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March 28, 2001
L-01-044

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

**Subject: Beaver Valley Power Station, Unit No. 2
Docket No. 50-412, License No. NPF-73
License Amendment Request No. 137
Credit for Soluble Boron**

Pursuant to 10 CFR 50.90, FENOC requests an amendment to the above license in the form of changes to the technical specifications. The proposed change will credit soluble boron for reactivity control in the Beaver Valley Power Station (BVPS) Unit No. 2 spent fuel pool. The proposed change does not credit the Boraflex in the Unit No. 2 spent fuel pool. The justification for the proposed change is based on the NRC approved methodology developed by the Westinghouse Owners Group and described in WCAP-14416-NP-A, "Westinghouse Spent Fuel Rack Criticality Analysis Methodology," as supplemented by Westinghouse letter FENOC-00-110, dated November 3, 2000.

The proposed change splits technical specification 3/4.9.14, "FUEL STORAGE – SPENT FUEL STORAGE," into two technical specifications to be consistent with the Improved Standard Technical Specifications contained in NUREG-1431, "Standard Technical Specifications - Westinghouse Plants," Revision 1 and TSTF-70 and 255. The new technical specifications consist of a revision to technical specification 3/4.9.14, whose title is changed to "SPENT FUEL POOL STORAGE." This technical specification will control the storage of spent fuel assemblies in the spent fuel pool. The new technical specification, 3/4.9.15, "FUEL STORAGE BORON CONCENTRATION," will control the boron concentration in the fuel storage pool.

The proposed technical specification changes are presented in Attachment A. The safety analysis and no significant hazard evaluation are presented in Attachment B. Two plant specific analyses, justifying the proposed change, are provided as attachments to this license amendment request. Attachment C contains "Beaver Valley Unit 2 Spent Fuel Rack Criticality Analysis With Credit for Soluble Boron," CAA-98-158, Revision 1, dated November 1998. Attachment D contains "Beaver Valley Unit 2 Spent Fuel Pool Dilution Analysis," Revision 0, dated July 17, 1998.

A001

Following approval of the proposed change, appropriate procedures will be revised to ensure that the boundary checkerboarding configurations and the boundary between all cell storage configurations are controlled to prevent an undesirable increase in reactivity. This will be accomplished by adhering to the guidance provided in the criticality analysis supplied as Attachment C.

A response to Generic Letter 96-04, "Boraflex Degradation in Spent Fuel Pool Storage Racks," was provided in an October 24, 1996 letter from Duquesne Light Company (former operator of BVPS Units No. 1 and No. 2) to the NRC. This letter outlined a program in which BVPS committed to periodical sampling of the Boraflex in the BVPS Unit No. 2 spent fuel pool. Approval of this license amendment request will relieve BVPS Unit No. 2 from the above commitment to Generic Letter 96-04. Presently BVPS Unit 2 periodically samples the condition of the Boraflex in the spent fuel pool. Since the criticality analysis justifying the proposed change does not credit the Boraflex, the need to sample and evaluate the condition of the Boraflex will no longer exist following approval of the proposed changes.

This change has been reviewed by the Beaver Valley review committees. The change was determined to be safe and does not involve a significant hazard consideration as defined in 10 CFR 50.92 based on the attached safety analysis and no significant hazard evaluation. An implementation period of up to 60 days is requested following the effective date of this amendment.

If there are any questions concerning this matter, please contact Mr. Thomas S. Cosgrove, Manager, Regulatory Affairs at 724-682-5203.

Sincerely,

Lew W. Myers

c: Mr. L. J. Burkhart, Project Manager
Mr. D. M. Kern, Sr. Resident Inspector
Mr. H. J. Miller, NRC Region I Administrator
Mr. D. A. Allard, Director BRP/DEP
Mr. L. E. Ryan (BRP/DEP)

Subject: **Beaver Valley Power Station, Unit No. 2**
BV-2 Docket No. 50-412, License No. NPF-73
License Amendment Request No. 137
Credit for Soluble Boron

I, Lew W. Myers, being duly sworn, state that I am Senior Vice President of FirstEnergy Nuclear Operating Company (FENOC), that I am authorized to sign and file this submittal with the Nuclear Regulatory Commission on behalf of FENOC, and that the statements made and the matters set forth herein pertaining to FENOC are true and correct to the best of my knowledge and belief.

FirstEnergy Nuclear Operating Company

Lew W. Myers
Senior Vice President - FENOC

COMMONWEALTH OF PENNSYLVANIA

COUNTY OF BEAVER

Subscribed and sworn to me, a Notary Public, in and for the County and State above named, this 28 th day of March, 2001.

My Commission Expires:

Sheila M. Fattore, Notary Public
Shippingport Boro, Beaver County
My Commission Expires Sept. 30, 2002
Member, Pennsylvania Association of Notaries

ATTACHMENT A

Beaver Valley Power Station, Unit No. 2
License Amendment Request No. 137

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BASES

(Proposed wording)

INDEX

BASES

DESIGN FEATURES

ADMINISTRATIVE CONTROLS

(Proposed Wording)

pool

3/4.9.14 ~~FUEL STORAGE~~ SPENT FUEL pool STORAGE ~~POOL~~

LIMITING CONDITION FOR OPERATION

3.9.14 Fuel is to be stored in the spent fuel storage pool with:

a. The boron concentration in the spent fuel pool maintained greater than or equal to 1050 ppm when moving fuel in the spent fuel pool; and

b. Fuel assembly storage in Region 1 restricted to fuel with an enrichment less than or equal to 4.85 w/o stored in a 3-out-of-4 checkerboard configuration; and

c. Fuel assembly storage in Region 2 restricted to fuel which has been qualified in accordance with Table 3.9-1.

APPLICABILITY: During storage of fuel in the spent fuel pool.

ACTION:

a. Suspend all actions involving movement of fuel in the spent fuel pool if it is determined a fuel assembly has been placed in the incorrect Region until such time as the correct storage location is determined. Move the assembly to its correct location before resumption of any other fuel movement.

b. Suspend all actions involving the movement of fuel in the spent fuel pool if it is determined the pool boron concentration is less than 1050 ppm, until such time as the boron concentration is increased to 1050 ppm or greater.

c. The provisions of Specifications 3.0.3 and 3.0.4 are not applicable.

SURVEILLANCE REQUIREMENTS

4.9.14.1 Prior to placing fuel or moving fuel in the spent fuel pool, verify through fuel receipt records for new fuel or by burnup analysis and comparison with Table 3.9-1 that fuel assemblies to be place into or moved in the spent fuel pool are within the above enrichment limits.

4.9.14.2 Verify the spent fuel pool boron concentration is $\geq$ 1050 ppm:

a. Within 8 hours prior to and at least once per 24 hours during movement of fuel in the spent fuel pool, and

b. At least once per 31 days.

REPLACE WITH INSERT 1

(Proposed Wording)

INSERT 1

The combination of initial enrichment and burnup of each fuel assembly stored in the spent fuel storage pool shall comply with the limits specified in Table 3.9-1.

APPLICABILITY: Whenever any fuel assembly is stored in the spent fuel storage pool.

ACTION: With the above requirements not satisfied:

a. Immediately initiate action to move the non-complying fuel assembly to a location that complies with Table 3.9-1.

b. The provisions of Specifications 3.0.3 and 3.0.4 are not applicable.

SURVEILLANCE REQUIREMENTS

4.9.14 Verify, by administrative means, the initial enrichment and burnup complies with Table 3.9-1 prior to storing a fuel assembly in the spent fuel storage pool.

Table 3.9-1

BEAVER VALLEY FUEL ASSEMBLY MINIMUM VS. INITIAL U_{235}
ENRICHMENT FOR STORAGE IN REGION 2 SPENT FUEL RACKS

Initial U_{235} Enrichment	Assembly Discharge Burnup (GWD/MTU)
3.6	0
4.0	2.6
4.4	5.3
4.85	8.2

NOTE 1: Linear interpolation yields conservative results.

NOTE 2: The maximum burnup in the peak fuel rod should not exceed 60 GWD/MTU. See the safety evaluation associated with Amendment No. 12 for details.

REPLACE WITH INSERT 2

Attachment A
Beaver Valley Power Station, Unit No. 2
License Amendment Request No. 137

INSERT 2

FUEL ASSEMBLY MINIMUM BURNUP VS. U-235 NOMINAL ENRICHMENT
FOR STORAGE IN SPENT FUEL RACK REGIONS 1,2,3

Nominal Enrichment (w/o U-235)	Region 3 4-out-of-4 Burnup (MWD/MTU)	Region 2 3-out-of-4 Checkerboard Burnup (MWD/MTU)	Region 1 2-out-of-4 Checkerboard Burnup (MWD/MTU)
1.9	0	0	0
2.0	1615	0	0
2.2	4629	0	0
2.4	7295	0	0
2.6	9677	0	0
2.8	11877	1798	0
3.0	13995	3556	0
3.2	16112	5268	0
3.4	18235	6940	0
3.6	20349	8581	0
3.8	22443	10198	0
4.0	24503	11800	0
4.2	26519	13394	0
4.4	28492	14979	0
4.6	30428	16552	0
4.8	32329	18110	0
5.0	34201	19650	0

Note 1: Linear interpolation yields conservative results.

3/4.9.15 FUEL STORAGE POOL BORON CONCENTRATION

LIMITING CONDITION FOR OPERATION

3.9.15 The fuel storage pool boron concentration shall be greater than or equal to 2000 ppm.

APPLICABILITY: When fuel assemblies are stored in the fuel storage pool.

ACTION: With fuel storage pool boron concentration not within limits,

a. Immediately suspend all operations involving the movement of fuel assemblies in the fuel storage pool and initiate action to restore the fuel storage pool boron concentration to within the limit.

b. The provisions of Specifications 3.0.3 and 3.0.4 are not applicable.

SURVEILLANCE REQUIREMENTS

4.9.15 Verify the fuel storage pool boron concentration is within the limit at least once per 7 days.

BASES

3/4.9.12 and 3/4.9.13 FUEL BUILDING VENTILATION SYSTEM

The limitations on the storage pool ventilation system ensure that all radioactive material released from an irradiated fuel assembly will be filtered through the HEPA filters and charcoal adsorber prior to discharge to the atmosphere. The OPERABILITY of this system and the resulting iodine removal capacity are consistent with the assumptions of the accident analysis. The spent fuel pool area ventilation system is non-safety related and only recirculates air through the fuel building. The fuel building portion of the SLCRS is safety related and continuously filters the fuel building exhaust air. This maintains a negative pressure in the fuel building.

3/4.9.14 FUEL STORAGE - SPENT FUEL STORAGE POOL

The requirements for fuel storage in the spent fuel pool ensure that: (1) the spent fuel pool will remain subcritical during fuel storage; ~~and (2) a uniform boron concentration is maintained in the water volume in the spent fuel pool to provide negative reactivity for postulated accident conditions under the guidelines of ANSI 16.1-1975.~~ The value of 0.95 or less for K_{eff} which includes all uncertainties at the 95/95 probability/confidence level is the acceptance criteria for fuel storage in the spent fuel pool.

Verification that peak fuel rod burnup is less than 60 GWD/MTU is provided in the reload evaluation report associated with each fuel cycle.

The Action Statement applicable to fuel storage in the spent fuel pool ensures that: (1) the spent fuel pool is protected from distortion in the fuel storage pattern that could result in a critical array during the movement of fuel; and (2) the boron concentration is maintained at ≥ 1050 ppm (this includes a 50 ppm conservative allowance for uncertainties) during all actions involving movement of fuel in the spent fuel pool.

The Surveillance Requirements applicable to fuel storage in the spent fuel pool ensure that: (1) the fuel assemblies satisfy the analyzed U-235 enrichment limits or an analysis has been performed and it was determined that K_{eff} is ≤ 0.95; and (2) the boron concentration meets the 1050 ppm limit.

Insert 3

(Proposed Wording)

INSERT 3

The spent fuel storage racks contain storage locations for 1088 fuel assemblies. The spent fuel racks have been analyzed in accordance with the methodology contained in WCAP-14416-NP-A, "Westinghouse Spent Fuel Rack Criticality Analysis Methodology," Revision 1, November 1996 supplemented by Westinghouse letter FENOC-00-110, dated November 3, 2000. This methodology ensures that the spent fuel rack multiplication factor, K_{eff} is less than 0.95, as recommended by ANSI 57.2-1983 and the guidance contained in NRC letter to All Power Reactor Licensees from B. K. Grimes, "OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications," April 14, 1978. The codes, methods, and techniques contained in the methodology are used to satisfy this K_{eff} criterion. The spent fuel storage racks are analyzed to allow storage of Westinghouse 17 x 17 Standard fuel assemblies with nominal enrichments up to 5.0 w/o U-235 utilizing credit for checkerboard configurations and burnup, to ensure that K_{eff} is maintained ≤ 0.95, including uncertainties, tolerances, and accident conditions. In addition, the spent fuel pool K_{eff} is maintained < 1.0 including uncertainties and tolerances on a 95/95 probability/confidence level basis without soluble boron.

The 17 x 17 VANTAGE 5H fuel design parameters relevant to the criticality analysis are the same as the 17 x 17 Standard fuel assembly parameters and will yield equivalent results (credit is not taken for grids). Therefore, all references to 17 x 17 Standard fuel are taken to include 17 x 17 VANTAGE 5H fuel. Future fuel assembly upgrades do not require a criticality analysis if the fuel rod diameter continues to be 0.374 inches (Standard fuel) and the rod pitch is 0.490 inches.

The following storage configurations and enrichment limits were evaluated in the spent fuel rack criticality analysis:

Westinghouse 17 x 17 Standard fuel assemblies with nominal enrichments less than or equal to 1.90 w/o U-235 can be stored in any cell location. This configuration is considered Region 3. Fuel assemblies with initial nominal enrichments greater than these limits must satisfy a minimum burnup requirement as shown in Table 3.9-1.

Westinghouse 17 x 17 Standard fuel assemblies can be stored in a three out of four checkerboard arrangement of a 2 x 2 matrix of storage cells. This configuration is considered Region 2. In the three out of four 2 x 2 checkerboard arrangement, the three fuel assemblies must have an initial nominal enrichment less than or equal to 2.6 w/o U-235, or satisfy a minimum burnup requirement for higher initial enrichments as shown in Table 3.9-1.

