# TASK INTERFACE AGREEMENT 2011-004

# PEACH BOTTOM ATOMIC POWER STATION UNITS 2 AND 3 SPENT FUEL POOL

# NEUTRON ABSORBER DEGRADATION

## 1.0 INTRODUCTION

By letter dated January 25, 2011 (Reference 1), the U.S. Nuclear Regulatory Commission (NRC) Region I Office requested assistance from the Office of Nuclear Reactor Regulation (NRR) in evaluating Peach Bottom Atomic Power Station (PBAPS) Operability Determination (OD) 10-007. PBAPS performed OD 10-007 to address degradation of the spent fuel pool (SFP) neutron absorber Boraflex. Task Interface Agreement (TIA) 2011-004 specifically requested:

1. NRR conduct a technical assessment of OD 10-007 that PBAPS is using to support operability of the SFPs through 2014. If NRR determines that OD 10-007 does not provide reasonable assurance of operability through 2014, the Region I Office requests that NRR provide an estimate of when SFP operability will be challenged, including technical bases for any earlier time limitations.

2. NRR review whether the licensee's analyses as documented in OD 10-007 employ appropriate assumptions and calculation methodologies to demonstrate with reasonable assurance that the subcritical margin limit for the SFP as specified by Technical Specification (TS) 4.3.1.1.b ($K_{effective} \leq 0.95$) will continue to be met.

## 2.0 BACKGROUND

The NRC issued PBAPS Amendment Nos. 116 and 120 to Unit 2 and Unit 3, respectively, on February 19, 1986 (Reference 2). These amendments approved the installation of high density storage racks which contain a Boron-10 ($B^{10}$) based neutron absorbing material, Boraflex, in the PBAPS SFPs. The high density racks increased each SFP's capacity from 2608 to 3819 fuel assemblies. The criticality analysis contained in the amendments was for a fresh unpoisoned General Electric (GE) 7x7 3.5 uranium-235 ($U^{235}$) weight percent (w%) enriched fuel assembly.

The PBAPS SFP storage racks are made of "manufactured" and "developed" cells. The "manufactured" cells are a square stainless steel box nominally [[redacted]] inches thick and [[redacted]] inches to a side. The Boraflex is in sheets with initial nominal dimensions of [[redacted]] inches long, [[redacted]] inches wide, and [[redacted]] inches thick. The Boraflex panels were modeled as having a 'Minimum Certified' $B^{10}$ areal density of 0.021 g/cm$^2$; the analysis did not contain a provision for Boraflex degradation below the 'Minimum Certified' $B^{10}$ areal density. The Boraflex is attached to the square stainless steel box with a Dow silicone sealant during manufacturing to hold it in place while a stainless steel wrapper is spot welded to the stainless steel box. The wrapper is nominally [[redacted]] inches thick. It is preformed to provide a nominal enclosure of [[redacted]] inches, and the wrapper welds are about [[redacted]] inches apart. The "developed" cells are formed when the "manufactured" cells are welded together at the corners with the enclosed space being the "developed" cell.

Northeast Technology Company (NETCO) test reports (References 6, 7, 8, 9, 16, 17, 18, and 19) indicate the PBAPS Boraflex As-Built $B^{10}$ areal density ranged from a Maximum As-Built $B^{10}$

Batch areal density of 0.025 g/cm$^2$, to a Minimum As-Built $B^{10}$ Batch areal density of 0.0226 g/cm$^2$, with an Average As-Built $B^{10}$ Batch areal density of 0.0235 g/cm$^2$.

The NRC issued PBAPS Amendment Nos. 175 and 178 to Unit 2 and Unit 3 respectively on May 28, 1993. These amendments approved the change from the 17.3 g/cm $U^{235}$ (equivalent to 3.5 w% $U^{235}$) TS limit to a standard cold core geometry (SCCG) k-infinity ($k_{inf}$ or $k_{\infty}$) limit of 1.362 (Reference 3). The analysis set an 'enrichment bias' by comparing the in-core $k_{inf}$ of the fresh unpoisoned GE 7x7 3.5 w% $U^{235}$ enriched fuel assembly to the in-core $k_{inf}$ of a fresh poisoned GE11 4.5 w% $U^{235}$ enriched fuel assembly. Since this analysis was based on the earlier analysis, the Boraflex panels were still being modeled as having a 'Minimum Certified' $B^{10}$ areal density of 0.021 g/cm$^2$, without a provision for Boraflex degradation below the 'Minimum Certified' $B^{10}$ areal density.

The Peach Bottom SFP racks have been in service since 1986. These racks contain Boraflex with a minimum certified $B^{10}$ areal density of 0.021 g/cm$^2$, which was used in the criticality analysis of record to demonstrate compliance with NRC regulations governing subcriticality in SFPs. Since the 1970s, the nuclear industry has been aware that Boraflex degrades in a spent fuel pool environment resulting in a reduction in its ability to provide subcriticality margin. The degradation of the Boraflex releases silica into the SFP which can be measured and generally correlated to the degradation of the Boraflex panels. Gamma radiation induced cross linking of the silica based polymer causes the material to shrink. The gamma radiation comes from fuel assemblies adjacent to the Boraflex panels. Since the gamma field associated with the fuel assemblies was not uniform, the shrinkage of the Boraflex was not uniform. This non-uniform shrinkage is believed to be the cause of gaps/cracks that form in the Boraflex panels. Boraflex will also dissolve in the SFP environment after exceeding a threshold gamma dose of approximately 5 x $10^8$ rads. The Peach Bottom SFP contains Boraflex panels that have a wide range of absorbed dose, with numerous panels in excess of 5 x $10^8$ rads. Boraflex has also shown a propensity for localized degradation due to localized flow effects within the enclosure formed by the storage cell wall and the wrapper.

The NRC issued Generic Letter 1996-04, "Boraflex Degradation in Spent Fuel Pool Storage Racks," (Reference 4) to alert the industry and request each licensee crediting Boraflex to provide the NRC with its plan to manage the degradation. To determine whether the Boraflex in the Peach Bottom SFP is continuing to meet its current licensing basis, the licensee uses its analytical code, RACKLIFE, every 6 months to predict future degradation of Boraflex in the SFPs. In addition, to determine actual degradation levels, the licensee began periodic in-situ testing of its racks in 1996 using the Boron-10 Areal Density Gauge for Evaluating Racks (BADGER) tool, repeating the testing on a four year frequency. These test results were then used to benchmark the RACKLIFE predictions.

On June 25, 2008, PBAPS submitted a license amendment request to revise its TS $k_{inf}$ limit from 1.362 to 1.318 (Reference 20). After numerous meetings, teleconferences, and correspondence exchanges, PBAPS was unable to provide the technical information to resolve the NRR staff's questions and PBAPS withdrew the application on June 18, 2010 (Reference 21).

The OD was initiated because the RACKLIFE predicted areal density of some Boraflex panels is predicted to be below 0.021 g/cm$^2$. Since those panels have dropped below the areal density used in the nuclear criticality safety (NCS) analysis they are non-conforming to the PBAPS TS design basis.

Licensee Position

The PBAPS OD concluded that SFP storage cells loaded with fuel assemblies having a peak in-core $k_{inf}$ of 1.26 and Boraflex areal density ≥ 0.01155 g/cm$^2$ (i.e., 0.021 g/cm$^2$ x 55% Boraflex remaining) would meet the TS requirement for the SFP $k_{eff}$ to be ≤ 0.95. OD 10-007 set four compensatory measures:

1. Develop a method for ensuring new fuel design is limited to a maximum $k_{inf}$ of 1.26 for PBAPS Units 2 and 3.
2. Revise RT-R-004-990-2/3 (Boraflex Surveillance using the RACKLIFE Program) to include acceptance criteria sufficient to ensure that the minimum B-10 areal density of any in service panel is > 0.01155 gm/cm$^2$.
3. Revise RT-R-004-995-2/3 (Boraflex Surveillance using the BADGER Test Device) to include acceptance criteria sufficient to ensure that the minimum B-10 areal density of any in service panel is > 0.01155 gm/cm$^2$.
4. Develop a procedure to administratively remove any fuel rack storage cell from service which includes a Boraflex panel that does not meet the minimum B-10 areal density of 0.01155 gm/cm$^2$.

