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Northern States Power Prairie Island Units 1 and 2 Spent Fuel Rack Criticality Analysis Using Soluble Boron Credit

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1.0 Introduction

This report presents the results of a criticality analysis of the Northern States Power Prairie Island Units 1 and 2 spent fuel storage racks using credit for soluble boron in the spent fuel pool. The methodology employed here is contained in the topical report, "Westinghouse Spent Fuel Rack Criticality Analysis Methodology"[1].

The spent fuel storage rack design considered herein is an existing array of fuel racks, previously qualified[2] (with Boraflex) for storage of various 14x14 fuel assembly types with maximum enrichments up to 5.0 w/o ^{235}U. In this report, no credit is taken for the presence of Boraflex in the racks. Two different storage configurations are currently allowed. The first configuration allows fuel assemblies to be stored in a 2x2 checkerboard pattern of "burned" and "fresh" fuel assemblies with enrichments of 2.5 w/o ^{235}U (equivalent with burnup) and 5.0 w/o ^{235}U (no burnup), respectively. The second configuration allows storage of fuel assemblies in all storage cell locations (no checkerboard) if they satisfy a minimum burnup credit requirement as a function of enrichment.

The Prairie Island spent fuel racks are reanalyzed to allow storage of all 14x14 fuel assemblies used at Prairie Island with nominal enrichments up to 4.95 w/o ^{235}U in all storage cell locations using credit for checkerboard configurations and burnup credit. The analysis does not take any credit for the presence of the spent fuel rack Boraflex poison panels. Credit is taken for the presence of the integral absorber Gadolinium with 8 w/o Gd in the fuel and for the radioactive decay time of the spent fuel. The following storage configurations and enrichment limits are considered in this analysis:

All Cell Storage Enrichment Limits	Storage of 14x14 assemblies in any cell location with nominal enrichments no greater than 1.87 w/o ^{235}U for Westinghouse 14x14 OFA fuel assemblies and 1.77 w/o ^{235}U for Westinghouse 14x14 STD and Exxon 14x14 fuel assemblies. Fuel assemblies with initial nominal enrichments greater than these must satisfy a minimum burnup and decay time requirement.
3x3 Checkerboard Enrichment Limits	Storage of Westinghouse 14x14 OFA assemblies with nominal enrichments no greater than 4.95 w/o ^{235}U in the center of a 3x3 checkerboard. The surrounding fuel assemblies must have an initial nominal enrichment no greater than 1.30 w/o ^{235}U for Westinghouse 14x14 OFA fuel assemblies and 1.20 w/o ^{235}U for Westinghouse 14x14 STD and Exxon 14x14 fuel assemblies. Fuel assemblies with initial nominal enrichments greater than these must satisfy a minimum burnup and decay time requirement. The surrounding enrichment limits are increased with Gadolinium credit in the center assembly.

The soluble boron credit required for these storage configurations are 750 ppm for normal conditions and 1300 ppm for accidents.

The Prairie Island spent fuel rack analysis is based on maintaining $K_{eff} \leq 1.0$ including uncertainties and tolerances on a 95/95 basis without the presence of any soluble boron in the storage pool (No Soluble Boron 95/95 K_{eff} conditions). Soluble boron credit is used to provide safety margin by maintaining $K_{eff} \leq 0.95$ including uncertainties, tolerances, and accident conditions in the presence of spent fuel pool soluble boron.

1.1 Design Description

The Prairie Island spent fuel storage rack layout is depicted in Figure 1 on page 44 and the spent fuel rack storage cell is shown in Figure 2 on page 45. Nominal dimensions are provided on each figure.

Fuel types being considered in the analyses include the Westinghouse 14x14 OFA design being used in Prairie Island Units 1 and 2 and the Westinghouse 14x14 STD and Exxon 14x14 fuel assembly types previously used in the reactors and currently in storage in the Prairie Island spent fuel pool. The Westinghouse 14x14 STD design bounds the reactivity of the 14x14 Exxon fuel assemblies. The Westinghouse 14x14 OFA design is equivalent to the Westinghouse 14x14 Vantage Plus fuel type currently in use and is covered by this analysis.

The fuel parameters relevant to this analysis are given in Table 1 on page 25.

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 them. However, in this analysis no credit is taken for the presence of Boraflex panels in the racks.

In this report, the reactivity of the spent fuel rack is analyzed such that K_{eff} remains less than 1.0 under No Soluble Boron 95/95 K_{eff} conditions as defined in Reference 1. To provide safety margin in the criticality analysis of the spent fuel racks, credit is taken for the soluble boron present in the Prairie Island spent fuel pool. This parameter provides significant negative reactivity in the criticality analysis of the spent fuel rack and will be used here to offset the reactivity increase when ignoring the presence of the spent fuel rack Boraflex poison panels. Soluble boron credit provides sufficient relaxation in the enrichment limits of the spent fuel racks to allow the racks to be used under checkerboarded conditions with no credit for the Boraflex poison panels. If some amount of Boraflex material is considered remaining, the reactivity of the spent fuel rack and the amount of soluble boron required to maintain $K_{eff} \leq 0.95$ will be reduced.

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 rack array will be less than or equal to 0.95.

2.0 Analytical Methods

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, low moderator densities and spent fuel pool soluble boron.

The design method which insures the criticality safety of fuel assemblies in the fuel storage rack is described in detail in the Westinghouse Spent Fuel Rack Criticality Analysis Methodology topical report[1]. This report describes the computer codes, benchmarking, and methodology which are used to calculate the criticality safety limits presented in this report for Prairie Island.

As determined in the benchmarking in the topical report, the method bias using the described methodology of NITAWL-II, XSDRNPM-S and KENO-Va is 0.0077 ΔK with a 95 percent probability at a 95 percent confidence level standard deviation on the bias of 0.0030 ΔK. These values will be used throughout this report as needed.

3.0 Criticality Analysis of All Cell Storage

This section describes the analytical techniques and models employed to perform the criticality analysis and reactivity equivalencing evaluations for the Prairie Island spent fuel storage racks all cell enrichment limits using credit for soluble boron.

Section 3.1 describes the No Soluble Boron 95/95 K_{eff} KENO-Va calculations performed for the all cell storage configuration. Section 3.2 discusses the results of the spent fuel rack K_{eff} soluble boron credit calculations. Finally, Section 3.3 presents the results of calculations performed to show the minimum burnup requirements for assemblies with higher initial enrichments above those determined in Section 3.1 including decay time credit.

3.1 No Soluble Boron 95/95 K_{eff}

To determine the enrichment required to maintain $K_{eff} \leq 1.0$, KENO-Va is used to establish a nominal reference reactivity and PHOENIX-P 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-Va reference reactivity. The equation for determining the final 95/95 K_{eff} is defined in Reference 1.

The following assumptions are used to develop the No Soluble Boron 95/95 K_{eff} KENO-Va model for storage of fuel assemblies in the Prairie Island spent fuel storage racks:

1. The fuel assembly parameters relevant to the criticality analysis are based on the Westinghouse 14x14 OFA and 14x14 STD designs (see Table 1 on page 25 for fuel parameters). The Westinghouse 14x14 STD design bounds the reactivity of the 14x14 Exxon fuel assemblies.
2. Westinghouse 14x14 OFA and STD fuel assemblies contain uranium dioxide at a nominal enrichment of 1.87 w/o ^{235}U and 1.77 w/o ^{235}U, respectively, 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 or reduced enrichment axial blankets. This assumption results in equivalent or conservative calculations of reactivity for all fuel assemblies used at Prairie Island including those with annular pellets at the fuel rod ends.
5. No credit is taken for any ^{234}U or ^{236}U in the fuel, nor is any credit taken for the buildup 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. No credit is taken for the presence of spent fuel rack Boraflex poison panels. The Boraflex volume is replaced with water.

9. The moderator is water with 0 ppm soluble boron at a temperature of 68°F. A water density of 1.0 gm/cm^3 is used.

10. The fuel assembly array is infinite in lateral (x and y) extent and finite in axial (vertical) extent with a 6 inch water region on the top and bottom of the fuel in the axial direction or conservatively modeled as infinite.

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

With the above assumptions, the KENO-Va calculations of K_{eff} under normal conditions resulted in a K_{eff} of 0.96914 and 0.96799 for both Westinghouse OFA and STD fuel assemblies, respectively, as shown in Table 2 on page 26.

Calculational and methodology biases must be considered in the final K_{eff} summation prior to comparing against the 1.0 K_{eff} limit. The following biases are included:

Methodology: The benchmarking bias as determined for the Westinghouse KENO-Va methodology was considered.

Water Temperature: A reactivity bias is applied to account for the effect of the normal range of spent fuel pool water temperatures (50°F to 150°F).

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, perturbation calculations are performed using PHOENIX-P. For the Prairie Island spent fuel rack all cell enrichment storage configuration, UO_2 material tolerances are considered along with construction tolerances related to the cell I.D., storage cell pitch, and stainless steel wall thickness. 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:

^{235}U Enrichment: The enrichment tolerance of ±0.05 w/o ^{235}U about the nominal reference enrichments of 1.87 w/o ^{235}U and 1.77 w/o ^{235}U was considered.

UO_2 Density: A ±2.0% variation about the nominal reference theoretical density (the nominal reference values are listed in Table 1 on page 25) was considered.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to 2.0% (the nominal reference values are listed in Table 1 on page 25) was considered.

Storage Cell I.D.: The ±0.10 inch tolerance about the nominal 8.27 inch reference cell I.D.was considered.

Storage Cell Pitch: The ±0.06 inch tolerance about the nominal 9.50 inch reference cell pitch was considered.

Stainless Steel Thickness: The ±0.01 inch tolerance about the nominal 0.09 inch reference stainless steel thickness for all rack structures was considered.

Assembly Position: The KENO-Va reference reactivity calculation assumes fuel assemblies are symmetrically positioned within the storage cells. Conservative calculations show that an increase in reactivity can occur if the corners of four fuel assemblies are positioned together. This reactivity increase was considered in the statistical summation of spent fuel rack tolerances.

Calculation Uncertainty: The 95 percent probability/95 percent confidence level uncertainty on the KENO-Va nominal reference K_{eff} was considered.

Methodology Uncertainty: The 95 percent probability/95 percent confidence uncertainty in the benchmarking bias as determined for the Westinghouse KENO-Va methodology was considered.

The 95/95 K_{eff} for the Prairie Island spent fuel rack all cell storage configuration is developed by adding the temperature and methodology biases and the statistical sum of independent tolerances and uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 2 and results in a 95/95 K_{eff} of 0.99947 and 0.99893 for Westinghouse OFA and STD fuel assembly types, respectively.

Since K_{eff} is less than 1.0 for both fuel types, the Prairie Island spent fuel racks will remain subcritical when all cells are loaded with 1.87 w/o ^{235}U Westinghouse 14x14 OFA or 1.77 w/o ^{235}U Westinghouse 14x14 STD fuel assemblies and no soluble boron is present in the spent fuel pool water. In the next section, soluble boron credit will be used to provide safety margin by determining the amount of soluble boron required to maintain $K_{eff} \leq 0.95$ including tolerances and uncertainties.

3.2 Soluble Boron Credit K_{eff} Calculations

To determine the amount of soluble boron required to maintain $K_{eff} \leq 0.95$, KENO-Va is used to establish a nominal reference reactivity and PHOENIX-P 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-Va reference reactivity.

The assumptions used to develop the nominal case KENO-Va model for soluble boron credit for all cell storage in the Prairie Island spent fuel racks are the same as those in Section 3.1 except for assumption 9 regarding the moderator soluble boron concentration. The moderator used is water with 200 ppm boron for both the Westinghouse OFA and STD fuel assembly types.

With the above assumptions, the KENO-Va calculation for the nominal case results in a K_{eff} of 0.90395 and 0.90823 for Westinghouse OFA and STD fuel assembly types, respectively, as shown in Table 3 on page 27.

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: The benchmarking bias as determined for the Westinghouse KENO-Va methodology was considered.

Water Temperature: A reactivity bias is applied to account for the effect of the normal range of spent fuel pool water temperatures (50°F to 150°F).

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, PHOENIX-P perturbation calculations are performed. For the Prairie Island spent fuel rack all cell enrichment storage configuration, UO_2 material tolerances are considered along with construction tolerances related to the cell I.D., storage cell pitch, and stainless steel wall thickness. 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:

^{235}U Enrichment: The enrichment tolerance of ±0.05 w/o ^{235}U about the nominal reference enrichments of 1.87 w/o ^{235}U and 1.77 w/o ^{235}U was considered.

UO_2 Density: A ±2.0% variation about the nominal reference theoretical density (the nominal reference values are listed in Table 1 on page 25) was considered.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to 2.0% (the nominal reference values are listed in Table 1 on page 25) was considered.

Storage Cell I.D.: The ±0.10 inch tolerance about the nominal 8.27 inch reference cell I.D.was considered.

Storage Cell Pitch: The ±0.06 inch tolerance about the nominal 9.50 inch reference cell pitch was considered.

Stainless Steel Thickness: The ±0.01 inch tolerance about the nominal 0.09 inch reference stainless steel thickness for all rack structures was considered.

Assembly Position: The KENO-Va reference reactivity calculation assumes fuel assemblies are symmetrically positioned within the storage cells. Conservative calculations show that an increase in reactivity can occur if the corners of four fuel assemblies are positioned together. This reactivity increase was considered in the statistical summation of spent fuel rack tolerances.

Calculation Uncertainty: The 95 percent probability/95 percent confidence level uncertainty on the KENO-Va nominal reference K_{eff} was considered.

Methodology Uncertainty: The 95 percent probability/95 percent confidence uncertainty in the benchmarking bias as determined for the Westinghouse KENO-Va methodology was considered.

The 95/95 K_{eff} for the Prairie Island spent fuel rack all cell storage configuration is developed by adding the temperature and methodology biases and the statistical sum of independent tolerances and uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 3 and results in a 95/95 K_{eff} of 0.93505 and 0.94070 for Westinghouse OFA and STD fuel assembly types, respectively.

Since K_{eff} is less than 0.95 including soluble boron credit and uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met for the all cell enrichment storage of 14x14 fuel assemblies in the Prairie Island spent fuel racks. Storage of fuel assemblies with nominal enrichments up to 1.87 w/o ^{235}U and 1.77 w/o ^{235}U is acceptable for Westinghouse OFA or STD fuel assembly types, respectively, in all cells of the Prairie Island spent fuel racks including the presence of 200 ppm.

3.3 Burnup and Decay Time Reactivity Equivalencing

Storage of fuel assemblies with enrichments higher than 1.87 w/o ^{235}U and 1.77 w/o ^{235}U for the Westinghouse OFA and STD fuel types in the Prairie Island spent fuel rack all cell 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 and the radioactive decay of the spent fuel isotopes within the fuel assemblies.

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 3 on page 46 and Figure 4 on page 47 show the constant K_{eff} contours as a function of assembly average burnup, for different decay times, generated for the Prairie Island spent fuel rack all cell configuration. These curves represent combinations of fuel enrichment and discharge burnup which yield the same rack multiplication factor (K_{eff}) as the rack loaded with 1.87 w/o ^{235}U and 1.77 w/o ^{235}U fuel (at zero burnup) for Westinghouse OFA and STD fuel assemblies, respectively, in all cell locations.

Uncertainties associated with burnup credit include a reactivity uncertainty of 0.01 ΔK at 30,000 MWD/MTU applied linearly to the burnup credit requirement to account for calculational and depletion uncertainties and 4% on the calculated burnup to account for burnup measurement uncertainty. The amount of additional soluble boron needed to account for these uncertainties in the burnup requirement of Figure 3 and Figure 4 is 200 ppm and 250 ppm for the Westinghouse OFA and STD fuel assembly types, respectively. This is additional boron above the 200 ppm required for Westinghouse OFA and STD fuel assembly types, as calculated in Section 3.2. This results in a total soluble boron credit of 400 ppm and 450 ppm for the Westinghouse OFA and STD fuel assembly types, respectively.

Decay Time Credit is an extension of the Burnup Credit process which includes the time an assembly has been discharged as a variable. This methodology gains additional margin in reactivity and reduces the minimum burnup requirements. Spent fuel decay time credit results from the radioactive decay of isotopes in the spent fuel to daughter isotopes, which results in reduced reactivity. One of the major contributors is the decay of ^{241}Pu to ^{241}Am. In this report, credit is taken only for the decay of actinides. Decay of the fission products has the effect of further reducing the reactivity of the spent fuel.

In the decay time methodology reported here, the fission product isotopes are frozen at the concentrations existing at the time of discharge of the fuel (except ^{135}Xe which is removed). These calculations are performed at different discharge burnups. The actinide isotopes are allowed to decay based on their natural process. The loss in reactivity due to the radioactive decay of the spent fuel results in reducing the minimum burnup needed to meet the reactivity requirements. Thus for different decay times, a family of curves is generated which all yield the desired equivalent K_{eff} when stored in the spent fuel storage racks. In the decay time methodology the following assumptions are used in the models:

1. The fuel assemblies are modeled using the same criteria as Section 3.1.
2. Fuel is depleted using a conservatively high soluble boron letdown curve to enhance the buildup of plutonium making the fuel more reactive in the spent fuel storage racks. Sensitivity studies have shown that spectrum effects are also conservative for the decay time calculation.
3. No credit for fission product isotopic decay is used.
4. Actinide only isotopes decay is used.
5. Nominal spent fuel rack configuration/dimensions are used.

With the above assumptions, the calculation of the decay time burnup credit curves are found to be conservative for use in the spent fuel pool criticality analysis.

It is important to recognize that the curves in Figure 3 and Figure 4 are 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 3 and Figure 4 are also provided in Table 4 on page 28 and Table 5 on page 29. Use of linear interpolation between the tabulated values is acceptable since the curves shown in Figure 3 and Figure 4 are linear in between the tabulated points.

