Entergy

Entergy Nuclear Operations, Inc.
Pilgrim Nuclear Power Station
600 Rocky Hill Road
Plymouth. MA 02360

John A. Dent, Jr.
Site Vice President

November 3, 2016

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

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

Pilgrim Nuclear Power Station
Docket No. 50-293
Renewed License No. DPR-35

LETTER NUMBER 2.16.066

Dear Sir or Madam:

By letter dated April 7, 2016, the Nuclear Regulatory Commission (NRC) issued Generic Letter (GL) 2016-01, "Monitoring of Neutron-Absorbing Material in Spent Fuel Pools," to all power reactor licensees which included a request for information (RFI) in accordance with 10 CFR 50.54(f). Entergy Nuclear Operations, Inc. hereby provides its response to GL 2016-01 for the Pilgrim Nuclear Power Station (PNPS).

Entergy Nuclear Operations, Inc. has determined that Pilgrim Nuclear Power Station is a Category 4 licensee in accordance with GL 2016-01. 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 PNPS spent fuel pool credits Boraflex, Boral and Metamic as neutron absorbing materials and therefore is required to provide information in the following areas: (1-5), (1,2,4) and (1,2). Attachment 1 contains PNPS responses to the requested information.

If you have any questions regarding this submittal, please contact Mr. Everett P. Perkins Jr., Manager, Regulatory Assurance at (508) 830-8323.

There are no regulatory commitments contained in this letter.

A158
NRR

I declare under penalty of perjury that the foregoing is true and correct.

Executed on November 3, 2016.

Sincerely,

John A. Dent, Jr.
Site Vice President

JAD/sc

Attachment: PNPS Response to NRC Generic Letter 2016-01

cc: Mr. Daniel H. Dorman
Regional Administrator, Region I
U.S. Nuclear Regulatory Commission
2100 Renaissance Blvd., Suite 100
King of Prussia, PA 19406-2713

Ms. Booma Venkataraman, Project Manager
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Mail Stop O-8C2A
Washington, DC 20555

NRC Senior Resident Inspector
Pilgrim Nuclear Power Station

Attachment

Letter Number 2.16.066

RESPONSE TO NRC GENERIC LETTER 2016-01

(29 Pages)

PILGRIM NUCLEAR POWER STATION

Response to NRC Generic Letter 2016-01

A. Background

On April 7, 2016, the Nuclear Regulatory Commission (NRC) issued Generic Letter (GL) 2016-01, "Monitoring of Neutron-Absorbing Materials in Spent Fuel Pools". The following information provides the Pilgrim Nuclear Power Station (PNPS), 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*

PNPS Response

Manufacturer:

The PNPS High Density Spent Fuel Racks E1 through E9 were manufactured by Joseph Oat Corporation,

Racks N1 through N4 were manufactured by Holtec International and

Racks N5 and N6 were manufactured by Holtec International.

Date of manufacture:

Racks E1 through E9 were manufactured in 1985.

Racks N1 and N2 were manufactured in 1993.

Racks N3 and N4 were manufactured in 2000.

Racks N5 and N6 were manufactured in 2008.

Date of material installation:

Racks E1 through E9 were installed in April 1986

Rack N1 and N2 were installed in January 1995

Rack N3 was installed in January 2001

Rack N4 was installed in March 2005

Rack N5 was installed in November 2008

Rack N6 has not been installed

b) neutron-absorbing material specifications:

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

PNPS Response

Racks E1 through E9 contain Boraflex as the neutron absorbing material. The Boron 10 (B10) content is not specified on a weight percent basis of the neutron absorbing component. See response to 1 b) ii for minimum areal density.

Racks N1 through N4 contain Boral as the neutron absorbing material. Based on a reasonable search of plant records the certified content of the neutron absorbing material was not found.

Rack N5 contains Metamic as the neutron absorbing material. The minimum certified Boron Carbide Loading of the Metamic panels is 24.0%.

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

PNPS Response

The design B10 areal density of the Boraflex in racks E1 through E9 is not less than 0.018 g/cm^2 in boron content. Based on a reasonable search of plant records no minimum certified, minimum as-built, maximum as-built or nominal as-built areal density was found.

The minimum as-built certified B10 areal density of the Boral in racks N1 and N2 is 0.015 g/cm^2, and the maximum certified as-built B10 areal density is 0.0263 g/cm^2.

After a reasonable search of plant documents, no areal density could be found for the N3 and N4 racks.

After a reasonable search of plant documents, the as-built areal density for rack N5 could not be found. The nominal and minimum design B10 areal densities are 0.0185 gm/cm^2 and 0.0166 gm/cm^2 respectively.

iii. material characteristics, including porosity, density and dimensions

PNPS Response

The dimensions of the Boraflex in racks E1 through E9 are as follows 0.068" (± .008") thick x 5 9/16" (± 1/16") wide x 136 1/4" (±1/4") long. The porosity and density of the

Boraflex material were not specified. The Boraflex matrix material is Poly Dimethyl and the chemical form of absorber nuclide is Boron Carbide.

The dimensions of the Boral in racks N1 and N2 are as follows: 0.075" (±.004) thick x 5.0" (± 1/16") wide (4.75" +.125", -.0 for external sheathing) x 144" (+.18", -.00) long. Porosity and density were not specified.

The dimensions of the Boral in racks N3 and N4 are the same as racks N1 and N2 given above. The porosity and density of the Boral material were not specified.

The dimensions of the Metamic in rack N5 are as follows: 0.077" (±.005) thick x 5.0" (± 1/16") wide (4.75" +.125", -.0 for external sheathing) x 144"(+.25", -.00) long. The porosity and density of the Metamic were not specified. The Metamic matrix material is Aluminum 6061 and the chemical form of absorber nuclide is Boron Carbide.

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

PNPS Response

Boraflex

The Brand Industrial Services, Inc. (BISCO) qualification report presented data showing an exposure of Boraflex in air to 2.81 x 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 x 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 x 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 or 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 nor Boraflex composition has any effect on the neutron transmission, through a dose of 1.03x10^{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 x 10^{11} rads gamma thereby resulting in a negative effect regarding the suitability of Boraflex as a neutron shielding material.

