Entergy

**Entergy Nuclear Northeast**
Indian Point Energy Center
450 Broadway, GSB
P.O. Box 249
Buchanan, NY 10511-0249
Tel 914 254 6700

**Anthony J. Vitale**
Site Vice President

NL-16-128

November 3, 2016

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
11555 Rockville Pike, OWFN-2 FL
Rockville, MD 20852-2738

SUBJECT: Response to Generic Letter 2016-01, "Monitoring of Neutron Absorbing Materials in Spent Fuel Pools", Response to NRC Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f)
Indian Point Unit Number 2
Docket No. 50-247
License No. DPR-29

REFERENCE: NRC Generic Letter 2016-01, "Monitoring of Neutron-Absorbing Material in Spent Fuel Pools"

Dear Sir or Madam:

The purpose of this letter is to respond to Generic Letter (GL) 2016-01 the NRC issued on April 7, 2016 to all power reactor licensees except those that have permanently ceased operation with all power reactor fuel removed from on-site spent fuel pool storage.

For purposes of this response, Indian Point Unit 2 (IP2) has been determined to be a Category 4 licensee in accordance with the Reference. As a Category 4 licensee, information on the neutron absorber material, criticality analysis of record and neutron absorber monitoring program is requested depending on the type of neutron absorber material present and credited in the spent fuel pool. The IP2 spent fuel pool credits Boraflex and therefore is required to provide information requested in Appendix A of the Generic Letter in areas 1, 2, 3, 4 and 5. The Attachment contains responses to the requested information.

This letter contains no new regulatory commitments. Should you have any questions regarding this submittal, please contact Mr. Robert Walpole, Manager, Regulatory Assurance at (914) 254-6710.

A158
NRR

I declare under penalty of perjury that the foregoing is true and correct; executed on November 3, 2016.

Sincerely,

AJV / sp

Attachment: Response to Requested Information for Generic Letter 2016-01

cc: Mr. Douglas V. Pickett, Senior Project Manager, NRC NRR DORL
Mr. Daniel H. Dorman, Regional Administrator, NRC Region 1
NRC Resident Inspectors Office
Mr. John B. Rhodes, President and CEO, NYSERDA
Ms. Bridget Frymire, New York State Public Service Commission

ATTACHMENT TO NL-16-128

# RESPONSE TO REQUESTED INFORMATION

# FOR GENERIC LETTER 2016-01

ENTERGY NUCLEAR OPERATIONS, INC.
INDIAN POINT NUCLEAR GENERATING UNIT NO. 2
DOCKET NO. 50-247

ATTACHMENT TO NL-16-128

RESPONSE TO REQUESTED INFORMATION

FOR GENERIC LETTER 2016-01

ENTERGY NUCLEAR OPERATIONS, INC.
INDIAN POINT NUCLEAR GENERATING UNIT NO. 2
DOCKET NO. 50-247

**Response to Requested Information in for Generic Letter 2016-01**

**A. - Background**

On April 7, 2016, the U.S. Nuclear Regulatory Commission (NRC) issued Generic Letter 2016-01, "Monitoring of Neutron-Absorbing Materials in Spent Fuel Pools" (GL-2016-01) [1]. The following information provides the IPEC, Unit 2 response to the GL-2016-01, including the applicable Areas of Requested Information (ARI) in Appendix A. This response has been developed based on a reasonable search of the plant's records, including docketed information.

**B. Category 4 Licensee - GL 2016-01, Appendix A Response**

**ARI 1**

*Describe the neutron-absorbing material credited in the spent fuel pool (SFP) nuclear criticality safety (NCS) analysis of record (AOR) and its configuration in the SFP, including the following:*

a) *manufacturers, dates of manufacture, and dates of material installation in the SFP*

**Response**

Manufacturer: BISCO manufactured the Boraflex material, and the racks were designed and supplied by HOLTEC International)

Date of manufacture: Information not available after a reasonable search of IP2 records, including docketed information, IPEC determined that the requested information was not part of the original licensing basis or previously requested by the NRC as part of the licensing action that approved the neutron absorber monitoring program.

Date of material installation: 01/11/1991

b) *neutron-absorbing material specifications:*

i. *materials of construction, including the certified content of the neutron absorbing component expressed as weight percent*

**Response**

The Boraflex panels used are a dimethyl-polysiloxane polymer with powdered $B_4C$ dispersion. In Region I, strips of Boraflex are between the rack cell walls and a stainless steel cover plate, and the cells are separated by a specified water gap. In Region II, the Boraflex strips are between the checkerboard boxes and the sheathing without a water gap. Boraflex is not specified on a weight percent basis of the neutron absorbing component. See the response to ARI 1 b) ii for the certified areal density.

ii. *minimum certified, minimum as-built, maximum as-built and nominal as-built areal density of the neutron-absorbing component*

**Response**

Minimum Certified Areal Density (Region 1) = 0.028 g-B¬10/cm$^2$
Minimum Certified Areal Density (Region 2) = 0.022 g-B¬10/cm$^2$
Nominal Design Areal Density (Region 1)= 0.0324 g-B10/cm$^2$ + 0.0090
Nominal Design Areal Density (Region 2)= 0.0260 g-B10/cm$^2$ ± 0.0094

After a reasonable search of IP2 records, including docketed information, IPEC determined that the as built data were not part of the original licensing basis or previously requested by the NRC as part of the licensing action that approved the neutron absorber monitoring program.

*iii. material characteristics, including porosity, density and dimensions*

**Response**

Materials Characteristics:
Nominal Boraflex Length: 144 in. (Region 1)
Nominal Boraflex Length: 150 in. (Region 2)
Nominal Boraflex Thickness: 0.1022 in. ± 0.007 in. (Region 1)
Nominal Boraflex Thickness: 0.082 in. ± 0.007 in. (Region 2)
Nominal Boraflex Width: 7.5 in. ± 0.063 in.

