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July 20, 2007
L-07-084

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

Subject: **Beaver Valley Power Station, Unit Nos. 1 and 2**
BV-1 Docket No. 50-334, License No. DPR-66
BV-2 Docket No. 50-412, License No. NPF-73
Responses to a Request for Additional Information (RAI dated May 21, 2007) in Support of License Amendment Request Nos. 333 and 204 (TAC Nos. MD2377 MD2378)

By letter dated May 21, 2007, the U.S. Nuclear Regulatory Commission (NRC) issued a request for additional information (RAI) pertaining to License Amendment Request (LAR) Nos. 333 and 204. These LARs were submitted by FirstEnergy Nuclear Operating Company (FENOC) on June 14, 2006 by letter L-06-094 (Reference 1). The LARs propose Technical Specification changes that incorporate the results of a new spent fuel pool criticality analysis that will permit utilization of vacant storage locations in the Beaver Valley Power Station Unit No. 2 spent fuel storage pool. Attachment A contains the FENOC responses to the May 21, 2007 RAI questions.

Question 5 of the RAI requested a copy of Reference 6 of WCAP-16518-P Revision 1, "Beaver Valley Unit 2 Spent Fuel Pool Criticality Analysis," dated May 2006 (proprietary version). Enclosure 1 provides the requested document. The response to Question 28.g involves a correction of a transposition error in Table 3-25 of WCAP-16518. Since the WCAP requires a revision, the word "unity" will be replaced with "1.0" as stated in the response to Question 2. Neither of the changes to the WCAP affects the results of the analysis or the justification for the LAR. The revision to WCAP-16518 is being provided under a separate letter.

The staff's concurrence with the RAI responses is requested within one month of the date of this submittal. Approval of the proposed amendments is requested by December 2007 to support the Unit No. 2 refueling outage scheduled for the spring of 2008. Once approved, the amendments shall be implemented within 30 days.

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The RAI responses have no impact on either the proposed Technical Specification changes or the determination of no significant hazards consideration transmitted by Reference 1.

No new regulatory commitments are contained in this submittal. If you have questions or require additional information, please contact Mr. Thomas A. Lentz, Manager - Licensing, at 330-761-6071.

I declare under penalty of perjury that the foregoing is true and correct. Executed on July 20, 2007.

Sincerely,

Peter P. Sena, III

Attachment:

A. Responses to RAI dated May 21, 2007

Enclosure:

1. Westinghouse letter 98DL-G-0043, "Duquesne Light Company, Beaver Valley Power Stations Unit 2, Revision 1 to Soluble Boron Credit Analysis," dated November 12, 1998

Reference:

1. FENOC Letter L-06-094, License Amendment Requests 333 and 204, dated June 14, 2006.

c: Ms. N. S. Morgan, NRR Project Manager
Mr. D. L. Werkheiser, NRC Senior Resident Inspector
Mr. S. J. Collins, NRC Region I Administrator
Mr. D. J. Allard, Director BRP/DEP
Mr. L. E. Ryan (BRP/DEP)

Attachment A of L-07-084

REQUEST FOR ADDITIONAL INFORMATION

REGARDING THE SPENT FUEL POOL CRITICALITY

ANALYSIS LICENSE AMENDMENT REQUEST

FIRSTENERGY NUCLEAR OPERATING COMPANY

BEAVER VALLEY POWER STATION, UNIT NOS. 1 AND 2

DOCKET NOS. 50-334 AND 50-412

By letter dated June 14, 2006, FirstEnergy Nuclear Operating Company (FENOC, licensee) submitted letter L-06-094 (Reference 1) requesting a change to the Beaver Valley Power Station, Unit 2 (BVPS-2) spent fuel pool (SFP) Technical Specification (TS). The requested change would alter the approved BVPS-2 SFP storage configurations. To support this request, FENOC has submitted a new BVPS-2 SFP criticality analysis.

Appendix A General Design Criterion 62 of Part 50 to Title 10 of the *Code of Federal Regulations* (10 CFR) requires, "Criticality in the fuel storage and handling system shall be prevented by physical systems or processes, preferably by use of geometrically safe configurations."

10 CFR 50.68 (b) (4) states, "If no credit for soluble boron is taken, the k-effective [k_{eff}] of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95 percent probability, 95 percent confidence level, if flooded with unborated water. If credit is taken for soluble boron, the k_{eff} of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95 percent probability, 95 percent confidence level, if flooded with borated water, and the k_{eff} must remain below 1.0 (subcritical), at a 95 percent probability, 95 percent confidence level, if flooded with unborated water."

The new BVPS-2 SFP criticality analysis takes credit for soluble boron. Therefore, the acceptance criteria are that the SFP k_{eff} must remain below 1.0 (subcritical), at a 95 percent probability, 95 percent confidence level, if flooded with unborated water, and k_{eff} of the SFP storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95 percent probability, 95 percent confidence level, if flooded with borated water.

The Nuclear Regulatory Commission (NRC) staff has provided guidance on meeting the regulatory requirements in Reference 2.

The NRC staff request responses to the following questions in order to continue the review of the license amendment request (LAR):

1. **The LAR lists four SFP criticality analyses as precedents for its SFP criticality, specifically: R. E. Ginna (Reference 3), Diablo Canyon Power Plant (Reference 4), Millstone Power Station Unit 2 (Reference 5), and Vogtle Electric Generating Plant (Reference 6). However, the technical justification provided for the LAR in WCAP-16518 only references the R. E. Ginna licensing activity as precedent. Please explain how the other precedents are applicable to the LAR.**

RESPONSE:
The WCAP-16518 refers only to the earliest precedent (i.e., Ginna Analysis); however, the LAR additionally lists the subsequent analyses, which also utilize the same methodology applicable to the LAR.

2. **The LAR and technical justification state 'unity' is the acceptance criterion of maintaining sub-criticality when flooded with unborated water. This appears to be in conflict with the 10 CFR 50.46 (b)(4) requirement to maintain $k_{eff} < 1.0$ when flooded with unborated water. Please explain the use of 'unity' as the acceptance criterion, provide appropriate references.**

RESPONSE:
The term "unity" is used in both the LAR evaluation and the supporting technical justification documented in WCAP-16518 to represent 1.0, the 10 CFR 50.46(b)(4) acceptance criteria. The actual acceptance criteria used in the criticality analysis is < 0.995. The use of "unity" in the submittal should not be construed as anything more than a direct substitute for 1.0 and should not result in any confusion regarding the actual acceptance criteria value or compliance with 10 CFR 50.46(b)(4). This can be seen in the other submittals cited as precedent (References 3 through 6) and in the NRC Safety Evaluations for the Diablo Canyon and Vogtle amendments issued in 2002 and 2005, respectively. However, since WCAP-16518 is being revised to resolve the concern of RAI question 28.g, the term "unity" will be replaced with 1.0 in the WCAP revision.

3. **The licensee has concluded that the proposed change does not involve a significant increase in the probability of occurrence or consequences of an accident previously evaluated. Please provide the following information:**

    a. **Generally, will the new fuel storage configurations require more or fewer fuel moves than the current configuration, i.e., will the new configuration require more fuel shuffling or less?**

RESPONSE:
Based on the proposed loading pattern for the upcoming cycle, and projected assembly burnups, a total of 73 fuel moves will be needed to establish the new configurations. This will cause a one time increase in the number of refueling fuel moves from 748 to 821 as detailed in Table 1. After this setup, subsequent outages are not expected to require

additional moves relative to other outages because the general arrangement of the configurations will have been established.

Table 1 – Fuel Assembly Moves		
Condition	**Moves Without Change**	**Moves With Change**
Load New Fuel to Pool	60	60
Offload Core to Upender	157	157
Offload Upender to SFP	157	157
Reload SFP to Upender	157	157
Reload Upender to Core	157	157
B.5.b	60	60
Setup for new TS	0	73
Total	748	821

b. Does the new configuration require a more complex methodology to characterize fuel assemblies or to identify the correct storage rack locations?

RESPONSE:
The methodology for characterizing fuel to determine where it is eligible to be stored will be revised and somewhat more complex with the new configurations due to the use of additional credits (Integral Fuel Burnable Absorber (IFBA) and decay time) and an increased number of fuel regions.

The additional fuel regions are due to the number and structure of the new configurations. Under the current TS, there are three configurations (a 2-out-of-4 configuration, a 3-out-of-4 configuration, and a 4-out-of-4 configuration). Under the proposed TS, there are four configurations [a 1-out-of-9 configuration (3x3), two 1-out-of-4 configurations (one intended for fresh assemblies and one intended for once-burnt assemblies), and a 4-out-of-4 configuration (All-Cell)].

The new "All-Cell" configuration is essentially the same as the existing 4-out-of-4 configuration. The differences come with the other configurations. The existing 2-out-of-4 and 3-out-of-4 configurations use empty cells to complete the configurations. Therefore, there are a total of three fuel regions in the existing TS, one for each configuration.

In contrast to the existing configurations, the proposed 3x3 and the two 1-out-of-4 configurations use depleted fuel instead of empty cells to complete the configurations. Therefore, each of these three configurations has two fuel regions. With one fuel region in the "All-Cell" configuration, there are a total of seven fuel regions for the proposed configurations.

The effect on fuel characterization due to the differences between the current and new storage configurations for the affected fuel storage processes is discussed in the following paragraphs.

Refueling Outages: For normal refueling outages, under the current TS, assemblies being removed from the core are characterized using their burnup and initial enrichment to determine their eligibility for two of the three fuel regions. Under the new analysis, assemblies being removed from the core will continue to be characterized using their burnup and initial enrichment (decay time is conservatively set to zero and IFBA will not apply) to determine their eligibility for five of the seven fuel regions.

The characterization will be accomplished by comparing the burnup and initial enrichment of each fuel assembly to the requirements specified in TS Tables 3.7.14-2 through 3.7.14-5. Each of these four tables identifies the burnup requirements for the depleted fuel regions in each of the four configurations. Table 3.7.14-4 also identifies the burnup requirement (15,000 MWD/MTU) for the fuel region that is intended to be used to store once-burnt assemblies.

Initial Pool Setup: To initially set up the pool for the new analysis, the fuel in the pool will need to be characterized based on its burnup, initial enrichment and decay time to determine eligibility for five of the seven fuel regions. Characterization of the fuel for the current analysis only requires the use of burnup and initial enrichment and is therefore slightly less complex since decay time does not need to be reviewed.

Similar to the manner in which the characterization will be done for refueling outages, the characterization of the assemblies already in the pool will be accomplished by comparing the burnup and initial enrichment of each fuel assembly to the requirements specified in TS Tables 3.7.14-2 through 3.7.14-5. However, the assembly decay time will be used, in addition to burnup and enrichment, to determine its eligibility for the depleted fuel region of the 3x3 configuration as identified by TS Table 3.7.14-3.

New Fuel Receipt: Under the current TS, fresh fuel is stored in a 2-out-of-4 configuration. Under the new analysis, there are two configurations that will be used to store fresh fuel. The 1-out-of-4 configuration for the fresh fuel takes credit for IFBA. Therefore, the fresh fuel assemblies will need to be reviewed for IFBA loading to determine if they are eligible for the "1-out-of-4 3.85 w/o with IFBA" configuration. Since most fresh assemblies are expected to have more IFBA rods than the maximum IFBA requirement (63), this characterization is expected to be fairly simple. The fresh assemblies in the new 3x3 configuration, like the assemblies in the current 2-out-of-4 configuration, have no IFBA or burnup requirements.

The requirements that determine whether or not an assembly is eligible to be stored in the fresh region of the "1-out-of-4 3.85 w/o with IFBA" configuration are contained in TS Table 3.7.14-6.

Once the fuel is characterized, identifying the correct storage rack locations will not be any more complex than it is now. Identifying the correct storage location involves administratively identifying the location of the storage configurations in the pool, then matching the characterized fuel to the configurations.

Administrative control of the storage configurations in the Spent Fuel Pool is accomplished with a computer program called ShuffleWorks. The placement of the configurations for the new analysis is expected to be slightly less difficult despite the fact that there will be four configurations instead of three. The decrease in difficulty is due to a decrease in the complexity of the interface requirements. The current interfaces require specific use of empty cells to maintain an acceptable boundary. The new analysis only requires that depleted assemblies (i.e. – not fresh or once-burnt) from each of the configurations be located at the interface. This new interface requirement will be easier to visually verify in ShuffleWorks.

ShuffleWorks displays the pools storage cells on a grid. The user identifies which cells will be used for each configuration by clicking the cells to change their color. A separate color will be used to depict each of the seven fuel regions, so the interface boundary will be shown as a solid row of cells with a color representing the depleted region from one of the configurations on one side of the boundary, and a solid row of a different color representing the depleted region from another configuration on the other side of the boundary.

Once the configurations and fuel characterization are input, ShuffleWorks automatically matches the fuel assemblies to the correct region within each configuration when fuel movement sheets are developed.

c. Who identifies the correct location for a specific assembly?

RESPONSE:
The fuel movement sheets that specify, and document, where fuel assemblies are moved "to" and "from" locations are developed by Reactor Engineering or Core Design and Physics Support personnel using the ShuffleWorks program. Currently, there are eight employees in this grouping. The fuel movement sheets are independently reviewed by a second individual from this group.

Ensuring that an assembly is being moved to a correct location also requires that the assembly be characterized correctly. The characterization is performed by a person in the above grouping, and then reviewed by a second individual from this group. The

ShuffleWorks Administrator enters this data into ShuffleWorks along with the desired pool configuration.

d. What barriers are in place to prevent a mislocation? For example, is there a written procedure or plan that delineates what is to be moved and in what sequence? Is there independent verification of the procedure or plan? Is there independent verification of each move?

RESPONSE:
Fuel characterization is performed in accordance with a refueling procedure. Details regarding the storage configurations and interface requirements are also contained in the procedure. The fuel characterization and pool configuration are stored in the ShuffleWorks program which is used to develop fuel movement sheets. The fuel movement sheets are developed in ShuffleWorks and identify which assemblies are to be moved and where they are to be moved to and from. ShuffleWorks ensures that the assembly moves produced for the fuel movement sheets are acceptable according to the fuel characterization and pool configuration. The fuel movement sheets are verified by two individuals. Actual fuel movement is controlled by refueling procedures in accordance with the fuel movement sheets. During the movement of the fuel the "to" and "from" locations are visually verified by two separate individuals.

e. Should a fuel assembly be misloaded, how would the error be detected?

RESPONSE:
The locations of all fuel assemblies in the pool are verified yearly. While the assembly IDs are not checked during the verification, passing the verification with misplaced assemblies would require multiple misplacements that happened to result in the same expected pool configuration.

If a fresh assembly is misplaced, it would be found on the offload if it was placed in a location designated for an offload assembly. If it was not in a location designated for an offload assembly, it would be found prior to reload when the tops of the reload assemblies are viewed to ensure there is no debris.

If an offloaded assembly is misplaced, it would be found on the reload, as with the fresh assembly, if it was to be reloaded. If it was to be discharged, it would be found during the yearly pool verification.

f. What barriers are in place to prevent a common mode human error in misloading several assemblies, i.e., an initial error followed by dependent errors, such as inadvertently sequencing the fuel moves incorrectly, or mis-identifying the assemblies or locations?

RESPONSE:
For the movement of new fuel to the pool and for movement of fuel within the pool, dependent errors are prevented by the use of fuel movement sheets. The fuel movement

sheets contain a single line for each fuel move with the "from" location, the "to" location, and a sign-off for the move. If a step was inadvertently not signed off, attempting to perform the step again would identify that the "from" location was empty. If a step was inadvertently skipped, subsequent steps would be unaffected because they each contain their own "to" and "from" locations. Similarly, if an assembly is placed in the wrong "to" location or taken from the wrong location, subsequent steps would be unaffected unless a subsequent "to" location coincided with the misplaced assembly or mistaken location. In each case there are no dependent errors.

Offloads and reloads are also controlled by move sheets, but are different in that half of the steps are performed in Containment while the other half is performed in the Spent Fuel Pool. This provides the opportunity for an additional different error. If a step is skipped, dependent misplacements are possible.

For example, on an offload, the first step (1a) on the fuel movement sheets might be to move an assembly from reactor core location A8 to the upender (which is used to transfer the assembly from Containment to the Spent Fuel Pool). The second step (1b) on the move sheets would be in the Spent Fuel Pool to move that same assembly from the upender to a specific location in the pool. If step 1b is skipped and step 2b is performed instead, the assembly would be placed in the wrong pool location and the personnel running the pool crane could believe that their next step is 3b. The reactor crane operator would perform step 2a next, moving another assembly to the upender. If the pool crane operator performed step 3b next, this assembly would also be placed in the wrong location.

To preclude this possibility, the offload and reload are controlled by a Fuel Movement Coordinator (FMC). The FMC communicates via headset with both the reactor crane operator and the pool crane operator. The FMC directs the movement of the fuel in accordance with the fuel movement sheets which identify the specific locations for both the core and pool. The FMC uses a hardcopy of the fuel movement sheets as well as ShuffleWorks in the Outage Monitoring mode to monitor and document the fuel movement. Additionally, the locations for each move are verified by two additional personnel in the field. Using the FMC to control fuel movement serves to ensure that the "from" locations in the reactor are synchronized to the correct "to" locations in the pool.

4. **Provide additional detail in TS 3.7.14 and TS Bases 3.7.14 to preclude a misloading event. The proposed revision to TS 3.7.14 and TS Bases 3.7.14 lack sufficient detail to avoid confusion and possible misapplication of the storage configuration requirements. In some cases an implicit relationship may be inferred. However, given the increased complexity of the proposed storage configurations, the NRC staff considers implicit assumptions, relationships, or requirements to be insufficient to ensure adequate control. See the following examples of the lack of specificity:**

RESPONSE:
The BVPS-2 TS 3.7.14 was revised based on the content and level of detail in NUREG-1431 Revision 3 and the current BVPS TSs.

The NUREG-1431 version of TS 3.7.14 contains burnup and enrichment requirements that dictate into what region of the spent fuel pool a fuel assembly must be placed. The TS also refers to the Design Features Section of TS that lists the criticality related design features of the spent fuel storage racks. The number and requirements associated with spent fuel pool regions are identified as plant-specific. The NUREG-1431 version contains a curve of burnup versus enrichment. Thus, burnup and enrichment are used in NUREG-1431 as the storage defining characteristics.

The current BVPS TS calls out enrichment and burnup in the LCO and uses a table for each unit to define the requirements (burnup and enrichment) associated with each region. The current BVPS TS does not reference the Design Features of TS, but the appropriate information is contained in the Design Features Section, which is not changed by this submittal. The current BVPS Unit 1 TS table contains an equation that may be used to conservatively determine burnup that in turn is used in determining into which of the three regions the assembly is to be placed. The Unit 1 table also has notes stating that the data may be linearly interpolated. The current BVPS Unit 2 TS table has the note addressing linear interpolation, but does not have the equation to calculate burnup. Both units have three regions for assembly storage. However, Unit 2 has an additional condition in its table, that being checkerboarding. For the sake of this discussion, checkerboarding can be considered as a storage configuration. Therefore, the current Unit 2 TS uses burnup and enrichment as the storage defining characteristics used to determine the proper storage configuration.

The curve used in NUREG-1431 is not in the current BVPS TS because more accurate results can be obtained through the use of an equation. The proposed version of the Unit 2 TS modifies the LCO statement by replacing the reference to burnup and enrichment with a reference to tables. This was done because with the criticality analysis supporting this LAR, there is more to consider than burnup and enrichment in determining the storage defining characteristics of an assembly. With the proposed change the additional storage defining characteristics of an assembly include decay time and the number of IFBA. These are provided in the proposed tables for Unit 2. Thus, the proposed Unit 2 tables provide the requirements imposed on each of the storage defining characteristics for each storage configuration.

A review of the precedent submittals revealed a wide range of detail contained in the subject TS and the Design Features Section. Only one of the submittals contains changes to the Design Features Section. In all cases these submittals update existing information, thus the level of detail was not increased by the associated LAR. In some of these submittals, pictorial representations of the fuel assembly storage configuration or the spent fuel pool is provided in the TS or the Bases. However, the use of the pictorial representations still requires reference to the text description of the storage defining characteristics to assure fuel assembly configuration requirements are met. Thus, the pictorial representations do not by themselves completely specify the various storage defining characteristics of an assembly.

Paragraph (c)(4) of 10 CFR 50.36 states that the Design Features Section should contain those features of the facility such as materials of construction and geometric arrangements that are not covered by paragraphs (c)(1), (2) or (3). This discussion demonstrates that the geometric arrangements of the fuel assemblies in the SFP are covered by both the current and proposed version of TS 3.7.14 as permitted by paragraph (c)(1) of 10 CFR 50.36. Additional operator aids, such as pictorial representation of the various storage configurations and interfaces, are provided in the refueling procedures, but the limits and restraints imposed on the storage defining characteristics are totally specified in the proposed TS. As a result, the proposed revision to BVPS Unit 2 TS 3.7.14 is appropriate as well as consistent with the level of detail presented in NUREG-1431 and the current TS, adequate to preclude a misloading event and consistent with the requirements of 10 CFR 50.36 paragraph (c)(4), in that TS 3.7.14 adequately addresses the geometric arrangements, which, if altered or modified, would have a significant effect on safety.

The Bases for TS 3.7.14 provide additional details associated with the storage configurations and the storage defining characteristics of a fuel assembly. Because the Bases would be enhanced by incorporating the clarification provided in some of the following responses, the clarifications will be added where identified. The revised Bases, including the clarifications, will be issued as part of the normal amendment implementation process.

Unlike many other TSs, compliance and adherence to TS 3.7.14 is limited to certain qualified individuals, i.e., the Reactor Engineering and Core Design and Physics Support personnel described in the response to Request for Additional Information (RAI) question 3.c. These are the individuals that must be knowledgeable regarding the TS in order to place the fuel assembly in the proper SFP location, and they are the ones that determine the proper steps to comply with the Required Actions and Surveillance Requirements of the TS.

In summary, the proposed revision to TS 3.7.14 is consistent with the level of detail in NUREG-1431 and the current version of the TS and meets the requirements of 10 CFR 50.36. The proposed revision specifies the storage defining characteristics (enrichment, burnup, decay time, number of IFBA and interface requirements, through the statements pertaining to assemblies at the interface with another configuration) used to determine the storage configuration requirements of an assembly. Adherence to these requirements is sufficient and adequate to avoid a misloading event. In addition, since all necessary requirements to assure safety are covered by the TS, no revision to the Design Features Section is necessary.

a. **The proposed TS Bases 3.7.14 describes the "All-Cell" storage configuration as, "Westinghouse 17 x 17 Standard fuel assemblies with nominal enrichments less than or equal to 1.856 w/o U-235 can be stored in any cell location. This configuration is designated as "All-Cell." Fuel assemblies with initial nominal enrichments greater than these limits must satisfy a minimum burnup requirement as shown in Table 3.7.14-2."**

i. **Where are the RFA [Robust Fuel Assembly], RFA-2, and other fuel designs to be placed? Does BVPS have other fuel designs which are stored in the SFP?**

RESPONSE:
The analysis applies to all of the assembly designs used at BVPS Unit 2 – Standard, V5H, RFA, and RFA-2. Westinghouse produces two lines of 17x17 fuel assemblies - standard and Optimized Fuel Assembly (OFA). All of the assemblies stored in the Unit 2 pool are the standard type of assembly. However, using upper case for the word "Standard" may be misleading because it could be interpreted as identifying a specific type of standard assembly. Therefore, the word "Standard" will be changed to lower case in the Bases.

ii. **Westinghouse 17 x 17 Standard fuel assemblies with nominal enrichments less than or equal to 1.856 w/o U-235 can not be stored in any cell location as the reactivity inherent in the "All-Cell" nominal case will exceed that of the reactivity in the nominal case of all subsequently described storage configurations.**

RESPONSE:
The TS Bases wording will be changed for clarification as follows.

"In the first configuration, Westinghouse 17 x 17 standard fuel assemblies can be stored in a repeating 2x2 matrix of storage cells where all the assemblies have nominal enrichments less than or equal to 1.856 w/o U-235. This configuration is designated as "All-Cell". Fuel assemblies with initial nominal enrichments greater than 1.856 w/o U-235 must satisfy a minimum burnup requirement as shown in Table 3.7.14-2 to be eligible for storage in this configuration.

iii. **WCAP-16518-P Section 3.5.1 describes the "All-Cell" storage configuration as a repeating 2x2 array of storage cells that contain depleted fuel assemblies. That the "All-Cell" storage configuration is a 2x2 array is not captured in either the TS or the TS Bases.**

RESPONSE:
The Bases wording will be changed for clarification as follows.

"Westinghouse 17 x 17 standard fuel assemblies can be stored in a 2x2 matrix of storage cells where all the assemblies have nominal enrichments less than or equal to 1.856 w/o U-235. This configuration is designated as "All-Cell." Fuel assemblies with initial nominal enrichments greater than 1.856 w/o U-235 must satisfy a minimum burnup requirement as shown in Table 3.7.14-2."

iv. There is no discussion of boundary conditions.

RESPONSE:
The following text will be added to the Bases regarding interfaces.

"The interfaces between these four configurations must be maintained such that only the depleted assemblies from each of the configurations are located along the interface. Using the depleted assemblies at the interface precludes locating more highly reactive assemblies (fresh or 15,000 MWD/MTU) next to each other where the configurations meet. Each configuration has its own requirements for its depleted assemblies which are identified in Tables 3.7.14-2 through 3.7.14-5. In the case of the "All-Cell" configuration, all of the assemblies are depleted and, therefore, can be located at the interface with any of the other configurations."

b. TS Table 3.7.14-2, Fuel Assembly Minimum Burnup versus Initial Enrichment for the "All-Cell" Storage Configuration, states "Any fuel assembly may be loaded at the interface with another configuration." As noted above, what constitutes the "All-Cell" Storage Configuration has not been defined. The statement does not limit itself to fuel assemblies in an "All-Cell" Storage Configuration.

