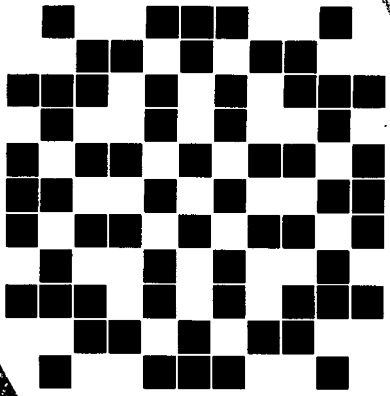
Westinghouse
Commercial Nuclear Fuel Division



CRITICALITY ANALYSIS
OF THE INDIAN POINT UNIT 3
FRESH AND SPENT FUEL RACKS

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1.0 INTRODUCTION

This report presents the results of a criticality re-analysis of the Indian Point Unit 3 Fresh and Spent Fuel Storage Racks. The fresh and spent designs considered herein are existing arrays of racks, previously qualified for storage of Westinghouse 15x15 fuel assemblies with enrichments up to 4.5 w/o U^{235}. The Indian Point Unit 3 Spent Fuel Rack design employs two separate and different arrays of storage racks which are referred to as Region 1 and Region 2.

The Indian Point Unit 3 Fresh and Spent Fuel Storage Racks are being reanalyzed to allow storage of all Westinghouse 15x15 fuel assembly types (STD, OFA, VANTAGE 5, and VANTAGE+) with nominal enrichments up to 5.0 w/o U^{235}. The following storage configurations and enrichment limits are considered in this analysis:

Fresh Fuel Rack	Storage of fuel assemblies with nominal enrichments up to 5.0 w/o in all locations, with no requirements for burnup or burnable absorbers.
Region 1 Close Packed	The Region 1 spent fuel rack will be analyzed for storage of assemblies with nominal enrichments up to 4.6 w/o using all cells. To differentiate this type of storage configuration from the checkerboard scheme described below, the term "close packed" will be used.
Region 1 Checkerboard	The Region 1 spent fuel rack will be analyzed for storage of "burned" and "fresh" fuel assemblies in a 2x2 checkerboard pattern. Fuel assemblies stored in "burned" cell locations must have an initial enrichment less than 4.2 w/o (nominal) or satisfy a minimum burnup requirement. Fuel assemblies stored in the "fresh" cell locations can have enrichments up to 5.0 w/o, with no requirements for burnup or IFBA.
Region 2 Close Packed	The Region 2 spent fuel rack will be analyzed for storage of fuel assemblies which satisfy the Region 2 minimum burnup requirements. There are no restrictions on assembly position or minimum IFBA content for these assemblies.

The Indian Point Unit 3 Fresh and Spent Fuel Rack analyses are based on maintaining $K_{eff} \leq 0.95$ for storage of Westinghouse 15x15 fuel assemblies under full water density conditions and ≤ 0.98 under low water density (optimum moderation) conditions. The optimum moderation condition applies only to the fresh fuel rack since this rack is used to store fuel in a dry environment.

1.1 DESIGN DESCRIPTION

The Indian Point Unit 3 fresh fuel rack array consists of part length stainless steel angle irons which support the fuel assemblies at the top and bottom. The fresh fuel rack layout is shown in Figure 1 on page 39 and Figure 2 on page 40.

The Indian Point Unit 3 Region 1 and 2 spent fuel storage cell designs are depicted schematically in Figure 3 on page 41 and Figure 4 on page 42, respectively, with nominal dimensions provided on each figure. A schematic of the Region 1 checkerboard pattern of burned and fresh storage cells is given in Figure 5 on page 43.

The fuel parameters relevant to this analysis are given in Table 1 on page 29. Given the simplifying assumptions employed in the analysis (no grids, sleeves, axial blankets, etc.), all Westinghouse 15x15 fuel assembly types are essentially identical. For simplicity, the 15x15 OFA fuel assembly type is assumed in all analyses. The 15x15 STANDARD (LOPAR) assembly is nearly identical to the OFA design, except for the use of Inconel grids and slightly larger guide and instrument tubes (both differences result in lower reactivity relative to the OFA assembly). The 15x15 VANTAGE 5 design parameters relevant to the criticality analysis are the same as the OFA parameters and will yield equivalent results. The 15x15 VANTAGE+ design is nearly the same as the VANTAGE 5 assembly (for the parameters relevant to the criticality analysis) except for use of ZIRLO cladding material which contains trace amounts of Niobium and results in a slightly decreased reactivity relative to the VANTAGE 5 design. Therefore, the results of this study will bound all Westinghouse 15x15 fuel designs, including those clad with ZIRLO and those which utilize low enrichment axial blankets.

1.2 DESIGN CRITERIA

Criticality of fuel assemblies in a fuel storage rack is prevented by the design of the rack which limits fuel assembly interaction. This is done by fixing the minimum separation between fuel assemblies and inserting neutron poison between fuel assemblies.

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_{eff}, of the fuel assembly array will be less than 0.95 as recommended by ANSI 57.2-1983, ANSI 57.3-1983 and NRC guidance(1), and less than 0.98 under low water density (optimum moderation) conditions as recommended by NUREG-0800. The optimum moderation condition applies only to the fresh fuel rack since this rack is used to store fuel in a dry environment.

2.0 ANALYTICAL METHODS

2.1 CRITICALITY CALCULATION METHODOLOGY

The criticality calculation method and cross-section values are verified by comparison with critical experiment data for fuel assemblies similar to those for which the racks are designed. This benchmarking data is sufficiently diverse to establish that the method bias and uncertainty will apply to rack conditions which include strong neutron absorbers, large water gaps and low moderator densities.

The design method which insures the criticality safety of fuel assemblies in the fuel storage rack uses the AMPX(2, 3) system of codes for cross-section generation and KENO Va(4) for reactivity determination.

The 227 energy group cross-section library that is the common starting point for all cross-sections used for the benchmarks and the storage rack is generated from ENDF/B-V(2) data. The NITAWL(3) program includes, in this library, the self-shielded resonance cross-sections that are appropriate for each particular geometry. The Nordheim Integral Treatment is used. Energy and spatial weighting of cross-sections is performed by the XSDRNPM(3) program which is a one-dimensional S_n transport theory code. These multigroup cross-section sets are then used as input to KENO Va(4) which is a three dimensional Monte Carlo theory program designed for reactivity calculations.

A set of 44 critical experiments has been analyzed using the above method to demonstrate its applicability to criticality analysis and to establish the method bias and uncertainty. The benchmark experiments cover a wide range of geometries, materials, and enrichments, ranging from relatively low enriched (2.35, 2.46, and 4.31 w/o), water moderated, oxide fuel arrays separated by various materials (B4C, aluminum, steel, water, etc) that simulate LWR fuel shipping and storage conditions to dry, harder spectrum, uranium metal cylinder arrays at high enrichments (93.2 w/o) with various interspersed materials (Plexiglas and air). Comparison with these experiments demonstrates the wide range of applicability of the method. Details of the experiments are provided in References 5 through 9. Table 2 on page 30 summarizes these experiments.

The highly enriched benchmarks show that the criticality code sequence can correctly predict the reactivity of a hard spectrum environment, such as the optimum moderation condition often considered in fresh rack and shipping cask analyses. However, the results of the 12 highly enriched benchmarks are not incorporated into the criticality method bias because the enrichments are well above any encountered in commercial nuclear power applications. Basing the method bias solely on the 32 low enriched benchmarks results in a more appropriate and more conservative bias.

The 32 low enriched, water moderated experiments result in an average KENO Va K_{eff} of 0.9933. Comparison with the average measured experimental K_{eff} of 1.0007 results in a method bias of 0.0074. The standard deviation of the bias value is 0.0013 ΔK. The 95/95 one-sided tolerance limit factor for 32 values is 2.20. Thus, there is a 95 percent probability with a 95 percent confidence level that the uncertainty in reactivity, due to the method, is not greater than 0.0029 ΔK. This KENO Va bias and uncertainty are consistent with the previous Westinghouse bias and uncertainty calculated for KENO IV(10).

2.2 REACTIVITY EQUIVALENCING FOR BURNUP

Storage of spent fuel assemblies with initial enrichments higher than that allowed by the methodology described in Section 2.1 is achievable by means of the concept of reactivity equivalencing. Reactivity equivalencing is predicated upon the reactivity decrease associated with fuel depletion. A series of reactivity calculations is performed to generate a set of enrichment-burnup ordered pairs which all yield an equivalent K_{eff} when the fuel is stored in the Indian Point Unit 3 spent fuel racks.

The data points on the reactivity equivalence curve are generated with a transport theory computer code, PHOENIX(11). PHOENIX is a depletable, two-dimensional, multigroup, discrete ordinates, transport theory code. A 25 energy group nuclear data library based on a modified version of the British WIMS(12) library is used with PHOENIX.

A study was done to examine fuel reactivity as a function of time following discharge from the reactor. Fission product decay was accounted for using CINDER(13). CINDER is a point-depletion computer code used to determine fission product activities. The fission products were permitted to decay for 30 years after discharge. The fuel reactivity was found to reach a maximum at approximately 100 hours after discharge. At this time, the major fission product poison, Xe^{135}, has nearly completely decayed away. Furthermore, the fuel reactivity was found to decrease continuously from 100 hours to 30 years following discharge. Therefore, the most reactive time for a fuel assembly after discharge from the reactor can be conservatively approximated by removing the Xe^{135}.

The PHOENIX code has been validated by comparisons with experiments where the isotopic fuel composition has been examined following discharge from a reactor. In addition, an extensive set of benchmark critical experiments has been analyzed with PHOENIX. Comparisons between measured and predicted uranium and plutonium isotopic fuel compositions are shown in Table 3 on page 31. The measurements were made on fuel discharged from Yankee Core 5(14). The data in Table 3 on page 31 shows that the agreement between PHOENIX predictions and measured isotopic compositions is good.

The agreement between reactivities computed with PHOENIX and the results of 81 critical benchmark experiments is summarized in Table 4 on page 32. Key parameters describing each of the 81 experiments are given in Table 5 on page

33. These reactivity comparisons again show good agreement between experiment and PHOENIX calculations.

Uncertainties associated with the burnup reactivities computed with PHOENIX are accounted for in the development of the individual reactivity equivalence limits. For burnup credit, an uncertainty is applied to the PHOENIX calculational results which starts at zero for zero burnup and increases linearly with burnup, passing through 0.01 ΔK at 30,000 MWD/MTU. This bias is considered to be very conservative and is based on consideration of the good agreement between PHOENIX predictions and measurements and on conservative estimates of fuel assembly reactivity variances with depletion history. Additional information concerning the specific uncertainties included in each of the Indian Point Unit 3 burnup credit limits is provided in the individual sections of this report.

3.0 CRITICALITY ANALYSIS OF FRESH FUEL RACKS

This section describes the analytical techniques and models employed to perform the criticality analysis for the storage of fresh fuel in the Indian Point Unit 3 Fresh Fuel Storage Racks.

Since the fresh fuel racks are normally maintained in a dry condition, the criticality analysis will show that the rack K_{eff} is less than 0.98 for the accidental low water density (optimum moderation) flooding scenario. The full density water flooding scenerio is not a credible event for the Indian Point Unit 3 fresh fuel racks due to the geometric layout of the storage rack array. However, for informational purposes, the full density water flooding scenerio K_{eff} is still shown in this report. The criticality methodology employed in this analysis is discussed in Section 2 of this report.

The following assumptions were used to develop the KENO model for the storage of fresh fuel in the Indian Point Unit 3 Fresh Fuel Storage Rack under various water density conditions:

1. The limiting fuel assembly type is assumed.
2. The fuel assembly is modeled at its most reactive point in life.
3. All fuel rods contain uranium dioxide at an enrichment of 5.00 w/o (nominal) and 5.05 w/o (worst case) over the entire length of each rod.
4. The fuel pellets are modeled at 96% of theoretical density without dishing or chamfering to bound the maximum fuel assembly loading.
5. No credit is taken for any axial blankets.
6. No credit is taken for any U^{234} or U^{236} in the fuel, nor is any credit taken for the build up of fission product poison material.
7. No credit is taken for any spacer grids or spacer sleeves.
8. No credit is taken for any burnable absorber in the fuel rods.
9. At all water densities, there is no soluble boron present in the water.
10. Fuel rods are modelled with a fuel stack height of 144 inches long.

The fuel assembly parameters assumed in the analysis are based on the Westinghouse 15x15 OFA design (see Table 1 on page 29 for fuel parameters). Under all water density conditions, the OFA is the most reactive fuel type of the available 15x15 designs in use or storage at Indian Point Unit 3.

The maximum K_{eff} under normal conditions arises from consideration of mechanical and material thickness tolerances resulting from the manufacturing process in addition to asymmetric positioning of fuel assemblies with the storage cells. Studies of asymmetric positioning of fuel assemblies within the storage cells have shown that symmetrically placed fuel assemblies yield conservative results in rack K_{eff}. Due to the relatively large cell spacing, the small tolerance on the cell center-to-center spacing is not considered since it will have an insignificant effect on the fuel rack reactivity. The most conservative, or "worst case", KENO model of the fresh fuel storage racks contains no fuel rack steel with symmetrically placed fuel assemblies. The fuel enrichment is assumed to be 5.05 w/o U^{235} to conservatively account for enrichment variability. The fuel array model is finite in all directions and concrete walls and floor are modeled.

Analysis of the Indian Point Unit 3 Fresh Fuel Racks shows that the maximum rack K_{eff} under low density moderation conditions occurs at 0.06 gm/cm^3 water density. The K_{eff} of the fresh rack at 0.06 gm/cm^3 water density is 0.9467 with a 95 percent probability and 95 percent confidence level uncertainty of ±0.0078. Figure 6 on page 44 shows the fresh fuel rack reactivity as a function of water density over the range from 0.0 gm/cm^3 to 1.0 gm/cm^3 .

Based on the analysis described above, the following equation is used to develop the maximum K_{eff} for the Indian Point Unit 3 Fresh Fuel Storage Racks:

$$K_{eff} = K_{worst} + B_{method} + \sqrt{[(ks)^2_{worst} + (ks)^2_{method}]}$$

where:

K_{worst} = worst case KENO K_{eff} that includes material, mechanical and enrichment tolerances

B_{method} = method bias determined from benchmark critical comparisons

ks_{worst} = 95/95 uncertainty in the worst case KENO K_{eff}

ks_{method} = 95/95 uncertainty in the method bias

Substituting calculated values in the order listed above, the result is:

$$K_{eff} = 0.9467 + 0.0074 + \sqrt{[(0.0078)^2 + (0.0029)^2]} = 0.9624$$

Since K_{eff} is less than 0.98 including uncertainties at a 95/95 probability confidence level, the acceptance criteria for criticality is met.