There are two pieces to the OD. An Operability Evaluation which asks the formulaic questions and a Technical Evaluation that provides the technical justification for the OD. The PBAPS Operability Evaluation number is 10-007, Revision 1, dated November 5, 2010. The Technical Evaluation number is IR864431-15, Revision 3. These revisions were made based on the NETCO test reports.

## 3.0 EVALUATION

**TIA Request 1:** Conduct a technical assessment of OD 10-007 that PBAPS is using to support operability of the SFPs through 2014. If NRR determines that OD 10-007 does not provide reasonable assurance of operability through 2014, the Region I Office requests that NRR provide an estimate of when SFP operability will be challenged, including technical bases for any earlier time limitations.

The NRR staff has performed a technical review of OD 10-007 as requested. In support of this review, NRR staff also reviewed the following supporting documents: the Technical Evaluation, Revision 3, the NETCO reports, and the compensatory measures.

Based on the staff's review of the documents, the NRR staff has the following concerns:

- Uncertainty of the OD,
- Non-conservative Technical Evaluation, Revision 3, and
- Uncertainty in the analysis of BADGER and RACKLIFE data in the NETCO reports.

In order to assess the SFP operability through 2014, the staff reviewed the technical basis for OD 10-007: Technical Evaluation, Revision 3, and the NETCO reports. The licensee has determined that it will continue to meet TS 4.3.1.1.b and NRC regulations as long as the areal density of $B^{10}$ in the Boraflex panels does not degrade below 0.01155 g/cm$^2$ and $k_{inf}$ remains below 1.26 for fuel loaded in the SFP racks. On page 14 of the Technical Evaluation, Revision 3, the licensee concludes that the Boraflex degradation will not reach this degradation limit until 2014. The primary basis for this determination is Figure 7, "Peach Bottom 2 RACKLIFE Peak Panel % $B^{10}$ Density Loss Projection" which depicts the RACKLIFE predicted peak $B^{10}$ areal density degradation over time (actual and projected). Since Figure 7 serves as the primary basis for the licensee's OD, the staff's review has focused on this figure. To better analyze this figure and explain the staff's concerns with the licensee's OD, the staff has recreated the data from Figure 7 below in Graph 1.

Graph 1: Recreation of Figure 7 in Technical Evaluation, Revision 3

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Note: The "PB 2 Peak B-10 Density Loss – ACTUAL" is the RACKLIFE prediction using the acutal SFP data/conditions at that date. The "PB 2 Peak B-10 Density Loss- RACKLIFE PROJECTED" is the RACKLIFE prediction going forward with an estimate of the SFP conditions.

The staff's major concerns with Figure 7 and the licensee's analysis are listed below. The concern numbers correspond to the numbers on Graph 1.

Concern 1. In the Technical Evaluation, the licensee based its degradation limit of 45 percent (0.01155 g/cm$^2$)[1] on the minimum certified areal density reference value (0.021 g/cm$^2$). However, by comparing the data in the NETCO reports to the data points in Figure 7, the Figure 7 data appears to be based on a reference value of 0.0235 g/cm$^2$, which is the average areal density, and <u>not</u> the minimum certified areal density. The mismatch in the areal density reference values raises staff concerns that the Technical Evaluation analysis of Figure 7 is inconsistent with the plant licensing basis and may be potentially non-conservative. The staff concludes that

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[1] NRR staff evaluated the adequacy of PBAPS OD 10-007 determination of degradation allowance in the section addressing TIA Request 2.

the reference values for the percent degradation limit of 45 percent and the data points in Figure 7 should be the same in order to allow an accurate comparison.

Concern 2. The mid-2006 point on Graph 1 (labeled #2) and the peak measured degradation on page ii of the 2006 NETCO report (NET-264-01) do not correlate. One possible explanation for this difference is that the data in Figure 7 was not recalibrated based on the BADGER results. In Electric Power Research Institute (EPRI) TR-1003413, "Guidance and Recommended Procedures for Maintaining and Using RACKLIFE Version 1.10," the industry has stated that RACKLIFE should be recalibrated with the BADGER results after every BADGER campaign. Based on the staff's analysis, if RACKLIFE were recalibrated, the 2006 point on Figure 7/Graph 1 should be close to the 2006 NETCO report measured peak degradation of [[redacted]] percent. Graph 1/Figure 7 shows a peak degradation of approximately [[redacted]] percent. Therefore, the staff cannot determine if RACKLIFE was recalibrated.

Concern 3. According to the licensee, the RACKLIFE analysis predictions are calculated every 6 months. Therefore, on the graph, there should be no period longer than 6 months. However, the interval between the RACKLIFE predictions on January 1, 2011 and January 2, 2012 is approximately 12 months. The staff is concerned that the licensee's Figure 7 may have missed a RACKLIFE prediction between January 1, 2011 and January 2, 2012. In addition, upon analyzing the degradation rate for this 12 month interval, the rate is about [[redacted]] percent degradation/6 months vs. [[redacted]] percent degradation/6 months for the 6 month intervals after January 2, 2012. This raises staff concerns about the adequacy of the operability limit prediction since there is no evidence that the degradation rate should be decreasing at any point in time. In addition, EPRI TE-114126, "The Surface Composition and Solubility of Irradiated Boraflex and Silica Treated in Metal Ion Solutions," provides the only known method to decrease the rate of degradation of Boraflex in the SFP, and there is no indication in the licensee's licensing basis to indicate this method is employed at PBAPS.

Concern 4. During the interval between mid-2009 and early-2010, there appears to be a significant increase in the degradation rate. To the staff, this would be indicative of the start of an increasing rate of degradation in the SFP. According to EPRI TR-108761, there is a point at which the rate of degradation will start to increase and become non-linear. In addition, as discussed in Concern 3, this increased degradation rate is not carried forward in the prediction of future degradation as expected in industry guidance documents. The staff is concerned that this possible increase in the degradation rate was not accounted for in future predictions of degradation and, therefore, the licensee may be approaching the degradation limit faster than predicted.

Concern 5. On page 3 of the OD 10-007, the current degradation projection from RACKLIFE, as of November 1, 2010, was that the Unit 2 peak degradation is approximately 38% degradation. This is more than the [[redacted]]% peak degradation indicated by the licensee's Figure 7. The Technical Evaluation does not appear to reflect the current RACKLIFE projection from November 1, 2010 (OD 10-007). The staff is concerned that the licensee has not updated its OD to account for the new data. The staff believes that inclusion of this new data will result in reaching the degradation limit earlier than currently projected by the licensee.

Based primarily on these concerns, the NRR staff has determined that OD 10-007 and its supporting documents do not provide reasonable assurance of SFP operability through 2014 without compensatory measures. The staff's concerns with the adequacy of the licensee's compensatory measures are described later in this evaluation. Additional staff comments that are not directly correlated to the assessment of SFP operability through 2014 are discussed in the Appendix.

In order to determine approximately when the operability of the SFP will be challenged, the NRR staff has performed an independent assessment of the data and graphs with the limited amount of information provided.

The staff performed many different case studies to determine a date at which operability would be challenged. The staff's determination is provided in Graph 2, which addresses each of the five major concerns listed above.

Graph 2: NRR Staff Adjusted Plot of Boraflex Degradation at Peach Bottom

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Note: The "PB 2 Peak B-10 Density Loss – ACTUAL" is the RACKLIFE prediction using the acutal SFP data/conditions at that date. The "PB 2 Peak B-10 Density Loss- RACKLIFE PROJECTED" is the RACKLIFE prediction going forward with an estimate of the SFP conditions.

Addressing the concerns cited previously:

Concern 1. The licensee used a 45 percent degradation limit in determining the operability limit of 2014. The staff does not believe this is appropriate for determining the operability limit on Figure 7, Graph 1, and Graph 2, because of the reference value used to create the graphs/figure. The licensee's OD 10-007 concluded that 45% degradation from 0.021 g/cm$^2$ areal density was acceptable, which set a minimum areal density limit of 0.01155 g/cm$^2$. However, the data from the figure and graphs uses a reference value of 0.0235 g/cm$^2$. Therefore, the percentage of degradation should be based on this reference value. Using this reference value, the staff has recalculated a degradation percentage that should be used. The staff's calculation determined that at 50.8 percent degradation of this reference value, the areal density limit would be 0.01156 g/cm$^2$. As such, to determine the date when the operability limit will be reached on Figure 7 and the graphs, one should use a 50.8 percent degradation limit, 0.01156 g/cm$^2$. This is displayed on Graph 2 by the solid lines.