However, due to unexpected behavior of Boraflex being observed at two sites, in the early 1990's, Electric Power Research Institute (EPRI) undertook an evaluation which provided a clearer understanding of the gap phenomenon, including the range of

maximum gap size and the axial distribution of gaps. It was further demonstrated that the reactivity effect of such gaps is very small, usually within the existing design basis of most spent fuel racks.

<u>Boral</u>

Boral, which was the patented product of Allen Aircraft Radio Inc. (AAR) Brooks and Perkins, is a poison material used in spent fuel storage racks as a neutron absorber material. Around 1990, Holtec International undertook an assessment of the use of Boral, compiling information from in-plant operating experience, laboratory tests and coupon data.

Boron carbide is considered a strong neutron absorbing material known to be both physically stable and "chemically inert in the radiation, thermal, and aqueous environment of the spent fuel pools." Boral was originally manufactured by AAR Brooks and Perkins under a computer-aided/quality control program in conformance with requirements found in Title 10 of the United States Code of Federal Regulations Part 50 (10CFR50), Appendix B. The core of a Boral plate is made from a composite of finely divided Boron Carbide (B_4C) powder, with Type 1100 aluminum powder. Construction of a specific Boral plate is dependent upon the Boron-10 loading requirement.

AAR and its predecessor, Brooks and Perkins, conducted extensive qualification testing to demonstrate the suitability of Boral for spent fuel storage and transportation applications. Radiation qualification testing consisted of subjecting a series of BORAL™ samples to gamma, thermal neutron and fast neutron radiation in water at the reactor core face at the University of Michigan 2 MWth Ford Nuclear Reactor. The tests ran for a period of nine years and periodically three samples were removed for inspection and testing. Test results are reported up to 7×10^{11} rads gamma. At this gamma exposure, the samples had also received fast and thermal neutron exposures of 3.6×10^{18} neutron velocity time (nvt) and 2.7×10^{19} nvt, respectively. The test specimens were severely oxidized having been in the pool water for nine years. The oxidation could be removed by brushing with a wire brush. Aside from the corrosion, the samples showed no other signs of physical deterioration. Neutron attenuation testing and neutron radiography showed no loss of boron carbide. This was confirmed by chemical analysis. Tensile test results indicate no change in the ultimate strength. It is noted that the test conditions in the pool of the Ford Nuclear Reactor are far more severe in terms of radiation damage than conditions in spent fuel storage applications.

The use of Boral in the spent fuel pool environment is extensive and this provides a basis for the knowledge of Boral in such environments. This helps to provide confidence in the acceptability of Boral in the spent fuel racks as a neutron absorber. Available surveillance coupon data at the time of the evaluation of the acceptability for Boral in spent fuel pool racks confirmed that there was no loss of boron content during in-service operation under the radiation, thermal and chemical environments.

Corrosion of Boral is related to general corrosion and localized pitting. This was not deemed as a cause for concern at the time of the evaluation of the acceptability for Boral in spent fuel pool racks, as no significant loss of the B_4C would occur. In general, corrosion of Boral appeared to be essentially that of the aluminum used in manufacture with no contribution from the inert B_4C.

In the evaluation of the acceptability for Boral in spent fuel pool racks, coupons from two plants (Susquehanna and Cooper Station) were reviewed, which showed some blistering on the coupons. However, analysis of the B10 content by neutron attention and wet chemical technique confirmed that there was no loss of boron.

Available information at the time of the evaluation of the acceptability for Boral in spent fuel pool racks demonstrated that the performance of Boral in environments representative of spent fuel storage pools showed that Boral is fully capable of maintaining its effectiveness as a control poison over an anticipated 40 or 50 year lifetime. Cladding and the core aluminum of Type 1100 aluminum alloy exhibits good corrosion resistance. When exposed to water, the aluminum reacts to form a tightly adhering layer of hydrated oxide, which provided a protective later that affords good corrosion resistance to Boral.

<u>Metamic</u>

Metamic is a fully-dense, discontinuously-reinforced, metal matrix composite material. It consists of a high-purity Type 6061 aluminum alloy matrix reinforced with Type 1 American Society for Testing and Materials C-750 isotopically-graded B_4C. To ensure its satisfactory performance in the environments that exist in spent fuel pools, Metamic has been subjected to many tests that simulate the conditions to which the material will be exposed in actual service.

Metamic has been subjected to the following tests:

- short term (48 hour) elevated temperature (900°F) testing;
- long term elevated temperature (750°F) testing for times in excess of one year;
- accelerated corrosion testing (195°F) for times in excess of one year;
- accelerated radiation testing at exposures up to $1.5x10^{11}$ rads gamma;
- mechanical properties testing at temperatures up to 900°F; and
- neutron transmission testing of coupons before and after corrosion testing.

The accelerated corrosion testing of Metamic was carried out in two media: deionized water to simulate Boiling Water Reactor (BWR) pool conditions, and deionized water containing 2500 ppm boron as boric acid to simulate Pressurized Water Reactor (PWR) pool conditions. Mill finish and anodized coupons containing 15 wt. % and 31 wt. % B_4C were placed in each simulated pool environment. The tests showed the deionized water was a harsher environment for Metamic than was the borated water

Neutron transmission tests were carried out on archive coupons and on coupon samples before those samples were placed in 1) 200°F deionized water and 2) 200°F deionized water containing 2500 parts per million (ppm) boron as boric acid. Intermediate transmission tests have been completed on the archive coupons and the coupons that had been exposed to the 200°F water environments. The tests show uniformity of absorption across the samples, as well as consistency in absorption between the archive coupons and the coupons exposed to the pool environments.

Testing has proved Metamic to be an excellent, desirable material for use as the neutron absorber in high-density fuel storage applications. When impurities deposited during the

fabrication process have been cleaned from its surfaces, either by glass-beading of mill-finish material or by the cleaning that precedes anodizing, Metamic is highly resistant to corrosion when exposed to the environments present in fuel storage pools. It is not subject to deformation or deterioration under environments far more hostile than those in fuel storage pools, and it remains an extremely consistent and effective neutron absorber.

To qualify Metamic panels for wet and dry storage applications, four types of measurements were employed. These included:

- Chemical analysis
- Neutron attenuation
- Thickness measurements
- Density measurements

The results of these tests indicated that Metamic panels are fully acceptable for use as a neutron absorber in storage applications.

d) configuration in the SFP

PNPS Response

The PNPS Spent Fuel Pool (SFP) employs two rack designs. Nine of the racks are designed by Joseph Oat Corporation and use Boraflex as the neutron absorber. The remaining five racks are designed by Holtec and use either Boral or Metamic as the neutron absorber.