As mentioned earlier, the full density water flooding condition is not considered a credible event for the Indian Point Unit 3 fresh fuel racks. The racks are built and located in such a way that the entry of full density water into the storage area is not possible. However, for informational purposes, Figure 6 on page 44 shows the KENO Va K_{eff} for the full density water flooding scenerio as calculated using the above described model. The best-estimate K_{eff} (including the KENO Va bias) is 0.9466. Incorporating 95/95 uncertainties, the K_{eff} at the full density water flooding condition becomes 0.9543. From the information on Figure 6 on page 44, it can be shown that a water density of 0.963 gm/cm^3 will satisfy the 0.95 K_{eff} limit including the KENO Va bias and uncertainties.

4.0 REGION 1 CLOSE PACKED ANALYSIS

This section develops and describes the analytical techniques and models employed to perform the criticality analysis of the Indian Point Unit 3 Region 1 spent fuel racks, assuming close packed storage. Close packed storage is based on all cells having the same storage requirements and limits. With this type of storage, all cells can be utilized and no special cell position requirements are imposed.

Section 4.1 describes the analyses performed to show that close packed storage of Westinghouse 15x15 fuel assemblies with nominal enrichments up to 4.6 w/o U^{235} is acceptable. Section 4.2 presents the results of calculations performed to show the reactivity sensitivity caused by variations in enrichment, center-to-center spacing, and BORAL poison loading.

4.1 REACTIVITY CALCULATIONS

To show that Region 1 close packed storage of Westinghouse 15x15 fuel assemblies with nominal enrichments up to 4.6 w/o satisfies the 0.95 K_{eff} criticality acceptance criteria, KENO is used to establish a nominal reference reactivity and PHOENIX is used to assess the effects of material and construction tolerance variations. A final 95/95 K_{eff} is developed by statistically combining the individual tolerance impacts with the calculational and methodology uncertainties and summing this term with the nominal KENO reference reactivity.

The following assumptions are used to develop the nominal KENO model for close packed storage of fuel assemblies in the Indian Point Unit 3 Region 1 spent fuel rack:

1. The fuel assembly parameters relevant to the criticality analysis are based on the Westinghouse 15x15 OFA design (see Table 1 on page 29 for fuel parameters). The 15x15 OFA fuel assembly is modeled since it is equivalent to or more reactive than all other Westinghouse 15x15 fuel types when all assemblies have the same enrichment.

2. All fuel rods contain uranium dioxide at a nominal enrichment of 4.60 w/o over the entire length of each rod.

3. The fuel pellets are modeled assuming nominal values for theoretical density and dishing fraction.

4. No credit is taken for any natural enrichment axial blankets.

5. No credit is taken for any U^{234} or U^{236} in the fuel, nor is any credit taken for the build up of fission product poison material.

6. No credit is taken for any spacer grids or spacer sleeves.

7. No credit is taken for any burnable absorber in the fuel rods.

8. The moderator is pure water (no boron) at a temperature of 68°F. A limiting value of 1.0 gm/cm^3 is used for the density of water to conservatively bound the range of normal (68° to 140°F) spent fuel pool water temperatures.

9. Nominal BORAL dimensions for width, thickness, and length are assumed. Loss of material from notching during rack assembly is conservatively accounted for by reducing the nominal panel width by 1.51%.

10. The minimum BORAL poison material loading of 0.020 grams B^{10} per square centimeter is used throughout the array.

11. The array is infinite in lateral (x and y) extent and finite in axial (vertical) extent. This allows neutron leakage from only the axial direction.

12. All available storage cells are loaded with fuel assemblies.

With the above assumptions, the KENO calculation for the nominal case results in a K_{eff} of 0.9325 with a 95 percent probability/95 percent confidence level uncertainty of ±0.0047. This K_{eff} will be used as the reference reactivity for the Region 1 close packed storage configuration.

Calculational and methodology biases must be considered in the final K_{eff} summation prior to comparing against the 0.95 K_{eff} limit. The following biases are included:

> **Methodology:** As discussed in Section 2 of this report, benchmarking of the Westinghouse KENO Va methodology resulted in a method bias of 0.0074 ΔK.
>
> **B10 Self Shielding:** To correct for the modeling assumption that individual B10 atoms are homogeneously distributed within the absorber material (versus clustered about each B4C particle), a bias of 0.0014 ΔK is applied.

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, PHOENIX perturbation calculations are performed. For the Indian Point Unit 3 Region 1 close packed storage configuration, UO_2 and BORAL material tolerances are considered along with construction tolerances related to the cell I.D., water box I.D., stainless steel thickness, and BORAL absorber panel dimensions. Uncertainties associated with calculation and methodology accuracy are also considered in the statistical summation of uncertainty components.

The following tolerance and uncertainty components are considered in the total uncertainty statistical summation:

U^{235} Enrichment: The standard DOE enrichment tolerance of ±0.05 w/o U^{235} about the nominal 4.60 w/o U^{235} reference enrichment was evaluated with PHOENIX and resulted in a reactivity increase of 0.0018 ΔK.

UO_2 Density: A ±1.5% variation about the nominal 95% reference theoretical density was evaluated with PHOENIX and resulted in a reactivity increase of 0.0017 ΔK.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to 2.0% (about the nominal 1.1870% reference value) was evaluated with PHOENIX and resulted in a reactivity increase of 0.0013 ΔK.

Storage Cell I.D.: The ±0.03 inch tolerance about the nominal 8.83 inch reference cell I.D. was evaluated with PHOENIX and resulted in a reactivity increase of 0.0010 ΔK.

Water Box I.D.: The ±0.03 inch tolerance about the nominal 1.44 inch reference water box I.D. was evaluated with PHOENIX and resulted in a reactivity increase of 0.0024 ΔK.

Stainless Steel Thickness: The ±0.004 inch tolerance about the nominal 0.085 inch reference stainless steel thickness for all rack structures was evaluated with PHOENIX and resulted in a reactivity increase of 0.0014 ΔK.

BORAL Thickness/Width: The ±0.005 inch thickness and ±0.06 inch width tolerances about the nominal 0.075 thickness and 7.50 inch BORAL width dimensions were evaluated with PHOENIX and resulted in a combined reactivity increase of 0.0017 ΔK.

BORAL Panel Length: The ±0.25 inch tolerance about the nominal 133 inch BORAL panel length could not be assessed with PHOENIX due to the 3D nature of the effect. Instead, the impact was assessed using the results of Westinghouse generic evaluations on this subject(15). The generic data indicates a reactivity increase of 0.01 ΔK per inch of absorber panel removal in the range of the Indian Point Unit 3 nominal panel length. If all BORAL panels were shortened by the 0.25 inch tolerance, reactivity would increase by 0.0025 ΔK.

Assembly Position: The KENO reference reactivity calculation assumes fuel assemblies are symmetrically positioned within the storage cells since experience has shown that centered fuel assemblies yield equal or more conservative results in rack K_{eff} than non-centered (asymmetric) positioning. Therefore, no reactivity uncertainty needs to be applied for this tolerance since the most reactive configuration is considered in the calculation of the reference K_{eff}.

Calculation Uncertainty: The KENO calculation for the nominal reference reactivity resulted in a K_{eff} with a 95 percent probability/95 percent confidence level uncertainty of ±0.0047 ΔK.

Methodology Uncertainty: As discussed in Section 2 of this report, comparison against benchmark experiments showed that the 95 percent probability/95 percent confidence uncertainty in reactivity, due to method, is not greater than 0.0029 ΔK.

The maximum K_{eff} for the Indian Point Unit 3 Region 1 close packed storage configuration is developed by adding the calculational and methodology biases and the statistical sum of independent uncertainties to the nominal KENO reference reactivity. The summation is shown in Table 6 on page 35 and results in a maximum K_{eff} of 0.9488.

Since K_{eff} is less than 0.95 including uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met for close packed storage of Westinghouse 15x15 fuel assemblies with nominal enrichments up to 4.6 w/o U^{235} in the Indian Point Unit 3 Region 1 spent fuel rack.

4.2 SENSITIVITY ANALYSIS

To show the dependence of K_{eff} on fuel and storage cells parameters as requested by the NRC(11), the variation of the K_{eff} with respect to the following parameters was developed using the PHOENIX computer code:

1. Fuel enrichment, with a 0.50 w/o U^{235} delta about the nominal case enrichment.
2. Center-to-center spacing of storage cells, with a half inch delta about the nominal case center-to-center spacing.
3. Poison loading, with a 0.01 gm-B^{10}/cm^2 delta about the nominal case poison loading.

Results of the sensitivity analysis are shown in Figure 7 on page 45.

5.0 REGION 1 CHECKERBOARD ANALYSIS

This section develops and describes the analytical techniques and models employed to perform the criticality analysis and reactivity equivalencing evaluations for the Indian Point Unit 3 Region 1 spent fuel racks using a checkerboard arrangement of burned and fresh fuel assemblies. In this configuration, each fresh fuel location is separated from the nearest adjacent fresh fuel location by a burned fuel assembly (see Figure 5 on page 43 for layout).

Section 5.1 describes the reactivity calculations for the Region 1 checkerboard arrangement of burned and fresh fuel assemblies. For the KENO analysis, the "burned" fuel assemblies are represented by fresh fuel assemblies with a reduced enrichment. Section 5.2 describes the PHOENIX reactivity equivalencing analysis which establishes the minimum burnup requirements of the "burned" fuel assemblies in the checkerboard. Finally, Section 5.3 presents the results of calculations performed to show the reactivity sensitivity of variations in enrichment, center-to-center spacing, and BORAL poison loading.

5.1 REACTIVITY CALCULATIONS

To show that checkerboard storage of burned and fresh Westinghouse 15x15 fuel assemblies in Region 1 satisfies the 0.95 K_{eff} criticality acceptance criteria, KENO is used to establish a nominal reference reactivity and PHOENIX is used to assess the effects of material and construction tolerance variations. A final 95/95 K_{eff} is developed by statistically combining the individual tolerance impacts with the calculational and methodology uncertainties and summing this term with the nominal KENO reference reactivity.

The following assumptions are used to develop the nominal case KENO model for checkerboard storage fuel assemblies in the Indian Point Unit 3 Region 1 spent fuel rack:

1. The fuel assembly parameters relevant to the criticality analysis are based on the Westinghouse 15x15 OFA design (see Table 1 on page 29 for fuel parameters). The 15x15 OFA fuel assembly is modeled since it is equivalent to or more reactive than all other Westinghouse 15x15 fuel types when all assemblies have the same enrichment.
2. All fuel assemblies stored in the "burned" fuel locations contain uranium dioxide at a nominal enrichment of 4.20 w/o over the entire length of each rod.
3. All fuel assemblies stored in the "fresh" fuel locations contain uranium dioxide at a nominal enrichment of 5.00 w/o over the entire length of each rod.

4. The fuel pellets are modeled assuming nominal values for theoretical density and dishing fraction.
5. No credit is taken for any natural enrichment axial blankets.
6. No credit is taken for any U^{234} or U^{236} in the fuel, nor is any credit taken for the build up of fission product poison material.
7. No credit is taken for any spacer grids or spacer sleeves.
8. No credit is taken for any burnable absorber in the fuel rods.
9. The moderator is pure water (no boron) at a temperature of 68°F. A limiting value of 1.0 gm/cm^3 is used for the density of water to conservatively bound the range of normal (68° to 140°F) spent fuel pool water temperatures.
10. Nominal BORAL dimensions for width, thickness, and length are assumed. Loss of material from notching during rack assembly is conservatively accounted for by reducing the nominal panel width by 1.51%.
11. The minimum BORAL poison material loading of 0.020 grams B^{10} per square centimeter is used throughout the array.
12. The array is infinite in lateral (x and y) extent and finite in axial (vertical) extent. This allows neutron leakage from only the axial direction.
13. All available storage cells are loaded with fuel assemblies.
14. Fuel assemblies are arranged in a checkerboard pattern of burned and fresh locations, as depicted in Figure 5 on page 43.

With the above assumptions, the KENO calculation for the nominal case results in a K_{eff} of 0.9318 with a 95 percent probability/95 percent confidence level uncertainty of ±0.0053. This K_{eff} will be used as the reference reactivity for the Region 1 checkerboard storage configuration.

Calculational and methodology biases must be considered in the final K_{eff} summation prior to comparing against the 0.95 K_{eff} limit. The following biases are included:

> **Methodology:** As discussed in Section 2 of this report, benchmarking of the Westinghouse KENO Va methodology resulted in a method bias of 0.0074 ΔK.
>
> **B10 Self Shielding:** To correct for the modeling assumption that individual B10 atoms are homogeneously distributed within the absorber material (versus clustered about each B4C particle), a bias of 0.0014 ΔK is applied.

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, PHOENIX perturbation calculations are performed. For the Indian Point Unit 3 Region 1 checkerboard storage configuration, UO_2 and BORAL material tolerances are considered along with construction tolerances related to the cell I.D., water box I.D., stainless steel thickness, and BORAL absorber panel dimensions. Uncertainties associated with calculation and methodology accuracy are also considered in the statistical summation of uncertainty components.

The following tolerance and uncertainty components are considered in the total uncertainty statistical summation:

U^{235} Enrichment: The standard DOE enrichment tolerance of ±0.05 w/o U^{235} about the nominal burned/fresh reference enrichments of 4.20/5.00 w/o U^{235} was evaluated with PHOENIX and resulted in a reactivity increase of 0.0022 ΔK.

UO_2 Density: A ±1.5% variation about the nominal 95% reference theoretical density was evaluated with PHOENIX and resulted in a reactivity increase of 0.0019 ΔK.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to 2.0% (about the nominal 1.1870% reference value) was evaluated with PHOENIX and resulted in a reactivity increase of 0.0014 ΔK.

Storage Cell I.D.: The ±0.03 inch tolerance about the nominal 8.83 inch reference cell I.D. was evaluated with PHOENIX and resulted in a reactivity increase of 0.0010 ΔK.

Water Box I.D.: The ±0.03 inch tolerance about the nominal 1.44 inch reference water box I.D. was evaluated with PHOENIX and resulted in a reactivity increase of 0.0024 ΔK.

Stainless Steel Thickness: The ±0.004 inch tolerance about the nominal 0.085 inch reference stainless steel thickness for all rack structures was evaluated with PHOENIX and resulted in a reactivity increase of 0.0013 ΔK.

BORAL Thickness/Width: The ±0.005 inch thickness and ±0.06 inch width tolerances about the nominal 0.075 thickness and 7.50 inch BORAL width dimensions were evaluated with PHOENIX and resulted in a combined reactivity increase of 0.0017 ΔK.

BORAL Panel Length: The ±0.25 inch tolerance about the nominal 133 inch BORAL panel length could not be assessed with PHOENIX due to the 3D nature of the effect. Instead, the impact was assessed using the results of Westinghouse generic evaluations on this subject(15). The generic data indicates a reactivity increase of 0.01 ΔK per inch of absorber panel removal in the range of the Indian Point Unit 3 nominal panel length. If all BORAL panels were shortened by the 0.25 inch tolerance, reactivity would increase by 0.0025 ΔK.

