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GNRO-2016/00059

November 1, 2016

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

SUBJECT: Response to Generic Letter 2016-01
Grand Gulf Nuclear Station, Unit 1
Docket No. 50-416
License No. NPF-29

REFERENCE: 1. NRC Generic Letter 2016-01, dated April 7, 2016, "Monitoring of Neutron-Absorbing Materials in Spent Fuel Pools." (GNRI-2016/00037)

Dear Sir or Madam:

Per Reference 1, the Nuclear Regulatory Commission (NRC) issued Generic Letter (GL) 2016-01 to address degradation of neutron-absorbing materials in wet storage systems for reactor fuel at power and non-power reactors. Facilities were requested to submit information which demonstrates the credited neutron-absorbing material in wet storage systems are in compliance with the licensing and design basis, and with applicable regulatory requirements; and that there are measures in place to maintain this compliance. This information was requested within 210 days of the issuance of GL 16-01. No additional regulatory action is necessary at this time; the NRC will determine if additional regulatory action is necessary upon review of the requested information.

Based on the GL 16-01 guidance, Grand Gulf Nuclear Station, Unit 1 (GGNS) is providing requested information as a Category 4 responder. The GGNS response to GL 16-01 is provided in the Attachment to this letter.

This letter contains no new commitments. Should you have any questions or require additional information, please contact Christina Brogdon at (601) 437-2111.

I declare under penalty of perjury, the foregoing is true and correct. Executed on the 1st day of November 2016.

Sincerely,

VF/tmm

Attachment: Response to Generic Letter 2016-01

cc:

U.S. Nuclear Regulatory Commission
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NRC Senior Resident Inspector
Grand Gulf Nuclear Station
Port Gibson, MS 39150

Attachment to GNRO-2016/00059

Response to Generic Letter 2016-01

Grand Gulf Nuclear Station

Response to Requested Information in 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 Grand Gulf Nuclear Station (GGNS) 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

The credited neutron-absorbing material (Boraflex) used in the spent fuel pool (SFP) was made by BISCO Products, Inc. The fuel storage racks that house the Boraflex was made by the Joseph Oat Corporation. The installation of the storage racks into the Grand Gulf SFP was completed on 03/17/1986.

After a reasonable search of the plant records, including docketed information, GGNS determined that the date of manufacture 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.

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 composition is given in the response to ARI 1 b) iii below. The spent fuel storage racks themselves are constructed of SA 240, Type 304, austenitic steel sheet material, SA 240, Type 304 austenitic steel plate material, and SA 182, Type F 304

austenitic steel forgings material. This is used to employ double-walled stainless steel boxes with Boraflex neutron absorber sheets in the space between the walls. The GGNS Boraflex is not specified on a weight percent basis of the neutron absorbing component. See response to 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

- The minimum certified areal density is 0.0190 gm/cm^2 B10.
- As-built AD (calculated based on batch sample data sheets):
  - Minimum: 0.0190 gm/cm^2 B10.
  - Maximum: 0.0224 gm/cm^2 B10.
  - Nominal: 0.0204 gm/cm^2 B10.

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

Response

The arithmetically determined elemental composition of the batches of Boraflex is as follows:

Silicone	21.6 wt. %	Hydrogen	2.4 wt. %
Oxygen	19.5 wt. %	Boron	37.1 wt. %
Carbon	19.3 wt. %	Specific Gravity = 1.8 gm/cc nom.	

The Boraflex sheets in the storage cells have the following dimensions: length of 144 inches, width of 5.63 inches, and thickness of 0.070 inches. Grand Gulf has no data or information on the porosity of Boraflex.

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

Response

The 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 1.03x1011 Rads.

Based on the studies undertaken, no evidence was determined that indicated the deterioration of Boraflex occurring using a cumulative irradiation in excess of 1×10^{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 90's, 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.

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

The spent fuel storage racks at GGNS consist of individual cells with panels of neutron absorber material (Boraflex) tightly sandwiched between sheets of stainless steel. These sandwiched sheets are then fused on the endcaps using a Melt-Thru T.I.G. weld. Each cell has one sheet of Boraflex 144 inches long, 5.63 inches wide and 0.070 inches thick (nominal) between each of the four outside faces and the neighboring cells. The individual storage cells are formed by creating a configuration of "cruciform", "tee", and "ell" shaped elements, shown in Figure 3.2, that are fillet welded together. The cruciform element is made of 4 angular sub-elements, "A" (Figure 3.3) with neutron absorber material tightly sandwiched between the stainless sheets. The long edges of the cruciform are welded using a 3/8" thick stainless steel backing strip as shown in Figure 3.4. The bottom of the cruciform assembly has 7 7/8" high stainless strips, which ensure against slippage of the Boraflex material downwards direction. The top of the cruciform is also welded using a spacer strip as shown in Figure 3.4. Continuous welding of the straight segments of the top edges produces a smooth lead-in surface. Ample venting is available through the roof openings of cell corners. This venting is to preclude bulging of the cell walls due to gas entrapments. The "ell" and "tee" elements are constructed similarly using angular sub-elements "B", and flat sub-elements "C" (Figure 3.5). The assembly is performed by welding all the contiguous spokes of the elements using fillet welds. The cells are then bonded to each other along their long edges. The bottom ends of the cell walls are welded to the baseplate. Machined sleeve elements are positioned concentric

with the cell center lines above the holes drilled in the bas eplate, and attached to the base plate through circular fillet welds.

