CRITICALITY ANALYSIS
OF THE PRAIRIE ISLAND UNITS 1 & 2
FRESH AND SPENT FUEL RACKS

February 1993

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1.0 INTRODUCTION

This report presents the results of a criticality re-analysis of the Prairie Island Units 1 & 2 Fresh and Spent Fuel Storage Racks. The fresh rack designs considered in this analysis are existing arrays of unpoisoned racks, previously qualified for storage of 14x14 fuel assemblies with enrichments up to 4.27 w/o U^{235}. The spent rack designs are existing arrays of poisoned racks, previously qualified for storage of 14x14 fuel assemblies with enrichments up to 4.27 w/o U^{235}.

The Prairie Island fresh and spent fuel racks are being reanalyzed to allow storage of all 14x14 fuel assemblies with enrichments up to 5.0 w/o U^{235}. Only one type of spent fuel storage rack exists at Prairie Island. Two different storage configurations are analyzed as discussed below. 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 selected locations, with no requirements for burnup or burnable absorbers.
Spent Fuel Rack Region 1 (Checkerboard)	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 2.5 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 burnable absorbers.
Spent Fuel Rack Region 2 (Close Packed)	Storage of fuel assemblies which satisfy a minimum burnup requirement as a function of enrichment.

The Prairie Island Units 1 & 2 Fresh and Spent Fuel Rack criticality analyses are based on maintaining $K_{eff} \leq 0.95$ under full water density conditions and ≤ 0.98 under low water density (optimum moderation) conditions. The Spent Fuel Rack criticality analysis is based on maintaining $K_{eff} \leq 0.95$. Fuel types being considered in the analyses include the Westinghouse 14x14 STD and OFA designs and the Exxon 14x14 fuel assembly types currently in storage in the Prairie Island spent fuel pool.

1.1 DESIGN DESCRIPTION

The Prairie Island fresh fuel rack layout is shown in Figure 1 on page 27 and Figure 2 on page 28. The Prairie Island spent fuel storage cell design is depicted in Figure 3 on page 29 and Figure 4 on page 30, with nominal dimensions provided on each figure. A schematic of the spent fuel checkerboard pattern of burned and fresh storage cell is given in Figure 6 on page 32.

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 for the fresh and spent fuel racks and also inserting neutron poison between fuel assemblies for the spent fuel racks.

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 Reference 1, or 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 Storage Rack since this rack is used to store fuel in a dry configuration.

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 21 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 shown to be acceptable 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 are performed to generate a set of enrichment-burnup ordered pairs which all yield an equivalent K_{eff} when the fuel is stored in the Prairie Island Units 1 & 2 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 22. The measurements were made on fuel discharged from Yankee Core 5[14]. The data in Table 3 on page 22 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 23. Key parameters describing each of the 81 experiments are given in Table 5 on page

24. 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. 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 Prairie Island 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 Prairie Island Units 1 & 2 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 0.95 for the accidental full water density flooding scenario and less than 0.98 for the accidental low water density (optimum moderation) flooding scenario. 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 Prairie Island Units 1 & 2 Fresh Fuel Storage Rack under full density and low density optimum moderation conditions:

1. The limiting fuel assembly type is assumed for each condition.

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. This assumption results in conservative calculations of reactivity for all fuel assemblies in use at Prairie Island, including those which contain gadolinium fuel rods.

5. No credit is taken for any natural or enriched axial blankets. This assumption results in equivalent or conservative calculations of reactivity for all fuel assemblies in use at Prairie Island including those with annular pellets at the fuel rod ends.

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. For both the full density and optimum moderation cases, there is no boron in the water.

10. Fuel rods are modelled with a fuel stack height which is infinitely long for the full density moderation scenario and 144 inches long for the optimum moderation scenario.

3.1 FULL DENSITY MODERATION ANALYSIS

In the KENO model for the full density moderation analysis, the moderator is pure water at a temperature of 68°F. A conservative value of 1.0 gm/cm^3 is used for the density of water. The fuel array is infinite in lateral (x and y) and axial (vertical) extent which precludes any neutron leakage from the array.

The fuel assembly parameters assumed in the full density analysis are based on the Westinghouse 14x14 OFA design (see Table 1 on page 20 for fuel parameters). Under fully flooded conditions and at the enrichment level considered in this evaluation, the OFA is the most reactive fuel type of the available 14x14 designs in use or storage at Prairie Island.

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. Furthermore, the fuel enrichment is assumed to be 5.05 w/o U^{235} to conservatively account for enrichment variability.

Based on the analysis described above, the following equation is used to develop the maximum K_{eff} for the Prairie Island Units 1 & 2 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:

$$K_{eff} = 0.9150 + 0.0074 + \sqrt{[(0.0083)^2 + (0.0029)^2]} = 0.9312$$

Since K_{eff} is less than 0.95 including uncertainties at a 95/95 probability confidence level, the acceptance criteria for criticality is met.

3.2 LOW DENSITY OPTIMUM MODERATION ANALYSIS

For the low density optimum moderation analysis, the fuel array is finite in all directions. The "worst case" assumptions from the full density analysis are used in modeling the entire fresh fuel rack array. Only 74 specific cells of the 88 available storage locations are utilized as depicted in Figure 2 on page 28. Fuel rods are modeled with a nominal active fuel length of 144 inches. Concrete walls and floor are modeled. Under low water density conditions, the presence of concrete is conservative because neutrons are reflected back into the fuel array more efficiently than they would be with just low density water. The area above the fresh fuel rack is filled with water at the optimum moderation density.

The fuel assembly parameters assumed in the low density analysis are based on the Westinghouse 14x14 STD design (see Table 1 on page 20 for fuel parameters). Under optimum moderation conditions, experience has shown that the 14x14 STD design is the most reactive fuel type of the available 14x14 designs. This is because the STD fuel assembly contains a higher uranium loading than the other assemblies, and when optimum moderation conditions are present, higher loadings result in higher reactivity.

Analysis of the Prairie Island Units 1 & 2 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 0.9539 with a 95 percent probability and 95 percent confidence level uncertainty of ±0.0071. Figure 5 on page 31 shows the fresh fuel rack reactivity as a function of water density in the range where the optimum moderation peak occurs. Over the remainder of the density range between 0.10 gm/cm^3 and 1.00 gm/cm^3 (fully flooded), the rack reactivity will be less than the values calculated for the optimum moderation peak and for the full density condition.

The following equation is used to develop the maximum K_{eff} for the Prairie Island Units 1 & 2 Fresh Fuel Storage Racks under low water density optimum moderation conditions:

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

where:

$K_{optimum}$ = maximum KENO K_{eff} with low density optimum moderation

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

kS_{base} = 95/95 uncertainty in the base case KENO K_{eff}

$k_{S_{method}}$ = 95/95 uncertainty in the method bias

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

$$K_{eff} = 0.9539 + 0.0074 + \sqrt{[(0.0071)^2 + (0.0029)^2]} = 0.9690$$

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

4.0 SPENT FUEL RACK CRITICALITY ANALYSIS FOR THE REGION 1 CONFIGURATION

This section develops and describes the analytical techniques and models employed to perform the criticality analysis and reactivity equivalencing evaluations for the Prairie Island Units 1 & 2 spent fuel racks Region 1 configuration using a checkerboard arrangement of burned and fresh fuel assemblies. In this configuration, each fresh location is separated from the nearest adjacent fresh fuel location by a burned fuel assembly (see Figure 6 on page 32 for layout).

Section 4.1 describes the KENO 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 low enrichment. Section 4.2 describes the PHOENIX reactivity equivalencing analysis which establishes the minimum burnup requirements of the "burned" fuel assemblies in the checkerboard. Section 4.3 presents the results of calculations performed to show the reactivity sensitivity of variations in enrichment, center-to-center spacing, and BORAFLEX poison loading. Finally, Section 4.4 discusses soluble boron worth calculations in the Region 1 configuration.

4.1 KENO REACTIVITY CALCULATIONS

The following assumptions are used to develop the nominal case KENO model for checkerboard storage of burned and fresh fuel assemblies in the Prairie Island spent fuel rack (see Figure 6 on page 32 for layout).