INSERT 3 (Continued)

Westinghouse 17 x 17 Standard fuel assemblies with nominal enrichments less than or equal to 5.0 w/o U-235 can be stored in a two out of four checkerboard arrangement. This configuration is considered Region 1. In the two out of four checkerboard storage arrangement, the two fuel assemblies shall be stored corner adjacent and cannot be stored face adjacent.

The requirements of this specification ensure that fuel assemblies are stored in the spent fuel racks in accordance with the configurations assumed in the spent fuel rack criticality analysis. The surveillance requirements require "administrative means" be used to verify initial enrichment and burnup of fuel assemblies prior to storage. Administrative means refers to the site refueling procedures.

3/4.9.15 FUEL STORAGE POOL BORON CONCENTRATION

The requirements for boron concentration in the fuel storage pool ensure that a uniform boron concentration is maintained in the water volume in the spent fuel pool to provide negative reactivity for postulated accident conditions under the guidelines of ANSI/ANS 8.1-1983, "Nuclear Criticality Safety in Operations and Fissionable Materials Outside Reactors," Section 4.3. The most limiting accident with respect to the storage configurations assumed in the spent fuel rack criticality analysis is the misplacement of a Westinghouse 17 x 17 Standard 5.0 w/o U-235 fuel assembly between the rack module and pool wall at a corner interface of two rack modules. The amount of soluble boron required to maintain K_{eff} less than 0.95 due to this fuel misload accident is 1400 ppm. The 2000 ppm limit specified in the Limiting Condition for Operation is consistent with the normal boron concentration maintained in the fuel storage pool and bounds the 1400 ppm required for a fuel misload accident.

Design Feature 5.3.1.1.c. requires a boron concentration of 450 ppm to be maintained in the fuel storage pool to ensure $K_{eff} \leq 0.95$. The soluble boron concentration required to maintain $K_{eff} \leq 0.95$ under normal conditions is 450 ppm. A fuel storage pool boron dilution analysis was performed to determine that sufficient time is available to detect and mitigate dilution of the fuel storage pool prior to exceeding the K_{eff} design basis limit of 0.95. The fuel storage pool boron dilution analysis concluded that an inadvertent or unplanned event that would result in dilution of the fuel storage pool boron concentration from 2000 ppm to 450 ppm is not a credible event.

The action statement ensures that the boron concentration is maintained $\geq$ 2000 ppm during all actions involving movement of fuel in the fuel storage pool and when fuel assemblies are stored in the fuel storage pool.

5.1 SITE LOCATION

The Beaver Valley Power Station Unit No. 2 is located in Shippingport Borough, Beaver County, Pennsylvania, on the south bank of the Ohio River. The site is approximately 1 mile southeast of Midland, Pennsylvania, 5 miles east of East Liverpool, Ohio, and approximately 25 miles northwest of Pittsburgh, Pennsylvania. The exclusion area boundary has a minimum radius of 2000 feet around the Unit No. 1 containment building.

5.2 REACTOR CORE

5.2.1 FUEL ASSEMBLIES

The reactor shall contain 157 fuel assemblies. Each assembly shall consist of a matrix of Zircaloy or ZIRLO fuel rods with an initial composition of natural or slightly enriched uranium dioxide (UO_2) as fuel material. Limited substitutions of zirconium alloy or stainless steel filler rods for fuel rods, in accordance with approved applications of fuel rod configurations, may be used. Fuel assemblies shall be limited to those fuel designs that have been analyzed with applicable NRC staff approved codes and methods and shown by tests or analyses to comply with all fuel safety design bases. A limited number of lead test assemblies that have not completed representative testing may be placed in nonlimiting core regions.

5.2.2 CONTROL ROD ASSEMBLIES

The reactor core shall contain 48 full length and no part length control rod assemblies. The full length control rod assemblies shall contain a nominal 142 inches of absorber material. The nominal values of absorber material shall be 80 percent silver, 15 percent indium and 5 percent cadmium. All control rods shall be clad with stainless steel tubing.

5.3 FUEL STORAGE

5.3.1 CRITICALITY

5.3.1.1 The spent fuel storage racks are designed and shall be maintained with:

Insert 4

b ~~a~~. Fuel assemblies having a maximum U-235 enrichment as set forth in Specification 3.9.14;

c ~~b~~. $K_{eff} \leq 0.95$ if fully flooded with ~~unborated~~ water, borated to 450 ppm which includes an allowance for uncertainties as described in UFSAR Section 9.1;

(Proposed Wording)

INSERT 4

a. K_{eff} < 1.0 if fully flooded with unborated water, which includes an allowance for uncertainties as described in UFSAR Section 9.1;

d ~~c~~. A minimum center to center distance between fuel assemblies placed in the fuel storage racks of 10.4375 inches;

e ~~d~~. Fuel assembly storage shall comply with the requirements of Specification 3.9.14.

5.3.1.2 The new fuel storage racks are designed and shall be maintained with:

a. Fuel assemblies having a maximum U-235 enrichment of 4.85 weight percent;

b. $K_{eff} \leq 0.95$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in UFSAR Section 9.1;

c. $K_{eff} \leq 0.95$ if moderated by aqueous foam, which includes an allowance for uncertainties as described in UFSAR Section 9.1;

d. A nominal 21 inch center to center distance between fuel assemblies placed in the storage racks.

5.3.2 DRAINAGE

The spent fuel storage pool is designed and shall be maintained to prevent inadvertent draining of the pool below elevation 751'-3".

5.3.3 CAPACITY

The fuel storage pool is designed and shall be maintained with a storage capacity limited to no more than 1088 fuel assemblies.

ATTACHMENT B

Beaver Valley Power Station, Unit No. 2
License Amendment Request No. 137
SPENT FUEL POOL BORON CREDIT

A. DESCRIPTION OF AMENDMENT REQUEST

The proposed amendment revises the Technical Specification (TS) requirements to credit the soluble boron in the fuel storage pool analyses. This amendment revises the Index, modifies TS 3.9.14 FUEL STORAGE - SPENT FUEL STORAGE POOL, adds TS 3.9.15 FUEL STORAGE POOL BORON CONCENTRATION, modifies applicable Bases and revises Design Feature Section 5.3.1.1 Criticality.

TS 3.9.14 has been modified by separating this specification into two specifications to support crediting soluble boron in the fuel storage pool. The revised TS 3.9.14 provides controls for fuel assembly enrichment and burnup in the spent fuel pool and also includes an increase in the maximum enrichment from 4.85 weight percent (w/o) to 5.0 w/o. A new TS 3.9.15 provides controls for soluble boron requirements in the spent fuel pool. Separating this specification into two specifications follows the guidance provided in the Improved Standard Technical Specifications (ISTS) of NUREG-1431 which provides TS 3.7.17 for Spent Fuel Pool Storage and TS 3.7.16 for Fuel Storage Pool Boron Concentration. The proposed TS 3.9.15 differs from ISTS Specification 3.7.16 by deleting the ISTS Applicability and Action A.2.2 option that would allow performance of a fuel storage pool verification. In addition, Action "b" has been added to state: "The provisions of TS 3.0.3 and TS 3.0.4 are not applicable."

The Index has been revised to address the title change to TS 3.9.14 and the addition of TS 3.9.15. The title of Bases 3/4.9.14, "FUEL STORAGE - SPENT FUEL STORAGE POOL," has been changed to "SPENT FUEL POOL STORAGE" and the content has been modified to credit the soluble boron in the fuel storage pool analyses. Bases 3/4.9.15 "Fuel Storage Pool Boron Concentration" has been added to provide a basis for the spent fuel pool boron concentration requirements.

A new Design Feature 5.3.1.1.a has been added and states: "$K_{eff} < 1.0$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in UFSAR Section 9.1." Design Feature 5.3.1.1.a has been changed to 5.3.1.1.b. Design Feature 5.3.1.1.b has been changed to 5.3.1.1.c and modified to state: "$K_{eff} \leq 0.95$ if fully flooded with water borated to 450 ppm, which includes an

allowance for uncertainties as described in UFSAR Section 9.1." Design Feature 5.3.1.1.c has been changed to 5.3.1.1.d and Design Feature 5.3.1.1.d has been changed to 5.3.1.1.e.

Editorial and format changes have been included as necessary to allow for the addition and deletion of text.

B. DESIGN BASES

The spent fuel storage pool contains spent fuel racks that incorporate a fixed neutron poison referred to as "Boraflex." Boraflex is an elastomer that contains boron, is manufactured in sheet form and contained in the sides of the spent fuel racks, and is credited for reduction of the reactivity associated with spent fuel. The spent fuel pool contains borated water, which has not previously been credited in the reduction of reactivity associated with spent fuel. The spent fuel racks are described in Updated Final Safety Analysis Report (UFSAR) Section 9.1.2, "Spent Fuel Storage."

The spent fuel pool has been analyzed for storage of fuel assemblies with a maximum enrichment of 4.85 w/o U-235 for both criticality and design basis accident radiological doses. Proposed revisions to the UFSAR design basis accident radiological doses have been submitted to the Nuclear Regulatory Commission (NRC) for approval as a result of the recent reevaluation of all Beaver Valley Power Station (BVPS) dose calculations. These analyses included fuel enrichments up to 5.0 w/o U-235. Letter L-00-008 dated May 12, 2000, submitted the results of BVPS-2 design basis accident dose calculations and UFSAR changes except for the fuel handling analysis. This was submitted separately by Letter L-00-048 dated May 1, 2000. These analyses utilized revised radionuclide inventories using updated fuel parameters by selecting the maximum activity from a range of core enrichments up to 5.0 w/o U-235. The new analyses caused a slight increase in the source terms; therefore, these changes were submitted to the NRC per 10 CFR 50.59(c) for NRC approval.

The spent fuel pool has been analyzed to store fuel assemblies in three configurations based on a four cell 2x2 matrix. These are "four out of four" meaning All Cells, "three out of four," and "two out of four." Fuel assemblies with enrichments up to 5.0 w/o U-235 may be stored in all four cells, provided they meet the burnup limits specified in Technical Specifications. Fuel assemblies with

enrichments up to 5.0 w/o U-235 may be stored in three out of four storage configuration, provided they meet separate burnup limits specified in Technical Specifications. Finally, all fuel assemblies with enrichments up to 5.0 w/o U-235 may be stored in two out of four diagonal storage configuration without any restriction on burnup. A spent fuel pool boron concentration of 450 ppm and 1400 ppm is required to ensure a K_{eff} less than or equal to 0.95 for normal and accident conditions, respectively.

Attachments C and D provide analyses that support crediting borated water in the spent fuel storage pool for reduction of reactivity associated with the spent fuel. Attachment C (CAA-98-158 Rev. 1 "Beaver Valley Unit 2 Spent Fuel Rack Criticality Analysis With Credit for Soluble Boron," November 1998) provides a criticality analysis to demonstrate that the borated water in the spent fuel storage pool provides criticality control that meets NRC requirements for spent fuel storage without crediting the poison affects of the Boraflex in the spent fuel storage racks. Attachment D ("Beaver Valley Unit 2 Spent Fuel Pool Dilution Analysis," Revision 0, July 7, 1998) provides a boron dilution analysis, since the borated water in the spent fuel storage pool is subject to dilution. Westinghouse letter FENOC-00-110 provides additional credits for reduction of reactivity to address a non-conservatism in the axial burnup bias calculation which was part of the methodology used by Westinghouse for calculating criticality of spent fuel pool configurations. The proposed Technical Specification changes are provided to assure that the assumptions of these spent fuel storage pool analyses remain valid.

C. JUSTIFICATION

The proposed Technical Specification changes credit the use of soluble boron in the spent fuel pool criticality analyses. These criticality analyses were performed using the NRC approved methodology developed by the Westinghouse Owners Group (WOG) and described in WCAP-14416-NP-A, Revision 1, "Westinghouse Spent Fuel Rack Criticality Analysis Methodology," November 1996, supplemented by Westinghouse letter FENOC-00-110, dated November 3, 2000.

The spent fuel storage racks were analyzed using the Westinghouse methodology, which has been reviewed and approved by the NRC. The WCAP methodology is supplemented with an evaluation (Westinghouse letter FENOC-00-110) that incorporates conservatisms inherent in the methodology in order to offset potentially non-conservative axial burnup bias calculations. This methodology takes partial

credit for soluble boron in the fuel storage pool criticality analyses and requires conformance with the following NRC acceptance criteria for preventing criticality outside the reactor.

(1) K_{eff} shall be less than 1.0 if the pool is fully flooded with unborated water, which includes an allowance for uncertainties at a 95% probability, with a 95% confidence level (95/95 level) as described in WCAP-14416-NP-A, Revision 1; and

(2) K_{eff} shall be less than or equal to 0.95 if the pool is fully flooded with borated water, which includes an allowance for uncertainties at a 95/95 level as described in WCAP-14416-NP-A, Revision 1.

The analysis of the reactivity effects of fuel storage in the spent fuel racks was performed with the three-dimensional Monte Carlo code, KENO-Va, with neutron cross-sections generated with the NITAWL-II and XSDRNPM-S codes using the 227 group ENDF/B-V cross-section library. Since the KENO-Va code package does not have burnup capability, depletion analyses and the determination of small reactivity increments due to manufacturing tolerances were made with the two-dimensional transport theory code, PHOENIX-P, which uses a 42 energy group nuclear data library. The analytical methods and models used in the reactivity analysis have been benchmarked against experimental data for fuel assemblies similar to those for which the racks are designed and have been found to adequately reproduce the critical values. This experimental data is sufficiently diverse to establish that the method bias and uncertainty will apply to rack conditions which include close proximity storage and strong neutron absorbers. The NRC has concluded that the analysis methods used are acceptable and capable of predicting the reactivity of the storage racks with a high degree of confidence. The NRC approved methodology is supplemented by Westinghouse letter FENOC-00-110. This letter documents non-conservatism in the axial burnup bias calculations that incorporate conservatisms inherent in the methodology in order to offset potentially non-conservative axial burnup bias calculations.

