Attachment 2
Turkey Point Units 3 and 4
License Amendment Request No. 207
Fuel Storage Criticality Analysis

WCAP-17094-NP, Rev 2,
Turkey Point Units 3 and 4
New Fuel Storage Rack and
Spent Fuel Pool Criticality Analysis

Westinghouse Non-Proprietary Class 3

WCAP-17094-NP
Revision 2

July 2010

Turkey Point Units 3 and 4 New Fuel Storage Rack and Spent Fuel Pool Criticality Analysis

Westinghouse

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REVISION HISTORY

Revision	Description and Impact of the Change	Date
0	Not Issued	05/2010
1	Original Issue	05/2010
2	Removed allowances for the current AOR; the analysis documented here will completely supersede the current AOR. Addressed customer comments.	07/2010

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TRADEMARK STATEMENT

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1 INTRODUCTION AND RESULTS

The purpose of this report is to support the Extended Power Uprate (EPU) at Turkey Point Units 3 and 4. The EPU has two major impacts on the criticality analysis: (1) The fuel maximum enrichment Technical Specification is increased from 4.5 wt% ^{235}U to 5.0 wt% ^{235}U, and (2) the depletion of fuel at the EPU conditions results in the fuel being more reactive at the same burnup than fuel depleted under pre-EPU conditions. This is due to the higher fuel and moderator temperatures that result in a harder neutron spectrum, resulting in more plutonium production.

This report documents the criticality safety evaluation for the storage of PWR nuclear fuel assemblies in the New Fuel Storage Rack and the Spent Fuel Pool (SFP). The SFP consists of the permanent Region 1 and Region 2 racks and the removable Cask Area Rack. The criticality analysis contained in this report will completely supersede Reference 9.

1.1 OVERVIEW

The existing Region 1 and 2 racks analyzed in this report are evaluated for the placement of fuel with new allowable storage configurations. Consistent with the storage patterns in License Amendment No. 234 (Unit 3) and No. 229 (Unit 4), this evaluation credits neutron absorber inserts placed into the Region 2 racks to partially offset an assumed full loss of the Boraflex. In this analysis, credit is taken for the negative reactivity associated with burnup and post-irradiation cooling time. Additionally, credit is taken for the presence of soluble boron in the spent fuel pool and for the presence of full-length rod cluster control assemblies (RCCAs) placed in selected fuel assemblies. The presence of Integrated Fuel Burnable Absorber (IFBA) rods is also credited for certain fresh fuel evaluations.

The Cask Area Rack in the SFP (Amendments 226 (Unit 3) and 222 (Unit 4)) is evaluated for the use of the higher fresh fuel enrichment (5.0 wt% ^{235}U). The Cask Area Rack is currently licensed for placement of fresh fuel of up to 4.5 wt% ^{235}U. Similarly, the New Fuel Storage Rack is analyzed for the higher enrichment.

To clearly distinguish between the inserts placed into rack cells and the control components inserted into fuel assemblies, the term "insert" by itself always refers to the Metamic™ neutron absorber inserts placed into the Region 2 racks. The full-length control components are always referred to as RCCAs, and other inserts placed into assemblies during depletion are always clearly characterized, e.g., as Pyrex inserts, Wet Annular Burnable Absorber (WABA) inserts, or hafnium inserts.

The relevant fuel assembly and fuel rack specifications are identical between Turkey Point Unit 3 and Unit 4. All analyses and conclusions presented in this report therefore apply to both units.

1.2 REGIONS 1 AND 2 FUEL STORAGE ARRAYS

In order to achieve the objective of qualifying the existing racks for placement of fuel of higher enrichment and operation under EPU conditions, it is necessary to separate fuel assemblies into categories and define appropriate storage configurations for each fuel assembly category. The combination of a fuel assembly category and a storage configuration will be termed a "storage array."

Eleven different 2x2 storage arrays are defined and analyzed to be subcritical. These are shown in Figures 1-1 and 1-2. These arrays are developed to efficiently store the fuel projected from EPU fuel management studies. These storage arrays are designed to accommodate both fresh fuel and spent discharged fuel. The array and fuel category nomenclature is the same as the current Boraflex remedy Technical Specifications (Reference 9) except that two fuel categories and two storage arrays are added. This analysis will completely supersede the analysis documented in Reference 9.

The analyses summarized in this report confirm the acceptability of each storage array and determine what limitations are placed on the use of each array. It is important to note that each 2x2 array is analyzed with fuel of the maximum allowable reactivity for the category. Therefore, fuel of a lower reactivity (i.e., greater burnup) may also be placed in the array. It is not necessary to use all defined arrays in the configuration of the spent fuel pool.

A total of 13 (thirteen) fuel categories are established and are presented below in Table 1-1.

Table 1-1 Fuel Categories Ranked by Reactivity

Region 1	I-1	High Reactivity
	I-2	
	I-3	
Region 2	II-1	
	II-2a	
	II-2b	
	II-2c	
	II-3	
	II-4	
	II-5	
	II-6	
	II-7	Low Reactivity
	II-8	

Notes:

1. Fuel Category is ranked by decreasing order of reactivity without regard for any reactivity-reducing mechanisms, e.g., Category I-2 is less reactive than Category I-1, etc. The more reactive fuel categories require compensatory measures to be placed in Regions 1 and 2 of the SFP, e.g., use of water filled cells, Metamic inserts, or full length RCCAs.
2. Category I-1 is fresh fuel up to 5.0 wt% ^{235}U. Category I-2 is fresh fuel up to 4.7 wt% ^{235}U with no burnable absorber rods, fresh fuel up to 5.0 wt% ^{235}U with at least 16 IFBA rods (or an equivalent amount of other burnable absorber), or burned fuel up to 5.0 wt% ^{235}U that is burned to at least 500 MWD/MTU. The reactivity of an assembly with only 16 IFBA rods (or an equivalent amount of other burnable absorber) monotonically decreases with burnup, therefore Category I-2 includes any fuel assembly with 16 IFBA rods (or an equivalent amount of other burnable absorber), regardless of burnup.

These fuel categories are utilized in the allowed configurations shown in Figures 1-1 and 1-2.

All categories except I-1 and I-2 require a loading curve that specifies the minimum assembly burnup as a function of initial ^{235}U enrichment and cooling time.

1.2.1 Interface Requirements

In addition to the storage configurations described above there are special restrictions on configurations next to the pool wall and the Region 1/Region 2 interface. There are no special restrictions for the interface with the cask area rack.

Along the interface between Region 1 and Region 2 racks, the following restrictions apply to the placement of assemblies in the Region 2 racks:

- For arrays requiring two inserts, there must be an insert in at least every other assembly in the outer row of Region 2 cells facing the Region 1 rack (see Figure 1-3 for examples); and
- For fuel arranged as required by Arrays II-A, II-C, or II-D, the insert or empty cell required by these arrays, as applicable, must be located in the outer row of Region 2 cells facing the Region 1 rack.
- There are no restrictions for placement of Arrays II-E and II-F

Figure 1-3 below illustrates the interface requirements between Region 1 and Region 2 racks.

For the cells facing the pool wall, calculations have been performed to provide flexibility on how fuel can be placed. Fuel assemblies of higher reactivity (Category II-2b or II-2c) can be placed facing the pool wall without inserts or full length RCCAs as an alternative to the use of the storage arrays described in Figure 1-2. Placement of this fuel without inserts or full length RCCAs is acceptable if the fuel in the adjacent 2x2 interior cells contains at least one insert and fuel placed in the 2nd and 3rd row of cells matches Arrays II-B1 through II-D criteria. Arrays II-E and II-F can be placed next to Category II-2b fuel placed without inserts or full length RCCAs along the periphery with no restrictions.

Examples of permissible arrangements along the pool walls with either Category II-2b or II-2c fuel on the periphery are illustrated in Figure 1-4.

1.2.2 Additional Loading Restrictions

The Metamic inserts placed in Region 2 storage racks must be positioned with the same spatial orientation within the 2x2 array and each overlapping 2x2 to be credited. Any inserts installed in the 2x2 array and each overlapping 2x2 with an orientation different from the predominant orientation of the installed inserts are not to be credited for reactivity control unless specific calculations considering the as-installed geometric arrangement are performed and demonstrate acceptable results. Placement of extra inserts, use of arrays that don't require inserts and selected placement of full length RCCAs can be used to acceptably change the insert orientation within the pool.

Empty (water-filled) storage cells required for Arrays I-A and II-A are not to contain a fuel rod basket, trash or non-fuel hardware, unless condition-specific calculations are performed to show that these items meet the criticality requirements.

A maximum of 57 GWD/MTU of burnup credit can be taken for any 6 inch natural blanket assemblies depleted under EPU conditions. It is anticipated that this restriction will only apply to the first Uprate cycle since the fuel design is being transitioned to the Upgrade fuel that utilizes 8 inch blankets. Since the use of the previous design will be limited, it is appropriate to handle this restriction using internal administrative controls.

1.3 BURNUP VERSUS ENRICHMENT CURVES

For all Fuel Categories except I-1 and I-2, an equation specifying the minimum required burnup as a function of the initial enrichment and post-irradiation cooling time is developed. The uncertainty in the reactor record burnup is included in the determination of the minimum burnup requirement and so it is appropriate to use the nominal reactor record burnup before comparing to the minimum required burnup determined from the loading curves. The burnup requirements are established as 3rd degree polynomial functions in the form of

$$Bu = (A_1 + A_2*En + A_3*En^2 + A_4*En^3)* \exp[-(A_5 + A_6*En + A_7*En^2 + A_8*En^3)*Ct] + A_9 + A_{10}*En + A_{11}*En^2 + A_{12}*En^3$$

where:

Bu	=	Minimum required assembly average burnup (GWD/MTU)
En	=	Initial ^{235}U Enrichment (wt%)
Ct	=	Post Irradiation Cooling Time (years)
A_i	=	Coefficients (see Tables 1-2 and 1-3)

Separate functional relationships are developed for axial blanketed fuel assemblies and pre-EPU fuel assemblies without axial blankets. The loading curves for blanketed fuel assemblies are developed by depleting the fuel under EPU conditions. Pre-EPU assemblies with axial blankets must use the EPU curves. The EPU curves are conservative for pre-EPU conditions (see Section 4.4). Note that for blanketed assemblies, the enrichment to be used in the loading curve equation is the enrichment of the axial section between the blanket material (the enrichment of the axial blankets is excluded when determining the assembly enrichment for application of the loading curve).

Since the loading curve is an exponential in cooling time, any cooling time between 72 hours and 25 years is allowed to be evaluated by the curve for blanketed fuel assemblies and between 10 years and 25 years for non-blanketed fuel assemblies. Fuel assemblies with cooling times greater than 25 years must conservatively use a value of 25 years.

The loading curves are valid for any enrichment between 2.0 and 5.0 for blanketed assemblies and between 1.8 and 4.0 for non-blanketed assemblies.

Coefficients for all loading curves, for both EPU blanketed assemblies and pre-EPU non-blanketed assemblies, are listed in Tables 1-2 and 1-3. Required burnup values for selected initial enrichments are determined from these coefficients and are listed in Tables 1-4 and 1-5 for information. Note that some burnups are above the current licensed limits but they are included for completeness. It is anticipated that the burnup requirements generated from the loading curves will be used for the actual placement of the fuel.

1.4 REGION 1 AND REGION 2 ANALYSIS RESULTS

Analyses demonstrate that the effective neutron multiplication factor (k_{eff}) of all permissible fuel storage arrangements is less than 0.95 when the storage racks are assumed to be flooded with borated water. Analyses also demonstrate that the k_{eff} is less than 0.95 under all postulated accident conditions. Finally, the analyses demonstrate that the k_{eff} of each fuel storage arrangement remains less than 1.0 when the pool is assumed to be flooded with unborated water. The maximum calculated values of the neutron multiplication factor include the appropriate bias, allowance for statistical uncertainty in the reactivity calculations, allowance for the effect of manufacturing tolerances on reactivity, allowance for the effect of eccentric positioning within the storage cell, allowance for uncertainty in the depletion calculations, and allowance for uncertainty in the assigned burnup of each assembly. These allowances are calculated with a 95% probability at a 95% confidence level (Reference 1). In all cases, the maximum k_{eff} calculated is less than 0.995 for margin to the 1.0 limit. For the cases that include soluble boron, the maximum k_{eff} calculated is less than 0.945 for margin to the 0.95 limit.

A minimum soluble boron concentration of 500 ppm must be maintained in the spent fuel pool to ensure that k_{eff} is less than 0.945 under all normal conditions.

A minimum soluble boron concentration of 1600 ppm must be maintained in the spent fuel pool to ensure that k_{eff} is less than 0.945 under all postulated accident conditions. The most limiting accident condition involves placing a fresh fuel assembly, enriched to 5.0 wt% ^{235}U, into an empty (water-filled) storage cell in the Array II-A storage arrangement (see Figure 1-2). A soluble boron concentration of 1600 ppm ensures that k_{eff} is less than 0.945 under this condition. Turkey Point Unit 3 and Unit 4 current Technical Specifications require that the fuel pool soluble boron concentration be maintained ≥1950 ppm at all times (Reference 8). As part of the EPU, a soluble boron concentration of ≥2300 ppm has been proposed; this will provide significant margin to the boron concentration needed to maintain k_{eff} less than 0.945 for the worst accident.

Specifically, the results of the analysis of Region 1 demonstrate that:

- 5.0 wt% ^{235}U fresh assemblies can be placed in Region 1 in a checkerboard pattern with water-filled cells (Array I-A).
- Category I-3 assemblies can be placed anywhere in Region 1 without restriction (Array I-B).
- Category I-2 assemblies (containing a full length RCCA) may be placed in any location instead of a Category I-3 assembly, without requiring a specific pattern (Array I-C).

Each 2x2 array in the Region 1 area of the pool must match one of the Arrays I-A through I-C. In this context, the term "match" means that the fuel assemblies forming the array have at least the required burnup (Category I-3) or an inserted full length RCCA (Category I-2) or they are checker boarded with empty (water-filled) cells (Category I-1).

The results of the analysis of Region 2 confirm that:

- Arrays II-A through II-F meet the criticality criteria.
- The presence of a full length RCCA in an assembly produces a lower reactivity than the same configuration where that assembly is stored in a cell containing a Metamic insert (without the RCCA). For Arrays II-B1 through II-D, it is therefore acceptable to use a full length RCCA in place of a Metamic insert.
- Fuel rod baskets may be placed in any spent fuel storage cell without restriction.

1.5 CASK AREA RACK

Analyses show that fresh fuel of up to 5.0 wt% ^{235}U can be stored in the cask area rack under fully flooded conditions and meet the acceptance criteria in Section 2.1.

1.6 NEW FUEL STORAGE RACK

Results confirm that Category I-2 (fresh fuel assemblies up to 4.7 wt% ^{235}U or up to 5.0 wt% with 16 or more IFBA rods or an equivalent amount of other burnable absorber) may be placed anywhere in the new fuel storage rack. The IFBA rods shall have a nominal boron content that is [

]^{a,c}

Table 1-2 Blanketed Fuel – Coefficients to Calculate the Minimum Required Fuel Assembly Burnup (Bu) as a Function of Enrichment (En) and Cooling Time (Ct)
(See Notes 1-5 for use of Table 1-2)

	Fuel Category					
Coefficients	**I-3**	**II-1**	**II-2a**	**II-2b**	**II-2c**	**II-3**
A1	3.94	-36.24	-25.34	-16.44	-4.202	21.29
A2	-6.213	33.85	24.57	16.93	6.41	-17.14
A3	2.867	-8.995	-6.372	-4.233	-1.332	5.681
A4	-0.2985	0.8217	0.5852	0.3995	0.1507	-0.511
A5	0.5688	0.6421	0.4329	0.4518	0.4025	-0.03822
A6	-0.2571	-0.4493	-0.2863	-0.3209	-0.2906	0.1354
A7	0.03994	0.1171	0.07647	0.08887	0.08382	-0.04176
A8	-0.001656	-0.009999	-0.006719	-0.007952	-0.007768	0.00387
A9	-31.8	2.918	-5.612	-9.132	-13.37	-34.54
A10	23.25	-2.415	6.56	11.58	16.96	38.72
A11	-3.643	3.949	1.51	-0.0305	-1.535	-7.927
A12	0.3011	-0.4073	-0.1932	-0.04359	0.08915	0.6882

Notes:

1. All relevant uncertainties are explicitly included in the criticality analysis. For instance, no additional allowance for burnup uncertainty or enrichment uncertainty is required. For a fuel assembly to meet the requirements of a Fuel Category, the assembly burnup must exceed the "minimum burnup" (GWD/MTU) given by the curve fit for the assembly "cooling time" and "initial enrichment." The specific minimum burnup required for each fuel assembly is calculated from the following equation:
$$\mathbf{Bu = (A_1 + A_2{*}En + A_3{*}En^2 + A_4{*}En^3){*}\ exp\ [- (A_5 + A_6{*}En + A_7{*}En^2 + A_8{*}En^3){*}Ct\ ] + A_9 + A_{10}{*}En + A_{11}{*}En^2 + A_{12}{*}En^3}$$
2. Initial enrichment, En, is the nominal central zone ^{235}U enrichment. Axial blanket material is not considered when determining enrichment. Any enrichment between 2.0 and 5.0 may be used.
3. Cooling time, Ct, is in years. Any cooling time between 72 hours and 25 years may be used. An assembly with a cooling time greater than 25 years must use 25 years.
4. Category I-1 is fresh unburned fuel up to 5.0 wt% ^{235}U enrichment. No burnup is required.
5. Category I-2 is fresh unburned fuel up to 4.7 wt% ^{235}U enrichment, fresh unburned fuel up to 5.0 wt% ^{235}U that contains at least 16 IFBA rods (or an equivalent amount of other burnable absorber), or 5.0 wt% ^{235}U with no burnable absorber rods burned to at least 500 MWD/MTU. For fuel with 16 IFBA rods (or an equivalent amount of other burnable absorber), no burnup is required but any amount of burnup is allowed.

Table 1-2 (cont.) Blanketed Fuel – Coefficients to Calculate the Minimum Required Fuel Assembly Burnup (Bu) as a Function of Enrichment (En) and Cooling Time (Ct)
(See Notes 1-3 for use of Table 1-2)

Coefficients	Fuel Category				
	II-4	**II-5**	**II-6**	**II-7**	**II-8**
A1	29.37	35.19	23.04	22.79	19.2
A2	-24.3	-29.28	-16.54	-15.59	-11.38
A3	7.817	9.348	5.604	5.376	4.194
A4	-0.7103	-0.8568	-0.512	-0.4954	-0.3908
A5	-0.07327	-0.1466	-0.02031	-0.04904	-0.1143
A6	0.1728	0.2426	0.1193	0.1427	0.1799
A7	-0.05314	-0.07373	-0.03703	-0.04334	-0.04983
A8	0.004935	0.00686	0.00344	0.004006	0.004345
A9	-34.59	-34.09	-14.9	-10.19	-4.624
A10	40.5	41.96	26.55	23.93	19.79
A11	-8.566	-9.168	-4.793	-4.151	-2.908
A12	0.7586	0.8309	0.4338	0.3871	0.2749

Notes:

1. All relevant uncertainties are explicitly included in the criticality analysis. For instance, no additional allowance for burnup uncertainty or enrichment uncertainty is required. For a fuel assembly to meet the requirements of a Fuel Category, the assembly burnup must exceed the "minimum burnup" (GWD/MTU) given by the curve fit for the assembly "cooling time" and "initial enrichment". The specific minimum burnup required for each fuel assembly is calculated from the following equation:

$$\mathbf{Bu = (A_1 + A_2*En + A_3*En^2 + A_4*En^3)* \exp [- (A_5 + A_6*En + A_7*En^2 + A_8*En^3)*Ct] + A_9 + A_{10}*En + A_{11}*En^2 + A_{12}*En^3}$$

2. Initial enrichment, En, is the nominal central zone ^{235}U enrichment. Axial blanket material is not considered when determining enrichment. Any enrichment between 2.0 and 5.0 may be used.
3. Cooling time, Ct, is in years. Any cooling time between 72 hours and 25 years may be used. An assembly with a cooling time greater than 25 years must use 25 years.

