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PROPRIETARY INFORMATION – WITHHOLD UNDER 10 CFR 2.390

10 CFR 50.90

November 3, 2011

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

Peach Bottom Atomic Power Station, Units 2 and 3
Renewed Facility Operating License Nos. DPR-44 and DPR-56
NRC Docket Nos. 50-277 and 50-278

Subject: License Amendment Request – Use of Neutron Absorbing Inserts in Units 2 and 3 Spent Fuel Pool Storage Racks

In accordance with 10 CFR 50.90, Exelon Generation Company, LLC (Exelon) requests a proposed change to modify the Technical Specifications (TS) to include the use of neutron absorbing spent fuel pool rack inserts for the purpose of criticality control in the spent fuel pools at Peach Bottom Atomic Power Station (PBAPS), Units 2 and 3.

The proposed changes have been reviewed by the PBAPS Plant Operations Review Committee, and approved by the Nuclear Safety Review Board in accordance with the requirements of the Exelon Quality Assurance Program.

Exelon requests approval of the proposed amendment by November 3, 2012. Implementation of this amendment at PBAPS, Units 2 and 3 shall be conducted over the course of four years, scheduled to begin in early 2013 and will be complete in both units by December 31, 2016.

Attachment 1 contains the evaluation of the proposed changes. Attachment 2 provides the marked up TS pages and a proposed license condition. There are no Bases associated with the Design Features section of the TS.

Attachment 3 contains a figure of the NETCO-SNAP-IN® Rack Insert. Attachment 5 contains NETCO Report NET-259-03, "Material Qualification of Alcan Composite for Spent Fuel Storage," August 2008, Revision 5. Attachment 9 contains an example of a completed array of a rack module with inserts.

Attachments 4 and 6 contain information proprietary to Global Nuclear Fuel. Global Nuclear Fuel requests that these documents be withheld from public disclosure in accordance with 10 CFR 2.390. Attachments 7 and 8 contain a non-proprietary version of the Global Nuclear Fuel documents. Affidavits supporting this request are contained in Attachment 10.

Attachments 4 and 6 transmitted herewith contain Proprietary Information.
When separated from attachments, this document is decontrolled.

In accordance with 10 CFR 50.91, Exelon is notifying the Commonwealth of Pennsylvania of this application for license amendment by transmitting a copy of this letter and its attachments to the designated State Official.

A summary of the regulatory commitments contained in this submittal is provided in Attachment 11.

Should you have any questions concerning this letter, please contact Tom Loomis at (610) 765-5510.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 3rd day of November 2011.

Respectfully,

Michael D. Jesse
Director, Licensing & Regulatory Affairs
Exelon Generation Company, LLC

Attachment 1: Evaluation of Proposed Changes
Attachment 2: Markup of Technical Specifications Pages and Proposed License Condition
Attachment 3: Figure of NETCO-SNAP-IN® Rack Insert
Attachment 4: "Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Rack Inserts," Global Nuclear Fuel, NEDC-33672P, September 2011, Revision 0 (Proprietary Version)
Attachment 5: NETCO Report NET-259-03, "Material Qualification of Alcan Composite for Spent Fuel Storage," August 2008, Revision 5
Attachment 6: "Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Boraflex," Global Nuclear Fuel, NEDC-33686P, September 2011, Revision 0 (Proprietary Version)
Attachment 7: "Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Rack Inserts," Global Nuclear Fuel, NEDO-33672, September 2011, Revision 0 (Non-Proprietary Version)
Attachment 8: "Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Boraflex," Global Nuclear Fuel, NEDO-33686, September 2011, Revision 0 (Non-Proprietary Version)
Attachment 9: Example of a Completed Array of a Rack Module with Inserts
Attachment 10: Affidavits
Attachment 11: Summary of Commitments

cc: USNRC Region I, Regional Administrator
USNRC Senior Resident Inspector, PBAPS
USNRC Project Manager, PBAPS
R. R. Janati, Bureau of Radiation Protection
S. T. Gray, State of Maryland

ATTACHMENT 1
Evaluation of Proposed Changes

1.0 SUMMARY DESCRIPTION

In accordance with 10 CFR 50.90, "Application for amendment of license, construction permit, or early site permit," Exelon Generation Company, LLC (Exelon) requests an amendment to Renewed Facility Operating License Nos. DPR-44 and DPR-56 for Peach Bottom Atomic Power Station (PBAPS), Units 2 and 3. The proposed change allows the use of NETCO-SNAP-IN® neutron absorbing rack inserts in the Units 2 and 3 spent fuel pool storage rack cells.

2.0 DETAILED DESCRIPTION

The proposed change requests NRC approval for use of an alternate mechanism other than Boraflex for criticality control. This application requests approval to use a neutron absorbing rack insert that can be installed into a spent fuel pool storage rack cell and credited as a replacement for the neutron absorbing properties of the Boraflex panels. Exelon is requesting this license amendment to use NETCO-SNAP-IN® rack inserts to provide an alternative method of ensuring neutron absorption in the Unit 2 and Unit 3 spent fuel pool storage racks to meet the effective neutron multiplication factor, K_{eff}, criticality control requirement without reliance on Boraflex. This license amendment request is modeled after a license amendment request for the LaSalle County Station, Units 1 and 2, to use the NETCO-SNAP-IN® inserts that has been partially approved by the NRC ("LaSalle County Station, Units 1 and 2, Issuance of Amendments Concerning Spent Fuel Neutron Absorbers (TAC Nos. ME2376 and ME2377) (RS-09-133)," dated January 28, 2011, Accession No. ML110250051).

In the period of time during installation of the rack inserts, the interim configuration criticality analysis (Attachment 6) will apply. Accordingly, a license condition (see Section 2.2) is proposed to ensure criticality safety in the spent fuel pool during the rack insert installation period. This license condition provides a graded approach to the Boraflex degradation during the installation period and is based on the LaSalle County Station, Units 1 and 2 Safety Evaluation Report (ML110250051).

Fabrication of the NETCO-SNAP-IN® rack inserts is scheduled to begin in 2012. Installation of the inserts in all accessible and undamaged spent fuel pool storage rack cells (e.g., cells with no obstructions or damage preventing a rack insert from being placed in the cell) is scheduled to begin in the Unit 2 spent fuel pool in early 2013. Installation of all inserts in both spent fuel pools is scheduled to be complete in both units by December 31, 2016.

Upon installation of all rack inserts, reliance on Boraflex as a neutron poison material will have been completely eliminated. However, the NETCO-SNAP-IN® rack inserts will not be credited for criticality control prior to gaining NRC approval of this proposed change.

2.1 Proposed Changes to Technical Specifications

The PBAPS, Units 2 and 3 Technical Specification (TS) requirements related to spent fuel storage are contained in TS Section 4.3, "Fuel Storage." TS 4.3.1 currently identifies requirements pertaining to the design of the spent fuel pool storage racks. Specifically, TS 4.3.1.1.a currently requires a maximum k-infinity of 1.362 in the normal reactor core configuration at cold conditions. TS 4.3.1.1.b currently requires K_{eff} to be $\leq$ 0.95 if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 10.3 of the Updated Final Safety Analysis Report (UFSAR). TS 4.3.1.1.c currently requires a nominal 6.280-inch center-to-center distance between fuel assemblies placed in the spent fuel pool storage racks.

The proposed changes in this license amendment request include a revision to TS 4.3.1.1.a and the addition of one new TS requirement, 4.3.1.1.d. Those changes are as follows:

a. Fuel assemblies having a maximum k-infinity of ~~1.362~~ 1.270 in the normal reactor core configuration at cold conditions.

d. The installed neutron absorbing rack inserts having a Boron-10 areal density ≥ 0.0102 g/cm^2.

A markup of the proposed TS changes is provided in Attachment 2. The UFSAR will also be revised, upon implementation of the approved amendment, as part of Exelon's configuration control process.

We note that a maximum fuel assembly enrichment is not included in these proposed TS changes. This is consistent with the standard TS for General Electric BWR/4s in NUREG-1433, "Standard Technical Specifications General Electric Plants, BWR/4," April 1995, as approved for the PBAPS, Units 2 and 3 TS conversion (Safety Evaluation Report dated August 30, 1995). Technical Specification 4.3.1.1.a in NUREG-1433 includes the maximum k-infinity in the normal reactor core configuration at cold conditions and the maximum average U-235 enrichment as alternative choices for this technical specification. An in-core k-infinity limit is included in proposed TS 4.3.1.1.a for PBAPS, Units 2 and 3 in this amendment request. The enrichment and in-core k-infinity limits each, individually, provide adequate protection to ensure public health and safety in that they determine the reactivity limit for the fuel assemblies that are allowed to be stored in the spent fuel pool storage racks.

The in-core k-infinity limit is an effective limiting specification because it accounts for factors that could affect in-rack reactivity in the future, including the principal fuel assembly drivers of U-235 enrichment and gadolinia loading. Enrichment and gadolinia loading can vary from assembly design to assembly design. However, the in-core k-infinity limit in proposed TS 4.3.1.1.a ensures peak in-rack reactivity does not exceed the design basis supporting the technical specification limit. Using the in-core k-infinity limit ensures that the spent fuel pool criticality analysis remains bounding.

2.2 Proposed Operating License Condition Before and During Insert Installation Period

In the period of time during installation of the rack inserts, the interim configuration criticality analysis (Attachment 6) applies. This analysis assumes a peak in-core k-infinity at cold conditions of 1.235. Accordingly, the following new operating license condition, which is based on the LaSalle County Station, Units 1 and 2 Safety Evaluation Report (ML110250051) is proposed to ensure criticality safety in the spent fuel pool during the rack insert installation period:

> Storage cells in spent fuel storage rack modules without NETCO-SNAP-IN® rack inserts will be placed into one of three categories: Unrestricted, Restricted, and Unusable.
>
> a) Unrestricted will be cells whose minimum panel Boron-10 areal density is greater than or equal to 0.0140 g/cm^2. Unrestricted cells may contain fuel assemblies up to a maximum in-core cold reactivity of 1.235.

b) Restricted will be cells whose minimum panel Boron-10 areal density is between 0.0140 g/cm^2 and 0.0112 g/cm^2. Restricted cells will only contain PBAPS Units 2 and 3 General Electric (GE) 7x7 and GE14 fuel assemblies (maximum in-core cold reactivity of 1.217).

c) Unusable will be cells whose minimum panel Boron-10 areal density is less than or equal to 0.0112 g/cm^2. Unusable cells will be administratively controlled to remain empty of any fuel assembly.

3.0 TECHNICAL EVALUATION

3.1 Overview

3.1.1 Current Spent Fuel Pool Design Basis

UFSAR Section 10.3.3 (Revision 23, April 2011) documents the PBAPS, Units 2 and 3 spent fuel pool safety design bases as summarized below. The spent fuel pool storage rack designs for the two units permit a single set of supporting analyses to apply to both units.

a) All arrangements of fuel in the spent fuel storage racks are maintained in a subcritical configuration having $K_{eff} \leq 0.95$ for all conditions.

b) Each spent fuel storage rack loaded with fuel and the pool structure are designed to withstand seismic loading to minimize distortion of the spent fuel storage arrangement or loss of spent fuel pool level.

PBAPS has two separate spent fuel pools, one for each unit, that provide for storage of new (unirradiated) and spent fuel in a safe manner. The spent fuel pool storage racks provide storage for spent fuel assemblies received from the reactor vessel and new fuel for loading into the reactor vessel. The fuel storage racks are freestanding, full-length, top entry, and are designed to maintain the spent fuel in a space geometry that precludes the possibility of criticality (K_{eff} will not exceed 0.95) under design conditions.

The high-density spent fuel pool storage racks are of the "poison" type, utilizing a neutron absorbing material (currently Boraflex) to maintain a subcritical fuel array (see UFSAR Figures 10.3.1, 10.3.2, and 10.3.3 (Revision 23, April 2011)). The rack modules are rectilinear in shape and are of nine different array sizes (see UFSAR Figures 10.3.4 for Unit 2 and 10.3.5 for Unit 3 (Revision 23, April 2011)). A total of 3,819 storage locations among 15 spent fuel pool storage racks are provided in each pool. A spent fuel storage criticality evaluation is performed for each reload to demonstrate that the reload fuel assemblies meet in-core k-infinity and rack K_{eff} storage criticality requirements. Rack module data are provided in UFSAR Table 10.3.2 (Revision 23, April 2011).

The high density spent fuel pool storage racks are constructed of stainless steel and each rack module is composed of cell assemblies, a base plate, and base support assembly. Each cell assembly is composed of a full-length enclosure constructed of 0.075-inch thick stainless steel, sheets of Boraflex neutron absorbing material, and wrapper plates constructed of 0.020-inch thick stainless steel.

The nominal inside square dimension of each fuel cell enclosure is 6.070 inches, which accommodates either channeled or unchanneled fuel, and consolidated fuel assemblies. The Boraflex was initially certified to contain an initial Boron-10 areal density of 0.021g/cm^2. The Boraflex panels are continuous sheets centered on the length of the active fuel in the fuel cell. The stainless steel wrapper plates are attached to the outside of the cell wall by intermediate stitch welding along the entire length of the wrapper, forming an encapsulation of the Boraflex panel. A water-tight seal is not provided for the wrapper plates attached to the cell walls.

3.1.2 Boraflex Degradation

Boraflex is currently in use in the PBAPS, Units 2 and 3 spent fuel pools and is credited in the current licensing basis criticality analysis for the wet storage racks. NRC Generic Letter 96-04, "Boraflex Degradation in Spent Fuel Pool Storage Racks," documents a concern with the Boraflex neutron absorbing material used in spent fuel pools. Specifically, when Boraflex is subjected to gamma radiation in a spent fuel pool environment, the silicon polymer matrix becomes degraded and silica filler, boron carbide, and soluble silica are released. The degradation of Boraflex in the PBAPS spent fuel pools has reduced its ability to perform its neutron absorption design function since the degradation was discovered, and is continuing.

A Boraflex monitoring program, comprised of BADGER testing and RACKLIFE analyses, is currently used to track and trend the rate of neutron absorber material degradation. The Boraflex monitoring program will continue to be maintained for as long as Exelon continues to credit Boraflex for criticality control, until the installation of NETCO-SNAP-IN® rack inserts is complete in both spent fuel pools.

3.1.3 Proposed Method for Mitigation of Boraflex Degradation

This proposed change requests approval to install NETCO-SNAP-IN® rack inserts into individual spent fuel pool storage rack cells to ensure that the requirement to maintain K_{eff} less than or equal to 0.95, if fully flooded with unborated water, continues to be met. Attachment 3 provides a figure of a NETCO-SNAP-IN® rack insert.

The rack insert has a vertical length equal to the length of the spent fuel pool storage rack cell and the lower end of the insert is tapered to facilitate insertion into the spent fuel pool storage rack cell. The rack insert material contains boron carbide particles homogeneously distributed in the metal.

The NETCO-SNAP-IN® inserts are formed with a greater than 90 degree bend angle. This requires compression of the rack insert to install it into the spent fuel pool storage rack cell. After installation, the insert will conform to the 90 degree angle between adjacent spent fuel storage rack cell walls. When installed, the rack insert wings abut against the two adjacent faces of the spent fuel pool storage rack cell wall.

The PBAPS inserts are slightly thicker (0.075 in. vs. 0.065 in.) and contain slightly more Boron (19% B_4C vs. 17% B_4C) than the inserts used at the LaSalle County Station. The dimensions of the PBAPS inserts are also slightly different as they are specifically designed to fit into the PBAPS spent fuel pool storage racks.

Near the top of the NETCO-SNAP-IN® rack insert is a hole in each wing that engages the installation tool. The rack insert is designed to become an integral part of the spent fuel storage rack once it has been installed. This is achieved through the elastic deformation of the rack insert bearing against the spent fuel pool storage rack cell wall, and the associated friction force. The force exerted due to this deformation is determined by the material properties of the rack insert. The force between the wings of the rack insert and the spent fuel storage rack cell walls in conjunction with the static friction between these surfaces serves to retain the NETCO-SNAP-IN® rack insert and make it an integral part of the spent fuel pool storage rack once it is installed.

A criticality analysis for the PBAPS, Unit 2 spent fuel pool crediting the NETCO-SNAP-IN® rack inserts has been performed to support this design change (Attachment 4). This analysis also bounds the condition in the Unit 3 spent fuel pool. Criticality analyses have been performed using a peak reactivity lattice for each fuel assembly (k-infinity of 1.270 at cold conditions). This assumed reactivity is more reactive than the lattice for any fuel assembly stored in either the Unit 2 or Unit 3 spent fuel pool and operating in either the Unit 2 or Unit 3 reactor, to assure compliance with the spent fuel criticality control requirements in 10 CFR 50.68(b).

The analysis demonstrates that K_{eff} remains less than or equal to 0.95 for the normal and abnormal cases evaluated, with credit for the NETCO-SNAP-IN® rack inserts and no soluble boron in the spent fuel pool water. It is important to note that the Boraflex panels will remain in place in the spent fuel pool storage rack cells, which will provide additional neutron absorption capability that is not credited in the rack insert criticality analysis. Water is modeled in the criticality analysis in spaces where the Boraflex panels are located.

It is also known that some specific spent fuel pool storage rack cells will not be able to accept the insertion of either the NETCO-SNAP-IN® rack insert or spent fuel, or both, due to rack damage or inaccessibility caused by a physical interference. Spent fuel will not be stored in those cells that do not contain a NETCO-SNAP-IN® rack insert. Rack cells that can accommodate an insert but not a fuel assembly may have an insert installed if needed for storage of a fuel assembly in an adjacent cell. The criticality analysis addresses the effect on the spent fuel pool storage array K_{eff} when both rack inserts and fuel assemblies cannot be inserted into a spent fuel pool storage rack cell. The misloading of a design basis, peak reactivity fuel assembly into a cell location without an insert is analyzed as an accident condition in the criticality analysis (see Attachment 4, Section 5.5).

3.1.4 Demonstration of Proposed Method for Rack Insert Installation

The mechanical feasibility of the use of NETCO SNAP-IN® rack inserts will be verified by installing several rack inserts into the PBAPS Unit 2 spent fuel pool storage rack cells in a demonstration program. Fuel assembly insertion and removal testing in cells with inserts installed will be performed with a dummy fuel assembly. The demonstration program in Unit 2 also applies to Unit 3.

The NETCO-SNAP-IN® rack inserts to be used in the PBAPS demonstration program are designed, fabricated, tested, and inspected under the NETCO quality assurance program to ensure they meet the design requirements for the permanent inserts. A small number of the inserts will be left in the rack cells for permanent use. No credit for the neutron absorption capabilities of these PBAPS demonstration rack inserts will be taken. The purpose of the PBAPS insert demonstration program is to:

- Ensure that the NETCO-SNAP-IN® rack insert design to be used at PBAPS, Units 2 and 3 fits in all rack cell types and can be installed and removed before final fabrication and installation of the balance of the inserts,

- Train personnel and dry run the procedures and tooling used for insert installation and removal,

- Ensure spent fuel assemblies will fit into rack cells containing inserts and can be installed and removed without hang-up or significant drag forces between the fuel assembly and the insert or rack cell wall, and

- Verify the inserts will not dislodge during installation and removal of fuel assemblies.

3.1.5 Final Implementation of Proposed Method for Rack Insert Installation

When installed, the rack insert wings abut against the two adjacent faces of the spent fuel pool storage rack cell wall. The rack insert is made entirely of the Rio Tinto Alcan composite neutron absorbing material and encompasses the full length of the active fuel region of the fuel assembly when installed in the storage rack cell. The rack insert is nominally the same length as a rack cell (169 inches) and will rest on the bottom of the spent fuel pool rack cell at the same elevation as the bottom of the fuel assembly situated in the rack cell.

The permanent NETCO-SNAP-IN® rack inserts will be installed in stages to take credit for the rack inserts for criticality control on a rack module by rack module basis. In order to take credit for rack inserts for criticality control, the following conditions must be met:

a) The rack inserts are installed in all accessible and undamaged locations in the rack module;

b) The rack inserts are installed in all accessible and undamaged cells in the first row and first column of the rack modules adjacent to the rack module where the cell sides are not already covered by a wing of the rack insert (see Attachment 9); and

c) This license amendment is approved.

This will ensure that at least one rack insert wing will be installed between all fuel assembly storage locations in a rack module before criticality control credit is taken for a NETCO-SNAP-IN® rack insert in that rack module.

Exelon plans to install rack inserts in one spent fuel pool storage rack module at a time. Once the three conditions listed above are met, the installation will be consistent with the criticality analysis and that rack module can be credited for the neutron absorption provided by the NETCO SNAP-IN® rack inserts. Using this approach, storage rack modules will be either completely credited or non-credited for rack inserts during the four-year insert installation process. The installation of the rack inserts will not adversely affect the criticality of the remainder of the spent fuel storage rack modules without inserts installed or only partially installed.

The installation of the NETCO-SNAP-IN® rack inserts will be controlled as a design change. Site reactor engineers are responsible for identifying the correct spent fuel storage rack cell for all fuel assemblies and planning fuel moves. All fuel moves will be conducted in accordance with existing plant procedures governing special nuclear material control.

Because the NETCO-SNAP-IN® rack inserts will be installed in stages, there will be periods when some individual spent fuel storage rack modules will have reactivity control via the installed rack inserts and other spent fuel storage rack modules will have reactivity control via Boraflex. Since each of these configurations have individually been shown to meet the 0.95 K_{eff} criterion, any combination of these configurations in the spent fuel pool will also meet the 0.95 K_{eff} criterion. After all the undamaged and accessible rack cells in an individual spent fuel pool storage rack module have had rack inserts installed and the above criteria are satisfied, the Boraflex monitoring program on that spent fuel storage rack module is no longer necessary and will be discontinued for that storage rack module.

3.1.6 Installation Schedule

Several inserts will be installed in the PBAPS, Unit 2 spent fuel pool during the demonstration program and a small number will be left in place. However, the majority of the rack inserts will be installed over a four-year period beginning in early 2013 using the 10 CFR 50.59 change process and will be complete in both units by December 31, 2016. No credit for the neutron absorption capabilities of these PBAPS demonstration rack inserts will be taken until the license amendment request is approved.

3.2 Criticality

3.2.1 Criticality Evaluation for Final Spent Fuel Pool Configuration

A criticality safety analysis was performed to support the storage of spent fuel in the PBAPS, Units 2 and 3 spent fuel pools in various configurations with the NETCO-SNAP-IN® rack inserts installed. The analysis (Attachment 4) demonstrates that, for a fuel assembly with a maximum in-core k-infinity of 1.270 at cold conditions, the effective neutron multiplication factor, K_{eff}, is less than or equal to 0.95 with:

a) The spent fuel pool storage racks fully loaded with a GNF2 fuel design that has higher reactivity than any as-fabricated fuel in the PBAPS, Unit 2 or Unit 3 spent fuel pools;

b) No negative reactivity credit taken for the Boraflex installed between spent fuel pool storage rack cells (Boraflex is modeled as water);

c) NETCO-SNAP-IN® rack inserts installed in all accessible and undamaged spent fuel pool storage rack cells;

d) The spent fuel pool assumed to be flooded with unborated water; and

e) Moderator temperature effects studied and appropriate reactivity biases conservatively applied in the analysis based on the results.

The reactivity of the PBAPS, Units 2 and 3 spent fuel pool storage racks fitted with NETCO-SNAP-IN® rack inserts has been calculated using the computer codes MCNP-05P (the GEH/GNF proprietary version of MCNP5) and TGBLA06. MCNP-05P has been validated and verified for spent fuel pool storage rack evaluations by benchmarking calculations of light water reactor (LWR) critical experiments (included as part of Attachment 4). TGBLA06 has been benchmarked against MCNP.

The NRC has previously approved the MCNP-05P/TGBLA06 code package for use in a similar spent fuel pool criticality analysis (see GNF Report NEDC-33374P-A, "Safety Analysis Report for Fuel Storage Racks Criticality Analysis for ESBWR Plants," September 2010 (ML102860687)). Draft NRC Interim Staff Guidance (ISG) DSS-ISG-2010-01 (Reference 5) was also considered when performing the criticality analysis.

3.2.2 Interim Criticality Evaluation of Rack Insert Installation Period

An interim criticality safety analysis was also performed to support the storage of spent fuel in the PBAPS, Units 2 and 3 spent fuel pools with Boraflex as the neutron absorber. The analysis is provided to address the rack modules that do not yet have NETCO-SNAP-IN® rack inserts installed, so no credit is taken in this analysis for rack inserts. This analysis will be part of the PBAPS spent fuel pool licensing basis until rack inserts are installed in all accessible and undamaged cells in the PBAPS, Units 2 and 3 spent fuel pools. The analysis (provided as Attachment 6 to this LAR) demonstrates that the effective neutron multiplication factor, K_{eff}, is less than or equal to 0.95 with:

a) The areal densities as described in the license condition contained in Section 2.2;

b) The spent fuel pool assumed to be flooded with unborated water;

c) Moderator temperature effects studied and appropriate reactivity biases conservatively applied in the analysis based on the results; and

d) Boraflex degradation, as described in Section 3.1.2, is modeled in the analysis. The analysis also includes uncertainties in the measurement and projection of Boraflex degradation. The specific modeling parameters used are described below.

Boraflex degradation can occur through several different degradation mechanisms. The Boraflex criticality safety analysis conservatively models the degradation mechanisms discussed below. It also conservatively bounds the uncertainties involved in measuring and predicting the degradation when determining if the Boraflex cell can be used to store fuel to support the proposed license condition in Section 2.2. Each of the degradation mechanisms is addressed individually. Since it is unlikely that all of these degradation mechanisms are concurrently in a worst case degradation condition as modeled in the analysis, this analysis methodology produces conservative results. Moreover, the methodology used to calculate the measurement and prediction uncertainties is also conservative. Hence, the criticality safety analysis includes a large margin for Boraflex degradation and measurement, in all its forms.