The Note "The maximum burnup in the peak fuel rod should not exceed 60 GWD/MTU. See the safety evaluation associated with Amendment No. 12 for details." is not maintained in the proposed Table 3.9-1. The concern for peak fuel rod burnup is addressed in WCAP 12610-P-A, "VANTAGE+ Fuel Assembly Reference Core Report." This topical report is used in establishing the core

operating limits documented in the Core Operating Limits Report for each reload cycle as required in accordance with Administrative Control 6.9.1.12.

The proposed TS 3.9.15 omits the ISTS option to allow performance of a fuel storage pool verification from the Applicability and Action A.2.2. The ISTS includes this relaxation as an acceptable alternative to verify by administrative means that the fuel storage pool verification has been performed since the last movement of fuel assemblies in the fuel storage pool. This option has been omitted since maintaining the minimum boron concentration is the preferred method and the relaxation is not desired.

In addition, the storage of fuel assemblies and the boron concentration in the spent fuel storage pool are independent of reactor operation. The inability to satisfy the fuel assembly storage requirements or maintain the spent fuel storage pool boron concentration to within the limits do not require a reactor shutdown or limit mode changes. Therefore, TS 3.9.14 and TS 3.9.15 include an exception to TS 3.0.3 and TS 3.0.4 to preclude an inappropriate reactor shutdown and limit mode change restrictions.

The proposed changes will not have a significant impact on the safety of the plant or on the spent fuel storage pool and are consistent with the NRC approved changes identified for other plants (i.e., Prairie Island Units 1 and 2, Vogtle Units 1 and 2).

D. SAFETY ANALYSIS

<u>Radiological Consequences</u>

The radiological consequences of 5.0 weight percent (w/o) U-235 fuel on accidents previously evaluated in the UFSAR are not significant. Letters L-00-008 dated May 12, 2000, and L-00-048 dated May 1, 2000, were submitted to the NRC pursuant to 10 CFR 50.59(c), which requested approval of UFSAR revisions to BVPS-2 design basis accident radiological dose. Increasing the enrichment from 4.85 w/o up to and including 5.0 w/o U-235 has minor effects on the radiological source terms and subsequently the potential releases, both normal and accidental, are not significantly affected. Evaluations performed in WCAP-12610-P-A considered the source term, gap fraction, and the accident doses for a maximum fuel enrichment of 5.0 w/o U-235. It was concluded that operating with and storing fuel with 5.0 w/o U-235 enrichment may result in minor changes in the normal annual

releases of long half-life fission products that are not significant. Also, the radiological consequences of accidents are minimally affected due to the very small changes in the core inventory and the fact that the currently assumed gap fractions remain bounding.

Spent Fuel Criticality Analysis

The spent fuel storage racks have previously been qualified for storage of various Westinghouse 17 x 17 fuel assembly types with maximum enrichments up to 4.85 w/o U-235. The spent fuel rack Boraflex absorber panels were considered in this previous analysis. Because of the Boraflex deterioration that has been observed, the spent fuel storage racks have been reanalyzed neglecting the presence of Boraflex to allow storage of Westinghouse 17 x 17 fuel assemblies with nominal enrichments up to 5.0 w/o U-235 (enrichment tolerance of ±0.05 w/o U-235) using credit for checkerboarding, burnup, and soluble boron.

The moderator was assumed to be pure water at a temperature of 68°F and a density of 1.0 gm/cc and the array was assumed to be infinite in lateral extent. Uncertainties due to tolerances in fuel enrichment and density, storage cell inner diameter, storage cell pitch, stainless steel thickness, assembly position, calculational uncertainty, and methodology bias uncertainty were accounted for. These uncertainties were appropriately determined at the 95/95 level. A methodology bias (determined from benchmark calculations) as well as a reactivity bias to account for the effect of the normal range of spent fuel pool water temperatures (50°F to 185°F) were included. These biases and uncertainties meet the previously stated NRC requirements.

An enrichment of 1.90 w/o U-235 was found to be adequate to maintain K_{eff} less than 1.0 with all cells filled with Westinghouse 17 x 17 fuel assemblies and no soluble boron in the pool water. This resulted in a nominal K_{eff} of 0.96992. The 95/95 level K_{eff} was then determined by adding the temperature and methodology biases and the statistical sum of independent tolerances and uncertainties to the nominal K_{eff} values. This resulted in a 95/95 level K_{eff} of 0.99952. Since these values are less than 1.0 and were determined at a 95/95 level, they meet the NRC criterion for precluding criticality with no credit for soluble boron.

Soluble boron credit is used to provide safety margin by maintaining the effective multiplication factor, K_{eff}, less than or equal to 0.95 including 95/95 level

uncertainties. The soluble boron credit calculations assumed the All Cell Storage configuration moderated by water borated to 200 ppm. As previously described, the individual tolerances and uncertainties, and the temperature and methodology biases, were added to the calculated nominal K_{eff} to obtain a 95/95 level value. The resulting 95/95 level K_{eff} was 0.94151 for fuel enriched to 1.90 w/o U-235. Since K_{eff} is less than 0.95 with 200 ppm of boron and uncertainties at a 95/95 level, the NRC acceptance criterion for precluding criticality is satisfied. These values are well below the minimum spent fuel pool boron concentration value of 2000 ppm required by proposed TS 3.9.15.

The concept of reactivity equivalencing due to fuel burnup was used to achieve the storage of fuel assemblies with enrichments higher than 1.90 w/o U-235 for all cell storage configuration. The NRC has previously accepted the use of reactivity equivalencing predicated upon the reactivity decrease associated with fuel depletion. Westinghouse issued letter FENOC-00-110 as notification that the axial burnup bias used in the reactivity equivalencing portion of WCAP-14416 methodology was non-conservative. Additional conservatism was determined to exist in the WCAP methodology that could be applied to offset the non-conservative axial burnup bias. The credits applied to the Beaver Valley Unit 2 Spent Fuel Pool Criticality Analysis are tabulated in Attachment 2 (All Cell and 3 of 4 Configurations) of the Westinghouse letter. The evaluation of the identified conservatism credit and the axial burnup bias penalty demonstrates that K_{eff} remains less than or equal to 0.95 (with a 95% probability at a 95% confidence level) when accounting for the presence of boron. In addition, K_{eff} remains less than or equal to 1.00 (with a 95% probability at a 95% confidence level) when not accounting for any boron presence.

To determine the amount of soluble boron required to maintain $K_{eff} \leq 0.95$ for storage of fuel assemblies with enrichments up to 5.0 w/o U-235, a series of reactivity calculations were performed to generate a set of enrichment versus fuel assembly discharge burnup ordered pairs, which all yield an equivalent K_{eff} when stored in the spent fuel storage racks. These are shown in Attachment C Figure 2 and represent combinations of fuel enrichment and discharge burnup, which yield the same rack K_{eff} as the rack loaded with fresh 1.90 w/o fuel. Uncertainties associated with burnup credit include a reactivity uncertainty of 0.01 Δk at 30,000 MWD/MTU applied linearly to the burnup credit requirement to account for calculation and depletion uncertainties and 5% on the calculated burnup to account for burnup measurement uncertainty.

The amount of additional soluble boron, above the value required above, that is needed to account for these uncertainties is 250 ppm. This results in a total soluble boron credit for the all cell configuration of 450 ppm. These values are well below the minimum spent fuel pool boron concentration value of 2000 ppm required by proposed TS 3.9.15.

The spent fuel pool was also analyzed assuming a three out of four checkerboard storage configuration containing three initially enriched 2.60 w/o U-235 assemblies and an empty cell. This resulted in a 95/95 level K_{eff} of 0.99564 with no credit for soluble boron or Boraflex. These values meet the NRC criterion of K_{eff} less than 1.0 with no credit for boron. The same configurations were then analyzed to obtain the required 5% subcritical margin assuming 200 ppm of soluble boron. The resulting 95/95 level K_{eff} was 0.94582. Since this K_{eff} value is less than 0.95, including soluble boron credit and uncertainties at a 95/95 level, the NRC acceptance criterion is met for the three out of four cells storage configuration.

Burnup reactivity equivalencing, as previously described, was also used to determine the allowed storage of fuel assemblies with enrichments higher than 2.60 w/o but no greater than 5.0 w/o U-235 in the three out of four configuration. The amount of soluble boron needed to account for the additional uncertainties associated with burnup credit was 150 ppm. This is additional boron above the 200 ppm required above, resulting in a total soluble boron requirement of 350 ppm. This is well below the minimum spent fuel pool boron concentration value of 2000 ppm required by proposed TS 3.9.15.

A separate criticality analysis for a two out of four checkerboard storage configuration in unborated water resulted in a 95/95 level K_{eff} of 0.94577. Soluble boron is not required to maintain $K_{eff} \leq 0.95$ for the two out of four cell storage configuration. There is no burnup requirement for fuel with 5.0 w/o U-235 or less in this storage configuration.

Although most accidents will not result in a reactivity increase, 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 accident 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 show that the highest reactivity increase (0.00363ΔK) occurs in the all cell case.

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 5.0 w/o Westinghouse 17 x 17 Standard 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 show that the highest reactivity increase (0.13882 ΔK) occurs in the two out of four checkerboard case.

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 5.0 w/o Westinghouse 17 x 17 Standard 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 show that the highest reactivity increase (0.16002 ΔK) occurs in the two out of four checkerboard case.

The calculations for these accidents show that the presence of 1400 ppm of soluble boron in the spent fuel pool water will maintain $K_{eff} \leq 0.95$. However, 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. Therefore, the minimum boron concentration required by TS 3.9.15 (2000 ppm) is more than sufficient to cover these accidents and the presence of additional soluble boron in the storage pool water (above the concentration required for normal conditions and reactivity equivalencing 450 ppm maximum) can be assumed as a realistic initial condition since not assuming its presence would be a second unlikely event.

Based on the above, the criticality aspects of the proposed license amendment request are acceptable and meet the requirements of General Design Criterion 62 for the prevention of criticality in fuel storage and handling. The analysis assumed credit for soluble boron, as allowed by WCAP-14416-NP-A, but no credit for the Boraflex neutron absorber panels. The required amount of soluble boron for each analyzed storage configuration is shown in Table 1.

Proposed Technical Specification Associated with Criticality Analysis

The Technical Specification changes proposed as a result of the revised criticality analysis are consistent with the changes stated in the NRC Safety Evaluation (SE) for WCAP-14416-P. Westinghouse submitted a revised topical report, WCAP-14416-NP-A, Rev. 1, which incorporated the changes stated in the NRC SE. Also, since the staff disagreed with the proprietary finding of the original WCAP-14416-P, Westinghouse's revised topical report was submitted as a nonproprietary version. This report's SE is dated October 25, 1996 (TAC No. M93254). Removing some of the conservatisms from the reactivity equivalencing analysis for the axial burnup bias calculation, and accounting for the additional identified conservatisms, shows that the proposed technical specification limits remain valid.

Proposed TS 3.9.15, "Fuel Storage Pool Boron Concentration," requires that a minimum boron concentration of 2000 ppm be maintained in the spent fuel storage pool. The 2000 ppm concentration is acceptable since it exceeds that assumed in the criticality analysis. Similarly, the proposed limit of $K_{eff} < 1.0$, when the spent fuel racks are flooded with unborated water, in accordance with proposed TS 5.3.1.1.a, and a $K_{eff} \leq 0.95$ when flooded with water borated to 450 ppm in accordance with proposed TS 5.3.1.1.c are acceptable since these limits on K_{eff} are consistent with the criticality analysis.

Proposed TS 3.9.14, "Spent Fuel Pool Storage," and proposed TS 5.3, "Fuel Storage," describe allowable spent fuel storage configurations. The following storage configurations and U-235 enrichment limits for Westinghouse 17 x 17 fuel assemblies were determined to be acceptable.

Assemblies with initial nominal enrichments no greater than 1.90 w/o U-235 can be stored in any cell location. Fuel assemblies with initial nominal enrichments greater than 1.90 w/o U-235 and up to 5.0 w/o U-235 must satisfy a minimum burnup requirement as shown in proposed TS Table 3.9-1, "Fuel Assembly Burnup vs. U_{235} Nominal Enrichment for storage in Spent Fuel Rack Regions 1, 2, 3."

Assemblies with initial nominal enrichments no greater than 2.60 w/o U-235 can be stored in a three out of four checkerboard arrangement. Fuel assemblies with initial nominal enrichments greater than 2.60 w/o U-235 and up to 5.0 w/o U-235 must satisfy a minimum burnup requirement as shown in proposed TS Table 3.9-1, "Fuel Assembly Burnup vs. U_{235} Nominal Enrichment for Storage in Spent Fuel Rack Regions 1, 2, 3."

Assemblies with initial nominal enrichments no greater than 5.0 w/o U-235 can be stored in a two out of four checkerboard arrangement as shown in proposed TS Table 3.9-1 "Fuel Assembly Burnup vs. U_{235} Nominal Enrichment for Storage in Spent Fuel Rack Regions 1, 2, 3."

Storage of fuel assemblies and the boron concentration in the spent fuel storage pool are independent of reactor operation. The inability to satisfy the fuel assembly storage requirements or maintain the spent fuel storage pool boron concentration to within the limits do not require a reactor shutdown or limit mode changes. Therefore, TS 3.9.14 and TS 3.9.15 include an exception to TS 3.0.3 and TS 3.0.4 to preclude an inappropriate reactor shutdown and limit mode change restrictions.

Boron Dilution Analysis

In accordance with the NRC SE of the Westinghouse methodology described in WCAP-14416-NP-A, a boron dilution analysis was performed (Attachment D) to ensure that sufficient time is available to detect and mitigate the dilution prior to exceeding the 0.95 K_{eff} design basis. Potential events were quantified to show that sufficient time is available to enable adequate detection and suppression of any dilution event.

A boron dilution evaluation was performed to define the dilution times and volumes necessary to dilute the spent fuel pool from the minimum Technical Specification boron concentration of 2000 ppm to a soluble boron concentration of 450 ppm. This concentration is conservative with respect to the criticality analysis, which indicated that a soluble boron credit of 450 ppm is sufficient to maintain K_{eff} less than or equal to 0.95. The volume required to dilute 269,000 gallons in the spent fuel pool from the Technical Specification limit of 2000 ppm to 450 ppm is 401,000 gallons. The various events that were considered included dilution from the primary water storage tank, demineralized water system, hot water heating system, service water system, fire protection system, and other events that may affect the boron concentration of the pool, such as seismic events or random pipe breaks, and spent fuel pool ion exchanger.

