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March 21, 2001

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555

SUBJECT: COMANCHE PEAK STEAM ELECTRIC STATION (CPSES)
DOCKET NOS. 50-445 AND 50-446
INFORMATION RELATED TO LICENSE AMENDMENT REQUEST (LAR) 00-05: REVISION TO TECHNICAL SPECIFICATION SPENT FUEL ASSEMBLY STORAGE RACKS AND FUEL STORAGE CAPACITY (TAC NOS. MB0207 AND MB0208)

Ref: 1) TXU Electric Letter logged TXX-00144, from C. L. Terry to the NRC dated October 4, 2000

Gentlemen:

Pursuant to 10CFR50.90, TXU Electric requested, via Reference 1 an amendment to the CPSES Unit 1 Operating License (NPF-87) and CPSES Unit 2 Operating License (NPF-89) to increase the spent fuel storage capacity by incorporating changes to the CPSES Unit 1 and 2 Technical Specifications.

As a result of conversations between the NRC Staff (David H. Jaffe) and TXU Electric (D. R. Woodlan) on March 21, 2001, it was agreed that an advance copy of an updated Westinghouse criticality analysis would be transmitted to the NRC (Enclosure 1). Enclosure 1 will be resubmitted under oath and affirmation in the near future as part of a supplement to the subject License Amendment Request. This updated Westinghouse Criticality Analysis will replace Enclosure 2 of Reference 1.

D029

TXU Electric
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In accordance with 10CFR50.91(b), TXU Electric is providing the State of Texas with a copy of this submittal related to the proposed License Amendment Request.

Should you have any questions, please contact Carl B. Corbin at (254) 897-0121.

Sincerely,

C. L. Terry

By: ______________________
D. R. Woodlan
Docket Licensing Manager

CBC/cbc

Enclosure 1. Comanche Peak High Density Spent Fuel Rack Criticality Analysis Using Soluble Boron Credit and No Outer Wrapper Plates, dated January 2001

c - E. W. Merschoff, Region IV
J. I. Tapia, Region IV
D. H. Jaffe, NRR
Resident Inspectors, CPSES

Mr. Authur C. Tate
Bureau of Radiation Control
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ENCLOSURE 1 to TXX-01052

Criticality Analysis

CAB-00-163 Rev 1

Comanche Peak High Density Spent Fuel Rack Criticality Analysis Using Soluble Boron Credit And No Outer Wrapper Plates

January 2001

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Westinghouse Electric Company LLC
Nuclear Fuel Business Unit

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1.0 Introduction

This report presents the results of a criticality analysis of the TXU Electric Comanche Peak spent fuel storage racks with credit for spent fuel pool soluble boron and with no outer wrapper plates of the Boraflex poison panels. 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 in References 2 and 3 (without Boraflex) for storage of various 17x17 fuel assembly types with maximum enrichments up to 5.0 w/o ^{235}U. Multiple storage configurations are currently allowed. These configurations allow fuel assemblies with maximum enrichments up to 5.0 w/o ^{235}U (with burnup credits) to be stored.

The base enrichment limits reported in Reference 2 for the all cell and the 3-out-of-4 storage configurations were determined assuming the existence of the outer wrapper plates of the Boraflex poison panels. The base enrichment limits reported in Reference 3 for the 2-out-of-4 and the 1-out-of-4 storage configurations were determined assuming no outer wrapper plates of the Boraflex poison panels. The base enrichment limits reported in Reference 4 for the 3-out-of-4 and 4-out-of-4 storage configuration were determined assuming no outer wrapper plates of the Boraflex panels. The Comanche Peak spent fuel racks for the all cell and the 3-out-of-4 storage configurations previously analyzed in Reference 4 are being reanalyzed in this report to revise the axial burnup bias in the burnup credit calculation and to remove the decay time credit.

The Comanche Peak spent fuel rack analysis is based on maintaining $K_{eff} < 1.0$ including uncertainties and tolerances on a 95/95 (95 percent probability at 95 percent confidence level) 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 95/95 $K_{eff} \leq 0.95$ including uncertainties, tolerances, and accident conditions in the presence of spent fuel pool soluble boron.

The following storage configurations and enrichment limits are considered in this analysis:

High Density Spent Fuel Rack Enrichment Limits

All Cell Storage — Storage of Westinghouse and Siemens 17x17 fuel assemblies in any cell location. Fuel assemblies must have an initial nominal enrichment no greater than 1.04 w/o ^{235}U or satisfy a minimum burnup requirement for higher initial enrichments up to 5.00 w/o ^{235}U. The soluble boron credit required for this storage configuration is 800 ppm. Including accidents, the soluble boron credit required for this storage configuration is 1700 ppm.

3-out-of-4 Checkerboard Storage Storage of Westinghouse and Siemens 17x17 fuel assemblies in a 3-out-of-4 checkerboard arrangement with empty cells. Fuel assemblies must have an initial nominal enrichment no greater than 1.51 w/o ^{235}U or satisfy a minimum burnup requirement for higher initial enrichments up to 5.00 w/o ^{235}U. A 3-out-of-4 checkerboard with empty cells means that no more than 3 fuel assemblies can occupy any 2x2 matrix of storage cells. The soluble boron credit required for this storage configuration is 700 ppm. Including accidents, the soluble boron credit required for this storage configuration is 1900 ppm.

1.1 Design Description

The Comanche Peak High Density storage cell is shown in Figure 1 on page 26 with nominal dimensions provided on the figure.

The fuel parameters relevant to this analysis are given in Table 1 on page 18. With the simplifying assumptions employed in this analysis (no grids, sleeves, axial blankets, etc.), the various types of Westinghouse 17x17 STD and OFA (V5, V+, and P+) fuel are beneficial in terms of extending burnup capability and improving fuel reliability, but do not contribute to any meaningful increase in the basic assembly reactivity. This includes small changes in guide tube and instrumentation tube dimensions. Therefore, future fuel assembly upgrades do not require a criticality analysis if the fuel parameters specified in Table 1 remain bounding.

The fuel rod and guide tube claddings are modeled with zircaloy in this analysis. This is conservative with respect to the Westinghouse ZIRLO™ product which is a zirconium alloy containing additional elements including niobium. Niobium has a small absorption cross section which causes more neutron capture in the cladding regions, resulting in a lower reactivity. Therefore, this analysis is conservative with respect to fuel assemblies containing ZIRLO™ cladding in fuel rods, guide tubes, and instrumentation tubes.

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 the Boraflex poison panels including the outer wrapper plates have been removed from the racks.

In this report, the reactivity of the spent fuel racks 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 Comanche Peak spent fuel pool. This parameter provides significant negative reactivity in the criticality analysis of the spent fuel racks and will be used here to offset the reactivity increase after the spent fuel rack Boraflex poison panels were removed. Soluble boron credit provides sufficient relaxation in the enrichment limits of 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 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 Comanche Peak.