Concern 2. In order to address the recalibration concern, the staff recalibrated the data to more closely match the BADGER data. Using the 2006 BADGER results from NET-264-01, the staff shifted the corresponding point on Graph 2 to more closely match the BADGER result, in effect recalibrating the data. If RACKLIFE were recalibrated, it can be reasonably assumed that the rest of the data would have shifted in accordance to the calibration. Therefore, the staff shifted the rest of the "PB 2 Peak B-10 Density Loss – ACTUAL" points on the graph to account for the recalibration discrepancy. The staff views this recalibration as a reasonable estimate of how an actual recalibration should have affected the licensee's OD 10-007.

Concern 3. In order to address the appearance of a missed RACKLIFE prediction, the staff has doubled the rate for that interval to account for the missed prediction, since the rate for that interval was [[redacted]] percent degradation/6 months and the subsequent points were [[redacted]] percent degradation/6 months. While actually performing the RACKLIFE prediction may give more accurate results, the staff believes that doubling the rate for this interval gives a reasonable approximation in the absence of data from the code.

Concern 4. The rate of the interval, represented on Graph 1 by the circle labeled 4, changed to approximately [[redacted]] percent degradation/6 months from the rate in preceding 6-month interval (end-2009 to start of 2010) of approximately [[redacted]] percent degradation/6 months. Although it may be suggested by EPRI TR-108761 that the rate should no longer be linear but instead now exponential, there is no way for the staff to model this accurately with the few data points that would indicate non-linear behavior. Therefore, propagating the increased degradation rate through the rest of the data is an approximation of the degradation during the next few years. The later data points (a few years out) on Graph 2 may actually be non-conservative since the degradation may now be becoming exponential. However, this is the staff's estimate in order to determine a more reasonable operability limit.

Concern 5. After creating Graph 2, the staff compared the prediction at point #5 to the RACKLIFE predication from November 1, 2010 (OD 10-007). The staff's prediction is slightly higher, but provides reasonable assurance that the staff's determination of the operability limit is slightly conservative and not overly conservative.

As stated previously, this analysis is the staff's estimate predicated on the validity of the base data. The staff created Graph 2 in an attempt to resolve all the major concerns using assumptions that address apparent inconsistencies in the licensee's analysis. Graph 2 yields a new operability limit of mid-2011. In addition, the data from the November 1, 2010, RACKLIFE prediction (OD 10-007) validates the conservatism of staff's analysis. The staff's analysis is slightly higher, but is within the realm of uncertainty by the BADGER tool ([[redacted]]%) as noted by the BADGER vendor[2]. Therefore, the staff has reasonable assurance that the Boraflex in the Unit 2 SFP will not exceed the degradation limit established by the licensee until mid-2011.

<u>Compensatory Measures Evaluation</u>

The NRR staff has analyzed the compensatory measures described in OD 10-007 and the updates to procedures as described in the compensatory measures. No other documents related to changes in the procedures were reviewed.

Compensatory Measure #1 Develop a method for ensuring new fuel design is limited to a maximum $k_{inf}$ of 1.26 for PBAPS Units 2 and 3

This measure is addressed under the evaluation for TIA Request 2 below.

Compensatory Measure #2 Revise RT-R-004-990-2/3 (BORAFLEX Surveillance using the RACKLIFE Program) to include acceptance criteria sufficient to ensure that the minimum B-10 areal density of any in service panel is > 0.01155 gm/cm$^2$

On page 12 of the updated procedure (Reference 15), the acceptance criteria for a RACKLIFE prediction is that less than 58.4[3] percent degradation is acceptable. If any RACKLIFE prediction is greater than 58.4 percent, then the prediction would have to be reanalyzed and more actions may be taken. According to the procedure, the 58.4 percent degradation value comes from the use of the reference value of 0.0256 g/cm$^2$, the "nominal as built" areal density[4], in the RACKLIFE analysis. Contrary to this, in the NETCO reports, the nominal areal density (average) is 0.0235 g/cm$^2$ and the batch minimum and maximum areal densities are 0.0226 g/cm$^2$ and 0.025 g/cm$^2$, respectively. The RACKLIFE and BADGER values are calculated from a reference value of 0.0235 g/cm$^2$. Therefore, there is uncertainty about what reference areal density is used for the RACKLIFE predictions and whether it is consistent. If RACKLIFE is using the maximum batch areal density, 0.025 g/cm$^2$, the staff believes this would be non-conservative. The staff would consider using the minimum certified areal density, 0.021 g/cm$^2$, to be more conservative.

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[2] NRC currently has a RES program that is evaluating the BADGER inspection tool uncertainty

[3] NRR staff evaluated the adequacy of PBAPS OD 10-007 determination of degradation allowance in the section addressing TIA Request 2.

[4] The BADGER test reports list the average As-Built areal density as 0.0235 g/cm$^2$. The 0.0256 g/cm$^2$ value for the average As-Built areal density initially appears in the procedure revisions implemented by PBAPS to incorporate the compensatory measures from OD 10-007. This revised areal density value has not been reviewed by the NRR staff.

It is the staff's understanding that RACKLIFE only predicts silica loss and then generally correlates it to percent degradation of the areal density of $B^{10}$ in a Boraflex panel. Therefore, if the reference point of RACKLIFE were the minimum certified areal density instead of the "nominal as built" areal density, it would predict more degradation. For example, RACKLIFE predicts "X" amount of silica dissolution, which correlates to 10 percent degradation according to the panel reference/starting value. Based on the licensee's procedure, RACKLIFE uses 0.0256 g/cm$^2$, the "nominal as built" areal density, as the reference point. Using its procedure, the licensee would calculate 0.02304 g/cm$^2$ left. Re-calculating the percent degradation for the NETCO reports using the average areal density (0.0235 g/cm$^2$) will show that the results are non-conservative. Converting to a percent degradation from the average areal density (0.0235 g/cm$^2$ - 0.02304 g/cm$^2$)/(0.0235 g/cm$^2$ x 100) for the NETCO reports, the licensee would have calculated only 2 percent degradation instead of the 10 percent degradation based on a reference value of 0.0256 g/cm$^2$. Therefore, staff believes that the NETCO report values may be non-conservative.

As such, the staff does not have reasonable assurance that compensatory measure #2 will ensure the degradation does not exceed the limits.

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| Compensatory Measure #3 | Revise RT-R-004-995-2/3 (Boraflex Surveillance using the BADGER Test Device) to include acceptance criteria sufficient to ensure that the minimum B-10 areal density of any in service panel is > 0.01155 gm/cm$^2$ |

In the procedure, the acceptance criteria is that any panel measuring below 0.01155 g/cm$^2$ by BADGER testing shall be deemed out of compliance. The staff is concerned because the licensee does not appear to have any margin to the limiting value. First, BADGER measurements have an approximate +/- [[redacted]]% uncertainty as stated in the Technical Evaluation. Therefore, there should be some margin added on to the limit of 0.01155 g/cm$^2$ to account for the uncertainty. Also, BADGER is only performed every 4 years. In the interval between the tests, there should be margin to account for the degradation during this time to provide reasonable assurance that the degradation will not exceed the limit during the period until the next BADGER test. For example, if a BADGER measurement was 0.0116 g/cm$^2$, this would meet the criteria and nothing would be done. Due to measurement uncertainty, this value could be as low as 0.010672 g/cm$^2$; therefore, action would be required. Additionally, the panel would still be degrading over time, and could be reasonably assumed to exceed the degradation limit before the next scheduled BADGER test in 4 years. Therefore, the staff does not have reasonable assurance that compensatory measure #3 will ensure the degradation does not exceed the limit.

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| Compensatory Measure #4 | Develop a procedure to administratively remove any fuel rack storage cell from service which includes a Boraflex panel that does not meet the minimum B-10 areal density of 0.01155 g/cm$^2$ |

This is an update to the procedure. The technical changes made to this procedure are detailed in the above compensatory measures; therefore, there is no technical evaluation necessary for this compensatory measure.

Based on the reasons stated above, the staff does not have reasonable assurance that the licensee's compensatory measures can demonstrate that the Boraflex panels will remain above the degradation limit of 0.01155 g/cm$^2$.

