FENOC
FirstEnergy Nuclear Operating Company

Withhold from Public Disclosure under 10CFR2.390

When separated from Attachment 1, the remainder of this submittal may be decontrolled.

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February 18, 2011
L-11-057

10 CFR 50.90

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

SUBJECT:
Beaver Valley Power Station, Unit No. 2
Docket No. 50-412, License No. NPF-73
Responses to NRC Staff Request for Additional Information Regarding
Unit No. 2 Spent Fuel Pool Rerack Criticality Analyses (TAC No. ME1079)

A license amendment request to revise the Beaver Valley Power Station Unit No. 2 (BVPS-2) Technical Specifications to support installation of high density fuel storage racks in the spent fuel pool was submitted on April 9, 2009 (Accession No. ML091210251), and supplemented on June 15, 2009 (Accession No. ML091680614) and October 18, 2010 (Accession No. ML102940454). With respect to the supporting criticality analyses for the amendment, responses to a Nuclear Regulatory Commission (NRC) request for additional information (RAI) were provided in letters dated March 18, 2010 (Accession No. ML100820165) and June 1, 2010 (Accession No. ML101610118). Subsequently, the NRC staff provided additional criticality analysis RAI items in a letter dated January 24, 2011 (Accession No. ML110200602).

Attachment 1 provides responses to the January 2011 RAI items. A portion of the information in the responses is considered proprietary; therefore Attachment 2 provides a nonproprietary version of the responses. Pursuant to 10 CFR 2.390, an affidavit from Holtec International, the owner of the information sought to be withheld, is provided as an enclosure.

There are no new regulatory commitments contained in this submittal. If there are any questions or if additional information is required, please contact Mr. Thomas A. Lentz, Manager - Fleet Licensing, at (330) 761-6071.

I declare under penalty of perjury that the foregoing is true and correct. Executed on February 18, 2011.

Sincerely,

Paul A. Harden

A001
NRR

ATTACHMENTS:

1. Response to NRC RAI on BVPS-2 Spent Fuel Pool Rerack Criticality Analysis (Proprietary Version)
2. Response to NRC RAI on BVPS-2 Spent Fuel Pool Rerack Criticality Analysis (Nonproprietary Version)

ENCLOSURE:
10 CFR 2.390 Proprietary Affidavit from Holtec International

cc: NRC Region I Administrator (without Proprietary Attachment)
NRC Resident Inspector (without Proprietary Attachment)
NRC Project Manager (without Proprietary Attachment)
Director BRP/DEP (without Proprietary Attachment)
Site Representative (BRP/DEP) (without Proprietary Attachment)

Response to NRC RAI on BVPS-2 Spent Fuel Pool Rerack Criticality Analysis (Nonproprietary Version)

By letter dated January 24, 2011, the Nuclear Regulatory Commission (NRC) staff provided a request for additional information (RAI) on the FirstEnergy Nuclear Operating Company (FENOC) license amendment request (LAR) for Unit 2 of the Beaver Valley Power Station (BVPS-2), regarding criticality analyses that support a spent fuel pool rerack. The NRC RAI items are presented below in bold type, followed by the FENOC response. Triple brackets denote the start and end of proprietary information.

1. **RAI-15: The response to RAI-15 is adequate, but raises some additional questions.**

   a. **Provide an explanation for the large differences between the predicted nuclear design report values and the corrected/measured soluble boron concentrations. The issue is that some reactor parameter, such as temperatures, power, and coolant flow rate, may be significantly different than what was used in the fuel depletion calculations. If core reactivity is mispredicted by nearly 1% Δk-effective (k_{eff}), you may also be under predicting the reactivity of the fuel in storage. The explanation of the misprediction should also address its impact on the analysis.**

Response

The largest difference (approximately 760 pcm (percent milli-rho)) was seen in Cycle 11. The measurements determine total boron, and in Cycles 1 thru 11, boron-10 depletion was not accounted for, which contributed to some of the difference between the measured and predicted values. The response for RAI-15 notes that boron-10 depletion was accounted for in Cycles 12-14. The differences seen in Cycles 12-14 are on the order of 300-450 pcm. This is lower than the Technical Specification (TS) surveillance requirement of ±1000 pcm (± 1% Δk/k).

The methodology utilizes the Westinghouse ANC/Phoenix codes based on design values (for example, the end-of-cycle burnup may not reflect the actual end-of-cycle burnup, and the assumed boron-10 content is 19.9 atom%). The methodology used in the criticality analysis is based on the CASMO-4 and MCNP codes, and uses bounding values, tolerance calculations, CASMO-4/MCNP code bias and/or uncertainties, and sensitivity calculations to maximize the reactivity, thus bounding the actual reactivity of assemblies stored in the spent fuel pool. Such conservatisms are meant to provide reasonable assurance that variations in normal operating parameters do not impact the bounding reactivity as evaluated by the criticality analysis. CASMO-4 was not used to calculate absolute reactivity within the criticality analysis; it was only used to calculate delta reactivity. A CASMO-4 bias uncertainty

was incorporated into the criticality analysis. The ability of CASMO-4 to calculate delta reactivity is demonstrated qualitatively in Figures 4 through 6 in response to RAI 3.f.

Therefore, this data is not used as direct input into the criticality safety analysis, other than to demonstrate that the assumed boron concentration in the criticality safety analysis bounds the historical measured cycle-average boron concentrations. Since this data is not input into the criticality safety analysis or into any of the parameters used in the criticality safety analysis, any difference has no impact on the analysis.

b. The RAI-15 response includes the following statement:

> *A process will be established prior to receipt of the next reload batch of BVPS Unit 2 fuel to ensure that the design features and operating parameters of fuel used in the future at BVPS Unit 2 are consistent with the assumptions of the criticality analysis.*

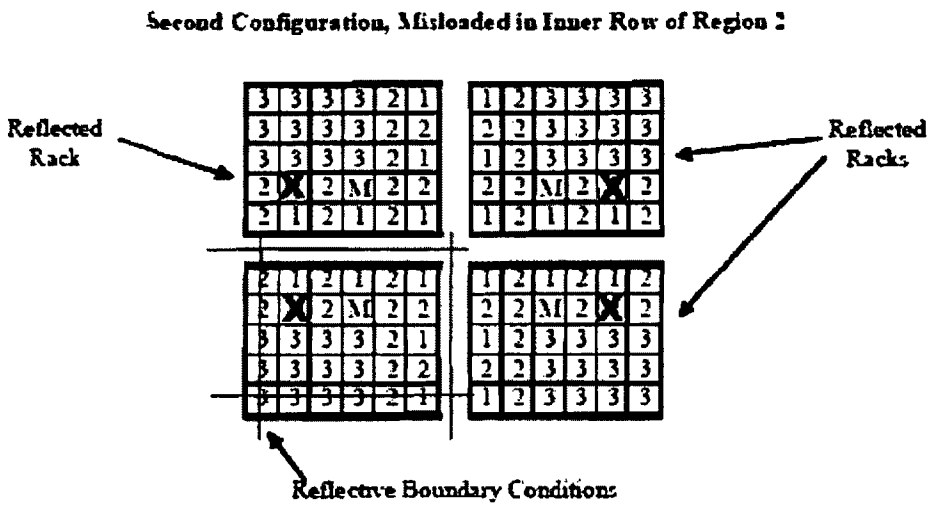
Which design features and operating parameters will be reviewed in the process? Will the "process" be reviewed by NRC staff prior to implementation?

Response

The design features reviewed by this process are fuel design and dimensional characteristics (fuel pin pitch, fuel rod diameters, pellet diameter, enrichment/IFBA loadings and associated restrictions, guide tube/instrument tube dimensions, fuel length, and overall assembly type). The operational (depletion-related) features reviewed by this process are cycle-average boron concentration, core-average moderator temperature, core outlet temperature, axial burnup profile, fuel assembly burnup, and other control restrictions such as use of removable burnable absorbers including WABA/pyrex absorbers. It should be noted that this is only a summary of design features and operating parameters and the process is not necessarily limited to the review of just the parameters listed above.

This process, which has already been implemented and is available in the site document management system, is licensee-controlled. The site document management system is available to the Nuclear Regulatory Commission, for information.

2. **The response to RAI-29 may not be adequate. The second of the three figures that were provided might have a more reactive configuration. See the modified figure below:**



The locations marked with "M" are the evaluated misload locations. It is not clear that an alternate misload location, marked "X", will not yield a higher k_{eff} value. The alternate locations have more type "3" fuel assemblies around them than the originally evaluated locations. Type 3 fuel has a higher reactivity than the type 2 fuel.

a. **Confirm that the k_{eff} for the alternate misload location is bounded by the already evaluated misloads.**

Response

The alternative misloading configuration for the Region 2 inner row that is described in the RAI was analyzed. The results are listed in the following table, together with the results of the two already evaluated misloading conditions for Region 2 fuel (inner row and outer row). Comparing the results shows that the alternative configuration has a higher soluble boron requirement than the already evaluated configuration for the inner row misloading. However, it is still bounded by the already evaluated configuration for the Region 2 outer row misloading configuration, which therefore is and remains overall bounding.

Region 2 Enrichment (weight percent (wt%) U-235)	2.0	3.5	5.0
Region 2 Burnup (GWD/MTU†)	9	32	50
Region 3 Enrichment (wt% U-235)	5.0	5.0	5.0
Region 3 Burnup (GWD/MTU)	39.00	39.00	39.00
Misloaded Fresh Fuel Assembly in Region 2 (inner row) Alternative Configuration			
Reactivity, 0 ppm†	1.0132	1.0106	1.0127
Reactivity, 2500 ppm	0.7875	0.7952	0.7998
Target k_{eff} (0.945-corrections)	0.9196	0.9177	0.9160
Interpolated Soluble Boron Requirement, ppm	1036	1078	1136

Misloaded Fresh Fuel Assembly in Region 2 (inner row) Previously Analyzed Configuration			
Reactivity, 0 ppm	1.0024	0.9989	1.0017
Reactivity, 2500 ppm	0.7786	0.7856	0.7917
Target keff (0.945-corrections)	0.9196	0.9177	0.9160
Interpolated Soluble Boron Requirement, ppm	924	952	1020
Misloaded Fresh Fuel Assembly in Region 2 (outer row) Previously Analyzed Bounding Configuration			
Reactivity, 0 ppm	1.0202	1.0175	1.0187
Reactivity, 2500 ppm	0.7972	0.8022	0.8068
Target k_{eff} (0.945-corrections)	0.9196	0.9177	0.9160
Interpolated Soluble Boron Requirement, ppm	1127	1159	1212

†GWD/MTU = Gigawatt Days per Metric Ton Uranium; ppm = parts per million.

b. **Figure 4.5.7, which did not exist in the original analysis and varies significantly from Figure 1.1, appears to show locations where an assembly could be placed between rack modules. If this is true, evaluate the soluble boron requirement for assemblies incorrectly placed in these non-storage locations.**

Response

Figure 4.5.7 is not to scale, and therefore does not depict actual rack-to-rack distances. In the actual rack configuration, there is not enough room between rack modules for the accidental placement of an extra assembly. The purpose of the figure was to provide clarification of acceptable mixed zone three region (MZTR) loading configurations, specifically along the rack interfaces where "cut-outs" exist.

c. **Figure 4.5.7 seems to indicate that four fresh fuel assemblies will not be placed into the neighboring corners of four rack modules. Is this configuration prohibited? If so, how is this restriction captured in the TS?**

Response

The analytical model of the rack contains a fresh assembly in the corner of the rack that is modeled. With the reflecting boundary conditions used in the analyses, this represents a configuration where fresh assemblies are placed in the neighboring corners of four racks. This configuration is therefore supported by the analysis and hence permitted. Consequently, no corresponding restriction is required in the TS.