1. The fuel assembly parameters relevant to the criticality analysis are based on the Westinghouse 14x14 OFA design (see Table 1 on page 20 for fuel parameters). Calculations for spent fuel rack analyses herein have shown that the Westinghouse OFA fuel assemblies yield a larger K_{eff} than the Westinghouse STD fuel assemblies for the same U^{235} enrichment.

2. All burned fuel locations contain uranium dioxide at an enrichment of 2.50 w/o (nominal) and 2.55 w/o (worst case) over the entire length of each fuel rod.

3. All fresh fuel locations 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 fuel rod.

4. The fuel pellets are modeled at 96% of theoretical density without dishing or chamfering to bound the maximum fuel assembly loading. This assumption results in conservative calculations of reactivity for all fuel as-

semblies in use at Prairie Island, including those which contain gadolinium fuel rods.

5. No credit is taken for any natural or enriched axial blankets. This assumption results in equivalent or conservative calculations of reactivity for all fuel assemblies in use at Prairie Island including those with annular pellets at the fuel rod ends.

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 spent fuel pool water temperatures.

10. The minimum Boraflex poison material loading of 0.040 grams B^{10} per square centimeter is used throughout the array. A four inch mid-plane gap in the Boraflex absorber panels is assumed in the both the nominal and worst case calculations to conservatively account for material degradation effects.

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. A reflector of clean, full density, water is also placed at the top and bottom of the array to conservatively provide neutron reflection.

12. All available storage cells are loaded with fuel assemblies. Fuel assemblies are arranged in a checkerboard pattern of burned and fresh fuel locations, as depicted in Figure 6 on page 32.

The KENO calculation for the nominal case resulted in a K_{eff} of 0.9042 with a 95 percent probability/95 percent confidence level uncertainty of ±0.0054. The nominal case result can be compared to the worst case result to determine the relative impact of applying worst case assumptions. The nominal case is also used as the center point for the sensitivity analyses.

The maximum K_{eff} under normal conditions arises from consideration of mechanical and material tolerances resulting from the manufacturing process. For the Prairie Island spent fuel racks Region 1 configuration, the sheet metal and Boraflex absorber tolerances are considered along with construction tolerances related to the cell I.D. and cell spacing. This resulted in a reduction of the center to center spacing and Boraflex material dimensions to their minimum values. The water gap between cells is also reduced from a nominal dimension of 0.752" to a "worst case" dimension of 0.562". The 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} relative to asymmetric (non-centered) positioning. Furthermore, fuel enrichments are increased by 0.05 w/o U^{235} to conservatively account for enrichment vari-

ability. Enrichments are assumed to be 2.55 w/o U^{235} for the assemblies stored in the burned cell positions and 5.05 w/o U^{235} for assemblies stored in the fresh cell positions. Thus, the most conservative or "worst case" KENO model of the Prairie Island spent fuel storage rack Region 1 configurations assumes minimum center to center spacings, minimum Boraflex material dimensions, minimum water gap thickness, and symmetrically placed fuel assemblies at their maximum authorized enrichments.

Based on the assumptions described above, the following equation is used to develop the maximum K_{eff} for the Prairie Island Units 1 & 2 spent fuel storage rack Region 1 configuration:

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

where:

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

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

B_{part} = method bias to account for Boraflex poison particle self-shielding

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

$k_{Smethod}$ = 95/95 uncertainty in the method bias

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

$$K_{eff} = 0.9307 + 0.0074 + 0.0010 + \sqrt{[(0.0049)^2 + (0.0029)^2\ ]} = 0.9448$$

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 the checkerboard arrangement, Region 1, of burned fuels cells at a nominal enrichment of 2.5 w/o and fresh fuel cells at a nominal enrichment of 5.0 w/o U^{235}.

4.2 BURNUP CREDIT REACTIVITY EQUIVALENCING

Storage of burned fuel assemblies with in the Prairie Island Region 1 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. 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 7 on page 33 shows the constant K_{eff} contour generated for the Prairie Island Region 1 configuration. Note the endpoints at 0 MWD/MTU where the enrichment is 2.5 w/o, and at 28,670 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 28,670 MWD/MTU burnup is equivalent to the reactivity of the rack containing fresh fuel having an initial nominal enrichment of 2.5 w/o. The burnup credit curve shown in Figure 7 on page 33 includes a reactivity uncertainty of 0.0096 ΔK, consistent with the minimum burnup requirement of 28,670 MWD/MTU at 5.0 w/o.

It is important to recognize that the curve in Figure 7 on page 33 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 7 on page 33 is also provided in Table 6 on page 26. The tabulated values have been conservatively reported to allow the use of linear interpolation between the provided data points (the tabulated data may not match the figure).

4.3 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}/cm^2 delta about the nominal case poison loading.

Results of the sensitivity analysis are shown in Figure 8 on page 34.

4.4 SOLUBLE BORON WORTH

PHOENIX calculations were performed to evaluate the reactivity benefits of soluble boron for the Region 1 rack configuration. Results of these calculations are provided in Figure 9 on page 35. As the curves show, the presence of soluble boron in the Prairie Island spent fuel pool provides substantial reactivity margin.

5.0 SPENT FUEL RACK CRITICALITY ANALYSIS FOR THE REGION 2 CONFIGURATION

This section develops and describes the analytical techniques and models employed to extend the previous reactivity equivalencing evaluations[15] performed for the Prairie Island Units 1 & 2 spent fuel racks Region 2 configuration 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.

Previous criticality analyses[15] performed for Prairie Island developed burnup credit curves for the spent fuel racks with 0, 2", and 4" mid-plane Boraflex gaps. These curves represent lines of equivalent reactivity for each condition. The burnup credit curves were limited to enrichments below 4.27 w/o. In Section 5.1, the burnup credit curve for the 4" mid-plane Boraflex gap is extended using a reference equivalence reactivity from the previous analysis.

5.1 BURNUP CREDIT REACTIVITY EQUIVALENCING

Storage of fuel assemblies in the Region 2 configuration of the spent fuel racks was previously analyzed for Prairie Island with four inch mid-plane Boraflex gaps[15]. A burnup credit curve was reported for U^{235} enrichments from 3.87 w/o to 4.27 w/o. The minimum discharge burnup required for a 3.87 w/o assembly was previously found to be 2000 MWD/MTU. The reactivity of such an assembly will be used as the basis for assemblies with enrichments between 4.27 w/o and 5.00 w/o U^{235}. To calculate the burnup credit, a series of reactivity calculations are performed to generate a set of enrichment-fuel assembly discharge burnup ordered pairs which all yield a K_{eff} equivalent to the 3.87 w/o U^{235} assembly with 2000 MWD/MTU burnup.

Figure 10 on page 36 shows the constant K_{eff} contour generated for close packed storage in the Prairie Island Region 2 spent fuel racks. Note the endpoints at 2000 MWD/MTU where the enrichment is 3.87 w/o, and at 10,640 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 10,640 MWD/MTU burnup is equivalent to the reactivity of the rack containing fuel having an enrichment of 3.87 w/o at 2000 MWD/MTU burnup. The burnup credit curve shown in Figure 10 on page 36 includes a reactivity uncertainty of 0.0036 ΔK, consistent with the minimum burnup requirement of 10,640 MWD/MTU at 5.0 w/o.

It is important to recognize that the curve in Figure 10 on page 36 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 36 is also provided on Table 6 on page 26. The tabulated values have been conservatively reported to allow the use of linear interpolation between the provided data points (the tabulated data may not match the figure).

6.0 STORAGE CONFIGURATION INTERFACE REQUIREMENTS

The Prairie Island Units 1 & 2 spent fuel racks are split into two different configurations designated as Region 1 and Region 2. The Region 1 configuration is for checkerboard storage, where neighboring cells have different requirements and limits. The Region 2 configuration is for close packed storage, where all cells share the same storage requirements and limits. A schematic of the Region 1 checkerboard pattern of burned and fresh storage cells is given in Figure 6 on page 32.

For the Region 1 configuration, the burned/fresh checkerboard zone can be positioned anywhere within the spent fuel racks, but the interface boundaries shared with the Region 2 areas must be aligned as follows:

Region 1 checkerboard configuration next to the Region 2 close packed configuration	The boundary between the Region 1 checkerboard zone and the neighboring Region 2 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. Figure 6 on page 32 illustrates the interface configuration.

By employing the above boundary configuration controls, the pattern of fuel assemblies at the interface will not be more reactive than the patterns allowed on either side of the boundary.