RESPONSE:
See reworded TS Bases description of the "All-Cell" storage configuration provided in the response to RAI question 4.a.ii. Also, as indicated in the title of the table, the table is only for the "All-Cell" configuration. The note applies to the table and is therefore limited to "All-Cell" assemblies.

c. TS Tables 3.7.14-3, 3.7.14-4, and 3.7.14-5 state, "Only depleted fuel assemblies may be loaded at the interface with another configuration." Again, the statements do not limit themselves to the particular storage configuration in the table and the concept of what constitutes a 'depleted' fuel assembly changes with each storage configuration.

RESPONSE:
Each of these tables refers only to a single configuration as indicated by the table's title. Each table defines the requirements for the depleted assemblies in that particular configuration. The statement refers to the table and, therefore, to the depleted assemblies for that configuration.

d. TS Table 3.7.14-6 does not have a discussion of an interface requirement.

RESPONSE:
Table 3.7.14-6 provides the IFBA requirements for the fresh fuel in the "1-out-of-4 3.85 w/o fresh with IFBA" configuration. The interface requirements for this configuration are shown with Table 3.7.14-5 which provides the requirements for the depleted assemblies in the same configuration.

e. The Note provided with each table is identical with no specific correlation to a particular table.

RESPONSE:
The notes are shown directly beneath the tables to which they refer. Each table with its notes is shown on a separate page.

f. In the proposed TS Bases, the first paragraph on page B 3.7.14-3 provides a list of 'credits' taken into account for the SFP criticality analysis to ensure k_{eff} less than or equal to 0.95, but the list does not include initial enrichment or specific storage configuration. Explain why they were not included in the list.

RESPONSE:
The Bases paragraph will be reworded as follows.

"The four storage configurations for the Unit 2 spent fuel storage racks are analyzed, for a range of initial assembly enrichment up to 5.0 w/o, utilizing credit for burnup, burnable absorbers, decay time and soluble boron, to ensure k_{eff} is maintained $\leq$ 0.95, including uncertainties, tolerances, and accident conditions. The Unit 2 spent fuel pool k_{eff} can only be maintained < 1.0, including uncertainties and tolerances on a 95/95 probability/confidence level, without crediting soluble boron."

5. Section 1.3 of the technical justification provided in WCAP-16518 states, "The most reactive SFP temperature (with full moderator density of 1 g/cc) is used for each fuel assembly storage configuration such that the analysis results are valid over the nominal spent fuel temperature range (50°F to 185°F) (Reference 6)." Please provide Reference 6.

RESPONSE:
Reference 6, Westinghouse letter 98DL-G-0043, "Duquesne Light Company, Beaver Valley Power Station Unit 2, Revision 1 to Soluble Boron Credit Analysis," dated November 12, 1998, is provided as Enclosure 1 of this submittal.

6. **Section 1.4.3 of the technical justification provided in WCAP-16518 states, "For fresh fuel conditions, the fuel nuclide number densities were derived within the CSAS25 module using input consistent with the data in Table 1-3." Explain the term "...using input consistent with..."**

RESPONSE:
Fresh fuel nuclide number densities were calculated within the CSAS25 module of the SCALE package based on the data presented in Table 1-3. Specifically, fresh fuel was defined in the KENO input with a maximum of 5.0 w/o ^{235}U with 97.5% of theoretical density at 293.15 K.

7. **Section 1.5 of the technical justification provided in WCAP-16518 states, "The Westinghouse 17x17 Standard fuel was modeled as the design basis fuel assembly to conservatively represent all fuel assemblies residing in all the storage configurations. The model bounds Westinghouse fuel products with a 0.3740-inch fuel pin, such as the Westinghouse Standard design, the V5H product, as well as the Robust Fuel Assembly (RFA) and RFA-2 products." Provide the justification for using this design as the bounding assembly design. Include a consideration of manufacturing parameters and design tolerances for the applicable parameters.**

RESPONSE:
Westinghouse fuel products with a 0.3740-inch diameter fuel pin [Standard, V5H, RFA, RFA-2, collectively referred to as standard assemblies] differ in their grid, nozzle, and other structural material designs. Since these structural materials are not credited in the criticality analysis, these assembly designs are neutronically equivalent. One other minor difference between the Standard and other designs is the diameter of the instrumentation tube in the center of the assembly, which will have little impact on the analysis, typically within the Monte Carlo uncertainty (statistically insignificant). Therefore, the Standard assembly design conservatively bounds all other designs. Furthermore, nominal fuel pin and clad dimensions are considered for this analysis, since any manufacturing tolerance in the fuel pin and clad dimensions, due to its small magnitude, will result in an insignificant neutronic impact, again typically within the Monte Carlo calculation uncertainty (statistically insignificant) or are bounded by other conservatisms.

a. **Section 3.2 of the technical justification provided in WCAP-16518 states, "No credit is taken for any spacer grids or sleeves." The analysis in WCAP-16518 indicates the BVPS-2 SFP is over moderated. Not modeling the spacer grids or sleeves increases the moderator to fuel ratio with a potentially beneficial negative reactivity effect. That effect must be balanced against the negative reactivity associated with the absorption cross section of the spacer grids or sleeves. Was the decision to not credit spacer grids or sleeves based on analysis or engineering judgment? How does crediting soluble boron affect the assumption?**

RESPONSE:

Consistent with the current BVPS-2 SFP criticality analyses (Westinghouse letter 98DL-G-0043 in Enclosure 1), spacer grids or sleeves were not modeled. This is based on engineering judgment which is reinforced by Westinghouse's experience that not modeling these removes the negative reactivity impact due to absorption and outweighs the negative reactivity impact due to over-moderation, providing more conservative results. This is also valid for soluble boron credit calculations. Note that all the precedent analyses were performed in the same manner.

8. **Section 1.5 of the technical justification provided in WCAP-16518 states, "Fresh fuel assemblies were conservatively modeled with a U02 density of 10.686 g/cm3 (97.5% of theoretical density). This translates into a pellet density equal 98.6% of theoretical density with a 1.1% dishing (void) fraction." Provide the justification for this assumption. Is the 1.1% dishing (void) fraction a minimum, nominal, or maximum value?**

RESPONSE:

The 1.1% dishing fraction is the nominal value associated with the manufacturing process. However, dishing and chamfering is not modeled in the supporting criticality analysis. Not modeling dishing and chamfering increases the amount of fissile material in the model, which effectively increases the theoretical density that results in conservatively bounding fuel pellets with dishing and chamfering.

a. **Section 3.2 of the technical justification provided in WCAP-16518 states, "The design basis fuel assemblies are modeled with the fresh fuel pellets as a solid right cylinder with a UO2 density of 10.686 g/cm3 (97.5% of theoretical density). No credit is taken for the nominal 1.1 void fraction percentage that is associated with dishing or chamfering. In addition, no credit is taken for any natural or reduced enrichment pellets, even for the blanketed assemblies. This assumption results in conservative calculations of reactivity for all fuel assemblies stored in the racks. No credit is taken for any spacer grids or sleeves."**

i. **Is this the same 1.1% dishing (void) fraction cited in Section 1.5? If so, reconcile the use of the 1.1% dishing (void) fraction to reduce the maximum theoretical density used in the analysis and the claim that "No credit is taken for the nominal 1.1 void fraction percentage that is associated with dishing or chamfering."**

RESPONSE:
Yes, this is the same 1.1% dishing (void) fraction cited in Section 1.5. Had dishing and chamfering been considered, a 98.6% theoretical density (TD) would have been used in the analysis. Instead, the analysis conservatively assumes 97.5% TD, which is the highest credible density for PWR fuel available and bounds the fuel manufactured by Westinghouse. Therefore, not modeling any dishing and chamfering is additional conservatism in the analysis.

ii. **If it is the same, justify using a nominal value rather than a bounding value or establishing an uncertainty for the dishing & chamfer on the fuel pellets.**

RESPONSE:
Since dishing and chamfering were not explicitly modeled, and highest credible 97.5% TD was used, no uncertainty was established for the dishing and chamfering.

9. **Section 1.5 of the technical justification provided in WCAP-16518 states, "All fuel assemblies, fresh and depleted, were conservatively modeled as containing solid right cylindrical pellets and uniformly enriched over the entire length of the fuel stack height. This conservative assumption bounds fuel assembly designs that incorporate lower enrichment blanket or annular pellets." What is the tolerance on enrichment? How is this tolerance used in the criticality analysis?**

RESPONSE:
The fuel rod manufacturing tolerance on enrichment for the reference design fuel assembly is assumed to consist of an increase in fuel enrichment of 0.05 w/o ^{235}U. This is also stated in Section 3.4 of WCAP-16518 (page 29). This tolerance is used in the criticality analysis as an uncertainty statistically included in the final $k_{95/95}$ results for each configuration. The details of these evaluations are given in responses to Questions 16 (a) (v), 17 (a) (v), 18 (a) (v), and 19 (a) (vi) for each of the storage configurations.

10. **The LAR and Section 1.5 of the technical justification provided in WCAP-16518 states, "All of the Boraflex poison material residing in the storage racks was conservatively omitted for this analysis." Please provide the following information concerning this assumption:**

a. **What does the analysis use in place of the Boraflex? What is the justification for that replacement?**

RESPONSE:
The geometry of the Boraflex poison is represented as water in the KENO model, thus no credit is taken for the presence of the neutron absorbing, Boraflex material. This is stated in Section 3.1 of WCAP-16518 (page 23). Replacing the absorber material with water produces conservative results relative to the physical condition.

b. **How does the analysis treat the material which holds the Boraflex in place? What is the justification for that treatment?**

RESPONSE:
Although the poison material is conservatively excluded, the stainless steel wrappers are modeled, as they are an integral part of the storage cells. The Boraflex poison panels are modeled as centered on the surface of the stainless steel canisters by an outer stainless steel sheathing panel. The sheathing surfaces of two adjacent storage cells are separated by pool water. The dimensions of the Boraflex poison panel are 7.5 inch in width by 0.078 inch in thickness. The sheathing panels are included as 0.0293 inch in thickness and are located at the outside surface of the nominal Boraflex poison panel position.

c. **WCAP-16518 Section 2.3, Table 2-2, and Figure 2-2 provide various dimensions for the individual storage cells.**

i. **In Section 2.3, how is the thickness of the Boraflex sheathing known to four decimal places when the manufacturing tolerance is only given to three?**

RESPONSE:
The wrapper thickness 0.0293 +/- 0.005 inches is based on the data provided in the reference drawing.

ii. **All other dimensions have a tolerance specified, what is the tolerance on Boraflex thickness?**

RESPONSE:
It is not specified in the design input and the reference drawing. Furthermore, since Boraflex is modeled as water, the tolerance on its thickness is immaterial for the analysis.

iii. What material is in the 'Gap+Boraflex' in Figure 2-2? How is this material modeled?

RESPONSE:
The "Gap+Boraflex" region shown in Figure 2-2 consists of an actual gap, filled with water, and Boraflex. However, "Gap+Boraflex" region is conservatively modeled as water.

iv. How are the tolerances associated with these dimensions factored into the SFP criticality analysis?

RESPONSE:
Only the tolerance on the wrapper thickness is factored into the analysis as part of the sum of all bias and uncertainties to determine $k_{95/95}$.

11. Section 1.5 of the technical justification provided in WCAP-16518 states, "In addition, the IFBA [Integral Fuel Burnable Absorber] pins were modeled as annular cylinders 120 inches in length and centered about the midplane of the active fuel. Therefore, the IFBA coating is modeled with a 12-inch "cut-back" on the total length of the fuel (blanket and non-IFBA section). Also, [proprietary] on the 1.5X IFBA loading [proprietary] is assumed to cover manufacturing uncertainty and tolerances." Provide the justification for this assumption.

a. Confirm that the 1.5X IFBA loading bounds all IFBA loadings previously used or currently in use at BVPS-2.

RESPONSE:
All fuel assemblies previously used or currently at BVPS-2 have 1.5X or less IFBA loading.

b. What effect would a 2.0X IFBA loading have on the analysis?

RESPONSE:
A 2.0X IFBA loading will reduce the number of IFBA pins to meet the requirements. However, since only 1.5X loading has been analyzed, any assembly with a greater loading will still have to meet the requirements of the 1.5X loading for number of IFBA pins. An assembly with 2.0X IFBA loading that has the required number of IFBA pins (based on 1.5X loading) would conservatively have more IFBA than necessary to meet the assumptions of the analysis.

c. How does the manufacturing phenomenon of Axial Offset Deviation affect the assumption?

RESPONSE:
While Axial Offset Deviation (AOD) may cause the axial distribution of the poison to vary slightly, the correct overall load is still in the pin.

12. **Section 1.5 of the technical justification provided in WCAP-16518 states, "The design-basis limit for k_{eff} at the zero soluble boron condition was conservatively reduced from 1.0 to 0.995 for this analysis." Given that the regulatory requirement is that $k_{eff} < 1.0$ at the zero soluble boron condition and that for the same number of significant digits 0.995 is equal to 1.0, please explain how this assumption is conservative?**

RESPONSE:
Monte Carlo simulations performed for the BVPS-2 criticality analysis have generated k_{eff} values with ±~0.00030 precision. This indicates that one can simulate the physics of the neutrons well within the 1.0-0.995 = 0.005 Δk_{eff} margin. Subsequently, this margin translates into a penalty in the burnup and IFBA requirements in a conservative manner.

13. **Section 2.3, Figure 2-2, and Table 2-2 of the technical justification provided in WCAP-16518 provide various dimensions for the individual storage cells. Provide the following information:**

    a. **Figure 2-2 shows what appears to be 'sheathing' extending the entire outside width of a cell. What is the material and how is it modeled? How does that affect the results?**

RESPONSE:
The "Sheathing" is modeled as 0.0293 inch thick stainless steel extending the outside width of a cell. Since it is very thin, its impact on the results is very small.

    b. **How are the tolerances associated with these dimensions factored into the SFP criticality analysis?**

RESPONSE:
The tolerances associated with these dimensions were used to calculate the reactivity impact in terms of a Δk and included in the total bias and uncertainties in Tables 3-4 through 3-7 in the WCAP.

14. **Section 3.3 discusses the modeling of axial burnup distributions. The methodology employed in WCAP-16518-P uses fewer axial zones than either the R. E. Ginna analysis (Reference 3), as cited precedent, or NUREG/CR-6665, "Review and Prioritization of Technical Issues Related to Burnup Credit for LWR Fuel," (Reference 7) recommends.**

    a. **Provide the justification for using fewer axial zones than either of the cited precedents.**

RESPONSE:
Analyses subsequent to Ginna have used fewer axial zones (e.g., Vogtle, Millstone Unit 2, Diablo Canyon, etc.). It is Westinghouse's experience that as long as the "end-effect" is captured, employing fewer axial zones is equally conservative. Westinghouse has performed calculations and verified this conclusion.

b. Provide the justification for the size of the zones used in the analysis.

RESPONSE:
For any given spent fuel assembly, the fuel burnup is a continuous function of axial position. However, from a calculational point of view, this function can be discretized (modeled as discrete segments) so that the axial "end-effect" is adequately captured. It is common practice to divide the fuel assembly into several axial zones with each zone assumed to be uniform in burnup. Moreover, the size of the top and bottom axial zones must be small (typically 6 to 8 inches) to capture the steep burnup gradient with axial position, while that of the central zone may be larger. In SFP criticality calculations, Westinghouse has found that a four-zone axial model is adequate to represent the spent fuel assembly and capture the end-effects. Such a four-zone model would have three zones with fine mesh spacing (three at the top of the fuel assembly) and the fourth zone is the remainder of the fuel assembly.

c. It is not clear from WCAP-16518-P as to how the axial burnup distribution is used to derive an uncertainty, what the uncertainty is, and how it is used.

i. Provide the description of how the axial burnup distribution is used to derive the uncertainty.

ii. Provide the derived uncertainty. Is it bounding for all scenarios?

iii. Explain how the uncertainty is used.

RESPONSE:
Input to this analysis was based on the limiting axial burnup profile data provided in the Department of Energy (DOE) Topical Report, as documented in Reference 20 of the WCAP. The burnup profile in the DOE Topical Report is based on a database of 3,169 axial-burnup profiles for Pressurized Water Reactor (PWR) fuel assemblies compiled by Yankee Atomic. This profile is derived from the burnups calculated by utilities or vendors based on core-follow calculations and in-core measurement data. The axial burnup profile in the DOE report is based on the most limiting axial burnup shape found in the database. The four-zone model is constructed based on this limiting axial burnup profile. Since this is a very limiting/bounding profile, no uncertainty was considered for it. However, the assembly average burnup uncertainty is conservatively calculated as 5% of the maximum fuel burnup credited in storage configuration analysis for zero ppm

boron condition as well as to compute the soluble boron requirement for reactivity uncertainties.

d. **Has BVPS-2 experienced any occurrence of Axial Offset Anomaly/Crud Induced Power Shift or Axial Offset Deviation? If so were these factored into the axial burnup distribution?**

RESPONSE:
BVPS Unit 2 has not experienced any significant Axial Offset issues. The majority of each cycle has operated with Axial Offset within 3 percent of predictions. The very conservative nature of the axial power/burnup shape assumed for the analysis is still skewed enough to account for the minor deviations.

15. **Section 3.3.1 discusses the impact of the extended power uprate on SFP criticality. Specifically, the maximum core outlet temperature is stated as increasing from 615.1°F to 621.4°F, with a range between 608.6°F and 621.4°F. The actual core outlet temperature used, as given in Table 3-2, is in the lower portion of the range. NUREG/CR-6665 recommends using the maximum core outlet temperature. Justify using less than the maximum core outlet temperature.**

RESPONSE:
The most important reactivity aspect of the axial burnup profile is the difference between the average fuel burnup and the burnup in the top section of the fuel assembly. A secondary effect is the difference between the average fuel temperature and moderator density and the values at the top of the fuel assembly. From Table 3-2, the analysis assumes ~33°F difference (between the core average value and the value for the top of the assembly) which adequately captures the "end-effects." The temperatures used in the analysis are very close to the original and the uprated values. Furthermore, the average assembly power utilized to generate isotopics for burnup calculations was chosen such that it conservatively covers the original and the uprated power levels and any other power level in-between.

16. **According to the technical justification provided in WCAP-16518-P, the "All-Cell" Storage Configuration consists of a repeating 2 x 2 array of depleted assemblies. Depleted assemblies must meet the enrichment/burnup limits in Table 3-9. Provide the following information with respect to the "All-Cell" Storage Configuration.**

a. **With respect to Table 3-4, provide the following information:**

i. **Provide the dimensions and tolerances used in each case that was run to obtain the data. Tabular form is acceptable. If this information is identical for each storage configuration, provide only one table.**

RESPONSE:
Table 2 provides the dimensions and tolerances utilized for the "All-Cell" storage configuration.

Table 2 - Dimensions and Tolerances (All-Cell)	
All-Cell Case	**Description**
^{235}U Enrichment Uncertainty	See response to RAI question 16. a. v.
Increase in UO_2 Density	Not evaluated since calculations were performed at the highest credible value of 97.5% TD
Decrease in Cell Pitch	10.4375 ± 0.0469 inches (From Table 2-2)
Decrease in Rack Thickness	0.090 ± 0.010 inches (From Table 2-2)
Decrease in Rack ID	8.9375 ± 0.0469 inches (From Table 2-2)
Off-Center Assembly Positioning	See response to RAI question 16. a. ii.
Wrapper Thickness	0.0293 ± 0.005 (From Table 2-2)
Burnup Uncertainty	See response to RAI question 16. a. vi.
Methodology Uncertainty	See response to RAI question 16. a. vii.
Pool Temperature Bias	See response to RAI question 16. a. viii.

ii. Explain how the Off-Center Assembly Positioning uncertainty was maximized.

RESPONSE:
As the assemblies were being positioned closer to four adjacent storage cells, the reactivity monotonically increased and became the highest when they were positioned as close as possible. In the absence of absorber material such as Boral/Boraflex, this behavior is expected.

iii. How are the manufacturing tolerances of the fuel assemblies incorporated into the uncertainties?

RESPONSE:
Pellet diameter and density tolerances were accounted for by using a bounding density and modeling the pellet stack as a solid right cylinder. See the response to RAI question 8 for further information.

The tolerance on clad diameter was not considered because its impact is minimal, mostly within the Monte Carlo calculational uncertainty, and bounded by all the other conservatism in the calculations.

iv. Why is 1.911 w/o U235 used as the enrichment for the nominal case?

RESPONSE:
The enrichment value at 0.0 MWD/MTU that satisfies the burnup versus enrichment curve for the "All-Cell" configuration is calculated based on a target k_{eff} value less than 0.995, including all biases and uncertainties. Bias and uncertainty evaluations utilize an initial estimate of this fresh enrichment. For the "All-Cell" configuration, the initial estimate was 1.911 w/o ^{235}U as stated. Once all biases and uncertainties and the final target k_{eff} were evaluated using this initial estimate, the actual fresh enrichment was subsequently calculated as 1.856, which is sufficiently close to the estimated value.

v. With respect to the U235 enrichment uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the U235 enrichment uncertainty was determined.

RESPONSE:
The k_{eff} values were evaluated at 3.0, 4.0, and 5.0 w/o ^{235}U fresh enrichments, and the $\Delta k_{eff}/\Delta$(Enrichment) was evaluated at (4.0 + 0.05) w/o ^{235}U using the 2[nd] order polynomial passing through the 3 data points as shown on Figure 1.

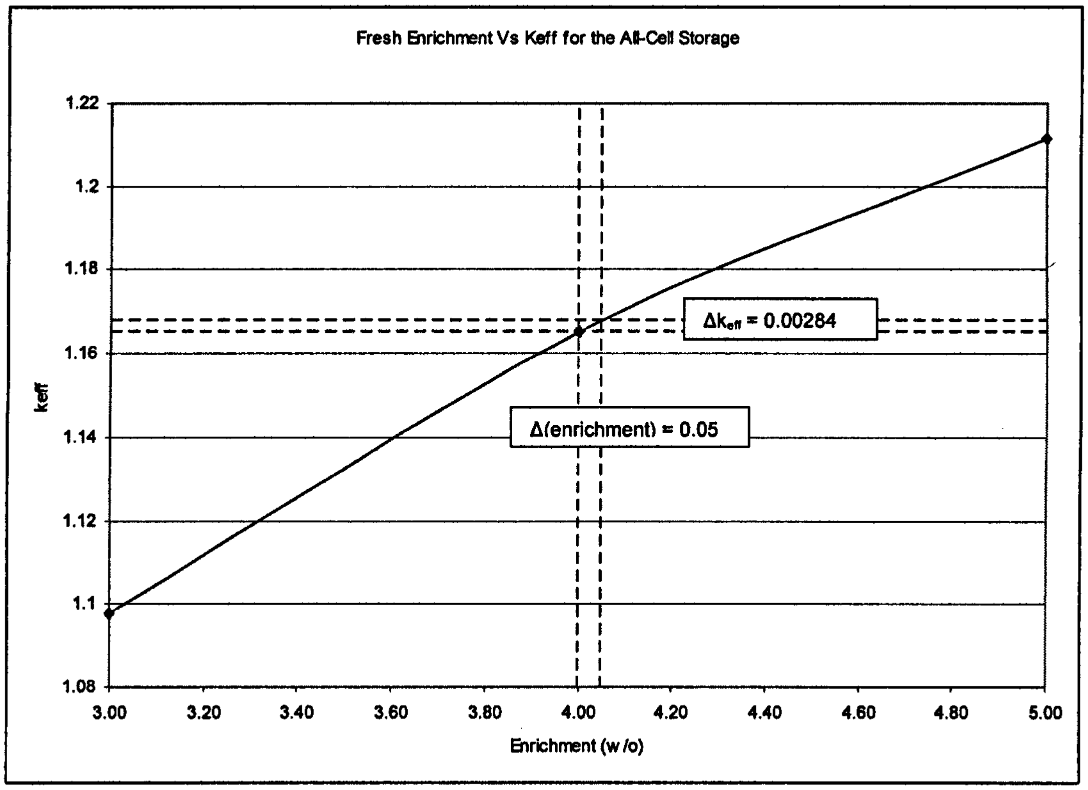

Figure 1 – Fresh Enrichment vs. k_{eff} for "All-Cell"

vi. **With respect to the burnup uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the burnup uncertainty was determined.**

RESPONSE:

A 5% burnup measurement uncertainty is applied by evaluating the differential burnup worths at the conservative maximum burnup credited value of 35,000 MWD/MTU with 5.0 w/o ^{235}U initial enrichment for the "All-Cell" Configuration. Figure 2 shows the k_{eff} values at the highest burnup limit of 35000 MWD/MTU and 33250 (=35000 – 35000*5%) MWD/MTU and the Δk_{eff} is calculated between these two points. For further explanation please see response to RAI question 19 (a) (vii).