The effect of axial burnup distribution on assembly reactivity has been considered in the development of the Prairie Island burnup credit limit. Previous evaluations have been performed to quantify axial burnup reactivity effects and to confirm that the reactivity equivalencing methodology described in Reference 1 results in calculations of conservative burnup credit limits. The evaluations show that axial burnup effects can cause assembly reactivity to increase only at

burnup-enrichment combinations which are beyond those calculated for the Prairie Island burnup credit limit. Therefore, additional accounting of axial burnup distribution effects in the Prairie Island burnup credit limit is not necessary.

4.0 Criticality Analysis of 3x3 Checkerboard Storage

This section describes the analytical techniques and models employed to perform the criticality analysis and reactivity equivalencing evaluations for the Prairie Island spent fuel storage racks 3x3 checkerboard storage enrichment limits using credit for soluble boron. The purpose of the 3x3 checkerboard storage configuration is to allow the most reactive fresh fuel to be stored in the Prairie Island spent fuel racks. The most reactive fresh fuel for Prairie Island has a nominal enrichment of 4.95 w/o ^{235}U in a Westinghouse 14x14 OFA fuel assembly.

Section 4.1 describes the No Soluble Boron 95/95 K_{eff} KENO-Va calculations performed for the 3x3 checkerboard storage configuration. Section 4.2 discusses the results of the spent fuel rack K_{eff} soluble boron credit calculations. Finally, Section 4.3 presents the results of calculations performed to show the minimum burnup requirements for assemblies with higher initial enrichments above those determined in Section 4.1 including decay time and Gadolinium credit.

4.1 No Soluble Boron 95/95 K_{eff} Calculations

To determine the enrichment required to maintain $K_{eff} \leq 1.0$, KENO-Va is used to establish a nominal reference reactivity and PHOENIX-P 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-Va reference reactivity. The equation for determining the final 95/95 K_{eff} is defined in Reference 1.

The following assumptions are used to develop the No Soluble Boron 95/95 K_{eff} KENO-Va model for storage of fuel assemblies in the Prairie Island spent fuel storage rack:

1. The fuel assembly parameters relevant to the criticality analysis are based on the Westinghouse 14x14 OFA and STD designs (see Table 1 on page 25 for fuel parameters). The Westinghouse 14x14 STD design bounds the reactivity of the 14x14 Exxon fuel assemblies currently stored in the Prairie Island spent fuel pool.
2. Westinghouse 14x14 OFA fuel assemblies stored in the middle of the 3x3 checkerboard contain uranium dioxide at a nominal enrichment of 4.95 w/o ^{235}U over the entire length of each rod.
3. Westinghouse 14x14 OFA and STD fuel assemblies surrounding the center of the 3x3 checkerboard contain uranium dioxide at nominal enrichments of 1.30 w/o ^{235}U and 1.20 w/o ^{235}U respectively, 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 or reduced enrichment axial blankets. This assumption results in equivalent or conservative calculations of reactivity for all fuel assemblies used at Prairie Island including those with annular pellets at the fuel rod ends.

6. No credit is taken for any ^{234}U or ^{236}U in the fuel, nor is any credit taken for the buildup 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. (Burnable absorber credit is calculated in Section 4.3)
9. No credit is taken for the presence of spent fuel rack Boraflex poison panels. The Boraflex volume is replaced with water.
10. The moderator is water with 0 ppm soluble boron at a temperature of 68°F. A water density of 1.0 gm/cm^3 is used.
11. The fuel assembly array is infinite in lateral (x and y) extent and finite in axial (vertical) extent with a 6 inch water region on the top and bottom of the fuel in the axial direction or conservatively modeled as infinite.
12. Storage cells are loaded with fuel assemblies in a 3x3 checkerboard pattern as shown in Figure 5 on page 48. The center of the 3x3 checkerboard is always a fresh 4.95 w/o ^{235}U Westinghouse OFA assembly. The surrounding assemblies are Westinghouse OFA or STD fuel assemblies with the specified enrichment limits.

With the above assumptions, the KENO-Va calculations of K_{eff} under normal conditions resulted in a K_{eff} of 0.96157 and 0.95918 for the both Westinghouse OFA and STD fuel assemblies respectively, as shown in Table 6 on page 30.

Calculational and methodology biases must be considered in the final K_{eff} summation prior to comparing against the 1.0 K_{eff} limit. The following biases are included:

Methodology: The benchmarking bias as determined for the Westinghouse KENO-Va methodology was considered.

Water Temperature: A reactivity bias is applied to account for the effect of the normal range of spent fuel pool water temperatures (50°F to 150°F).

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, PHOENIX-P perturbation calculations are performed. For the Prairie Island spent fuel rack 3x3 checkerboard storage configuration, UO_2 material tolerances are considered along with construction tolerances related to the cell I.D., storage cell pitch, and stainless steel wall thickness. 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:

^{235}U Enrichment: The enrichment tolerance of ±0.05 w/o ^{235}U about the nominal fresh reference enrichment of 4.95 w/o ^{235}U and nominal enrichments of 1.30 w/o ^{235}U and 1.20 w/o ^{235}U was considered.

UO_2 Density: A ±2.0% variation about the nominal reference theoretical density (the nominal reference values are listed in Table 1 on page 25) was considered.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to 2.0% (the nominal reference values are listed in Table 1 on page 25) was considered.

Storage Cell I.D.: The ±0.10 inch tolerance about the nominal 8.27 inch reference cell I.D.was considered.

Storage Cell Pitch: The ±0.06 inch tolerance about the nominal 9.50 inch reference cell pitch was considered.

Stainless Steel Thickness: The ±0.01 inch tolerance about the nominal 0.09 inch reference stainless steel thickness for all rack structures was considered.

Assembly Position: The KENO-Va reference reactivity calculation assumes fuel assemblies are symmetrically positioned within the storage cells. Conservative calculations show that an increase in reactivity can occur if the corners of four fuel assemblies are positioned together. This reactivity increase is considered in the statistical summation of spent fuel rack tolerances.

Calculation Uncertainty: The 95 percent probability/95 percent confidence level uncertainty on the KENO-Va nominal reference K_{eff} was considered.

Methodology Uncertainty: The 95 percent probability/95 percent confidence uncertainty in the benchmarking bias as determined for the Westinghouse KENO-Va methodology was considered.

The 95/95 K_{eff} for the Prairie Island spent fuel rack 3x3 checkerboard storage configuration is developed by adding the calculational and methodology biases and the statistical sum of independent uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 6 and results in a 95/95 K_{eff} of 0.99983 and 0.99944 for Westinghouse OFA and STD fuel assembly types, respectively.

Since K_{eff} is less than 1.0 for all fuel types considered, the Prairie Island spent fuel racks will remain subcritical when cells are loaded in a 3x3 checkerboard as specified in Figure 5 with a 4.95 w/o ^{235}U Westinghouse OFA fuel assembly surrounded by any combination of 1.30 w/o ^{235}U Westinghouse OFA or 1.20 w/o ^{235}U Westinghouse STD fuel assemblies, respectively. In the next section, soluble boron credit will be used to provide safety margin by determining the amount of soluble boron required to maintain $K_{eff} \leq 0.95$ including tolerances and uncertainties.

4.2 Soluble Boron Credit K_{eff} Calculations

To determine the amount of soluble boron required to maintain $K_{eff} \leq 0.95$, KENO-Va is used to establish a nominal reference reactivity and PHOENIX-P 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-Va reference reactivity.

The assumptions used to develop the nominal case KENO-Va model for soluble boron credit for 3x3 checkerboard cell storage in the Prairie Island spent fuel racks are the same as those in Section 4.1 except for assumption 10 regarding the moderator soluble boron concentration. The moderator is water with 250 ppm or 300 ppm for the Westinghouse OFA and STD fuel assembly types, respectively.

With the above assumptions, the KENO-Va calculation for the nominal case results in a K_{eff} of 0.90802 and 0.89614 for Westinghouse OFA and STD fuel assembly types, respectively as shown in Table 7 on page 31.

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: The benchmarking bias as determined for the Westinghouse KENO-Va methodology was considered.

Water Temperature: A reactivity bias is applied to account for the effect of the normal range of spent fuel pool water temperatures (50°F to 150°F).

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, PHOENIX-P perturbation calculations are performed. For the Prairie Island spent fuel rack 3x3 checkerboard storage configuration, UO_2 material tolerances are considered along with construction tolerances related to the cell I.D., storage cell pitch, and stainless steel wall thickness. 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:

^{235}U Enrichment: The enrichment tolerance of ±0.05 w/o ^{235}U about the nominal fresh reference enrichment of 4.95 w/o ^{235}U and nominal enrichments of 1.30 w/o ^{235}U and 1.20 w/o ^{235}U was considered.

UO_2 Density: A ±2.0% variation about the nominal reference theoretical density (the nominal reference values are listed in Table 1 on page 25) was considered.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to 2.0% (the nominal reference values are listed in Table 1 on page 25) was considered.

Storage Cell I.D.: The ±0.10 inch tolerance about the nominal 8.27 inch reference cell I.D.was considered.

Storage Cell Pitch: The ±0.06 inch tolerance about the nominal 9.50 inch reference cell pitch was considered.

Stainless Steel Thickness: The ±0.01 inch tolerance about the nominal 0.09 inch reference stainless steel thickness for all rack structures was considered.

Assembly Position: The KENO-Va reference reactivity calculation assumes fuel assemblies are symmetrically positioned within the storage cells. Conservative calculations show that an increase in reactivity can occur if the corners of four fuel assemblies are positioned together. This reactivity increase is considered in the statistical summation of spent fuel rack tolerances.

Calculation Uncertainty: The 95 percent probability/95 percent confidence level uncertainty on the KENO-Va nominal reference K_{eff} was considered.

Methodology Uncertainty: The 95 percent probability/95 percent confidence uncertainty in the benchmarking bias as determined for the Westinghouse KENO-Va methodology was considered.

The 95/95 K_{eff} for the Prairie Island spent fuel rack 3x3 checkerboard storage configuration is developed by adding the calculational and methodology biases and the statistical sum of independent tolerances and uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 7 and results in a 95/95 K_{eff} of 0.94134 and 0.93466 for Westinghouse OFA and STD fuel assembly types, respectively.

Since K_{eff} is less than 0.95 including soluble boron credit and uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met for the 3x3 checkerboard configuration storage of 14x14 fuel assemblies in the Prairie Island spent fuel racks when cells are loaded in a 3x3 checkerboard with a 4.95 w/o ^{235}U Westinghouse OFA fuel assembly surrounded by any combination of 1.30 w/o ^{235}U Westinghouse OFA or 1.20 w/o ^{235}U Westinghouse STD fuel assemblies, respectively, including the presence of soluble boron as specified above.

4.3 Reactivity Equivalencing

Increased flexibility for storage of higher enrichment fuel assemblies is achievable using reactivity equivalencing. Reactivity equivalencing is predicated upon the reactivity decrease associated with fuel depletion, addition of Gadolinium burnable absorbers (GAD), and radioactive decay of the spent fuel.

4.3.1 Burnup and Decay Time Reactivity Equivalencing

Storage of fuel assemblies with enrichments higher than 1.30 w/o ^{235}U and 1.20 w/o ^{235}U for the Westinghouse OFA and STD fuel types in the Prairie Island spent fuel rack 3x3 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 and the radioactive decay of the spent fuel isotopes within the fuel assemblies.

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 6 on page 49 and Figure 7 on page 50 shows the constant K_{eff} contours as a function of assembly average burnup, for different decay times, generated for the Prairie Island spent fuel rack 3x3 checkerboard storage configuration. These curves represent combinations of fuel enrichment and discharge burnup which yield the same rack multiplication factor (K_{eff}) as the rack loaded with 1.30 w/o ^{235}U or 1.20 w/o ^{235}U fuel (at zero burnup) for Westinghouse OFA and STD fuel assemblies, respectively.

Uncertainties associated with burnup credit include a reactivity uncertainty of 0.01 ΔK at 30,000 MWD/MTU applied linearly to the burnup credit requirement to account for calculational and depletion uncertainties and 4% on the calculated burnup to account for burnup measurement uncertainty. The amount of additional soluble boron needed to account for these uncertainties in the burnup requirement of Figure 6 and Figure 7 are 350 ppm for Westinghouse OFA and 450 ppm for Westinghouse STD fuel assembly types. This is additional boron above the 250 ppm and 300 ppm required for Westinghouse OFA and STD fuel assembly types, respectively, as calculated in Section 4.2. This results in a total soluble boron credit of 600 ppm and 750 ppm for Westinghouse OFA and STD fuel assembly types, respectively.

Decay Time Credit is an extension of the Burnup Credit process which includes the time an assembly has been discharged as a variable. This methodology gains additional margin in reactivity and reduces the minimum burnup requirements. Spent fuel decay time credit results from the radioactive decay of isotopes in the spent fuel to daughter isotopes, which results in reduced reactivity. One of the major contributors is the decay of ^{241}Pu to ^{241}Am. In this report, credit is taken only for the decay of actinides. Decay of the fission products has the effect of further reducing the reactivity of the spent fuel.

In the decay time methodology reported here, the fission product isotopes are frozen at the concentrations existing at the time of discharge of the fuel (except ^{135}Xe which is removed). These calculations are performed at different discharge burnups. The actinide isotopes are allowed to decay based on their natural process. The loss in reactivity due to the radioactive decay of the spent fuel results in reducing the minimum burnup needed to meet the reactivity requirements. Thus for different decay times, a family of curves is generated which all yield the desired equivalent K_{eff} when stored in the spent fuel storage racks. In the decay time methodology the following assumptions are used in the models:

1. The fuel assemblies are modeled using the same criteria as Section 4.1.
2. Fuel is depleted using a conservatively high soluble boron letdown curve to enhance the buildup of plutonium making the fuel more reactive in the spent fuel storage racks. Sensitivity studies have shown that spectrum effects are also conservative for the decay time calculation.
3. No credit for fission product isotopic decay is used.
4. Actinide only isotopes decay is used.
5. Nominal spent fuel rack configuration/dimensions used.

With the above assumptions, the calculation of the decay time burnup credit curves are found to be conservative for use in the spent fuel pool criticality analysis.

It is important to recognize that the curves in Figure 6 and Figure 7 are 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 6 and Figure 7 are also provided in Table 9 on page 33 and Table 10 on page 34. Use of linear interpolation between the tabulated values is acceptable since the curves shown in Figure 6 and Figure 7 are linear in between the tabulated points.

The effect of axial burnup distribution on assembly reactivity has been considered in the development of the Prairie Island burnup credit limit. Previous evaluations have been performed to quantify axial burnup reactivity effects and to confirm that the reactivity equivalencing methodology described in Reference 1 results in calculations of conservative burnup credit limits. Since the 3x3 checkerboard burnup curves exceed the burnup-enrichment combinations at which the axial burnup reactivity effect is positive, an axial burnup reactivity bias is included in the generation of the burnup credit curves.

4.3.2 Gadolinium Credit Reactivity Equivalencing

Storage of fuel assemblies with enrichments higher than 1.30 w/o ^{235}U and 1.20 w/o ^{235}U for the Westinghouse OFA and STD fuel types in the Prairie Island spent fuel rack 3x3 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 the presence of Gadolinium burnable absorbers (GAD). GAD rods consist of the Gadolinium isotope mixed within the UO_2 fuel pellet. This neutron absorbing material is a non-removable part of the fuel assembly once it is manufactured.

Gadolinium in the fuel is handled by modeling the effect of the presence of the absorber in a 3x3 checkerboard configuration and then determining the acceptable enrichment of the surrounding fuel to assure the criticality limit.

The credit for the presence of Gadolinium in the fuel assemblies is based on matching the reactivity of these assemblies to an "equivalent enrichment" of fresh assemblies, without any burnup or any Gadolinium. This "equivalent enrichment" is determined using PHOENIX-P and using the maximum reactivity of the Gadolinium bearing assemblies during their lifetime. The assemblies with "equivalent enrichment" are put in a 3x3 checkerboard configuration (described in Section 4.1) and the enrichment for the assemblies surrounding the center location is determined so that the new 3x3 checkerboard configuration will still meet the reactivity limits. Table 8 on page 32 shows the results for the placement of the 4.95 w/o ^{235}U enrichment OFA assemblies with varying number of Gadolinium rods and the corresponding maximum permitted enrichment of the surrounding OFA and STD fuel.

The following assumptions are used for the GAD rod assemblies in the PHOENIX-P models:

1. The fuel assembly is modeled at its most reactive point in life. This includes the net effect of reactivity increase due to depletion of Gadolinium and loss of reactivity due to fuel burnup.
2. The fuel assembly uses a homogenized ^{235}U loading corresponding to the Gadolinium rod length and blanket enrichment.
3. The Gadolinium loading used in the analysis is 8 w/o Gd with a 132 inch length.
4. The fuel pellets are modeled assuming conservative theoretical density and dishing fraction.
5. The Gadolinium loading is reduced by an amount which corresponds to the minimum poison length offered for the given fuel assembly type. For instance, a 144 inch fuel stack with a minimum poison length of 132 inches would result in a 8.33% Gadolinium loading reduction to conservatively model the minimum poison length for that fuel assembly type.

With the above assumptions, the calculation of the Gadolinium burnup credit curves are found to be conservative for use in the spent fuel pool criticality analysis.

