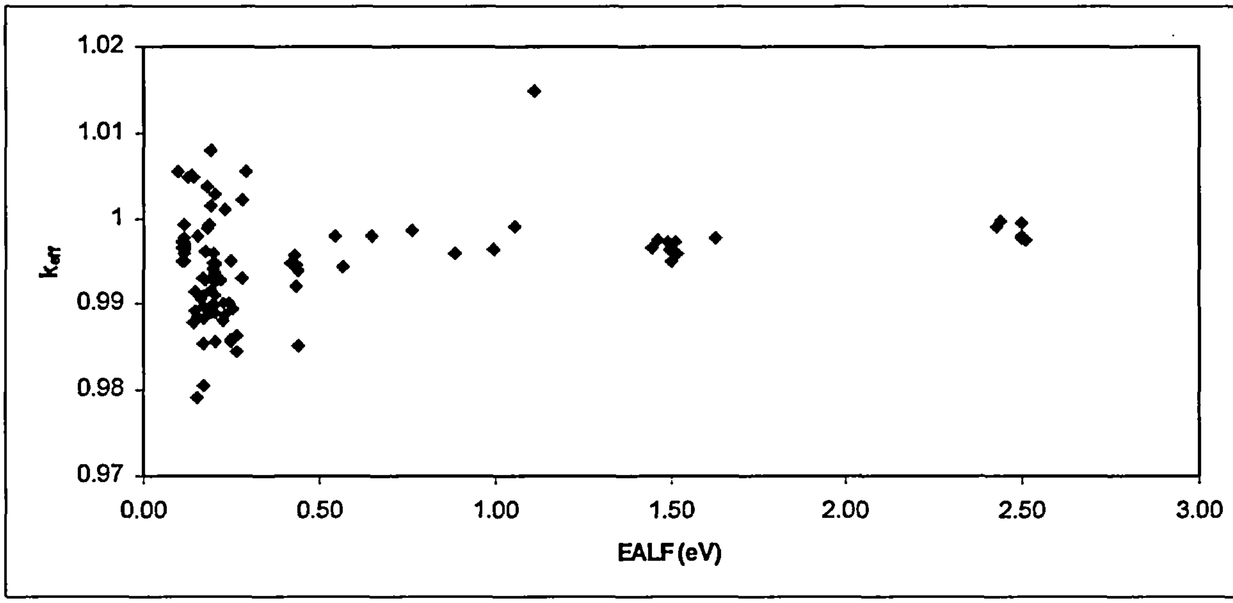

Figure A.5-1 Distribution of k_{eff} Data versus EALF for the Selected Pool of Benchmark Experiments

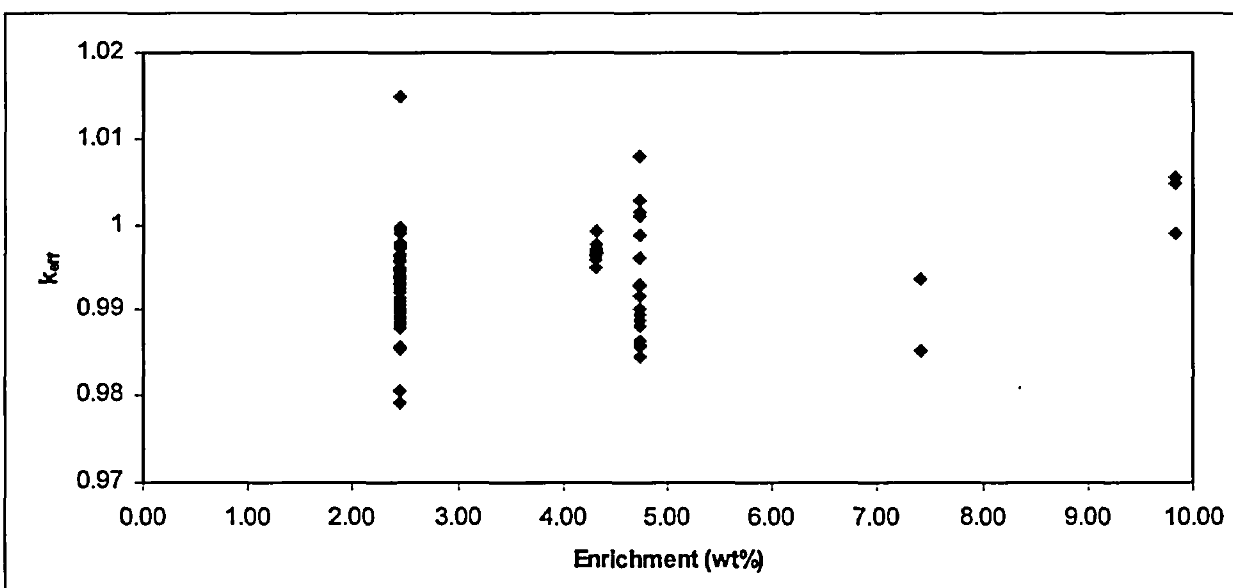

Figure A.5-2 Distribution of k_{eff} Data versus Enrichment (^{235}U) for the Selected Pool of Benchmark Experiments

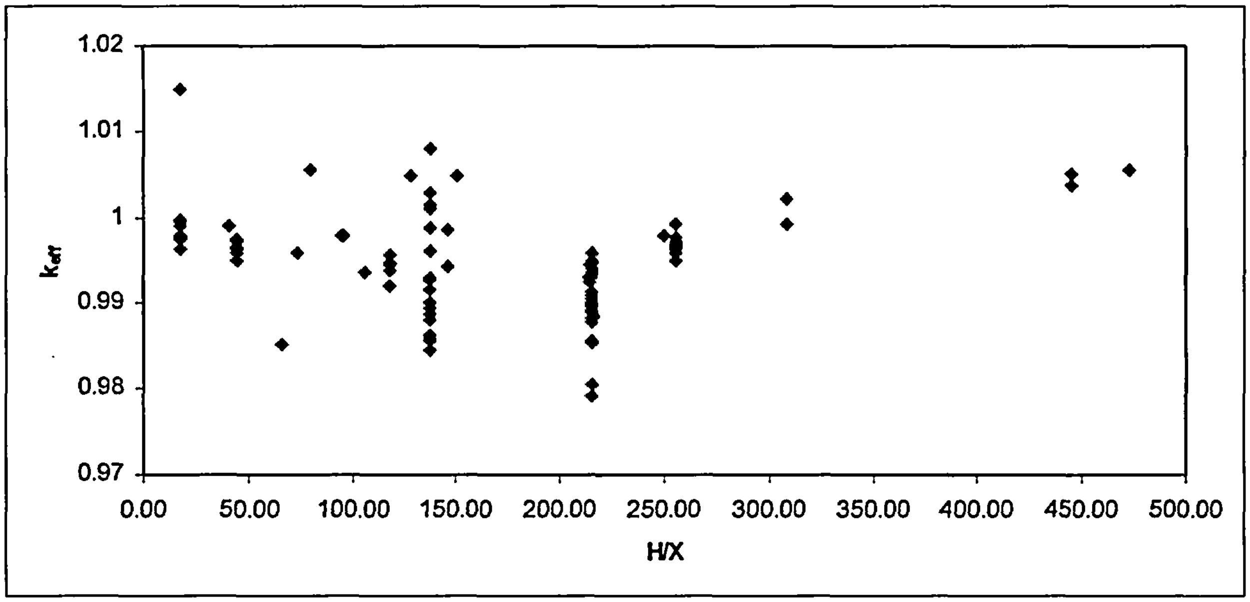

Figure A.5-3 Distribution of k_{eff} Data versus H/X for the Selected Pool of Benchmark Experiments

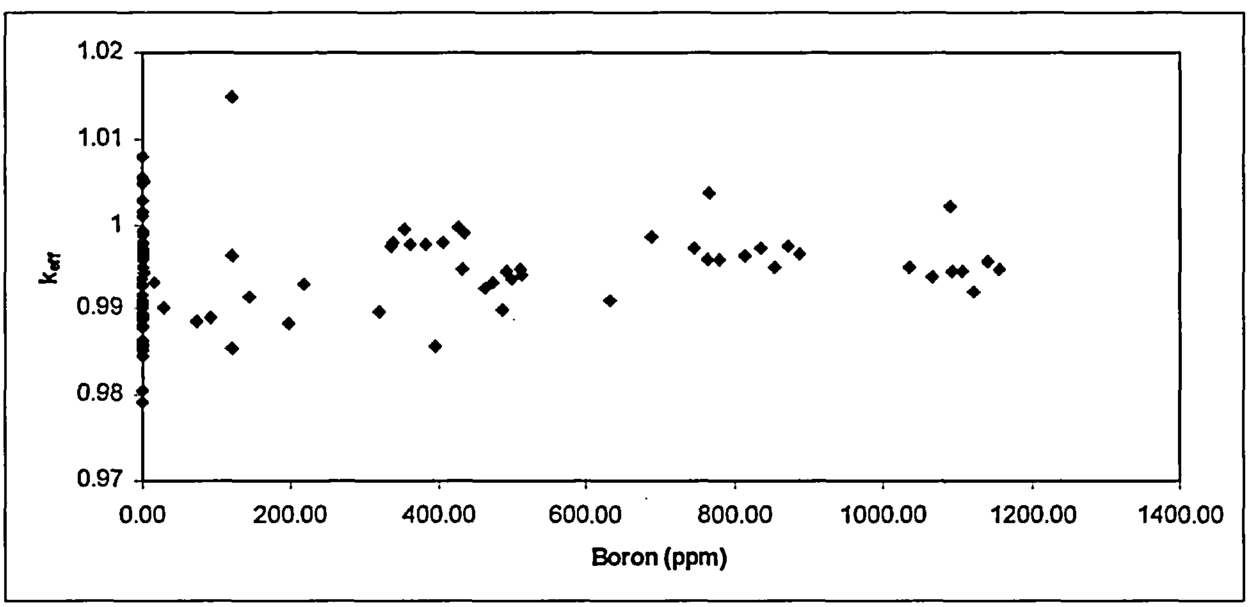

Figure A.5-4 Distribution of k_{eff} Data versus Soluble Boron Concentration for the Selected Pool of Benchmark Experiments

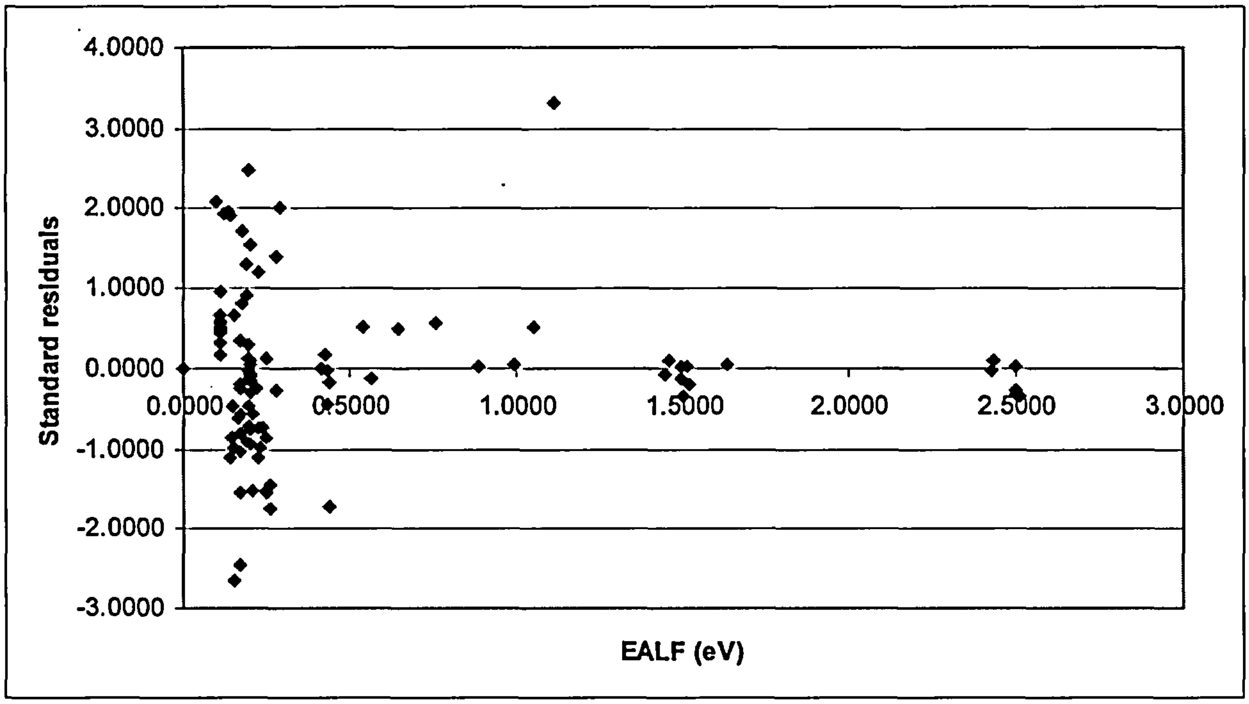

Figure A.5-5 Plot of Standard Residuals for Regression Analysis with EALF as Trending Parameter

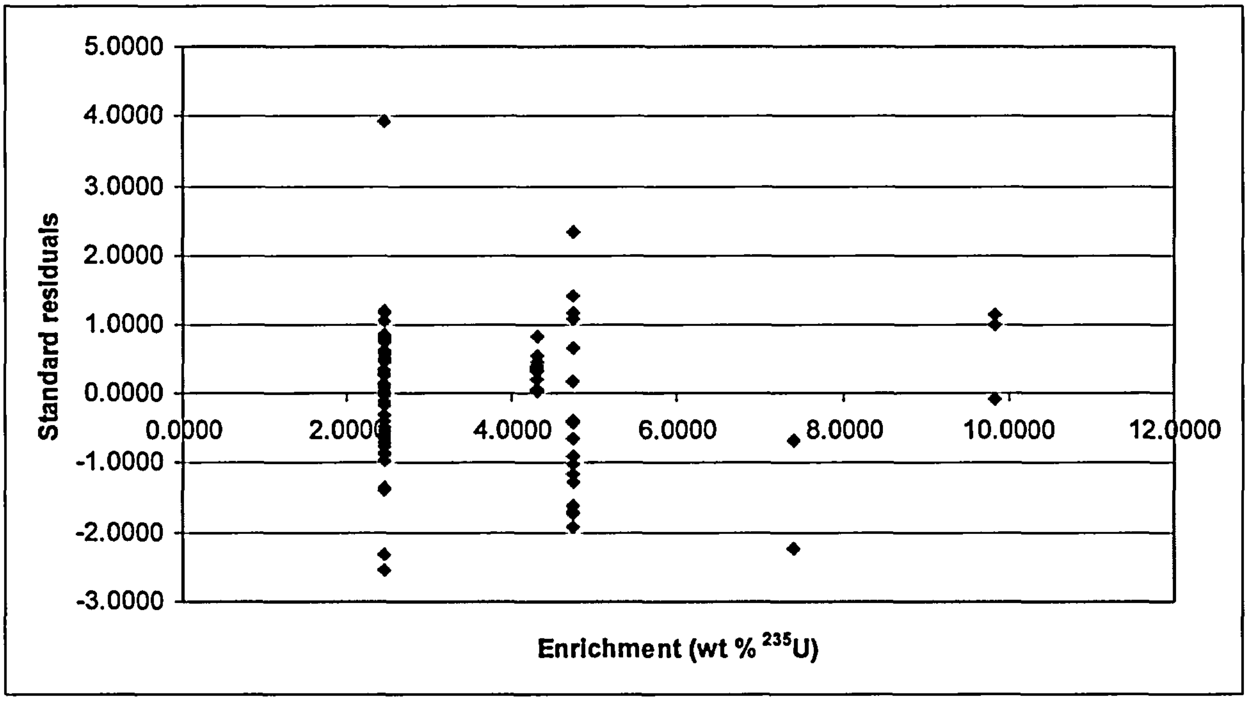

Figure A.5-6 Plot of Standard Residuals for Regression Analysis with Enrichment as Trending Parameter

A.6 Bias and Bias Uncertainty

For situations in which no significant trending in bias is identified, the statistical methodology presented in Reference A.2 suggests to first check the normality of the pool of k_{eff} data. Applying the Shapiro-Wilk test (Reference A.2) the null hypothesis of a normal distribution is not rejected. A visual inspection of the normal probability plot of the k_{eff} data is shows that the pool of k_{eff} data for the selected benchmarks can be considered normally distributed.

This situation allows the application of the weighted single-sided lower tolerance limit to determine the bias uncertainty (Reference A.2). First by determining of the factor for 95% probability at the 95% confidence level ($C_{95/95}$) and then multiplying it with the evaluated squared-root of the pooled variance, the uncertainty limit is determined.

From Reference A.10, $C_{95/95}$ for n equal to 100 is [ ]. The squared root of the pooled variance calculated using the formulas presented is:

$$s_P = \sqrt{s^2 + \bar{\sigma}^2} = [\qquad]$$

$$\textit{\textbf{Bias Uncertainty}} = C_{95/95} * s_P = [\qquad]$$

The bias is obtained using the formula that includes the weighted average of k_{eff}

$$\textbf{Bias} = \bar{k}_{eff} - 1 = [\qquad]$$

These represent the final results which can be used to evaluate the maximum k_{eff}, $K_{95/95}$, values in the criticality analysis of the Shearon Harris spent fuel pool. Note that this bias will be applied as a positive penalty in the equation for computation of $K_{95/95}$.

A.7 Area of Applicability

A brief description of the spectral and physical parameters characterizing the set of selected benchmark experiments is provided in Table A.7-1.

Table A.7-1 Range of Values of Key Parameters in Benchmark Experiments

Parameter	Range of Values
Geometrical shape	Heterogeneous lattices; Rectangular and hexagonal
Fuel type	UO_2 rods MOX fuel rods
Enrichment (for UO_2 fuel)	2.46 to 9.83 wt % ^{235}U
Lattice pitch	1.04 to 2.6416 cm
H/X	17.4 to 445
EALF	0.11 to 2.51 eV
Absorbers	Soluble boron Boron in plates:
Reflectors	Water Stainless Steel Aluminum

A.8 Bias Summary and Conclusions

This evaluation considers a selected set of criticality benchmark experiments with enrichments ranging from about 2.5 to about 10 wt% ^{235}U and includes some experiments with MOX fuel rods. The results of the evaluation provide the following information relative to the SCALE4.4a bias:

$$\textbf{Bias} = \bar{k}_{eff} - 1 = [\qquad\qquad]$$

Note that this bias will be applied as a positive penalty in the equation for computation of k_{max};

$$\textbf{Bias Uncertainty} = C_{95/95} * s_P = [\qquad\qquad]$$

The bias and its uncertainty (95/95 weighted single-sided tolerance limit) was obtained applying the appropriate steps of the statistical methodology presented in NUREG 6698 (Reference A.2) taking into account the possible trending of k_{eff} with various spectral and/or physical parameters. The results are intended to support the criticality analysis of Shearon Harris spent fuel pool.

A.9 Appendix A References

A.1 Nuclear Energy Agency, "International Handbook of Evaluated Criticality Safety Benchmark Experiments." NEA/NSC/DOC(95)03, Nuclear Energy Agency, Organization for Co-operation and Development, 2002.

A.2 Nuclear Regulatory Commission, "Guide for Validation of Nuclear Criticality Safety Calculational Methodology", NUREG/CR-6698, January 2001.

A.3 Bierman, S.R., Durst, B.M., Clayton, E.D., "Critical Separation Between Subcritical Clusters of 4.29 Wt% ^{235}U Rods in Water With Fixed Neutron Poisons," Battelle Pacific Northwest Laboratories, NUREG/CR-0073(PNL-2615).

A.4 Baldwin et.al., "Critical Experiments Supporting Close Proximity Water Storage Of Power Reactor Fuel," BWA-1484-7, July 1979.

A.5 Hoovler, G.S., et.al., "Critical Experiments Supporting Underwater Storage of Tightly Packed Configurations of Spent Fuel Pins," BAW-1645-4, November 1981.

A.6 "Dissolution and Storage Experimental Program with $U[4.75]O_2$ Rods," Transactions of the American Nuclear Society, Vol. 33, pg. 362.

A.7 Rosenkrantz W.A., *Introduction to Probability and Statistics for Scientists and Engineers*, The McGraw-Hill, New York, NY, 1989.