3. **RAI-33: This RAI focused on how the reactivity control penalty was calculated. The response leads to some additional questions.**

a. **The calculation of the reactivity control penalties was performed using CASMO. It does not appear that CASMO's ability to calculate Δk_{eff} penalties as used in the analysis has been validated. Provide the validation for using CASMO to calculate the Δk_{eff} penalty.**

Response

Rather than validating CASMO for the calculation of the delta-k penalties, the calculations have been re-performed using CASMO only to determine the isotopic compositions of the fuel, and then performing the calculation of the delta-k penalty in MCNP. The following contains a description of the main considerations of the analyses:

- Past reactivity control configurations were analyzed separately. These include a total of 20 configurations of IFBA patterns, IFBA patterns together with WDR rod patterns, and WABA rod patterns. The list of those 20 configurations is shown in the table at the end of this response. Each configuration is analyzed at the actual enrichment level(s) and axial burnup profile applicable to the pattern. Note that several configurations were used at different enrichment levels; in those cases, applicable enrichment levels for that configuration are individually analyzed to ensure the bounding condition is determined.
- Additionally, configurations with 200 IFBA rods were analyzed for fuel with enriched blankets and various fuel enrichments. This bounds IFBA patterns anticipated in the future, which will be controlled by the process described in response to RAI 1.b.
- [[[PROPRIETARY -

]]]

- Calculations are performed for the full three-dimensional design basis rack model that includes Region 1, Region 2 and Region 3 fuel. Spent fuel compositions of Region 2 and Region 3 assemblies are taken from the reactivity control depletion calculations; specifically, it is assumed that spent fuel assemblies in each model were exposed to the same reactivity control configuration.
- Cases without any reactivity control effect were performed for relevant enrichment and axial profile combinations as reference cases, also using pin specific compositions, so that the delta-k penalties can be calculated.
- Burnups are determined from the applicable loading curves for Region 2 and Region 3 assemblies, based on the fuel enrichment and the axial profile for each configuration. Fuel in those analyses therefore represent fuel that exactly matches the burnup requirements. Many configurations use enrichments such as 3.2 or 3.4 wt% that were not directly evaluated in the design basis calculations. The polynomial functions established to define the loading curves were used to determine the burnups for each of those enrichments.
- The fresh fuel in Region 1 is always modeled without any burnable poison.

The calculated reactivity differences (delta-k) for configurations range between -0.0007 and 0.0038, with an uncertainty of 0.0011 at the 95/95 level. The highest value corresponds to the configuration with 200 IFBA rods (which bounds future conditions) at an enrichment of 4.6 wt%. This is about half of the value of 0.0063 delta-k determined in the original analyses using CASMO. In conclusion, using more detailed MCNP calculations to determine the reactivity control bias demonstrates that the bias previously determined using CASMO-4 is conservative.

Analyzed Past Reactivity Control Configurations

Configuration	Number of Patterns
32 IFBA Rods	2
48 IFBA Rods	2
64 IFBA Rods	3
80 IFBA Rods	2
100 IFBA Rods	1
104 IFBA Rods	1
128 IFBA Rods	3
20 WABAs	1
16 WABAs	1
12 WABAs	1
100 IFBA Rods and 4 WDRs	1
128 IFBA Rods and 4 WDRs	1
128 IFBA Rods and 8 WDRs	1
Total	**20**

See also the response to RAI 5.e for a discussion of the impact of a reduced penalty on the loading curves.

b. **It looks like the reactivity control penalties were calculated using 2-D CASMO calculations. If this is true, this represents a significant simplification over the real 3-D problem. Provide justification for the use of 2-D calculations and provide data that supports this justification. If appropriate, incorporate and justify additional margin to cover the modeling simplification.**

Response

As discussed in the response to RAI 3.a, calculations for the reactivity control penalty are now performed in 3-D MCNP models rather than 2-D CASMO models. No further justification for the modeling is therefore required.

c. **The IFBA penalty calculations were presented for only fuel with initial enrichments of 3, 3.8 and 5 weight percent (wt%). Provide the data and justify the use of the rather limited set of enrichments evaluated.**

Response

As discussed in the response to RAI 3.a, previously used configurations, and configurations bounding future reactivity control are now analyzed. No further justification for the selection of cases is therefore required.

d. **The IFBA penalty calculations were presented for only 100, 128, and 200 IFBA rod patterns. Justify not examining other patterns already used at Beaver Valley, which also include 32, 48, 64, and 80 IFBA rod patterns, and provide data that support this justification.**

Response

As discussed in the response to RAI 3.a, previously used IFBA configurations, and IFBA configurations bounding future conditions are now analyzed. No further justification for the selection of IFBA patterns is therefore required.

e. **The analysis does not describe how the IFBA rods were modeled in CASMO. The IFBA coating is a very thin layer of a strong neutron absorber on the outside of the pellet. Provide a description and justify how this was modeled in CASMO. The description should address the model geometry, and relevant CASMO solution parameters such as quadrature used.**

Response

IFBA is a very thin, absorbing layer on the outside of the fuel pellet and requires appropriate treatment in the Method of Characteristics that is used for the two dimensional (2-D) transport solution in CASMO-4, and consideration is required prior to the 2-D transport solution.

IFBA modeling in CASMO-4 is performed by homogenizing the thin outer IFBA layer with the fuel pellet by using a one-dimensional, pincell based, collision probabilities solution prior to the 2-D characteristics transport solution. Through the use of heterogeneity factors, applied to the cross sections subsequently used in the 2-D transport calculation, this calculation preserves the homogeneous to heterogeneous reaction rates.

This homogenization process eliminates the need to refine the quadrature (number of azimuthal angles, number of polar angles, and ray-spacing) of the 2-D transport solution, and the default quadrature is used and the calculation proceeds normally.

This homogenization process is a concession to run-time as with sufficiently fine ray-spacing, the Method of Characteristics can be applied directly to these types of problems albeit with an associated increase in runtime. No further treatment for IFBA fuels is performed in CASMO-4. As discussed in the response to RAI 3.a, calculations for the reactivity control penalty are now performed in MCNP models rather than CASMO models.

f. Describe the experience and performance of modeling IFBA using CASMO. Have CASMO IFBA cross sections been used in reactor simulation for operating reactors? If so, provide data that shows how well the simulated power distributions and soluble boron agree with measurements.

Response

CASMO-4 is licensed by the NRC for reload analysis and some utilities use CASMO-4 to perform reload licensing for cores containing IFBA. Some examples are:

- "Safety Evaluation by the Office of Nuclear Reactor Regulation Relating to Topical Report DOM-NAF-1 Qualification of the Studsvik Core Management System Reactor Physics Methods for Application to North Anna and Surry Power Stations, Units 1 and 2, Docket Nos. 50-280, 50-281, 50-338, and 50-339"
- "Palo Verde Nuclear Generating Station (PVNGS), Units 1, 2, and 3 – Issuance of Amendments on CASMO-4/SIMULATE-3 (TAC Nos. MA9279, MA9280, and MA9281)"

Although Beaver Valley does not use CASMO-4 for licensed reload analysis, it uses CASMO-4 and SIMULATE-3 for independent verification of vendor analysis.

The following figures provide a sample of power distribution and soluble boron data for BVPS-2 Cycles 12 through 14. There are a limited number of feed fuel assemblies in detector locations, so the selected axial power distributions are from feed fuel assemblies located in detector locations. Feed fuel assemblies were selected because they contain fresh IFBA at beginning-of-cycle (BOC). The measured (Meas) axial power distribution data are from flux map traces of the moveable in-core detector surveillance data. The predicted axial power distribution data are from SIMULATE-3 (S3) 3-D nodal code, which uses CASMO-4 cross-section data with IFBA. Recent Beaver Valley fuel assemblies have some number of fuel pins with IFBA-coated pellets. The axial power distributions are shown in Figures 1 through 3. The soluble boron concentration letdown curves between measured Reactor Coolant System (RCS) surveillance data (adjusted for boron-10 depletion) and predicted SIMULATE-3 data is provided below in Figures 4 through 6 for Cycles 12 through 14. The assembly-average power distribution is also provided for Cycle 12 through 14, as shown in Figures 7 through 15, with the feed assemblies indicated by the circles. Note that core locations in the 2-D power distribution maps that are showing zero power (0.000) are due to inoperable in-core detectors. As discussed in the response to RAI 3.a, calculations for the reactivity control penalty are now performed in MCNP models rather than CASMO models.

Figure 1
Comparison between Measured and SIMULATE-3 Axial Power Distribution for Assembly Location F-8 in Beaver Valley Unit 2 Cycle 12