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

PNPS Response

The Boraflex racks are composed of welded stainless steel sheets in the shape of cruciform, angles and tees. Sheets of Boraflex are sandwiched between the stainless steel sheets. Stainless steel strips are welded to the top, bottom and side of the stainless steel sheets, encapsulating the Boraflex. The resulting cruciform, angle and tee sub-assemblies are welded together to form an array of storage cells for each rack module.

The Boral and Metamic racks are constructed of welded stainless steel boxes. The Boral or Metamic panels are sandwiched between the box outer wall and a stainless steel sheath that is welded to the box wall.

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

PNPS Response

Both the Joseph Oat and Holtec rack designs limit access between the neutron absorber and the spent fuel pool environment. However, both designs allow limited exchange of water between the spent fuel pool and neutron absorber encapsulation area. Water may migrate through view areas, vent holes and areas between welds used in the rack construction.

e) *current condition of the credited neutron-absorbing material in the SFP*

   i. *estimated current minimum areal density*

PNPS Response

RACKLIFE calculations are used to determine the minimum areal density for Boraflex spent fuel storage racks. Recent calculations determined the minimum areal density in the racks as 0.01965 gm-B10/cm^2. This value is based on a projection to September 1, 2017. While slightly conservative due to the additional operational time, this value is considered an appropriate estimate. RACKLIFE calculations were also performed in conjunction with the April 2016 BADGER test conducted at PNPS. These calculations show a conservative bias and a 1-sigma uncertainty of 0.000403 gm-B10/cm^2.

For Boral, the as-built areal densities described in response to question 1.b.ii above provide the current estimate since no change in areal density is anticipated based on material qualification, operating experience and monitoring results to-date.

For Metamic, since no as-built data was found after a reasonable search of plant records, the minimum design value can be assumed from the response to question 1.b.ii above, since no change in areal density is anticipated based on material qualification, operating experience and monitoring results to-date.

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

PNPS Response

The NCS AOR Boraflex rack analysis uses a nominal areal density of 0.0214 gm-B10/cm^2, with a manufacturing tolerance of 0.0035 gm-B10/cm^2. Additionally, the analysis contains a parametric study of the reactivity effects of 0% to 50 % loss in panel thickness. The resulting reactivity penalties are combined with similar parametric results for gap size, panel width and bundle reactivity. The monitoring program maintains the current reactivity limit by applying the RACKLIFE determined areal density and the BADGER determined maximum gap size. Based on BADGER tests conducted in 2012, a 25.6% Boraflex thickness loss was established as the maximum value which would

maintain the racks below the 0.95 k-effective acceptance criteria. This Boraflex thickness limit is based on a 4.1% width reduction, T/S bundle k-infinity limit and a gap size of 8.8 inches.

BADGER tests conducted in 2016 identified higher Boraflex gaps than supported by the NCS AOR. An interim analysis has been performed to support an operability assessment for the racks. This interim analysis assumes the areal density is equal to 0.0160 gm-B10/cm^2. This value includes a BADGER to RACKLIFE uncertainty, design areal density tolerance and a conservative densification credit. These factors are combined arithmetically with the nominal design areal density to establish the interim analysis inputs for all credited Boraflex panels.

The NCS AOR for the PNPS Boral racks assumes a nominal areal density of 0.0162 gm-B10/cm^2. The analysis also includes a 0.0012 gm-B10/cm^2 allowance for manufacturing tolerances.

The design basis areal density for PNPS Metamic racks is 0.0185 gm-B10/cm^2 with a tolerance of 0.0019 gm-B10/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)

PNPS Response

PNPS has conducted various Blackness and BADGER tests including a recent BADGER test completed in April 2016. The test measured 71 panels with a doses ranging from 1.7×10^9 to 1.1×10^{10} Rads. The lowest areal density for an intact portion of a panel was 0.0183 gm-B10/cm^2. One panel experienced a cumulative gap loss of 36.4 inches from the 9 gaps identified in that panel. The next highest cumulative gap loss is 6 inches which corresponds approximately to the expected loss due to shrinkage. The PNPS BADGER results treated observed local dissolution as a gap.

Boral coupons have been examined since 2000 with the latest performed in 2016. None of the coupons have shown a loss of neutron absorption capability. As expected surface oxide is present along with some pitting and surface blistering. The 2016 draft coupon inspection report noted that the tested Boral coupon contained blisters over approximately 3% of the coupon surface.

Metamic coupon examinations have been conducted in 2012 and 2016. Both examination indicated no loss in neutron absorption capability. The 2012 inspection noted presence of surface pits as well as expected corrosion. The 2016 examination

report noted the presence of pitting with more depth than previously tested coupons. These results are currently being evaluated.

ARI 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*

PNPS Response

Boraflex

The PNPS approach to determine if its Boraflex monitoring program is consistent with NUREG-1801, Section XI.M22, Boraflex Monitoring. An aging management program should include: "(a) completing sampling and analysis for silica levels in the spent fuel pool water on a regular basis, such as monthly, quarterly, or annually (depending on Boraflex panel condition), and trending the results by using the RACKLIFE predictive code or its equivalent; and (b) performing neutron attenuation testing or blackness testing to determine gap formation in Boraflex panels or measuring boron areal density by techniques such as the BADGER device."

The Boraflex Monitoring Program assures that degradation of the Boraflex panels in the spent fuel racks does not compromise the criticality analysis in support of the design of the spent fuel storage racks. The program relies on periodic inspection of the Boraflex, monitoring of silica levels in the spent fuel pool water, and analysis of criticality to assure that the required 5% subcriticality margin is maintained. Silica levels in the spent fuel pool water are monitored monthly. In addition, Gap formation by areal density (BADGER) is periodically measured and the RACKLIFE predictive model is used. The PNPS License Renewal Application states the Boraflex monitoring program is consistent with NUREG-1801 to perform a periodic material surveillance of the Boraflex material cell panels installed on spent fuel pool racks. PNPS performed BADGER testing in 2006, 2012 and 2016. These actions are consistent with NUREG-1801, Section XI.M22.