The following Boraflex degradation issues have been considered for the interim criticality safety analysis:

a) Overall Boraflex panel thinning results in a reduced Boron-10 areal density. The analysis determines the minimum allowable areal densities. These areal densities are included in the proposed operating license condition in Section 2.2, and will be included in the Boraflex monitoring program as described in Section 3.1.2.

b) Gaps in the Boraflex panels have been seen at PBAPS. The latest BADGER testing indicated that the maximum cumulative gap size at PBAPS is 2.7 inches. As an additional conservatism, and to bound future gap size growth, the gap size modeled in the analysis is 3.0 inches.

c) The PBAPS BADGER testing had concluded that gap formation is random. However, in order to most conservatively model the gaps, they have been co-located at the same axial level. This modeling technique results in the most conservative neutron streaming effect.

d) Due to the limitations of BADGER testing measurement capabilities, it is possible that some small cracks (less than one-third inch), may not be detected during testing. Based on previous sensitivity studies for PBAPS, a bias of 0.40% delta-k is applied to account for undetected cracks.

e) Width reduction (edge dissolution) and shrinkage is also possible in Boraflex panels. A 5% width reduction has been applied in the analysis. Very little edge dissolution has been seen in the PBAPS BADGER results. Since the BADGER probes are within 1/8 inch of the edge of the panel, and the panel width is 4.9 inches, any edge dissolution greater than about 2.5% would be evident in the BADGER traces.

f) Boraflex particle self-shielding could also impact the results of the criticality safety analysis, because Boraflex particle size is non-uniform. Based on previous PBAPS sensitivity studies, a bias of 0.253% delta-k is applied to account for particle self-shielding.

g) Since the BADGER test results and RACKLIFE analysis predictions are in terms of average panel density, non-uniform degradation (thinning) is not specifically addressed. After review of the BADGER test results, some non-uniform thinning is observed. However, it is on a limited basis, and a substantial portion occurs at the panel edges and ends, and near gaps. Since the ends of the panels are not the limiting axial position in the criticality analysis, there is no negative impact on the calculated margin in the criticality safety analysis. The local non-uniform thinning near the panel edges is bounded by the 5% panel width reduction. Finally, the very limited local dissolution in the center region of the panel is bounded by the conservative gap assumptions used in the analysis (3.0-inches co-located gaps).

h) In the event of a seismic event, it is possible that Boraflex panels could shift within the wrapper plate. The Boraflex is generally confined within the wrapper plate, but it is possible that the Boraflex could shift downward and the gaps would then be accumulated at the top of the panel. However, this is bounded by the modeling of co-located 3.0-inch gaps, which bounds the maximum cumulative gaps size seen in the PBAPS BADGER testing to date.

i) A detailed calculation of the bias and bias uncertainty of the BADGER testing measurements and RACKLIFE analysis projections has been performed. This calculation closely follows the methodology described in NUREG/CR-6698 ("Guide for Validation of Nuclear Criticality Safety Calculational Methodology", dated January 2001) for calculational (RACKLIFE) and experimental (BADGER) uncertainties. The results of this calculation showed that the RACKLIFE prediction bias was positive (the RACKLIFE predicted degradation was higher than the BADGER measured degradation). This bias is conservatively ignored. The bias uncertainty calculated was 33.2% degradation. This value is applied in the interim criticality safety analysis. This uncertainty is large compared to typical measurement and calculational uncertainties, likely due to limited BADGER measured data. Improvements in the BADGER testing equipment and measurement techniques are likely to result in improvements in this area. Furthermore, the positive bias in the RACKLIFE model (conservatively ignored) ensures that the model used to determine the usability of individual cells is conservative. BADGER test reports have been previously submitted to the NRC in Exelon letters dated February 9, 2011 and April 18, 2011.

The application of the above modeling parameters and uncertainties ensures that the interim criticality safety analysis results in a conservative K_{eff}.

The reactivity of the PBAPS, Units 2 and 3 spent fuel pool storage racks with Boraflex has been calculated using the same methodology and benchmarking techniques described in Section 3.2.1 for the rack insert analysis.

3.3 Materials

The NETCO-SNAP-IN® rack Rio Tinto Alcan composite insert material must ensure that the neutron absorber remains in place over the lifetime of the spent fuel pool storage racks during normal operation and abnormal events. Attachment 5 provides a detailed evaluation of the Rio Tinto Alcan composite material for use in the PBAPS spent fuel pool environment. This report demonstrates that the material meets the requirements as a neutron absorber to maintain the spent fuel pools within design and regulatory limits over the life of the spent fuel pool storage racks. Testing has been performed to confirm its acceptability and the surveillance programs described in Section 3.9 will be established to confirm its continued acceptability to perform its required design functions in the PBAPS spent fuel pools.

The production process for manufacturing the rack inserts is described in detail in Attachment 5. The rack insert is made from one sheet of composite material. Rio Tinto Alcan has found that by adding small amounts of titanium to the molten aluminum, the B_4C particles become stable in the molten aluminum, eliminating particle clusters, and a uniform blend is achieved.

Coupons will be cut from each rolled rack insert blank, which is of sufficient size to manufacture two rack inserts. Samples from the coupons are subjected to neutron attenuation testing to verify the as-manufactured Boron-10 areal density and mechanical testing to assure sufficient ductility to permit forming.

3.3.1 Areal Density of Boron-10

The insert manufacturing quality assurance testing lower limit for the areal density of boron in the Rio Tinto Alcan composite is given in terms of the isotope of Boron-10, and is 0.0105 g/cm^2. This minimum certified value used for manufacturing ensures the Boron-10 areal density value used in the criticality analysis, 0.0102 g/cm^2, is met, with some additional margin. Verification of the minimum certified areal density of Boron-10 in the rack inserts is performed during manufacturing. Verification of the areal density of Boron-10 over the lifetime of the racks will be performed through the long-term coupon surveillance program described in Section 3.9.3.

The measurement uncertainty of the neutron attenuation testing is taken into account, at a 95% confidence level, when determining the acceptability of a given test result. Individual tested coupons must exceed the 0.0105 g/cm^2 Boron-10 limit with this uncertainty subtracted from the measured value. Additionally, an analysis is performed on the coupon population's areal density to ensure that the 95/95 limit of the production batch exceeds the minimum specified areal density value of 0.0105 g/cm^2. Production batches encompass all inserts made from the same stock of raw material.

3.3.2 Corrosion

Resistance to material loss, pitting, cracking, and blistering is important to ensuring that the Boron-10 will not be lost, and that distortion of the rack insert will not interfere with future fuel movement. Attachment 5 provides detailed discussion of the corrosion-resistance properties of the Rio Tinto Alcan composite material. The material qualification program included material at 16% and 25% B_4C loadings of boron carbide. The as-tested boron carbide loadings of the test coupons bound the loading to be used at PBAPS (19% B_4C).

An accelerated corrosion test program was performed to determine the susceptibility of the Rio Tinto Alcan composite to general (i.e., uniform) and localized (i.e., pitting) corrosion in BWR spent fuel pools. This program is described in detail in Attachment 5. Three types of coupons were tested: (1) rectangular general coupons, to determine the rate at which a uniform oxide film forms; (2) bend coupons, formed to the same bend angle and bend radius used for the NETCO-SNAP-IN® rack insert, to determine whether or not bend deformation and stress adversely affect the corrosion susceptibility of the Rio Tinto Alcan material; and (3) galvanic (i.e., bi-metallic) coupons, prepared with the Rio Tinto Alcan composite and 304L stainless steel, Inconel 718, and Zircaloy materials to evaluate the potential for galvanic corrosion. Coupons have been tested at the NETCO laboratory in deionized water, simulating BWR pool conditions at 195°F (90.5°C) to accelerate any corrosion effects, for greater than 8,000 hours. Coupons were removed after approximately 2,000, 4,000, 6,000, and 8,000 hours and subjected to testing. This test program has been completed and the evaluation is presented in Attachment 5, Table 5-7.

Prior to testing, the coupons were pre-characterized with respect to thickness, weight, and Boron-10 areal density. After testing, the coupons were subjected to post-test characterization of these same attributes. The testing results are described in Attachment 5. Measured corrosion rates were very low. The reason for the low corrosion rates is that once an oxide film forms on all surfaces, the film tends to be self-passivating and tends to inhibit further corrosion. This property of the oxide film lends to the excellent corrosion resistance of AA1100 aluminum alloy. It is noted that the conversion of a thin, uniform layer to the oxide does not result in a loss of the boron carbide neutron absorber. This is confirmed by the neutron attenuation measurement results that show no change in Boron-10 areal density.

Optical microscopy was performed to verify that the oxide films were substantially removed prior to determining coupon weight loss and prior to inspecting for any anomalies along the outer bend radii of the bend coupons. Optical microscopy of the inside and outside radius of the bend coupons before and after acid cleaning revealed no cracks or other anomalistic corrosion behavior.

Initial corrosion rates for the NETCO-SNAP-IN® rack insert will be established using the LaSalle County Station fast start coupon surveillance program described in Section 3.9.2. Corrosion rates will be confirmed to be within acceptable limits via the long-term coupon surveillance program described in Section 3.9.3.

Once installed, the NETCO-SNAP-IN® rack inserts assume a constant strain condition within the spent fuel pool storage rack cell. This compression leads to internal stresses, especially at the bend, that might make the rack inserts susceptible to stress corrosion cracking. An examination of the literature on the subject (i.e., References 1 and 2) indicates that, in general, high-purity aluminum and low-strength aluminum alloys are not susceptible to stress corrosion cracking. However, surveillance bend coupons to be placed in the spent fuel pool prior to the installation of the rack inserts will be maintained under the same strain conditions to provide indication of any unexpected crack phenomena.

3.4 Mechanical

3.4.1 Fuel Assembly Clearance

Placement of the rack inserts in a spent fuel pool storage rack cell slightly reduces the cell inside dimensions available for fuel assembly insertion. The insert demonstration program in the Unit 2 spent fuel pool will be used to demonstrate adequate clearance between a fuel assembly and rack cells containing inserts by inserting and removing a dummy fuel bundle that is dimensionally the same as a channeled fuel assembly. The design clearance in a rack cell containing an insert is nominally 0.25 inch on all sides.

If there is unexpected warping or bowing of the rack insert after installation that reduces the fuel assembly-to-spent fuel storage rack insert clearance, then the fuel handler would notice increased force indicated on the hoist load cell when attempting to raise (i.e., remove) an assembly. If the rack insert did inadvertently come out of a spent fuel storage rack cell with an assembly, then this condition would be bounded by the missing rack insert evaluation of the criticality analysis (i.e., Section 5.5 of Attachment 4).

If a spent fuel assembly cannot fit into the Unit 2 or Unit 3 spent fuel storage rack cells containing rack inserts due to mechanical clearances, the fuel assembly will be de-channeled and stored.

3.4.2 Mechanical Wear

Minimal insert material wear is expected due to adequate clearance between the fuel assembly and rack insert that will be verified during the on-site demonstration program. The spent fuel storage rack cells allow a nominal 0.25 inch of clearance between the fuel assembly and the cell wall on all four sides, with an insert installed. The combined effects of adequate clearance and infrequent fuel assembly movement will preclude significant wear of the rack insert. Rack inserts in high duty rack cell locations (i.e., those with a relatively high number of fuel assembly insertions and removals) will be inspected for wear as described in Section 3.9.4, "Full Rack Insert Surveillance Inspections."

Manufacturing experience with the inserts has shown that handling and environmental damage may lead to scratches and surface imperfections locally along the insert length. Local effects have been accounted for in the criticality analysis by conservatively assuming that an entire insert is missing from a cell. Because the clearance between the fuel and insert is verified by a suitably-sized dummy fuel assembly, it is unlikely that a significant number of those events would result in any contact leading to uniform degradation of the insert face. Ongoing mechanical wear will be tested as part of the full rack insert surveillance inspection program described in Section 3.9.4.

3.4.3 Retention Forces

The rack inserts are intended to be a permanent addition to the spent fuel storage racks. Therefore, it is important to ensure that the installed rack inserts remain in place under loads experienced during insertion and removal of fuel assemblies from the spent fuel storage rack cells. The retention forces will be measured in the PBAPS demonstration program to ensure that the inserts will not dislodge during fuel assembly placement and removal.

3.4.4 Insertion and Removal Forces

In competition with the need to provide sufficient retention force for the rack inserts is the need to control the amount of force required to install and remove the rack inserts to avoid damage to the insert and the rack cell wall. Testing of the rack inserts will be performed during the PBAPS insert demonstration program for the following phenomena: insertion forces, drag forces, and withdrawal forces.

The insertion force is developed from the weight of the insert tool and insert. The NETCO-SNAP-IN® rack inserts each weigh approximately 12 pounds. The combined weight of the installation tool and insert will weigh less than 1000 pounds. This limits the force available to be applied to the rack insert during installation since the gravitational weight of the installation tool is the only force applied to install the rack insert. This insertion force will not damage the existing spent fuel pool storage rack structural integrity or the rack insert itself. The insert tool and insert combined weight meets the requirements of UFSAR Section 10.4.11 (Revision 23, April 2011), which requires loads over the spent fuel pool storage racks to be limited to less than or equal to 1200 pounds.

Acceptance testing will be performed to establish the force required to withdraw an insert from a fuel storage rack cell. The acceptance criterion will be that each insert must resist a minimum specified upward load and remain in position.

3.4.5 Stress Relaxation in the Absorber Rack Inserts

During installation, the NETCO-SNAP-IN® rack inserts are compressed from an initial bend angle greater than 90 degrees to the square dimensions of the spent fuel storage rack cell interior. Once installed, the internal stresses in the rack inserts may be susceptible to slight relaxation over time. This relaxation would result in less force against the spent fuel storage rack cell wall and lower retention force. An analysis of stress relaxation in aluminum alloys has been performed to establish the expected performance of the rack inserts in this regard.

During initial NETCO prototype testing, it was demonstrated that the Rio Tinto Alcan W1100N.16B alloy had similar mechanical characteristics to Type 6061 aluminum alloys. Reference 3 details the stress relaxation performance of 6061-T6 alloy after 1000 hours at various temperatures. The data show approximately 15% stress relaxation after 1000 hours at 100°C (212°F).

The bulk water temperature in the PBAPS spent fuel pools is maintained less than 150°F. Stress relaxation at this temperature is expected to be significantly lower than 15% over 1000 hours. As an upper limit, however, data for Type AA1100-H112 series aluminum was analyzed (Reference 4) to estimate total stress relaxation after 20 years of service. The results of that analysis showed that the Type AA1100 series aluminum was, based upon extrapolated data, expected to have experienced an approximate stress reduction of 50% over 20 years.

Breakaway withdrawal forces will be measured. The acceptance criterion will be established taking into account a reduction in retention force of 50%. This value is adequate to maintain the rack inserts in their configuration during fuel movement operations. However, a reduction in retention force of less than 50% is anticipated due to the following factors that tend to mitigate the stress relaxation effects:

a) Stress relaxation in boron carbide reinforced aluminum would be less than for the pure alloy, and

b) The formation of an oxide film on the surface of the rack inserts would increase the stress by increasing the spacing between the spent fuel storage rack cell wall and the rack insert, as well as the coefficient of friction between the rack insert and the spent fuel storage rack cell wall.

3.5 Structural

A structural analysis is being performed to show that the in-service loads on the NETCO-SNAP-IN® rack insert during normal and seismic conditions are insufficient to cause an operational failure of the rack insert. An operational failure in this context is the inability of the rack insert to perform its intended function as a neutron absorber or to maintain the critical characteristics to which it was manufactured.

The rack insert has a pre-installed angle of greater than 90 degrees. After installation, the insert will be at approximately 90 degrees. The rack inserts will exert a force against the spent fuel pool storage rack cell wall less than or equal to the force required to install them. The combined weight of the tool and insert is the only force available for installation and is less than 1000 pounds. The stress on the structure of the existing spent fuel pool storage racks due to the force exerted from the rack insert is being evaluated. The calculated stress will be below the allowable stress of the spent fuel pool storage racks, and is, therefore, acceptable.

3.6 Seismic

A calculation was performed to evaluate the effects of the inserts on the existing plant structures, systems, and components (SSCs). The calculation documents that the inserts, when installed, become integral with the spent fuel pool storage rack. The calculation documents that the weight of the insert combined with the weight of a channeled PBAPS fuel assembly is less than the weight used in the original PBAPS Westinghouse spent fuel pool storage rack design, and is thus bounded by the Westinghouse design. Therefore the structural integrity of the Reactor Building, spent fuel pool, and storage racks is not compromised. Additionally, the force exerted to the insert by a fuel bundle during a seismic event will produce a stress much less than the insert minimum material yield stress.

3.7 Thermal-Hydraulic

Installation of the rack inserts does not alter the allowed maximum number of fuel assemblies, maximum heat loads, or methods of determining decay heat loads in the spent fuel pool. The rack inserts displace a small amount of water inventory in the spent fuel pool and may reduce natural circulation flow in the region within the spent fuel pool storage rack cell but outside of the fuel channel/assembly. This has an insignificant impact on the heat transferred to the spent fuel pool and the heat removal capability of the spent fuel pool cooling system. The volume of water displaced by the rack inserts is negligible compared to the total spent fuel pool water volume. Fuel assembly heat removal via natural circulation through the fuel assembly itself is not significantly affected. There is also a negligible impact on the time-to-boil and boil-off rate for the spent fuel pool. Therefore, there is an insignificant overall effect on the thermal-hydraulic design of the spent fuel pool due to installation of the rack inserts.

3.8 Abnormal and Accident Conditions

3.8.1 Accident/Abnormal Considerations Related to Criticality

Abnormal configurations related to the depletion conditions of the stored spent fuel assemblies were explicitly considered (see Section 5.5 of Attachments 4 and 6). Each description defines a credible abnormal condition that all bundles in storage are assumed to experience over their entire exposure histories.

Additionally, the spent fuel rack configuration was analyzed for credible accident scenarios. The scenarios considered are presented in the bulleted list that follows and are discussed in Section 5.5 of Attachments 4 and 6. Unless otherwise noted, these scenarios are considered in both the rack insert and Boraflex analyses:

- Missing NETCO-SNAP-IN® rack insert (rack insert analysis only)
- Misplaced high reactivity bundle (in-core k-infinity = 1.270), in Boraflex region with allowable in-core k-infinity = 1.235 (Boraflex analysis only)
- Dropped/damaged fuel
- No inserts on rack periphery (rack insert analysis only)
- No Boraflex panels on rack periphery (Boraflex analysis only)
- Abnormal positioning of a fuel assembly outside the fuel storage rack
- Dropped bundle on rack
- Rack module sliding which causes water gap between rack modules to close
- Loss of spent fuel pool cooling
- Inaccessible storage locations (rack insert analysis only)

As discussed in Attachments 4 and 6, the criticality analyses performed showed a storage rack maximum K_{eff} less than 0.95 for normal and credible abnormal and accident conditions with tolerances and uncertainties taken into account.

3.8.2 Fuel Handling Accident

Use of the NETCO-SNAP-IN® rack insert does not affect the radiological consequences of the fuel handling accident in the spent fuel pool. The licensing basis fuel handling accident assumes that during a refueling operation, a fuel assembly is moved over the top of the core. While the fuel grapple is in the overhoist condition with the bottom of the assembly above the top of the core (the maximum height allowed by the fuel handling equipment), a main hoist cable fails allowing the assembly, the fuel grapple mast and head to fall on top of the core impacting a group of four assemblies. The dose consequences are limited by the number of rods that fail. Additionally, the radiological consequences of a drop over the spent fuel pool are discussed in section 14.9.2.2 (Refueling Accident) (Revision 23, April 2011) of the UFSAR. Because the rack insert and removal/insert tool are of similar geometry and lighter in weight than a fuel assembly and grapple, use of the rack insert and removal/insert tool is bounded by these events.

3.9 Rack Insert Surveillance Program

3.9.1 Surveillance Program Overview

Rio Tinto Alcan provides an aluminum boron carbide composite from which the NETCO-SNAP-IN® rack inserts are fabricated. Rio Tinto Alcan material has been previously approved for use in spent fuel racks as described in the LaSalle County Station, Units 1 and 2 Safety Evaluation Report (ADAMS Accession No. ML110250051). Initial corrosion testing in simulated spent fuel pool conditions has been described in Section 3.3.2. Exelon will implement three surveillance programs described in the following Sections 3.9.2, 3.9.3, and 3.9.4 that consist of monitoring the physical properties of the absorber material, performing periodic neutron attenuation testing to confirm the physical properties, and observing the inserts for wear.

During any surveillance, if an off-normal condition is confirmed, the condition would be entered into Exelon's corrective action program for disposition.

3.9.2 Fast Start Coupon Surveillance Program

The fast start coupon surveillance program was initiated at LaSalle County Station before the first deployment of NETCO-SNAP-IN® rack inserts. This program consisted of a series of 24 coupons cut from extra Rio Tinto Alcan composite produced for the LaSalle demonstration program. This coupon string was installed in the LaSalle spent fuel pool. The coupons cut from the demonstration program Rio Tinto Alcan material were 2x4 inches and had two 0.25 inch diameter holes along the top and bottom edge. The purpose of the fast start program is to provide early performance data on the Rio Tinto Alcan composite in a spent fuel pool environment.

Following each LaSalle County Station refueling outage, the fast start coupons will be placed in a spent fuel storage rack cell surrounded in all eight locations with freshly discharged fuel and remain there until the next refueling outage. In this manner the gamma energy deposition and temperatures of the coupons will be maximized. Two coupons will be removed from the string approximately every six months and sent to a qualified laboratory for testing and inspection. The coupons will have been subjected to pre-installation characterization and will be post-test characterized.

The fast-start surveillance program at LaSalle was performed as part of the production development and demonstration effort undertaken by NETCO after Exelon decided to employ NETCO-SNAP-IN® rack inserts made from Rio Tinto Alcan material at LaSalle. The Rio Tinto Alcan material was tested and demonstrated to perform well in the laboratory as part of an 8,000-hour accelerated corrosion test in simulated PWR and BWR pool environments. The fast start coupons were used in the LaSalle spent fuel pools as a confirmatory measure to show that the lab results were truly indicative of actual spent fuel pool performance. Thus, while the fast-start program was prudent when deploying the NETCO-SNAP-IN® rack insert technology for the first application, it is not necessary for subsequent applications given both the LaSalle County Station and PBAPS environments are typical for BWR plants. In addition, the long-term coupon surveillance program will be performed at PBAPS as described in Section 3.9.3.

3.9.3 Long-Term Coupon Surveillance Program

The long-term coupon surveillance program at PBAPS will consist of a specially designed surveillance "tree" to which a series of surveillance coupons are attached. The surveillance "tree" will be placed within a PBAPS spent fuel pool as part of the first installation campaign of NETCO-SNAP-IN® rack inserts and will reside there as long as the spent fuel storage racks with NETCO-SNAP-IN® rack inserts continue to be used. Periodically, as described below, coupons will be removed and sent to a qualified laboratory for testing.

The types and numbers of the long-term surveillance coupons are described in the table below. All coupons will be manufactured to the same material specification as the PBAPS rack inserts. A typical coupon tree is described in more detail in Attachment 5.

Long-Term Surveillance Coupons

Coupon Type	Number	Objective
General	48	(See next Table)
Bend	24	Track effects along bend radii
Galvanic (bi-metallic)	24	Trend galvanic corrosion with 304SS, Inconel 718 and Zircaloy coupons

Specific coupons will be removed from the tree on a frequency schedule in the following tables. The general coupons will be subject to pre- and post-examination according to the following:

ATTACHMENT 1
Evaluation of Proposed Changes

Long-Term Surveillance General Coupon Characterization

Test	Pre-Characterization	Post-Characterization	Acceptance Criteria
Visual (high resolution digital photo)	√	√	Evidence of visual indications
Dimension	√	√	Min. thickness: 0.005 inch less than nominal thickness Length Change: Any change of +/- 0.02 inch Width Change: Any change of +/- 0.02 inch Thickness Change: Any change of +0.010 inch / -0.004 inch
Dry Weight	√	√	Any change of +/- 5%
Density	√	√	Any change of +/- 5%
Areal Density	√ on select coupons	√	0.0102 Boron-10 g/cm^2 minimum loading
Weight Loss		√	Any change of +/- 5%
Corrosion Rate		√	< 0.05 mil/yr
Microscopy		√ as required	At the discretion of the test engineer

The frequency for coupon inspection is shown in the following table.

Frequency for Coupon Inspection

Coupon Type	First Ten Years	After 10 Years with Acceptable Performance
General	2 coupons every 2 years	2 coupons every 4 years
Bend	1 coupon every 2 years	1 coupon every 4 years
Galvanic Couples		
304 Stainless	1 couple every 6 years	
Zircaloy	1 couple every 6 years	
Inconel 718	1 couple every 6 years	

3.9.4 Full Rack Insert Surveillance Inspections

3.9.4.1 Insert In-Situ Inspections

Two rack inserts will be visually inspected by camera at the frequency of the general coupon removal schedule described above to visually monitor for physical deformities such as bubbling, blistering, corrosion pitting, cracking, or flaking. Special attention will be paid to development of any edge or corner defects.

3.9.4.2 Insert Removal and Inspection

A region of high duty spent fuel storage rack cell locations will be identified for this surveillance program. These locations will be monitored for fuel insertion and removal events to ensure that their service bounds that of the general population of storage locations. Once every 10 years, an insert will be removed from this region and will be inspected for thickness along its length at several locations. This collection of measurements will then be compared with the as-built thickness measurements of the removed insert to verify it has sustained uniform wear over its service life.

3.10 Installation of Rack Inserts

A typical installation tool with a NETCO-SNAP-IN® rack insert engaged is shown in Figure 2-3 of Attachment 5. This tool has been modified for use at PBAPS. UFSAR Section 10.4.11 (Revision 23, April 2011) requires loads over the spent fuel storage racks be limited to less than or equal to 1200 pounds unless a specific evaluation of the load is performed. The design weight of the installation tool with the rack insert is limited to no more than 1200 pounds to stay within the PBAPS design basis definition of a heavy load.

The installation tool does not have the capability of removal of a rack insert. A separate removal tool has been designed and fabricated for rack insert removal. Any required removal of rack inserts will be treated as a maintenance/repair activity with the associated configuration controls and confirmation of restored configuration.

The rack inserts will be installed in stages, with each stage of installation resulting in the use of a rack insert in all the spent fuel storage rack cells of a given individual spent fuel storage rack module and cells of the first row and first column of the adjoining spent fuel storage rack modules, so that an insert wing is installed between all adjacent fuel assembly storage locations.

3.11 Summary and Conclusions

The proposed change is necessary to resolve the issue of Boraflex degradation in the PBAPS, Units 2 and 3 spent fuel pool storage racks. The proposed change to install NETCO-SNAP-IN® rack inserts in the spent fuel pool storage racks has been evaluated and shown to be a safe and effective manner in which to resolve the Boraflex degradation issue for the remaining period of time that spent fuel needs to be stored in the PBAPS spent fuel pool storage racks.