The evaluation concluded that an event that would dilute the spent fuel pool boron concentration from 2000 ppm to 450 ppm is not credible. The combination of the large volume of water required for a dilution event, Technical Specification-controlled spent fuel pool concentration and 7-day sampling requirement, spent fuel pool alarms and other alarms, plant personnel rounds, and other administrative controls, such as procedures, should adequately detect a dilution event prior to K_{eff} reaching 0.95 (450 ppm) and, therefore, the analysis and proposed Technical Specification controls are acceptable for the boron dilution aspects of the request.

Additionally, the criticality analysis for the spent fuel storage pool shows that K_{eff} would remain less than 1.0 at a 95/95 level even if the pool were completely filled with unborated water. Therefore, even if the spent fuel storage pool was diluted to zero ppm, the racks are expected to remain subcritical.

Proposed Technical Specification Associated with Boron Dilution

The proposed TS 3.9.15 boron concentration of 2000 ppm and 7-day surveillance requirement, together with the proposed remedial action requirements, are acceptable to ensure that sufficient time is available to detect and mitigate the dilution of the spent fuel pool prior to exceeding the design basis K_{eff} of 0.95.

E. NO SIGNIFICANT HAZARDS EVALUATION

The proposed amendment revises the Technical Specification (TS) requirements to credit the soluble boron in the fuel storage pool analyses. This amendment revises the Index, modifies TS 3.9.14 FUEL STORAGE - SPENT FUEL STORAGE POOL, adds TS 3.9.15 FUEL STORAGE POOL BORON CONCENTRATION, modifies applicable Bases and revises Design Feature Section 5.3.1.1 Criticality.

TS 3.9.14 has been modified by separating this specification into two specifications to support crediting soluble boron in the fuel storage pool. The revised TS 3.9.14 provides controls for fuel assembly enrichment and burnup in the spent fuel pool and also includes an increase in the maximum enrichment from 4.85 weight percent (w/o) to 5.0 w/o. A new TS 3.9.15 provides controls for soluble boron requirements in the spent fuel pool. Separating this specification into two specifications follows the guidance provided in the Improved Standard Technical Specifications (ISTS) of NUREG-1431 which provides TS 3.7.17 for Spent Fuel Pool Storage and TS 3.7.16 for Fuel Storage Pool Boron Concentration. The proposed TS 3.9.15 differs from ISTS Specification 3.7.16 by deleting the ISTS Applicability and Action A.2.2 option that would allow performance of a fuel storage pool verification. In addition, Action "b" has been added to state: "The provisions of TS 3.0.3 and TS 3.0.4 are not applicable."

The no significant hazard considerations involved with the proposed amendment have been evaluated. The three standards set forth in 10 CFR 50.92(c) are as quoted below:

> The Commission may make a final determination, pursuant to the procedures in paragraph 50.91, that a proposed amendment involves no significant hazards consideration, if operation of the facility in accordance with the proposed amendment would not:
>
> (1) Involve a significant increase in the probability or consequences of an accident previously evaluated; or
>
> (2) Create the possibility of a new or different kind of accident from any accident previously evaluated; or
>
> (3) Involve a significant reduction in a margin of safety.

The following evaluation is provided for the no significant hazards consideration standards.

1. Does the change involve a significant increase in the probability or consequences of an accident previously evaluated?

   Because of the Boraflex deterioration that has been observed, the spent fuel racks have been reanalyzed neglecting the presence of Boraflex to allow storage of Westinghouse 17x17 fuel assemblies with nominal enrichments up to 5.0 weight percent (w/o) using credit for checkerboarding, burnup and soluble boron. The proposed changes will not have a significant impact on the safety of the plant or on the spent fuel storage pool and are consistent with the NRC approved changes identified for other plants (i.e., Prairie Island Units 1 and 2, Vogtle Units 1 and 2). Criteria set forth in Table 3.9-1 provide qualification requirements for fuel assembly storage to ensure the NRC acceptance criteria and accident analysis assumptions are satisfied. Increasing the enrichment from 4.85 w/o up to and including 5.0 w/o U-235 has minor effects on the radiological source terms and subsequently the potential releases, both normal and accidental, are not significantly affected.

   The proposed Technical Specification changes credit the use of soluble boron in the spent fuel pool criticality analyses. These criticality analyses were performed using the NRC approved methodology developed by the Westinghouse Owners Group (WOG) and described in WCAP-14416-NP-A, Revision 1, "Westinghouse Spent Fuel Rack Criticality Analysis Methodology," November 1996. The analysis includes evaluations that factor in the axial burnup bias correction and utilizing identified conservatisms in the analysis demonstrate that K_{eff} remains less than or equal to the design limits.

   The proposed changes do not involve a change to plant equipment and do not affect the performance of plant equipment used to mitigate an accident. They do not affect the operation of the spent fuel pool cooling system or any other system and are consistent with applicable analyses including fuel handling accidents. They will not affect the ability of any system to perform its design function; therefore, the proposed changes do not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. Does the change create the possibility of a new or different kind of accident from any accident previously evaluated?

   There are no hardware changes associated with this license amendment nor are there any changes in the method by which any safety-related plant system performs its safety function. No new accident scenarios, transient precursors, failure mechanisms or limiting single failures are introduced as a result of the proposed changes. The proposed changes do not introduce any adverse effects or challenges to any safety-related systems.

   The potential criticality accidents have been reanalyzed to demonstrate that the pool remains subcritical. Soluble boron has been maintained in the fuel storage pool water since its initial operation. The possibility of a fuel storage pool dilution is not affected by the proposed changes to the Technical Specifications. Therefore, the implementation of Technical Specification controls for the soluble boron will not create the possibility of a new or different kind of accidental pool dilution.

   With credit for soluble boron now a major factor in controlling subcriticality, an evaluation of fuel storage pool dilution events was completed. This evaluation concluded that no credible events would result in a reduction of the criticality margin below the 5% margin recommended by the NRC. In addition, the No Soluble Boron 95/95 probability/confidence level criticality analysis assures that dilution to 0 ppm will not result in criticality.

   The proposed Technical Specification changes ensure the maintenance of the fuel pool boron concentration and storage configuration. Therefore, the proposed changes will not create the possibility of any new or different kind of accident from any accident previously evaluated.

3. Does the change involve a significant reduction in a margin of safety?

   The proposed changes do not affect the acceptance criteria for any analyzed event nor impact any plant safety analyses since the analysis assumptions are not changed. The safety limits assumed in the accident analyses and the design function of the equipment required to mitigate the consequences of any postulated accidents will not be changed since the proposed changes do not affect equipment required to mitigate design basis accidents described in the

Updated Final Safety Analysis Report. The Technical Specifications continue to assure that applicable operating parameters are maintained within the required limits.

The proposed changes to the fuel storage pool boron concentration and storage requirements will provide adequate margin to assure that the fuel storage array will always remain subcritical by the 5% margin recommended by the NRC. These limits are based on a criticality analysis performed in accordance with NRC approved Westinghouse fuel storage rack criticality analysis methodology.

While the criticality analysis utilized credit for soluble boron, the storage configurations have been defined using K_{eff} calculations to ensure that the spent fuel rack K_{eff} will be less than 1.0 with no soluble boron. Soluble boron credit is used to offset off-normal conditions (such as a misplaced assembly) and to provide subcritical margin such that the fuel storage pool K_{eff} is maintained less than or equal to 0.95.

The spent fuel pool boron dilution analysis concludes that an unplanned or inadvertent event which would result in dilution of the spent fuel pool boron concentration from 2000 ppm to 450 ppm is not a credible event. This conclusion is based on the substantial volume of unborated water required to dilute the pool and the fact that a large dilution event would be readily detected by plant personnel via alarms, flooding in the fuel handling building or detected during normal operator rounds through the spent fuel pool area.

The margin of safety depends upon maintenance of specific operating parameters within design limits. The Technical Specifications continue to require that these limits be maintained and provide appropriate remedial actions if a limit is exceeded. The maintenance of these limits continues to be assured through performance of surveillances. Therefore, the plant will be maintained within the analyzed limits and the proposed changes will not involve a significant reduction in a margin of safety.

F. NO SIGNIFICANT HAZARDS CONSIDERATION DETERMINATION

Based on the considerations expressed above, it is concluded that the activities associated with this license amendment request satisfy the requirements of 10 CFR 50.92(c) and, accordingly, a no significant hazards consideration finding is justified.

G. ENVIRONMENTAL CONSIDERATION

This license amendment request changes a requirement with respect to a facility component located within the restricted area as defined in 10 CFR Part 20. It has been determined that this license amendment request involves no significant increase in the amounts, and no significant change in the types of any effluents that may be released offsite, and that there is no significant increase in individual or cumulative occupational radiation exposure. This license amendment request changes a surveillance requirement with respect to a facility component located within the restricted area; however, the category of this licensing action does not individually or cumulatively have a significant effect on the human environment. Accordingly, this license amendment request meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). Pursuant to 10 CFR 51.22(b) no environmental impact statement or environmental assessment need be prepared in connection with the issuance of this license amendment request.

TABLE 1

Beaver Valley Power Station, Unit No. 2
License Amendment Request No. 137
SPENT FUEL POOL BORON CREDIT

Summary of Soluble Boron Credit Requirements

Storage Configuration	Soluble Boron Required for $K_{eff} \leq 0.95$ (ppm)	Soluble Boron Required for Reactivity Equivalencing Including Uncertainties (ppm)	Total Soluble Boron Credit Required Without Accidents (ppm)	Soluble Boron Credit Required for Accident (ppm)	Total Soluble Boron Credit Required Including Accidents (ppm)
4-out-of-4 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

ATTACHMENT C

Beaver Valley Power Station, Unit No. 2
License Amendment Request No. 137
SPENT FUEL POOL BORON CREDIT

Beaver Valley Unit 2
Spent Fuel Rack Criticality Analysis With Credit for Soluble Boron
(November 1998)

CAA-98-158-Rev 1

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

November 1998

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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:

__Unit 2 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.

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 ± 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} ≤ 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)	0.01416	0.01389

$$\sqrt{\sum_{i=1}^{10}((tolerance_i...or...uncertainty_i)^2)}$$

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
$\sqrt{\sum_{i=1}^{10}((tolerance_i...or...uncertainty_i)^2)}$	
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