After a reasonable search of IP2 records, including docketed information, IPEC determined that the density and porosity was not part of the original licensing basis or previously requested by the NRC as part of the licensing action that approved the neutron absorber monitoring program.

c) *qualification testing approach for compatibility with the SFP environment and results from the testing*

**Response**

Qualification testing for the neutron absorbing material Boraflex was conducted by BISCO in the late 1970's. BISCO included tests to extremely high radiation doses, but these tests were relatively short in duration. In IP2's re-racking report of 1989, it was remarked that in published reports up to the time that Boraflex had been subjected in a reactor using the equivalent gamma dose of 2 x $10^{12}$ rads (taking credit for neutron dose). The net result was that the test indicated a substantial margin of safety against material degradation. Testing dating back to 1979 demonstrated that Boraflex is a stable "poison" material in a long-term spent fuel pool environment.

The available information in 1989 confirmed that there was no loss of boron during irradiation, although it was noticed that there was some radiation-induced shrinkage. This shrinkage occurs as Boraflex is irradiated, in which it becomes a hard ceramic-like material. The net result is the material shrinks 2 – 2.5 %. To combat this issue for use in the Boraflex panels in the spent fuel environment, Indian Point 2 panels were installed in a gap-sufficient size to allow for shrinkage to preclude any mechanism that might cause gaps to develop.

BISCO Qualification Testing

The BISCO Report from 1979 presented data showing an exposure of Boraflex in air to $2.81 \times 10^8$ rads gamma from a spent fuel source that resulted in no significant physical changes, nor in the generation of any gas.

The study also presented data showing irradiation to a level of $1.03 \times 10^{11}$ rads gamma with a substantial concurrent neutron flux in air, deionized water, and borated water environments. This caused an increase in hardness and a change of the tensile strength of Boraflex. It was observed that a certain amount of gas is generated, but beyond the level of approximately $1 \times 10^{10}$ rads gamma, the rate of gas generation did not exceed the rate observed when a sample container filled with borated or deionized water only was irradiated. Neutron attenuation measurement results indicate no discernable trend nor effect by any environment of any variation of boron content within the Boraflex related to a change in attenuation. Most of the measurement data correlated within confidence limits to the extent that it may be concluded that neither irradiation, environment or Boraflex composition has any effect on the neutron transmission, through a dose of $1.03 \times 10^{11}$ Rads.

Based on the studies undertaken, no evidence was determined that indicated the deterioration of Boraflex occurring using a cumulative irradiation in excess of $1 \times 10^{11}$ rads gamma thereby resulting in a negative effect regarding the suitability of Boraflex as a neutron shielding material.

Summary

Initial testing and qualification of Boraflex did not indicate that it was not suitable for use in the spent fuel pool environment. However, it was later determined that the qualification tests did not adequately evaluate the synergistic effects of gamma radiation and long-term exposure to the aqueous pool environment. Such long-term exposure can transform the Boraflex to a silica-dominated material, which is somewhat soluble in water.

*d) configuration in the SFP*

*i. method of integrating neutron-absorbing material into racks (e.g., inserts, welded in place, spot welded in place, rodlets)*

**Response**

Region 1:

The rack module manufacturing begins with fabrication of the so-called box. Each box constitutes a storage location. Each side of a box facing another box is equipped with 'a narrow rectangular cavity which houses one integral Boraflex sheet (poison material).

The design objective calls for installing Boraflex with minimal surface loading. This is accomplished by die forming "picture frame sheathing. This sheathing is made to precise dimensions such that the offset is .010 to .005 inches greater than the poison material thickness.

The poison material is placed in the customized flat depression region of the sheathing, which is next laid on a side of the "box". The precision of the shape of the sheathing obtained by die forming guarantees that the poison sheet installed in it will not be subject to surface compression. The flanges of the sheathing (on all four sides) are attached to the box using skip welds. The sheathing serves to locate and position the poison sheet accurately, and to preclude its movement under seismic conditions.

Region 1 Boraflex Sheathing
Width: 7.70 in. (Minimum)
Thickness: 0.035 in. ± 0.003 in.
Distance from Cell Wall: 0.112 in. ± 0.003 in.

Region 2:

Region 2 employs storage cell locations with a single poison panel sandwiched between adjacent austenitic steel surfaces. A "picture frame sheathing" in the manner of Region I is attached to each side of the box with the poison material installed in the sheathing cavity.

It is noted that, unlike Region I, the top of the sheathing extends to the top of the box. The edges of the sheathing and the box are welded together to form a smooth edge. We will refer to the box with integrally connected sheathing as the "composite box". The "composite boxes" are arranged in a checkerboard array to form an assemblage of storage cell locations welded edge to edge, resulting in a honeycomb structure.

Region 2 Boraflex Sheathing
Width: 8.00 in. (Maximum)
Thickness: 0.035 in. ± 0.003 in.
Distance from Cell Wall: 0.092 in. ± 0.003 in.

As for the susceptibility to water ingress, and as a result, Boraflex dissolution, the Indian Point Unit 2 Boraflex panels in the spent fuel storage racks were evaluated, and determined not to be excessively open to water flow.

ii. *sheathing and degree of physical exposure of neutron absorbing materials to the spent fuel pool environment*

**Response**

See the response to ARI 1 d) i for details on poison sheathing.

e) *current condition of the credited neutron-absorbing material in the SFP* *i. estimated current minimum areal density*

**Response**

The latest BADGER test in the IP2 spent fuel pool was conducted in November 2013. For Region 2-2, the lowest intact panel average areal density was 0.0179 gms-$^{10}B/cm^2$. For Region 1-2, the lowest intact panel average areal density was 0.0236 gms-$^{10}B/cm^2$.

The most recent RACKLIFE projection was performed for 1/1/2017. The maximum projected boron carbide loss for Region 1-2 is 44% for panel H18 North; however, it was measured with BADGER in 2013 and determined to have 15% boron carbide mass loss, so it not expected to physically be that high of a loss. The next highest projected boron carbide loss for Region 1-2 is 32.8%. The maximum projected boron carbide loss for any panel still credited in Region 2-2 is 18.6%.

*ii. current credited areal density of the neutron-absorbing material in the NCS AOR*

**Response**

The current NCS AOR credits 50% of the minimum certified areal density of 0.028 gms-$^{10}B/cm^2$ in Region 1-2, while Region 2-2 assume 70% of the minimum certified areal density of 0.022 gms-$^{10}B/cm^2$.