7.0 DISCUSSION OF POSTULATED ACCIDENTS

7.1 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. The full density and low density optimum moderation cases analyzed in this report are the 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 on top of the rack). 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. Since the normal, dry fresh fuel rack reactivity is less than 0.62 (see Figure 5 on page 31), there is sufficient reactivity margin to the 0.95 limit to cover the above postulated accidents.

7.2 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 dropped horizontally 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 dropped between rack modules	Design of spent fuel rack is such that it precludes the insertion of fuel assembly in other than prescribed locations.

Fuel assembly dropped between rack modules and wall	Design of spent fuel rack is such that it precludes the insertion of fuel assembly in other than prescribed locations.

However, accidents can be postulated which would increase reactivity. For these accident conditions, the double contingency principle of ANSI N16.1-1975 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.

A postulated accident that would increase reactivity beyond the analyzed condition in the Region 1 configuration is the misloading of a fuel assembly into a position for which the restrictions on location, enrichment, or burnup are not satisfied. To estimate the reactivity impacts of such an occurrence in the Region 1 configuration, a calculation was run to determine the impact of misloading a number of fresh, 5.0 w/o fuel assemblies into burned cell locations such that 3 out of 4 locations would contain fresh, 5.0 w/o fuel assemblies. The calculations show that reactivity would increase by only 0.04 ΔK. This result is conservative since, for simplification reasons, the calculational models actually simulate the misloading of a single, fresh, 5.0 w/o fuel assembly into every 4 cell combination.

The worth of soluble boron in the Prairie Island spent fuel pool Region 1 configuration is shown in Figure 9 on page 35. As the curve shows, the presence of soluble boron in the pool water reduces rack reactivity significantly and is more than sufficient to offset the positive reactivity impact of a misload accident. To bound the 0.04 ΔK reactivity increase in Region 1, it is conservatively estimated that 300 ppm will be required.

Therefore, 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.

8.0 SUMMARY OF CRITICALITY RESULTS

The acceptance criteria for criticality requires the effective neutron multiplication factor, K_{eff}, in the fresh fuel storage rack to be less than or equal to 0.95, including uncertainties, under flooded conditions and less than or equal to 0.98, including uncertainties, under optimum moderation conditions. For the spent fuel racks, K_{eff} must be maintained less than 0.95, including uncertainties, for all conditions.

This report shows that the acceptance criteria for criticality is met for the Prairie Island Units 1 & 2 fresh and spent fuel Region 1 and 2 storage racks for the storage of Westinghouse 14x14 fuel assemblies and the Exxon 14x14 fuel assembly types currently in storage in the Prairie Island spent fuel pool with the following configurations and enrichment limits:

Fresh Fuel Rack	Storage of assemblies with nominal enrichments up to 5.0 w/o in selected locations as shown in Figure 2 on page 28.
Region 1 Checkerboard Configuration	Storage of "burned" and "fresh" fuel assemblies in a 2x2 checkerboard pattern as shown in Figure 6 on page 32. Fuel assemblies stored in "burned' cell locations must have an initial enrichment less than 2.5 w/o (nominal) or satisfy the minimum burnup requirements of Figure 7 on page 33. Fuel assemblies stored in the "fresh" cell locations can have nominal enrichments up to 5.0 w/o, with no requirements for a minimum accumulated burnup.
Region 2 Close Packed Configuration	Storage of fuel assemblies which satisfy the Region 2 minimum burnup requirements shown in Figure 10 on page 36. For these assemblies, there are no special placement restrictions.

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 N16.9-1975, "Validation of Calculational Methods for Nuclear Criticality Safety"; NRC Standard Review Plan, Section 9.1.2, "Spent Fuel Storage"; and ANSI 57.3-1983, "Design Requirements for New Fuel Storage Facilities at Light Water Reactor Plants."

Table 1. Fuel Parameters Employed in the Criticality Analysis

Parameter	W 14x14 STD	W 14x14 OFA
Number of Fuel Rods per Assembly	179	179
Rod Zirc-4 Clad O.D. (inch)	0.422	0.400
Clad Thickness (inch)	0.0243	0.0243
Fuel Pellet O.D.(inch)	0.3659	0.3444
Fuel Pellet Density (% of Theoretical)	96	96
Fuel Pellet Dishing Factor	0.0	0.0
Rod Pitch (inch)	0.556	0.556
Number of Zirc-4 Guide Tubes	16	16
Guide Tube O.D. (inch)	0.539	0.526
Guide Tube Thickness (inch)	0.017	0.017
Number of Instrument Tubes	1	1
Instrument Tube O.D. (inch)	0.422	0.399
Instrument Tube Thickness (inch)	0.0240	0.0235

Table 2. Benchmark Critical Experiments [5,6]

Critical Number	General Description	Enrichment U235 (w/o)	Reflector	Separating Material	Soluble Boron (ppm)	Measured Keff	KENO Reactivity (Keff +/- One Sigma)
1	UO2 Rod Lattice	2.46	water	water	0	1.0002	0.9966 +/- 0.0024
2	UO2 Rod Lattice	2.46	water	water	1037	1.0001	0.9914 +/- 0.0019
3	UO2 Rod Lattice	2.46	water	water	764	1.0000	0.9943 +/- 0.0019
4	UO2 Rod Lattice	2.46	water	B4C pins	0	0.9999	0.9871 +/- 0.0022
5	UO2 Rod Lattice	2.46	water	B4C pins	0	1.0000	0.9902 +/- 0.0022
6	UO2 Rod Lattice	2.46	water	B4C pins	0	1.0097	0.9948 +/- 0.0021
7	UO2 Rod Lattice	2.46	water	B4C pins	0	0.9998	0.9886 +/- 0.0021
8	UO2 Rod Lattice	2.46	water	B4C pins	0	1.0083	0.9973 +/- 0.0021
9	UO2 Rod Lattice	2.46	water	water	0	1.0030	0.9966 +/- 0.0021
10	UO2 Rod Lattice	2.46	water	water	143	1.0001	0.9973 +/- 0.0021
11	UO2 Rod Lattice	2.46	water	stainless steel	514	1.0000	0.9992 +/- 0.0020
12	UO2 Rod Lattice	2.46	water	stainless steel	217	1.0000	1.0031 +/- 0.0021
13	UO2 Rod Lattice	2.46	water	borated aluminum	15	1.0000	0.9939 +/- 0.0022
14	UO2 Rod Lattice	2.46	water	borated aluminum	92	1.0001	0.9882 +/- 0.0022
15	UO2 Rod Lattice	2.46	water	borated aluminum	395	0.9998	0.9854 +/- 0.0021
16	UO2 Rod Lattice	2.46	water	borated aluminum	121	1.0001	0.9848 +/- 0.0022
17	UO2 Rod Lattice	2.46	water	borated aluminum	487	1.0000	0.9892 +/- 0.0021
18	UO2 Rod Lattice	2.46	water	borated aluminum	197	1.0002	0.9944 +/- 0.0022
19	UO2 Rod Lattice	2.46	water	borated aluminum	634	1.0002	0.9956 +/- 0.0020
20	UO2 Rod Lattice	2.46	water	borated aluminum	320	1.0003	0.9893 +/- 0.0022
21	UO2 Rod Lattice	2.46	water	borated aluminum	72	0.9997	0.9900 +/- 0.0022
22	UO2 Rod Lattice	2.35	water	borated aluminum	0	1.0000	0.9980 +/- 0.0024
23	UO2 Rod Lattice	2.35	water	stainless steel	0	1.0000	0.9933 +/- 0.0022
24	UO2 Rod Lattice	2.35	water	water	0	1.0000	0.9920 +/- 0.0024
25	UO2 Rod Lattice	2.35	water	stainless steel	0	1.0000	0.9877 +/- 0.0022
26	UO2 Rod Lattice	2.35	water	borated aluminum	0	1.0000	0.9912 +/- 0.0022
27	UO2 Rod Lattice	2.35	water	B4C	0	1.0000	0.9921 +/- 0.0021
28	UO2 Rod Lattice	4.31	water	stainless steel	0	1.0000	0.9968 +/- 0.0023
29	UO2 Rod Lattice	4.31	water	water	0	1.0000	0.9963 +/- 0.0025
30	UO2 Rod Lattice	4.31	water	stainless steel	0	1.0000	0.9950 +/- 0.0026
31	UO2 Rod Lattice	4.31	water	borated aluminum	0	1.0000	0.9952 +/- 0.0025
32	UO2 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	1.6580	0.0
5	Hexa	1.328	4.89	7.52	.9855	Aluminum	1.1506	.07110	1.8520	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	2.093	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. Prairie Island Spent Fuel Storage Minimum Burnup Requirements

Region	Enrichment (w/o)	Burnup (MWD/MTU)
Region 1		
	2.5	0
	3.0	7400
	4.0	18800
	5.0	28800
Region 2		
	3.87	2000
	4.07	3800
	4.27	5200
	4.40	6400
	4.60	7900
	4.80	9300
	5.00	10800

Note: The minimum burnup requirements in this table have been conservatively reported to allow the use of linear interpolation between burnups.