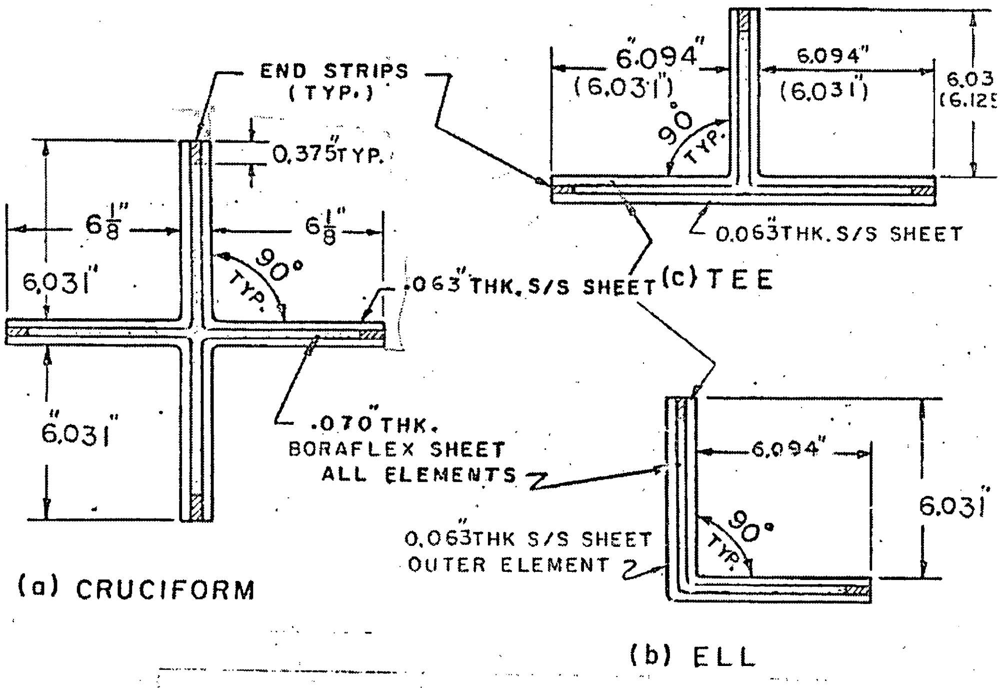

FIGURE 3.2 ELEMENTS CROSS SECTION

3-8

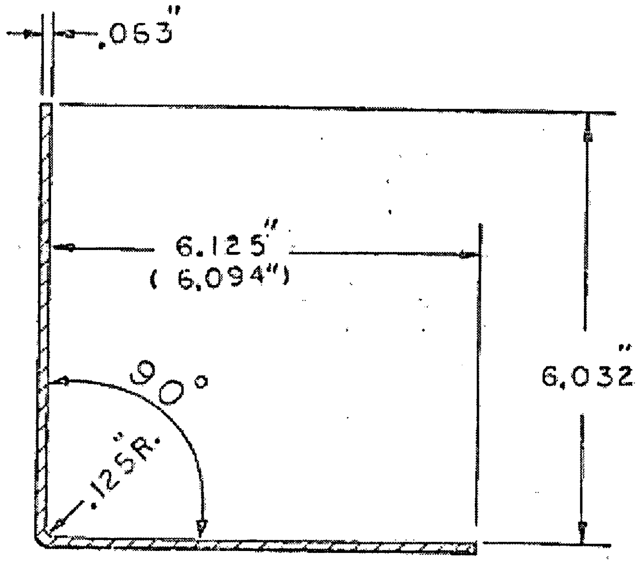

FIG. 3.3 ANGULAR
SUB ELEMENT 'A'