Assembly Position: The KENO reference reactivity calculation assumes fuel assemblies are symmetrically positioned within the storage cells since experience has shown that centered fuel assemblies yield equal or more conservative results in rack K_{eff} than non-centered (asymmetric) positioning. Therefore, no reactivity uncertainty needs to be applied for this tolerance since the most reactive configuration is considered in the calculation of the reference K_{eff}.

Calculation Uncertainty: The KENO calculation for the nominal reference reactivity resulted in a K_{eff} with a 95 percent probability/95 percent confidence level uncertainty of ±0.0053 ΔK.

Methodology Uncertainty: As discussed in Section 2 of this report, comparison against benchmark experiments showed that the 95 percent probability/95 percent confidence uncertainty in reactivity, due to method, is not greater than 0.0029 ΔK.

The maximum K_{eff} for the Indian Point Unit 3 Region 1 checkerboard storage configuration is developed by adding the calculational and methodology biases and the statistical sum of independent uncertainties to the nominal KENO reference reactivity. The summation is shown in Table 7 on page 36 and results in a maximum K_{eff} of 0.9486.

Since K_{eff} is less than 0.95 including uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met for checkerboard storage of Westinghouse 15x15 fuel assemblies in the Indian Point Unit 3 Region 1 spent fuel rack. Storage of fuel assemblies with nominal enrichments up to 4.2 w/o U^{235} is acceptable in the "burned" fuel locations of the checkerboard. Storage of fuel assemblies with nominal enrichments up to 5.0 w/o U^{235} is acceptable in the "fresh" fuel locations of the checkerboard.

5.2 BURNUP CREDIT REACTIVITY EQUIVALENCING

Storage of burned fuel assemblies in the Indian Point Unit 3 Region 1 checkerboard configuration is achievable by means of the concept of reactivity equivalencing. The concept of reactivity equivalencing is predicated upon the reactivity decrease associated with fuel depletion or the addition of IFBA fuel rods. For burnup credit, a series of reactivity calculations are performed to generate a set of enrichment-fuel assembly discharge burnup ordered pairs which all yield an equivalent K_{eff} when stored in the spent fuel storage racks.

Figure 8 on page 46 shows the constant K_{eff} contour generated for the Indian Point Unit 3 Region 1 checkerboard configuration. This curve represents combinations of fuel enrichment and discharge burnup which yield the same rack multiplication factor (K_{eff}) as the rack loaded with a checkerboard of 4.2 w/o fuel (at zero burnup) in the "burned" cell locations and 5.0 w/o fuel in the "fresh" cell locations.

Note in Figure 8 on page 46 the endpoints at 0 MWD/MTU where the enrichment is 4.2 w/o, and at 6000 MWD/MTU where the enrichment is 5.0 w/o. The interpretation of the endpoint data is as follows: the reactivity of the Region 1 checkerboard configuration containing fresh 5.0 w/o fuel in the "fresh" fuel cells and burned 5.0 w/o fuel at 6000 MWD/MTU in the "burned" fuel cells is equivalent to the reactivity of a checkerboard of fresh 5.0 w/o fuel in the "fresh" fuel cells and fresh 4.2 w/o in the "burned" fuel cells. The burnup credit curve shown in Figure 8 on page 46 includes a reactivity uncertainty of 0.0020 ΔK, consistent with the minimum burnup requirement of 6000 MWD/MTU at 5.0 w/o.

It is important to recognize that the curve in Figure 8 on page 46 is based on calculations of constant rack reactivity. In this way, the environment of the storage rack and its influence on assembly reactivity is implicitly considered. For convenience, the data from Figure 8 on page 46 is also provided on Table 9 on page 38. Use of linear interpolation between the tabulated values is acceptable since the curve shown in Figure 8 on page 46 is linear.

5.3 SENSITIVITY ANALYSIS

To show the dependence of K_{eff} on fuel and storage cells parameters as requested by the NRC[1], the variation of the K_{eff} with respect to the following parameters was developed using the PHOENIX computer code:

1. Fuel enrichment, with a 0.50 w/o U^{235} delta about the nominal case enrichment. For this sensitivity, both the "fresh" and "burned" fuel assembly enrichments were adjusted simultaneously. Note that both "fresh" and "burned" fuel assemblies are at zero burnup.

2. Center-to-center spacing of storage cells, with a half inch delta about the nominal case center-to-center spacing.

3. Poison loading, with a 0.01 gm-B^{10}/cm2 delta about the nominal case poison loading.

Results of the sensitivity analysis are shown in Figure 9 on page 47.

6.0 REGION 2 CLOSE PACKED ANALYSIS

This section develops and describes the analytical techniques and models employed to perform the criticality analysis and reactivity equivalencing evaluations for the Indian Point Unit 3 Region 2 spent fuel racks, assuming close packed storage. Close packed storage is based on all cells having the same storage requirements and limits. With this type of storage, all cells can be utilized and no special cell position requirements are imposed.

Section 6.1 describes the analyses performed to show that close packed storage of Westinghouse 15x15 fuel assemblies with nominal enrichments up to 1.75 w/o U^{235} is acceptable. Section 6.2 describes the reactivity equivalencing analysis which establishes the minimum burnup requirements for assemblies with nominal enrichments above 1.75 w/o. Finally, Section 6.3 presents the results of calculations performed to show the reactivity sensitivity caused by variations in enrichment, center-to-center spacing, and BORAL poison loading.

6.1 REACTIVITY CALCULATIONS

To show that Region 2 close packed storage of Westinghouse 15x15 fuel assemblies with nominal enrichments up to 1.75 w/o satisfies the 0.95 K_{eff} criticality acceptance criteria, KENO is used to establish a nominal reference reactivity and PHOENIX is used to assess the effects of material and construction tolerance variations. A final 95/95 K_{eff} is developed by statistically combining the individual tolerance impacts with the calculational and methodology uncertainties and summing this term with the nominal KENO reference reactivity.

The following assumptions are used to develop the nominal case KENO model for close packed storage of fuel assemblies in the Indian Point Unit 3 Region 2 spent fuel rack:

1. The fuel assembly parameters relevant to the criticality analysis are based on the Westinghouse 15x15 OFA design (see Table 1 on page 29 for fuel parameters). The 15x15 OFA fuel assembly is modeled since it is equivalent to or more reactive than all other Westinghouse 15x15 fuel types when all assemblies have the same enrichment.

2. All fuel rods contain uranium dioxide at a nominal enrichment of 1.75 w/o over the entire length of each rod.

3. The fuel pellets are modeled assuming nominal values for theoretical density and dishing fraction.

4. No credit is taken for any natural enrichment axial blankets.

5. No credit is taken for any U^{234} or U^{236} in the fuel, nor is any credit taken for the build up of fission product poison material.

6. No credit is taken for any spacer grids or spacer sleeves.

7. No credit is taken for any burnable absorber in the fuel rods.

8. The moderator is pure water (no boron) at a temperature of 68°F. A limiting value of 1.0 gm/cm^3 is used for the density of water to conservatively bound the range of normal (68° to 140°F) spent fuel pool water temperatures.

9. Nominal BORAL dimensions for width, thickness, and length are assumed. Loss of material from notching during rack assembly is conservatively accounted for by reducing the nominal panel width by 1.70%.

10. The minimum BORAL poison material loading of 0.020 grams B^{10} per square centimeter is used throughout the array.

11. The array is infinite in lateral (x and y) extent and finite in axial (vertical) extent. This allows neutron leakage from only the axial direction.

12. All available storage cells are loaded with fuel assemblies.

With the above assumptions, the KENO calculation for the nominal case results in a K_{eff} of 0.9293 with a 95 percent probability/95 percent confidence level uncertainty of ±0.0040. This K_{eff} will be used as the reference reactivity for the Region 2 close packed storage configuration.

Calculational and methodology biases must be considered in the final K_{eff} summation prior to comparing against the 0.95 K_{eff} limit. The following biases are included:

> **Methodology:** As discussed in Section 2 of this report, benchmarking of the Westinghouse KENO Va methodology resulted in a method bias of 0.0074 ΔK.
>
> **B10 Self Shielding:** To correct for the modeling assumption that individual B10 atoms are homogeneously distributed within the absorber material (versus clustered about each B4C particle), a bias of 0.0014 ΔK is applied.

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, PHOENIX perturbation calculations are performed. For the Indian Point Unit 3 Region 2 close packed storage configuration, UO_2 and BORAL material tolerances are considered along with construction tolerances related to the cell I.D., stainless steel thickness, and BORAL absorber panel dimensions. Uncertainties associated with calculation and methodology accuracy are also considered in the statistical summation of uncertainty components.

The following tolerance and uncertainty components are considered in the total uncertainty statistical summation:

U^{235} Enrichment: The standard DOE enrichment tolerance of ±0.05 w/o U^{235} about the nominal 1.75 w/o U^{235} reference enrichment was evaluated with PHOENIX and resulted in a reactivity increase of 0.0089 ΔK.

UO_2 Density: A ±1.5% variation about the nominal 95% reference theoretical density was evaluated with PHOENIX and resulted in a reactivity increase of 0.0024 ΔK.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to 2.0% (about the nominal 1.1870% reference value) was evaluated with PHOENIX and resulted in a reactivity increase of 0.0018 ΔK.

Storage Cell I.D.: The ±0.03 inch tolerance about the nominal 8.83 inch reference cell I.D. was evaluated with PHOENIX and resulted in a reactivity increase of 0.0011 ΔK.

Stainless Steel Thickness: The ±0.004 inch tolerance about the nominal 0.085 inch reference stainless steel thickness for all rack structures was evaluated with PHOENIX and resulted in a reactivity increase of 0.00003 ΔK.

BORAL Thickness/Width: The ±0.005 inch thickness and ±0.06 inch width tolerances about the nominal 0.075 thickness and 8.00 inch BORAL width dimensions were evaluated with PHOENIX and resulted in a combined reactivity increase of 0.0033 ΔK.

BORAL Panel Length: The ±0.25 inch tolerance about the nominal 136 inch BORAL panel length could not be assessed with PHOENIX due to the 3D nature of the effect. Instead, the impact was assessed using the results of Westinghouse generic evaluations on this subject(15). The generic data indicates a reactivity increase of 0.005 ΔK per inch of absorber panel removal in the range of the Indian Point Unit 3 nominal panel length. If all BORAL panels were shortened by the 0.25 inch tolerance, reactivity would increase by 0.0013 ΔK.

Assembly Position: The KENO reference reactivity calculation assumes fuel assemblies are symmetrically positioned within the storage cells since experience has shown that centered fuel assemblies yield equal or more conservative results in rack K_{eff} than non-centered (asymmetric) positioning. Therefore, no reactivity uncertainty needs to be applied for this tolerance since the most reactive configuration is considered in the calculation of the reference K_{eff}.

Calculation Uncertainty: The KENO calculation for the nominal reference reactivity resulted in a K_{eff} with a 95 percent probability/95 percent confidence level uncertainty of ±0.0040 ΔK.

Methodology Uncertainty: As discussed in Section 2 of this report, comparison against benchmark experiments showed that the 95 percent probability/95 percent confidence uncertainty in reactivity, due to method, is not greater than 0.0029 ΔK.

The maximum K_{eff} for the Indian Point Unit 3 Region 2 close packed storage configuration is developed by adding the calculational and methodology biases and the statistical sum of independent uncertainties to the nominal KENO reference reactivity. The summation is shown in Table 8 on page 37 and results in a maximum K_{eff} of 0.9493.

Since K_{eff} is less than 0.95 including uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met for close packed storage of Westinghouse 15x15 fuel assemblies with nominal enrichments up to 1.75 w/o U^{235} in the Indian Point Unit 3 Region 2 spent fuel rack.

6.2 BURNUP CREDIT REACTIVITY EQUIVALENCING

Storage of close packed fuel assemblies with nominal enrichments greater than 1.75 w/o U^{235} in the Indian Point Unit 3 Region 2 spent fuel storage racks is achievable by means of the concept of reactivity equivalencing. The concept of reactivity equivalencing is predicated upon the reactivity decrease associated with fuel depletion or the addition of IFBA fuel rods. For burnup credit, a series of reactivity calculations are performed to generate a set of enrichment-fuel assembly discharge burnup ordered pairs which all yield an equivalent K_{eff} when stored in the spent fuel storage racks.

Figure 10 on page 48 shows the constant K_{eff} contour generated for close packed storage in the Indian Point Unit 3 Region 2 spent fuel racks. This curve represents combinations of fuel enrichment and discharge burnup which yield the same rack multiplication factor (K_{eff}) as the rack loaded with fresh fuel at 1.75 w/o U^{235}.

Note the endpoints at 0 MWD/MTU where the enrichment is 1.75 w/o and at 40,000 MWD/MTU where the enrichment is 5.0 w/o. The interpretation of this endpoint data is as follows: the reactivity of the spent fuel rack containing 5.0 w/o U^{235} fuel at 40,000 MWD/MTU burnup is equivalent to the reactivity of the rack containing fresh fuel having an initial nominal enrichment of 1.75 w/o. The burnup credit curve shown in Figure 10 on page 48 includes a reactivity uncertainty of 0.0133 ΔK, consistent with the minimum burnup requirement of 40,000 MWD/MTU at 5.0 w/o.

It is important to recognize that the curve in Figure 10 on page 48 is based on calculations of constant rack reactivity. In this way, the environment of the storage rack and its influence on assembly reactivity is implicitly considered. For convenience, the data from Figure 10 on page 48 is also provided on Table 9 on page 38. The tabulated values have been conservatively chosen to allow the use of linear interpolation between data points.

6.3 SENSITIVITY ANALYSIS

To show the dependence of K_{eff} on fuel and storage cells parameters as requested by the NRC(1), the variation of the K_{eff} with respect to the following parameters was developed using the PHOENIX computer code:

1. Fuel enrichment, with a 0.50 w/o U^{235} delta about the nominal case enrichment.
2. Center-to-center spacing of storage cells, with a quarter inch delta about the nominal case center-to-center spacing.
3. Poison loading, with a 0.01 gm-B^{10}/cm^2 delta about the nominal case poison loading.

Results of the sensitivity analysis are shown in Figure 11 on page 49.

7.0 STORAGE CONFIGURATION INTERFACE REQUIREMENTS

The Indian Point Unit 3 spent fuel pool is composed of two different types of racks, designated as Region 1 and Region 2. Each of these spent fuel pool areas has been analyzed for close packed storage, where all cells share the same storage requirements and limits. The Region 1 area has also been analyzed for checkerboard storage, where neighboring cells have different requirements and limits. A schematic of the Region 1 checkerboard pattern of "burned" and "fresh" storage cells is given in Figure 5 on page 43.

Implementation of the checkerboard configuration in Region 1 is optional. However, when implemented, the boundary between the checkerboard zone and the surrounding close packed fuel areas must be controlled to prevent an undesirable increase in reactivity.