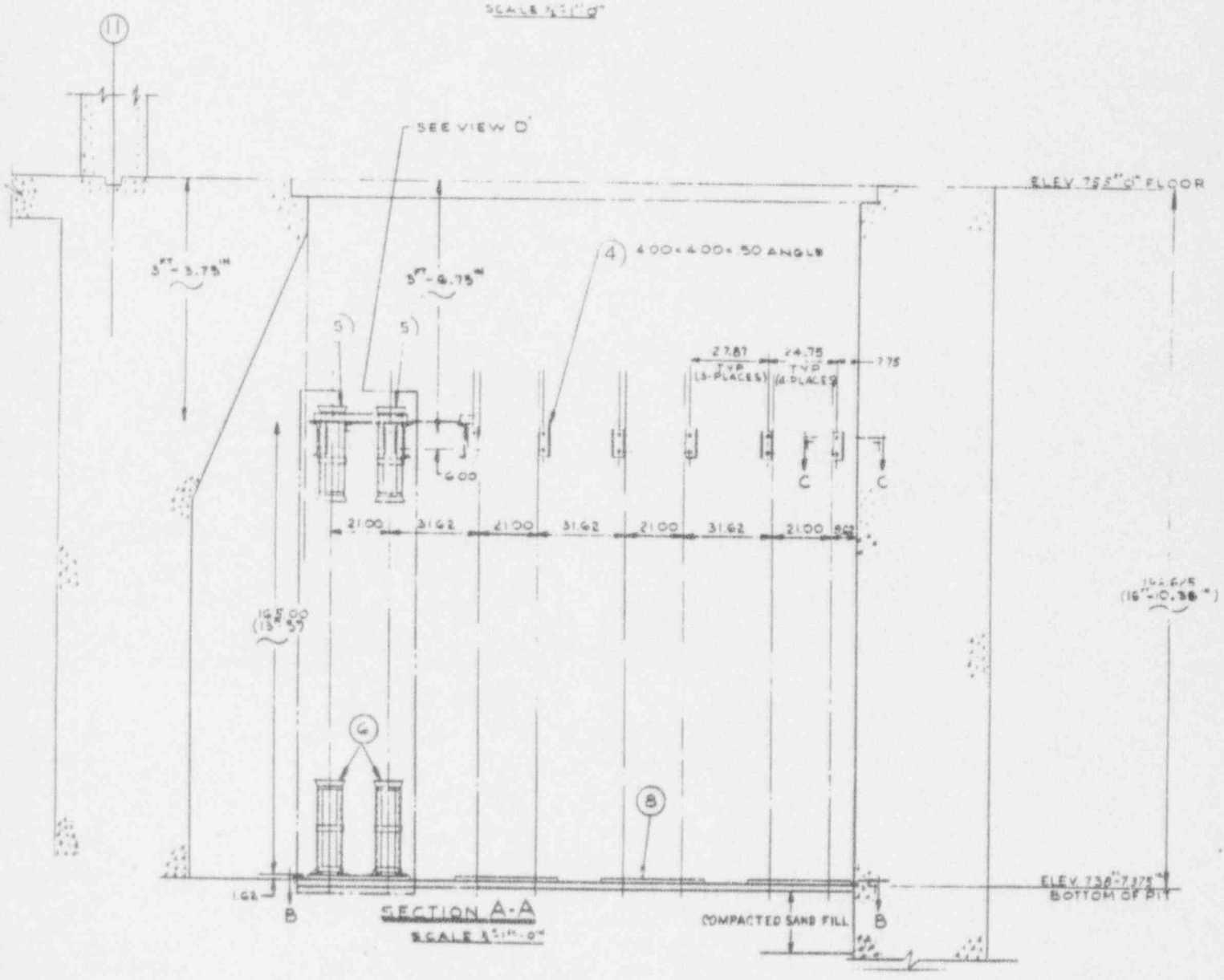


Figure 1 Prairie Island Fresh Fuel Storage Rack Axial Layout

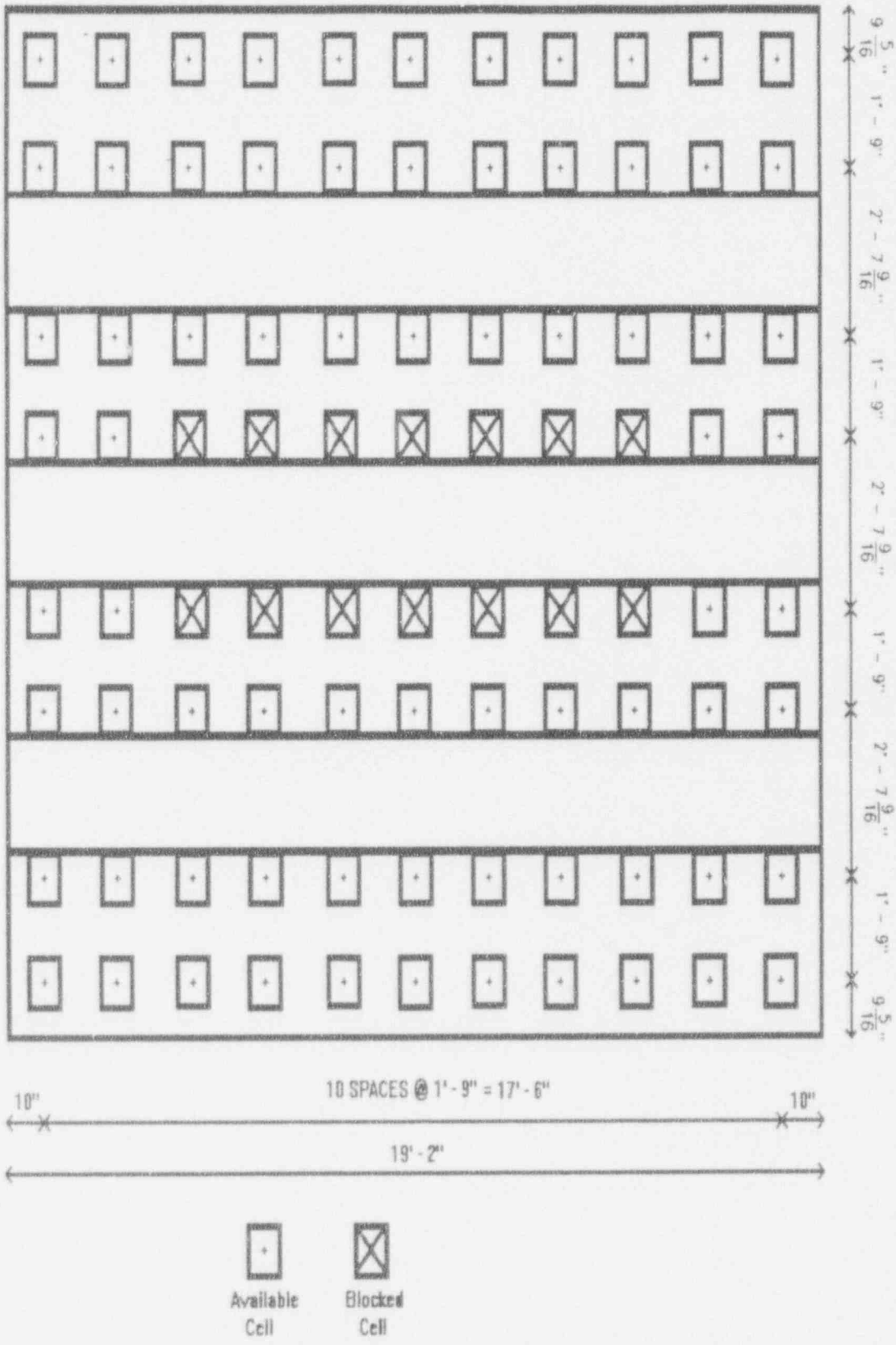


Figure 2 Prairie Island Fresh Fuel Rack Radial Layout