4.0 REGULATORY EVALUATION

4.1 Applicable Regulatory Requirements/Criteria

10 CFR 50.68, "Criticality accident requirements," paragraph (b)(4) states that if no credit for soluble boron is taken, the K_{eff} of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with unborated water. The rack insert criticality analyses provided as Attachments 4 and 6 to this submittal demonstrate that this requirement is met.

Paragraph (b)(7) of 10 CFR 50.68 states that the maximum nominal U-235 enrichment of the fresh fuel assemblies is limited to five (5.0) percent by weight. PBAPS new fuel is below 5.0 percent by weight U-235 enrichment.

General Design Criterion (GDC) 5, "Sharing of structures, systems, and components," specifies that structures, systems, and components important to safety shall not be shared among nuclear power units unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions, including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units. The spent fuel pools at PBAPS, Units 2 and 3 are physically separated.

GDC 62, "Prevention of criticality in fuel storage and handling," states that criticality in the fuel storage and handling system shall be prevented by physical systems or processes, preferably by use of geometrically safe configurations. The evaluation of PBAPS's conformance with GDC 62 is discussed in Section 10.3 of the PBAPS UFSAR (Revision 23, April 2011). The NETCO-SNAP-IN® rack insert criticality analysis has been performed to demonstrate that K_{eff} will remain less than or equal to 0.95 with no credit for the Boraflex neutron poison material present in the spent fuel storage racks in the final configuration. Credit for Boraflex is taken in the interim configuration criticality analysis, that demonstrates that K_{eff} will remain less than or equal to 0.95 for that configuration.

4.2 Precedent

Licensing precedent has been established for the use of NETCO-SNAP-IN® rack inserts as described in the LaSalle County Station, Units 1 and 2 Safety Evaluation Report (ADAMS Accession No. ML110250051) to provide an alternate method of criticality control, to address Boraflex degradation. Thus, the proposed amendment would be the second use of NETCO-SNAP-IN® rack inserts in an Exelon plant spent fuel pool for neutron control.

4.3 No Significant Hazards Consideration

Exelon Generation Company, LLC (Exelon) has evaluated whether or not a significant hazards consideration is involved with the proposed amendment by focusing on the three standards set forth in 10 CFR 50.92, "Issuance of amendment," as discussed below.

1. Does the proposed change involve a significant increase in the probability or consequences of an accident previously evaluated?

   Response: No

   The proposed change revises Technical Specification (TS) 4.3.1 to permit installation of NETCO-SNAP-IN® rack inserts in spent fuel storage rack cells. The change is necessary to ensure that, with continued Boraflex degradation over time, the effective neutron multiplication factor, K_{eff}, is less than or equal to 0.95, if the spent fuel pool is fully flooded with unborated water as required by 10 CFR 50.68. Because the proposed change pertains only to the spent fuel pool, only those accidents that are related to movement and storage of fuel assemblies in the spent fuel pool could potentially be affected by the proposed change.

   The installation of NETCO-SNAP-IN® rack inserts does not result in a significant increase in the probability of an accident previously analyzed because there are no changes in the manner in which spent fuel is handled, moved, or stored in the rack cells. The probability that a fuel assembly would be dropped is unchanged by the installation of the NETCO-SNAP-IN® rack inserts. These events involve failures of administrative controls, human performance, and equipment failures that are unaffected by the presence or absence of Boraflex and the rack inserts.

   The installation of NETCO-SNAP-IN® rack inserts does not result in a significant increase in the consequences of an accident previously analyzed because there is no change to the fuel assemblies that provide the source term used in calculating the radiological consequences of a fuel handling accident. In addition, consistent with the current design, only one fuel assembly will be moved at a time. Thus, the consequences of dropping a fuel assembly onto any other fuel assembly or other structure remain bounded by the previously analyzed fuel handling accident. The proposed change does not affect the effectiveness of the other engineered design features to limit the offsite dose consequences of the limiting fuel handling accident.

   Therefore, the proposed change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. Does the proposed change create the possibility of a new or different kind of accident from any accident previously evaluated?

   Response: No

   Onsite storage of spent fuel assemblies in the Peach Bottom Atomic Power Station (PBAPS), Units 2 and 3 spent fuel pools is a normal activity for which PBAPS has been designed and licensed. As part of assuring that this normal activity can be performed without endangering public health and safety, the ability to safely accommodate different possible accidents in the spent fuel pool, such as dropping a fuel assembly or misloading a fuel assembly, have been analyzed. The proposed spent fuel storage configuration does not change the methods of fuel movement or spent fuel storage. The proposed change allows for continued use of spent fuel pool storage rack cells with degraded Boraflex within those spent fuel pool storage rack cells.

The rack inserts are passive devices. These devices, when inside a spent fuel storage rack cell, perform the same function as the previously licensed Boraflex neutron absorber panels in that cell. These devices do not add any limiting structural loads or affect the removal of decay heat from the assemblies. No change in total heat load in the spent fuel pool is being made. The devices will maintain their design function over the life of the spent fuel pool. The existing fuel handling accident, which assumes the drop of a fuel assembly, bounds the drop of a rack insert and/or rack insert installation tool. This proposed change does not create the possibility of misloading an assembly into a spent fuel storage rack cell.

Therefore, the proposed change does not create the possibility of a new or different kind of accident from any accident previously evaluated.

3. Does the proposed change involve a significant reduction in a margin of safety?

   Response: No

   PBAPS TS 4.3.1.1 requires the spent fuel storage racks to maintain the effective neutron multiplication factor, K_{eff}, less than or equal to 0.95 when fully flooded with unborated water, which includes an allowance for uncertainties. Therefore, for criticality, the required safety margin is 5% including a conservative margin to account for engineering and manufacturing uncertainties.

   The proposed change provides a method to ensure that K_{eff} continues to be less than or equal to 0.95, thus preserving the required safety margin of 5%. The criticality analyses demonstrate that the required margin to criticality of 5%, including a conservative margin to account for engineering and manufacturing uncertainties, is maintained assuming an infinite array of fuel with all fuel at the peak reactivity. In addition, the radiological consequences of a dropped fuel assembly are unchanged because the event involving a dropped fuel assembly onto a spent fuel storage rack cell containing a fuel assembly with a rack insert is bounded by the radiological consequences of a dropped fuel assembly without a rack insert. The proposed change also maintains the capacity of the Unit 2 and Unit 3 spent fuel pools to be no more than 3,819 fuel assemblies each.

   Therefore, the proposed change does not involve a significant reduction in a margin of safety.

Based on the above evaluation, Exelon concludes that the proposed amendment presents no significant hazards consideration under the standards set forth in 10 CFR 50.92(c), and accordingly, a finding of no significant hazards consideration is justified.

4.4 Conclusions

In conclusion, based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or the health and safety of the public.

5.0 ENVIRONMENTAL CONSIDERATION

Exelon has determined that the proposed amendment would change a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20, "Standards for Protection Against Radiation." However, the proposed amendment does not involve: (i) a significant hazards consideration, (ii) a significant change in the types or significant increase in the amounts of any effluent that may be released offsite, or (iii) a significant increase in individual or cumulative occupational radiation exposure. Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set forth in 10 CFR 51.22, "Criterion for categorical exclusion; identification of licensing and regulatory actions eligible for categorical exclusion or otherwise not requiring environmental review," paragraph (c)(9). Therefore, pursuant to 10 CFR 51.22, paragraph (b), no environmental impact statement or environmental assessment needs to be prepared in connection with the proposed amendment.

6.0 REFERENCES

1. J. R. Davis, Corrosion of Aluminum and Aluminum Alloys, ASM International, dated November 2000.

2. M. Bauccio, ASM Metals Reference Book, Third Edition, ASM International, dated April 2003.

3. K. Farrell, "ORNL/TM-13049 Assessment of Aluminum Structural Materials for Service Within the ANS Reflector Vessel," Oak Ridge National Laboratory, dated August 1995.

4. John Gilbert Kaufman, Properties of Aluminum Alloys, ASM International, dated 1999.

5. NRC Draft Interim Staff Guidance DSS-ISG-2010-01, "Staff Guidance Regarding the Nuclear Criticality Safety Analysis for Spent Fuel Pools," dated September 1, 2010.

ATTACHMENT 2

Markup of Technical Specifications Pages and Proposed License Condition

<u>Revised TS Pages and License Condition</u>

TS Page 4.0-2 (Units 2 and 3)

License Condition (Units 2 and 3)

4.0 DESIGN FEATURES (continued)

4.3 Fuel Storage

4.3.1 Criticality

4.3.1.1 The spent fuel storage racks are designed and shall be maintained with:

a. Fuel assemblies having a maximum k-infinity of ~~1.362~~ 1.270 in the normal reactor core configuration at cold conditions;

b. $k_{eff} \leq 0.95$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 10.3 of the UFSAR; and

c. A nominal 6.280 inch center to center distance between fuel assemblies placed in the storage racks.

d. The installed neutron absorbing rack inserts having a Boron-10 areal density ≥ 0.0102 g/cm^2.

4.3.1.2 The new fuel storage racks shall not be used for fuel storage. The new fuel shall be stored in the spent fuel storage racks.

4.3.2 Drainage

The spent fuel storage pool is designed and shall be maintained to prevent inadvertent draining of the pool below plant elevation 219 ft.

4.3.3 Capacity

The spent fuel storage pool is designed and shall be maintained with a storage capacity limited to no more than 3819 fuel assemblies.

4.0 DESIGN FEATURES (continued)

4.3 Fuel Storage

4.3.1 Criticality

4.3.1.1 The spent fuel storage racks are designed and shall be maintained with:

1.270

a. Fuel assemblies having a maximum k-infinity of ~~1.362~~ in the normal reactor core configuration at cold conditions;

b. $k_{eff} \leq 0.95$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 10.3 of the UFSAR; and

c. A nominal 6.280 inch center to center distance between fuel assemblies placed in the storage racks.

d. The installed neutron absorbing rack inserts having a Boron-10 areal density ≥ 0.0102 g/cm^2.

4.3.1.2 The new fuel storage racks shall not be used for fuel storage. The new fuel shall be stored in the spent fuel storage racks.

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License Condition for Peach Bottom Atomic Power Station, Units 2 and 3

Storage cells in spent fuel storage rack modules without NETCO-SNAP-IN® rack inserts will be placed into one of three categories: Unrestricted, Restricted, and Unusable.

a) Unrestricted will be cells whose minimum panel Boron-10 areal density is greater than or equal to 0.0140 g/cm^2. Unrestricted cells may contain fuel assemblies up to a maximum in-core cold reactivity of 1.235.

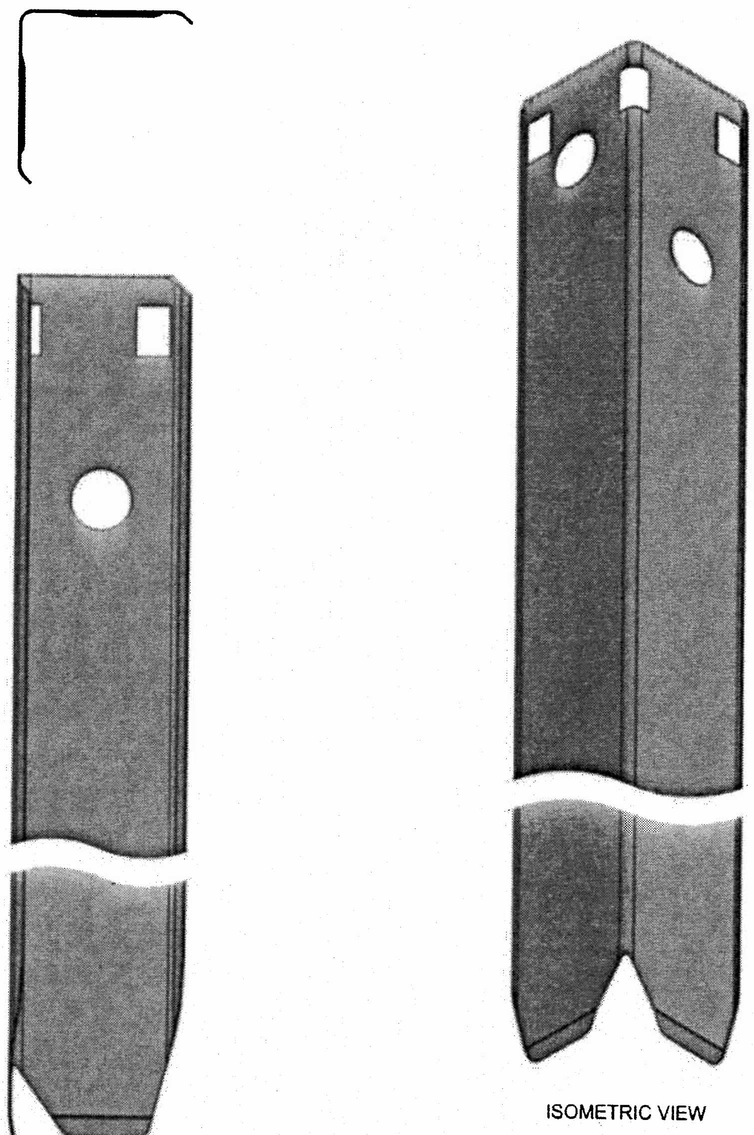
b) Restricted will be cells whose minimum panel Boron-10 areal density is between 0.0140 g/cm^2 and 0.0112 g/cm^2. Restricted cells will only contain PBAPS Units 2 and 3 General Electric (GE) 7x7 and GE14 fuel assemblies (maximum in-core cold reactivity of 1.217).

c) Unusable will be cells whose minimum panel Boron-10 areal density is less than or equal to 0.0112 g/cm^2. Unusable cells will be administratively controlled to remain empty of any fuel assembly.

ATTACHMENT 3

Figure of NETCO-SNAP-IN® Rack Insert

Attachment 3
Figure of NETCO-SNAP-IN® Rack Insert



BCR 4/27/11
KSL 4/27/11
PROJECT 300005

CURTISS WRIGHT Flow Control Company NETCO

TITLE
PEACH BOTTOM SNAP-IN

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SCALE 1:2

ATTACHMENT 5

NETCO Report NET-259-03, "Material Qualification of Alcan Composite for Spent Fuel Storage," August 2008, Revision 5

NET-259-03

MATERIAL QUALIFICATION OF ALCAN COMPOSITE FOR SPENT FUEL STORAGE

Prepared by:

Northeast Technology Corp.
108 N. Front Street
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August 2008

Rev.	Date	Prepared by:	Reviewed by:	Approved (QA):
5	7/30/09	[signature]	[signature]	L. P. Mariani

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1.0 Introduction and Summary

The purpose of this topical report is to demonstrate that aluminum/B_4C sheet produced from DC (direct chill) cast rolling billets supplied by Rio Tinto Alcan Inc. is a suitable 3
material for use as a neutron absorber in spent nuclear fuel storage applications and in particular it is a suitable material from which to fabricate NETCO-SNAP-IN® neutron absorber inserts. The NETCO-SNAP-IN® neutron absorber insert is installed in existing spent fuel storage racks to restore the reactivity hold-down capability of racks with degraded Boraflex. Once installed, these neutron absorber inserts become permanently affixed to the storage racks.

The suitability of Rio Tinto Alcan Inc. material as demonstrated herein is based upon:

- detailed comparison with highly similar material with a successful record of industry-wide, in-service performance
- accelerated corrosion testing in simulated BWR and PWR spent fuel pool environments 4
- evaluating and testing of mechanical properties to verify acceptability of installed insert retention force
- measurement of B_{10} areal density to confirm satisfactory neutron absorption capability
- short term and long term in-situ coupon surveillance programs.

These evaluations are detailed in the various sections of this report.

The Alcan material is supplied as 6x6 inch rectangular DC cast rolling billets that are hot rolled to final gage. The material is designated as aluminum boron carbide composite W1100N.XYB where XY is the boron carbide content which can range from 16 to 30 volume percent. The reinforcing phase of the composite is boron carbide powder containing at least 76 w/o boron and with an average particle size of 7.5 ± 2 μm (D_{50}).

As stated above, one particular application of the W1100N.XYB composite in spent fuel 4
pools is the NETCO-SNAP-IN® neutron absorber insert. The NETCO-SNAP-IN® is proprietary to NETCO and is protected by U.S. Patent No. 6,741,669 B2.[1-1] The first use of NETCO-SNAP-IN® absorber inserts will be at Exelon's LaSalle Unit 2 Station. Other applications of the W1100N.XYB composite include newly fabricated spent fuel storage racks and dry spent fuel storage and transportation casks. With respect to the latter use, this material has been used in dry storage/transportation in the U.S. and extensively in Europe.

Recent guidance has been published for the qualification and acceptance of new boron based metallic neutron absorbers for storage and transportation casks. [1-2] Using this document as a guide, the qualification process described in this report consists of the following elements:

- Review of the composition and manufacturing process of the W1100N.XYB composite and a detailed comparison with the composition and manufacturing process for BORAL™, a neutron absorber material that has been successfully used extensively worldwide for spent nuclear fuel storage racks for the last 40 years.
- An accelerated corrosion program has been completed in both demineralized
water and boric acid (2500 ppm as boron). The program ran for one year in 5
duration. Interim and final results are reported.
- A fast start surveillance coupon program has been initiated (March 08) at LaSalle Unit 2 to provide in-service performance data on the W1100N.16B composite in the actual proposed service environment. This will provide performance data that will always lead the installed NETCO-SNAP-IN® inserts in both time of exposure and absorbed gamma dose. The fast start coupon program consists of a string of 24 coupons connected by stainless links. The coupons have been precharacterized with respect to dimensions, dry weight, density and boron-10

areal density. Periodically coupons will be removed from the string and sent to a qualified laboratory for post exposure testing and inspection.

- A long term surveillance assembly will be placed in the LaSalle pool prior to the installation of the first NETCO-SNAP-IN® inserts. These coupons will differ from the "Fast-Start" and, in particular, will be composed of 17 vol-% B_4C instead of 16 vol-% B_4C material. This modification is due to a manufacturing revision of the 5 NETCO-SNAP-IN® inserts intended to ensure compliance with minimum areal density requirements. The tree will hold the following types of coupons:
  - unclad Alcan W1100N.17B composite coupons
  - W1100N.17B composite coupons with 304L stainless steel, In-718 and Zircaloy samples
  - W1100N.17B composite bend coupons

  Periodically coupons will be removed from the assembly and sent to a qualified laboratory for testing and inspection.

The following sections of this report describe:

- NETCO-SNAP-IN® and Installation Tooling
- Manufacturing process and quality control used for NETCO-SNAP-IN® inserts
- Composition and physical properties of the W1100N.XYB composite
- Description of accelerated corrosion testing and interim results
- Comparative evaluation of W1100N.XYB composite and BORAL™
- Anticipated performance of W1100N.XYB in spent fuel pools
- Detailed description of the "fast start" coupon surveillance program
- Detailed description of long term coupon surveillance program
- Conclusions

References Section 1

1-1. Lindquist, K. O., U.S. Patent No. 6,741,669 B2, "Neutron Absorber Systems and Method for Absorbing Neutrons," May 25, 2004.

1-2. ASTM C 1671-07, "Standard Practice for Qualification and Acceptance of Boron Based Metallic Neutron Absorbers for Nuclear Criticality Control for Dry Cask Storage Systems and Transportation Packaging."

2.0 Description of the NETCO-SNAP-IN® and Installation Tooling

Neutron absorber materials are incorporated in spent fuel storage racks to permit the safe storage of LWR fuel assemblies in close proximity to each other. One or two panels of a neutron absorber material are placed between each face of every fuel assembly in order to maintain the stored fuel in a sufficiently sub-critical condition.

One neutron absorber material used for this purpose, Boraflex, has been observed to experience in service degradation well in advance of its design service life. As degradation proceeds, the matrix intended to retain the neutron absorber (boron carbide) dissolves and the boron carbide slumps to the bottom of the pool. As this occurs, less and less of the neutron absorber is in place to maintain the fuel in a sub-critical condition.

The NETCO-SNAP-IN® insert mitigates the boron carbide loss from Boraflex by inserting a thin chevron-shaped metallic sleeve into the fuel storage cell of the rack. The sleeve is fabricated from an aluminum/boron carbide composite. When installed, this sleeve, or insert, abuts two adjacent faces of the rack wall. It is intended that an insert be installed in all the storage cells of a given module as shown in Figure 2-1. With each insert installed in the same configuration, every face of all fuel assemblies will have neutron absorber material between it and one face of the adjacent fuel assemblies. Since the inserts are fabricated of a neutron absorbing material, replacement of the initial reactivity hold-down system is effectively achieved.

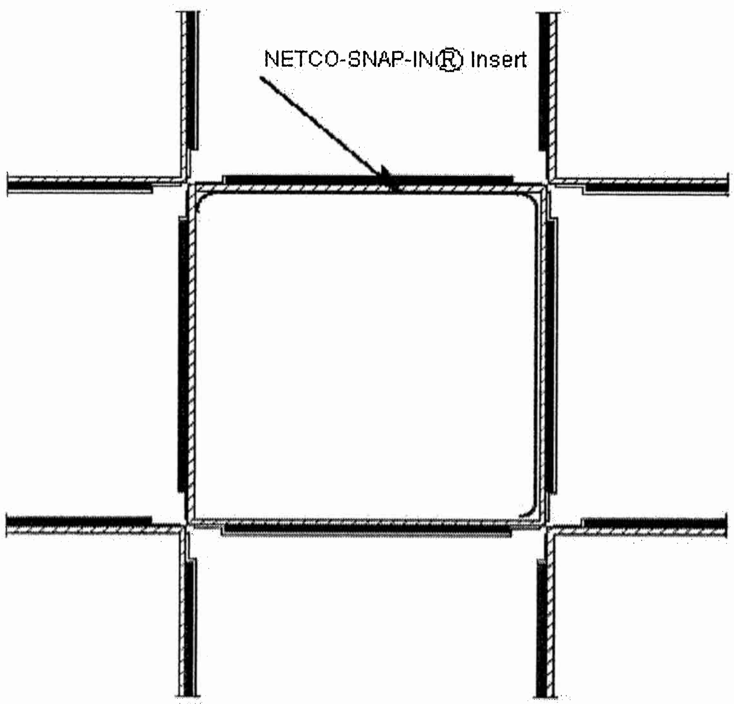

Figure 2-1 NETCO-SNAP-IN® Insert Installed in a Spent Fuel Storage Rack

Figure 2-2 shows a typical NETCO-SNAP-IN®. The insert has a length equivalent to the length of the fuel storage cell and the lower end is tapered to facilitate insertion into the fuel storage cell. The chevron is formed with a central bend angle along its length greater than 90°. The width of each wing of the chevron is slightly less than the minimum inside dimension of the fuel storage cell. Each edge of the wing is roll formed and it is this feature that accommodates cell to cell variations in inside dimensions. Near the top of the NETCO-SNAP-IN® is a hole in each wing that engages the installation tool.

It is noted that the chevrons are formed with a greater than 90° bend angle and this causes compression of the insert as it is "pushed" into the rack cell and assumes the

90° angle between adjacent rack cell walls. The insert is designed to become an integral part of the fuel rack once it has been installed. This is achieved through the elastic deformation of the insert bearing against the rack cell wall and the associated friction force. The force exerted due to this deformation is predicted by the effective spring constant of the insert, which is described in detail elsewhere. The force between the insert wings and the rack cell walls in conjunction with the static friction between these surfaces serves to retain the NETCO-SNAP-IN® and make it a permanent part of the rack once it is installed.

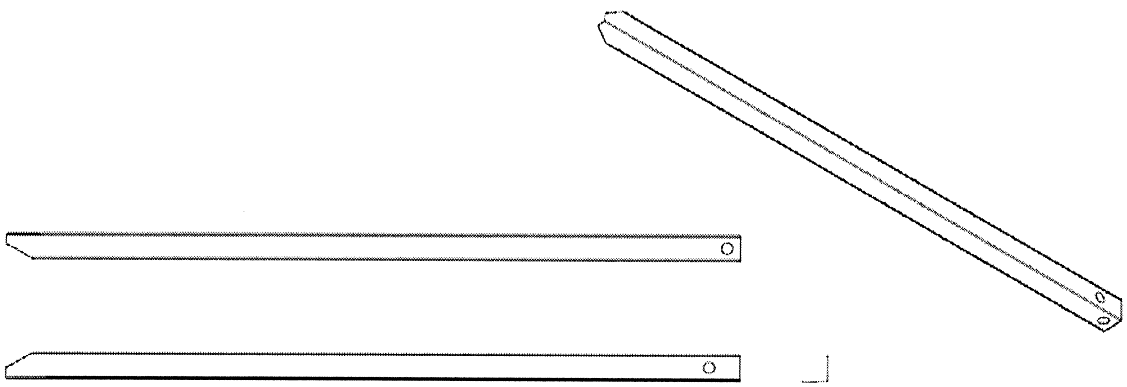

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Figure 2-2 NETCO-SNAP-IN® Insert

The installation tool with a NETCO-SNAP-IN® engaged is shown in Figure 2-3. At the top of the tool is a bail that replicates the bail on a BWR fuel assembly. As such the installation tool can be engaged with a fuel grapple or with the refueling mast. The bail is attached to an anvil assembly that provides a bearing surface on the top edge of the insert. Immediately below the anvil assembly is the head assembly. The head assembly contains two spring loaded cylinders, that engage the insert while it is being moved to the storage cell into which it is destined for installation. When, during installation, the cylinders come into contact with the rack cell wall they retract, thus allowing full insertion of the insert. The curvature of the upper edge of each cylinder is so configured that when the insert is fully installed, upward movement of the tool allows the cylinder to clear the engagement holes in the insert, leaving the insert fully seated in the rack cell.