*iii. recorded degradation and deformations of the neutron-absorbing material in the SFP (e.g., blisters, swelling, gaps, cracks, loss of material, loss of neutron-attenuation capability)*

**Response**

Gaps, loss of material, and loss of neutron attenuation capability have been observed through in-situ testing. See the response to ARI 2 a) iv for more details.

**ARI 2**

***2)*** *Describe the surveillance or monitoring program used to confirm that the credited neutron-absorbing material is performing its safety function, including the frequency, limitations, and accuracy of the methodologies used.*

*a) Provide the technical basis for the surveillance or monitoring method, including a description of how the method can detect degradation mechanisms that affect the material's ability to perform its safety function. Also, include a description and technical basis for the technique(s) and method(s) used in the surveillance or monitoring program, including:*

*i. approach used to determine frequency, calculations and sample size*

**Response**

BADGER testing was performed in 2000, 2003, 2006, 2010, and 2013, as specified in Tech Spec Bases B 3.7.12-1. The current frequency is every 4 years, which is more conservative than the no more than 5-year frequency recommended in NUREG-1801 Rev2, Section XI.M22.

A sample size of 60 panels has typically been used, as 60 data points is the minimum sample size required to determine a 95/95 minimum areal density using non-parametric (distribution free) methods. This is consistent with the methodology in NUREG-6698.

Prior to 2013, the IP2 RACKLIFE model was updated just prior to the upcoming BADGER test campaign. The purpose of the update was to select panels for the upcoming BADGER test campaign. Since 2013, RACKLIFE evaluations have been performed on a periodic basis at 6-month intervals to project boron carbide loss and panel dose in order to: 1) determine the panel dose that meets or exceeds the 8.9E9 dose threshold (as calculated via the LWRDOSE method) for panels that exhibited excessive local dissolution beyond the CAOR limits as measured during the 2013 BADGER Test; and 2) compare RACKLIFE projected boron carbide loss distributions and panel maps to the assumptions incorporated into the NCS AOR.

*ii. parameters to be inspected and data collected*

**Response**

The data collected by BADGER testing is the total neutron counts passing through the Boraflex material. The neutron count rate is then used to estimate the effective Boron-10 areal density of the intact Boraflex panels based on piecewise linear fits of Boron-10 areal density vs count rate, as determined from a reference mock-up test cell, fabricated specifically for the Indian Point 2 spent fuel rack cells. In addition, estimates of gap size are determined based on a linear fit of count rate vs gap size determined by known gap sizes (1" and 3") within the mock-up test cell.

*iii. acceptance criteria of the program and how they ensure that the material's structure and safety function are maintained within the assumptions of the NCS AOR*

**Response**

At the completion of a test campaign, BADGER test results are compared to assumptions employed in the NCS AOR. In addition, RACKLIFE projections (at 6 month intervals) of panel boron carbide loss are compared to the uniform panel boron carbide loss distributions and panel loss patterns assumed in the NCS AOR. Panels that do not meet either of these criteria are removed from service. RACKLIFE projections of panel absorbed dose are screened against dose/time criteria (discuss below) to determine if any panels meet the criteria and should be removed from service.

**Region 1-2**

The measured degradation for the Region 1-2 panels are compared to the panel models assumed in the NCS AOR to determine if the panels measured in Region 1-2 are bounded by the discrete panel models assumed in the NCS AOR.

**Region 2-2**

Acceptance criteria for Region 2 is somewhat more intensive than comparison of the discrete panel models for Region 1-2 due to the statistical models of panel degradation that formed the basis of the Region 2-2 NCS AOR. Panel acceptability is based on: 1) Confirmation of panel condition by comparison of BADGER measurements of areal density (uniform loss), gap size, and cumulative panel lengths to the NCS AOR assumptions, and 2) comparisons of future RACKLIFE projections of boron carbide loss to the distribution of uniform loss and panel co-location assumed in the NCS AOR. If the projected loss values are not bounded by the NCS AOR, then panels are removed from service to maintain operability of the U2 SFP as documented in CR-IP2-2016-04959.

As a conservative measure, fuel movement rules have been developed to manage the storing of fuel within the vicinity of panels in which accelerated dissolution may have occurred. NETCO Letter dated 2/25/14, Subject: "Extent of Condition of IP2 Boraflex Degradation and Guidance for Future Moves", summarizes the analysis performed and provides the fuel movement rules that are used to ensure operability in the U2 SFP. This is documented in CR-IP2-2014-04414.

*iv. monitoring and trending of the surveillance or monitoring program data*

**<u>Response</u>**

Panels of Boraflex are used to maintain adequate subcriticality of the fuel in the spent fuel racks.

Boron-10 areal density gage for evaluating racks (BADGER) testing was performed in February 2000, July 2003 and again in July 2006. The results confirmed the predictions of the RACKLIFE computer model. This provides reasonable assurance that the program is effective for managing changes in material properties (reduction in neutron-absorbing capacity) for Boraflex neutron absorber panels.

Since 2006, the following BADGER test campaigns have been conducted as described below.

B. Year 2010 BADGER TEST CAMPAIGN

<u>Overview</u>

Prior to a BADGER campaign, IP2 updated the RACKLIFE model of the spent fuel pool and racks. The model provides the ability to identify storage cells and specific Boraflex panels, which had been subjected to the most severe service histories (in terms of integrated gamma exposure and residence time) and potential boron carbide loss.

For the 2010 campaign, a population of panels was selected in each of the regions where Boraflex is still credited (Region 1-2 and 2-2), and where panels have experienced exposures up to $8.4 \times 10^9$ rads. This provided for an assessment of the condition of the Boraflex as a function of the evolving service history, while at the same time placing emphasis on the regions of the spent fuel pool where partial credit for Boraflex is taken.

Results

Twenty-four panels from the IP2 Region 1-2 and Region 2-2 spent fuel racks were subjected to non-destructive BADGER testing. The purpose of the tests was to assess the condition of the Boraflex in credited regions.