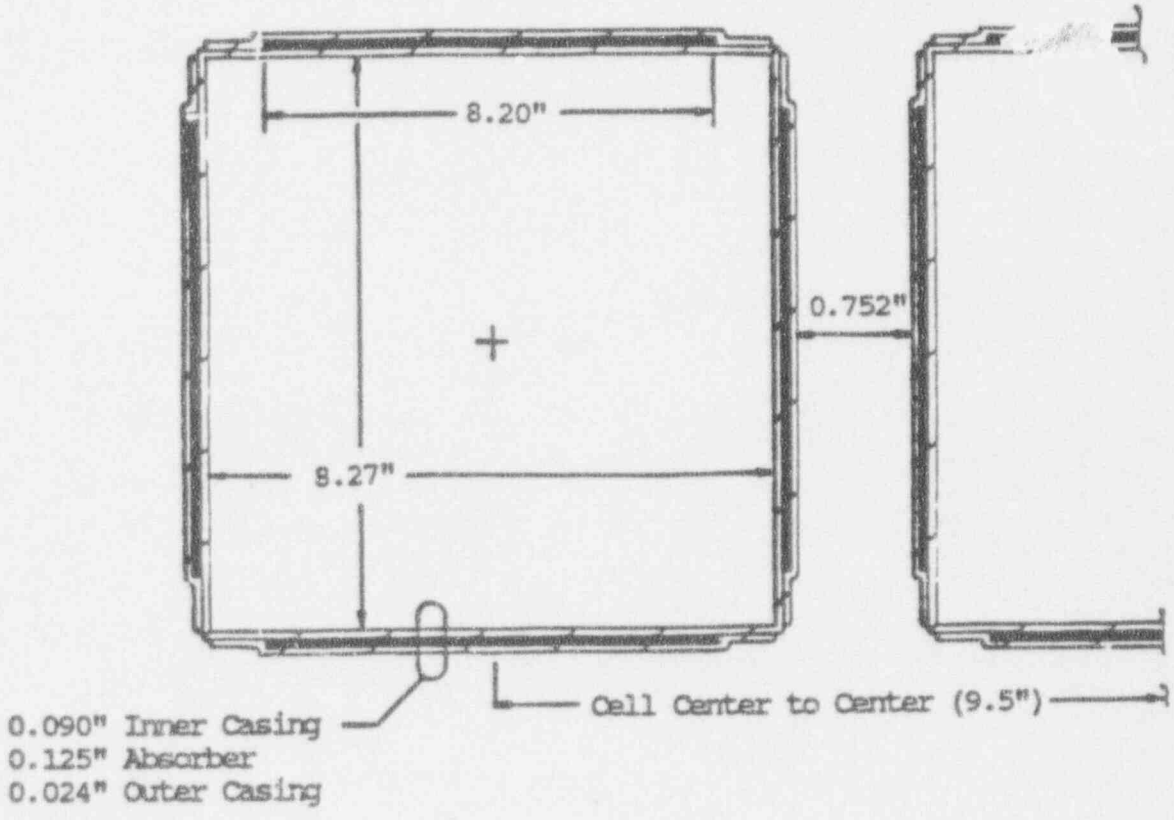


Figure 3 Prairie Island Spent Fuel Storage Cell Nominal Dimensions

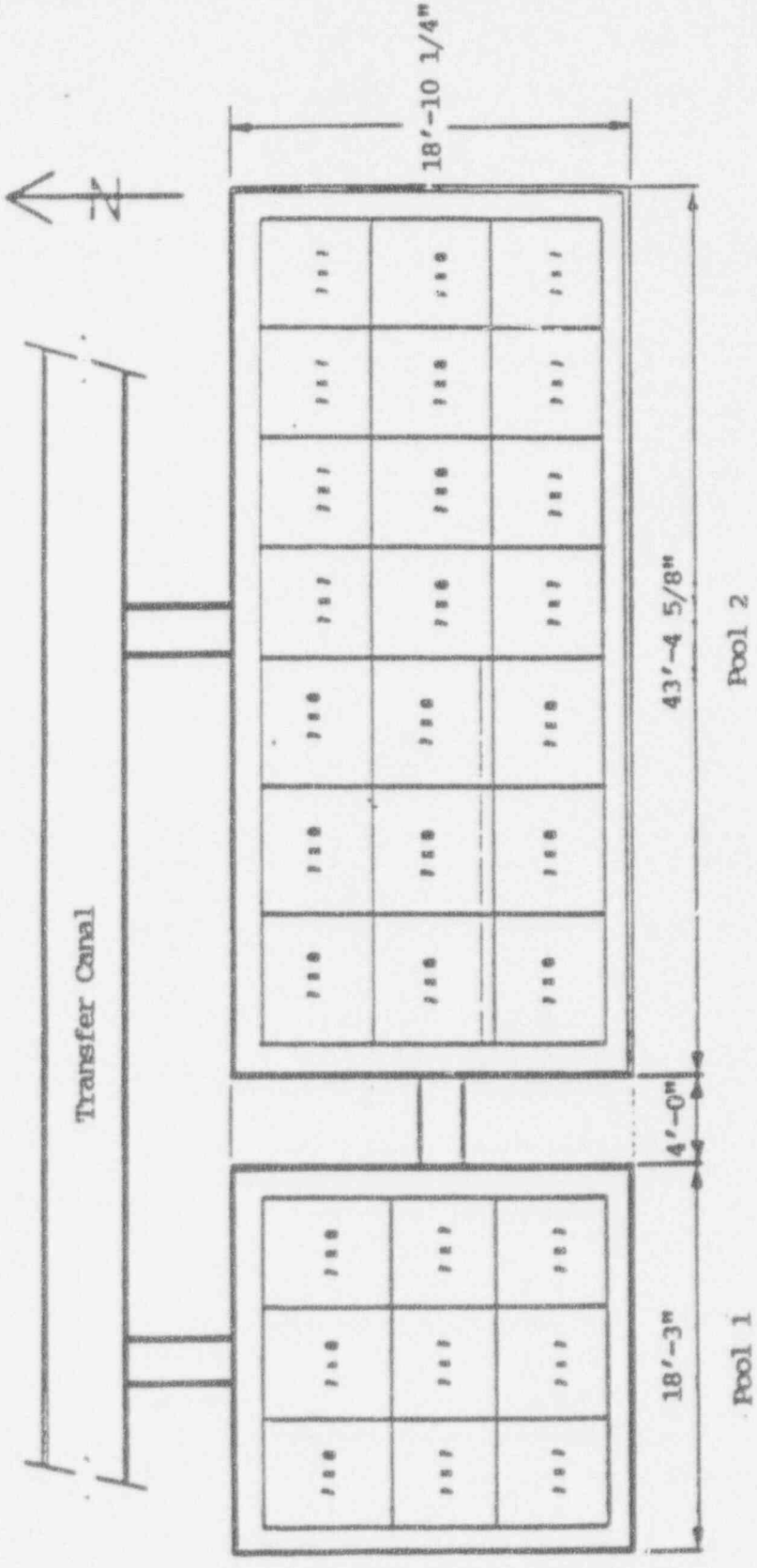
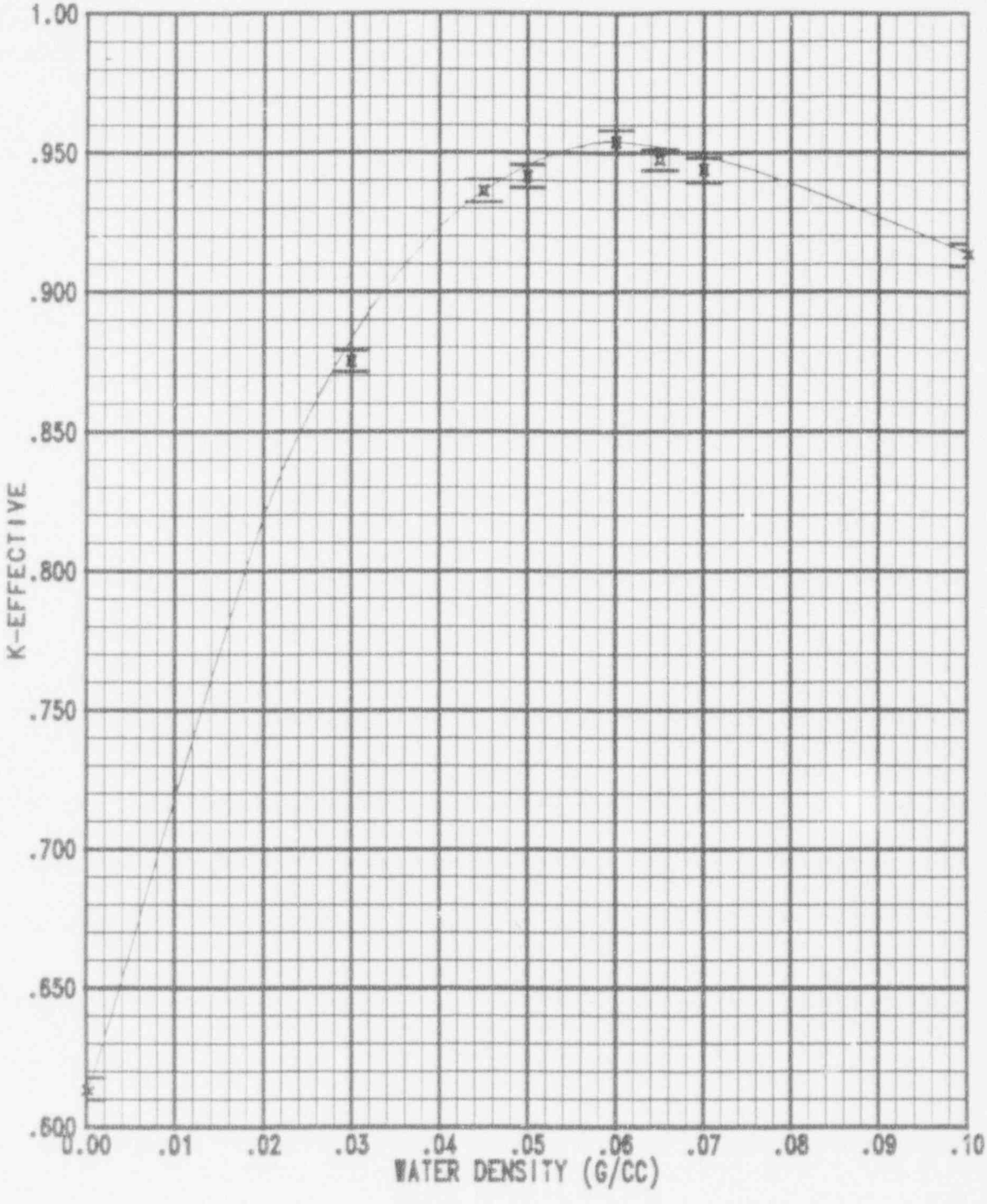