**TIA Request 2**: Review whether the licensee's analyses as documented in OD 10-007 employs appropriate assumptions and calculation methodologies to demonstrate with reasonable assurance that the subcritical margin limit for the SFP as specified by TS 4.3.1.1.b ($K_{effective} \leq 0.95$) will continue to be met.

The methodology in the Technical Evaluation estimates '%$\Delta k_{eff}$ Margin' based on the 1985 Westinghouse Electric Company (WEC) analysis (WNEP 8542, Revision 1) that supported the initial licensing of the Boraflex SFP racks and the 1992 GE Nuclear Energy (GENE) analysis (GENE-512-92073) that accompanied the amendment request that changed the TSs from a $U^{235}$ loading limit of 17.3 g/cm to an in-core $k_{inf}$ limit of 1.362. The Technical Evaluation also estimates the '%$\Delta k_{eff}$ Margin Loss' associated with several aspects of Boraflex degradation. So long as there is positive '%$\Delta k_{eff}$ Margin' remaining after the '%$\Delta k_{eff}$ Margin Losses' are subtracted, the Technical Evaluation methodology would conclude that the requirement for $k_{eff}$ to be ≤ 0.95 at a 95 percent probability with 95 percent confidence (95/95) is met.

*Estimation of '%$\Delta k_{eff}$ Margin'*

The Technical Evaluation estimates that based on the WNEP 8542 and GENE-512-92073 analyses the PBAPS SFPs have 11.01% $\Delta k_{eff}$ Margin. This margin has two components. One component is based on the difference between the PBAPS TS in-core $k_{inf}$ limit of 1.362 and the maximum SCCG $k_{inf}$ of fuel assemblies currently on site, 1.2344. The in-core $k_{inf}$ are converted to in-rack $k_{inf}$ by an in-core/in-rack $k_{inf}$ relationship extracted from the GENE-512-92073 analysis. The in-core/in-rack $k_{inf}$ relationship in the GENE-512-92073 analysis is for a fresh GE11 fuel assembly with 4.5 w% $U^{235}$ and a varying amount of gadolinia. The Technical Evaluation concludes that this provides 9.58% $\Delta k_{eff}$ Margin. The other component is that the WNEP 8542 analysis calculated an in-rack 95/95 $k_{inf}$ of 0.9357, which the Technical Evaluation credits as providing 1.43% $\Delta k_{eff}$ Margin to the 0.95 $k_{eff}$ limit. The NRR staff has the following concerns regarding the Technical Evaluation's estimation of the available %$\Delta k_{eff}$ Margin (numbering of concerns is continued from above for differentiability).

Concern 6. There is an unsupported implicit assumption that the in-core/in-rack $k_{inf}$ relationship extracted from the GENE-512-92073 analysis for the GE11 fuel assembly would apply to all fuel assembly designs at PBAPS.

Concern 7. There is an unsupported implicit assumption that the differences between computer codes and nuclear data libraries used in the WNEP 8542, GENE-512-92073 analyses, or the General Electric Standard Application for Reactor Fuel (TGBLA) used today, will have no impact on the comparisons.

Concern 8. There are two unsupported concurrent implicit assumptions: (1) that the nominal in-rack $k_{inf}$ for all fuel assemblies at PBAPS will be essentially identical and (2) that the $\Delta k$ increase (i.e., the sum of biases and uncertainties) to a 95/95 in-rack $k_{inf}$ for all fuel assemblies at PBAPS will be essentially identical. The analyses referenced in the Technical Evaluation do not support these assumptions. In the WNEP 8542 analysis, the fuel assembly and rack biases and uncertainties added approximately 0.0159 $\Delta k$ to the nominal as the in-rack $k_{inf}$ went from 0.9198 to 0.9357. A 95/95 in-rack $k_{inf}$ was not calculated in the GENE-512-92073 analysis; therefore, the amount of margin the fuel assembly had to the 0.95 in-rack $k_{eff}$ is unknown. From the 2009 NETCO analysis referenced in the Technical Evaluation, the fuel assembly and rack biases and uncertainties added approximately [[redacted]] $\Delta k$ to the nominal in-rack $k_{inf}$ of a GNF2 fuel assembly. Therefore, since the biases and uncertainties are likely larger, either the difference between the 95/95 in-rack $k_{inf}$ and the limit of 0.95 is reduced or the nominal in-rack $k_{inf}$ is lower. The first would reduce the 1.43% $\Delta k_{eff}$ Margin to the 0.95 $k_{eff}$ limit and the second would reduce the 9.58% $\Delta k_{eff}$ Margin to the 0.95 $k_{eff}$ limit. Either case would reduce the 11.01% $\Delta k_{eff}$ Margin determined in the Technical Evaluation. Therefore, the NRR staff does not consider it appropriate to include the 1.43% $\Delta k_{eff}$ as part of the estimated %$\Delta k_{eff}$ Margin.

Concern 9. There is an apparent inconsistency in the Technical Evaluation's in-core/in-rack $k_{inf}$ relationship extracted from the GENE-512-92073 analysis. From the GENE-512-92073 analysis' in-core/in-rack $k_{inf}$ relationship, an in-core $k_{inf}$ of 1.362 will yield an in-rack $k_{inf}$ of 0.918. In the Technical Evaluation's in-core/in-rack $k_{inf}$ relationship an in-core $k_{inf}$ of 1.362 yields an in-rack $k_{inf}$ of 0.9129, an under prediction of the in-rack $k_{inf}$ of by 0.0051 $\Delta k$. Since the Technical Evaluation's methodology is based on the in-rack $k_{inf}$ difference between the SCCG in-core $k_{inf}$ of 1.362 and 1.2344 a constant under prediction would not affect that difference because the under prediction would be the same at both points. However, it is unknown whether the in-core $k_{inf}$ of 1.2344 will yield an in-rack $k_{inf}$ with the same under prediction. Therefore, the 9.58% $\Delta k_{eff}$ of the total 11.01% $\Delta k_{eff}$ Margin is suspect.

Concern 10. The GENE-512-92073 analysis determined the in-core $k_{inf}$ limit by determining an 'enrichment bias' based on the in-rack $k_{inf}$ of a fresh poisoned GE11 fuel assembly with 4.5 w% $U^{235}$ and a fresh unposioned GE 7x7 fuel assembly with 3.5 w% $U^{235}$. By the methodology in the GENE-512-92073 analysis, higher $U^{235}$ enrichments would have a larger 'enrichment bias.' Therefore, the TS $k_{inf}$ limit of 1.362 should be viewed as non-conservative for fuel assemblies with an enrichment greater than 4.5 w% $U^{235}$. The 2009 NETCO analysis analyzed a fuel assembly with a $U^{235}$ enrichment of [[redacted]] w% $U^{235}$, indicating that under the GENE-512-92073 analysis methodology the TS $k_{inf}$ limit of 1.362 may not be appropriate for those fuel assemblies and may not provide the same %$\Delta k_{eff}$ Margin.

The maximum in-core $k_{inf}$ 1.2344 for current fuel assemblies would provide some margin relative to the TS $k_{inf}$ limit of 1.362 to offset some Boraflex degradation below the 0.021 g/cm$^2$ $B^{10}$ areal density used in the WNEP 8542 analysis. However, because of the issues cited above, the NRR staff believes it is inappropriate to conclude from the Technical Evaluation's methodology that the PBAPS SFPs have 11.01% $\Delta k_{eff}$ Margin to the 0.95 $k_{eff}$ limit. With the information provided, the NRR staff believes that it is virtually impossible to adequately quantify the effect of the issues cited above on the estimated %$\Delta k_{eff}$ Margin. However, for the sake of further analysis of the OD, the NRR staff will assume there is 9.5% $\Delta k_{eff}$ Margin. The NRR staff's assumption allows most of the %$\Delta k_{eff}$ Margin attributed to the delta in fuel assembly $k_{inf}$, but does not allow the %$\Delta k_{eff}$ Margin attributed to the delta between the 95/95 $k_{inf}$ and the limit of 0.95. The NRR staff believes that 9.5% $\Delta k_{eff}$ Margin is reasonably the most margin that can be considered with the information provided in PBAPS OD 10-007.

*Estimation of '%$\Delta k_{eff}$ Margin Loss'*

The Technical Evaluation has estimated %$\Delta k_{eff}$ Margin Losses for uniform Boraflex degradation, BADGER uncertainty, RACKLIFE uncertainty, Boraflex Random Gapping, and Boraflex Undetected Cracking. The Technical Evaluation includes an estimated %$\Delta k_{eff}$ Margin Loss for a potential future increase in in-core $k_{inf}$ of actual fuel assemblies from 1.2344 to 1.26.