REGION 1-2

The average panel areal density of the Region 1-2 panels measured is 0.0336 g-Boron 10/cm$^2$. This is higher than the minimum certified value, which is 0.028 g-Boron 10/cm$^2$. The lowest panel average areal density value measured (Region 1-2) was 0.0210 g-Boron 10/cm$^2$. This is larger than 50% of the minimum certified areal density assumed in the NCS AOR (0.5 x 0.028 = 0.014 g-Boron 10/cm$^2$).

Gaps

Region 1-2 results show that the panels tested had a gap at various axial elevations. It is noted that there is a tendency for gaps biased toward the top quarter of the panel. Two Region 1-2 panels exhibited local dissolution of two inches total. The largest single gap observed in Region 1-2 was approximately 0.7 inch. The largest cumulative gap size of all Region 1-2 panels measured was 0.7 inches in the same panel. The other four panels did not exhibit any dissolution or gaps.

REGION 2-2

The average panel areal density for the Region 2-2 panels measured was 0.0261 g-Boron 10/cm$^2$. This is slightly higher than the minimum certified value, which is 0.022 g-Boron 10/cm$^2$. The lowest panel average areal density measured (Region 2-2) was 0.0244 g-Boron 10/cm$^2$. This is larger than 70% of the minimum certified areal density assumed in the NCS AOR (0.7 x 0.022 = 0.0154 g-Boron 10/cm$^2$).

Gaps

Results show that local dissolution of the Region 2-2 panels tends to occur at the top of the panel. For any given elevation, no more than 9% of the panels show evidence of local dissolution. The majority of panels have less than 4 inches of local of dissolution. Two panels exhibited 26 and 32 inches of total inches of dissolution, respectively. In general, gaps were more numerous in Region 2-2 than in Region 1-2. The largest single gap observed is seen to be ~4.3 inches in one panel, with the majority of the panels with gaps having a size of less than 1 inch. The largest cumulative gap size was 6.3 inches.

Summary

In summary, the comparisons of the BADGER campaign results with the predictions of the RACKLIFE model indicate:

• Moderate further Boraflex degradation in the regions tested.
• An average boron carbide loss for the panels tested has increased at a rate comparable to or bounded by the RACKLIFE model.

C. Year 2013 BADGER TEST CAMPAIGN

Overview

To improve system performance and reliability, NETCO has subjected the BADGER system to a detailed redesign. This second generation BADGER system was used in the 2013 campaign at IP2. The test was performed on a sample population of the panels selected to include some of the highest exposed panels (1.88 x $10^{10}$ rads), as well as a series of panels which had accumulated a spectrum of exposures ranging from lower dose panels up to the highest dose panels. Sixty (60) of these panels were included in this campaign.

Results

A total of sixty Boraflex panels were subjected to non-destructive BADGER testing. However, there are 19 panels that, due to the presence of gaps or dissolution, fewer than 59 intact elevation-specific areal density values could be calculated. Therefore, the minimum areal density value was conservatively calculated by taking the three sigma-calculated uncertainty and subtracting it from the average areal density value. The minimum areal densities presented below represent the 95/95 minimum areal density value. The 95/95 minimum areal density value is the minimum value calculated per NUREG-6698 guidance.

REGION 1-2

The average intact panel areal density of all Region 1-2 panels measured is 0.0294 g-Boron 10/$cm^2$. This is slightly higher than the minimum certified value, which is 0.028 g-Boron 10/$cm^2$. The two-sigma standard deviation in the spread of the panels is 0.0025 g-Boron 10/$cm^2$. The lowest intact panel average areal density value measured (Region 1-2) was 0.0236 g-Boron 10/$cm^2$. The lowest areal density value measured within an intact panel area was 0.0151 g-Boron 10/$cm^2$. This is larger than 50% of the minimum certified areal density assumed in the NCS AOR (0.5 x 0.028 = 0.014 g-Boron 10/$cm^2$).

REGION 2-2

The average intact panel areal density for the Region 2-2 panels measured was 0.0247 g-Boron 10/cm$^2$. This is slightly higher than the minimum certified value, which is 0.022 g-Boron 10/cm$^2$. The two-sigma standard deviation in the spread of the panels is 0.0021 g-Boron 10/cm$^2$. The lowest intact panel average areal density measured (Region 2-2) was 0.0179 g-Boron 10/cm$^2$. The lowest areal density value measured within an intact panel area was 0.0155 g-Boron 10/cm$^2$. This is larger than 70% of the minimum certified areal density assumed in the NCS AOR (0.7 x 0.022 = 0.0154 g-Boron 10/cm$^2$).

<u>Gaps</u>

First, it is noted that there is a general trend for the amount of gapping in a panel which increases with increasing gamma dose. Second, even if a panel has a relatively low gamma dose, the panel can still exhibit a significant amount of cumulative gap size. Third, and perhaps most important is that even though the gap size increases with increasing gamma dose, gap formation appears to still be a random process. This is confirmed in that multiple locations were observed to show different degradation levels, yet have the same dose. In addition, there are also panels with similar degradation and very different doses. These observations tend to indicate that in addition to gamma dose, gap formation is influenced by other random time dependent and fuel storage rack fabrication factors.

For a majority of the panels tested, the cumulative gap size was less than six (6) inches. This is an important result, because research has shown that radiation induced shrinkage asymptotically approaches 4.1% of panel length, as gamma dose continues to increase. In this case, 4.1% of the IPEC panel length is about 6 inches. This being said, however, 11 panels did exhibit cumulative gap sizes over 6 inches. This additional gapping can be attributed to time dependent dissolution around the gaps. Of these panels with cumulative gap greater than 6 inches, only two exhibited a cumulative gap size greater than twenty (20) inches, but less than thirty (30) inches.

REGION 1-2

Out of the 13 Region 1-2 panels measured, in all but one case the cumulative gap length was less than 5.9 inches of total panel length. For each panel tested, except H20 South, a representative NCS AOR panel can be assigned that would bound the measured panels, thereby providing assurance that the current measured degradation in Region 1-2 does not exceed that assumed in the NCS AOR.

For panel H20S, the total boron carbide loss was greater than that of six of the nine Region 1-2 NCS AOR panels but less than or equal to that of the remaining three panels. Only 1 out of 13 of the measured panels (7.7%) had a mass loss of 23.5% from the minimum certified areal density, whereas the NCS AOR had a higher proportion (3 of the 9 simulated panels (33%) that exceeded this amount). Therefore, it can be concluded that the Region 1-2 measurements are compliant with the NCS AOR.