Boral

A separate commitment was made to an accelerated surveillance program for Boral test coupons installed in the spent fuel rack area as part of License Amendment 155 (increased spent fuel storage capacity). The coupon test frequency and sample size of one coupon per interval is based on operating experience with Boral and is not based on

an analytic determination. Based on accelerated test programs and years of operating experience, Boral is considered a satisfactory material for reactivity control. Ongoing programs at various spent fuel pools have not demonstrated cases where loss of neutron absorbing capability has occurred when utilizing industry standard monitoring programs. The coupon program consists of eight to ten coupons, with a recommendation of testing to not exceed a ten-year period. This program called for the placing of eight Boral test coupons (mounted on a tree) in the SFP rack area. A testing schedule of a removal and testing of one Boral test coupon at the 1st, 2nd, 3rd, 5th, and 8th refuel outages after the rack modification was complete, and at 5 years, 10 years, and 16 years after the 8th refueling outage was provided. Subsequently, the License Renewal Application for PNPS committed to Boral monitoring program consistent with the program described in NUREG-1801, XI.M40 and LR-ISG-2009-01. The coupon testing frequency committed to within the License Renewal Application is for one test on each material to be performed within the five years preceding the period of extended operation (PEO), with additional testing performed on each material at least once every 10 years during the PEO. A Table with the Boral and Metamic Surveillance Coupon Schedule is provided below.

PRIOR TO REFUELING OUTAGE #	REMOVE BORAL COUPON	REMOVE METAMIC COUPON
16 (2007)	**YES**	N/A
17 (2009)	**YES**	N/A
18 (2011)	NO	**YES**
19	**YES**	**YES**
20	NO	**YES**
21	NO	NO
22	**YES**	**YES**
23	NO	NO
24	**YES**	**YES**
25	NO	NO
26	NO	NO
27	**YES**	**YES**
28	NO	NO
29	NO	NO
30	NO	NO

<u>Metamic</u>

In 2006, Holtec revised its standard procedure for neutron absorber surveillance program to consider all neutron absorber panels currently used by Holtec. The License Renewal Application for PNPS committed to a Boral and Metamic monitoring program consistent with the program described in NUREG-1801 XI.M40 and LR-ISG-2009-01.

Therefore, the Metamic surveillance program is similar to that as described above for Boral.

The PNPS Metamic coupon tree contained 10 coupons when initially installed.

ii. parameters to be inspected and data collected

PNPS Response

Boraflex

NUREG-1801, Section XI.M22 states that "parameters monitored include physical conditions of the Boraflex panels, such as gap formation and decreased boron areal density, and the concentration of the silica in the spent fuel pool. These are conditions directly related to degradation of the Boraflex material." Parameters monitored include physical conditions of the Boraflex panels, such as gap formation and decreased boron areal density, and the concentration of the silica in the spent fuel pool. Therefore, PNPS parameters monitored and inspected are consistent with NUREG-1801 Section XI.M22.

Boral

The coupon surveillance program is intended to monitor changes in physical and chemical properties of the neutron absorber material by performing the following measurements on a pre-planned schedule:

- Visual Observation and Photography
- Neutron Attenuation
- Dimensional Measurements (length, width and thickness)
- Weight and Specific Gravity

The most significant measurements are the thickness (to monitor for swelling) and neutron attenuation (to confirm the concentration of Boron-10 in the absorber material).

Metamic

For Metamic the coupon measurement program is intended to monitor changes in physical properties of the Metamic absorber material by performing the following measurements on a preplanned schedule:

- Visual Observation and Photography
- Neutron Attenuation
- Dimensional Measurements (length, width and thickness)
- Weight and Specific Gravity

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*

PNPS Response

The purpose of the surveillance program is to characterize certain properties of the neutron absorbing material with the objective of providing data necessary to assess the capability of the panels in the racks to continue to perform their intended function. The surveillance program is not designed to confirm the safety function of the in-service material, but it is capable of detecting the onset of any significant degradation with ample time to take such corrective actions as may be necessary.

Boraflex

The acceptance criterion for Boraflex is that 5% subcriticality margin of the spent fuel racks will be maintained for the period of extended operation. The NCS AOR provides the capability to confirm reactivity limits are met for various combinations of Boraflex panel gaps size, panel width loss and panel thickness loss assumptions. This is consistent with NUREG-1801, Section XI.M22. It should also be noted that an interim NCS is under development to address the operation of the pool pending implementation of long-term corrective actions. The interim analysis no longer credits Boraflex for areas of the pool that are susceptible to gap size greater than 10 inches. The balance of the pool applies partial Boraflex credit. For the Boraflex area, all panels are assumed to have a single co-planar gap at the most reactive axial location of the specific fuel bundle/type being analyzed. This is more fully discussed in the response to ARI 4 b).

Boral

The acceptance criteria are as follows:

- A decrease of no more than 5% in B10 content, as determined by neutron attenuation, is acceptable. This is tantamount to a requirement for no loss in boron within the accuracy of the measurement.

- An increase in thickness at any point should not exceed 25% of the initial thickness at that point.

Changes in excess of either of these two criteria requires investigation and engineering evaluation which may include early retrieval and measurement of one or more of the remaining coupons to provide corroborative evidence that the indicated change(s) is real. If the deviation is determined to be real, an engineering evaluation shall be performed to identify further testing or any corrective action that may be necessary.

Metamic

Acceptance criteria are as follows:

- A decrease of no more than 5% in B10 content, as determined by neutron attenuation, is acceptable.

- An increase in thickness at any point should not exceed 10% of the initial thickness at that point.

Changes in excess of either of these two criteria require investigation and engineering evaluation which may include early retrieval and measurement of one or more of the remaining coupons.

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

PNPS Response

Boraflex

The surveillance program for the Boraflex spent fuel racks consists of the use of the RACKLIFE code, complemented with BADGER testing. The PNPS program model collected data from January 1986 to the present. The surveillance program at PNPS uses the elements of EPRI guidelines on monitoring degradation of the Boraflex panels in the spent fuel pool. The PNPS program uses complete Boraflex rack scope, preventive actions, parameters monitored and inspection, detection of aging effects, monitoring and trending, acceptance criteria, corrective actions, confirmation process, administrative controls and operating experience to manage Boraflex degradation. Escape coefficients are updated based on BADGER test results. Where data is unavailable conservative assumptions are made to bound the missing data's effect on the B_4C percent loss values.