From these configurations, Figure 8 on page 51 through Figure 15 on page 58 shows the constant K_{eff} contour generated for the Prairie Island spent fuel rack 3x3 checkerboard storage configuration with the use of GAD. These curves represent combinations of fuel enrichment and discharge burnup which yield the same rack multiplication factor (K_{eff}) as the rack loaded with the enrichments specified in Table 8 (at zero burnup) for Westinghouse OFA and STD fuel assemblies. When assemblies contain more than 16 GAD rods, the burnup curves for 16 GAD rods should be used. This is because maximum reactivity of the 16 GAD rod depletion is always higher than that of an assembly containing more Gadolinium rods. Once the Gadolinium is gone, the reactivity behavior is consistent with unpoisoned fuel depletions.

It is important to recognize that the curves in Figure 8 through Figure 15 are 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 through Figure 15 are also provided in Table 11 on page 35 through Table 18 on page 42. Use of linear interpolation between the tabulated values is acceptable since the curves shown in Figure 8 through Figure 15 are linear in between the tabulated points.

Uncertainties associated with Gadolinium credit include 3% for manufacturing and 10% for calculational uncertainties. The amount of additional soluble boron needed to account for these uncertainties in the burnup requirement of Figure 8 through Figure 15 is 150 ppm for Westinghouse OFA fuel assembly type since GAD is only in the center assembly location which is an OFA fuel assembly. This is additional boron above the 250 ppm and 300 ppm required for Westinghouse OFA and STD fuel assembly types, respectively, as calculated in Section 4.2. This results in a total soluble boron credit of 400 ppm and 450 ppm for Westinghouse OFA and STD

fuel assembly types, respectively. The Gadolinium boron concentrations are bounded by the burnup credit boron concentration for reactivity equivalencing. The Gadolinium boron concentration is not additive since each is calculated using an independent integral method.

The Gadolinium rod patterns used in this analysis are shown in Figure 16 on page 59 .

5.0 Discussion of Postulated Accidents

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

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 or between rack modules and spent fuel pool wall	Design of the spent fuel racks is such that it precludes the insertion of a fuel assembly in these locations.

However, two accidents can be postulated for each storage configuration which would increase reactivity beyond the analyzed condition. The first postulated accident would be a loss of fuel pool cooling system and the second would be a misload of an assembly into a cell for which the restrictions on location, enrichment, burnup, decay time, or Gadolinium credit are not satisfied.

For the loss of fuel pool cooling system accident, calculations were performed for both all cell storage and 3x3 checkerboard storage to show the reactivity increase caused by a rise in the Prairie Island spent fuel pool water temperature from 150°F to 240°F. The reactivity increase for all cell storage is 0.01729 ΔK and 0.00835 ΔK for Westinghouse OFA and STD fuel assembly types, respectively. The reactivity increase for 3x3 checkerboard storage is 0.00661 ΔK and 0.00691 ΔK for Westinghouse OFA and STD fuel assembly types, respectively. The Westinghouse OFA and STD fuel assembly types conservatively bound the Exxon fuel assembly types.

For the misload assembly accident, calculations were performed for both all cell storage and 3x3 checkerboard storage to show the largest reactivity increase caused by a 4.95 w/o ^{235}U Westinghouse OFA fuel assembly misplaced into a storage cell. The reactivity increase caused by misplacing a fuel assembly in the storage cell will bound the reactivity increase caused by placing a fuel assembly into the cask loading area. This is because in the cask loading area only two faces of the assembly has interaction with other assemblies and in the storage cell all four faces of the assembly have interaction with other assemblies. The largest reactivity increase for all cell storage is 0.05201 ΔK and 0.05166 ΔK for Westinghouse OFA and STD fuel assembly types, respectively. The largest reactivity increase for 3x3 checkerboard storage is 0.05200 ΔK and 0.05891 ΔK for Westinghouse OFA and STD fuel assembly types, respectively. The Westinghouse OFA and STD fuel assembly types conservatively bound the Exxon fuel assembly types.

For an occurrence of the above postulated accident condition, 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 additional soluble boron in the storage pool water (above the concentration required for normal conditions and reactivity equivalencing) can be assumed as a realistic initial condition since not assuming its presence would be a second unlikely event.

The reactivity change due to the presence of soluble boron in the Prairie Island spent fuel pool has been calculated with PHOENIX-P for the all cell storage and the 3x3 checkerboard storage. The additional amount of soluble boron needed for accident conditions is shown below:

Storage Configuration	Fuel Assembly Type	Reactivity Increase (ΔK)	Soluble Boron Required for Accidents (ppm)	Total Soluble Boron Required (ppm)
All Cell Storage	W - OFA	0.05201	300	700
	W - STD	0.05166	350	800
3x3 Checkerboard Storage	W - OFA	0.05200	400	1000
	W - STD	0.05891	550	1300

Based on the above discussion, should a loss of spent fuel pool cooling accident or a fuel assembly misload occur in the Prairie Island spent fuel racks, K_{eff} will be maintained less than or equal to 0.95 due to the presence of at least 1300 ppm of soluble boron in the spent fuel pool water.

Table 19 shows a maximum of 750 ppm soluble boron without accidents assures the reactivity requirements of all fuel types and storage configurations considered here. Soluble boron concentration of 1300 ppm, similarly meets the requirements with the consideration of accidents discussed above. The limiting accident is found to be the misloading of a single assembly in the pool. If the single assembly misload accident can be eliminated from consideration through spent fuel pool verification and administrative controls, the loss of cooling is the limiting accident. Total soluble boron credit required with the inclusion of loss of pool water cooling is 900 ppm.

6.0 Soluble Boron Credit Summary

Spent fuel pool soluble boron has been used in this criticality analysis to offset storage rack and fuel assembly tolerances, calculational uncertainties, uncertainty associated with burnup credit and the reactivity increase caused by postulated accident conditions. The total soluble boron concentration required to be maintained in the spent fuel pool is a summation of each of these components. Table 19 on page 43 summarizes the storage configurations, fuel types and corresponding soluble boron credit requirements.

7.0 Storage Configuration Interface and Miscellaneous Requirements

The Prairie Island spent fuel pool is composed of single type of rack. The spent fuel pool areas have been analyzed for all cell storage, where all cells share the same storage requirements and limits, and a 3x3 checkerboard storage, where neighboring cells have different requirements and limits.

The following interface requirements are applicable for the Prairie Island storage cells:

All Cell Storage Next to 3x3 Checkerboard	The boundary between all cell storage and 3x3 checkerboard can be either separated by a vacant row of cells or the interface must be configured such that the first row of carryover uses the lower enrichment of the 3x3 checkerboard fuel assemblies. Figure 17 on page 60 illustrates the carryover configuration.
Open Water Cells	The all cell and 3x3 checkerboard configurations have been analyzed with every location containing a fuel assembly. In any location of the spent fuel pool, an open water cell is permitted to replace a fuel assembly since the water cell will not cause any increase in reactivity in the spent fuel pool.
Neutron Source in a Cell	The placement of a neutron source in the spent fuel pool will not cause any increase in reactivity in the spent fuel pool because the source displaces water which reduces reactivity.

8.0 Summary of Criticality Results

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. This report shows that the acceptance criteria for criticality is met for the Prairie Island spent fuel racks for the storage of 14x14 fuel assemblies under both normal and accident conditions with soluble boron credit, credit for the presence of the integral absorber Gadolinium in the fuel, credit for the radioactive decay time of the spent fuel, and no credit for the spent fuel rack Boraflex poison panels and the following storage configurations and enrichment limits:

All Cell Storage Enrichment Limits	Storage of 14x14 assemblies in any cell location with nominal enrichments no greater than 1.87 w/o ^{235}U for Westinghouse 14x14 OFA fuel assemblies and 1.77 w/o ^{235}U for Westinghouse 14x14 STD and Exxon 14x14 fuel assemblies. Fuel assemblies with initial nominal enrichments greater than these must satisfy the minimum burnup requirement and decay time shown in Figure 3 and Figure 4.
3x3 Checkerboard Enrichment Limits	Storage of Westinghouse 14x14 OFA assemblies with nominal enrichments no greater than 4.95 w/o ^{235}U in the center of a 3x3 checkerboard. The surrounding fuel assemblies must have an initial nominal enrichment no greater than 1.30 w/o ^{235}U for Westinghouse 14x14 OFA fuel assemblies and 1.20 w/o ^{235}U for Westinghouse 14x14 STD and other Exxon fuel assemblies. With Gadolinium credit, surrounding enrichments limits are increased as shown in Table 8. Fuel assemblies with initial nominal enrichments greater than these must satisfy the minimum burnup requirement and decay time shown in Figure 6 through Figure 15.

The soluble boron credit required for these storage configurations are 750 ppm for normal conditions and 1300 ppm for accidents.

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"; and the NRC Standard Review Plan, Section 9.1.2, "Spent Fuel Storage".

Table 1. Fuel Parameters Employed in the Criticality Analysis

Parameter	Westinghouse 14x14 OFA	Westinghouse 14x14 STD
Number of Fuel Rods per Assembly	179	179
Rod Zirc-4 Clad O.D. (inch)	0.400	0.422
Clad Thickness (inch)	0.0243	0.0243
Fuel Pellet O.D.(inch)	0.3444	0.3659
Fuel Pellet Density (% of Theoretical)	95	95
Fuel Pellet Dishing Factor (%)	1.1926	1.1870
Rod Pitch (inch)	0.556	0.556
Number of Zirc Guide Tubes	16	16
Guide Tube O.D. (inch)	0.526	0.539
Guide Tube Thickness (inch)	0.0170	0.0170
Number of Instrument Tubes	1	1
Instrument Tube O.D. (inch)	0.399	0.422
Instrument Tube Thickness (inch)	0.0235	0.0240

Table 2. Prairie Island All Cell Storage No Soluble Boron 95/95 K_{eff}

	W - OFA	W - STD
Nominal KENO-Va Reference Reactivity:	**0.96914**	**0.96799**
Calculational & Methodology Biases:		
Methodology (Benchmark) Bias	0.00770	0.00770
Pool Temperature Bias (50°F - 150°F)	0.00588	0.00663
TOTAL Bias	0.01358	0.01433
Tolerances & Uncertainties:		
UO_2 Enrichment Tolerance (±0.05 w/o ^{235}U)	0.00870	0.00901
UO_2 Density Tolerance (±2%)	0.00365	0.00336
Fuel Pellet Dishing Variation (0 to 2%)	0.00190	0.00174
Cell Inner Diameter (±0.10 inch)	0.00079	0.00102
Cell Pitch (±0.06 inch)	0.00733	0.00743
Cell Wall Thickness (±0.01 inch)	0.00765	0.00792
Asymmetric Assembly Position	0.00766	0.00672
Methodology Bias Uncertainty (95/95)	0.00300	0.00300
Calculational Uncertainty (95/95)	0.00272	0.00271
TOTAL Uncertainty (statistical)	0.01675	0.01661
Final K_{eff} Including Uncertainties & Tolerances:	**0.99947**	**0.99893**

Table 3. Prairie Island All Cell Storage Soluble Boron Credit K_{eff}

	W - OFA	W - STD
Nominal KENO-Va Reference Reactivity:	**0.90395**	**0.90823**
Calculational & Methodology Biases:		
Methodology (Benchmark) Bias	0.00770	0.00770
Pool Temperature Bias (50°F - 150°F)	0.00600	0.00668
TOTAL Bias	0.01370	0.01438
Tolerances & Uncertainties:		
UO_2 Enrichment Tolerance (±0.05 w/o ^{235}U)	0.00880	0.00909
UO_2 Density Tolerance (±2%)	0.00415	0.00378
Fuel Pellet Dishing Variation (0 to 2%)	0.00221	0.00198
Cell Inner Diameter (±0.10 inch)	0.00022	0.00039
Cell Pitch (±0.06 inch)	0.00757	0.00776
Cell Wall Thickness (±0.01 inch)	0.00561	0.00588
Asymmetric Assembly Position	0.00992	0.01075
Methodology Bias Uncertainty (95/95)	0.00300	0.00300
Calculational Uncertainty (95/95)	0.00262	0.00266
TOTAL Uncertainty (statistical)	0.01740	0.01809
Final K_{eff} Including Uncertainties & Tolerances:	**0.93505**	**0.94070**

Table 4. Prairie Island All Cell OFA Fuel Minimum Burnup Requirements

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	2377	2367	2357	2348	2339	2331	2324	2317	2311	2304	2298	2286	2274	2265	2257	2247
2.20	4995	4957	4923	4891	4861	4832	4805	4780	4757	4737	4718	4686	4653	4614	4577	4571
2.40	7521	7456	7397	7342	7289	7240	7193	7150	7110	7076	7045	6990	6934	6870	6808	6799
2.60	9964	9870	9786	9707	9633	9562	9496	9435	9379	9329	9285	9206	9128	9041	8956	8938
2.80	12330	12207	12097	11995	11899	11807	11722	11643	11570	11505	11446	11342	11242	11133	11029	10998
3.00	14625	14474	14338	14212	14094	13982	13878	13781	13692	13611	13538	13407	13284	13156	13036	12987
3.20	16856	16677	16515	16365	16225	16094	15971	15857	15752	15655	15567	15410	15264	15118	14983	14914
3.40	19029	18823	18635	18462	18301	18150	18009	17878	17757	17645	17542	17358	17189	17027	16878	16788
3.60	21151	20918	20706	20510	20328	20158	20000	19852	19716	19589	19471	19260	19069	18891	18730	18617
3.80	23229	22970	22734	22517	22315	22126	21951	21787	21635	21493	21362	21124	20912	20719	20545	20410
4.00	25269	24986	24727	24488	24267	24061	23869	23690	23523	23367	23222	22959	22726	22517	22331	22175
4.20	27278	26972	26691	26432	26193	25970	25762	25569	25388	25218	25060	24773	24520	24296	24096	23922
4.40	29262	28934	28634	28357	28100	27861	27638	27430	27236	27054	26883	26574	26302	26062	25848	25658
4.60	31229	30881	30562	30268	29995	29741	29504	29283	29076	28882	28701	28372	28081	27823	27594	27394
4.80	33184	32818	32483	32173	31886	31618	31368	31134	30915	30711	30520	30173	29866	29589	29342	29136
4.95	34647	34268	33923	33603	33306	33028	32768	32525	32298	32087	31890	31532	31213	30921	30658	30453

Table 5. Prairie Island All Cell STD Fuel Minimum Burnup Requirements

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	4195	4170	4144	4121	4102	4086	4072	4058	4043	4026	4007	3971	3949	3955	3970	3907
2.20	6890	6819	6753	6694	6640	6591	6546	6504	6464	6426	6389	6321	6267	6230	6201	6145
2.40	9493	9377	9274	9180	9093	9013	8939	8870	8807	8747	8692	8594	8508	8432	8365	8308
2.60	12009	11853	11713	11585	11467	11358	11257	11163	11076	10997	10924	10793	10677	10567	10467	10403
2.80	14446	14251	14076	13917	13769	13632	[illegible]	13387	13279	13180	13088	12926	12780	12640	12512	12436
3.00	16810	16578	16370	16180	16004	15841	15689	15549	15420	15302	15193	14999	14824	14657	14504	14413
3.20	19107	18840	18601	18382	18179	17991	17817	17655	17506	17369	17243	17018	16815	16624	16449	16339
3.40	21343	21044	20774	20528	20300	20088	19892	19710	19542	19387	19244	18988	18759	18545	18351	18221
3.60	23526	23196	22897	22624	22372	22139	21922	21721	21535	21362	21203	20917	20662	20428	20217	20064
3.80	25660	25301	24976	24678	24403	24148	23912	23693	23489	23300	23125	22809	22530	22277	22050	21875
4.00	27753	27367	27016	26694	26398	26123	25868	25631	25411	25207	25016	24672	24369	24098	23856	23659
4.20	29811	29399	29024	28680	28363	28069	27797	27543	27307	27087	26882	26511	26186	25897	25641	25422
4.40	31840	31404	31006	30641	30305	29993	29703	29434	29182	28948	28729	28333	27986	27679	27407	27170
4.60	33847	[illegible]	32969	32584	32229	31900	31594	31309	31043	30795	30563	30143	29775	29450	29162	28910
4.80	35838	35357	34919	34515	34143	33797	33475	33175	32895	32634	32390	31948	31560	31216	30910	30646
4.95	37324	36828	36376	35959	35574	35216	34882	34571	34281	34011	33758	33302	32900	32540	32219	31950

Table 6. Prairie Island 3x3 Checkerboard Storage No Soluble Boron 95/95 K_{eff}

	W - OFA	W - STD
Nominal KENO-Va Reference Reactivity:	**0.96157**	**0.95918**
Calculational & Methodology Biases:		
Methodology (Benchmark) Bias	0.00770	0.00770
Pool Temperature Bias (50°F - 150°F)	0.00416	0.00474
TOTAL Bias	0.01186	0.01244
Tolerances & Uncertainties:		
UO_2 Enrichment Tolerance (±0.05 w/o ^{235}U)	0.01332	0.01420
UO_2 Density Tolerance (±2%)	0.00404	0.00374
Fuel Pellet Dishing Variation (0 to 2%)	0.00214	0.00198
Cell Inner Diameter (±0.10 inch)	0.00039	0.00056
Cell Pitch (±0.06 inch)	0.00649	0.00653
Cell Wall Thickness (±0.01 inch)	0.00703	0.00723
Asymmetric Assembly Position	0.01985	0.02113
Calculational Uncertainty (95/95)	0.00195	0.00195
Methodology Bias Uncertainty (95/95)	0.00300	0.00300
TOTAL Uncertainty (statistical)	0.02640	0.02782
Final K_{eff} Including Uncertainties & Tolerances:	**0.99983**	**0.99944**