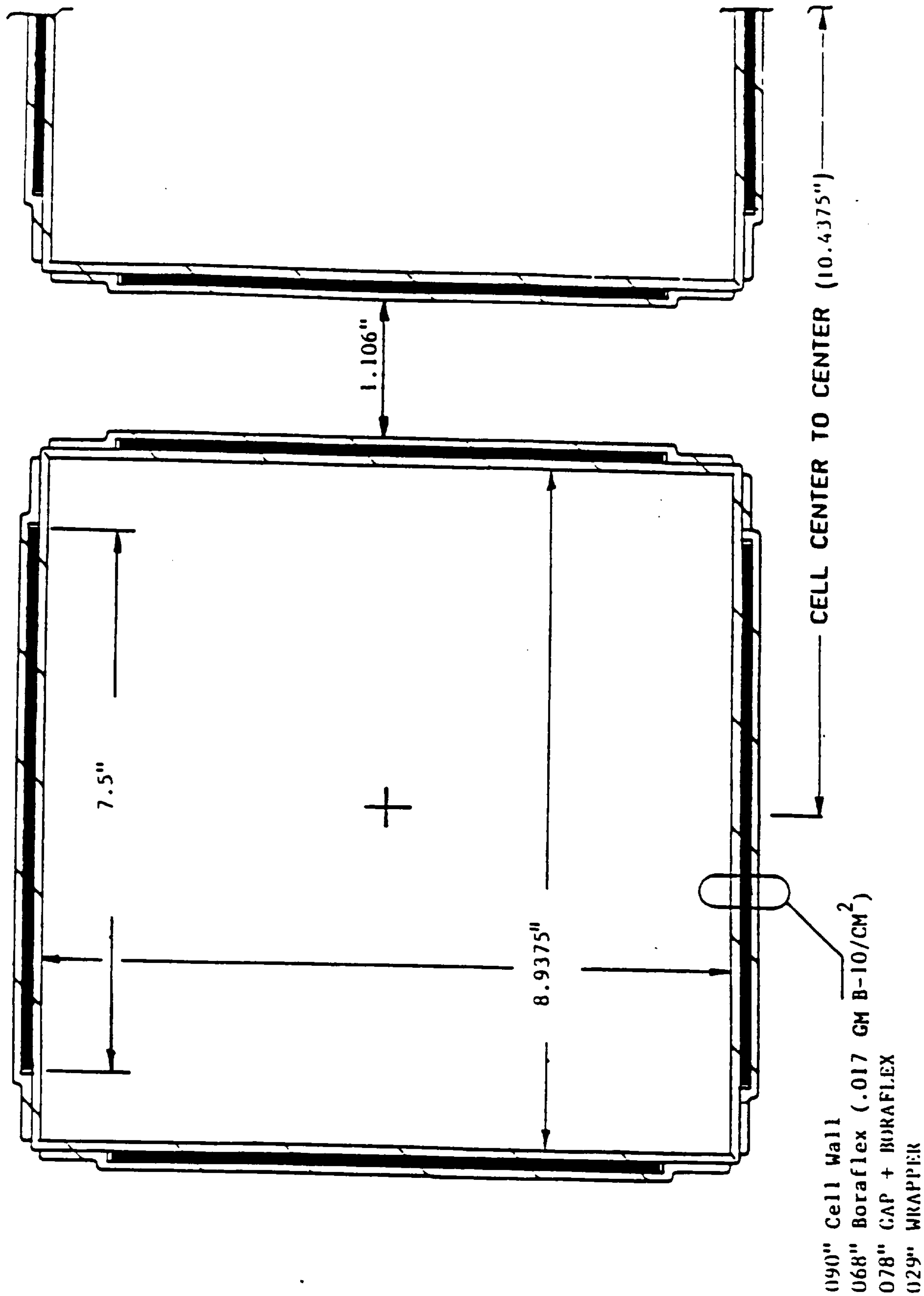


Figure 1. Beaver Valley Unit 2 Spent Fuel Storage Cell Nominal Dimensions

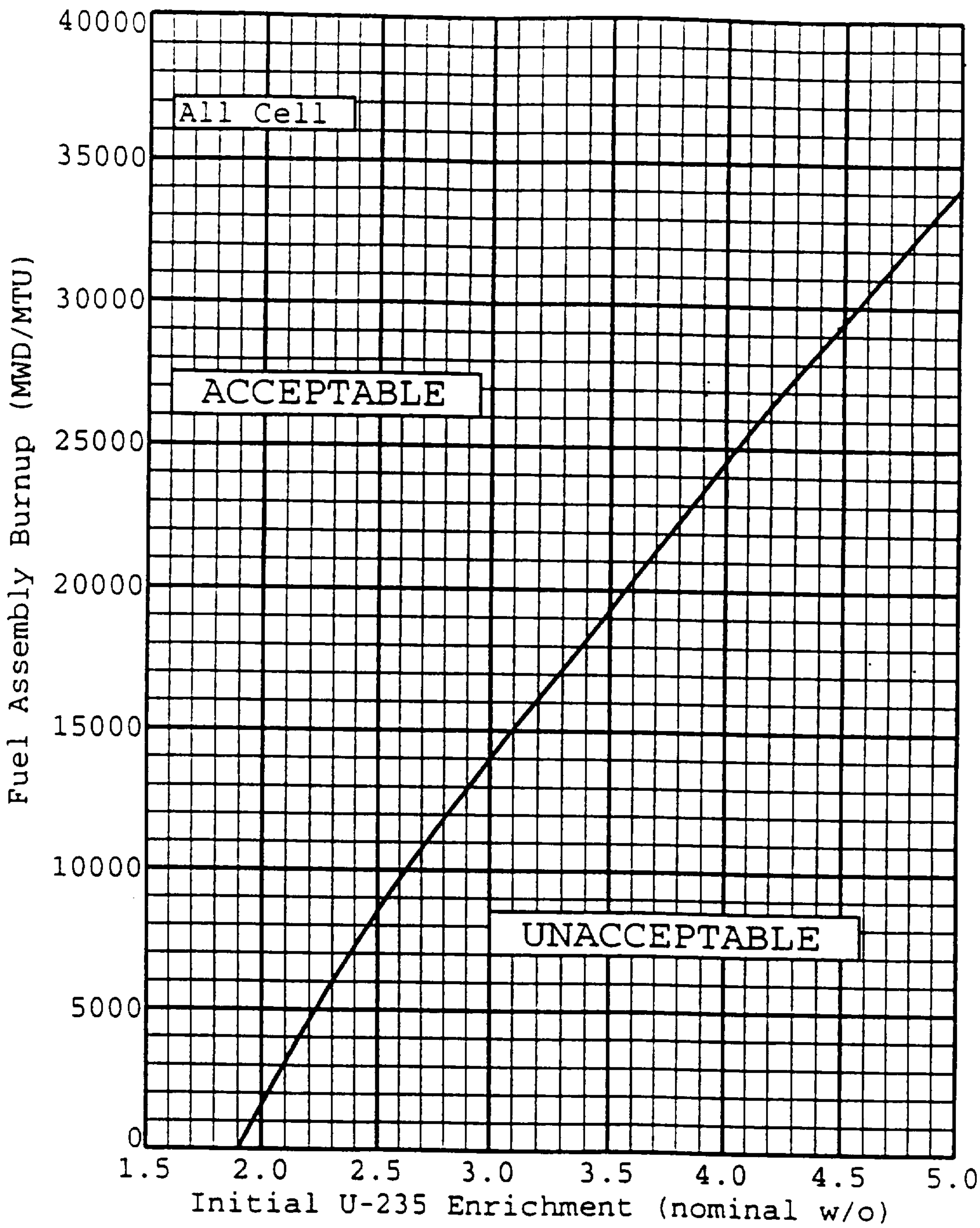


Figure 2. Beaver Valley Unit 2 Burnup Credit Requirements for All Cell Storage

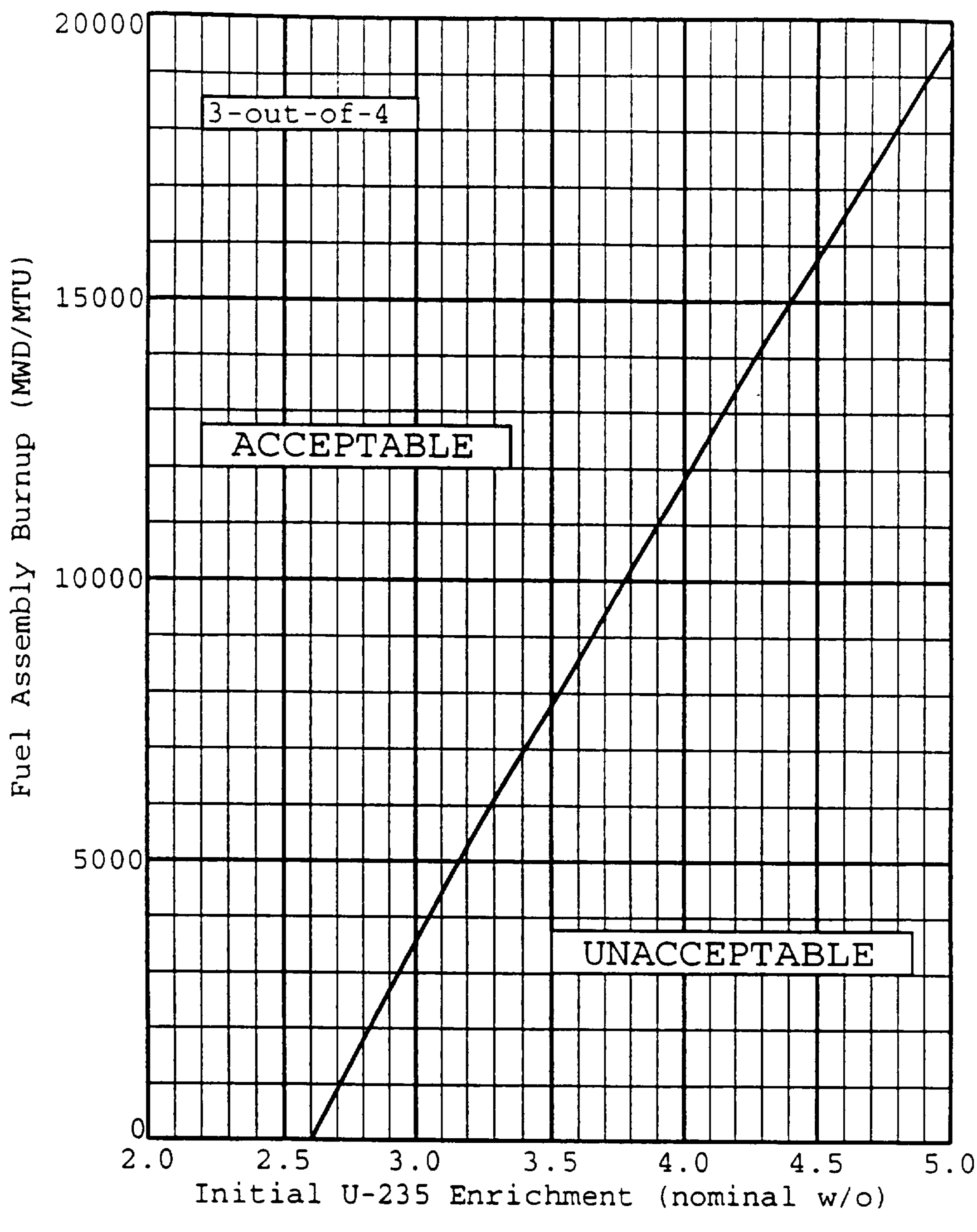


Figure 3. Beaver Valley Unit 2 Burnup Credit Requirements for 3-Out-Of-4 Storage

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

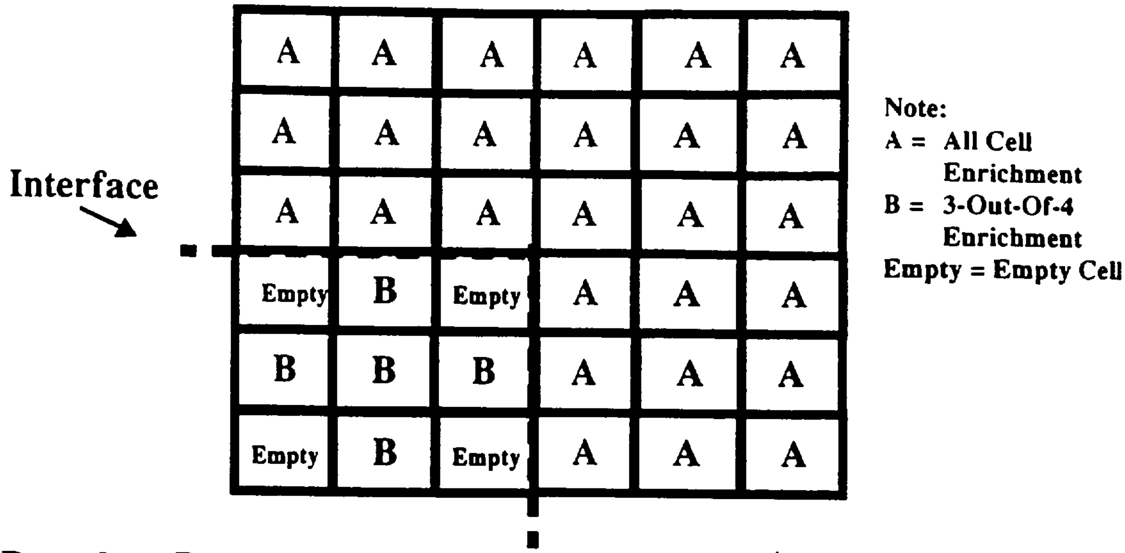
3-Out-Of-4 Storage

5.0 w/o	Empty
Empty	5.0 w/o

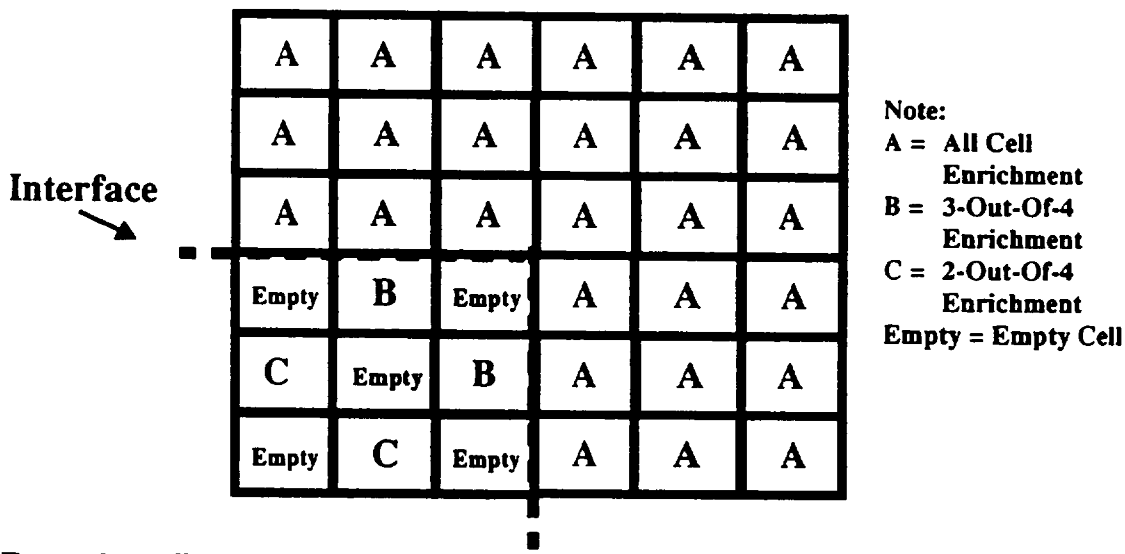
2-Out-Of-4 Storage

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.

ATTACHMENT D

Beaver Valley Power Station, Unit No. 2
License Amendment Request No. 137
SPENT FUEL POOL BORON CREDIT

Beaver Valley Unit 2
Spent Fuel Pool Dilution Analysis Rev. 0 (7/17/98)

BEAVER VALLEY UNIT 2

SPENT FUEL POOL DILUTION ANALYSIS

Prepared By: ____________________

Verified By: ____________________

Rev. 0

7/17/98

WESTINGHOUSE ELECTRIC COMPANY

Table of Contents

1.0 INTRODUCTION

A boron dilution analysis has been completed for crediting boron in the Beaver Valley Unit 2 spent fuel rack criticality analysis. The boron dilution analysis includes an evaluation of the following plant specific features:

- Dilution Sources
- Boration Sources
- Instrumentation
- Administrative Procedures
- Piping
- Loss of Offsite Power Impact
- Boron Dilution Initiating Events
- Boron Dilution Times and Volumes
- Licensee Event Reports

The boron dilution analysis was performed to ensure that sufficient time, administrative procedures, and instrumentation are available to detect and mitigate the dilution before the spent fuel rack criticality analysis 0.95 k_{eff} design basis is exceeded. The design basis assumes normal plant operations and fuel movement. No other accidents such as misloading a fuel assembly are assumed to occur during the dilution accident.

2.0 SPENT FUEL POOL AND RELATED SYSTEM FEATURES

This section provides background information on the spent fuel pool and its related systems and features. A one-line diagram of the spent fuel pool related systems is provided as Figure 1. A spent fuel pool is provided for each of the two Units at Beaver Valley. Only the spent fuel pool at Unit 2 will be addressed in this evaluation.

2.1 Spent Fuel Pool

The design purpose of the spent fuel pool is to provide for the safe storage of irradiated fuel assemblies. The pool is filled with borated water. The water removes decay heat, provides shielding for personnel handling the fuel, and provides for removal of a portion of the iodine released during a fuel handling accident. Pool water evaporation takes place on a continuous basis, requiring periodic makeup. The makeup source can be unborated water, since the evaporation process does not carry off the boron. Evaporation actually increases the boron concentration in the pool.

The spent fuel pool is a reinforced concrete structure with a stainless steel liner. The water-tight liner has dedicated drain lines (channels) to collect and detect liner leakage. The pool structure is designed to meet seismic requirements. The pool water depth is approximately 38 feet. The top of the pit is located on the 766' - 4" elevation of the fuel handling building. The bottom of the pit is at the 727'- 4" elevation.