The uniform Boraflex degradation, BADGER uncertainty, RACKLIFE uncertainty, and Boraflex Random Gapping estimated %$\Delta k_{eff}$ Margin Losses were derived with an in-rack $k_{inf}$/uniform $B^{10}$ areal density relationship extracted from the WNEP 8542 analysis. The WNEP 8542 analysis had a $B^{10}$ areal density sensitivity study for the 3.5 w% enriched 7x7 fuel assembly. The graph plotted $k_{eff}$ for areal densities of 0.016 g/cm$^2$, 0.021 g/cm$^2$, and 0.026 g/cm$^2$. The WEC 1985 graph has error bars that are listed as meeting the 95/95 level. The Technical Evaluation calculated a '%$\Delta k_{eff}$ per 1% $B^{10}$ loss' by taking those error bars and maximizing the $k_{eff}$ at the 0.016 g/cm$^2$ point and minimizing the $k_{eff}$ at the 0.021 g/cm$^2$ point. This provided a 0.1177% $\Delta k_{eff}$ per 1% $B^{10}$ loss relationship. The estimated %$\Delta k_{eff}$ Margin Loss for Boraflex Undetected Cracking was taken from the 2009 NETCO analysis. The potential future increase in in-core $k_{inf}$ estimated %$\Delta k_{eff}$ Margin Loss was derived using the in-core/in-rack $k_{inf}$ relationship extracted from the GENE-512-92073 analysis. The NRR staff has the following concerns regarding the Technical Evaluation's estimation of the %$\Delta k_{eff}$ Margin Losses.

Concern 11. The '1% $B^{10}$ loss' in the Technical Evaluation's 0.1177% $\Delta k_{eff}$ per 1% $B^{10}$ loss is based on the Minimum Certified areal density of 0.021 g/cm$^2$. However, the RACKLIFE predicted Boraflex degradation percentages are based on the Average As-Built Batch areal density of 0.0235 g/cm$^2$. A '1% $B^{10}$ loss' from 0.021 g/cm$^2$ is 0.00021 g/cm$^2$. A '1% $B^{10}$ loss' from 0.0235 g/cm$^2$ is 0.000235 g/cm$^2$. The latter is 11.9 percent larger, therefore since the 0.1177% $\Delta k_{eff}$ per 1% $B^{10}$ loss relationship was determined from 0.021 g/cm$^2$, the relationship should be increased by 11.9 percent to 0.1317% $\Delta k_{eff}$ per 1% $B^{10}$ loss.

- The Technical Evaluation considers both Uniform Average Panel and Uniform Peak Panel degradation. The NRR staff believes it is not appropriate to consider the Average Panel degradation because the SFP $k_{eff}$ will be largely determined by the peak degradation and not the SFP average. For a Peak Panel degradation of 45 percent the Technical Evaluation estimates the %$\Delta k_{eff}$ Margin Loss as 5.30% $\Delta k_{eff}$. Adjusted estimated %$\Delta k_{eff}$ Margin Loss is 5.93% $\Delta k_{eff}$, accounting for the 11.9 percent increase described in Concern 11.

- The Technical Evaluation takes the [[redacted]] percent BADGER uncertainty from the 2009 NETCO analysis to estimate a %$\Delta k_{eff}$ Margin Loss of [[redacted]]% $\Delta k_{eff}$. Adjusted estimated %$\Delta k_{eff}$ Margin Loss is [[redacted]]% $\Delta k_{eff}$, accounting for the 11.9 percent increase described in Concern 11.

- The Technical Evaluation considers RACKLIFE uncertainty to be [[redacted]] percent, resulting in an estimated %$\Delta k_{eff}$ Margin Loss of [[redacted]]% $\Delta k_{eff}$. Adjusted estimated %$\Delta k_{eff}$ Margin Loss is [[redacted]]% $\Delta k_{eff}$, accounting for the 11.9 percent increase described in Concern 11.

- For the Boraflex Random Gapping estimated %$\Delta k_{eff}$ Margin Loss, the Technical Evaluation referred to the Unit 3 2009 BADGER measurement campaign report, NET-311-01 Revision 0, dated July 8, 2010 (Reference 8). The Technical Evaluation took the largest cumulative gap height of [[redacted]] inches and converted it to a uniform panel loss of [[redacted]] percent $B^{10}$ loss to estimate a %$\Delta k_{eff}$ Margin Loss of [[redacted]]% $\Delta k_{eff}$. Adjusted estimated %$\Delta k_{eff}$ Margin Loss is [[redacted]]% $\Delta k_{eff}$, accounting for the 11.9 percent increase described in Concern 11.

Concern 12. The BADGER Test Reports state: "[[redacted]]" Absent information to the contrary, the NRR staff assumed a first-in-first-out manufacturing process, i.e., all of the panels on a 'manufactured' cell will likely be from the same batch. There is also a high likelihood that the panels on 'manufactured' cells in the same rack module will likely be from the same or similar batches. Therefore, the average of all 7600 panels is an inappropriate estimation for the areal density to be used in a NCS analysis. The Technical Evaluation did not consider that collocated panels will be at the Minimum As-Built areal density from which all other degradation starts. That would be a 3.83 percent $B^{10}$ loss from the Average As-Built areal density, resulting in an additional 0.50% $\Delta k_{eff}$ Margin Loss (i.e., 3.83% * 0.1317% $\Delta k_{eff}$ per 1% $B^{10}$ loss).

Concern 13. The Technical Evaluation did not consider the effects of non-uniform thinning, despite the Operability Evaluation statement that degradation is not uniform. The NRC has performed sensitivity studies on the effect of non-uniform degradation. The NRR staff's sensitivity study looked at cosine and sine shaped degradation profiles considered minor, moderate, and severe deviations from a uniform degradation, while keeping the normalized degradation equal to the amount of uniform degradation. Those sensitivity studies indicate an increase of over 5.0% $\Delta k_{eff}$ for the severe deviation from a uniform degradation. The minor degradation had an increase of approximately 1.0% $\Delta k_{eff}$. However, a review of the BADGER reports for PBAPS indicate the non-uniform degradation in excess of the reported uniform degradation is not offset by other areas of less degradation as was done in the NRR staff's sensitivity study. Therefore the NRR staff's sensitivity studies may not be bounding on the condition of the PBAPS Boraflex panels. Because an explicit modeling of the non-uniform degradation would likely result in higher estimates of $k_{eff}$ the NRR staff believes it is reasonable to include a '$\Delta k_{eff}$ Margin Loss' to account for non-uniform degradation. For the purposes of this evaluation the NRR staff estimates the effect to be a 1.0% $\Delta k_{eff}$ Margin Loss to account for non-uniform degradation.

Note 1. The estimated %$\Delta k_{eff}$ Margin Loss for Boraflex Undetected Cracking was taken from the 2009 NETCO analysis as [[redacted]]% $\Delta k_{eff}$. In the 2009 NETCO analysis the undetected cracks were modeled explicitly rather than estimating them as an equivalent uniform thinning. Therefore, Concern 11 does not apply to this %$\Delta k_{eff}$ Margin Loss.

Note 2. The potential future increase in in-core $k_{inf}$ estimated %$\Delta k_{eff}$ Margin Loss was derived using the in-core/in-rack $k_{inf}$ relationship extracted from the GENE-512-92073 analysis and estimated as %$\Delta k_{eff}$ Margin Loss of 1.92% $\Delta k_{eff}$. The NRR staff did not include this loss as these fuel assemblies are not currently in use at PBAPS and therefore do not affect the current operability of the SFP storage cells.