Table 7. Prairie Island 3x3 Checkerboard Storage Soluble Boron Credit K_{eff}

	W - OFA	W - STD
Nominal KENO-Va Reference Reactivity:	**0.90802**	**0.89614**
Calculational & Methodology Biases:		
Methodology (Benchmark) Bias	0.00770	0.00770
Pool Temperature Bias (50°F - 150°F)	0.00434	0.00481
TOTAL Bias	0.01204	0.01251
Tolerances & Uncertainties:		
UO_2 Enrichment Tolerance (±0.05 w/o ^{235}U)	0.01312	0.01390
UO_2 Density Tolerance (±2%)	0.00455	0.00427
Fuel Pellet Dishing Variation (0 to 2%)	0.00246	0.00229
Cell Inner Diameter (±0.10 inch)	0.00023	0.00019
Cell Pitch (±0.06 inch)	0.00670	0.00683
Cell Wall Thickness (±0.01 inch)	0.00470	0.00455
Asymmetric Assembly Position	0.01320	0.01949
Calculational Uncertainty (95/95)	0.00188	0.00191
Methodology Bias Uncertainty (95/95)	0.00300	0.00300
TOTAL Uncertainty (statistical)	0.02128	0.02601
Final K_{eff} Including Uncertainties & Tolerances:	**0.94134**	**0.93466**

Table 8. Gadolinium Credit Equivalent Enrichments for 3x3 Checkerboard

Center Assembly Fuel Type and Enrichment	Number of Gad Rods in Center Assembly	Enrichment and Fuel Type of Surrounding Burned Assemblies (w/o ^{235}U)
4.95 w/o OFA	0	1.30 w/o OFA
	4	1.44 w/o OFA
	8	1.58 w/o OFA
	12	1.65 w/o OFA
	16 or more	1.72 w/o OFA
	0	1.20 w/o STD
	4	1.34 w/o STD
	8	1.46 w/o STD
	12	1.54 w/o STD
	16 or more	1.62 w/o STD

Table 9. Prairie Island 3x3 Checkerboard OFA Minimum Burnup Requirements (No GAD Credit)

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	15184	14908	14660	14435	14229	14040	13866	13706	13558	13423	13298	13076	12881	12705	12549	12430
2.20	18088	17770	17483	17222	16983	16763	16560	16372	16199	16040	15892	15629	15398	15190	15005	14862
2.40	20887	20532	20211	19918	19649	19401	19171	18959	18763	18581	18413	18113	17849	17611	17398	17233
2.60	23591	23203	22851	22530	22234	21960	21706	21472	21254	21053	20867	20533	20239	19972	19733	19550
2.80	26207	25789	25410	25063	24743	24447	24171	23916	23680	23461	23258	22894	22572	22278	22014	21815
3.00	28743	28298	27895	27526	27184	26867	26572	26299	26045	25810	25592	25200	24853	24534	24246	24034
3.20	31207	30738	30314	29924	29563	29228	28915	28625	28356	28106	27874	27458	27087	26744	26434	26210
3.40	33606	33116	32673	32265	31887	31535	31207	30901	30617	30354	30111	29672	29279	28914	28582	28349
3.60	35948	35440	34979	34556	34162	33795	33452	33133	32836	32561	32306	31846	31433	31047	30696	30453
3.80	38243	37717	37241	36803	36395	36014	35658	35326	35017	34731	34466	33987	33555	33150	32779	32529
4.00	40496	39955	39465	39013	38593	38199	37831	37487	37167	36870	36595	36099	35650	35225	34837	34579
4.20	42717	42161	41658	41194	40761	40356	39976	39621	39290	38984	38700	38186	37721	37279	36874	36609
4.40	44912	44343	43828	43352	42907	42490	42099	41734	41394	41078	40785	40255	39774	39316	38895	38622
4.60	47091	46508	45981	45493	45037	44610	44208	43832	43482	43157	42856	42310	41814	41340	40905	40623
4.80	49261	48665	48124	47625	47158	46720	46308	45922	45562	45228	44918	44357	43845	43357	42908	42617
4.95	50887	50280	49730	49222	48747	48300	47880	47487	47120	46779	46462	45888	45366	44867	44408	44110

Table 10. Prairie Island 3x3 Checkerboard STD Minimum Burnup Requirements (No GAD Credit)

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	20043	19540	19081	18671	18308	17985	17693	17424	17171	16929	16699	16281	15956	15750	15601	15238
2.20	23074	22533	22042	21600	21203	20846	20520	20220	19940	19676	19428	18980	18615	18343	18122	17792
2.40	26011	25433	24910	24438	24010	23620	23263	22934	22629	22344	22078	21600	21196	20867	20587	20277
2.60	28860	28246	27692	27190	26732	26313	25928	25572	25243	24937	24653	24145	23706	23328	22997	22698
2.80	31625	30977	30393	29863	29378	28931	28519	28139	27787	27462	27161	26622	26151	25730	25357	25060
3.00	34312	33631	33019	32462	31951	31479	31043	30640	30267	29923	29606	29038	28537	28079	27669	27370
3.20	36925	36213	35575	34993	34458	33963	33504	33080	32689	32327	31994	31398	30868	30378	29936	29632
3.40	39469	38729	38066	37461	36904	36388	35909	35466	35056	34679	34331	33708	33152	32633	32163	31850
3.60	41950	41184	40498	39873	39296	38760	38263	37802	37376	36984	36622	35975	35395	34848	34351	34031
3.80	44372	43583	42877	42233	41638	41086	40571	40094	39653	39247	38873	38203	37601	37028	36505	36180
4.00	46741	45931	45208	44548	43938	43369	42839	42347	41893	41474	41089	40400	39777	39178	38628	38302
4.20	49061	48234	47497	46823	46199	45616	45072	44567	44100	43671	43276	42571	41928	41302	40722	40402
4.40	51338	50496	49748	49065	48429	47833	47276	46759	46281	45842	45441	44722	44061	43404	42792	42485
4.60	53576	52724	51969	51278	50632	50026	49457	48928	43440	47994	47587	46860	46182	45490	44840	44557
4.80	55780	54922	54164	53468	52815	52199	51619	51079	50583	50132	49721	48990	48296	47565	46869	46622
4.95	57414	56554	55796	55099	54442	53819	53232	52685	52184	51729	51317	50585	49880	49116	48381	48171

Table 11. Prairie Island 3x3 Checkerboard OFA 4 GAD Minimum Burnup Requirement

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	11271	11107	10958	10822	10697	10583	10478	10381	10292	10209	10133	9996	9877	9770	9676	9601
2.20	14117	13906	13714	13538	13377	13229	13093	12968	12852	12744	12644	12464	12308	12172	12053	11947
2.40	16862	16608	16377	16166	15972	15794	15630	15479	15338	15208	15086	14867	14677	14512	14367	14235
2.60	19512	19221	189[illegible]	18713	18489	18284	18094	17919	17756	17604	17463	17209	16988	16794	16624	16472
2.80	22076	21751	21455	21184	20935	20704	20491	20294	20110	19940	19781	19496	19245	19024	18827	18660
3.00	24561	24206	23883	23587	23314	23061	22827	22609	22407	22219	22045	21731	21454	21205	20983	20803
3.20	26975	26593	26246	25927	25633	25360	25106	24870	24651	24448	24259	23919	23617	23342	23095	22906
3.40	29325	28919	28551	28212	27899	27607	27335	27083	26848	26631	26429	26065	25740	25440	25169	24972
3.60	31618	31191	30804	30448	30117	29808	29520	29252	29003	28773	28559	28174	27828	27504	27209	27006
3.80	33863	33417	33012	32640	32293	31969	31666	31384	31122	30879	30654	30249	29883	29537	29220	29012
4.00	36067	35603	35183	34796	34434	34096	33779	33484	33209	32955	32720	32296	31911	31544	31207	30993
4.20	38237	37757	37323	36921	36546	36195	35865	35557	35271	35006	34761	34319	33917	33530	33174	32954
4.40	40382	39886	39438	39023	38635	38271	37929	37609	37312	37037	36783	36323	35904	35499	35126	34898
4.60	42508	41998	41535	41107	40707	40330	39976	39646	39338	39053	38789	38312	37877	37456	37068	36830
4.80	44623	44099	43622	43181	42768	42379	42014	41672	41354	41059	40786	40291	39840	39405	39005	38754
4.95	46207	45672	45184	44733	44310	43912	43539	43189	42863	42561	42280	41772	41308	40865	40458	40194

Table 12. Prairie Island 3x3 Checkerboard OFA 8 GAD Minimum Burnup Requirement

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	7975	7891	7816	7747	7683	7623	7567	7515	7468	7425	7386	7316	7251	7184	7121	7093
2.20	10736	10606	10488	10380	10280	10188	10102	10023	9950	9883	9821	9709	9609	9516	9430	9372
2.40	13404	13231	13074	12930	12798	12676	12563	12458	12361	12271	12188	12038	11906	11786	11679	11595
2.60	15984	15773	15580	15404	15242	15093	14954	14826	14707	14596	14494	14309	14146	14001	13871	13764
2.80	18484	18238	18013	17808	17619	17444	17282	17132	16992	16862	16742	16524	16333	16163	16011	15884
3.00	20910	20632	20379	20147	19933	19735	19551	19380	19222	19074	18937	18690	18472	18277	18104	17960
3.20	23269	22962	22683	22427	22190	21971	21767	21577	21401	21237	21084	20809	20567	20349	20153	19995
3.40	25567	25235	24932	24654	24396	24157	23934	23727	23534	23355	23189	22888	22622	22381	22164	21993
3.60	27812	27455	27131	26833	26556	26299	26059	25835	25627	25434	25254	24930	24642	24378	24141	23959
3.80	30009	29631	29287	28970	28676	28402	28145	27907	27684	27478	27286	26940	26631	26346	26088	25897
4.00	32166	31768	31406	31072	30761	30471	30200	29946	29711	29492	29289	28922	28593	28287	28009	27811
4.20	34289	33872	33493	33144	32817	32512	32227	31960	31712	31481	31268	30882	30534	30208	29910	29705
4.40	36385	35951	35556	35191	34850	34531	34232	33952	33692	33451	33227	32822	32456	32111	31794	31583
4.60	38461	38009	37599	37219	36864	36532	36220	35928	35657	35405	35171	34749	34365	34001	33667	33449
4.80	40523	40054	39628	39235	38866	38521	38196	37893	37610	37348	37105	36666	36265	35883	35532	35308
4.95	42065	41583	41146	40741	40363	40008	39674	39362	39072	38802	38552	38100	37687	37292	36929	36699

Table 13. Prairie Island 3x3 Checkerboard OFA 12 GAD Minimum Burnup Requirement

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	6505	6449	6401	6357	6314	6273	6234	6198	6165	6137	6112	6069	6024	5967	5909	5909
2.20	9221	9121	9032	8950	8874	8803	8737	8675	8619	8567	8520	8435	8357	8281	8210	8171
2.40	11847	11707	11580	11464	11357	11257	11165	11080	11001	10927	10859	10736	10628	10531	10443	10372
2.60	14389	14212	14051	13903	13767	13641	13525	13417	13316	13222	13135	12977	12840	12720	12614	12517
2.80	16854	16643	16450	16273	16110	15959	15820	15691	15570	15458	15353	15163	14998	14854	14728	14611
3.00	19248	19005	18783	18579	18392	18218	18057	17907	17768	17638	17517	17298	17107	16939	16790	16657
3.20	21577	21305	21056	20828	20617	20422	20241	20072	19915	19769	19633	19387	19170	18978	18806	18661
3.40	23848	23548	23276	23025	22793	22577	22376	22190	22016	21855	21705	21434	21194	20977	20782	20627
3.60	26066	25742	25446	25175	24923	24688	24469	24266	24077	23901	23738	23444	23181	22940	22722	22560
3.80	28238	27890	27575	27284	27013	26761	26525	26305	26102	25913	25737	25422	25138	24873	24632	24463
4.00	30370	30001	29666	29357	29069	28800	28548	28314	28096	27895	27708	27371	27067	26780	26518	26343
4.20	32469	32079	31726	31400	31096	30812	30545	30297	30066	29852	29655	29298	28975	28667	28384	28203
4.40	34540	34131	33761	33420	33100	32801	32521	32259	32016	31790	31582	31206	30864	30537	30237	30047
4.60	36590	36163	35777	35420	35086	34773	34480	34205	33950	33714	33495	33100	32741	32397	32082	31882
4.80	38625	38181	37779	37407	37060	36734	36428	36142	35876	35629	35399	34985	34609	34251	33924	33710
4.95	40145	39689	39275	38892	38535	38200	37885	37591	37317	37061	36824	36395	36007	35641	35306	35079

Table 14. Prairie Island 3x3 Checkerboard OFA 16 or More GAD Minimum Burnup Requirement

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	5124	5090	5061	5034	5007	4981	4956	4933	4912	4894	4879	4853	4823	4782	4740	4748
2.20	7799	7725	7639	7598	7541	7487	7436	7389	7347	7308	7273	7211	7152	7087	7025	7008
2.40	10386	10274	10174	10082	9996	9915	9840	9771	9707	9648	9595	9499	9411	9322	9240	9200
2.60	12892	12745	12612	12490	12377	12271	12173	12082	11998	11921	11849	11721	11605	11494	11393	11330
2.80	15323	15143	14979	14829	14690	14560	14440	14329	14225	14130	14042	13883	13740	13607	13486	13403
3.00	17684	17473	17281	17104	16941	16789	16648	16517	16395	16282	16178	15990	15822	15667	15527	15425
3.20	19982	19742	19523	19322	19135	18962	18801	18651	18512	18383	18263	18047	17855	17679	17521	17401
3.40	22223	21956	21712	21487	21279	21086	20906	20738	20582	20438	20303	20061	19845	19649	19472	19336
3.60	24413	24120	23852	23606	23378	23165	22967	22783	22611	22452	22304	22036	21798	21581	21386	21235
3.80	26558	26240	25951	25684	25437	25206	24991	24791	24604	24431	24269	23978	23719	23482	23269	23104
4.00	28663	28323	28013	27727	27462	27214	26983	26767	26567	26380	26206	25892	25613	25357	25125	24949
4.20	30735	30374	30045	29741	29458	29195	28948	28718	28504	28305	28119	27784	27485	27210	26961	26774
4.40	32780	32399	32052	31731	31433	31154	30893	30649	30422	30211	30015	29660	29342	29048	28781	28585
4.60	34804	34404	34040	33704	33390	33097	32822	32565	32326	32104	31897	31524	31188	30875	30590	30387
4.80	36813	36395	36015	35664	35336	35029	34742	34473	34222	33989	33773	33382	33029	32697	32394	32186
4.95	38314	37883	37491	37130	36792	36475	36178	35900	35642	35401	35178	34775	34410	34064	33748	33536

Table 15. Prairie Island 3x3 Checkerboard STD 4 GAD Minimum Burnup Requirement

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	14876	14559	14277	14022	13789	13575	13379	13201	13040	12894	12762	12529	12318	12112	11924	11833
2.20	17900	17528	17198	[illegible]	16625	16372	16140	15928	15735	15560	15401	15120	14865	14617	14390	14276
2.40	20805	20385	20011	[illegible]	19360	19073	18809	18566	18344	18142	17957	17631	17337	17053	16793	16653
2.60	23601	23137	22724	22349	22004	21686	21392	21121	20873	20646	20439	20070	19739	19424	19136	18969
2.80	26296	25795	25347	24939	24563	24217	23896	23601	23329	23079	22850	22442	22078	21735	21425	21228
3.00	28900	28366	27886	27448	27046	26674	26330	26012	25718	25448	25199	24754	24359	23993	23664	23437
3.20	31422	30859	30351	29887	29460	29065	28699	28361	28048	27758	27491	27012	26589	26202	25856	25600
3.40	33872	33283	32750	32262	31812	31396	31011	30654	30324	30017	29733	29223	28773	28368	28006	27722
3.60	36258	35647	35090	34581	34111	33677	33274	32900	32553	32231	31931	31392	30918	30495	30119	29809
3.80	38590	37958	37381	36852	36364	35913	35494	35104	34742	34405	34092	33526	33029	32589	32198	31866
4.00	40877	40226	39631	39084	38579	38112	37678	37274	36898	36548	36221	35631	35113	34655	34249	33898
4.20	43128	42459	41848	41285	40764	40282	39834	39416	39027	38664	38326	37713	37175	36698	36275	35910
4.40	45353	44667	44039	43462	42927	42430	41968	41538	41136	40761	40412	39779	39221	38724	38281	37907
4.60	47560	46857	46215	45623	45075	44564	44089	43645	43231	42845	42486	41835	41258	40737	40271	39894
4.80	49759	49038	48382	47777	47215	46691	46202	45745	45319	44923	44554	43887	43292	42744	42249	41877
4.95	51408	50673	50007	49393	48821	48287	47787	47320	46885	46481	46105	45428	44818	44247	43728	43365

Table 16. Prairie Island 3x3 Checkerboard STD 8 GAD Minimum Burnup Requirement

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	11272	11075	10907	10753	10607	10468	10338	10221	10119	10033	9960	9837	9702	9516	9327	9374
2.20	14225	13970	13747	13544	13354	13175	13010	12859	12724	12605	12501	12322	12143	11932	11727	11718
2.40	17062	16754	16482	16235	16005	15791	15592	15410	15246	15098	14966	14736	14517	14282	14058	14001
2.60	19791	19436	19121	18834	18569	18322	18093	17883	17691	17518	17361	17084	16828	16569	16326	16228
2.80	22422	22025	21671	21349	21051	20775	20519	20283	20067	19870	19690	19372	19082	18798	18536	18404
3.00	24963	24529	24141	23787	23461	23158	22877	22618	22379	22161	21961	21605	21284	20976	20695	20532
3.20	27424	26957	26539	26157	25804	25477	25174	24893	24635	24397	24178	23788	23438	23107	22806	22618
3.40	29814	29318	28872	28465	28089	27740	27416	27116	26839	26584	26348	25927	25550	25197	24877	24666
3.60	32142	31620	31150	30720	30322	29953	29611	29293	28999	28727	28476	28026	27624	27250	26911	26680
3.80	34418	33872	33380	32929	32512	32124	31764	31430	31120	30833	30568	30092	29666	29271	28915	28665
4.00	36650	36083	35570	35100	34664	34260	33884	33534	33209	32909	32630	32128	31681	31267	30894	30626
4.20	38848	38261	37729	37240	36788	36368	35976	35612	35273	34959	34667	34142	33673	33241	32853	32567
4.40	41020	40414	39864	39358	38890	38454	38048	37670	37318	36990	36686	36137	35647	35200	34798	34492
4.60	43176	42552	41984	41461	40977	40526	40106	39714	39349	39009	38692	38119	37610	37148	36734	36407
4.80	45325	44683	44096	43557	43057	42592	42158	41752	41374	41021	40691	40093	39565	39090	38666	38315
4.95	46938	46281	45681	45128	44617	44140	43696	43280	42892	42528	42188	41572	41029	40547	40117	39745