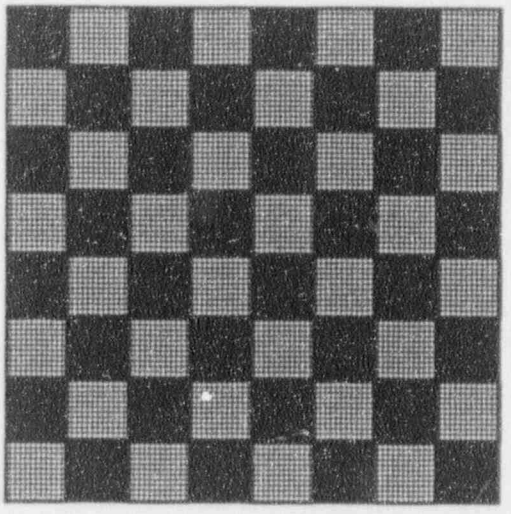
Figure 4 Prairie Island Spent Fuel Rack Layout



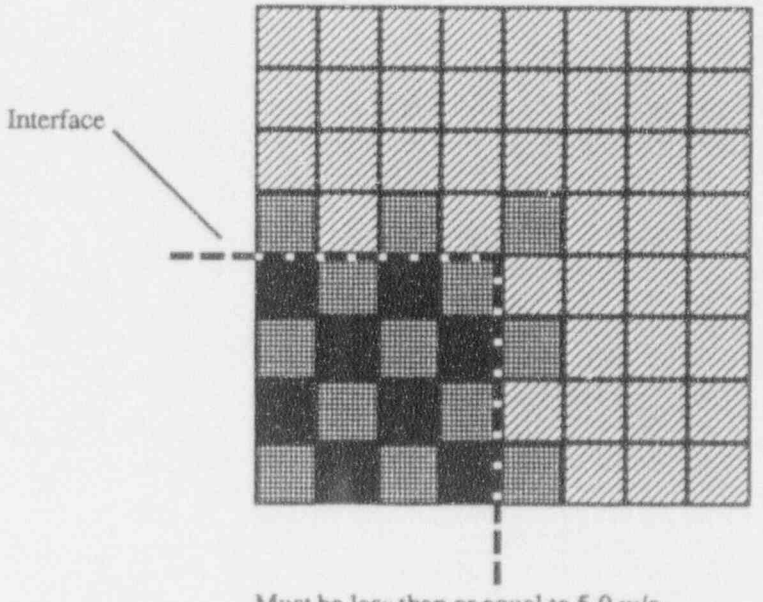
NOTE: Error bars represent a one sigma tolerance about the KENO K-eff

Figure 5 Prairie Island Sensitivity of K_{eff} to Water Density in the Prairie Island Fresh Fuel Racks

REGION 1 CHECKERBOARD PATTERN



BOUNDARY BETWEEN REGION 1 AND REGION 2 ZONES



Fresh Fuel:	Must be less than or equal to 5.0 w/o
Region 1 Burned Fuel:	Must satisfy the minimum burnup requirements of Figure 7.
Region 2 Burned Fuel:	Must satisfy the minimum burnup Requirements of Figure 10.

Note: The Region 1 and Region 2 zones can alternatively be seperated by a single row of vacant cells on each adjacent face.