Table 1-3 Non-Blanketed Fuel – Coefficients to Calculate the Minimum Required Fuel Assembly Burnup (Bu) as a Function of Enrichment (En) and Cooling Time (Ct)
(See Notes 1-4 for use of Table 1-3)

	Fuel Category					
Coefficients	**I-3**	**II-1**	**II-2a**	**II-2b**	**II-2c**	**II-3**
A1	-35.18	-10.95	-85.44	-41.76	-3.86	-30.33
A2	37.24	7.053	101.1	47.68	2.495	32.89
A3	-12.45	-0.5508	-34.92	-15.55	1.017	-9.444
A4	1.414	0	3.869	1.687	-0.2178	0.9173
A5	1.318	-0.5039	0.262	0.5439	1.056	0.5915
A6	-0.7817	0.3565	-0.2987	-0.6332	-1.204	-0.663
A7	0.13	-0.05129	0.107	0.2377	0.4525	0.2469
A8	-0.00307	0	-0.0111	-0.02719	-0.05352	-0.02849
A9	-21.4	-25.13	42.21	2.733	-7.353	14.57
A10	12.42	18.47	-62.25	-14.23	-1.402	-22.93
A11	-0.3007	-0.9294	27.68	11.17	7.4	14.27
A12	0.008347	0	-3.139	-1.364	-1.051	-1.723

Notes:

1. All relevant uncertainties are explicitly included in the criticality analysis. For instance, no additional allowance for burnup uncertainty or enrichment uncertainty is required. For a fuel assembly to meet the requirements of a Fuel Category, the assembly burnup must exceed the "minimum burnup" (GWD/MTU) given by the curve fit for the assembly "cooling time" and "initial enrichment." The specific minimum burnup required for each fuel assembly is calculated from the following equation:

$$\mathbf{Bu} = (A_1 + A_2{*}En + A_3{*}En^2 + A_4{*}En^3){*}\exp[-(A_5 + A_6{*}En + A_7{*}En^2 + A_8{*}En^3){*}Ct] + A_9 + A_{10}{*}En + A_{11}{*}En^2 + A_{12}{*}En^3$$

2. Initial enrichment, En, is the nominal ^{235}U enrichment. Any enrichment between 1.8 and 4.0 may be used.
3. Cooling time, Ct, is in years. Any cooling time between 10 years and 25 years may be used. An assembly with a cooling time greater than 25 years must use 25 years.
4. This Table applies only for pre-EPU fuel assemblies without axial blankets. If an unblanketed assembly is depleted at EPU conditions none of the burnup accrued at EPU conditions can be credited (i.e., only burnup accrued at pre-EPU conditions may be used as burnup credit).

Table 1-3 (cont.)	Non-Blanketed Fuel – Coefficients to Calculate the Minimum Required Fuel Assembly Burnup (Bu) as a Function of Enrichment (En) and Cooling Time (Ct) (See Notes 1-4 for use of Table 1-3)				
	Fuel Category				
Coefficients	II-4	II-5	II-6	II-7	II-8
A1	-35.55	-22.12	-20.42	-15.32	-82.47
A2	39.21	24.48	21.91	16.33	97.23
A3	-11.72	-6.23	-4.78	-2.554	-33.42
A4	1.18	0.5118	0.2802	-0.00474	3.782
A5	0.7689	0.7824	-0.6527	0.7264	0.4198
A6	-0.8497	-0.8901	0.8281	-0.7902	-0.3959
A7	0.3126	0.3369	-0.2977	0.2894	0.1245
A8	-0.03608	-0.04	0.03405	-0.03319	-0.01113
A9	21.35	18.32	-50.43	22.01	40.38
A10	-29.32	-26.14	56.6	-25.98	-44.56
A11	16.73	16.25	-13.93	15.89	21.97
A12	-2.024	-2.038	1.453	-1.955	-2.568

Notes:

1. All relevant uncertainties are explicitly included in the criticality analysis. For instance, no additional allowance for burnup uncertainty or enrichment uncertainty is required. For a fuel assembly to meet the requirements of a Fuel Category, the assembly burnup must exceed the "minimum burnup" (GWD/MTU) given by the curve fit for the assembly "cooling time" and "initial enrichment". The specific minimum burnup required for each fuel assembly is calculated from the following equation:

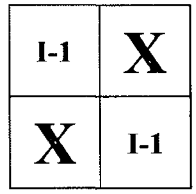
$$\mathbf{Bu = (A_1 + A_2*En + A_3*En^2 + A_4*En^3)* \exp [- (A_5 + A_6*En + A_7*En^2 + A_8*En^3)*Ct] + A_9 + A_{10}*En + A_{11}*En^2 + A_{12}*En^3}$$

2. Initial enrichment, En, is the nominal ^{235}U enrichment. Any enrichment between 1.8 and 4.0 may be used.
3. Cooling time, Ct, is in years. Any cooling time between 10 years and 25 years may be used. An assembly with a cooling time greater than 25 years must use 25 years.
4. This Table applies only for pre-EPU fuel assemblies without axial blankets. If an unblanketed assembly is depleted at EPU conditions none of the burnup accrued at EPU conditions can be credited (i.e., only burnup accrued at pre-EPU conditions may be used as burnup credit).

DEFINITION **ILLUSTRATION**

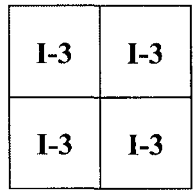
Array I-A

Checkerboard pattern of Category I-1 assemblies and empty (water-filled) cells.



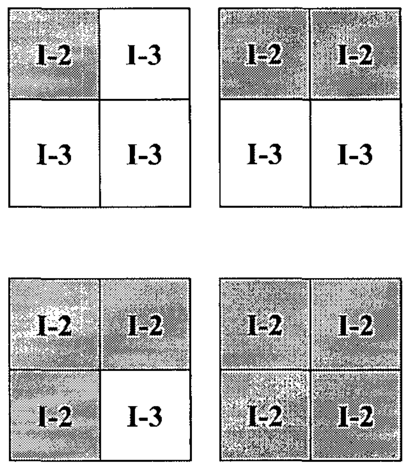
Array I-B

Category I-3 assembly in every cell.



Array I-C

Category I-2 and I-3 assemblies. Each Category I-2 shall have a full length RCCA in the assembly.



Notes:

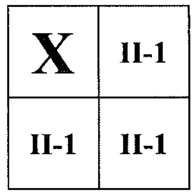
1. Category I-1 is fresh fuel enriched to 5.0 wt% ^{235}U. I-2 is fresh fuel enriched to 4.7 wt%, fresh fuel enriched to 5.0 wt% with at least 16 IFBA rods (or an equivalent amount of other burnable absorber), or fuel enriched to 5.0 wt% with no burnable absorber rods burned to at least 500 MWD/MTU. Category I-3 is determined from Tables 1-2 and 1-3. In all arrays, an assembly of lower reactivity can replace an assembly of higher reactivity.
2. Shaded cells indicate that the fuel assembly contains a full length RCCA.
3. **X** indicates an empty (water-filled) cell.
4. Attributes for each 2x2 array are as stated in the definition. Diagram is for illustrative purposes only.

Figure 1-1. Allowable Region 1 Storage Arrays

DEFINITION | **ILLUSTRATION**

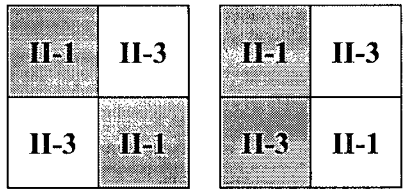
Array II-A

Category II-1 assemblies in three of every four cells;
One of every four cells is empty (water-filled).



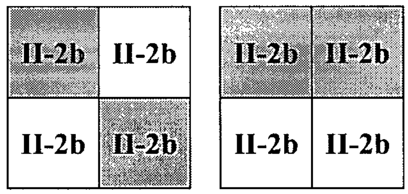
Array II-B1

Checkerboard pattern of Category II-1 and II-3 assemblies with two of every four cells containing a Metamic insert or full length RCCA.



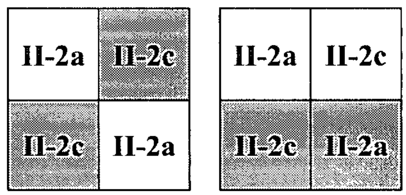
Array II-B2

Category II-2b assembly in every cell with two of every four cells containing a Metamic insert or full length RCCA.



Array II-B3

Checkerboard pattern of Category II-2a and II-2c assemblies with two of every four cells containing a Metamic insert or full length RCCA.



Notes:

1. Fuel categories are determined from Tables 1-2 and 1-3. In all arrays, an assembly of lower reactivity can replace an assembly of higher reactivity.
2. Shaded cells indicate that the cell contains a Metamic insert or the fuel assembly contains a full length RCCA.
3. **X** indicates an empty (water-filled) cell.
4. Attributes for each 2x2 array are as stated in the definition. Diagram is for illustrative purposes only.

Figure 1-2. Allowable Region 2 Storage Arrays

DEFINITION | **ILLUSTRATION**

Array II-C

Checkerboard pattern of Category II-3 and II-5 assemblies with one of every four cells containing a Metamic insert or full length RCCA.

II-3	II-5
II-5	II-3

II-5	II-3
II-3	II-5

Array II-D

Category II-4 assembly in every cell with one out of every four cells containing a Metamic insert or full length RCCA.

II-4	II-4
II-4	II-4

Array II-E

Checkerboard pattern of Category II-6 and II-8 assemblies.

II-6	II-8
II-8	II-6

Array II-F

Category II-7 assembly in every cell.

II-7	II-7
II-7	II-7

Notes:

1. Fuel categories are determined from Tables 1-2 and 1-3. In all arrays, an assembly of lower reactivity can replace an assembly of higher reactivity.
2. Shaded cells indicate that the cell contains a Metamic insert or the fuel assembly contains a full length RCCA.
3. **X** indicates an empty (water-filled) cell.
4. Attributes for each 2x2 array are as stated in the definition. Diagram is for illustrative purposes only.

Figure 1-2. Allowable Region 2 Storage Arrays (cont.)

DEFINITION | **ILLUSTRATION**

For Array II-A, the empty cell shall be in the row adjacent to the Region 1 rack.

Region 1 Rack

I-3	I-3	I-3	I-3
I-3	I-3	I-3	I-3
II-1	X	II-1	X
II-1	II-1	II-1	II-1

Array II-A

For Arrays requiring two inserts, there shall be an insert in at least every other cell in the row facing the Region 1 rack.

Region 1 Rack

I-3	I-3	I-3	I-3
I-3	I-3	I-3	I-3
II-1	II-3	II-1	II-3
II-3	II-1	II-3	II-1

Array II-B1

Region 1 Rack

I-3	I-3	I-3	I-3
I-3	I-3	I-3	I-3
II-2b	II-2b	II-2b	II-2b
II-2b	II-2b	II-2b	II-2b

Array II-B2

Region 1 Rack

I-3	I-3	I-3	I-3
I-3	I-3	I-3	I-3
II-2a	II-2c	II-2a	II-2c
II-2c	II-2a	II-2c	II-2a

Array II-B3

For Arrays requiring one insert, the insert shall be placed in the row facing the Region 1 rack.

Region 1 Rack

I-3	I-3	I-3	I-3
I-3	I-3	I-3	I-3
II-3	II-5	II-3	II-5
II-5	II-3	II-5	II-3

Array II-C

Region 1 Rack

I-3	I-3	I-3	I-3
I-3	I-3	I-3	I-3
II-5	II-3	II-5	II-3
II-3	II-5	II-3	II-5

Array II-C

Region 1 Rack

I-3	I-3	I-3	I-3
I-3	I-3	I-3	I-3
II-4	II-4	II-4	II-4
II-4	II-4	II-4	II-4

Array II-D

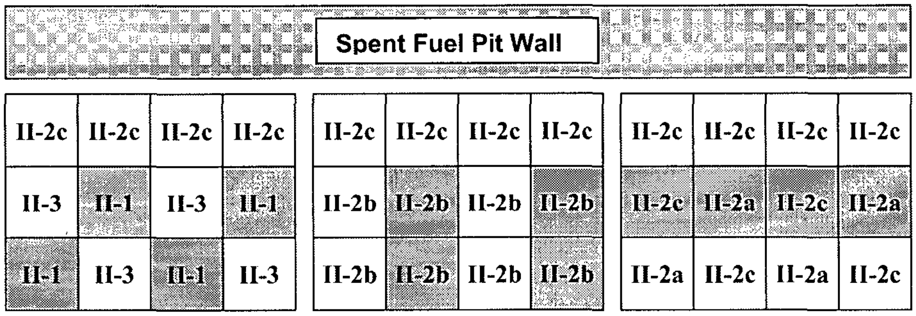
Notes:

1. Fuel categories are determined from Tables 1-2 and 1-3. In all arrays, an assembly of lower reactivity can replace an assembly of higher reactivity.
2. Shaded cells indicate that the cell contains a Metamic insert or the fuel assembly contains a full length RCCA.
3. **X** indicates an empty (water-filled) cell.
4. Attributes for each 2x2 array are as stated in the definition. Diagram is for illustrative purposes only. Region 1 Array I-3 is depicted as the example; however, any Region 1 array is allowed.
5. Figure 1-3 is not applicable to the Region II – cask area rack interface

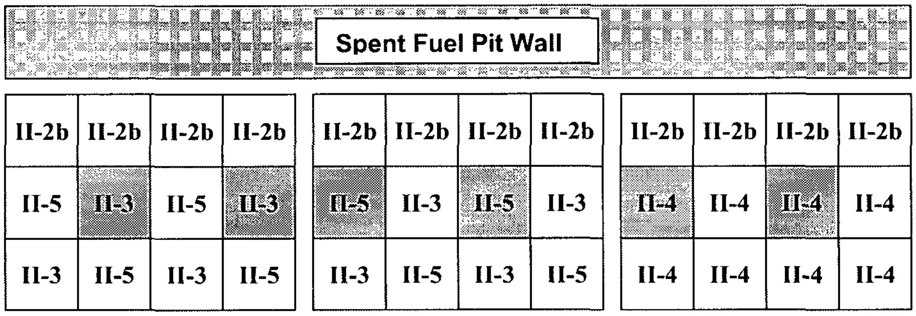
Figure 1-3. Interface Restrictions between Region 2 and Region 1 Arrays

DEFINITION **ILLUSTRATION**

For Arrays requiring two inserts, there shall be an insert in at least every other cell adjacent to the peripheral row containing the II-2c assemblies.



For Arrays requiring one insert, the insert shall be adjacent to the peripheral row containing the II-2b assemblies.



Notes:

1. Fuel categories are determined from Tables 1-2 and 1-3. Fuel category of rank II-2b or lower reactivity can be placed in the peripheral row next to the spent fuel pit wall without inserts, subject to the constraints listed here. For arrays requiring 2 inserts, the peripheral row must contain Category II-2c or lower reactivity. Alternatively, the peripheral row may contain inserts as required for any 2x2 array.
2. Shaded cells indicate either a Metamic insert in the cell or the fuel assembly contains a full length RCCA.
3. **X** indicates an empty (water-filled) cell.
4. Attributes for each 2x2 array are as stated in the definition. Diagram is for illustrative purposes only.
5. There are no restrictions for placement of Arrays II-E and II-F.
6. Any defined Region 2 array may be placed against the spent fuel pit wall or one of the additional configurations shown above may be used.

Figure 1-4. Allowable Exceptions to Region 2 Storage Arrays When Adjacent to Spent Fuel Pit Walls

Table 1-4	Burnup Requirements for Pre-EPU Non-Blanketed Fuel				
Cooling Time	Fuel Category I-3 Initial Enrichment (wt% ^{235}U)				
	1.8	2.5	3.0	3.5	4.0
	GWD/MTU				
10 y	0.02	8.51	14.84	20.87	26.41
15 y	0.03	8.22	14.46	20.46	25.66
20 y	0.03	8.07	14.18	20.13	25.14
25 y	0.03	7.99	13.97	19.86	24.79

Table 1-4 (cont.)	Burnup Requirements for Pre-EPU Non-Blanketed Fuel				
Cooling Time	Fuel Category II-1 Initial Enrichment (wt% ^{235}U)				
	1.8	2.5	3.0	3.5	4.0
	GWD/MTU				
10 y	5.05	16.90	23.77	30.33	36.94
15 y	5.04	16.43	23.02	29.36	35.72
20 y	5.04	16.09	22.57	28.82	34.99
25 y	5.03	15.85	22.31	28.52	34.55

Table 1-4 (cont.)	Burnup Requirements for Pre-EPU Non-Blanketed Fuel				
Cooling Time	Fuel Category II-2a Initial Enrichment (wt% ^{235}U)				
	1.8	2.5	3.0	3.5	4.0
	GWD/MTU				
10 y	7.14	19.10	25.83	32.73	39.14
15 y	6.96	18.66	25.02	31.85	37.99
20 y	6.80	18.24	24.31	31.16	37.18
25 y	6.63	17.84	23.70	30.64	36.60

Table 1-4 (cont.)	Burnup Requirements for Pre-EPU Non-Blanketed Fuel				
Cooling Time	Fuel Category II-2b Initial Enrichment (wt% ^{235}U)				
	1.8	2.5	3.0	3.5	4.0
	GWD/MTU				
10 y	8.36	20.98	27.94	34.61	41.11
15 y	8.14	20.43	27.02	33.58	39.91
20 y	7.93	19.94	26.30	32.87	39.08
25 y	7.73	19.50	25.74	32.38	38.51

Table 1-4 (cont.)	Burnup Requirements for Pre-EPU Non-Blanketed Fuel				
Cooling Time	Fuel Category II-2c Initial Enrichment (wt% ^{235}U)				
	1.8	2.5	3.0	3.5	4.0
	GWD/MTU				
10 y	9.70	22.62	30.04	36.56	43.07
15 y	9.37	21.99	29.03	35.39	41.89
20 y	9.10	21.47	28.32	34.64	41.00
25 y	8.88	21.04	27.82	34.16	40.33

Table 1-4 (cont.)	Burnup Requirements for Pre-EPU Non-Blanketed Fuel				
Cooling Time	Fuel Category II-3 Initial Enrichment (wt% ^{235}U)				
	1.8	2.5	3.0	3.5	4.0
	GWD/MTU				
10 y	12.12	24.74	32.35	39.27	45.44
15 y	11.73	23.97	31.22	38.02	44.15
20 y	11.40	23.31	30.37	37.17	43.23
25 y	11.11	22.75	29.72	36.57	42.57

Table 1-4 (cont.) Burnup Requirements for Pre-EPU Non-Blanketed Fuel

Cooling Time	Fuel Category II-4 Initial Enrichment (wt% ^{235}U)				
	1.8	**2.5**	**3.0**	**3.5**	**4.0**
	GWD/MTU				
10 y	13.57	26.41	34.00	40.91	47.18
15 y	13.08	25.54	32.80	39.62	45.85
20 y	12.68	24.82	31.91	38.75	44.87
25 y	12.36	24.21	31.25	38.15	44.16

Table 1-4 (cont.) Burnup Requirements for Pre-EPU Non-Blanketed Fuel

Cooling Time	Fuel Category II-5 Initial Enrichment (wt% ^{235}U)				
	1.8	**2.5**	**3.0**	**3.5**	**4.0**
	GWD/MTU				
10 y	15.26	28.27	35.90	42.68	48.58
15 y	14.70	27.31	34.59	41.32	47.37
20 y	14.23	26.51	33.64	40.40	46.44
25 y	13.84	25.85	32.95	39.79	45.72

Table 1-4 (cont.) Burnup Requirements for Pre-EPU Non-Blanketed Fuel

Cooling Time	Fuel Category II-6 Initial Enrichment (wt% ^{235}U)				
	1.8	**2.5**	**3.0**	**3.5**	**4.0**
	GWD/MTU				
10 y	17.31	30.35	38.04	44.73	50.15
15 y	16.55	29.04	36.60	43.35	48.87
20 y	16.02	28.21	35.58	42.33	47.99
25 y	15.65	27.67	34.87	41.57	47.39

Table 1-4 (cont.)	Burnup Requirements for Pre-EPU Non-Blanketed Fuel				
Cooling Time	Fuel Category II-7 Initial Enrichment (wt% ^{235}U)				
	1.8	2.5	3.0	3.5	4.0
	GWD/MTU				
10 y	18.89	32.11	39.85	46.43	51.52
15 y	18.13	30.94	38.32	44.90	50.22
20 y	17.53	29.99	37.21	43.89	49.31
25 y	17.06	29.22	36.41	43.22	48.68

Table 1-4 (cont.)	Burnup Requirements for Pre-EPU Non-Blanketed Fuel				
Cooling Time	Fuel Category II-8 Initial Enrichment (wt% ^{235}U)				
	1.8	2.5	3.0	3.5	4.0
	GWD/MTU				
10 y	20.38	33.85	41.36	48.11	53.63
15 y	19.56	32.64	39.93	46.54	51.73
20 y	18.91	31.62	38.82	45.50	50.67
25 y	18.40	30.76	37.96	44.81	50.07

Table 1-5 Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel

Cooling Time	Fuel Category I-3 Initial Enrichment (wt% ^{235}U)				
	2.0	3.4	4.0	4.5	5.0
	GWD/MTU				
72 h	3.13	21.19	28.03	33.33	38.25
2.5 y	2.90	20.34	27.06	32.24	37.02
5 y	2.75	19.65	26.24	31.32	35.99
10 y	2.62	18.67	24.99	29.90	34.44
15 y	2.57	18.05	24.13	28.89	33.37
20 y	2.55	17.65	23.53	28.19	32.63
25 y	2.54	17.40	23.12	27.69	32.13