Again referring to Figure 2-3, a counterweight is suspended from three rods below the head assembly. In addition to partially providing downward insertion force, the counterweight, which contributes to insert stability during installation, lowers the center of gravity of the tool. The insertion tool is constructed entirely of stainless steel and weighs less than 1290 lbs. 3

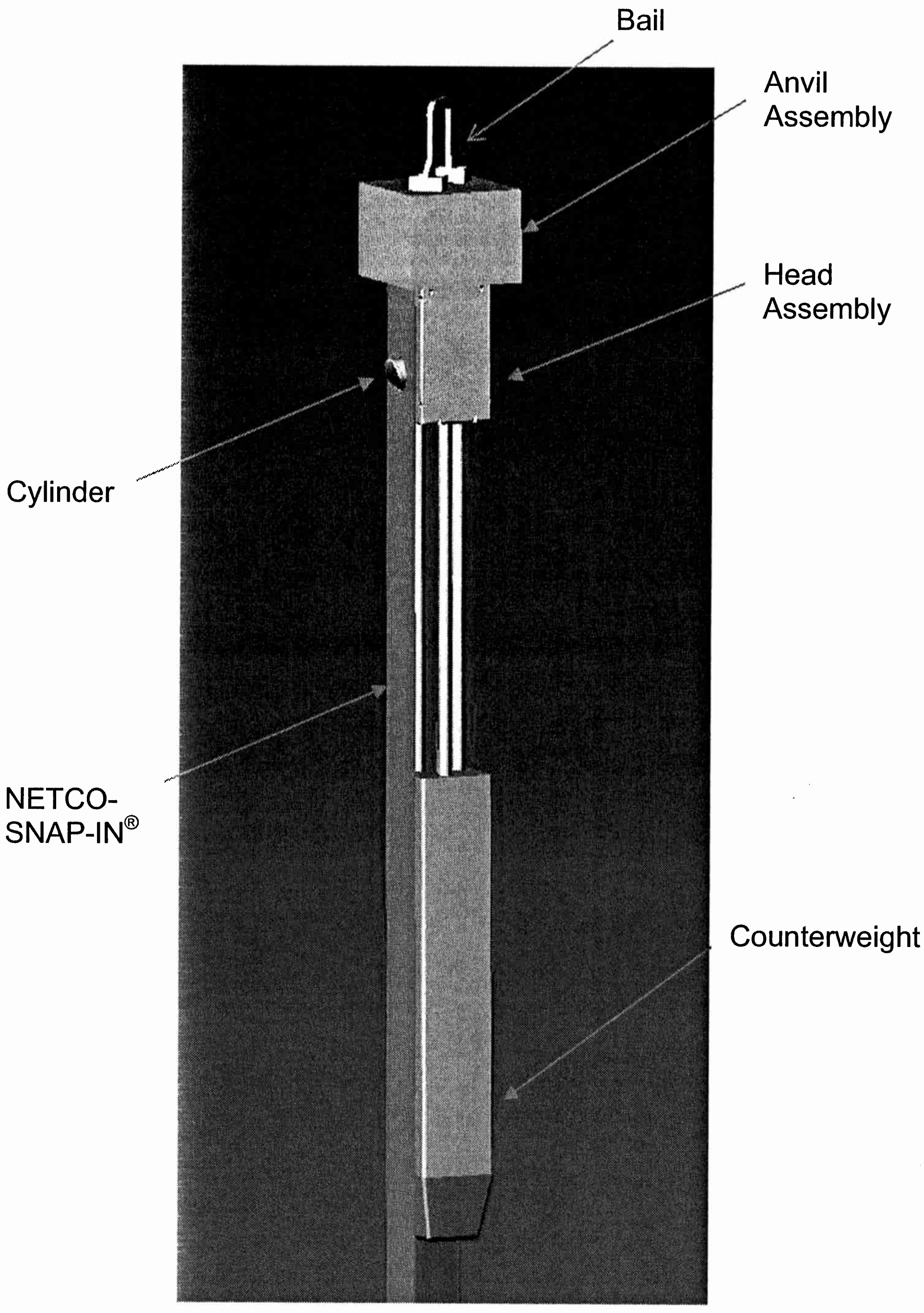

Figure 2-3 Installation Tool

3.0 Manufacturing the NETCO-SNAP-IN® Neutron Absorber Insert

3.1 Billet Production

There are two basic methods for producing aluminum/boron carbide metal matrix composites: powder metallurgy and liquid metal mixing. In the case of powdered metallurgy, atomized metal powder is blended with boron carbide particles, compacted and sintered to form a billet for further processing. The billet is generally extruded to produce rectangular preforms for rolling to final gage. This method has proved to be expensive due to the high cost of atomized metal powders and time consuming processing steps. In addition, wear products from the extrusion die on the surface of the preform need to be removed by cleaning or machining so as not to result in galvanic corrosion in wet storage applications.[3-1] Furthermore, and depending on the process used to produce the billets, the final rolled sheet may have limited ductility making the sheet difficult to form by bending. [3-2]

Alcan has developed a liquid mixing process for producing aluminum/boron carbide composites that use mechanical stirring to mix the powdered B_4C in the molten aluminum. As this mixing process is conducted at temperatures well over the melting point of aluminum, significant aluminum and boron carbide interactions can occur that can result in degraded mechanical and physical properties. [3-3] A significant physical property effect can be the agglomeration of B_4C particles resulting in a non-uniform boron distribution in the composite. Alcan has found that by adding small amounts of Ti (< 2.5%) to the molten aluminum, the B_4C particles become stable in the molten aluminum, eliminating particle clusters, and a uniform blend is achieved. It is thought that a Ti rich zone forms around each boron carbide particle, preventing Al/B_4C interactions.

The molten aluminum/boron carbide blend is direct chill cast into 6"x6" rectangular billets. The length of the billets is determined by the size and gage of the final rolled product. The rectangular billets can be rolled directly without an intermediate extrusion step and the potential problems and cost associated with extrusion.

3.2 NETCO-SNAP-IN® Production

The Alcan billets are heated to ~ 950°F and hot rolled to final gage. After one transverse rolling the billet is rotated 90° and reduced to final gage in 33 passes in the rolling mill. The rolled sheet is trimmed on a shear to final blank size.

Once the blanks have been produced, the final fabrication steps required to produce the finished NETCO-SNAP-IN® inserts are as follow. The two long edges are trimmed on a shear to provide a tapered lead-in at the bottom of the inserts to facilitate installation. The inserts are then formed on a press brake to an angle somewhat larger than 90° and the two remaining long edges roll formed. The holes that engage the installation tool can be formed by stamping or water jet cutting.

3.3 Applicable Codes, Standards and Regulatory Guidance

The following codes, standards and practices are used as applicable for the design and manufacture of the NETCO-SNAP-IN® inserts.

- ANSI.ANS 8.1 - Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors.
- ANSI/ANS 8.12 - Nuclear Criticality Control and Safety of Plutonium - Uranium Fuel Mixtures Outside Reactor.
- ANSI/ANS 8.17 - Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR Fuel Outside Reactors.
- ANSI/ANS 57.2 - Design Requirements for Light Water Reactor Spent Fuel Storage Facilities at Nuclear Power Plants.
- ANSI N45.2.1 - Cleaning of Fluid Systems and Associated Components during Construction Phase of Nuclear Power Plants - 1973 (R.G. 1.37).
- ANSI N45.2.2 - Packaging, Shipping, Receiving, Storage and Handling of Items for Nuclear Power Plants - 1972 (R.G. 1.38).

- American Society for Nondestructive Testing SNT-TC-1A, June 1980, Recommended Practice for Personnel Qualifications and Certification in Nondestructive Testing.
- ASTM C750 - Standard Specification for Nuclear-Grade Boron Carbide Powder.
- ASTM C992 - Standard Specification for Boron-Based Neutron Absorbing Material Systems for Use in Nuclear Spent Fuel Storage Racks.
- ASME NQA-1 - Quality Assurance Program Requirements for Nuclear Facilities.
- ASME NQA-2 - Quality Assurance Requirements for Nuclear Power Plants.
- General Design Criterion 62, Prevention of Criticality in Fuel Storage and Handling.
- Memorandum from L. Kopp, SRE, to Timothy Collins, Chief, Reactor Systems Branch, Division of Systems Safety and Analysis, "Guidance on the Regulatory Requirements for Criticality Safety Analysis of Fuel Storage at Light Water Reactor Power Plants," August 19, 1988.
- "OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications," dated April 14, 1978, and the modifications to this document of January 18, 1979.
- 10CFR21 - Reporting of Defects and Non-compliance.
- 10CFR50 Appendix B - Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.
- 10CFR50.68 - Criticality Accident Requirements.
- USNRC Standard Review Plan, NUREG-0800, Section 9.1.1, New Fuel Storage and Section 9.1.2, Spent Fuel Storage.
- USNRC Regulatory Guide 1.13, Spent Fuel Storage Facility Design Basis, Rev. 2, December 1981.

3.4 Quality Assurance

The NETCO-SNAP-INs® are designed and fabricated under control and surveillance of NETCO's Quality Assurance Program[3-4] that conforms to the requirements of 10CFR50 Appendix B. Since the NETCO-SNAP-INs® are used for reactivity control of fuel assemblies stored in close proximity, they are classified as nuclear Safety Related (SR).

As such, and as required by NETCO's Quality Assurance Program[3-4], they are designed and fabricated to preclude the use of any material or manufacturing process that deviates from a rigorous set of specifications established by the NETCO design team. Process controls for materials and fabrication are established to preclude the incidence of errors and inspection steps are implemented to ensure that all critical attributes, as identified by the design team, for the feed material and rolled sheet are met in the final product.

The raw materials including AA1100, B_4C and Ti used to make the cast billets are obtained by Rio Tinto Alcan from qualified suppliers. The material certifications supplied with the feed material are independently confirmed. An independent mass spectroscopic measurement of boron-10 fraction is performed on each lot of boron carbide powder used. Each cast of B_4C and aluminum is chemically analyzed to assure that the composition conforms to the design specification for weight fraction of boron, Al and Ti. Permanent records of these analyses are retained in NETCO's quality assurance files. Each completed NETCO-SNAP-IN® has a unique identifying number etched along the inside upper surface and this number is fully traceable to the billet, cast and feed material lots.

For these purposes, coupons are cut from each rolled insert blank, which is of sufficient size to manufacture two NETCO-SNAP-INs®. Samples from the coupons are subjected to neutron attenuation testing to verify as-manufactured boron-10 areal density and mechanical testing to assure sufficient ductility to permit forming.

Quality Assurance procedures are enforced on the fabrication shop floor that provide all controls necessary to comply with all quality assurance requirements. One hundred percent final inspection at the shop includes dimensions, formed angle, bend, twist, cleanliness, identifying markings and freedom from imperfections.

A summary table of critical characteristics and qualification tests performed in support of those characteristics is listed below: 5

Table 3-1 Insert Quality Assurance Testing Summary

Critical Characteristic	Qualification Testing Performed	Acceptance Criteria
Minimum B-10 Areal Density	Neutron Attenuation Testing	> 0.0087 g B10/cm^2
Material Composition	ICP Analysis	Boron, Carbon, Titanium and Aluminum within specification limits
Mechanical Properties	Tensile and Bend Testing	Tensile Strength >10 ksi Elongation > 3% Bend Test to support design specification for insert retention force.

5

References Section 3

3-1. "Qualification of METAMIC for Spent-Fuel Storage Application," EPRI Report No. 1003137, Prepared for EPRI by Northeast Technology Corp., Kingston, NY, 10/2001.

3-2. "Handbook of Neutron Absorber Materials for Spent Nuclear Fuel Transportation and Storage Applications, 2006 Edition," EPRI Report No. 1003721, Prepared by Northeast Technology Corp., Kingston, NY, 10/2006.

3-3. Z. Zhazy, A. Charlette, R. Ghomusheki, X.-G Chen, "Effect of Titanium on Solidification Microstructure of A-16% B_4C Composites," *Light Metals*, 2005, Calgary, Alberta, Canada.

3-4. Quality Assurance Manual, Rev. 1, Northeast Technology Corp., 2007.

4.0 Engineering Evaluation of the Alcan Composite

The Alcan composite is very similar in composition to another neutron absorber material, BORAL™, that has been used extensively for more than 40 years for both wet and dry storage applications. The in-service performance of BORAL™ has been good. In this section the composition, physical properties and mechanical properties of both materials are compared and the industry experience with the BORAL™ neutron absorber reviewed.

4.1 Comparison of the Alcan Composite with BORAL™

<u>Composition</u>

Both of these neutron absorber materials utilize AA1100 as the base alloy for the metal 5
matrix that retains the boron carbide. The compositions of the alloy matrices are compared in Table 4-1. With the exception of the addition of Ti to the Alcan composite, as noted previously, the compositions are almost identical. In fact, the Alcan requirement for other elements is somewhat more stringent than the BORAL™ requirement.

Table 4-1

Comparison of Aluminum Alloy Matrices

Property	AA1100 UNS A91100 Temper O	BORAL Metal Matrix Material Spec	ALCAN Composite Metal Matrix Material Spec	ALCAN Composite Vol 16% B_4C Typical Properties	ALCAN Composite Vol 17% B_4C Typical Properties
Al	99.00% min	99.00% min	99.00% min	82.7%	82.0%
Si & Fe	0.95% max	1.00% max	0.45% max	0.38%	0.39%
Cu	0.05-0.20%	0.05-0.20%	0.05-0.20%	0.11%	0.11%
Mn	0.05% max	0.05% max	0.05% max	< 0.01%	< 0.01%
Zn	0.10% max	0.10% max	0.10% max	<0.01%	0.01%
Mg	---	---	0.05% max	< 0.01%	<0.01%
Ti	---	---	1.00% - 2.50%*	1.85%	2%
B_4C	---	---	---	15.3%	15.9%
Other Elements	0.15% total 0.05% max each	0.15% max each	0.15% total 0.05% max each	0.08%	0.08%
Tensile	11 ksi to 15.5 ksi	10 ksi	Not Specified	17 ksi	17 ksi
Yield	3.5 ksi min	---	Not Specified	10 ksi	10 ksi
Elongation	30% min	0.1	Not Specified	5% - 8%	5% - 8%

5

*Titanium is added during mixing of the B_4C and not part of the matrix material specification.

The boron carbide specifications are compared in Table 4-2. The Alcan specification is somewhat tighter in terms of allowable impurities and requires a much smaller particle size. With respect to the latter, the smaller particle size results in a more homogeneous absorber, less potential for neutron streaming and a more effective neutron absorber material.

Table 4-2
Comparison of Boron Carbide

BORAL™	**Constituent**	**Alcan Composite**
70.0 min	Total Boron	76 w/o min
3.0 max	Boric Oxide	0.03 % Typ.
2.0 max	Iron	0.075% Typ.
94.0 min	Total Boron & Carbon	99.6% Typ.
75 - 250 μm	Particle Size	17.5 ± 2 μm

5

Manufacturing Process Physical Form

The manufacturing processes for BORAL™ and the Alcan composite are compared in Figure 4-1. The manufacture of BORAL™ starts with the complete blending of atomized AA1100 powder and boron carbide. An AA1100 rectangular box ~ 12 to 15 inches on a side and a few inches high depending on the thickness of the finished product is filled with the blended powder. The walls of the box are ~ 1 inch thick. After a top is welded on the box, the billet is ready for hot rolling to final gage.

The production process for the Alcan material differs from the BORAL™ process in that the boron carbide powder is blended into molten aluminum and a rectangular billet formed by direct chill casting. Hot rolling is used to produce the final sheet.

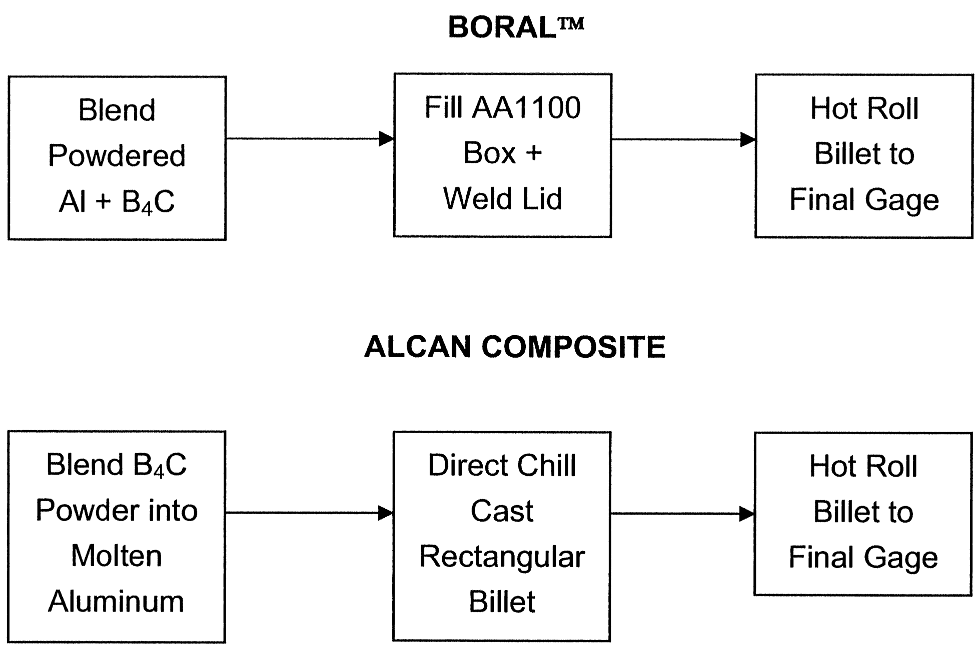

Figure 4-1: Comparison of Manufacturing Processes

In its finished form, BORAL™ consists of 1) a core of uniformly mixed and distributed boron carbide and alloy AA1100 aluminum particles; and 2) an AA1100 surface cladding on both sides of the core, serving as a solid barrier. Figure 4-2 is a micro photograph of the edge of a BORAL™ sample showing the core and clad region. BORAL™ has been produced with the core containing anywhere between 35 w% and 65 w% boron carbide. For most cores produced recently, the core contains about 50 w% boron carbide. In addition, the core is not fully dense and contains as much as 5% open and interconnected porosity.

The Alcan composite, on the other hand, in its final form is a fully dense homogeneous
mixture of fine boron carbide particles embedded in the matrix aluminum alloy. As such 5
it contains no porosity that can allow water intrusion and potential problems associated
with internal moisture.

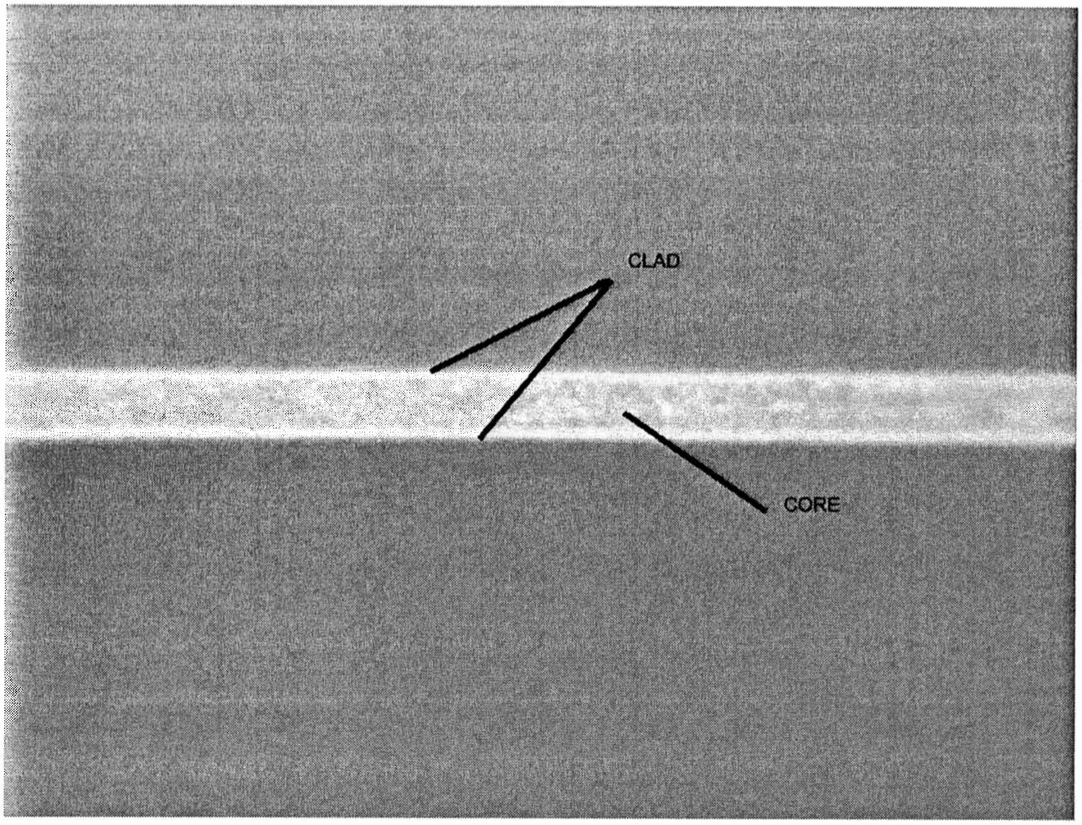

Figure 4-2: Micro Photograph of BORAL™

Mechanical Properties

The mechanical properties of BORAL™ and the Alcan composite are compared in Table 4-3.

Table 4-3

Room Temperature Mechanical Properties of BORAL™ and the Alcan Composite

BORAL™		**Alcan Composite**
10	Tensile Strength, ksi	10
	Ultimate Strength, ksi	17
0.1	Elongation, %	7.0

This comparison shows that the tensile properties of the two materials are similar but the Alcan composite has improved ductility.

Stress Relaxation

During installation, the absorber inserts are compressed from an initial bend angle greater than 90° to the square dimensions of the rack cell interior. Once installed, the inserts maintain a fixed strain within the rack storage cell that may be susceptible to relaxation over time. An analysis of stress relaxation in aluminum alloys has been performed to establish the expected performance of the inserts in this regard.

As shown above, the Rio Tinto Alcan W1100N.16 B alloy had similar mechanical characteristics to 6061 aluminum alloy based Boral material. Reference 4-1 details stress relaxation performance of 6060-T6 alloy after 1000 hours at various temperatures. The data shows approximately 15% stress relaxation after 1000 hours at 100° C.[4-1]

Average bulk pool temperatures within the LaSalle spent fuel pool are approximately 85° F. Stress relaxation at this temperature is expected to be significantly lower than 15% over 1000 hours. As an upper limit, however, data for AA1100-H112 series aluminum[4-2] was analyzed to estimate total stress relaxation after 20 years of service. The results of that analysis showed that the AA1100 series aluminum was, based upon extrapolated data, expected to have experienced an approximate stress reduction of 50% over 20 years. Given the reduced elongation of the Rio-Tinto Alcan composite in comparison with AA1100 series aluminum, this stress relaxation is likely an upper limit for the performance of the W1100N series material.

Typical breakaway withdrawal forces were measured and are typically several hundred pounds. At the 15% relaxation predicted for the 6061-T6 alloy, a reduction in retention force between 45 and 90 lbf after 1000 hours at 100° C would be expected. At the limiting case of a 50% reduction in retention force over 20 years, the inserts would still maintain greater than 150 lbf of retention within the cell if there were no other mitigating factors. These values are adequate to maintain the inserts in their configuration during fuel movement operations provided the fuel bundles are qualified for use in those locations (i.e. they fit within the specified dimensions). However, the following factors would tend to mitigate the stress relaxation effects:

1. Stress relaxation in boron carbide reinforced aluminum will be less than for the pure alloy; 4
2. The formation of an oxide film on the surface of the inserts will increase the stress (by increasing the spacing between the rack wall and the insert) as well as the coefficient of friction between the insert and the cell wall.

<u>Neutronic Properties</u>

It has been previously noted that the average particle size of boron carbide in BORAL™ is 85 microns and individual particles can range up to 250 microns. Particles of these dimensions introduce self shielding effects that can diminish the neutron absorption effectiveness. NETCO has measured the neutron attenuation characteristics of BORAL™ and the Alcan composite, the latter material with average boron carbide particle size of 17.5 microns.

Figure 4-3 compares the neutron attenuation characteristics of BORAL™ and the Alcan composite. The neutron attenuation characteristics are measured using a collimated thermal energy neutron beam. A sample of a neutron absorber is placed in this neutron beam and the intensity of the beam incident on the absorber, I_i, is measured. The intensity of the beam transmitted through the material, I_t, is also measured and the neutron attenuation characteristic, NA, is calculated as:

$$NA = 1 - I_t/I_i$$

Figure 4-3 shows that for the same areal density BORAL™ absorbs fewer neutrons than the Alcan absorber. This illustrates the importance of neutron channeling effects in absorbers with relatively large particles when a normal mono-directional neutron beam is incident on the absorber.

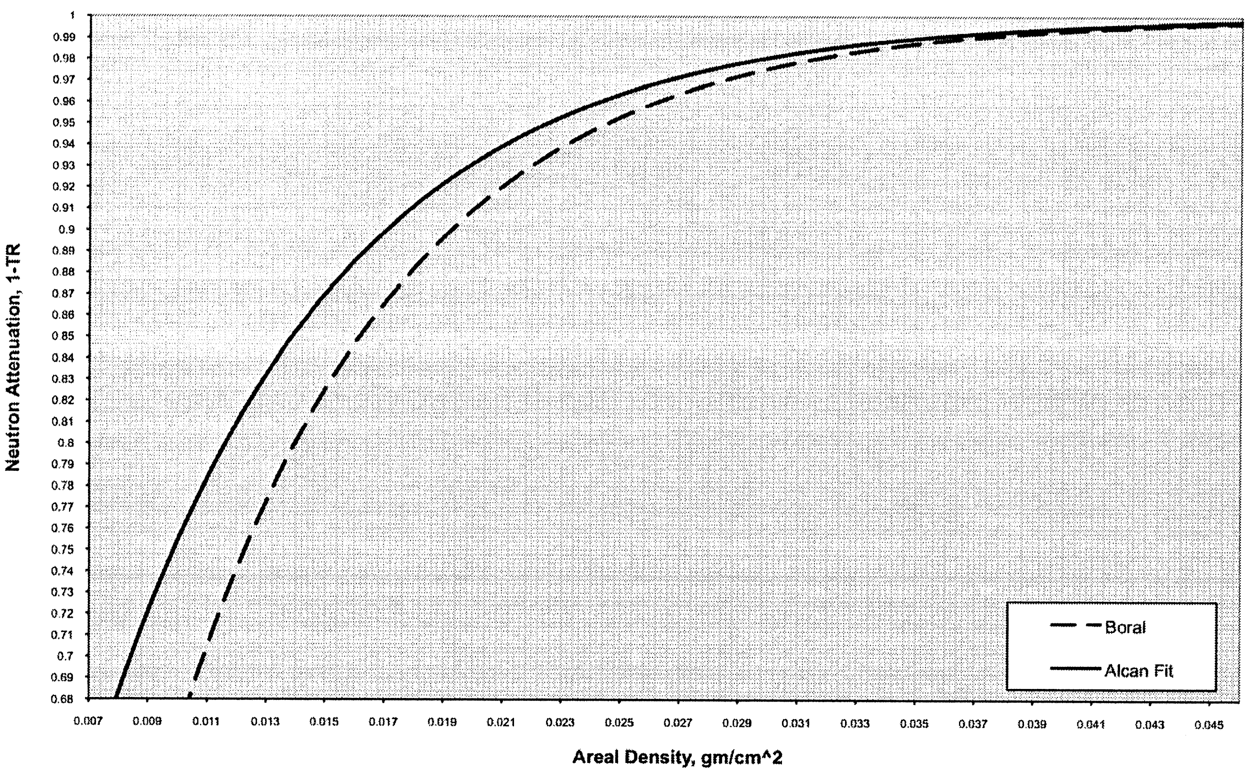

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Figure 4-3: Neutron Attenuation Comparison: BORAL™ vs. Alcan Aluminum Matrix Absorber

4.2 In-Service Performance of Aluminum Matrix Neutron Absorber Material

BORAL™ has been used for nuclear applications for almost 45 years starting in 1964 when it was used for reactivity control in the Yankee Rowe spent fuel racks. Nuclear applications include control elements for test reactors, fuel storage racks for spent nuclear fuel and in dry fuel storage and transportation casks. Table 4-4 contains a partial listing of research reactors where BORAL™ has been used. Table 4-5 contains a partial list of LWR plants where BORAL™ has been used in spent fuel storage racks. It is noted that LaSalle Unit 2 sister unit currently has some 43,000 lbs of BORAL™ in its racks. Table 4-6 is a partial list of plants where BORAL™ has been used for reactivity control in dry storage casks.