Figure 6 Prairie Island Region 1 Burned/Fresh Checkerboard Cell Layout

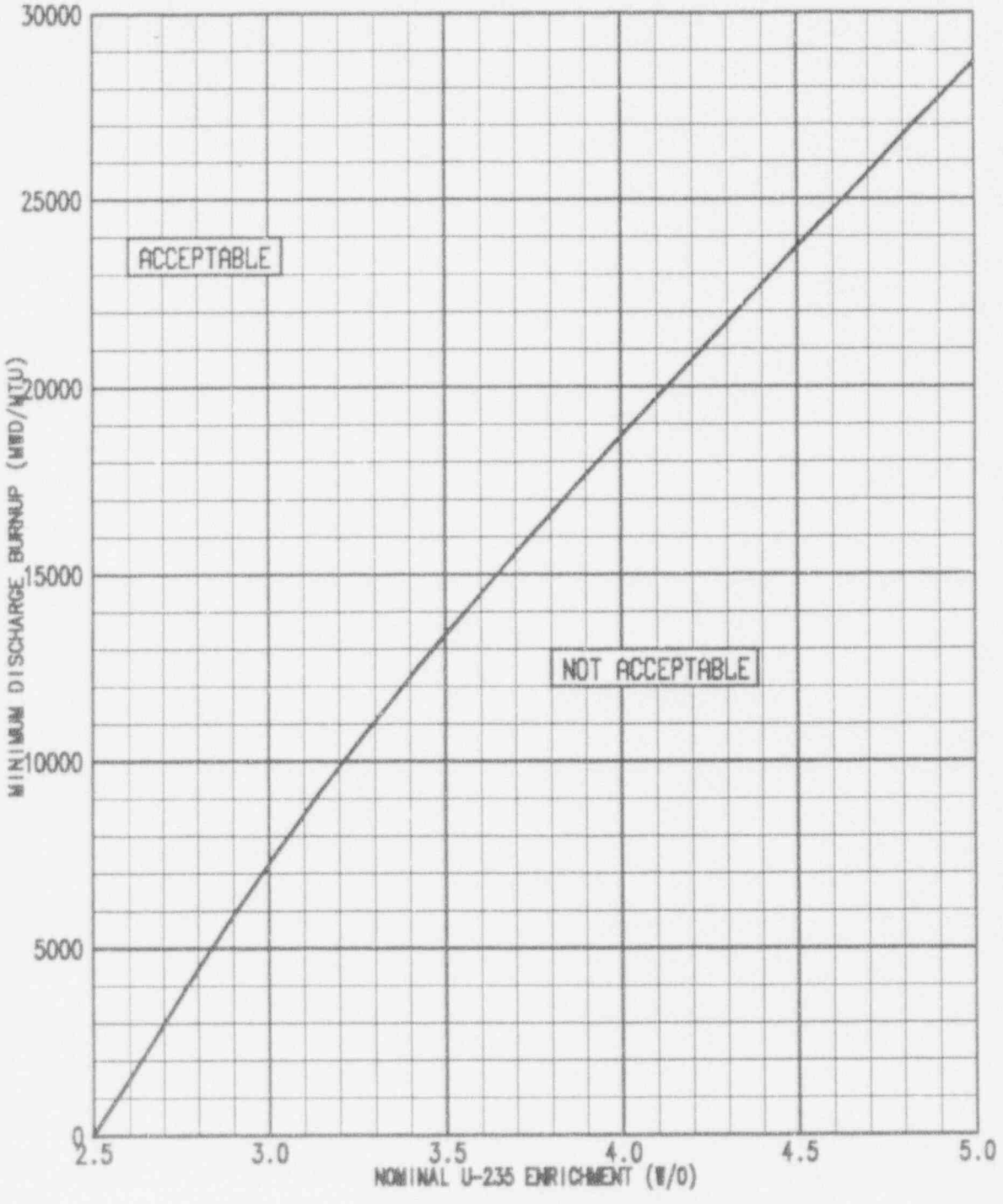


Figure 7 Prairie Island Region 1 Minimum Burnup Requirements

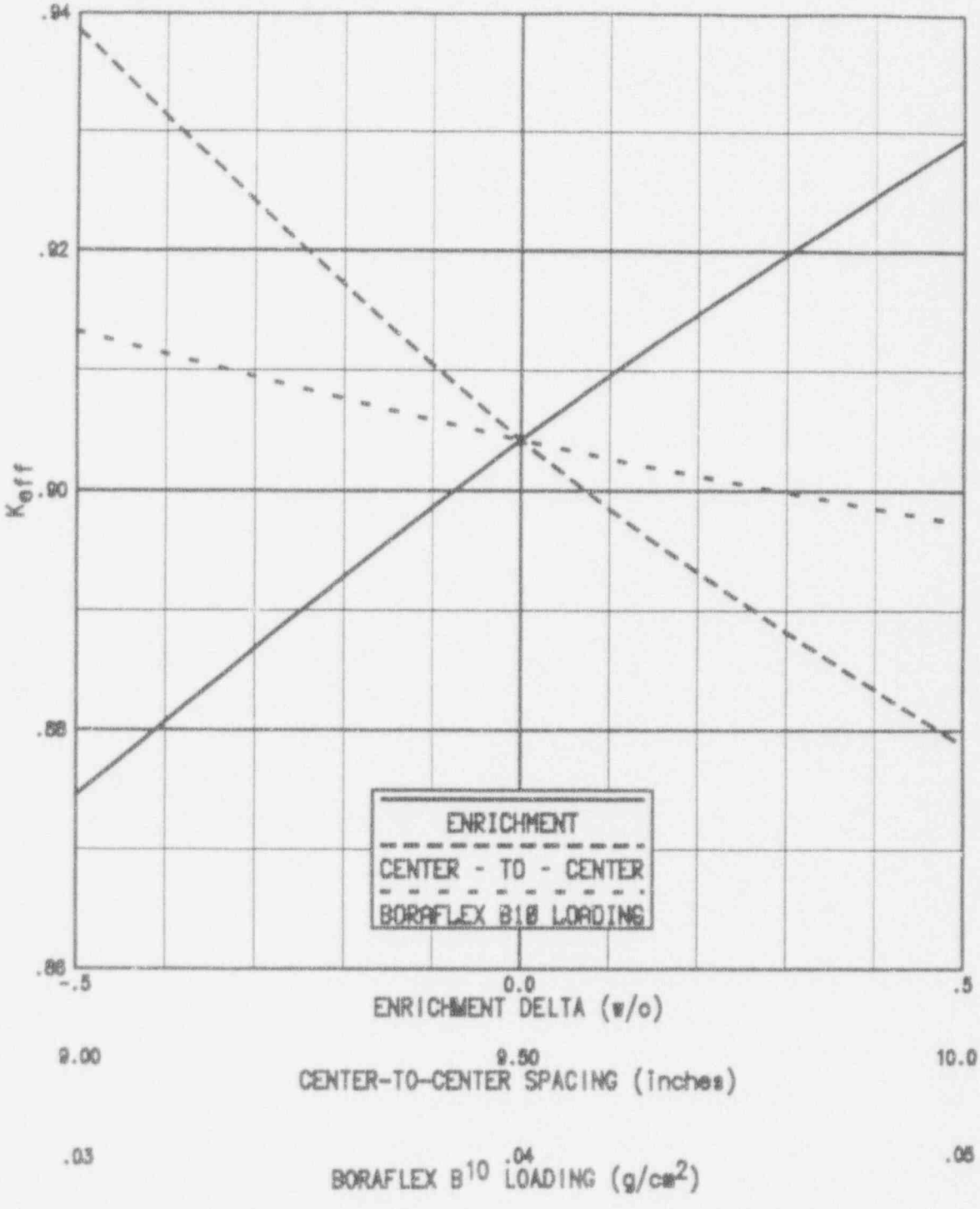


Figure 8 Prairie Island Region 1 Reactivity Sensitivities

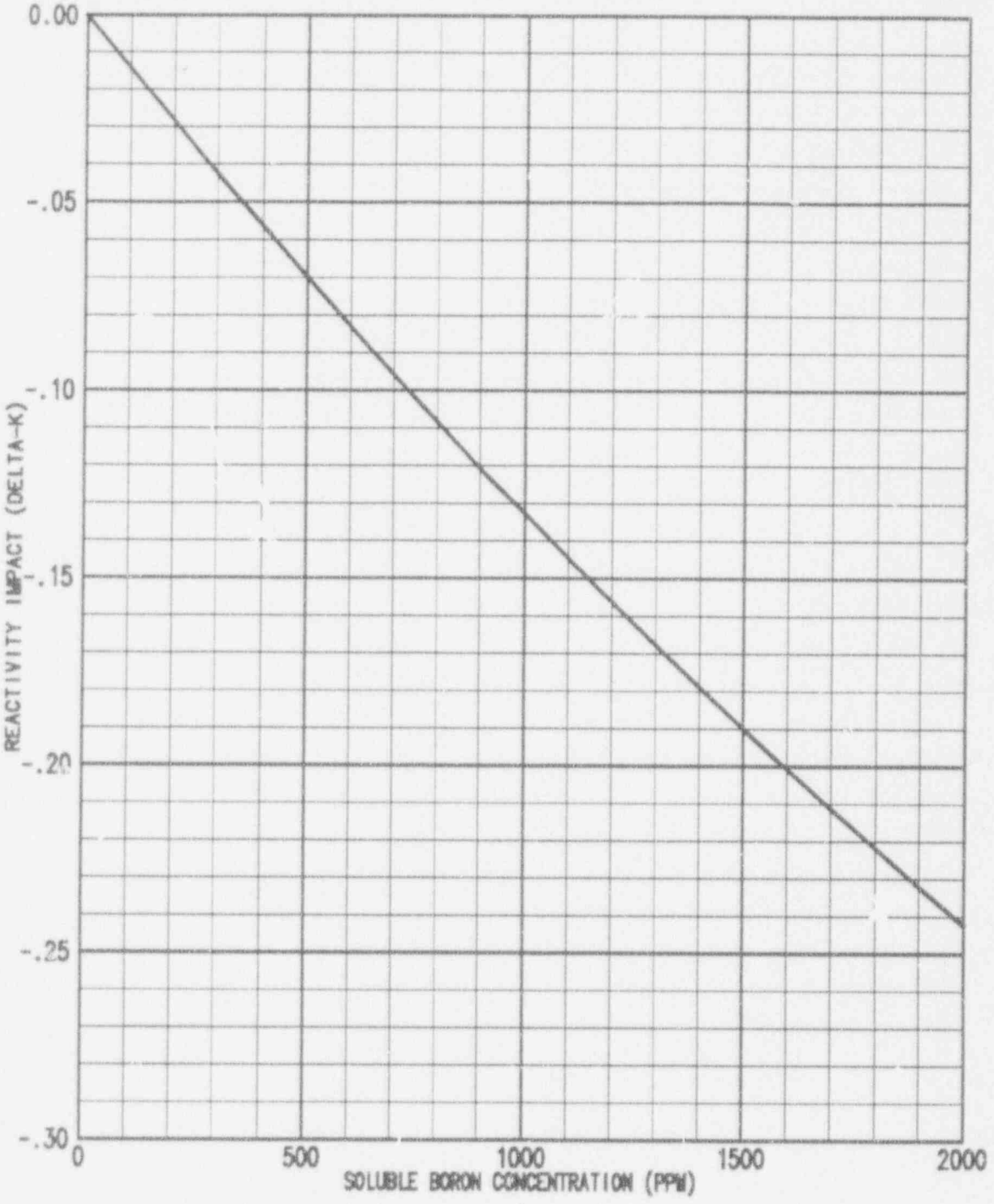


Figure 9 Prairie Island Region 1 Spent Fuel Pool Soluble Boron Worth

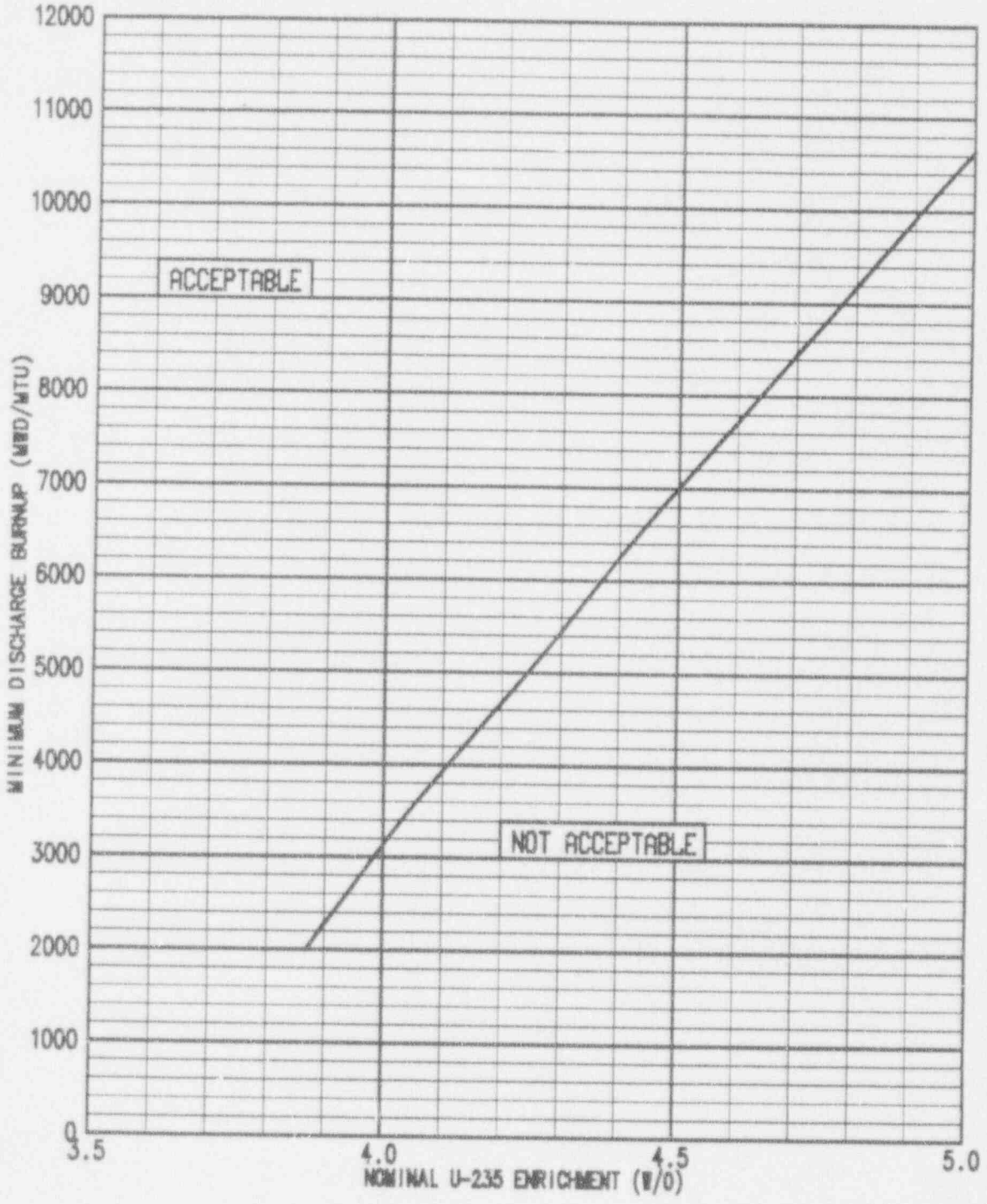


Figure 10 Prairie Island Region 2 Minimum Burnup Requirements

BIBLIOGRAPHY

1. Nuclear Regulatory Commission, Letter to All Power Reactor Licensees, from B. K. Grimes *OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications,*, April 14, 1978.

2. W. E. Ford III, *CSRL-V: Processed ENDF/B-V 227-Neutron-Group and Pointwise Cross-Section Libraries for Criticality Safety, Reactor and Shielding Studies*, ORNL/CSD/TM-160, June 1982.

3. N. M. Greene, *AMPX: A Modular Code System for Generating Coupled Multigroup Neutron-Gamma Libraries from ENDF/B*, ORNL/TM-3706, March 1976.

4. L. M. Petrie and N. F. Landers, *KENO Va--An Improved Monte Carlo Criticality Program With Supergrouping*, NUREG/CR-0200, December 1984.

5. M. N. Baldwin, *Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel*, BAW-1484-7, July 1979.

6. S. R. Bierman and E. D. Clayton, *Criticality Separation Between Subcritical Clusters of 2.35 wt% 235U Enriched UO2 Rods in Water with Fixed Neutron Poisons*, PNL-2438, October 1977.