REGION 2-2

An evaluation of the 48 Region 2-2 panels measured during the BADGER campaign requires a different approach than used for the Region 1-2 locations. This is due to the fact that 15 of the 48 panels exhibited cumulative gap lengths in excess of 6 inches. None of the 48 panels exhibited a total mass loss greater than or equal to 22% of the minimum initial panel areal density assumed in the NCS AOR, (the maximum value for any one panel incorporated in the NCS AOR). Panels DK68 East and DM68 West exhibited large regions of local dissolution between gaps that occurs when the Boraflex fully densifies, resulting in the maximum possible formation of gaps. In contrast, several panels that have seen more severe service histories (e.g., DL71 North, DL69 South and DK70 East) appear to be in relatively good condition.

A noticeable trend among panels exhibiting excessive cumulative gap length relates to service history, in that the panels had attained the radiation induced shrinkage saturation gamma dose limit of 8.9E9 rads on or before July 2006 based on review of the RACKLIFE calculations of absorbed dose. Thus, for phase 2 comparisons, it was determined that a radiation dose greater than or equal to 8.9E9 rads accumulated on or before July 2006 provides a simple and conservative selection criteria to identify Region 2 panels which may also challenge NCS AOR degradation assumptions.

Summary

Sixty Boraflex panels from the IP2 spent fuel racks were subjected to non-destructive BADGER testing to determine the condition of the Boraflex neutron absorber material. Excessive degradation was observed in Region 2-2 panels that had achieved a high dose. Therefore, the affected panels in this category are now subject to an interim NCS analysis and operability assessment pending the implementation of long term corrective actions.

*v. industry standards used*

**Response**

The IP2 program is consistent with NUREG-1801 XI.M22. NUREG-1801 states that an aging management program relies on the periodic inspection, testing, monitoring, and analysis of the criticality design to ensure that 5% subcriticality margin is maintained. Parameters to be monitored or inspected include:

- The physical condition of the Boraflex panels
  - Gap formation
  - Decreased boron areal density
- Concentration of the silica in the spent fuel pool

Sampling for an analysis of the silica levels in the spent fuel pool water is conducted on a regular basis with the trending of the results using the EPRI RACKLIFE predictive code or equivalent. Silica levels in the spent fuel pool water are monitored monthly. Gap formation is periodically measured by areal density (BADGER) testing.

The IP2 program relies on the following considerations to assure that the required 5% subcriticality margin is maintained. These are:

(1) Areal density and gap testing.
(2) Use of a predictive computer code.
(3) Determination of boron loss through correlation of silica levels in spent fuel water samples.

Corrective actions are initiated if the test results find that the 5% subcriticality margin cannot be maintained because of current or projected Boraflex degradation. It is noted that NUREG-1801 specifies measuring gap formation by blackness testing or BADGER testing. The IP2 program specifies areal density measurements for Boraflex degradation.

In its review of the IP2 Boraflex Monitoring Program, the NRC determined that those program elements, "for which the applicant claimed consistency with the GALL Report are consistent". The NRC further concluded:

> "[following] the staff review [of] the program consistency with GALL AMP XI.M22, [it was] determined that [the] Boraflex Monitoring Program elements "scope of program," "parameters monitored or inspected," "monitoring and trending," and "acceptance criteria," are consistent with the corresponding elements in GALL AMP XI.M22. Because these elements are consistent with the GALL Report elements, the staff finds that they are acceptable."

*b) For the following monitoring methods, include these additional discussion items:*

*i. If there is visual inspection of in-service material:*

*1. Describe the visual inspection performed on each sample.*

**Response**

N/A – No visual inspection of in-service material is performed.

*2. Describe the scope of the inspection (i.e., number of panels or inspection points per inspection period).*

**Response**

N/A – No visual inspection of in-service material is performed.

*ii. If there is a coupon monitoring program:*

1. *Provide a description and technical basis for how the coupons are representative of the material in the racks. Include in the discussion, the material radiation exposure levels, SFP environment conditions, exposure to the SFP water, location of the coupons, configuration of the coupons (e.g., jacketing or sheathing, venting bolted on, glued on, or free in the jacket, water flow past the material, bends, shapes, galvanic considerations, and stress-relaxation considerations), and dimensions of the coupons.*

**Response**

Coupons are not part of the current IP2 monitoring program.

2. *Provide the dates of coupon installation for each set of coupons.*

**Response**

Coupons are not part of the current IP2 monitoring program.

3. *If the coupons are returned to the SFP for further evaluation, provide the technical justification of why the reinserted coupons would remain representative of the materials in the rack.*

**Response**

Coupons are not part of the current IP2 monitoring program.

4. *Provide the number of coupons remaining to be tested and whether there are enough coupons for testing for the life of the SFP. Also provide the schedule for coupon removal and testing.*

**Response**

Coupons are not part of the current IP2 monitoring program.

*iii. If RACKLIFE is used:*

1. *Note the version of RACKLIFE being used (e.g., 1.10, 2.1).*

**Response**

The current NCS AOR is based on an equivalent uniform loss that was determined based on RACKLIFE 1.10 (which uses the same methods as version 2.0) projections of boron carbide loss. The RACKLIFE projected boron carbide loss was assumed to be uniform loss and was used as input to a Monte-Carlo sampling algorithm that created 3-D models of degraded Boraflex panels (by also sampling local degradation patterns and gaps).

Current projections are performed with RACKLIFE version 2.1. Projections of panel absorbed dose are done using the LWR Dose methodology, which conservatively estimates panel absorbed dose. Projections of boron carbide loss are performed with version 2.1 using the "cooling-time-corrected (CTC) method". In order to match SFP silica, the CTC method is used, which leads to a higher predicted boron carbide loss and thus a more conservative prediction of loss. Version 2.1 contains an enhanced local panel cavity fluid temperature model that attempts to more accurately estimate the higher panel cavity temperature, since silica dissolution is strong function of fluid temperature. The version 2.0 dissolution model assumed that the panel cavity temperature was the same as the bulk pool temperature (which is lower than the panel cavity temperature in the racks) and could underestimate the silica release rate (and consequently under predict boron carbide loss). Note that the methodology for calculating dose is the same in version 2.0 and 2.1, so either version may be used for that calculation.