Table 1-5 (cont.) Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel

Cooling Time	Fuel Category II-1 Initial Enrichment (wt% ^{235}U)				
	2.0	3.4	4.0	4.5	5.0
	GWD/MTU				
72 h	12.68	31.51	38.20	43.71	49.50
2.5 y	12.10	30.29	36.81	42.11	47.69
5 y	11.69	29.27	35.66	40.80	46.18
10 y	11.17	27.73	33.94	38.85	43.87
15 y	10.91	26.67	32.78	37.54	42.27
20 y	10.77	25.94	32.00	36.67	41.16
25 y	10.70	25.44	31.47	36.08	40.39

Table 1-5 (cont.) Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel

Cooling Time	Fuel Category II-2a Initial Enrichment (wt% ^{235}U)				
	2.0	3.4	4.0	4.5	5.0
	GWD/MTU				
72 h	14.99	34.09	40.86	46.39	52.14
2.5 y	14.26	32.74	39.31	44.66	50.25
5 y	13.71	31.62	38.05	43.24	48.66
10 y	12.97	29.96	36.17	41.12	46.25
15 y	12.56	28.85	34.92	39.71	44.57
20 y	12.32	28.09	34.09	38.77	43.41
25 y	12.18	27.59	33.53	38.14	42.61

Table 1-5 (cont.) Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel

Cooling Time	Fuel Category II-2b Initial Enrichment (wt% ^{235}U)				
	2.0	3.4	4.0	4.5	5.0
	GWD/MTU				
72 h	17.24	36.06	43.02	48.81	54.87
2.5 y	16.41	34.71	41.35	46.87	52.77
5 y	15.77	33.58	39.99	45.29	51.02
10 y	14.89	31.88	37.96	42.95	48.37
15 y	14.36	30.72	36.61	41.40	46.55
20 y	14.04	29.92	35.71	40.38	45.30
25 y	13.85	29.37	35.11	39.71	44.44

Table 1-5 (cont.)	Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel				
Cooling Time	Fuel Category II-2c Initial Enrichment (wt% ^{235}U)				
	2.0	3.4	4.0	4.5	5.0
	GWD/MTU				
72 h	19.62	38.17	45.38	51.38	57.58
2.5 y	18.67	36.73	43.53	49.23	55.32
5 y	17.93	35.55	42.03	47.47	53.44
10 y	16.87	33.77	39.83	44.90	50.59
15 y	16.21	32.57	38.38	43.21	48.61
20 y	15.80	31.76	37.43	42.10	47.25
25 y	15.55	31.21	36.81	41.38	46.30

Table 1-5 (cont.)	Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel				
Cooling Time	Fuel Category II-3 Initial Enrichment (wt% ^{235}U)				
	2.0	3.4	4.0	4.5	5.0
	GWD/MTU				
72 h	22.34	41.12	48.47	54.52	60.64
2.5 y	21.13	39.36	46.43	52.28	58.20
5 y	20.18	37.96	44.77	50.44	56.19
10 y	18.85	35.97	42.32	47.68	53.18
15 y	18.03	34.70	40.70	45.81	51.14
20 y	17.52	33.90	39.63	44.54	49.77
25 y	17.20	33.39	38.93	43.68	48.84

Table 1-5 (cont.)	Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel				
Cooling Time	Fuel Category II-4 Initial Enrichment (wt% ^{235}U)				
	2.0	3.4	4.0	4.5	5.0
	GWD/MTU				
72 h	24.57	43.09	50.68	56.91	63.08[1]
2.5 y	23.17	41.18	48.47	54.51	60.49
5 y	22.08	39.65	46.66	52.53	58.35
10 y	20.57	37.50	44.02	49.56	55.16
15 y	19.65	36.15	42.27	47.55	53.01
20 y	19.09	35.31	41.12	46.18	51.57
25 y	18.75	34.78	40.36	45.26	50.59

Table 1-5 (cont.)	Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel				
Cooling Time	Fuel Category II-5 Initial Enrichment (wt% ^{235}U)				
	2.0	3.4	4.0	4.5	5.0
	GWD/MTU				
72 h	26.97	45.27	53.03	59.44	65.75[1]
2.5 y	25.41	43.14	50.64	56.87	62.95[1]
5 y	24.18	41.47	48.69	54.75	60.66
10 y	22.48	39.11	45.81	51.56	57.24
15 y	21.44	37.64	43.92	49.40	54.96
20 y	20.80	36.73	42.67	47.92	53.44
25 y	20.42	36.17	41.84	46.92	52.42

1. Although this value is above the currently allowable burnup limit, it is provided for information only.

Table 1-5 (cont.)	**Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel**				
Cooling Time	**Fuel Category II-6 Initial Enrichment (wt% ^{235}U)**				
	2.0	**3.4**	**4.0**	**4.5**	**5.0**
	GWD/MTU				
72 h	30.77	48.47	56.14	62.47[1]	68.68[1]
2.5 y	28.98	46.11	53.53	59.68	65.70[1]
5 y	27.58	44.23	51.40	57.39	63.25[1]
10 y	25.62	41.56	48.29	53.97	59.60
15 y	24.41	39.88	46.25	51.69	57.17
20 y	23.67	38.82	44.91	50.15	55.54
25 y	23.22	38.15	44.04	49.13	54.45

Table 1-5 (cont.)	**Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel**				
Cooling Time	**Fuel Category II-7 Initial Enrichment (wt% ^{235}U)**				
	2.0	**3.4**	**4.0**	**4.5**	**5.0**
	GWD/MTU				
72 h	33.31	50.85	58.62	65.06[1]	71.38[1]
2.5 y	31.38	48.29	55.82	62.09[1]	68.19[1]
5 y	29.85	46.24	53.54	59.65	65.58[1]
10 y	27.70	43.34	50.21	56.02	61.72
15 y	26.36	41.51	48.03	53.60	59.16
20 y	25.53	40.36	46.60	51.98	57.45
25 y	25.01	39.63	45.66	50.90	56.32

1. Although this value is above the currently allowable burnup limit, it is provided for information only.

Table 1-5 (cont.)	**Burnup Requirements for EPU and Pre-EPU Axial Blanket Fuel**				
Cooling Time	**Fuel Category II-8 Initial Enrichment (wt% ^{235}U)**				
	2.0	**3.4**	**4.0**	**4.5**	**5.0**
	GWD/MTU				
72 h	35.61	53.47	61.36	67.89[1]	74.28[1]
2.5 y	33.76	50.68	58.32	64.69[1]	70.88[1]
5 y	32.25	48.45	55.86	62.07[1]	68.10[1]
10 y	30.01	45.28	52.27	58.21	64.00[1]
15 y	28.52	43.27	49.94	55.64	61.29
20 y	27.52	42.01	48.42	53.94	59.50
25 y	26.86	41.21	47.43	52.81	58.31

1. Although this value is above the currently allowable burnup limit, it is provided for information only.

2 ACCEPTANCE CRITERIA

2.1 SPENT FUEL POOL CRITERIA

The objective of this analysis is to ensure that all calculations of the effective neutron multiplication factor (k_{eff}) performed for each permissible storage arrangement, yield results less than 0.95 when the storage racks are fully loaded with fuel of the highest permissible reactivity, and assuming the pool is flooded with borated water at a temperature corresponding to the highest reactivity. Also, the analysis must demonstrate that k_{eff} is less than 0.95 under all postulated accident conditions. Finally, the analysis must demonstrate that k_{eff} is less than 1.0 with unborated water in the spent fuel pool. The maximum calculated values of neutron multiplication must include a margin for statistical uncertainty in the reactivity calculations, include the effect of manufacturing tolerances and eccentric positioning, include an allowance for uncertainty in the depletion calculations and the assigned burnup, and be calculated with a 95% probability at a 95% confidence level (Reference 1).

2.2 NEW FUEL STORAGE RACK CRITERIA

For the new fuel storage rack, analyses must demonstrate:

1. The estimated ratio of neutron production to neutron absorption and leakage (k_{eff}) of the fresh fuel in the fresh fuel storage racks shall be calculated assuming the racks are loaded with fuel of the maximum fuel assembly reactivity and flooded with unborated water and must not exceed 0.95, at a 95 percent probability, 95 percent confidence level.

2. If optimum moderation in the fresh fuel storage racks occurs when the racks are assumed to be loaded with fuel of the maximum fuel assembly reactivity and filled with low-density hydrogenous fluid, the k-effective corresponding to this optimum moderation must not exceed 0.98, at a 95 percent probability, 95 percent confidence level.

The maximum k_{eff} must account for all biases and uncertainties.

3 ASSUMPTIONS

The major assumptions are listed below:

1. The only fuel types considered are the Westinghouse 15x15 STD and the Westinghouse 15x15 OFA (which includes Upgrade fuel) fuel assembly designs. These are the only fuel types used at Turkey Point. The Westinghouse 15x15 STD and OFA designs are similar in all dimensions that are important to reactivity with the exception of the guide and instrumentation tubes and minor changes to the clad material. These small differences are not significant to criticality (see Section 6.3.1). Upgrade fuel is the same as OFA fuel for all the key dimensions listed on Table 4.1.

2. The pellet smear density is assumed to be 97.5% of theoretical density with no credit for dishing or chamfering. This is the highest density that is being manufactured including tolerances. The higher the fuel density, the more reactive the fuel will be.

3. For criticality analyses that take credit for IFBA rods in fresh fuel, the nominal ^{10}B loading is assumed to be [

   ]^{a,c}

4. All EPU fuel is assumed to contain 8 inch axial blankets with the blanket material enriched to 2.6 wt% ^{235}U and the blanket pellets are annular. This assumption is conservative for blankets enriched to less than 2.6 wt% or blankets that are longer than 8 inches. This assumption does not cover shorter blankets or solid pellets. However, in the special case of 6 inch natural uranium blankets, it is shown that the 8 inch enriched blanket depleted under EPU conditions is conservative (see subsection 6.3.2).

5. All non-blanketed fuel (i.e., full length) is assumed to be characterized by the non-blanketed fuel currently in the Turkey Point spent fuel pools and exposed to pre-EPU conditions. The analysis does not cover non-blanketed fuel that might be used in the future. If an existing non-blanketed assembly is re-inserted into the core, the extra burnup received cannot be credited. Only the burnup received under pre-EPU conditions can be credited for non-blanketed fuel.

6. Depletion conditions for both pre-EPU and EPU fuel are chosen to conservatively maximize the reactivity at a given burnup (hardened spectrum, higher plutonium production, etc.). See Section 4.4.

7. The fuel pool temperature that results in the highest reactivity for each fuel category is used in the calculations.

8. The uncertainty in the depletion calculations is 5% of the difference between the reactivity of fresh fuel and the reactivity at the burnup of interest. This is consistent with the Kopp memo (Reference 4). The uncertainty in the burnup reactor records is assumed to be 5% of the burnup. Both are included in the analysis with and without soluble boron credit.

9. The effective multiplication factor of an infinite radial array of fuel assemblies or assembly patterns is used in the analyses, except for the assessment of peripheral and interface effects and to analyze the worst case accident condition. Specifically, all gaps between adjacent Region 2 rack modules are conservatively ignored, i.e., cells in neighboring Region 2 rack modules are assumed to be separated by a single cell wall only. The actual configuration in the Turkey Point spent fuel pool has a cell wall on each side of the Region 2 rack-to-rack gap.

Additionally, the following modeling assumptions are used.

1. Neutron absorption in minor structural members is neglected, i.e., spacer grids are replaced by water. [

   ]^{a,c}

2. For freshly unloaded fuel, a cooling time of 72 hours is used in the analysis. This value is a technical specification at Turkey Point (Reference 7). Also, the Xe-135 concentration in the fuel is conservatively set to zero at all cooling times.

3. In the KENO models, 60 cm of unborated water is used above and below the active region of the fuel, even when soluble boron is credited in the active fuel region. This is conservative because the end fittings absorb neutrons and if they were to be modeled explicitly, the reactivity would decrease.

4 DESIGN AND INPUT DATA

4.1 FUEL ASSEMBLY AND RCCA SPECIFICATIONS

The design specifications of fuel assemblies, which are used for this analysis, are given in Table 4-1. Table 4-2 shows specifications for the full length RCCA used in the analysis. Please note that RCCA always refers to full length RCCAs. Part length control elements are not included as RCCAs in this report.

Table 4-1 Fuel Assembly Specifications

Parameter	Value		
Assembly Type	W 15x15 STD or OFA		
Rod Array Size	15x15		
Rod Pitch, inch	0.563 ± [ ]^{a,c}		
Active Fuel Length, inches	144		
Stack density, % TD	97.5		
Maximum enrichment, wt% ^{235}U	5.0		
Enrichment tolerance (for enrichments less than 5.0 wt%), wt%	± .05		
Total number of Fuel Rods	204		
Fuel cladding outer diameter, inch	0.4220 ± [ ]^{a,c}		
Fuel cladding inner diameter, inch	0.3734 ± [ ]^{a,c}		
Fuel cladding thickness, inch	0.0243 ± [ ]^{a,c}		
Pellet diameter, inch	0.3659[(1)] ± [ ]^{a,c}		
IFBA ^{10}B loading, mg/inch	[ ]^{a,c}		
Number of Guide/Instrument tubes	20/1		
	STD	OFA	Toler.
Guide/Instrument tube OD, inch	0.546	0.533	± [ ]^{a,c}
Guide/Instrument tube ID, inch	0.512	0.499	± [ ]^{a,c}
Guide/Instrument tube thickness, inch	0.017	0.017	± [ ]^{a,c}

1 The nominal pellet diameter is 0.3659 inches. However there have been some fuel rods with pellet diameters outside of the manufacturing tolerances shown. Smaller than nominal diameter pellets are conservatively bounded by this analysis since the smaller pellet diameter results in less fuel thus less reactivity. The effect of the rods with the large pellet diameter is negligible since there are only 4 rods of this diameter.

Table 4-2 RCCA Specifications	
Parameter	**Value**
Material	Silver-Indium-Cadmium
Silver content, wt%	80 ± [ ]a,c
Indium content, wt%	15 ± [ ]a,c
Cadmium content, wt%	5 ± [ ]a,c
Poison OD, inch	0.3900 ± [ ]a,c
Clad inner diameter, inch	0.4005 ± [ ]a,c
Clad outer diameter, inch	0.4390 ± [ ]a,c
Clad material	SS
Poison density, g/cc	10.17

Table 4-3 Pyrex and WABA Specifications		
Parameter	**Pyrex**	**WABA**
Burnable Absorber Material	Borosilicate Glass	B4C
BA Inner Diameter	0.2440	0.2780
BA Outer Diameter	0.3890	0.3180
BA Clad Material	SS	Zr
BA Inner Clad Thickness	0.0065	0.0210
BA Inner Clad OD	0.2360	0.2670
BA Outer Clad Thickness	0.0188	0.0260
BA Outer Clad OD	0.4310	0.3810

Tables 4-1 and 4-2 above list tolerances for the fuel and the full length RCCA control insert. [

]a,c

For the burnable absorbers during depletion (Pyrex, WABA, and IFBA), nominal values are used because nominal values are used in fuel management. [

]a,c

The stack density is set to the highest possible density without credit for dishing and chamfering. Experience shows that the higher the stack density, the more reactive the assembly is (there is more fuel present). Except for stack density, the criticality analysis is performed at the nominal fuel dimensions using STD fuel. [

]^{a,c} If the true tolerance were greater, there would have been a history of fuel assemblies getting stuck during refueling which has not been the case. Uncertainties in the k_{eff} calculations due to tolerances are then calculated separately. An additional analysis shows that the guide tube differences between Optimized Fuel Assembly (OFA) and Standard (STD) fuel is insignificant (see subsection 6.3.1).

Fuel rod baskets can be stored in any fuel storage cell in the pool without restriction; this includes fuel storage cells in Region 1, Region 2, and the cask area rack. These baskets consist of regular arrays of stainless steel tubes. Individual fuel rods are placed in these tubes. The specifications of these fuel rod baskets are given in Table 4-4.

Table 4-4 Fuel Rod Basket Specification

Parameter	Value
Tube Array	8x8 – 4x3 (see Section 6.9)
Number of Tubes	52
Tube OD, inch	0.625
Tube thickness, inch	0.035
Tube pitch, inch	0.937
Tube material	SS

4.2 STORAGE RACK SPECIFICATIONS

The storage cell characteristics that are used in the criticality analysis are summarized in Table 4-5 for the Region 1, Region 2, cask area, and new fuel racks, and in Table 4-6 for the Metamic neutron absorber inserts. Note that the poison areal density listed for Regions 1 and 2 is not used in the analysis since it is assumed that the Boraflex has completely degraded. The Boraflex material is replaced with water. There is no credible mechanism that would allow the ^{10}B to escape without the whole material dissolving so replacing the Boraflex with water is appropriate (i.e., if there is any Boraflex material remaining, it would also contain the neutron absorbing ^{10}B). For the Metamic inserts, maximum reactivity is obtained by using the maximum value for the thickness and minimum values for the width and length. The water near the Metamic is important to slow down neutrons that can then be absorbed by the Metamic. Therefore, less water (because the Metamic thickness is larger) will be less effective for Metamic absorption and result in higher reactivity. Also, note that the insert length used in the analysis is shorter than the active fuel length, i.e., it is assumed that the lower 6 inches of the active length are not covered by the insert.

Table 4-5 Fuel Rack Specifications				
	Value			
Parameter	Region 1	Region 2	Cask Area	New Fuel Rack
Cell ID, inches	8.75 [ ]a,c	8.80 [ ]a,c	8.75 [ ]a,c	9.00 [ ]a,c
Wall thickness, inch	0.075 [ ]a,c	0.075 [ ]a,c	0.075 [ ]a,c	0.075 [ ]a,c
Cell Pitch, inch	10.60 [ ]a,c	9.00 [ ]a,c	10.10 [ ]a,c	21.0 [ ]a,c
Poison cavity thickness, inch	0.090 [ ]a,c	0.064 [ ]a,c	0.083 [ ]a,c	–
Poison thickness, inch	0.078 [ ]a,c	0.051 [ ]a,c	0.075 [ ]a,c	–
Sheathing thickness, inch	0.02 [ ]a,c	0.02 [ ]a,c	0.0235 [ ]a,c	–
Sheathing width, inches	7.50 [ ]a,c	7.50 [ ]a,c	7.50[ ]a,c	–
Poison areal density, ^{10}B g/cm^2	0.020 (modeled as 0)	0.012 (modeled as 0)	0.0204 (min)	–

Table 4-6 Metamic Insert Specification	
Parameter	Value
Material	Al-B_4C
^{10}B loading, g/cm^2	0.016 [ ]a,c
Thickness, inch	[ ]a,c
Width, inches	8.35 [ ]a,c
Length, inches	[ ]a,c

4.3 SPENT FUEL POOL SPECIFICATION

Figure 4-1 shows the rack layout in the pools. The "11x12 NEW REGION 1" rack is called the cask area rack in this report. The minimum separation between rack modules and the pool wall is 2 inches.

Pool water temperature effects on reactivity can be modeled directly in the SCALE 5 code system. The water temperature is analyzed at the minimum temperature of 39 deg-F (maximum water density) and the maximum temperature of 150 deg-F (maximum bulk pool water temperature) for each fuel category. The temperature that resulted in the highest reactivity is used in the final calculations. For Region 1 with no water cells, the most reactive condition is hot because reactivity is being held down by the excess water between the fuel assemblies. For the Region 1 checkerboard and for the cask area rack, the most reactive condition is cold because the reactivity is being driven by a single assembly so the water between fuel pins is more important that the water between fuel assemblies. For Region 2 with no inserts, both hot and cold give very similar results but hot is slightly more reactive. For Region 2 with one or two inserts, the cold condition is most reactive because the water between fuel pins is more important than the water between fuel assemblies. Temperatures beyond this nominal range are covered in Section 6.12 as accident conditions. The examples discussed above are for unborated cases; however the same approach was used when determining the boron needed to offset the most limiting accident. The borated cases tended to be more restrictive at the hotter temperature.

For this analysis, the pool is modeled as a 2x2 array of four assemblies using a periodic boundary condition, thereby creating an infinite array of 2x2 storage cells. No credit is taken for the Boraflex. All the analysis is performed with the Boraflex material replaced with water. Table 4-7 describes the material composition of all structural and absorber materials used in the KENO model.