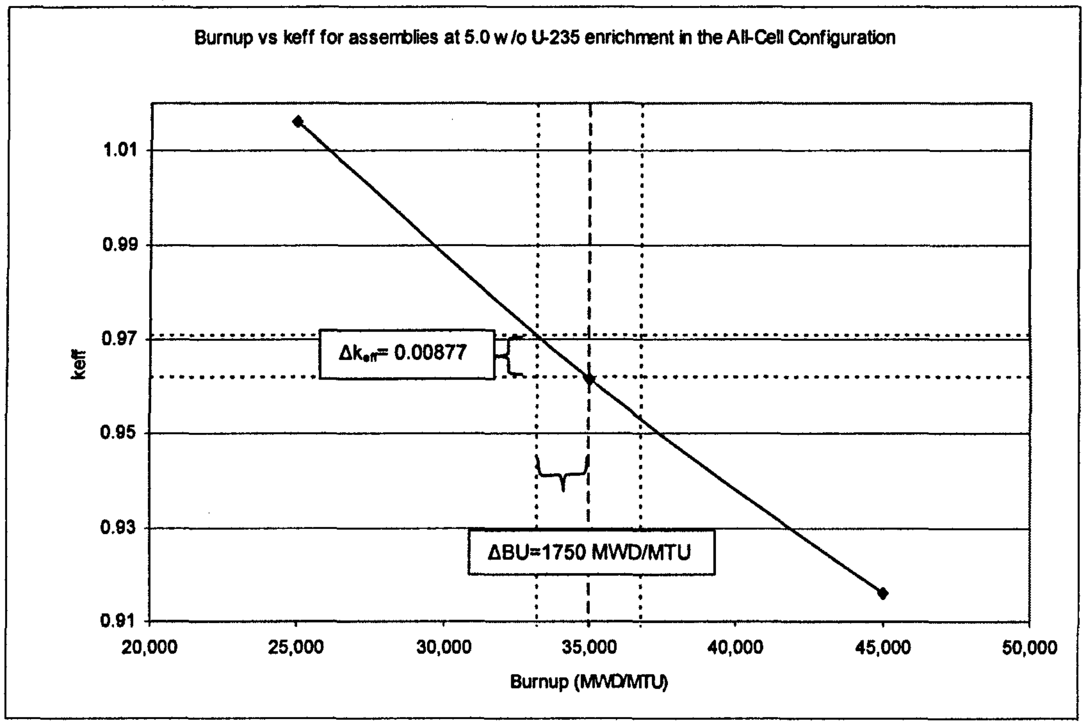

Figure 2 – Burnup vs. k_{eff} at 5.0 w/o ^{235}U for "All-Cell"

vii. **With respect to the methodology uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the methodology uncertainty was determined.**

RESPONSE:

$k_{95/95}$ is calculated as:

$$k_{95/95} = k_{keno} + \Delta k_{bias} + M_{95/95}\left(\sigma_m^2 + \sigma_{KENO}^2\right)^{1/2}$$

Where,

k_{keno}	is the KENO-calculated multiplication factor
Δk_{bias}	is the mean calculational method bias = (0.00310)
$M_{95/95}$	is the 95/95 multiplier appropriate to the degrees of freedom for the number of validation analyses = (2.22)
σ_m^2	is the mean calculational method variance deduced from the validation analyses = $(0.00285)^2$
σ_{KENO}^2	is the square of the KENO standard deviation = $(0.00052)^2$

The methodology uncertainty in Table 3-4 is therefore calculated using:

$$= 2.22\left[(0.00285)^2 + (0.00052)^2\right]^{1/2} = 0.00643$$

viii. With respect to the pool temperature bias, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the pool temperature bias was determined. Include the justification for the use of 4.0 w/o initial enrichment at 25,000 MWD/MTU of burnup for determining the temperature bias.

RESPONSE:
The pool temperature bias was calculated utilizing a whole pool modeled as filled with depleted fuel assemblies with 4.0 w/o initial enrichment at 25,000 MWD/MTU burnup in "All-Cell" configuration. Two sets of calculations were performed: one at 50°F and one at 185°F. Then the bias was computed as: $\Delta k = k_{eff}(185°F) - k_{eff}(50°F)$. Performing calculations with a representative burnup rather than fresh fuel provided a more conservative bias value.

b. With respect to Table 3-9, provide the following information:

i. The initial enrichment values are calculated to the third decimal place. Provide the justification for this precision. Are the enrichments in Table 3-9 nominal values?

RESPONSE:
The enrichments in Table 3-9 are nominal values. The PWR fuel assembly as-built enrichment values are reported in three decimal places. Therefore, the analysis consistently utilized enrichment values with three decimal places.

ii. Accompanying Table 3-9 is a third degree polynomial equation describing the relationship between initial enrichment and burnup. All factors are given to three decimal places. The third factor has eight significant digits. Provide a justification for the precision of the factors in that equation.

RESPONSE:
When the data point enrichments are plugged into this polynomial, the exact burnup values in the table are obtained. The number of decimal points or significant digits accurately represents the burnup vs. enrichment curve.

iii. The third degree polynomial is a fit to four points. Three of those points are the result of second degree polynomial fits to three points. Explain how this does not create a new uncertainty that must be accounted for in the analysis.

RESPONSE:
Each of these polynomials reproduces the exact data points they are generated from; therefore any new uncertainty that might have been introduced will be very small and negligible.

iv. Have any confirmatory calculations been performed to verify these enrichment and burnup combinations actually provide a k_{eff} that meets the specific configuration target k_{eff}?

RESPONSE:
Yes, the fresh 1.856 w/o at 0.0 MWD/MTU case has been confirmed to remain below the target k_{eff} as indicated in Table 3-8. This calculation is sufficient to verify that all enrichment and burnup combinations in the table remain below the k_{eff} target.

c. In Section 3.5.1, the last sentence of the second paragraph states, "Therefore, the target k_{eff} value for the "All-Cell" storage configuration is 0.96457 (0.995-0.03034)." However, when the calculational uncertainty is added to the nominal k_{eff} for the initial enrichment of 1.856 w/o U235 with no burnup entry in Table 3-8, the target k_{eff} is exceeded. Please explain why this is acceptable.

RESPONSE:
The maximum of calculational uncertainty of all bias and uncertainty calculations (0.00052) has already been folded into the target k_{eff} value; therefore, adding the uncertainty for the 1.856 w/o ^{235}U with no burnup entry would be double accounting.

17. According to the technical justification provided in WCAP-16518-P, the "3x3" Storage Configuration consists of a repeating 3x3 array with a fresh fuel assembly with an initial enrichment up to 5.0 w/o, surrounded by depleted assemblies. Depleted assemblies must meet the enrichment/burnup/decay limits in Table 3-10. Provide the following information with respect to the "3 x 3" Storage Configuration.

a. With respect to Table 3-5, provide the following information:

i. Provide the dimensions and tolerances used in each case that was run to obtain the data. Tabular form is acceptable. If this information is identical for each storage configuration, provide only one table.

RESPONSE:
Table 3 provides the dimensions and tolerances utilized for the "3x3" storage configuration.

Table 3 - Configuration Dimensions and Tolerances (3x3)	
3x3 Case	**Description**
^{235}U Enrichment Uncertainty	See response to RAI question 17. a. v.
Increase in UO_2 Density	Not evaluated since calculations were performed at the highest credible value of 97.5% TD
Decrease in Cell Pitch	10.4375 ± 0.0469 inches (From Table 2-2)
Decrease in Rack Thickness	0.090 ± 0.010 inches (From Table 2-2)
Decrease in Rack ID	8.9375 ± 0.0469 inches (From Table 2-2)
Off-Center Assembly Positioning	See response to RAI question 17. a. ii.
Wrapper Thickness	0.0293 ± 0.005 (From Table 2-2)
Burnup Uncertainty	See response to RAI question 17. a. vi.
Methodology Uncertainty	See response to RAI question 17. a. vii.
Pool Temperature Bias	See response to RAI question 17. a. viii.

ii. Explain how the Off-Center Assembly Positioning uncertainty was maximized.

RESPONSE:
As the peripheral assemblies were being positioned closer to the center fresh fuel, the reactivity monotonically increased and became the highest when they were positioned as close as possible. In the absence of absorber material such as Boral, this behavior is expected.

iii. How are the manufacturing tolerances of the fuel assemblies incorporated into the uncertainties?

RESPONSE:
Fuel pellet and clad manufacturing tolerances, namely tolerances on the pellet and clad diameters were not considered because their impact is minimal, mostly within the Monte Carlo calculational uncertainty, and bounded by all the other conservatism in the calculations.

iv. Why is 1.263 w/o U235 the enrichment used for the peripheral assemblies for the nominal case?

RESPONSE:
The enrichment value at 0.0 MWD/MTU that satisfies the burnup versus enrichment curve for the "3x3" configuration is calculated based on a target k_{eff} value less than 0.995, including all biases and uncertainties. Bias and uncertainty evaluations utilize an initial estimate of this fresh enrichment. For the "3x3" configuration the initial estimate was 1.263 w/o ^{235}U, as stated. Once all biases and uncertainties and the final target k_{eff} were evaluated using this initial estimate, the actual fresh enrichment was subsequently calculated as 1.194 w/o ^{235}U, which is sufficiently close to the estimated value.

v. **With respect to the U235 enrichment uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the U235 enrichment uncertainty was determined.**

RESPONSE:
The k_{eff} values for the "3x3" configuration were evaluated with the central fresh fuel assembly at 5.0 w/o ^{235}U and 5.05 w/o ^{235}U enrichments, while the peripheral assemblies were kept at 1.194 w/o ^{235}U and the reactivity difference was calculated.

vi. **With respect to the burnup uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the burnup uncertainty was determined.**

RESPONSE:
A 5% burnup measurement uncertainty is applied by evaluating the differential burnup worths at the conservative maximum burnup credited value of 56,000 MWD/MTU with 5.0 w/o ^{235}U initial enrichment for the peripheral assemblies in the "3x3" configuration. Figure 3 shows the k_{eff} values at the highest burnup limit of 56,000 MWD/MTU and 53,200 (=56,000 – 56,000*5%) MWD/MTU and the Δk_{eff} is calculated between these two points. For further explanation please see response to RAI question 19 (a) (vii).

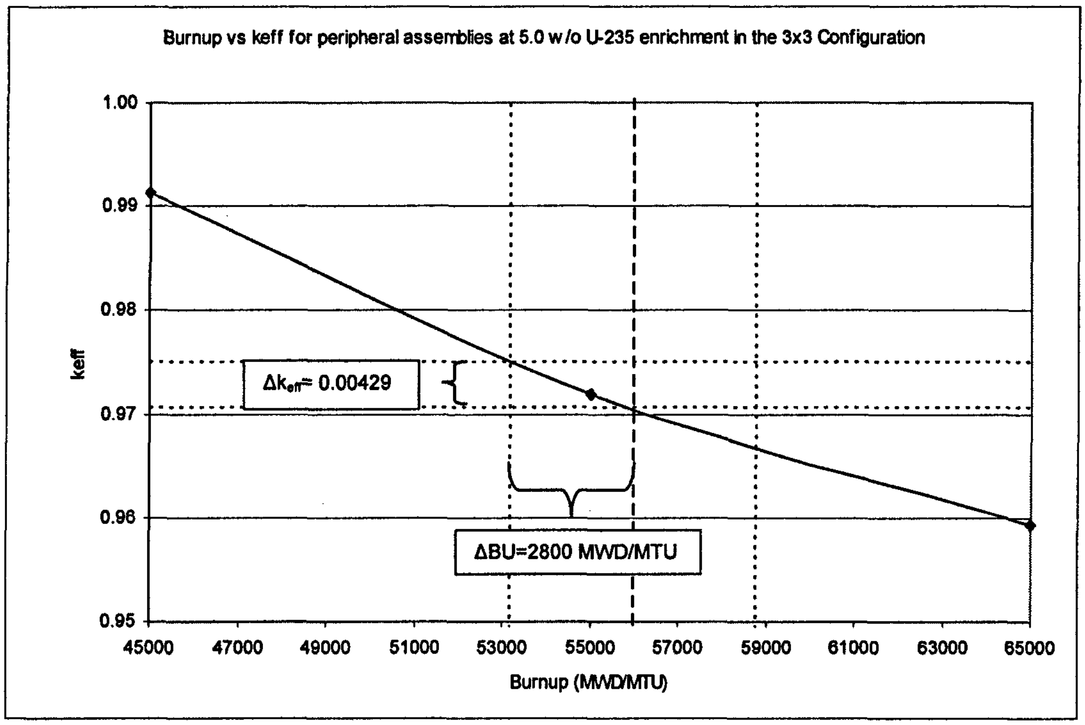

Figure 3 – Burnup vs. k_{eff} for peripheral assemblies in the 3x3 Configuration

vii. With respect to the methodology uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the methodology uncertainty was determined.

RESPONSE:

$k_{95/95}$ is calculated as:

$$k_{95/95} = k_{keno} + \Delta k_{bias} + M_{95/95}\left(\sigma_m^2 + \sigma_{KENO}^2\right)^{1/2}$$

Where,

k_{keno}	is the KENO-calculated multiplication factor
Δk_{bias}	is the mean calculational method bias = (0.00310)
$M_{95/95}$	is the 95/95 multiplier appropriate to the degrees of freedom for the number of validation analyses = (2.22)
σ_m^2	is the mean calculational method variance deduced from the validation analyses = $(0.00285)^2$
σ_{KENO}^2	is the square of the KENO standard deviation = $(0.00056)^2$

The methodology uncertainty in Table 3-4 is therefore calculated using:

$$= 2.22\left[(0.00285)^2 + (0.00056)^2\right]^{1/2} = 0.00645$$

viii. With respect to the pool temperature bias, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the pool temperature bias was determined. Include the justification for the use of 4.0 w/o initial enrichment at 45,000 MWD/MTU of burnup for determining the temperature bias.

RESPONSE:

The pool temperature bias was calculated utilizing a whole pool model filled with "3x3" configuration cells with fresh 5.0 w/o fresh fuel in the center and depleted fuel assemblies with 4.0 w/o initial enrichment at 45,000 MWD/MTU burnup in the periphery. Two sets of calculations were performed: one at 50°F and one at 185°F. A reactivity bias was computed as: $\Delta k = k_{eff}(185°F) - k_{eff}(50°F)$. Performing calculations with a representative burnup rather than fresh fuel provided a more conservative bias value.

b. Section 3.5.6 states, "For the 3x3 storage configuration that credits 241Pu decay, burnup requirements for intermediate decay time points should be determined using at least a second order polynomial." The results of the 241Pu decay effects are presented in Table 3-10. They are used to develop the enrichment/burnup/decay requirements in Table 3-11.

i. Why is this polynomial left to the reader, but all other polynomials are specified?

ii. How would this polynomial be applied? With five decay times specified in Table 3-10, a higher degree polynomial should be warranted.

RESPONSE:

Burnup versus enrichment curves were generated at 5 year decay time intervals. A fourth order polynomial fit based on decay time will calculate the exact data points in Table 3-11. However, for a specific decay time and initial enrichment, the burnup limit could be calculated using a second order polynomial generated using the burnup versus enrichment curves at 3 of the 5 decay points. This will still calculate the exact data points from which the polynomial was constructed.

An example of how this polynomial can be utilized: The burnup limit for an assembly with 3.5 w/o initial enrichment and 12 year storage time can be computed by plugging the enrichment value in the 5, 10, and 15 year curves. Then a second order polynomial fit can be utilized to compute the burnup requirement from these 3 points for 12 year decay.

iii. How would it affect Table 3-11?

RESPONSE:
The data in Table 3-11 would be unaffected by using a higher degree polynomial.

iv. Provide the controls necessary for the use of any polynomial for interpolating between specified decay times.

RESPONSE:
The burnup requirements for intermediate decay time points should be determined using at least a second order polynomial using three decay time data points for a given enrichment. These three points should be chosen such that the intermediate decay time point falls in between two of them. If there are multiple choices to encompass the intermediate decay time point, the ones that would yield the most conservative burnup requirement should be chosen.

c. With respect to Table 3-11, provide the following information:

i. Enrichment is shown to three decimal places. Provide the justification for this precision. Are the enrichments in Table 3-11 nominal values?

RESPONSE:
The enrichments in Table 3-11 are nominal values. The PWR fuel assembly as-built enrichment values are reported in three decimal places. Therefore, the analysis consistently utilized enrichment values with three decimal places.

ii. Accompanying Table 3-11 are five third degree polynomial equation describing the relationship between initial enrichment and burnup. All factors are given to three decimal places. The third factor has eight significant digits. Provide a justification for the precision of the factors in these equations.

RESPONSE:
When the data point enrichments are plugged into this polynomial, the exact burnup values in the table are obtained. The number of decimal points or significant digits accurately represents the burnup vs. enrichment curve.

iii. **Each third degree polynomial is a fit to four points. Three of those points are the result of second degree polynomial fits to three points. Explain how this does not create a new uncertainty that must be accounted for in the analysis.**

RESPONSE:
Each of these polynomials reproduces the exact data points they are generated from; therefore, any new uncertainty that might have been introduced will be very small and negligible.

iv. **Have any confirmatory calculations been performed to verify these enrichment and burnup combinations actually provide a k_{eff} that meets the specific configuration target k_{eff}?**

RESPONSE:
Yes, the fresh 1.194 w/o at 0.0 MWD/MTU case has been confirmed to remain below the target k_{eff} as indicated in Table 3-10. This calculation is sufficient to verify that all enrichment and burnup combinations in the table remain below the k_{eff} target.

d. **In Section 3.5.2, the last sentence of the second paragraph states, "Therefore, the target k_{eff} value for the "3x3" storage configuration is 0.97077 (0.995-0.02423)." However, when the calculational uncertainty is added to the nominal k_{eff} for the initial enrichment of 1.194 w/o U235 with no burnup entry in Table 3-10, the target k_{eff} is exceeded. Please explain why this is acceptable.**

RESPONSE:
The maximum of calculational uncertainty of all bias and uncertainty calculations (0.00056) has already been folded into the target k_{eff} value; therefore, adding the uncertainty for the 1.194 w/o ^{235}U with no burnup entry would be double accounting.

18. **According to the technical justification provided in WCAP-16518-P, the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" Storage Configuration consists of a repeating 2x2 array with one fresh fuel assembly, with an initial enrichment up to 5.0 w/o, and three depleted assemblies. Depleted assemblies must meet the enrichment/burnup limits in Table 3-13. Provide the following information with respect to the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" Storage Configuration.**

a. **With respect to Table 3-6, provide the following information:**

i. **Provide the dimensions and tolerances used in each case that was run to obtain the data, tabular form is acceptable. If this information is identical for each storage configuration, provide only one table.**

RESPONSE:
Table 4 provides the dimensions and tolerances utilized for the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" storage configuration.

Table 4 – Dimensions and Tolerances (1-out-of-4 5.0 w/o at 15,000 MWD/MTU)	
"1-out-of-4 5.0 w/o at 15,000 MWD/MTU" Case	**Description**
^{235}U Enrichment Uncertainty	See response to RAI question 18. a. v.
Increase in UO_2 Density	Not evaluated since calculations were performed at the highest credible value of 97.5% TD
Decrease in Cell Pitch	10.4375 ± 0.0469 inches (From Table 2-2)
Decrease in Rack Thickness	0.090 ± 0.010 inches (From Table 2-2)
Decrease in Rack ID	8.9375 ± 0.0469 inches (From Table 2-2)
Off-Center Assembly Positioning	See response to RAI question 18. a. ii.
Wrapper Thickness	0.0293 ± 0.005 (From Table 2-2)
Burnup Uncertainty	See response to RAI question 18. a. vi.
Methodology Uncertainty	See response to RAI question 18. a. vii.
Pool Temperature Bias	See response to RAI question 18. a. viii.

ii. Explain how the Off-Center Assembly Positioning uncertainty was maximized.

RESPONSE:
As the assemblies were being positioned closer to four adjacent storage cells, the reactivity monotonically increased and became the highest when they were positioned as close as possible. In the absence of absorber material such as Boral, this behavior is expected.

iii. How are the manufacturing tolerances of the fuel assemblies incorporated into the uncertainties?

RESPONSE:
Fuel pellet and clad manufacturing tolerances, namely tolerances on the pellet and clad diameters, were not considered because their impact is minimal, mostly within the Monte Carlo calculational uncertainty, and bounded by all the other conservatism in the calculations.

iv. Why is 1.627 w/o U235 the enrichment used for the 'depleted' assemblies for the nominal case?

RESPONSE:
The enrichment value at 0.0 MWD/MTU that satisfies the burnup versus enrichment curve for the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" configuration is calculated based on a target k_{eff} value less than 0.995, including all biases and uncertainties. Bias and uncertainty evaluations utilize an initial estimate of this fresh enrichment. For the

"1-out-of-4 5.0 w/o at 15,000 MWD/MTU" configuration, the initial estimate was 1.569 w/o ^{235}U, as stated. Once all biases and uncertainties and the final target k_{eff} were evaluated using this initial estimate, the actual fresh enrichment was subsequently calculated as 1.627, which is sufficiently close to the estimated value.

v. **With respect to the U235 enrichment uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the U235 enrichment uncertainty was determined.**

<u>RESPONSE:</u>
The k_{eff} values were evaluated at 3.0, 4.0, and 5.0 w/o ^{235}U fresh enrichments, and the $\Delta k_{eff}/\Delta$(Enrichment) was evaluated at (4.0 + 0.05) w/o ^{235}U using the 2nd order polynomial passing through the 3 data points, while one of the assemblies was kept at 5.0 w/o, 15,000 MWD/MTU. See Figure 4.

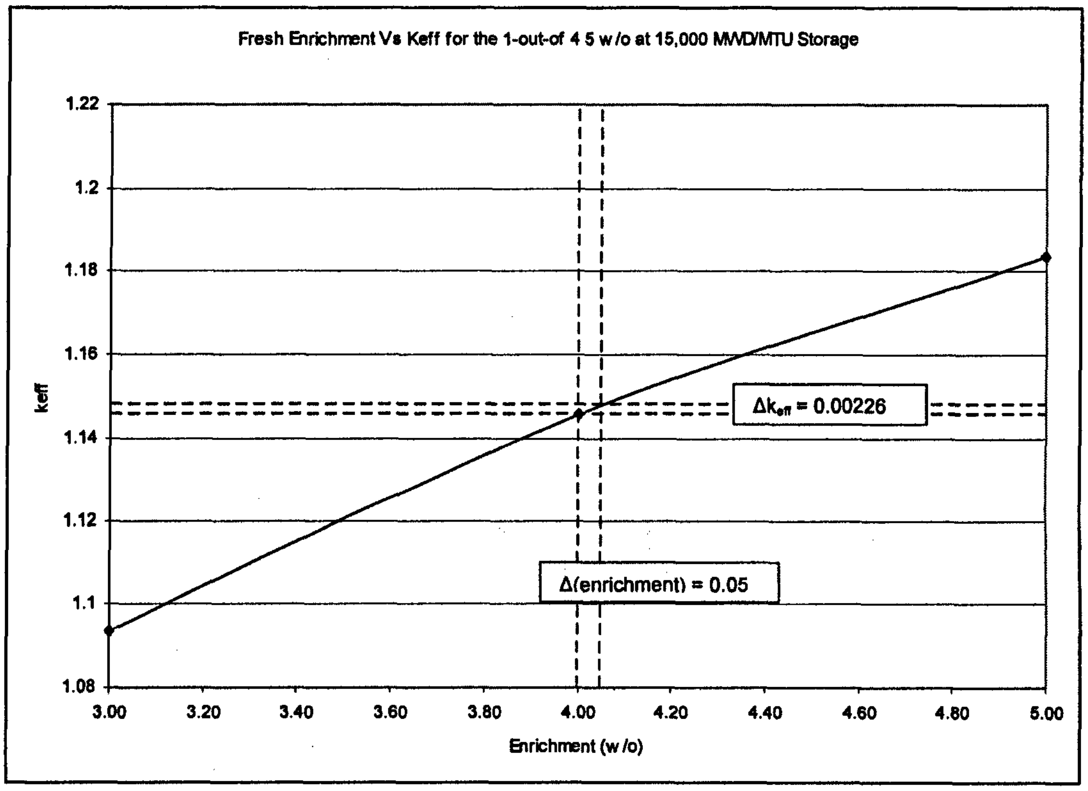

Figure 4 – Enrichment vs. k_{eff} for 1-out-of 4

vi. **With respect to the burnup uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the burnup uncertainty was determined.**

RESPONSE:
A 5% burnup measurement uncertainty is applied by evaluating the differential burnup worths at the conservative maximum burnup credited value of 44,000 MWD/MTU with 5.0 w/o ^{235}U initial enrichment for the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" configuration. Using the burnup vs. k_{eff} curve, k_{eff} values at the highest burnup limit of 44000 MWD/MTU and 41800 (=44000 – 44000*5%) MWD/MTU are determined and the Δk_{eff} is calculated between these two points. For further explanation please see response to RAI question 19 (a) (vii).