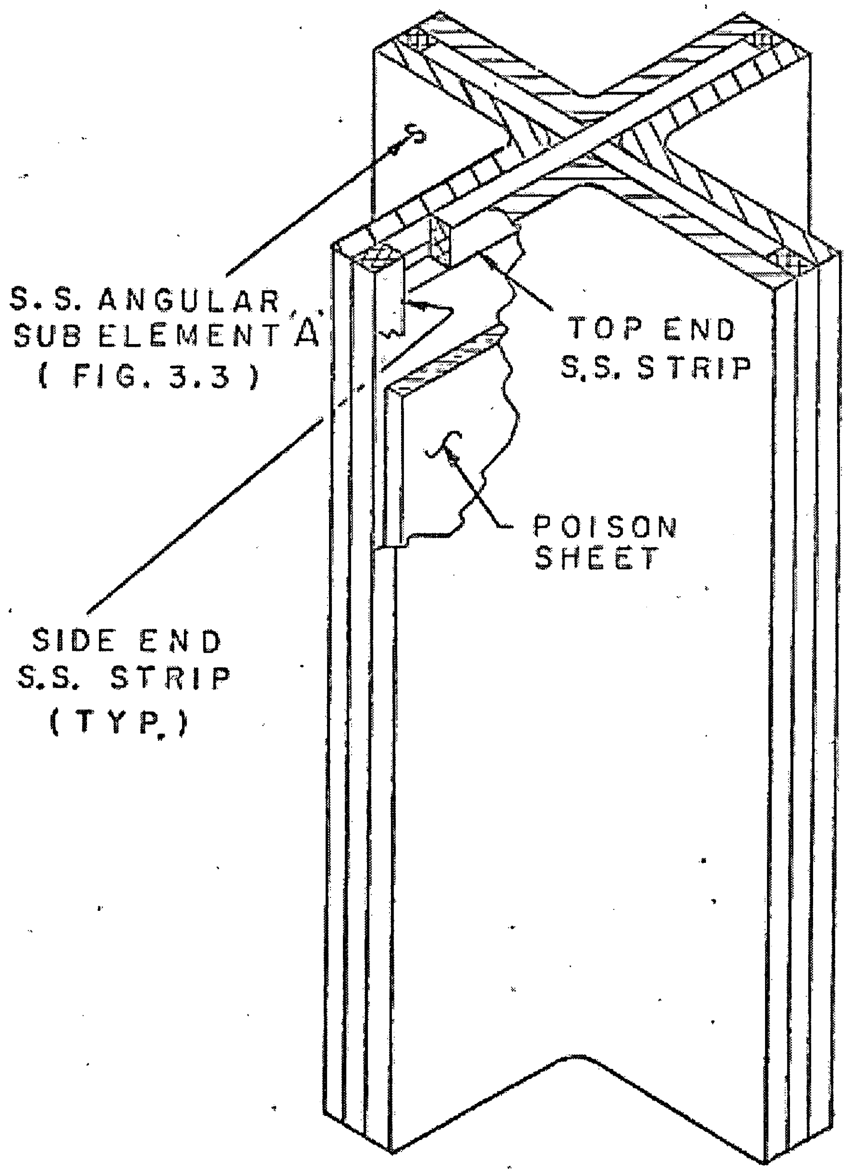

FIG. 3.4 CRUCIFORM ELEMENT
(ISOMETRIC VIEW)

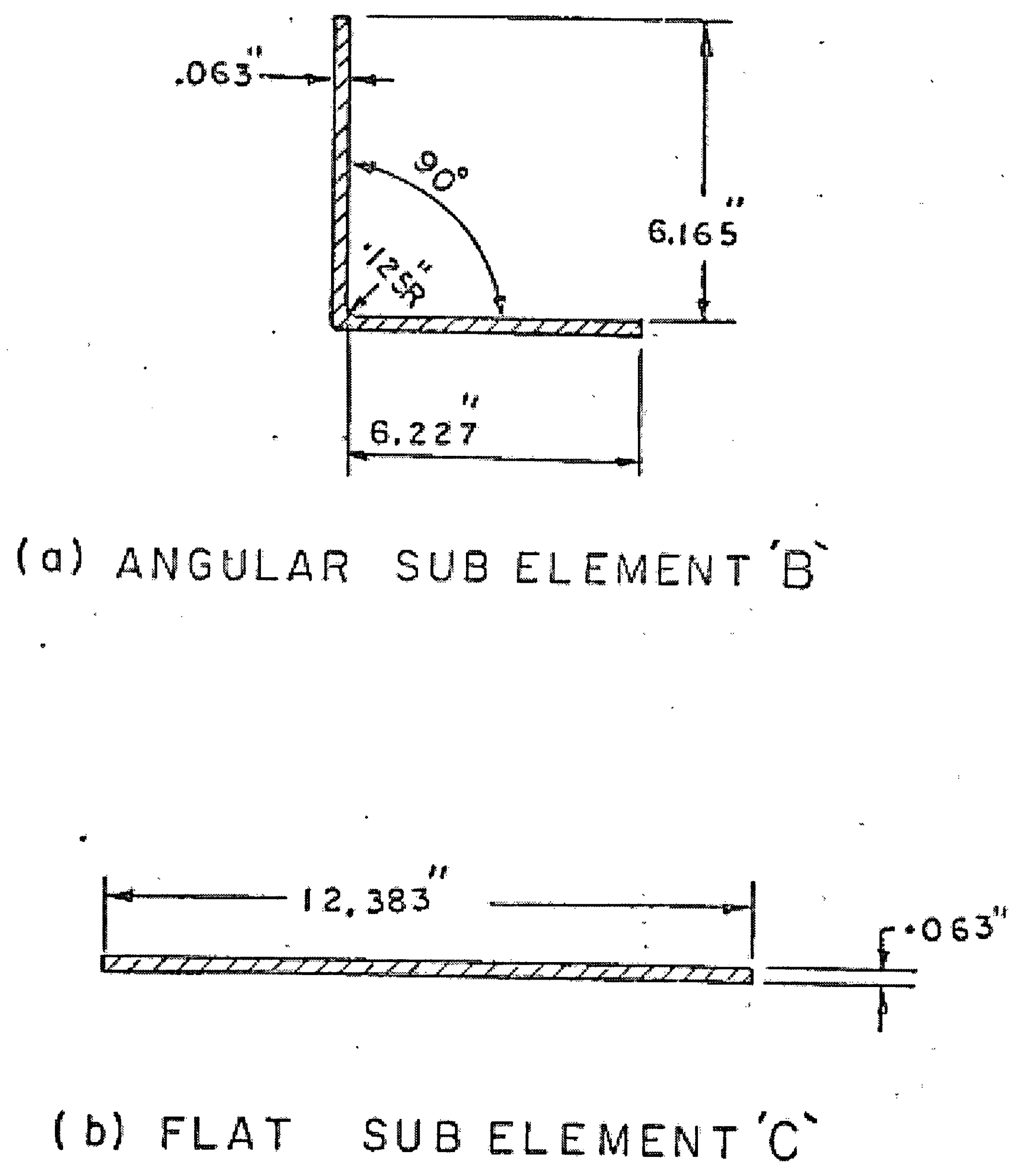

FIG. 3.5 SUB ELEMENTS

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

Response

There is limited contact of the water with the Boraflex due to the Boraflex being positioned between the stainless steel. Two inch welds, spaced approximately every four inches are used to form a stable and relatively "tight" configuration which minimizes the potential for water ingress. There is water present inside the racks but the Boraflex is not directly exposed to flowing water. Venting is available through the openings where each element is welded to the other elements (i.e., another cruciform, tee, or ell).

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

i. *estimated current minimum areal density*

Response

The most recent RACKLIFE calculation shows the peak Region I panel at a 9.79% B4C loss on 2/21/16, which corresponds to an areal density of 0.0184 g/cm^2. This conversion is described in the response to ARI 2 b) iii (4). Region II does not credit Boraflex, so the areal density of these panels is not estimated.