The Region 1 burned/fresh checkerboard zone can be positioned anywhere within the Region 1 racks, but the interface boundaries shared with adjacent fuel regions must be configured as follows:

Region 1 Checkerboard Next to Region 1 Close Packed	The boundary between the Region 1 checkerboard zone and the neighboring Region 1 close packed zone can be either separated by a vacant row of cells or the interface must be configured such that there is a one row carryover of the pattern of "burned" assemblies from the checkerboard zone into the first row of the close packed zone. The carryover assures that the pattern of fuel assemblies at the interface will not be more reactive than the patterns allowed on either side of the boundary. Figure 5 on page 43 illustrates the carryover configuration.
Region 1 Checkerboard Next to Region 2 Close Packed	The boundary between the Region 1 checkerboard zone and the neighboring Region 2 close packed storage areas must be configured such that one row of vacant cells is maintained between the regions (the vacant row can be positioned in either region) or such that the Region 1 checkerboard pattern is carried to the boundary, but the last row of Region 1 leaves the "fresh" assembly checkerboard positions vacant.

There are no restrictions on the interface between Regions 1 and 2 for zones of close packed storage.

8.0 DISCUSSION OF POSTULATED ACCIDENTS

8.1 FRESH FUEL STORAGE RACKS

Under normal conditions, the fresh fuel racks are maintained in a dry environment. The introduction of water into the fresh fuel rack area is the worst case accident scenario and in the case of Indian Point 3, an incredible accident scenario. The water flooding cases analyzed in this report are bounding accident situations which result in the most conservative fuel rack K_{eff}.

Other accidents can be postulated which would cause some reactivity increase (i.e., dropping a fuel assembly between the rack and wall, or dropping an assembly on top of the rack). For these other accident conditions, the double contingency principle is applied. This states that one is not required to assume two unlikely, independent, concurrent events to ensure protection against a criticality accident. Thus, for these other accident conditions, the absence of a moderator in the fresh fuel storage racks can be assumed as a realistic initial condition since assuming its presence would be a second unlikely event.

Experience has shown that the maximum reactivity increase associated with postulated accidents (dropping a fuel assembly between the rack and wall, or dropping an assembly on top of the rack) is less than 10 percent ΔK.

Therefore, since the normal, dry fresh fuel rack reactivity is less than 0.74, and the maximum reactivity increase for the postulated accidents is less than 10 percent ΔK, the maximum rack K_{eff} under these other postulated accidents conditions will be less than 0.95.

8.2 SPENT FUEL STORAGE RACKS

Most accident conditions will not result in an increase in K_{eff} of the rack. Examples are:

Loss of cooling systems	Reactivity decreases since loss of cooling causes an increase in temperature, which causes a decrease in water density, which results in decreased reactivity.

Fuel assembly drop on top of rack	The rack structure pertinent for criticality is not excessively deformed and the dropped assembly which comes to rest horizontally on top of the rack has sufficient water separating it from the active fuel height of stored assemblies to preclude neutronic interaction.
Fuel assembly drop between rack modules	Design of spent fuel rack is such that it precludes the Insertion of fuel assembly in other than prescribed locations.

However, a few accidents can be postulated which would increase reactivity beyond the analyzed condition. One such postulated accident would be a fuel assembly misload into a position for which the restrictions on location, enrichment, or burnup are not satisfied. To very conservatively estimate the reactivity impacts of such an occurrence in Region 1, the enrichment sensitivity curve of Figure 7 on page 45 can be used. The enrichment sensitivity indicates that if ALL Region 1 storage locations were accidentally loaded with fresh, 5.0 w/o fuel assemblies, reactivity would increase by no more than 0.02 ΔK. For Region 2, evaluations indicate that the impact of misloading a single fresh, 5.0 w/o fuel assembly into a fully loaded zone of close packed fuel assemblies would cause reactivity to increase by no more than 0.04 ΔK. For both regions, the spent fuel racks remain subcritical since storage limits are based on maintaining a subcritical K_{eff} of 0.95.

Another postulated accident which could increase reactivity would be a vertical fuel assembly drop into an already loaded cell. For this accident, the upward axial leakage of that cell will be reduced, however the effect on rack reactivity will be insignificant. This is because the total axial leakage in both the upward and downward directions for the entire spent fuel array is worth only about 0.003 ΔK. Thus, minimizing the upward-only leakage of just a single cell will not cause any significant increase in rack reactivity. Furthermore, the neutronic coupling between the dropped assembly and the already loaded assembly will be very low due to the several inches of assembly nozzle structure which would separate the active fuel regions.

Finally, the reactivity impact of placing a fresh, 5.0 w/o fuel assembly adjacent to the fully loaded racks was analyzed. For Region 1, this accident is not considered credible since sufficient space does not exist between the rack and wall to allow accidental insertion. For Region 2, this accident is considered credible and calculations were performed to determine the reactivity impact. The calculations showed that the limiting Region 2 impact was caused by placing a 5.0 w/o fuel assembly in the open cask area adjacent to the spent fuel racks on two sides of the fuel assembly. For this situation, reactivity was shown to increase by less than 0.11 ΔK.

For occurrences of any of the above postulated accidents, the double contingency principle of ANSI/ANS 8.1-1983 can be applied. This states that one is not required to assume two unlikely, independent, concurrent events to ensure protection against a criticality accident. Thus, for these postulated accident conditions, the presence of soluble boron in the storage pool water can be assumed as a realistic initial condition since not assuming its presence would be a second unlikely event.

The worth of soluble boron in the Indian Point Unit 3 spent fuel pool has been calculated with PHOENIX and is shown in Figure 12 on page 50 for Regions 1 and 2. As the curves show, the presence of soluble boron in the pool water reduces rack reactivity significantly and is more than sufficient to offset the positive reactivity impacts of any of the postulated accidents. To bound the 0.02 ΔK reactivity increase from the most limiting accident in Region 1, it is conservatively estimated that 200 ppm of soluble boron is required. Similarly, to bound the 0.11 ΔK of excess reactivity from the limiting accident in Region 2, the boron worth curve indicates that 700 ppm is required.

Since the Indian Point Unit 3 spent fuel pool boron concentration is required by Tech Specs to be greater than 1000 ppm (administrative controls actually require greater than or equal to 2400 ppm) during fuel handling operations, should a postulated accident occur which causes a reactivity increase, K_{eff} will be maintained less than or equal to 0.95 due to the effect of dissolved boron.

9.0 SUMMARY OF CRITICALITY RESULTS

For the storage of fuel assemblies in the fresh fuel storage racks, the acceptance criteria for criticality requires the effective neutron multiplication factor, K_{eff}, to be less than or equal to 0.98, including uncertainties, under optimum moderation conditions, and less than or equal to 0.95 at full density water flooding conditions. Since the full density water flooding scenerio is not considered a credible event for the Indian Point Unit 3 fresh fuel racks due to the geometric layout and position of the fresh fuel racks, it is not necessary to meet the requirement of K_{eff} under full density water flooding conditions.

For the storage of fuel assemblies in the spent fuel storage racks, the acceptance criteria for criticality requires the effective neutron multiplication factor, K_{eff}, to be less than or equal to 0.95, including uncertainties, under all conditions.

This report shows that the acceptance criteria for criticality is met for the Indian Point Unit 3 Fresh and Spent Fuel Storage Racks for the storage of Westinghouse 15x15 fuel assemblies with the following configurations and enrichment limits:

Fresh Fuel Rack	Storage of assemblies with nominal enrichments up to 5.0 w/o in any location.
Region 1 Close Packed	Storage of assemblies with nominal enrichments up to 4.6 w/o in any location. There are no requirements for minimum burnup.
Region 1 Checkerboard	Storage of "burned" and "fresh" fuel assemblies in a 2x2 checkerboard pattern as shown in Figure 5 on page 43. Fuel assemblies stored in "burned" cell locations must have an initial enrichment less than 4.2 w/o (nominal) or satisfy the minimum burnup requirements of Figure 8 on page 46. Fuel assemblies stored in the "fresh" cell locations can have nominal enrichments up to 5.0 w/o, with no requirements for minimum accumulated burnup.
Region 2 Close Packed	Storage of fuel assemblies which satisfy the Region 2 minimum burnup requirements shown in Figure 10 on page 48. For these assemblies, there are no restrictions on cell placement.

The analytical methods employed herein conform with ANSI N18.2-1973, "Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants," Section 5.7, Fuel Handling System; ANSI 57.2-1983, "Design Objectives for LWR Spent Fuel Storage Facilities at Nuclear Power Stations," Section 6.4.2; ANSI 57.3-1983, "Design Requirements for New Fuel Storage Facilities at Light Water

Reactor Plants," ANSI N16.9-1975, "Validation of Calculational Methods for Nuclear Criticality Safety"; and the NRC Standard Review Plan, Section 9.1.2, "Spent Fuel Storage".

Table 1. Fuel Parameters Employed in the Criticality Analysis

Parameter	**W 15x15 STD (LOPAR)**	**W 15x15 OFA, V5, V+**
Number of Fuel Rods per Assembly	204	204
Rod Zirc-4 Clad O.D. (inch)	0.422	0.422
Clad Thickness (inch)	0.0243	0.0243
Fuel Pellet O.D.(inch)	0.3659	0.3659
Fuel Pellet Density (% of Theoretical)	95	95
Fuel Pellet Dishing Factor	1.1870	1.1870
Rod Pitch (inch)	0.563	0.563
Number of Zirc-4 Guide Tubes	20	20
Guide Tube O.D. (inch)	0.546	0.533
Guide Tube Thickness (inch)	0.017	0.017
Number of Instrument Tubes	1	1
Instrument Tube O.D. (inch)	0.546	0.533
Instrument Tube Thickness (inch)	0.017	0.017

Table 2. Benchmark Critical Experiments

Critical Number	General Description	Enrichment U235 (w/o)	Reflector	Separating Material	Soluble Boron (ppm)	Measured Keff	KENO Reactivity (Keff +/- One Sigma)
1	U02 Rod Lattice	2.46	water	water	0	1.0002	0.9966 +/- 0.0024
2	U02 Rod Lattice	2.46	water	water	1037	1.0001	0.9914 +/- 0.0019
3	U02 Rod Lattice	2.46	water	water	764	1.0000	0.9943 +/- 0.0019
4	U02 Rod Lattice	2.46	water	B4C pins	0	0.9999	0.9871 +/- 0.0022
5	U02 Rod Lattice	2.46	water	B4C pins	0	1.0000	0.9902 +/- 0.0022
6	U02 Rod Lattice	2.46	water	B4C pins	0	1.0097	0.9948 +/- 0.0021
7	U02 Rod Lattice	2.46	water	B4C pins	0	0.9998	0.9886 +/- 0.0021
8	U02 Rod Lattice	2.46	water	B4C pins	0	1.0083	0.9973 +/- 0.0021
9	U02 Rod Lattice	2.46	water	water	0	1.0030	0.9966 +/- 0.0021
10	U02 Rod Lattice	2.46	water	water	143	1.0001	0.9973 +/- 0.0021
11	U02 Rod Lattice	2.46	water	stainless steel	514	1.0000	0.9992 +/- 0.0020
12	U02 Rod Lattice	2.46	water	stainless steel	217	1.0000	1.0031 +/- 0.0021
13	U02 Rod Lattice	2.46	water	borated aluminum	15	1.0000	0.9939 +/- 0.0022
14	U02 Rod Lattice	2.46	water	borated aluminum	92	1.0001	0.9882 +/- 0.0022
15	U02 Rod Lattice	2.46	water	borated aluminum	395	0.9998	0.9854 +/- 0.0021
16	U02 Rod Lattice	2.46	water	borated aluminum	121	1.0001	0.9848 +/- 0.0022
17	U02 Rod Lattice	2.46	water	borated aluminum	487	1.0000	0.9892 +/- 0.0021
18	U02 Rod Lattice	2.46	water	borated aluminum	197	1.0002	0.9944 +/- 0.0022
19	U02 Rod Lattice	2.46	water	borated aluminum	634	1.0002	0.9956 +/- 0.0020
20	U02 Rod Lattice	2.46	water	borated aluminum	320	1.0003	0.9893 +/- 0.0022
21	U02 Rod Lattice	2.46	water	borated aluminum	72	0.9997	0.9900 +/- 0.0022
22	U02 Rod Lattice	2.35	water	borated aluminum	0	1.0000	0.9980 +/- 0.0024
23	U02 Rod Lattice	2.35	water	stainless steel	0	1.0000	0.9933 +/- 0.0022
24	U02 Rod Lattice	2.35	water	water	0	1.0000	0.9920 +/- 0.0024
25	U02 Rod Lattice	2.35	water	stainless steel	0	1.0000	0.9877 +/- 0.0022
26	U02 Rod Lattice	2.35	water	borated aluminum	0	1.0000	0.9912 +/- 0.0022
27	U02 Rod Lattice	2.35	water	B4C	0	1.0000	0.9921 +/- 0.0021
28	U02 Rod Lattice	4.31	water	stainless steel	0	1.0000	0.9968 +/- 0.0023
29	U02 Rod Lattice	4.31	water	water	0	1.0000	0.9963 +/- 0.0025
30	U02 Rod Lattice	4.31	water	stainless steel	0	1.0000	0.9950 +/- 0.0026
31	U02 Rod Lattice	4.31	water	borated aluminum	0	1.0000	0.9952 +/- 0.0025
32	U02 Rod Lattice	4.31	water	borated aluminum	0	1.0000	1.0006 +/- 0.0024
33	U-metal Cylinders	93.2	bare	air	0	1.0000	0.9968 +/- 0.0023
34	U-metal Cylinders	93.2	bare	air	0	1.0000	1.0082 +/- 0.0025
35	U-metal Cylinders	93.2	bare	air	0	1.0000	0.9935 +/- 0.0024
36	U-metal Cylinders	93.2	bare	air	0	1.0000	0.9982 +/- 0.0028
37	U-metal Cylinders	93.2	bare	air	0	1.0000	0.9916 +/- 0.0025
38	U-metal Cylinders	93.2	bare	air	0	1.0000	0.9922 +/- 0.0025
39	U-metal Cylinders	93.2	bare	plexiglass	0	1.0000	0.9972 +/- 0.0025
40	U-metal Cylinders	93.2	paraffin	plexiglass	0	1.0000	0.9973 +/- 0.0029
41	U-metal Cylinders	93.2	bare	plexiglass	0	1.0000	1.0019 +/- 0.0027
42	U-metal Cylinders	93.2	paraffin	plexiglass	0	1.0000	1.0103 +/- 0.0025
43	U-metal Cylinders	93.2	paraffin	plexiglass	0	1.0000	1.0021 +/- 0.0026
44	U-metal Cylinders	93.2	paraffin	plexiglass	0	1.0000	1.0022 +/- 0.0029

Table 3. Comparison of PHOENIX Isotopics Predictions to Yankee Core 5 Measurements

Quantity (Atom Ratio)	% Difference
U235/U	-0.67
U236/U	-0.28
U238/U	-0.03
Pu239/U	+3.27
Pu240/U	+3.63
Pu241/U	-7.01
Pu242/U	-0.20
Pu239/U238	+3.24
Mass(Pu/U)	+1.41
FISS-Pu/TOT-Pu	-0.02