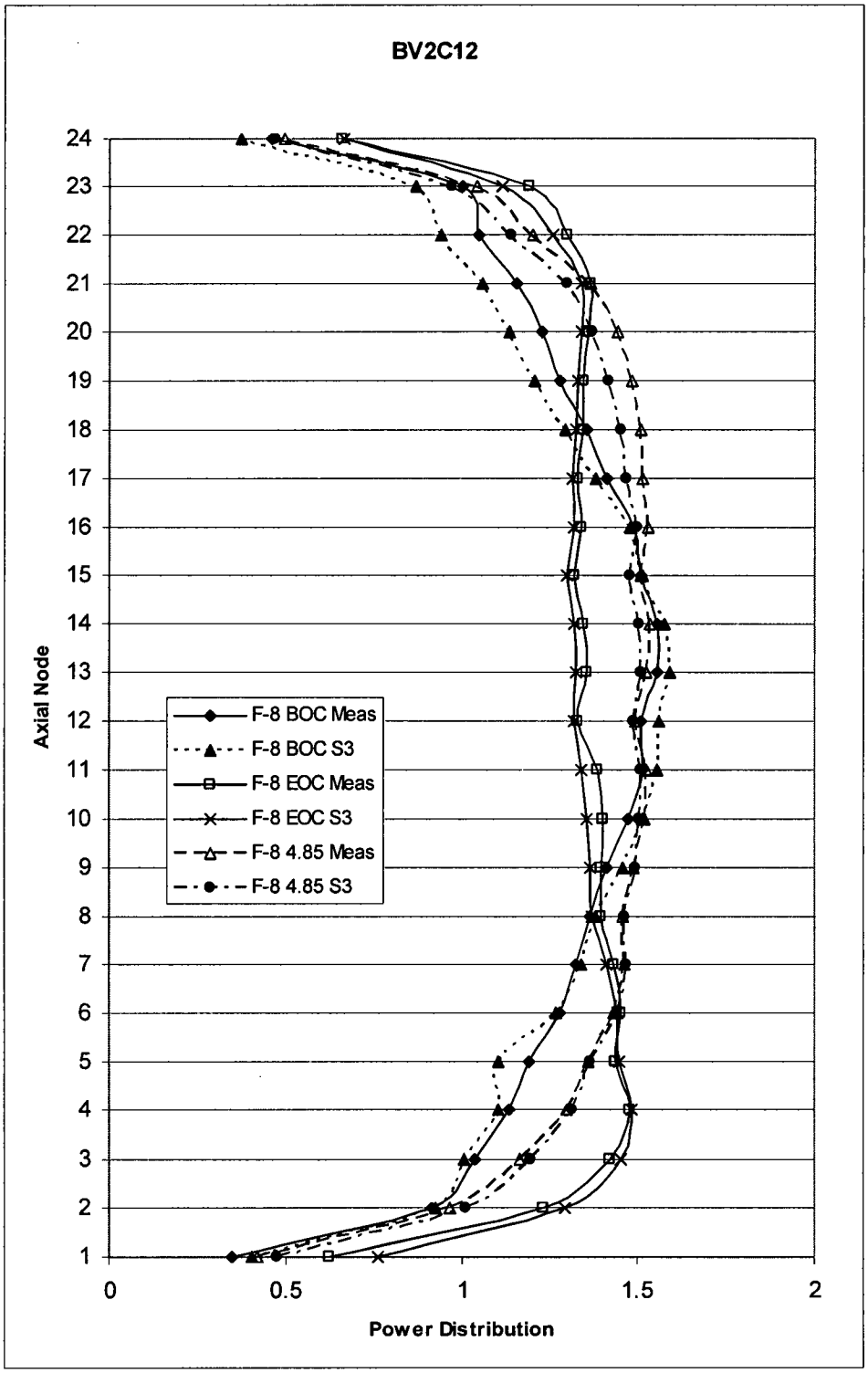


Figure 2
Comparison between Measured and SIMULATE-3 Axial Power Distribution for Assembly Location L-4 in Beaver Valley Unit 2 Cycle 13

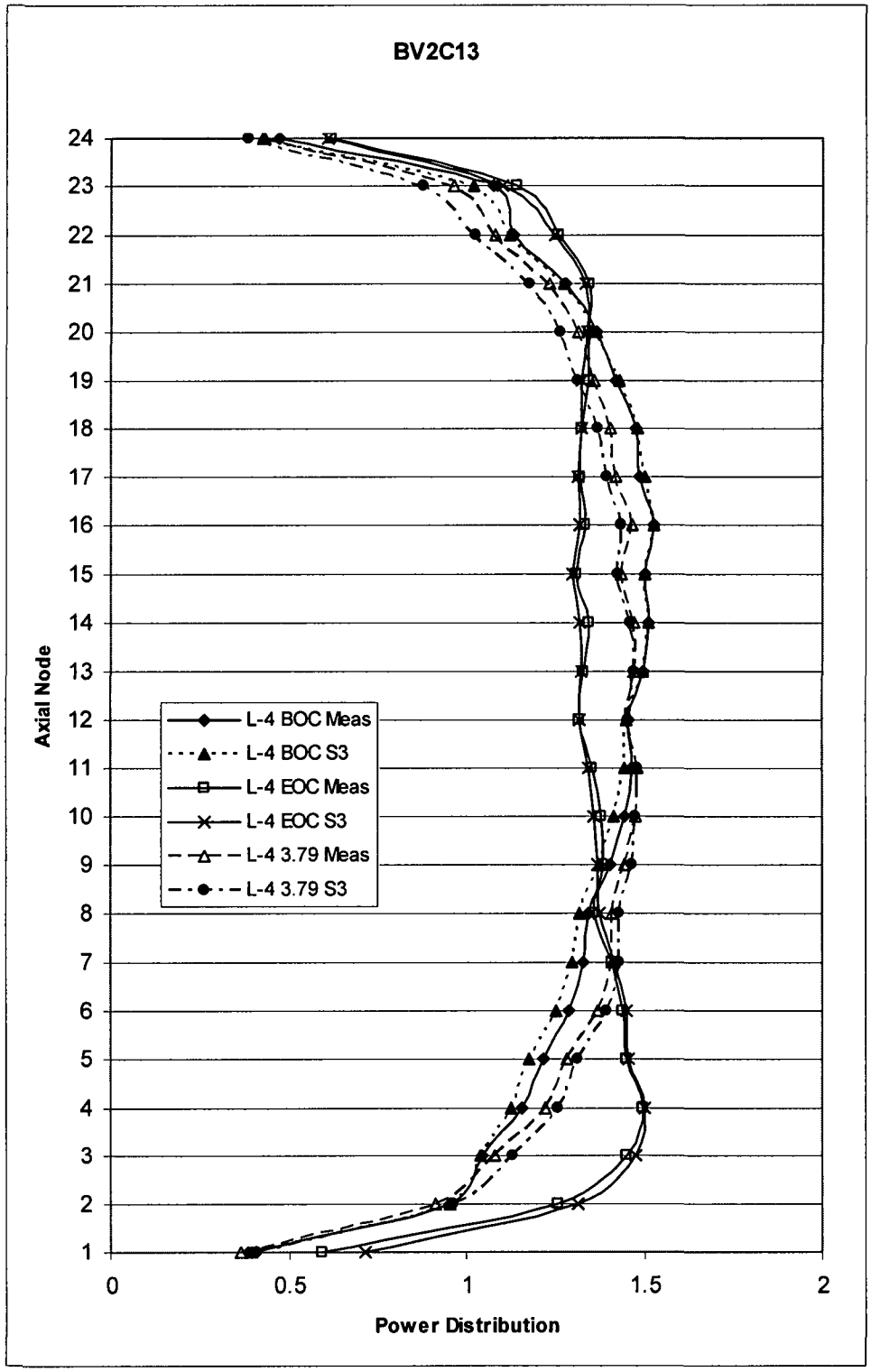


Figure 3
Comparison between Measured and SIMULATE-3 Axial Power Distribution for Assembly Location F-13 in Beaver Valley Unit 2 Cycle 14

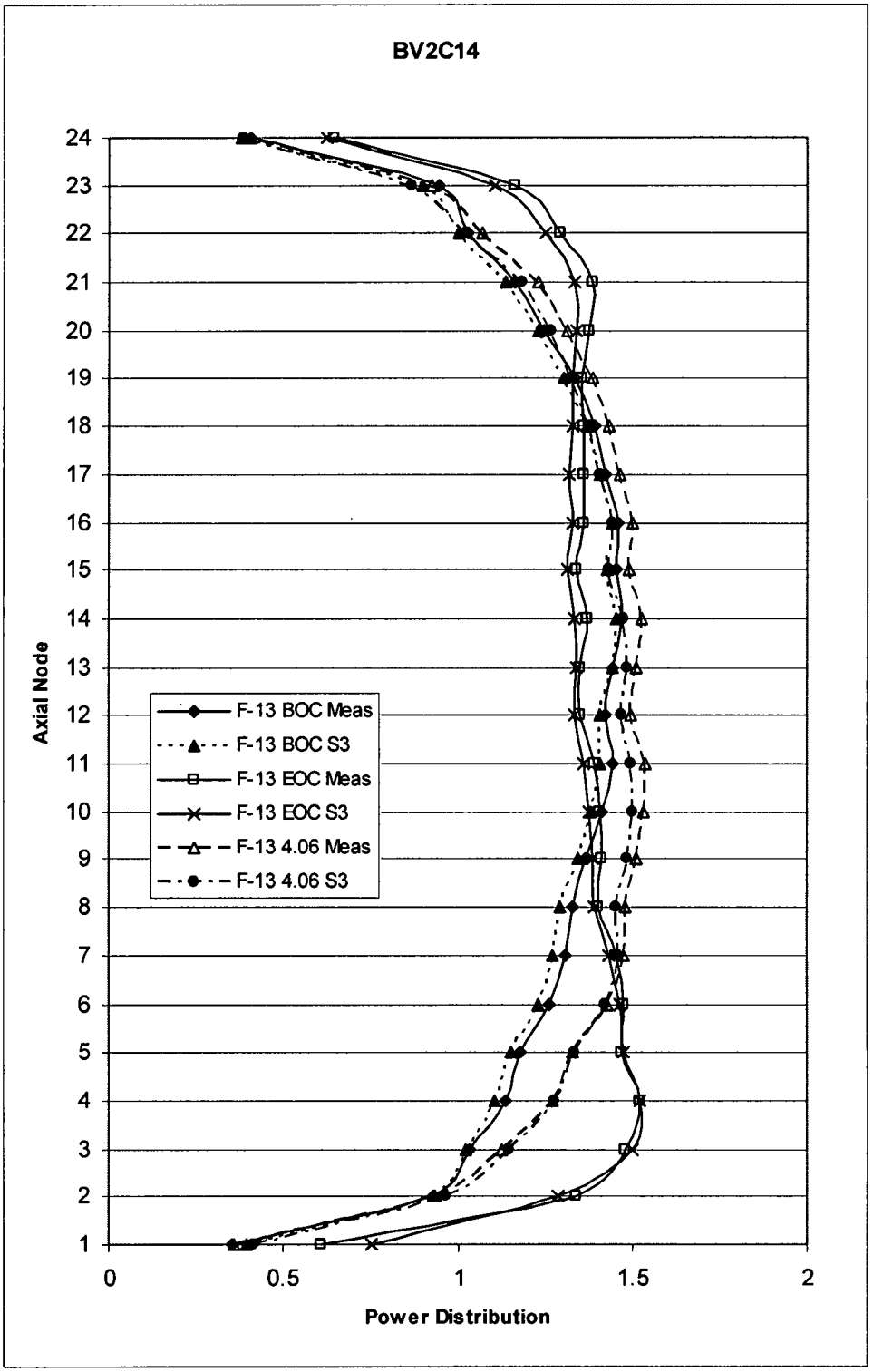


Figure 4
Comparison between Measured and SIMULATE-3 Critical Boron Concentration for Beaver Valley Unit 2 Cycle 12

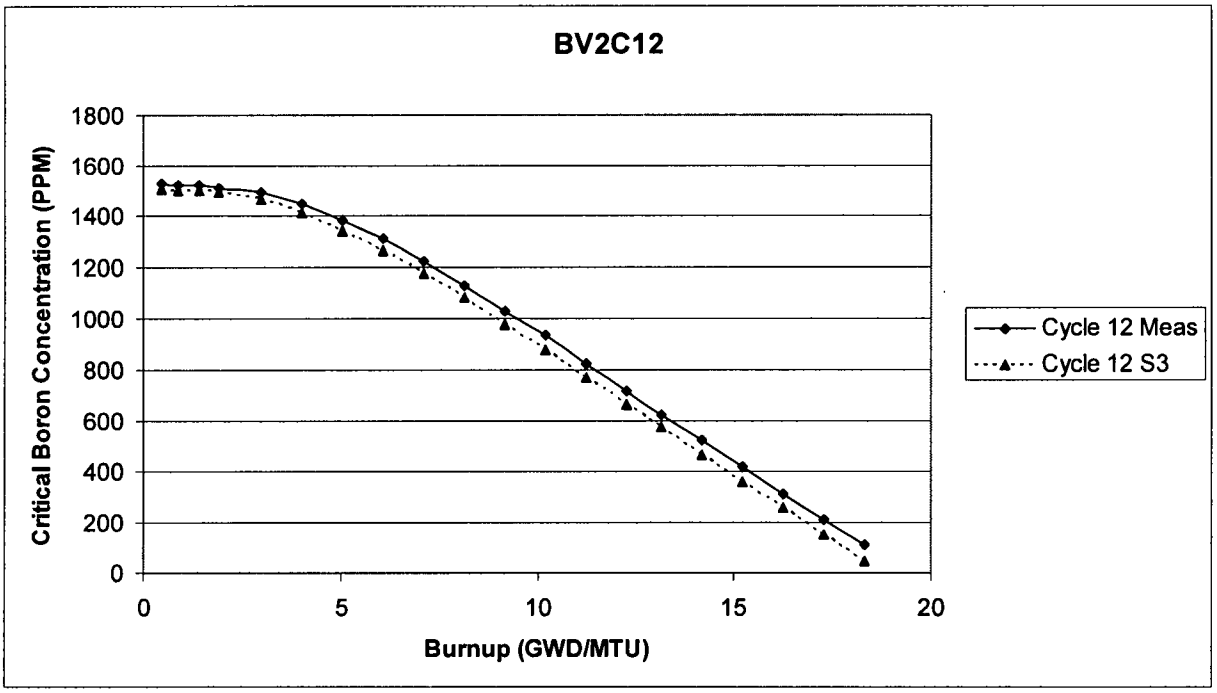


Figure 5
Comparison between Measured and SIMULATE-3 Critical Boron Concentration for Beaver Valley Unit 2 Cycle 13