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

Response

The current credited areal density in the NCS AOR is 0.0133 g/cm^2. Added to this value are the RACKLIFE to BADGER uncertainty (0.0022 g/cm^2) and the design areal density tolerance (0.001 g/cm^2), which results in the minimum allowed RACKLIFE calculated areal density of 0.0165 g/cm^2 found in the technical specifications (4.3.1.1 e).

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

The seventh and final Blackness testing campaign was performed in selected cells of the Grand Gulf spent fuel storage rack in 1999. During this campaign 52 cells (208 Boraflex panels) in the test area that had contained spent fuel were tested. Note that the test area had freshly discharged fuel placed in it after each cycle up to this last Blackness test, so it significantly led the rest of the pool. At the time of this last Blackness test, almost all of the panels scanned were significantly above the current dose limit. All but one of the 52 tested cells had gaps in at least three panels, with more than half of the cells showing gaps in all four panels. In total, 362 gaps of 0.5 inches or larger were detected with an average gap size of 1.4 inches. The largest single gap was measured at 6.0 inches and the largest cumulative gap size was 13.5 inches. Note that all of these panels are now Region II panels, and do not credit Boraflex.

BADGER tests have been performed to measure panel average areal densities and gap sizes. Almost all of the Region I panels in these tests measured above the minimum certified areal density. The few panels that were below it were only slightly below. The average areal density of all panels tested in the 2007 test that were eligible for classification as Region I was 0.01918, and the average areal density of all Region I panels tested in the 2013 test was 0.0214 gm/cm2 B10. Note that the BADGER test in 2013 used the update BADGER equipment, which produces more accurate results. No Region I panels measured during either BADGER test saw gaps as large as those in the last Blackness test. No single gap in excess of 2.5 inches was observed in the 2007 BADGER test for Region I panels, and no single gap in excess of 6 inches was observed in the 2013 BADGER test. Cumulative gap sizes extended over six inches, but were limited to only three panels in the 2013 BADGER test.

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

While GGNS currently has Boraflex coupons remaining in the pool, the site is in the process of formalizing the removal of coupons from the monitoring program, which is consistent with the guidance provided in NUREG-1801, Section XI.M22. The current monitoring program consists of BADGER testing and RACKLIFE calculations.

The frequency of the GGNS Boraflex monitoring program is consistent with NUREG-1801, Section XI.M22. It states 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 EPRI 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".

GGNS performs periodic monitoring of the Boraflex neutron absorbing material at least once every 5 years using BADGER testing, which is consistent with the recommendations in NUREG-1801 Section XI.M22. Gap growth is projected to the next BADGER test interval plus one year, in order to show margin exists to the AOR limits with sufficient time to perform and review the results of the next BADGER test. Thus, a 5 year frequency of BADGER testing is acceptable. See the response to 2 b) iv (1) for the BADGER sample size and its basis.

A RACKLIFE model of the GGNS racks and pool is used to estimate the service history of each panel of Boraflex in the storage racks, specifically the estimated gamma exposure. The RACKLIFE analysis is performed each cycle, and includes a comparison of the RACKLIFE predicted silica to the plant measured silica, which is monitored quarterly. This comparison is used as a secondary check to ensure the RACKLIFE results are still conservative. After each BADGER test, the RACKLIFE results are compared to the BADGER results to determine if a change to the escape coefficient is necessary. This process is discussed in the response to ARI 2 b) iii (4). The analysis includes projections to the next planned RACKLIFE analysis date (plus margin) to ensure current Region I storage locations will not exceed the dose or areal density requirements that would require them to be reclassified as Region II storage locations in the analysis interval. While the boron loss rate is increasing over time as expected, it is still relatively low at less than 1% per year. This loss rate is not significant compared to the margin between the current condition and condition assumed in the AOR. Thus, performing RACKLIFE evaluations once per cycle is acceptable. See the response to RAI 1 in GNRO-2011/00104 for more details on the basis of performing RACKLIFE analyses once per cycle.

ii. parameters to be inspected and data collected

<u>Response</u>

BADGER testing is used to monitor the areal density and gap size distributions in the Boraflex panels. BADGER collects data on count rates, which is then used to convert the areal density and determine the distribution of gaps. RACKLIFE is also used as part of the monitoring program, and it requires that chemistry data (e.g., silica) is collected.

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

The monitoring program was designed to determine the extent of degradation in the neutron absorbing material. Results that indicate unanticipated degradation or deformation are occurring will be entered into the corrective action program for further assessment of impacts, extent of condition, trending, determination of functionality, and implementation of corrective actions. The monitoring program measures the critical parameters of the neutron absorber to show it continues to meet the AOR assumptions. The corrective action program will be used to confirm the safety function in the presence of degradation outside the AOR assumptions.

The following acceptance criteria were made as commitments to the NRC as part of License Amendment 195 and are confirmed after every BADGER test:

a) Confirm all measured panels have an areal density above the AOR bases value of 0.0133 g/cm^2.

b) Ensure the AOR gap size and location probability distribution assumptions are still valid.

c) Confirm the new BADGER to RACKLIFE uncertainty is less than the AOR bases value of 0.0022 g/cm2.

d) Confirm the measured dissolution distribution is bounded by the local dissolution analysis.

e) Confirm the gap growth analysis is still bounding when incorporating the new data from the BADGER test. Project gap growth from the BADGER test through the next planned BADGER campaign plus one year (6 years total) to ensure AOR gap distributions will remain bounding.