A.8 D'Agostino, R.B. and Stephens, M.A., *Goodness-of-fit Techniques*. Statistics, Textbooks and Monographs, Volume 68, New York, New York, 1986.

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Appendix B Tolerance Calculations

Appendix B addresses tolerances that apply to the dry new fuel storage racks and Pool A and B racks that are used in the determination of $K_{95/95}$. The base case for the tolerance evaluations consider completely degraded Boraflex racks for either fresh or spent fuel. Fuel and rack parameters are for nominal conditions, so that fabrication tolerance uncertainties must be factored into the results. For the fresh rack, the moderator temperature is assumed to be 20°C. For spent racks and combinations of fresh and spent racks, a moderator temperature of [ ] is assumed. The difference in the choice of temperatures is based upon the temperature coefficient of reactivity as discussed later in the section. The base case provides the nominal k_{eff} of the system to which must be added the biases and uncertainties related to the methodology and the system uncertainties to determine $K_{95/95}$. This latter value is that which is compared to the criticality safety criterion to ensure criticality safety.

The $K_{95/95}$ for the evaluation is calculated using the following formulation:

$$K_{95/95} = k_{eff} + bias_{method} + \Delta k_{sys} + [C^2(\sigma_k^{\,2} + \sigma_{bias}^{\,2} + \sigma_{sys}^{\,2}) + \Delta k_{tol}^{\,2}]^{1/2},$$

where,

k_{eff}	=	the KENO V.a calculated result;
$bias_{method}$	=	the bias associated with the calculation methodology;
Δk_{sys}	=	summation of Δk values associated with the variation of system and base case modeling parameters, e.g. moderator temperature and off-centered assembly in cell;
C	=	confidence multiplier based upon the number of benchmark cases;
σ_k, σ_{bias}, σ_{sys}	=	standard deviation of k_{eff}, methodology bias, and system Δk_{sys};
Δk_{tol}	=	statistical combination of statistically independent Δk values due to manufacturing tolerances, e.g. fuel enrichment, cell pitch, etc.

The bias for the code system has been determined from a comparison of experimental results with those from the KENO V.a model of the experiments (Appendix A). That evaluation provided a calculated bias of [ ] (bias ± σ_{bias}) with a single-sided confidence factor C of [ ] based upon the 100 experiments included in the evaluation. The determination of values for the other terms in the above equation is discussed in this section.

B.1 Rack and Assembly Manufacturing Tolerances

The manufacturing tolerances for the racks and the fuel were based primarily upon CASMO-3 calculations for the 4-of-4 fuel loading pattern of the spent fuel rack. The model for these calculations is discussed in Section 2.3.2 and is applicable to both the wet and dry racks. Table B.1-1 gives the reactivity calculation results for the fuel assembly tolerances with the tolerance values listed at the top of the table. Bolded values in the

Tables identify the changes from the nominal design values to account for tolerances. Table B.1-2 provides similar data and results for tolerances on the rack unit.

A similar calculation for the 2-of-4 loading pattern for the fresh fuel rack is not possible in CASMO-3 due to geometrical modeling limitations. Due to the large water gaps between fuel assemblies in the 2-of-4 configuration, it is judged that a variation in the cell pitch would not exhibit such a large reactivity effect for this configuration. Thus a KENO V.a calculation was performed to determine the Δk for the pitch tolerance for this configuration. Table B.1-3 lists the results for KENO V.a pitch evaluation for the fresh rack. The first set of cases examines the explicit CASMO-3 4-of-4 model with KENO V.a to ensure methodology consistency. The CASMO-3 model for 20°C was used for

Table B.1-1 SHNPP HTP-17 Advanced Fuel Assembly CASMO-3 Tolerance Effects

Table B.1-2 CASMO-3 Rack Tolerance Effects

this evaluation. The KENO V.a Δk values for the 4-of-4 loading pattern show the same trend as the CASMO3 results with agreement between the two results within the uncertainty of the KENO V.a calculation. Thus, the CASMO-3 tolerance values for close packed storage of fuel assemblies are verified with the KENO V.a code, or vice-versa. The KENO V.a model was then modified to a 2-of-4 checkerboard pattern. The results for this evaluation are listed in the second set of cases in Table B.1-3. The Δk results for both the plus and minus tolerance are within ~2σ of the nominal case, and each other. This indicates that the small pitch change is statistically insignificant for the checkerboard loading pattern. However, for conservatism, the largest Δk+2σ uncertainty, i.e. [ ], will be assumed to bound any Δk uncertainty due to pitch. It is judged that a similar calculation would reduce the tolerance value for the cell ID variation, but was not investigated due to its relatively small value.

Table B.1-3 Rack Cell Pitch Reactivity Effects

Table B.1-4 lists the worst positive Δk values for manufacturing tolerances for both the racks and the fuel assembly. Values are determined independently for the fresh and the spent rack to account for the difference in Δk value for the pitch tolerance. It is assumed that each of the tolerances is independent. Thus, they can be statistically rather than arithmetically combined to provide a total $\Delta k_{tol\text{-}rack}$ and $\Delta k_{tol\text{-}fuel}$, which are then statistically combined to determine the total value. It is noted that the CASMO-3 total uncertainty is applied to both the spent PWR rack and the BWR rack due to the high density loading of these racks.

Table B.1-4 Manufacturing Tolerances

B.2 System Bias Effects

Table B.1-4 provides the manufacturing tolerance Δk values for use in the determination of $K_{95/95}$. The other Δk value of interest is due to system parameters. For the rack evaluations five parameters are significant: moderator temperature effects, off-center placement of the assembly in the rack cell, rack interaction effects, spectrum hardening effects from removal of absorber components, and placement of non-fuel containers in the rack. Determination of the appropriate system Δk values are discussed below. The values are summarized in Table B.2.5-1 for both the fresh and spent racks.

B.2.1 Moderator Temperature Effects

Similar to the manufacturing tolerance evaluation two sets of calculations were made to evaluation system temperature effects. The first used a 4-of-4 CASMO-3 model that is representative of the spent fuel racks. The second examined the fresh rack 2-of-4 arrangement with a KENOV.a model. Both evaluations are discussed in this section.

The spent rack model is the base 4-of-4 model used for the manufacturing tolerance evaluations. Table B.2.1-1 lists the results for the pool water temperature reactivity effects with no soluble boron and with 500 ppm soluble boron in the pool water. Figure B.2.1-1 illustrates these results. The slopes of the curves with temperature are similar for both boron concentrations. The effect of fuel burnup on the pool temperature variation was also analyzed. The fuel was depleted to 45 GWd/mtU with CASMO-3 for normal full power core conditions and then placed in the rack. The same infinite array model of the no fuel burnup cases were executed with no soluble boron and with 500 ppm boron. Table B.2.1-2 gives the results. Figure B.2.1-2 shows the reactivity trend with increasing pool temperature to be the same as for the no burnup condition. The trend of increased reactivity with increasing pool temperature applies for racks that are fully filled.

Table B.2.1-1 Pool Temperature Effects - No Fuel Burnup

Figure B.2.1-1 Pool Reactivity Effects from Changing Pool Temperature, No Fuel Burnup

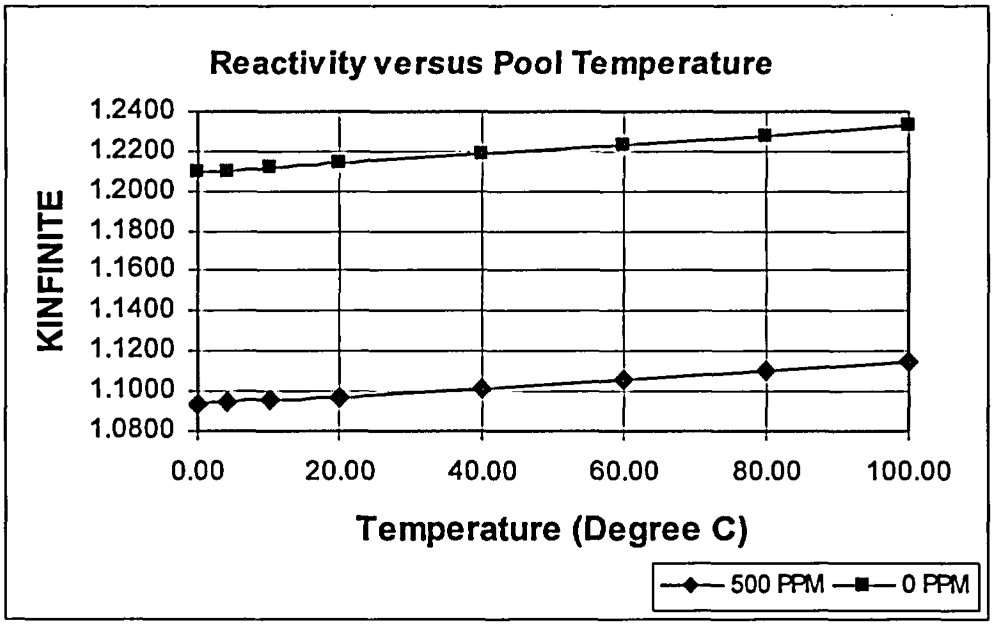


Table B.2.1-2 Pool Temperature Effects at 45 GWd/mtU Fuel Burnup

The results in Table B.2.1-1 show a positive bias as the temperature increases. For the 4-of-4 configuration, the decrease in moderator density with increasing temperature essentially reduces the separation between assemblies in the rack to more closely couple them. This increases the rack reactivity. is the 4-of-4 configuration results are applicable to the spent fuel racks. However, these results do not apply to the fresh racks with a 2-of-4 (or sparser) loading pattern.

As in the pitch evaluation, the moderator temperature effects for the fresh racks use a series of KENO V.a cases. Table B.2.1-3 lists the results of these cases. The first set of cases represents the KENO V.a explicit representation of the CASMO-3 model for 20°C and 100°C, as well as a listing of the CASMO-3 results from Table B.2.1-1. There is reasonably good agreement between the KENO V.a and CASMO-3 Δk values for the 20°C and 100°C cases. This validates the temperature results from these two codes for the fully loaded configuration. The second set of data represents the KENO V.a results

Figure B.2.1-2 Pool Reactivity Effects from Changing Pool Temperature for 45 GWd/mtU Burnup

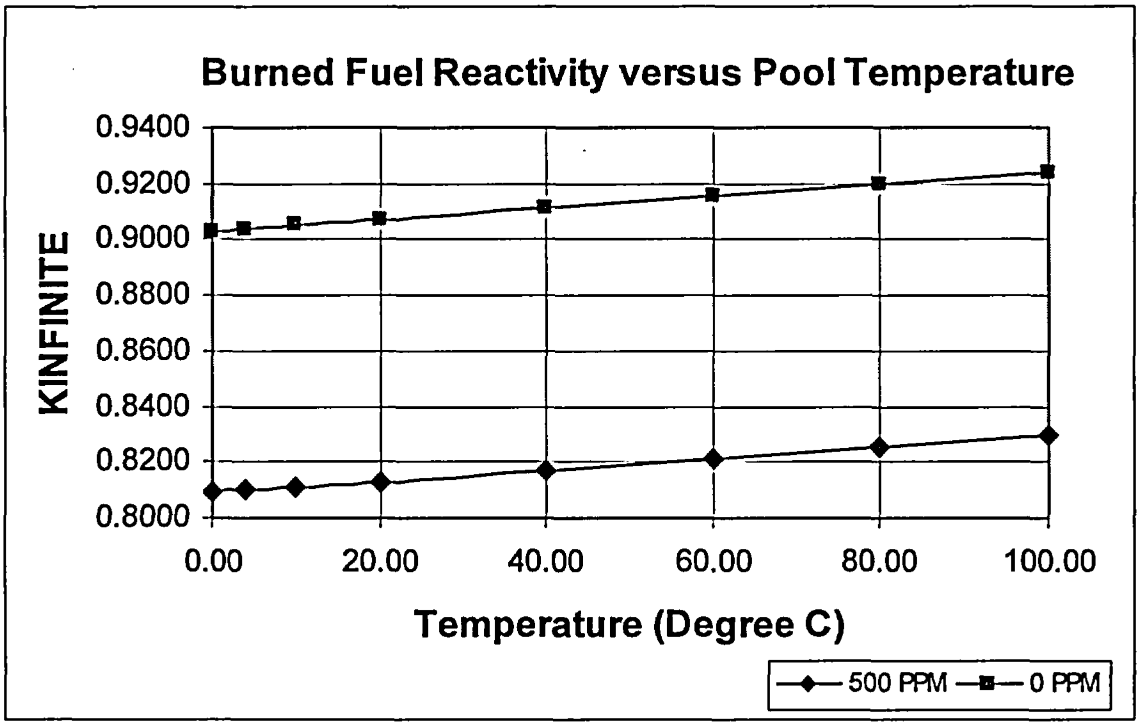


Table B.2.1-3 Moderator Temperature Reactivity Effects

The results show that for the fresh racks, the reactivity decreases with increasing moderator temperature with a relatively small variation over the range. This contrasts with the 4-of-4 loading pattern in which the reactivity increases as the temperature increases and has a relatively large variation. Based upon these results, no Δk correction is made to the nominal fresh racks (20°C) with 2-or-4 loading pattern when isolated from the spent fuel racks. However, evaluations for a combination of fresh and spent fuel racks will require an adjustment if the higher nominal temperature is not used in those evaluations for the fresh fuel 2-of-4 loading pattern.

It is assumed that for normal conditions the pool temperature will never be above ~66°C (150°F) and nor below 20 °C (68 °F). For the fresh rack(s), the base case assumes 20°C (68 °F). For spent racks or a combination of fresh and spent racks, the required temperature is 66°C. However, the base case for this condition was set at [ ] with water densities of 1.0. Thus, the fresh rack $K_{95/95}$ calculation has a system temperature Δk of zero, while the spent and fresh/spent racks require a positive system temperature Δk to account for the density differences between the base case with a density at 4°C temperature and the density at the maximum nominal temperature of 66°C. Note that temperatures above 66°C are considered accident conditions and covered by a boron credit requirement. The 66°C temperature reactivity effect is obtained from linear interpolation between the [ ] CASMO-3 Δk values in Table B.2.1-1. The interpolation provides a k_{inf} value of [ ] The difference between this value and 4°C value provides a temperature Δk value of [ ] This value represents the temperature portion of Δk_{sys} in the $K_{95/95}$ formulation for the spent and fresh/spent rack evaluations. It is assumed that the BWR assemblies exhibit the same temperature dependence, so the [ ] value will also be applied to the BWR rack boundary condition cases.

B.2.2 Off-Center Fuel Placement

The second factor in the system Δk is the alignment of the fuel assembly within the rack cell. For modeling convenience it is generally assumed that the assembly is centered in the cell. An evaluation was performed to assess the effect of off-centered placement in both the fresh and the spent fuel racks. For modeling convenience the Boraflex wrappers were homogenized with the cell wall as was done for the CASMO-3 tolerance studies. This model increases the cell wall thickness to 0.266694 cm to account for the added wrapper thickness. The cell is then modeled with the assembly (½ width= 10.70864 cm centered), the wall (½ inner width = 11.1125 cm and outer width = 13.37919 cm), and the cell width (½ width = 13.335 cm). The off-set of the assembly is obtained by adjusting the assembly array origin ± 0.40386 cm. Table B.2.2-1 lists the results of the KENO V.a evaluation. The first set examined the fresh fuel rack. The first case in the set is that of a centered assembly with the revised model. It is ~ 0.5%Δk higher than the explicit model with wrappers. However, since this model is used to obtain differences, the difference in reactivates between the models is immaterial. Case 2 for the fresh rack assumes that the assemblies in two diagonally adjacent assemblies are moved diagonally to the adjacent cell corners. This arrangement is repeated for each set of two assemblies in the rack. Case 3 examines blocks of five diagonally adjacent assemblies (in the form of an X) comprising a centered assembly with the diagonally adjacent assemblies moved toward the centered assembly. Four such blocks can be placed in the 6x10 module. Assemblies not in the blocks are either centered or moved diagonally together as in Case 1. The results for both cases indicated no significant bias for off-centered placement in the fresh fuel rack.

The second series of cases examine the spent fuel rack module. Case 4 represents a centered assembly and provides values consistent with the CASMO-3 model. Case 5 is an infinite 2x2 array model such that the assemblies are off-set diagonally toward each other to the adjacent corners of the cell. Case 6 models a 6x10 rack module with the center most assemblies diagonally touch the adjacent cell corners and the remainder of the assemblies diagonally off-set toward the center of the rack. The results of these two cases are statistically identical. However, they are [ ] larger than the centered case. Due to the large number of assemblies in the spent fuel racks it is probable that a least one set of four could result in the assumed alignment. Thus, this should be considered a bias rather than a strictly random arrangement.

Table B.2.2-1 Assembly Alignment in Rack Cell Reactivity Effects

B.2.3 Rack Interaction Effects

A system parameter Δk evaluated is that due to interface effects between the 2-of-4 loaded racks and the 4-of-4 racks (both spent PWR and BWR racks). In general, the most reactive component will control the reactivity of the combined system. The evaluations for the fresh and spent PWR racks indicate that the spent PWR rack is controlling and demonstrates that the system reactivity is slightly higher than that of the fresh rack. This increase is due to the higher density of the spent rack which provides additional coupling of the fresh assemblies in the fresh rack. Thus, an interface Δk must be applied to the fresh rack. Based upon the evaluation, the value is [ ] Δk. Similarly, since the postulated Boraflex-free BWR racks are more reactive than either the fresh or the spent racks, they provide the controlling reactivity. Due to the relatively large differences in reactivity between the BWR and PWR racks, placing the PWR racks adjacent to the BWR racks results in no significant increase in reactivity due to the interfacing. Thus, for the BWR racks, the interface Δk is 0.0.

B.2.4 Fuel Type Assessment and Spectral Hardening Effects from Removable Absorber Components

Another system parameter relates to the different types of fuel stored in the pools. As mentioned previously, the FANP Advanced 17x17 HTP PWR assembly was chosen as the assembly type for the base calculations. The base 17x17 assembly assumes a uniform enrichment throughout the assembly with no integral poisons. Several other irradiated assemblies reside in the storage pool including FANP 15x15 PWR assemblies, several types of Westinghouse PWR assemblies, and BWR assemblies. An evaluation was performed to assess any reactivity differences between the base assembly and the various other PWR assemblies. The evaluation used CASMO-3 to determine the reactivity of an infinite rack array as a function of assembly burnup up to 55 GWd/mtU.

The results showed that the base assembly does not always bound the other assemblies At beginning of life the 15x15 assembly is slightly more reactive. For higher burnups other assemblies may be more reactive due to the depletion of absorbers subsequent to removal of WABA clusters. If [ ] ppm boron is added to the moderator of these assemblies, they will be less reactive than the base assembly. Alternately, a Δk for this effect can be included in the system Δk value. This alternative is used and the maximum reactivity difference between the base assembly and any other assembly at any burnup point is chosen as the value. This maximum difference, [ ], is obtained after the removal of the WABA cluster. Thus, [ ] is the Δk applicable for irradiated assemblies. Only fresh fuel that is bounded by the design basis fuel will be inserted into the fresh fuel rack, thus, for the fresh rack the Δk is 0.0. The BWR fuel information represents the fresh assembly whose reactivity bounds any that will be placed into the storage pool. This implies that the Δk associated with that fuel type is 0.0.

Table B.2.4-1 CASMO Reactivity Results for Fuel Assembly Type Comparison

B.2.5 Non-Fuel Bearing Container Effects in PWR Racks

The last system parameter to be defined relates to inserting non-fuel bearing components (NFBC) into empty cells in the fresh PWR rack. The evaluation of this condition is for NFBC comprised of 100% stainless steel, a conservative assumption. For the Δk determination it is assumed that no more than one NFBC will be loaded in any adjacent six cells in only the fresh racks. Based upon this restriction, the Δk was shown to be [ ] from KENO V.a calculations. These components have an impact on system reactivity only when inserted into water holes in the fresh racks. Otherwise, when replacing fuel in either the fresh or spent racks, the Δk values for are 0.0. This also applies to a NFBC for the BWR racks.

B.2.6 Summary of System Biases

Table B.2.6-1 summarizes the system parameter Δk values for the fresh rack, spent rack, and the fresh/spent rack evaluations.