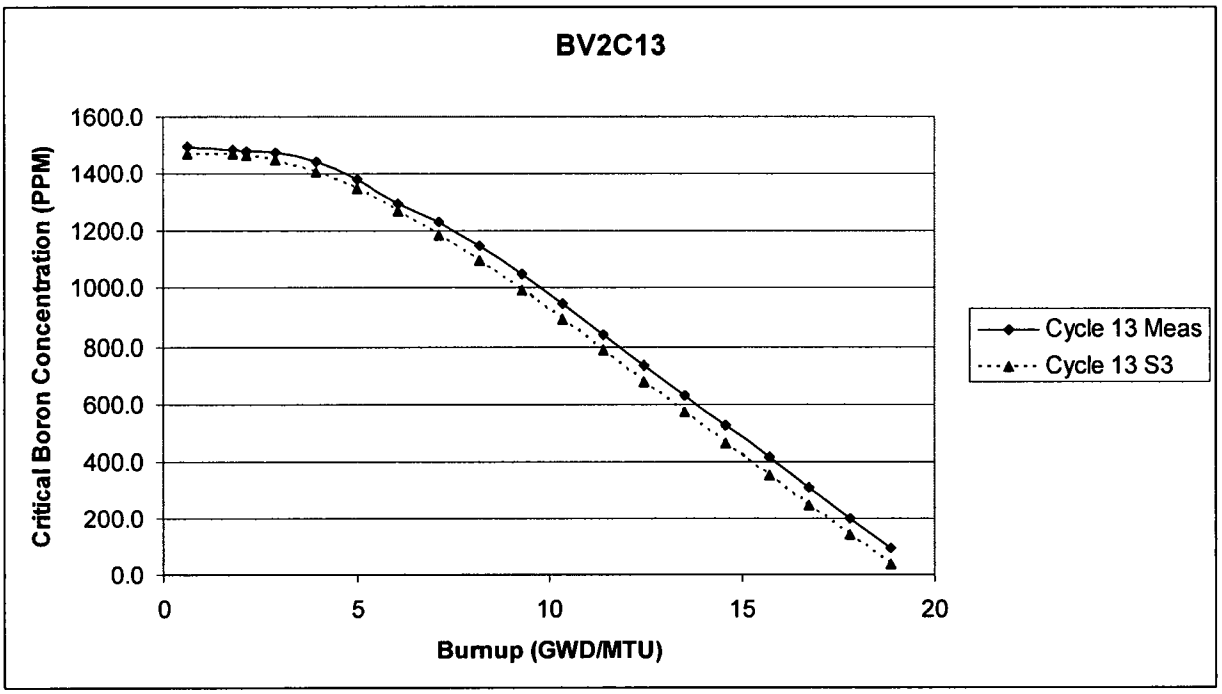


Figure 6
Comparison between Measured and SIMULATE-3 Critical Boron Concentration for Beaver Valley Unit 2 Cycle 14

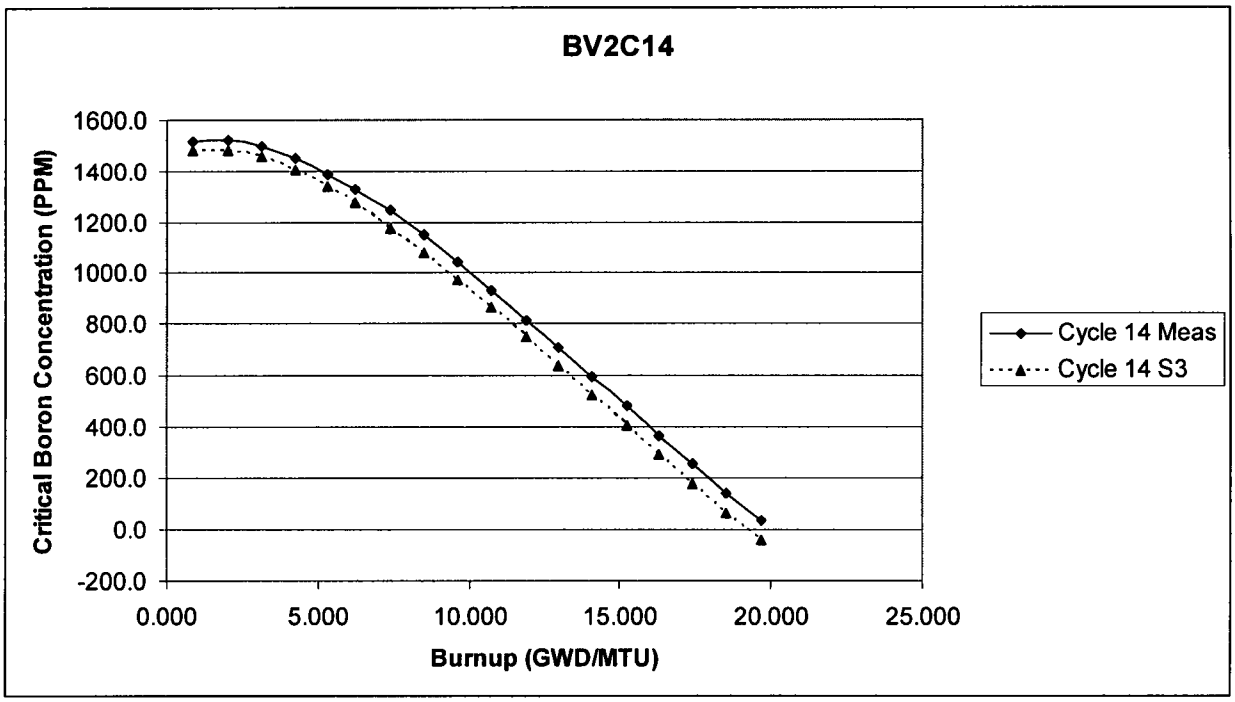


Figure 7

Comparison between Measured and SIMULATE-3 Assembly-Average Power Distribution at Beginning of Cycle (BOC) Beaver Valley Unit 2 Cycle 12

ASSEMBLY-AVERAGE POWER DISTRIBUTION MAP

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1								0.291 0.290 -0.001 -0.28								1
2										0.463 0.454 -0.009 -1.91						2
3				0.359 0.358 -0.001 -0.29			1.194 1.173 -0.021 -1.72	1.121 1.130 0.008 0.73				0.361 0.351 -0.010 -2.72				3
4					1.378 1.351 -0.028 -2.01			1.034 1.044 0.010 0.94		1.290 1.280 -0.010 -0.76						4
5			0.973 0.987 0.014 1.44		1.336 1.350 0.014 1.02		1.212 1.214 0.002 0.20				1.364 1.350 -0.014 -1.05	1.393 1.351 -0.042 -3.03		0.279 0.272 -0.007 -2.52		5
6					1.160 1.170 0.010 0.83			1.196 1.213 0.017 1.46		1.119 1.114 -0.004 -0.39						6
7			1.139 1.175 0.036 3.16				1.125 1.144 0.019 1.70		1.139 1.144 0.005 0.42			1.110 1.093 -0.017 -1.56		0.000 0.000 0.000 0.00		7
8	0.288 0.290 0.002 0.89		1.108 1.130 0.022 2.00		1.028 1.071 0.043 4.23					1.231 1.213 -0.018 -1.45			1.141 1.130 -0.012 -1.04	0.000 0.000 0.000 0.00		8
9					1.192 1.214 0.022 1.89				1.128 1.144 0.016 1.42	1.068 1.075 0.008 0.72					0.000 0.000 0.000 0.00	9
10			1.186 1.173 -0.013 -1.11				1.049 1.075 0.026 2.49					1.309 1.280 -0.029 -2.20		0.000 0.000 0.000 0.00		10
11					1.360 1.350 -0.011 -0.78			1.025 1.071 0.047 4.56		1.166 1.170 0.003 0.28	1.372 1.350 -0.022 -1.62					11
12			0.364 0.358 -0.006 -1.63				1.070 1.094 0.024 2.20					0.966 0.927 -0.038 -3.96	0.367 0.351 -0.016 -4.41			12
13								1.110 1.130 0.020 1.81		1.202 1.173 -0.029 -2.42						13
14					0.000 0.000 0.000 0.00				0.995 0.984 -0.011 -1.13							14
15							0.240 0.240 0.000 -0.20			MEASURED SIMULATE-3 ABS. DIFF. (S3-M) REL. DIFF. (100*(S3-M)/M)						15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

Figure 8

Comparison between Measured and SIMULATE-3 Assembly-Average Power Distribution at 4.85 GWD/MTU Beaver Valley Unit 2 Cycle 12

ASSEMBLY-AVERAGE POWER DISTRIBUTION MAP

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1								0.365 0.362 -0.003 -0.70								1
2										0.523 0.518 -0.004 -0.80						2
3				0.369 0.377 0.008 2.11			1.324 1.317 -0.018 -1.32	0.000 0.000 0.000 0.00				0.370 0.371 0.000 0.12				3
4					1.362 1.355 -0.007 -0.51			1.031 1.043 0.012 1.17		1.229 1.222 -0.007 -0.55						4
5			1.001 1.011 0.010 1.02		1.252 1.252 0.000 0.00		1.332 1.316 -0.016 -1.23				1.267 1.252 -0.015 -1.17	0.000 0.000 0.000 0.00		0.305 0.306 0.002 0.56		5
6					0.000 0.000 0.000 0.00			1.311 1.305 -0.006 -0.49		1.354 1.335 -0.018 -1.37						6
7			1.309 1.318 0.009 0.70				1.097 1.104 0.007 0.66		0.000 0.000 0.000 0.00			1.081 1.088 0.007 0.66		0.000 0.000 0.000 0.00		7
8	0.358 0.362 0.004 1.03		1.161 1.171 0.010 0.85		1.057 1.086 0.029 2.71					1.323 1.305 -0.019 -1.40			1.171 1.171 0.000 0.04	1.238 1.222 -0.016 -1.28		8
9					1.310 1.316 0.006 0.44				1.107 1.104 -0.002 -0.22	1.087 1.101 0.014 1.32					0.000 0.000 0.000 0.00	9
10			0.000 0.000 0.000 0.00				1.090 1.101 0.012 1.07					1.230 1.222 -0.008 -0.66		0.000 0.000 0.000 0.00		10
11					1.259 1.252 -0.007 -0.58			0.000 0.000 0.000 0.00		1.133 1.146 0.013 1.13	0.000 0.000 0.000 0.00					11
12			0.379 0.377 -0.002 -0.40				1.070 1.089 0.019 1.78					0.915 0.907 -0.008 -0.87	0.372 0.371 -0.002 -0.42			12
13								1.158 1.171 0.013 1.15		1.289 1.274 -0.015 -1.17						13
14					0.000 0.000 0.000 0.00				1.110 1.103 -0.007 -0.65							14
15							0.291 0.295 0.004 1.51			MEASURED SIMULATE-3 ABS. DIFF. (S3-M) REL. DIFF. (100*(S3-M)/M)						15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