There are two acceptance criteria for Region I panels described in the technical specifications (4.3.1.1 e) for dose (2.3E10 rads) and areal density (0.0165 g/cm^2). RACKLIFE calculations are done to compare panels in Region I to these acceptance criteria to determine if any panels need to be reclassified as Region II.

These acceptance criteria ensure the in-service Boraflex is maintained within the assumptions of the AOR by using trending to project future performance to ensure the AOR assumptions are protected.

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

Response

GGNS has performed two BADGER test campaigns where areal density and gap sizes were measured. In addition, a comparison of the most recent BADGER test to the AOR assumptions was performed. The sections below more fully describe the campaigns, along with the number of panels tested.

Background

A BADGER test campaign was conducted at GGNS in December 2007 to measure the Boron-10 areal densities and panel losses from gaps. The gap measurement results for panels with doses below $2.3E^{10}$ were consistent with the maximum shrinkage predicted by the EPRI Boraflex shrinkage model. Badger gap measurement results for panels with doses above $2.3E^{10}$ are consistent with the results of the seven blackness tests, and show additional losses since the previous blackness test in March, 1999. Thirty-two total panels were measured in Region I and Region II cell locations. The Region I panels that were tested had accumulated doses up to $1.77E^{10}$ rads. The Region II panels had accumulated doses as high as $3.83E^{10}$ rads.

Results

The BADGER test acceptance criteria are described in the response to ARI 2 a) iii. The Region I results were above the AOR assumption of 0.0133 gm/cm^2. The difference between the Region I BADGER test results and the RACKLIFE results are bounded by a 95/95 uncertainty of 0.0022 gm/cm^2. This value is used as the BADGER to RACKLIFE uncertainty that is applied to the monitoring program results. The Region II analysis does not credit any Boraflex absorption.

<u>Year 2013 BADGER Test</u>

Background

GGNS's RACKLIFE model provided a means to identify those storage cells and specific Boraflex panels that had been subjected to the most severe service histories in terms of

integrated gamma exposure and, potentially, the greatest boron carbide loss. A sample population of sixty of the panels was selected, which included some of the highest exposed panels (1.88×10^{10} rads). Panels were chosen from dose groups of a spectrum of exposures, ranging from lower dose panels up to the highest dose panels.

For the GGNS spent fuel pool there is a large spread of dose across the pool. The cells near to the pool edge tend to be lower dose, while the cells near the center of the pool have higher dose. The majority of the panels in the testing region have doses over 2×10^9. The region just north of the test cells has a very high concentration of panels with high dose. The peak dose of a tested panel during the campaign was 1.88×10^{10} Rads.

Results

The average intact panel areal density of all panels measured was 0.0214 g-Boron 10/cm^2. The lowest intact panel areal density value (i.e., intact panel average areal density minus a 3 sigma panel average uncertainty) of all the panels tested was 0.0176 g-Boron 10/cm^2. This shows that all panels have tested higher than the credited 0.0133 g-Boron 10/cm^2 value. For the panels tested, the results do not indicate extensive panel thinning; however, most of the tested panels exhibit some level of shrinkage induced gapping.

<u>Comparison: 2013 BADGER Test Results to the AOR Assumptions [3]</u>

A calculation was performed to ensure that the AOR assumptions are still valid after analyzing the new BADGER test results. The calculation demonstrated that all of the acceptance criteria have been met.

a) The minimum measured intact average panel areal density was 0.0195 g/cm2, which is greater than the AOR assumption of 0.0133 g/cm^2.

b) The AOR assumed gap distributions remain bounding as illustrated in Figures 1-3 below [3].

c) The BADGER to RACKLIFE uncertainty was determined to be 0.00198 g/cm^2, which is less than the 0.0022 g/cm^2 used in the AOR. Note that 0.0022 g/cm^2 continues to be used as the uncertainty.

d) Local dissolution is now conservatively captured in the gap analysis due to NETCO's new method of accounting for gaps in the BADGER analysis, which includes all material local dissolution as gaps. The areal density of all individual 2 inch intact regions of the panel were above the AOR assumption; thus the AOR assumptions are met and local dissolution was not separately characterized.

e) The gap growth rate of 0.19219 in/yr was determined to be conservative when including the new data. When projecting the data to six years after the BADGER test (9/2019) using the gap growth rate, the AOR gap distributions were determined to still be bounding.