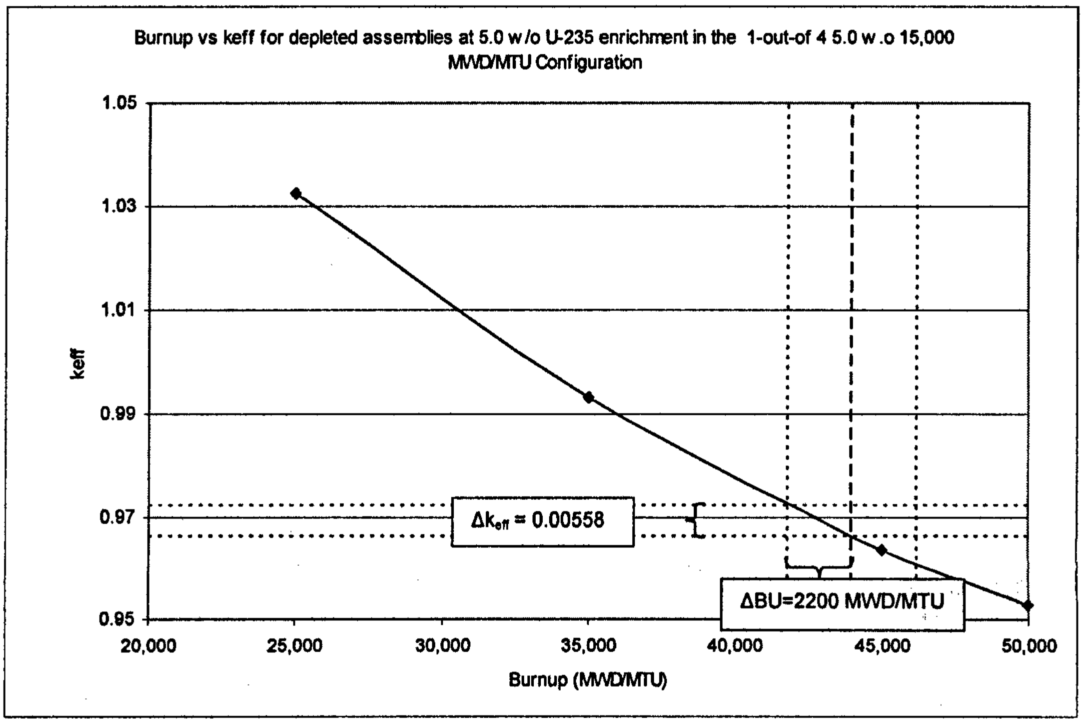

Figure 5 – Burnup vs. k_{eff} at 5.0 w/o ^{235}U 1-out-of-4

vii. **With respect to the methodology uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the methodology uncertainty was determined.**

RESPONSE:

$k_{95/95}$ is calculated as:

$$k_{95/95} = k_{keno} + \Delta k_{bias} + M_{95/95}\left(\sigma_m^2 + \sigma_{KENO}^2\right)^{1/2}$$

Where,

k_{keno}	is the KENO-calculated multiplication factor
Δk_{bias}	is the mean calculational method bias = (0.00310)
$M_{95/95}$	is the 95/95 multiplier appropriate to the degrees of freedom for the number of validation analyses = (2.22)
σ_m^2	is the mean calculational method variance deduced from the validation analyses = $(0.00285)^2$
σ_{KENO}^2	is the square of the KENO standard deviation = $(0.00052)^2$

The methodology uncertainty in Table 3-4 is therefore calculated using:

$$= 2.22\left[(0.00285)^2 + (0.00052)^2\right]^{1/2} = 0.00643$$

viii. **With respect to the pool temperature bias, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the pool temperature bias was determined. Include the justification for the use of 4.0 w/o initial enrichment at 25,000 MWD/MTU of burnup for determining the temperature bias.**

RESPONSE:

The pool temperature bias was calculated utilizing a whole pool model filled with "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" configuration cells with a 5.0 w/o enriched at fuel assembly at 15,000 MWD/MTU burnup and three depleted fuel assemblies with 4.0 w/o initial enrichment at 25,000 MWD/MTU burnup. Two sets of calculations were performed: one at 50°F and one at 185°F. A reactivity bias was computed as: $\Delta k = k_{eff}(185°F) - k_{eff}(50°F)$. Performing calculations with a representative burnup for the depleted assemblies rather than fresh fuel provided a more conservative bias value.

b. **With respect to Table 3-13, provide the following information:**

i. **The initial enrichment values are calculated to the third decimal place. Provide the justification for this precision. Are the enrichments in Table 3-13 nominal values?**

RESPONSE:
The enrichments in Table 3-13 are nominal values. The PWR fuel assembly as-built enrichment values are reported in three decimal places. Therefore, the analysis consistently utilized enrichment values with three decimal places.

ii. **Accompanying Table 3-13 is a third degree polynomial equation, describing the relationship between initial enrichment and burnup. All factors are given to three decimal places. The third factor has eight significant digits. Provide a justification for the precision of the factors in these equations.**

RESPONSE:
When the data point enrichments are plugged into this polynomial, the exact burnup values in the table are obtained. The number of decimal points or significant digits accurately represents the burnup vs. enrichment curve.

iii. **The third degree polynomial is a fit to four points. Three of those points are the result of second degree polynomial fits to three points. Explain how this does not create a new uncertainty that must be accounted for in the analysis.**

RESPONSE:
Each of these polynomials reproduces the exact data points they are generated from; therefore, any new uncertainty that might have been introduced will be very small and negligible.

iv. **Have any confirmatory calculations been performed to verify these enrichment and burnup combinations actually provide a k_{eff} that meets the specific configuration's target k_{eff}?**

RESPONSE:
Yes, the fresh 1.569 w/o at 0.0 MWD/MTU case has been confirmed to remain below the target k_{eff} as indicated in Table 3-12. This calculation is sufficient to verify that all enrichment and burnup combinations in the table remain below the k_{eff} target.

c. **In Section 3.5.3, the last sentence of the second paragraph states, "Therefore, the target k_{eff} value for the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" storage configuration is 0.96742 (0.995-0.02758)." However, when the calculational uncertainty is added to the nominal k_{eff} for the initial enrichment of 1.569 w/o U235 with no burnup entry in Table 3-12, the target k_{eff} is exceeded. Please explain why this is acceptable.**

RESPONSE:
The maximum of calculational uncertainty of all bias and uncertainty calculations (0.00052) has already been folded into the target k_{eff} value; therefore, adding the uncertainty for the 1.569 w/o ^{235}U with no burnup entry would be double accounting.

19. According to the technical justification provided in WCAP-16518-P, the "1-out-of-4 3.85 w/o Fresh with IFBA" Storage Configuration consists of a repeating 2x2 array with one fresh fuel assembly, with an initial enrichment up to 3.85 w/o, and three depleted assemblies. Depleted assemblies must meet the enrichment/burnup limits in Table 3-15. Fresh assemblies must meet the IFBA limits in Table 3-19. Provide the following information with respect to the "1-out-of-4 3.85 w/o Fresh with IFBA" Storage Configuration.

a. With respect to Table 3-7, provide the following information:

i. Provide the dimensions and tolerances used in each case that was run to obtain the data. Tabular form is acceptable. If this information is identical for each storage configuration, provide only one table.

RESPONSE:
Table 5 provides the dimensions and tolerances utilized for the "3x3" storage configuration.

Table 5 – Dimensions and Tolerances (3x3)

"1-out-of-4 3.85 w/o Fresh with IFBA" Case	**Description**
^{235}U Enrichment Uncertainty	See response to RAI question 19. a. vi.
Increase in UO_2 Density	Not evaluated since calculations were performed at the highest credible value of 97.5% TD
Decrease in Cell Pitch	10.4375 ± 0.0469 inches (From Table 2-2)
Decrease in Rack Thickness	0.090 ± 0.010 inches (From Table 2-2)
Decrease in Rack ID	8.9375 ± 0.0469 inches (From Table 2-2)
Off-Center Assembly Positioning	See response to RAI question 17. a. ii.
Wrapper Thickness	0.0293 ± 0.005 (From Table 2-2)
Burnup Uncertainty	See response to RAI question 17. a. vii.
Methodology Uncertainty	See response to RAI question 17. a. viii.
Pool Temperature Bias	See response to RAI question 17. a. ix.

ii. Explain how the Off-Center Assembly Positioning uncertainty was maximized.

RESPONSE:
As the assemblies were being positioned closer to four adjacent storage cells, the reactivity monotonically increased and became the highest when they were positioned as close as possible. In the absence of absorber material such as Boral, this behavior is expected.

iii. How are the manufacturing tolerances of the fuel assemblies incorporated into the uncertainties?

RESPONSE:
Fuel pellet and clad manufacturing tolerances, namely tolerances on the pellet and clad diameters, were not considered because their impact is minimal, mostly within the Monte Carlo calculational uncertainty, and bounded by all the other conservatism in the calculations.

iv. How are the IFBA manufacturing and calculation uncertainties applied?

RESPONSE:
The 15% reduction on the 1.5X IFBA loading (2.355 mg ^{10}B/inch) is used to cover manufacturing tolerances. Calculation uncertainties based on the highest KENO standard deviation (σ_{KENO}) are applied as explained in Response to RAI question 18. a. vii.

v. Why is 1.296 w/o U235 the enrichment used for the 'depleted' assemblies for the nominal case?

RESPONSE:
The enrichment value at 0.0 MWD/MTU that satisfies the burnup versus enrichment curve for the "1-out-of-4 3.85 w/o Fresh with IFBA" configuration is calculated based on a target k_{eff} value less than 0.995, including all biases and uncertainties. Bias and uncertainty calculations evaluations utilize an <u>initial estimate</u> of this fresh enrichment. For the "1-out-of-4 3.85 w/o Fresh with IFBA" configuration" the initial estimate was 1.296 w/o ^{235}U, as stated. Once all biases and uncertainties and the final target k_{eff} were evaluated using this initial estimate, the actual fresh enrichment was subsequently calculated as 1.279, which is sufficiently close to the estimated value.

vi. With respect to the U235 enrichment uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the U235 enrichment uncertainty was determined.

RESPONSE:
The k_{eff} values for the "1-out-of-4 3.85 w/o Fresh with IFBA" configuration were evaluated with the fresh fuel assembly at 3.85 w/o ^{235}U and 3.90 w/o ^{235}U enrichments with 0 IFBA pins. Then the reactivity difference was calculated as $\Delta k_{eff} = [k_{eff}(3.90 \text{ w/o } ^{235}U) - k_{eff}(3.85 \text{ w/o } ^{235}U)]$. Note that the depleted assemblies were kept at nominal fresh enrichment, i.e., 1.296 w/o ^{235}U.

vii. **With respect to the burnup uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the burnup uncertainty was determined.**

RESPONSE:
A 5% burnup measurement uncertainty is applied by evaluating the differential burnup worth at the conservative maximum burnup credit value of 53,000 MWD/MTU with 5.0 w/o ^{235}U initial enrichment for the depleted fuel assemblies in the "1-out-of-4 3.85 w/o Fresh with IFBA" configuration. See Figure 6.

At 5.0 w/o ^{235}U initial enrichment, k_{eff} is calculated at three burnups (as seen in Table 3-14) and a quadratic function is constructed for k_{eff} as a function of burnup:

$$k_{eff} = A * BU^2 + B * BU + C$$

where A, B, and C are given below with arbitrary number of decimal points:
A = 2.955E-11
B =-5.386E-06
C = 1.17370125

Taking the derivative of this quadratic function with respect to burnup:

$$\frac{\partial k_{eff}}{\partial BU} = 2 * A * BU + B$$

Then,

$$\Delta k_{eff} = (2 * A * BU + B) * \Delta BU$$

For the highest burnup limit of 53,000 MWD/MTU, ΔBU = 2,650 MWD/MTU, then the corresponding Δk_{eff} is calculated as 0.00597.

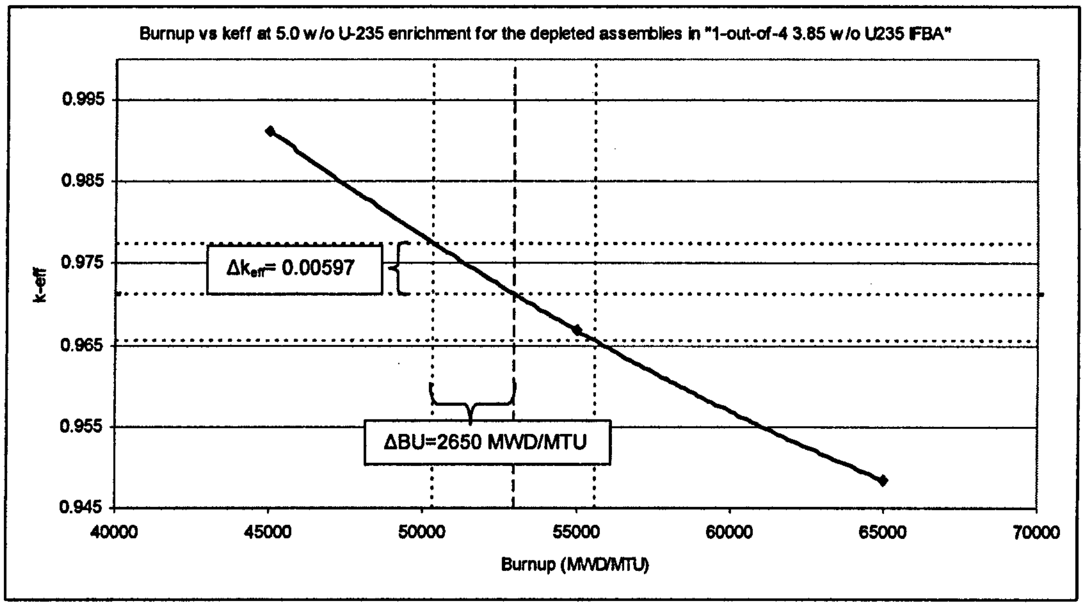

Figure 6 - Burnup vs. k_{eff} for the 1-out-of-4 3.85 w/o Fresh with IFBA Configuration

viii. **With respect to the methodology uncertainty, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the methodology uncertainty was determined.**

<u>RESPONSE:</u>

$k_{95/95}$ is calculated as:

$$k_{95/95} = k_{keno} + \Delta k_{bias} + M_{95/95}\left(\sigma_m^2 + \sigma_{KENO}^2\right)^{1/2}$$

Where,

k_{keno}	is the KENO-calculated multiplication factor
Δk_{bias}	is the mean calculational method bias = (0.00310)
$M_{95/95}$	is the 95/95 multiplier appropriate to the degrees of freedom for the number of validation analyses = (2.22)
σ_m^2	is the mean calculational method variance deduced from the validation analyses = $(0.00285)^2$
σ_{KENO}^2	is the square of the KENO standard deviation = $(0.00052)^2$

The methodology uncertainty in Table 3-4 is therefore calculated using:

$$= 2.22\left[(0.00285)^2 + (0.00052)^2\right]^{1/2} = 0.00643$$

ix. **With respect to the pool temperature bias, the footnote does not provide sufficient information to make an assessment of adequacy of the value in the table. Provide a detailed explanation of how the pool temperature bias was determined. Include the justification for the use of 4.0 w/o initial enrichment at 25,000 MWD/MTU of burnup for determining the temperature bias.**

RESPONSE:
The pool temperature bias was calculated utilizing a whole pool model filled with "1-out-of-4 3.85 w/o Fresh with IFBA" configuration cells with 3.85 w/o fresh fuel with no IFBA pins and depleted fuel assemblies with 4.0 w/o initial enrichment at 25,000 MWD/MTU burnup. Two sets of calculations were performed: one at 50°F and one at 185°F. A reactivity bias was computed as: $\Delta k = k_{eff}(185°F) - k_{eff}(50°F)$. Performing calculations with a representative burnup for the depleted assemblies rather than fresh fuel provided a more conservative bias value.

b. **With respect to Table 3-15, provide the following information:**

i. **Enrichment is shown to three decimal places. Provide the justification for this precision. Are the enrichments in Table 3-15 nominal values?**

RESPONSE:
The enrichments in Table 3-15 are nominal values. The PWR fuel assembly as-built enrichment values are reported in three decimal places. Therefore, the analysis consistently utilized enrichment values with three decimal places.

ii. **Accompanying Table 3-15 is a third degree polynomial equation, describing the relationship between initial enrichment and burnup. All factors are given to three decimal places. The third factor has eight significant digits. Provide a justification for the precision of the factors in these equations.**

RESPONSE:
When the data point enrichments are plugged into this polynomial, the exact burnup values in the table are obtained. The number of decimal points or significant digits accurately represents the burnup vs. enrichment curve.

iii. **The third degree polynomial is a fit to four points. Three of those points are the result of second degree polynomial fits to three points. Explain how this does not create a new uncertainty that must be accounted for in the analysis.**

RESPONSE:
Each of these polynomials reproduces the exact data points they are generated from; therefore, any new uncertainty that might have been introduced will be very small and negligible.

iv. **Have any confirmatory calculations been performed to verify these enrichment and burnup combinations actually provide a k_{eff} that meets the specific configuration's target k_{eff}?**

RESPONSE:
Yes, the fresh 1.279 w/o at 0.0 MWD/MTU case has been confirmed to remain below the target k_{eff} as indicated in Table 3-14. This calculation is sufficient to verify that all enrichment and burnup combinations in the table remain below the k_{eff} target.

c. **With respect to Table 3-19, provide the following information:**

i. **Enrichment is shown to three decimal places. Provide the justification for this precision. Are the enrichments in Table 3-19 nominal values?**

RESPONSE:
The enrichments in Table 3-19 are nominal values. The PWR fuel assembly as-built enrichment values are reported in three decimal places. Therefore, the analysis consistently utilized enrichment values with three decimal places.

ii. **Accompanying Table 3-19 is a third degree polynomial equation, describing the relationship between initial enrichment and IFBA pins. All factors are given to three decimal places. The third factor has six significant digits. Provide a justification for the precision of the factors in these equations.**

RESPONSE:
When an enrichment value in the table is plugged into this polynomial, the exact number of IFBA pins in the table is obtained. The number of decimal points or significant digits accurately represents the IFBA vs. enrichment curve.

iii. The third degree polynomial is a fit to four points. Three of those points are the results of second degree polynomial fits to four points. Explain how this does not create a new uncertainty that must be accounted for in the analysis.

RESPONSE:
Each of these polynomials reproduces the exact data points they are generated from; therefore, any new uncertainty that might have been introduced will be very small and negligible.

iv. The analysis was performed using the IFBA loading patterns in Figure 3-5. What is the sensitivity of the analysis to those loading patterns? Provide the justification for that conclusion.

RESPONSE:
Additional calculations were performed for a 5.0 w/o fresh fuel assembly with 64 IFBA pins in an alternative pattern in order to assess the sensitivity of IFBA loading patterns. This alternative pattern resulted in 91 pcm higher reactivity relative to the base IFBA pattern of Figure 3-5. The calculations were repeated with a nominal IFBA loading (without the 15% reduction), and it was determined that the 15% reduction provides 143 pcm and 288 pcm for the Base and alternative IFBA patterns, respectively. Therefore, it is concluded that the 15% reduction assumed in the ^{10}B loading in the IFBA pins provides sufficient margin to cover any uncertainties related to deviations from base IFBA loading patterns. See Table 6.

Table 6 – Calculations for IFBA Sensitivity	
Case	$k_{eff} \pm \sigma$
Base IFBA pattern	0.98859 ± 0.00019
Alternative IFBA pattern	0.98950 ± 0.00019
Base IFBA pattern without IFBA reduction	0.98716 ± 0.00019
Alternative IFBA pattern without IFBA reduction	0.98662 ± 0.00019

v. Identify any restrictions on the IFBA loading patterns using the results of Table 3-19. Provide the justification for those restrictions.

RESPONSE:
No restrictions are identified on the IFBA loading patterns.

vi. Explain how the 3.85 w/o enrichment case was determined to not require any IFBAs.

RESPONSE:
In the "1-out-of-4 3.85 w/o Fresh with IFBA" configuration, the fresh fuel enrichment was determined by first setting a tentative value for the fresh enrichment, then determining the burnup requirement for the remaining depleted assemblies. This tentative value was adjusted until the final burnup requirement reached acceptable levels.

vii. Table 3-19 includes odd numbers and the third degree polynomial presents the possibility of fractional IFBAs. How are these scenarios addressed?

RESPONSE:
Any fractional IFBA number shall be rounded up to an integer number.

viii. How are fresh assemblies addressed that has IFBAs, but do not meet the requirements of Table 3-19?

RESPONSE:
Any fresh assembly with IFBA pins that do not meet the requirements of Table 3-19 can not be stored in this configuration and would need to be stored in the "3x3" configuration.

d. In Section 3.5.4.1, the last sentence of the first paragraph states, "Therefore, the target k_{eff} value for the "1-out-of-4 3.85 w/o Fresh with IFBA" storage configuration is 0.97283 (0.995-0.02217)." However, when the calculational uncertainty is added to the nominal k_{eff} for the initial enrichment of 1.279 w/o with no burnup entry in Table 3-14, the target k_{eff} is exceeded. Please explain why this is acceptable.

RESPONSE:
The maximum of calculational uncertainty of all bias and uncertainty calculations (0.00052) has already been folded into the target k_{eff} value; therefore, adding the uncertainty for the 1.279 w/o ^{235}U with no burnup entry would be double accounting.

e. Section 3.5.4.3 states, "Analysis have shown that reactivity at any point in the burnup history of a 17x17 Standard fuel assembly with 5.0 w/o enrichment and [proprietary] IFBA pins is less than the BOC reactivity. Therefore, in the case of an early discharge part way through a cycle, the discharged fuel assembly with IFBA can be stored in the "1-out-of-4 3.85 w/o Fresh with IFBA" storage configuration provided that it meets the storage requirements of that configuration."

i. **It is unclear what this paragraph means. Does it mean that slightly burned fuel assembly, that met the requirements of Table 3-19 as a fresh assembly, may be stored as if it were unburned? Or does it have to meet the depleted requirements of Table 3-15? Please provide clarification.**

RESPONSE:
Slightly burned fuel, such as an early discharged fuel assembly with IFBA, that meet the requirements of Table 3-19 as a fresh assembly may be stored as if it were unburned.

ii. **As cores, which use IFBAs, can exhibit a flat or even increasing critical boron concentration for the early portion of the cycle, the first sentence cannot be considered applicable to all combinations of enrichment and IFBA loading. Provide clarification and the supporting analysis to address other scenarios.**

RESPONSE:
Any early discharged assembly with a number of IFBA pins > 64 is bounded by 64 pin fresh IFBA case. The maximum number of IFBA pins credited in the analysis is 63 as shown in Table 3-19. For assemblies with this amount of IFBA, the reactivity of the assembly as it burns is always less than its initial reactivity. For assemblies with higher numbers of IFBA, it is possible for the reactivity of the assembly to increase as it burns. However, the additional IFBA (relative to the maximum credited 63) reduces the reactivity of the assembly to a level that cannot increase beyond the reactivity of a similar fresh assembly with 63 IFBA pins. This is illustrated in Figure 7 for a 5.0 w/o fresh fuel assembly with 0 to 128 IFBA pins. Note that the depletion calculations were performed with 800 ppm soluble boron and similar behavior was observed for 0 ppm soluble boron.

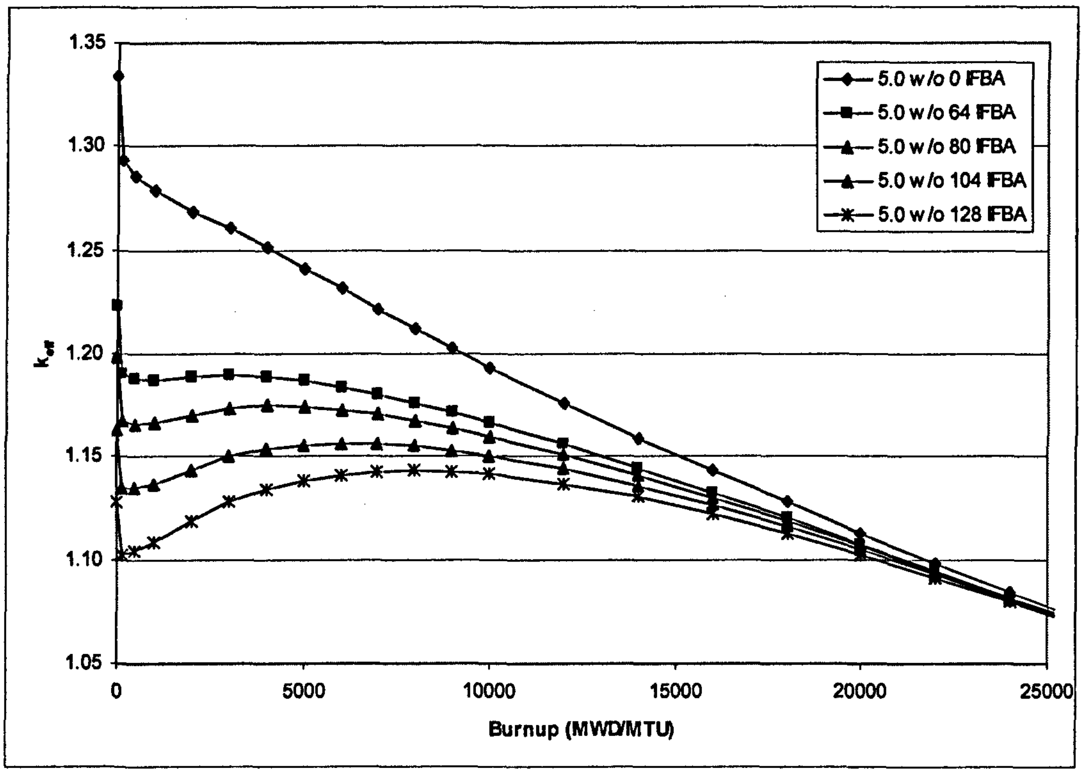

Figure 7 – Burnup vs. k_{eff} at 5.0 w/o for 1-out-of-4 with different number of IFBA pins

20. According to the technical justification provided in WCAP-16518-P, the interface requirements were determined by taking a single array of a specific storage configuration and surrounding it with repeating arrays of a different storage configuration until the SFP was filled. The arrangement was considered acceptable, if the k_{eff} of the composite SFP was less than the k_{eff} of the most reactive storage configuration. The SFP pool dimensions are provided in Table 2-1. The composite SFP analysis was performed at a moderator temperature of 20°C and a density of 1.0 gm/cc. Per Table 3-21, the interface between storage configurations is limited to depleted fuel assemblies. With respect to the storage configuration interface requirements, please provide the following information:

a. Section 2.2 and Table 2-1 of the technical justification provided in WCAP-16518 provide various dimensions for the SFP.

i. How are these dimensions used?

RESPONSE:
These dimensions were used to construct a 3D Monte Carlo model of the spent fuel pool.

ii. What is the tolerance/uncertainty associated with them?

RESPONSE:
Tolerance and uncertainty have not been considered in the spent fuel pool dimensions.

iii. How is that factored into the SFP criticality analysis?