Table 4. Benchmark Critical Experiments PHOENIX Comparison

Description of Experiments	Number of Experiments	PHOENIX k_{eff} Using Experiment Bucklings
UO_2		
Al clad	14	0.9947
SS clad	19	0.9944
Borated H_2O	7	0.9940
Subtotal	40	0.9944
U-Metal		
Al clad	41	1.0012
TOTAL	81	0.9978

Table 5. Data for U Metal and UO_2 Critical Experiments (Part 1 of 2)

Case Number	Cell Type	A/O U-235	H2O/U Ratio	Fuel Density (G/CC)	Pellet Diameter (CM)	Material Clad	Clad OD (CM)	Clad Thickness (CM)	Lattice Pitch (CM)	Boron PPM
1	Hexa	1.328	3.02	7.53	1.5265	Aluminum	1.6916	.07110	2.2050	0.0
2	Hexa	1.328	3.95	7.53	1.5265	Aluminum	1.6916	.07110	2.3590	0.0
3	Hexa	1.328	4.95	7.53	1.5265	Aluminum	1.6916	.07110	2.5120	0.0
4	Hexa	1.328	3.92	7.52	.9855	Aluminum	1.1506	.07110	1.5580	0.0
5	Hexa	1.328	4.89	7.52	.9855	Aluminum	1.1506	.07110	1.6520	0.0
6	Hexa	1.328	2.88	10.53	.9728	Aluminum	1.1506	.07110	1.5580	0.0
7	Hexa	1.328	3.58	10.53	.9728	Aluminum	1.1506	.07110	1.6520	0.0
8	Hexa	1.328	4.83	10.53	.9728	Aluminum	1.1506	.07110	1.8060	0.0
9	Square	2.734	2.18	10.18	.7620	SS-304	.8594	.04085	1.0287	0.0
10	Square	2.734	2.92	10.18	.7620	SS-304	.8594	.04085	1.1049	0.0
11	Square	2.734	3.86	10.18	.7620	SS-304	.8594	.04085	1.1938	0.0
12	Square	2.734	7.02	10.18	.7620	SS-304	.8594	.04085	1.4554	0.0
13	Square	2.734	8.49	10.18	.7620	SS-304	.8594	.04085	1.5621	0.0
14	Square	2.734	10.38	10.18	.7620	SS-304	.8594	.04085	1.6891	0.0
15	Square	2.734	2.50	10.18	.7620	SS-304	.8594	.04085	1.0617	0.0
16	Square	2.734	4.51	10.18	.7620	SS-304	.8594	.04085	1.2522	0.0
17	Square	3.745	2.50	10.27	.7544	SS-304	.8600	.04060	1.0617	0.0
18	Square	3.745	4.51	10.37	.7544	SS-304	.8600	.04060	1.2522	0.0
19	Square	3.745	4.51	10.37	.7544	SS-304	.8600	.04060	1.2522	0.0
20	Square	3.745	4.51	10.37	.7544	SS-304	.8600	.04060	1.2522	456.0
21	Square	3.745	4.51	10.37	.7544	SS-304	.8600	.04060	1.2522	709.0
22	Square	3.745	4.51	10.37	.7544	SS-304	.8600	.04060	1.2522	1260.0
23	Square	3.745	4.51	10.37	.7544	SS-304	.8600	.04060	1.2522	1334.0
24	Square	3.745	4.51	10.37	.7544	SS-304	.8600	.04060	1.2522	1477.0
25	Square	4.069	2.55	9.46	1.1278	SS-304	1.2090	.04060	1.5113	0.0
26	Square	4.069	2.55	9.46	1.1278	SS-304	1.2090	.04060	1.5113	3392.0
27	Square	4.069	2.14	9.46	1.1278	SS-304	1.2090	.04060	1.4500	0.0
28	Square	2.490	2.84	10.24	1.0297	Aluminum	1.2060	.08130	1.5113	0.0
29	Square	3.037	2.64	9.28	1.1268	SS-304	1.1701	.07163	1.5550	0.0
30	Square	3.037	8.16	9.28	1.1268	SS-304	1.2701	.07163	2.1980	0.0
31	Square	4.069	2.59	9.45	1.1268	SS-304	1.2701	.07163	1.5550	0.0
32	Square	4.069	3.53	9.45	1.1268	SS-304	1.2701	.07163	1.6840	0.0
33	Square	4.069	8.02	9.45	1.1268	SS-304	1.2701	.07163	2.1980	0.0
34	Square	4.069	9.90	9.45	1.1268	SS-304	1.2701	.07163	2.3810	0.0
35	Square	2.490	2.84	10.24	1.0297	Aluminum	1.2060	.08130	1.5113	1677.0
36	Hexa	2.096	2.06	10.38	1.5240	Aluminum	1.6916	.07112	2.1737	0.0
37	Hexa	2.096	3.09	10.38	1.5240	Aluminum	1.6916	.07112	2.4052	0.0
38	Hexa	2.096	4.12	10.38	1.5240	Aluminum	1.6916	.07112	2.6162	0.0
39	Hexa	2.096	6.14	10.38	1.5240	Aluminum	1.6916	.07112	2.9891	0.0
40	Hexa	2.096	8.20	10.38	1.5240	Aluminum	1.6916	.07112	3.3255	0.0
41	Hexa	1.307	1.01	18.90	1.5240	Aluminum	1.6916	.07112	2.1742	0.0
42	Hexa	1.307	1.51	18.90	1.5240	Aluminum	1.6916	.07112	2.4054	0.0

Table 5. Data for U Metal and UO_2 Critical Experiments (Part 2 of 2)

Case Number	Cell Type	A/O U-235	H2O/U Ratio	Fuel Density (G/CC)	Pellet Diameter (CM)	Material Clad	Clad OD (CM)	Clad Thickness (CM)	Lattice Pitch (CM)	Boron PPM
43	Hexa	1.307	2.02	18.90	1.5240	Aluminum	1.6916	.07112	2.6162	0.0
44	Hexa	1.307	3.01	18.90	1.5240	Aluminum	1.6916	.07112	2.9896	0.0
45	Hexa	1.307	4.02	18.90	1.5240	Aluminum	1.6916	.07112	3.3249	0.0
46	Hexa	1.160	1.01	18.90	1.5240	Aluminum	1.6916	.07112	2.1742	0.0
47	Hexa	1.160	1.51	18.90	1.5240	Aluminum	1.6916	.07112	2.4054	0.0
48	Hexa	1.160	2.02	18.90	1.5240	Aluminum	1.6916	.07112	2.6162	0.0
49	Hexa	1.160	3.01	18.90	1.5240	Aluminum	1.6916	.07112	2.9896	0.0
50	Hexa	1.160	4.02	18.90	1.5240	Aluminum	1.6916	.07112	3.3249	0.0
51	Hexa	1.040	1.01	18.90	1.5240	Aluminum	1.6916	.07112	2.1742	0.0
52	Hexa	1.040	1.51	18.90	1.5240	Aluminum	1.6916	.07112	2.4054	0.0
53	Hexa	1.040	2.02	18.90	1.5240	Aluminum	1.6916	.07112	2.6162	0.0
54	Hexa	1.040	3.01	18.90	1.5240	Aluminum	1.6916	.07112	2.9896	0.0
55	Hexa	1.040	4.02	18.90	1.5240	Aluminum	1.6916	.07112	3.3249	0.0
56	Hexa	1.307	1.00	18.90	.9830	Aluminum	1.1506	.07112	1.4412	0.0
57	Hexa	1.307	1.52	18.90	.9830	Aluminum	1.1506	.07112	1.5926	0.0
58	Hexa	1.307	2.02	18.90	.9830	Aluminum	1.1506	.07112	1.7247	0.0
59	Hexa	1.307	3.02	18.90	.9830	Aluminum	1.1506	.07112	1.9609	0.0
60	Hexa	1.307	4.02	18.90	.9830	Aluminum	1.1506	.07112	2.1742	0.0
61	Hexa	1.160	1.52	18.90	.9830	Aluminum	1.1506	.07112	1.5926	0.0
62	Hexa	1.160	2.02	18.90	.9830	Aluminum	1.1506	.07112	1.7247	0.0
63	Hexa	1.160	3.02	18.90	.9830	Aluminum	1.1506	.07112	1.9609	0.0
64	Hexa	1.160	4.02	18.90	.9830	Aluminum	1.1506	.07112	2.1742	0.0
65	Hexa	1.160	1.00	18.90	.9830	Aluminum	1.1506	.07112	1.4412	0.0
66	Hexa	1.160	1.52	18.90	.9830	Aluminum	1.1506	.07112	1.5926	0.0
67	Hexa	1.160	2.02	18.90	.9830	Aluminum	1.1506	.07112	1.7247	0.0
68	Hexa	1.160	3.02	18.90	.9830	Aluminum	1.1506	.07112	1.9609	0.0
69	Hexa	1.160	4.02	18.90	.9830	Aluminum	1.1506	.07112	2.1742	0.0
70	Hexa	1.040	1.33	18.90	19.050	Aluminum	2.0574	.07620	2.8687	0.0
71	Hexa	1.040	1.58	18.90	19.050	Aluminum	2.0574	.07620	3.0086	0.0
72	Hexa	1.040	1.83	18.90	19.050	Aluminum	2.0574	.07620	3.1425	0.0
73	Hexa	1.040	2.33	18.90	19.050	Aluminum	2.0574	.07620	3.3942	0.0
74	Hexa	1.040	2.83	18.90	19.050	Aluminum	2.0574	.07620	3.6284	0.0
75	Hexa	1.040	3.83	18.90	19.050	Aluminum	2.0574	.07620	4.0566	0.0
76	Hexa	1.310	2.02	18.88	1.5240	Aluminum	1.6916	.07112	2.6160	0.0
77	Hexa	1.310	3.01	18.88	1.5240	Aluminum	1.6916	.07112	2.9900	0.0
78	Hexa	1.159	2.02	18.88	1.5240	Aluminum	1.6916	.07112	2.6160	0.0
79	Hexa	1.159	3.01	18.88	1.5240	Aluminum	1.6916	.07112	2.9900	0.0
80	Hexa	1.312	2.03	18.88	.9830	Aluminum	1.1506	.07112	1.7250	0.0
81	Hexa	1.312	3.02	18.88	.9830	Aluminum	1.1506	.07112	1.9610	0.0

Table 6. Indian Point Unit 3 Region 1 Close Packed K_{eff} Summary

	ΔK	K_{eff}
Nominal KENO Reference Reactivity:		0.9325
Calculational & Methodology Biases:		
Methodology (Benchmark) Bias	+0.0074	
BORAL B10 Self Shielding Bias	+0.0014	

TOTAL Bias	+0.0088	
Best-Estimate Nominal Keff:		0.9413
Tolerances & Uncertainties:		
U02 Enrichment Tolerance	+0.0018	
U02 Density Tolerance	+0.0017	
Fuel Pellet Dishing Variation	+0.0013	
Storage Cell ID Tolerance	+0.0010	
Water Box ID Tolerance	+0.0024	
Stainless Steel Thickness Tolerance	+0.0014	
BORAL Thickness/Width Tolerance	+0.0017	
BORAL Panel Length Tolerance	+0.0025	
Calculational Uncertainty (95/95)	+0.0047	
Methodology Bias Uncertainty (95/95)	+0.0029	

TOTAL Uncertainty (statistical)	+0.0075	
Final Keff Including Uncertainties & Tolerances:		0.9488

Table 7. Indian Point Unit 3 Region 1 Checkerboard K_{eff} Summary

	ΔK	K_{eff}
Nominal KENO Reference Reactivity:		**0.9318**
Calculational & Methodology Biases:		
Methodology (Benchmark) Bias	+0.0074	
BORAL B10 Self Shielding Bias	+0.0014	

TOTAL Bias	+0.0088	
Best-Estimate Nominal Keff:		**0.9406**
Tolerances & Uncertainties:		
U02 Enrichment Tolerance	+0.0022	
U02 Density Tolerance	+0.0019	
Fuel Pellet Dishing Variation	+0.0014	
Storage Cell ID Tolerance	+0.0010	
Water Box ID Tolerance	+0.0024	
Stainless Steel Thickness Tolerance	+0.0013	
BORAL Thickness/Width Tolerance	+0.0017	
BORAL Panel Length Tolerance	+0.0025	
Calculational Uncertainty (95/95)	+0.0053	
Methodology Bias Uncertainty (95/95)	+0.0029	

TOTAL Uncertainty (statistical)	+0.0080	
Final Keff Including Uncertainties & Tolerances:		**0.9486**

Table 8. Indian Point Unit 3 Region 2 Close Packed K_{eff} Summary

	ΔK	K_{eff}
Nominal KENO Reference Reactivity:		0.9293
Calculational & Methodology Biases:		
Methodology (Benchmark) Bias	+0.0074	
BORAL B10 Self Shielding Bias	+0.0014	

TOTAL Bias	+0.0088	
Best-Estimate Nominal Keff:		0.9381
Tolerances & Uncertainties:		
UO2 Enrichment Tolerance	+0.0089	
UO2 Density Tolerance	+0.0024	
Fuel Pellet Dishing Variation	+0.0018	
Storage Cell ID Tolerance	+0.0011	
Stainless Steel Thickness Tolerance	+0.0000	
BORAL Thickness/Width Tolerance	+0.0033	
BORAL Panel Length Tolerance	+0.0013	
Calculational Uncertainty (95/95)	+0.0040	
Methodology Bias Uncertainty (95/95)	+0.0029	

TOTAL Uncertainty (statistical)	+0.0112	
Final Keff Including Uncertainties & Tolerances:		0.9493

Table 9. Indian Point Unit 3 Spent Fuel Rack Minimum Burnup Requirements

Region & Configuration	Enrichment (w/o)	Burnup (MWD/MTU)
Region 1 Checkerboard		
	4.20	0
	4.40	1500
	4.60	3000
	4.80	4500
	5.00	6000
Region 2		
	1.75	0
	2.00	5500
	2.50	12750
	3.00	18200
	3.50	23900
	4.00	29750
	4.50	35000
	5.00	40000

Note: The Region 2 minimum burnup requirements shown above have been conservatively reported to allow the use of linear interpolation between burnups. As such, these data points will be slightly more conservative than the Region 2 minimum burnup requirement curve shown in Figure 10 on page 48.