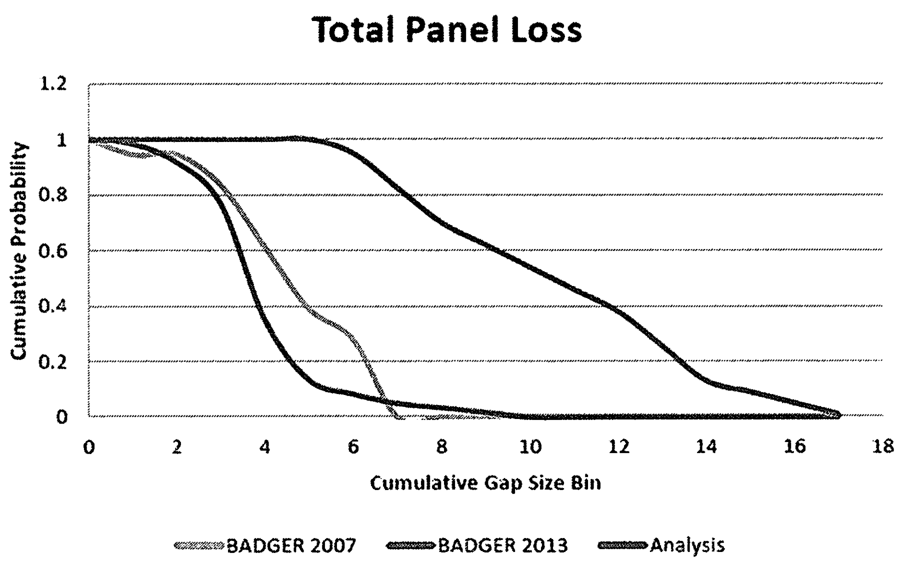

Figure 1. Total Panel Loss Cumulative Probability Distributions

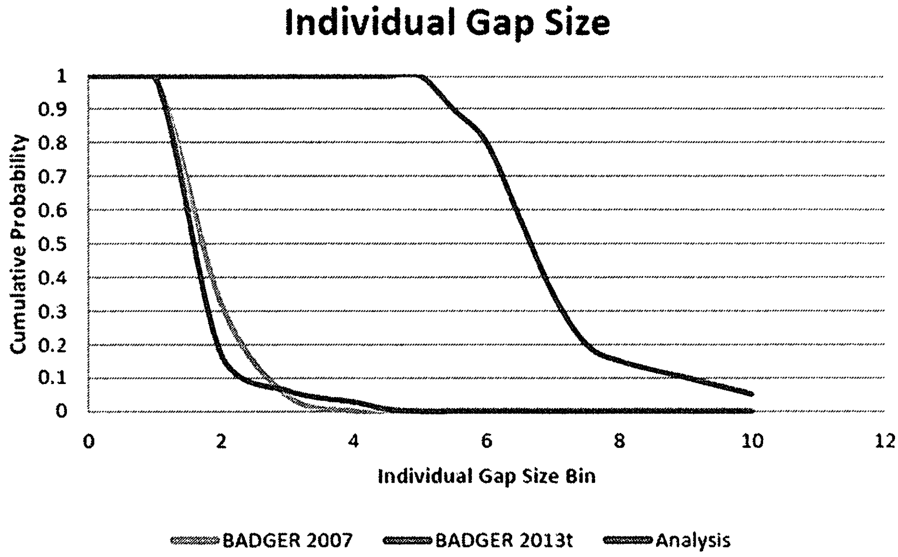

Figure 2. Individual Gap Size Cumulative Probability Distribution

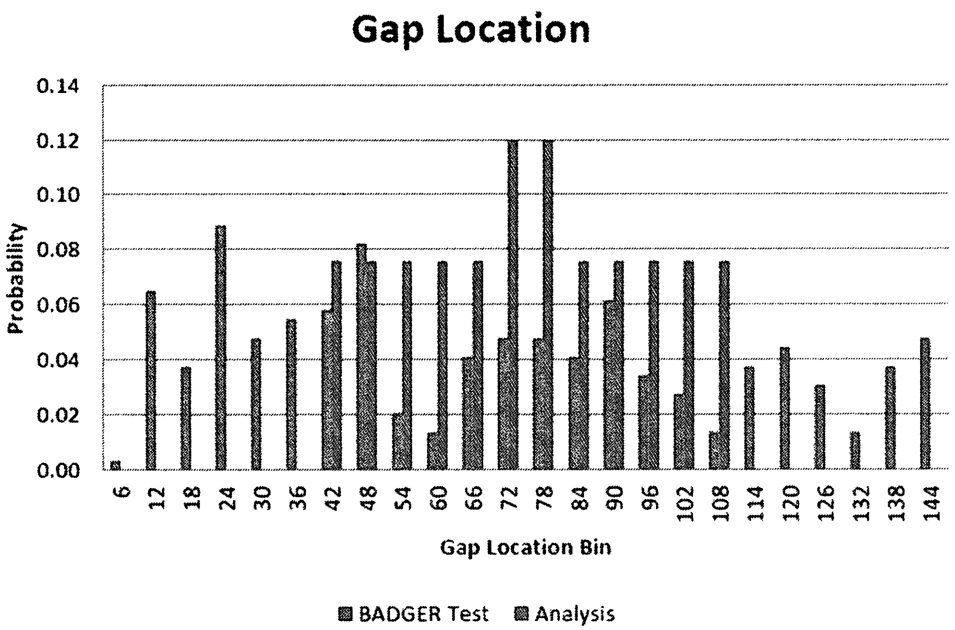

Figure 3. Gap Location Probability Distribution

Conclusive Statement

Recent tests and calculations have demonstrated that all the Boraflex monitoring acceptance criteria are met and confirm the AOR Boraflex assumptions are still bounding and will remain bounding well past the next BADGER test interval.

v. industry standards used

Response

License Amendment 195 does not specify any codes and standards that pertain directly to the monitoring program; however, the GGNS Boraflex monitoring program is consistent with the guidance provided in NUREG-1801, Section XI.M22. As recommended in NUREG-1801, Section XI.M22, para. 5 and 6, 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. In accordance with this recommendation, GGNS monitors the following parameters:

- The physical condition of the Boraflex panels (see ARI 2 a ii.)
  - Gap formation
  - Decreased boron areal density
- Concentration of the silica in the spent fuel pool (see ARI 2 a ii.)

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 quarterly. Gap formation is periodically measured by in-situ areal density (BADGER) testing every five years.

It is also noted that NUREG-1801, Section XI.M22, para. 4 specifies measuring gap formation by blackness testing. The GGNS program specifies areal density measurements for Boraflex degradation every 5 years (see ARI 2 a i.), and is therefore is consistent with current guidance.

Conclusive Statement

The responses provided in sub-parts *i, ii, and iv* of ARI 2 a) provide satisfactory conclusions that the GGNS Boraflex Monitoring Program meets the regulatory guidelines.

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.*

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

Response

Visual inspections for the in-service material are not performed at GGNS.