RESPONSE:
Tolerance and uncertainty on the pool dimensions have not been considered for 3D Monte Carlo models of the spent fuel pool. Any small tolerance and uncertainty on the pool dimensions will have negligible impact on the 3D calculations and will not change the conclusions of the analysis. Note that 3D pool simulations are performed only for interface conditions, soluble boron requirements, and accident simulations. All burnup requirement calculations have been performed with 2D, infinite array models to maximize reactivity and include all bias and uncertainties associated with the storage configurations.

iv. Is Figure 2-1 supposed to be Reference 17?

RESPONSE:
Yes.

b. Were sensitivity studies performed to determine the most reactive moderator temperature and density? In over moderated conditions, as is likely in the SFP, the maximum moderator density is not the most reactive condition.

RESPONSE:
The impact of moderator temperature and density on the reactivity was accounted for in the 2D infinite array calculations. For each storage configuration, a reactivity bias, relative to the reference analysis conditions, associated with operation of the spent fuel pool over a temperature range of 50°F to 185°F was evaluated (including the density change) and added to the final k_{eff} of that storage configuration.

c. Table 3-20 provides the results for a "3x3" Storage Configuration surrounded by the "All-Cell" Storage Configuration, but does not include the results for the "All-Cell" Storage Configuration surrounded by the "3x3" Storage Configuration. In keeping with that example, Table 3-20 only provides results for half of the possible combinations. Provide the justification for not performing analysis for the rest of the possible combinations.

RESPONSE:
Calculations for the interface configurations were performed to verify that assemblies placed at the interface result in multiplication factors that are less than the maximum of the infinite array multiplication factors of the involved storage configurations. In this respect, it is sufficient to perform one set of calculation for each interface, because the other half results in the same interface configuration bounded by the loading requirements of Table 3-21.

d. "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" and "1-out-of-4 3.85 w/o Fresh with IFBA" storage configurations are 2x2 arrays with one non-depleted fuel assembly.

i. With respect to the analysis, explain how the limitation of only depleted assemblies being in contact with another storage configuration will be met for the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" and "1-out-of-4 3.85 w/o Fresh with IFBA" storage configurations.

RESPONSE:
In order to comply with the TS requirement, procedures specify that the boundary conditions will be met by adding a row of depleted assemblies as necessary to ensure that the more highly reactive assemblies in the configuration are not at the boundary.

Boundary Example 1 is shown in Figure 8 for a "1-out-of-4 3.85 w/o Fresh with IFBA" configuration surrounded by a "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" configuration. The assemblies from the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" designated as "15K_1B" for the 15,000 MWD/MTU assembly and "15K_D" for the depleted assembly. The assemblies in the "1-out-of-4 3.85 w/o Fresh with IFBA" configuration are designated as "IFBA_F" for the fresh assembly and "IFBA_D" for the depleted assemblies.

15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D
15K_D	15K_1B	15K_D	15K_1B	15K_D	15K_1B	15K_D	15K_1B	15K_D	15K_1B	15K_D
15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D
15K_D	15K_1B	15K_D	IFBA_D	IFBA_D	IFBA_D	IFBA_D	IFBA_D	15K_D	15K_1B	15K_D
15K_D	15K_D	15K_D	IFBA_D	IFBA_F	IFBA_D	IFBA_F	IFBA_D	15K_D	15K_D	15K_D
15K_D	15K_1B	15K_D	IFBA_D	IFBA_D	IFBA_D	IFBA_D	IFBA_D	15K_D	15K_1B	15K_D
15K_D	15K_D	15K_D	IFBA_D	IFBA_F	IFBA_D	IFBA_F	IFBA_D	15K_D	15K_D	15K_D
15K_D	15K_1B	15K_D	IFBA_D	IFBA_D	IFBA_D	IFBA_D	IFBA_D	15K_D	15K_1B	15K_D
15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D
15K_D	15K_1B	15K_D	15K_1B	15K_D	15K_1B	15K_D	15K_1B	15K_D	15K_1B	15K_D

Figure 8 – Boundary Example 1

In Boundary Example 1, the heaviest line depicts the configuration boundary. The next heaviest line shows the 2x2 arrays within each configuration. The lightest line shows individual cells. The more highly reactive assemblies in each configuration are shown with a gray background. In no case are the more highly reactive assemblies located at the configuration boundary.

The acceptability of adding a row of depleted assemblies to form a boundary for the two 1-out-of-4 configurations can be shown by examining the configurations and their boundaries. From Boundary Example 1, it can be seen that the bottom and left boundaries have 2x2 arrays of each configuration on either side of the boundary and are therefore acceptable. The top and right boundaries have the added rows/columns of depleted assemblies. However, further inspection shows that the boundaries are actually symmetric with the top and right boundaries being the same as the bottom and left boundaries. The top five rows from Boundary Example 1 can be redrawn as Boundary Example 2, shown in Figure 9, with new 2x2 array positions to demonstrate this.

15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D
15K_D	15K_1B	15K_D	15K_1B	15K_D	15K_1B	15K_D	15K_1B	15K_D	15K_1B	15K_D
15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D	15K_D
15K_D	15K_1B	15K_D	IFBA_D	IFBA_D	IFBA_D	IFBA_D	IFBA_D	15K_D	15K_1B	15K_D
15K_D	15K_D	15K_D	IFBA_D	IFBA_F	IFBA_D	IFBA_F	IFBA_D	15K_D	15K_D	15K_D

Figure 9 – Boundary Example 2

ii. **The proposed controls do not preclude the potential for multiple locations of a storage configuration and the inherent repetitive interfacing between storage locations. With respect to the actual use in the SFP, explain how the limitation of only depleted assemblies being in contact with another storage configuration will be met for the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" and "1-out-of-4 3.85 w/o Fresh with IFBA" storage configurations.**

RESPONSE:
As with the previous response, the requirement is met by adding a row of depleted assemblies, as necessary, to form the boundary between the configurations. If multiple locations of a given configuration are used, each location will need to meet the boundary requirements and may need additional depleted assemblies to do so.

iii. **What controls prevent the non-depleted fuel assemblies in these configurations from being side by side?**

RESPONSE:
The two 1-out-of-4 configurations are defined as repeating arrays. This restriction will be identified both in words and visually in the refueling procedures. At the interface between these configurations, the non-depleted assemblies are kept apart by the requirement that only depleted assemblies are to be located at the boundary.

The configuration definitions and boundary requirements will also be placed in the refueling procedures. The ShuffleWorks administrator will use these definitions and requirements to set up the pool configurations in ShuffleWorks.

21. Tables 3-4, 3-5, 3-6, and 3-7 present uncertainties that have been determined for each specific configuration. While the physical dimensions and tolerance do not change for each storage configuration, the uncertainties do. This indicates a dependency on initial conditions and/or assumptions in the analysis. Have any confirmatory calculations been performed to determine the sensitivity of the uncertainties to the various conditions that the specific configuration will see?

RESPONSE:
All bias and uncertainty results were conservatively applied to burnup and IFBA requirements that were determined via 2D, infinite array models to maximize reactivity. Therefore, evaluation of sensitivities of the uncertainties was not necessary.

22. Tables 3-16, 3-17, and 3-18 are presented as fresh fuel enrichment versus depleted fuel burnup versus IFBA tables. However, no information for the 'depleted' fuel is given except burnup. What are the other parameters for this 'depleted' fuel in each table? What is the sensitivity of the analysis to these parameters?

RESPONSE:
The depleted fuel assemblies in these tables have all 5.0 w/o ^{235}U initial enrichment. The purpose of these calculations was to determine the IFBA requirement of the fresh fuel assembly, while the remaining depleted fuel assemblies were at 5.0 w/o initial enrichment and satisfy the burnup requirement of 52205 MWD/MTU in that storage configuration. Utilizing this highest burnup value in these calculations minimized the IFBA worth, thereby conservatively maximizing the minimum IFBA requirements in the fresh assembly.

23. Section 3.5.7 states, "For all configurations at Beaver Valley Unit 2, an empty cell is permitted in any location of the SFP to replace an assembly since the water cell will not cause any increase in reactivity in the SFP. Non-fissile material and debris canisters may be stored in empty cells of All-Cell storage configuration provided that the canister does not contain fissile materials." Is this section based on analysis, evaluation, or engineering judgment?

RESPONSE:
It is based on engineering judgment and past experience.

24. Section 3.5.8 states, "Non fissile equipment, such as UT cleaning equipment is permitted on top of the fuel storage racks, as these equipments will not cause any increase in reactivity in the SFP." Have these non fissile equipments been evaluated for other potential adverse impact on the SFP, such as blocking cooling flow through the storage cells?

RESPONSE:
No, the intent of the subject statement is only to identify that the criticality analysis supports the placement of such equipment in that it will not cause an increase in reactivity in the SFP. However, engineering practice at BVPS prohibits the placement of equipment on the racks unless it is supported by an evaluation that would include discussion of other potential adverse impact on the SFP and its fuel. The need to procedurally control the requirement to conduct such an evaluation has been entered into the BVPS Corrective Action Program.

25. **Section 3.5.9 states, "Table 3-22 lists the k_{eff} values for the storage configurations with one of the depleted fuel assemblies replaced with an FRSC [Fuel Rod Storage Canister] containing fresh 5.0 w/o 235U fuel rods. The calculations were performed at 68°F, with maximum water density of 1.0 g/cm3 to maximize the array reactivity. As seen from Table 3-22, the resulting k_{eff} values were less than the nominal k_{eff} values of the storage configurations. Therefore, FRSCs filled with fresh fuel rods with a maximum enrichment of 5.0 w/o 235U and no burnable absorbers can be stored in any storage configuration."**

    a. **Should the need arise, where would fresh fuel pins that contain a burnable absorber be stored?**

RESPONSE:
Since no credit is taken for burnable absorbers in the FRSC calculations, fresh fuel pins with burnable absorbers may be stored in any storage configuration.

    b. **According to Section 3.1.4, the FRSC is modeled as a stainless steel box. Please explain what this means.**

RESPONSE:
The FRSC is modeled as a canister with four stainless steel walls, each 0.593 inch thick, 8.125 inch wide and 144-inch tall, surrounding a fixed array of 52 stainless-steel tubes filled with fresh 5.0 w/o fuel pins.

c. **Section 2.4, of the technical justification provided in WCAP-16518-P, provides various dimensions for the Fuel Rod Storage Canister. How are these dimensions used? What is the tolerance/uncertainty associated with them? How is that factored into the SFP criticality analysis?**

RESPONSE:
These dimensions were used to construct 3D dimensional Monte Carlo model of the FRSC. The nominal dimensions were used and tolerance/uncertainty calculations were not performed for the FRSC model. Since FRSC by itself is significantly less reactive than any other storage configuration, small tolerances and uncertainties in these dimensions will not impact the storability of FRSC in those configurations.

d. **How were the bias and uncertainties from Tables 3-4, 3-5, 3-6, and Tables 3-7 used in the analysis to determine the values in Table 3-22?**

RESPONSE:
The bias and uncertainties from Tables 3-4, 3-5, 3-6, and 3-7 were used to determine the values in Table 3-22. The fresh fuel enrichments of fuel assemblies in a storage configuration are based on target $k_{95/95}$ values which include all biases and uncertainties associated with the storage configurations. Storage of FRSC was deemed acceptable as long as the k_{eff} of the storage configuration with FRSC was less than the k_{eff} of the configuration without the FRSC, hence the target $k_{95/95}$.

e. **Were sensitivity studies performed to determine if one cell in the storage configuration was more limiting than another for the placement of a FRSC?**

RESPONSE:
Since these calculations were performed in an infinite array configuration, there would not be a need to perform such sensitivity.

f. **Were any analysis performed to determine the effects of placing an FRSC on an interface boundary between storage configurations?**

RESPONSE:
No additional analysis was performed for FRSC on an interface boundary. However, examining Table 3-20 and Table 3-22 indicates that FRSC placed at the interface boundary will result in lower reactivity relative to no FRSC cases.

26. According to Section 3.6 of WCAP-16518-P, the SFP soluble boron requirements are based on a third degree polynomial equation. The third degree polynomial equation is based on four cases of varying soluble boron content for a "3x3" Storage Configuration utilizing 5.0 w/o enriched fuel with 55,000 MWD/MTU of burnup as the depleted fuel assemblies. With respect to Table 3-23 and the third degree polynomial equation, please provide the following information:

a. Explain why the Table 3-23 k_{eff} for the 0 ppm case is different from the 0 Decay and 0 ppm case in Table 3-10 for the "3x3" Storage Configuration utilizing 5.0 w/o enriched fuel with 55,000 MWD/MTU of burnup as the depleted fuel assemblies.

RESPONSE:
All soluble boron calculations were performed using the full 3D spent fuel pool model, whereas calculations in Table 3-10 were performed using infinite array models. Therefore, results from pool calculations are expected to be slightly lower than infinite array results due to some leakage.

b. In the third degree polynomial equation, describing the relationship between k_{eff} and soluble boron, all factors are given to three decimal places. The third factor has eight significant digits. Provide a justification for the precision of the factors in that equation.

RESPONSE:
When a reactivity increment from the table in terms of Δk_{eff} is plugged into this polynomial, the exact ppm soluble boron worth in the table is obtained. The number of decimal points or significant digits accurately represents the soluble boron ppm vs. enrichment curve.

c. The third degree polynomial is a fit to four points. Explain how this does not create a new uncertainty that must be accounted for in the analysis.

RESPONSE:
The polynomial reproduces the exact data points it is generated from; therefore, any new uncertainty that might have been introduced will be very small and negligible.

d. Section 3.6.1 states, "Table 3-23 contains the KENO-calculated k_{eff} values for the SFP from 0 to 600 ppm of soluble boron, in increments of 200 ppm. These KENO models assume that the pool is filled with the "3x3" storage configuration containing depleted fuel at 55,000 MWD/MTU with 5.0 w/o 235U initial enrichment. The initial enrichment and burnup chosen to represent the storage configuration was based on minimizing the soluble boron worth. The soluble boron

worth decreases as burnup increases." Provide the results of the analysis that show "3x3" Storage Configuration containing depleted fuel at 55,000 MWD/MTU with 5.0 w/o 235U initial enrichment. Provide the limiting soluble boron requirements for the "3x3" Storage Configuration.

RESPONSE:
A series of 3D KENO runs were performed using the whole spent fuel pool model filled with "3x3" storage configuration with fresh 5.0 w/o ^{235}U enriched fuel in the middle surrounded by depleted fuel assemblies at 55,000 MWD/MTU 5.0 w/o ^{235}U initial enrichment. The soluble boron concentration was increased from 0 ppm to 600 ppm in 200 ppm increments and a Δk_{eff} was computed relative to 0.0 ppm k_{eff} at each step. Table 7 shows these results:

Table 7- KENO Runs		
ppm	k_{eff}	Δk
0.0	0.97102±0.00032	0.000000
200.0	0.93533±0.00031	0.035690
400.0	0.90529±0.00032	0.065730
600.0	0.87873±0.00030	0.092290

Utilizing the soluble boron ppm and the Δk_{eff} values, a third order polynomial was constructed. With this polynomial the limiting soluble boron requirement necessary to reduce k_{eff} by 0.05 (i.e., Δk_{eff}=0.05) was calculated as 291.7 ppm.

e. **Table 3-23 and its associated equation is used to determine the soluble boron concentrations for all proposed storage configurations. Provide the analysis that shows how Table 3-23 and its associated equation is bounding for the other storage configurations.**

RESPONSE:
The highest burnup requirement calculated for all storage configurations was 55,000 MWD/MTU at 5.0 w/o ^{235}U initial enrichment (for the 3x3 storage configuration). This burnup value was utilized to minimize the burnup worth in the whole pool soluble boron calculations. Since the storage configurations other than "3x3" have smaller burnup requirements, Table 3-23 and its associated equation are bounding for the other storage configurations. Table 8 shows results of the analysis which demonstrates that 291.7 ppm soluble boron, which is based on the Table 3-23 equation is bounding to reduce the reactivity by 0.05 Δk_{eff} for the other storage configurations:

Table 8 – Burnup vs. Soluble Boron			
Configuration	**0 ppm**	**291.7 ppm**	**Δk_{eff}**
All-Cell	0.95315 ± 0.00022	0.89776 ± 0.00022	0.05539
3x3	0.97102 ± 0.00032	0.92119 ± 0.00029	0.04983*
1-out-of-4 5 w/o at 15,000 MWD/MTU	0.95835 ± 0.00023	0.90377 ± 0.00022	0.05458
1-out-of-4 3.85 w/o Fresh with IFBA	0.96084 ± 0.00028	0.90497 ± 0.00022	0.05587

*Deviation from 0.05 Δk_{eff} is statistically insignificant.

Note that the "All-Cell" configuration above included: Depleted fuel assemblies with 5.0 w/o ^{235}U initial enrichment at 35,000 MWD/MTU; the "3x3" configuration: 5.0 w/o ^{235}U initial enrichment at 55,000 MWD/MTU; the "1-out of-4 5 w/o at 15,000 MWD/MTU" configuration: 5.0 w/o ^{235}U initial enrichment at 45,000 MWD/MTU; the "1-out-of-4 3.85 w/o Fresh with IFBA" configuration: 5.0 w/o ^{235}U initial enrichment at 55,000 MWD/MTU to minimize soluble boron worth.

27. According to Section 3.6.2, reactivity uncertainties for fuel assembly reactivity and burnup are determined. With respect to these uncertainties, provide the following information.

a. The fuel assembly reactivity uncertainty, "...is calculated by employing a depletion reactivity uncertainty of 0.010 delta k_{eff} units per 30,000 MWD/MTU of burnup (obtained from Reference 2) and multiplying by the maximum amount of burnup credited in a storage configuration." Reference 2 to WCAP-16518-P is the Safety Evaluation Report for WCAP-14416-P-A, Westinghouse Spent Fuel Rack Criticality Analysis Methodology, (Reference 8). However, the NRC subsequently withdrew its approval of WCAP-14416 in Reference 9. Therefore, provide the justification for the continued use of this means of determining the fuel assembly reactivity.

RESPONSE:
The approval of WCAP-14416 was withdrawn by the NRC due to non-conservatism in the 2D/3D methodology. The analysis in WCAP-16518-P utilizes a 3D methodology based on a very conservative axial burnup profile, thereby removing the non-conservative aspect of the earlier methodology. However, it continues to use other conservative elements of the methodology, such as the assembly reactivity and burnup uncertainties. Precedent approved analyses (e.g., Vogtle, Diablo Canyon) all have utilized this method.

b. Section 3.6.2 states, "The uncertainty in absolute fuel burnup values is conservatively calculated as 5% of the maximum fuel burnup credited in a storage configuration analysis. The maximum fuel burnup credited in the various storage configurations, the 5% uncertainty in these burnup values, and the corresponding reactivity values are given in Table 3-24."

i. Provide the justification for the use of 5% of maximum fuel burnup as conservative.

RESPONSE:
This LAR demonstrates that two acceptance criteria are met: 1) k_{eff} is less than or equal to 0.95 with soluble boron credit; and 2) k_{eff} is less than or equal to 0.995 when the spent fuel pool is unborated. The NRC guidance document, "Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," has always been interpreted by Westinghouse to require a 5% burnup uncertainty and a reactivity depletion uncertainty equal to 1.0 % Δk_{eff} per 30,000 MWD/MTU to be applicable to acceptance criteria (1), that is, that k_{eff} be less than or equal to 0.95 with soluble boron credit. Additionally, a 5% burnup uncertainty is conservatively applied to the unborated k_{eff} limit, as demonstrated in responses to RAI questions 16 (a) (vi), 17 (a) (vi), 18 (a) (vi), 19 (a) (vii).

The NRC has previously approved this approach for the following plant submittals: R. E. Ginna Nuclear Power Plant – Amendment RE: Revision to the Storage Configuration Requirements Within the Existing Storage Racks and Taking Credit for a Limited Amount of Soluble Boron (TAC No. MA8443) dated December 7, 2000; Millstone Power Station, Unit No. 2 – Issuance of Amendment RE: Spent Fuel Pool Requirements (TAC No. MB 3386) dated April 1, 2003; Diablo Canyon Nuclear Power Plant, Unit Nos. 1 and 2 – Issuance of Amendment RE: Credit for Soluble Boron in the Spent Fuel Pool Criticality Analysis (TAC Nos. MB2982 and MB2984) dated September 2002; and Joseph M. Farley Nuclear Plant, Units 1 and 2 RE: Issuance of Amendments (TAC Nos. MC6987 and MC6988) dated June 28, 2005.

ii. Explain how the 5% of the maximum fuel burnup credited in a storage configuration analysis is converted into the delta k_{eff} numbers in Table 3-24.

RESPONSE:
The Westinghouse method determines the reactivity trend with burnup (accounting for whether it is linear, quadratic, etc.), and factors the slope of this trend at the burnup limit with 5% of the maximum credited burnup, as shown in responses to RAI questions 16 (a) (vi), 17 (a) (vi), 18 (a) (vi), 19 (a) (vii). This reserves the reactivity equivalent of a 5% change in burnup for the burnup uncertainty.

The Δk_{eff} values in Table 3-24 were computed using the k_{eff} vs. burnup curves for each storage configuration, factoring in the maximum credited burnup (results from 5.0 w/o ^{235}U initial enrichment). The largest of these of Δk_{eff} values was then used to compute the corresponding soluble boron requirement.

c. **Explain why the uncertainties from Tables 3-4, 3-5, 3-6, and 3-7 are not included.**

RESPONSE:
The Δkeff values attributed to burnup uncertainty entries in Tables 3-4, 3-5, 3-6, and 3-7 are actually included in Table 3-24. Any minor difference is within the statistical uncertainty and inconsequential.

d. **Explain why the fuel assembly reactivity uncertainty and burnup uncertainties are not included in determination of the zero boron condition.**

RESPONSE:
As given above in response to RAI question 27 (b) (i), the NRC guidance document, "Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," has always been interpreted by Westinghouse to require a 5% burnup uncertainty and a reactivity depletion uncertainty equal to 1.0 % Δk_{eff} per 30,000 MWD/MTU to be applicable to acceptance criteria (1), that is, that k_{eff} be less than or equal to 0.95 with soluble boron credit. Note that Westinghouse has conservatively included the 5% burnup uncertainty in the determination of zero boron condition.

28. **According to Section 3.6.3, soluble boron required to mitigate accidents is based on the evaluation/analysis of four potential accident scenarios. A fuel assembly dropped onto the SFP storage racks is considered creditable, but not analyzed as the distance between the dropped assembly, and the fuel in the storage racks is considered to be sufficient to neutronically decouple the configuration. The mishandling of a fuel assembly, a reduction in the intramodule water gap due to a seismic event, and an elevated SFP temperature is considered creditable and is analyzed. With respect to the soluble boron required to mitigate an accident, provide the following information:**

a. **What is the distance between the top of a fuel assembly in the storage cell and the top of the storage racks?**

RESPONSE:
The minimum distance between the top of the active fuel (pellet stack) of a fresh assembly and the top of the storage cells is 19.7 inches.

b. Is it possible for the non-fissile materials, which may be stored in the SFP cell, to displace a sufficient amount of water such that a dropped assembly may become neutronically coupled with the fuel in the storage cells?

RESPONSE:
Storage of non-fissile materials will not change the distance between the top of the storage racks and the dropped assembly, given that non-fissile material is not stored in a cell with an assembly. Therefore, this configuration will still be neutronically decoupled.

c. The fuel mishandling analysis events all assumed a fresh Westinghouse standard 17x17 fuel assembly enriched to 5.0 w/o U235 was misloaded. Justify this fuel assembly design as appropriate for the analysis.

RESPONSE:
The 17x17 Standard design with fresh 5.0 w/o ^{235}U fuel is the most reactive fuel bounding other Westinghouse fuel products with 0.3740-inch fuel pins, and leading to the highest reactivity increase when misloaded. Had there been OFA fuel assemblies (0.360-inch fuel pins) used at BVPS-2, these would have been considered for misload analyses. Please also see response to RAI question 7.

d. The fuel mishandling analyses all consist of an SFP filled with a single storage configuration. Why was the possibility of a misload of a fuel assembly on the interface boundary between storage configurations not considered?

RESPONSE:
Additional calculations were performed for misload accidents on the interface boundary between storage configurations. Similar to the misload cases presented in WCAP-16518, a depleted fuel assembly was replaced with a fresh 5.0 w/o ^{235}U assembly on the interface boundary. Table 9 shows six interface configurations and the corresponding k_{eff} and Δk_{eff} results from the nominal and misload accident cases. As seen from Table 9, the largest reactivity increase occurs for the misload at the interface of "All-Cell" and "3x3" storage configurations. This maximum reactivity increase, however, is still bounded by the Δk_{eff} (=0.06323) from the misload accident case reported in WCAP-16518 (Table 3-25).