For dry storage applications, it is noted that the Alcan composite is now approved for use in the NUHOMS dry storage system as well as the Transnuclear metal cask storage system. The Alcan composite is being used at Peach Bottom, Limerick and St. Lucie as well as in Europe.

Table 4-4

Partial Listing of Research and Test Reactors Where BORAL™ Has Been Used

Research and Test Reactors
AE-6 (USAEC)
BORAX-5 (USAEC)
Brookhaven Medical Research Reactor
JEN-1 (Spain)
Philippine Research-1
Rhode Island Reactor
Triga Mark II (Italy, Austria, etc.)
University of Kansas Reactor
University of Wisconsin Reactor
Venezuela-1
Washington State University Reactor

Table 4-5

Partial List of LWRs Where BORAL™ Has Been Used in Spent Fuel Storage Racks

Pool	Plant Type	Manufacturer	Storage Locations	Country
BEAVER VALLEY 1	PWR	Holtec	1621	USA
BELLEFONTE 1	PWR	Westinghouse	1058	USA
BRAIDWOOD 1&2	PWR	Holtec	2984	USA
BROWNS FERRY 1	BWR	GE	3471	USA
BROWNS FERRY 2	BWR	GE	3471	USA
BROWNS FERRY 3	BWR	GE	3471	USA
BRUNSWICK 1	BWR	Holtec	1839	USA
BYRON 1&2	PWR	Holtec	2984	USA
CALLAWAY	PWR	Holtec	1302	USA
COMANCHE PEAK 1	PWR	Holtec	222	USA
COMANCHE PEAK 2	PWR	Holtec	219	USA
CONN YANKEE	PWR	Holtec		USA
COOK 1&2	PWR	Holtec	3613	USA
COOPER	BWR	NES		USA
CRYSTAL RIVER 3	PWR	Westinghouse	932	USA
DAVIS BESSE 1	PWR	Holtec	1624	USA
DRESDEN 1	BWR	CECO	3537	USA
DRESDEN 2	BWR	CECO	3537	USA
DRESDEN 3	BWR	CECO	3537	USA
DUANE ARNOLD	BWR	PAR	1898	USA
DUANE ARNOLD	BWR	Holtec	1254	USA
FERMI 2	BWR	Holtec	559	USA
FITZPATRICK	BWR	PAR	2797	USA
FITZPATRICK	BWR	Holtec		USA
FT. CALHOUN	PWR	Holtec	160	USA
HARRIS 1	PWR	Holtec	484	USA
HATCH 1	BWR	GE	5830	USA
HATCH 2	BWR	GE	2765	USA
HOPE CREEK	BWR	Holtec	3998	USA
HUMBOLDT BAY 3	BWR	Unknown		USA
INDIAN POINT 3	PWR	UST&D	1340	USA

Table 4-5 (con't.)

Partial List of LWRs Where BORAL™ Has Been Used in Spent Fuel Storage Racks

KEWAUNEE	PWR	Holtec	215	USA
KOEBERG 1	PWR	Holtec		South Africa
KOEBERG 2	PWR	Holtec		South Africa
KORI-4	PWR	Holtec		South Korea
KUOSHENG 1	BWR	ENSA	1578	Taiwan
KUOSHENG 2	BWR	ENSA	1578	Taiwan
LAGUNA VERDE 1	BWR	Holtec		Mexico
LAGUNA VERDE 2	BWR	Holtec		Mexico
LASALLE 1	BWR	UST&D	4029	USA
LIMERICK 1	BWR	Holtec	2500	USA
LIMERICK 2	BWR	Holtec	2766	USA
MAINE YANKEE	PWR	PAR	1464	USA
MCGUIRE 1	PWR	Holtec	286	USA
MCGUIRE 2	PWR	Holtec	286	USA
MILLSTONE 3	PWR	Holtec	1104	USA
MONTICELLO	BWR	GE	2229	USA
NINE MILE POINT 1	BWR	Holtec	3496	USA
OYSTER CREEK	BWR	Holtec	390	USA
PERRY 1	BWR	PAR	2400	USA
PERRY 2	BWR	PAR	1620	USA
PILGRIM	BWR	Holtec	1539	USA
SALEM 1	PWR	ENC	1117	USA
SALEM 1	PWR	Holtec	1117	USA
SALEM 2	PWR	ENC	1139	USA
SALEM 2	PWR	Holtec	1139	USA
SEABROOK 1	PWR	Westinghouse	576	USA
SEQUOYAH 1	PWR	Westinghouse	2091	USA
SEQUOYAH 2	PWR	Holtec		USA
SEQUOYAH 2	PWR	PAR	2091	USA
SIZEWELL B	PWR	Holtec	1901	United Kingdom
SUMMER 1	PWR	Holtec	1712	USA
SUSQUEHANNA 1	BWR	PAR	2840	USA
SUSQUEHANNA 2	BWR	PAR	2840	USA

Table 4-5 (con't.)

Partial List of LWRs Where BORAL™ Has Been Used in Spent Fuel Storage Racks

THREE MILE ISLAND 1	PWR	Holtec	1284	USA
TURKEY POINT 3	PWR	Holtec	131	USA
TURKEY POINT 4	PWR	Holtec	131	USA
ULCHIN 1	PWR	Holtec	1000	South Korea
VERMONT YANKEE	BWR	UST&D	2860	USA
VOGTLE 1	PWR	Unknown	1476	USA
WATERFORD 3	PWR	Holtec	2232	USA
WATTS BAR 1	PWR	Holtec	1610	USA
WATTS BAR 2	PWR	Holtec	1610	USA
YANKEE ROWE	PWR	PAR	721	USA
YONGGWANG 1	PWR	Holtec	1152	South Korea
YONGGWANG 2	PWR	Holtec	1152	South Korea
ZION 1	PWR	Holtec	3012	USA
ZION 2	PWR	Holtec	3012	USA
ANGRA 1	PWR	Holtec	1252	Brazil
CATTENOM-1	PWR	Framatome	2520	France
CATTENOM-2	PWR	Framatome	2520	France
CATTENOM-3	PWR	Framatome	2520	France
CATTENOM-4	PWR	Framatome	2520	France
BELLEVILLE-1	PWR	Framatome	1260	France
BELLEVILLE-2	PWR	Framatome	1260	France
NOGENT-1	PWR	Framatome	1260	France
NOGENT-2	PWR	Framatome	1260	France
PENLY-1	PWR	Framatome	1260	France
PENLY-2	PWR	Framatome	1260	France
GOLFECH-1	PWR	Framatome	1260	France
GOLFECH-2	PWR	Framatome	1260	France

Table 4-6

Partial Listing of LWRs Where BORAL™ Has Been Used in Dry Storage Casks

Plant	Type	Supplier	Current Inventory	Module Capacity	Absorber Type
ARKANSAS 2	Hi-Storm 100(MPC-32)	Holtec	416	32	BORAL
CATAWBA 1	UMS-24	NAC		24	BORAL
DIABLO CANYON 1	Hi-Storm 100(MPC-32)	Holtec			BORAL
DIABLO CANYON 2	Hi-Storm 100(MPC-24)	Holtec			BORAL
DRESDEN 2	Hi-Storm 100(MPC-68)	Holtec	1632	68	BORAL
DUANE ARNOLD	NUHOMS-61BT	Transnuclear	610	61	BORAL
FITZPATRICK	Hi-Storm 100(MPC-68)	Holtec	204	68	BORAL
HADDAM NECK	MPC-24	NAC	651	24	BORAL
HATCH 2	Hi-Storm 100(MPC-68)	Holtec	1496	68	BORAL
MAINE YANKEE	UMS-24	NAC	1440	24	BORAL
PALO VERDE 1	UMS-24	NAC	624	24	BORAL
PEACH BOTTOM 2	TN-68	Transnuclear	1632	68	BORAL
PRAIRIE ISLAND 1	TN-40	Transnuclear	680	40	BORAL
SEQUOYAH 2	Hi-Storm 100(MPC-32)	Holtec	96	32	BORAL
TROJAN	MPC(24)-Only	Holtec	816	24	BORAL
SUSQUEHANNA 1	NUHOMS-61BT	Transnuclear	183	61	BORAL
* as of mid 2005					

In-Service Experience

BORAL™ Plate and Sheet in Wet Storage

It has been noted that in conventional storage racks, once BORAL™ is installed in fuel racks, it is not accessible for inspection to determine its in-service performance. Accordingly, the NRC has, in the past, required utilities to initiate a coupon surveillance program when new racks were installed. A coupon surveillance program consists of a series of small coupons either in a shroud (simulating the manner in which the BORAL™ is encapsulated) or bare. The coupons are generally attached to a surveillance assembly, which is placed in a spent fuel rack storage cell.

The surveillance assembly is generally surrounded by recently discharged fuel assemblies to accelerate the rate at which the coupons accumulate gamma exposure. Prior to placing the assembly in service, the coupons are generally characterized with respect to:

- visual appearance
- dry weight
- dimensions
- specific gravity and density
- boron-10 areal density

Periodically, coupons are removed from the surveillance assembly and sent to an independent laboratory for testing. The post-irradiation test results generally mirror the pre-irradiation test results. As the surveillance coupons are prepared from BORAL™ coupons cut from panels taken from the same production lot(s) used in the racks, the performance of the coupons should be indicative of the performance of the material in the racks.

NETCO maintains laboratory facilities and offers inspection and testing services of neutron absorber surveillance coupons. In that capacity, NETCO has inspected hundreds of aluminum matrix surveillance coupons, many of them BORAL™, from spent fuel pools around the world. It has been observed during testing that some surveillance coupons can be subject to a generalized corrosion, that includes the development of a uniform oxide film. This film, once it forms, tends to be self passivating and prevents further corrosion. Depending on pool conditions, other coupons can be susceptible to localized pitting corrosion. It should be noted that while these corrosion effects can occur in aluminum matrix neutron absorbers, to date this in-service corrosion has not resulted in any detectable decrease in the boron-10 areal density. It is therefore concluded that the aluminum alloy matrix serves as suitable matrix to retain the boron
carbide in spent fuel storage racks. Additional qualification testing has been performed 5
to further demonstrate the corrosion resistance of the Alcan W1100.XYB material in

BWR and PWR spent fuel pool applications. This testing is described in Section 5.0 of this report.

4.3 NETCO Credentials

NETCO has been evaluating, specifying and qualifying neutron absorber material for storage systems and transportation packaging for more than a quarter of a century. In this capacity, NETCO has become an internationally recognized expert in assessing the in-service performance of this class of materials.

In 1987, the Electric Power Research Institute (EPRI) retained NETCO to evaluate the instances of unanticipated performance of one neutron absorber, Boraflex, at two Midwest plants. NETCO's first report on this phenomenon concluded the observed shrinkage of the sheets of absorber would be expected when cross linking polymer was exposed to gamma radiation. NETCO notified EPRI that the BISCO materials qualification program did not adequately test the synergistic effects of gamma radiation and long term exposure to the pool water.

These projections subsequently proved to be remarkably accurate and formed the bases for NETCO's development of BADGER and RACKLIFE. BADGER (Boron-10 Areal Density Gage for Evaluating Racks) is a non-destructive test method that measures the residual boron-10 in spent fuel racks. BADGER has now been used in some 35 test campaigns to assess the reactivity hold down capability of both Boraflex racks and racks with other neutron absorbers.

RACKLIFE is a comprehensive computer program that tracks the performance of each and every Boraflex panel (as many as 4,000) in a typical rack installation. RACKLIFE is based on first principles and on the mass balance of soluble silica as it dissolves from the degraded Boraflex matrix and gradually migrates to the bulk pool volume. NETCO tested samples of irradiated Boraflex and measured the rate of dissolution as a function of both absorbed dose and temperature in its laboratory. This experimental data serves as the basis for the RACKLIFE dissolution model. This model and the RACKLIFE software upon which it is based as verified by BADGER measurements, serve to assure that spent fuel pool criticality limits are met.

At the Penn State Breazeale Research Reactor laboratory, NETCO routinely tests neutron absorber surveillance coupons. These tests include Alcan composite material, BORAL™, Boraflex, borated stainless steel, METAMIC, Talbor, Carborundum and ESK borated graphite and nano steel.

NETCO was selected by Reynolds Metals Company to conduct qualification testing of its new neutron absorber material, METAMIC. In this test sequence, NETCO conducted accelerated radiation testing, accelerated corrosion testing and elevated temperature testing to qualify this material for use in spent fuel racks and storage and transportation casks. The resulting test report has been accepted by the NRC for both wet and dry applications. A second qualification test sequence for another new neutron absorber BorTec™ was completed by NETCO for DWA Technologies, the manufacturer of BorTec™. As such NETCO is the only organization to have successfully qualified new neutron absorber materials for wet storage applications since BORAL™ was qualified some 40 years ago.

NETCO was retained by EPRI, ENRESA and AAR (former BORAL™ manufacturer) to evaluate clad blister formation under cask drying conditions. Laboratory testing by NETCO simulating cask drying condition lead to recommended changes in the AAR rolling schedule and lead to an improved BORAL™ product that is largely blister resistant.

References Section 4:

4-1 K. Farrell, "ORNL/TM-13049 Assessment of Aluminum Structural Materials for Service Within the ANS Reflector Vessel," Oak Ridge National Laboratory, August 1995 4

4-2 John Gilbert Kaufman, Properties of Aluminum Alloys, ASM International, 1999

5.0 Accelerated Corrosion Testing

5.1 Test Description

The accelerated corrosion test program has been designed to determine the susceptibility of the Rio Tinto Alcan composite to general (uniform) and localized (pitting) corrosion in PWR and BWR spent fuel pools. Two sets of coupons have been tested at the NETCO laboratory; one set in deionized water, simulating BWR pool conditions and one set in deionized water containing 2500 ppm boron as boric acid, simulating PWR pool conditions. Both tests were conducted at 195°F (90.5°C) to accelerate any corrosion effects, which might occur after the 8000 hour (~ 1 year) test period. The tests are accelerated by testing at elevated temperatures relative to typical temperatures in the actual service environment. Typically, spent fuel pools are operated in the temperature range of 80 to 100°F (27 to 38°C) with short term 4
excursions to 130°F (54°C) during refueling outages.

Coupons from each environment were removed after approximately 2000, 4000, 6000 and 8000 hours and subjected to testing. Prior to testing the coupons were precharacterized with respect to thickness, weight and boron-10 areal density. After testing, the coupons were subjected to post-test characterization of these same attributes. The testing after 2000, 4000, 6000 and 8000 hours has been completed. This document represents the final report for this accelerated corrosion test.

5.2 Test Matrices and Coupon Description

The coupon test matrix for the accelerated corrosion test is shown in Table 5-1. A total of 168 coupons have been tested; 84 in deionized water and 84 in 2500 ppm boron as 4
boric acid. As shown in Table 5-1, coupons with two levels of boron carbide loadings were tested. The coupons with an intermediate loading contain 16 vol% boron carbide. The coupons with the maximum boron carbide loading contain 25 vol% boron carbide.

Table 5-1

Coupon Test Matrix for Accelerated Corrosion Testing

Type of Coupon	Number of Coupons	
	16 vol % B_4C	**25 vol % B_4C**
General	12	12
Bend	12	12
Galvanic (bi-metallic)*	18	18
Subtotal	42	42
Total	84	

*Note: For the galvanic bi-metallic coupons, there are 3 subtypes. These are SS-304L, Zircaloy and Inconel 718, each separately in combination with the Alcan composite. 4

At each of the scheduled test campaigns specific coupons were removed from the baths and subjected to testing. The number and type of coupons tested at 2000 and 6000 hours is summarized in Table 5-2. The number and type of coupons tested at 4000 and 8000 hours is summarized in Table 5-3. Three types of coupons at two boron carbide loadings have been tested as described in Tables 5-2 and 5-3.

Table 5-2

Number and Type of Coupons per Bath Tested After 2000 and 6000 Hours

Type of Coupon	Boron Carbide Loading	
	16 vol %	**25 vol %**
General (G)	3	3
Bend (B)	3	3
Total	12	

Table 5-3

Number and Type of Coupons per Bath Tested After 4000 and 8000 Hours

Type of Coupon	**Boron Carbide Loading**	
	16 vol %	**25 vol %**
General (G)	3	3
Bend (B)	3	3
Bi-Metallic (BSS)	3	3
Bi-Metallic (BZ)	3	3
Bi-Metallic (BI)	3	3
Total	30	

Since the NETCO-SNAP-INs® are to be used with a mill finish absorber material, that is the finish of the coupons tested. For each coupon type the corrosion rates are determined. The three coupon types are described below.

General 4

General coupons are rectangular (nominally 4 in. x 2 in. in length and width). A test objective of the general coupons is to determine the rate at which a uniform oxide film forms. The rate of oxide build-up is determined by changes in the coupon weight and thickness. Post test exposure, the coupons are subject to precision weighing prior to testing and after a sequence of nitric acid washes and drying after testing.

Bend

Coupons with press brake formed bends are included in the test matrix. These coupons have been deformed to the same bend angle and bend radius used for the NETCO-SNAP-IN®. The test objective of the bend coupons is to determine whether or not bend deformation and stress adversely affect the corrosion susceptibility of the Alcan material. These will be subject to the same pre and post testing as the general coupons. In addition the inner and outer bend radius will be subject to microscopy before and after acid cleaning.

Galvanic (Bi-Metallic) Coupons

In conventional spent fuel racks the neutron absorber material is enclosed in 304L stainless steel wrapper plate, thus the potential for aluminum/stainless steel galvanic corrosion exists. In the NETCO-SNAP-IN® application this material is used unsheathed so that is could be in contact with LWR fuel assemblies. Of the materials in LWR fuel assemblies supplied by U.S. fuel manufacturers, only stainless steel, Inconel and Zircaloy could contact the surface of fuel racks. Accordingly bi-metallic coupons have been prepared with Alcan composite and: 4

304L stainless steel
Inconel 718
Zircaloy

The test objective of the galvanic coupon is to evaluate the potential for galvanic corrosion. The above alloy coupons are nominally 2 in. x 4 in. x 0.065 in. thick. A piece of 2 in. x 4 in. Alcan composite forms the other piece of each couple. The two metals comprising each couple are fastened to each other mechanically with AA1100 wire. Inspection of the galvanic coupons is via optical microscopy, thickness and dry weight measurements. Post test acid cleaning is used depending on the depth of any oxide films.

5.3 Water Chemistry

The laboratory tap water was processed by first passing it through two universal ion
exchange columns and then through two research grade ion exchange columns. The 4
typical quality of the deionized water used for both the BWR and PWR corrosion baths and make up water is shown in Table 5-4.

Table 5-4

Water Specification for Corrosion Baths

pH	5.75 @ 20°C
Conductivity, :µs/cm	0.5
Resistivity, : Ω/cm	2.0
Aluminum	< 0.010 ppm
SiO_2	< 0.100 ppm
Cl	< 0.010 ppm
Na	< 0.030 ppm

To the PWR bath, sufficient reagent grade boric acid was added to bring the boron 4
concentration to ~ 2500 ppm. This increased the initial conductivity from < 1.0 µs/cm to ~ 40 µs/cm @ 20.0°C and decreased the initial pH from 5.75 @ 20.0°C to ~ 4.76 at 20.0°C.

The conductivity and pH of each of the baths was measured at an approximate frequency of once per week. Figures 5-1 and 5-2 are plots of the measured pH and conductivity of the BWR bath versus time. The plots of the measured pH and conductivity versus time of the PWR bath are shown in Figures 5-3 and 5-4, respectively.

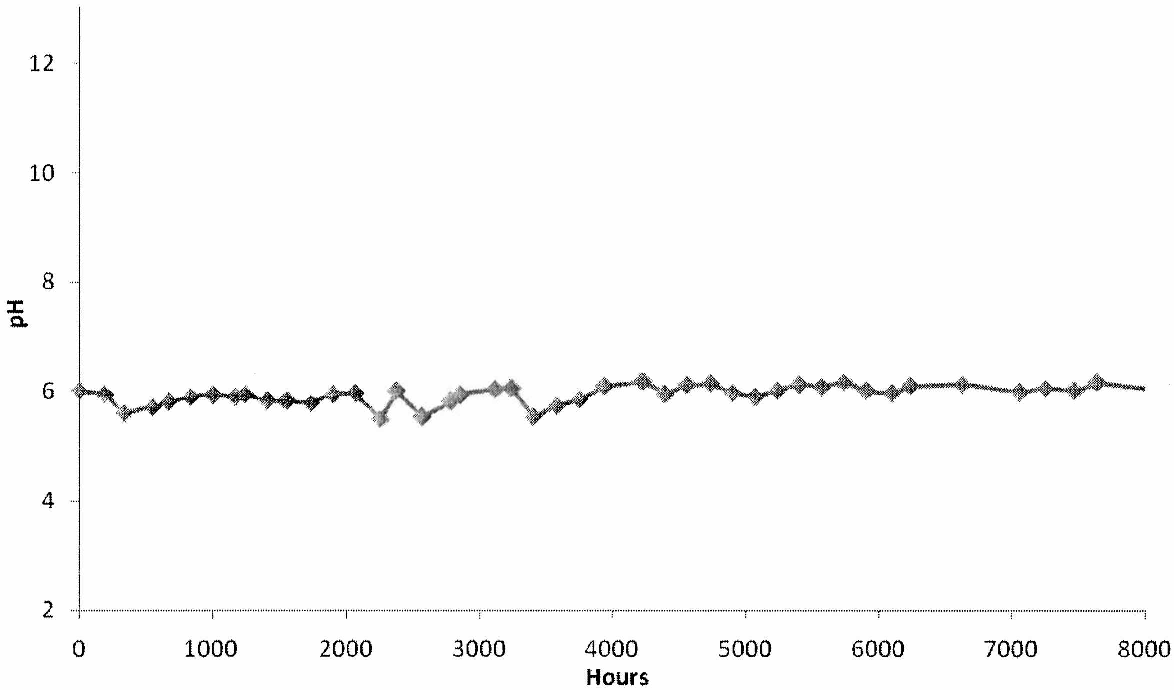

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Figure 5-1: pH versus Time: BWR Accelerated Corrosion Test

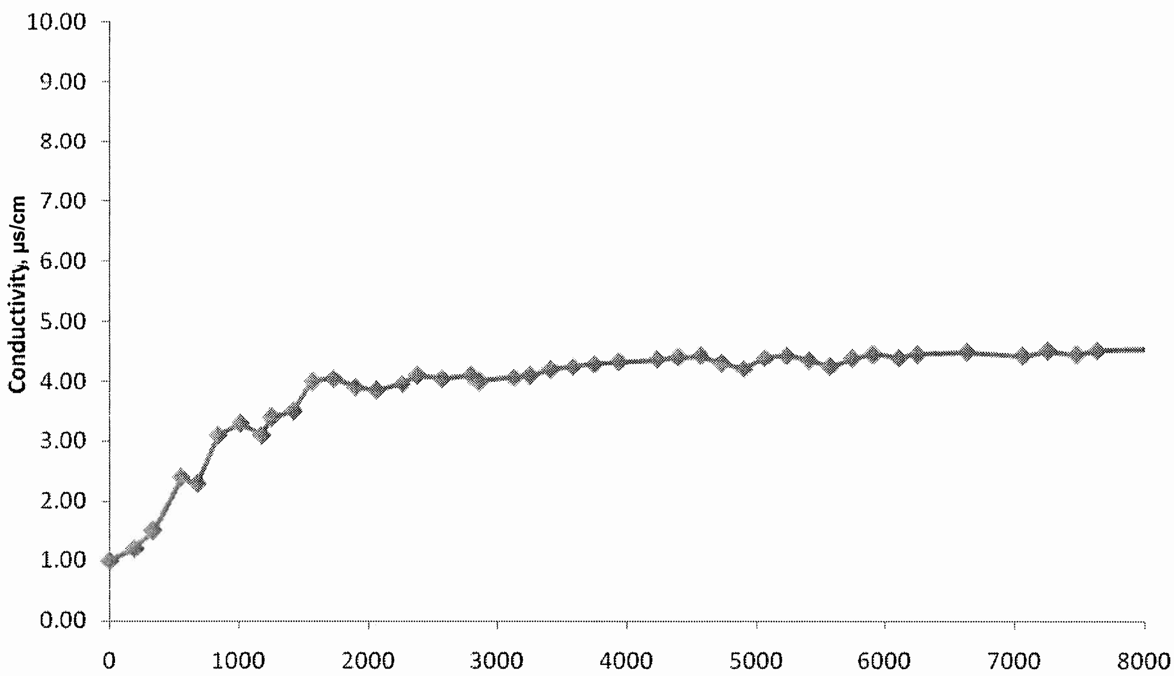

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Figure 5-2: Water Conductivity versus Time: BWR Accelerated Corrosion Test