RACKLIFE is used to determine if the fuel can be placed in a specific region of the SFP and that 5% subcriticality margin of the spent fuel racks will be maintained. Spent fuel pool BADGER tests have been performed in 2006, 2012, and 2016. It is noted that the 2006 and 2012 BADGER campaigns were performed using "older" methods.

A. Year 2006

A series of 50 Boraflex panels from the PNPS Station fuel racks have been subjected to non-destructive BADGER testing to determine the condition of the Boraflex neutron absorber material. The average panel loss is compared well with the RACKLIFE predicted average panel loss at the time of the test.

B. Year 2012

A series of 45 Boraflex panels from the PNPS Station fuel racks have been subjected to non-destructive BADGER testing to determine the condition of the Boraflex neutron absorber material. The test results indicate that some of the Boraflex panels have sustained some in-service degradation and a few higher dose panels showed moderate loss of boron carbide.

The average panel loss from the BADGER test compares well with the RACKLIFE predicted average panel loss at the time of the test.

Gaps are predisposed towards forming in the upper 2/3 of the panel with a peak at about 110 inches. The largest cumulative length of gap is 6.9 inches, which approaches 5% of the panel length. The largest single gap measured was 1.78 inch.

C. Year 2016

A series of 71 Boraflex panels from the PNPS Station fuel racks have been subjected to non-destructive BADGER testing to determine the condition of the Boraflex neutron absorber material. The test results indicate that some of the Boraflex panels have sustained some in-service radiation induced shrinkage, while one panel sustained more extensive loss of boron carbide.

The average areal density of all panels tested is 0.0240 ± 0.0003 grams B10/cm^2. This compares with an assumed as-fabricated value of 0.0214 grams B10/cm^2. It should be noted that the as fabricated value does not take radiation induced densification effects into consideration. The average dose of all panels tested was 6.25 x 10^9 Rads. One panel, RR35 South, had larger gaps due to increased dissolution resulting in 36.4 inches of total gap. Aside from panel RR35 South the largest cumulative length of gap is 6.0 inches, in S28 West. This approaches 4.4% of the panel length. The RACKLIFE model was benchmarked to the results of this BADGER test as described in the response to ARI 2 b) iii (4).

<u>Boral</u>

A. Year 2000

PNPS removed Boral Surveillance Coupon TS362818-2-7 from the coupon tree and sent it Holtec International for testing in 2000. The results of this test showed that the Boral absorbers in the spent fuel racks have retained their dimensional qualities (no bulging or swelling) and neutron absorbing qualities, that there were no previously unrecognized mechanisms for degradation, and revealed no possible long-term synergistic effects.

The B10 areal density was measured via neutron attenuation testing. No change in the B10 content was noted between the pre and post measurements. In addition, the average pre-irradiation thickness was 0.078 inches, with a post-irradiation thickness average of 0.079 inches. Therefore, the coupon met the acceptance criteria in that it did not have a decrease of more than 5% in B10 content, or a change of thickness greater than 25%.

B. Year 2009

The coupon was in overall good condition, with some clad blistering noted and with no significant deterioration. The B10 areal density was measured via neutron attenuation testing conducted at five locations on the coupon. The average areal density was 0.0220g B10/cm^2, which is above the areal density in the criticality NCS AOR (0.0162g B10/cm^2). Thus, the coupon met the acceptance criterion.

C. Year 2013

This coupon was removed from the pool in 2013 and tested in 2016. The Boron-10 areal density was measured via neutron attenuation testing conducted at five locations on the coupon. The average areal density, post-irradiation, was 0.0218 g B-10/cm^2, with pre-irradiation average of 0.0212 g B-10/cm^2, resulting in a change of 2.83%. This demonstrates that the coupon met the areal density acceptance criteria in that it does not result in a decrease of more than 5% in Boron-10 content. Furthermore, the coupon experienced an increase in thickness of 0.35%, with a pre-irradiation value of 0.0744 inches and a post-irradiation value of 0.07466 inches. Thus, the coupon met the acceptance criteria in that it did not have a decrease of more than 5% in Boron-10 content, or a change of thickness greater than 25%.

<u>Metamic</u>

A. Year 2012

The B10 areal density was measured via neutron attenuation testing conducted at five locations on the coupon. The average areal density was 0.0230 g B10/cm^2, which is above the areal density in the criticality AOR (0.0185 g B10/cm^2). The coupon showed a 1.5% change between the pre- and post-thickness measurements. Thus, the coupon met the acceptance criterion.

B. Year 2013

Coupon 400-205C-3

This coupon was removed in 2013 and tested in 2016. The B10 areal density was measured via neutron attenuation testing conducted at five locations on the coupon. The average areal density, post-irradiation, was 0.02360 g B10/cm^2, with an estimated pre-irradiation average of 0.0232 g B10/cm^2, resulting in a change of 1.72%. This demonstrates that the coupon met the areal density acceptance criteria in that it did not result in a decrease of more than 5% in B10 content. Furthermore, the coupon experienced an increase in thickness of 1.55%, with a pre-irradiation value of 0.0788 inches and a post-irradiation value of 0.08002 inches. Thus, the coupon met the acceptance criteria in that it did not have a decrease of more than 5% in B10 content, or a change of thickness greater than 10%.

C. Year 2015

Coupon 103-036C-4

This coupon was removed in 2015 and tested in 2016. The B10 areal density was measured via neutron attenuation testing conducted at five locations on the coupon. The average areal density, post-irradiation, was 0.01934 g B10/cm^2, with an estimated pre-irradiation average of 0.0196 g B10/cm^2, resulting in decrease of 1.84%. This demonstrates that the coupon met the areal density acceptance criteria in that it did not result in a decrease of more than 5% in B10 content. Furthermore, the coupon experienced a change in thickness of 0.83%, with a pre-irradiation value of 0.0804 inches and a post-irradiation value of 0.08107 inches. Thus, the coupon met the acceptance criteria in that it did not have a decrease of more than 5% in B10 content, or a change of thickness greater than 10%.

Conclusive Statement

Boraflex

The surveillance of the PNPS SFP Boraflex racks conforms with the commitments made as part of License Renewal. It effectively provides a method for assessment of the physical condition of the Boraflex, including any deterioration of the physical condition of the Boraflex, including any deterioration on the basis of current accumulated gamma exposure and water ingress into the panel wrapper and the margin of sub-criticality maintained over time by the use of the RACKLIFE code. The program also provides the continual monitoring of the chronological trends in spent fuel pool reactive silica. The PNPS program also relates silica level to refueling events.