*Summation of Estimation of '%Δ$k_{eff}$ Margin'*

The following table reflects the Technical Evaluation's summation of the remaining %Δ$k_{eff}$ Margin and the NRR staff's adjusted estimation of the remaining %Δ$k_{eff}$ Margin at a RACKLIFE predicted pool peak panel uniform degradation of 45 percent.

| | PB Technical Evaluation | Adjusted Estimate | Basis for NRR's Adjusted Estimate |
|---|---|---|---|
| Margin to WEC $k_{eff}$ ≤ 0.9357 | 9.58% | 9.5% | Concern 8 |
| Additional Margin to $k_{eff}$ ≤ 0.95. | 1.43% | 0.0% | Concern 8 |
| Initial Total Margin | 11.01% | 9.5% | |
| RACKLIFE predicted Peak Uniform $B^{10}$ Loss of 45% | -5.30% | -5.93% | Concern 11 |
| Increase in actual maximum SCCG $k_{inf}$ to 1.26 | -1.92% | | Note 2 |
| BADGER Uncertainty | [[redacted]]% | [[redacted]]% | Concern 11 |
| BADGER/RACKLIFE Uncertainty | [[redacted]]% | [[redacted]]% | Concern 11 |
| Boraflex Random Gapping | [[redacted]]% | [[redacted]]% | Concern 11 |
| Boraflex Undetected Cracking | [[redacted]]% | [[redacted]]% | Note 1 |
| Collocated Minimum As-Built areal density panels | | -0.50% | Concern 12 |
| Non-uniform Boraflex Thinning | | -1.00% | Concern 13 |
| Remaining Margin | [[redacted]]% | [[redacted]]% | |

The NRR staff believes PBAPS OD 10-007 has overestimated the amount of remaining '%Δ$k_{eff}$ Margin' at RACKLIFE predicted Peak Uniform $B^{10}$ Loss of 45 percent. The [[redacted]]% Δ$k_{eff}$ Margin in the Adjusted Estimate indicates that the RACKLIFE predicted Peak Uniform $B^{10}$ Loss of 36 percent would be a more appropriate limit (i.e., 45% degradation [[redacted]]% Δ$k_{eff}$ / 0.1317% Δ$k_{eff}$ per 1% $B^{10}$ loss, truncated to 36%).

*Additional Considerations for the Estimation of '%Δ$k_{eff}$ Margin'*

These considerations are included in the Appendix.

4.0 CONCLUSION

Based on the review of TIA Request 1:

The NRR staff has concluded that PBAPS OD 10-007 is under predicting the peak Boraflex degradation rate, and therefore does not support operability of Boraflex panels through 2014. Based on the NRR staff's estimated degradation rate, PBAPS Unit 2 SFP Boraflex panels with peak degradation will drop below the PBAPS OD 10-007 minimum acceptable $B^{10}$ areal density of 0.01155 g/cm$^2$ by mid-2011. The Unit 3 pool appears to be less degraded, and the licensee may be able to justify operation of the Unit 3 pool past mid-2011.

However, in the review of TIA request 2, the NRR staff determined that a $B^{10}$ areal density of 0.01504 g/cm$^2$ (36 percent degradation of 0.0235 g/cm$^2$) would be a more appropriate minimum acceptable $B^{10}$ areal density limit than 0.01155 g/cm$^2$. PBAPS OD 10-007 indicates that RACKLIFE predicted that several Boraflex panels had less $B^{10}$ areal density than 0.01504 g/cm$^2$ as of November 2010.

Based on the review of TIA Request 2:

The NRR staff has concluded that PBAPS Operability Evaluation 10-007, Revision 1, and accompanying Technical Evaluation, does not demonstrate reasonable assurance that the SFP $k_{eff}$ is ≤ 0.95 with a 95 percent probability and 95 percent confidence level with a Boraflex panel minimum $B^{10}$ areal density of 0.01155 g/cm$^2$ and a fuel assembly with a SCCG $k_{inf}$ of 1.2344. The NRR staff has concluded that PBAPS OD 10-007 does not apply appropriate assumptions and calculation methodologies in that the amount of $\%\Delta k_{eff}$ Margin appears to be over predicted and the amount of $\%\Delta k_{eff}$ Margin Losses appear to be under predicted.

Additionally, the NRR staff concludes that:

- PBAPS OD 10-007 Compensatory Measure #1 to limit the PBAPS future fuel assemblies to a peak SCCG of $k_{inf}$ of 1.26 is non-conservative.

- PBAPS OD 10-007 Compensatory Measures #2, #3, and #4 to change procedures to remove from service any cell containing a Boraflex panel with a $B^{10}$ areal density less than 0.01155 g/cm$^2$ (45 percent degradation of 0.021 g/cm$^2$ and 50.8 percent degradation of .0235 g/cm$^2$) is non-conservative.

## 5.0 REFERENCES


1. NRC letter from James W. Clifford, Acting Director, Division of Reactor Projects, Region I, to John R. Jolicoeur, Acting Deputy Director, Division of Policy and Rulemaking, Office of Nuclear Reactor Regulation, “Request for Technical Assistance Regarding Peach Bottom Atomic Power Station (PBAPS) Units 2 and 3 Spent Fuel Pool Neutron Absorber Degradation (TIA 2011-004),” January 25, 2011 (ADAMS Accession No. ML110250738).

2. NRC letter from Gerald E. Gears, Project Manager BWR Project Directorate #2, Division of BWR Licensing, to Edward G. Bauer, Jr., Vice President and General Counsel, Philadelphia Electric Company, February 19, 1986 (ADAMS Accession No. ML021570574).

3. NRC letter from Joseph W. Shea, Project Manager, Project Directorate I-2, Division of Reactor Projects, to George A. Hunger, Jr., Director – Licensing, MC 52A-5, Philadelphia Electric Company, “Fuel Storage Criticality Criteria, Peach Bottom Atomic Power Station, Units 2 and 3 (TAC Nos. M85766 and M85757) May 28, 1993 (ADAMS Accession No. ML011430179).

4. NRC Generic Letter 1996-04: Boraflex Degradation in Spent Fuel Pool Storage Racks, June 26, 1996 (ADAMS Accession No. ML031110008).

5. "Technical Evaluation to Verify the Adequacy of the Peach Bottom Atomic Power Station Spent Fuel Pool (SFP) Storage Rack Criticality Margins Dated August 16, 2010" (ADAMS Accession No. ML110450420 [Non-Proprietary] and ML110450421 [Proprietary]).

6. "BADGER Test Campaign at Peach Bottom Atomic Power Station Unit 3," NET-247-01, Revision 1 (Proprietary) (ADAMS Accession No. ML110450422).

7. "BADGER Test Campaign at Peach Bottom Unit 2," NET-264-01, Revision 3 (Proprietary) (ADAMS Accession No. ML110450423).

8. "BADGER Test Campaign at Peach Bottom Atomic Power Station Unit 3," NET-311-01, Revision 0 (Proprietary) (ADAMS Accession No. ML110450424).

9. "2010 BADGER Test Campaign at Peach Bottom Unit 2," NET-350-01, Revision 0 (Proprietary) (ADAMS Accession No. ML110450425).

10. Letter from David P. Helker (Exelon Generation Company LLC) to US NRC regarding “Spent Fuel Pool Criticality Documents” dated February 23, 2011. Attached is OD 10-007 (ADAMS Accession No. ML110550313).

11. Letter from Exelon Generation Company LLC to US NRC regarding “Response to Request for Additional Information License Amendment Request to Revise Technical Specification 4.3.1.1.a Concerning k-infinity,” March 26, 2010 (ADAMS Accession No. ML100910076 [Proprietary], ML100910075 [Non-Proprietary])

12. EPRI TR-108761, “Synopsis of the Technology Developed to Address the Boraflex Degradation Issue” dated December 9, 1997.

13. EPRI TR-1003413, “Guidance and Recommended Procedures for Maintaining and Using RACKLIFE Version 1.10.” dated April 2002.

14. EPRI TE 114126, “The Surface Composition and Solubility of Irradiated Boraflex and Silica Treated in Metal Ion Solutions,” dated November 1999.

15. Compensatory measure #2 p12/14 (ADAMS Accession No. ML111151192)

16. "BADGER Test Campaign at Peach Bottom Unit 3," designated as NET-174-01, Rev 1 (Proprietary) (ADAMS Accession No. ML111120273)

17. "BADGER Test Campaign at Peach Bottom Unit 2," designated as NET-192-01, Rev 1 (Proprietary) (ADAMS Accession No. ML111120273)

18. "BADGER Test Campaign at Peach Bottom Unit 2," designated as NET-264-01, Rev 4 (Proprietary) (ADAMS Accession No. ML111120273)

19. "2010 BADGER Test Campaign at Peach Bottom Unit2," designated as NET-350-01, Rev 1. (Proprietary) (ADAMS Accession No. ML111120273)

20. Letter from Pamela B. Cowan (Exelon Generation Company, LLC) to US NRC, “License Amendment Request – Revision to Technical Specification 4.3.1.1.a Concerning k-infinity,” dated June 25, 2008 (ADAMS Accession No. ML081820348)

21. Letter from Pamela B. Cowan (Exelon Generation Company, LLC) to US NRC, indicating withdrawal of License Amendment Request – Revision to Technical Specification 4.3.1.1.a Concerning k-infinity, dated June 18, 2010 (ADAMS Accession No. ML101690377)

Attachment: Appendix - Additional Staff Comments Related to the Operability Determination

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Date: June 30, 2011

**Appendix: Additional Staff Comments Related to the Operability Determination**

These additional staff comments were compiled to support the concerns listed in the main document about the determination of the adequacy of the operability evaluation. Some of these comments may be addressed through interaction with the licensee.