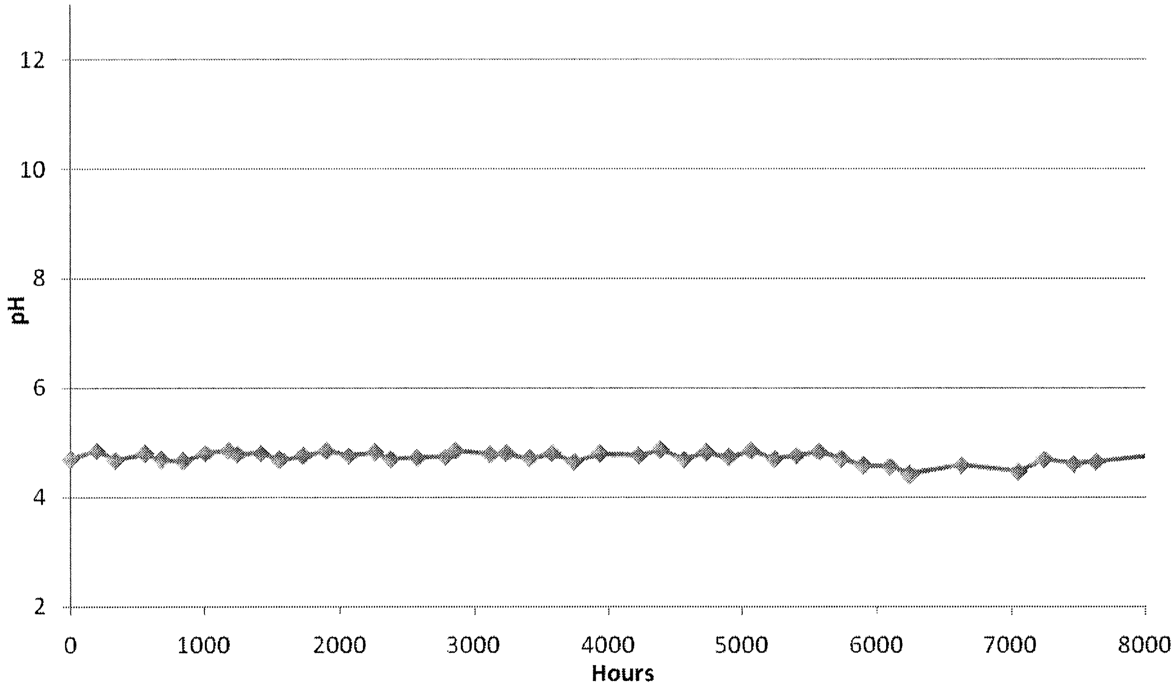

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Figure 5-3: pH versus Time: PWR Accelerated Corrosion Test

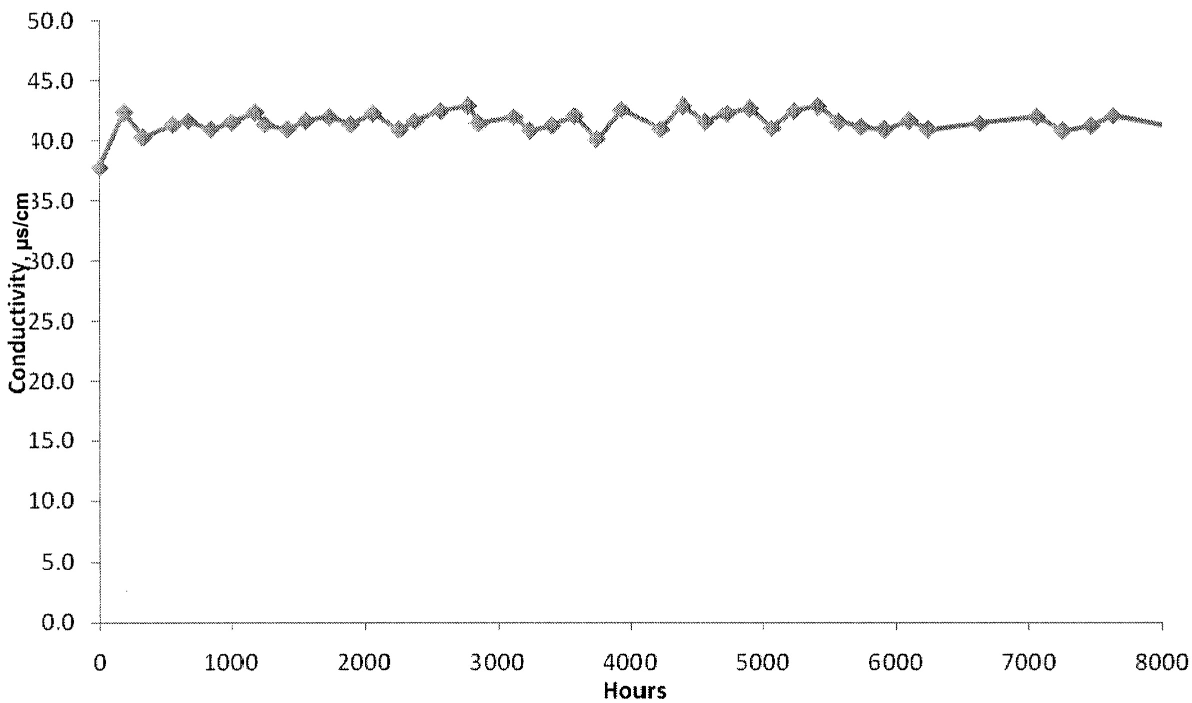

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Figure 5-4: Water Conductivity versus Time: PWR Accelerated Corrosion Test

5.4 Corrosion Test Results

Visual Inspection and Microscopy

All coupons removed from the BWR and PWR accelerated corrosion tests after 2000, 4000, 6000 and 8000 hours were subjected to visual inspection. Some of the coupons were subjected to optional microscopy. In addition, high resolution macro photographs were taken both upon removal from the test solutions and after air drying. Optical microscopy was also performed to verify that the oxide films were substantially removed prior to determining coupon weight loss and prior to inspecting for any anomalies along the outer bend radii of the bend coupons. The coupons and the digital data files of all macro photographs, microphotographs and photo micrographs are in permanent storage.

A sampling of photographs and photomicrographs are included in this report to illustrate the pre and post test appearance of the coupons. Photographs and photomicrographs from the 4000 hour and 8000 hour inspections are compared to illustrate little change in coupon surface appearance once an initial oxide film forms. This suggests that the initial oxide film is largely self-passivating, limiting the rate of subsequent oxidation of
the base metal. 4

Figure 5-5 is a macrophotograph that compares the appearance of the 16 vol % coupons exposed to the BWR and PWR test conditions for 4000 hours with an as-fabricated archive coupon. The archive coupon is a somewhat darker grey color than pure AA1100 aluminum. This appearance is characteristic of mill finish aluminum that is darkened somewhat by numerous small black boron carbide particles embedded in its surface. Figure 5-6 contains a similar macrophotograph for coupons inspected after 8000 hours.

The coupons exposed to the BWR environment have a more or less uniform white oxide coating with some larger black areas where the boron carbide areas have been exposed. The areas of exposed boron carbide are larger than on the archive material. This may be due to boron carbide that was near the surface but covered by a thin layer of aluminum in the as-produced material. Once oxidized, the thin oxide layer has insufficient strength to adhere to the underlying boron carbide and is loosened by the circulating bath water.

The coupons exposed to the PWR environment appear somewhat different. The background color is a light grey with smaller areas of exposed boron carbide on the surface. Examination of the surface under a microscope revealed the surface is covered with a uniform translucent film showing some of the color of aluminum through the film. Randomly interspersed are smaller dark areas of exposed boron carbide particles. The surface appearance is similar after 4000 hours and 8000 hours.

Figures 5-7 and 5-8 compare the post test coupons with archive material for the composite with 25 vol % boron carbide loading after 4000 and 8000 hours, respectively. It is noted that the archive material has a darker appearance than the archive material with 16 vol % due to the higher B_4C loading. Similarly, the post test coupons are somewhat darker for the same reason. The oxidized surfaces of these post test coupons are similar to the surfaces of the 16 vol % post test coupons and the appearances maintain their similarity after 4000 and 8000 hours exposure. 4

Figures 5-9 and 5-10 are microphotographs that compare the appearance of the 16 vol % post test coupons after 4000 and 8000 hours, respectively, with archive material at 8X magnification. Figures 5-11 and 5-12 are microphotographs of 25 vol % coupons exposed to demineralized water and boric acid after 4000 hours and 8000 hours, respectively.

Figures 5-13 and 5-14 are photomicrographs of the surfaces of 16 vol % and 25 vol % boron carbide composite, respectively, in the as-fabricated condition. These can serve as a reference when evaluating the surface condition of the composites after 8000 hours exposure to demineralized water and boric acid.

Figures 5-15 and 5-16 are photomicrographs of the 16 vol % B_4C composite after 8000 hours in demineralized water and boric acid, respectively. The surface appearance in Figure 5-15 is characteristic of areas of between locally heavy surface boron carbide (see e.g. Figure 5-10).

Figures 5-17 and 5-18 are photomicrographs of the 25 vol % B_4C composite after 8000 hours in demineralized water and boric acid, respectively.

The photograph and microphotographs contained in Figures 5-5 through 5-18 serve to illustrate that all coupons develop a more or less uniform oxide film on all surfaces. The appearance of the coupons after 4000 hours exposure compared to their appearance after 8000 hours exposure show that they are essentially identical. This suggests that the oxide film, once formed, is self-passivating and retards subsequent corrosion of the 4
base metal. This conclusion is further supported by the quantitative corrosion rate measurements described subsequently.

The difference in appearance of the coupons exposed to demineralized water and boric acid suggests the different pHs of the baths result in different forms of the oxide. Subsequent acid cleaning of the oxide to measure weight loss further supports this hypothesis. For the coupons exposed to demineralized water, the oxided layer is readily removed by one short soak in nitric acid. For the coupons exposed to the boric acid solution, it required several longer soak periods in order for oxide removal and the coupons to achieve constant weight. It is postulated that at lower pH in the boric acid condition, $\propto$ -alumina (Al_2O_3) forms, which is less soluble in nitric acid than the oxide formed at a higher pH in demineralized water. The latter form of the oxide formed at the higher pH in demineralized water is thought to be a hydrated form or Gibbsite ($Al_2O_3 \cdot 3H_2O$). Optical microscopy of the inside and outside radius of the bend coupons before and after acid cleaning revealed no cracks or other anomalistic corrosion behavior.

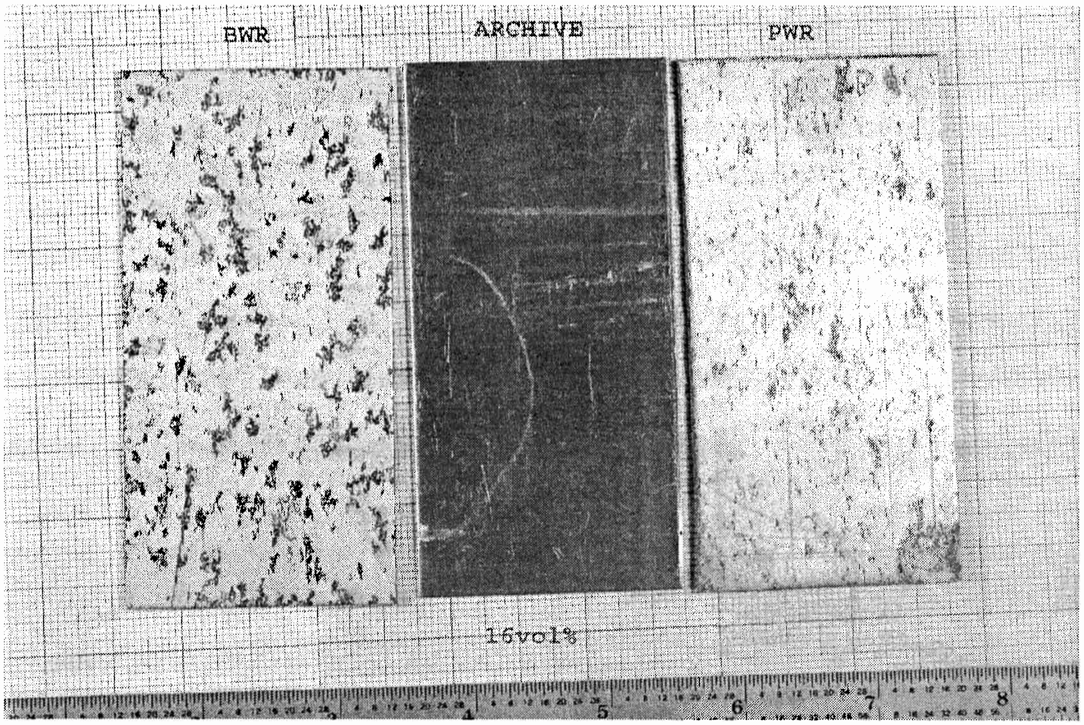

Figure 5-5: Comparison of Post-Test Coupon Appearance with Archive Material: 16 vol % Boron Carbide Loading after 4000 Hours 4

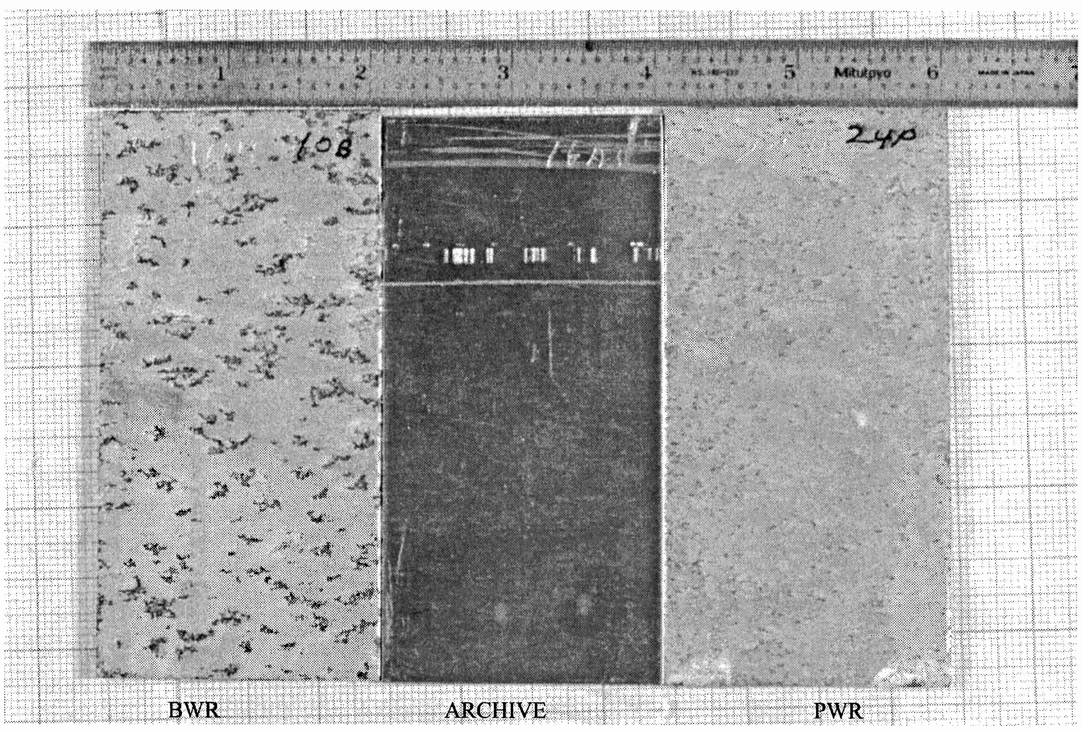

Figure 5-6: Comparison of Post-Test Coupon Appearance with Archive Material: 16 vol % Boron Carbide Loading after 8000 Hours

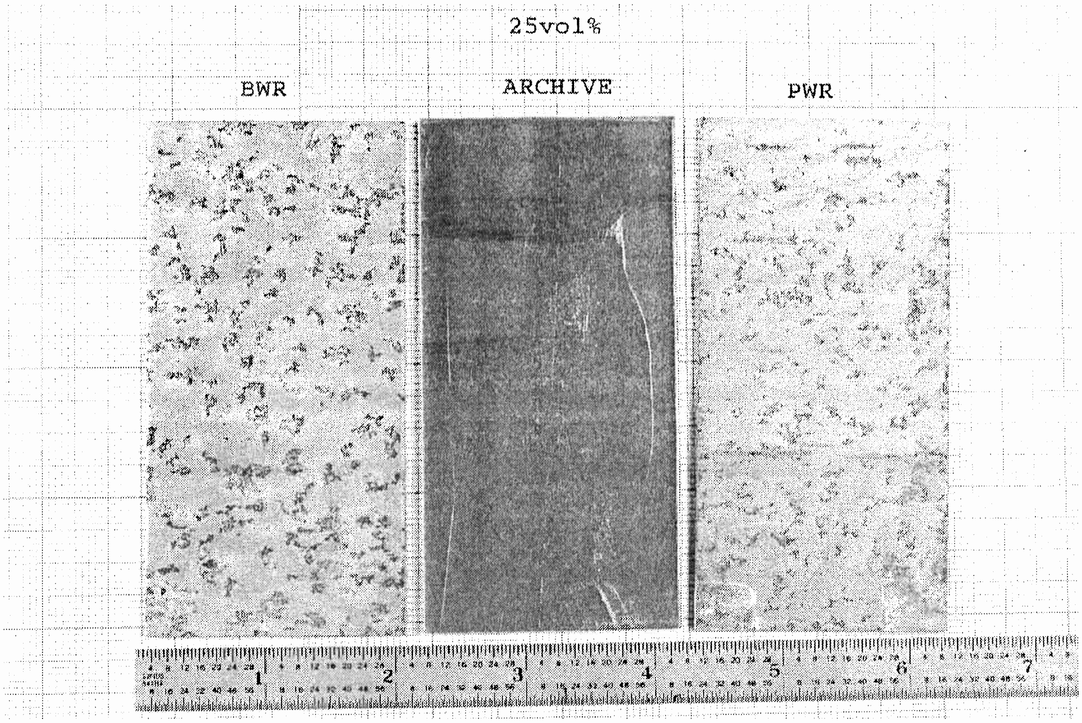

Figure 5-7: Comparison of Post-Test Coupon Appearance with Archive Material: 4
25 vol % Boron Carbide Loading after 4000 Hours

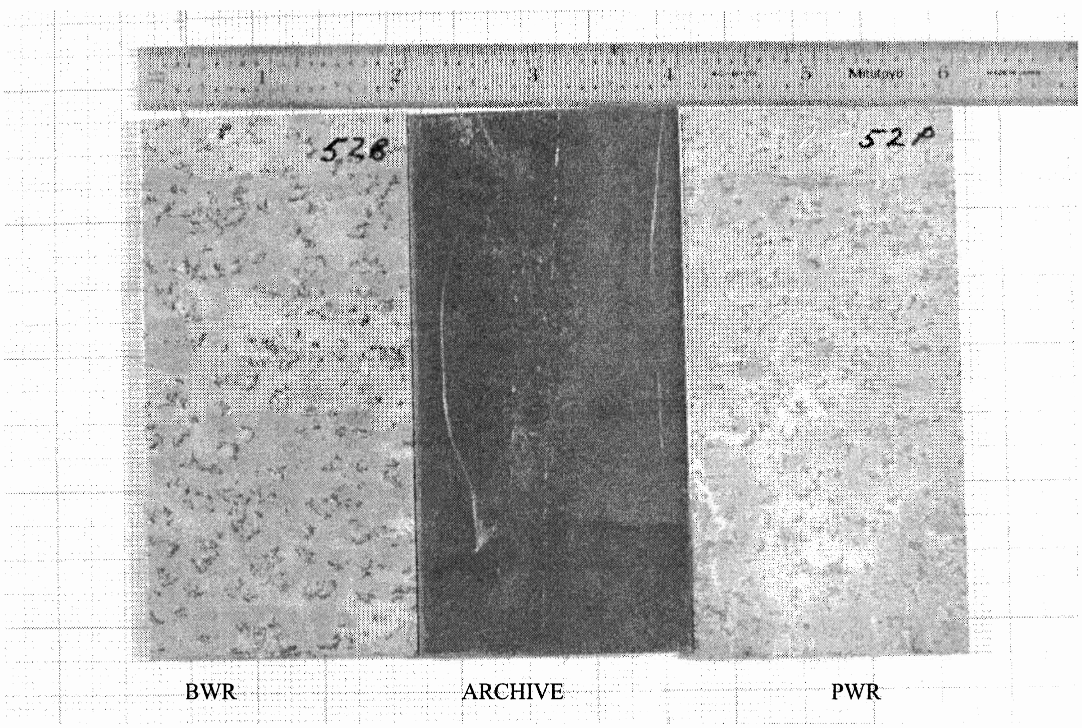

Figure 5-8: Comparison of Post-Test Coupon Appearance with Archive Material:
25 vol % Boron Carbide Loading after 8000 Hours

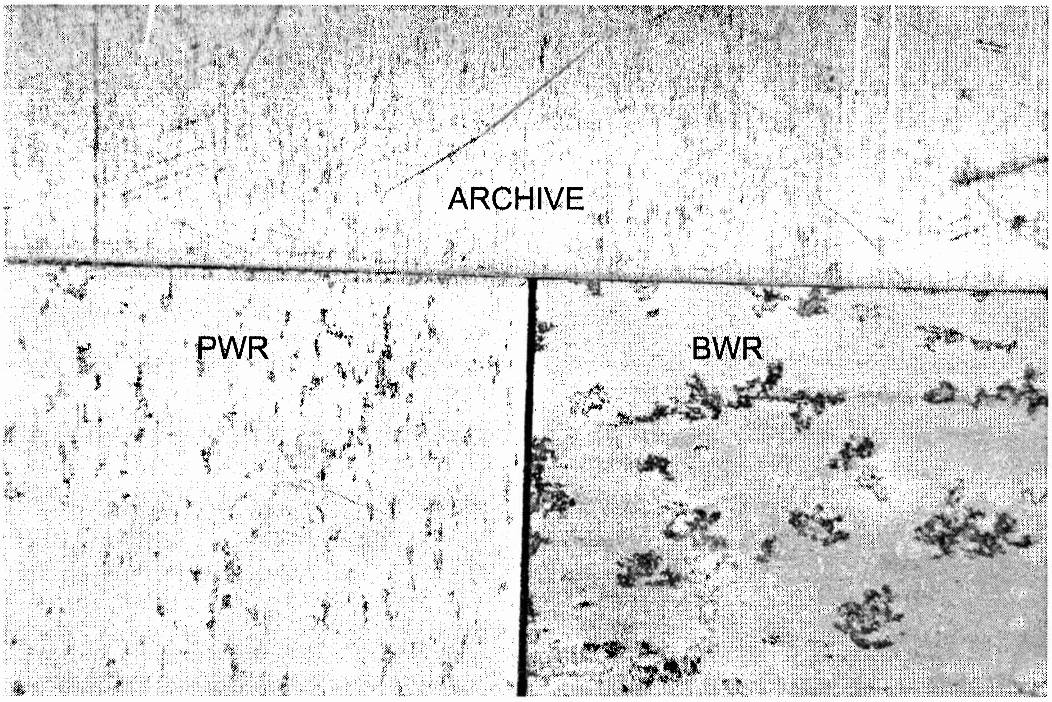

Figure 5-9: Comparison of Post-Test Coupon Appearance with Archive Material: 16 vol % Boron Carbide Loading at 8X Magnification after 4000 Hours 4

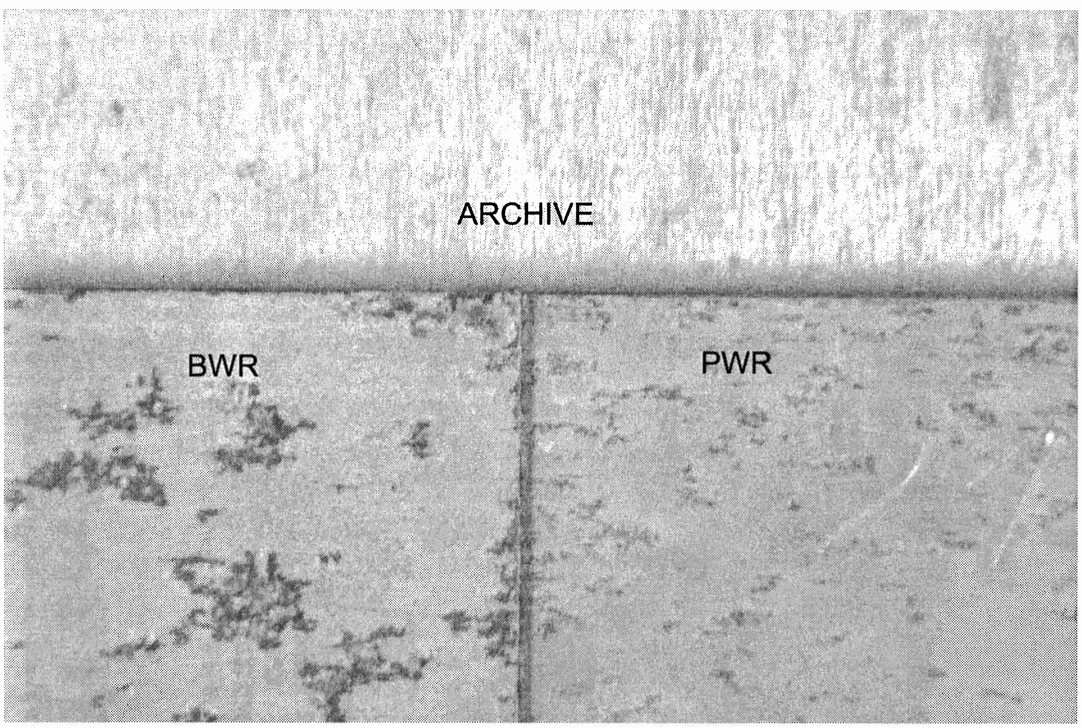

Figure 5-10: Comparison of Post-Test Coupon Appearance with Archive Material: 16 vol % Boron Carbide Loading at 8X Magnification after 8000 Hours