Table B.2.6-1 System Uncertainties ($\Delta k_{sys} \pm \sigma_{sys}$)

B.3 Final $K_{95/95}$ Formulation

Table B.3-1 summarizes the components of the $K_{95/95}$ formulations used for the evaluation of this document. They are based upon the isolated fresh rack(s) base case assumptions of centered assemblies with a moderator temperature of 20°C. The basis for the spent fuel racks, both BWR and PWR, and a combination of fresh and spent racks are assemblies centered in the rack and a moderator temperature of [ ]. $K_{95/95}$ is defined as:

$$K_{95/95} = k_{eff} + bias_{method} + \Delta k_{sys} + [C^2(\sigma_k^2 + \sigma_{bias}^2 + \sigma_{sys}^2) + \Delta k_{tol}^2]^{1/2}$$

Table B.3-1 Summary of Bias and Δk Values

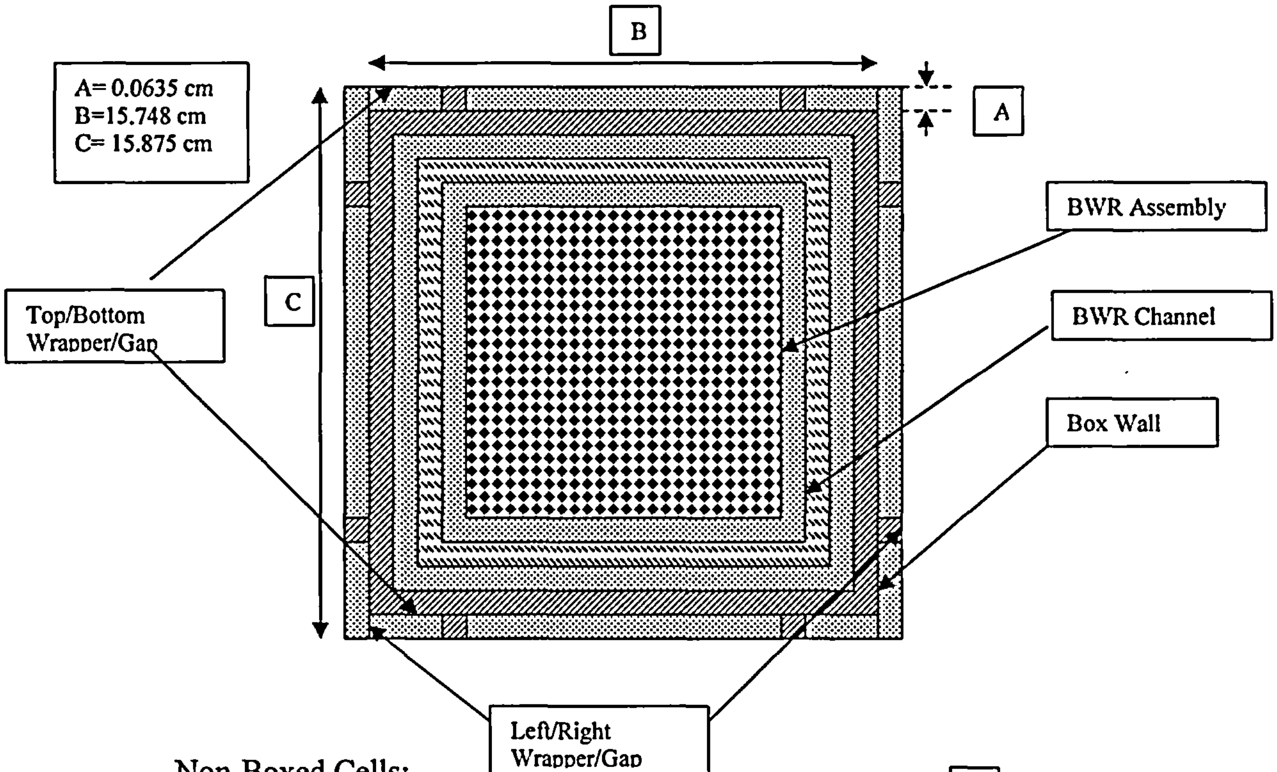
Appendix C BWR Rack Cell Details

Unlike the PWR rack model, the BWR model has multiple cell configurations. The two basic configurations are those for the interior cells. The 'boxed' cell contains the stainless steel tube that surrounds the fuel assembly and supports the wrapper plates. Cells of this design are connected at each corner to form a egg-crate rack array. The 'non-boxed' cells are the 'holes' formed by the connection of the boxed cells. As illustrated in Figure C.1, the model of the cells requires a combination of several KENO V.a units. The interior box cell configurations are illustrated in Figure C.1. The total box cell comprises the unit containing the fuel with channel and the stainless steel rack tube plus four units containing a small portion of the wrapper area. The total non-box cell contains the fuel assembly with channel and the water surrounding the channel out to the outer edge of the wrappers plus four units containing the bulk of the wrapper regions. Both total cells are squares with sides 15.875 cm long. Note the left and right sub-units are longer than the top/bottom sub units and the wrapper components are centered in each unit.

These cell configurations must be modified at the edges of the rack module for two reasons: first, the edge cells did not contain Boraflex and thus did not need wrappers, and second, the outer edges of the rack base plate extends beyond the outer edges of the egg-crate structure. For these two reasons some of the edge cell sub-units have different dimensions and configurations. Both of the sub-units types extending along the edges must have the wrapper plate portions removed. In addition, the sub-unit for the non-boxed cell must have a plate inserted to close the open side of the unit. The edge of the module base is 3.5" from the center plane of the exterior cells. Thus, for the boxed cell with the outer edge of the box 3.1" from the center plane, the overlap is 0.4" (1.016 cm). For the non-boxed cell, the outer edge of the wrapper (the basis for the central unit dimension of this cell model) is 3.055" from the center plane, to provide an overlap of 0.445" (1.1303 cm). For the exterior cells, the overlap units replace the respective outer units of each cell, as illustrated in Figure C.2 for a top, interior edge cell for both the boxed and non-boxed units. For the boxed cell, this overlap unit is just water. For the non-boxed cell, the overlap unit contains the tie plate to close the unit. It is assumed that this plate is the same thickness as the boxed cell walls and is tack welded along the face of adjacent boxed cells. Thus, its inner edge is aligned with the outer edge of the boxed cell walls. To facilitate modeling, this plate is not extended across the left/right sub-units of the exterior cells nor is the overlap and weldment in the box cells represented. The neglect of the small amount of steel in these regions will not significantly affect the results of this evaluation. An additional approximation is made relative to the left/right cells for modeling convenience. Rather than have multiple cells for the top and bottom edges of the module, the added thickness of the overlap units is added to the total length of the left/right units. Thus, the representation of the wrapper region in these cells is not centered on the fuel assembly but moves slightly upward in all cells. Again this slight movement will not significantly affect the results of the evaluation. Note that Figure B.2 only represents a top interior edge unit; rotation of this unit provides a bottom unit and approximates a left/right unit (note that the length of this unit is not changed for these edges). Four corner units are also necessary with two overlay units in each cell.

Figure C.1 Interior Cell Configurations

Boxed Cell:



Non-Boxed Cells:

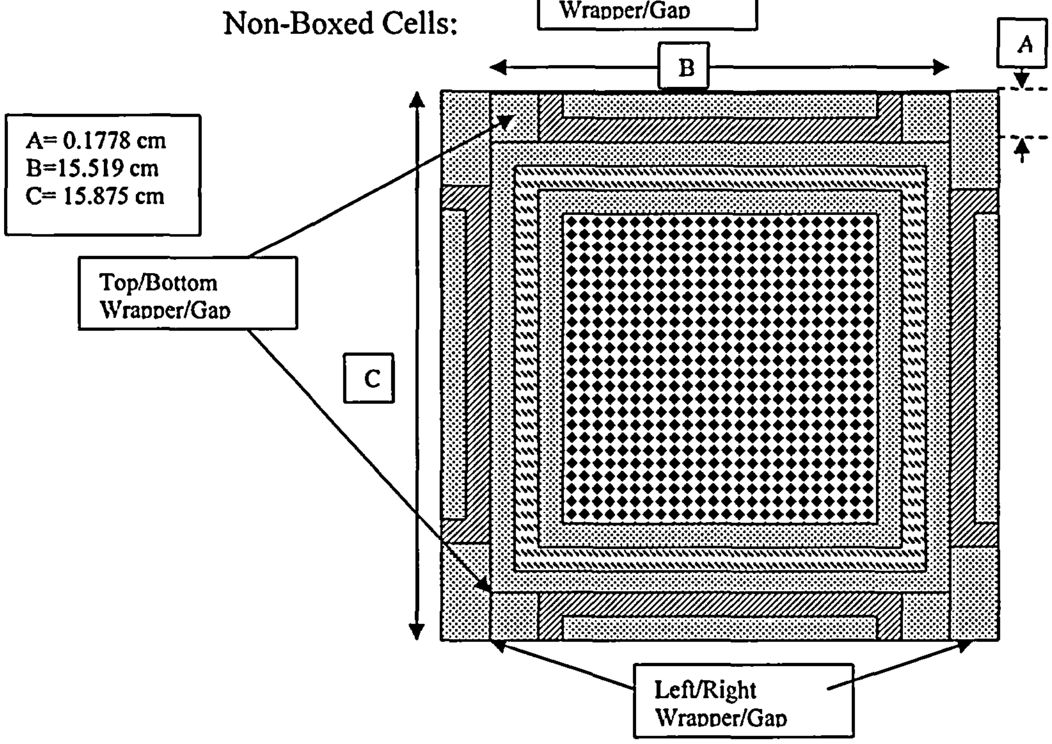
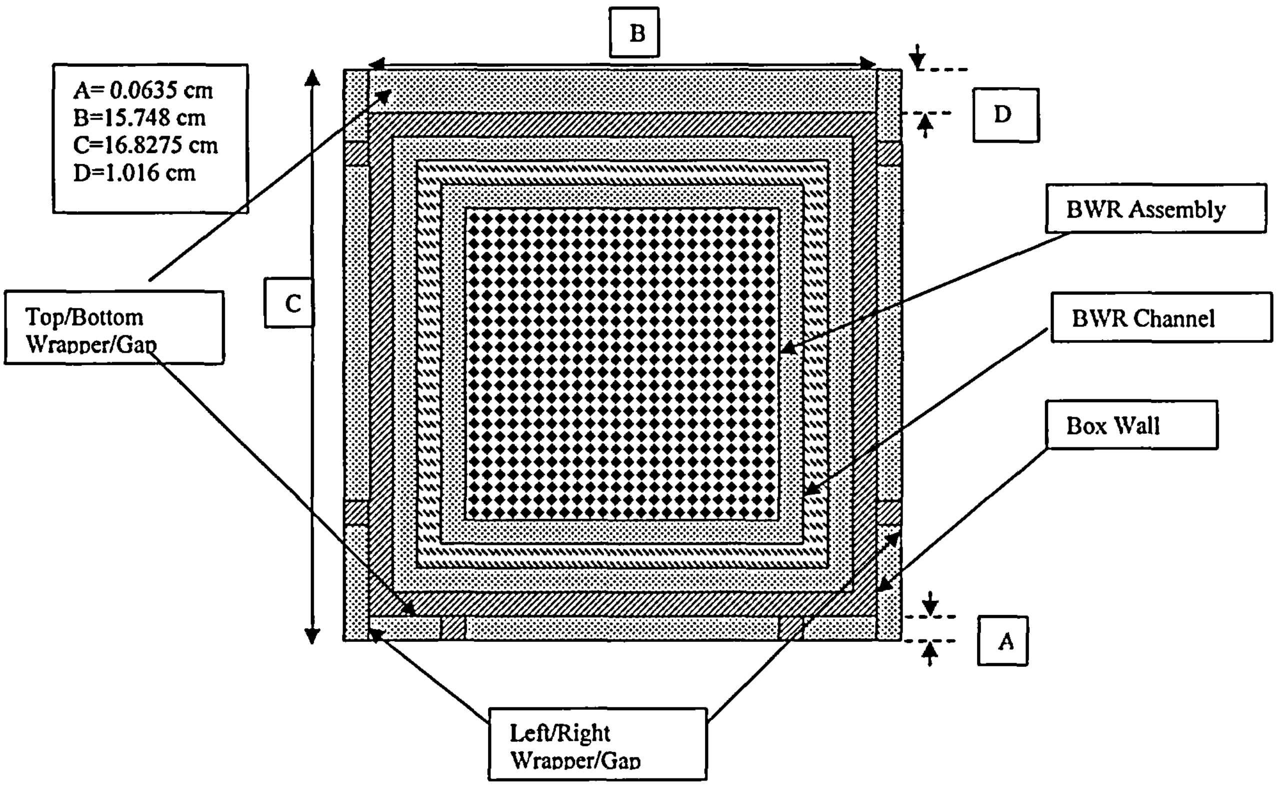
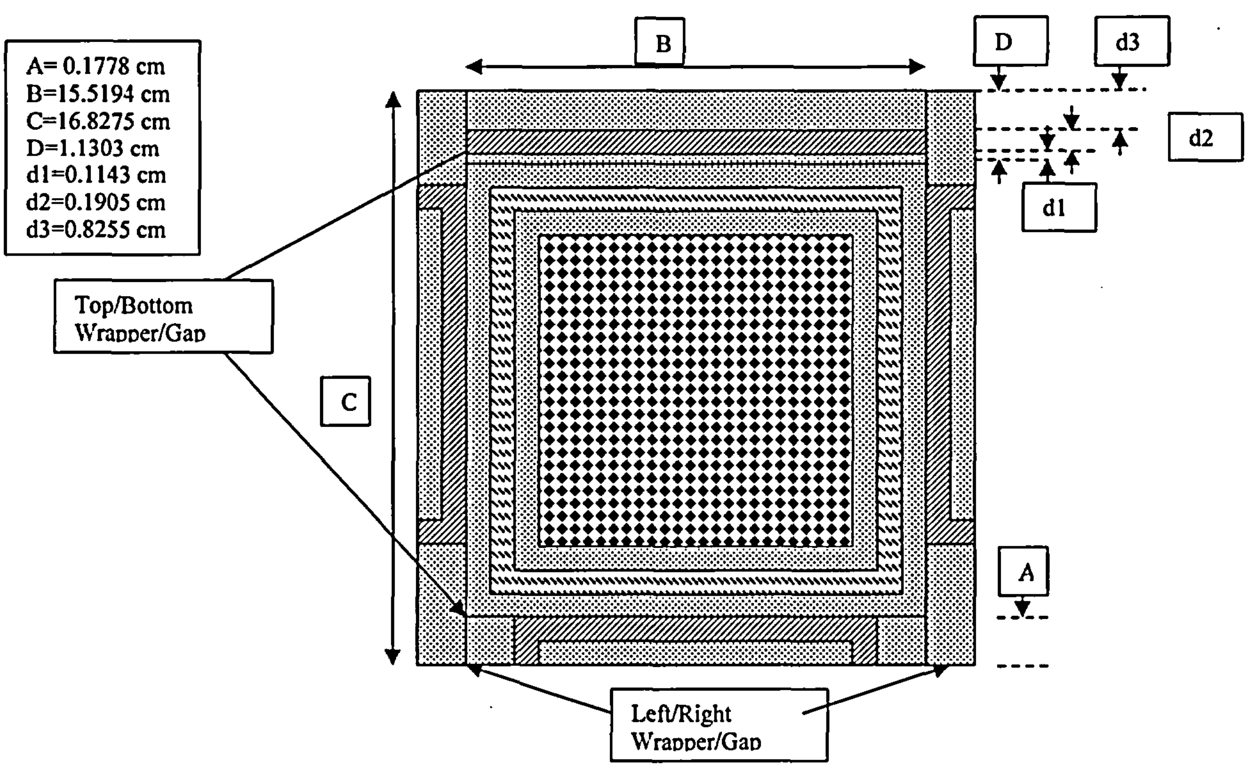


Figure C.2 Exterior Cell Configurations

Boxed Cells on Edge of Rack:



Non-Boxed Cell on Edge of Rack:



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Appendix D Burnup Credit Analysis for Pools A and B

The Harris SFP storage rack criticality design basis is being changed to reflect a zero Boraflex credit and will become an unpoisoned storage rack system. This change represents a significant impact and the loss of credit for the rack poison material needs to be counter balanced with both burnup credit (BUC) and soluble boron credit to continue to fully load the storage racks. There are multiple combinations of BUC / soluble boron (PPM) possible to counter the reactivity increase due to the Boraflex loss is. Upon evaluating the given configurations it is very clear that the soluble boron credit must be limited to avoid de-boration time requirements and for the $K_{95/95}$ value to remain below 1.00 for an unborated SFP. Similarly, the BUC loading curve should not be excessively demanding (i.e., require very high assembly burnup values) to remain useful and applicable to expected fuel assembly discharge burnups. Therefore, the BUC rack analysis must be performed for a selected "Design Condition" as the first step in the analysis. Then, the BUC conditions will be evaluated relative to the regulatory $K_{95/95}$ acceptance criteria in order to set the soluble boron PPM requirements for both storage and fuel handing.

The target design criterion to be applied to the BUC analysis will be that the BUC K_{Design} [ ] with the following equation:

$$K_{Design} = k_{KENO} + bias + [C^2(\sigma_k^2 + \sigma_{bias}^2) + \Delta k_{tolerances}^2]^{1/2},$$

The BUC K_{Design} equation is the $K_{95/95}$ equation (Section 2.5.1) without the Δk_{sys} and σ_{sys} terms. The Δk_{sys} and σ_{sys} terms will represent those parameters and conditions which will require soluble boron PPM credit and will be handle separately after the BUC loading curve and requirements are determined. In most cases the parameters and conditions represented by Δk_{sys} can and will be represented as a delta reactivity relative to the BUC design basis configuration conditions. Hence, the following approximate relationship is developed:

$$K_{95/95} = \underset{\text{(BUC Credit)}}{K_{Design}} + \underset{\text{(Soluble Boron PPM Credit)}}{\Sigma \Delta k_{sys}}$$

In this manner a reasonable combination of BUC and PPM credit can be used to demonstrate that $K_{95/95} \leq 0.95$ to meet the regulatory requirements.

D.1 BUC K_{Design} and $K_{95/95}$ Value Basis

The BUC loading curve formulation is based upon a target K_{Design} that accounts for methods bias and normal tolerances / uncertainties. These values are determined in order to develop a simple relationship for BUC analysis:

$$K_{Design} = k_{KENO} + bias + [C^2(\sigma_k^2 + \sigma_{bias}^2) + \Delta k_{tolerances}^2]^{1/2} = k_{KENO} + N$$

Where: $N = bias + [C^2(\sigma_k^2 + \sigma_{bias}^2) + \Delta k_{tolerances}^2]^{1/2}$

is a known numeric value. Inserting the appropriate values from Table B.3-1,

$K_{95/95}$ equation becomes:

$$K_{Design} = k_{KENO} + [\qquad]$$

A conservative estimate for σ_k can be used to complete the determination of the constant N. The BUC KENO V.a runs will need to check σ_k against the value to ensure that value for N remains applicable and conservative. Thus, for $\sigma_k \leq$ [ ], the BUC target design criterion becomes:

$$K_{Design} = k_{KENO} + [\qquad]$$

This equation is used for the K_{Design} values provided in tables for the BUC fuel rack loading curve evaluation and the BUC design criteria K_{Design} [ ]. The soluble boron requirement will change with K_{Design} criteria.

The results of Appendix B indicate that evaluations for the spent fuel rack will require a moderator temperature adjustment if the high temperature is not used in the evaluation. The BUC rack evaluation will be performed with a cross section temperature of [ ] [ ] and the moderator density set to 1.00 g/cc. Therefore, the $K_{95/95}$ determination will need to include a moderator density adjustment in the soluble boron PPM determination, as well as an adjustment to the 66 °C (150 °F) limit.

The BUC credit calculations will be based upon modeling an infinite lattice of fully loaded storage cells with the assemblies modeled in the center of the storage cells. As indicated above, there are aspects of the BUC modeling that will not address the full range of conditions for the normal condition. These items will be identified and included in the soluble boron PPM evaluation to determine the regulatory $K_{95/95}$ SFP values.