Table 4-7 Material Compositions

Component	Density (g/cc)	Material	wt%
Rack	7.94	SS304	100.0
Sheathing	7.94	SS304	100.0
Metamic	2.65	B4C	20.595
		Al	79.405
Boral (in cask area)	2.65	B4C	28.009
		Al	71.991

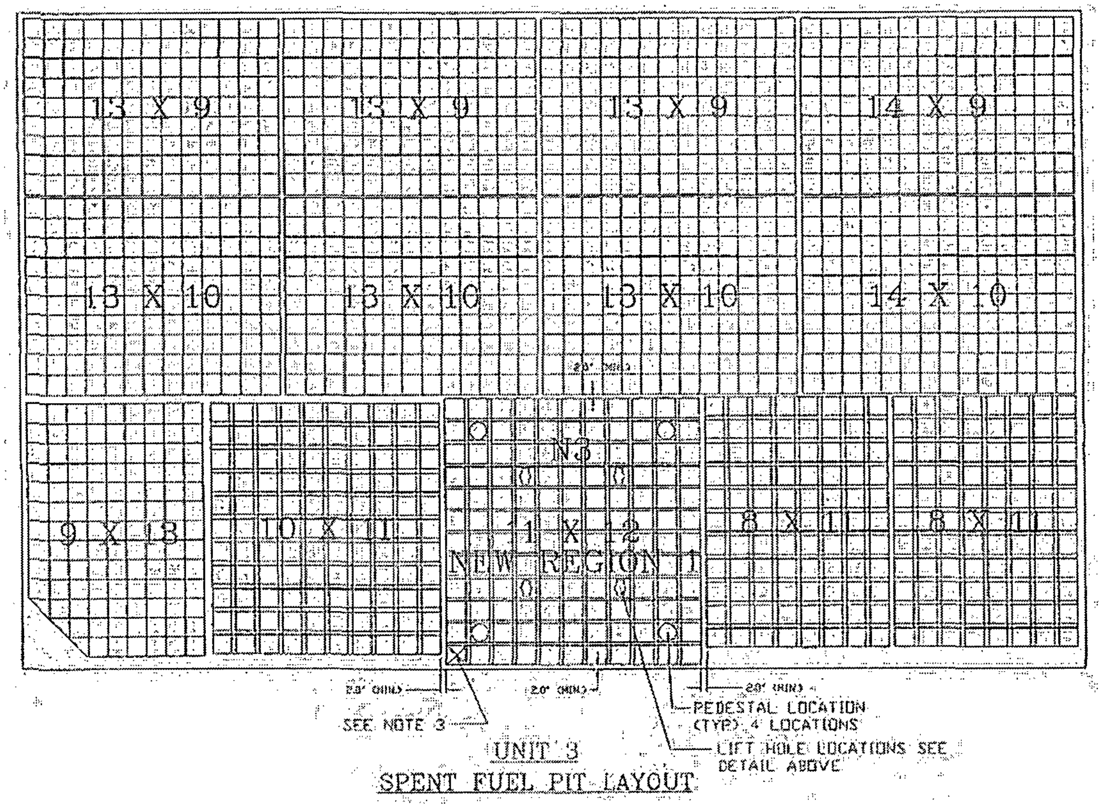


Figure 4-1. Turkey Point Spent Fuel Layout (Unit 4 is the same except a mirror image)

4.4 DEPLETION ASSUMPTIONS

For the axially blanketed fuel, EPU conditions are assumed for the moderator temperature (corresponding to the core outlet temperature at the higher power level), the specific power, and the average boron concentration during depletion. The guidance in NUREG/CR-6665 indicates that the most conservative nuclide composition is developed assuming the maximum core outlet temperature. The value used in this analysis represents a bounding core exit temperature developed for the licensing basis accident analysis using the most conservative set of thermal performance parameters of maximum thermal power, minimum Reactor Coolant System flow allowed by Technical Specifications (thermal design flow), maximum feedwater temperature, maximum bypass flow, and a maximum steam generator tube plugging level. [

$]^{a,c}$ Table 4-8 provides the numeric values for the depletion parameters used in the calculations. Prior to the EPU, the core outlet temperature is lower, the specific power is lower, and the cycle average core boron concentration is smaller. Depleting with the EPU conditions results in a higher reactivity at the same burnup than depleting with pre-EPU conditions (due to a harder spectrum and more plutonium production). Therefore, using the EPU results for pre-EPU axially blanketed fuel is conservative.

To support the EPU, fuel management studies are performed where the number of feed assemblies varies from 64 to 72 fresh fuel assemblies. These fuel management studies are used to establish the cycle average soluble boron content and the burnable absorber assumptions. [

]^{a,c}

For non-blanketed fuel, the depletion parameters used are the most limiting prior to the EPU and the burnable absorber assumptions used are consistent with actual use (see Table 4-9). [

]^{a,c} To reflect that actual assembly data is used, the minimum cooling time reported is 10 years. If fresh non-blanketed fuel is ever used in the core again, it will have to be handled as having no burnup until an analysis is performed to justify burnup credit. If existing non-blanketed fuel is to be re-inserted into the core, the additional burnup received cannot be credited. Only the burnup received under pre-EPU conditions can be credited for full length fuel.

Table 4-8 Core Operating Parameters for Depletion Analyses

Parameter	Non-Blanketed Fuel Value (pre EPU)	Blanketed Fuel Value (EPU)
Soluble Boron Concentration, ppm	780	[ ]^{a,c}
Reactor Specific Power, MW/MTU	31.7	35.32
Moderator Temperature, °F (Core Outlet Temperature)	611.31	[ ]^{a,c}
System Pressure, psi	2250	2250
In-Core Assembly Pitch, Inches	8.465	8.465
Burnable Absorber	See Table 4-9	[ ]^{a,c}
Burnup the Removable Absorber is removed (GWD/MTU)	See Table 4-9	[ ]^{a,c}

Table 4-9 Burnable Absorber Modeling For Non-Blanketed Fuel Depletion

Enrichment	Number of Rodlets	Removed
1.8	[ ]^{a,c}	[ ]^{a,c}
2.5	[ ]^{a,c}	[ ]^{a,c}
3.0	[ ]^{a,c}	[ ]^{a,c}
3.5	[ ]^{a,c}	[ ]^{a,c}
4.0	[ ]^{a,c}	[ ]^{a,c}

For pre-EPU non-blanketed fuel, two different burnable poison insert designs (Pyrex and WABA) were used (these early fuel cycle designs predate the introduction of IFBA rods). To determine the bounding burnable absorber insert for pre-EPU fuel, three sets of PARAGON fuel lattice calculations are performed: [

]^{a,c}

Note that, as discussed earlier, the presence of Pyrex inserts in pre-EPU assemblies during depletion is a conservative assumption. In reality, only a limited number of assemblies are exposed to any burnable inserts. Further, only a fraction of the assemblies exposed to a burnable absorber were exposed to a Pyrex insert since this absorber design was only used in the earliest cycles of plant operation. [

]^{a,c} No credit is taken for the potential presence of residual neutron absorption of burnable poison inserts when determining neutron multiplication in the spent fuel pool.

For EPU fuel, [

]^{a,c}

In addition to the burnable poison inserts, there were also control components containing hafnium that could be placed in an assembly prior to discharge. These are called reduced length annular Hafnium Vessel Flux Depression (HFVD) absorbers. The hafnium absorber material was positioned near the mid-plane of the fuel assembly's axial length, and was only inserted in an assembly on the core periphery during its third cycle of operation. However, there were a few pre-EPU assemblies that contained a burnable poison insert during their first cycle of operation and a hafnium insert in their third cycle. Since the hafnium absorber is near the mid-plane and not in the upper part of the fuel assembly, the flux would be pushed toward the top and result in increased burnup at the top compared to a fuel assembly without a hafnium insert. Since the reactivity of burned fuel assemblies is dominated by the end effect, the reactivity of a fuel assembly that contained a burnable poison insert during its first cycle and then contained a hafnium insert in its third cycle would be bounded by the same fuel assembly depleted without a hafnium insert. This is also the conclusion from a special analysis performed for hafnium inserts in the previously approved criticality analysis (Reference 2).

4.5 REACTIVITY EFFECT OF AXIAL BURNUP DISTRIBUTION

The fuel in this report is either blanketed or non-blanketed. There are no plans to use non-blanketed fuel in the future so the analysis of non-blanketed fuel is specific to the non-blanketed fuel currently in the spent fuel pools. Blanketed fuel is modeled under the most reactive conditions expected. Since depletion under EPU conditions is more limiting than depletion under pre-EPU conditions, the blanketed fuel used prior to the EPU is bounded by the EPU conditions. The axial burnup profile for the blanketed fuel covering current and future fuel is generated differently than the axial profile for the existing full length fuel whose burnup is already completed.

The blanketed fuel is assumed to use 8 inch long blankets with 2.6 wt% ^{235}U enrichment in the blanket region and the blanket pellets are annular. This assumption is conservative for any enrichment less than 2.6 wt% ^{235}U in the 8 inch annular blankets. In general, this assumption does not bound shorter blankets. However, for the particular case of 6 inch blankets with natural uranium, a separate analysis is performed to show that 6 inch natural blankets can be accommodated (see subsection 6.3.2)

For each assembly in the model, an axial burnup distribution is needed. The model allows a different number of axial nodes for each fuel type to be loaded. [ ]^{a,c} The atom densities for each node are generated using the PARAGON code and the depletion parameters from Table 4-8. The next two subsections describe the determination of the bounding axial burnup distributions for both blanketed and non-blanketed fuel.

4.5.1 Axial Burnup Distribution for the Blanketed Fuel

There is no standard which provides axial burnup distributions for axially blanketed fuel. NUREG/CR-6801, Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analyses, (Reference 12) only addresses axial burnup profiles for non-blanketed fuel. In order to gain the benefit of the lower enrichment associated with axial blankets for spent fuel pool criticality calculations, a set of limiting axial profiles for blanketed fuel is needed. [

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a,c

a,c

[ ]

The axial burnup profiles are actually provided for each radial quadrant of each fuel assembly. This is conservative since an assembly average is less severe. The axial burnup distributions are normalized to the assembly average burnup.

[

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Table 4-10 [

]a,c

a,c

For very low burnups, the limiting axial profile will be a uniform profile (the end effect becomes important only at higher burnups). Both the end effect limiting shape and the uniform shape are considered when generating the loading curves.

Table 4-11 shows the limiting axial burnup profiles for 8-inch 2.6 wt% blanketed fuel.

Table 4-11	**Axial Burnup Profiles for Blanketed Fuel (Node 1 is the top node)**							
Blanket Length	8	8	8	8	8	8	8	8
Blanket Enrichment	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6

a,c

Table 4-11 identifies the limiting burnup profile within each burnup range for blanketed fuel. [

]a,c

4.5.2 Axial Burnup Distribution for the Non-Blanketed Fuel

For the pre-EPU non-blanketed fuel, burnup profile data from the Turkey Point reactor records are used to find the most limiting profiles (the pre-EPU non-blanketed loading curves are only used for the existing fuel). [

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[

]a,c

Table 4-12 Assemblies with the Most Limiting Axial Burnup Profiles

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2 [ ]a,c

a,c

[

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Table 4-13 [ ]^{a,c}

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3 [
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Table 4-14 [ ]a,c							

a,c

Table 4-15 [ ]a,c

5 METHODOLOGY

The criticality safety criteria are shown to be met by use of the three dimensional Monte Carlo code, KENO-V.a (Reference 3). Any mention of KENO in this report refers to KENO-V.a. KENO is run using the 44 group cross section library based on ENDF/B-V. Prior to the actual KENO analysis the 44 group cross sections must be processed for the resonance self shielding and for the thermal characteristics of the problem. The cross section processing and the running of KENO are done using a sequence, CSAS25, which is part of the SCALE 5.1 code package.

The criticality sequence of SCALE 5.1 is validated using [

]^{a,c} The details of the validation are found in Appendix A. The validation showed that SCALE 5.1 is an accurate tool for calculation of k_{eff}. [

]^{a,c} The benchmark calculations utilize the same computer platform and cross-section libraries as are used for the design basis calculations. [

]^{a,c} Any additional uncertainty associated with depletion from the fresh fuel condition to the burned fuel condition is covered by the 5% of the delta-k due to depletion (Reference 4).

The convergence of a Monte Carlo criticality problem is sensitive to the following parameters: (1) number of particle histories per generation, (2) the number of generations skipped before averaging, (3) the total number of generations and (4) the initial source distribution. The KENO criticality output contains a great deal of useful information that may be used to determine the acceptability of the problem convergence. This information is used to develop appropriate values for the aforementioned parameters applied in storage rack criticality calculations. Based on this information, the calculations use 12,000 histories per generation and 3000 generations are accumulated for a total of 36 million neutron histories per case. The number of generations skipped that results in the minimum statistical uncertainty in the value of k_{eff} is determined automatically by SCALE. The standard deviation of a calculation is typically only ±0.0001 in k_{eff}. The initial source is specified as uniform over the fueled regions (assemblies), which is found to achieve convergence in fewer than 100 generations.

For fresh fuel analyses, the atom densities used in the KENO analysis are directly derived from the material descriptions. For spent fuel, depletion analyses are performed using the PARAGON Version 1.2.0 code (Reference 6). PARAGON is a depletion code that is approved for use as a direct replacement of PHOENIX-P (Reference 13) which is still used for the standard fuel management lattice calculations performed by Westinghouse.

PARAGON is Westinghouse's state-of-the-art two-dimensional lattice transport code. It is being used as part of Westinghouse's core design package, providing lattice cell data for three-dimensional core simulator codes. These data include macroscopic cross sections, microscopic cross sections for feedback adjustments, pin factors for pin power reconstruction calculations, and discontinuity factors for three-dimensional nodal method solution of the diffusion equation. PARAGON uses the collision probability theory within the interface current method to solve the integral transport equation. Throughout the whole calculation, PARAGON uses the exact heterogeneous geometry of the assembly and the same energy groups as in the cross-section library to compute the multi-group fluxes for each micro-region location of the assembly. In order to generate the multi-group data, PARAGON goes through four steps of calculations: resonance self-shielding, flux solution, homogenization and burnup calculation. The 70-group PARAGON cross-section library is based on the ENDF/B-VI.3 basic nuclear data. It includes explicit multigroup cross-sections and other nuclear data for 174 isotopes, without any lumped fission products or pseudo cross sections. PARAGON and its 70-group cross-section library are benchmarked, qualified, and licensed both as a standalone transport code and as a nuclear data source for a core simulator in a complete nuclear design code system for core design, safety and operational calculations.

PARAGON is generically approved for depletion calculations. The use of PARAGON for spent fuel criticality is chosen since it has improvements relative to PHOENIX-P and has all the attributes needed for this work. There are no SER limitations for the use of PARAGON in UO_2 criticality analysis.

Prior to inputting the PARAGON generated atom densities into the SCALE/KENO model, the atom densities are adjusted for decay to 72 hours, 2.5 years, 5 years, 10 years, 15 years, 20 years, and 25 years. The decay analysis is straightforward and described in subsection 6.1.1.

The burnup credit analysis is iterative. The analyst must estimate an allowable burnup for each enrichment, deplete to that burnup using PARAGON, place the depleted atom densities in KENO, and finally compare the calculated k_{eff} to the criticality safety criteria. Before comparing to the safety criteria, the bias and the combination of uncertainties must be added.

The evaluation performed to develop Tables 1-2 and 1-3 of this report consisted of KENO calculations performed at many combinations of enrichment, burnup and post-irradiation cooling time for each of the proposed fuel storage patterns. After fitting the data points to the curve described in Section 1, the curve-evaluated burnups are then used in subsequent KENO runs to calculate the k_{eff} for all enrichment, burnup, and cooling time combinations. All of these calculations demonstrate that the maximum k_{eff} met the acceptance criteria with and without soluble boron including appropriate biases and uncertainties (see Section 6.7).

6 ANALYSIS

This section describes the calculations that are used to determine acceptable storage criteria for the Region 1 and Region 2 racks as well as the Cask Area Rack and the New Fuel Storage Rack. This section also summarizes the results of these calculations. In addition, this section discusses the possible abnormal and accident conditions. Unless otherwise stated, all calculations assumed nominal characteristics for the fuel and the fuel storage cells. The effect of the manufacturing tolerances is accounted for by combining the reactivity effects associated with manufacturing tolerances (rack, fuel, etc) with other uncertainties as discussed below.

As discussed in Section 5, KENO is the criticality code used in the Turkey Point criticality calculations. KENO is used to determine the reactivity effect of tolerances and to perform calculations needed for eccentric fuel positioning, and fuel misloading.

All calculations are made using an explicit model of the fuel and storage cell geometry. KENO three-dimensional calculations model a 2-by-2 array of cells surrounded by periodic boundary conditions. The three-dimensional KENO models assume 60 cm of water above and below the active fuel length. Additional KENO models with more than four cells and different boundary conditions are generated to investigate the effect of interfaces between racks and to analyze accident conditions. These models are discussed in the appropriate sections below.

6.1 DEPLETION MODEL DESCRIPTION

As discussed in Section 5, the fuel lattice code, PARAGON, is used for all the depletion calculations. The depletion model is a 15x15 standard fuel assembly in an infinite lattice of fuel assemblies separated by the fuel assembly gap in the reactor core. The depletion conditions are different for pre-EPU fuel and EPU fuel as discussed in Section 4.4. After depleting to each burnup step, the conditions are brought down from full power to room temperature and pressure before extracting the isotopic compositions. This is necessary to correct the fuel density which is depleted at full power temperatures.

6.1.1 Isotopic Compositions

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With the depletion assumptions given in Section 4.4, 15x15 fuel is depleted to 72 GWD/MTU using PARAGON at the following ^{235}U enrichments:

- Full length(non-blanketed) fuel: 1.8, 2.5, 3.0, 3.5, and 4.0
- Axial blanketed fuel: 2.0, 3.4, 4.0, 4.5, and 5.0

The burnup steps chosen are 0, 0.15, 0.50, 1.00, 2.00, 3.00, and every 1.0 GWD/MTU up to 72 GWD/MTU (although 72 GWD/MTU is not allowed for an assembly average, the isotopic inventory at high burnups are needed for the center of highly burned fuel). The isotopic concentration at room temperature conditions is obtained from PARAGON at each burnup step for 77 nuclides. The advantage of using PARAGON is that all of the major and minor actinides and fission products are tracked. For the [

]^{a,c}.

The PARAGON calculations that produce isotopic compositions for use in KENO are performed generically, with one set of depletion steps for each enrichment, at burnup increments of 1.0 GWD/MTU or less. The isotopic composition at any given burnup is then determined by quadratic interpolation using the nearest three burnup steps.

6.2 KENO MODEL DESCRIPTION

6.2.1 Infinite Model Description

Using the dimensions and materials described in Section 4, a 2x2 array of the spent fuel rack is modeled in KENO. An illustration of the KENO model for the two insert case is shown in Figure 6-1 below. In this Figure, the two inserts are shown in a checkerboard pattern. However, all of the final two insert calculations are run with the two inserts in the same row (a "parallel" configuration) because this gives a higher k_{eff} than the checkerboard arrangement. The region above and below the active fuel is modeled as 60 cm of pure water (i.e., no soluble boron credited in the water reflector).

The grids and sleeves in the fuel are replaced with water. Analysis confirms that this is conservative.

Some of the cases allow for a checkerboard of high and low burned fuel. [

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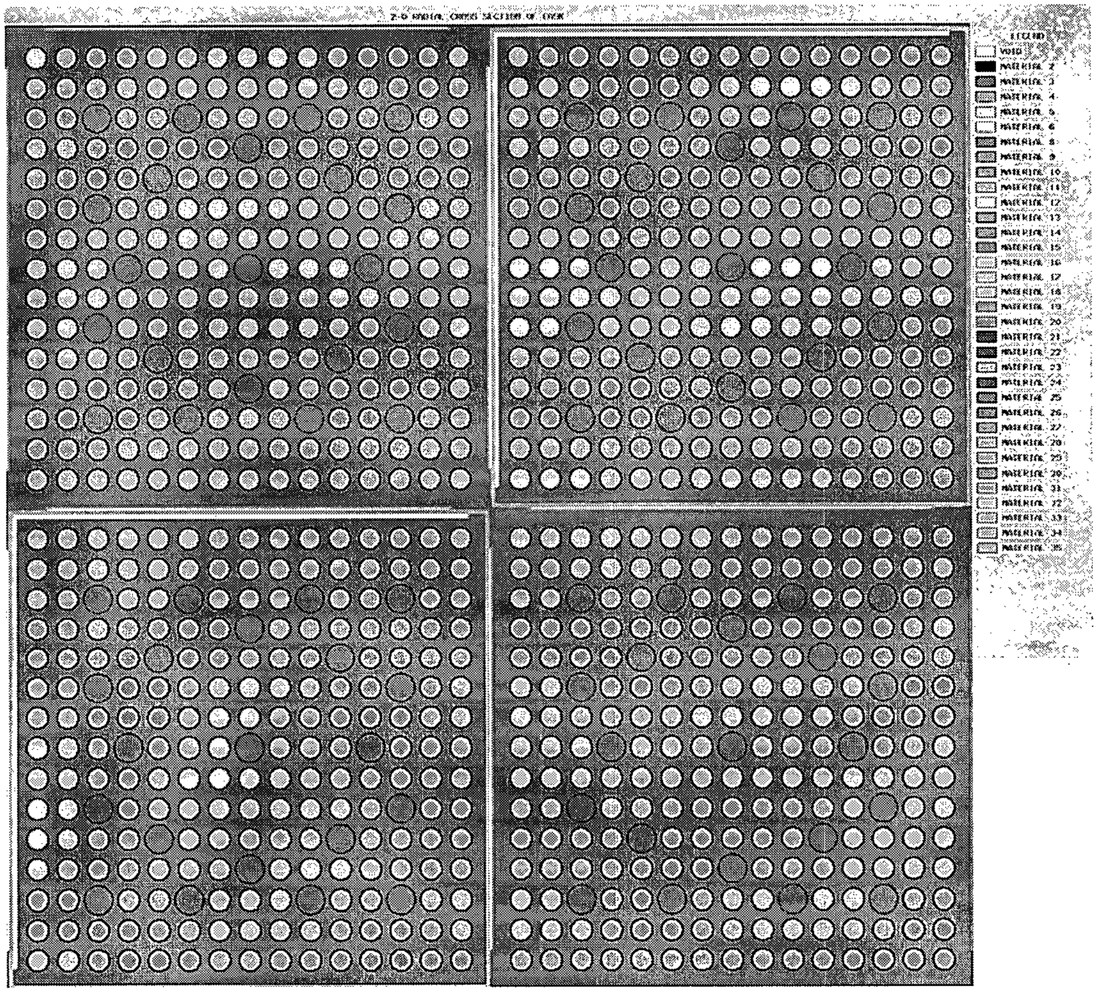

Figure 6-1. KENO Model of a Two Insert Case

6.2.2 Large Pool Model Description

Larger, full-pool models are created to adequately address 1) the reactivity of eccentric positioning of the fuel, 2) reduced burnup requirements (higher reactivity fuel) along the pool periphery, 3) the Region 1 and Region 2 interface, and 4) a misloaded fresh fuel assembly.