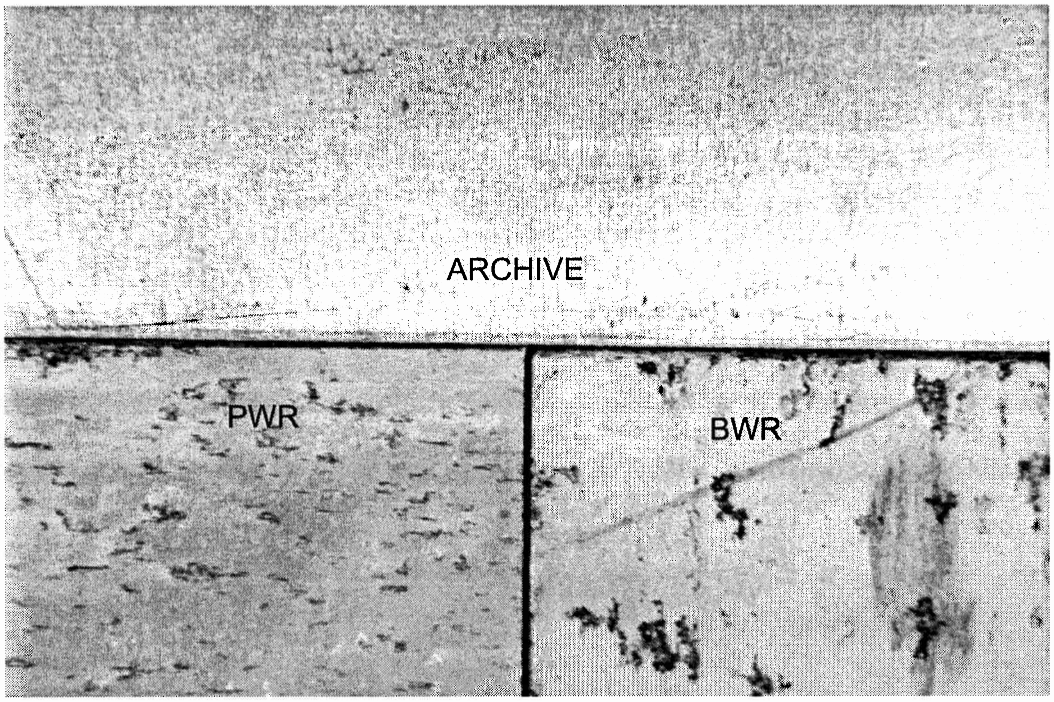

Figure 5-11: Comparison of Post-Test Coupon Appearance with Archive Material: 25 vol % Boron Carbide Loading at 8X Magnification after 4000 Hours 4

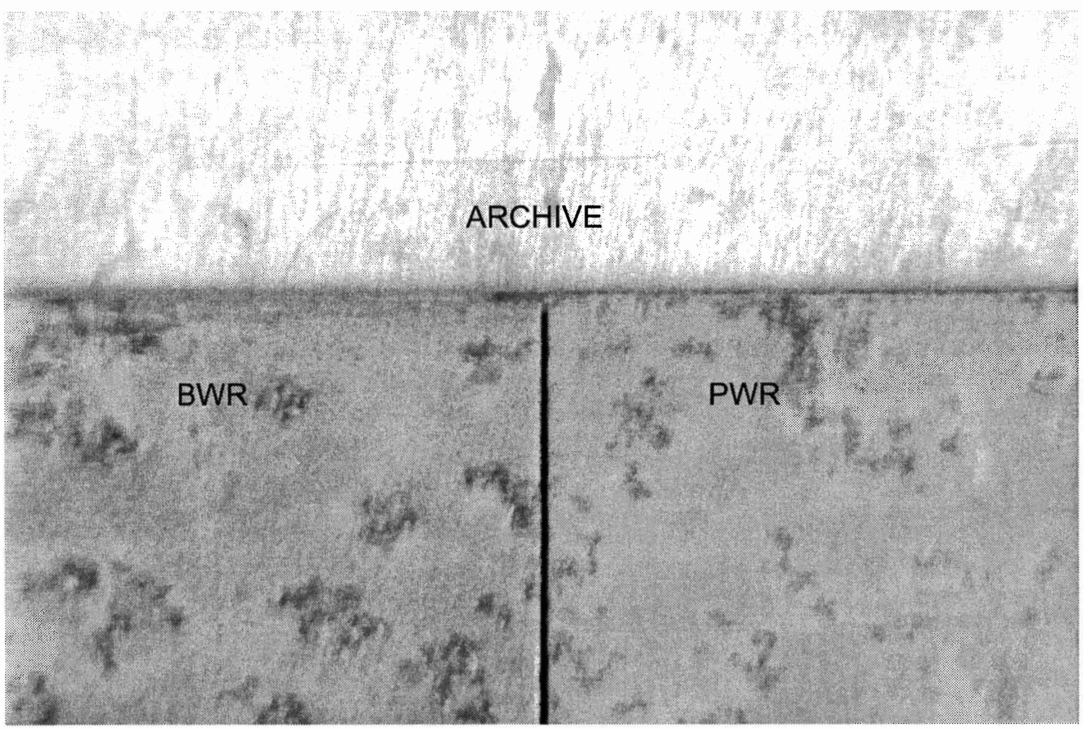

Figure 5-12: Comparison of Post-Test Coupon Appearance with Archive Material: 25 vol % Boron Carbide Loading at 8X Magnification after 8000 Hours

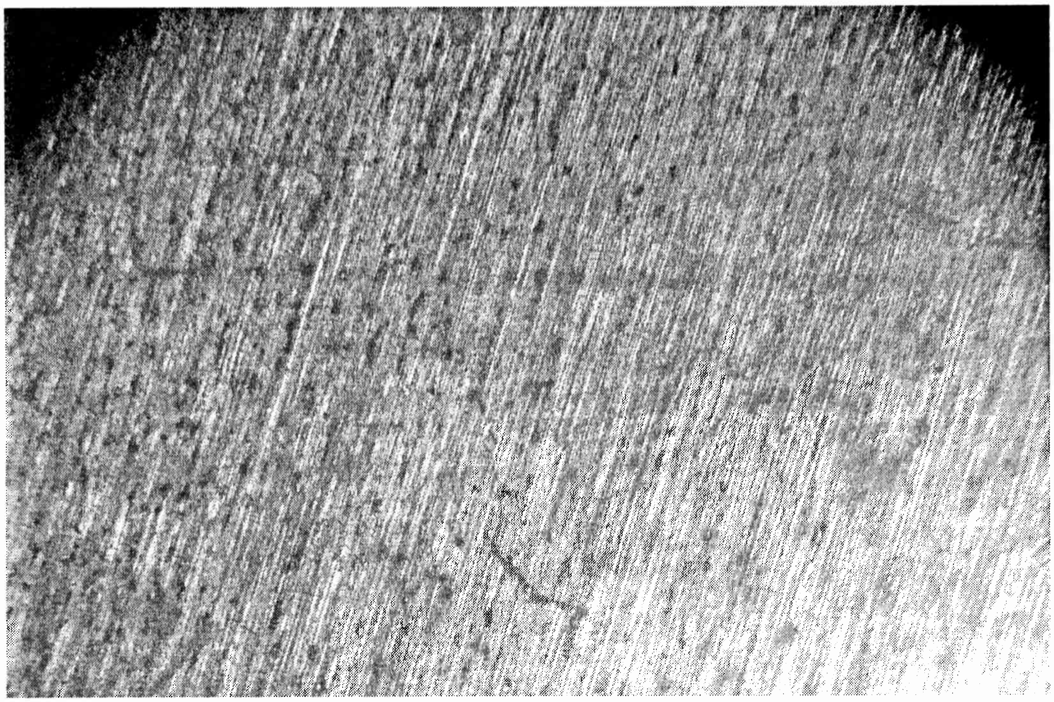

Figure 5-13: Photomicrograph of 16 vol % B_4C Composite As-Fabricated (45X) 4

Figure 5-14: Photomicrograph of 25 vol % B_4C Composite As-Fabricated (45X)

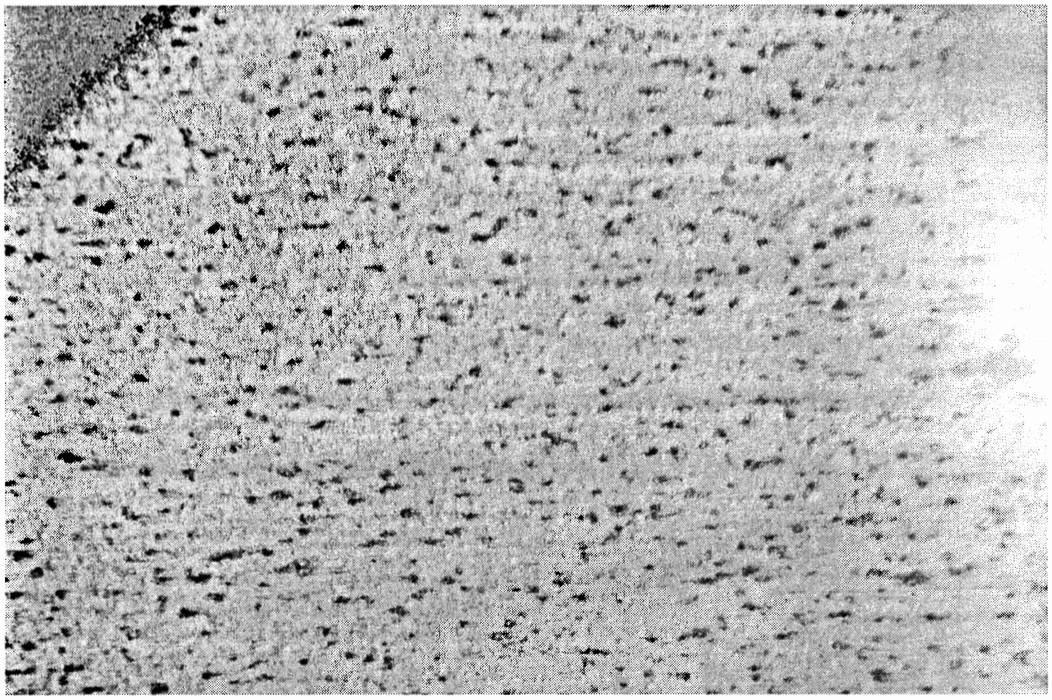

Figure 5-15: Photomicrograph of 16 vol % B_4C Composite after 8000 Hours in Demineralized Water (45X) 4

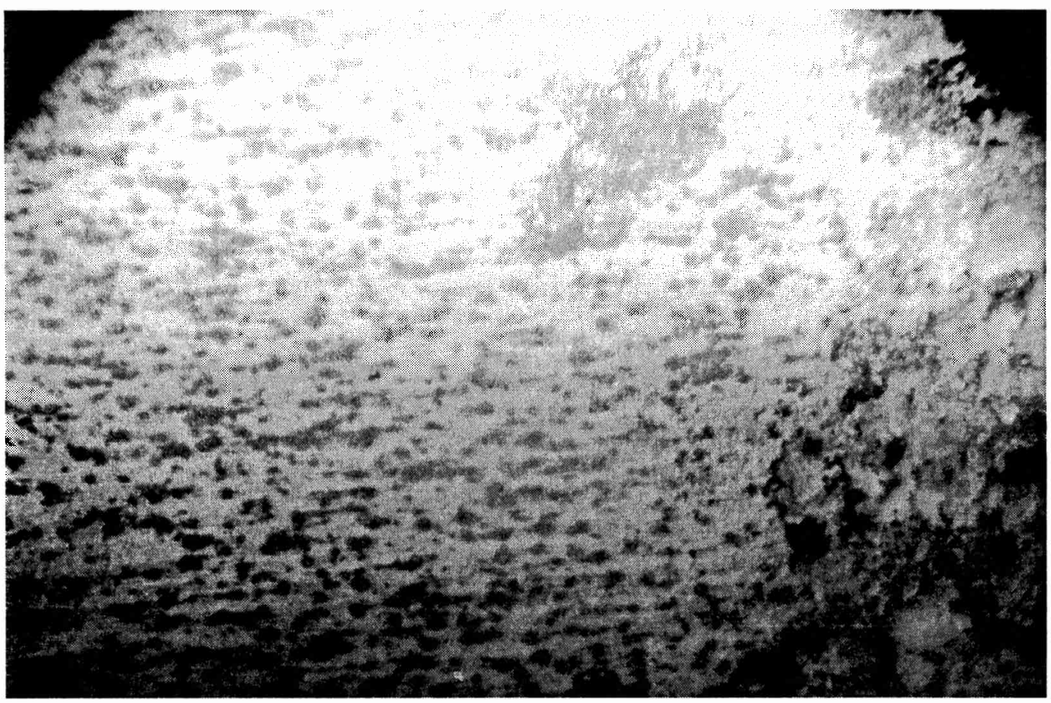

Figure 5-16: Photomicrograph of 16 vol % B_4C Composite after 8000 Hours in Boric Acid (45X)

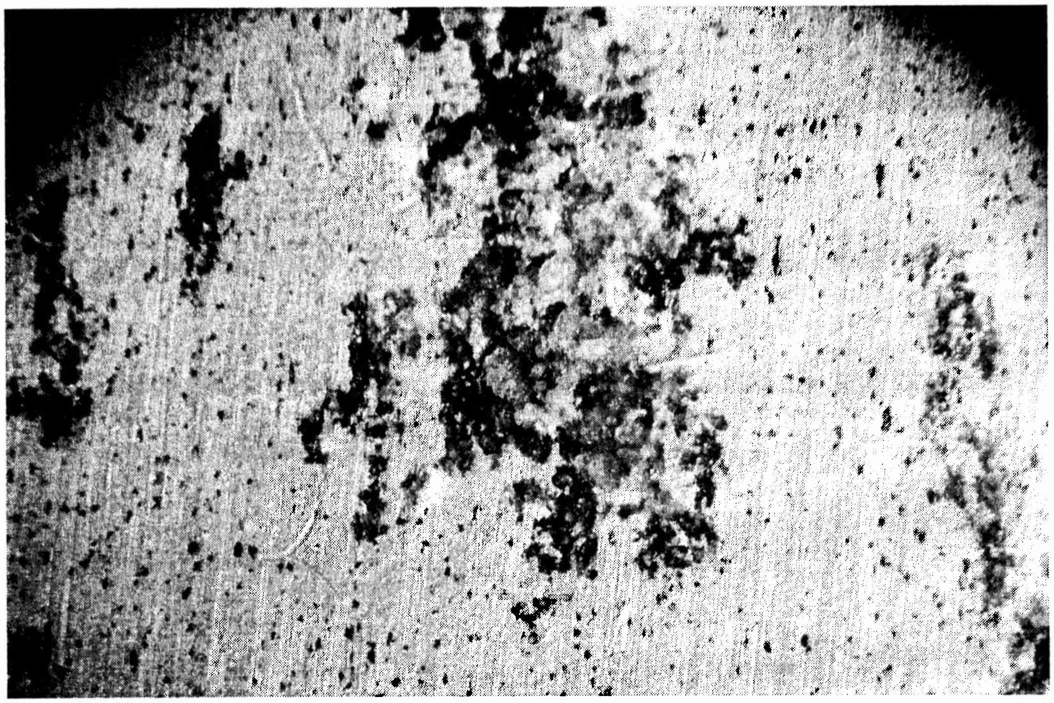

Figure 5-17: Photomicrograph of 25 vol % B_4C Composite after 8000 Hours in Demineralized Water (45X) 4

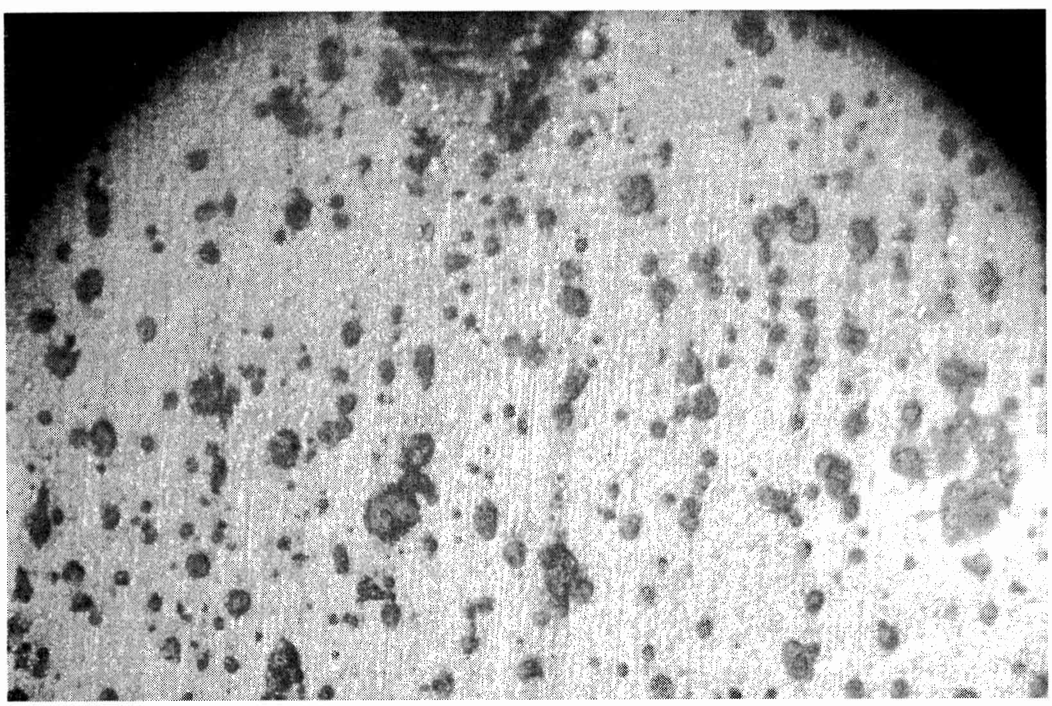

Figure 5-18: Photomicrograph of 25 vol % B_4C Composite after 8000 Hours in Boric Acid (45X)

Quantitative Corrosion Measurements

The change in coupon thickness can provide a semi-quantitative measure of the extent and progression of corrosion. The change in coupon weight, on the other hand, can provide a more accurate measure of the extent and progression of corrosion. As the aluminum base metal on the surface of the coupons is converted to the oxide (either Al_2O_3 or $Al_2O_3 \cdot n\ H_2O$), the volume of the oxide exceeds the volume of the original base metal consumed. Concurrent with this conversion is an increase in thickness and increase in weight.

The pre-test thickness of each general coupon was measured at nine locations. The pre-test thickness of each bend coupon was measured at six locations. The post-test thickness was measured at the same nine and six locations on the general and bend coupons, respectively. The values reported are the average of either nine or six measurements for each coupon. The pre and post test coupons' weights were measured for each coupon after a one hour drying at 110°C to remove surface moisture. 4

Figures 5-19 and 5-20 contain the results of the average coupon thickness changes versus exposure times for the BWR and PWR coupons, respectively. The data show that, with one exception, the coupons show a measurable increase in thickness. The scatter in the data is likely attributable to measuring small changes in thickness in relatively thin samples. To place this data in perspective, a 5% increase in thickness on a coupon of initial thickness of 0.080 inches is 0.004 inches or 4 mils. If it is assumed that both sides of the coupon contribute equally then the increase is 0.002 inches per side. After 8000 hours, the average change in the thickness of the coupons exposed to accelerated BWR conditions is 4.2%; the corresponding value for the PWR coupons is 4.1%. Figures 5-21 and 5-22 contain plots of coupon weight change versus exposure time.

At the 4000 hour and 8000 hour tests, eighteen of the galvanic corrosion couples were removed from each test bath and were subjected to testing. These included three 304L stainless steel couples, three Inconel 718 couples and three Zircaloy coupons at each

B_4C loading. No couples were tested at 2000 hours and 6000 hours. Figures 5-23 and 5-24 show the weight change of the BWR and PWR couple samples after coupon drying.

In accordance with ASTM G-31-72[1] and ASTM G-1-03[2], the coupons were cleaned in 1.42 sp.gr. nitric acid to remove the corrosion products. The intent of cleaning is to remove all of the corrosion products but none of the base metal so that the weight of the corrosion products can be determined. This weight change can subsequently be used to determine the corrosion rate in mils/year.

As noted previously, the oxide on coupons in the BWR test was easily removed by one or two ten-minute soaks in nitric acid at room temperature. For the PWR coupons it required several successive soak periods. After each cleaning cycle, the coupons were dried and reweighed. The cleaning proceeded until the coupons achieved constant weight or visual and/or microscopic examination indicated the oxide film had been removed. 4

Figures 5-25 and 5-26 show the average change in coupon thickness after acid cleaning for the BWR and PWR general and bend coupons, respectively. Figures 5-27 and 5-28 show the change in coupon thickness after acid cleaning for the BWR and PWR galvanic coupons, respectively, after 4000 hours and 8000 hours. These values represent the thickness of oxide removed by acid cleaning. The average change in thickness by coupon type are summarized in Table 5-5. The data in Table 5-5 illustrate the difficulty in obtaining accurate changes in coupon thickness when the specimens are very thin. This is further evidenced by the variability in the coupon thickness data.

The coupon weight changes as a result of acid cleaning are shown in Figures 5-29 and 5-30 for the BWR and PWR general and bend coupons, respectively. The coupon weight changes as a result of acid cleaning are shown in Figures 5-31 and 5-32 for the BWR and PWR galvanic coupons, respectively. The average change in coupon weight by coupon type are summarized in Table 5-6. This table shows the weight changes exhibit far less variability than the thickness changes in Table 5-5. Accordingly, the weight change data are used subsequently to compute corrosion rates.

Table 5-5

Summary of Coupon Thickness Changes by Coupon Type

	Thickness Change, %			
Coupon Types	**2153 Hours**	**4019 Hours**	**5871 Hours**	**8119 Hours**
BWR General and Bend				
16 vol % B_4C	-1.14% ± 0.59%	-3.08% ± 0.64%	-1.40% ± 1.07%	-0.55% ± 0.88%
25 vol % B_4C	-0.72% ± 0.89%	-2.09% ± 1.40%	0.08% ± 0.44%	-0.94% ± 0.79%
BWR Galvanic				
16 vol % B_4C		-0.07% ± 0.68%		-0.91% ± 0.35%
25 vol % B_4C		-1.05% ± 0.35%		-0.98% ± 0.81%
PWR General and Bend				
16 vol % B_4C	-0.03% ± 0.51%	-2.73% ± 1.14%	-0.70% ± 0.92%	-3.32% ± 4.64%
25 vol % B_4C	-0.55% ± 0.46%	-1.24% ± 1.05%	0.44% ± 1.10%	-0.13% ± 0.82%
PWR Galvanic				
16 vol % B_4C		-1.04% ± 0.81%		-2.55% ± 3.25%
25 vol % B_4C		-1.24% ± 0.27%		-0.40% ± 0.88%

Table 5-6 4

Summary of Coupon Weight Changes by Coupon Type

	Weight Change, %			
Coupon Types	**2153 Hours**	**4019 Hours**	**5871 Hours**	**8119 Hours**
BWR General and Bend				
16 vol % B_4C	-0.15% ± 0.12%	-0.28% ± 0.22%	-0.68% ± 0.19%	-0.50% ± 0.17%
25 vol % B_4C	-0.29% ± 0.27%	-0.36% ± 0.38%	-0.68% ± 0.25%	-0.69% ± 0.75%
BWR Galvanic				
16 vol % B_4C		0.05% ± 0.2%		-0.34% ± 0.19%
25 vol % B_4C		-0.24% ± 0.27%		-0.81% ± 0.28%
PWR General and Bend				
16 vol % B_4C	-0.12% ± 0.04%	-0.07% ± 0.09%	-0.10% ± 0.12%	-0.26% ± 0.37%
25 vol % B_4C	-0.04% ± 0.07%	-0.02% ± 0.05%	-0.17% ± 0.12%	-0.16% ± 0.09%
PWR Galvanic				
16 vol % B_4C		-0.64% ± 0.77%		-0.89% ± 0.46%
25 vol % B_4C		-0.79% ± 0.98%		-0.66% ± 0.46%

Boron-10 Areal Density

The boron-10 areal density of the general coupons was measured using neutron attenuation testing. The results of the post-test measurements were compared with similar testing of archive coupons. Figures 5-33 and 5-34 contain plots of the change in boron-10 areal density versus exposure time for the BWR and PWR coupons, 4
respectively. To place these measurements in perspective, the average areal density of the 16 vol % coupons is 0.010 gms B-10/cm^2; the corresponding areal density of the 25 vol % coupons is 0.0176 gms B-10/cm^2. The variation in areal density changes are within ± 1.0 to 2.0% of zero change, which is within the absolute uncertainty of the areal density measurements.