The BUC model addresses the base set of conditions and modeling uncertainties that represent a symmetrically loaded storage cell will full density water in an infinite lattice. The following conditions are required to be evaluated as part of the normal operating conditions that could exist for the Shearon Harris SFP.

1) Moderator density variation up to the Technical Specification limit of 150.0 Deg. F (65.56 °C, 150 °F).
2) Asymmetric assembly position within a storage cell.
3) Fuel assembly spectral history effects for removable BP assemblies (i.e., WABA inserts).
4) BUC rack module interaction with other storage rack module types (i.e., BWR and Fresh PWR loaded racks).
5) Storage of non-fuel bearing material storage canisters (i.e., non-fuel bearing parts in a steel can)

The impact of any reactivity increase from these items will set the minimum SFP soluble boron requirement for BUC storage rack configurations. These reactivity impacts (i.e., Δk_{sys} term) have been evaluated in Appendix B.2.6.

Therefore, similar to the BUC K_{design} formulation, a $K_{95/95}$ formulation can be created for KENO V.a soluble boron calculations.

$$K_{95/95} = k_{KENO} + bias + \Delta k_{sys} + [C^2(\sigma_k^2 + \sigma_{bias}^2 + \sigma_{sys}^2) + \Delta k_{tolerances}^2]^{½}$$
$$= k_{KENO} + M \leq 0.95$$

Where: $M = bias + \Delta k_{sys} + [C^2(\sigma_k^2 + \sigma_{bias}^2 + \sigma_{sys}^2) + \Delta k_{tolerances}^2]^{½}$

is a known numeric value.

Using the data provided in Table B.3-1, the $K_{95/95}$ equation becomes:

$K_{95/95} = k_{KENO} + [$ $]$

A conservative estimate for σ_k can be used to complete the determination of the constant M. The BUC KENO V.a runs will need to check σ_k against the value to ensure that value for M remains applicable and conservative. Thus, for $\sigma_k \leq 0.0009$, the BUC acceptance criterion becomes:

$K_{95/95} = k_{KENO} + [$ $] \leq 0.95$

This equation is used for the $K_{95/95}$ values provided in subsequent tables for the BUC fuel rack soluble boron requirement(s) evaluation.

D.2 Assembly Operation and Depletion Data

In order to perform the burnup credit (BUC) SFP storage rack calculations the design basis fuel assembly must be characterized with in-core depletion calculations. The depletion calculations are intended to maximize the assembly reactivity at a given burnup by conservatively modeling moderator and fuel temperatures during reactor operation. This section documents the reactor operational data needed to perform the CASMO-3 depletion calculations.

The moderator and fuel temperatures for the depletion calculations were obtained from an existing data base for a 17x17 OFA fuel assembly. However, as shown below, the resulting moderator temperature distribution provides a core exit temperature that is near, or slightly above, the value that is allowed by plant operating technical specifications. Therefore, generally the moderator temperature distribution can be generically applied to PWR reactor operation for the purposes of criticality safety BUC evaluations. Similarly the fuel temperature values are conservatively high based upon the conservative models applied to evaluate the fuel temperatures.

The moderator and fuel temperatures are not sensitive to pin diameters; therefore, this data is applicable. However, these temperatures are sensitive to operating temperatures which are a function of core power level and RCS core flow. A comparison of some of these parameters to the Shearon Harris plant is provided in Table D.2-1.

Table D.2-1 Comparison of Shearon Harris and Typical Plant Parameters

	Harris	Typical Plant	% difference
Power per assembly, MW/assembly	2900/157 =18.47	3411/193=17.67	4.5
Inlet Enthalpy, Btu/Lbm	556	558.71	
Inlet Temperature, °F	557.4	559.5	0.4
Core Tave, °F	591.3 core based on 8% bypass (~588.8 vessel)	591.2	

Using the first order relationship: Power = $M*Cp*\Delta T$ and assuming Cp is constant we can determine the following based upon the data listed for Harris and Typical Plant reactors.

Typical Plant ΔT ~(591.2-559.5)*2 = 63.4 °F
Harris ΔT ~(591.3-557.4)*2 = 67.8 °F

The ratio of the delta-temperatures results in a power to mass-flow ratio between the plants which is 6.9% higher in Harris relative to Typical Plant. As indicated above, 4.5 % is due to the core power differences and the remaining must be the RCS flow. Based upon the above T_{in} and T_{ave} data the core outlet temperatures are:

Typical Plant outlet = 622.9 °F
Harris outlet = 625.2 °F
Difference = 2.3°F

An additional [ ] will be added to all the moderator temperatures (not just the outlet temperatures) to account for the plant differences. The higher temperatures will increase the spectral history effect and increase the reactivity at a given burnup.

A reasonable axial core average moderator temperature distribution can be obtained for this purpose which is generally applicable. It is the core average history values at the end of cycle for Δ(Specific Volume) and Δ(Fuel Temperature). The data is provided in 32 equally spaced nodes and is listed in Table D.2-2. The listed data was averaged (volume weighted partial values) to correspond to the mesh used in the KENO V.a calculations.

The mesh in the KENO V.a calculations are based upon the axial burnup distribution provided in Section D.3 below that has [ ] axial node segments of the following lengths from bottom to top of the active fuel: [ ] for a total of 144". The Δ(specific volume) is converted to absolute specific volume, converted to °F, and finally to °K. The [ ] was added to the end result (Note delta °C = delta °K). The Δ(fuel temperature) is converted to absolute temperature in °F and then converted to °K. The values are shown in the following tables D.2-3 and D.2-4.

Table D.2-2 Average Representative Fuel Temperature Distribution

Table D.2-3 Moderator and Fuel Temperature Distribution For BUC Calculation

D.3 Assembly Axial Burnup Data for Rack BUC Analysis

Typical burnup credit analyses have used a uniform, average burnup distribution over the entire length of the assembly. Such a uniform distribution underestimates the burnup at the center of the assembly and over estimates the burnup at the top and bottom of the assembly. Thus, to adequately utilize burnup credit the impact of the axial burnup distribution at any given assembly average burnup must be understood. This requires an estimation of the reactivity effects of the axial burnup distribution relative to a uniform distribution be determined that is appropriately applied to the results, i.e., an axial burnup distribution penalty factor. Alternatively, an explicit axial burnup distribution can be modeled in KENO V.a calculations which remove the need for application of such an axial factor. The BUC evaluation for the Shearon Harris SFP racks uses the latter approach, i.e., use an explicit axial burnup distribution.

The Shearon Harris plant site includes Boral absorber plate BUC racks in the SFP C and D. These pools use an axial burnup distribution similar to that provided in Table D.3-1 and illustrated in Figure D.3-1. The data provided is based upon an active fuel length of 144 inches. The relative axial distribution provided in Table D.3-1 is consistent, and not significantly different, than the relative axial distributions for higher burnups, i.e., for assembly average burnups greater than [ ] GWd/MTU, that have been applied to other SFP rack BUC criticality safety analysis. The axial shapes are also consistent with those published for use for Geologic Disposal at Yucca Mountain.

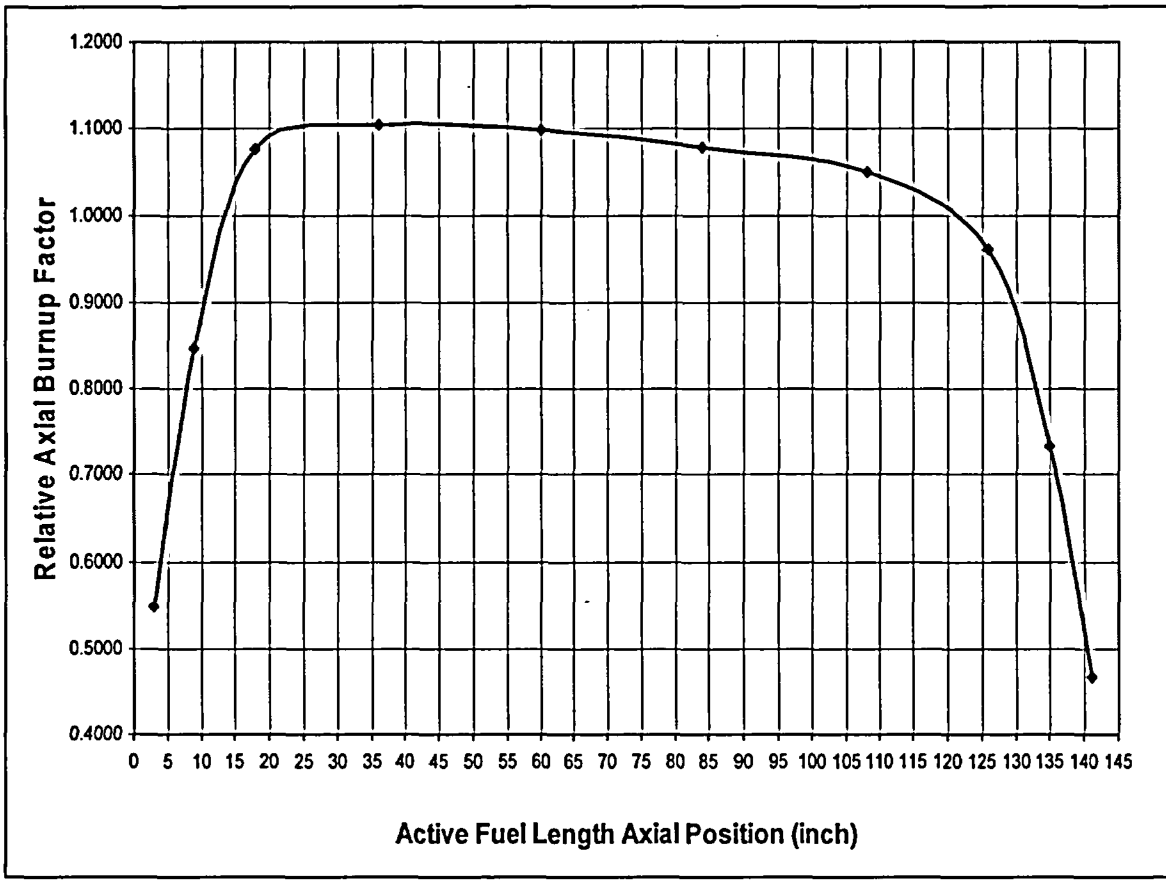
Finally, since the Table D.3-1 axial burnup distribution factors are current applied to SFP storage at the Shearon Harris plant a review of past discharge fuel to verify applicability is not necessary for this analysis. Therefore, the use of the listed axial burnup distribution factors for this analysis is acceptable and conservative.

Table D.3-1 Design Basis Assembly Relative Axial Burnup Distribution for BUC Analysis

[

]

Figure D.3-1 Design Basis Assembly Relative Axial Burnup Distribution for BUC Analysis



D.4 BUC Calculational Method

The Shearon Harris spent fuel pool (SFP) storage racks use fixed spacing, burnup credit (BUC), and soluble boron (PPM) credit to provide safe storage of discharged fuel assemblies. For BUC applications the reactivity effect of the following items must be evaluated and factored into the analysis:

- Operating history of the fuel including fuel and moderator temperatures;
- Axial burnup distributions as a function of assembly average burnup;
- Measured burnup uncertainty.

These parameters contribute to the residual reactivity of the burned fuel with the axial distribution having a significant impact at higher assembly average burnups.

The methodology used to apply BUC utilizes CASMO-3 to generate the fuel assembly isotopic composition at a given burnup for each axial assembly node. The isotopics are then provided to KENO V.a to perform the K_{Design} calculations for the specific SFP rack configuration and loading. The process is complicated by the fact that KENO V.a cross section data bases do not have the ability to accept all of the isotopes for a burned assembly, i.e., actinides plus all fission products, and CASMO-3 uses a "lumped" fission product cross section set. Therefore, an intermediate step is needed in which CASMO-3 is used to perform a reactivity equivalencing calculation [

] Thus, the isotopic composition provided to KENO V.a represents an equivalent reactivity composition which is supported by the KENO V.a cross section data base.

D.4.1 Isotopics Generation Method

The process of generating isotopic data set for a given assembly burnup begins with a CASMO-3 hot full power in-core depletion with selected core fuel and moderator temperatures. Generally, a CASMO-3 restart file is written to save the assembly depletion data to facilitate repeated use. A set CASMO-3 restart calculation(s) at the selected burnup state point are then performed to generate isotopic data set which is supported by KENO V.a and represents a reactivity equivalent assembly in the SFP rack geometry. The general process is outlined as follows:

D.4.2 Loading Curve Generation Method

The general objective of the loading curve is to identify which assemblies of a given initial enrichment loading and assembly average burnup can be stored in a given storage rack configuration. Typically, for a BUC-only analysis, $K_{95/95} = K_{Design}$ and the KENO V.a modeling will include all aspects of regulatory requirements. This is why many BUC only SFP will contain two or three loading curves for specific rack storage requirements (i.e., 4/4, 3/4, 2/4, 1/4, or more complicated patterns). [

]

However, for the Shearon Harris SFP rack configuration this type of BUC analysis is not practical given the "zero Boraflex" absorber credit requirement. Therefore, since both BUC and soluble boron PPM credit will be applied $K_{95/95} \neq K_{Design}$ for the BUC portion of the analysis. The BUC analysis for this evaluation will provide a single loading curve which will reasonably bound the existing fuel being stored in the Harris SFP. To accomplish this, some aspects of the "normal" conditions will not be included in the BUC analysis model and will be addressed later as a soluble boron PPM requirement. Therefore, the BUC analysis will use a K_{Design} [ ] criterion to generate the BUC loading curve and will then perform an additional analysis to set the soluble boron PPM requirements such that regulatory criterion of $K_{95/95} \leq 0.95$ is met.

The general process for generating a BUC loading curve is outlined as follows:

D.5 KENO V.a Model for BUC Calculations

The BUC calculations will require the evaluation of several assembly initial enrichments and lattice burnup combinations in order to provide a SFP burnup loading curve. The changes required in the KENO V.a input are mainly the fuel rod material isotopic composition. The main portion of the SCALE4.4a forming the geometry portion of the input deck will not change for these configurations. Hence, a SCALE4.4a CSAS KENO V.a base deck was developed with the parameters needing change described below.

Figure D.5-1 provides the x-y layout of the model and Figure D.5-2 lists the KENO V.a base deck to be used for this analysis. The KENO V.a base deck includes the fuel composition input for [ ] of each fuel pin. The rack geometry modeled represents a 2x2 array of storage locations which represent an infinite array of storage cells with the application of a periodic boundary condition on all sides. The overall geometry is an infinite x-y array of fully loaded storage cells with 12 inches (30.48 cm) of water at the top and bottom of the active fuel length. The periodic boundary condition is also conservatively applied to the axial dimensional as well.

As indicated, the fuel composition for each of the [ ] is provided by CASMO-3 depletion and reactivity equivalencing methods for each case to be evaluated. The changes required to the KENO V.a base deck involve substituting the "arbm" material cards and ensuring that the proper material ID values are used. Note that the Dancoff correction data has been included in the "more data" section of the input. These values were determined based upon the given geometry and are not sensitive to the material composition changes that are performed for this calculation. Therefore, these values can be used for all of the BUC calculations. Note, that unless otherwise indicated the KENO V.a cases to support K_{design} = [ ] will use [ ] particles/generation and [ ] generations with the first [ ] generations skipped (i.e., KENO V.a keff will be based on [ ] neutron history tracks).

Figure D.5-1 Model of Central Region of Racks with Adv. HTP

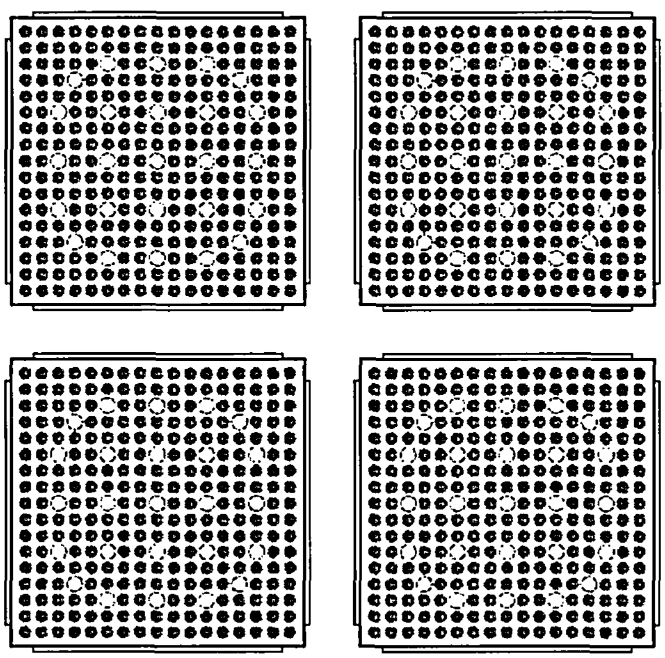


Figure D.5-2 KENO V.a SFP In-Rack Base Deck

D.6 KENO V.a BUC Calculations

The KENO V.a loading curve calculations will be performed following the prescription of Section D.4. CASMO-3 in-core depletions and in-rack reactivity equivalencing are performed to generate the proper assembly isotopic modeling. The results provide the enrichment/burnup pairs that are used generate the loading curve described in the next section. Note that the design basis model places the assemblies in the center of the rack cell that is moderated with unborated water.

The Zero Burnup state point sets the assembly enrichment below which no storage restrictions are needed. Table D.6-1 lists the results that show that a limiting initial enrichment of 1.76 wt% U235 is required to meet the design acceptance criteria.

Table D.6-1 Zero Burnup Maximum Initial Enrichment for K_{design} = [ ]

The maximum assembly initial U^{235} enrichment allowed at the Harris plant is 5.0 wt% U^{235}. Table D.6-2 lists the results that show that the required assembly average burnup is 42.35 GWd/mtU to meet the design acceptance criteria.

Table D.6-2 Required Burnup for Initial Enrichment of 5.0% for K_{design} = [0.967]

Table D.6-3 lists the results for a set of cases at 4.5 wt% U^{235}. The results show that for the K_{Design} = [ ] the required assembly average burnup is 36.10 GWd/mtU.

Table D.6-3 Required Burnup for Initial Enrichment of 4.5 % for K_{design} = [ ]

Table D.6-4 lists the results for 4.0 wt% U^{235}. The results show that the required assembly average burnup is 30.15 GWd/mtU.

Table D.6-4 Required Burnup for Initial Enrichment of 4.0 % for K_{design} = [ ]

The results for an initial assembly enrichment of 3.5 wt% U235 are provided in Table D.6-5 and show that the required assembly average burnup is 23.85 GWd/mtU to meet the design acceptance criteria. These results were calculated based upon an axial burnup distribution, as is recommended for higher burnup fuel. Table D.6-6 provides the corresponding results based upon a "flat" burnup distribution with the same burnup data in all axial nodes. The results show that the required assembly average burnup is also [ ] GWd/mtU for the flat distribution.

Note that the results for the two axial burnup distributions are close, but clearly the explicit axial burnup distribution case provides results that bound the "flat" case. This indicates that the explicit, or "high burnup" assembly axial power shape is conservative for fuel assembly average burnup values >[ ] GWd/mtU for these racks. The burnup curve data point for an initial enrichment of 3.5 wt% U^{235} will use the results from the explicit axial power distribution to conservatively bound the types of axial burnup distributions that are possible for assembly average burnup values greater than [ ] GWd/mtU.

Table D.6-5 Req. Burnup for Initial Enrichment of 3.5wt% U235 for K_{design} = [ ]

Table D.6-6 Req. Burnup Initial Enrich. of 3.5% Flat Axial Dist. for K_{design} = [ ]

Table D.6-7 lists the results for 3.0 wt% U^{235} for a flat axial distribution that satisfies K_{Design} = [ ] . The results show that an average burnup of 17.90 GWd/mtU is required to meet the design acceptance criteria.

Table D.6-7 Req. Burnup for Initial Enrich. 3.0% Flat Axial Dist. for K_{design} = [ ]

[

]

Table D.6-8 lists the results for 2.5 wt% U^{235} that show that the required assembly average burnup is 11.55 GWd/mtU to meet design acceptance criteria.

Table D.6-8 Req. Burnup for Initial Enrich. 2.5% Flat Axial Dist. for K_{design} = [ ]

[

]

Table D.6-9 lists the results for 2.0 wt% U^{235}. The results show that the required assembly average burnup is 4.50 GWd/mtU.