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. There is a 95 percent probability at a 95 percent confidence level that the uncertainty in reactivity due to the method is no greater than 0.0030 ΔK. These values will be used in the final evaluation of the 95/95 basis K_{eff} in this report.

3.0 Criticality Analysis of High Density Storage Racks

This section describes the analytical techniques and models employed to perform the criticality analysis and reactivity equivalencing evaluations for the storage of fuel in the High Density spent fuel storage racks with credit for soluble boron.

Section 3.1 describes the allowed storage configurations for fuel assemblies in the High Density spent fuel storage racks. Section 3.2 describes the No Soluble Boron 95/95 K_{eff} KENO-Va calculations. Section 3.3 discusses the results of the spent fuel rack K_{eff} soluble boron credit calculations. Section 3.4 presents the results of calculations performed to show the minimum burnup requirements for assemblies with initial enrichments above those determined in Section 3.2.

3.1 Configuration Descriptions

Two different configurations are analyzed for the High Density spent fuel storage racks. The first configuration contains fresh fuel assemblies of the same enrichment of 1.04 w/o in all of the cells. The second configuration uses a 3-out-of-4 assembly checkerboard with 1 empty cell and 3 fresh assemblies of 1.51 w/o in the other cells. The two configurations are shown in Figure 2 on page 27.

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

To determine the enrichment required to maintain $K_{eff} < 1.0$, KENO-Va is used to establish a nominal reference reactivity and PHOENIX-P is used to assess the temperature bias of a normal pool temperature range and 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 temperature and method biases and 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 Comanche Peak High Density spent fuel storage racks:

1. The fuel assembly parameters relevant to the criticality analysis are based on the Westinghouse 17x17 STD design, which is the most reactive fuel type under spent fuel rack conditions (see Table 1 on page 18 for fuel parameters).
2. Fuel assemblies contain uranium dioxide at the nominal enrichments 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, 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. The moderator is water with 0 ppm soluble boron at a temperature of 68°F. A value of 1.0 gm/cm^3 is used for the density of water.
9. The array is infinite in the lateral (x and y) extent. The fuel assembly array is finite in the axial (vertical) extent with 12 inch water regions on the top and bottom of the fuel.
10. All allowable storage cells are loaded with fuel assemblies.

Temperature 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 is 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 Comanche Peak spent fuel rack High Density storage configurations, 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 is 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 18) is considered.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to twice the nominal value (the nominal reference values are listed in Table 1 on page 18) is considered.

Storage Cell I.D.: The ±0.025 inch tolerance about the nominal 8.83 inch reference cell I.D. is considered.

Storage Cell Pitch: A ±0.06 inch tolerance about a nominal 9.0 inch reference cell pitch is considered.

Stainless Steel Thickness: The ±0.004 inch tolerance about the nominal 0.075 inch reference stainless steel thickness for all rack structures is 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 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} is considered.

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

3.2.1 All Cell No Soluble Boron 95/95 K_{eff} Calculation

With the previously stated assumptions, the KENO-Va calculation for the all cell configuration under nominal conditions with no soluble boron in the moderator resulted in a K_{eff} of 0.96756, as shown in Table 2 on page 19.

The 95/95 K_{eff} is developed by adding the temperature and methodology biases and the statistical sum of independent uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 2 and results in a 95/95 K_{eff} of 0.99574.

Since K_{eff} is less than 1.0 including uncertainties at a 95/95 probability/confidence level, the High Density spent fuel racks will remain subcritical when all cells are loaded with Westinghouse and Siemens 17x17 fuel assemblies having a nominal enrichment no greater than 1.04 w/o ^{235}U and no soluble boron is present in the spent fuel pool water.

3.2.2 3-out-of-4 Checkerboard No Soluble Boron 95/95 K_{eff} Calculation

With the previously stated assumptions, the KENO-Va calculation for the 3-out-of-4 checkerboard configuration under nominal conditions with no soluble boron in the moderator resulted in a K_{eff} of 0.97785, as shown in Table 4 on page 21.

The 95/95 K_{eff} is developed by adding the temperature and methodology biases and the statistical sum of independent uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 4 and results in a 95/95 K_{eff} of 0.99811.

Since K_{eff} is less than 1.0 including uncertainties at a 95/95 probability/confidence level, the High Density spent fuel racks will remain subcritical for the 3-out-of-4 checkerboard configuration storage of Westinghouse and Siemens 17x17 fuel assemblies in a 2x2 checkerboard arrangement with 1 empty cell and the remaining 3 cells containing fuel assemblies having a nominal enrichment no greater than 1.51 w/o ^{235}U and no soluble boron is present in the spent fuel pool water.

3.3 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 temperature bias of a normal pool temperature range and 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 temperature and method biases and the nominal KENO-Va reference reactivity.

The assumptions used to develop the nominal case KENO-Va model for soluble boron credit for storage in the High Density spent fuel racks are similar to those in Section 3.2 except for assumption 8 regarding the moderator soluble boron concentration. The moderator boron concentration is increased by the amount required to maintain $K_{eff} \leq 0.95$.

Temperature 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 is 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 Comanche Peak spent fuel rack High Density storage configurations, 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 same tolerance and uncertainty components as in the No Soluble Boron case are considered in the total uncertainty statistical summation.

3.3.1 All Cell Soluble Boron Credit K_{eff} Calculation

With the previously stated assumptions, the KENO-Va calculation for the all cell configuration under nominal conditions with 200 ppm soluble boron in the moderator resulted in a K_{eff} of 0.90641, as shown in Table 3 on page 20.

The 95/95 K_{eff} is developed by adding the temperature and methodology biases and the statistical sum of independent uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 3 and results in a 95/95 K_{eff} of 0.93531.

Since K_{eff} is less than or equal to 0.95 including soluble boron credit and uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met for all cell storage of Westinghouse and Siemens 17x17 fuel assemblies in the High Density spent fuel racks. Storage of fuel assemblies with nominal enrichments no greater than 1.04 w/o ^{235}U is acceptable in all cell storage including the presence of 200 ppm soluble boron.

3.3.2 3-out-of-4 Checkerboard Soluble Boron Credit K_{eff} Calculation

With the previously stated assumptions, the KENO-Va calculation for the 3-out-of-4 checkerboard configuration under nominal conditions with 200 ppm soluble boron in the moderator resulted in a K_{eff} of 0.91997, as shown in Table 5 on page 22.

The 95/95 K_{eff} is developed by adding the temperature and methodology biases and the statistical sum of independent uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 5 and results in a 95/95 K_{eff} of 0.94061.