On the floor elevation there is a curb approximately 25" high surrounding the pool. The curb, in addition to open floor drains, minimizes any pool dilution source from the floor elevation level.

As shown in Figure 2, a transfer canal lies adjacent to the pool and connects to the reactor refueling water cavity during refueling operations. The pool and the transfer canal are connected by fuel transfer slots that can be closed by pneumatically sealed gates. The transfer canal is normally empty. However, the accidental opening of the gates would lower the water level approximately four feet, leaving approximately 20 feet of water above the top of the active fuel. The elevation of the top of the gates, when installed, is approximately just below the floor level of the spent fuel pool area. The removable gates support the full height of water remaining on the pool side after the canal side is completely drained.

The gates between the pool and the fuel cask pool are normally removed. However, credit is taken for the fuel cask pool water volume only if a dilution source discharges directly into the fuel cask pool. The majority of the water volume displaced by objects in the pool is due to the spent fuel assemblies. The maximum number of assembly locations is 1088. Since it is conservative to assume all sites are usable, the volume of all 1088 assemblies (21,729 gallons) is subtracted from the total pool volume. The racks themselves occupy a relatively small volume(4377 gallons), but they are subtracted as well. Finally, it is conservatively assumed that 1072 WABAs and 720 damper rods are included as fuel assembly inserts, which displaces about 49 gallons. When the above volumes are subtracted from the pool volume, the remaining water volume is conservatively rounded down to 269,000 gallons at the low level alarm setpoint elevation of 765'. If the fuel cask pool is included, the total minimum volume increases to 327,000 gallons.

2.2 Spent Fuel Storage Racks

The spent fuel racks are designed to support and protect the spent fuel assemblies under normal and credible accident conditions. Their design ensures the ability to withstand combinations of dead loads, live loads (fuel assemblies), operating basis and safe shutdown earthquake loads.

2.3 Spent Fuel Pool Cooling Subsystem

The spent fuel pool cooling subsystem is designed to remove the heat generated by stored spent fuel elements from the spent fuel pool. System design does not incorporate redundant active components except for the spent fuel pool cooling pump and heat exchanger. System piping is configured so that failure of any pipeline in the cooling system does not drain the spent fuel pool below 10 feet above the top of the stored spent fuel assemblies.

The portion of the spent fuel pool cooling subsystem which, if it failed, could result in a significant release of pool water, is seismically designed.

Each of the two trains of the cooling subsystem consists of a pump, a heat exchanger, valves, piping and instrumentation. The pumps takes suction from the fuel pool at a single inlet located 13 feet below the normal pool water level, transfers the pool water through a heat exchanger and returns it back into the pool through a discharge header on an adjacent wall and about 20 feet horizontal from the cooling

system inlet. See Figure 3. The return line terminates at elevation 764'-10" to limit loss of pool inventory in the event that the return line breaks below the normal water level. The heat exchangers are cooled by component cooling water.

2.4 Spent Fuel Pool Cleanup Subsystem

The spent fuel pool cleanup subsystem is designed to maintain water clarity and to control borated water chemistry. The purification pumps take suction from the fuel pool from a separate single inlet located approximately 18" below the normal pool water level, transfers the pool water through a filter and ion exchanger and returns it to the fuel cask pool. See Figure 3. The return line terminates at elevation 764' to limit loss of pool inventory in the event that the return line breaks below the normal water level. Each fuel pool purification pump can provide 400 gpm to the spent fuel pool filters. The filters remove particulates from the spent fuel pool water and the spent fuel pool ion exchanger removes ionic impurities. The flow rate in the loop is limited to 150 gpm administratively to accommodate the design flow of the spent fuel pool ion exchanger.

The refueling water purification loop also uses the spent fuel pool ion exchanger and filters to clean up the refueling water storage tank after refueling operations.

The spent fuel pool has a surface skimmer system designed to provide optical clarity by removing surface debris. The system consists of a surface skimmer, which provides suction to the fuel pool purification pumps to make use of the fuel pool filters and ion exchanger.

2.5 Dilution Sources

The following spent fuel pool dilution sources were identified as a result of a plant walkdown and review of process and instrumentation diagrams and operating procedures. In addition, Licensee Event Reports related to the spent fuel pool and makeup operations for both Units 1 and 2 were reviewed, but no new or unique dilution sources were identified.

2.5.1 Primary Water System

The primary water system (PWS) includes two primary water storage tanks (PWST) and two PW supply pumps. During normal operation, two PW pumps are running on recirculation to provide PW on demand to multiple users. Each PWST contains approximately 75,000 gallons of non-borated, reactor grade, deionized water. Makeup to the tanks is provided administratively from the raw water treatment system.

The PWS connects to the spent fuel pool cooling system directly in the return header to the pool. Using the direct connection, the contents of the PWST can be transferred directly to the spent fuel pool via the PW supply pumps. The direct connection is normally isolated from the PWS by a locked closed remotely operated valve. The flow rate through this path is estimated to be 190 gpm, assuming both PW pumps are operating. The direct connection is used as the normal water supply to the spent fuel pool and is a source of makeup water in case of a loss of spent fuel pool inventory.

PW is also used as a backup source of sluice water for spent resin from the spent fuel pool ion exchanger. This path is normally isolated by a remotely operated valve. If PW is used for sluicing and an outlet process isolation valve is inadvertently left open, a flow of 195 gpm can enter the spent fuel pool via the purification flow path to the fuel cask pool, assuming both PW pumps are operating.

PW is also used for makeup to the spent fuel pool via the chemical and volume control system makeup system. Normally, this path is used to provide a blended flow of PW and boric acid at the desired spent fuel pool boron concentration. However, should the "DILUTE" control be set on the makeup system inadvertently, a flow of 170 gpm can enter the spent fuel pool via the purification flow path to the fuel cask pool, assuming both PW pumps are operating.

2.5.2 Demineralized Water System

The demineralized water system includes a demineralized water storage tank and two distribution pumps. The storage tank capacity is 600,000 gallons. A flow path from the pump discharge header feeds directly into the spent fuel pool via two parallel, ¾" valve segments mounted on the pool wall. The maximum flow from this flowpath, assuming both caps are removed is estimated to be 70 gpm, assuming two distribution pumps are operating.

2.5.3 Component Cooling Water System

Component cooling water is the cooling medium for the spent fuel pool cooling system heat exchangers. There is no direct connection between the component cooling system and the spent fuel pool cooling system. If, however, a leak were to develop in a heat exchanger that is in service, the connection would be made. The component cooling system normally operates at a higher pressure than that of the spent fuel pool cooling system. Therefore, it is likely that a breach in a spent fuel pool cooling system heat exchanger tube would result in non-borated component cooling water entering the spent fuel pool cooling system.

The flow rate of any leakage of component cooling water into the spent fuel pool cooling system would be low due to the relatively small difference in operating pressures between the two systems. Even if there was significant leakage from the component cooling water system to the spent fuel pool, the impact on the spent fuel pool boron concentration would be limited to the loss of component cooling water surge tank volume that would initiate alarms and control room indications to alert the control room operators.

A low surge tank level alarm would alert the control room operators of a component cooling water system leak. If this alarm were to fail and leakage from the component cooling water system to the spent fuel pool cooling system were to continue undetected, the component cooling water surge tank would be periodically refilled with water from the demineralized water or PW system. The resulting dilution from the demineralized water or PW system would be bounded by the dilution events discussed in Sections 2.5.2 and 2.5.3.

Because a spent fuel pool heat exchanger leak is bounded by other analyzed events, it is not considered further in this analysis.

2.5.4 Hot Water Heating System

This closed system supplies hot water to seven fan heaters in the spent fuel pool area. The system includes six 270 gallon expansion tanks and two circulating pumps. Since the system is not seismically designed, it is assumed that the fans break off during an earthquake, exposing the 2" feed and return water lines which are assumed to blow down directly into the spent fuel pit. It is estimated

that up to 824 gpm could blow down from each fan, or a total of 5771 gpm from the system. The volume of the system consists primarily of the expansion tanks. However, makeup can be provided from the demineralized water system through a 3" line.

2.5.5 Service Water System

The service water system is used as an emergency supply to recover spent fuel pool level. Administrative procedures require that it be used only as a last resort. The service water system includes three 15,000 gpm pumps supplied by an infinite source (Ohio River). The supply line to the spent fuel pool is normally isolated by a manually closed valve and a blind flange connection. To initiate flow, a spool piece must be installed to replace the blind flange. With two service water pumps operating, this flowpath is capable of providing approximately 3000 gpm directly to the spent fuel pool.

2.5.6 Drain Systems

The equipment or floor drain systems connect directly to the spent fuel pool cooling system and skimmer system at the drain connections for the spent fuel pool pumps, heat exchangers (tube side), filters, and ion exchanger. Each connection has a normally closed isolation valve. Backflow through these paths is not considered credible, because the situation would cause water to back up through floor drains in a number of locations before getting into the spent fuel pool cooling system.

2.5.7 Fire Protection System

In the case of a loss of spent fuel pool inventory, two local fire hose stations are a potential makeup source. These stations are capable of providing a total flow of approximately 200 gpm of non-borated water. Any planned addition of fire system water to the spent fuel pool is under the control of an approved procedure and is used only as a last resort.

There is a 3" fire protection hose supply piping header located under the hose stations outside the spent fuel pool area. If this line were to break, a significant amount of water would, if not isolated by operator action, be released into the area outside and beneath the spent fuel pool area. The fire protection system contains instrumentation which would alarm in the control room should this type of flow develop in the fire protection system. Thus, the break of this fire protection hose supply piping is

not considered further in this analysis. There is also a 6" piping header located along a wall above the spent fuel pool. Breakage of this line is addressed in section 2.9.

2.5.8 Air Conditioning Unit Drain Tank

A 265 gallon tank is provided to collect drains from the fuel building air conditioning units. On a high tank level signal, a 20 gpm transfer pump drains the tank to the spent fuel pool. Normal operation of the system is intermittent, and the flow is limited to the runout flow of the pump (40 gpm). Because the source of unborated water is limited and intermittent, its potential as a dilution source for the spent fuel pool is judged to be insignificant and is not considered further in this analysis.

2.5.9 Spent Fuel Pool Ion Exchanger

The spent fuel pool ion exchanger has a maximum capacity of 15 ft^3 of 1:1 equivalent mixed bed resin. This implies a volume ratio of 60%/40% anion to cation resin. If we assume the bed was loaded with 100% anion, it would bound the capacity to remove boron when it is first aligned to the system. The ion exchanger would be operated at 150 gpm maximum flow rate. Dilution of the spent fuel pool resulting from operation of the ion exchanger will not result in a change in the spent fuel pool inventory.

2.5.10 Dilution Source and Flow Rate Summary

Based on the evaluation of potential spent fuel pool dilution sources summarized above, the following dilution sources were determined to be capable of providing a significant amount of non-borated water to the spent fuel pool. The potential for these sources to dilute the spent fuel pool boron concentration will be evaluated in Section 3.0.

SOURCE	APPROXIMATE FLOW RATE (GPM)
Primary Water System	
- 2" connection to return header	190
- 2" makeup to spent resin sluice header	195
- 2" makeup via boric acid blender	170
Demineralized Water System	
- ¾" capped piping on spent fuel pool wall	70
Hot Water Heating System	5771

Service Water System - 6" emergency makeup connection	3000
Fire Protection System - Fire hose stations in spent fuel pool area	200
Air Conditioning Drain Tank	50
Spent Fuel Pool Ion Exchanger	150

2.6 Boration Sources

The normal source of borated water to the spent fuel pool is from the refueling water storage tank via the refueling water storage tank cooling water pump. A connection is also provided from the chemical and volume control system makeup system. It is also possible to borate the spent fuel pool by the addition of dry boric acid directly to the spent fuel pool water. A discussion of each source follows:

2.6.1 Refueling Water Storage Tank

The refueling water storage tank (RWST) connects to the spent fuel pool via the purification loop. This connection is normally used to purify the RWST water when the purification loop is isolated from the spent fuel pool. This connection can also supply borated water to the spent fuel pool by using the RWST cooling water pump via the inlet to the spent fuel pool cooling system purification loop. The RWST cooling water pump is powered from a non-safeguards bus power supply. It must be re-started manually following a loss of offsite power. The RWST is required by Technical Specifications to be kept at a minimum boron concentration of 2000 ppm.

2.6.2 Direct Addition of Boric Acid

If necessary, the boron concentration of the spent fuel pool can be increased by emptying drums of dry boric acid directly into the spent fuel pool. However, boric acid dissolves very slowly at room temperature and requires that the spent fuel pool cooling pumps be available for mixing throughout the pool. (See section 3.1 for further discussion on spent fuel pool mixing.)

2.7 Spent Fuel Pool Instrumentation

Instrumentation is available to monitor spent fuel pool water level and temperature. Additional instrumentation is provided to monitor the pressure and flow of the spent fuel pool cleanup system, and pressure, flow, and temperature of the spent fuel pool cooling system.

Redundant spent fuel pool water level and temperature instrumentation provides local indication, control room high alarms and indication, and plant computer data points. Three radiation monitors are available in the spent fuel pool area which provide high radiation alarms locally and in the control room.

A change of one foot in spent fuel pool level with the fuel cask pool isolated requires approximately 7850 gallons of water. If the pool level was raised from the low level alarm point to the high level alarm (12"), a dilution of approximately 7850 gallons could occur before an alarm would be received in the control room. If the spent fuel pool boron concentration were at 2000 ppm initially, a dilution using unborated water would only result in a reduction of the pool boron concentration of approximately 57 ppm.

2.8 Administrative Controls

The following administrative controls are in place to control the spent fuel pool boron concentration and water inventory:

1. Procedures are available to aid in the identification and termination of dilution events.

2. The procedures for loss of inventory (other than evaporation) specify that the selection of makeup source be based on the results of the most recent boron analysis results.

3. In accordance with procedures, plant personnel perform rounds in the spent fuel pool enclosure once every 8 hours. The personnel making rounds to the spent fuel pool are trained to be aware of the change in the status of the spent fuel pool. They are instructed to check the temperature and level in the pool and conditions around the pool during plant rounds.

4. Administrative controls (locked-closed primary water supply valve, caution statements in procedures) are placed on some of the potential dilution paths.