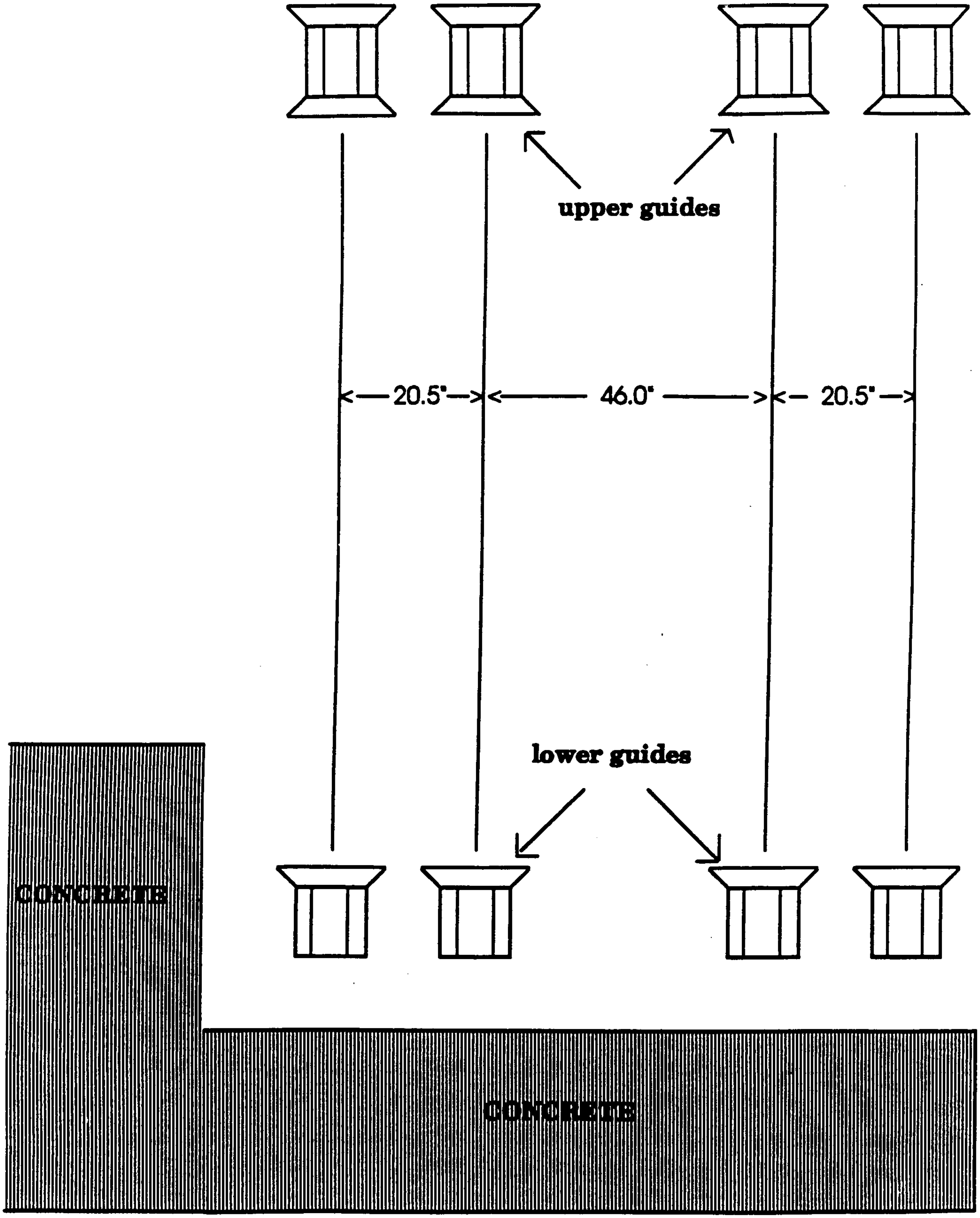


Figure 1 Indian Point Unit 3 Fresh Fuel Rack Cell Layout

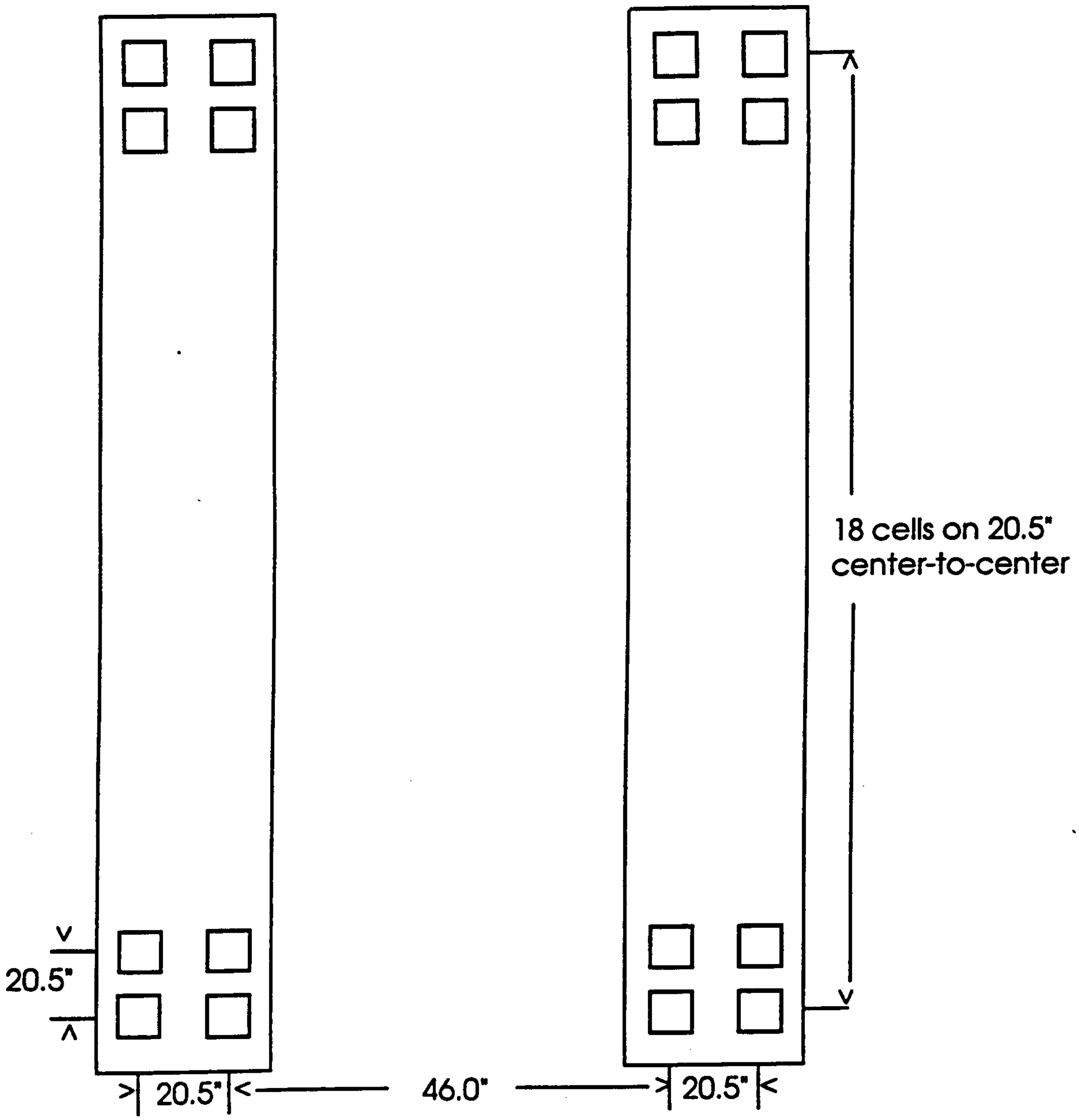


Figure 2 Indian Point Unit 3 Fresh Fuel Rack Array Layout

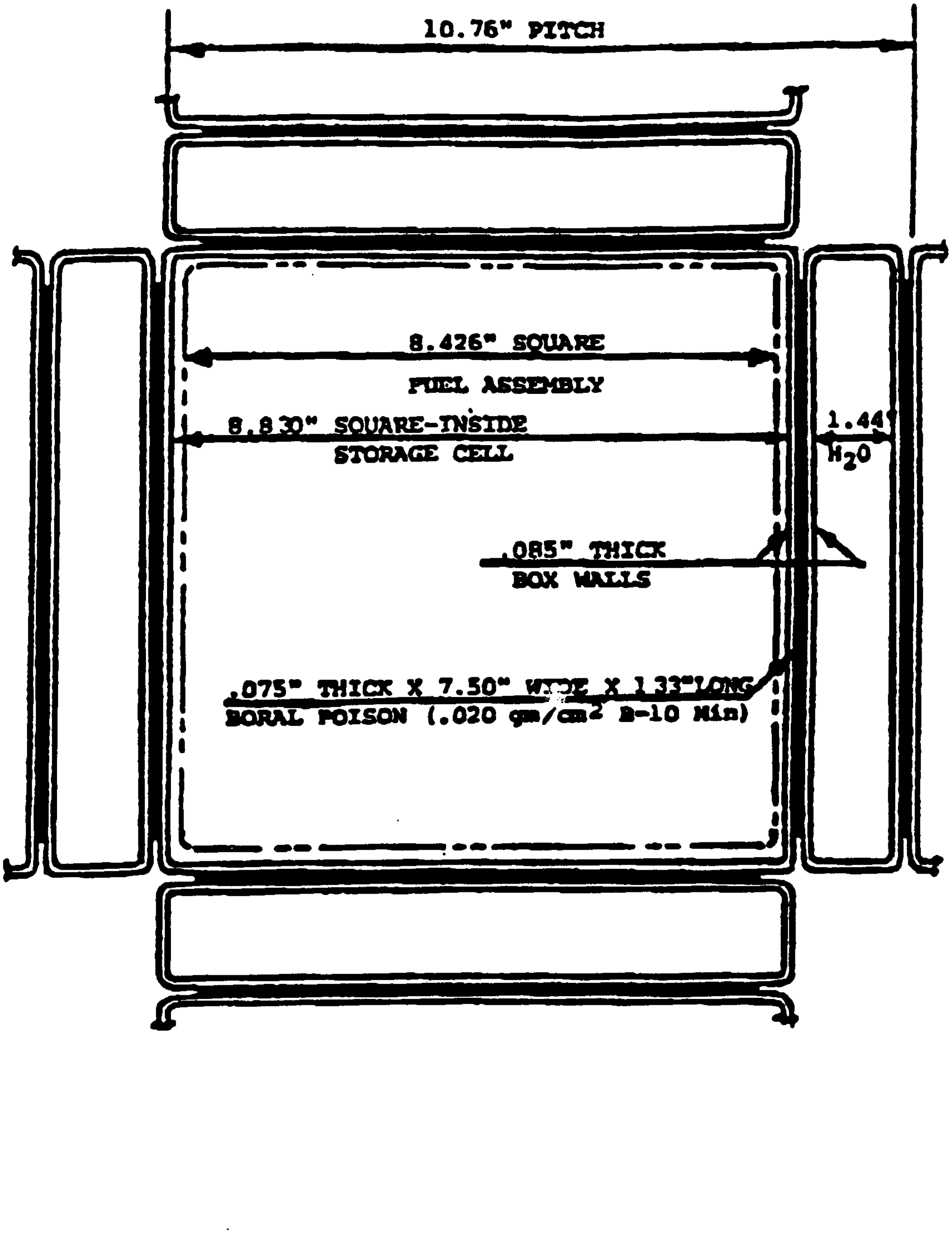


Figure 3 Indian Point Unit 3 Region 1 Spent Fuel Storage Cell Nominal Dimensions

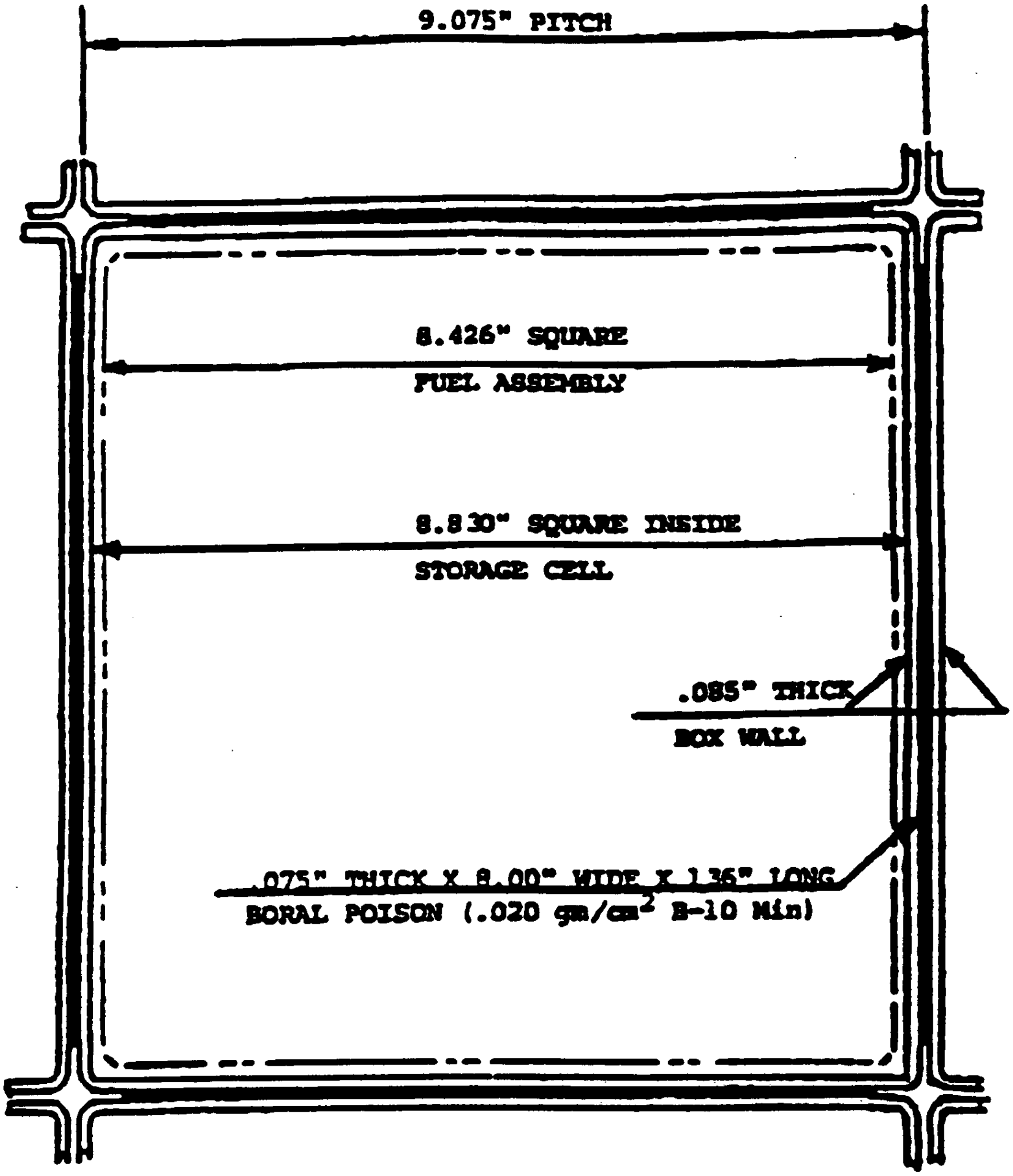
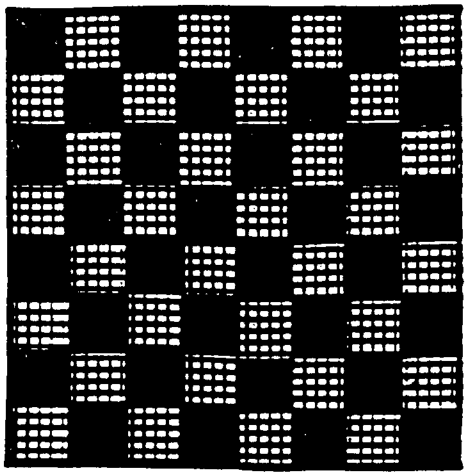
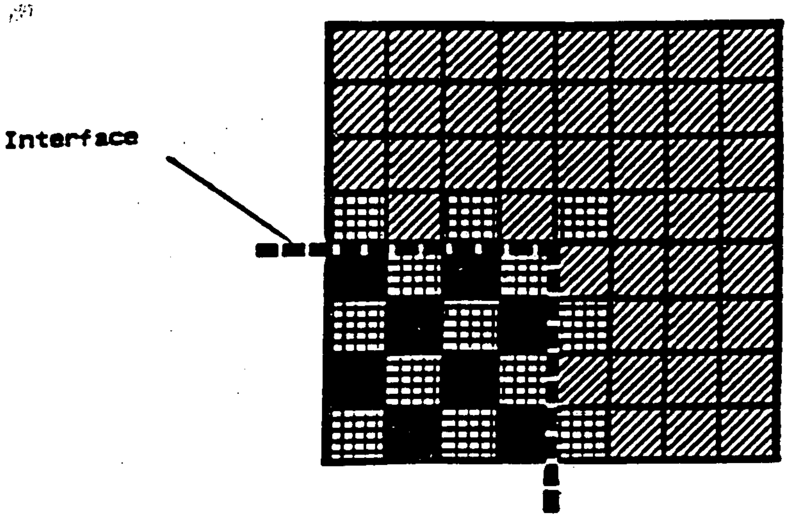