The large pool model is sized such that the effect of radial leakage is minimized. [ ]^{a,c} The Region 2 racks actually consists of 53 by 19 storage cells (in several rack modules plus a separate 9 by 13 rack module). The Region 2 racks in the full-pool model is [ ]^{a,c} versus the actual 1124 storage cells in the Turkey Point spent fuel pools. [ ]^{a,c} The Region 1 spent fuel racks in the spent fuel pool are actually three storage rack modules (two 8 by 11 modules separated from an 11 by 10 rack module). The Region 2 rack model is separated from the Region 1 rack module by [ ]^{a,c}. The cask area rack is not modeled in the large pool model. Figure 4-1 shows the actual spent fuel pool layout. Figure 6-2 shows the large pool model.

The large pool model is an expansion of the 2x2 infinite model; therefore, all the detailed modeling of the fuel and rack is identical.

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[ ]

6.3 MANUFACTURING TOLERANCES

In calculating the final value of k_{eff}, the reactivity effect of manufacturing tolerances must be included. KENO is used to quantify these effects. A bounding fuel smear density of 97.5% of theoretical density is used in both the depletion calculations and the KENO analysis and so no separate tolerance calculation for density is needed. [ ]^{a,c}

1. Rack cell ID [ ]^{a,c}
2. Rack cell pitch [ ]^{a,c}
3. Rack cell wall thickness [ ]^{a,c}
4. Fuel position in the cell [ ]^{a,c}
5. Fuel rod pitch [ ]^{a,c}
6. Fuel clad OD [ ]^{a,c}
7. Fuel clad ID [ ]^{a,c}
8. Guide tube OD and ID(1) [ ]^{a,c}
9. Pellet OD [ ]^{a,c}
10. Metamic areal density [ ]^{a,c}
11. Metamic width [ ]^{a,c}
12. Gaps and holes in the Metamic insert due to damage
13. Fuel initial enrichment [ ]^{a,c}

To conservatively model potential minor manufacturing/handling defects in the Metamic inserts, a 0.25 inch gap is assumed to exist in the middle of each panel that extended the full length of the insert. This would bound any credible damage from scratches and holes that might be caused by moving the inserts into and out of the cells.

The reactivity effect of tolerances are established separately for Region 1 and Region 2 racks. The reference condition for each rack type consists of nominal dimensions and properties. Worst case dimensions are used for the cask area so separate tolerance calculations for these regions are not performed. For the new fuel storage rack, most of the analysis was performed with the worst case dimensions. For the 4.7 wt% ^{235}U fully flooded case, the worst case dimensions and positioning were separated from the enrichment uncertainty. These two uncertainties were then statistically combined with the validation uncertainty.

1 The guide tube OD and ID were conservatively changed [ ]^{a,c} to maximize reactivity.

To determine the Δk associated with a specific manufacturing tolerance, the k_{eff} calculated for the reference condition is compared to the k_{eff} from a calculation with an individual tolerance included. [

]^{a,c} The Δk due to a tolerance is then calculated as follows:

$$\Delta k = k_1 - k_R + 2\sqrt{\sigma_1^2 + \sigma_R^2}$$

where:

k_I = k_{eff} with the tolerance included,
k_R = k_{eff} for the reference case,
σ_I = Monte Carlo standard deviation for the case with the tolerance included, and
σ_R = Monte Carlo standard deviation of the reference case.

[

]^{a,c} Table 6-1 below summarizes the results for Region 1 and Region 2 with and without full length RCCAs or Metamic inserts as appropriate. It should be noted that both low enriched, low burnup and high enriched, high burnup assemblies are analyzed for the tolerance calculations and the worst tolerance effect is tabulated. For Region 2 with inserts, both one insert and two insert cases are analyzed with the most limiting total tolerance uncertainty listed. Tolerance calculations for Region 2 with full length RCCAs are bounded by the tolerance calculations for Region 2 with inserts. All of the Δk values from the various tolerance effect calculations are statistically combined (square root of the sum of the squares) with the enrichment, depletion, burnup and validation uncertainties to determine the final reactivity penalty.

6.3.1 OFA versus STD Fuel

Westinghouse STD fuel was modeled in this analysis. The Turkey Point reactors have used two fuel types, Westinghouse OFA and Westinghouse STD fuel. These fuel types have identical geometrical properties for those parameters important to reactivity, with the exception of the guide tube thickness. The reactivity effect of changing the guide tube OD and ID of the STD fuel assembly at the same time (to achieve minimum thickness) increases k_{eff} by a maximum of only 0.0005 (see Table 6-1). As seen from Table 4-1, the STD fuel assembly guide tube has a larger geometric cross-sectional area than the OFA assembly, thereby displacing more moderator. If OFA fuel is explicitly analyzed in the depletion calculations, there would be more moderator, resulting in a softer spectrum and producing less plutonium. So OFA fuel would lose reactivity with depletion faster than STD fuel. It is concluded, therefore, that the reactivity effect of OFA fuel is either negative or insignificant compared to STD fuel. (Upgrade fuel has the same dimensions important to criticality as OFA fuel.)

Table 6-1 Effect of Tolerances on Reactivity

Tolerance	Region 1	Region 1 w/RCCAs	Region 2	Region 2 w/inserts
Rack cell ID				
Rack cell pitch				
Rack wall thickness				
Eccentric positioning				
Fuel rod pitch				
Fuel clad ID				
Fuel clad OD				
Guide tube OD/ID				
Pellet OD				
Metamic areal density				
Metamic width				
Metamic damage				
Total tolerance uncertainty				

a,c

6.3.2 Natural Uranium Axial Blankets

As noted above, the blanketed assemblies are assumed to contain 2.6 wt% enriched annular axial blankets that are 8 inches in length. 8 inch blankets that are less than 2.6 wt% are covered by this analysis since there is less ^{235}U. Generally, shorter blankets would not be covered by this analysis (since there is more midplane fuel) but since Turkey Point has used 6 inch solid and annular natural uranium blankets in the past, a separate analysis is performed to show that these assemblies are bounded by the 8 inch, 2.6 wt% blanketed assemblies. These assemblies are only applicable to pre-EPU operating conditions. A calculation is performed for fuel Category II-2b requiring two out of four inserts. A fuel assembly with a central zone enrichment of 4.0 wt% ^{235}U and 6 inch natural uranium solid blankets is depleted under pre-EPU conditions to 40 GWD/MTU. The k_{eff} for this configuration is 0.9683. The same fuel assembly but with 8 inch 2.6 wt% enriched annular blankets is depleted under EPU conditions to 40 GWD/MTU. The k_{eff} for this configuration is 0.9839. The 8 inch, 2.6 wt% enriched annular blanket is clearly more limiting and so the axial blanket loading curves apply to 6 inch natural uranium solid (or annular) blankets depleted under pre-EPU conditions.

During the transition from pre-EPU to EPU fuel, there will be 6 inch annular natural uranium blanket assemblies that will be partially depleted under EPU conditions. An analysis is performed to confirm that these assemblies would be bounded by the 8 inch enriched blankets. For this confirmation, the 6 inch natural blanket assemblies are assumed to be depleted under EPU conditions. At 40 GWD/MTU, the k_{eff} for the 4.0 wt% fuel assembly with an 8 inch enriched blanket is 0.0042 higher than the k_{eff} for the fuel assembly with a 6 inch natural blanket. At 50 GWD/MTU, the fuel assembly with an 8 inch enriched blanket is 0.0026 higher and at 60 GWD/MTU, the fuel assembly with the 8 inch enriched blanket is

0.0009 lower. The 6 inch natural blanket is bounded by the axial blanket loading curves up to 57 GWD/MTU. Therefore, a maximum of 57 GWD/MTU of burnup credit can be taken for any 6 inch natural blanket assemblies depleted under EPU conditions. An administrative control will be placed on the transition cycles to implement this limit.

6.4 UNCERTAINTIES WITH SOLUBLE BORON

[

]^{a,c}

6.5 UNCERTAINTY IN DEPLETION, BURNUP, AND ENRICHMENT

The depletion uncertainty is taken to be 5% of the delta-k difference between the reactivity at the fresh fuel condition to the reactivity at the burned fuel condition of interest:

$$\text{Depletion uncertainty} = (k_{fresh} - k_{burn}) * 0.05$$

This is consistent with Reference 4. KENO calculations for each fuel category are performed for each enrichment using unburned fresh fuel to obtain the fresh fuel k_{eff}.

The uncertainty in the burnup records is assumed to be 5% of the burnup. To estimate the uncertainty in k_{eff} due to uncertainty in the burnup, the burnup slope is needed (that is, the delta-k per unit of burnup). This slope can be obtained directly from the fresh fuel k_{eff}. That is,

$$\text{BU slope} = (k_{fresh} - k_{burn}) / \text{BU}$$

This slope is conservative for the burnup uncertainty calculation because the actual slope at a particular burnup is always smaller (the k_{eff} versus burnup curve is concave). Multiplying the above BU slope by 0.05 x BU, we obtain:

$$\text{Burnup uncertainty} = (k_{fresh} - k_{burn}) * 0.05$$

which is exactly the same as the depletion uncertainty. This makes physical sense because the depletion is dominated by the burnup and a 5% error in the burnup translates into a 5% error in the depletion (and vice-versa).

The uncertainty in the enrichment is assumed to be ± 0.05 wt% ^{235}U. The uncertainty due to enrichment can be obtained from the k-fresh of fuel of different enrichments as follows:

$$\text{Enrichment uncertainty}^{(1)} = 0.05 * (k_{fresh\ E1} - k_{fresh\ E2}) / (E1 - E2)$$

1 For blanketed fuel assemblies, this enrichment is the enrichment of the central zone. Analyses is performed to separately account for enrichment uncertainty in the blanketed regions and found to be insignificant.

where:

E1 = enrichment 1
E2 = enrichment 2

The depletion, burnup, and enrichment uncertainties are statistically combined with the other uncertainties when determining the maximum k_{eff} for comparison to the limits.

The actual pool loading in any 2x2 storage array can contain four assemblies having different combinations of burnup and enrichment as long as each assembly meets the fuel category requirements.
[

]^{a,c}

6.6 ECCENTRIC FUEL ASSEMBLY POSITIONING

The fuel assembly is assumed to be normally located in the center of the storage rack cell. [

]^{a,c}

[

]^{a,c}

The final analysis uses the maximum value of the eccentric loading reactivity for each configuration. The final eccentric fuel positioning uncertainty is given on Table 6-3.

a,c

Figure 6-3 Eccentric Positioning in the [

]^{a,c}

Table 6-2 Eccentric Loading Cases Analyzed

a,c

Table 6-3 Summary of Eccentric Loading Uncertainty [ ]^{a,c}

a,c

Case Identification	Maximum Uncertainty in k_{eff} due to Eccentric Loading

6.7 CALCULATION OF BURNUP VERSUS ENRICHMENT CURVES

This analysis considers the following parameters and parameter combinations:

Two fuel storage rack styles (Region 1 and Region 2), with a total of eleven different loading configurations (allowable 2x2 arrays) using thirteen different fuel categories,

- Assemblies with and without axial blankets,
- Fuel enrichments between 1.8 and 4.0 wt% 235U for pre-EPU non-blanketed fuel,
- Fuel enrichments between 2.0 and 5.0 wt% 235U for blanketed fuel, and
- Cooling times between 72 hours and 25 years.

All calculations to establish and validate the burnup versus enrichment curves are performed as full three-dimensional criticality calculations considering the axial burnup distribution of each assembly in the model.

The coefficients of the loading curves for all conditions listed above are shown in Table 1-2 for assemblies containing axial blankets and in Table 1-3 for non-blanketed assemblies. The required minimum burnup for selected values of initial enrichment are shown in Tables 1-4 and 1-5.

[ ]^{a,c} The maximum k_{eff} including all biases and uncertainties from Region II is 0.9937 (array II-F) and the maximum k_{eff} for Region I is 0.9939 (array I-C). The most limiting calculation for each allowable 2x2 array is shown in Table 6-4 along with a tabulation of all biases and uncertainties applied to the calculated value prior to comparison to the 1.0 k_{eff}

limit. This table also shows the total addition for each configuration (the sum of all the applicable biases and uncertainties). Table 6-5 lists the detailed calculations for the conditions producing the two highest k_{eff} for all the configurations. The following equation is used to perform the k_{eff} calculation:

$$k_{eff} = k(calc) + \Delta k(bias) + \Delta k(uncert)$$

where:

k(calc) = k_{eff} calculated by the KENO model

Δk(bias) = bias determined from critical benchmark comparisons (see Appendix A)

Δk(uncert) = statistical summation of all tolerance and uncertainty components (square root of the sum of the squares)

Table 6-4 Most Limiting Calculation for Each Allowable Array

2x2 Array	I-A	I-B	I-C	II-A	II-B1	II-B2	II-B3
Region	1	1	1	2	2	2	2
Fuel Category	I-1	I-3	I-2	II-1	II-1/II-3	II-2b	II-2a/II-2c
Axial Blanket?	[						]^{a,c}
Enrichment	5.0	2.5	5.0$^{(1)}$	1.8	2.5	3.5	3.5
Burnup (GWD/MTU)	[						]^{a,c}
Cooling Time	0.0	20 y	0.0	10 y	25 y	10 y	10 y
Calculated k_{eff}							
Bias							
Uncertainties							
Total Addition							
Maximum k_{eff}	0.9498	0.9931	0.9939	0.9919	0.9933	0.9933	0.9935

a,c

Notes:
1. This 5.0 wt% fuel contains 16 IFBA rods
2. [ ]^{a,c}

Table 6-4 Most Limiting Calculation for Each Allowable Array (cont.)

2x2 Array	**II-C**	**II-D**	**II-E**	**II-F**
Region	2	2	2	2
Fuel Category	II-3/II-5	II-4	II-6/II-8	II-7
Axial Blanket?	[			]^{a,c}
Enrichment	2.5	3.5	2.5	4.0
Burnup (GWD/MTU)	[			]^{a,c}
Cooling Time	10 y	15 y	10 y	10 y
Calculated k_{eff}				
Bias				
Uncertainties				
Total Addition				
Maximum k_{eff}	0.9932	0.9932	0.9930	0.9937

a,c

Note:
1. [ ]^{a,c}

Table 6-5 Detailed Results for Arrays I-C and II-F		
2x2 Array	**I-C**	**II-F**
Fuel Category	I-2	II-7
Region	1	2
Axial Blanket?	[	]a,c
Enrichment	5.0	4.0
Burnup	[	]a,c
Cooling Time	72 hr	10 y
Calculated k_{eff}		
k_{eff} with fresh fuel at 5.0/4.0		
k_{eff} with fresh fuel at 4.5/3.5		
Depletion Uncertainty(1)		
Burnup Uncertainty(2)		
Enrichment Uncertainty(3)		
Rack Cell ID Tolerance		
Rack Cell Wall Tolerance		
Rack Cell Pitch Tolerance		
Insert Areal Density Tolerance		
Insert Width Tolerance		
Insert Damage		
Fuel Rod Pitch		
Fuel Clad OD		
Fuel Clad ID		
Fuel Pellet OD		
Guide Tube OD/ID		
Eccentricity Effect		
Monte Carlo Uncertainty (2 σ)		
Validation Uncertainty		
Combined Uncertainty		
Validation Bias		
Bias plus Uncertainty		
Maximum k_{eff}	0.9939	0.9937

a,c

Notes:
1. Depletion uncertainty = (k-fresh – k-calc)*.05
2. Burnup uncertainty = (k-fresh – k-calc)*.05
3. Enrichment uncertainty = ($k\text{-fresh}_1$ – $k\text{-fresh}_2$)*.05 / (En_1 – En_2)

It should be noted that no correction for axial distribution in burnup is needed since the effect is included explicitly in k(calc); that is, a full 3-D analysis is utilized in all cases. The tolerance and uncertainty components listed in Table 6-5 are combined statistically using the square root of the sum of the squares since they are independent variables.

The highest maximum k_{eff} for all the storage arrays is 0.9939 which is below the regulatory limit of 1.00, when considering no soluble boron to be present in the fuel pool water. It should be noted that these calculations contain significant amounts of embedded safety margin as a result of the underlying conservative assumptions, such as:

1. Each assembly is depleted [

   ]^{a,c}

2. Conservative axial burnup distributions are used. In reality, only a few assemblies would actually have these burnup distributions. Most assemblies have a nominal axial burnup distribution which is less reactive.

3. The loading curves provide the minimum burnup required. In reality, the loading of the pool in each 2x2 array will contain assemblies that exceed these burnup requirements resulting in lower reactivity.

4. The calculations assume worst case pool temperatures for each case. In reality, the pool temperature would not be at either extreme temperature resulting in a lower reactivity.

The embedded conservatisms will ensure that the actual reactivity of the stored fuel array, under the assumed condition of the loss of all soluble boron in the pool, will always be significantly below 1.0. All burnup versus enrichment curves are therefore acceptable and result in reactivity values below the regulatory limit.

All of the analyses are performed with the same enrichment/burnup (except for high reactivity/low reactivity cases) in all four locations in the model. Since it is allowable to use differing enrichment/burnup combinations from a fuel category some confirmatory cases are run. For example, it may be desirable to pair a pre-EPU 1.8 wt% full length fuel assembly cooled for 25 years with an EPU blanketed 5.0 wt% assembly cooled for 72 hours requiring two inserts in the 2x2 array. The pre-EPU assembly will be a Category II-3 assembly to hold down the reactivity of a Category II-1 EPU assembly. This is configuration II-B1. The II-3 required burnup for 1.8 wt% fuel at 25 years cooling is 11.11 GWD/MTU. The II-1 required burnup for 5.0 wt% fuel at 72 hour cooling is 49.50 GWD/MTU. The calculated k_{eff} for this condition is [ ]^{a,c}. For the calculation of burnup and enrichment uncertainties, the average enrichment in the array is 3.4 wt% and the average burnup is 30.31 GWD/MTU. The statistical combination of uncertainties for this case is [ ]^{a,c}, so the maximum k_{eff} would be 0.9893, clearly meeting the regulatory requirements. A summary of other confirmatory cases are shown in Table 6-6 below.

Table 6-6 Check Cases for Different Burnup/Enrichment Combinations (Two different fuel assemblies labeled 1 and 2)

2x2 Array	II-B3	II-B1	II-B3	II-B1	II-B3
Region	2	2	2	2	2
Fuel Category	II-2c/II-2a	II-3/II-1	II-2c/II-2a	II-3/II-1	II-2c/II-2a
Axial Blanket 1	[				]^{a,c}
Axial Blanket 2	[				]^{a,c}
Enrichment 1	1.8	1.8	4.0	4.0	4.0
Enrichment 2	5.0	5.0	2.0	2.0	2.0
Burnup 1 (GWD/MUT)	8.88	12.12	40.33	45.44	43.07
Burnup 2 (GWD/MTU)	52.14	40.39	14.99	10.70	12.18
Cooling Time 1	25 y	10 y	25 y	10 y	10 y
Cooling Time 2	72 h	25 y	72 h	25 y	25 y
Maximum k_{eff}	0.9871	0.9898	0.9885	0.9898	0.9912

a,c

6.8 SOLUBLE BORON CREDIT

Calculations are performed to confirm that a soluble boron concentration of 500 ppm in the spent fuel pool under normal conditions ensures that k_{eff} does not exceed 0.95 (after applying all appropriate uncertainties) for each fuel storage arrangement. [

]^{a,c} For all storage arrays, the k_{eff} is less than 0.95 after applying all biases and uncertainties. The details of the calculation for Array II-B2 with 5.0 wt% ^{235}U fuel are shown in Table 6-7. This array is used for illustration because the ppm worth will be minimum due to the high burnup requirements and the presence of two Metamic inserts. Note that in this limiting case, there is significant margin to the 0.95 limit.