5. Normally, the spent fuel pool is maintained above 2000 ppm boron per Technical Specification 3.9.14, and is consistent with the refueling water storage tank concentration.

6. The spent fuel pool boron concentration is verified by sample analysis every 7 days or within 8 hours prior to and at least once every 24 hours during fuel movement in the spent fuel pool per Technical Specification 3.9.14.

Administrative controls on the spent fuel pool boron concentration and water inventory ensure that the boron concentration is administratively controlled during both normal and accident situations. The procedures ensure that the proper provisions, precautions and instructions are in place to control the pool boron concentration and water inventory.

2.9 Piping

There are no systems (other than those listed in section 2.5.1 to 2.5.6) identified which have piping in the vicinity of the spent fuel pool which could result in a dilution of the spent fuel pool if they were to fail.

2.10 Loss of Offsite Power Impact

Of the dilution sources listed in Section 2.5.9, only the fire protection system is capable of providing non-borated water to the spent fuel pool during a loss of offsite power.

The loss of offsite power would not significantly affect the ability to respond to a dilution event. The spent fuel pool level instrumentation is powered from emergency diesel generator-backed power supplies.

Regarding boration sources, the RWST cooling water pump is not powered from a safeguards supply and would have to be manually loaded on to the emergency diesel generator to deliver borated water from the RWST. Alternatively, the RWST can be gravity-drained to the spent fuel pool through the RWST cooling water pump, because the spent fuel pool minimum level is below the maximum level of the RWST. Finally, manual addition of dry boric acid to the pool could be used if it became necessary to increase the spent fuel pool boron concentration during a loss of offsite power.

The spent fuel pool cooling pumps must be manually restarted following a loss of offsite power. The pumps are supplied by power supplies backed by safeguards feeds from the diesel generators to assure cooling and good mixing in the spent fuel pool.

3.0 SPENT FUEL POOL DILUTION EVALUATION

3.1 Calculation of Boron Dilution Times and Volumes

For the purposes of evaluating spent fuel pool dilution times and volumes, the total pool volume available for dilution, as described in section 2.1, is conservatively (low) assumed to be 269,000 gallons.

Based on the criticality analysis (Reference 1), the soluble boron concentration required to maintain the spent fuel pool boron concentration at $k_{eff} < 0.95$, including uncertainties and burnup, with a 95% probability at a 95% confidence level (95/95) is 450 ppm. This concentration assumes no fuel misloading accident.

The spent fuel pool boron concentration is currently maintained at or above 2000 ppm. For the purposes of calculating dilution times and volumes, the initial spent fuel pool boron concentration is assumed to be 2000 ppm. The evaluations are based on the spent fuel pool boron concentration being diluted from 2000 ppm to 450 ppm. To dilute the pool water volume of 269,000 gallons from 2000 ppm to 450 ppm would require 401,000 gallons of non-borated water, based on a feed-and-bleed operation (constant volume). If the fuel cask pool is included, dilution of the resulting 327,000 gallons from 2000 ppm to 450 ppm would require 488,000 gallons of non-borated water.

This analysis assumes thorough mixing of all the non-borated water added to the spent fuel pool with the contents of the spent fuel pool. Refer to Figure 3. Based on the design flow of 750 gpm for one fuel pool cooling pump and 400 gpm from one fuel pool purification pump, the 269,000 gallon system volume is turned over approximately every four hours. It is unlikely, with pump flow and convection from the spent fuel decay heat, that thorough mixing would not occur. However, if mixing were not adequate, it would be conceivable that a localized pocket of non-borated water could form somewhere in the spent fuel pool. This possibility is addressed by the calculation in Reference 1 which shows that the spent fuel rack K_{eff} will be less than 1.0 on a 95/95 basis with the spent fuel pool filled with non-borated water. Thus, even if a pocket of non-borated water formed in the spent fuel pool, K_{eff} would not exceed 1.0 anywhere in the pool.

The time to dilute the spent fuel pool depends on the initial volume of the pool and the postulated rate of dilution. The dilution volumes and times for the dilution scenarios discussed in Sections 3.2 and 3.3 are calculated based on the following equation:

$$t_{end} = \ln (C_0 / C_{end}) V/Q \qquad \text{(Equation 1)}$$

Where:

C_0 = the boron concentration of the pool volume at the beginning of the event (2000 ppm)

C_{end} = the boron endpoint concentration (450 ppm)

Q = dilution rate (gallons/minute)

V = water volume of spent fuel pool (269,000 or 327,000 gallons)

t_{end} = time to reach C_{end} (minutes)

3.2 Evaluation of Boron Dilution Events

The potential spent fuel pool dilution events that could occur are evaluated below:

3.2.1 Dilution From Primary Water Storage Tank

The primary water system consists of two primary water storage tanks and two primary water supply pumps. Each primary water storage tank contains approximately 75,000 gallons of non-borated, reactor grade water. Makeup to the tank from the raw water treatment system is not automatic. Thus, the contents of both tanks without makeup are not sufficient to dilute the spent fuel pool from 2000 to 450 ppm, which requires 401,000 gallons.

The contents of the primary water storage tank can be transferred via the primary water supply pumps to the spent fuel pool via the cooling loop return header. This connection is normally isolated from the primary water system by a locked-closed remotely operated valve. It can be used as the normal makeup supply to the spent fuel pool and is a source of makeup water in case of a loss of spent fuel pool inventory event.

The path from the primary water supply pumps to the spent fuel pool via the 2" connection to the spent fuel pool cooling return header cah provide approximately 190 gpm. If the open path were left unattended, it would take 41 minutes to increase the spent fuel pool level from the low to high alarm

setpoints, and 35 hours to provide the 401,000 gallons required to dilute the pool from 2000 to 450 ppm boron, if sufficient makeup water were available.

The path from the primary water supply pumps to the spent fuel pool via spent resin sluice pump discharge header can provide approximately 195 gpm. If the flow path were left unattended, it would take 45 min. to increase the spent fuel pool level from the low to high alarm setpoints, and 42 hr. to provide the volume required to dilute the pool from 2000 to 450 ppm boron. Since this path discharges into the fuel cask pool, the dilution volume required is 488,000 gallons (see Section 3.1).

The path from the primary water supply pumps to the spent fuel pool via the boric acid blender can provide approximately 170 gpm. If the flow path were left unattended, it would take 52 minutes to increase the spent fuel pool level from the low to high alarm setpoints, and 48 hours to provide the volume required to dilute the pool from 2000 to 450 ppm boron. Since this path discharges into the fuel cask pool, the dilution volume required is 488,000 gallons (see Section 3.1).

3.2.2 Dilution From Demineralized Water System

The demineralized water system includes a demineralized water storage tank and two distribution pumps. The non-borated contents of the demineralized water storage tank can be transferred directly to the spent fuel pool. The volume of the demineralized water storage tank (600,000 gallons) is greater than the 401,000 gallons required to dilute the pool from 2000 to 450 ppm boron.

The path from the demineralized water distribution pump to the spent fuel pool cooling return header via the 2" connection can provide approximately 70 gpm. If the flow path were left unattended, it would take 1.9 hr. to increase the spent fuel pool level from the low to high alarm setpoints, and 96 hours to provide the 401,000 gallons required to dilute the pool from 2000 to 450 ppm boron.

3.2.3 Dilution from Hot Water Heating System

This is a closed system which provides heated water to seven fans located near the spent fuel pool for area heating. Circulating pumps provide hot water at approximately 61 psig. Since the system is not seismically qualified, an earthquake could rupture the supply and return lines from each fan box and the hot water system could blow down into the pool. Based on an estimated blowdown flow of 5771

gpm, it would take about 1.4 minutes to increase the spent fuel pool level from the low to high alarm setpoints. However, in reality, even though makeup is available from the demineralized water system, this large flow rate is not indefinite. At 5771 gpm, the six 270 gallon surge tanks and the system piping would be emptied in a few seconds. The demineralized water makeup connection is a 3" diameter pipe, so its flow capacity would be limited to approximately 460 gpm, based on a 20 ft./sec. velocity. Thus, about 1620 gallons would be added to the spent fuel pool quickly, then dilution would continue at about 460 gpm until the operator took action. After the initial 1620 gallons were added to the spent fuel pool, it would take approximately 14 hours to provide the remaining 399,634 gallons required to dilute the pool from 2000 to 450 ppm.

3.2.4 Dilution from Service Water System

The service water system draws from the Ohio River. Thus, there is an infinite water source which would exceed the 401,000 gallons required to dilute the spent fuel pool from 2000 to 450 ppm boron. Assuming two service water pumps are operating, this flow path is capable of providing approximately 3000 gpm. At this rate, it would take 2.6 minutes to increase the spent fuel pool level from the low to high alarm setpoints, and 2 hours to provide the 401,000 gallons required to dilute the pool from 2000 to 450 ppm boron.

3.2.5 Dilution from Fire Protection System

The fire protection system also draws from the Ohio River. Thus, there is an infinite water source which would exceed the 401,000 gallons required to dilute the spent fuel pool from 2000 to 450 ppm boron. The path from the fire water pump to the two fire hose stations in the spent fuel pit area can provide approximately 200 gpm. If the hoses were placed in the spent fuel pool and left unattended, it would take 39 minutes to increase the spent fuel pool level from the low to high alarm setpoints, and 33 hours to provide the 401,000 gallons required to dilute the pool from 2000 to 450 ppm boron.

3.2.6 Dilution Resulting From Seismic Events or Random Pipe Breaks

The 3" fire protection system piping header located along a wall above the spent fuel pool is a potential dilution source if the pipe break faced the pool instead of the floor, wall, or ceiling. The Unit 2 fuel building fire header is supplied via two Unit 1 fire pumps, one motor driven and one diesel driven.

Each pump has a capacity of 2500 gpm and 125 psig with the motor driven pump auto-starting at 105 psig and diesel driven pump auto-starting at 95 psig. The pumps must be manually shut off after auto-starting. The system is maintained at 125 psig by a hydro-pneumatic tank in association with a pressure maintenance pump. Runout flow for each fire pump is 3750 gpm. In the event of a break in the fire header in the Unit 2 fuel building, the motor driven fire pump will auto-start at 105 psig and an alarm, "Motor Driven Fire Pump Running" will initiate in the Unit 1 control room. This requires the operator to investigate the location of the leak or fire. For this break, the motor driven fire pump cannot maintain sufficient header pressure, so the diesel driven fire pump will auto-start at 95 psig and another alarm, "Engine Driven Fire Pump Running" will initiate in the control room requiring still further investigation by the operator. The break of this fire protection system header is considered very unlikely due to its seismic design. Furthermore, even if the pipe break were to result in flow directly into the pool, the resulting fire protection system alarms would bring prompt operator action.

A seismic event could cause piping ruptures in the vicinity of the spent fuel pool in piping that is not seismically qualified. For a seismic event with offsite power available, rupture of the primary and demineralized water supply lines to the spent fuel pit cooling loop will not result in a direct addition of unborated water to the spent fuel pool. If offsite power is not available, the primary and demineralized water systems would not operate and thus, there would be no dilution source.

In the event of a break in one of the fire protection hose station supply lines which are outside the spent fuel pool enclosure but in the general area surrounding the spent fuel pool, water would approach the spent fuel pool, but would be blocked by the 25" curb surrounding the pool. Three inch diameter electrical penetrations are located in the curb, approximately eight inches above the floor. In addition, there is an open stairwell and floor drains through which this water would drain to lower elevations of the fuel handling building. For the purposes of this analysis, it is conservatively assumed that a fire protection hose station line break floods the entire area to a depth of eight inches, at which point water would enter the spent fuel pool through the electrical penetrations. This is conservative because of the openings to the new fuel storage, and the drop area opening leading to bay doors in the building. Even before the water level reached eight inches, the drop area would be capable of draining the full flow of any fire protection hose station supply line break.

Once the water depth was equalized at eight inches inside the curb (pool side) and outside curb (floor area), the driving head to force additional water into the enclosure would be significantly reduced. At

that point, most of the flow from the pipe break would bypass the spent fuel pool enclosure, taking the path of least resistance around the enclosure to the drop area opening.

The total amount of water added to the spent fuel pool enclosure to raise the water level to eight inches above the floor would be approximately 16,000 gallons assuming the spent fuel pool level was initially at the low level alarm setpoint. This is much less than the 401,000 gallons required to dilute the spent fuel pool from 2000 ppm to 450 ppm. While a limited amount of flow through the enclosure would continue until the line break were isolated, a fire protection system line break on the order of several thousand gallons per minute would be readily detected in the control room and break flow should be terminated within a few minutes, which is less than the 80 minutes required to dilute the spent fuel pool boron concentration to 450 ppm at 5000 gpm (both fire pumps at design flow).

Because of the limited flow into the spent fuel pool enclosure, and because a fire protection hose station supply line break would be terminated long before the spent fuel pool boron concentration would be reduced to 450 ppm, this event is not considered a credible event and is given no further consideration in this analysis.

3.2.7 Dilution From Spent Fuel Pool Ion Exchanger

When the spent fuel pool ion exchanger is first placed in service after being recharged with fresh resin, it can initially remove boron from the water passing through it. In the worst case, assuming 15 ft^3 of anion resin per ion exchanger, it is conservatively estimated that 9 ppm of boron could be removed from the spent fuel pool water before the resin becomes saturated. The deborating effect of the ion exchangers is modeled by removing 150 gpm of borated water per train and returning 150 gpm of deborated water per train until the ion exchange capacity is depleted. Since each ion exchanger normally utilizes a mixed bed of anion and cation resin, less boron would actually be removed before saturation. Because of the small amount of boron removed by the ion exchangers, it is not considered a credible dilution source for the purposes of this evaluation.