Figure 9

Comparison between Measured and SIMULATE-3 Assembly-Average Power Distribution at End of Cycle (EOC) Beaver Valley Unit 2 Cycle 12

ASSEMBLY-AVERAGE POWER DISTRIBUTION MAP

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1								0.436 0.438 0.002 0.50								1
2										0.601 0.599 -0.002 -0.27						2
3				0.439 0.447 0.008 1.71			1.311 1.313 0.001 0.09	0.000 0.000 0.000 0.00				0.441 0.441 0.000 0.11				3
4					1.334 1.332 -0.002 -0.17			1.021 1.034 0.013 1.27		1.170 1.169 -0.001 -0.12						4
5			1.054 1.055 0.001 0.10		1.178 1.178 0.000 -0.01		1.303 1.294 -0.009 -0.67				1.182 1.178 -0.004 -0.32	0.000 0.000 0.000 0.00		0.374 0.380 0.006 1.65		5
6					0.000 0.000 0.000 0.00			1.294 1.291 -0.003 -0.20		1.316 1.299 -0.017 -1.30						6
7			1.314 1.313 -0.001 -0.08				1.081 1.081 -0.001 -0.09		0.000 0.000 0.000 0.00			1.058 1.066 0.007 0.69		0.000 0.000 0.000 0.00		7
8	0.437 0.438 0.001 0.30		1.140 1.137 -0.003 -0.24		1.064 1.066 0.003 0.26					1.302 1.291 -0.011 -0.81			1.138 1.137 -0.001 -0.10	1.223 1.221 -0.002 -0.20		8
9					1.298 1.294 -0.004 -0.32				1.086 1.081 -0.006 -0.53	1.068 1.073 0.005 0.48					0.000 0.000 0.000 0.00	9
10			0.000 0.000 0.000 0.00				1.069 1.073 0.004 0.38					1.173 1.169 -0.004 -0.32		0.000 0.000 0.000 0.00		10
11					1.185 1.178 -0.007 -0.56			0.000 0.000 0.000 0.00		1.082 1.094 0.012 1.10	0.000 0.000 0.000 0.00					11
12			0.448 0.447 -0.001 -0.18				1.054 1.066 0.012 1.11					0.934 0.940 0.005 0.54	0.439 0.441 0.002 0.47			12
13								1.130 1.137 0.008 0.67		1.311 1.302 -0.009 -0.66						13
14					0.000 0.000 0.000 0.00				1.147 1.139 -0.008 -0.73							14
15							0.363 0.367 0.004 1.12			MEASURED SIMULATE-3 ABS. DIFF. (S3-M) REL. DIFF. (100*(S3-M)/M)						15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

Figure 10

Comparison between Measured and SIMULATE-3 Assembly-Average Power Distribution at BOC Beaver Valley Unit 2 Cycle 13

ASSEMBLY-AVERAGE POWER DISTRIBUTION MAP

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1								0.473 0.472 -0.001 -0.15								1
2										0.505 0.503 -0.002 -0.40						2
3				0.334 0.342 0.007 2.19			1.272 1.252 -0.021 -1.61	1.099 1.082 -0.017 -1.54				0.317 0.328 0.011 3.43				3
4					1.260 1.247 -0.013 -1.04			1.104 1.105 0.001 0.06		1.319 1.294 -0.025 -1.90						4
5			1.025 1.011 -0.014 -1.34		1.258 1.241 -0.017 -1.34		1.389 1.382 -0.007 -0.52				1.260 1.241 -0.019 -1.50	0.000 0.000 0.000 0.00		0.268 0.280 0.013 4.70		5
6					0.000 0.000 0.000 0.00			1.280 1.280 0.000 -0.01		1.191 1.189 -0.002 -0.20						6
7			1.257 1.252 -0.004 -0.33				1.230 1.240 0.010 0.79		0.000 0.000 0.000 0.00			1.193 1.212 0.020 1.64		0.000 0.000 0.000 0.00		7
8	0.462 0.472 0.010 2.20		1.083 1.082 -0.001 -0.10		1.144 1.142 -0.002 -0.21					1.276 1.280 0.004 0.28			1.058 1.082 0.024 2.30	1.129 1.133 0.004 0.38		8
9					1.408 1.382 -0.026 -1.86				1.226 1.240 0.013 1.09	1.116 1.125 0.009 0.84					0.000 0.000 0.000 0.00	9
10			0.000 0.000 0.000 0.00				1.129 1.125 -0.004 -0.34					1.289 1.294 0.005 0.42		0.000 0.000 0.000 0.00		10
11					1.259 1.241 -0.018 -1.39			0.000 0.000 0.000 0.00		1.246 1.254 0.007 0.60	0.000 0.000 0.000 0.00					11
12			0.336 0.342 0.006 1.67				1.212 1.213 0.001 0.11					0.661 0.665 0.005 0.70	0.317 0.328 0.011 3.51			12
13								1.058 1.082 0.024 2.31		1.230 1.228 -0.002 -0.16						13
14					0.000 0.000 0.000 0.00				1.059 1.060 0.001 0.06							14
15							0.269 0.277 0.008 3.10			MEASURED SIMULATE-3 ABS. DIFF. (S3-M) REL. DIFF. (100*(S3-M)/M)						15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

Figure 11

Comparison between Measured and SIMULATE-3 Assembly-Average Power Distribution at 3.79 GWD/MTU Beaver Valley Unit 2 Cycle 13

ASSEMBLY-AVERAGE POWER DISTRIBUTION MAP

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1								0.491 0.493 0.002 0.41								1
2										0.513 0.514 0.001 0.27						2
3				0.332 0.340 0.008 2.52			1.341 1.316 -0.024 -1.81	0.000 0.000 0.000 0.00				0.321 0.327 0.006 1.95				3
4					1.249 1.243 -0.006 -0.49			1.040 1.043 0.003 0.32		1.217 1.196 -0.021 -1.69						4
5			0.994 0.989 -0.005 -0.55		1.122 1.126 0.004 0.32		1.395 1.386 -0.009 -0.62				1.132 1.126 -0.006 -0.50	1.251 1.243 -0.009 -0.68		0.275 0.285 0.009 3.44		5
6					1.144 1.137 -0.008 -0.66			1.371 1.367 -0.004 -0.29		1.131 1.133 0.003 0.24						6
7			1.319 1.317 -0.002 -0.14				1.327 1.328 0.002 0.14		1.326 1.328 0.003 0.21			1.128 1.141 0.013 1.18		0.000 0.000 0.000 0.00		7
8	0.486 0.493 0.007 1.46		1.067 1.068 0.000 0.03		1.104 1.105 0.001 0.05					1.372 1.367 -0.004 -0.32			1.061 1.068 0.007 0.63	1.208 1.205 -0.003 -0.25		8
9					1.405 1.386 -0.019 -1.33				1.330 1.328 -0.001 -0.11	1.100 1.106 0.006 0.58					0.286 0.291 0.005 1.87	9
10			1.281 1.255 -0.026 -2.01				1.102 1.106 0.004 0.37					1.202 1.196 -0.006 -0.46		0.000 0.000 0.000 0.00		10
11					1.126 1.126 0.000 0.01			1.097 1.105 0.008 0.76		1.133 1.136 0.003 0.25	1.116 1.126 0.010 0.91					11
12			0.335 0.340 0.005 1.46				1.136 1.142 0.006 0.49					0.646 0.653 0.007 1.07	0.317 0.327 0.010 3.03			12
13								1.049 1.068 0.019 1.79		1.260 1.255 -0.005 -0.39						13
14					0.000 0.000 0.000 0.00				1.081 1.078 -0.003 -0.29							14
15							0.284 0.291 0.007 2.37			MEASURED SIMULATE-3 ABS. DIFF. (S3-M) REL. DIFF. (100*(S3-M)/M)						15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

Figure 12
Comparison between Measured and SIMULATE-3 Assembly-Average Power Distribution at EOC Beaver Valley Unit 2 Cycle 13

ASSEMBLY-AVERAGE POWER DISTRIBUTION MAP

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1								0.000 0.000 0.000 0.00								1
2										0.594 0.596 0.002 0.35						2
3				0.428 0.433 0.005 1.25			1.299 1.318 0.018 1.40	0.000 0.000 0.000 0.00				0.409 0.419 0.010 2.33				3
4					1.288 1.290 0.001 0.10			0.000 0.000 0.000 0.00		1.144 1.137 -0.007 -0.62						4
5			1.041 1.054 0.013 1.27		1.082 1.083 0.001 0.10		0.000 0.000 0.000 0.00				1.082 1.083 0.001 0.11	1.300 1.290 -0.010 -0.80		0.359 0.366 0.007 1.83		5
6					1.070 1.066 -0.004 -0.33			1.339 1.329 -0.010 -0.75		1.066 1.058 -0.008 -0.78						6
7			1.324 1.318 -0.006 -0.46				1.302 1.305 0.003 0.23		1.315 1.305 -0.010 -0.75			1.086 1.085 -0.001 -0.11		0.000 0.000 0.000 0.00		7
8	0.578 0.586 0.008 1.31		1.041 1.048 0.007 0.67		1.055 1.053 -0.002 -0.17					1.317 1.329 0.011 0.86			1.052 1.048 -0.003 -0.32	1.236 1.229 -0.007 -0.59		8
9					1.346 1.331 -0.015 -1.14				1.316 1.305 -0.011 -0.83	1.055 1.053 -0.002 -0.16					0.360 0.365 0.005 1.35	9
10			1.301 1.286 -0.015 -1.17				1.043 1.053 0.010 0.99					0.000 0.000 0.000 0.00		0.000 0.000 0.000 0.00		10
11					1.082 1.083 0.001 0.10			1.055 1.053 -0.002 -0.18		1.074 1.066 -0.009 -0.81	1.079 1.083 0.004 0.39					11
12			0.427 0.433 0.006 1.34				1.090 1.086 -0.004 -0.39					0.753 0.755 0.002 0.29	0.410 0.419 0.009 2.11			12
13								1.044 1.048 0.004 0.41		1.297 1.286 -0.010 -0.81						13
14					0.000 0.000 0.000 0.00				1.099 1.104 0.005 0.42							14
15							0.361 0.365 0.004 1.22			MEASURED SIMULATE-3 ABS. DIFF. (S3-M) REL. DIFF. (100*(S3-M)/M)						15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