Boral & Metamic

The Boral and Metamic monitoring program demonstrate that the tested coupons consistently meet the acceptance criteria with an acceptable level of consistency. Therefore, the monitoring program performs its intended function to ensure criticality is maintained in the PNPS SFP.

v. industry standards used

PNPS Response

Boraflex

The PNPS program is consistent with NUREG-1801 XI.M22. 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 RACKLIFE predictive code or equivalent.

Gap formation is periodically measured by areal density (BADGER) testing and use of the RACKLIFE computer code.

Corrective actions are initiated if the test results find that the 5% subcriticality margin cannot be maintained because of current or projected Boraflex degradation

<u>Boral</u>

The PNPS Boral surveillance program is consistent with the guidance provided in NUREG-1801, Section XI.M40 and ISG-2009-01. As recommended in NUREG-1801, Section XI.M40, para.3 parameters that should be monitored "include the physical condition of the neutron-absorbing materials, such as in-situ gap formation, geometric changes in the material (formation of blisters, pits, and bulges) as observed from coupons or in situ, and decreased boron areal density, etc." In accordance with the above guidance, PNPS monitors the following parameters:

- physical condition of the neutron absorbing materials (see ARI 2 a) ii.)
- geometric changes in the material (e.g., formation of blisters, pits, and bulges) as observed from coupons (see ARI 2 a ii.)
- boron areal density (see ARI 2 a ii.)

PNPS follows recommendation in NUREG-1801, Section XI.M40, para.4 and ISG-2009-01, which states that the "frequency of the inspection and testing depends on the condition of the neutron-absorbing material and is determined and justified with plant-specific operating experience by the licensee, not to exceed 10 years." This is demonstrated in the ARI 2 a i, that indicates testing will not exceed a timeframe of 10 years.

Lastly, PNPS also compares coupon results to as-manufactured data for each coupon (see ARI 2 a) iv. This is consistent with the guidance of paragraph 5 in section XI.M40 of NUREG-1801, which states that "measurements from periodic inspections and analysis are compared to baseline information or prior measurements and analysis for trend analysis."

<u>Conclusive Statement</u>

The responses provided in sub-parts i, ii, and iv of ARI 2 a) provide satisfactory conclusions that the PNPS Boral Surveillance Program meets the regulatory guidelines.

Metamic

The Metamic program is consistent with guidance provided in in NUREG-1801, Section XI.M40 and ISG-2009-01. Given that Metamic is a relatively new neutron absorbing material, with a limited operational experience, it should be noted that the NRC provided the following guidance to Palisades Nuclear Power Plant, which is also deemed applicable and appropriate NRC guidance for PNPS:

> "Given the relatively slow nature of material degradation seen in other neutron absorbing materials used in the SFP, favorable results from industry testing concerning the performance of Metamic in a SFP environment, and no operational experience concerning the degradation of the Metamic currently in use as a neutron absorbing material in other SFPs, the staff has reasonable assurance that the licensee's surveillance program will allow enough time for the licensee to take corrective actions prior to any degradation challenging the minimum areal density of the Metamic panels. Therefore, the staff finds that licensee's proposed surveillance program 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.

PNPS Response

The monitoring program does not include direct visual inspections of the Boraflex, Boral, or Metamic in-service racks for the purpose of condition monitoring.

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

PNPS Response

In response to question ARI 2 b) i. 1. above PNPS stated that the monitoring program does not include direct visual inspections so the response to this question is Not Applicable.

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.

PNPS Response

Boral

Each refueling outage, recently discharged fuel is placed adjacent to the coupon trees to ensure that the coupons receive a cumulative radiation exposure that is equal to or greater than the Boral racks. Individual coupons are removed from the rack and analyzed at the frequency reported in ARI 2 a). Evaluation of the coupons removed will provide information of the effects of the radiation, thermal and chemical environment of the pool and by inference, comparable information of the Boral panels in the racks. Over the duration of the coupon testing program, the coupons will have accumulated more radiation dose than the expected lifetime for normal storage cells.

Each coupon is slightly different in its size. However, the coupons are generally approximately 6 in. x 4 in. with an average thickness of 0.075 in. The coupons are in Stainless Steel jackets attached to the coupon tree.

Metamic

Each refueling outage, recently discharged fuel is placed adjacent to the coupon trees to ensure that the coupons receive a cumulative radiation exposure that is equal to or greater than the Boral racks. Individual coupons are removed from the rack and analyzed at the frequency reported in ARI 2a)i.

Each coupon is slightly different in its size. However, the coupons are generally approximately 6 in. x 4 in. with an average thickness of 0.078 in.

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

PNPS Response

Coupons were installed into the Boral racks in November 1999.

Coupons were installed into the Metamic rack in 2009 prior to placing discharge fuel into the rack in refueling outage 17.

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.*

PNPS Response

The coupons are not returned to the pool following testing.

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.*

PNPS Response

The schedule for coupon removal and testing is discussed in ARI 2 a) i.

There are seven Boral coupons and seven Metamic coupons remaining in the SFP. Based on the amount of remaining coupons and the schedule for coupon removal, there is enough coupons for testing in the SFP through the extended period of operation (i.e., through 2032).

iii. If RACKLIFE is used:

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

PNPS Response

The version of RACKLIFE used at PNPS is 2.0.

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

PNPS Response

RACKLIFE is run once per cycle.

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.*

PNPS Response

In-situ testing has been performed five times at PNPS, two using Blackness testing and three using BADGER. The results of the BADGER testing are benchmarked to RACKLIFE, as described in the response to (4) below, to ensure the RACKLIFE predictions are representative of the actual condition of the Boraflex with respect to neutron attenuation.

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

PNPS Response

The most recent RACKLIFE calculation shows the peak panel at an 8.1902% B_4C loss on September 1, 2017. This corresponds to an areal density of 0.01965 g/cm^2. This areal density is calculated using the nominal design areal density of 0.0214 g/cm^2 reduced by the percent loss. The calculation internal to RACKLIFE to determine the percent B_4C loss is described in Section 3 of EPRI report TR-107333.