Comparisons of BADGER measurements to the NCS AOR are based upon RACKLIFE projected boron carbide loss values calculated using Version 2.0. This is done since the boron carbide loss assumptions incorporated into the NCS AOR were based on the RACKLIFE 2.0 calculation model.

2. *Note the frequency at which the RACKLIFE code is run.*

**Response**

Historically, RACKLIFE was run prior to each BADGER test campaign in order to select panels for testing. Since the 2013 BADGER test, RACKLIFE has been run roughly at six-month intervals to perform projections of boron carbide loss for operability evaluations for compliance with the NCS AOR where Boraflex panels are being credited.

3. *Describe the confirmatory testing (e.g., in-situ testing) being performed and how the results confirm that RACKLIFE is conservative or representative with respect to neutron attenuation.*

**Response**

BADGER testing is performed every 4 years to confirm the Boraflex panels are degrading as expected. A measured boron carbide loss is calculated for each panel relative to a dose corrected initial panel areal density to benchmark to the RACKLIFE measurements.

The average loss measured for Region 1 BADGER panels in 2013 was 15.5%. RACKLIFE 2.0 predicted an average loss of 20.1% for the Region 1 panels tested, and thus was conservative by 4.6% boron carbide loss.

The average loss measured for Region 2 BADGER panels in 2013 was 8.6%. RACKLIFE 2.0 predicted an average loss of 12.4% for the Region 2 panels tested, and thus was conservative by 3.8% boron carbide loss.

4. *Provide the current minimum RACKLIFE predicted areal density of the neutron-absorbing material in the SFP. Discuss how this areal density is calculated in RACKLIFE. Include in the discussion whether the areal densities calculated in RACKLIFE are based on the actual as-manufactured areal density of each panel, the nominal areal density of all of the panels, the minimum certified areal density, the minimum as-manufactured areal density, or the areal density credited by the NCS AOR. Also discuss the use of the escape coefficient and the total silica rate of Boraflex degradation in the SFP*

**Response**

RACKLIFE does not calculate areal density. RACKLIFE calculates the panel boron carbide loss, by solving a reactive silica mass balance equation between all panel cavity silica concentrations and the bulk spent fuel pool silica concentration. Once the silica mass loss for each panel is determined, the corresponding mass of boron carbide lost is calculated and the relative boron carbide percentage lost is calculated relative to the initial mass of boron carbide. Assuming the boron carbide loss is fully attributed to uniform thinning, the predicted areal density can be estimated by reducing the initial areal density by the calculated percent boron carbide loss.

The initial mass fractions of the Boraflex panels modeled in RACKLIFE were based on typical nominal Boraflex properties for late vintage Boraflex, which is the vintage used at IP2. Based on the panel properties input into RACKLIFE and default material properties, the initial areal density used in RACKLIFE for the Region 1 Boraflex panels is 0.034 gms-$^{10}B/cm^2$ and for the Region 2 panels is 0.027 gms-$^{10}B/cm^2$.

A single escape coefficient is used for the entire pool. This escape coefficient is adjusted periodically to best match the measured bulk pool reactive silica.

iv. *If in-situ testing with a neutron source and detector is used (e.g., BADGER testing, blackness testing):*

1. *Describe the method and criteria for choosing panels to be tested and include whether the most susceptible panels are chosen to be tested. Provide the statistical sampling plan that accounts for both sampling and measurement error and consideration of potential correlation in sample results. State whether it is statistically significant enough that the result can be extrapolated to the state of the entire pool.*

**Response**

Panels are chosen based on the panel estimated absorbed dose and predicted Boron carbide loss as calculated by the RACKLIFE model. 40 panels were tested in 2000, 2003, and 2006 while only 24 panels were tested in 2010. For current IP2 BADGER tests, a minimum of 60 panels are tested, which is consistent with the methodology of NUREG-6698 that specifies at least 59 measurements must be made in order to provide a 95% degree of confidence that 95% of the population is above the smallest observed value (areal density). In the 2013 test, the panels in the pool were divided up into

Severe, Moderate and Low loss categories based on RACKLIFE results. Panels were selected from each of these categories in order to validate the RACKLIFE model predictions. About 25% of the panels selected were in Region 1-2 and 75% were in Region 2-2. The most susceptible panels were chosen for testing.

1. *State if the results of the in-situ testing are trended and whether there is repeat panel testing from campaign to campaign.*

**Response**

Two panels were repeat tested in Region 1 between the 2010 and 2013 test campaigns. The 2013 test was performed with the second generation BADGER equipment, which has made significant improvements to the accuracy of the results. Thus, the results were not trended with previous measurements.

Two panels (DJ73 East and DK74 West) were repeat tested in the 2003 and 2006 campaigns. The estimated areal densities increased from 2003 to 2006 by approximately 0.0037 and 0.0029 gms-$^{10}$B/cm$^2$ respectively.

2. *Describe the sources of uncertainties when using the in-situ testing device and how they are incorporated in the testing results. Include the uncertainties outlined in the technical letter report titled "Initial Assessment of Uncertainties Associated with BADGER Methodology," September 30, 2012 (Agency wide Access and Management Systems Accession No. ML12254A064). Discuss the effect of rack cell deformation and detector or head misalignment, such as tilt, twist, offset, or other misalignments of the heads and how they are managed and accounted for in the analysis.*

**Response**

Uncertainties included in the BADGER measurements of areal density include uncertainties in the calibration fits such as uncertainty in the areal density standards and statistical uncertainty in the count rates, as they relate to derivation of the calibration slopes and intercepts. These uncertainties are calculated for each 2 inch elevation measurement and the uncertainty for the overall panel average is conservatively chosen to be the highest elevation specific uncertainty of that panel. The gap size uncertainties are calculated on a per gap basis and then summed over the entire panel to provide the cumulative gap size uncertainty that is reported.