Figure 13

Comparison between Measured and SIMULATE-3 Assembly-Average Power Distribution at BOC Beaver Valley Unit 2 Cycle 14

ASSEMBLY-AVERAGE POWER DISTRIBUTION MAP

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1								0.257 0.265 0.008 3.26								1
2										0.458 0.463 0.005 1.04						2
3				0.315 0.329 0.014 4.49			1.264 1.249 -0.016 -1.24	0.000 0.000 0.000 0.00				0.322 0.330 0.007 2.19				3
4					1.272 1.284 0.012 0.93			1.182 1.184 0.002 0.21		1.200 1.192 -0.009 -0.71						4
5			0.975 0.985 0.011 1.09		1.220 1.242 0.022 1.81		1.321 1.337 0.016 1.19				1.254 1.242 -0.012 -0.94	0.000 0.000 0.000 0.00		0.266 0.269 0.003 1.08		5
6					0.000 0.000 0.000 0.00			1.346 1.338 -0.008 -0.57		1.276 1.273 -0.003 -0.22						6
7			1.251 1.251 -0.001 -0.05				1.162 1.189 0.027 2.34		0.000 0.000 0.000 0.00			1.266 1.259 -0.007 -0.58		0.000 0.000 0.000 0.00		7
8	0.255 0.265 0.010 3.88		1.190 1.189 -0.001 -0.07		1.286 1.285 0.000 -0.02					1.352 1.338 -0.014 -1.02			1.207 1.189 -0.018 -1.51	0.996 0.974 -0.022 -2.25		8
9					1.337 1.337 0.000 0.01				1.189 1.189 0.000 0.03	1.282 1.271 -0.011 -0.82					0.000 0.000 0.000 0.00	9
10			0.000 0.000 0.000 0.00				1.274 1.271 -0.003 -0.21					1.203 1.192 -0.012 -0.98		0.000 0.000 0.000 0.00		10
11					1.231 1.242 0.011 0.90			0.000 0.000 0.000 0.00		1.310 1.293 -0.017 -1.31	0.000 0.000 0.000 0.00					11
12			0.317 0.329 0.012 3.80				1.256 1.259 0.003 0.20					0.790 0.802 0.012 1.52	0.324 0.330 0.006 1.83			12
13								1.184 1.189 0.005 0.46		1.206 1.185 -0.021 -1.71						13
14					0.000 0.000 0.000 0.00				0.977 0.960 -0.016 -1.69							14
15							0.224 0.227 0.003 1.35			MEASURED SIMULATE-3 ABS. DIFF. (S3-M) REL. DIFF. (100*(S3-M)/M)						15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

Figure 14

Comparison between Measured and SIMULATE-3 Assembly-Average Power Distribution at 4.06 GWD/MTU Beaver Valley Unit 2 Cycle 14

ASSEMBLY-AVERAGE POWER DISTRIBUTION MAP

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1								0.301 0.305 0.004 1.22								1
2										0.495 0.499 0.003 0.65						2
3				0.328 0.340 0.012 3.67			1.358 1.329 -0.029 -2.12	0.000 0.000 0.000 0.00				0.337 0.340 0.003 1.03				3
4					1.301 1.299 -0.002 -0.17			1.106 1.117 0.011 0.97		1.141 1.137 -0.004 -0.36						4
5			1.011 1.016 0.005 0.48		1.146 1.165 0.019 1.68		1.401 1.396 -0.005 -0.34				1.165 1.165 -0.001 -0.06	0.000 0.000 0.000 0.00		0.286 0.289 0.003 0.89		5
6					0.000 0.000 0.000 0.00			1.383 1.372 -0.012 -0.87		1.414 1.401 -0.012 -0.87						6
7			1.336 1.332 -0.005 -0.36				1.049 1.077 0.027 2.62		0.000 0.000 0.000 0.00			1.209 1.198 -0.011 -0.91		0.000 0.000 0.000 0.00		7
8	0.297 0.305 0.007 2.52		1.166 1.176 0.010 0.87		1.232 1.236 0.004 0.33					1.386 1.372 -0.014 -1.04			1.179 1.176 -0.003 -0.23	1.116 1.099 -0.016 -1.46		8
9					1.402 1.396 -0.006 -0.41				1.064 1.077 0.013 1.24	1.220 1.225 0.005 0.42					0.000 0.000 0.000 0.00	9
10			0.000 0.000 0.000 0.00				1.224 1.225 0.001 0.11					1.138 1.137 0.000 -0.04		0.000 0.000 0.000 0.00		10
11					1.151 1.165 0.014 1.17			0.000 0.000 0.000 0.00		1.243 1.234 -0.009 -0.72	0.000 0.000 0.000 0.00					11
12			0.332 0.340 0.009 2.56				1.195 1.198 0.003 0.28					0.788 0.794 0.007 0.85	0.336 0.340 0.005 1.41			12
13								1.174 1.176 0.002 0.15		1.281 1.254 -0.027 -2.12						13
14					0.000 0.000 0.000 0.00				1.056 1.042 -0.014 -1.31							14
15							0.254 0.258 0.002 1.25			MEASURED SIMULATE-3 ABS. DIFF. (S3-M) REL. DIFF. (100*(S3-M)/M)						15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

Figure 15

Comparison between Measured and SIMULATE-3 Assembly-Average Power Distribution at EOC Beaver Valley Unit 2 Cycle 14

ASSEMBLY-AVERAGE POWER DISTRIBUTION MAP

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	
1								0.404 0.413 0.009 2.15								1
2										0.605 0.607 0.002 0.41						2
3				0.434 0.443 0.010 2.25			1.317 1.316 -0.001 -0.07	0.000 0.000 0.000 0.00				0.433 0.443 0.011 2.47				3
4					1.315 1.316 0.001 0.11			1.046 1.048 0.002 0.23		1.088 1.089 0.002 0.14						4
5			1.121 1.118 -0.003 -0.29		1.084 1.100 0.017 1.58		1.307 1.305 -0.002 -0.13				1.101 1.100 -0.001 -0.06	1.329 1.316 -0.013 -0.99		0.381 0.388 0.007 1.75		5
6					1.120 1.134 0.014 1.22			1.302 1.288 -0.014 -1.09		1.321 1.305 -0.016 -1.22						6
7			1.318 1.317 -0.001 -0.06				1.002 1.009 0.007 0.67	1.006 1.009 0.002 0.23				1.118 1.119 0.001 0.10		0.000 0.000 0.000 0.00		7
8	0.401 0.413 0.012 2.94		1.124 1.129 0.005 0.46		1.134 1.127 -0.007 -0.64					1.316 1.288 -0.028 -2.14			1.126 1.129 0.003 0.27	1.173 1.166 -0.007 -0.62		8
9					1.317 1.305 -0.012 -0.89				1.019 1.009 -0.010 -0.98	1.127 1.118 -0.009 -0.77					0.346 0.354 0.009 2.50	9
10			1.312 1.304 -0.008 -0.60				1.130 1.118 -0.012 -1.05					1.090 1.089 -0.001 -0.08		0.000 0.000 0.000 0.00		10
11					1.093 1.100 0.008 0.72			1.130 1.127 -0.003 -0.28		1.138 1.133 -0.005 -0.41	1.095 1.100 0.005 0.46					11
12			0.435 0.443 0.008 1.94				1.111 1.119 0.007 0.67					0.868 0.878 0.009 1.06	0.438 0.443 0.005 1.23			12
13								1.121 1.129 0.008 0.72		1.318 1.304 -0.014 -1.08						13
14					0.000 0.000 0.000 0.00				1.140 1.133 -0.007 -0.59							14
15							0.345 0.354 0.009 2.63			MEASURED SIMULATE-3 ABS. DIFF. (S3-M) REL. DIFF. (100*(S3-M)/M)						15
	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A	

g. **The last seven lines of the CASMO IFBA depletion results in the RAI-33 response appear to be duplicates of the preceding seven lines. Was some other content intended?**

Response

The last seven lines should have shown results for 5.0 wt%, instead, they repeated the results for 4.5 wt% shown in the previous seven lines. The correct lines (for 5.0 wt%) are shown below. The omission of these lines did not affect the overall conclusion; specifically, it does not change the bounding case.

CASMO-4 Results for Reactivity Comparison of Calculations with and without IFBA

		Reference Case (no IFBA)		IFBA (IFBA B-10 removed in storage rack				IFBA			
gwd/ mtu	wt%	Input File	kinf	# IFBA	Input File	kinf	Delta kinf (IFBA - no_IFBA)	# IFBA	Input File	kinf	Delta kinf (IFBA - no_IFBA)
10	5	bv-dep-50-0-rack-creep	1.1178	200	bv-ifba200-out-50-0	1.1156	-0.0022	200	bv-ifba200-50-0-rack-creep	1.0335	-0.0843
15	5	bv-dep-50-0-rack-creep	1.0840	200	bv-ifba200-out-50-0	1.0828	-0.0011	200	bv-ifba200-50-0-rack-creep	1.0403	-0.0436
20	5	bv-dep-50-0-rack-creep	1.0524	200	bv-ifba200-out-50-0	1.0521	-0.0003	200	bv-ifba200-50-0-rack-creep	1.0309	-0.0215
25	5	bv-dep-50-0-rack-creep	1.0226	200	bv-ifba200-out-50-0	1.0228	0.0002	200	bv-ifba200-50-0-rack-creep	1.0126	-0.0100
30	5	bv-dep-50-0-rack-creep	0.9940	200	bv-ifba200-out-50-0	0.9945	0.0005	200	bv-ifba200-50-0-rack-creep	0.9897	-0.0042
45	5	bv-dep-50-0-rack-creep	0.9133	200	bv-ifba200-out-50-0	0.9146	0.0013	200	bv-ifba200-50-0-rack-creep	0.9142	0.0009
60	5	bv-dep-50-0-rack-creep	0.8419	200	bv-ifba200-out-50-0	0.8435	0.0017	200	bv-ifba200-50-0-rack-creep	0.8435	0.0016

4. **RAI-34: Response is adequate. However, WABA rods were evaluated at only 2.6 and 3 wt%. It appears that the applicant does not intend to use WABAs in the future. This restriction should be captured in the "procedure" that will be used to screen future cycles.**

Response

As part of the FENOC procedure, also referred to as the process in RAI 1.b, the evaluation of operational (depletion-related) parameters, such as not using WABAs, is addressed.

5. **RAI-38: Validation has been revised to address many of the issues and concerns. The following issues resulted from a review of the revised validation work:**

   a. **Tables 7.1-8 and 7.2-8 include trending analysis results for multiple subgroups, but look at only EALF for the overall set, which is the critical experiment set used to derive the bias and bias uncertainty.**

      i. **Trending analysis of the overall set should have also included enrichment, boron concentration, Plutonium (Pu) content {g Pu/(g U + g pu)}, and pin pitch. Provide supplementary trending analysis for the overall set. If the bias and bias uncertainty changes as a result of the supplementary trending analysis, update the criticality analysis to use the revised bias and bias uncertainty.**

Response

To address the various aspects of this RAI, the following changes were made to the statistical analyses of the benchmarking calculations:

- Trending analyses of the overall set was expanded to include enrichment, boron concentration, plutonium content, and pin pitch.
- Experiments that include neutron absorbers or reflectors not applicable to the BVPS-2 analyses were removed from the set. This addresses RAI 5.b.
- Experiments that were recommended not to be used in Section 3.2 of NUREG/CR-6979 were also removed from the set. This addresses RAI 5.c.