Since K_{eff} is less than or equal to 0.95 including soluble boron credit and uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met for the 3-out-of-4 checkerboard configuration storage of Westinghouse and Siemens 17x17 fuel assemblies in the High Density spent fuel racks. Storage of fuel assemblies in a 2x2 checkerboard arrangement with 1 empty cell and the remaining 3 cells containing fuel assemblies having a nominal enrichment no greater than 1.51 w/o ^{235}U is acceptable including the presence of 200 ppm soluble boron.

3.4 Burnup Credit Reactivity Equivalencing

Storage of fuel assemblies with enrichments higher than those described in Section 3.2 in the Comanche Peak High Density spent fuel racks is achievable by using 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 is performed to generate a set of enrichment and 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 28 and Figure 4 on page 29 show the constant K_{eff} contours generated for the all cell configuration and the 3-out-of-4 configuration, respectively, for fuel storage in the High Density spent fuel racks. These curves represent combinations of fuel enrichment and discharge burnup which yield the same rack multiplication factor (K_{eff}) as the rack loaded with zero burnup fuel assemblies with maximum allowed enrichments described in Section 3.2 for the two configurations.

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 calculation and depletion uncertainties and 5% 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 is 600 ppm for the all cell configuration and 500 ppm for the 3-out-of-4 checkerboard configuration. This is additional boron above the soluble boron required in Section 3.3. This results in a total soluble boron credit of 800 ppm for the all cell configuration and 700 ppm for the 3-out-of-4 checkerboard configuration.

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 6 on page 23 and Table 7 on page 24, respectively. Use of linear interpolation between the tabulated values is acceptable since the change in reactivity is approximately linear as a function of enrichment between the tabulated points.

The calculations for burnup credit reactivity equivalencing are done on a radial, two-dimensional (2D) basis with the PHOENIX-P code. Inherent in a 2D treatment for this calculation is a uniform axial burnup distribution. To account for the varying burnup and reactivity axially along the assembly, that is, the three-dimensional (3D) burnup effect, a bias term had been defined in Reference 1 using the PHOENIX-P and ANC codes.

A recent investigation concluded that the Reference 1 axial burnup bias could be non-conservative. The generic axial burnup bias term, at the minimum allowed burnup for 5 w/o fuel, has been revised and is shown in the following tables labeled "3-out-of-4 Storage" and "4-out-of-4 Storage".

From a generic evaluation of previous analyses performed by Westinghouse, certain excess conservatisms in the methodology were identified which would be sufficient to offset the effects of the revised axial burnup bias. The generic excess conservatisms applicable to this plant specific analysis which are used to offset the revised axial burnup bias term include:

1. In the KENO model described in Section 3.2, the spent fuel pool is modeled with an infinitely repeating array of individual storage cells. This assumption conservatively neglects leakage into the gaps between storage rack modules, which for Comanche Peak Steam Electric Station are approximately 3 inches in width. The reactivity effect of leakage between storage racks was determined with a KENO calculation in which the gaps were explicitly modeled.
2. In the actual storage pool, leakage occurs between the rack modules and the pool wall. The reactivity effect of rack-to-wall leakage was determined with explicit KENO calculations.
3. In the methodology described in Section 3.2, no credit for samarium and fission products is assumed. Calculations were performed to conservatively determine the reactivity effect of samarium and fission products at 100 hrs after shutdown, which is the minimum cooling time requirement for core offload.
4. In the burnup credit reactivity equivalencing methodology, fuel assembly depletion calculations are performed with a conservatively high constant value of soluble boron (a value of 1500 ppm is used for burnup from 0 to 60,000 MWD/MTU). In actual operation, the soluble boron varies from about 1500 ppm at the beginning-of-cycle to near zero at the end-of-cycle. The lower cycle average boron value, for actual operations, results in a softer neutron spectrum and makes the fuel assemblies less reactive with burnup due to the smaller buildup of plutonium. To determine the reactivity effect of the overly conservative soluble boron and burnable absorber assumption, a calculation was performed with a more realistic but still bounding boron letdown curve.
5. Credit can be taken for excess margin to the K_{eff} limit. The excess margin to the K_{eff} limit is the difference between the K_{eff} limit of 1.00 (for soluble boron credit) and the calculated value of K_{eff}, from Table 2 for the 4-out-of-4 and Table 4 for the 3-out-of-4 configurations, determined on a 95/95 basis.

6. In the methodology described in Section 3.2, the uncertainty allowance for the standard DOE tolerance for enrichment is determined by considering a 0.05 w/o ^{235}U variation about the allowable enrichment for fresh fuel with no burnup. The allowable initial enrichment in the base methodology is low (less than 2.0 w/o). The reactivity uncertainty allowance for the enrichment tolerance for high burnup fuel at a higher enrichment of up to 5.0 w/o ^{235}U, in the range where the axial burnup bias issue applies, is significantly lower than that for low enriched fresh fuel.

7. Under the methodology of Section 3.2, no credit is taken for the presence of grids and sleeves. The reactivity effect of grids and sleeves can be determined by explicit calculations.

The conclusions drawn from the evaluation are that the credits for the overall conservatisms identified are sufficient to offset the effect of the revised axial burnup bias. The previously discussed axial burnup bias penalty and credits are summarized in the following two tables for Comanche Peak.

4-out-of-4 Storage

Region 2, All Cell Configuration(60000* MWD/MTU, 5.0 w/o)	Penalty/Credit Description	Penalty/Credit value (ΔK)
Summary of Penalties	Revised Axial Burnup Bias Penalty	- 0.04359
	Original WCAP-14416-NP-A axial burnup bias penalty	+ 0.00312
Summary of Credits	Samarium and fission product buildup	+ 0.00086
	Leakage due to gaps between rack modules	+ 0.01100
	Boron letdown curve for HFP depletion credit	+ 0.01063
	Enrichment tolerance credit	+ 0.01202
	Existing delta to the K_{eff} limit	+ 0.00426
	Grid and sleeve credit	+ 0.00130
	Pool leakage credit	+ 0.00044
Net Balance		+ 0.00004

*Currently licensed lead rod burnup

3-out-of-4 Storage

Region 2, 3 of 4 Configuration (42156 MWD/MTU, 5.0 w/o)	Penalty/Credit Description	Penalty/Credit value (ΔK)
Summary of Penalties	Revised Axial Burnup Bias Penalty	- 0.02091
	Original WCAP-14416-NP-A axial burnup bias penalty	+ 0.00000
Summary of Credits	Samarium and fission product buildup	+ 0.00086
	Leakage due to gaps between rack modules	+ 0.01100
	Boron letdown curve for HFP depletion credit	+ 0.00431
	Enrichment tolerance credit	+ 0.00535
	Existing delta to the K_{eff} limit	+ 0.00189
	Grid and sleeve credit	+ 0.00098
	Pool leakage credit	+ 0.00044
Net Balance		+ 0.00392

4.0 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	Design of the spent fuel racks and fuel handling equipment is such that it precludes the insertion of a fuel assembly in other than prescribed locations.
Fuel assembly drop between rack modules and spent fuel pool wall	For High Density storage areas, this accident is bounded by the fuel assembly misload accident discussed below since placing a fuel assembly inside the racks next to other fuel assemblies will result in a higher K_{eff}.