Table D.6-9 Req. Burnup for Initial Enrich. 2.0% Flat Axial Dist. for K_{design} = [ ]

[

]

D.7 Burnup Loading Curve and Usage Requirements

Table D.7-1 summarizes the BUC loading curve that is illustrated in Figure D.7-1. This table provides both the assembly initial enrichment and assembly average burnup data pairs and the equation fit that can be used to qualify assemblies for storage under the BUC requirements. Note that the curve fit is conservative, especially for enrichments less than 2.5 wt%. The equation provides a simple, yet conservative basis for qualifying fuel that may be placed in the spent storage racks..

Table D.7-1 BUC Loading Curve Equation Fit Data for K_{design} = [ ]

Least Square Coefficients for

$$Y = C0 + C1*X$$

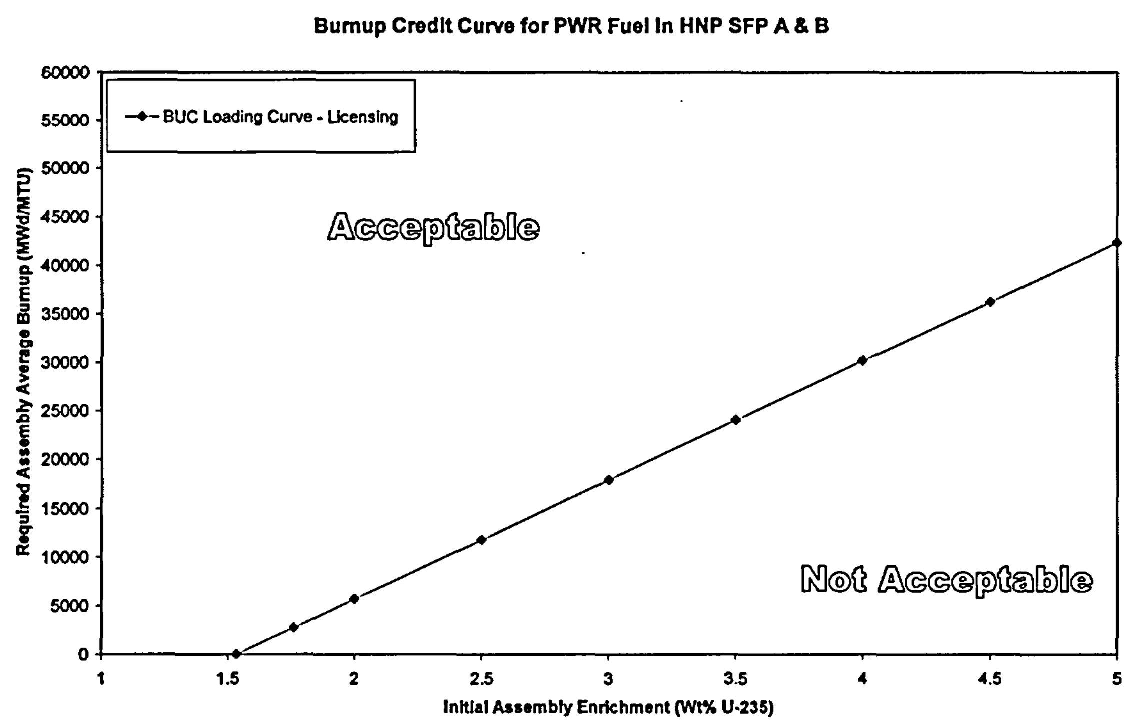
Note: X is initial assembly enrichment as wt% U^{235} (i.e., 5.0 max)
Y is required minimum assembly average burnup in GWd/mtU

[ ]

BUC State Points for Equation Fit

Initial Enrichment	Calculated	Linear Fit	Differnce
wt% U235	MWd/mtU	MWd/mtU	MWd/mtU
1.53	-	0.00	0.00
1.76	0.00	2755	2755
2.00	4500	5690	1190
2.50	11550	11805	255
3.00	17900	17920	20
3.50	23850	24035	185
4.00	30150	30150	0
4.50	36100	36265	165
5.00	42350	42380	30

Figure D.7-1 BUC Loading Curve for K_{design} = [ ]



Note that the burnup curve evaluation includes the allowances for bias and uncertainties for codes, methods, and manufacturing tolerances. The manufacturing tolerance allowance includes an explicit 0.05 wt% tolerance for assembly initial enrichment variations. Therefore, an administrative adjustment for assembly initial enrichment is not required, but may be conservatively used, to determine if an assembly qualifies for storage using the BUC requirements. On the other hand, the uncertainty associated with the reactor plant's ability to measure the assembly average burnup is not explicitly accounted for as part of the BUC loading curve analysis. Typically, a [ ] uncertainty is used to bound the assembly average burnup measurement uncertainty. The quantity of this factor must be determined and factored into the determination as to whether a specific assembly qualifies for storage using the BUC requirements.

A typical procedure to qualify assemblies for storage is as follows (assuming a [ ] burnup measurement uncertainty):

[ ]

D.8 Evaluation of $K_{95/95}$ Soluble Boron Requirements

Table D.8-1 summarizes the unborated regulatory $K_{95/95}$ values for each calculated data point provided in Section D.7 for K_{Design} = [ ]. Clearly, a soluble boron requirement for normal operation will be required. As expected, all of the BUC state points are statistically not significantly different. The soluble boron calculation will use the both the (1.76, 0.0) state point as the limiting condition since it shows a slightly higher Δk reduction requirement and the (4.50, 36.10) state point to evaluate axial shape effects. This [ ] boron requirement accounts for: 1) the boron needed to cover the temperature increase for normal conditions of [ ] to 150 °F; 2) the fact that BUC calculations were run with a moderator density = 1.0 g/cc and there is a density variation with temperature; 3) asymmetric assembly positioning; and 4) boron needed to get to less than 0.95 without consideration of accidents.

Table D.8-1 BUC Rack Normal Condition – No PPM Adjustment for K_{design} = [ ]

A summary of the calculations is provided in Table D.8-2. The data indicates that a conservative value of [ ] Boron is required in order to meet the regulatory $K_{95/95} \leq 0.95$ criterion for normal conditions for K_{Design} = [ ].

Table D.8-2 BUC Rack Normal Condition With PPM Adjustment for K_{design} = [ ]

Note that the initial enrichment has a significant impact on soluble boron worth. Therefore, soluble boron worth calculations are done with high initial enrichments, i.e., initial enrichment [ ]. Note that these calculations are based upon an infinite array of fully loaded rack storage locations. Therefore, the BUC rack results are applicable to any rack models which are separated by at least the width of the rack flux trap dimension. The lead-in funnels in the racks ensure that the PWR racks meet this requirement. [

]

D.9 Accident and Upset Conditions

Criticality safety analyses need to evaluate the limiting accident and operator induced upset conditions in order to demonstrate that the "double contingency" principle is met. The limiting types of reactivity accidents and upset conditions to be considered for the Shearon Harris SFP are:

1) Abnormal positioning of a fuel assembly outside the BUC storage rack.
2) Misloading of a fuel assembly in a storage cell of the BUC storage rack.
3) SFP water temperature elevated to 100 °C (212 °F).
4) Lateral motion of a fuel storage rack module causing the rack-rack water gap to close.

These configurations are judged to be the bounding set of accident and upset conditions. Each of these cases must also consider a BWR assembly and BWR storage racks. However, the design basis BWR assembly is dimensionally smaller (x-y plane), much lighter fuel loading (i.e, approx 1/2 the kgU mass), has an assembly enrichment that is only slightly higher than the maximum zero burnup PWR assembly enrichment of 1.76 wt% U^{235}, and the Harris SFP will <u>NOT</u> have a fresh BWR assembly on site. The Harris SFP is a storage location which receives ONLY BWR discharged BWR assemblies and has no logical reason to receive fresh BWR fuel assemblies. Therefore, based upon these considerations a PWR assembly, either a fresh PWR or a peak BUC PWR assembly, will be more reactive than a BWR assembly for any accident and upset condition in a PWR SFP rack. This engineering judgment is supported by the reduction in kgU from the PWR assembly to the BWR assembly alone for the listed accident conditions. Therefore, the BWR assembly considered for accident and upset conditions with the PWR SFP racks will not increase k_{eff} of the system and the accident condition is non-limiting.

Also, the BUC racks are modeled as an infinite array of storage cells and no credit it taken for the rack module to rack module gaps, nor the rack module to SFP wall gaps that exist for the Shearon Harris SFP. This means that any gaps larger than the flux trap gap that exists increases the local separation and will result in a less reactive configuration. Note that the PWR rack models are such that the lead-in funnels will maintain a rack-to-rack gap that is slightly larger than the flux trap gap between individual storage cells. Therefore, the lateral motion of the SFP racks will not increase k_{eff} of the system and the accident condition is non-limiting. Calculations similar to these conditions were preformed for Pool A and support this conclusion.

However, note that analysis in Appendix E addresses the fresh assembly storage rack and BUC storage rack module configurations that are possible. Appendix E identifies the limiting configuration to be a "checker board" of fresh assembly and BUC storage rack modules that allows the corner storage locations of the four modules to be fully loaded (i.e., 2 diagonally adjacent fresh assemblies and 2 diagonally adjacent BUC assemblies in a 2x2 arrangement). This configuration is equivalent to 2 misloaded BUC assemblies in a fresh storage rack. [

]

The Shearon Harris SFP could experience a loss of cooling which will elevate the SFP water temperature. As indicated in Section B.2, the fully loaded BUC PWR rack reactivity will increase with increasing temperature. Also, as indicated in Section B.2.1, the normal operating temperature can be as high as 65.56 °C (150 °F). Therefore, the accident condition must address a SFP water temperature increase from 65.56 °C (150 °F) to 100 °C (212 °F) (i.e., a 34.44 °C (62 °F) increase). Section B.2.1 provides the system Δk increases and CASMO-3 k_{inf} data versus moderator temperature for the limiting fresh fuel. As indicated in Table B.2.1-3 CASMO-3 k_{inf} value at 65.56 °C (150 °F) is [ ] and the CASMO-3 k_{inf} value at 100 °C (212 °F) is [ ].

The resulting accident Δk increase is therefore [ ]. The limiting normal condition will increase Δk = [ ] for this accident. Therefore, the limiting normal condition KENO V.a model is used to evaluate the additional soluble boron that is needed to counter balance the increased reactivity. The results of the calculations are summarized in Table D.9-1.

The data indicates that a conservative value of [ ] boron is required in order to meet the regulatory $K_{95/95} \leq 0.95$ criterion for normal conditions at 4.5 wt% U^{235}. Thus, additional [ ] soluble boron is required [ ] for the increase in SFP water temperature consistent with accident or upset conditions.

Table D.9-1 BUC Rack Temperature with PPM Adjustment for Upset Condition (150 °F Increase to 212 °F)

The BUC PWR rack can be misloaded with either a non-qualifying PWR assembly or a BWR assembly. As discussed above, the BWR assembly will not be limiting. The limiting PWR assembly is a fresh 5.0 wt% assembly loaded into the BUC PWR rack. Since the accident analysis need only address a single assembly misloaded. The KENO V.a model for the limiting normal condition in unborated water will be changed to represent a 5x5 array of storage cells and the model will represent an infinite array of 5x5 storage cells. A fresh 5.0 wt% assembly will then be modeled in the center storage cell to obtain the accident condition Δk increase. The 5x5 misloaded configuration represents multiple misloaded assemblies at relatively interspersed locations and will conservatively represent a single misloaded assembly. The misload model will then have soluble boron added to determine the required boron ppm to counter the accident Δk increase.

The results of the calculations for each BUC Loading curve are summarized in Table D.9-2. The data indicates that a value of [ ] boron is required in order to meet the acceptance criterion. Thus, a total of [ ] ppm soluble boron is required to address the accident from just the reactivity component of misloading a fresh assembly in the spent fuel rack.

Table D.9-2 Fresh Assembly Misloaded Accident into Spent PWR Rack

The abnormal positioning of a fuel assembly outside the BUC rack can result in three basic configurations: 1) dropped assembly onto the top of the storage rack, 2) dropped or misplaced assembly between two rack module or between a rack and the SFP walls, and 3) storage of fuel assemblies in unpoisoned "damaged" fuel locations next to the SFP storage racks. The Shearon Harris SFP doe NOT have "damaged" fuel storage locations outside the existing SFP storage racks. Therefore, this configuration does not need to be considered. The dropped assembly onto the top of the storage rack places the fuel assembly horizontally on top of a fully loaded rack. The rack structure is such that the horizontal assembly has a significant thickness of water separating it from the assemblies stored in the rack. Thus, this is a non-limiting configuration relative to placing a fuel assembly against the side of the storage rack such that it is face adjacent to a loaded storage cell. While it is not possible to place an assembly between two rack modules, it is very possible to place an assembly between the storage rack and the SFP wall. Two possible limiting assembly types can identified for this configuration: 1) a fresh fuel assembly present during refueling/fuel receipt activities, and 2) a BUC qualified assembly present during any fuel handling operation. It is possible that a NON-qualified assembly for BUC can be handled during any fuel handling operation. Clearly the fresh fuel assembly represents the largest available reactivity and can be used to bound all other configurations.

The accident analysis need only address a single assembly misplacement. The KENO V.a model for the limiting normal condition in unborated water will be changed to represent a 7x7 array of storage cells and the model will represent an infinite array of 7x7 storage cells in three directions (+x, -x, and –y). A fresh 5.0 wt% assembly will then be modeled at the edge of the middle of one rack face (i.e., on the +y side) to obtain the accident condition Δk increase. The 7x7 array with the misplaced assembly configuration will have a 3 foot thick concrete wall placed [ ] inch from the misplace assembly to represent the minimum rack to SFP wall gap in which a PWR fuel assembly can be placed. Reflective boundary conditions will then be used and the model will represent multiple misplaced assemblies at relatively large interspersed locations. This model will conservatively represent a single misplaced assembly. The misplaced assembly model will then have soluble boron added to determine the required boron ppm to counter the accident Δk increase.

The results of the calculation for a misloaded fresh fuel assembly on the side of the spent fuel rack are summarized in Table D.9-3. The data indicates that a value of [ ] Boron is required to offset the reactivity effect of just the misloading of a fresh assembly on the side of the rack.

A similar calculation for a limiting BUC qualified spent fuel assembly will provide the limiting misplaced assembly accident condition if only high burnup fuel assemblies are being moved. Note that additional cases were run in which the SFP concrete wall was placed directly against the misplaced fuel assembly. The results of the calculations are summarized in Table D.9-4. The results indicate that if a water gap exists between the misplaced assembly and the SFP wall then [ ] The limiting case increased reactivity by less than 2mk and can easily be countered with [ ] soluble boron. The data indicates that a conservative value of 25 ppm Boron is required in order to meet the acceptance criterion.

Comparing the accident conditions for the spent fuel PWR racks the following limiting values occur; [ ] for a temperature increase from 150 °F to 212 °F, [ ] boron for a misloaded fresh assembly into the spent fuel PWR rack, [ ] boron for misplacing a fresh assembly along the side of the spent PWR rack, and [ ] boron for misplacing a spent fuel assembly along side the spent fuel PWR rack. Of these accident conditions, misplacing a fresh assembly on one side of the spent PWR fuel rack results in the greatest penalty [ ] and is used in Table D.9-5. Seismic penalties are not required for the Pool B racks if certain administrative controls are implemented. However, for the condition where fuel is not moved, a seismically induced lateral rack movement penalty of [ ], discussed earlier in this section and in Appendix E, was chosen to avoid the additional administrative loading controls for reactivity effects at the interface of the corners of four separate racks. No burnup shape penalties (see Table D.8-4; [ ] are applied to Pool B as they are in Pool A since the Pool B analyses were performed with axial burnup profiles considered.

The Shearon Harris SFP operations can have three distinct SFP operational options: 1) storage only with no fuel handling activities, 2) storage with fresh fuel receipt and reload fuel handling activities, and 3) storage with only high burnup assembly fuel handling. Note that "high burnup" fuel handling refers to fuel assemblies that WILL qualify for storage in a BUC designated rack module. If an assembly does NOT qualify for storage in a BUC designated rack module then it will be treated as a fresh, zero burnup assembly and the requirements for SFP operational mode 2) will need to be enforced.

The soluble boron requirement for each identified SFP operational mode is that required for the normal condition and the most limiting credible accident or upset condition in order to maintain $K_{95/95} \leq 0.950$. This combination ensures that the double contingency principle is met and that at least two accidents/upsets are required to occur concurrently for a criticality event to be possible. Table D.9-5 summarizes the SFP BUC rack soluble boron requirements.

Table D.9-3 Fresh Fuel Misplaced Assembly Accident on Side of Spent Fuel Rack

Table D.9-4 Spent Fuel Misplaced Assembly on Side of Spent Fuel Rack

Table D.9-5 Summary of BUC Rack SFP Soluble Boron Requirements

D.10 Summary of Pool B Results

The evaluation for BUC PWR storage racks will allow storage of the existing PWR assemblies in the Harris SFP. The regulatory requirement of $K_{95/95} \leq 0.95$ is met for the following requirements for fuel racks designated as BUC PWR storage racks:

1. **Assemblies must be demonstrated that they have an assembly average burnup greater than the BUC required minimum burnup for the assembly initial enrichment. Assemblies that meet this requirement may be stored unrestricted. Assemblies that fail this requirement may NOT be stored in the BUC rack and shall be treated as fresh fuel assemblies.**

    i. **Plant measured assembly average burnup shall be decreased by the plant measured burnup uncertainty (Typically [ ] specific value to be determined by plant procedures)**

    ii. **Assembly initial enrichment is to be the maximum planar enrichment if the assembly enrichment varies by axial location.**

    iii. **Assembly initial enrichment may optionally be conservatively increased by [ ] wt% U^{235} for enrichment uncertainty. Note that BUC loading curve includes the [ ] wt% U^{235} enrichment uncertainty.**

2. **Reload fuel assemblies shall be demonstrated to be less reactive than the SFP BUC rack Design Basis assembly at all assembly average burnups in the SFP rack geometry in order to qualify for storage.**

3. **FANP assemblies shall <u>not</u> be used with removable BP inserts during reactor operation. These assemblies do not generically qualify for storage in the BUC racks. They may be qualified with additional calculations.**

4. **Non-fuel bearing stainless steel containers may be stored in the BUC storage rack without restriction.**

5. **The Spent Fuel Pool water temperature shall not exceed 150 °F (65.56 °C) for normal operations.**

6. **A minimum SFP [ ] soluble boron concentration is required for fuel storage for normal conditions without fuel handling activity.**

7. A minimum SFP [ ] soluble boron concentration is required for fuel storage with fuel handling activity with fresh fuel assemblies or spent fuel assemblies that do not meet the BUC requirements for storage in a BUC designated rack.

8. A minimum [ ] soluble boron concentration is required for fuel storage with fuel handling activity with BUC rack qualified spent fuel assemblies. This value is not applicable to handling fresh fuel assemblies or spent fuel assemblies being moved that do not meet the BUC requirements for storage in a BUC designated rack.

9. The BWR storage rack must meet the assumptions/requirements described in this analysis.

The calculated results indicates that the limiting BUC rack multiplication factor is $K_{95/95}$ = [ ] with the SFP soluble boron requirements. Thus, the regulatory requirement of $K_{95/95} \leq 0.950$ for operating conditions is met.

The calculated results indicates that the limiting BUC rack multiplication factor is $K_{95/95}$ = [ ] in un-borated water. Thus, the regulatory requirement of $K_{95/95} \leq 1.000$ without soluble boron credit for the deboration accident condition is met.

The limiting accident condition is the misplacement/dropped fresh, high enrichment assembly between the SFP wall and a BUC rack module and requires a minimum SFP soluble boron concentration of [ ] for the BUC storage rack to meet regulatory requirements. Since normal storage requires a SFP soluble boron concentration of 225 ppm, the maximum SFP soluble boron requirement is [ ] for use of this BUC storage rack criticality analysis.

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Appendix E Pool A Fresh and Spent Fuel Rack Analysis

The Pool A analysis is different from the Pool B analysis in part due to the current HNP practice of placing new fuel and non-BUC qualified fuel into Pool A. The analyses described below are applicable to Pool B when a non-BUC (fresh or irradiated fuel) region is established in Pool B. The interaction effects between the fresh and spent PWR and BWR racks must be considered. Additionally, different accident consequences are possible with the fresh racks compared to a BUC region. Appendix E addresses Pool A racks consequences. Note that the Pool A accident scenarios are more limiting compared to those for Pool B. Therefore, the bounding accident results for Pool A will be applied to Pool B in the final determination of required boron credit since the pools are connected.