Table 9 – Burnup vs. Soluble Boron			
Interface Configuration	**Nominal k_{eff}**	**Misload k_{eff}**	**Δk_{eff}**
1-out-of-4 3.85 w/o fresh and 1-out-of-4 5.0 w/o at 15,000 MWD/MTU	0.96643 ± 0.0027	1.00646± 0.0032	0.04003
1-out-of-4 3.85 w/o fresh and 3x3	0.97026 ± 0.0032	1.02526± 0.0049	0.05500
1-out-of-4 5.0 w/o at 15,000 MWD/MTU and 3x3	0.97028± 0.0031	1.02631± 0.0030	0.05603
All-Cell and 1-out-of-4 3.85 w/o fresh	0.96598± 0.0026	0.99600± 0.0032	0.03002
All-Cell and 1-out-of-4 5.0 w/o at 15,000 MWD/MTU	0.96691± 0.0021	0.98650± 0.0030	0.02007
All-Cell and 3x3	0.96996± 0.0034	1.02879± 0.0030	0.05853

e. **There is no discussion of the cases that were used to derive the k_{eff} for the different accident scenarios in Table 3-25. Provide a description of those cases.**

RESPONSE:
The accident scenarios considered in Table 3-25 include:

- Misloaded fresh fuel assembly into burnup storage rack: A depleted fuel assembly in a storage configuration is replaced with a fresh 5.0 w/o ^{235}U enriched fuel assembly.
- Misloaded fresh assembly between storage racks and the pool wall: A fresh 5.0 w/o ^{235}U enriched fuel assembly was placed between the racks and the spent fuel pool wall, face adjacent to either a depleted fuel or fresh fuel assembly of a storage configuration. In this case, the most reactive case was found to be a fresh fuel assembly placed at the corner formed by three storage cells of modules 7, 8, and 11 (see Figure 2-1).
- Intramodule gap reduction due to seismic event: The nominal intra-module gap of 1.125 – inches was reduced to zero and cases were rerun to determine the reactivity impact.
- Spent Fuel Pool temperature greater than 185°F: Pool temperature was set to 240°F and the water density was adjusted accordingly and cases were rerun to determine the reactivity impact.

f. **The delta k_{eff} in Table 3-25 is based on the k_{eff} of the SFP filled with only that particular storage configuration. The development of these values is never discussed. Provide a discussion of their development.**

RESPONSE:

The BVPS-2 SFP is modeled in KENO as a rectangular water cell that is 473.5 inches long and 353.5 inches wide on the long side. Seventeen storage rack modules (8x8 cell array) along with an empty refueling transfer canal surrounded by 2-feet thick concrete walls occupy the pool. Storage rack modules span a region that is 422.3125 inches in the west to east direction at the north side and 168.25 inches at the south side, 252.9375 inches in the north-to-south direction at the east side, and 337.625 inches at the west side of the pool. The floor and walls of the spent fuel pool are modeled by surrounding the rectangular water cell with two feet of concrete on the bottom and sides. A 1.125-inch intra module water gap was modeled. The pool dimensions are shown in Table 2-1 of WCAP-16518. The pool water was modeled at room temperature conditions, 20°C, and full density (1.0 g/cm^3). Figure 3-7 shows a KENO-produced plot of the spent fuel pool. In order to determine the Δk_{eff} impact of the accident scenarios, nominal models were first developed. The nominal model consists of a SFP filled with a single storage configuration at the nominal enrichment of that storage configuration. These models were run at zero ppm soluble boron to determine the base multiplication factors reported in the footnotes 1-4 under the Table 3-25.

g. **The text says the misloading of a Westinghouse standard 17x17 fuel assembly enriched to 5.0 w/o U235 in the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" Storage Configuration produced the largest delta k_{eff}. However, in Table 3-25, the misloading of a Westinghouse standard 17x17 fuel assembly enriched to 5.0 w/o U235 in the "1-out-of-4 3.85 w/o Fresh with IFBA" Storage Configuration has the largest delta k_{eff}. Please correct the text.**

RESPONSE:

The k_{eff} and the Δk_{eff} values in the "misload accident" row of Table 3-25 of WCAP-16518 for the "1-out-of-4 5.0 w/o at 15,000 MWD/MTU" and "1-out-of-4 3.85 w/o Fresh with IFBA" configurations have inadvertently been switched. The WCAP will be revised to correct this discrepancy.

29. **Total soluble boron requirement is developed in Section 3.6.4. The previous sections determined a delta k_{eff}. That delta k_{eff} was then used in the third degree polynomial equation associated with Table 3-23 to determine the soluble boron necessary to offset that delta k_{eff}. Each soluble boron determination was initiated from a zero boron condition. The results are then summed algebraically. However, the equation associated with Table 3-23 clearly shows a decreasing incremental boron worth as the total boron concentration increases. If each delta k_{eff} is treated as an incremental increase, the total soluble boron requirement increases. The amount of soluble boron necessary to maintain k_{eff} less than 0.95, with bias and uncertainties, increases from 441.8 ppm to 486 ppm. The amount of soluble boron necessary to maintain k_{eff} less than 0.95, with bias and uncertainties, under the worst identified accident increases from 824.1 ppm to 1018 ppm.**

a. Explain this apparent non-conservative use of the third degree polynomial equation associated with Table 3-23.

RESPONSE:
The polynomial associated with Table 3-23 already captures the decreasing boron worth as the boron concentration increases. The current treatment of the soluble boron requirement includes sufficient conservatism, in that it is based on the maximum credited burnup to minimize boron worth, which far more exceeds the conservatism associated with the suggested piecewise treatment. The current treatment is consistent with the analyses the NRC has previously approved, such as: R. E. Ginna Nuclear Power Plant – Amendment RE: Revision to the Storage Configuration Requirements Within the Existing Storage Racks and Taking Credit for a Limited Amount of Soluble Boron (TAC No. MA8443) dated December 7, 2000; Millstone Power Station, Unit No. 2 – Issuance of Amendment RE: Spent Fuel Pool Requirements (TAC No. MB 3386) dated April 1, 2003; Diablo Canyon Nuclear Power Plant, Unit Nos. 1 and 2 – Issuance of Amendment RE: Credit for Soluble Boron in the Spent Fuel Pool Criticality Analysis (TAC Nos. MB2982 and MB2984) dated September 2002; and Joseph M. Farley Nuclear Plant, Units 1 and 2 RE: Issuance of Amendments (TAC Nos. MC6987 and MC6988) dated June 28, 2005.

b. Were results confirmed through computer cases?

RESPONSE:
Yes, the response to RAI question 26 (e) provides the details and results of the analysis.

30. In NRC Regulatory Issue Summary (RIS) 2001-12, "Nonconservatism in Pressurized Water Reactor Spent Fuel Storage Pool Reactivity Equivalencing Calculations," (Reference 10) the NRC informed the industry about the potential for a non-conservative result when using reactivity equivalencing. The reactivity equivalencing discussed in RIS 2001-12 equates the reactivity of a fuel assembly that has a particular initial enrichment and burnup combination to the reactivity of a fuel assembly that has a different initial enrichment and zero burnup. This is a fictitious fuel assembly that is used in subsequent analyses. The non-conservatism can occur when the equivalent fresh fuel enrichment is determined for a reference configuration (e.g., an infinite array of storage rack cells in unborated water) and then used for various similar, but not identical, configurations. As WCAP-16518-P uses reactivity equivalencing in this manner, explain how the potential non-conservatism is taken into account.

RESPONSE:
Fresh fuel reactivity equivalencing is not used in this analysis supporting this submittal. The maximum fresh enrichment is calculated with fresh fuel and represents fresh fuel. At no time is fresh fuel of any enrichment used to represent burned fuel. The zero burnup maximum enrichment is merely the endpoint of the burnup vs. enrichment curve.

While the fresh equivalent enrichment values were utilized in determining some of the bias and uncertainties, it should be noted that those cases were all evaluated in an infinite array storage rack cells in unborated water, for which there are not large spectral effects based on depleted isotopics or fresh isotopics. Any evaluation that requires spectral treatment, such as IFBA and soluble boron determination has utilized depleted assemblies to minimize reactivity for conservative results.

REFERENCES

1. FirstEnergy Nuclear Operating Company letter L-06-094 from James H. Lash, Site Vice President, Beaver Valley Power Station, to USNRC document control desk, re: "Beaver Valley Power Station, Unit Nos. 1 and 2, BV-1 Docket No. 50-334, License No. DPR-66, BV-2 Docket No. 50-412, License No. NPF-73, License Amendment Request Nos. 333 and 204," June 14, 2006. (ADAMS ML06170010).

2. NRC Memorandum from L. Kopp to T. Collins, Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," August 19, 1998. (ADAMS ML003728001)

3. R. E. Ginna Nuclear Power Plant - Amendment re: Revision to the Storage Configuration Requirements Within the Existing Storage Racks and Taking Credit for a Limited Amount of Soluble Boron (TAC NO. MA8443), dated December 7, 2000 (ADAMS ML003761578).

4. Diablo Canyon Nuclear Power Plant, Unit Nos. 1 and 2 - Issuance of Amendment re: Credit for Soluble Boron in the Spent Fuel Pool Criticality Analysis (TAC Nos. MB2982 and MB2984), dated September 25, 2002 (ADAMS ML022610080).

5. Millstone Power Station, Unit No. 2 - Issuance of Amendment re: Spent Fuel Pool Requirements (TAC No. MB3386), dated April 1, 2003 (ADAMS ML030910485).

6. Vogtle Electric Generating Plant, Units 1 and 2 re: Issuance of Amendments that Revise the SFP Rack Criticality Analyses (TAC Nos. MC4225 and MC4226), dated September 22, 2005 (ADAMS ML052420110).

7. NUREG/CR-6665, "Review and Prioritization of Technical Issues Related to Burnup Credit for LWR Fuel," (ADAMS ML003688150).

8. WCAP-14416-P-A, "Westinghouse Spent Fuel Rack Criticality Analysis Methodology," November 1996.

9. U.S. NRC letter "Non-Conservatisms in Axial Burnup Biases for Spent Fuel Rack Criticality Analysis Methodology," dated July 27, 2001 (ADAMS ML012080337).

10. NRC Regulatory Issue Summary 2001-12, "Nonconservatism in Pressurized Water Reactor Spent Fuel Storage Pool Reactivity Equivalencing Calculations," May 18, 2001 (ADAMS ML010990300).

Enclosure 1 of L-07-084

Westinghouse letter 98DL-G-0043, "Duquesne Light Company, Beaver Valley Power Stations Unit 2, Revision 1 to Soluble Boron Credit Analysis," dated November 12, 1998

Westinghouse Electric Company Energy Systems Box 355
Pittsburgh Pennsylvania 15230-0355

05268368

98DL-G-0043
November 12, 1998

Mr. R. D. Scherer
Duquesne Light Company
2837 New Beaver Avenue
Building #1 - MD-JPIC
Pittsburgh, PA 15233

DUQUESNE LIGHT COMPANY
BEAVER VALLEY POWER STATION UNIT 2
REVISION 1 TO SOLUBLE BORON CREDIT ANALYSIS

Reference: 98DL-G-0021 dated 7/30/98

Dear Mr. Scherer:

In the above reference, we issued the final report on our soluble boron credit analysis entitled, "Beaver Valley Unit 2 Spent Fuel Rack Criticality Analysis with Credit for Soluble Boron." The report shows that Westinghouse 17x17 STD fuel assemblies with enrichments up to 5.0 w/o can be safety stored in the Beaver Valley spent fuel storage racks using credit for spent fuel pool soluble boron. The enclosed Revision 1 of the report clarifies the use of soluble boron as it applies to the ANSI standards on Pages 24 and 25.

If you have any questions regarding the enclosed reports, please call me.

Very truly yours,

B. D. McKenzie

B. D. McKenzie
Project Engineer
Fuel Projects

cc: BVPS Nuclear Central File
S. C. Jain
W. R. Kline
G. H. Kammerdeiner
R. Ireland
K. J. Frederick
J. Mentzer
J. D. St. John
W. Williams (10)
G. F. Zupsic

Ref.: CAA-98-158 Rev. 1

Final Report Titled

"Beaver Valley Unit 2 Spent Fuel Rack Criticality Analysis

with Credit for Soluble Boron"

J R Lesko

J. R. Lesko
Core Analysis A

Date: 11/12/98

CAA-98-158-Rev 1

Beaver Valley Unit 2 Spent Fuel Rack Criticality Analysis With Credit for Soluble Boron

November 1998

J. R. Lesko
J. G. Hulme
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Prepared : ____________________
J. R. Lesko
Criticality Services Team

Verified: ____________________
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Criticality Services Team

Approved: ____________________
K. C. Hoskins, Manager
Core Analysis A

Westinghouse
Commerical Nuclear Fuel Division

Revision 1 of this report is being revised to clarify the use of soluble boron as it applies to the ANSI standards as discussed on pages 24 and 25.

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1.0 Introduction

This report presents the results of a criticality analysis of the Beaver Valley Unit 2 spent fuel storage racks with credit for spent fuel pool soluble boron. The methodology employed here is contained in the topical report, "Westinghouse Spent Fuel Rack Criticality Analysis Methodology"[1].

The Beaver Valley Unit 2 spent fuel racks have been analyzed to allow storage of Westinghouse 17x17 STD fuel assemblies with nominal (design) enrichments up to 5.00 w/o ^{235}U in the storage cell locations using credit for checkerboard configurations and burnup credit. The nominal fuel enrichment for the region is the enrichment of the fuel ordered from the manufacturer. This analysis does not take any credit for the presence of the spent fuel rack Boraflex poison panels.

The Beaver Valley Unit 2 spent fuel rack analysis is based on maintaining $K_{eff} < 1.0$ including uncertainties and tolerances on a 95/95 (95 percent probability at 95 percent confidence level) basis without the presence of any soluble boron in the storage pool (No Soluble Boron 95/95 K_{eff} condition). Soluble boron credit is used to provide safety margin by maintaining $K_{eff} \leq 0.95$ including uncertainties, tolerances, and accident conditions in the presence of spent fuel pool soluble boron.

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

<u>Unit 2 Enrichment Limits</u>

All Cell Storage

For storage of 17x17 STD fuel assemblies in all cell locations, fuel assemblies must have an initial nominal enrichment no greater than 1.90 w/o ^{235}U or satisfy a minimum burnup requirement for higher initial enrichments up to 5.0 w/o ^{235}U. The soluble boron concentration that results in a 95/95 K_{eff} of less than 0.95 was calculated as 450 ppm. Including accidents, the soluble boron credit required for this storage configuration is 1050 ppm.

3-out-of-4 Checkerboard Storage

For storage of 17x17 STD fuel assemblies in a 3-out-of-4 checkerboard arrangement with empty cells, fuel assemblies must have an initial nominal enrichment no greater than 2.60 w/o ^{235}U or satisfy a minimum burnup requirement for higher initial enrichments up to 5.0 w/o ^{235}U. A 3-out-of-4 checkerboard with empty cells means that no more than 3 fuel assemblies can occupy any 2x2 matrix of storage cells. The soluble boron concentration that results in a 95/95 K_{eff} of less than 0.95 was calculated as 350 ppm. Including accidents, the soluble boron credit required for this storage configuration is 1250 ppm.

2-out-of-4 Checkerboard Storage

For storage of 17x17 STD fuel assemblies in a 2-out-of-4 checkerboard arrangement with empty cells, fuel assemblies must have an initial nominal enrichment no greater than 5.00 w/o ^{235}U. A 2-out-of-4 checkerboard with empty cells means that two fuel assemblies may not be stored face adjacent. Fuel assemblies may be stored corner adjacent. The soluble boron concentration that results in a 95/95 K_{eff} of less than 0.95 was calculated as 0 ppm. There are no limitations on required burnup for this configuration. Including accidents, the soluble boron credit required for this storage configuration is 1400 ppm.

1.1 Design Description

The Beaver Valley Unit 2 spent fuel storage cell is shown in Figure 1 on page 33 with nominal dimensions provided in the figure.

The fuel parameters relevant to this analysis are given in Table 1 on page 26. With the simplifying but conservative assumptions employed in this analysis (no grids, sleeves, axial blankets, etc.), the other types of Westinghouse 17x17 STD fuel (V5H[2] and P+) do not contribute to any increase in the basic assembly reactivity. This includes small changes in guide tube and instrumentation tube dimensions. Therefore, future fuel assembly upgrades do not require a criticality analysis if the fuel rod diameter continues to be 0.374 inches (STD fuel) and the rod pitch is 0.490 inches.

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

Nominal enrichment in this report refers to the fuel enrichment as required for a specific fuel region in the loading pattern. There can be a tolerance of $\pm$ 0.05% in enrichment around the nominal value.

1.2 Design Criteria

Criticality of fuel assemblies in a fuel storage rack is prevented by the design of the rack which limits fuel assembly interaction. This is done by fixing the minimum separation between fuel assemblies and controlling the placement of assemblies into selected storage cell configurations.

The design basis for preventing criticality outside the reactor is that, including uncertainties, there is a 95 percent probability at a 95 percent confidence level that the effective neutron multiplication factor, K_{eff}, of the fuel rack array will be less than or equal to 0.95. In addition, the K_{eff} of the spent fuel rack is maintained below 1.0 on the 95/95 basis, without the presence of soluble boron as defined in Reference 1.

To provide safety margin in the criticality analysis of the spent fuel racks, credit is taken for the soluble boron present in the Beaver Valley Unit 2 spent fuel pool. This parameter provides significant negative reactivity in the criticality analysis of the spent fuel rack and will be used here in conjunction with administrative controls to insure the spent fuel rack limits are met.

2.0 Analytical Methods

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

The design method which ensures the criticality safety of fuel assemblies in the fuel storage rack is described in detail in the Westinghouse Spent Fuel Rack Criticality Analysis Methodology topical report[1]. This report describes the computer codes, benchmarking, and methodology which are used to calculate the criticality safety limits presented in this report for Beaver Valley Unit 2.

As determined in the benchmarking in the topical report, the method bias using the described methodology of NITAWL-II, XSDRNPM-S and KENO-Va is 0.00770 ΔK. There is a 95 percent probability at a 95 percent confidence level that the uncertainty in reactivity, due to the method, is no greater than 0.0030 ΔK. These values will be used in the final evaluation of the 95/95 basis K_{eff} in this report.

3.0 Criticality Analysis of Unit 2 All Cell Storage

This section describes the analytical techniques and models employed to perform the criticality analysis and reactivity equivalencing evaluations for the storage of fuel in all cells of the Beaver Valley Unit 2 spent fuel storage racks. The all cell configuration is shown in Figure 4 on page 36.

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

3.1 No Soluble Boron 95/95 K_{eff} Calculation

To determine the enrichment required to maintain $K_{eff} < 1.0$, KENO-Va is used to establish a nominal reference reactivity and PHOENIX-P is used to assess the temperature bias of the pool temperature range and the effects of material and construction tolerance variations. A final 95/95 K_{eff} is developed by statistically combining the individual tolerance impacts with the calculational and methodology uncertainties and summing this term with the temperature and method biases and the nominal KENO-Va reference reactivity. The equation for determining the final 95/95 K_{eff} is defined in Reference 1.

The following assumptions are used to develop the No Soluble Boron 95/95 K_{eff} KENO-Va model for storage of fuel assemblies in all cells of the Beaver Valley Unit 2 spent fuel storage rack:

1. The fuel assembly parameters relevant to the criticality analysis are based on the Westinghouse 17x17 STD designs (see Table 1 on page 26 for fuel parameters). The 17x17 VANTAGE 5H fuel design parameters relevant to the criticality analysis are the same as the STD parameters and will yield equivalent results (credit is not taken for grids).
2. Fuel assemblies contain uranium dioxide at a nominal enrichment of 1.90 w/o ^{235}U over the entire length of each rod, i.e. active fuel is conservatively assumed to extend to the axial blanket also.
3. The fuel pellets are modeled assuming nominal values for theoretical density (95.5%) and dishing fraction.
4. No credit is taken for any natural or reduced enrichment axial blankets. This assumption results in either equivalent or conservative calculations of reactivity for all fuel assemblies used at Beaver Valley, including those with annular pellets at the fuel rod ends.
5. No credit is taken for any ^{234}U or ^{236}U in the fuel, nor is any credit taken for the buildup of fission product poison material.
6. No credit is taken for any spacer grids or spacer sleeves.
7. No credit is taken for any burnable absorber in the fuel rods.
8. No credit is taken for the presence of spent fuel rack Boraflex poison panels. The Boraflex volume is replaced with water.

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

10. The array is infinite in the lateral (x and y) extent. In the axial (vertical) direction the model uses finite fuel (including blanket stack length) and with 12 inch (effectively infinite) water region on the top and bottom of the fuel.

11. All available storage cells are loaded with symmetrically positioned (centered within the storage cell) fuel assemblies. All rack modules are assumed to be aligned with each other. The effect of asymmetric placement of assemblies in the rack is discussed below.

With the above assumptions, the KENO-Va calculations of K_{eff} under nominal conditions resulted in a K_{eff} of 0.96992, as shown in Table 2 on page 27.

Temperature and methodology biases are added in the final K_{eff} summation prior to comparing against the 1.0 K_{eff} limit. The following biases were included:

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

Water Temperature: A reactivity bias determined in PHOENIX-P was applied to account for the effect of the range of spent fuel pool water temperatures (50°F to 185°F).

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, additional PHOENIX-P calculations were performed. For the Beaver Valley Unit 2 spent fuel rack all cell storage configuration, UO_2 material tolerances were considered along with construction tolerances related to the cell I.D., storage cell pitch, wrapper thickness and stainless steel wall thickness. Uncertainties associated with calculation and methodology accuracy were also considered in the statistical summation of uncertainty components. To evaluate the reactivity effect of asymmetric assembly positioning within the storage cells, KENO-Va calculations were performed.

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

^{235}U Enrichment: The enrichment tolerance of ±0.05 w/o ^{235}U about the nominal reference enrichment of 1.90 w/o ^{235}U was considered.

UO_2 Density: A ±2.0% variation about the nominal reference theoretical density (the nominal reference value is listed in Table 1 on page 26) was considered.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to twice the nominal dishing (the nominal reference value is listed in Table 1 on page 26) was considered.

Storage Cell I.D.: The ± 0.0469 inch tolerance about the nominal 8.9375 inch reference cell I.D. was considered.

Storage Cell Pitch: The ±0.0278 inch tolerance about the nominal 10.4375 inch reference cell pitch was considered.

Stainless Steel Wall Thickness: The ±0.010 inch tolerance about the nominal 0.090 inch reference stainless steel wall thickness was considered.

Wrapper Thickness: The ±0.005 inch tolerance about the nominal 0.0293 inch reference wrapper thickness was considered.

Asymmetric Assembly Position: Conservative calculations show that an increase in reactivity can occur if the corners of the four fuel assemblies were positioned together. This reactivity increase was considered.

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

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

The 95/95 K_{eff} for the Beaver Valley Unit 2 spent fuel rack all cell storage configuration is developed by adding the temperature and methodology biases and the statistical sum of independent tolerances and uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 2 on page 27 and results in a 95/95 K_{eff} of 0.99952.

Since K_{eff} is less than 1.0, the Beaver Valley Unit 2 spent fuel racks will remain subcritical when all cells are loaded with 1.90 w/o ^{235}U Westinghouse 17x17 STD fuel assemblies and no soluble boron is present in the spent fuel pool water. In the next section, soluble boron credit will be used to provide safety margin by determining the amount of soluble boron required to maintain $K_{eff} \leq 0.95$ including tolerances and uncertainties on a 95/95 basis.

3.2 Soluble Boron Credit K_{eff} Calculations

To determine the amount of soluble boron required to maintain $K_{eff} \leq 0.95$, KENO-Va is used to establish a nominal reference reactivity and PHOENIX-P is used to assess the temperature bias of a normal pool temperature range and the effects of material and construction tolerance variations. A final 95/95 K_{eff} is developed by statistically combining the individual tolerance impacts with the calculational and methodology uncertainties and summing this term with the temperature and method biases and the nominal KENO-Va reference reactivity.

The assumptions used to develop the nominal case KENO-Va model for soluble boron credit for all cell storage in the Beaver Valley Unit 2 spent fuel racks are similar to those in Section 3.1 except for assumption 9 regarding the moderator soluble boron concentration. The moderator is replaced with water containing 200 ppm soluble boron.

With the above assumptions, the KENO-Va calculation for the nominal case with 200 ppm soluble boron in the moderator resulted in a K_{eff} of 0.91220.

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

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

Water Temperature: A reactivity bias determined in PHOENIX-P was applied to account for the effect of the range of spent fuel pool water temperatures (50°F to 185°F).

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, additional PHOENIX-P calculations were performed. For the Beaver Valley Unit 2 spent fuel rack all cell storage configuration, UO_2 material tolerances were considered along with construction tolerances related to the cell I.D., storage cell pitch, wrapper thickness and stainless steel wall thickness. Uncertainties associated with calculation and methodology accuracy were also considered in the statistical summation of uncertainty components. To evaluate the reactivity effect of asymmetric assembly positioning within the storage cells, KENO-Va calculations were performed.

The same tolerance and uncertainty components as in the No Soluble Boron case were considered in the total uncertainty statistical summation.

The 95/95 K_{eff} is developed by adding the temperature and methodology biases and the statistical sum of independent tolerances and uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 2 on page 27 and results in a 95/95 K_{eff} of 0.94151.

Since K_{eff} is less than or equal to 0.95 including soluble boron credit and uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met for all cell storage of 17x17 STD Westinghouse fuel assemblies in the Beaver Valley Unit 2 spent fuel racks. Storage of fuel assemblies with nominal enrichments no greater than 1.90 w/o ^{235}U is acceptable in all cells including the presence of 200 ppm soluble boron.

3.3 Burnup Credit Reactivity Equivalencing

Storage of fuel assemblies with initial enrichments higher than 1.90 w/o ^{235}U in all cells of the Beaver Valley Unit 2 spent fuel racks is achievable by means of burnup credit using reactivity equivalencing. The concept of reactivity equivalencing with burnup credit is based upon the reactivity decrease associated with fuel depletion. For burnup credit, a series of reactivity calculations is performed to generate a set of enrichment-fuel assembly discharge burnup ordered pairs which all yield an equivalent K_{eff} when stored in the spent fuel storage racks [(1)].

Figure 2 on page 34 shows the constant K_{eff} contour generated for all cell storage in the Beaver Valley Unit 2 spent fuel racks. The curve of Figure 2 represents combinations of fuel enrichment and discharge burnup which yield an equivalent rack multiplication factor (K_{eff}) as compared to the rack loaded with 1.90 w/o ^{235}U Westinghouse 17x17 STD fuel assemblies at zero burnup in all cell locations.