However, two accidents can be postulated for each storage configuration which can increase reactivity beyond the analyzed condition. The first postulated accident would be a change in the spent fuel pool water temperature and the second would be a misload of an assembly into a cell for which the restrictions on location, enrichment, or burnup are not satisfied.

Calculations were performed for the Comanche Peak storage configurations to determine the reactivity change caused by a change in the Comanche Peak spent fuel pool water temperature outside the normal range (50°F to 150°F). For the change in spent fuel pool water temperature accident, a temperature range of 32°F to 212°F is considered. In all cases, additional reactivity margin is available to the 0.95 K_{eff} limit to allow for temperature accidents. The temperature change accident can occur at any time during operation of the spent fuel pool.

For the assembly misload accident, calculations were performed to show the largest reactivity increase caused by a Westinghouse or Siemens 17x17 fuel assembly misplaced into a storage cell for which the restrictions on location, enrichment, or burnup are not satisfied. The assembly misload accident can only occur during fuel handling operations in the spent fuel pool.

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 additional amount of soluble boron for accident conditions needed beyond the required boron for uncertainties and burnup is shown in Table 8 on page 25.

5.0 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 8 on page 25 summarizes the storage configurations and corresponding soluble boron credit requirements.

Based on the above discussion, should a spent fuel water temperature change accident or a fuel assembly misload accident occur in the High Density spent fuel racks, K_{eff} will be maintained less than or equal to 0.95 due to the presence of at least 800 ppm (no fuel handling) or 1900 ppm (during fuel handling) of soluble boron in the Comanche Peak spent fuel pool water.

6.0 Storage Configuration Interface Requirements

The Comanche Peak High Density spent fuel pool area has been analyzed for all cell storage, where all cells share the same storage requirements and limits, and checkerboard storage, where neighboring cells have different requirements and limits.

The boundary between different checkerboard zones and the boundary between a checkerboard zone and an all cell storage zone must be controlled to prevent an undesirable increase in reactivity. This is accomplished by examining all possible 2x2 matrices containing rack cells and ensuring that each of these 2x2 matrices conforms to checkerboard restrictions for the given region.

For example, consider a fuel assembly location E in the following matrix of storage cells.

A	B	C
D	E	F
G	H	I

Four 2x2 matrices of storage cells which include storage cell E are created in the above figure. They include (A,B,D,E), (B,C,E,F), (E,F,H,I), and (D,E,G,H). The fuel assemblies in each of these 2x2 matrices of storage cells are required to meet the checkerboard requirements determined for the given region.

Using the requirement that all 2x2 matrices within the storage racks must conform to both all cell and 2x2 checkerboard requirements, the following interface requirements are applicable to High Density storage cells:

All Cell Storage Next to 3-out-of-4 Storage or 2-out-of-4 Storage	The boundary between all cell storage and 3-out-of-4 storage or 2-out-of-4 storage can be either separated by a vacant row of cells or the interface must be configured such that the first row of carryover in the checkerboard storage zone uses 1.51 w/o fuel assemblies alternating with empty cells. Figure 5 on page 30 illustrates the carryover configuration.
3-out-of-4 Storage Next to 2-out-of-4 Storage	The boundary between 3-out-of-4 storage and 2-out-of-4 storage can be either separated by a vacant row of cells or the interface must be configured such that the first row of carryover in the 2-out-of-4 storage zone uses 2.90[3] w/o fuel assemblies alternating with empty cells. Figure 6 on page 31 illustrates the carryover configuration.
1-out-of-4 Storage Next to All Cell Storage and 3-out-of-4 Storage	The boundary between 1-out-of-4 storage and all cell storage or 3-out-of-4 storage must be separated by a vacant row of cells. Figure 7 on page 32 illustrates the carryover configuration.
2-out-of-4 Storage Next to 1-out-of-4 Storage	The boundary between 2-out-of-4 storage and 1-out-of-4 storage must be separated by a vacant row of cells. Figure 8 on page 33 illustrates the carryover configuration.

7.0 Summary of Criticality Results

For the storage of Westinghouse and Siemens 17x17 fuel assemblies in the Comanche Peak spent fuel storage racks, the acceptance criteria for criticality requires the effective neutron multiplication factor, K_{eff}, to be less than 1.0 under No Soluble Boron 95/95 conditions, and less than or equal to 0.95 including uncertainties, tolerances and accident conditions with the presence of spent fuel pool soluble boron. This report shows that the acceptance criteria for criticality is met for the Comanche Peak spent fuel racks for the storage of Westinghouse and Siemens 17x17 fuel assemblies under both normal and accident conditions with soluble boron credit and the following storage configurations and enrichment limits:

High Density Spent Fuel Rack Enrichment Limits

All Cell Storage	Storage of Westinghouse and Siemens 17x17 fuel assemblies in any cell location. Fuel assemblies must have an initial nominal enrichment no greater than 1.04 w/o ^{235}U or satisfy a minimum burnup requirement for higher initial enrichments up to 5.00 w/o ^{235}U. The soluble boron credit required for this storage configuration is 800 ppm. Including accidents, the soluble boron credit required for this storage configuration is 1700 ppm.
3-out-of-4 Checkerboard Storage	Storage of Westinghouse and Siemens 17x17 fuel assemblies in a 3-out-of-4 checkerboard arrangement with empty cells. Fuel assemblies must have an initial nominal enrichment no greater than 1.51 w/o ^{235}U or satisfy a minimum burnup requirement for higher initial enrichments up to 5.00 w/o ^{235}U. A 3-out-of-4 checkerboard with empty cells means that no more than 3 fuel assemblies can occupy any 2x2 matrix of storage cells. The soluble boron credit required for this storage configuration is 700 ppm. Including accidents, the soluble boron credit required for this storage configuration is 1900 ppm

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, except for the use of pure water; ANSI 57.2-1983, "Design Requirements for Light Water Reactor Spent Fuel Storage Facilities at Nuclear Power Plants," Section 6.4.2; ANSI/ANS 8.1-1983, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," Section 4.3; and the NRC Standard Review Plan, Section 9.1.2, "Spent Fuel Storage". The spent fuel rack criticality analysis takes credit for the soluble boron in the spent fuel pool water as discussed in Reference 1.