Other storage arrangements are checked and it is confirmed that the two insert case is the most limiting configuration.

Table 6-7 Detailed Results of Array II-B2 with Soluble Boron

2x2 Array	II-B2
Fuel Category	II-2b
Soluble Boron (ppm)	500
Region	2
Enrichment	5.0
Burnup	54.87
Cooling Time	72 hour
Calculated k_{eff}	
k_{eff} with fresh fuel at 5.0	
k_{eff} with fresh fuel at 4.5	
Depletion Uncertainty[(1)]	
Burnup Uncertainty[(2)]	
Enrichment Uncertainty[(3)]	
Rack Cell ID Tolerance	
Rack Cell Wall Tolerance	
Rack Cell Pitch Tolerance	
Insert Areal Density Tolerance	
Insert Width Tolerance	
Eccentricity Effect	
Fuel Tolerances	
Monte Carlo Uncertainty (2 σ)	
Validation Uncertainty	
Combined Uncertainty	
Bias	
Bias plus Uncertainty	
Maximum k_{eff}	0.9339

a,c

Notes:
1. Depletion uncertainty = (k-fresh$_{5.0}$ – k-calc)*.05
2. Burnup uncertainty = (k-fresh$_{5.0}$ – k-calc)*.05
3. Enrichment uncertainty = (k-fresh$_{5.0}$ – k-fresh$_{4.5}$)*.05 / (5.0 – 4.5)

6.9 FUEL ROD BASKETS

Storage of a fuel rod basket in one or more Region 2 cells, instead of a fuel assembly, is evaluated. The basket is an 8x8 array of stainless steel tubes with the three tubes closest to each corner of the array omitted, i.e., the total number of tubes is 8x8 – 4x3 = 52 (the KENO model conservatively models all 64 tubes). The dimensions used in the analysis are listed in Table 4-4. A picture of the KENO model is shown below in Figure 6-4. For the fuel rod basket, it is conservatively assumed that all tubes are filled with fuel rods, and that all fuel rods consist of fresh fuel of 5.0 wt% enrichment. [

]^{a,c} The k_{eff} for this model is [ ]^{a,c}. Since tolerance, burnup, depletion, and enrichment uncertainties are all zero, the only uncertainty that needs to be added to this value is bias and uncertainty from the validation (a total adder of [ ]^{a,c}). The result is 0.9919, which is below the limit of 1.0 with 0.0081 margin. To summarize, a fuel rod basket can be placed in any Region 2 fuel storage cell without restriction. Since Region 1 and the cask area rack are less reactive for the same fuel, a fuel rod basket can also be placed in fuel storage cells in these two regions without restriction.

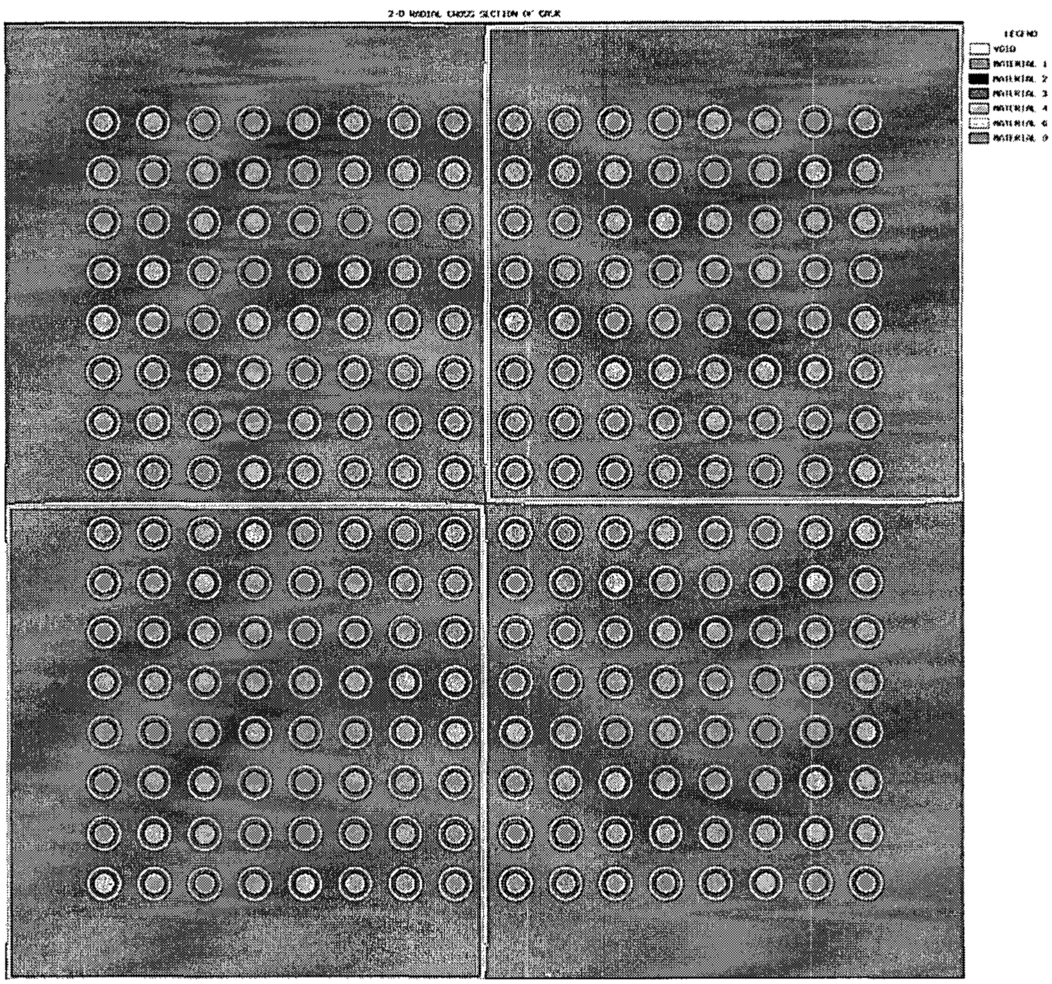

Figure 6-4. Radial View of Fuel Rod Basket Model

6.10 CASK AREA RACK

A picture of the KENO model for the cask area rack is shown in Figure 6-5 below. For this calculation, all fuel and rack dimensions are set using the worst case tolerances and position. The fuel is fresh 5.0 wt% ^{235}U. The k_{eff} for this model is [ ]^{a,c}. The only applicable uncertainties are the bias and uncertainty from the validation (a total adder of [ ]^{a,c}). The worst case k_{eff} after adding uncertainty is 0.9712, well below the regulatory limit of 1.0.

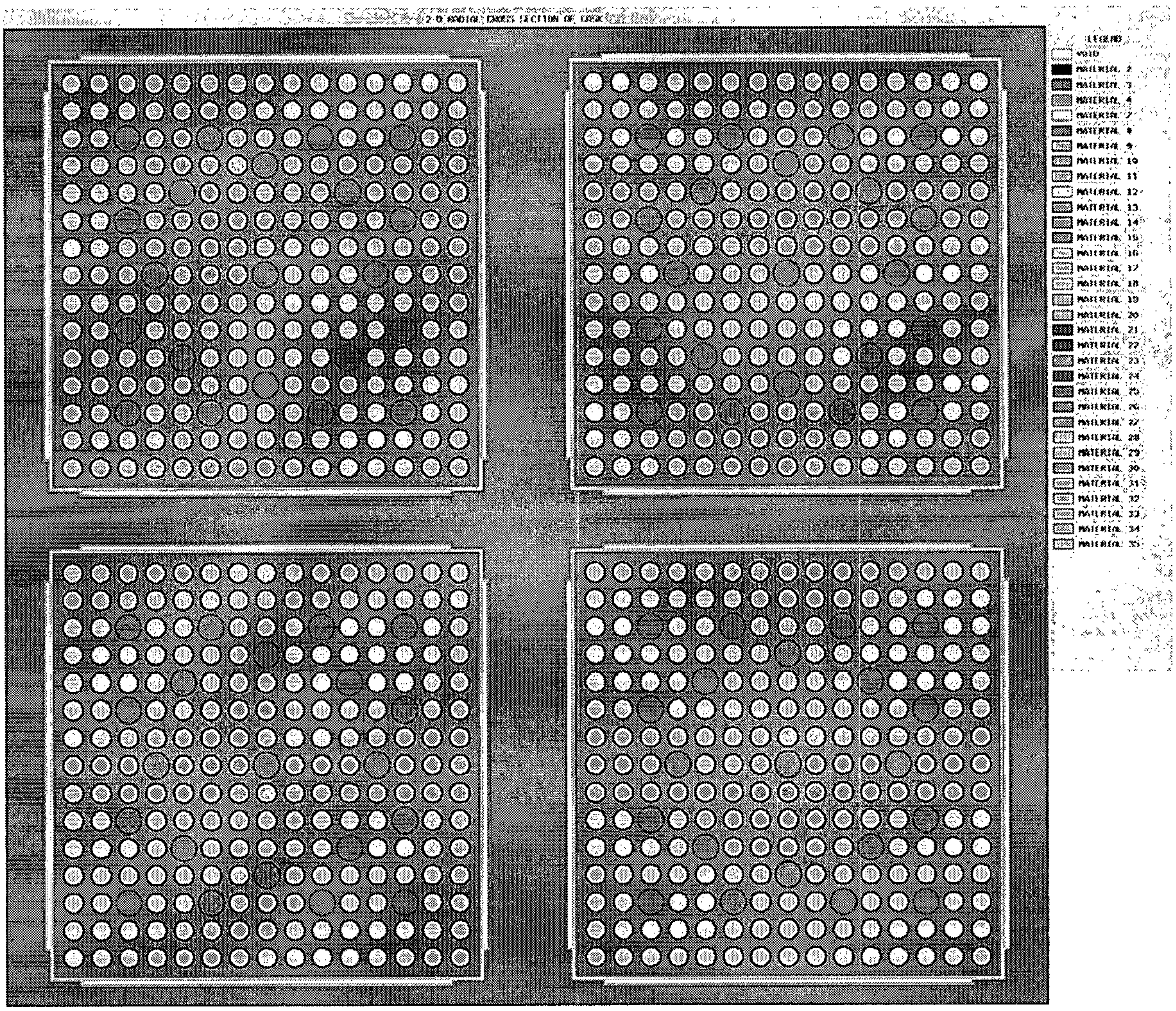

Figure 6-5. KENO Model for the Cask Area Rack

6.11 INTERFACES

The following subsections discuss the analyses and conclusions for the various interface configurations.

6.11.1 Storage Arrangement Interfaces within the Region 2 Racks

Interfaces between different fuel storage arrangements within a rack module and across a rack-to-rack gap between Region 2 rack modules are permissible if the following rules are met:

- Each 2x2 configuration in the Region 2 area of the pool that does not contain cells facing the pool wall or Region 1 racks must match one of the analyzed arrays II-A through II-F.
- In this context, the term "match" means that the configuration has at least the required number of inserts, full length RCCAs or empty cells and that the assemblies have at least the required burnup for the appropriate Category.

The requirement to check all possible 2x2 configurations considers each storage cell as part of up to four 2x2 configurations: one each where the cell is the top left, top right, bottom left and bottom right cell of the 2x2 configuration. All four of these arrangements must match one of the acceptable categories, but not necessarily all of them will match the same category. The application of this requirement will automatically establish rows or columns of boundary cells at the interface, if required. These boundary cells conservatively fulfill the requirements of cells on each side of the interface. As an example, Figure 6-6 shows an acceptable interface between Array II-F and II-B2 with an intermediate row satisfying Array II-D. Array II-F requires no inserts, Array II-B2 requires two inserts, and Array II-D requires one insert. Fulfilling the rules stated above creates a boundary between the two cases consistent with allowable configurations but with reduced reactivity fuel. For example, the Array II-D pattern (one insert for the 2x2 uniformly loaded with Category II-4 fuel), contains two II-4 assemblies and two II-7 (lower reactivity) assemblies.

II-7	II-7	II-7	II-4	II-2b	II-2b
II-7	II-7	II-7	II-4	II-2b	II-2b
II-7	II-7	II-7	II-4	II-2b	II-2b
II-7	II-7	II-7	II-4	II-2b	II-2b

Figure 6-6. Example of an Interface between Array II-F and II-B2 (Shaded cells contain an insert)

Following these rules, every 2x2 configuration matches an analyzed condition, and therefore no interface-specific analyses are required. Gaps between Region 2 rack modules are conservatively neglected, i.e., cells located across a rack-to-rack gap are considered the same as cells directly facing each other within a rack. The configurations wherein Region 2 cells face Region 1 rack modules or the pool wall require additional analyses and are discussed in Sections 6.11.3 and 6.11.4, respectively.

6.11.2 Storage Arrangement Interfaces within the Region 1 Racks

In Region 1 racks, the same approach is used as in Region 2 racks, i.e., case-to-case interfaces within a rack module and across a rack-to-rack gap between Region 1 rack modules are permissible if the following rules are met:

- Each 2x2 configuration in the Region 1 area of the pool must match one of the analyzed arrangements Array I-A through I-C.
- In this context, the term "match" means that the configuration has at least the required number of empty cells or full length RCCAs and/or the assemblies have at least the required burnup for the appropriate Category.

No special considerations need be given to cells facing the pool wall or other racks. Additionally, Category I-2 and I-3 cells can be used in any combination without following a specific pattern, as shown in Figure 1-1.

6.11.3 Region 1 to Region 2 Interface

It is possible that the interface between Region 1 and Region 2 could cause an increase in reactivity compared to the 2x2 infinite array models. This is possible since the outside of Region 1 does not have the same size water gap as the general gap between cells in the rest of Region 1. The cell to cell pitch for Region 1 is 10.6 inches while the pitch is only 9.0 inches for Region 2. The gap between Region 1 and Region 2 is conservatively modeled as only one inch such that the assemblies are 0.6 inches closer together at the interface than in Region 1. Although the distance between the cells is larger than the Region 2 cell to cell pitch, the Region 1 assemblies are more reactive than the Region 2 assemblies. To minimize the effect of the interface, loading restrictions are applied to the Region 2 cells adjacent to Region 1 (see Figure 1-3). Even with these restrictions, some increase in reactivity may be observed.
[

]a,c

The interface analysis is straightforward. Region 1 has only three loading arrangements, checker boarded fresh fuel, uniform loading of fresh fuel with full length RCCAs inserted, or uniform loading with burnup requirements from Table 1-4 and 1-5 (Fuel Category I-3). The fresh fuel checkerboard has a lower reactivity since there is some margin and the empty storage cells within the checkerboard would minimize the interaction. For the first set of interface cases analyzed, Region 1 contains either the highest or lowest burned fuel from type I-3 fuel. Region 2 fuel can contain zero, one, or two inserts and highest or lowest burnup. It can also contain a 3 out of 4 arrangement of fuel (array II-A). After the cases with uniform burned fuel in Region 1 are completed, the results are reviewed and the possible limiting cases with fresh fuel and full length RCCAs are identified and analyzed. [
]a,c

As can be seen in Table 6-8 the effect of the interface on reactivity is very small. From Table 6-8 [

]^{a,c}.

Table 6-8 Interface Reactivity Effects [ ]^{a,c}			a,c
Region 2 Characteristics			
No Absorber Inserts			
1 in 4 Absorber Inserts			
2 in 4 Absorber Inserts			
1 in 4 Empty Cells			
Note: The Monte Carlo uncertainty with each calculation is about 0.0001.			

6.11.4 Cells Facing the Pool Wall in Region 2 Racks

The effects of radial neutron leakage for the fuel assemblies placed into Region II facing a pool wall allows for an exception to the normal fuel placement categories. It has been shown that specific fuel of higher reactivity can be placed on the outer row of Region 2 racks facing the pool wall without inserts if certain restrictions on the interior fuel locations are applied (See Figure 1-4). Use of this exception to the normal fuel placement is optional; it is always acceptable to configure these locations under the normal 2x2 array requirements. These more reactive assemblies correspond to the assemblies permitted by Category II-2b or lower reactivity, without any inserts. To qualify this configuration on the peripheral storage cells for all Region 2 fuel storage arrangements, [ ]^{a,c} For this calculation, the Region 1 area of the model has no fuel in the racks. This stored array of fuel is assumed to face a pool wall on three sides, and to contain Category II-2b fuel without inserts in all peripheral locations (Category II-2c fuel is required for arrays requiring two inserts). For fuel arranged in accordance with Categories II-2 through II-8, the required inserts are placed in the second row from the interface, i.e., directly adjacent to the row with the Category II-2b or II-2c assemblies. For Category II-7, variations of the rack to wall distance are analyzed. The results of this study, as seen on Table 6-9, show no statistically significant effect on the reactivity. Therefore, all other cases are analyzed using a fixed distance of [ ]^{a,c} Storing Category II-2b or II-2c fuel on the periphery without inserts is acceptable as long as the required inserts or empty cells in each 2x2 array are placed in the row adjacent to the peripheral row.

Using more reactive fuel on the periphery of the rack will always increase reactivity compared to the reference 2x2 model of the storage configuration, [

]^{a,c}. Table 6-10 shows the delta k due to using the more reactive fuel on the Region 2/wall boundaries.

Table 6-9 Effect of Separation between the Wall and Rack			
Case Identification	k_{eff}	Sigma	Difference from 5 cm separation
1 cm between wall and rack	[ ]^{a,c}	0.00007	0.00012
5 cm between wall and rack	[ ]^{a,c}	0.00006	N/A
10 cm between wall and rack	[ ]^{a,c}	0.00005	0.00002
30 cm between wall and rack	[ ]^{a,c}	0.00006	0.00013

Table 6-10 Wall Reactivity Effects [ ]^{a,c}		
Region 2 Characteristics	[	
No Absorber Inserts (Category II-2b on wall)		
1 in 4 Absorber Inserts (Category II-2b on wall)		
2 in 4 Absorber Inserts (Category II-2c on wall)	]	
Note: 1 in 4 empty cells is not in the above table since the burnup requirements of II-2b and II-2c are greater than that needed for 1 in 4 empty cells.		

a,c

The conclusions applicable to Turkey Point fuel storage near the pool walls are summarized as follows:

- For any 2x2 arrangement requiring one or no inserts in the Region 2 area of the pool that are adjacent to cells facing the pool wall, the cells facing the pool wall may contain Category II-2b fuel assemblies without inserts.

- For any 2x2 arrangement requiring two inserts that are adjacent to cells facing the pool wall, the cells facing the pool wall may contain Category II-2c fuel assemblies without inserts.

Additionally, the 2nd row from the pool wall of each 2x2 array containing cells facing the fuel pool wall must contain at least one insert if fuel placed in the 2nd and 3rd row of cells matches Arrays II-B1 through II-D criteria.

6.11.5 Combined Effect of Wall and Region 1/Region 2 Interface

[

]^{a,c}

[

]a,c

Table 6-11 Combined Interface and Wall Reactivity Effects [ ]a,c			a,c
Region 2 Characteristics			
No Absorber Inserts			
1 in 4 Absorber Inserts			
2 in 4 Absorber Inserts			
1 in 4 Empty Cells			

Note:
All cases have a Monte Carlo uncertainty of about 0.0001. The cases are run at the minimum burnup requirement for 5 wt% ^{235}U fuel and 72 hours cooling.

6.11.6 Configurations during Loading and Unloading of Assemblies

An insert can be placed into a cell only after the fuel assembly is placed into the cell. Therefore, during the loading and unloading of fuel, a condition could exist wherein a storage location requiring an insert to comply with the final fuel storage loading pattern does not contain that insert during the intermediate steps. However, under such conditions, the same requirements as for the case-to-case interfaces can be applied (see subsections 6.11.1 and 6.11.2), which ensures that all configurations conform to an analyzed condition. As an example, Figure 6-7 shows the possible loading sequence for an assembly into a cell ultimately requiring an insert in an Array II-B2 configuration. Performed in reverse order, the steps of Figure 6-7 show an unloading sequence for an assembly in a cell containing an insert. All steps of the loading and unloading sequence conform to an analyzed configuration.