Uncertainties associated with burnup credit include a reactivity uncertainty of 0.01 ΔK at 30,000 MWD/MTU applied linearly to the burnup credit requirement to account for calculation and depletion uncertainties and 5% on the calculated burnup to account for burnup measurement uncertainty [(1)]. The amount of additional soluble boron needed to account for these uncertainties in the burnup requirement of Figure 2 was 250 ppm. This is an additional soluble boron requirement above the 200 ppm required in Section 3.2. This results in a total soluble boron requirement of 450 ppm for burnup credit.

It is important to recognize that the curve in Figure 2 is based on calculations of constant rack reactivity. In this way, the environment of the storage rack and its influence on assembly reactivity is implicitly considered. For convenience, the data from Figure 2 are also provided in Table 3 on page 28. Use of linear interpolation between the tabulated values is acceptable since the curve shown in Figure 2 is approximately linear between the tabulated points.

Previous evaluations have quantified axial burnup reactivity effects and to confirm that the reactivity equivalencing methodology described in Reference 1 results in calculations of conservative burnup credit limits. The effect of axial burnup distribution on assembly reactivity has thus been addressed in the development of the all cell storage burnup credit limit in Beaver Valley Unit 2 spent fuel racks.

4.0 Criticality Analysis of Unit 2 3-out-of-4 Storage

This section describes the analytical techniques and models employed to perform the criticality analysis and reactivity equivalencing evaluations for the storage of fuel in 3-out-of-4 cells of the Beaver Valley Unit 2 spent fuel storage racks. The 3-out-of 4 configuration is shown in Figure 4 on page 36

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

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

To determine the enrichment required to maintain $K_{eff} < 1.0$, KENO-Va is used to establish a nominal reference reactivity and PHOENIX-P is used to assess the temperature bias of the pool temperature range and the effects of material and construction tolerance variations. A final 95/95 K_{eff} is developed by statistically combining the individual tolerance impacts with the calculational and methodology uncertainties and summing this term with the temperature and method biases and the nominal KENO-Va reference reactivity. The equation for determining the final 95/95 K_{eff} is defined in Reference 1.

The following assumptions are used to develop the No Soluble Boron 95/95 K_{eff} KENO-Va model for storage of fuel assemblies in 3-out-of-4 cells of the Beaver Valley Unit 2 spent fuel storage rack:

1. The fuel assembly parameters relevant to the criticality analysis are based on the Westinghouse 17x17 STD designs (see Table 1 on page 26 for fuel parameters). The 17x17 VANTAGE 5H fuel design parameters relevant to the criticality analysis are the same as the STD parameters and will yield equivalent results (credit is not taken for grids).
2. Fuel assemblies contain uranium dioxide at a nominal enrichment of 2.60 w/o ^{235}U over the entire length of each rod, i.e. active fuel is conservatively assumed to extend to the axial blanket also.
3. The fuel pellets are modeled assuming nominal values for theoretical density (95.5%) and dishing fraction.
4. No credit is taken for any natural or reduced enrichment axial blankets. This assumption results in either equivalent or conservative calculations of reactivity for all fuel assemblies used at Beaver Valley, including those with annular pellets at the fuel rod ends.
5. No credit is taken for any ^{234}U or ^{236}U in the fuel, nor is any credit taken for the buildup of fission product poison material.
6. No credit is taken for any spacer grids or spacer sleeves.
7. No credit is taken for any burnable absorber in the fuel rods.

8. No credit is taken for the presence of spent fuel rack Boraflex poison panels. The Boraflex volume is replaced with water.

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

10. The array is infinite in the lateral (x and y) extent. In the axial (vertical) direction the model uses finite fuel (including blanket stack length) and with 12 inch (effectively infinite) water region on the top and bottom of the fuel.

11. Fuel storage cells are loaded with symmetrically positioned (centered within the storage cell) fuel assemblies in a 3-out-of-4 checkerboard arrangement. A 3-out-of-4 checkerboard with empty cells means that no more than three fuel assemblies can occupy any 2x2 matrix of storage cells. All rack modules are assumed to be aligned with each other. The effect of asymmetric placement of assemblies in the rack is discussed below.

With the above assumptions, the KENO-Va calculations of K_{eff} under nominal conditions resulted in a K_{eff} of 0.97235, as shown in Table 4 on page 29.

Temperature and methodology biases are added in the final K_{eff} summation prior to comparing against the 1.0 K_{eff} limit. The following biases were included:

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

Water Temperature: A reactivity bias determined in PHOENIX-P was applied to account for the effect of the range of spent fuel pool water temperatures (50°F to 185°F).

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, additional PHOENIX-P calculations were performed. For the Beaver Valley Unit 2 spent fuel rack 3-out-of-4 checkerboard configuration, UO_2 material tolerances were considered along with construction tolerances related to the cell I.D., storage cell pitch, wrapper thickness and stainless steel wall thickness. Uncertainties associated with calculation and methodology accuracy were also considered in the statistical summation of uncertainty components. To evaluate the reactivity effect of asymmetric assembly positioning within the storage cells, KENO-Va calculations were performed.

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

^{235}U Enrichment: The enrichment tolerance of ±0.05 w/o ^{235}U about the nominal reference enrichment of 2.60 w/o ^{235}U was considered.

UO_2 Density: A ±2.0% variation about the nominal reference theoretical density (the nominal reference value is listed in Table 1 on page 26) was considered.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to twice the nominal dishing (the nominal reference value is listed in Table 1 on page 26) was considered.

Storage Cell I.D.: The ±0.0469 inch tolerance about the nominal 8.9375 inch reference cell I.D. was considered.

Storage Cell Pitch: The ±0.0278 inch tolerance about the nominal 10.4375 inch reference cell pitch was considered.

Stainless Steel Wall Thickness: The ±0.010 inch tolerance about the nominal 0.090 inch reference stainless steel wall thickness was considered.

Wrapper Thickness: The ±0.005 inch tolerance about the nominal 0.0293 inch reference wrapper thickness was considered.

Asymmetric Assembly Position: Conservative calculations show that an increase in reactivity can occur if the corners of the three fuel assemblies were positioned together. This reactivity increase was considered.

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

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

The 95/95 K_{eff} for the Beaver Valley Unit 2 spent fuel rack 3-out-of-4 checkerboard configuration is developed by adding the temperature and methodology biases and the statistical sum of independent tolerances and uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 4 and results in a 95/95 K_{eff} of 0.99564.

Since K_{eff} is less than 1.0, the Beaver Valley Unit 2 spent fuel racks will remain subcritical when 3-out-of-4 cells are loaded with 2.60 w/o ^{235}U Westinghouse 17x17 STD fuel assemblies and no soluble boron is present in the spent fuel pool water. In the next section, soluble boron credit will be used to provide safety margin by determining the amount of soluble boron required to maintain $K_{eff} \leq 0.95$ including tolerances and uncertainties on a 95/95 basis.

4.2 Soluble Boron Credit K_{eff} Calculations

To determine the amount of soluble boron required to maintain $K_{eff} \leq 0.95$, KENO-Va is used to establish a nominal reference reactivity and PHOENIX-P is used to assess the temperature bias of a normal pool temperature range and the effects of material and construction tolerance variations. A final 95/95 K_{eff} is developed by statistically combining the individual tolerance impacts with the calculational and methodology uncertainties and summing this term with the temperature and method biases and the nominal KENO-Va reference reactivity.

The assumptions used to develop the nominal case KENO-Va model for soluble boron credit for 3-out-of-4 cell storage in the Beaver Valley Unit 2 spent fuel racks are similar to those in Section 4.1 except for assumption 9 regarding the moderator soluble boron concentration. The moderator is replaced with water containing 200 ppm soluble boron.

With the above assumptions, the KENO-Va calculation for the nominal case with 200 ppm soluble boron in the moderator resulted in a K_{eff} of 0.92292.

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

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

Water Temperature: A reactivity bias determined in PHOENIX-P was applied to account for the effect of the normal range of spent fuel pool water temperatures (50°F to 185°F).

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, additional PHOENIX-P calculations were performed. For the Beaver Valley Unit 2 spent fuel rack 3-out-of-4 checkerboard configuration, UO_2 material tolerances were considered along with construction tolerances related to the cell I.D., storage cell pitch, wrapper thickness and stainless steel wall thickness. Uncertainties associated with calculation and methodology accuracy were also considered in the statistical summation of uncertainty components. To evaluate the reactivity effect of asymmetric assembly positioning within the storage cells, KENO-Va calculations were performed.

The same tolerance and uncertainty components as in the No Soluble Boron case were considered in the total uncertainty statistical summation.

The 95/95 K_{eff} is developed by adding the temperature and methodology biases and the statistical sum of independent tolerances and uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 4 on page 29 and results in a 95/95 K_{eff} of 0.94582.

Since K_{eff} is less than or equal to 0.95 including soluble boron credit and uncertainties at a 95/95 probability/confidence level, the acceptance criteria for criticality is met for 3-out-of-4 storage of 17x17 STD fuel assemblies in the Beaver Valley Unit 2 spent fuel racks. Storage of fuel assemblies with nominal enrichments no greater than 2.60 w/o ^{235}U is acceptable in 3-out-of-4 cells including the presence of 200 ppm soluble boron.

4.3 Burnup Credit Reactivity Equivalencing

Storage of fuel assemblies with initial enrichments higher than 2.60 w/o ^{235}U in 3-out-of-4 storage of the Beaver Valley Unit 2 spent fuel racks is achievable by means of burnup credit using reactivity equivalencing. The concept of reactivity equivalencing with burnup credit is based upon the reactivity decrease associated with fuel depletion. For burnup credit, a series of reactivity calculations is performed to generate a set of enrichment-fuel assembly discharge burnup ordered pairs which all yield an equivalent K_{eff} when stored in the spent fuel storage racks (1).

Figure 3 on page 35 shows the constant K_{eff} contour generated for 3-out-of-4 storage in the Beaver Valley Unit 2 spent fuel racks. The curve of Figure 3 represents combinations of fuel enrichment and discharge burnup which yield an equivalent rack multiplication factor (K_{eff}) as compared to the rack loaded with 2.60 w/o ^{235}U Westinghouse 17x17 STD fuel assemblies at zero burnup in 3-out-of-4 storage locations.

Uncertainties associated with burnup credit include a reactivity uncertainty of 0.01 ΔK at 30,000 MWD/MTU applied linearly to the burnup credit requirement to account for calculation and depletion uncertainties and 5% on the calculated burnup to account for burnup measurement uncertainty (1). The amount of additional soluble boron needed to account for these uncertainties in the burnup requirement of Figure 3 was 150 ppm. This is an additional boron above the 200 ppm required in Section 4.2. This results in a total soluble boron requirement of 350 ppm for burnup credit.

It is important to recognize that the curve in Figure 3 is based on calculations of constant rack reactivity. In this way, the environment of the storage rack and its influence on assembly reactivity is implicitly considered. For convenience, the data from Figure 3 are also provided in Table 3 on page 28. Use of linear interpolation between the tabulated values is acceptable since the curve shown in Figure 3 is approximately linear between the tabulated points.

Previous evaluations have quantified axial burnup reactivity effects and to confirm that the reactivity equivalencing methodology described in Reference 1 results in calculations of conservative burnup credit limits. The effect of axial burnup distribution on assembly reactivity has thus been addressed in the development of the all cell storage burnup credit limit in Beaver Valley Unit 2 spent fuel racks.

5.0 Criticality Analysis of Unit 2 2-out-of-4 Storage

This section describes the analytical techniques and models employed to perform the criticality analysis and reactivity equivalencing evaluations for the storage of fuel in 2-out-of-4 cells of the Beaver Valley Unit 2 spent fuel storage racks. The 2-out-of 4 configuration is shown in Figure 4 on page 36

Section 5.1 describes the No Soluble Boron 95/95 K_{eff} KENO-Va calculations performed for the 2-out-of-4 cells storage configuration. Soluble boron is not required in the spent fuel pool to maintain $K_{eff} \leq 0.95$. There is no burnup requirement for fuel with 5.0 w/o ^{235}U or less.

5.1 No Soluble Boron 95/95 K_{eff}

To determine the enrichment required to maintain $K_{eff} < 1.0$, KENO-Va is used to establish a nominal reference reactivity and PHOENIX-P is used to assess the temperature bias of the pool temperature range and the effects of material and construction tolerance variations. A final 95/95 K_{eff} is developed by statistically combining the individual tolerance impacts with the calculational and methodology uncertainties and summing this term with the temperature and method biases and the nominal KENO-Va reference reactivity. The equation for determining the final 95/95 K_{eff} is defined in Reference 1.

The following assumptions are used to develop the No Soluble Boron 95/95 K_{eff} KENO-Va model for storage of fuel assemblies in the Beaver Valley Unit 2 spent fuel storage racks:

1. The fuel assembly parameters relevant to the criticality analysis are based on the Westinghouse 17x17 STD designs (see Table 1 on page 26 for fuel parameters). The 17x17 VANTAGE 5H fuel design parameters relevant to the criticality analysis are the same as the STD parameters and will yield equivalent results (credit is not taken for grids).
2. Fuel assemblies contain uranium dioxide at a nominal enrichment of 5.0 w/o ^{235}U over the entire length of each rod, i.e. active fuel is conservatively assumed to extend to the axial blanket also.
3. The fuel pellets are modeled assuming nominal values for theoretical density (95.5%) and dishing fraction.
4. No credit is taken for any natural or reduced enrichment axial blankets. This assumption results in equivalent or conservative calculations of reactivity for all fuel assemblies used at Beaver Valley including those with annular pellets at the fuel rod ends.
5. No credit is taken for any ^{234}U or ^{236}U in the fuel, nor is any credit taken for the buildup of fission product poison material.
6. No credit is taken for any spacer grids or spacer sleeves.
7. No credit is taken for any burnable absorber in the fuel rods.
8. No credit is taken for the presence of spent fuel rack Boraflex poison panels. The Boraflex volume is replaced with water.

9. The moderator is water with 0 ppm soluble boron at a temperature of 68°F. A water density of 1.0 gm/cm^3 is used.
10. The fuel assembly array is conservatively modeled as infinite in lateral (x and y) and axial (vertical) extents.
11. Fuel storage cells are loaded with symmetrically positioned (centered within the storage cell) fuel assemblies in a 2-out-of-4 checkerboard arrangement. A 2-out-of-4 checkerboard with empty cells means that two fuel assemblies may not be stored face adjacent. Fuel assemblies may be stored corner adjacent. All rack modules are assumed to be aligned with each other. The effect of asymmetric placement of assemblies in the rack is discussed below.

With the above assumptions, the KENO-Va calculations of K_{eff} under normal conditions resulted in a K_{eff} of 0.93203, as shown in Table 5 on page 30.

Temperature and methodology biases are added in the final K_{eff} summation prior to comparing against the 1.0 K_{eff} limit. The following biases were included:

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

Water Temperature: A reactivity bias is applied to account for the effect of the normal range of spent fuel pool water temperatures (50°F to 185°F).

To evaluate the reactivity effects of possible variations in material characteristics and mechanical/construction dimensions, additional PHOENIX-P calculations were performed. For the Beaver Valley Unit 2 spent fuel rack 2-out-of-4 checkerboard configuration, UO_2 material tolerances were considered along with construction tolerances related to the cell I.D., storage cell pitch, wrapper thickness and stainless steel wall thickness. Uncertainties associated with calculation and methodology accuracy were also considered in the statistical summation of uncertainty components. To evaluate the reactivity effect of asymmetric assembly positioning within the storage cells, KENO-Va calculations were performed.

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

^{235}U Enrichment: The enrichment tolerance of ±0.05 w/o ^{235}U about the nominal reference enrichment of 5.0 w/o ^{235}U was considered.

UO_2 Density: A ±2.0% variation about the nominal reference theoretical density (the nominal reference value is listed in Table 1 on page 26) was considered.

Fuel Pellet Dishing: A variation in fuel pellet dishing fraction from 0.0% to twice the nominal dishing (the nominal reference value is listed in Table 1 on page 26) was considered.

Storage Cell I.D.: The ±0.0469 inch tolerance about the nominal 8.9375 inch reference cell I.D. was considered.

Storage Cell Pitch: The ±0.0278 inch tolerance about the nominal 10.4375 inch reference cell pitch was considered.

Stainless Steel Thickness: The ±0.010 inch tolerance about the nominal 0.090 inch reference stainless steel thickness for all rack structures was considered.

Wrapper Thickness: The ±0.005 inch tolerance about the nominal 0.0293 inch reference wrapper thickness was considered.

Asymmetric Assembly Position: Conservative calculations show that an increase in reactivity can occur if the corners of the two fuel assemblies were positioned together. This reactivity increase was considered.

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

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

The 95/95 K_{eff} for the Beaver Valley Unit 2 spent fuel rack 2-out-of-4 cells storage configuration is developed by adding the temperature and methodology biases and the statistical sum of independent tolerances and uncertainties to the nominal KENO-Va reference reactivity. The summation is shown in Table 5 and results in a 95/95 K_{eff} of 0.94577.

Since K_{eff} is less than 1.0, the Beaver Valley Unit 2 spent fuel racks will remain subcritical when 2-out-of-4 cells are loaded with 5.0 w/o ^{235}U Westinghouse 17x17 STD fuel assemblies and no soluble boron is present in the spent fuel pool water.

Soluble boron credit is not needed to provide safety margin because $K_{eff} \leq 0.95$, including tolerances and uncertainties, with no soluble boron.

6.0 Fuel Rod Storage Canister Criticality

A criticality analysis[3] was performed for the Fuel Rod Storage Canister (FRSC) which was provided to Beaver Valley. This report compared the FRSC, loaded with 5.0 w/o ^{235}U fuel rods, to an intact assembly with 5.0 w/o ^{235}U fuel rods. The conclusion was that the FRSC is less reactive than an assembly with 5.0 w/o ^{235}U fuel rods. However, this analysis was done independent of any rack geometry. Therefore, for storage of the FRSC in the racks, the FRSC must be treated as if it were an assembly with enrichment and burnup of the rod in the canister with the most limiting combination of enrichment and burnup.

6.1 Assemblies Reconstituted with Stainless Steel Rods

Assemblies with some fuel rods replaced by stainless steel rods, have a reactivity lower than that of the original un-reconstituted assembly. Therefore, such reconstituted assemblies can be placed in locations and configurations where the corresponding un-reconstituted assembly can be placed, as described in this report.

7.0 Discussion of Postulated Accidents

Possible accidents which can affect pool criticality are addressed in this section.

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

Fuel assembly drop on top of rack	The rack structure pertinent for criticality is not excessively deformed, and the dropped assembly which comes to rest horizontally on top of the rack has sufficient water separating it from the active fuel height of stored assemblies to preclude neutronic interaction.
Fuel assembly drop between rack modules	The design of the spent fuel racks and fuel handling equipment is such that it precludes the insertion of a fuel assembly between the rack modules.

However, four accidents can be postulated for each storage configuration which can increase reactivity beyond the analyzed condition. The first postulated accident would be a change in the spent fuel pool water temperature outside the normal operating range. The second accident would be dropping an assembly into an already loaded cell. The third would be a misload of an assembly into a cell for which the restrictions on location, enrichment, or burnup are not satisfied. The fourth accident is a misload between the rack module and the spent fuel pool wall.

For the change in spent fuel pool water temperature accident, a temperature range of 32°F to 240°F is considered. The range of water temperature of 50°F to 185°F is included in the normal condition evaluation. Calculations were performed for all Beaver Valley Unit 2 storage configurations to determine the reactivity increase caused by a change in the spent fuel pool water temperature outside the normal range. The results of these calculations are tabulated in Table 6 on page 31.

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

For the accident where a single assembly is misloaded into a storage cell, calculations were performed to show the largest reactivity increase caused by a 5.00 w/o Westinghouse 17x17 STD unirradiated fuel assembly that is misplaced into a storage cell for which the restrictions on location, enrichment, or burnup are not satisfied. The results of these calculations are also tabulated in Table 6.

For an accident where an assembly is misloaded between the rack module and pool wall, calculations were performed to show the largest reactivity increase caused by a 5.00 w/o Westinghouse 17x17 STD unirradiated fuel assembly misplaced at a corner interface of two rack modules. This misload is more limiting than a misload within the storage racks. The results of these calculations are also tabulated in Table 6.

For an occurrence of the above postulated accident conditions, the double contingency principle of ANSI/ANS 8.1-1983 can be applied. This states that two unlikely, independent, concurrent accident events are not required to be assumed to ensure protection against a criticality accident. Thus, for these postulated accident conditions, the presence of additional soluble boron in the storage pool water (above the concentration required for normal conditions and reactivity equivalencing) can be assumed as a realistic initial condition since not assuming its presence would be a second unlikely event.

The amount of soluble boron required to offset each of the postulated accidents and storage configuration was determined with PHOENIX-P calculations, where the impact of the reactivity equivalencing methodologies on the soluble boron is appropriately taken into account. The additional amount of soluble boron for accident conditions needed beyond the required boron for uncertainties and burnup is shown in Table 6.

8.0 Soluble Boron Credit Summary

Spent fuel pool soluble boron has been used in this criticality analysis to offset storage rack and fuel assembly tolerances, calculational uncertainties, uncertainty associated with reactivity equivalencing (burnup credit) and the reactivity increase caused by postulated accident conditions. The total soluble boron concentration required to be maintained in the spent fuel pool is a summation of each of these components. Table 7 on page 32 summarizes the storage configurations and corresponding soluble boron credit requirements.

Based on the above discussion, K_{eff} will be maintained less than or equal to 0.95 for all considered configurations due to the presence of at least 1400 ppm soluble boron in spent fuel pool water in the Beaver Valley Unit 2 storage racks.

9.0 Storage Configuration Interface Requirements

The Beaver Valley Unit 2 spent fuel pool is composed of a single type of rack. The spent fuel pool has been analyzed for all cell storage, where all cells share the same storage requirements and limits and checkerboard storage, where neighboring cells have different requirements and limits.

The boundary between checkerboarded zones and the boundary between all cell storage zones must be controlled to prevent an undesirable increase in reactivity. This is accomplished by examining all possible 2x2 matrices of rack cells near the boundary (within the first few rows of the boundary) and ensuring that each of these 2x2 matrices conforms to the checkerboard restrictions for the given region.

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

A	B	C
D	E	F
G	H	I

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

9.1 Interface Requirements within Beaver Valley Unit 2 Spent Fuel Racks

The following discussion of interface requirements illustrates example configurations that demonstrate the interface requirements discussed in Section 9.0 which are applicable to the Beaver Valley Unit 2 spent fuel racks:

All Cell Storage Next to 3-out-of-4 Storage

The boundary between all cell storage and 3-out-of-4 storage can be either separated by a vacant row of cells or the interface must be configured such that the first row of cells after the boundary in the 3-out-of-4 storage region uses alternating empty cells and cells containing assemblies at the 3-out-of-4 configuration enrichment of up to 2.60 w/o ^{235}U. Figure 5 on page 37 illustrates the configuration at the boundary.

All Cell Storage Next to 2-out-of-4 Storage

The boundary between all cell storage and 2-out-of-4 storage can be either separated by a vacant row of cells or the interface must be configured such that the first row of cells after the boundary in the 2-out-of-4 storage region uses alternating empty cells and cells containing assemblies at the 3-out-of-4 configuration enrichment of up to 2.60 w/o ^{235}U. Figure 5 on page 37 illustrates the configuration at the boundary.

2-out-of-4 Storage Next to 3-out-of-4 Storage

The boundary between 2-out-of-4 and 3-out-of-4 storage can be either separated by a vacant row of cells or the interface must be configured such that the first row of cells after the boundary in the 3-out-of-4 storage region contain alternating empty cells and cells containing fuel assemblies at the 3-out-of-4 configuration enrichment of up to 2.60 w/o ^{235}U. Figure 6 on page 38 illustrates the configuration at the boundary.

Open Water Cells

For all configurations at Beaver Valley Unit 2, an open water cell is permitted in any location of the spent fuel pool to replace an assembly since the water cell will not cause any increase in reactivity in the spent fuel pool.

Non-Fissile Components

For all configurations at Beaver Valley Unit 2, non-fissile components may be stored in open cells of the spent fuel pool provided at least one row of empty cells separates the components from the stored fuel.

Neutron Sources and RCCA in a Cell

The placement of neutron sources or Rod Cluster Control Assemblies (RCCA) will not cause any increase in reactivity in the spent fuel pool because the neutron source and RCCA are absorbers which reduce reactivity. Therefore, neutron sources and RCCAs may be stored in an empty cell or in an assembly.

Non-Fuel Bearing Assembly Components

Non-Fuel Bearing Assembly components (i.e. thimble plugs, discrete burnable absorbers, etc.) may be stored in assemblies without affecting the storage requirements of that assembly.