Table 1. Fuel Parameters Employed in the Criticality Analysis

Parameter	Westinghouse 17x17 OFA	Westinghouse 17x17 STD	Siemens 17x17 OFA	Siemens 17x17 STD
Number of Fuel Rods per Assembly	264	264	264	264
Fuel Rod Zirc-4 Clad O.D. (inch)	0.360	0.374	0.360	0.376
Clad Thickness (inch)	0.0225	0.0225	0.0250	0.0240
Fuel Pellet O.D.(inch)	0.3088	0.3225	0.3035	0.3215
Fuel Pellet Density (% of Theoretical)	95.5	95.5	95.5	95.5
Fuel Pellet Dishing Factor (%)	1.211	1.2074	1.3579	1.2737
Rod Pitch (inch)	0.496	0.496	0.496	0.496
Number of Zirc Guide Tubes	24	24	24	24
Guide Tube O.D. (inch)	0.474	0.482	0.480	0.480
Guide Tube Thickness (inch)	0.016	0.016	0.016	0.016
Number of Instrument Tubes	1	1	1	1
Instrument Tube O.D. (inch)	0.474	0.482	0.480	0.480
Instrument Tube Thickness (inch)	0.016	0.016	0.016	0.016

Table 2. Comanche Peak High Density All Cell Storage No Soluble Boron 95/95 K_{eff}

Nominal KENO-Va Reference Reactivity:	**0.96756**
Calculational & Methodology Biases:	
Methodology (Benchmark) Bias	0.00770
Pool Temperature Bias (50°F - 150°F)	0.00033
TOTAL Bias	0.00803
Tolerances & Uncertainties:	
UO_2 Enrichment Tolerance	0.01868
UO_2 Density Tolerance	0.00313
Fuel Pellet Dishing Variation	0.00185
Cell Inner Diameter	0.00017
Cell Pitch	0.00443
Cell Wall Thickness	0.00213
Asymmetric Assembly Position	0.00320
Calculational Uncertainty (95/95)	0.00073
Methodology Bias Uncertainty (95/95)	0.00300
TOTAL Uncertainty (statistical)	0.02015
Final K_{eff} Including Uncertainties & Tolerances:	**0.99574**

$$\sqrt{\sum_{i=1}^{9}((\text{tolerance}_i \ldots \text{or} \ldots \text{uncertainty}_i)^2)}$$

Table 3. Comanche Peak High Density All Cell Storage 200 ppm Soluble Boron 95/95K_{eff}

Nominal KENO-Va Reference Reactivity:	**0.90641**
Calculational & Methodology Biases:	
Methodology (Benchmark) Bias	0.00770
Pool Temperature Bias (50°F - 150°F)	0.00084
TOTAL Bias	0.00854
Tolerances & Uncertainties:	
UO_2 Enrichment Tolerance	0.01874
UO_2 Density Tolerance	0.00379
Fuel Pellet Dishing Variation	0.00223
Cell Inner Diameter	0.00013
Cell Pitch	0.00550
Cell Wall Thickness	0.00172
Asymmetric Assembly Position	0.00110
Calculational Uncertainty (95/95)	0.00069
Methodology Bias Uncertainty (95/95)	0.00300
TOTAL Uncertainty (statistical)	0.02036

$$\sqrt{\sum_{i=1}^{9}\left((\text{tolerance}_i \ldots \text{or} \ldots \text{uncertainty}_i)^2\right)}$$

Final K_{eff} Including Uncertainties & Tolerances: 0.93531

Table 4. Comanche Peak High Density 3-out-of-4 Checkerboard Storage No Soluble Boron 95/95 K_{eff}

Nominal KENO-Va Reference Reactivity:	**0.97785**
Calculational & Methodology Biases:	
Methodology (Benchmark) Bias	0.00770
Pool Temperature Bias (50°F - 150°F)	0.00002
TOTAL Bias	0.00772
Tolerances & Uncertainties:	
UO_2 Enrichment Tolerance	0.01070
UO_2 Density Tolerance	0.00290
Fuel Pellet Dishing Variation	0.00172
Cell Inner Diameter	0.00017
Cell Pitch	0.00288
Cell Wall Thickness	0.00193
Asymmetric Assembly Position	0.00309
Calculational Uncertainty (95/95)	0.00092
Methodology Bias Uncertainty (95/95)	0.00300
TOTAL Uncertainty (statistical)	0.01254

$$\sqrt{\sum_{i=1}^{9}((\text{tolerance}_i \text{ ... or ... uncertainty}_i)^2)}$$

Final K_{eff} Including Uncertainties & Tolerances: **0.99811**

Table 5. Comanche Peak High Density 3-out-of-4 Checkerboard Storage 200 ppm Soluble Boron 95/95 K_{eff}

Nominal KENO-Va Reference Reactivity:	**0.91997**
Calculational & Methodology Biases:	
Methodology (Benchmark) Bias	0.00770
Pool Temperature Bias (50°F - 150°F)	0.00006
TOTAL Bias	0.00776
Tolerances & Uncertainties:	
UO_2 Enrichment Tolerance	0.01091
UO_2 Density Tolerance	0.00352
Fuel Pellet Dishing Variation	0.00208
Cell Inner Diameter	0.00014
Cell Pitch	0.00352
Cell Wall Thickness	0.00151
Asymmetric Assembly Position	0.00238
Calculational Uncertainty (95/95)	0.00092
Methodology Bias Uncertainty (95/95)	0.00300
TOTAL Uncertainty (statistical)	0.01288

$$\sqrt{\sum_{i=1}^{9}((\text{tolerance}_i \ldots \text{or} \ldots \text{uncertainty}_i)^2)}$$

Final K_{eff} Including Uncertainties & Tolerances:	**0.94061**

Table 6. Summary of Burnup Requirements for Comanche Peak High Density All Cell Configuration

Enrich. (w/o)	Burnup (MWD/MTU)
1.04	0
1.20	10180
1.25	11315
1.40	14574
1.60	18540
1.80	22051
2.00	25229
2.20	28214
2.40	31058
2.60	33794
2.80	36452
3.00	39064
3.20	41654
3.40	44216
3.60	46737
3.80	49203
4.00	51601
4.20	53920
4.40	56161
4.60	58330
4.80	60430
4.95	61963
5.00	62466

Table 7. Summary of Burnup Requirements for Comanche Peak High Density 3-out-of-4 Checkerboard Configuration

Enrich. (w/o)	Burnup (MWD/MTU)
1.51	0
1.60	1268
1.80	5270
2.00	8853
2.20	11953
2.40	14646
2.60	17043
2.80	19256
3.00	21397
3.20	23554
3.40	25731
3.60	27910
3.80	30071
4.00	32197
4.20	34273
4.40	36300
4.60	38286
4.80	40236
4.95	41678
5.00	42156