The resulting set still contains 165 experiments. The overall bias and bias uncertainty (95/95 level) of those experiments is 0.0012 ± 0.0086, which is essentially the same as the bias and bias uncertainty used previously, which was 0.0013 ± 0.0086. The results of the trending analyses are summarized in the following table:

[[[PROPRIETARY

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Therefore, in summary, the revised statistical and trend analyses of the benchmark experiments result in a bias and bias uncertainty of 0.0029 ± 0.0078, without any significant trends.

If this revised bias would be applied to the previous calculations, the calculated maximum k_{eff} values would increase by 0.0016 delta-k (0.0029 – 0.0013) due to the

increase in bias[1], if no other changes are made, and if the burnup and soluble boron requirements are maintained. Those burnup and soluble boron requirements were based on maximum k_{eff} values of 0.995 and 0.945, respectively. Applying the revised bias would increase those values to 0.9966 and 0.9466, respectively, which still maintains those values below the corresponding regulatory limits. Expressed differently, the analyses contain sufficient margin to accommodate the revised bias, without the need to adjust the required burnup or soluble boron levels. It is therefore not considered necessary to update the criticality analyses. Additionally, please see the discussion at the end of the response to RAI 5.e, where a combination of various adjustments to biases and uncertainties is evaluated. This evaluation shows that the combined effect of those adjustments in fact increases the margin; in other words, it does not result in an increase of the previously calculated maximum k_{eff} values. The criticality analysis therefore remains valid.

ii. Pu enrichment was listed in Tables 7.1-8 and 7.2-8, but was not defined. Provide the definition for "Pu enrichment."

Response

The Pu enrichment is defined as Pu/(U+Pu).

b. The critical experiment set should have been evaluated to determine if some of the experiments include significant features that are not present in the BVPS-2 safety analysis cases and that could impact the bias and bias uncertainty. For example, some of the Haut Taux de Combustion (HTC) phase 3 and 4 experiments include neutron absorbers and/or reflectors that are not present in the safety analysis models. Evaluate the impact on the bias and bias uncertainty of including critical experiments that vary significantly from the safety analysis cases.

Response

As discussed in the response to RAI 5.a.i, experiments with neutron absorbers and/or reflectors that are not used in the safety analyses models are now excluded.

c. The HTC configurations that were used included some configurations that Section 3.2 of NUREG/CR-6979 recommended not be used. Explain and justify the use of these configurations.

Response

As discussed in the response to RAI 5.a.i, experiments that Section 3.2 of NUREG/CR-6979 recommended not be used are now excluded.

d. Neither the revised report nor the revised validation provided in Appendix E address the applicability of the validation to the BVPS-2 criticality safety analysis. This should be done by comparing and

[1] Additionally there would also be a small reduction due to the reduced uncertainty, but this is neglected here.

contrasting the ranges of parameters in the BVPS-2 safety analysis and in the set of critical experiments. Such parameters might include enrichment, pin pitch, soluble boron concentration, Pu content, EALF, fuel forms, absorber materials, etc. Note that Table 9-1 in Appendix E appears to be presenting a comparison of the validation with some generic criticality analysis. The design application column in this table is not BVPS-2 specific. Provide a BVPS-2 specific analysis of the applicability of the validation set.

Response

A comparison of the ranges of parameters in the BVPS-2 safety analyses and in the set of critical experiments used to establish the bias and bias uncertainty is presented in the table below.

Parameter	BVPS-2	Validated by Benchmark
Fuel Assemblies	Fresh and Spent UO_2 fuel	^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am
Initial Fuel Enrichments	2.1 to 4.95 wt%	< 5 wt%
Pu Content (Pu/(U+Pu))	0 to 1.5%	0 to 20%
Rod OD††	0.95 cm (0.374 inch (in))	0.58 to 1.44 cm
Rod Pitch	1.26 cm (0.496 in)	0.97 to 2.0 cm†
Fuel Density	10.6312 g/cc††	9.2 to 10.7 g/cc
Burnup Range	up to about 55 GWD/MTU for 4.95% enrichment	0 and 37.5 GWD/MTU, MOX††
Moderator Material	Water	Water
Soluble Boron	0 to 1212 ppm	0 to 2550 ppm
Neutron Poison	B-10 (Metamic)	B-SS, Boral, Cadmium
Interstitial Material	Steel	Steel or Lead
Fuel Cladding	Zirconium Alloy	Zirconium Alloy
Reflector	Water	Water, Steel , Lead
EALF Range, eV††	0.2 to 0.4	0.07 to 1.52

† Experiments with larger pitch values up to 4.32 cm were also analyzed but excluded from the bias evaluation, see response to RAI 5.a.

†† OD = outer diameter; g/cc = grams per cubic centimeter; MOX = Mixed Oxide fuel; eV = electron volts.

Note that the benchmark calculations do not cover the entire burnup range used in the design basis analyses. However, the benchmark calculations contain a significant number of MOX critical experiments, with plutonium contents that cover and in fact exceed that of spent fuel. The actinide composition of spent fuel is therefore appropriately represented in the selection of benchmark experiments, and

the plutonium content, not the burnup, is used as the appropriate parameter in the trend analyses (see Response to RAI 5.a.i).

e. **The analysis should identify any validation gaps (e.g. missing materials, nuclides, and model features, etc.) and address what additional margin, if any is needed to cover such gaps. For example, is margin needed to cover fission product k_{eff} validation?**

Response

The comparison of parameters presented in the response to RAI 5.d shows that relevant parameters of the analyses are covered by the benchmarking calculations, except for the depletion calculations and the fission product (including lumped fission product) reactivity worth. The depletion uncertainty and the lumped fission product (LFP) uncertainty were already considered in the analyses using appropriate uncertainty terms when calculating the maximum k_{eff} values to establish the loading curves. However, a term to account for the fission product (FP) reactivity worth uncertainty had not been applied. To include the FP uncertainty, the approach for the LFP uncertainty is used and expanded by adding remaining fission products when determining the uncertainty. To that extent, additional MCNP calculations are performed where fission products (lumped and individual) are removed. The reactivity difference to the case with isotopes included is then calculated, multiplied with an appropriate factor, and now used instead of the lumped fission product uncertainty previously applied. The factor is determined in a similar way as that for the LFPs, specifically, by combining the uncertainty from each isotope. However, the isotopic composition in the fuel is used as the weighting factor when combining LFP with the other FP uncertainties. This approach allows an easy combination of the uncertainties for the LFPs and the other FPs, and ensures that the factor is consistent with the actual fuel compositions. This is performed for three burnup and enrichment combinations. Note that as for the method used for the LFP, uncertainties are multiplied by two so they are valid at a 95/95 level. Results are shown in the following table:

Enrichment, wt% U-235	Burnup, GWD/MTU	Uncertainty in FP (including LFP) cross sections, %
2.0	10	11.70
3.5	35	11.52
5.0	55	11.51

As a bounding value, a factor of 12 percent is therefore applied to the reactivity difference between cases with and without FPs to determine the uncertainty of the FP reactivity worth. This value is smaller than the value of 15 percent used for the LFPs, since the other FPs have slightly smaller uncertainties than the LFPs, but dominate the overall reactivity effect. Note that as was previously done for the LFPs uncertainty, this approach is based on the conservative assumption that individual

uncertainties are perfectly correlated; in other words, that all cross sections are low at the same time. Specifically, the uncertainty of the LFPs and the remaining FPs are combined arithmetically, not statistically.

To show the effect of this revised uncertainty, together with the other changes resulting from the RAI responses (revised bias and bias uncertainty from response to RAI 5.a.i, and revised bias and additional uncertainty from the reactivity control configurations), revisions of the tables that established the burnup requirements are presented below. Specifically, the following changes were made from the original versions of those tables:

- LFP uncertainty (15 percent) replaced by Fission Product uncertainty (12 percent);
- Bias uncertainty from benchmarks changed from 0.0086 to 0.0078;
- Added uncertainty of 0.0011 for the reactivity control bias;
- Bias from benchmarks increased from 0.0013 to 0.0029;
- Bias from reactivity control reduced from 0.0063 to 0.0038, the maximum value listed in the response to RAI 3;
- A new row was added to show the margin to the existing polynomial functions for the loading curve.
- A conservatism in calculating reactivity differences between MCNP calculations was removed[2];

There is remaining margin, ranging from 0.10 to 2.35 GWD/MTU, between the re-calculated burnup values (including the 5 percent uncertainty) and the polynomial functions for the loading curves. The loading curves previously proposed for the BVPS-2 pool therefore remain valid.

[2] Previously the combined uncertainty in the difference was added *after* the difference was multiplied with the corresponding factor (for example, 5 percent, 15 percent), which overestimates the impact of this uncertainty. Now this uncertainty is added before the multiplication is performed.

Calculation of the Initial Enrichment and Burnup Combinations for Region 2, No Blankets Profile

Enrichment (wt% U-235)	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Burnup (GWD/MTU)	10.0	20.0	30.0	35.0	40.0	45.0	55.0
Reactivity Uniform Profile	0.9688	0.9649	0.9585	0.9633	0.9649	0.9648	0.9577
Reactivity Segmented Profile	0.9676	0.9623	0.9577	0.9613	0.9620	0.9652	0.9616
Max Reactivity	0.9688	0.9649	0.9585	0.9633	0.9649	0.9652	0.9616
Burnup (GWD/MTU)	5.0	15.0	25.0	30.0	35.0	40.0	50.0
Reactivity Uniform Profile	0.9811	0.9758	0.9703	0.9721	0.9743	0.9756	0.9682
Reactivity Segmented Profile	0.9805	0.9738	0.9668	0.9699	0.9738	0.9756	0.9682
Max Reactivity	0.9811	0.9758	0.9703	0.9721	0.9743	0.9756	0.9682
Manufacturing Tolerances Uncertainty†	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037
Fuel Tolerances Uncertainty†	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079
Metamic Measurement Uncertainty†	0.0028	0.0028	0.0028	0.0028	0.0028	0.0028	0.0028
CASMO-4 Bias Uncertainty	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Calculation Uncertainty (σ)	0.0006	0.0007	0.0006	0.0007	0.0007	0.0007	0.0007
Calculation Uncertainty (2σ)	0.0012	0.0014	0.0012	0.0014	0.0014	0.0014	0.0014
Depletion Uncertainty keff	0.9978	1.0305	1.0594	1.0841	1.1030	1.1214	1.1385
Depletion σ	0.0008	0.0007	0.0006	0.0007	0.0008	0.0007	0.0007
Depletion Uncertainty	0.0016	0.0034	0.0051	0.0061	0.0070	0.0079	0.0089
FP Uncertainty keff	0.9853	0.9978	1.0053	1.0164	1.0273	1.0285	1.0312
FP σ	0.0006	0.0007	0.0006	0.0007	0.0006	0.0007	0.0007
FP Uncertainty	0.0022	0.0042	0.0058	0.0066	0.0077	0.0078	0.0086
Eccentric Fuel Positioning	neg	neg	neg	neg	neg	neg	neg
MCNP Code Uncertainty	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
Reactivity Control Bias Uncertainty	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
Total Uncertainty (statistitical combination)	0.0127	0.0135	0.0146	0.0153	0.0162	0.0167	0.0175
Code Bias	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029
Temperature Bias†	0.0043	0.0043	0.0043	0.0043	0.0043	0.0043	0.0043
Reactivity Control Bias†	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Total Corrections	0.0237	0.0245	0.0256	0.0263	0.0272	0.0277	0.0285
Maximum keff	0.9950	0.9950	0.9950	0.9950	0.9950	0.9950	0.9950
Target k-eff (0.995-corrections)	0.9713	0.9705	0.9694	0.9687	0.9678	0.9673	0.9665
Calculated Burnup (GWD/MTU)	8.98	17.45	25.39	31.96	38.46	43.98	51.33
Calculated Burnup (GWD/MTU) + 5%	9.43	18.32	26.66	33.56	40.39	46.18	53.89
BU=-0.8731x^2+20.467x-26.25	11.19	19.46	27.29	34.69	41.65	48.17	54.26
Burnup Margin	1.77	1.14	0.63	1.13	1.26	1.99	0.37

† These values are the maximum from the entire burnup and enrichment range.