After BADGER testing, the RACKLIFE results are benchmarked to the BADGER measured results. The escape coefficient used for the most recent time period is then reduced/increased to reduce the bias between the RACKLIFE predicted loss and the BADGER measured losses, while keeping a slight positive bias in the RACKLIFE predictions. The silica trends are analyzed after each RACKLIFE update to ensure they are still accurately represented by the RACKLIFE prediction.

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.*

PNPS Response

The criteria and method for the BADGER test locations are based on RACKLIFE predictions of panel dose. The panels selected include panels with a wide range of dose values ($1.7 \times 10^9 - 1.1 \times 10^{10}$). This range includes panels at the highest predicted dose range for the pool's Boraflex racks. The panels in the pool's Boraflex racks typically have a significantly lower dose so this selection biased to higher dose and therefore higher degradation. The PNPS pool's Boraflex racks management has largely resulted in a given panel's dose being accumulated from a single set of discharge fuel assemblies. As such, the residence time is strongly related to dose. Therefore dose is a driver for both Boraflex gapping and dissolution. This panel selection is biased toward higher degradation but still covers a wide range of expected Boraflex performance.

There is no statistical sampling plan employed. The chosen test sample size of 71 panels was not derived through statistical process. Rather, this test plan is representative of approximately 1.4% of the Boraflex panels in the SFP. This test

population is sufficiently large to develop probability distributions and corresponding sets of confidence intervals based on these distributions.

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

PNPS Response

The results of the BADGER test campaigns are trended and repeat panels are selected for measurement. The most recent BADGER test campaign in 2016 measured sixteen panels that were tested previously in the 2006 and 2012 BADGER test campaigns.

3. *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.*

PNPS Response

Calculation uncertainties have been quantified and presented for areal density and gap size by the BADGER test vendor. These uncertainties include statistical uncertainty in count rates and uncertainties associated with the calibration fits derived from the scans of the calibration cell. The areal density uncertainties are calculated as the one sigma standard deviation in the panel average density. 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 mentioned in the ARI was based on the first generation BADGER, and many improvements have been made with the second generation BADGER employed at PNPS. The second generation included equipment and methodology updates. Stabilizing spring plungers are now incorporated into the detector and source heads to provide additional stabilization of the device in order to significantly reduce the effects of detector or head misalignment. The entire volume behind and beside the detectors in the detector head is filled with B_4C powder to increase neutron shielding of the detectors and reduce the effects of backscatter. The second generation BADGER method no longer uses a reference panel, and only utilizes a calibration cell of know properties, which provides a more accurate calibration.

4. *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.*

PNPS Response

A calibration test cell was designed and constructed to provide an accurate mock-up of actual neutron transport conditions in the PNPS Boraflex storage racks. This calibration cell contains Boraflex of known areal density, height, and gap size. The calibration cell is placed in the SFP in an acceptable location away from fuel assemblies, in order to minimize the background radiation from fuel assemblies. Calibration scans of the calibration cell are performed at least twice a day during the evolution. These calibration scans establish a correlation between areal density and neutron count rate, which is then used determine the areal density and gap size for each scan of the in-service panels.

The calibration cell was manufactured by the vendor to within the tolerances of the PNPS rack drawings. The cell wall is made of stainless steel and the absorber material in the scanned cell is Boraflex, which are the same as the materials used in the in-service racks.

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

PNPS Response

The calibration cell accounts for loss of neutron attenuation capability and gaps in the Boraflex by including Boraflex of different known areal densities and gaps of known size. The second generation BADGER only identifies intact areas and gaps. It does not attempt to determine areas of local dissolution (scallops), as any location that experiences an elevated transmission ratio is conservatively assumed to be a gap. This practice reduces the impact of these aging effects on the accuracy of the measurement, and results in not needing to account for local dissolution effects in the calibration.

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,*

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

   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.*

PNPS Response

PNPS employs the second generation BADGER system, which does not use a reference panel for calibration.

ARI 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.

PNPS Response

As previously discussed in ARI 2 a) i. the PNPS Boraflex Monitoring Program assures that degradation of the Boraflex panels in the spent fuel racks does not compromise the criticality analysis in support of the design of the spent fuel storage racks. The program relies on periodic inspection of the Boraflex, monitoring of silica levels in the spent fuel pool water, and analysis of criticality to assure that the required 5% subcriticality margin is maintained. Silica levels in the spent fuel pool water are monitored monthly. In addition, Gap formation and areal density (BADGER) are periodically measured and the RACKLIFE predictive model is used. A commitment was made as part of license renewal to a periodic material surveillance of the Boraflex material cell panels installed on spent fuel pool racks. PNPS performed BADGER testing in 2006, 2012 and 2016. These actions are consistent with NUREG-1801, Section XI.M22.

Justification of why the material properties of the neutron absorbing materials will continue to be consistent with the assumptions of the SFP NCS AOR between monitoring intervals is more fully discussed in ARI 4 b). In short, an interim NCS is under development to address the operation of the pool pending implementation of long-term corrective actions.

ARI 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.*

PNPS Response

The PNPS Boraflex rack NCS AOR contains a base case where the Boraflex is modeled without degradation. The analysis includes parametric analysis results where the reactivity impact due to the presents of gaps in the Boraflex panels, reductions in panel width and reductions in the panel thickness are determined. Gap sizes from 0 – 10 inches are evaluated. Panel width reductions from 0% to 42.5% are evaluated as well as panel thickness reductions of 0% to 50% are evaluated. The rack reactivity for a given set of Boraflex conditions is determined by adding the reactivity increase associated with panel gaps, width reductions and thickness reductions to the base case condition. The base case condition includes the bias and uncertainties due to manufacturing tolerances and the methodology benchmark. Localized effects, such as local panel thinning are not specifically addressed in the AOR, however this analysis does include significant conservatisms such as the use of large co-planar gaps in every panel and a conservative design bases bundle design.

The PNPS Boral NCS AOR is based on nominal Boral dimensions and material composition with allowances for manufacturing variances in these values. No specific allowances for material degradation are included in this analysis. This approach is based on results from accelerated material qualification programs and industry experience and PNPS specific coupon monitoring program. The coupon monitoring program was established to assure that any long-term processes, if any exist, are detected with ample time to take corrective actions so they do not become significant.