Table 8. Summary of the Soluble Boron Credit Requirements

Spent Fuel Rack	Storage Configuration	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)
High Density	All Cell Storage	200	600	800	900	1700
High Density	3-out-of-4 Checkerboard Storage	200	500	700	1200	1900

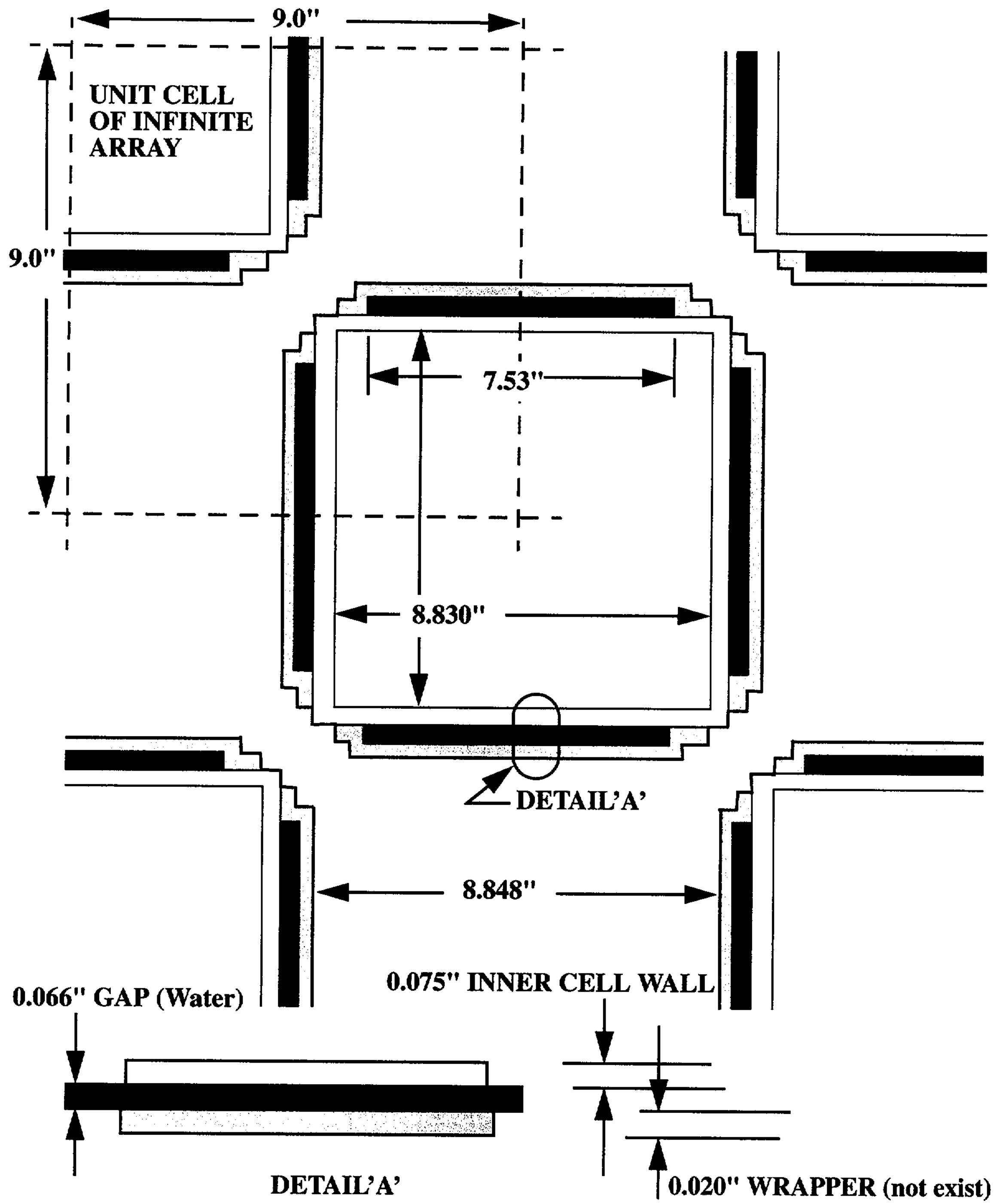


Figure 1. Comanche Peak High Density Spent Fuel Pool Storage Cell Nominal Dimensions

1.04 w/o	1.04 w/o
1.04 w/o	1.04 w/o

High Density All Cell Storage

1.51 w/o	1.51 w/o
Empty Cell	1.51 w/o

High Density 3-out-of-4 Storage

Note: All values are initial nominal enrichments.