Figure 4 Indian Point Unit 3 Region 2 Spent Fuel Storage Cell Nominal Dimensions

REGION 1 CHECKERBOARD PATTERN



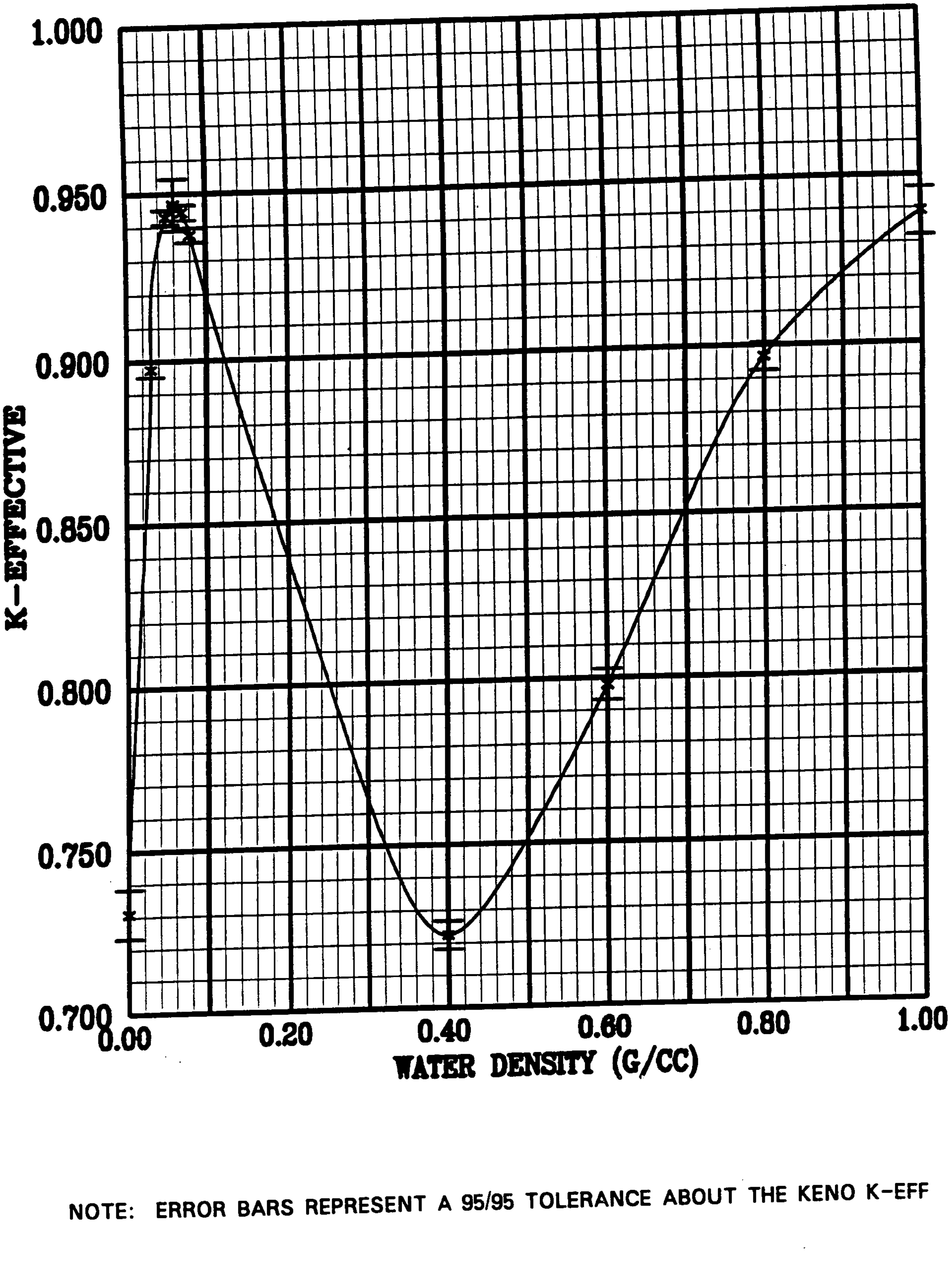
REGION 1 BOUNDARY BETWEEN CHECKERBOARD AND CLOSE PACKED ZONES



■	Checkerboard Fresh Fuel:	Must be less than or equal to 5.0 w/o.
▦	Checkerboard Burned Fuel:	Must satisfy the minimum burnup requirements of Figure 8.
▨	Close Packed Fuel:	Must be less than or equal to 4.6 w/o.

Note: The Region 1 checkerboard and close packed zones can alternatively be separated by a single row of vacant cells on each adjacent face.

Figure 5 Indian Point Unit 3 Region 1 Burned/Fresh Checkerboard Cell Layout



NOTE: ERROR BARS REPRESENT A 95/95 TOLERANCE ABOUT THE KENO K-EFF

Figure 6 Sensitivity of K_{eff} to Water Density in the Indian Point Unit 3 Fresh Fuel Racks