E.1 Pool A Fresh Fuel Rack Calculations

This section discusses the evaluation of the various rack configurations for the fresh fuel region in Pool A. Two types of FANP 17x17 fuel assemblies are considered for the fresh fuel evaluation: the current HTP design and the Advanced HTP design. The evaluation determines the bounding assembly configuration based upon the nominal dimensions of each assembly type and then uses that assembly for the rack evaluation as the design basis assembly. The rack evaluation examines the normal configuration, infinite and finite, plus selected upset conditions. The evaluations for the normal conditions comprise various configurations of the fresh rack only and interaction effects between the fresh rack and either the PWR or BWR spent fuel racks. These evaluations are discussed in the following sections.

E.1.1 Pool A Fresh Fuel Rack Module Only

This section concerns fresh rack only configurations. It examines the optimum fuel assembly type, finite and infinite rack arrays, and the placement of non-fuel bearing components in the rack module.

The first step of the evaluation was to define a design basis assembly from either the current FANP 17x71 HTP assembly or the proposed Advanced HTP assembly. This determination used a KENOV.a model of a 2x2 infinite rack with 2-of-4 cell loading of either HTP or Advanced HTP assemblies. Cases 1 and 2 of Table E.1.1-1 show statistically equal results for the two assemblies. To better define the relative reactivity of these assemblies, the CASMO-3 model developed for the tolerance studies (see Section 2.3.2) was used to provide deterministic results. The second set of cases in Table E.1.1-1 list the results for the CASMO-3 model and similar KENO V.a models. Case 3 and 4 are the CASMO-3 cases which show that the Advanced HTP assembly is slightly more reactive than the HTP assembly, but only by ~0.1% Δk. Based upon this evaluation, the Advanced HTP assembly is chosen as the design basis assembly for the fresh fuel evaluation. Cases 5 and 6 in the table examine KENO V.a representations of the CASMO-3 model and the explicit cell model. Case5 models all rack cells filled with fuel with the wrappers explicitly included and case 6 with the wrappers merged into the cell wall to explicitly duplicate the CASMO-3 model. Including the wrappers in the cell wall increases k_{eff} slightly over the explicit model, probably due to removing the 'mini-flux trap' of the wrapper, but provides agreement with the CASMO-3 results within 3σ. The excellent agreement between the two methodologies supports to the validity of the CASMO-3 tolerance studies and for the general results of the KENO V.a modeling. A comparison of the results cases 1 and 2 with those of 3 to 5 in Table E.1.1-1, i.e. 2-of-4 and 4-of-4 assembly loading, illustrates the need for the reduced loading to ensure that the rack remains sub-critical when there is no soluble boron in then pool water, i.e., deboration accident.

Table E.1.1-1 Comparison of HTP and Advanced HTP Assemblies

With the design basis fuel determined, the next series of cases examine various configurations of the rack. Rather than the 2x2 array of rack cells, the model is expanded to a 6x10 array of cells to explicitly model a typical PWR rack module in the HNP pool (see Figure 2.3.4-2). Table E.1.1-2 lists results for this series of cases. The first case is the 2x2 reflected cell infinite rack model, while the second is the 6x10 cell infinite rack model. The two models are identical except for the array size modeled. While there is reasonable agreement (within ~3σ) between the two models, cases 3 and 4 increased the number of histories from 1,000,000 to 2,000,000 whether the difference is purely statistical. The results for 2,000,000 histories show that the 2x2 Advanced HTP assembly results is now statistically equal to that of the 6x10 module for both the 2,000,000 and 1,000,000 history cases. Thus, 1,000,000 histories are sufficient for the cases of this evaluation. Cases 5, 6, and 7 examine less dense fuel loadings in the rack. Case 5 has a regular array of 1 assembly in every four cells, while case 6 allows 2 assemblies in every 6 cells (loaded in cells that would be reached by a 'knight' move on a chessboard). It is noted that in both cases, an assembly is not allowed to be either face-adjacent or diagonally-adjacent to another assembly in the rack. Case 7 has only one assembly inserted near the center of the 6x10 rack array. The k_{eff} values for the three cases are statistically equal. Thus, the 2-of-4 arrangement bounds any less dense loading arrangement and loading patterns with assembly densities of 1 assembly in four cells, or less, essentially represent an isolated assembly in the rack. Case 8 shows that a single isolated assembly in unborated water is more reactive than assemblies in the rack. This illustrates the absorber efficiency of the stainless steel materials in the rack. The next set of cases examines a 6x10 rack module with a 2-of-4 loading pattern. Case 9 through 11 examine reflector effects for a single 6x10 rack module. Case 9 has a water reflector on all sides, while cases 10 and 11 have with a 24" concrete wall on one and two adjacent sides, respectively. All three isolated rack cases provide statistically equal results. This is probably due to the small water region outside the wrapper plates included in all three cases provided by the lead-in funnels. The lead-in funnel in each cell extends to the mid-point of the gap between wrapper plates. Thus, the edge of the funnel maintains the

10.5" cell pitch across modules. It is assumed that this edge defines the outer edge of the module used to measure the minimum separation distance between modules.

Table E.1.1-2 Rack Normal Configuration Results with Advanced HTP Assemblies				

The specification for module placement requires a minimum 2" separation between modules. Cases 12 through 15 represent an infinite array of the 2-of-4 loaded 6x10 rack with and without the 2" minimum separations. Cases 12 and 13 examine the normal condition with the 2" separation. Based upon the $K_{95/95}$ formulation, i.e., $K_{95/95} \approx k_{eff}$ + [ ], at least [ ] ppm boron credit is required to satisfy the 0.95 criticality safety limit for the normal condition. Use of boron credit is acceptable since $K_{95/95} < 1.0$ with no soluble boron in the cooling water, i.e., deboration accident. Cases 14 and 15 examine the case with no spacing with [ ] and [ ] ppm boron to bound a seismic event that moves the racks together. An additional [ ] ppm soluble boron is required to mitigate this upset condition. Thus, to mitigate the seismic movement upset condition, a total of [ ] ppm boron is required, [ ] boron credit and the additional upset [ ] ppm soluble boron.

Table E.1.1-2 provides results for rack modules with a checkerboard arrangement of fresh fuel assemblies and water cells. Due to the lack of absorber materials, fuel bearing components may not be placed in the water cells. However, HNP would like the ability to store non-fuel bearing components in the water cells. Table E.1.1-3 provides results for non-fuel bearing components (NFBC) placed in the water cells. The first set of cases examines an isolated rack to assess the effect of NFBC in the water holes. The first case is just that for an isolated rack with only fuel and water holes for ease of comparison. Due to the uncertainty of the contents of the can, a 100% stainless steel block with the outer dimensions of a fuel assembly is conservatively assumed to bound all types of NFBC. Cases 2 through 9, add the NFBC to the isolated rack in various arrangements.

Case 2 with one can showed a slight increase in k_{eff} of ~0.4%Δk. Cases 2 through 6 add cans in cells around the same fuel assembly and in all water cells in the rack. For these cases, the k_{eff} monotonically increases to a value of ~0.96. Note that for these cases the NFBC are added to water cells adjacent to cells in which NFBC already reside. This tends to couple assemblies adjacent to the NFBC. Cases 7 and 9 illustrate that if the cans are selectively placed, the increase in k_{eff} can be minimized. Case 8 loads 9 NFBC, see Figure E.1.1-1, so that for any selected six adjacent cells no more than one NFBC occupies a water cell. This loading pattern results in a k_{eff} less than that of inserting two cans adjacent to the same fuel assembly. Case 9 places the cans only in the fourteen peripheral locations in the rack module (see Figure E.1.1-1) and has a k_{eff} value equivalent to case 8. Note that this case does not consider adjacent rack modules, thus is really only applicable to NFBC placement in cells facing the pool wall, or a wide water region (>~24" thick). Case 10 expands the case 8 model from an isolated rack module to an infinite array by reflecting 2x2 array with one module containing NFBC and the other three modules only water cells. The k_{eff} of this case is slightly larger than, but within 2 sigma of the isolated case 8 of the isolated case. Case 11 expands the model to 2 water modules and two NFBC modules with the one-of-six cell pattern as in Figure E.1.1.2. The k_{eff} increases by ~0.5%Δk over that for the single rack model of case 8. Case 12 expands case 9 in a manner similar to case 10, i.e., 1-of-4 modules with NFBC in the peripheral water cells (Figure E.1.1-.2). Note that both case 10 and 12 assume no spacing between modules rather than the 2" minimum separation. For case 12, a [ ] increase is obtained due to coupling of assemblies between modules by the NFBC relative to case 11 in Table E.1.1-2 without NFBC. Case 13 assumes that the NFBC stainless steel density is 50% full density with water filling the remaining volume. The case assumes all the water cells are filled with NFBC and provides a k_{eff} statistically equal to that for a module with a single 100% steel can in the module.

It is assumed that the 1-in-6 NFBC loading pattern provides the greatest flexibility for the fresh rack module. Thus, the next group of cases, 14 through 22, examines an infinite array of fresh modules with this loading pattern. Case 14 taken from Table E.1.1-2 provides the base case with no NFBC. The evaluation examines various combinations of NFBC and non-NFBC modules with and without NFBC either with a normal 2" or upset 0" spacing between modules. For the normal conditions, case 18 with a checkerboard arrangement of modules results in the highest k_{eff}. The Δk between this case and the base case without NFBC is [ ] This Δk represents the portion of the Δk_{sys} discussed in the $K_{95/95}$ formulation in Section 2.5.1. Case 19 considers that a seismic upset removes the spacing between modules. Case 20 repeats case 19 with [ ] ppm soluble boron to mitigate seismic rack movement. This amount of soluble boron reduces the keff of this case below that for the similar seismic event with no NFBC, see case 12 Table E.1.1-2. This is the same as that necessary for the rack without NFBC so that no additional soluble boron requirement is needed in addition to that base case.

This evaluation for the NFBC considered only placing the NFBC in water holes in the fresh fuel rack. By restriction, the NFBC does not contain fissile material. Thus, it can replace a fuel assembly in either the fresh, or the spent fuel racks without adversely affecting the criticality safety of the racks.

Table E.1.1-3 Non-fuel Bearing Component Evaluation

Figure E.1.1-1 Sketches of Non-fuel Bearing Can Locations in Isolated Rack Module

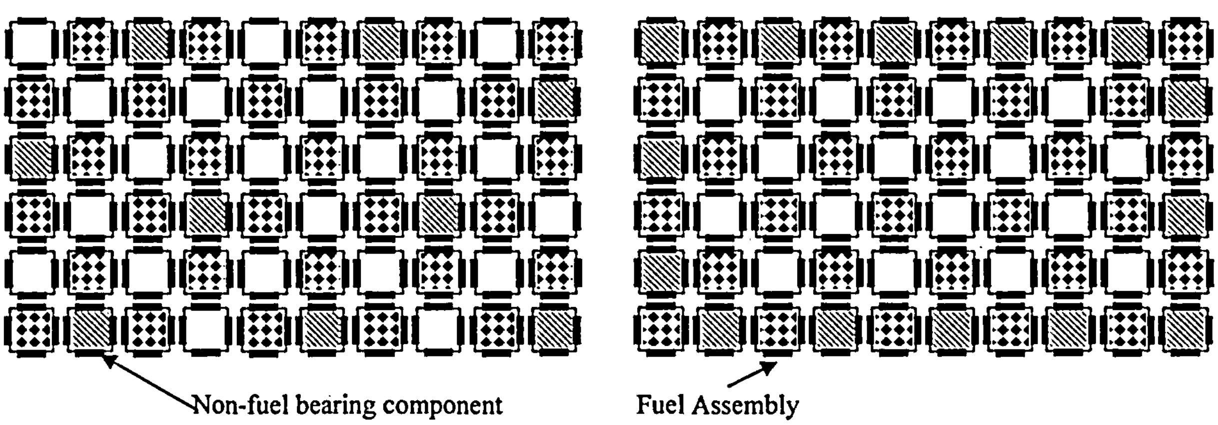
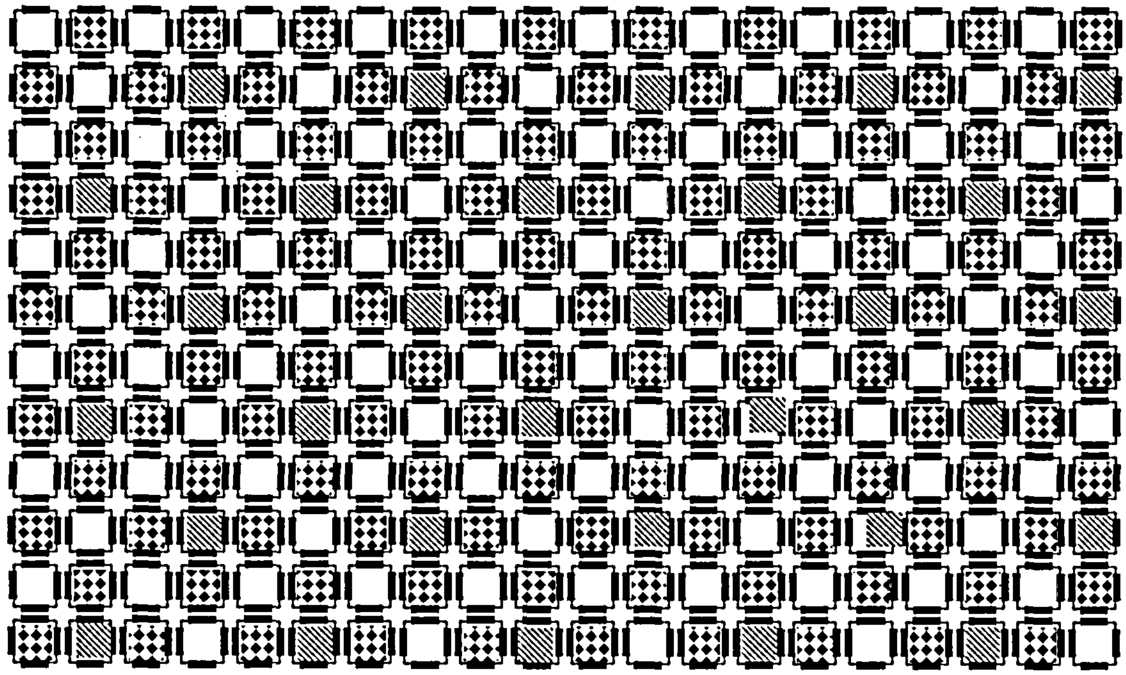
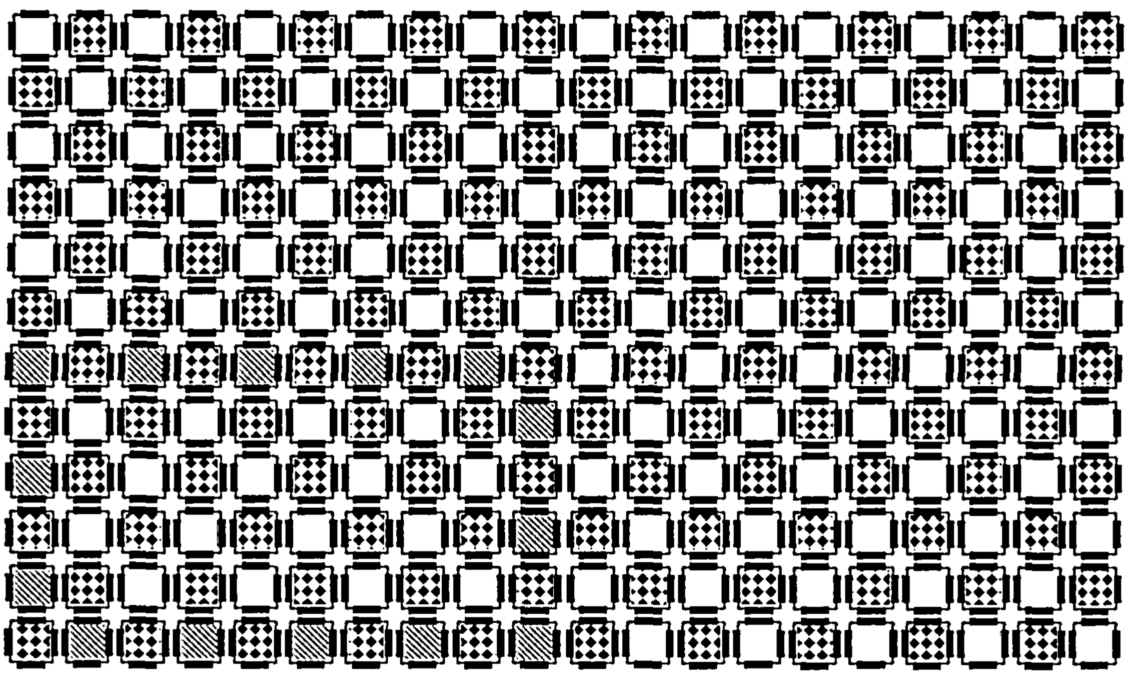


Figure E.1.1-2 Sketches of Non-fuel Bearing Can Locations in 2x2 Module Array





E.1.2 Pool A and B Interaction Effects with Spent Fuel Racks

The fresh rack modules may be placed adjacent to racks containing either spent PWR fuel or BWR fuel. This section examines the interaction effects between the fresh rack and either type of spent fuel rack in Pool A. The PWR spent fuel rack modules are examined first. It is noted that these racks have the same design as the fresh fuel racks. Thus, the only modeling change is insertion of PWR fuel assemblies that are equivalent to spent fuel in the previous fresh fuel interaction models. Due to the smaller size of the BWR assembly, the rack design is different from the PWR design and a new rack module must be developed that is added to the PWR interaction models above. Both evaluations are discussed below.

E.1.2.1 Pool A Interaction Effects with PWR Spent Fuel Racks

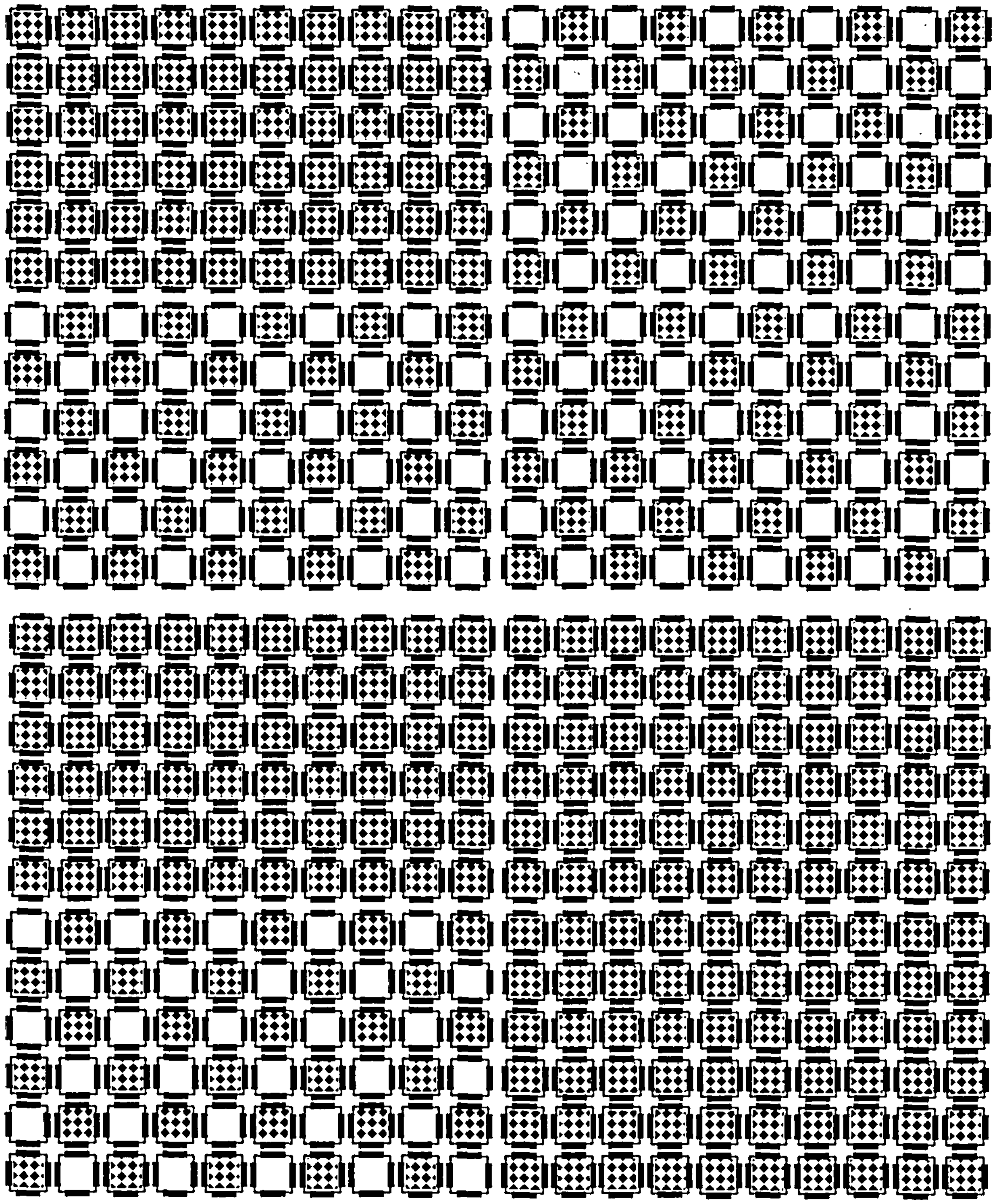
The fresh fuel and spent fuel PWR racks in the HNP storage pools are of the same design. The fresh racks model assumes a checkerboard pattern with no more than 2 out of every four cells containing 4.95 wt% fresh fuel. The spent fuel racks will contain fuel in all cells with reactivity controlled by a combination of burnup credit and boron credit. A fresh fuel enrichment of [ ] wt% is used for the spent racks to conform to the lower point on the spent fuel rack loading curve. As noted previously, all rack cells contain lead-in funnels that maintain the cell pitch across the modules. However, the rack modules are positioned to maintain a minimum of 2" between PWR and 1-7/8" between BWR modules. The evaluation discussed in this section examines the interaction between fresh and spent PWR fuel storage racks.