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.*

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

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.*

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

As discussed in the response to ARI 2 a) i, coupons are no longer part of the monitoring program at GGNS.

iii. *If RACKLIFE is used:*

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

Response

The version of RACKLIFE used at GGNS is 2.0.

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

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.*

Response

In-situ testing is performed on a 5 year frequency to confirm the Boraflex panels are degrading as expected. The results are benchmarked to RACKLIFE, as described in the response to ARI 2 b) iii (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*

Response

The most recent RACKLIFE calculation shows the peak Region I panel at a 9.79% B_4C loss on 2/21/16. This corresponds to an areal density of 0.0184 g/cm^2. This areal density is calculated using the nominal design areal density of 0.0204 g/cm^2 reduced by the RACKLIFE calculated percent B_4C loss. The calculation internal to RACKLIFE to determine the percent B_4C loss is described in Section 3 of EPRI report TR-107333.

After each BADGER test, the RACKLIFE results are benchmarked to the BADGER measured results. The escape coefficients used are then reduced/increased by a uniform percent to reduce the bias between the RACKLIFE predicted loss and the BADGER measured losses, while keeping a slightly conservative bias in the RACKLIFE predictions. The silica trends are analyzed during 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.*

Response

Panels are chosen for testing based on the accumulated gamma dose calculated by RACKLIFE. In order to accurately assess the gap growth model (described in the letter dated July 2, 2013 to the NRC as part of License Amendment 195, labeled GNRO-2013/00050), a range of panel doses are selected to be tested, while more emphasis is put on higher dose panels (i.e. more high dose panels are tested) to ensure the areal density limits are met. At least 60 panels are tested during each campaign, 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).

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

Response

The results of the in-situ test campaigns are trended and repeat panels are selected for measurement. Seven Blackness test measurement campaigns were performed over 11 years. Each campaign measured panels from the same test area, so the bulk of the panels tested in each campaign were repeat tests from previous campaigns. The 2007 BADGER test campaign measured fourteen panels that were measured previously in Blackness test campaigns. The most recent BADGER test campaign in 2013 measured seven panels that were tested previously in the 2007 BADGER test campaign.

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.*

Response

Calculational 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 and the areal density standards used in the calibration cell. The areal density 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 ARI was based on the first generation BADGER, and many improvements have been made with the second generation BADGER employed at GGNS. 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.*

Response

A calibration test cell was designed and constructed to provide an accurate mock-up of actual neutron transport conditions in the GGNS racks. This calibration cell contains Boraflex of known areal density, height, and gap size. The calibration cell is placed on top of the SFP racks in the area vacated for the BADGER test, in order to minimize the background radiation from fuel assemblies. Calibration scans of the calibration cell are performed at least twice a day, which include scanning the unattenuated region on top of the neutron absorber. These calibration scans establish a correlation between areal density and neutron count rate, which is then used to determine the areal density and gap size for each scan of the in-service panels.

The calibration cell was verified by the vendor to conform to the cell dimensions from GGNS rack drawings, including cell wall thickness and cell width. The cell wall is made of type 304 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.*

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 an elevated neutron transmission ratio at any location 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,*

Response

The second generation BADGER test methodology employed at GGNS does not utilize a reference panel, so this item is N/A.

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

Response

The second generation BADGER test methodology employed at GGNS does not utilize a reference panel, so this item is N/A.

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

The second generation BADGER test methodology employed at GGNS does not utilize a reference panel, so this item is N/A.

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

This ARI was answered in in the response to ARI 2 a) i. It is reproduced here for convenience.

GGNS performs periodic monitoring of the Boraflex neutron absorbing material at least once every 5 years using Boron-10 Areal Density Gage for Evaluating Racks (BADGER) testing, which is consistent with the recommendations in NUREG-1801 Section XI.M22. Gap growth is projected to the next BADGER test interval plus one year, in order to show margin exists to the AOR limits with sufficient time to perform and review the results of the next BADGER test. Thus, a 5 year frequency of BADGER testing is acceptable.

A RACKLIFE model of the GGNS racks and pool is used to estimate the service history of each panel of Boraflex in the storage racks, specifically the estimated gamma exposure. The RACKLIFE analysis is performed each cycle, and includes a comparison of the RACKLIFE predicted silica to the plant measured silica, which is monitored quarterly. This comparison is used as a secondary check to ensure the RACKLIFE results are still conservative. After each BADGER test, the RACKLIFE results are compared to the BADGER results to determine if a change to the escape coefficient is necessary. This process is discussed in the response to ARI 2 b) iii (4). The analysis includes projections to the next planned RACKLIFE analysis date (plus margin) to ensure current Region I storage locations will not exceed the dose or areal density requirements that would require them to be reclassified as Region II storage locations in the analysis interval. While the boron loss rate is increasing over time as expected, it is still relatively low at less than 1% per year. This loss rate is not significant compared to the margin between the current condition and condition assumed in the AOR. Thus, performing RACKLIFE evaluations once per cycle is acceptable. See the response to RAI 1 in GNRO-

2011/00104 for more details on the basis of performing RACKLIFE analyses once per cycle.

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

   The GGNS NCS AOR includes assumptions for the Boraflex panel Boron-10 areal density, the size and location of gaps in the Boraflex panels and localized effects due to non-uniform degradation. The specific Boraflex assumptions and their technical bases are described in GNRO-2010/00073, GNRO-2012/00120, GNRO-2013/00050 and the Safety Evaluation report associated with License Amendment 195. These assumptions include allowances which account for material loss and deformation. The assumptions are based on GGNS monitoring program results including allowances for uncertainties and significant allowance for additional degradation of the Boraflex. As described in the response to ARI 2 above, the assumptions are confirmed by execution of the Boraflex monitoring program. Additionally, the GGNS NCS AOR also includes storage configurations (Region II) where no credit for Boraflex is taken. The GGNS technical specifications (4.3.1.1 e) contain requirements for applying the Region II fuel storage configuration to locations that exceed either gamma dose or areal density criteria. The compliance with these criteria is implemented as part of the Boraflex monitoring program to ensure the GGNS NCS AOR Boraflex assumptions remain valid.