7. S. R. Bierman and E. D. Clayton, *Criticality Separation Between Subcritical Clusters of 4.29 wt% 235U Enriched UO2 Rods in Water with Fixed Neutron Poisons*, PNL-2615, August 1979.

8. S. R. Bierman and E. D. Clayton, *Criticality Experiments with Subcritical Clusters of 2.35 wt% and 4.31 wt% 235U Enriched UO2 Rods in Water at a Water-to-Fuel Volume Ratio of 1.6*, PNL-3314, July 1980.

9. J. T. Thomas, *Critical Three-Dimensional Arrays of U(93.2) Metal Cylinders*, Nuclear Science and Engineering, Volume 52, pages 350-359, 1973.

10. D. E. Mueller, W. A. Boyd, and M. W. Fecteau (Westinghouse NFD), *Qualification of KENO Calculations with ENDF/B-V Cross Sections*, American Nuclear Society Transactions, Volume 56, pages 321-323, June 1988.

11. A. J. Harris, *A Description of the Nuclear Design and Analysis Programs for Boiling Water Reactors*, WCAP-10106, June 1982.

12. Askew, J. R., Fayers, F. J., and Kemshell, P. B., *A General Description of the Lattice Code WIMS*, Journal of British Nuclear Energy Society, 5, pp. 564-584, 1966.

13. England, T. R., *CINDER - A One-Point Depletion and Fission Product Program*, WAPD-TM-334, August 1962.

14. Melehan, J. B., *Yankee Core Evaluation Program Final Report*, WCAP-3017-6094, January 1971.

15. Boyd, W. A., et al,, *Criticality Analysis of Prairie Island Units 1 and 2 Fuel Racks*,, March 1989.