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.*

PNPS Response

For the PNPS Boraflex racks, the NCS AOR provides the capability to confirm reactivity limits are met for various combinations of Boraflex panel gaps size, panel width loss and panel thickness loss assumptions. In order to evaluate the impact of degradation on the reactivity of the spent fuel pool, the maximum cumulative gap size is determined based on BADGER measurements. This determination includes an allowance for gap size growth based on multiple BADGER test results. Panel width loss is set at 4.1%, based on the full panel shrinkage predicted by the EPRI Boraflex model. Using these inputs, the panel thickness loss is determined which ensures the fuel storage criticality limits are met, based the method described in the NCS AOR. This limit on panel thickness loss is evaluated using RACKLIFE to determine the date when the panel thickness loss may be

challenged. Previous predictions determined that the maximum panel could reach this value in July 2016. A new BADGER test was scheduled and completed in April 2016. While the BADGER test did confirm that the panel thickness loss was less than predicted by RACKLIFE, it also identified cumulative gaps that exceeded the NCS AOR assumption.

An interim NCS is under development to address the operation of the pool pending implementation of long-term corrective actions. The interim analysis no longer credits Boraflex for areas of the pool that are susceptible to gap size greater than 10 inches. The balance of the pool applies partial Boraflex credit. For the Boraflex area, all panels are assumed to have a single co-planar gap at the most reactive axial location of the specific fuel bundle/type being analyzed. Gap sizes do vary from 4 to 10 inches based on a gap size probability distribution. The gap size probability distribution is based on a gap size model, which includes both the effects of panel shrinkage and edge dissolution. BADGER monitoring uncertainties are also included as well as accelerated gap growth for large gaps. The interim analysis uses an areal density assumption of 0.016 gm-B10/cm^2. This value is based on RACKLIFE predictions through September 1, 2017 and includes a BADGER to RACKLIFE 95/95 confidence limit, manufacturing uncertainty and a conservative credit for Boraflex densification. RACKLIFE will continue to be used as necessary to confirm the assumptions of this interim analysis.

For the PNPS Boral racks, coupon monitoring is used to confirm that the neutron absorber performs consistent with the material qualification and industry operating experience. Results from the coupon programs show expected surface corrosion, some blisters and minor pitting. No evidence of loss of neutron absorption capability has been observed.

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

PNPS Response

The PNPS Boraflex NCS AOR does not account for bias or uncertainties in the monitoring or surveillance program. The interim analysis described above includes BADGER gap size uncertainties and BADGER to RACKLIFE uncertainties in the development of the analysis assumptions. Areas of local dissolution are treated as gaps, so uncertainties associated with the degree of local dissolution do not apply.

No bias or uncertainties from the BORAL monitoring program are included in the NCS AOR. Industry and PNPS experience indicates that Boral does not lose neutron absorbing capability, so not including any bias or uncertainty from the monitoring program is appropriate. For Boral, the monitoring program is used as a confirmation that no loss of neutron absorbing capability has occurred.

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

PNPS Response

The PNPS Boraflex NCS AOR assumes all panels contain the same coplanar gap as well as the same width and thickness reduction. These assumptions, in effect, simulate 100% correlation between adjacent panels. The interim NCS described above assumes all gaps are coplanar and located at the maximum reactivity axial location. All gaps assigned to a cell have the same gap size. Gap sizes vary between cells based on a random sampling of a cumulative gap size probability distribution. All panels have the same areal density.

No degradation mechanism has been identified for Boral which merits consideration of a correlation between adjacent panels.

ARI 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*

PNPS Response

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 greater than 3 x 10^{10} rads. The measurements were performed on specimens prepared from small coupons irradiated in a Cobalt (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 during a limiting seismic event were less than the threshold failure stress by a substantial margin.

The Boraflex in the PNPS rack design is sandwiched between steel plates with little clearance. Interferences to movement of the Boraflex panels are sufficient to preclude movement as demonstrated by the formation of gaps from panel shrinkage. These

interferences would provide a significant resistance to the panels slumping downward during a seismic event. The PNPS Boraflex NCS AOR does not address the potential for Boraflex shifting or settling during a seismic event. The interim analysis assumes all panels have a single gap located at the most reactive axial position. The reactivity of Boraflex configuration resulting from slumping or settling is not greater than the analyzed configuration.

<u>Fuel Assembly Drop Accident</u>

For a dropped fuel assembly lying horizontally on top of the rack, the minimum separation distance is approximately 15 in. maximum expected deformation under seismic or accident conditions will not reduce the minimum spacing to less than 3 in. The 6 in. of natural uranium oxide blanket affords additional conservatism. Thus, a dropped fuel assembly will not constitute a criticality hazard, and the storage rack infinite multiplication factor will not be materially altered.

ii. increased dissolution or corrosion

<u>PNPS Response</u>

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. Extending the measured silica release rates to 212°F with a quadratic fit results in a silica release rate that is approximately 15 times higher than the rate for the normal operating temperature (approximately 120°F). While this release rate is significantly higher than normal pool operation, the short duration of such an event limits the impact on the overall performance of Boraflex. The NCS AOR confirms that reactivity is reduced with increases in pool temperature.

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

<u>Response</u>

No mechanism has been identified that would result in the neutron–absorbing material 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

<u>PNPS Response</u>

The BADGER tests provide measurements for areal density and gap size, as well as gap location. These parameters characterize the Boraflex attributes assumed in the NCS

AOR. As described in response to question 5.a.i above, the Boraflex panel geometry will largely remain intact. Therefore, the monitoring methodology remains applicable following such an event occurrence.

ii. parameters monitored

PNPS Response

The BADGER tests provide measurements for areal density and gap size, as well as gap locations. These parameters characterize the performance Boraflex attributes assumed in the NCS AOR. No additional parameters are needed following a design bases event.

iii. acceptance criteria

PNPS Response

The NCS AOR and interim analysis include assumptions for gap size and areal density. The acceptance criteria for the monitoring program are based on the analysis assumptions. The same acceptance criteria apply following a design bases event.

iv. intervals of monitoring

PNPS Response

The interim analysis assumes all panel have co-planar gaps located at the most reactive axial location. As described in response to question ARI 5 a) above, the postulated consequences of a design bases event would not result in Boraflex configuration that is more reactive than the interim analysis results. As such, additional monitoring is not needed to confirm the Boraflex configuration. A design bases event does not impact the Boraflex monitoring frequency.