Table E.1.2.1-1 lists the result for the interaction evaluation. The first set of cases examine the reactivity of the spent fuel rack with [ ]wt% fresh fuel, while the second set examines the interaction effect between the fresh and spent PWR racks. The base rack model for the new fuel rack is applicable to the spent rack. The primary change is the specification of the fuel material. Cases 1 through 5 provide the results for selected variations of the model with the [ ] wt% fuel. Cases 1 and 2 illustrate the interaction effect between the spent racks by modeling an isolated rack (12" water reflector) and an infinite array of racks with 2" module spacing. Case 2 also provides the base case for the nominal spent rack model. As noted in the table, the $K_{95/95}$ exceeds 0.95 ($K_{95/95} \approx k_{eff}$ + [ ] from the Table A-6) but is less that 1.0 for the deboration accident. Thus, boron credit is applicable, and required for the **normal condition** of the rack. Case 3 indicates the at least [ ] is required to satisfy the 0.95 criticality criterion. Cases 4 and 5 examine upset **seismic movement** of the rack that is mitigated by adding [ ] soluble boron, a total of [ ] boron.

The next set of cases in E.1.2.1-1assess the interaction effects between the fresh and spent racks. Various arrangements of the two modules in infinite arrays are examined in the table. It is noted that the fresh rack is more reactive than the spent rack and thus controls the system reactivity. Thus, the system Δk value applied to the spent racks is 0.0. Case 6 lists the base fresh rack result for ease of comparison. The cases examine both the normal minimum 2" separation between modules and no spacing, 0", due to seismic movement of the modules. For the normal condition without boron, the keff values for the mixed cases are higher than the fresh rack. This is due to the added coupling of the fresh assemblies by the proximity of the densely packed spent rack. The results of the normal mixed cases are statistically equal to that of an array of spent modules. However, to determine the interface penalty for the fresh racks, the maximum interface Δk for case 11 will be used. The portion of the system Δk due to PWR rack interfaces is obtained from the difference of cases 6 and 11, or [ ]. This is applied to only to the fresh rack. This Δk is seen to be worth [ ] ppm boron when it is recalled that [ ] ppm B is required for normal conditions for the controlling spent rack of case 6, e.g, for case 12, [ ] ppm – [ ] ppm. Table 1.2.1-1 also lists the effect of seismic shifting to remove the spacing between the racks for each configuration. Based upon a [ ] ppm boron requirement for each normal configuration, with seismic movement the following additional boron concentrations are needed to satisfy the 0.95 criterion: [ ] ppm for 3 fresh to 1 spent arrangement; [ ] ppm for the 1 fresh to 3 spent; [ ] ppm for the checkerboard arrangement; and [ ] ppm for adjacent rows of modules. The **checkerboard arrangement requires a total of [ ] ppm boron to cover both the normal and seismic event when no fuel is being moved** while the next bounding condition requires [ ] ppm boron.

Table E.1.2.1-1 Spacing Between Fresh and Spent PWR Fuel Modules

Figure E.1.2.1-1 Sketch of Fresh and Spent Fuel Rack Interaction Model

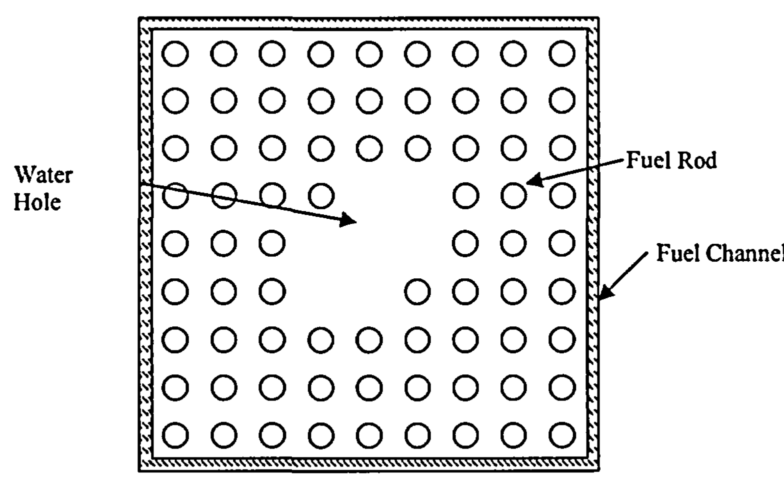


The design basis rack model requires a minimum 2" spacing between PWR modules and 1-7/8" between BWR modules. The above evaluation for the normal 2" and upset 0" spacings bounds other intermediate distances for the PWR modules. Thus, the requirement for [ ] ppm soluble boron to mitigate the 0" spacing upset condition also mitigates the intermediate conditions. If this minimum soluble boron is considered that required for normal operations, it will mitigate the assumed upset effect and effectively remove the minimum spacing requirements between the PWR rack modules. As demonstrated later, this also removes the minimum spacing requirement between BWR modules. This conclusion applies to any arrangement of rack modules in either spent pool as long as the [ ] ppm soluble boron requirement is met to mitigate the seismic upset condition.

E.1.2.2 Pool A and B Interaction Effects with BWR Spent Fuel Racks

The BWR racks are not of the same designed as the PWR racks. This is due to the smaller size of the BWR fuel assembly which results is a reduced reactivity that allows a reduce cell pitch in the rack. The BWR assembly that will be used for this evaluation is a GE-13 9x9 assembly with a [ ] wt% ^{235}U enrichment that Progress Energy has specified as the equivalent fresh assembly that satisfies the criticality safety criterion. Table E.1.2.2-3 lists the significant dimensions of this assembly design. The GE-13 assembly has two waterholes that replace 7 fuel rods near the center of the assembly. The assembly configuration is illustrated in Figure E.1.2.2-1. Note that the water rod region contains Zr tubes that are ignored for this evaluation. Due to their material composition and small wall thickness (0.03"), this modeling assumption will not significantly affect the evaluation results.

Figure E.1.2.2-1 GE-13 9x9 Fuel Assembly Configuration



The BWR rack is fabricated by linking together corners of stainless steel tubes with affixed wrapper plates that initially contained Boraflex. Figure E.1.2.2-2 provides a sketch of the rack arrangement. The linking arrangement provides a storage cell internal to each tube and one inside the 4 surrounding tubes. Table E.1.2.2-2 provides the dimensions of the rack plus the inferred dimensions of the inter-tube cell. Due to the

Figure E.1.2.2-2 Sketch of BWR Rack Arrangement

method of fabrication, the mid-point of the cell pitch does not lie on a boundary surface of the box cell, e.g., the outer edge of the wrapper. Thus, the KENO V.a modeling of the rack can not be obtained by forming an array of simple boxes containing a box cell or a non-boxed cell. Rather the cells used in the KENO V.a model comprise a portion of water gap for the box cell and the remainder of the gap plus the wrapper for the non-boxed cell. These cells are illustrated by the dashed lines in Figure E.1.2.2-2. This figure illustrates cells in the interior of the rack module. No Boraflex panels were added to the edge cells of the modules. Thus, the tubes do not have wrappers on the outer edge walls and the intermediate outer cells only have a plate connecting the adjacent tubes to form the internal box.

Table E.1.2.2-1 BWR Fuel Assembly Information

Table E.1.2.2-2 BWR Rack Dimensions

The information listed above for the BWR fuel dimensions and enrichment plus the rack dimensions are the only input information provided by Progress Energy. Fuel and rack tolerances values were not provided nor were the associated tolerance Δk values. It is noted that the Boraflex degradation of the BWR rack is currently being investigated and is expected to be significantly less than 100% degradation. Thus the bounding BWR assembly provided by Progress Energy is based upon an undegraded rack. In this evaluation it will be assumed that the Boraflex has fully degraded based upon as [ ] wt% uniform BWR assembly without integral absorbers. Table E.1.2.2-3 provides results of the evaluation of the BWR rack module with this assembly specification. A review of the results in table illustrates that there is ~1% Δk margin to the 1.0 safety limit for the deboration accident condition for BWR rack modules ($K_{95/95} \approx k_{eff}$ + [ ] from B.3-1). For future BWR evaluations that may directly assess the Boraflex degradation in these racks, application of the interface results requires a restriction on the bounding equivalent fresh BWR assembly to have a $K_{95/95}$ < [ ] when placed in the completely degraded rack under the deboration accident.

Table E.1.2.2-3 lists results from the BWR racks only. Three models were considered: case 1 represents a single BWR module; case 2 models 3 BWR modules in a row; and case 3 models two rows of three modules abreast. The results indicate a slight difference between a single module and either array of modules and statistically equal values for the array of modules. It is noted that for the BWR array cases, the module separation is 1-7/8", the minimum allowed in the storage pools rather than 2" as previously specified. Based upon the results of these cases, at least [ ] **ppm boron credit** will be required for the BWR racks under **normal conditions.** For **seismic shifting** of assemblies, **additional** [ ] **ppm** soluble boron is for this upset condition for a total of [ ] ppm boron. Note that the design basis BWR fuel assembly was only specified as a GE 13 9x9 design with a uniform axial and planar enrichment of [ ] wt%. The results in Table E.1.2.2-3 indicate that this **BWR design basis assembly has a $K_{95/95} \leq$ [**] for an infinite array of BWR racks for normal spacing. This $K_{95/95}$ value forms the basis for the Δk values due to interaction between the BWR and PWR racks in the storage pools. Thus, this value is a limiting value for this evaluation.

Table E.1.2.2-3 Model with Only BWR Rack Modules

The BWR racks are merged with the both the fresh and the [ ] wt% spent rack models to evaluate interaction effects between the different sets of racks. The BWR rack model was formulated to easily be integrated into the PWR model by the specification of all units and arrays >100. However, the BWR fuel is about 2" longer than the PWR fuel and the two types of racks are positioned at different heights above the floor. The base of the PWR pellet stack is ~10" above the floor while the BWR stack starts ~14.2" above the floor. Thus, the overlap of fuel stacks is only ~ 134" due to the lower position and shorter stack height of the PWR fuel. For conservatism, it is assumed here that the PWR fuel stack is centered on the BWR fuel stack. To effect this change, a 1" water region is placed above and below the PWR rack model unit. Table E.1.2.2-4 lists the results from the PWR and BWR rack evaluations. The first set of cases examines the fresh PWR racks adjacent to the BWR racks. Case 1 models two fresh PWR modules with 4.95 wt% fuel adjacent to 3 BWR modules with [ ] wt% fuel. This model has the two face adjacent PWR racks face adjacent to 3 BWR racks in a row. The minimum 2" separation between PWR and PWR/BWR modules is used with 1-7/8" minimum separation between BWR rack modules. Cases 2 and 3 are check cases in which the model contains all PWR and all BWR modules, respectively. These cases provide results comparable with those for the individual models discussed previously and thus verify that the modeling is adequate. As noted from these three cases, the more reactive BWR rack sets the reactivity for the combined system. This is illustrated in the results for both the interface between fresh and spent racks with the more reactive BWR rack. The results also illustrate that the reactivity of an array of BWR racks equal to, or greater than the mixture of racks for this configuration. Thus, the system Δk for the BWR/PWR interface is 0.0 for fresh PWR racks adjacent to BWR racks with nominal spacing. Cases 4 and 5 evaluate the effect of seismic movement of the racks to remove the normal inter-module spacing. For two adjacent rows, [ ] ppm boron ([ ] ppm) is required to mitigate the seismic movement[1]. Cases 6 and 7 models a checkerboard arrangement of two PWR and BWR racks. Note that only four modules are modeled with water around the outer areas. As noted previously, the reactivity of a single module is essentially that of an infinite array, so that this simplified model is representative of both. The results are more reactive and require [ ] ppm boron ([ ]) to satisfy the 0.95 criterion. These results are similar to those for the fresh and spent PWR interactions. Thus, it is judged that arrangements of 1 PWR and 3 BWR modules or 3 PWR and 1 BWR modules are bounded by the checkerboard and the row arrangements. The second set of cases repeats the first with spent racks containing [ ] wt% fuel. The results are substantially the same with a maximum of [ ] ppm boron ([ ]) required to mitigate the seismic event for spent racks.

In summary, no interaction system bias has been demonstrated for the normal condition of either fresh or spent PWR adjacent to the BWR racks. For maximum movement during a **seismic event**, a minimum of [ ] **ppm boron** is required to mitigate the effect of completely closing the gaps between rack modules. However, this is bounded by the minimum of [ ] ppm concentration required for the seismic event for fresh and spent interactions.

[1] It is noted that the ppm basis for this case, and case 7, is $K_{95/95}$ <0.95. However, the formulation of $K_{95/9}$ includes a system Δk for such movement. Thus, this concentration is conservative. However, because the seismic event for fresh and spent PWR requires a higher boron concentration, the conservatism is non-limiting.

Table E.1.2.2-4 PWR and BWR Modules Combined

E.1.2.3 Rack Calculations Fresh and Irradiated Fuel in Same Rack Module

The previous calculations examined PWR racks loaded with either fresh or spent fuel assemblies. To provide flexibility in use of the racks a series of cases were executed with a mixture of fresh and spent fuel in the same rack module. The base model for this evaluation assumes a single isolated module that is filled generally with a 50/50 split of a fresh checkerboard and spent dense packing. However, the results apply to any apportionment of assemblies within the rack if the follow the loading requirement for either fresh or spent fuel. Figure E.1.2.3-1 illustrates the loading patterns examined and Table E.1.2.3-1 the results of the evaluation. The results indicate that as long as there is an interface region between the fresh and spent assemblies, the k_{eff} of the mixed system is within the statistical uncertainty of the single module, or is less that the single module. The interface can either be a row of waterholes or a row of spent assemblies in a checkerboard pattern with the fresh assemblies. Although this evaluation examined only single modules, the interface effects evaluated in a previous section are applicable to these results. Thus, a mixed module can be placed in any place that a module loaded with either fresh or spent fuel with no additional impact on the storage pool criticality safety.

Figure E.1.2.3-1 Loading Arrangement of Fresh And Spent Assemblies in Same Rack Module

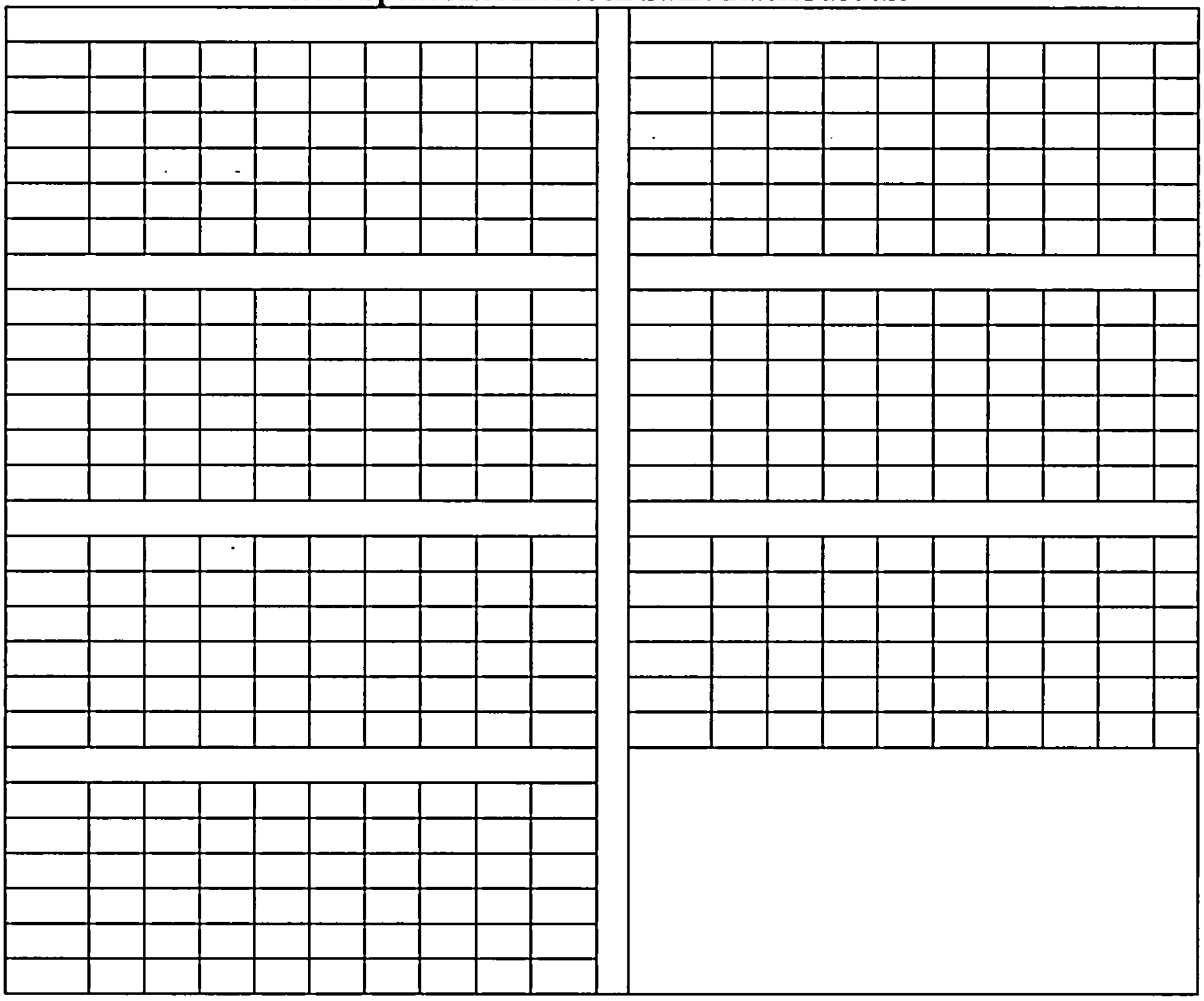


Table E.1.2.3-1 Results for Loading Fresh and Spent Assemblies in Same Rack Module

E.2 Pool A and B Rack Calculations for Accident Conditions

Several upset conditions must be considered for the fresh fuel storage racks. These include misloaded assemblies and dropped assemblies. It would also include rack movement during a seismic event and the deboration accident. However, these conditions were evaluated as part of the individual rack evaluation. Thus, only the misloaded and dropped upset conditions are examined in this section. Note that all the models for the misloaded/dropped conditions employ a single rack module model. This is adequate since during the upset condition the rack reactivity will be significantly higher than the rack in the normal condition. Thus, the upset rack modules control the reactivity so that there would be not interface effects with adjacent normal racks. The dropped condition normally includes both the drop adjacent to the side of the rack and across the top of the rack. The combination of end-fittings and rack height above the top of the assembly provides sufficient water to effectively isolate the dropped assembly from those in the rack. Thus, only evaluations of dropped assemblies next to the rack need be considered.