The technical letter report (TLR) mentioned in the AIR was based on the first generation BADGER equipment. The 2$^{nd}$ generation BADGER equipment employed at IP2 has reduced the effects of the uncertainties discussed in the TLR by increased neutron shielding of the detectors and stabilizing spring plungers incorporated into the detector head. The cavity behind the detector tubes is filled entirely with boron carbide powder (150 micron) to minimize backscattered neutrons from being detected. The 2$^{nd}$ generation BADGER method no longer uses a reference panel, and only utilizes a calibration cell of know properties matched to the IP2 racks, which provides a more accurate calibration.

3. *Describe the calibration of the in-situ testing device, including the following:*

a. *Describe how the materials used in the calibration standard compare to the SFP rack materials and how any differences are accounted for in the calibration and results.*

**Response**

The materials in the IP2 calibration cell are subjected to a commercial grade dedication and are verified to conform to critical characteristics as specified in NET-300068-CGDP, Revision 2. The calibration cell is fabricated to meet the as-built rack drawings and materials. Critical characteristics are defined and verified via measurement, neutron attenuation testing and/or chemical analysis.

The IP2 calibration cell contained 3 areal density standards of known areal density. The calibration standards are separated by gaps of known size to provide a fit of gap size versus transmission ratio. Calibration of the BADGER tool is performed at a minimum of two times per day during a test by performing a scan of the calibration standards, gaps, and the un-attenuated region above the areal density standards.

b. *Describe how potential material changes in the SFP rack materials caused by degradation or aging are accounted for in the calibration and results.*

**Response**

Changes in the material due to dissolution and gapping are accounted by incorporating Boraflex standards of 3 known areal densities into the calibration cell separated by gaps of known size. Densification of the Boraflex material is accounted for in the results by comparing the estimated boron carbide loss (calculated as a relative change in areal density) and compared to a density corrected initial panel areal density using the EPRI dose correlation (EPRI NP-6159, equation 5-10).

c. *If the calibration includes the in-situ measurement of an SFP rack "reference panel", explain the following:*

i. *the methodology for selecting the reference panel(s) and how the reference panels are verified to meet the requirements,*

**Response**

The most recent BADGER test campaign at IP2 utilized the 2nd generation BADGER system, which does not use a reference panel, and instead utilizes a calibration cell of known areal density and gapping.

*ii. whether all surveillance campaigns use the same reference panel(s)*

**Response**

As stated above, BADGER Tests since 2013 have not used a reference panel method.

*iii. If the same reference panels are not used for each measurement surveillance, describe how the use of different reference panels affects the ability to make comparisons from one campaign to the next.*

**Response**

As stated above, BADGER Tests since 2013 have not used a reference panel method.

**ARI 3**

***3)*** *For any Boraflex, Carborundum, or Tetrabor being credited, describe the technical basis for determining the interval of surveillance or monitoring for the credited neutron-absorbing material. Include a justification of why the material properties of the neutron-absorbing material will continue to be consistent with the assumptions in the SFP NCS AOR between surveillances or monitoring intervals.*

**Response**

As previously discussed in the responses to ARI 2 a) i, IP2 performs periodic monitoring of the Boraflex neutron absorbing material at a frequency of less than five years (3-4) using BADGER testing, which is consistent with the recommendations in NUREG-1801 Section XI.M22. Thus, the current frequency of BADGER testing is acceptable.

As recommended in NUREG-1801, sampling for an analysis of the silica levels in the spent fuel pool water is conducted on a regular basis with the trending of the results using RACKLIFE. Silica levels in the spent fuel pool water are monitored monthly. RACKLIFE evaluations are performed approximately every 6 months and the results are compared to the AOR and operability evaluation to determine if panels are projected to exceed the AOR assumptions. Using both the RACKLIFE projections and the BADGER test results will allow sufficient time to determine if the frequency of the BADGER test needs to be adjusted and subjected to an operability assessment.

Due to the observance of excessive degradation in the IP2 SFP racks, IP2 has undertaken various corrective actions. These include, limiting storage in rack locations based on an interim analysis and an associated operability assessment. Corrective actions have also been initiated to address the long term resolution of this condition, including the development of a new NCS analysis and elimination of credit for Boraflex.

**ARI 4**

**4)** *For any Boraflex, Carborundum, Tetrabor, or Boral being credited, describe how the credited neutron-absorbing material is modeled in the SFP NCS AOR, and how the monitoring or surveillance program ensures that the actual condition of the neutron-absorbing material is bounded by the NCS AOR:*

a) *Describe the technical basis for the method of modeling the neutron-absorbing material in the NCS AOR. Discuss whether the modeling addresses degraded neutron-absorbing material, including loss of material, deformation of material (such as blisters, gaps, cracks, and shrinkage), and localized effects, such as non-uniform degradation.*

**Response**

KENO was used to model the IP2 spent fuel pool. Region 1-1 and Region 2-1 are both assumed to have a 100% Boraflex loss, which means 0% credit was taken for the neutron absorbing material. Region 1-2 credited 50% of the neutron absorbing material in the KENO model, while Region 2-2 assumed a 30% loss of Boraflex. The AOR accounts for gaps due to shrinkage as well as uniform and local dissolution. The technical basis and the treatment and analysis method are described in detail in the LAR letter sent to the NRC in 2001 [NL-15-020 (ADAMS Accession ML15062A199)].

b) *Describe how the results of the monitoring or surveillance program are used to ensure that the actual condition of the neutron absorbing material is bounded by the SFP NCS AOR. If a coupon monitoring program is used, provide a description and technical basis for the coupon tests and acceptance criteria used to ensure the material properties of the neutron-absorbing material are maintained within the assumptions of the NCS AOR. Include a discussion on the measured dimensional changes, visual inspection, observed surface corrosion, observed degradation or deformation of the material (e.g., blistering, bulging, pitting, or warping), and neutron-attenuation measurements of the coupons.*

**Response**

The IP monitoring program results have determined that the SFP NCS AOR assumptions are not currently applicable for a portion of the racks (i.e., Region 2-2). As a consequence, some rack locations have been restricted from fuel storage while the balance of the impacted storage locations are in use based on an interim analysis and the associated operability assessment. Corrective actions have been initiated to address the long term resolution of this condition, including a new NCS analysis and elimination of credit for Boraflex.