Uncertainty of the Operability Determination (OD)

- On page 9 of the OD 10-007, it states:

  *3) The Boraflex panels that have been tested in multiple years have not shown an increase in the degradation rate*

  The staff believes that one cannot make a definite conclusion on the degradation rate based on the peak BADGER test results. By looking at the NETCO reports, in the 2002-2006 timeframe there is an increase in the degradation rate. However, looking at the peak 2010 results it would indicate that the degradation rate is decreasing. Therefore, the peak BADGER data does not support the above statement. The staff would conclude that more analysis would need to be performed in order to make a statement that there is not an increase in the degradation rate.

Technical Evaluation Revision 3 – Potential Non-conservatisms

- It does not appear to the staff that the Technical Evaluation was updated with the revised 2006 data. In addition, the staff does not believe that when the new RACKLIFE predictions were generated on November 1, 2010, that these predictions were updated in the Technical Evaluation. This is apparent in Figure 7 of the Technical Evaluation not being updated with the new data. Since the OD 10-007 degradation for November 1, 2010, is notably higher than indicated by Technical Evaluation Figure 7, had the Technical Evaluation been updated it should have been an indicator to PBAPS that the rate of degradation in the Technical Evaluation was too slow. Therefore, the staff does not believe that the Technical Evaluation, being outdated, fully supports the OD 10-007 conclusions.

- In Figures 1 and 1A, there is a gap between 1996 and 2002 where there should be data if RACKLIFE projections were performed every 6 months. In addition, these figures do not seem to be adjusted for the updated 2006 BADGER data and the November 1, 2010, data from OD 10-007. As such, the predicted peak degradation does not approximate the actual (BADGER) peak degradation. If the RACKLIFE data were recalibrated the peak should be approximately equal to the actual (BADGER) data. Therefore, the staff questions whether Figures 1 and 1A in the Technical Evaluation are relying on out-of-date or non-recalibrated data.

- Figure 1A does not appear to have a linear trend and may be exponential. However, in the licensee discussion of this Figure, the licensee describes the degradation as linear. Electric Power Research Institute (EPRI) TR-108761 supports the idea that the rate of degradation will not always be linear and may become more exponential. Therefore, the staff believes these trends may not be characterized appropriately.

- In the Technical Evaluation, degradation is reported in percent loss. Recently, the staff has observed that other plants have used different areal density reference points in different campaigns. This raises staff concern as to whether the same reference point was used in every campaign at PBAPS and whether these percentages can be directly compared. The licensee's Technical Evaluation does not provide sufficient information for the staff to reach a conclusion on this subject.

- On page 11 of the PBAPS Technical Evaluation, the licensee indicates that the uncertainty in the BADGER methodology is approximately 1 sigma. There is no justification provided for the use of a 1-sigma verses a more conservative and conventional 2-sigma uncertainty (standard statistical practice). Typical nuclear criticality safety analysis practice is to determine $k_{eff}$ to a 95 percent probability and 95 percent confidence level. NRC regulation 10 CFR 50.68 requires $k_{eff}$ be known to a 95 percent probability and 95 percent confidence level. Using a 1 sigma application of uncertainties would not meet a 95 percent probability and 95 percent confidence level. Therefore, the staff has some questions about the appropriateness and the conservativeness of the statistics performed by the licensee.

<u>Uncertainty in the analysis of BADGER and RACKLIFE data in the NETCO reports</u>

- Comments related to all reports: NET-264-01, NET-192-01, 2001 NET-174-01, NET-247-01, NET-350-01, and NET-311-01

    - In the NETCO reports, there is no discussion of how the BADGER data relates to the actual state of the entire SFP. Therefore, the staff does not have assurance that the BADGER data are representative of the actual state of the SFP.

    - In the NETCO reports, there appear to be conflicting values, from year to year, for the predicted and measured areal density and the corresponding analysis and data such as the "[[redacted]]" (discussed below). For instance, in the 2005 report (NET-247), the areal density and percent deviation values reported for the 2001 campaign (NET-174) do not match the values reported in the 2001 report (NET-174). In addition, there appear to be calculation errors in some of the reports (e.g., calculation of percent deviation). Because of these inconsistencies in reporting of the areal density and possible errors, it is difficult for the staff to ascertain the current state of the SFP in either unit.

    - In the NET-247-01 and NET-264-01 reports that were revised in 2010, there were notable changes in the areal density values from previously docketed values (Reference 11). The differences raise staff concerns regarding whether the new values may be less conservative with respect to the neutron attenuation capability of the material.

    - The NETCO reports indicate that there may not be a strict correlation between dose and degradation and that the fit plate and weld integrity may play a factor in degradation. The staff questions whether this would contribute to the RACKLIFE predictions becoming non-conservative since the escape coefficient may not be conservative due to these variations.

- All of the NETCO reports use the term "[redacted]." The staff questions how this term was determined and how it relates to the number of gaps. More specifically:
  - On page 33 of report NET-350-01, Table 5-1 shows [redacted] in the last column. This value appears to vary from year to year (e.g., [redacted] to [redacted] to [redacted] for panel [redacted]). The staff is unsure how, in one panel, the number of [redacted] can vary so greatly over time.
  - On page 34 of report NET-264-01, Table 5-1 shows [redacted] in the last column. It appears that the number of [redacted] have decreased over time (e.g., [redacted] to [redacted] for panel [redacted]). The staff is unsure how this is possible. Boraflex is not known to grow and therefore able to decrease the [redacted].

- <u>Comments on the most recent reports: NET-350 and -311</u>
  - In the Abstract on page ii of report NET-350-01, the maximum degradation measured was [redacted] percent. In 2006, the maximum degradation measured was approximately [redacted] percent. Therefore, the 2010 BADGER test results show that the peak value of degradation <u>is decreasing</u> from [redacted] percent (2006 value) to [redacted] percent (2010 value). The peak degradation value should not have decreased. Upon reviewing the sampling for the 2010 data set (see discussion below), the RACKLIFE-predicted, most-degraded cells were not tested, and the sampling did not appear to include the cells with greatest predicted degradation, such as the most degraded cell from the previous campaign. Therefore, the staff does not have reasonable assurance that the 2010 BADGER data is representative of the SFP conditions. In addition, the NETCO report offers an explanation for the decrease that "[redacted]," but it is not discussed comprehensively. Furthermore, the licensee's explanation appears to indicate that the BADGER methodology and equipment may have changed which raises concerns regarding the ability to compare older BADGER test results to more recent ones. The inability to effectively correlate results over time and therefore trend the degradation could be a significant limitation in the licensee's operability determination. Regardless, the staff concludes that the explanation is insufficient, and the test likely should have been repeated. Based on the above, the staff has concerns regarding the accuracy of the analysis, reports, and the licensee's methodology in choosing which panels to test.
  - On page 7 of report NET-350-01, panel [redacted] was identified as the worst panel as far as both absorbed dose and boron carbide loss. Subsequently, on page 13, Table 3-1 shows the panels that were tested in the campaign and the worst panel was not chosen to be tested.
  - On pages 35-36 of reports NET-311-01 and NET-350-01, the RACKLIFE model is stated to have a limitation, due to local temperature variations in the pool that are not accounted for by the model, making it non-conservative. The licensee offers no discussion of how this has been accounted for in its operability determination.

- On page 16 of report NET-350-01, there is discussion on the escape coefficient and a statement that variations in the coefficient are not modeled in RACKLIFE. However, the effect of the escape coefficient becomes more prominent over time (EPRI TR-1003413) resulting in potential non-conservative results. The staff is concerned that this issue may not be accounted for in the PBAPS degradation analyses out to 2014.