   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 response to ARI 2 a) iii above describes the acceptance criteria of the monitoring program, which ensure the in-service Boraflex is bounded by the AOR. The response to RAI 3 in GNRO-2013/00050 describes how the results of the monitoring program are projected to the next BADGER test period to prove the AOR assumptions continue to remain bounding at that point.

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

Response

The uncertainty in the monitored Boraflex areal density is accounted for in the BADGER to RACKLIFE 95/95 confidence limit uncertainty. This limit is added to the analytic limit, along with the design areal density tolerance, as part of the monitoring program acceptance criteria. This confidence limit is confirmed by the BADGER test results as described in the response to RAI 2 in GNRO-2011/00017.

As discussed in the responses to ARI 2 a), the BADGER gap size results are converted to measured gap size probability distributions for comparison to the AOR gap size assumptions. The measured distributions include allowances for the expected gap growth through the next BADGER test interval (6 years). The gap growth rate is also evaluated for each BADGER test. The growth rate is set at the 95/95 upper limit of the observed growth rates. The BADGER gap size measurement uncertainty (2-sigma) is confirmed to be less than the margin between the measured results and the AOR assumptions.

This ensures that the monitoring program acceptance criteria bound the AOR assumptions with appropriate allowances for uncertainties.

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

Response

There are several factors that affect the formation of gaps in a Boraflex panel. They include the accumulation of dose from the assembly in a specific cell and the adjoining cells. Since any single panel is equidistant to two storage cells in the GGNS design, the dose from both assemblies has the same potential impact. Other factors include variations in the Boraflex enclosure that would provide areas of resistance to Boraflex shrinkage. The dose from a given fuel assembly stored in a given cell would contribute to

degradation patterns that would be correlated between the panels surrounding the assembly. However, the dose from adjacent assemblies and the Boraflex enclosure details would not contribute to the degradation patterns that are not correlated.

The correlation of Boraflex gaps in adjacent panels was evaluated in support of the AOR. See the response to RAI 3 b. 1) in GNRO-2013/00050 for more details. The evaluation concluded that the amount of correlation observed in adjacent panels is adequately reflected in AOR gap distribution assumptions. The AOR distributions conservatively restrict the size and location of gaps producing an increase the correlation in adjacent panels. This conclusion is reflected in the NRC's safety evaluation report for License Amendment 195 (ML 13261A264).

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

This ARI was discussed in the response to RAI 14 on page 28 of GNRO-2012/00120. It is summarized below.

Seismic events

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, and 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 GGNS rack design is sandwiched between steel plates with little clearance. Interferences to movement of the Boraflex panels are sufficient to preclude movement 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. As a conservative approach, calculations were performed to demonstrate criticality margins would be maintained should slumping occur. These calculations were previously described in the response to RAI 30 provided in Entergy letter GNRO-2011/00025 (ADAMS Accession #ML11112A098).

Fuel Assembly Drop Accident

A GGNS-specific analysis was not readily available; however, an analysis for a similar rack was evaluated and determined to be bounding for the GGNS spent fuel racks and fuel handling equipment. The consequences of dropping a fuel bundle from the maximum height achievable with the refueling building 5-ton crane (~36 feet) was evaluated to determine the impact on the spent fuel racks. This drop does not credit fuel handling procedure limits. A drop from this height significantly bounds a drop from the fuel mast that is used to move fuel into and out of spent fuel pool storage locations. The drop assumed a channeled assembly and the supporting attachment (1200 lbs.) fell onto a corner of the spent fuel rack. The impact on the rack structure was evaluated using the LS-DYNA code. The two panels of the rack corner showed some amount of plastic deformation in the top 24 inches of the rack.

The top of the GGNS Boraflex panels are located ~17 inches below the top of the rack structure; therefore, some change in geometrical structure of the Boraflex would be expected. The reactivity consequence was determined by assuming that the event actually occurred in the center of the rack and the Boraflex material in the top 7 inches was removed from 4 panels arranged in a cross configuration. Since the top of active fuel is 3 inches above the top of the Boraflex, 10 inches of active fuel would be uncovered in the four impacted panels. The first six inches of active fuel is naturally-enriched Uranium, so only 4 inches of enriched fuel is impacted. Reactivity does not increase due to the high neutron leakage in the impacted area.

ii. increased dissolution or corrosion

Response

This ARI was discussed in the response to RAI 7 on page 36 of GNRO-2013/00050. It is summarized below.

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. 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 (~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.

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 materials 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.

Furthermore, in the event that GGNS should experience vibratory ground motion exceeding that of an Operating Basis Earthquake (OBE), "sufficient testing and analysis of the fuel pool storage racks shall be performed to ensure that any redistribution of gaps in the Boraflex is bounded by the criticality safety analysis. This analysis and testing shall be completed before the placement of any additional new or spent fuel bundles in any fuel pool storage racks."

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 a) iii and they would be unchanged as a result of a design basis event.

iv. intervals of monitoring

Response

As discussed in the response to ARI 5 b) i, an in-situ test will be performed prior to placement of additional fuel assemblies into the SFP following a design basis earthquake. The intervals of monitoring for the overall monitoring program are described in the responses to ARI 2 a) i and ARI 3. They would be unchanged as a result of a design basis event, outside of the additional test performed after an OBE.

References:

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