Table 17. Prairie Island 3x3 Checkerboard STD 12 GAD Minimum Burnup Requirement

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	9193	9059	8946	8842	8742	8646	8556	8474	8403	8343	8294	8212	8117	7979	7837	7884
2.20	12080	11887	11720	11567	11424	11288	11161	11045	10942	10851	10773	10638	10501	10334	10168	10172
2.40	14857	14611	14395	14199	14015	13843	13682	13535	13403	13284	13180	12997	12821	12625	12436	12402
2.60	17533	17238	16979	16743	16523	16318	16127	15951	15792	15648	15519	15292	15080	14857	14646	14577
2.80	20114	19777	19479	19206	18954	18719	18500	18299	18115	17948	17797	17529	17284	17035	16803	16703
3.00	22611	22236	21902	21597	21315	21053	20809	20584	20378	20190	20018	19714	19436	19164	18911	18783
3.20	25031	24622	24256	23922	23613	23326	23060	22813	22586	22378	22188	21849	21543	21247	20975	20822
3.40	27383	26943	26549	26188	25855	25545	25258	24991	24746	24520	24312	23942	23608	23291	23001	22823
3.60	29675	29208	28787	28403	28047	27717	27410	27125	26862	26620	26396	25996	25637	25299	24992	24792
3.80	31915	31423	30979	30573	30196	29847	29522	29220	28941	28683	28444	28016	27634	27277	26953	26732
4.00	34113	33598	33132	32705	32299	31942	31600	31283	30988	30716	30463	30008	29603	29228	28889	28647
4.20	36276	35740	35253	34806	34393	34009	33651	33319	33010	32723	32457	31977	31550	31158	30805	30542
4.40	38413	37856	37350	36885	36454	36054	35681	35334	35011	34711	34431	33927	33478	33071	32705	32421
4.60	40531	39955	39430	38946	38499	38083	37696	37335	36998	36685	36392	35863	35394	34972	34595	34289
4.80	42641	42045	41500	40999	40535	40104	39702	39327	38977	38649	38344	37790	37301	36866	36478	36148
4.95	44222	43611	43052	42537	42060	41617	41204	40819	40458	40121	39805	39232	38729	38284	37890	37541

Table 18. Prairie Island 3x3 Checkerboard STD 16 or More GAD Minimum Burnup Requirement

Enrichment	Decay Time (years)															
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
1.62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.00	7316	7231	7158	7091	7029	6969	6913	6862	6815	6775	6739	6677	6616	6541	6468	6468
2.20	10131	9990	9866	9753	9648	9549	9458	9373	9297	9228	9167	9060	8958	8848	8742	8717
2.40	12844	12651	12481	12326	12182	12048	11923	11809	11704	11610	11524	11374	11235	11092	10957	10906
2.60	15462	15223	15010	14816	14636	14470	14315	14173	14043	13924	13816	13625	13451	13278	13117	13041
2.80	17993	17711	17459	17230	17018	16822	16640	16472	16317	16176	16047	15818	15611	15411	15227	15125
3.00	20443	20123	19836	19574	19333	19109	18902	18710	18534	18372	18223	17958	17720	17495	17290	17162
3.20	22821	22466	22147	21856	21587	21338	21107	20894	20697	20516	20348	20049	19782	19534	19310	19157
3.40	25134	24748	24399	24080	23787	23515	23263	23029	22813	22613	22428	22097	21803	21534	21292	21115
3.60	27390	26975	26599	26255	25938	25645	25373	25120	24886	24670	24468	24107	23787	23498	23239	23039
3.80	29595	29154	28753	28386	28047	27734	27444	27174	26923	26690	26473	26083	25739	25431	25157	24934
4.00	31758	31292	30868	30479	30121	29789	29481	29194	28928	28679	28448	28031	27664	27337	27048	26804
4.20	33886	33397	32951	32542	32165	31815	31490	31188	30906	30643	30398	29955	29566	29222	28917	28654
4.40	35986	35475	35009	34581	34185	33818	33478	33160	32864	32587	32328	31860	31450	31088	30768	30487
4.60	38067	37535	37048	36601	36188	35805	35448	35116	34805	34515	34244	33752	33321	32942	32605	32308
4.80	40134	39581	39076	38610	38180	37780	37408	37061	36737	36433	36150	35636	35184	34786	34433	34122
4.95	41681	41113	40593	40114	39670	39258	38875	38516	38182	37869	37576	37045	36579	36166	35800	35480

Table 19. Summary of the Soluble Boron Credit Requirements

Storage Configuration	Fuel Assembly Type	Soluble Boron Required for Tolerances/ Uncertainties (ppm)	Soluble Boron Required for Reactivity Equivalencing (ppm)	Total Soluble Boron Credit Required Without Accidents (ppm)	Soluble Boron Required for Accidents (ppm)	Total Soluble Boron Credit Required With Accidents (ppm)
All Cell Storage	W - OFA W - STD	200 200	200 250	400 450	300 350	700 800
3x3 Checkerboard Storage	W - OFA W - STD	250 300	350 450	600 750	400 550	1000 1300

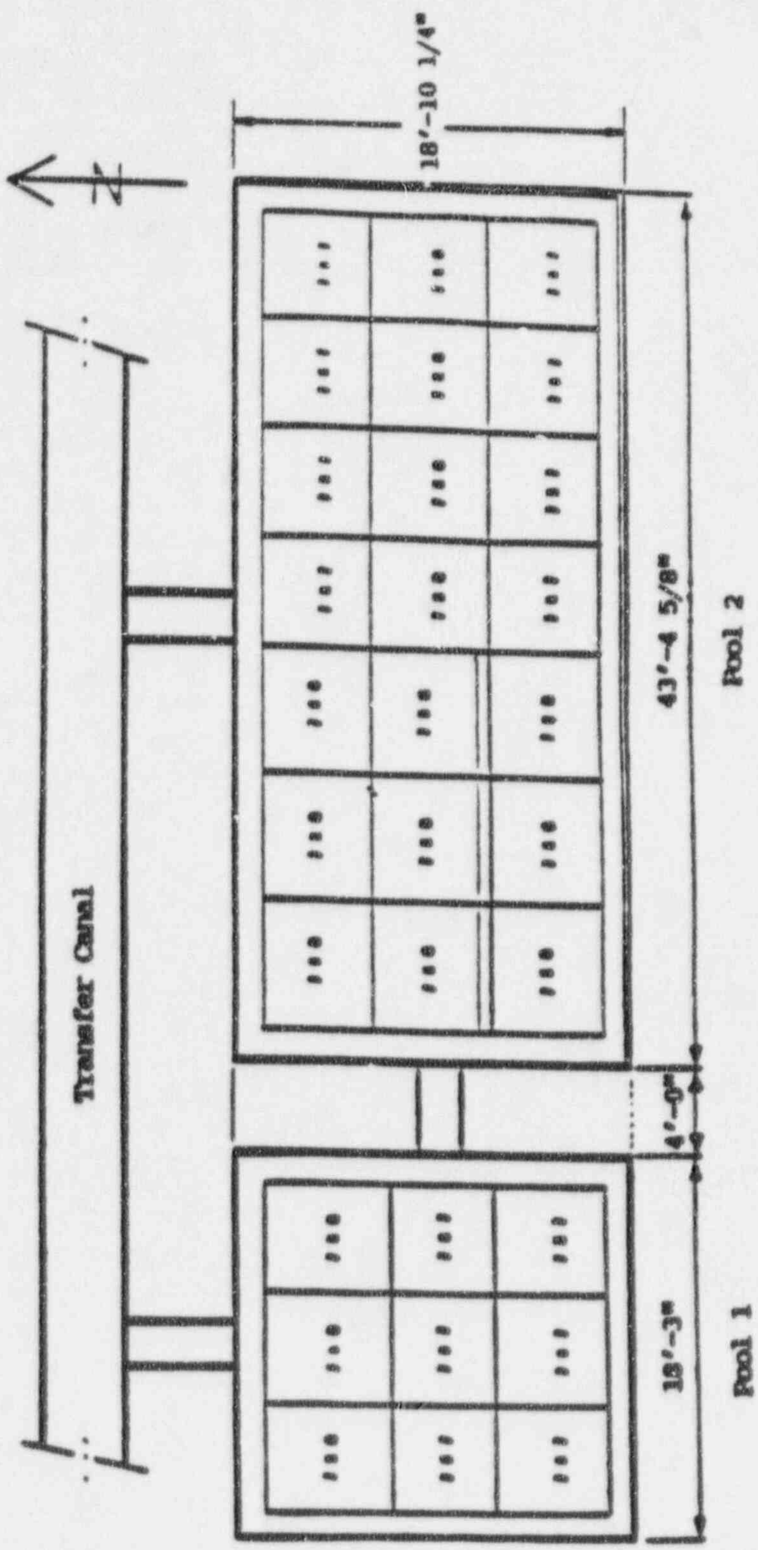


Figure 1. Prairie Island Spent Fuel Rack Layout

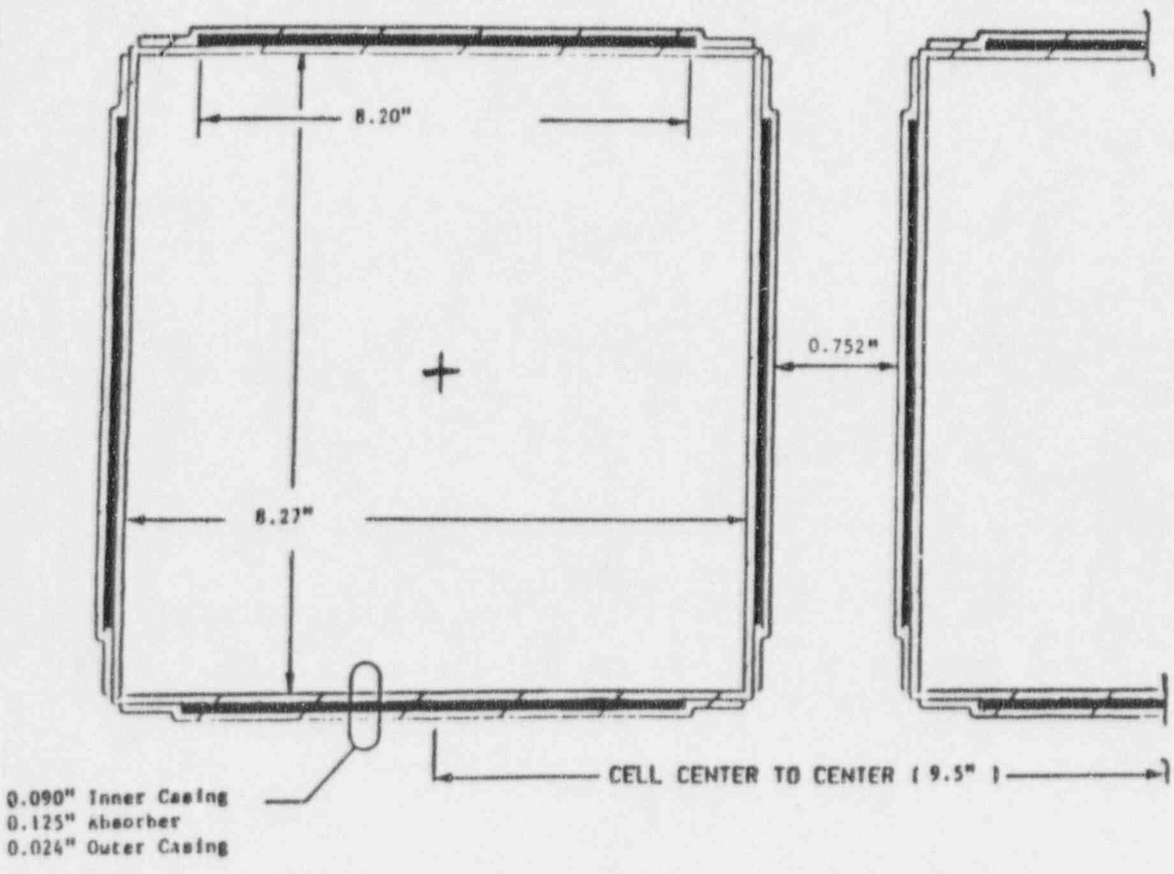


Figure 2. Prairie Island Spent Fuel Storage Cell Nominal Dimensions

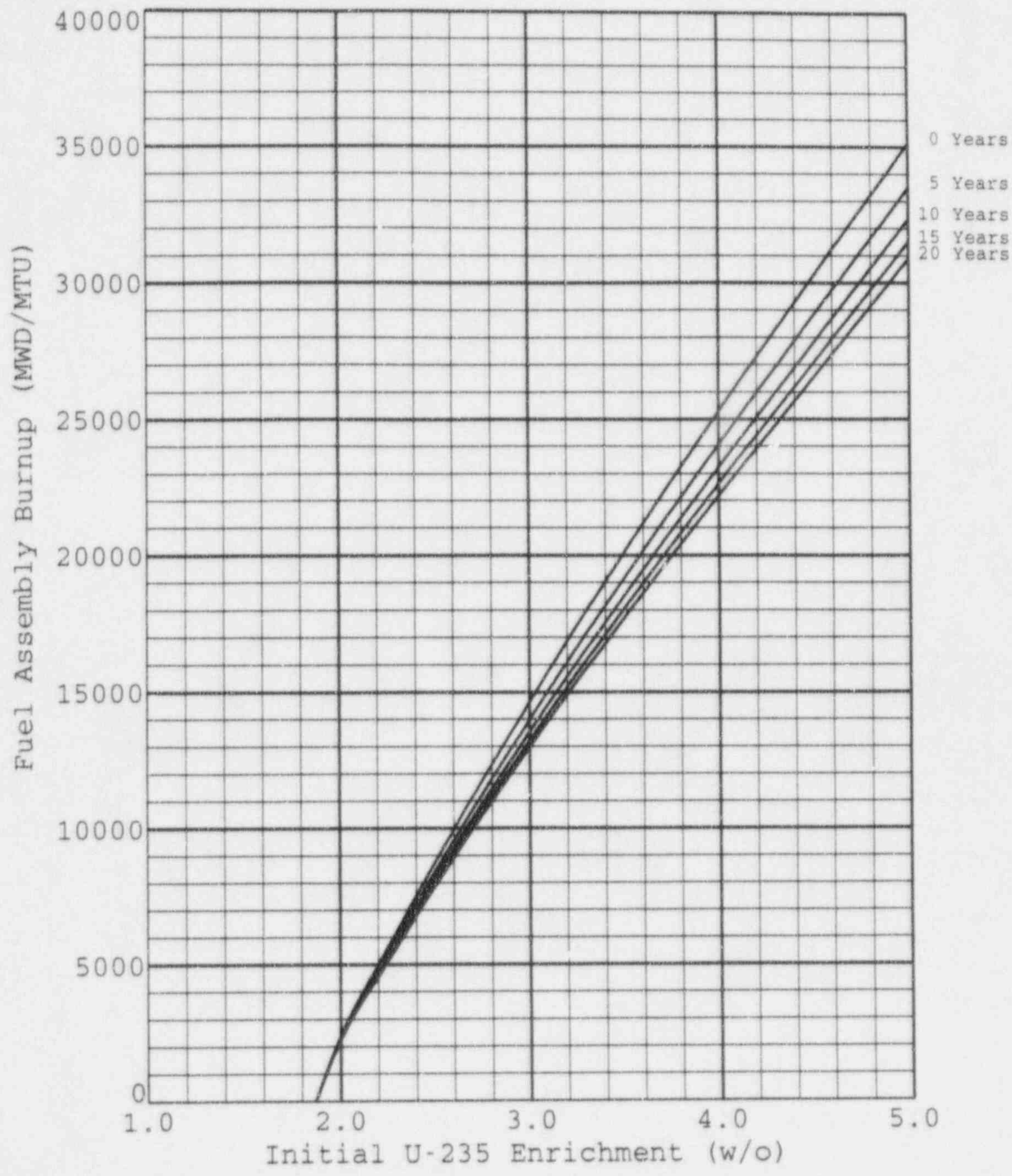


Figure 3. Prairie Island All Cell OFA Storage Burnup Credit and Decay Time Requirement