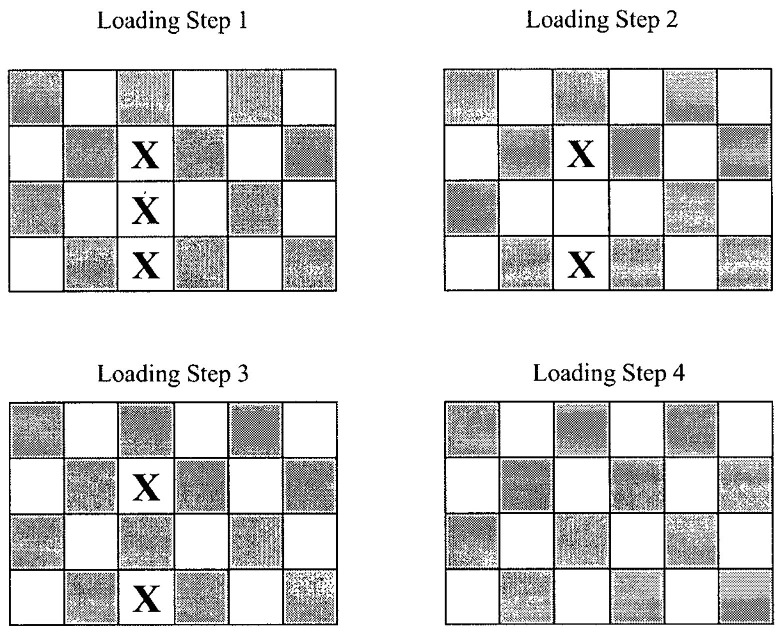

Figure 6-7 Example of Loading Steps for Array II-B2 (All locations contain an assembly except those with an X, shaded also contains an insert)

6.11.7 Interface with the Cask Area Rack

The cask area rack has sufficient absorber panels that the maximum k_{eff} is much less than the limiting k_{eff} in Region 1 or Region 2. Section 6.10 shows the most limiting cask area rack reactivity is 0.9712 where the limiting Region 1 or Region 2 reactivity is near 0.995. The Region 1 and Region 2 analyses assumed an infinite array of the same assemblies so placing a lower reactivity rack in the model would not increase the reactivity of the Region 1 or Region 2 racks. The cask area rack is also analyzed as infinite. Placing the Region 1 or Region 2 racks next to the cask area rack would increase the reactivity determined for the cask area rack but not above the Region 1 or Region 2 values. The cask area rack has Boral panels on the exterior of the rack so there is no local increase in reactivity at the rack interface. There are no interface loading constraints on the Cask Area Rack/Region 1 or Cask Area Rack/Region 2 interface.

6.12 ABNORMAL AND ACCIDENT CONDITIONS

6.12.1 Limiting Accident Case

All abnormal and accident conditions are bounded by the condition of placing a fresh assembly into the water-filled cell required by Array II-A. This is expected since the fresh assembly is being surrounded by the most reactive fuel allowed in Region 2. Therefore, this condition is calculated for 5.0 wt% ^{235}U fresh fuel with 1600 ppm soluble boron in the pool water. Table 6-12 below shows the results of the calculation. [

]^{a,c}

The misloaded assembly analysis presented in Table 6-12 is done at the highest enrichment/burnup point of the loading requirements. [

]^{a,c} The analysis is also done at both hot and cold water conditions. The results are very similar but the hot conditions are slightly more limiting and so the hot condition results are shown on Table 6-12.

All allowable loadings in Region 2 require burnup, so misloading a fresh fuel assembly into Region 2 would be very unlikely. A conservative analysis of misloaded 5.0 wt% ^{235}U fresh fuel in Region 1 was preformed; the reactivity increase from the misload was offset by 1500 ppm of soluble boron. Therefore the misload in Region 1 is bounded by the misload in Region 2.

Along with misloading an assembly it is required to consider an inadvertent removal of an absorber. The inadvertent removal of any absorber insert creates cases with higher burnup than that analyzed for the misloaded fresh assembly so these cases are covered by the misload analysis presented in this section.

Table 6-12 Results of Accident Condition with 1600 ppm Soluble Boron (Fresh Fuel Surrounded by Category II-1 Fuel)	
Soluble Boron (ppm)	1600
Region	2
Enrichment of II-1 Fuel	5.0
Burnup of II-1 Fuel	49.50
Cooling Time	72 hour
Pool Temperature (°F)	150
Calculated k_{eff}	
Depletion Uncertainty[(1)]	
Burnup Uncertainty[(2)]	
Enrichment Uncertainty[(3)]	
Rack Cell ID Tolerance	
Rack Cell Wall Tolerance	
Rack Cell Pitch Tolerance	
Insert Areal Density Tolerance	
Eccentricity Effect	
Fuel Tolerances	
Monte Carlo Uncertainty (2 σ)	
Validation Uncertainty	
Combined Uncertainty	
Bias	
Bias plus Uncertainty	
Maximum k_{eff}	0.9393

a,c

Note:
1. Depletion uncertainty for II-1 fuel in Array II-A
2. Burnup uncertainty for II-1 fuel in Array II-A
3. Enrichment uncertainty for II-1 fuel in Array II-A

6.12.2 Less Limiting Accident Conditions

A number of less limiting accident conditions must be considered and are discussed below.

The spent fuel pool is to be operated at less than 150 degrees F. However, under accident conditions this temperature could be higher. Due to the large volume of water in the spent fuel pool, boiling off the pool water before remediation is not credible; therefore the lowest density of the water is the water density at boiling and atmospheric pressure, .96 gm/cc. The cases with absorber inserts are limited by cold conditions. The water in empty cells is close to full neutron absorption at even 0.96 gm/cc. The case that increases the most with temperature is the Region 1 case with full loading of fuel. Analysis is performed on Region 1 with the highest burnup, 38.241 GWD/MTU, the highest enrichment, 5 wt%, and shortest cooling, 72 hours, to determine the effect of accident temperatures. Since this is an accident case, the water is assumed to contain at least 1600 ppm. With water at the boiling temperature and no voids k_{eff} is [ ]^{a,c} which is well below the safety limit. Although most voiding with boiling would be around the fuel pins where water has a positive worth, a few other cases are run with voiding and 1600 ppm. The cases assumed 5%, 22%, 48%, and 69% voiding. The k_{eff} for these cases are [ ]^{a,c} respectively. Although reactivity is increasing with increasing voids the reactivity with 69% voids still leaves considerable margin to the criticality safety limits.

During placement of the fuel assemblies in the racks, it is possible to drop the fuel assembly from the fuel handling machine. The dropped assembly could land horizontally on top of the other fuel assemblies in the rack. In this case, there is significant separation between the dropped fuel assembly and the rest of the fuel assemblies due to the top nozzle, fuel rod plenum, fuel rod end plug, and the separation between the fuel rod and the top nozzle. This separation is at least 10 inches. It is clear that the misloaded fresh fuel assembly described in subsection 6.12.1 is far more limiting than a single assembly lying horizontally on top of other assemblies in the rack. It is also possible that a fuel assembly could be dropped in its location with such force that the resultant fuel assembly deforms the support structure such that more of the fuel assembly is below the absorbers. The removal of an absorber insert represents 100% of the assembly below the absorber and this was seen in the previous subsection to be non-limiting.

It is possible to misplace a fuel assembly in a location not intended for fuel. Any assembly placed outside of the racks is surrounded by water on at least two sides. The misloaded fresh assembly in subsection 6.12.1 is surrounded by fuel on all four sides. The reactivity level of that fuel around the misloaded assembly is the highest of any fuel in Region 2. Analysis, also reported in subsection 6.12.1, showed that if the entire Region 1 rack is loaded with fresh fuel and 1500 ppm it would meet the subcriticality requirements. Adding a fresh fuel assembly outside of Region 1 is clearly less limiting than the already analyzed multiple misloadings in Region 1.

There are two conditions with the cask area rack that must be considered. First, the cask area rack has a corner where there is no storage cell box. It is possible, though very unlikely, that a fresh fuel assembly could be placed in this corner such that there is only one panel of Boral separating this misplaced fuel assembly from the fuel assemblies in the cask area rack. The infinite 2x2 model of the cask area rack is modified to model this scenario. See the Figure 6-8 below. The k_{eff} for this case with 1600 ppm boron in the water is [ ]^{a,c} which is significantly less than the limiting accident reported in subsection 6.12.1.

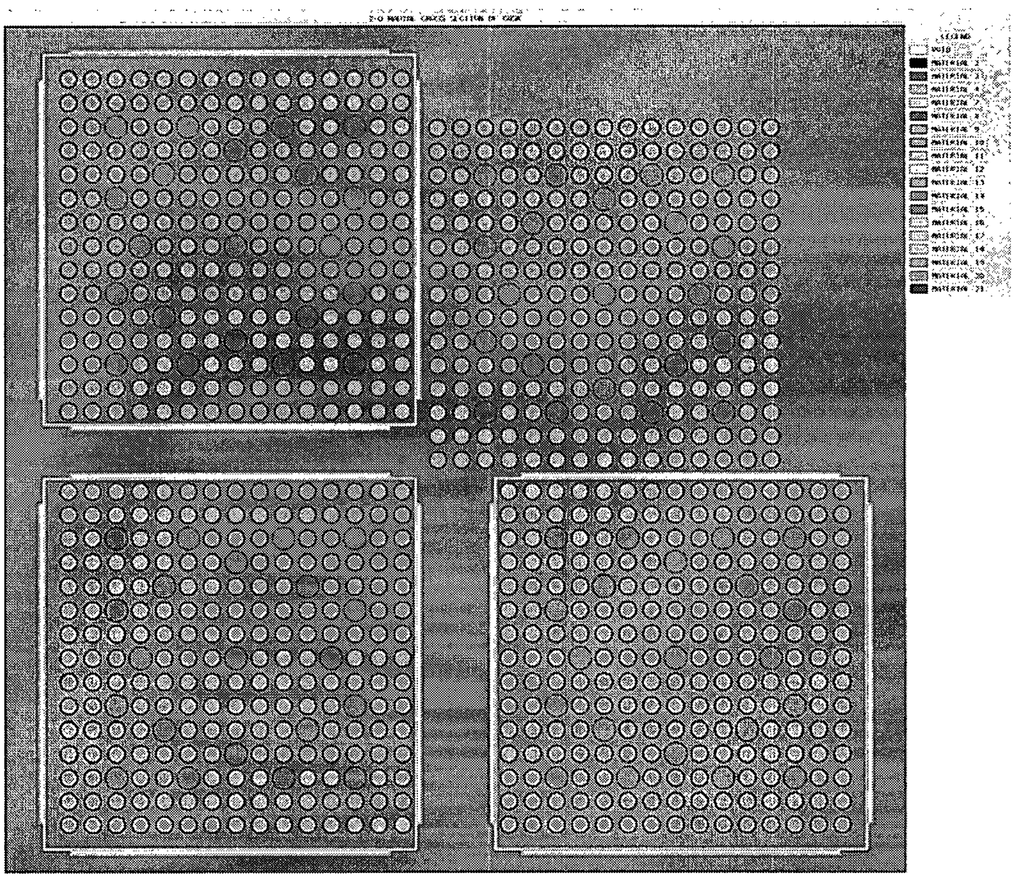

Figure 6-8. Model for Misloading a Fresh Assembly in the Cask Area Rack Corner Cut

The second condition to be analyzed is due to the side of the cask area rack designed to be placed next to the pool wall and therefore contains no Boral absorber. While it is considered extremely unlikely that the cask rack could be mis-positioned, if the entire rack is rotated 180 degrees, then the side with no Boral will be facing fuel assemblies in Region 2. The infinite cask area model is modified to remove the Boral absorber on two sides. This very conservatively represents the rack facing fuel assemblies in Region 2. The k_{eff} of this configuration with 1600 ppm boron in the water is [ ]^{a,c} which is significantly less than the limiting accident.

6.13 NEW FUEL STORAGE RACK

This section describes the analysis, which supports the safety conclusions (Section 1.5) for the new fuel storage rack.

6.13.1 Rack and Fuel Description

Figures 6-9 and 6-10 show the top and side views of the new fuel rack. As can be seen from the top view, the rack is L-shaped with a 10 by 3 array against an 8 by 3 array making for storage of 54 assemblies. The side view is shortened. The side view shows two column-like items, which are funnel type devices used to assure the fuel assemblies are correctly placed in the rack. Between the bottom funnel and top funnel the rack is open. The funnels are 2 feet 9 inches long. For this analysis, it is assumed that the fuel assemblies are bare with only water between them. The cell pitch in the rack is 21 ± 0.125 inches. The cell has an ID of 9 inches which is used for determining eccentric positioning. The fuel description is found in Section 4.1. For the final analysis of fuel greater than a nominal 4.7 wt% ^{235}U, the 16 IFBA rods [ ]^{a,c}.

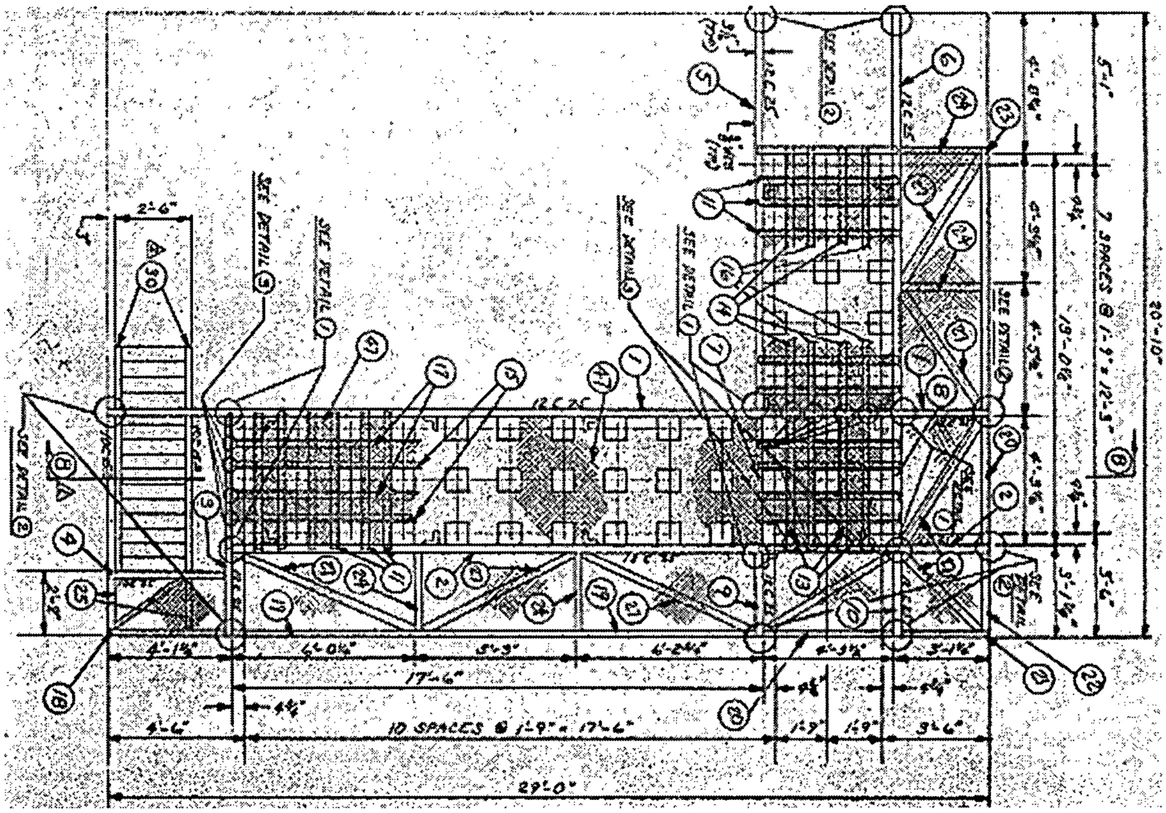

Figure 6-9. Top View of the Turkey Point New Fuel Racks

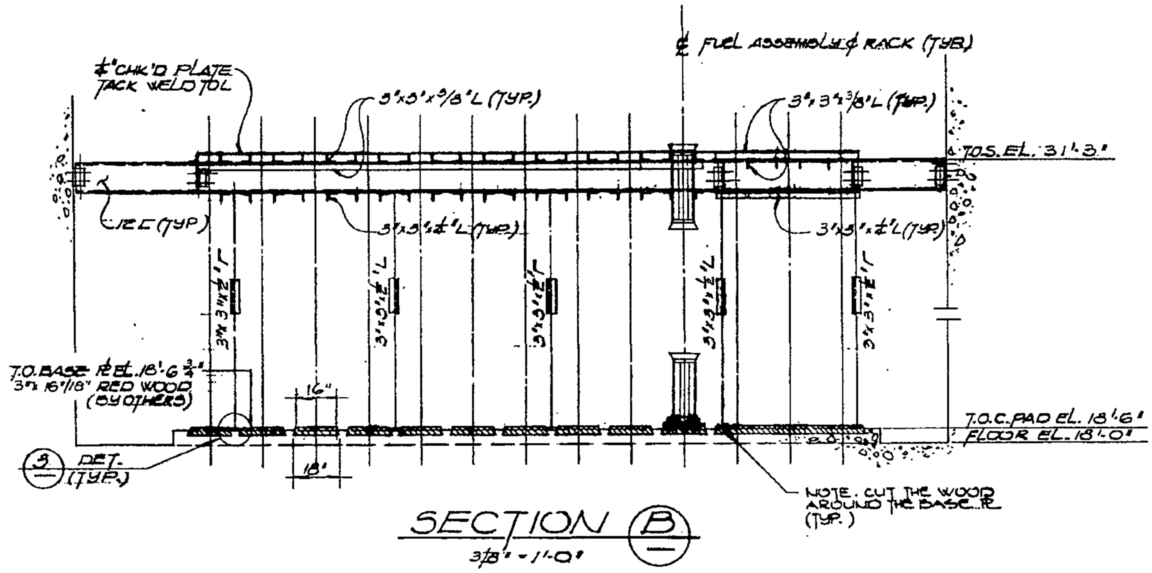

Figure 6-10. Side View of the Turkey Point New Fuel Racks

6.13.2 Model Description

The analysis is done with SCALE 5.1 (parm=NITAWL) and the 44 group ENDF/B-V library. The validation of SCALE is documented in Appendix A. The new fuel rack analysis is within the range of the validation shown on Table 8-1 of the Appendix. From the validation, [

]^{a,c}.

The SCALE model of the rack is shown in Figure 6-11.

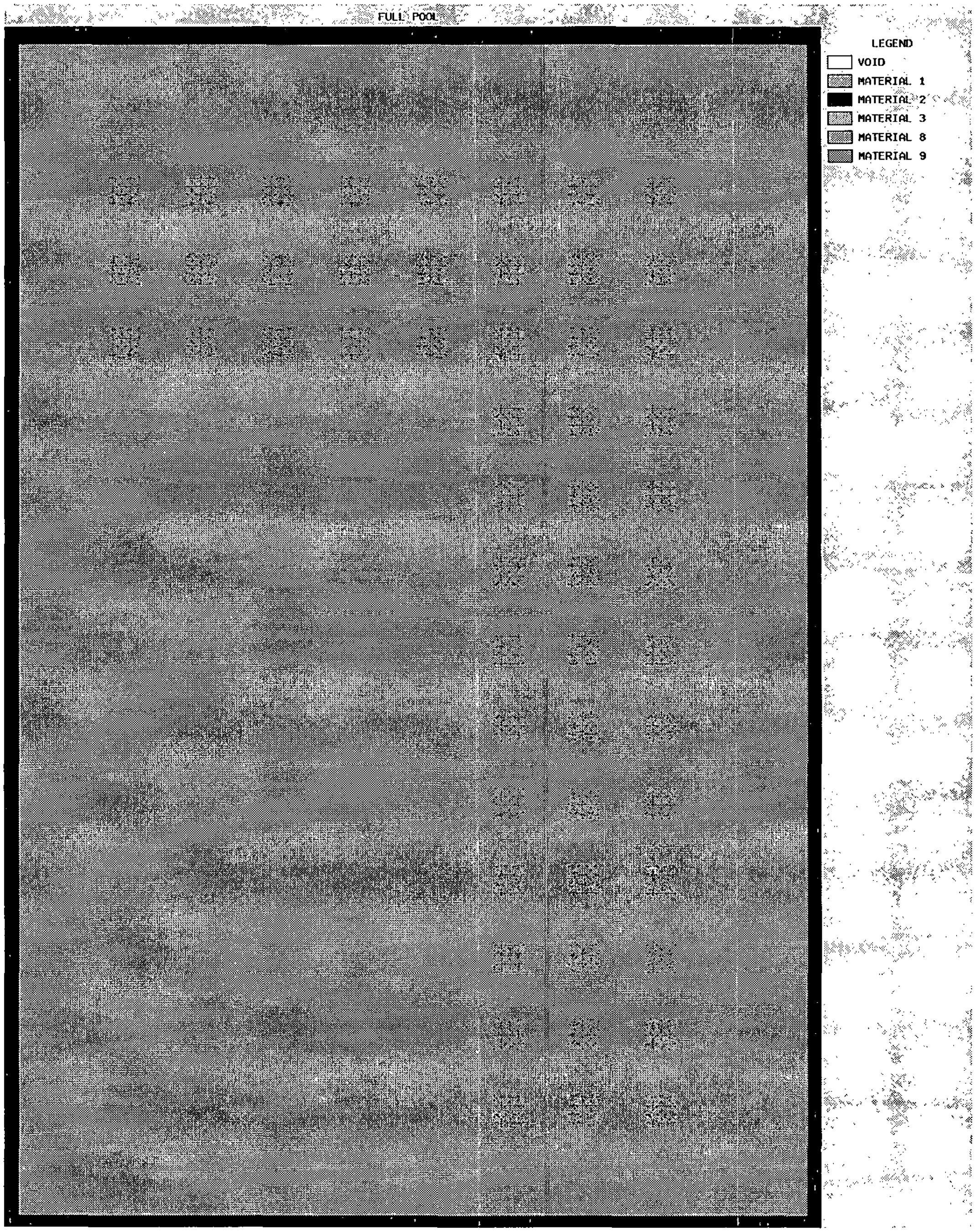

Figure 6-11. New Fuel Rack Model

The following are comments about the SCALE model:

1. The UO_2 density is selected as 97% of the theoretical density. This is lower than the 97.5 % of theoretical density used for the spent fuel pool analysis. This is the stack density – no dishing or chamfering is taken into account. The current fuel products use a theoretical density of 95.5% [ ]^{a,c}. Thus the assumed theoretical density covers the most limiting condition. If the nominal fuel density is raised to 97%, the dishing fraction would cover the uncertainty in density.