The combination of fresh and spent fuel types and water holes between assemblies provides the opportunity for the upset condition related to misloading. The primary misloaded condition is related to the fresh PWR assembly which can be placed in a water hole in the fresh rack or into a location in the spent rack. However, a spent assembly can also be misloaded into a water hole location in the fresh rack. The first section of Table E.2-1 examines the various misloaded conditions for PWR assemblies. Due to the small size and low enrichment of the equivalent BWR assembly, a misloaded condition with BWR assemblies is bounded by the similar condition for the [ ] wt% PWR assembly. Cases 1 through 3 examine fresh PWR misloading in the fresh rack. Three locations in the module were examined: a misloaded assembly in the center of the PWR fresh rack between four adjacent assemblies; a misloaded assembly at the edge of the rack between three adjacent assemblies; and a misloaded assembly in a corner position face-adjacent to two assemblies. In all cases, $K_{95/95}$ values >0.95 were obtained ($K_{95/95} \approx k_{eff}$ + [ ] from the Table A-6). However, with a soluble boron concentration of [ ] ppm boron, the 0.95 criticality safety criterion is obtained, case 4. For the spent rack, a fresh 4.95 wt% PWR assembly was placed in the center of a single spent PWR modules containing [ ] wt% fresh fuel. The results for this condition are contained in cases 5 and 6. They show a $K_{95/95}$ value >0.95 ($K_{95/95} \approx k_{eff}$ + [ ] see Section 2.5.5). The addition of at least [ ] ppm boron reduces $K_{95/95}$ below 0.95. Due to the smaller size of the BWR assemblies, a PWR assembly cannot physically fit in the BWR rack. On the other hand, while a BWR assembly can be loaded in the PWR racks, it will be less reactive than a fresh PWR assembly due to its smaller size and required minimum burnup. Thus, no misloading conditions need to be analyzed for the BWR racks or the BWR assembly. Inserting a [ ] wt% assembly into a water hole in the fresh 4.95 wt% assembly required [ ] ppm boron to satisfy the safety criterion.

The next upset condition explicitly examined is that of an assembly dropped adjacent to the outside of the rack. In this condition, the separation between two assemblies can be less than that in the rack since the wrapper forms the outer edge of the cells on the edge. The first set of cases examined dropping a fresh assembly. Three conditions were examined: the dropped assembly is adjacent to a water cell; the assembly is face-adjacent to an assembly in the rack; and finally, the assembly is dropped so as to tightly fit between the outer wrapper of a cell containing an assembly and the concrete pool wall. In all cases, the dropped assembly is assumed to be in contact with the outer wrapper of the rack. In the first two cases, a 12" water reflector is used on the outer surface of the assembly, while the last case has a 24" concrete wall on the outer face of the dropped assembly. For case 9 with the assembly dropped adjacent to a water hole, a small increase in reactivity is seen due to the reduced diagonal spacing between assemblies. The next two cases show a large increase in reactivity when the dropped assembly is aligned with an assembly in the rack. Case 11 with the concrete reflector provides the highest value. Introduction of at least [ ] ppm boron into the pool water is sufficient to reduce $K_{95/95}$ below 0.95 as shown in case 12. Since the normal condition requires [ ] ppm boron credit, the **dropped condition** requires **additional [ ] ppm** soluble boron ([ ] ppm). Similar dropped configurations were examined for both the spent PWR rack (cases 13 and 14 with $K_{95/95} \approx k_{eff} +$ [ ] and BWR rack (cases 15-19 with $K_{95/95} \approx k_{eff} +$ [ ] These cases produced reactivity values below those for the fresh PWR rack and consequently have a lower boron credit requirement. For spent racks the required additional boron for a dropped assembly is [ ] ppm boron ([ ]ppm), while the BWR racks need additional [ ] ppm boron ([ ] ppm)

The last set of cases examined dropping a spent [ ] wt% assembly instead of the 4.95 wt% assembly. It is assumed that fresh fuel movement will only occur to support refueling operations. In this case the spent fuel pool soluble boron concentration will be that required for the relatively short refueling operation. This concentration is generally greater than that during non-refueling periods. Since spent fuel movement occurs during this period during transfer from shipping casks to the racks, another evaluation was performed to determine the soluble boron requirement when only spent fuel that can be placed in the spent fuel racks is transferred. These cases use the same models as for the fresh fuel rack with the enrichment of the dropped assembly changed from 4.95 wt% to [ ] wt%. The drop adjacent to the fresh rack produces the highest reactivity and the requirement for an additional [ ] ppm soluble boron ([ ] ppm for fresh rack) to ensure a $K_{95/95}$ below 0.95.

Based upon the upset conditions, it is necessary to ensure that the soluble boron concentration in the storage pools is > [**] ppm during fresh fuel movements** to ensure that the criticality safety criterion is satisfied for credible upset conditions. For movement of either spent PWR or BWR fuel assemblies that may be placed in the spent fuel racks, the required boron concentration is reduced to [ ] ppm boron. Note that the misplaced fresh assembly is the bounding upset condition for all storage racks. However, offset condition for a misplaced spent assembly is bounded by the seismic movement upset condition. These results apply to a rack module containing a mixture of fresh and irradiated fuel with the appropriate interface between regions.

Table E.2-1 Rack Upset Conditions

E.3 Summary of Soluble Boron Requirements

This evaluation is based upon nominal dimensions for both the racks and fuel assemblies with tolerances applied as Δk values in the $K_{95/95}$ determination. The design basis fresh PWR assembly is the FANP Advanced HTP assembly with a uniform enrichment of 4.95 wt% U^{235} with no integral absorbers or axial blankets. The design basis irradiated PWR assembly is also an Advanced HTP assembly with a uniform enrichment of [ ] wt% U^{235} without integral absorbers or axial blankets. This assembly represents the lower, zero burnup point on spent rack loading curve. The design basis BWR assembly is a GE13 9x9 assembly uniformly loaded at [ ] wt% enrichment without integral absorbers, axial blankets, or part length rods. For this evaluation it is assumed that all racks have experienced 100% Boraflex degradation. This may be slightly conservative for the PWR racks for which significant degradation has been predicted. The amount of degradation in the BWR racks is being investigated. However, due to the longer cool time for transfer from the BWR plant to the Harris pool, significantly less degradation is expected in these racks. The PWR rack modules have a minimum separation of 2" between modules and the BWR modules a minimum of 1-7/8". Both isolated modules and infinite arrays of modules were evaluated. The arrangement indicating the maximum reactivity was chosen to ensure satisfaction of the criticality safety criterion. Boron credit is required for the criticality safety of the storage pools. Thus, the evaluation has shown that for appropriate limiting conditions the $K_{95/95}$ of the racks remain below 1.0 for the deboration accident and below 0.95 for normal and other accident conditions with the required amount of boron credit.

Table E.3-1 Fresh Rack Soluble Boron Requirements

Fresh 4.95 wt% Rack					
Pool Operations Condition	Limiting Upset Condition	Soluble Boron Requirement, ppm			
		Upset	Low Wt%[a]	Normal	Total Sol
Storage only, no fuel handing operations	Seismic movement for multiple racks	[ ]	[ ]	[ ]	450
Storage with fresh fuel receipt and reload operations	Fresh Assy Misplacement	[ ]	-	[ ]	1000
Storage with only high burnup assembly handling	Seismic movement for multiple racks	[ ]	[ ]	[ ]	450

a) This boron requirement is necessary to compensate for a Δk difference due to boron credit obtained using enrichments >~3 WT% and those below this value, such as [ ] wt%.

Table E.3-2 Spent Fuel Rack Soluble Boron Requirements

Burnup Credit Rack					
Pool Operations Condition	Limiting Upset Condition	Soluble Boron Requirement, ppm			
		Upset	Low Wt% [a]	Normal	Total Sol
Storage only, no fuel handing operations	Seismic movement for multiple racks	[ ]	[ ]	[ ]	500
Storage with fresh fuel receipt and reload operations	Fresh Assy Misplacement	[ ]	[ ]	[ ]	725
Storage with only high burnup assembly handling	Seismic movement for multiple racks	[ ]	[ ]	[ ]	500

a) This boron requirement is necessary to compensate for a Δk difference due to boron credit obtained using enrichments >~3 WT% and those below this value, such as [ ] wt%.

Note that the total soluble boron listed above for the burnup credit rack is [ ] ppm less than that developed in the burnup credit (BUC) criticality evaluation. The values in that document are [ ] respectively for no fuel, fresh fuel, and spent fuel handling. However, that analysis assumed an infinite array of rack cells. As shown by cases 4 and 5 in Table E.1.2.1-1, the difference between an infinite rack model and the normal configuration with 2" gaps between modules is [ ] ppm. Thus, the values in the BUC evaluation are too conservative by [ ] ppm. Therefore, the values in the table above for the BUC rack should be used for setting pool requirements rather than the overly conservative values in the BUC evaluation.

BWR Rack Rack					
Pool Operations Condition	Limiting Upset Condition	Soluble Boron Requirement, ppm			
		Upset	Low Wt%	Normal	Total Sol
Storage only, no fuel handing operations	Seismic movement for multiple racks	[ ]	-	[ ]	350
Storage with fresh fuel receipt and reload operations	Fresh Assy Misplacement	[ ]	-	[ ]	475
Storage with only high burnup assembly handling	Seismic movement for multiple racks	[ ]	-	[ ]	350

E.3 Appendix E References

E.1 SHNPP FSAR, Amendement 52, Section 4.3.2.6, page 4.3.2-21.

E.2 Siemens Doc. EMF-94-113, "H.B. Robinson New and Spent Fuel Criticality Analysis," C.D. Manning, July, 1994.

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Introduction

As part of the revision to the criticality analysis, an analysis of dilution events is required because criticality control is partially dependent on boron concentration. The soluble boron in the spent fuel pool water is normally maintained greater than 2000 ppm under operating conditions. Significant dilution of the soluble boron concentration is extremely unlikely. The required minimum boron concentration is 500 ppm under normal conditions and 1000 ppm for the most serious credible accident scenario.

Evaluation

The volume of water in each pool and transfer canals are as listed in Table 1. The volumes for Spent Fuel Pools A, B and C (SFP A, B and C) are net of the fuel and fuel storage racks assuming all the racks are completely loaded with fuel. SFP C is assumed to be fully racked even though it is currently only partially racked.

Table 1

Fuel Pool Sub-Volumes at the Low Level Alarm Setpoint Elevation

Location	Volume (gallons)
SFP A	127,888
SFP B	341,653
SFP C	335,055
SFP D	181,926
1 & 4 Transfer Canal	86,647
2 & 3 Transfer Canal	86,647
Main Transfer Canal	156,732
Total	1,316,548

Evaluation (continued)

The general equation for dilution is used, and the results are presented below:

$C(t) = C_0 e^{-(Q/V)t}$, where

$C(t)$ is the boron concentration at time, t,

C_0 is the initial boron concentration,

Q is the dilution flow rate of unborated water, and

V is the volume of the water in the pool.

The dilution cases that were examined included a small dilution flow rate not associated with a system or component failure, two dilution rates from postulated moderate energy system pipe cracks, a Spent Fuel Pool heat exchanger tube rupture and mixing of unborated SFP D with SFP A. The dilution flow rates analyzed are listed in Table 2.

Small failures or mis-aligned valves could possibly occur in the systems connected to the pool volume (e.g. leaking pump seals or leakage from the pool liner). These events are assessed by postulating a 2 gpm dilution rate. This value is comparable to normal evaporative loss and the increased frequency of makeup flow might not be observed. However, an assumed flow rate of 2 gpm dilution flow rate would require a leak duration of 62 days for Pool A (the smallest in-service pool) to reduce the boron concentration to the minimum required 500 ppm. Dilution duration of 30.7 days is required to dilute from 2000 ppm to the 1000 ppm required for the most severe fuel handling accident. Routine sampling of the soluble boron concentration would readily detect the reduction in soluble boron concentration with ample time for corrective action. The calculations assume that SFP A is isolated for the entire period of time; this is highly unlikely. Additional time would be available if the volume were increased to include the closest adjacent pool, SFP B, and the interconnecting canal.

Under certain accident conditions, it is calculated that a high flow rate of unborated water could flow onto the top of a pool. Such an accident scenario could result from a moderate energy pipe crack in the Demineralized Water System (DWS) or the Fire Protection System (FPS). Both of these events potentially allow unborated water to spray onto a pool. A flow rate was calculated for the rupture of a tube in the Spent Fuel Pool heat exchanger where the Component Cooling Water (CCW) System pressure is higher than the Fuel Pool Cooling and Cleanup System (FPCCS) pressure. The dilution flow rate for the respective events is listed in Table 2. The listed times conservatively assume all the unborated water instantaneously mixes with the borated water in the pool. The times to reach 500 ppm are calculated for

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Evaluation (continued)

SFP A and B. The time for SFP C and D are not relevant because the racks in these pools can maintain $k_{eff} \leq 0.95$ when flooded with unborated water. Also SFP C and D require only 400 ppm soluble boron for a fuel handling accident (FSAR Section 9.1.2.1) and are not limiting in the case of the 2 gpm dilution. Each event is briefly discussed below. The times for SFP A are used to illustrate the results. Table 2 provides the times for SFP A and SFP B.

For the fire protection pipe crack, upon the initial break, the fire protection system header pressure would drop to the auto start setpoint of the motor driven fire pump. The start is accompanied with an alarm in the main control room. The annunciator response is to dispatch an operator to find the source of the pump start. Approximately 16 minutes into the event (in the case of SFP A) a spent fuel pool high level alarm would be received in the main control room, assuming that the pool level started at the low alarm level. Each SFP has redundant high and low level alarms that are safety-related. The annunciator response for this spent fuel pool level is to investigate the cause. The coincidence of the 2 alarms would quickly lead to the discovery of the failure of the pipe and sufficient time to isolate the failure.

The flow rate for a failure of the DWS header would provide approximately 52 gpm into a fuel pool. Failure of the demineralized water header is not accompanied with a DWS alarm; however, the time to dilute a spent fuel pool is very large. For the SFP A, the time to reach 500 ppm is approximately 2.4 days. An alarm on SFP A level would occur within 53 minutes into the event in the main control room, assuming that the SFP A level started at the low alarm. In this scenario, there is sufficient time to isolate the failure and to prevent the spilling of some 180,000 gallons of water.

The flow rate for a tube failure in the spent fuel heat exchanger would provide approximately 238 gpm. Failure of the tube would quickly cause a low level alarm on the Component Cooling Water (CCW) system surge tank. The CCW system is a closed system and makeup to the system is performed manually. The surge tank has a normal level of about 500 gallons so the tube break would quickly cause low level alarms in the main control room. The operator's response would be to investigate the source of the leak and isolate the affected component. The CCW system pumps would be stopped if the CCW surge tank emptied and this would reduce the differential pressure between CCW and FPCCS. The time required to reach a boron concentration of 500 ppm is 12.6 hours. There is sufficient time to isolate this failure.

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Evaluation (continued)

Table 2

Dilution Rates and Time for Alarm and Mitigation

Dilution Source & Flow Rate	Pool A Time to High Level Alarm (hours)	Pool A Time to reach 500 ppm	Pool B Time to High Level Alarm (hours)	Pool B Time to reach 500 ppm
Unspecified 2 gpm Source	N/A	62 days	N/A	166 days
Demin Water System (DWS) Pipe Crack (52 gpm)	53 minutes	2.4 days	2.4 hours	6.4 days
Fire Protection System (FPS) Pipe Crack (178 gpm)	16 minutes	16.8 hours	43 minutes	45.0 hours
Combined DWS & FPS Pipe Cracks (230 gpm)	12 minutes	13.0 hours	33 minutes	34.8 hours
SFP Heat Exchanger Tube Break (238 gpm)	12 minutes	12.6 hours	32 minutes	33.7 hours

An event where SFP D is mixed with the contents of SFP A was also examined. SFP D is currently not used for spent fuel storage and is gated from the balance of the SFPs. The boron concentration of SFP D is not monitored. Under the worst conditions, the failure of SFP D's gate would result in no noticeable level change in the balance of the pools. The failure of this gate was evaluated assuming the instantaneous mixing of SFP D and SFP A along with the interconnecting canals. SFP A is smaller than SFP B and SFP C and thus would be more limiting. The result of the calculation is that the SFP A boron concentration would be 1431 ppm. This is greater than the 500 ppm required during normal operation or the 1000 ppm required during an accident. Therefore additional controls on the contents for SFP D are not required.

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Conclusion

In summary, it is not considered credible that multiple alarms would fail or be ignored or that the spilling of large volumes of water would not be observed. Therefore, failure of a fluid system causing a dilution would be detected in sufficient time for corrective action to maintain specified k_{eff} in the spent fuel pools.

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received
8/29/05

AREVA

August 26, 2005
FAB05-756

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References:
1. FANP Letter FAB05-329, "Acceptance of Progress Energy Task Work Authorization No: 05009A, HNP PWR Criticality Analysis for Total Degradation of Boraflex," March 11, 2005.
2. Progress Energy Letter 0197L05.CHF, "Contract No. 101659, Contract Work Release No. 101659-08, Task Work Authorization No: 05009A, HNP PWR Criticality Analysis for Total Degradation of Boraflex," March 9, 2005.
3. FANP Letter FAB05-283, "GPS102960: Proposal for Harris PWR Criticality Analysis for Total Boraflex Degradation," Febrauary 18, 2005.
4. FANP Letter FAB05-744, "Harris Criticality Evaluation," August 15, 2005.

Subject: **Harris Criticality Evaluation Documents**

Dear Stephanie,

In accordance with References 1, 2, and 3, attached are the Proprietary and Non-Proprietary versions of the Harris Criticality Evaluation (77-5069740-P-00 and 77-5069740-NP-00) and the associated Framatome ANP affidavit. This report and the supporting calculations and analyses have been prepared in accordance with Framatome ANP's approved quality assurance program.

This document is the same as the document transmitted in Reference 4 with the following minor exceptions. First, the brackets showing the proprietary information are added to the proprietary version and the data within the brackets is removed for the non-proprietary version. In addition, Reference 9, which referred to a proposal document that cannot be released to the public record, was deleted. Lastly, minor wording changes were made on page 11 in the beginning of the paragraph labeled "2." and the paragraph labeled "i.".

FRAMATOME ANP, INC.
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Should you have any questions or comments, feel free to call me at (434) 832-3165, or you can e-mail me at tony.roscioli@framatome-anp.com.

Sincerely,

Anthony J Roscioli

A. J. Roscioli
Project Manager

cc:
Randy Sass (Contract File 004564)
Ann Smith, Records Center, Contract 004564 T1.2
Dick Deveney
Tom Lotz
Pete Holman
Desk/Chron

AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
CITY OF LYNCHBURG)

1. My name is Gayle F. Elliott. I am Manager, Product Licensing in Regulatory Affairs, for Framatome ANP ("FANP"), and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by FANP to determine whether certain FANP information is proprietary. I am familiar with the policies established by FANP to ensure the proper application of these criteria.

3. I am familiar with document 77-5069740-P, Revision 0, "Shearon Harris Criticality Evaluation," dated August 2005 and referred to herein as "Document." Information contained in this Document has been classified by FANP as proprietary in accordance with the policies established by FANP for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by FANP and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure.

6. The following criteria are customarily applied by FANP to determine whether information should be classified as proprietary:

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(e) The information is vital to a competitive advantage held by FANP, would be helpful to competitors to FANP, and would likely cause substantial harm to the competitive position of FANP.

7. In accordance with FANP's policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside FANP only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. FANP policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

SUBSCRIBED before me this 26th

day of August, 2005.

Brenda C. Maddox

Brenda C. Maddox
NOTARY PUBLIC, COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES: 7/31/07