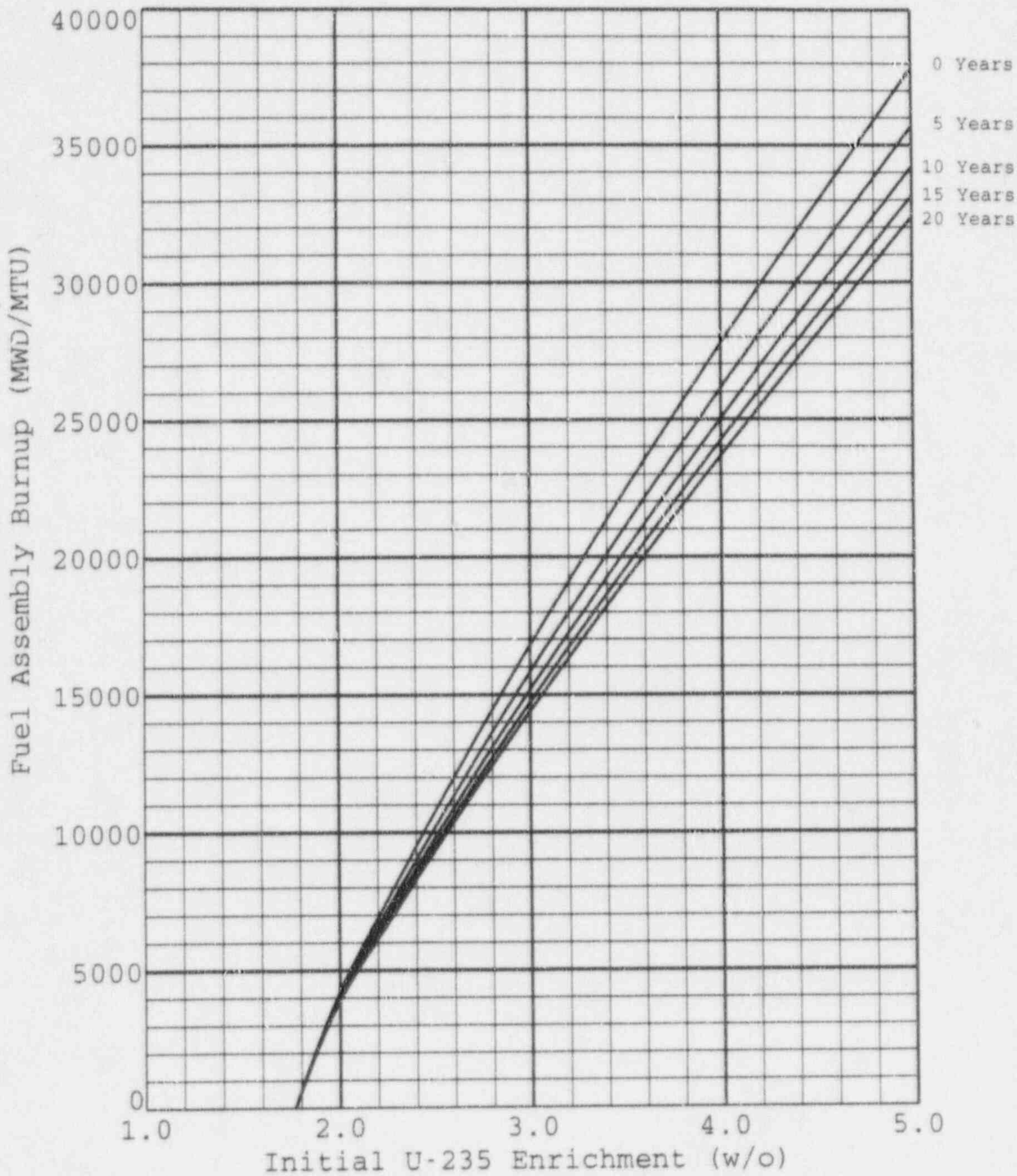
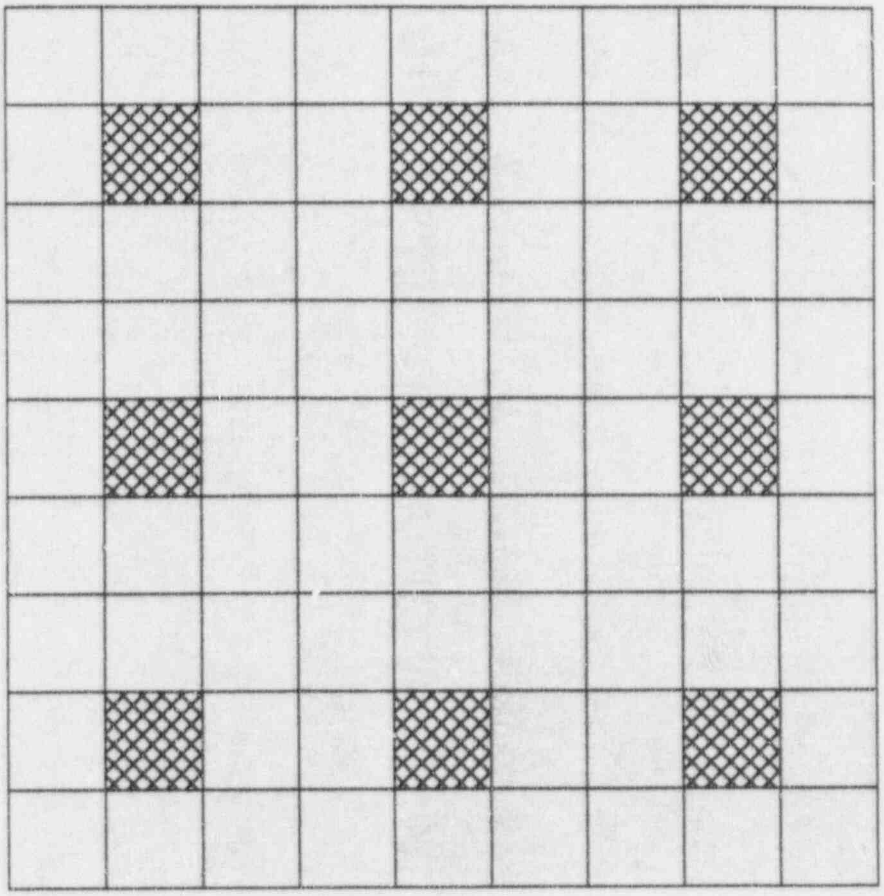


Figure 4. Prairie Island All Cell STD Storage Burnup Credit and Decay Time Requirement



Fresh Fuel: Must be less than or equal to nominal 4.95 w/o ^{235}U

Burned Fuel: Must satisfy the minimum burnup requirements of Figure 6 to 15 depending on number of GAD rods in fresh fuel

Figure 5. Prairie Island 3x3 Checkerboard Layout Requirement

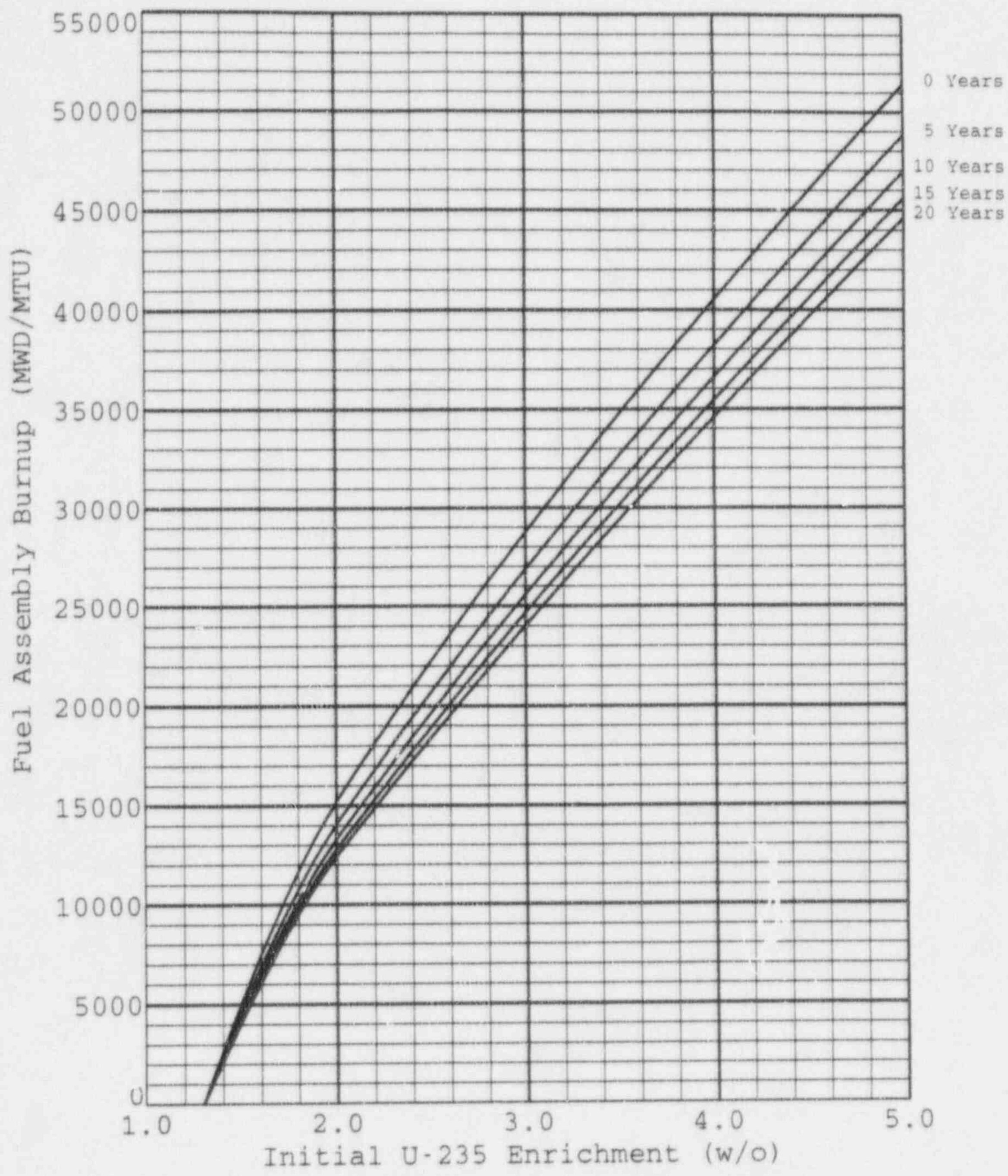


Figure 6. Prairie Island 3x3 Checkerboard OFA Storage Burnup Credit and Decay Time Requirement (No GAD Credit)

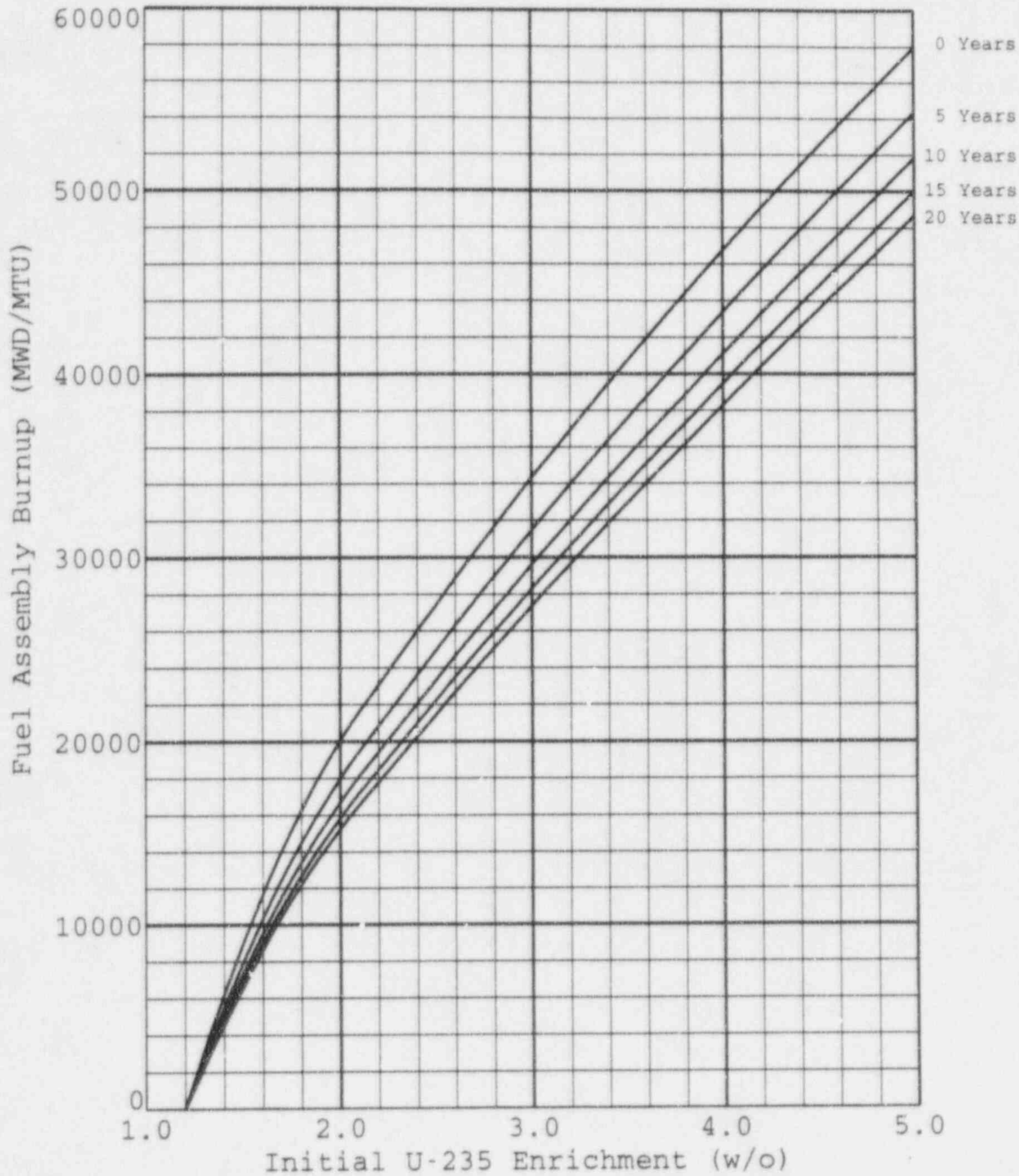


Figure 7. Prairie Island 3x3 Checkerboard STD Storage Burnup Credit and Decay Time Requirement (No GAD Credit)

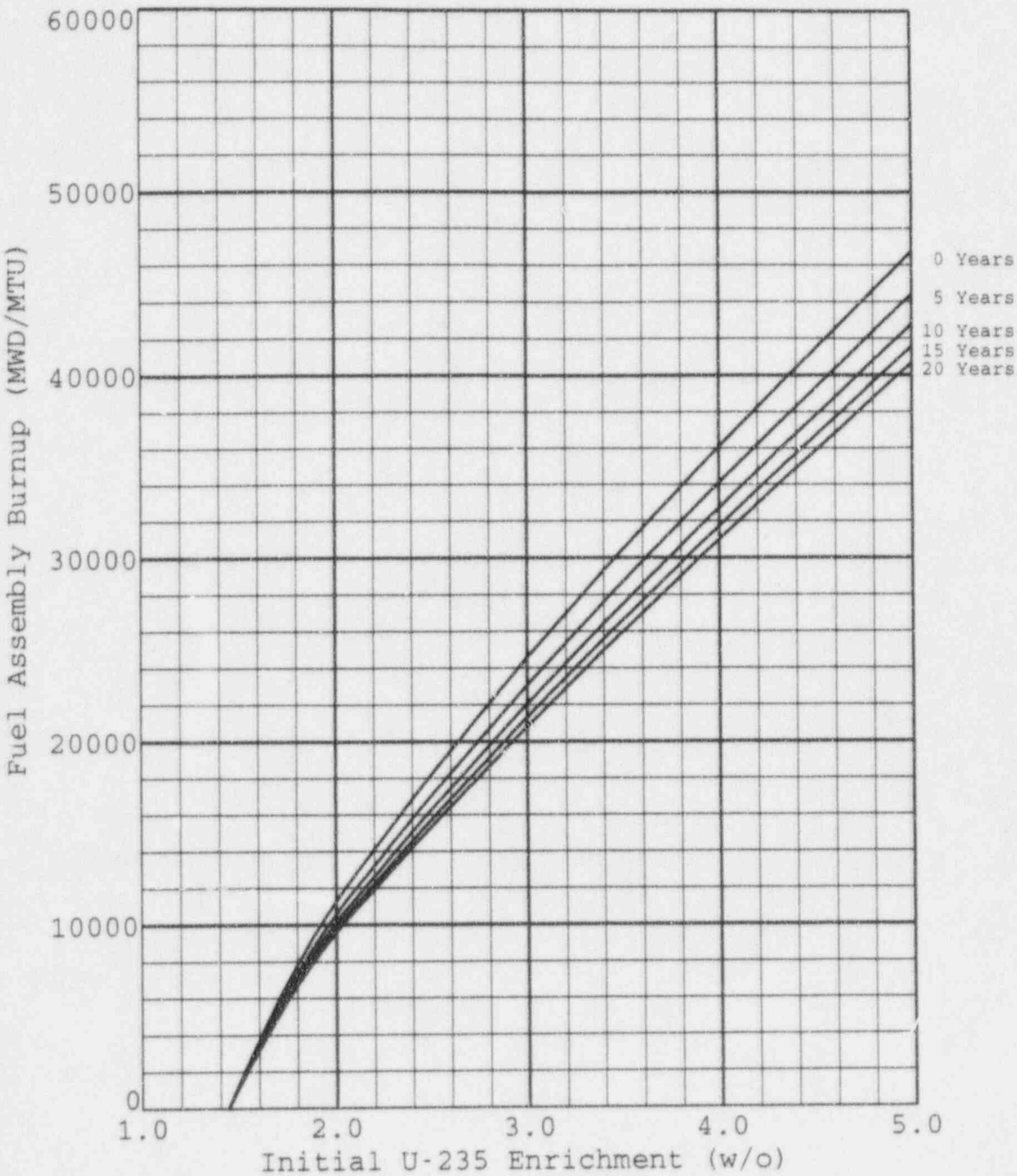


Figure 8. Prairie Island 3x3 Checkerboard OFA 4 GAD Storage Burnup Credit and Decay Time Requirement