Calculation of the Initial Enrichment and Burnup Combinations for Region 2, Natural Blankets Profile

Enrichment (wt% U-235)	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Burnup (GWD/MTU)	10.0	20.0	30.0	35.0	40.0	45.0	55.0
Reactivity Uniform Profile	0.9664	0.9651	0.9602	0.9613	0.9647	0.9652	0.9592
Reactivity Segmented Profile	0.9672	0.9604	0.9558	0.9564	0.9587	0.9600	0.9533
Max Reactivity	0.9672	0.9651	0.9602	0.9613	0.9647	0.9652	0.9592
Burnup (GWD/MTU)	5.0	15.0	25.0	30.0	35.0	40.0	50.0
Reactivity Uniform Profile	0.9830	0.9770	0.9693	0.9716	0.9745	0.9779	0.9689
Reactivity Segmented Profile	0.9810	0.9732	0.9649	0.9670	0.9702	0.9694	0.9609
Max Reactivity	0.9830	0.9770	0.9693	0.9716	0.9745	0.9779	0.9689
Manufacturing Tolerances Uncertainty†	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037
Fuel Tolerances Uncertainty†	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079
Metamic Measurement Uncertainty†	0.0028	0.0028	0.0028	0.0028	0.0028	0.0028	0.0028
CASMO-4 Bias Uncertainty	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Calculation Uncertainty (σ)	0.0006	0.0007	0.0007	0.0007	0.0007	0.0008	0.0007
Calculation Uncertainty (2σ)	0.0012	0.0014	0.0014	0.0014	0.0014	0.0016	0.0014
Depletion Uncertainty keff	0.9976	1.0312	1.0598	1.0821	1.1040	1.1213	1.1379
Depletion σ	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Depletion Uncertainty	0.0016	0.0034	0.0051	0.0061	0.0071	0.0079	0.0090
FP Uncertainty keff	0.9835	0.9962	1.0075	1.0184	1.0288	1.0346	1.0387
FP σ	0.0006	0.0006	0.0006	0.0006	0.0007	0.0006	0.0007
FP Uncertainty	0.0022	0.0040	0.0059	0.0071	0.0079	0.0086	0.0098
Eccentric Fuel Positioning	neg	neg	neg	neg	neg	neg	neg
MCNP Code Uncertainty	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
Reactivity Control Bias Uncertainty	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
Total Uncertainty (statistitical combination)	0.0127	0.0135	0.0147	0.0156	0.0163	0.0171	0.0182
Code Bias	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029
Temperature Bias†	0.0043	0.0043	0.0043	0.0043	0.0043	0.0043	0.0043
Reactivity Control Bias†	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Total Corrections	0.0237	0.0245	0.0257	0.0266	0.0273	0.0281	0.0292
Maximum keff	0.9950	0.9950	0.9950	0.9950	0.9950	0.9950	0.9950
Target k-eff (0.995-corrections)	0.9713	0.9705	0.9693	0.9684	0.9677	0.9669	0.9658
Calculated Burnup (GWD/MTU)	8.70	17.72	24.98	31.53	38.49	44.31	51.60
Calculated Burnup (GWD/MTU) + 5%	9.13	18.60	26.22	33.11	40.41	46.53	54.18
BU=-0.8553x^2+20.418x-26.425	10.99	19.27	27.13	34.56	41.56	48.14	54.28
Burnup Margin	1.86	0.67	0.91	1.45	1.15	1.61	0.10

† These values are the maximum from the entire burnup and enrichment range.

Calculation of the Initial Enrichment and Burnup Combinations for Region 2, Enriched Blankets Profile

Enrichment (wt% U-235)	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Burnup (GWD/MTU)	10.0	20.0	25.0	35.0	40.0	50.0	55.0
Reactivity Uniform Profile	0.9690	0.9648	0.9669	0.9647	0.9662	0.9586	0.9619
Reactivity Segmented Profile	0.9661	0.9625	0.9652	0.9594	0.9612	0.9540	0.9568
Max Reactivity	0.9690	0.9648	0.9669	0.9647	0.9662	0.9586	0.9619
Burnup (GWD/MTU)	5.0	15.0	20.0	30.0	35.0	45.0	50.0
Reactivity Uniform Profile	0.9821	0.9768	0.9800	0.9741	0.9740	0.9675	0.9685
Reactivity Segmented Profile	0.9813	0.9754	0.9786	0.9684	0.9715	0.9630	0.9639
Max Reactivity	0.9821	0.9768	0.9800	0.9741	0.9740	0.9675	0.9685
Manufacturing Tolerances Uncertainty†	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037
Fuel Tolerances Uncertainty†	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079
Metamic Measurement Uncertainty†	0.0028	0.0028	0.0028	0.0028	0.0028	0.0028	0.0028
CASMO-4 Bias Uncertainty	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Calculation Uncertainty (σ)	0.0007	0.0006	0.0007	0.0007	0.0007	0.0006	0.0007
Calculation Uncertainty (2σ)	0.0014	0.0012	0.0014	0.0014	0.0014	0.0012	0.0014
Depletion Uncertainty keff	0.9969	1.0304	1.0589	1.0846	1.1032	1.1228	1.1396
Depletion σ	0.0007	0.0007	0.0007	0.0007	0.0007	0.0006	0.0007
Depletion Uncertainty	0.0015	0.0034	0.0047	0.0061	0.0069	0.0083	0.0090
FP Uncertainty keff	0.9860	0.9980	1.0107	1.0198	1.0265	1.0324	1.0401
FP σ	0.0006	0.0007	0.0006	0.0007	0.0006	0.0007	0.0007
FP Uncertainty	0.0023	0.0042	0.0055	0.0068	0.0075	0.0091	0.0096
Eccentric Fuel Positioning	neg	neg	neg	neg	neg	neg	neg
MCNP Code Uncertainty	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078	0.0078
Reactivity Control Bias Uncertainty	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
Total Uncertainty (statistitical combination)	0.0127	0.0135	0.0144	0.0154	0.0161	0.0175	0.0181
Code Bias	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029
Temperature Bias†	0.0043	0.0043	0.0043	0.0043	0.0043	0.0043	0.0043
Reactivity Control Bias†	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038	0.0038
Total Corrections	0.0237	0.0245	0.0254	0.0264	0.0271	0.0285	0.0291
Maximum keff	0.9950	0.9950	0.9950	0.9950	0.9950	0.9950	0.9950
Target k-eff (0.995-corrections)	0.9713	0.9705	0.9696	0.9686	0.9679	0.9665	0.9659
Calculated Burnup (GWD/MTU)	9.13	17.63	23.96	32.94	38.89	45.54	51.97
Calculated Burnup (GWD/MTU) + 5%	9.58	18.51	25.15	34.59	40.83	47.82	54.57
BU=-0.8324x^2+20.523x-26.578	11.14	19.53	27.50	35.06	42.20	48.92	55.23
Burnup Margin	1.56	1.01	2.35	0.46	1.36	1.10	0.66

† These values are the maximum from the entire burnup and enrichment range.

Figure 16

[[[PROPRIETARY

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Figure 17

[[[PROPRIETARY

]]]

Enclosure to Letter L-11-057

Holtec International Affidavit Pursuant to 10 CFR 2.390

(Five Pages Follow)

HOLTEC INTERNATIONAL

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Telephone (856) 797-0900

Fax (856) 797-0909

Holtec International Document ID 1702-AFFI-14

AFFIDAVIT PURSUANT TO 10 CFR 2.390

I, Tammy S. Morin, being duly sworn, depose and state as follows:

(1) I have reviewed the information described in paragraph (2) which is sought to be withheld, and am authorized to apply for its withholding.

(2) The information sought to be withheld is information provided with Holtec letter 1702-14, specifically the information marked within RAI responses #3 and #5, and Holtec Report HI-2084003R8.

(3) In making this application for withholding of proprietary information of which it is the owner, Holtec International relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4) and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10CFR Part 9.17(a)(4), 2.390(a)(4), and 2.390(b)(1) for "trade secrets and commercial or financial information obtained from a person and privileged or confidential" (Exemption 4). The material for which exemption from disclosure is here sought is all "confidential commercial information", and some portions also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by Holtec's competitors without license from Holtec International constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

c. Information which reveals cost or price information, production, capacities, budget levels, or commercial strategies of Holtec International, its customers, or its suppliers;

d. Information which reveals aspects of past, present, or future Holtec International customer-funded development plans and programs of potential commercial value to Holtec International;

e. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraph 4.b, above.

(5) The information sought to be withheld is being submitted to the NRC in confidence. The information (including that compiled from many sources) is of a sort customarily held in confidence by Holtec International, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by Holtec International. No public disclosure has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to the NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary

agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within Holtec International is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his designee), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside Holtec International are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information classified as proprietary was developed and compiled by Holtec International at a significant cost to Holtec International. This information is classified as proprietary because it contains detailed descriptions of analytical approaches and methodologies not available elsewhere. This information would provide other parties, including competitors, with information from Holtec International's technical database and the results of evaluations performed by Holtec International. A substantial effort has been expended by Holtec International to develop this information. Release of this information would improve a competitor's position because it would enable Holtec's competitor to copy our technology and offer it for sale in competition with our company, causing us financial injury.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to Holtec International's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of Holtec International's comprehensive spent fuel storage technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology, and includes development of the expertise to determine and apply the appropriate evaluation process.

The research, development, engineering, and analytical costs comprise a substantial investment of time and money by Holtec International.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

Holtec International's competitive advantage will be lost if its competitors are able to use the results of the Holtec International experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to Holtec International would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive Holtec International of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

AFFIDAVIT PURSUANT TO 10 CFR 2.390

STATE OF NEW JERSEY)
) ss:
COUNTY OF BURLINGTON)

Ms. Tammy S. Morin, being duly sworn, deposes and says:

That she has read the foregoing affidavit and the matters stated therein are true and correct to the best of her knowledge, information, and belief.

Executed at Marlton, New Jersey, this 9th day of February, 2011.

Tammy S. Morin
Holtec International

Subscribed and sworn before me this 9th day of February, 2011.

Maria C. Massi

MARIA C. MASSI
NOTARY PUBLIC OF NEW JERSEY
My Commission Expires April 25, 2015