3.3 Summary of Dilution Events

SOURCE	APPROXIMATE FLOW RATE (GPM)	DILUTION TIME TO ALARM	TO 450 PPM
Primary Water System (limited source volume)			
- 2" connection to return header	190	41 min.	35 hr.
- 2" makeup to spent resin sluice header	195	45 min.	42 hr.
- 2" makeup via boric acid blender	170	52 min.	48 hr.
Demineralized Water System			
¾" capped piping on spent fuel pool wall	70	1.9 hr.	96 hr.
Hot Water Heating System	5771/460	1.4 min.	14 hr.
Service Water System			
- 6" emergency makeup connection	3000	2.6 min.	2 hr.
Fire Protection System			
- Fire hose stations in spent fuel pool area	200	39 min.	33 hr.
Spent Fuel Pool Ion exchangers	150	N/A(insufficient resin capacity)	

The addition of unborated water from the service water system provides the shortest dilution time. However, it is procedurally used as a last resort, and requires significant operator attention to physically make the connection and align the system. Therefore, it is unlikely that the operator would then ignore an open flowpath and a resulting high spent fuel pool alarm less than three minutes later.

The next shortest dilution time is from the hot water heating system. Dilution from this source requires that all seven heater fans break off during a seismic event, and that the feed and return lines all sever in such a way that they face directly into the spent fuel pool. This is judged to be very unlikely, and would result in a low expansion tank level and low temperature alarms in the hot water heating system. Finally, the operators would also notice the overflowing spent fuel pool during their rounds every shift.

The next shortest dilution time is from the fire hoses. Procedurally, this source is used for makeup only when other sources are not available. Given that local manual manipulations are required to bring the hoses to the spent fuel pool, and initiate flow, even if the operators would leave the area unattended, normal operator rounds every shift would detect a problem well within the 33 hours needed for dilution.

The next shortest dilution time and the most likely scenario for normal operation is based on using the primary water connection to the spent fuel pool for makeup when the process isolation valve is

inadvertently left opened. This connection is the normal flowpath for unborated water authorized for use under normal plant conditions by procedure. However, it is fed from a tank which has a capacity less than the required volume to dilute the spent fuel pool from 2000 to 450 ppm. Makeup is available from the raw water treatment system. For the limiting scenario to successfully result in the dilution of the spent fuel pool from 2000 ppm to 450 ppm, the addition of 401,000 gallons of water to the spent fuel pool over a period of 35 hours would have to go unnoticed. The first indication of such an event would be high level alarms in the control room from the pool level instrumentation. If the high level alarms fail, it is reasonable to expect that the significant increase in pool level and eventual pool overflow that would result from a pool dilution event will be readily detected by plant operators in time to take mitigative actions. A pool overflow condition would result in flooding of the fuel handling building sumps, and significant input flow rates would result in high sump level alarms. Although area radiation monitors are available, relatively clean spent fuel pool contents might not set off an alarm. In addition, it can be assumed that the operator rounds through the spent fuel pool area that occur once per 8 hours will detect the increase in the pool level even if the alarms fail and the flooding is not detected.

Furthermore, for any dilution scenario to successfully add up to 401,000 gallons of water to the spent fuel pool, plant operators would have to fail to question or investigate a significant volume of makeup water used from the primary water storage tank for the required time period, and fail to recognize that the need for 401,000 gallons of administrative makeup to the tank was unusual.

4.0 CONCLUSIONS

A boron dilution analysis has been completed for the spent fuel pool. As a result of this spent fuel pool boron dilution analysis, it is concluded that an unplanned or inadvertent event which would result in the dilution of the spent fuel pool boron concentration from 2000 ppm to 450 ppm is not a credible event. This conclusion is based on the following:

- In order to dilute the spent fuel pool to the design k_{eff} of 0.95, a substantial amount of water (401,000 or 488,000 gallons) is needed. To provide this volume, an operator would have to initiate the dilution flow, then abandon monitoring of pool level, violate administrative procedures, and ignore spent fuel pool and building sump high level alarms.

- Since such a large water volume turnover is required, a spent fuel pool dilution event would be readily detected by plant personnel via alarms, flooding in the fuel handling building or by normal operator rounds through the spent fuel pool area.

- It should be noted that this boron dilution evaluation was conducted by evaluating the time and water volumes required to dilute the spent fuel pool from 2000 ppm to 450 ppm. The 450 ppm end point was utilized to ensure that K_{eff} for the spent fuel racks would remain less than or equal to 0.95. As part of the criticality analysis for the spent fuel racks (Reference 1), a calculation has been performed on a 95/95 basis to show that the spent fuel rack K_{eff} remains less than 1.0 with non-borated water in the pool. Thus, even if the spent fuel pool were diluted to zero ppm, which would take significantly more water than evaluated above, the spent fuel would be expected to remain subcritical and the health and safety of the public would be assured.

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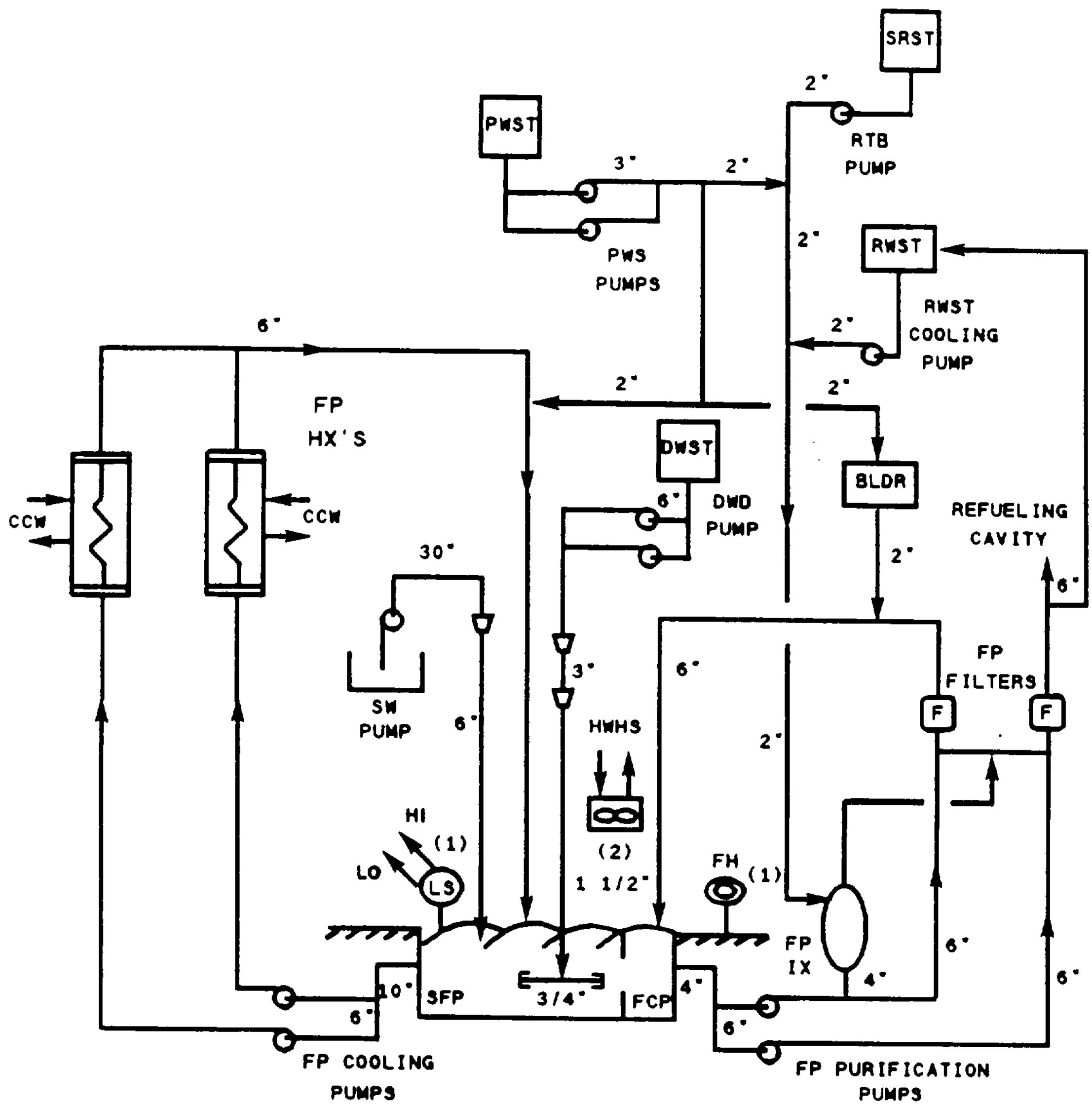
Figure 1

SPENT FUEL POOL AND RELATED SYSTEMS



LEGEND:

BLDR	Boric Acid Blender	LO	Low Alarm
CCW	Component Cooling Water	LS	Level Switch
DW	Demineralized Water	PWS	Primary Water Supply
DWD	Demin Water Distr.	PWST	Primary Water Storage Tank
DWST	Demineralized Water Storage Tank	RTB	Resin Transfer Booster
FCP	Fuel Cask Pool	RWST	Refueling Water Storage Tank
FH	Fire Hose	SFP	Spent Fuel Pool
FP	Fuel Pool	SRST	Spent Resin Storage Tank
HI	High Alarm	SW	Service Water
HWHS	Hot Water Heating System		
IX	Ion Exchanger		

NOTES:

(1) TYP. of 2

(2) TYP. of 7

GJCDLW

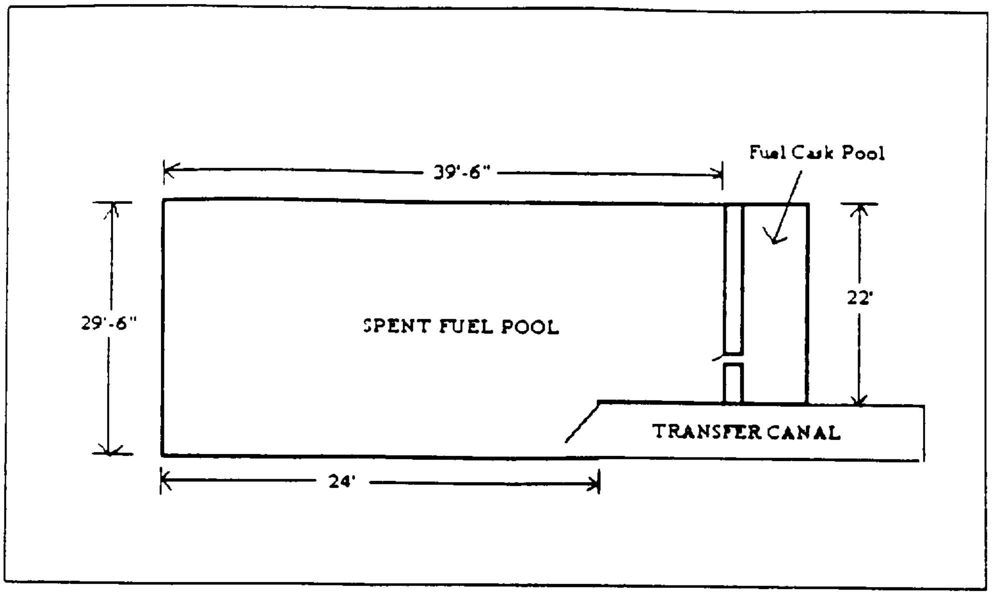


Figure 2 - Spent Fuel Pool Plan View

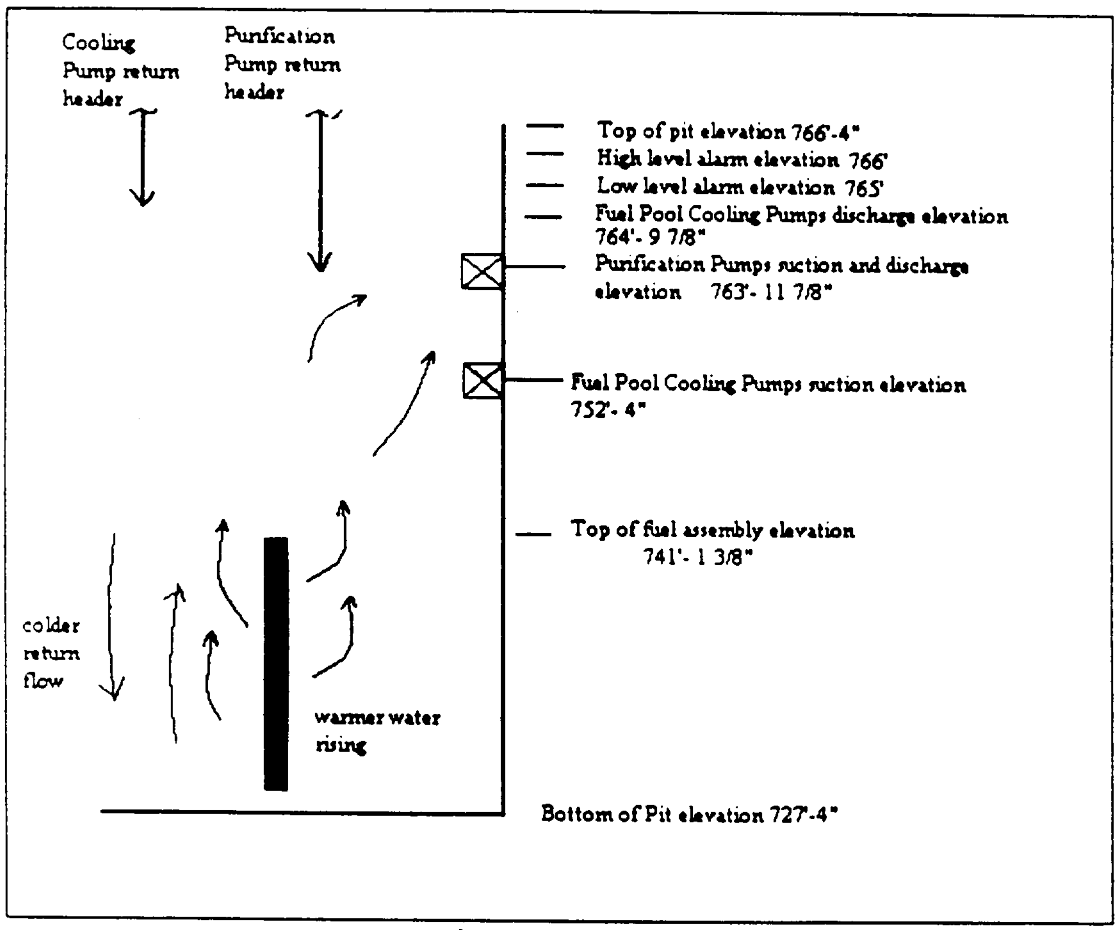


Figure 3 - Spent Fuel Pool Mixing/Elevations