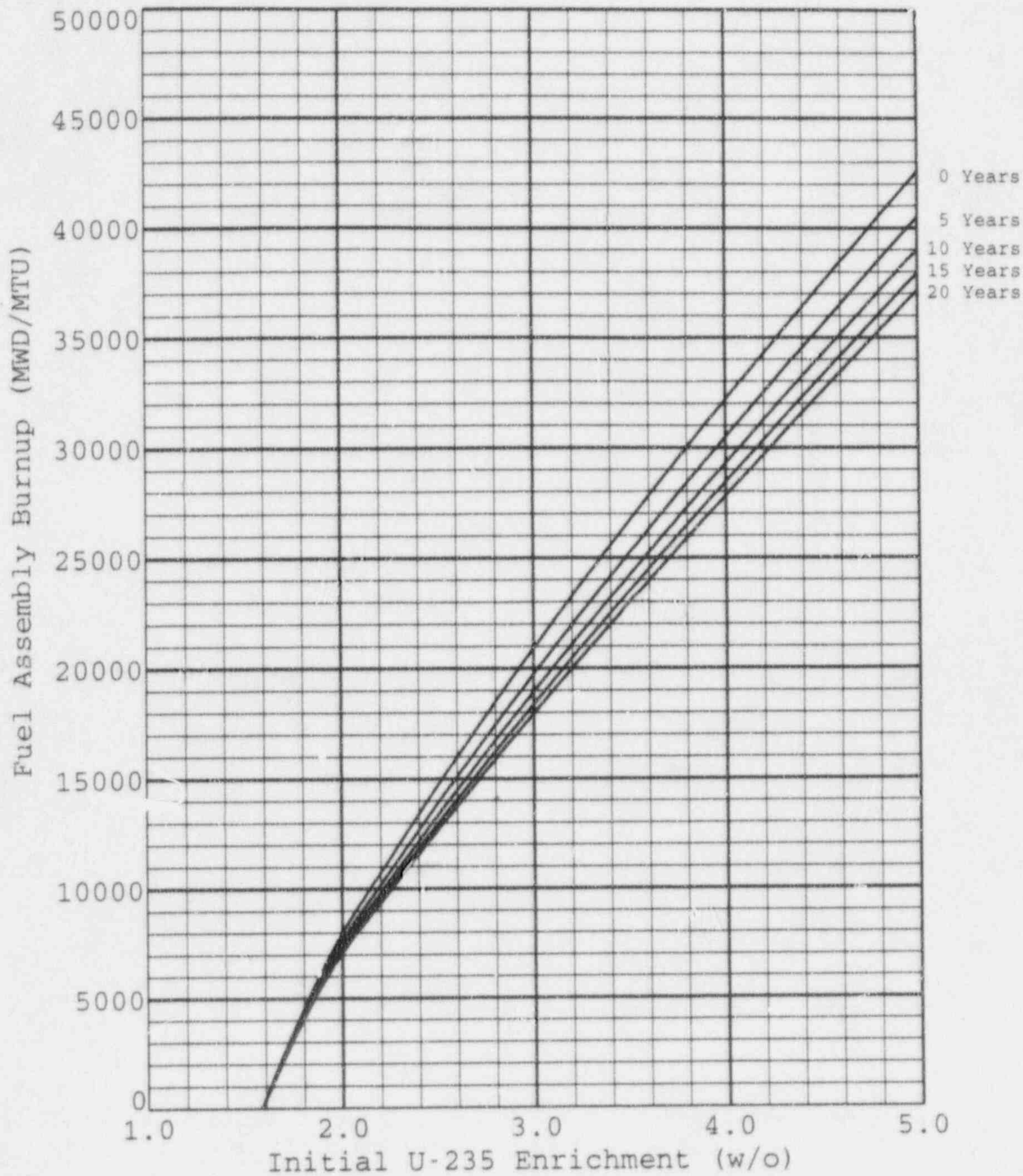


Figure 9. Prairie Island 3x3 Checkerboard OFA 8 GAD Storage Burnup Credit and Decay Time Requirement

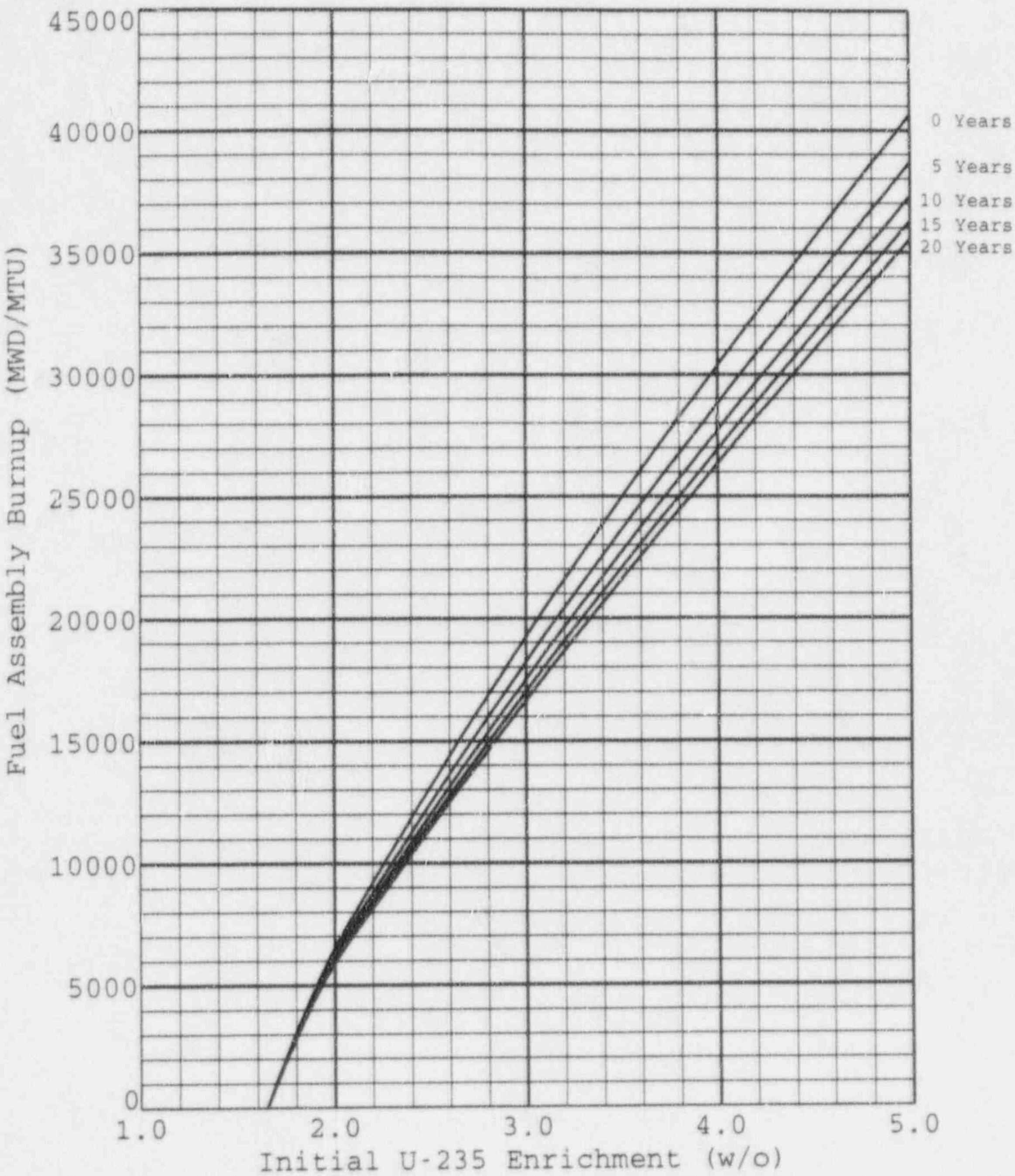


Figure 10. Prairie Island 3x3 Checkerboard OFA 12 GAD Storage Burnup Credit and Decay Time Requirement

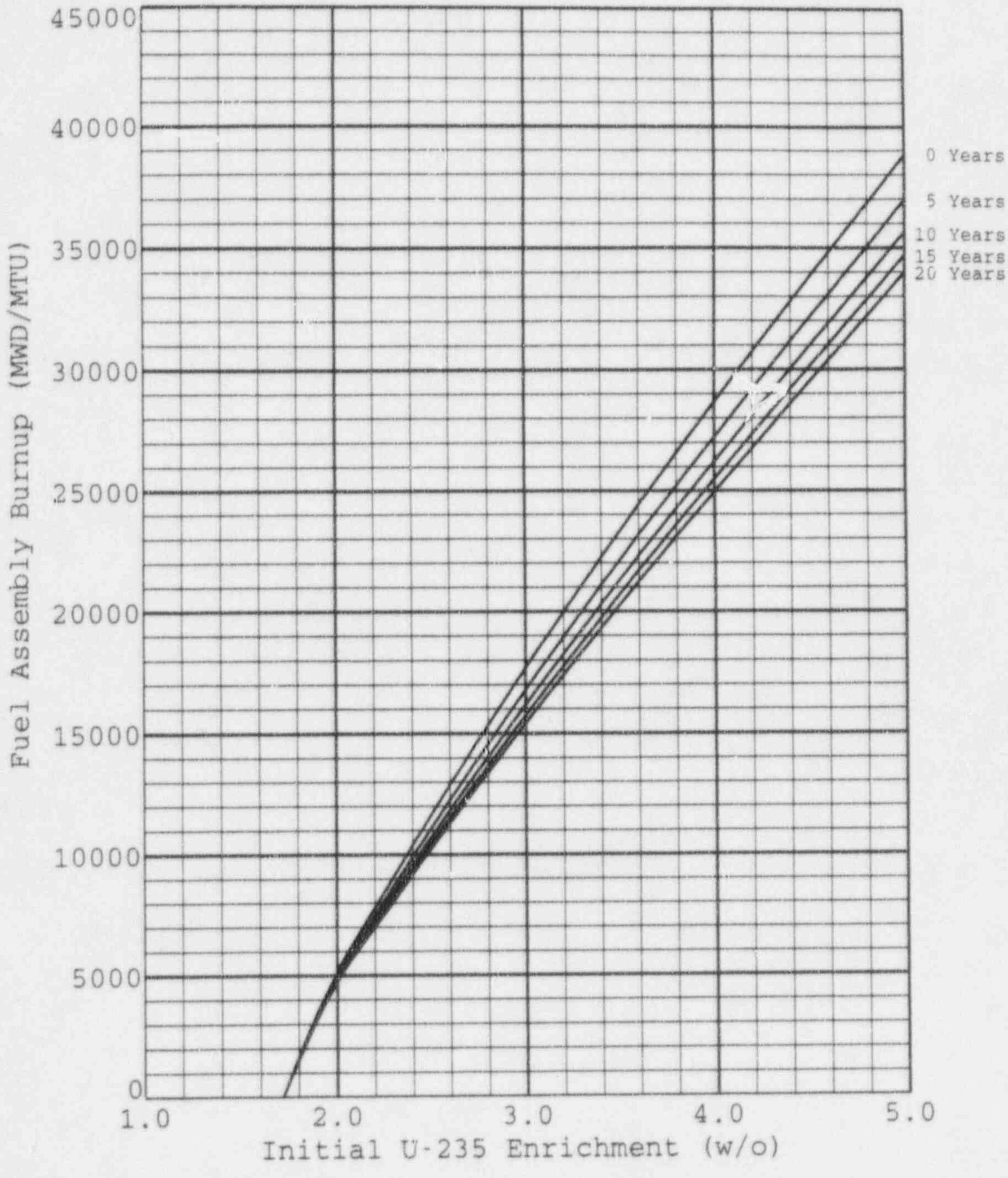


Figure 11. Prairie Island 3x3 Checkerboard OFA 16 or More GAD Storage Burnup Credit and Decay Time Requirement

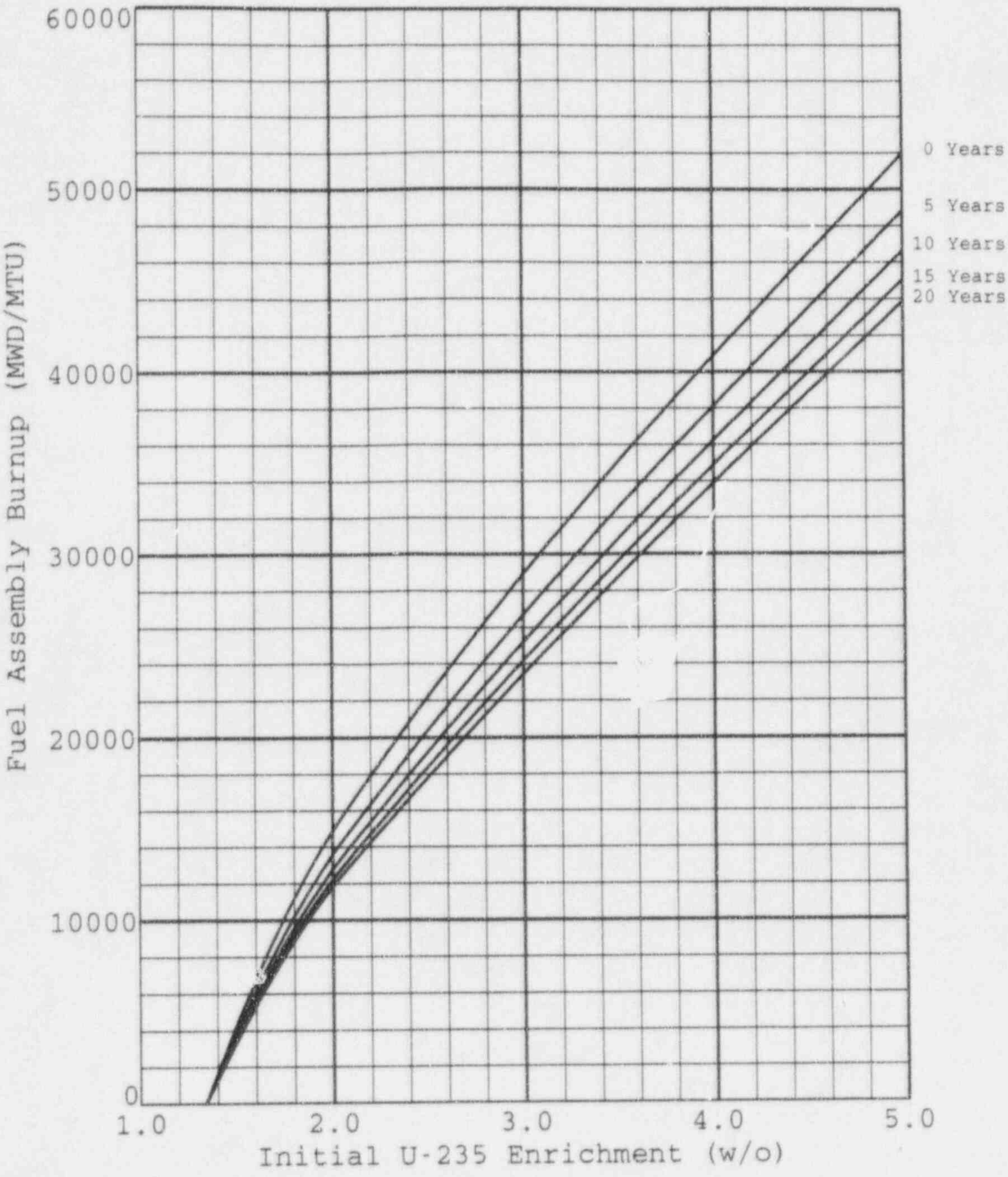


Figure 12. Prairie Island 3x3 Checkerboard STD 4 GAD Storage Burnup Credit and Decay Time Requirement

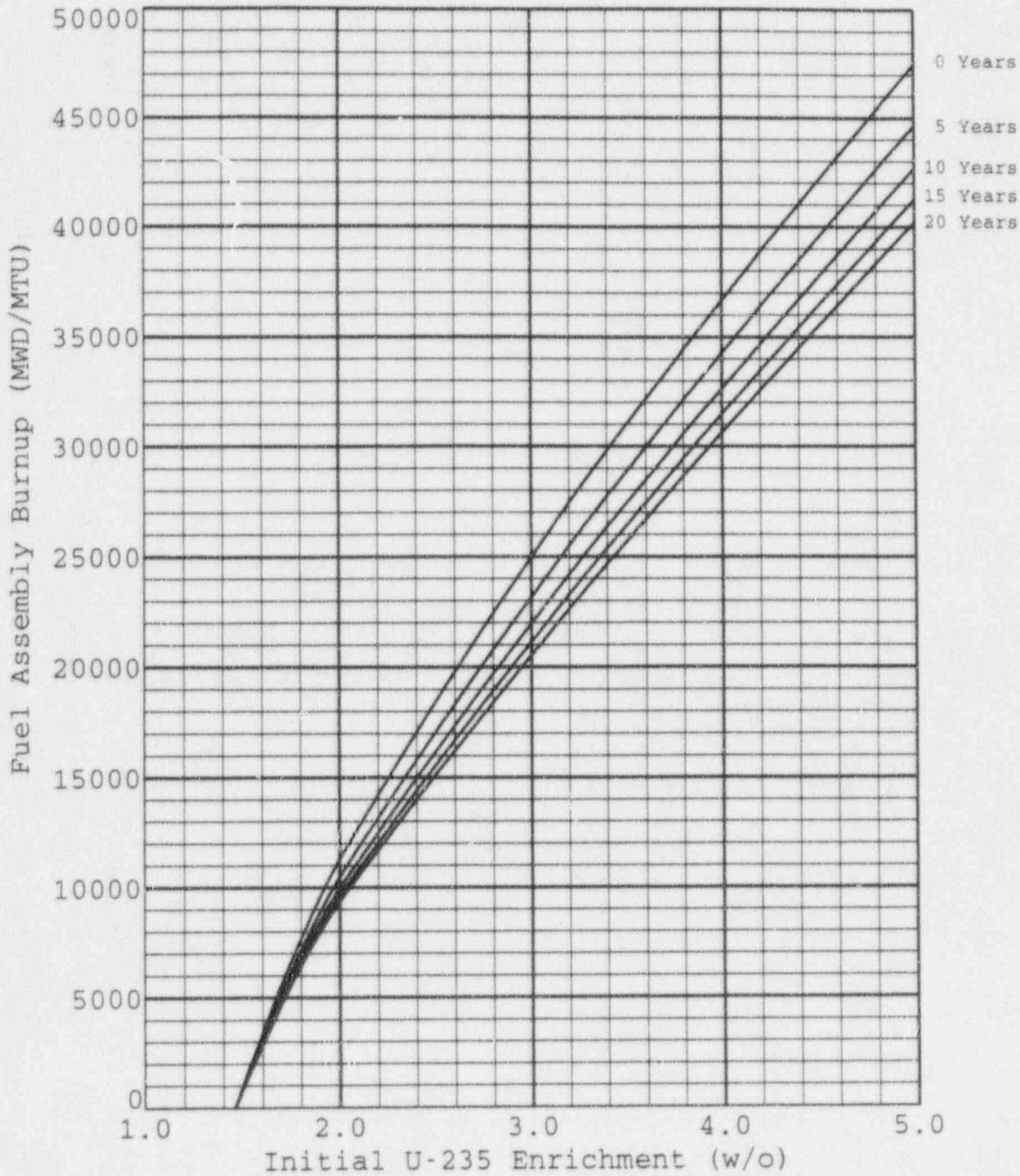


Figure 13. Prairie Island 3x3 Checkerboard STD 8 GAD Storage Burnup Credit and Decay Time Requirement