10.0 Summary of Criticality Results

For the storage of Westinghouse 17x17 STD fuel assemblies in the Beaver Valley Unit 2 spent fuel storage racks, the acceptance criteria for criticality requires the effective neutron multiplication factor, K_{eff}, to be less than 1.0 under No Soluble Boron 95/95 K_{eff} condition, and less than or equal to 0.95 including uncertainties, tolerances, and accident conditions in the presence of spent fuel pool soluble boron. This report shows that the acceptance criteria for criticality is met for the Beaver Valley Unit 2 spent fuel racks for the storage of Westinghouse 17x17 STD fuel assemblies under both normal and accident conditions with soluble boron credit and the following storage configurations and enrichment limits:

All Cell Storage	For storage of 17x17 STD fuel assemblies in all cell locations, fuel assemblies must have an initial nominal enrichment no greater than 1.90 w/o ^{235}U or satisfy a minimum burnup requirement for higher initial enrichments up to 5.0 w/o ^{235}U. The soluble boron concentration that results in a 95/95 K_{eff} of less than 0.95 was calculated as 450 ppm. Including accidents, the soluble boron credit required for this storage configuration is 1050 ppm.
3-out-of-4 Checkerboard Storage	For storage of 17x17 STD fuel assemblies in a 3-out-of-4 checkerboard arrangement with empty cells, fuel assemblies must have an initial nominal enrichment no greater than 2.60 w/o ^{235}U or satisfy a minimum burnup requirement for higher initial enrichments up to 5.0 w/o ^{235}U. A 3-out-of-4 checkerboard with empty cells means that no more than 3 fuel assemblies can occupy any 2x2 matrix of storage cells. The soluble boron concentration that results in a 95/95 K_{eff} of less than 0.95 was calculated as 350 ppm. Including accidents, the soluble boron credit required for this storage configuration is 1250 ppm.
2-out-of-4 Checkerboard Storage	For storage of 17x17 STD fuel assemblies in a 2-out-of-4 checkerboard arrangement with empty cells, fuel assemblies must have an initial nominal enrichment no greater than 5.00 w/o ^{235}U. A 2-out-of-4 checkerboard with empty cells means that two fuel assemblies may not be stored face adjacent. Fuel assemblies may be stored corner adjacent. The soluble boron concentration that results in a 95/95 K_{eff} of less than 0.95 was calculated as 0 ppm. There are no limitations on required burnup for this configuration. Including accidents, the soluble boron credit required for this storage configuration is 1400 ppm.

The analytical methods employed herein conform with ANSI N18.2-1973, "Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants," Section 5.7 Fuel Handling System except for the use of pure water; ANSI 57.2-1983, "Design Requirements for Light Water Reactor Spent Fuel Storage Facilities at Nuclear Power Plants", Section 6.4.2; ANSI/ANS 8.1 - 1983, " Nuclear Criticality Safety in Operations with Fissionable Materials

Outside Reactors", Section 4.3; and the NRC Standard Review Plan, Section 9.1.2, "Spent Fuel Storage". The spent fuel rack criticality analysis takes credit for the soluble boron in the spent fuel pool water as discussed in Reference 1.

Table 1. Nominal Fuel Parameters Employed in the Criticality Analysis

Parameter	Westinghouse 17x17 STD
Number of Fuel Rods per Assembly	264
Fuel Rod Clad O.D. (inch)	0.3740
Clad Thickness (inch)	0.0225
Fuel Pellet O.D. (inch)	0.3225
Fuel Pellet Density (% of Theoretical)	95.5
Fuel Pellet Dishing Factor (%)	1.2074
Rod Pitch (inch)	0.496
Number of Guide Tubes	24
Guide Tube O.D. (inch)	0.482
Guide Tube Thickness (inch)	0.016
Number of Instrument Tubes	1
Instrument Tube O.D. (inch)	0.482
Instrument Tube Thickness (inch)	0.016

Table 2. All Cell Storage 95/95 K_{eff} for Beaver Valley Unit 2

	No Soluble Boron	With Soluble Boron
Nominal KENO-Va Reference Reactivity:	0.96992	0.91220
Calculational & Methodology Biases:		
Methodology (Benchmark) Bias	0.00770	0.00770
Pool Temperature Bias (50°F - 185°F)	0.00774	0.00772
TOTAL Bias	0.01544	0.01542
Tolerances & Uncertainties:		
UO_2 Enrichment Tolerance	0.00774	0.00787
UO_2 Density Tolerance	0.00302	0.00349
Fuel Pellet Dishing Variation	0.00178	0.00205
Cell Inner Dimension	0.00010	0.00014
Cell Pitch	0.00306	0.00301
Cell Wall Thickness	0.00532	0.00386
Wrapper Thickness	0.00273	0.00198
Asymmetric Assembly Position	0.00855	0.00876
Calculational Uncertainty (95/95)	0.00099	0.00097
Methodology Bias Uncertainty (95/95)	0.00300	0.00300
TOTAL Uncertainty (statistical) $\sqrt{\sum_{i=1}^{10}((tolerance_i...or...uncertainty_i)^2)}$	0.01416	0.01389
Final K_{eff} Including Uncertainties & Tolerances:	0.99952	0.94151

Table 3. Minimum Burnup Requirements for Beaver Valley Unit 2

Nominal Enrichment (w/o ^{235}U)	All Cell Burnup (MWD/MTU)	3-out-of-4 Checkerboard Burnup (MWD/MTU)	2-out-of-4 Checkerboard Burnup (MWD/MTU)
1.90	0	0	0
2.00	1615	0	0
2.20	4629	0	0
2.40	7295	0	0
2.60	9677	0	0
2.80	11877	1798	0
3.00	13995	3556	0
3.20	16112	5268	0
3.40	18235	6940	0
3.60	20349	8581	0
3.80	22443	10198	0
4.00	24503	11800	0
4.20	26519	13394	0
4.40	28492	14979	0
4.60	30428	16552	0
4.80	32329	18110	0
5.00	34201	19650	0

Table 4. 3-out-of-4 Checkerboard 95/95 Keff for Beaver Valley Unit 2

	No Soluble Boron	With Soluble Boron
Nominal KENO-Va Reference Reactivity:	0.97235	0.92292
Calculational & Methodology Biases:		
Methodology (Benchmark) Bias	0.00770	0.00770
Pool Temperature Bias (50°F - 185°F)	0.00383	0.00361
TOTAL Bias	0.01153	0.01131
Tolerances & Uncertainties:		
UO_2 Enrichment Tolerance	0.00464	0.00479
UO_2 Density Tolerance	0.00270	0.00312
Fuel Pellet Dishing Variation	0.00158	0.00183
Cell Inner Dimension	0.00005	0.00014
Cell Pitch	0.00215	0.00222
Cell Wall Thickness	0.00453	0.00325
Wrapper Thickness	0.00232	0.00169
Asymmetric Assembly Position	0.00813	0.00834
Calculational Uncertainty (95/95)	0.00114	0.00111
Methodology Bias Uncertainty (95/95)	0.00300	0.00300
TOTAL Uncertainty (statistical)	0.01176	0.01159
$\sqrt{\sum_{i=1}^{10}((tolerance_i...or...uncertainty_i)^2)}$		
Final K_{eff} Including Uncertainties & Tolerances:	0.99564	0.94582

Table 5. 2-out-of-4 Checkerboard 95/95 Keff for Beaver Valley Unit 2

	No Soluble Boron
Nominal KENO-Va Reference Reactivity:	0.93203
Calculational & Methodology Biases:	
Methodology (Benchmark) Bias	0.00770
Pool Temperature Bias (50°F - 185°F)	0.00018
TOTAL Bias	0.00788
Tolerances & Uncertainties:	
UO_2 Enrichment Tolerance	0.00144
UO_2 Density Tolerance	0.00227
Fuel Pellet Dishing Variation	0.00126
Cell Inner Dimension	0.00001
Cell Pitch	0.00049
Cell Wall Thickness	0.00267
Wrapper Thickness	0.00131
Asymmetric Assembly Position	0.00238
Calculational Uncertainty (95/95)	0.00134
Methodology Bias Uncertainty (95/95)	0.00300
TOTAL Uncertainty (statistical)	0.00586
$\sqrt{\sum_{i=1}^{10}((tolerance_i \ldots or \ldots uncertainty_i)^2)}$	
Final K_{eff} Including Uncertainties & Tolerances:	0.94577

Table 6. Postulated Accident Summary for Beaver Valley Unit 2

Storage Configuration	Reactivity Increase Caused by a Temperature Change (ΔK)	Reactivity Increase Caused by Misloaded Fuel Assembly Within the Rack Module (ΔK)	Reactivity Increase Caused by Misloaded Fuel Assembly Between the Rack Module and the Wall (ΔK)	Soluble Boron Required for Misloaded Fuel Assembly Accident (ppm)
All Cells	0.00363	0.05079	0.07930	600
3-out-of-4 Checkerboard	0.00170	0.07818	0.10615	900
2-out-of-4 Checkerboard	0.0	0.13882	0.16002	1400

Table 7. Summary of Soluble Boron Credit Requirements for Beaver Valley Unit 2

Storage Configuration	Soluble Boron Required for Keff < 0.95 (ppm)	Soluble Boron Required for Reactivity Equivalencing (ppm)	Total Soluble Boron Credit Required (No Fuel Handling) (ppm)	Soluble Boron Required for Accident (ppm)	Total Soluble Boron Credit Required Including Accidents (ppm)
All Cells	200	250	450	600	1050
3-out-of-4 Checkerboard	200	150	350	900	1250
2-out-of-4 Checkerboard	0	0	0	1400	1400

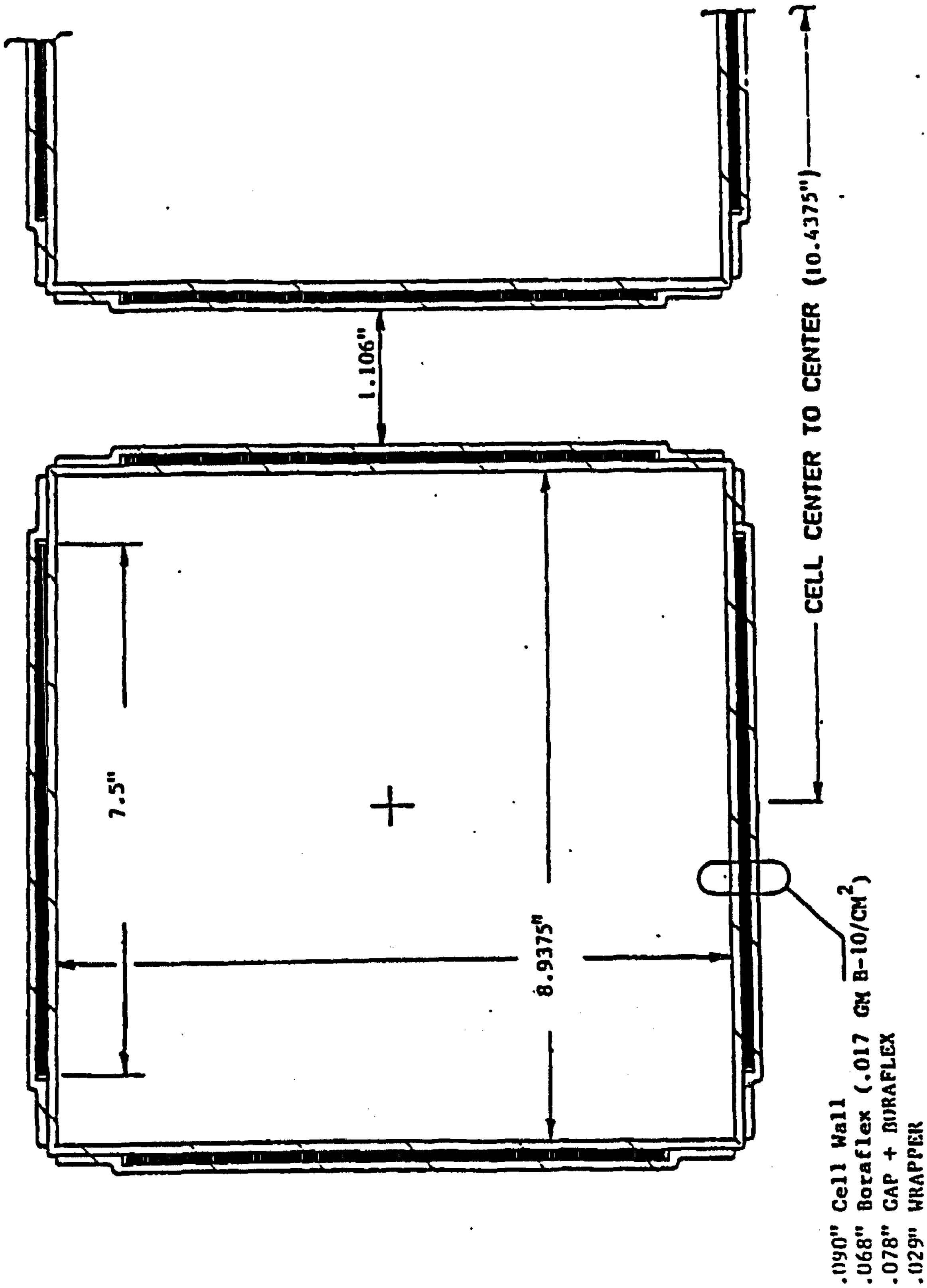


Figure 1. Beaver Valley Unit 2 Spent Fuel Storage Cell Nominal Dimensions

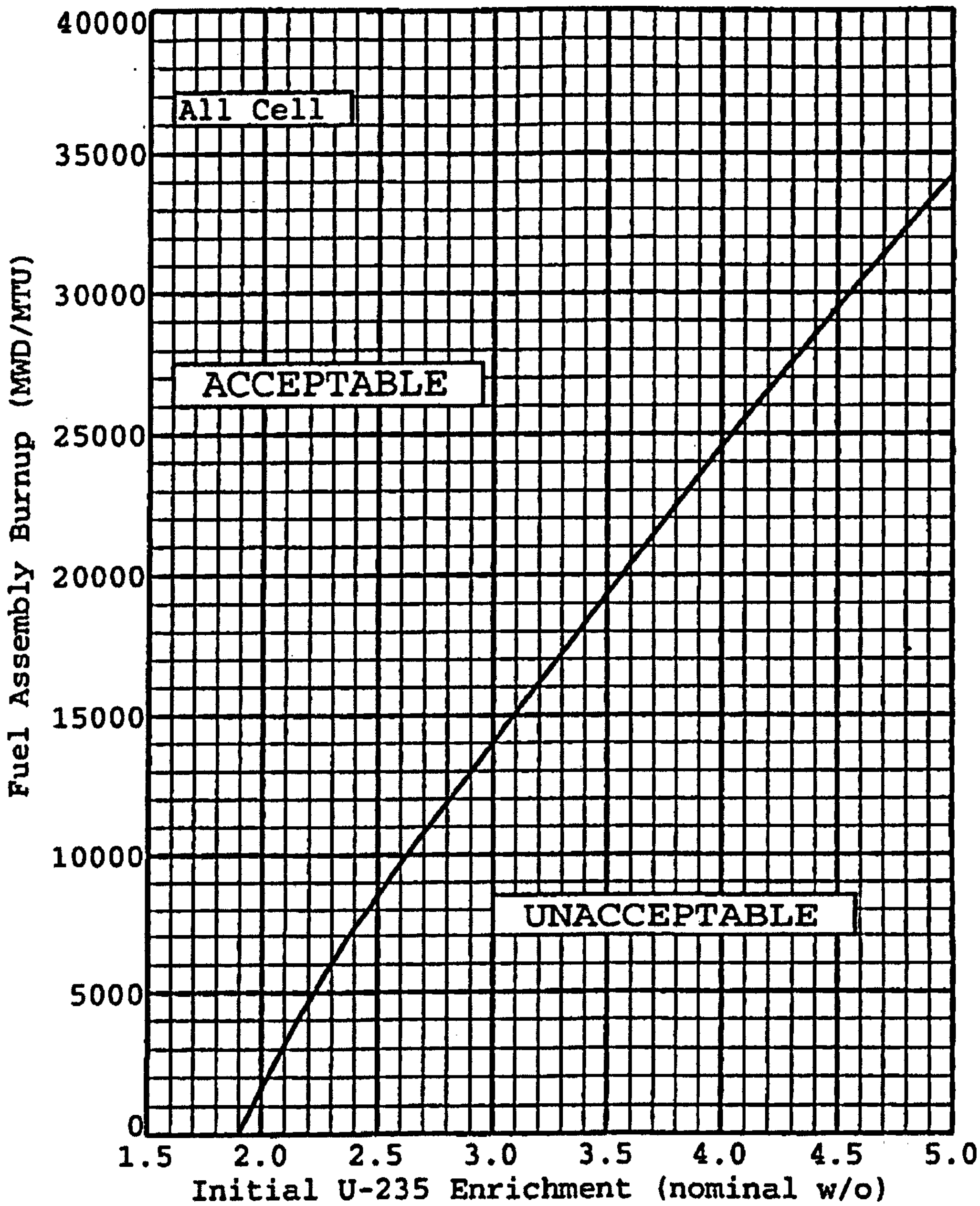


Figure 2. Beaver Valley Unit 2 Burnup Credit Requirements for All Cell Storage

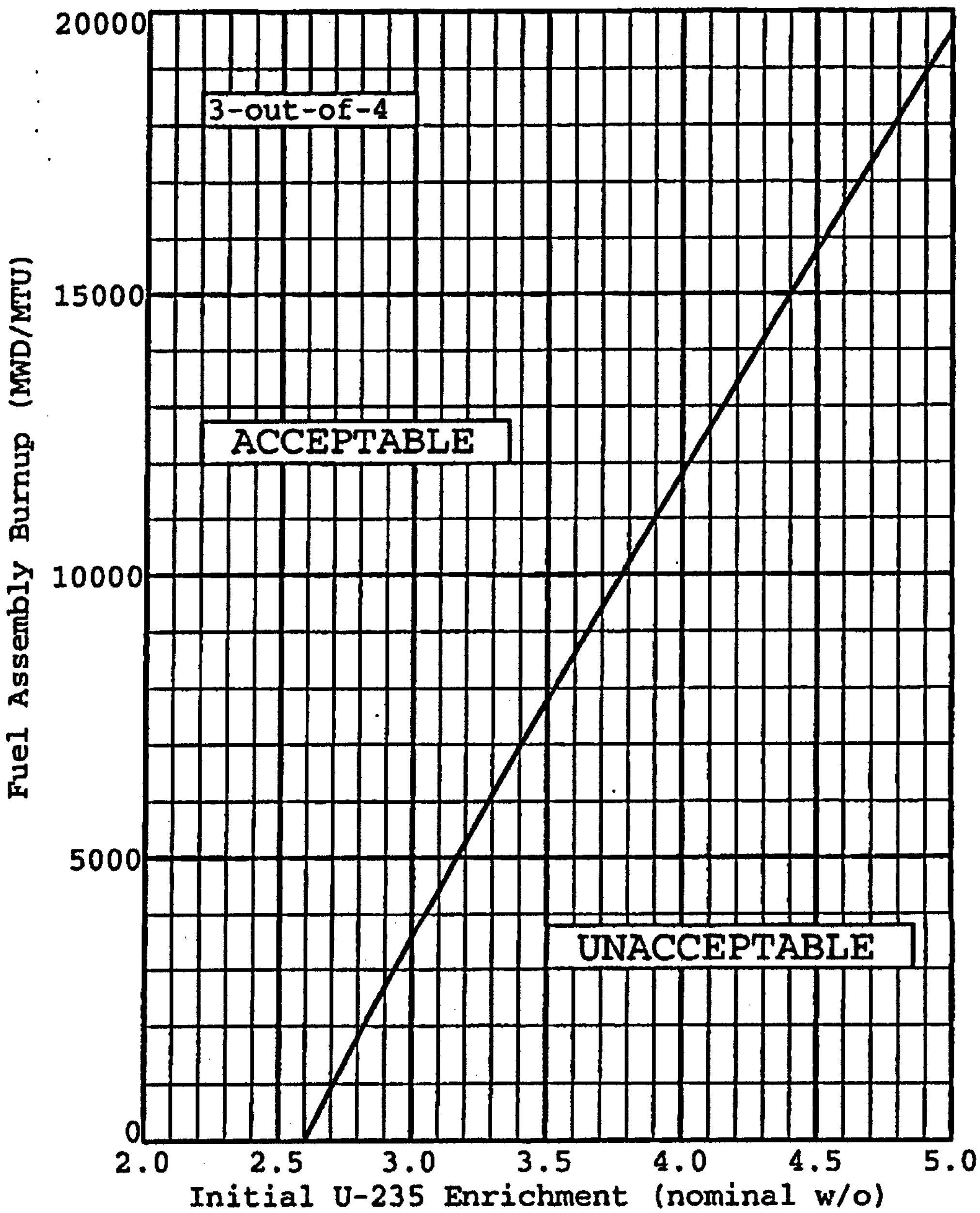


Figure 3. Beaver Valley Unit 2 Burnup Credit Requirements for 3-Out-Of-4 Storage

1.90 w/o	1.90 w/o
1.90 w/o	1.90 w/o

All Cell Storage

2.60 w/o	2.60 w/o
2.60 w/o	Empty

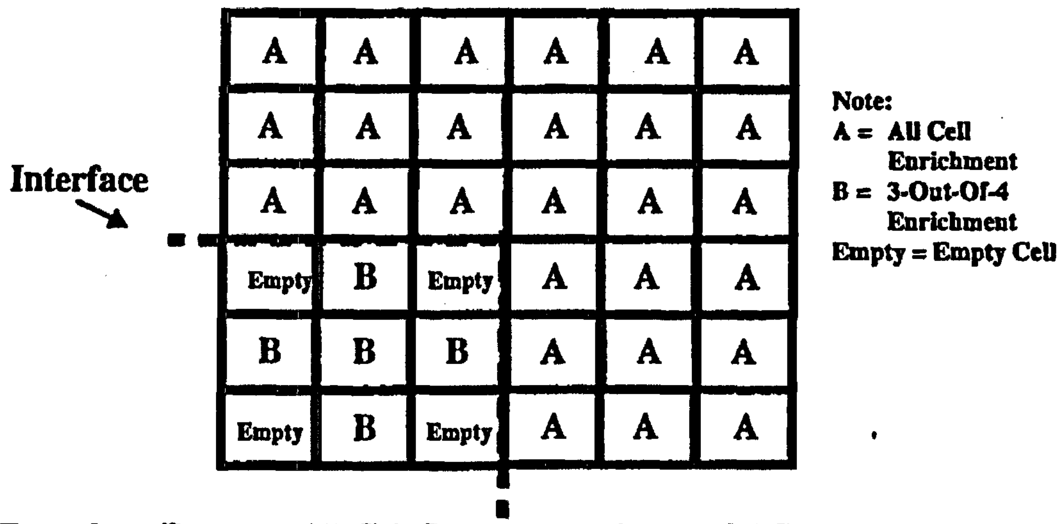
3-Out-Of-4 Storage

5.0 w/o	Empty
Empty	5.0 w/o

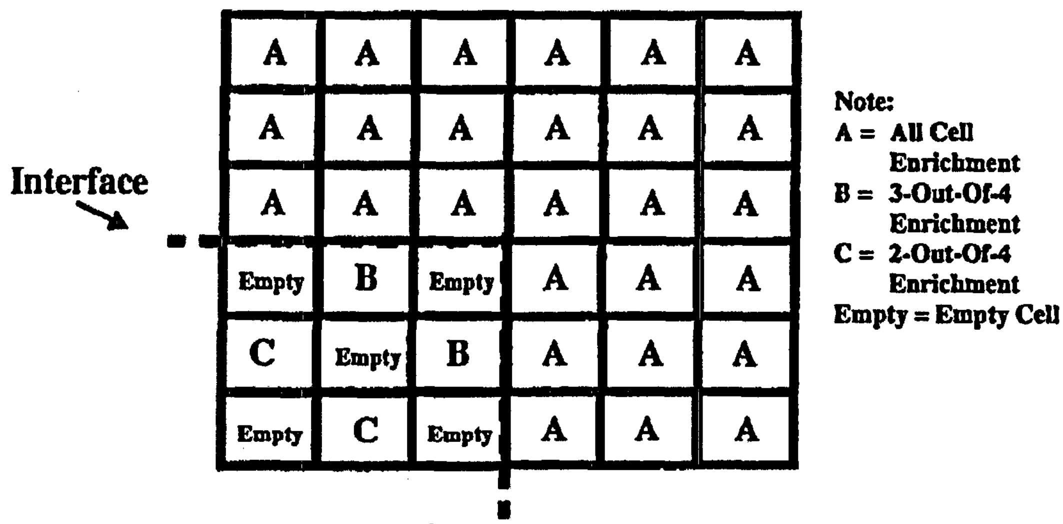
2-Out-Of-4 Storage

Note: All values are nominal enrichments.

Figure 4. Beaver Valley Unit 2 Storage Configurations



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



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

Note:

1. **A row of empty cells can be used at the interface to separate the configurations.**
2. **It is acceptable to replace an assembly with an empty cell.**

Figure 5. Beaver Valley Unit 2 Interface Requirements (All Cell to Checkerboard Storage)

Interface

B	Empty	B	Empty	B	Empty
B	B	B	B	B	B
B	Empty	B	Empty	B	Empty
Empty	C	Empty	B	B	B
C	Empty	C	Empty	B	Empty
Empty	C	Empty	B	B	B

Note:
B = 3-Out-Of-4 Enrichment
C = 2-Out-Of-4 Enrichment
Empty = Empty Cell

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

Interface

Empty	B	Empty	B	B	B
B	B	B	B	Empty	B
Empty	B	Empty	B	B	B
C	Empty	C	Empty	B	Empty
Empty	C	Empty	B	B	B
C	Empty	C	Empty	B	Empty

Note:
B = 3-Out-Of-4 Enrichment
C = 2-Out-Of-4 Enrichment
Empty = Empty Cell

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

Note:
1. A row of empty cells can be used at the interface to separate the configurations.
2. It is acceptable to replace an assembly with an empty cell.

Figure 6. Beaver Valley Unit 2 Interface Requirements (Checkerboard Storage Interface)

Bibliography

1. Newmyer, W.D., *Westinghouse Spent Fuel Rack Criticality Analysis Methodology,* WCAP-14416-NP-A Revision 1, November 1996.
2. Davidson, S.L., et al, *VANTAGE 5 Fuel Assembly Reference Core Report, Addendum 2A,* WCAP-10444-P-A, April 1988.
3. Newmyer. W.D., *Fuel Rod Storage Canister Criticality Analysis*, October 1994.