For the credited Boraflex panels, monitoring of silica levels in the storage pool water, measuring gap formation by blackness or Badger testing, measuring boron areal density every 4 years, and performing of criticality analyses of interim conditions based on the monitoring program results are currently in place. Predictions of the future condition of the Boraflex are performed based on RACKLIFE analysis and empirically developed gap distributions. These results are applied to ensure the operability analysis assumptions remain valid during the interim period credit for Boraflex can be eliminated.

c) *Describe how the bias and uncertainty of the monitoring or surveillance program are used in the SFP NCS AOR.*

**Response**

Uncertainties associated with measurements of Boraflex degradation are accounted for in the NCS AOR as an added bias to the 95/95 $k_{eff}$. A computational simulation was performed to assess measurement uncertainties associated with BADGER testing. For the Boron-10 density in the panels, the density that was used is a minimum Boron-10 density, which corresponds to the minimum certified areal density. For regions where Boraflex was credited, all computational models conservatively applied a bounding s 4.1% width shrinkage.

Thus, this bounding shrinkage is based on both analytical and experimental analyses and has been confirmed by a large number of proprietary laboratory studies and field observations. To account for the axial shrinkage with the possibility that very small gaps may have been missed with the BADGER system, it is conservatively assumed that every panel has 4.1% axial shrinkage in the form of 1/3rd inch gaps uniformly distributed up the panel.

These assumptions resulted in a higher than nominal reactivity model, which conservatively increases the reactivity effects of Boraflex loss. The BADGER associated reactivity effects was shown to be 0.00455 for Region 1-2 and 0.00502 for Region 2-2. These reactivity effects were included as a bias in the 95/95 keff for each respective region to account for BADGER measurement uncertainty.

d) *Describe how the degradation in adjacent panels is correlated and accounted for in the NCS AOR.*

**Response**

For the NCS AOR, a single pattern (layout) of projected degradation from RACKLIFE was assumed for uniform loss. Gaps were assumed to be randomly distributed in both axial location and size based on sampling of a distribution developed from the BADGER measurements performed in 2000.

**ARI 5**

***5)*** *For any Boraflex, Carborundum, or Tetrabor being credited, describe the technical basis for concluding that the safety function for the credited neutron-absorbing material in the SFP will be maintained during design-basis events (e.g., seismic events, loss of SFP cooling, fuel assembly drop accidents, and any other plant-specific design-basis events that may affect the neutron-absorbing material).*

a) *For each design-basis event that would have an effect on the neutron-absorbing material, describe the technical basis for determining the effects of the design-basis* *event on the material condition of the neutron-absorbing material during the design-basis event, including:*

*i. shifting or settling relative to the active fuel*

**Response**

Seismic

The flexural strength and Young's Modulus of irradiated Boraflex have been measured on specimens having been exposed to a range of gamma doses up to >3 x $10^{10}$ rads. The measurements were performed on specimens prepared from small coupons irradiated in a Co-60 facility as well as material destructively removed from fuel racks at two PWRs. The material taken from fuel racks shows no decrease in flexural strength at the higher doses whereas the samples prepared from small coupons do. Conservative assumptions were applied in determining how the strains in the structural stainless steel are transferred to the Boraflex using experimentally determined values of Young's Modulus, the peak stresses in the Boraflex were computed. In all cases the calculated Boraflex stresses were less than the threshold failure stress by a substantial margin. Generally, this provides the overall basis for considering any effect on the Boraflex neutron-absorbing material during a seismic event.

Slumping of the neutron absorbing material was not considered in the NCS AOR. However, is not expected that Boraflex will slump or shift based on the discussion above.

Dropped Fuel Assembly

The consequences of a spent fuel assembly drop were initially evaluated and found that the criticality acceptance criteria of keff ≤ 0.95 would not be violated. Furthermore, the results of an analysis showed that a dropped spent fuel assembly on the racks would not distort the racks such that they could not perform their safety function.

However, a requirement was later added of 38 ppm soluble boron as part of the current NCS AOR, to compensate for the increase in reactivity due to the penalty associated with this scenario. Thus, the consequences of this type of accident are not significantly changed from the previously evaluated spent fuel assembly drops, which have been found acceptable by the NRC.

*ii. increased dissolution or corrosion*

**Response**

Loss of SFP Cooling

The loss of cooling to the spent fuel pool results in a gradual increase in pool water temperature, up to the point of bulk boiling at the pool surface. As described in EPRI Report TR-107333, "The RACKLIFE Boraflex Rack Life Extension Computer Code:

Theory and Numerics," silica release from Boraflex is dependent on pool water temperature. Therefore, due to the short duration of such an event, this limits the impact on the overall performance of the neutron-absorbing material.

*iii. changes of state or loss of material properties that hinder the neutron-absorbing material's ability to perform its safety function*

**Response**

The design basis event answers are provided in the responses to ARI 5 a) i. and ii. No mechanism has been identified that would result in the neutron–absorbing material's to undergo a 'change in state' (i.e., consideration for the neutron–absorbing material moving from a solid to powder or liquid form).

b) *Describe how the monitoring program ensures that the current material condition of the neutron-absorbing material will accommodate the stressors during a design-basis event and remain within the assumptions of the NCS AOR, including:*

*i.* monitoring methodology

**Response**

The responses to ARI 5 a) demonstrate that the neutron-absorbing material will adequately accommodate stressors during a design basis event. Therefore, the assumptions in the NCS AOR will continue to be met during these types of events.

*ii. parameters monitored*

**Response**

The parameters monitoring are described in the response to ARI 2 a) ii, and they would be unchanged as a result of a design basis event.

*iii. acceptance criteria*

**Response**

The acceptance criteria for the overall monitoring program are described in the response to ARI 2) iii, and would be unchanged as a result of a design basis event.

*iv. intervals of monitoring*

**Response**

There is no commitment in the NCS AOR to perform additional monitoring in this area following a design basis event and therefore the intervals of monitoring as described in the responses to ARI 2 a) i and ARI 3 would remain unchanged.

**References:**

**[1]** (GL) 2016-01, “Monitoring of Neutron-Absorbing Materials in Spent Fuel Pools” [ML16097A169]