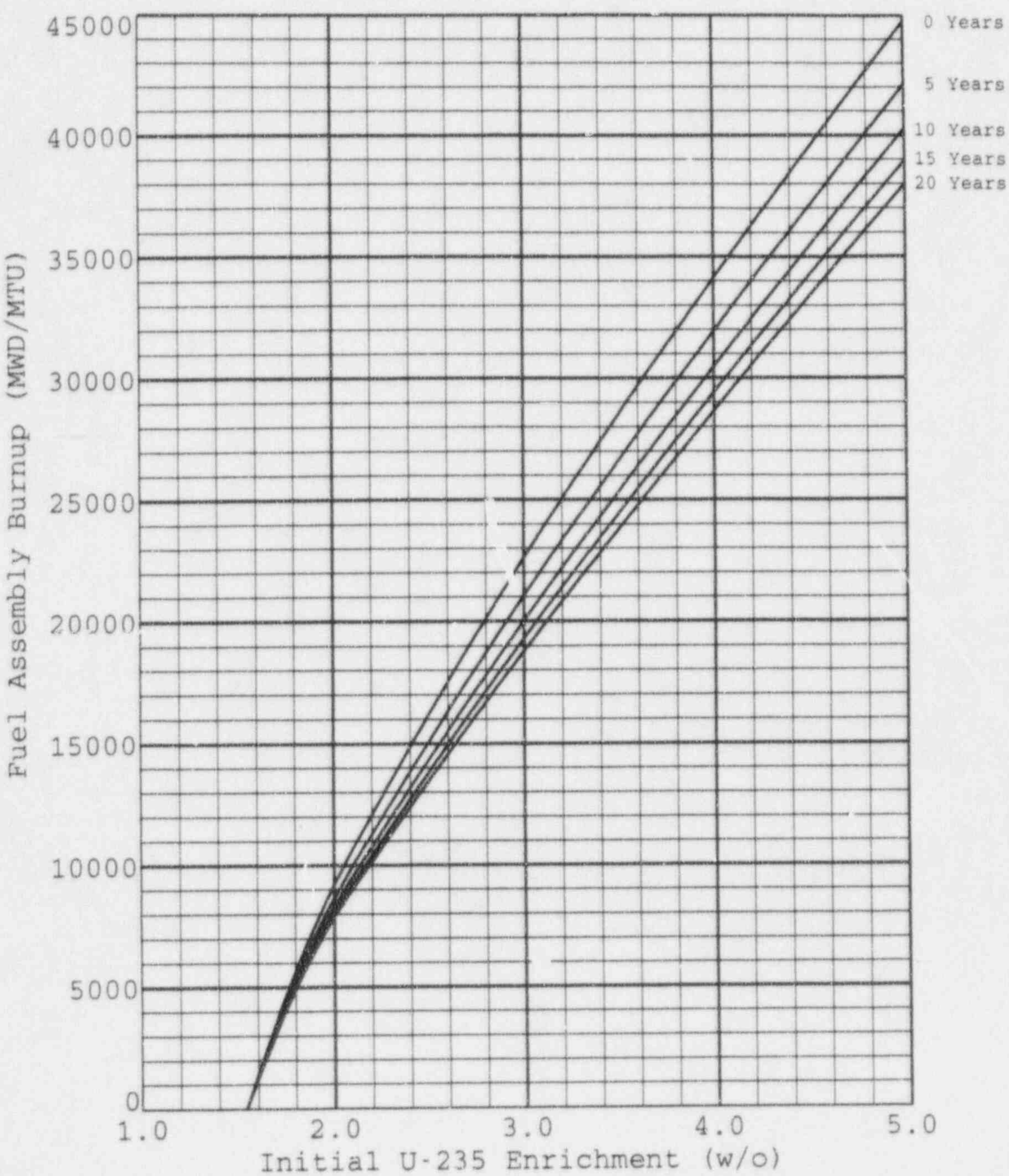


Figure 14. Prairie Island 3x3 Checkerboard STD 12 GAD Storage Burnup Credit and Decay Time Requirement

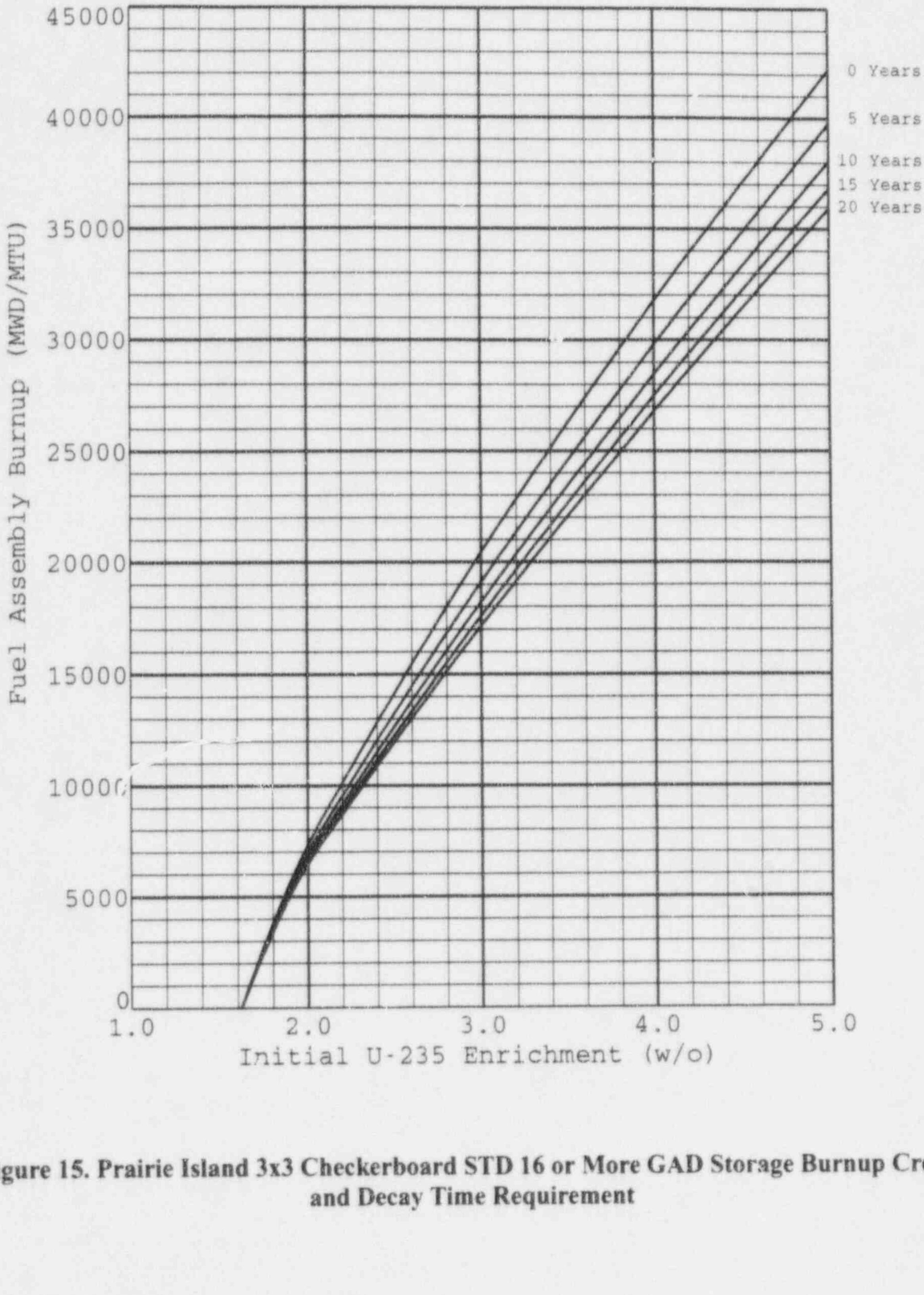


Figure 15. Prairie Island 3x3 Checkerboard STD 16 or More GAD Storage Burnup Credit and Decay Time Requirement

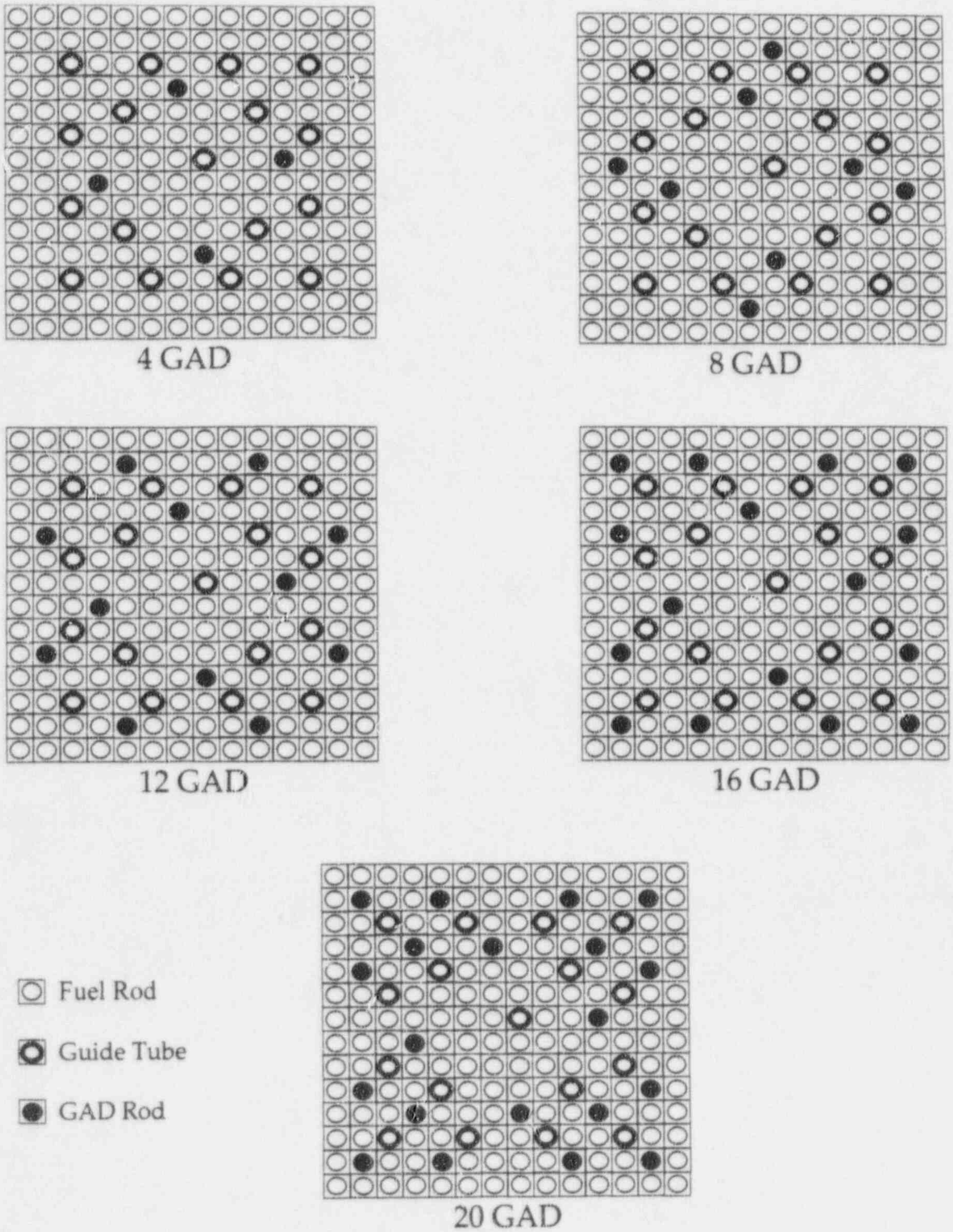


Figure 16. Gadolinium Rod Patterns within the Fuel Assembly

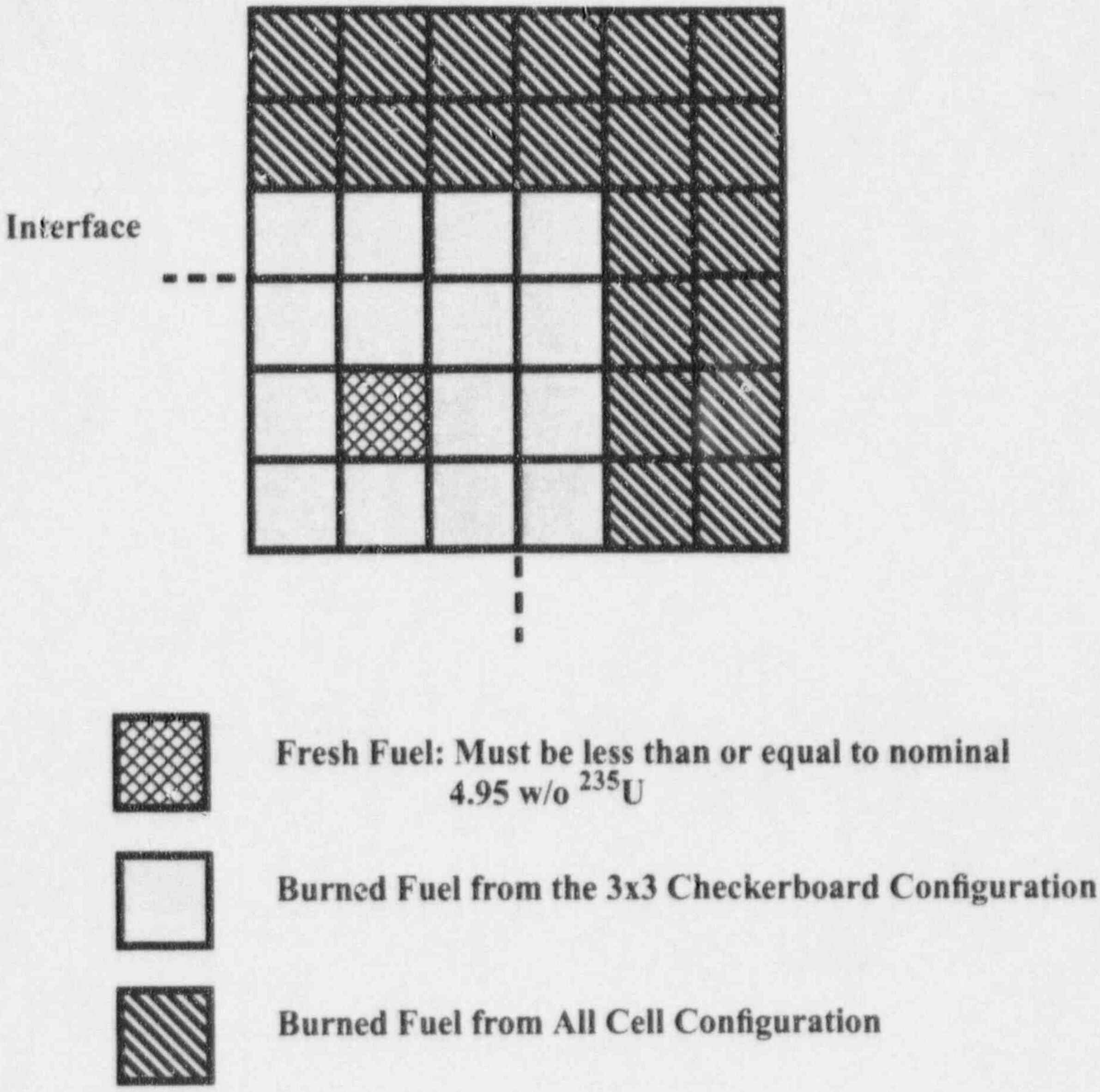


Figure 17. Prairie Island Interface Requirements

Bibliography

1. Newmyer, W.D., Westinghouse Spent Fuel Rack Criticality Analysis Methodology, WCAP-14416-NP-A, November 1995.
2. Newmyer, W.D., *Criticality Analysis of the Prairie Island Units 1 & 2 Fresh and Spent Fuel Racks,* February 1993.