- On page 33 of report NET-311-01, Figure 5-1 shows the comparison in measured areal density for 3 campaigns.

  - From the PBAPS Technical Evaluation, Revision 3, the BADGER uncertainty range is approximately ±[[redacted]] percent. If the BADGER uncertainty of ±[[redacted]] percent were included in the analysis, the staff questions whether the measurement uncertainty of the data will have an impact on the conclusions from this graph.

  - From the data in the graph, the staff calculated degradation rates for select panels. The overall degradation of [[redacted]] is [[redacted]] percent with a rate of about [[redacted]] percent degradation/year. The overall degradation of [[redacted]] is [[redacted]] percent with about a [[redacted]] percent degradation/year. These peak percentages are greater than predicted by RACKLIFE for the Unit 3 pool and do not account for any degradation that may have taken place prior to 2001. While this does not violate the criticality analysis for the minimum areal density allowable, this rate and overall degradation is of concern because it raises questions regarding the ability of RACKLIFE to predict peak degradation in the licensee's SFP, and therefore the acceptability of the licensee's reliance on it in performing an operability determination. Additionally, there is a point at which the rate of degradation will start to increase and become non-linear (EPRI TR-108761) and these panels appear to be closer than the rest to reaching non-linear degradation. The staff is concerned that the degradation rate was not calculated and appropriately factored into the licensee's operability determination.

Additional Considerations for the Estimation of '%$\Delta k_{eff}$ Margin'

The Technical Evaluation mentions two potential sources of additional %$\Delta k_{eff}$ Margin that were not quantified and alludes to others. Additionally, the NRR staff believes there are also sources of %$\Delta k_{eff}$ Margin Loss the Technical Evaluation did not consider. The NRR staff has the following observations and concerns regarding those considerations.

- The Technical Evaluation considers that since the WNEP 8542 determined $k_{inf}$ at the Minimum Certified areal density of 0.021 g/cm$^2$ and the Average As-Build Batch areal density was 0.0235 g/cm$^2$ there is some additional %$\Delta k_{eff}$ Margin. The Technical Evaluation estimated this at 1.4% $\Delta k_{eff}$. This margin is incongruous with the Operability Evaluation and Technical Evaluation statements that 45% degradation from 0.021 g/cm$^2$ is acceptable. However, the Technical Evaluation really evaluated the RACKLIFE predicted 45 percent degradation which is based on 0.0235 g/cm$^2$. So there may be some additional %$\Delta k_{eff}$ Margin, but the actual value of this margin is debatable and difficult to quantify as the

Technical Evaluation over estimates the margin as any comparison should be to the Minimum As-Built areal density and not the Average As-Built areal density. Therefore, the NRR staff does not believe it appropriate to use this to offset the finding that the PBAPS OD 10-007 has overestimated the amount of remaining '%$\Delta k_{eff}$ Margin'.

- The Technical Evaluation also states that additional %$\Delta k_{eff}$ Margin is available since most fuel assemblies in the PBAPS SFPs are depleted past the point of peak reactivity. However, no discussion is provided about how many fuel assemblies are actually at their peak reactivity or any controls that minimize the likelihood of their being collocated. Nor is there any discussion that would indicate fuel assemblies at their peak reactivity are not stored in locations with peak degradation. It appears to not consider that a full core offload will put a significant number of fuel assemblies at their peak reactivity into the SFP. Therefore, the NRR staff does not believe that this consideration provides any additional margin, with respect to the conclusions in PBAPS OD 10-007.

- The Technical Evaluation states that it is conservative because it is treating the BADGER and RACKLIFE uncertainties as biases. However, uncertainties can only be combined if they are independent. Since BADGER test results are used to 'tune' RACKLIFE predictions, it is not clear that those uncertainties would be independent. Additionally, these uncertainties are determined at the one sigma level, not a 95/95 level. Therefore, the NRR staff does not believe it appropriate to use this to offset the finding that the PBAPS OD 10-007 has overestimated the amount of remaining '%$\Delta k_{eff}$ Margin'.

- The Technical Evaluation states that it is conservative because it used the error bars from the WNEP 8542 analysis graph in determining the '%$\Delta k_{eff}$ per 1% $B^{10}$ Loss' relationship. However, given the potential error noted with the in-core/in-rack $k_{inf}$ relationship extracted from the GENE-512-92073 analysis due to either issues in plotting and/or reading the graph, this 'conservative' '%$\Delta k_{eff}$ per 1% $B^{10}$ Loss' is probably necessary to compensate for those issues. Therefore, the NRR staff does not believe it appropriate to use this to offset the finding that the PBAPS OD 10-007 has overestimated the amount of remaining '%$\Delta k_{eff}$ Margin'.

- The Technical Evaluation did not consider the effects of Boraflex settling within its enclosure between the cell wall and wrapper. This was identified during the PBAPS Unit 3 2005 BADGER testing and attributed to routine plant operations such as loading fuel assemblies into the SFP racks. At about 45 percent thinning there may be enough room in the enclosure that Boraflex pieces may slide past one another.

- The Technical Evaluation considered the gaps/cracks as randomly distributed. The NRR staff reviewed the BADGER test reports referenced in the Technical Evaluation. Since the gaps/cracks are attributed to the non-uniform gamma radiation seen by the Boraflex panel and since the four panels in a given cell will see half their non-uniform gamma radiation profile as identical, there is reason to believe that panels in the same cell will have similar gaps/cracks. Absent information to the contrary the NRR staff assumed a first-in-first-out manufacturing process, i.e., all of the panels on a 'manufactured' cell will likely be from the same batch. There is also a high likelihood that panels on 'manufactured' cells in the same rack module will be from the same or similar batches, therefore any manufacturing influence on the gaps/cracks will be similar within that area of the SFP. The NRR staff reviewed the PBAPS BADGER test campaign reports to see if there is evidence of correlation among the gaps/cracks in same cell. An example of what NRR found was PBAPS Unit 3 SFP cell [redacted] in which all four panels were measured during each Unit 3 BADGER campaign. In 2001 those four panels were determined to have [redacted] gaps/cracks, and only [redacted] were not correlated with a gap/crack in at least [redacted] other panel. In 2005 those four panels were determined to have [redacted] gaps/cracks, and only [redacted] was not correlated with a gap/crack in at least [redacted] other panel. In 2010 those four panels were determined to have [redacted] gaps/cracks, and only [redacted] was not correlated with a gap/crack in at least [redacted] other panel. In most cases there were correlated gaps/cracks on [redacted] panels. While not every cell had this high degree of correlation, correlation appears to be the norm rather than the exception. Therefore, the NRR staff believes it is non-conservative to assume that the gaps/cracks are randomly distributed. The NRR staff could not estimate an in-rack $\%\Delta k_{eff}$ Margin Loss for correlated Boraflex gaps/cracks.

- The Technical Evaluation converted Boraflex gaps/cracks to uniform thinning of the Boraflex. Where a gap/crack exists there is no Boraflex, thereby allowing streaming of neutrons through the gap/crack. The NRR staff believes that if the gaps/cracks were modeled then the neutron streaming through the gaps/cracks would raise the estimated $k_{inf}$. Therefore, the NRR staff believes it is non-conservative to convert the Boraflex gaps/cracks to uniform thinning. The NRR staff could not estimate an in-rack $\%\Delta k_{eff}$ Margin Loss for conversion of Boraflex gaps/cracks to uniform thinning.

- The Technical Evaluation includes an estimated $\%\Delta k_{eff}$ Margin Losses for a potential future increase in in-core $k_{inf}$ of actual fuel assemblies from 1.2344 to 1.26. The NRR staff did not consider this loss as those fuel assemblies are not actually on-site at PBAPS. The Technical Evaluation estimated the $\%\Delta k_{eff}$ Margin Loss by adding fuel assemblies with this increased reactivity to be 1.92% $\Delta k_{eff}$. With these fuel assemblies the Boraflex panels would reach the 0.95 $k_{eff}$ limit with 14-16 percent less degradation. This would reduce the acceptable RACKLIFE predicted Peak Uniform $B^{10}$ Loss to approximately 20 percent.

- Although the Operability Evaluation states affirmatively that "…all safety functions of the SSC required during normal operation and potential accident conditions been included," the NRR staff did not note any discussion regarding the state of the degraded Boraflex following a seismic event.