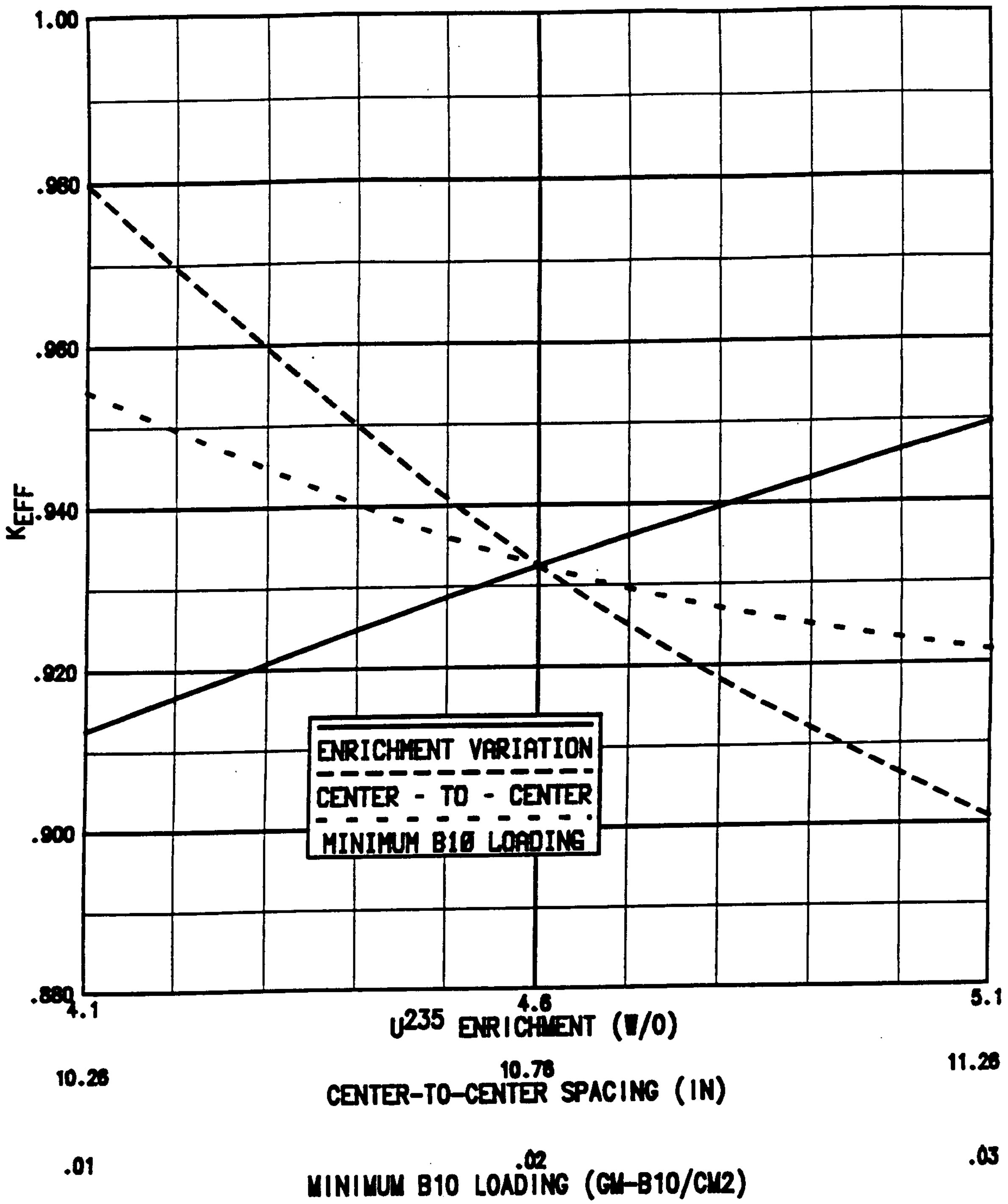


Figure 7 Indian Point Unit 3 Region 1 Close Packed Reactivity Sensitivities

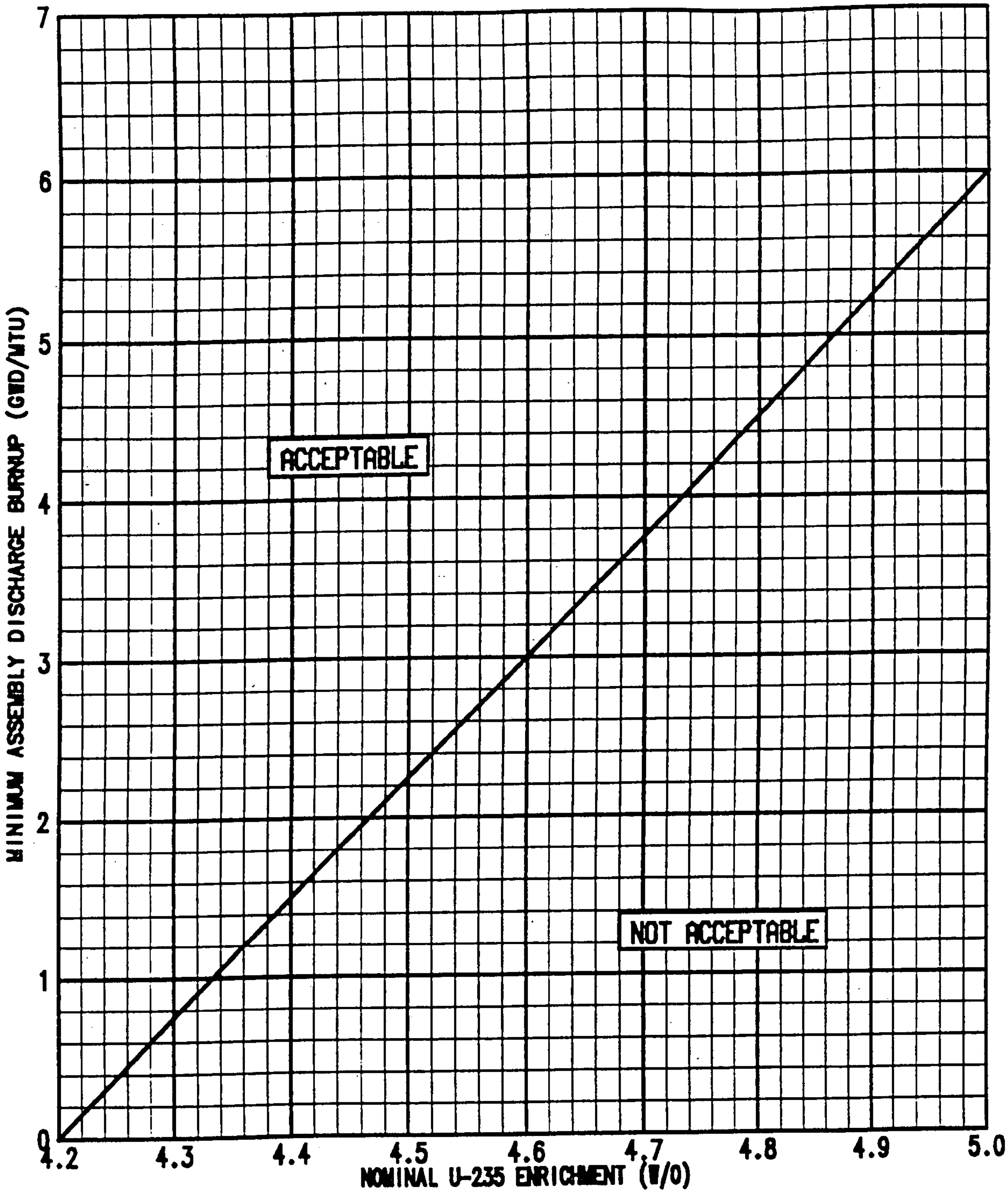


Figure 8 Indian Point Unit 3 Region 1 Checkerboard Minimum Burnup Requirements

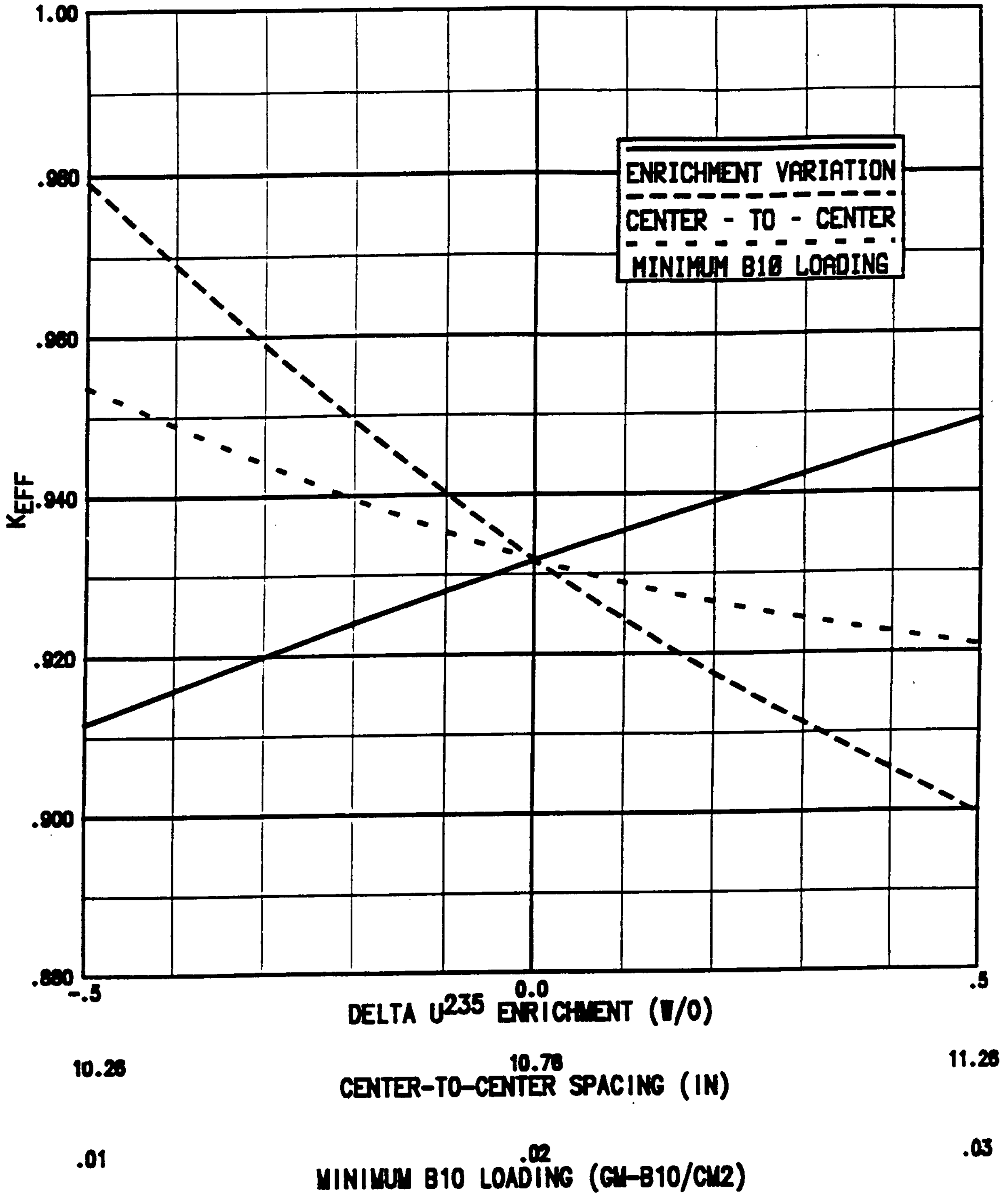


Figure 9 Indian Point Unit 3 Region 1 Checkerboard Reactivity Sensitivities

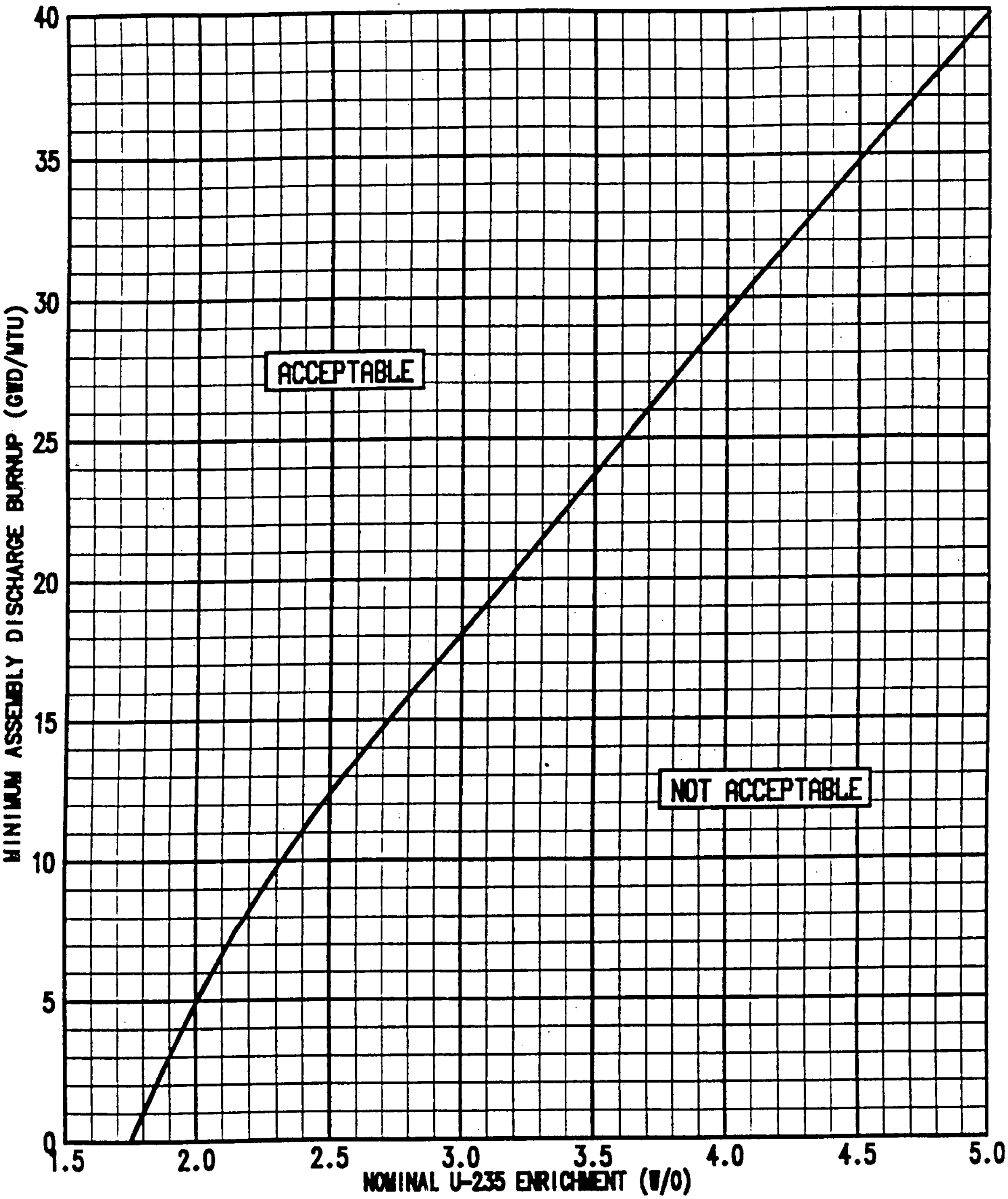


Figure 10 Indian Point Unit 3 Region 2 Close Packed Minimum Burnup Requirements

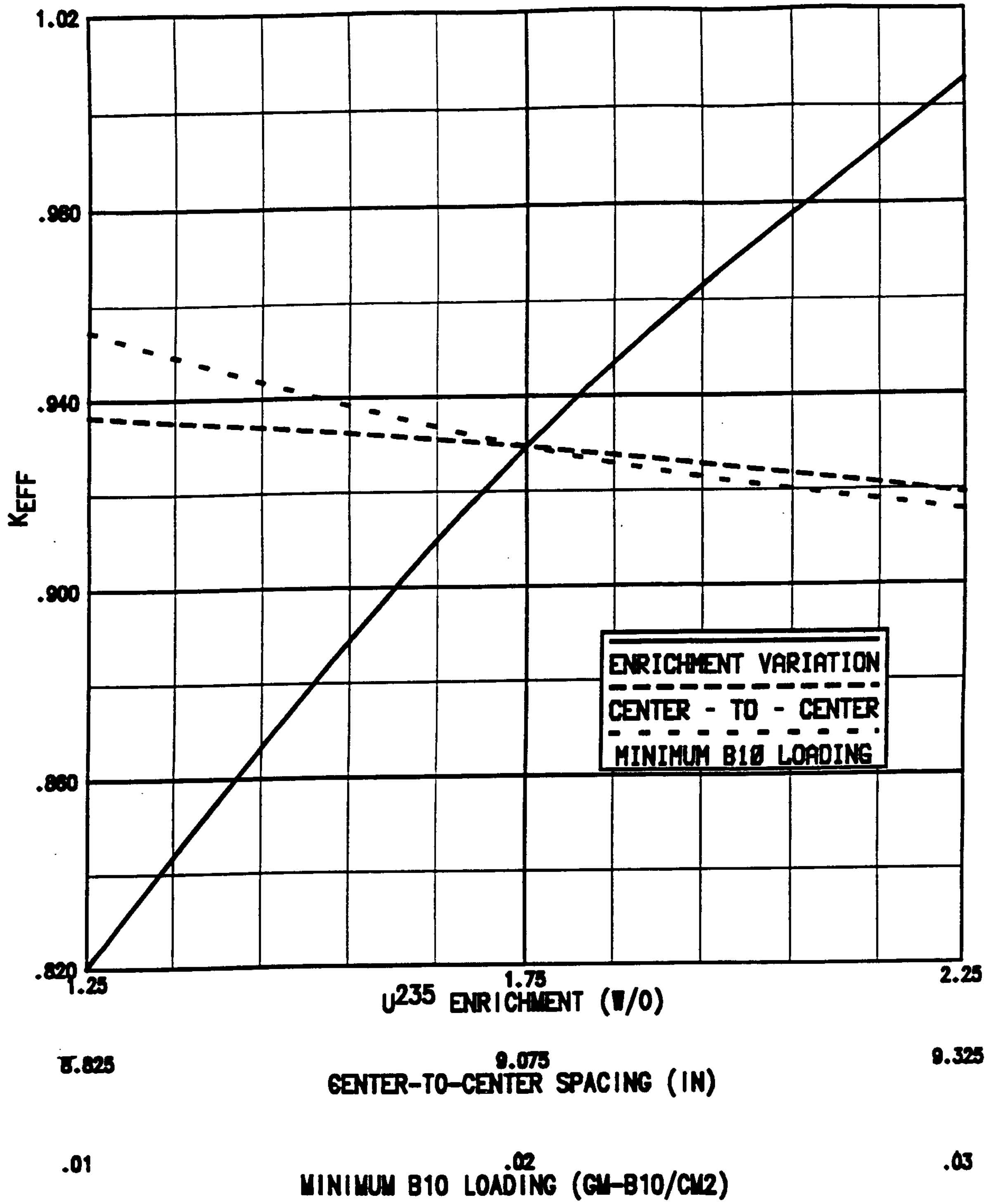


Figure 11 Indian Point Unit 3 Region 2 Close Packed Reactivity Sensitivities

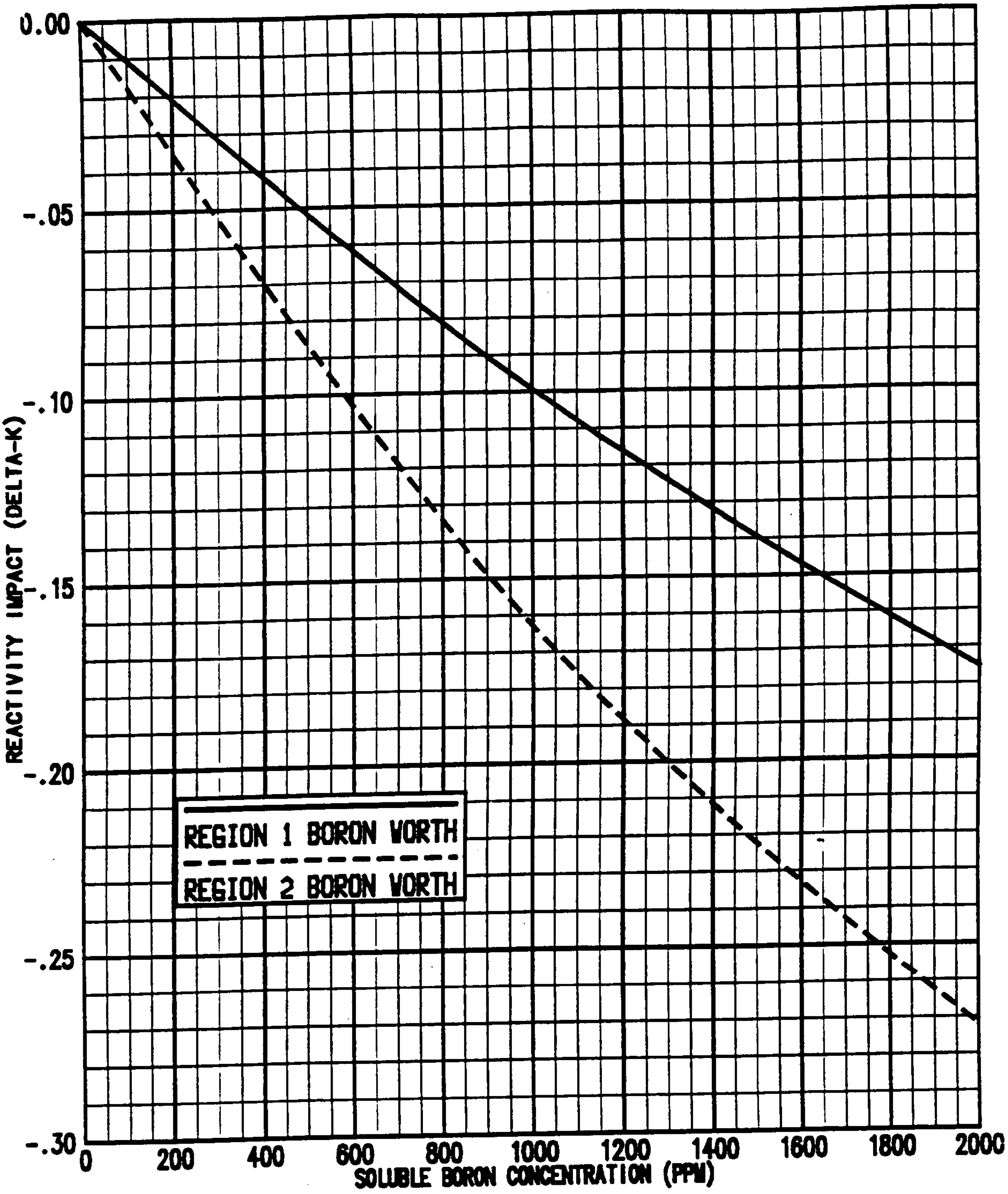


Figure 12 Indian Point Unit 3 Spent Fuel Rack Soluble Boron Worth

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