Figure 2. Comanche Peak High Density Spent Fuel Storage Configurations

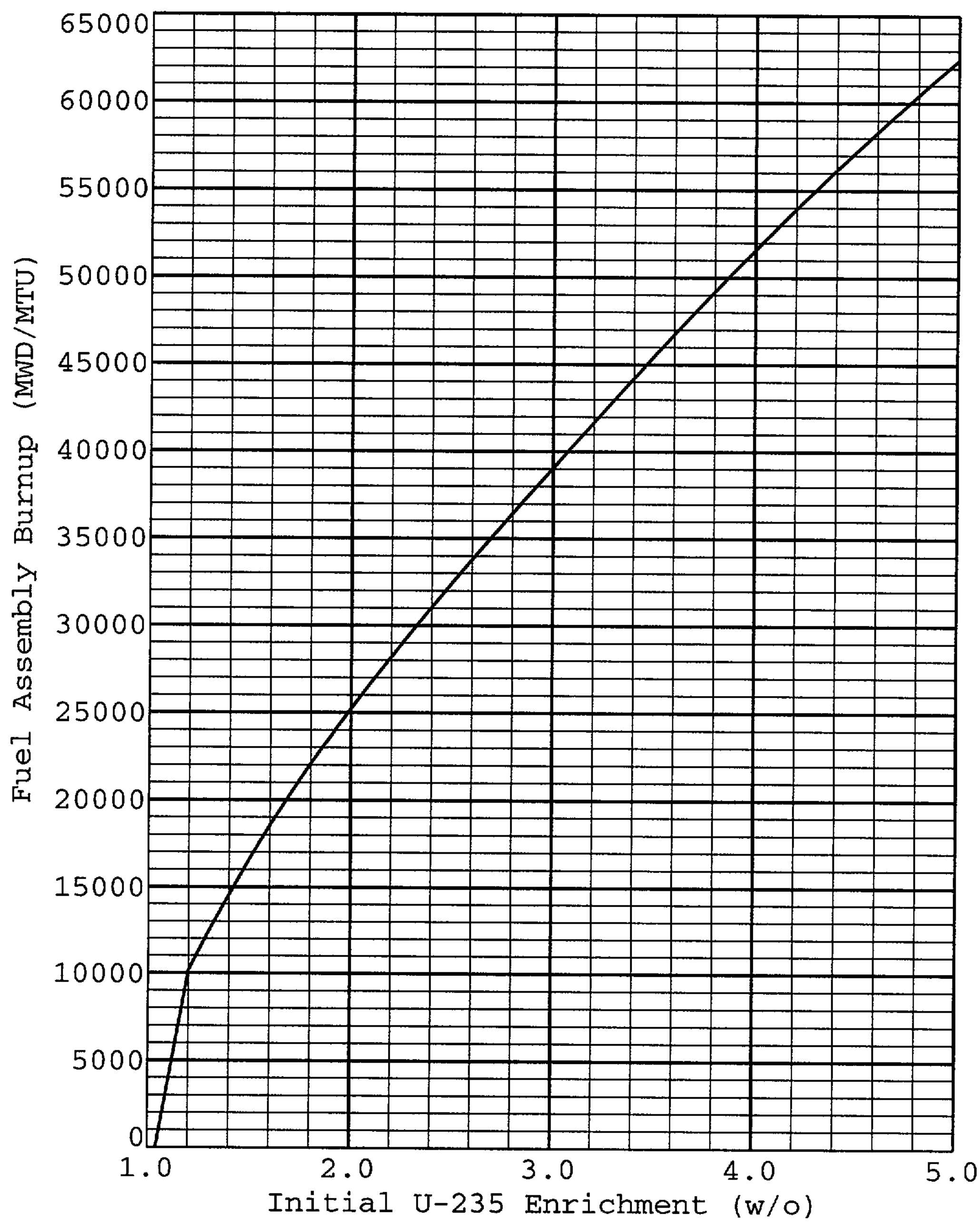


Figure 3. Comanche Peak High Density All Cell Configuration Burnup Credit Requirements

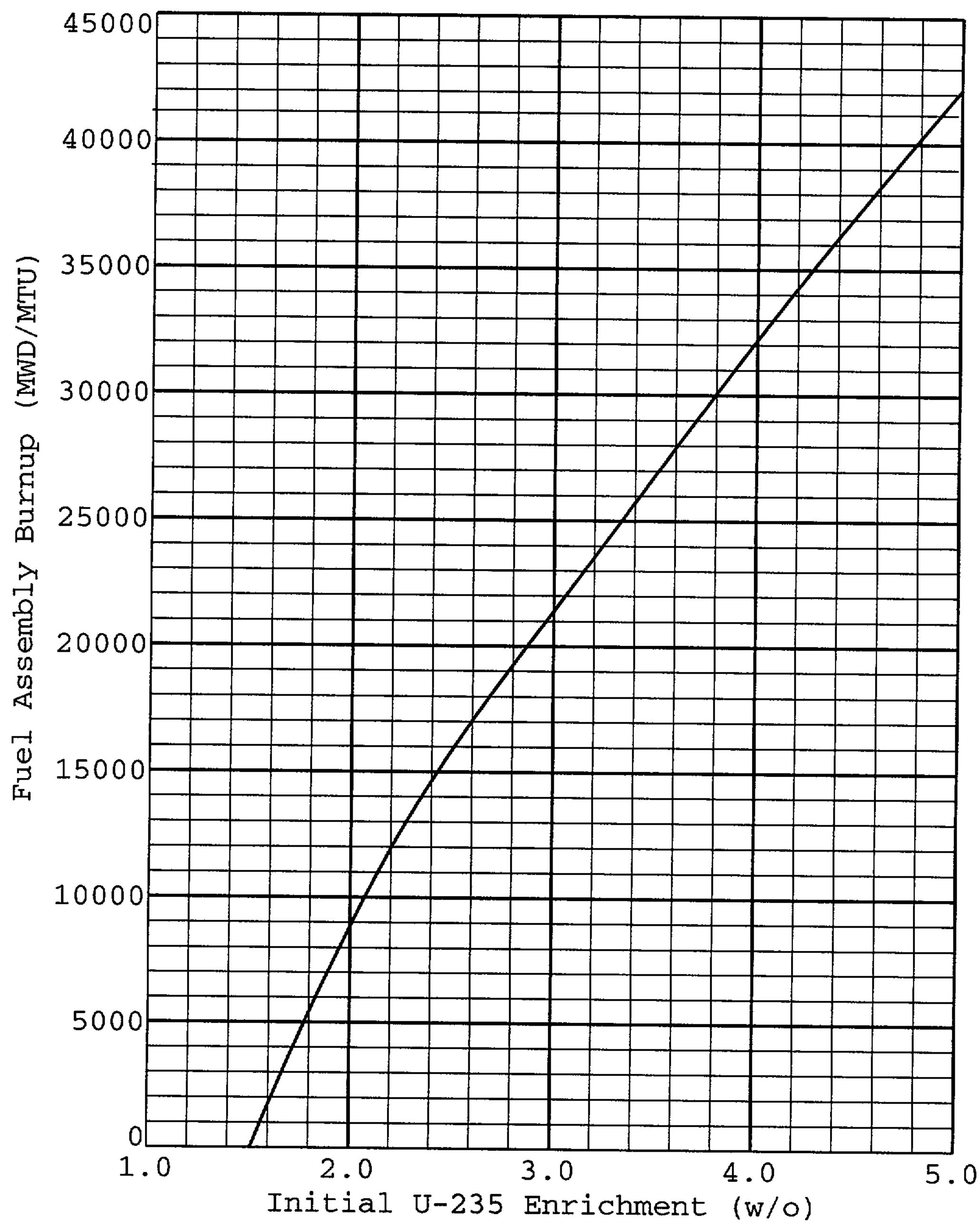


Figure 4. Comanche Peak High Density 3-out-of-4 Checkerboard Configuration Burnup Credit Requirements

Interface

1.04	1.04	1.04	1.04	1.04	1.04
1.04	1.04	1.04	1.04	1.04	1.04
1.04	1.04	1.04	1.04	1.04	1.04
Empty	1.51	Empty	1.04	1.04	1.04
1.51	1.51	1.51	1.04	1.04	1.04
Empty	1.51	Empty	1.04	1.04	1.04

High Density Boundary Between All Cell Storage and 3-out-of-4 Storage

Interface

1.04	1.04	1.04	1.04	1.04	1.04
1.04	1.04	1.04	1.04	1.04	1.04
1.04	1.04	1.04	1.04	1.04	1.04
Empty	1.51	Empty	1.04	1.04	1.04
2.90	Empty	1.51	1.04	1.04	1.04
Empty	2.90	Empty	1.04	1.04	1.04

High Density Boundary Between All Cell Storage and 2-out-of-4 Storage

Figure 5. High Density Interface Requirements (All Cell Storage to 3-out-4 and 2-out-4 Storages)