2. The water is modeled at the maximum density of 1.00 gm/cc.

3. For the final models, the axial reflector is assumed to be 100% water. Analysis is also performed with the axial reflector modeled as 50% water and 50% steel. In the fully flooded cases, the difference is less than the uncertainty. In the optimum moderation cases, the additional water increased reactivity. The radial reflector is water at the same density as in the lattice. a,c

4. [ ]

5. For the limiting cases the fuel is placed in the cells so that they are [ ]^{a,c}.

6.13.3 Rack Analysis

Analysis showed that 5 wt% ^{235}U fuel would not meet the 0.95 acceptance criterion in the fresh fuel rack without additional absorbers. The absorber selected is 16 IFBA rods in the assembly. The minimum number of IFBA rods in any Westinghouse IFBA design is 16 rods. It is assumed that the IFBA rods have a nominal ^{10}B loading of [ ]^{a,c}. Analysis further determined the maximum enrichment allowed without absorbers is a nominal 4.7 wt% ^{235}U.

Table 6-13 shows the results of the final analysis of the New Fuel Storage Racks. The acceptance criteria for dry storage racks are:

1. If the rack is fully flooded by water, k_{eff} must be less than 0.95.
2. If the rack is flooded with optimum reduced density water, k_{eff} must be less than 0.98.

Each criterion must be met including all biases and uncertainties. The 4.7 wt% ^{235}U fully flooded analysis is done using a nominal base case and the addition of the bias from the validation and a statistical combination of independent uncertainties. The rest of the cases shown on Table 6-13 started with a base case that used [ ]^{a,c}.

As seen from Table 6-13, racks with a large separation between assemblies can have higher reactivity at low water density. The cases with the [ ]^{a,c} are run changing the moderator density to find the low-density peak. Figures 6-12 and 6-13 show the resulting reactivity as a function of moderation.

The analysis for 4.7 wt % ^{235}U assumes an enrichment uncertainty of 0.05 wt%. The analysis of the 5.0 wt% ^{235}U assumes a maximum enrichment of 5.0 wt%. Although it is anticipated that this will be interpreted as a maximum nominal enrichment of 4.95 wt%, as long as the actual maximum enrichment is 5.0 wt% or less, the safety analysis applies.

A statistical combination of uncertainties is used for the 4.7 wt% ^{235}U fully flooded case.

Table 6-13 Results for the New Fuel Storage Racks

Case	4.7 wt% Fully Flooded	4.7 wt% Optimum Moderation	5.0 wt% w/16 IFBA Fully Flooded	5.0 wt% w/16 IFBA Optimum Moderation
k(calc)				
Validation Bias				
Validation Uncertainty				
Tolerance Uncertainty				
Enrichment Uncertainty				
Monte Carlo Uncertainty				
Combined Uncertainty				
Max k_{eff}	0.9440	0.9709	0.9417	0.9527
Regulatory Limit	0.95	0.98	0.95	0.98

a,c

Note:
[ ]^{a,c}

a,c

Figure 6-12. k_{eff} as a Function of Water Density for 4.75 wt% ^{235}U Fuel in the New Fuel Racks

a,c

Figure 6-13. k_{eff} as a Function of Water Density for 5 wt% ^{235}U Fuel with 16 IFBA Rods

6.13.4 Sensitivity Analysis

The eccentric positioning of the fuel in the New Fuel Rack cell is evaluated and found to have no effect for the fully flooded case and a small impact for the optimum moderation case. In the fully flooded cases the difference in the calculated k_{eff} for centered fuel and eccentric positioned fuel is less than [ ]^{a,c} in k_{eff}. Since the cell pitch is so large (21 inches), there is little interaction between assemblies in the flooded model, leading to similar results in the centered and eccentric cases. To show this more clearly, a case is run with a single 4.7 wt% ^{235}U fuel assembly in the middle of a pool of water. The k_{eff} for this case is [ ]^{a,c}, which means that the interaction of assemblies in the eccentric positioning only increased the k_{eff} by [ ]^{a,c} in k_{eff}. [

]^{a,c}

7 REFERENCES

1. Code of Federal Regulations, Title 10, Part 50, Section 68, "Criticality Accident Requirements".

2. "Boraflex Remedy at Turkey Point Nuclear Plant for FPL," Holtec Report HI-2043149 (Non-Proprietary), ADAMS Accession number ML060900259.

3. "SCALE: A Modular Code System for Performing Standard Computer Analyses for Licensing Evaluation," ORNL/TM-2005/39, Version 5.1, Vols. I–III, November 2006. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-732.

4. L. I. Kopp, "Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," NRC Memorandum from L. Kopp to T. Collins, August 19, 1998.

5. Appendix I to FPL letter L-2002-214, Turkey Point Units 3 and 4 Proposed License Amendments: Addition of Cask Area Spent Fuel Storage Racks, dated November 26, 2002 (Section 4.5.4).

6. M. Ouisloumen, H. Huria, et al, "Qualification of the Two-Dimensional Transport Code PARAGON," WCAP-16045-P-A, August 2004.

7. FPL Turkey Point Technical Specification Section 3/4.9.3 "Decay Time."

8. FPL Turkey Point Technical Specification Section 3/4.9.1, "Boron Concentration" and Section 3/4.9.14, "Spent Fuel Storage."

9. FPL License Amendment Request No. 178, Boraflex Remedy, L-2007-112.

10. Code of Federal Regulations, Title 10, Appendix A to Part 50, General Design Criteria 62, "Prevention of Criticality in Fuel Storage and Handling"

11. "Criticality Safety of Fresh and Spent Fuel Storage and Handling" NUREG-0800 Section 9.1.1, U.S. Nuclear Regulatory Commission, Washington, DC, June 1987.

12. J. C. Wagner, M. D. DeHart, and C. V. Parks, "Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analyses," NUREG/CR-6801 (ORNL/TM-2001/273), U.S. Nuclear Regulatory Commission, Washington, DC, March 2003.

13. WCAP-11596-P-A, "Qualification of the PHOENIX-P/ANC Nuclear Design System for Pressurized Water Reactor Cores," T.G. Nguyen et al., June, 1988.

APPENDIX A VALIDATION OF SCALE 5.1

A.1 INTRODUCTION

This document reports the validation of SCALE 5.1 [1] using the ENDF/B-V 44 group library for LWR fuel rack applications. SCALE was run with NITAWL to account for resonance self-shielding for all the analyses in this document therefore this validation uses NITAWL.

The validation consists [ ]^{a,c} and the determination of the bias and the uncertainty in the calculation of k_{eff} for fresh and burned fuel and follows the direction of NUREG/CR-6698, "Guide for Validation of Nuclear Criticality Safety Calculational Methodology," [ ]^{a,c} [2]. The guide establishes the following steps to validation:

1. Define operation/process to identify range of parameters to be validated
2. Select critical experiment data
3. Model experiments
4. Analyze the data
5. Define the area of applicability of the validation and limitations

It further defines the steps of "Analyze the data" as:

1. Determination of Bias and Bias Uncertainty
2. Identify Trends in Data, Including Discussion of Methods for Establishing Bias Trends
3. Test for Normal or Other Distribution
4. Select Statistical Method for Treatment of Data
5. Identify and Support Subcritical Margin
6. Calculation of Upper Safety Limit

This approach will be followed for the validation provided in this appendix.

A.2 DEFINITION OF OPERATION/PROCESS TO IDENTIFY RANGE OF PARAMETERS TO BE VALIDATED

The validation guidance document [2] states:

> *"Prior to the initiation of the validation activity, the operating conditions and parameters for which the validation is to apply must be identified. The fissile isotope, enrichment of fissile isotope, fuel density, fuel chemical form, types of neutron moderators and reflectors, range of moderator to fissile isotope, neutron absorbers, and physical configurations are among the parameters to specify. These parameters will come to define the area of applicability for the validation effort."*

This validation is for the Turkey Point Units 3 and 4 fuel racks. The racks are assumed to be flooded with water from zero to full density at a temperature range of 0°C to 100°C at atmospheric pressure. The fuel is low enriched uranium dioxide (less than or equal to 5.0 wt% ^{235}U). The fuel is in pellets with a density of greater than 94% of the theoretical density. The only significant neutron moderator is water (at all densities in the range) and the oxygen in the fuel pellet. The neutron absorbers credited are boron (as plates, rods or in solution) and Ag-In-Cd control rods. The reflector is water, steel, or concrete. The fuel is in assemblies but the analysis is also valid for ordered arrays of loose pins. The assembly arrangement can vary by design from totally isolated assemblies to a close packed array of assemblies.

A.3 SELECTION OF THE FRESH UO_2 CRITICAL BENCHMARK EXPERIMENTS

There are numerous sources for critical experiments. The OECD International Handbook [4] provides the most extensive set of well-documented critical experiments, but NUREG/CR-6361 [3] has historically provided a basis for benchmark experiments to be used in LWR analyses. In NUREG/CR-6361 173 lattice criticality benchmarks are evaluated. These benchmarks have been well tested and in general meet the needs of this validation. The next step is to select those critical experiments that are relevant to this analysis.

The UO_2 benchmarks were selected that met the following criteria: a,c

[ ]

Since the rack subcriticality depends on boron, additional benchmark experiments containing boron were identified for inclusion in this validation:

- [ ]a,c
- [ ]a,c

a,c

[ ]

The critical experiments chosen to be included in this analysis were selected to cover the range of parameters important to criticality. An evaluation of the area of applicability is provided in Section A.10.

Table A.3-1 Benchmark Experiment Summary

Case ID	Reference	Description

a,c

Table A.3-1 (continued) Benchmark Experiment Summary

Case ID	Reference	Description

a,c

Table A.3-1 (continued) Benchmark Experiment Summary		
Case ID	**Case ID**	**Case ID**

a,c

Table A.3-1 (continued) Benchmark Experiment Summary		
Case ID	Case ID	Case ID

a,c

A.4 ANALYSIS OF THE FRESH UO_2 BENCHMARK CRITICAL EXPERIMENTS

NUREG/CR-6698 [2] in section 2.3 states:

> *For specific critical experiments, the facility or site may choose to use input files generated elsewhere to expedite the validation process. The site has the responsibility for ensuring that input files and the options selected are appropriate for use. Regardless of the source of the input file, the site must have reviewed the description of each critical experiment and determined that the representation of the experiment, including simplifying assumptions and options, are consistent with the intended use. In other words, the site must assume ownership of the input file.*

Consistent with the NUREG/CR-6698 recommendations, [

]^{a,c}.

Table A.4-1 shows the results of the analysis of the [ ]^{a,c} critical experiments along with parameters that are used to check for trends in the results. [

]^{a,c}

Table A.4-1 Critical Experiment Results with SCALE 5.1 and the 44group Library

Case	Enrichment (wt% ^{235}U)	AEG	EALF (eV)	Pitch (cm)	Dancoff Factor	k_{eff}	σ

a,c

Table A.4-1 Critical Experiment Results with SCALE 5.1 and the 44group Library (cont.)

Case	Enrichment (wt% ^{235}U)	AEG	EALF (eV)	Pitch (cm)	Dancoff Factor	k_{eff}	σ

a,c

Table A.4-1 Critical Experiment Results with SCALE 5.1 and the 44group Library (cont.)

Case	Enrichment (wt% ^{235}U)	AEG	EALF (eV)	Pitch (cm)	Dancoff Factor	k_{eff}	σ

a,c

Table A.4-1 Critical Experiment Results with SCALE 5.1 and the 44group Library (cont.)

Case	Enrichment (wt% ^{235}U)	AEG	EALF (eV)	Pitch (cm)	Dancoff Factor	k_{eff}	σ

a,c

Table A.4-2 Summary of Critical Experiments Containing Boron

Case Name	Soluble Boron (ppm)	Separator Plate ^{10}B Areal Density (gm/cm^2)	Boron Rods?	k_{eff}	σ

a,c

Table A.4-2 Summary of Critical Experiments Containing Boron (cont.)

a,c

A.5 [

]a,c

[

]a,c

[

]^{a,c}

A.6 [

]a,c

[

]a,c

a,c

a,c

a,c

a,c

A.7 STATISTICAL ANALYSIS OF THE UO_2 AND COMBINED CRITICAL BENCHMARK SUITE RESULTS

This section examines two benchmark suites. The first suite is composed of [ ]a,c fresh UO_2 critical experiments discussed in Sections A.3 and A.4. The second benchmark suite combines [ ]a,c which ensure the area of applicability of the suite includes the actinides in spent fuel. In the rest of the discussion, these two suites will be referred to as the UO_2 and combined suites respectively. In order to demonstrate conservatism all benchmarking parameters are examined for both suites and the limiting values are used in the analysis.

[

]a,c

[

]^{a,c}

As recommended by NUREG/CR-6698, the results of the validation are checked for normality. The NIST has made publicly available a statistical package, DATAPLOT. [

]^{a,c}

Histogram plots of the results are shown in Figures A.7-1 and A.7-2 below and provide a visual check of the normality of the UO_2 and combined critical experiment suites. [

]^{a,c}

a,c

a,c

a,c

a,c

A.7.1 Neutron Spectrum Tests

[

]a,c

a,c

A.7.2 Geometry Tests

a,c

a,c

a,c

a,c

a,c

a,c

A.9 SUBCRITICAL MARGIN

The NRC has established subcritical margins for rack analysis. The subcritical margin for borated spent fuel pools, casks, and fully flooded dry storage racks is 5% in k. For dry storage racks analyzed with optimum moderation the subcritical margin is 2%. [

]a,c

A.10 AREA OF APPLICABILITY (BENCHMARK APPLICABILITY)

The critical benchmarks were selected to cover all commercial light water reactor fuel storage racks or casks. Little to no extrapolation for key parameters important to criticality is needed. To summarize the range of the benchmark applicability (or area of applicability), Table A.10-1 is provided below.

Table A.10-1 Area of Applicability (Benchmark Applicability)

a.c

Table A.10-1 Area of Applicability (Benchmark Applicability) (cont.)

a,c

A.11 SUMMARY

This validation follows the guidance of NUREG/CR-6698 [ ]^{a,c} Key aspects of the guidance are the selection of experiments, analysis of the experiments, statistical treatment, determination of the bias and the bias uncertainty, and finally identification of the area of applicability.

[ ]^{a,c} have been selected that cover the range of conditions for rack analysis. The experiments have been analyzed using SCALE 5.1 and the ENDF/B-V cross sections and the resulting bias in k is very small. [

]^{a,c}

While this validation is intended to cover the Turkey Point Units 3 and 4 fuel racks, the specifics of the area of applicability are found in Table A.10-1.

A.12 REFERENCES

1. "SCALE: Modular Code System for Performing Standard Computer Analyses for Licensing Evaluation," ORNL/TM-2005/39, Version 5.1, Vols. I–III, November 2006. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-25.

2. J.C. Dean and R.W. Tayloe, Jr., "Guide for Validation of Nuclear Criticality Safety Calculational Methodology," NUREG/CR-6698, Nuclear Regulatory Commission, Washington, DC January 2001.

3. [

   ]a,c

4. "International Handbook of Evaluated Criticality Safety Benchmark Experiments," NEA/NSC/DOC(95)03, Volume IV, Nuclear Energy Agency, OECD, Paris, September, 2008.

5. Not Used

6. [

   ]a,c

7. Not Used

8. Not Used

9. Kleinbaum, Kupper, and Muller, "Applied Regression Analysis and Other Multivariable Methods," Second Edition, page 48, PWS-KENT Publishing Company, Boston, MA 1988.

10. "PROPHET StatGuide: Examining Normality Test Results," http://www.basic.northwestern.edu/statguidefiles/n-dist_exam_res.html, located on June 8, 2009.

11. R. Mark Sirkin, "Statistics for the Social Sciences," Third Edition, 2005, page 245, Sage Publications, Thousand Oaks, CA.

12. M. Rahimi, E. Fuentes, and D. Lancaster, "Isotopic and Criticality Validation for PWR Actinide-Only Burnup Credit," DOE/RW-0497, U. S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, DC, May, 1997.

13. Not Used

14. [

   ]a,c

ACRONYMS

Acronyms	Definition
[	][a,c]
[	][a,c]
SCALE	Standardized Computer Analyses for Licensing Evaluation. This is the name of a computer code used in this case for criticality analysis.
OECD	Organization for Economic Co-operation and Development.
USL	Upper Subcriticality Limit on k_{eff} to assume safety.

Attachment 3
Turkey Point Units 3 and 4
License Amendment Request No. 207
Fuel Storage Criticality Analysis

Westinghouse Affidavit

WCAP-17094-P, Rev 2,
Turkey Point Units 3 and 4
New Fuel Storage Rack and
Spent Fuel Pool Criticality Analysis

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

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Proj. letter: NF-FP-10-172

CAW-10-2895

July 26, 2010

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: WCAP-17094-P, Revision 2, "Turkey Point Units 3 and 4 New Fuel Storage Rack and Spent Fuel Pool Criticality Analysis" (Proprietary)

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-10-2895 signed by the owner of the proprietary information, Westinghouse Electric Company LLC. The affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.390 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying affidavit by Florida Power and Light Company.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-10-2895 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Enclosures

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared J. A. Gresham, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed before me
this 26th day of July 2010

Renee Giampole
Notary Public

COMMONWEALTH OF PENNSYLVANIA
NOTARIAL SEAL
Renee Giampole, Notary Public
Penn Township, Westmoreland County
My Commission Expires September 25, 2013

(1) I am Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC (Westinghouse), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse Application for Withholding Proprietary Information from Public Disclosure accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of

Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in WCAP-17094-P, Revision 2, "Turkey Point Units 3 and 4 New Fuel Storage Rack and Spent Fuel Pool Criticality Analysis" (Proprietary), dated July 2010, for Turkey Point Units 3 and 4, being transmitted by Florida Power and Light Company letter and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted for use by Westinghouse for Turkey Point Units 3 and 4 is expected to be applicable for other licensee submittals in response to certain NRC requirements for justification of spent fuel pool criticality safety analysis.

This information is part of that which will enable Westinghouse to:

(a) Provide information in support of plant power spent fuel pool criticality safety analysis.

(b) Provide customer specific calculations.

(c) Provide licensing support for customer submittals.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for licensing documentation associated with spent fuel pool criticality safety analysis submittals.

(b) Westinghouse can sell support and defense of the technology to its customer in the licensing process.

(c) The information requested to be withheld reveals the distinguishing aspects of a methodology which was developed by Westinghouse.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar information and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

COPYRIGHT NOTICE

Florida Power and Light Company

Letter for Transmittal to the NRC

The following paragraphs should be included in your letter to the NRC:

Enclosed are:

1. 4 copies of WCAP-17094-P, Revision 2, "Turkey Point Units 3 and 4 New Fuel Storage Rack and Spent Fuel Pool Criticality Analysis" (Proprietary)

2. 2 copies of WCAP-17094-NP, Revision 2, "Turkey Point Units 3 and 4 New Fuel Storage Rack and Spent Fuel Pool Criticality Analysis" (Non-Proprietary)

Also enclosed is the Westinghouse Application for Withholding Proprietary Information from Public Disclosure CAW-10-2895, accompanying Affidavit, Proprietary Information Notice, and Copyright Notice.

As Item 1 contains information proprietary to Westinghouse Electric Company LLC, it is supported by an affidavit signed by Westinghouse, the owner of the information. The affidavit sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of Section 2.390 of the Commission's regulations.

Accordingly, it is respectfully requested that the information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Westinghouse affidavit should reference CAW-10-2895 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.