Interface

1.51	Empty	1.51	Empty	1.51	Empty
1.51	1.51	1.51	1.51	1.51	1.51
1.51	Empty	1.51	Empty	1.51	Empty
Empty	2.90	Empty	1.51	1.51	1.51
2.90	Empty	2.90	Empty	1.51	Empty
Empty	2.90	Empty	1.51	1.51	1.51

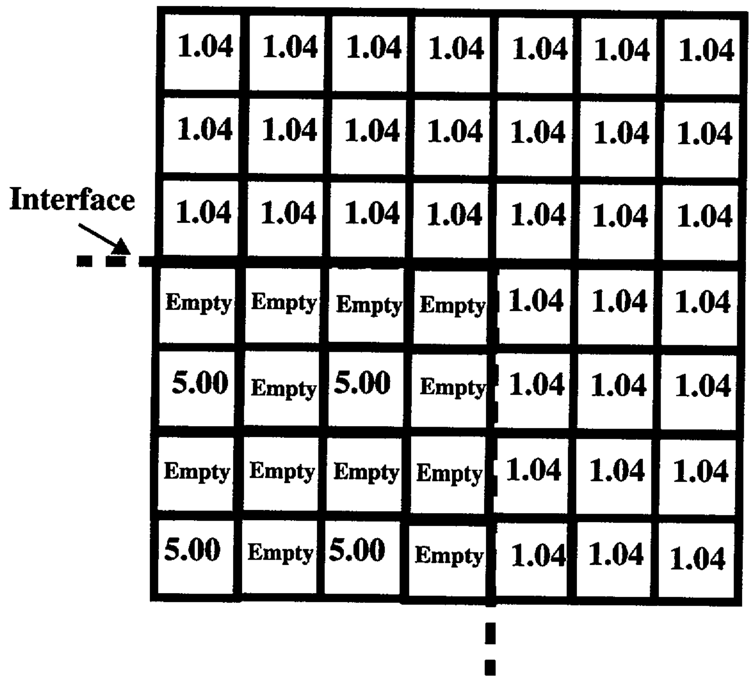
High Density Boundary Between 2-out-of-4 Storage and 3-out-of-4 Storage

Interface

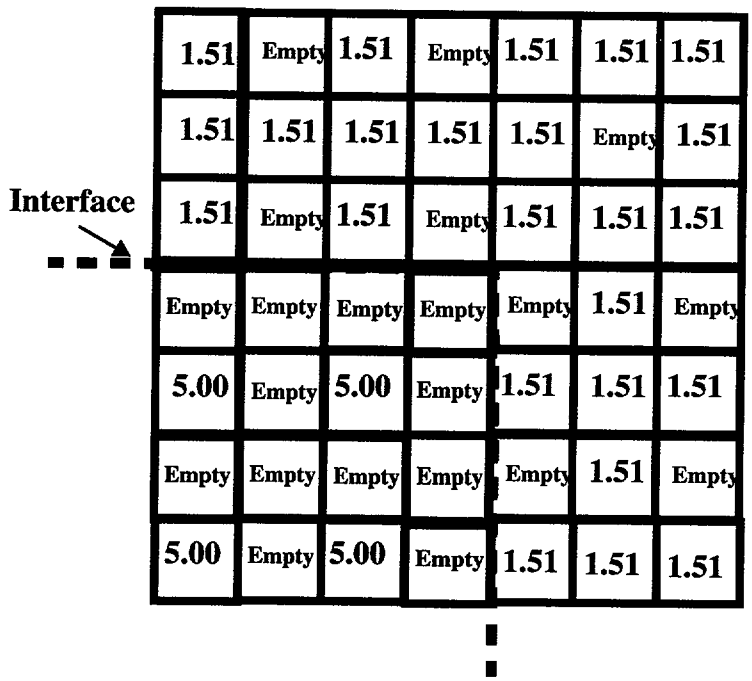
Empty	1.51	Empty	1.51	1.51	1.51
1.51	1.51	1.51	1.51	Empty	1.51
Empty	1.51	Empty	1.51	1.51	1.51
2.90	Empty	2.90	Empty	1.51	Empty
Empty	2.90	Empty	1.51	1.51	1.51
2.90	Empty	2.90	Empty	1.51	Empty

High Density Boundary Between 2-out-of-4 Storage and 3-out-of-4 Storage

Figure 6. High Density Interface Requirements (2-out-of-4 storage to 3-out-of-4 Storage)

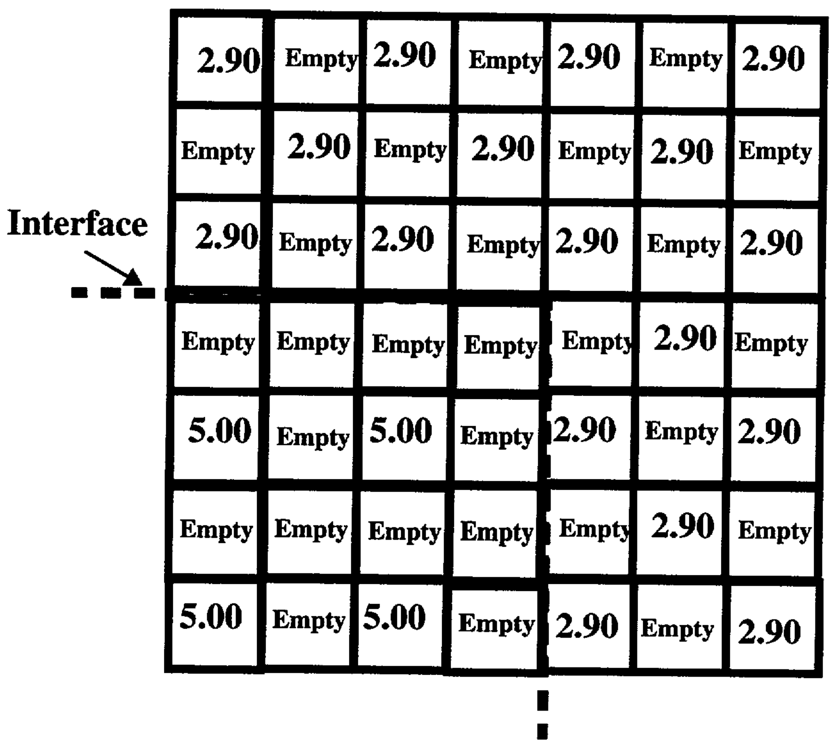


High Density Boundary Between All Cell Storage and 1-out-of-4 Storage



High Density Boundary Between 3-out-of-4 Storage and 1-out-of-4 Storage

Figure 7. High Density Interface Requirements (1-out-4 Storage to All Cell and 3-out-4 Storages)



High Density Boundary Between 2-out-of-4 Storage and 1-out-of-4 Storage

Figure 8. High Density Interface Requirements (2-out-4 Storage to 1-out-of-4 Storage)

Bibliography

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