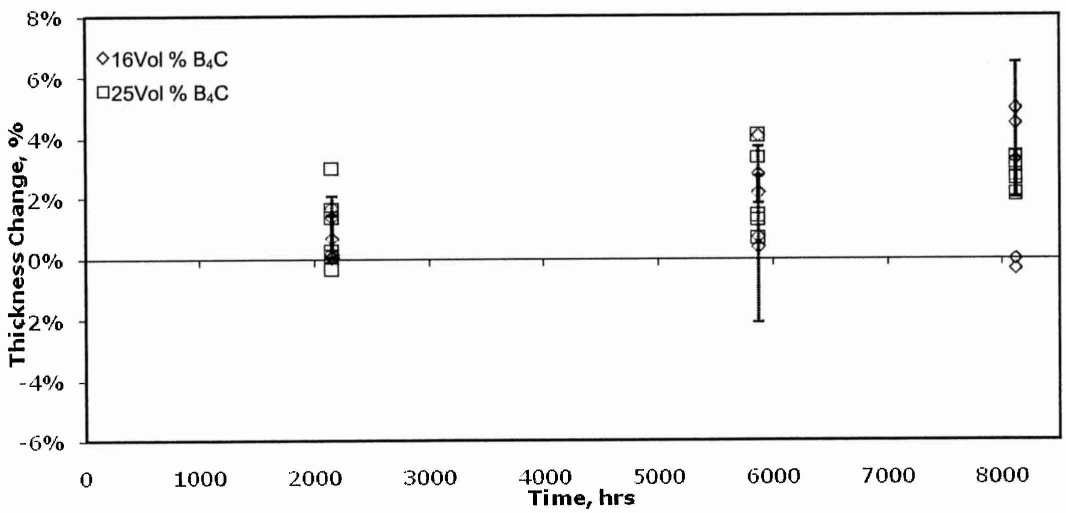

Figure 5-19: BWR Thickness Change (Pre-Test vs. Post-Test)

4

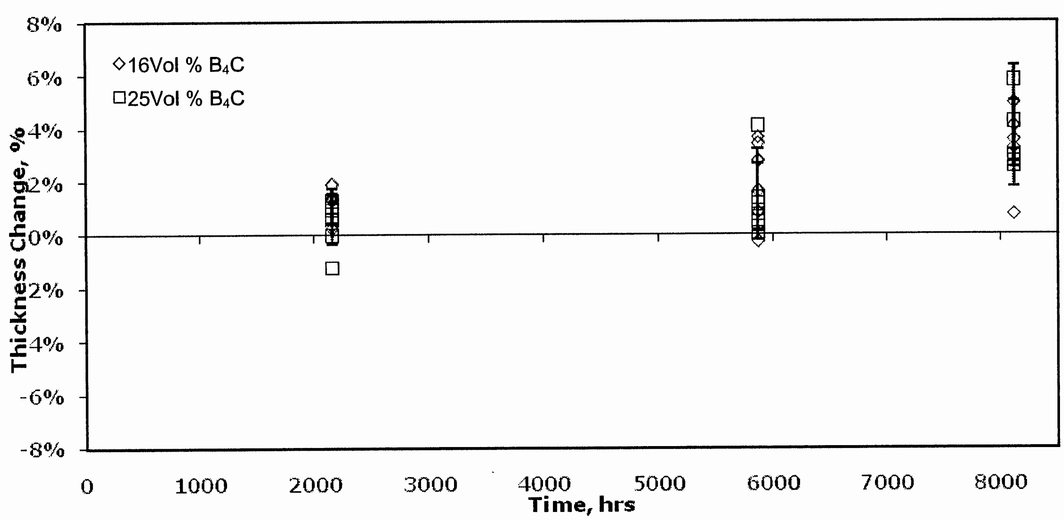

Figure 5-20: PWR Thickness Change (Pre-Test vs. Post-Test)

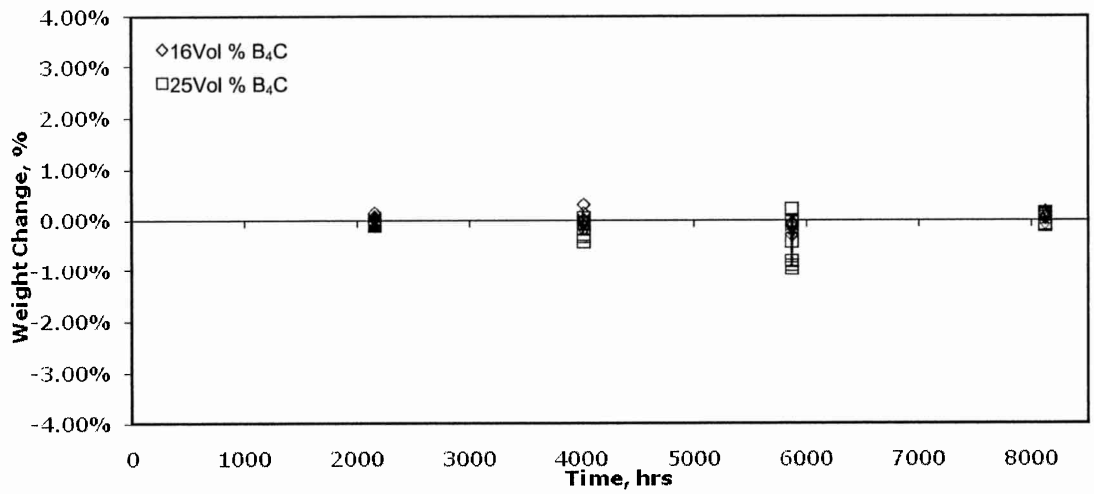

Figure 5-21: BWR Weight Change (Pre-Test vs. Post-Test)

4

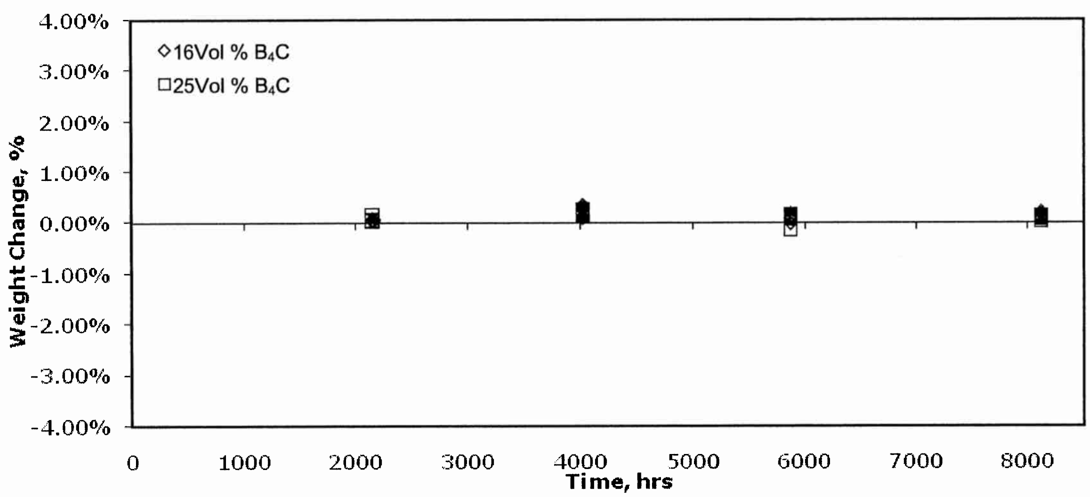

Figure 5-22: PWR Weight Change (Pre-Test vs. Post-Test)

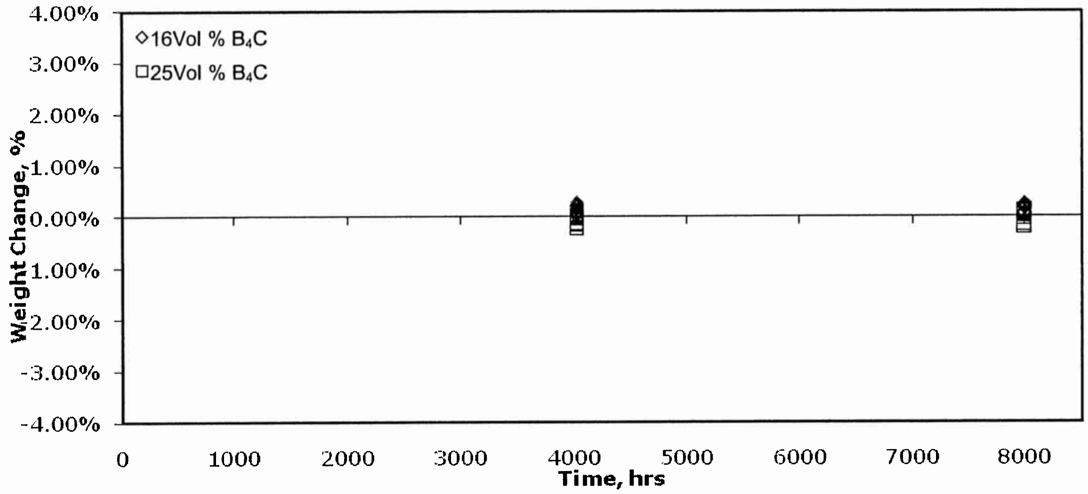

Figure 5-23: BWR Coupon Weight Change versus Time: Galvanic Couple Coupons

4

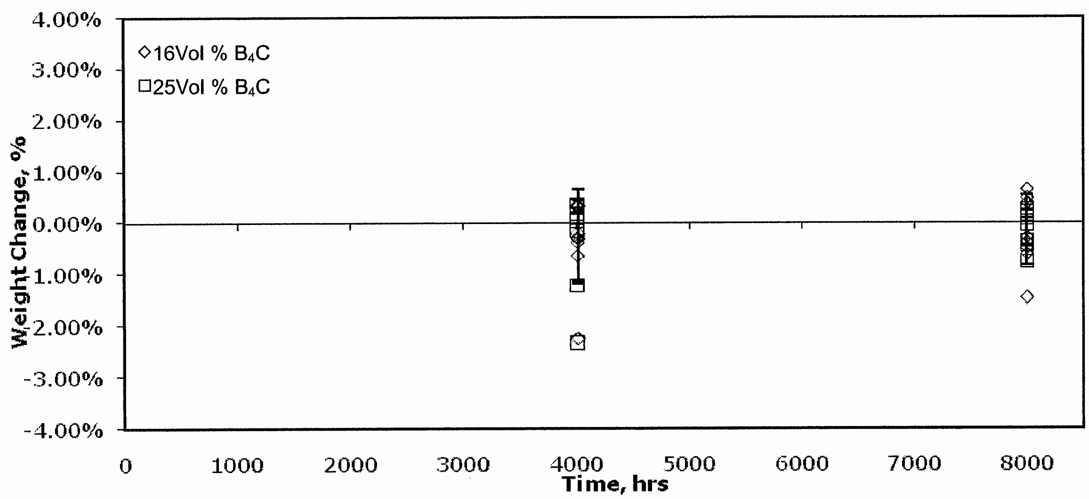

Figure 5-24: PWR Coupon Weight Change versus Time: Galvanic Couple Coupons

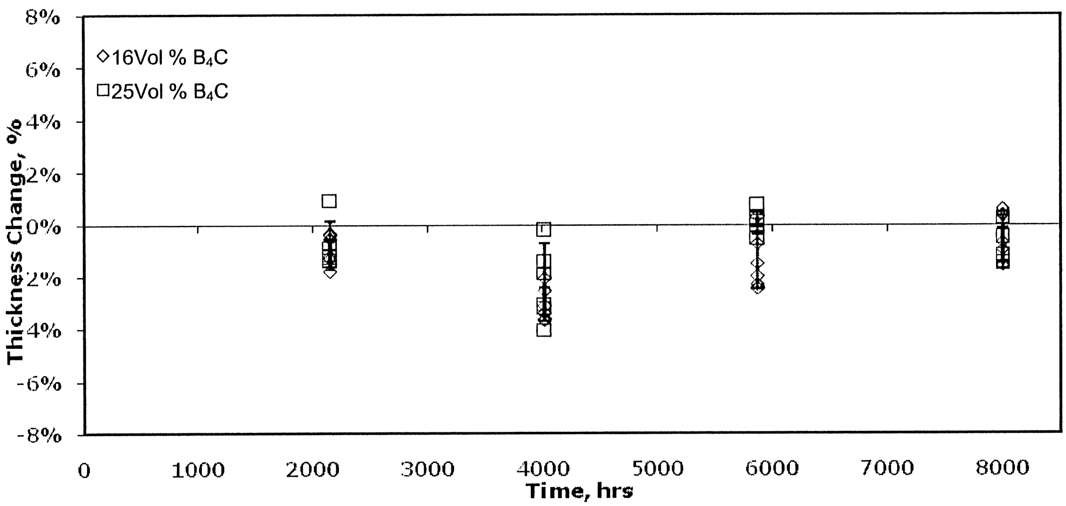

Figure 5-25: BWR Thickness Change (Pre-Test vs. Post-Test) After Acid Cleaning: General and Bend Coupons

4

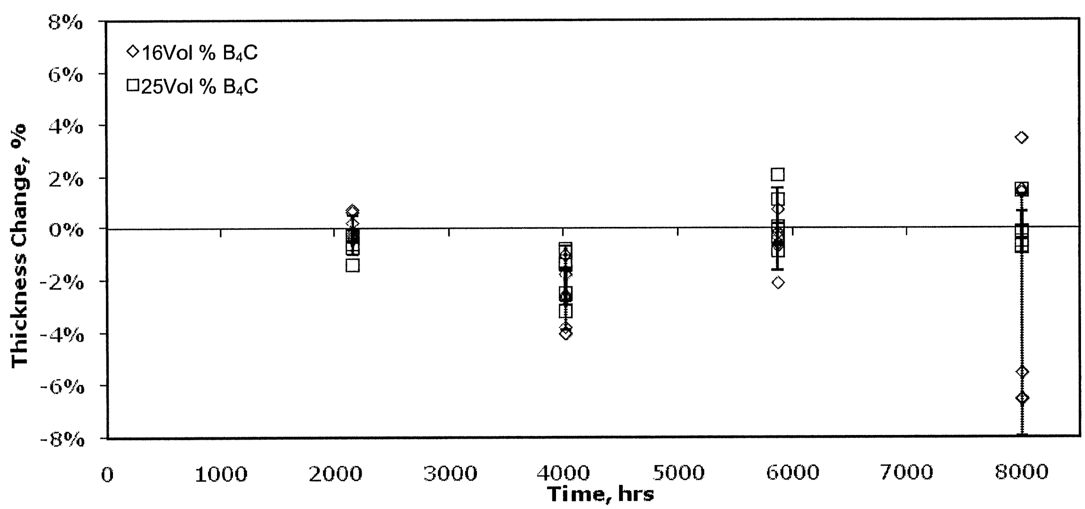

Figure 5-26: PWR Thickness Change (Pre-Test vs. Post-Test) After Acid Cleaning: General and Bend Coupons

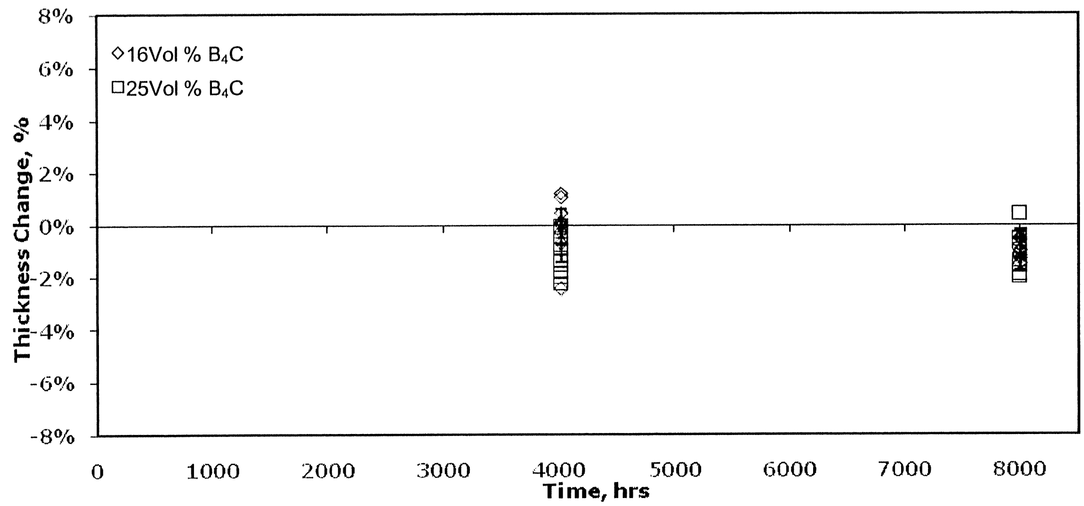

Figure 5-27: BWR Galvanic Coupons After Acid Cleaning: Coupon Thickness Change

4

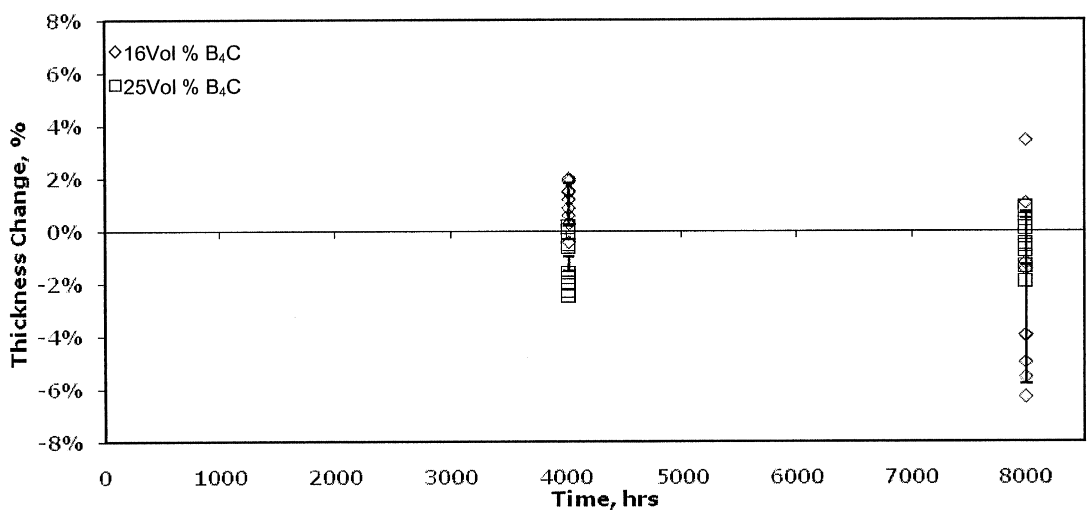

Figure 5-28: PWR Galvanic Coupons After Acid Cleaning: Coupon Thickness Change

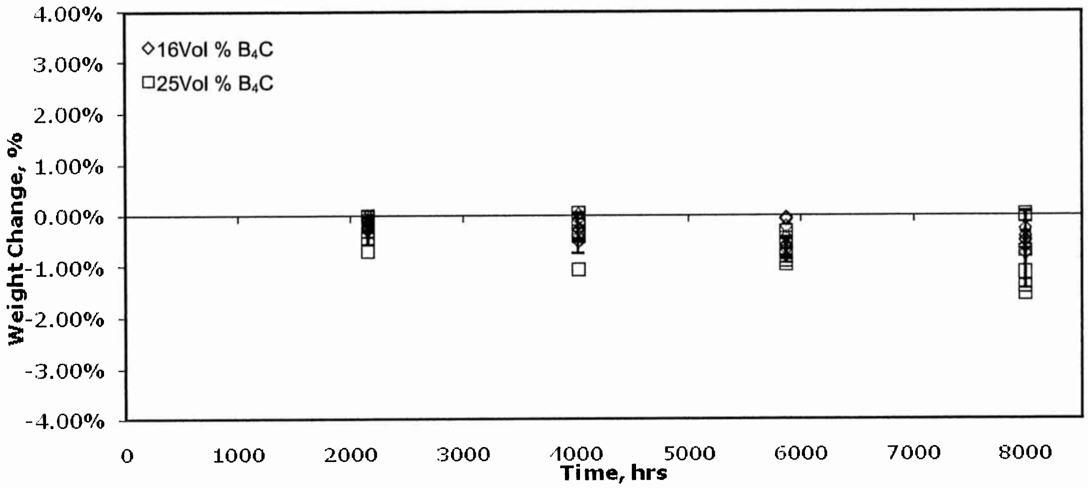

Figure 5-29: BWR Coupon Weight Change (Pre-Test vs. Post-Test) After Acid Cleaning: General and Bend Coupons Only

4

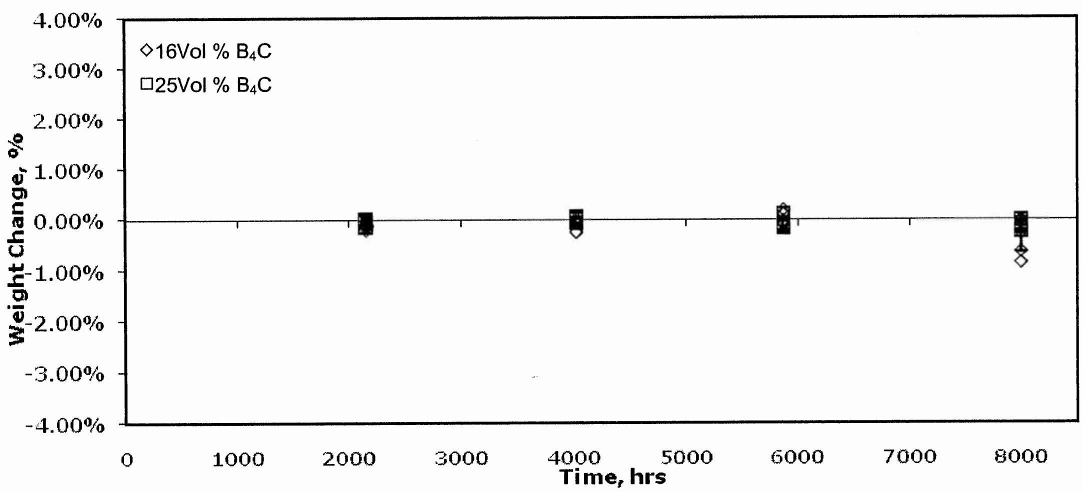

Figure 5-30: PWR Coupon Weight Change (Pre-Test vs. Post-Test) After Acid Cleaning: General and Bend Coupons Only

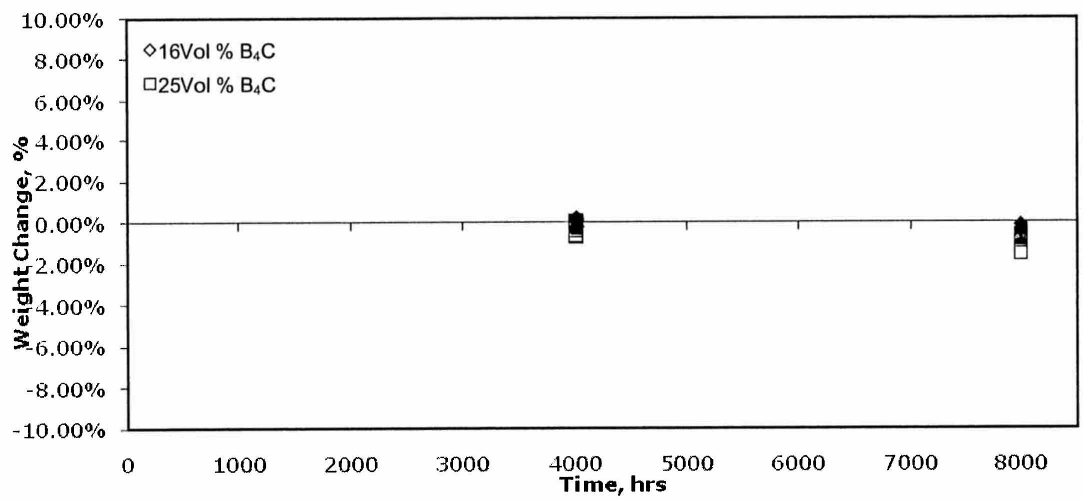

Figure 5-31: BWR Galvanic Coupon Weight Change versus Time 4

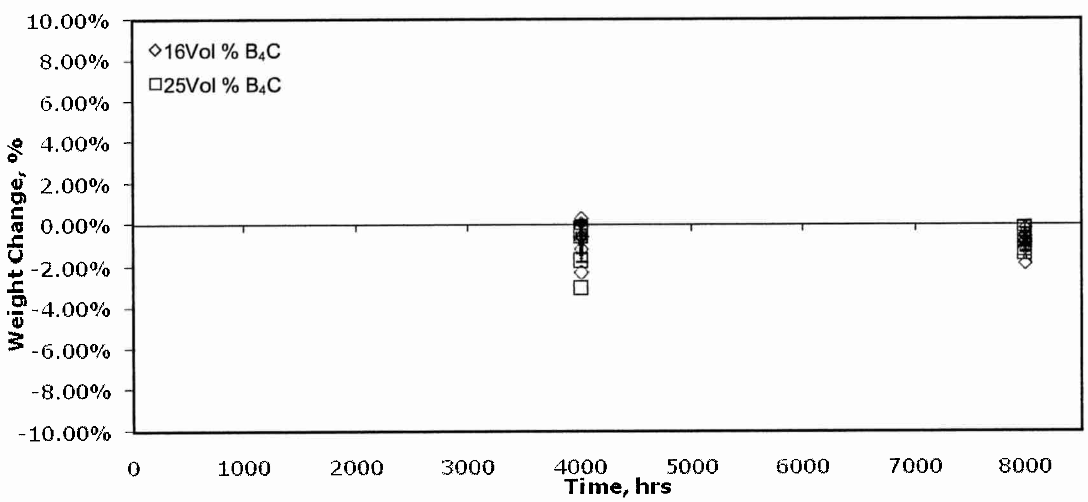

Figure 5-32: PWR Galvanic Coupon Weight Change versus Time

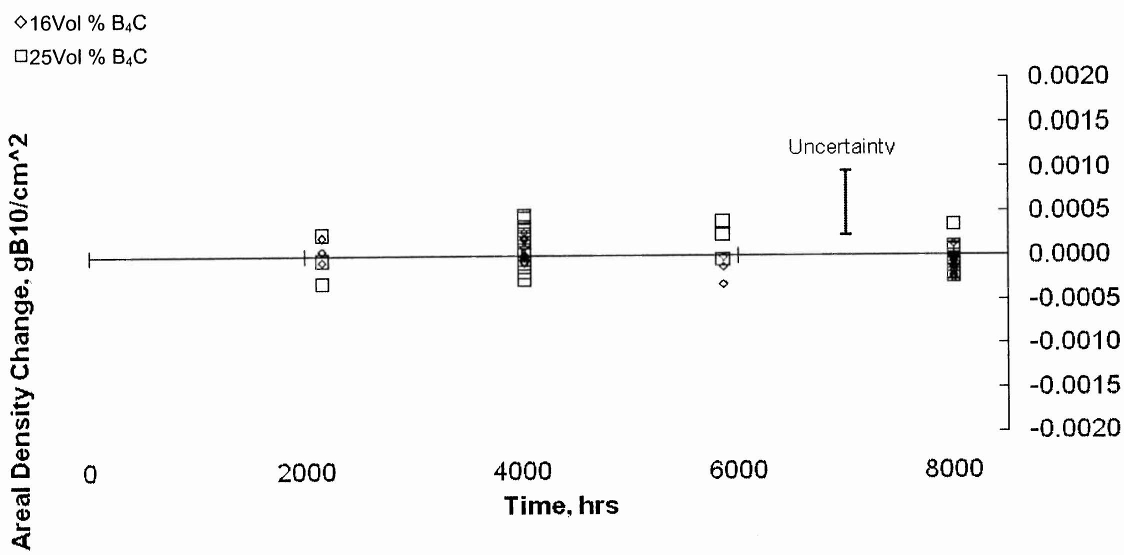

Figure 5-33: BWR Coupon Areal Density Change versus Time 4

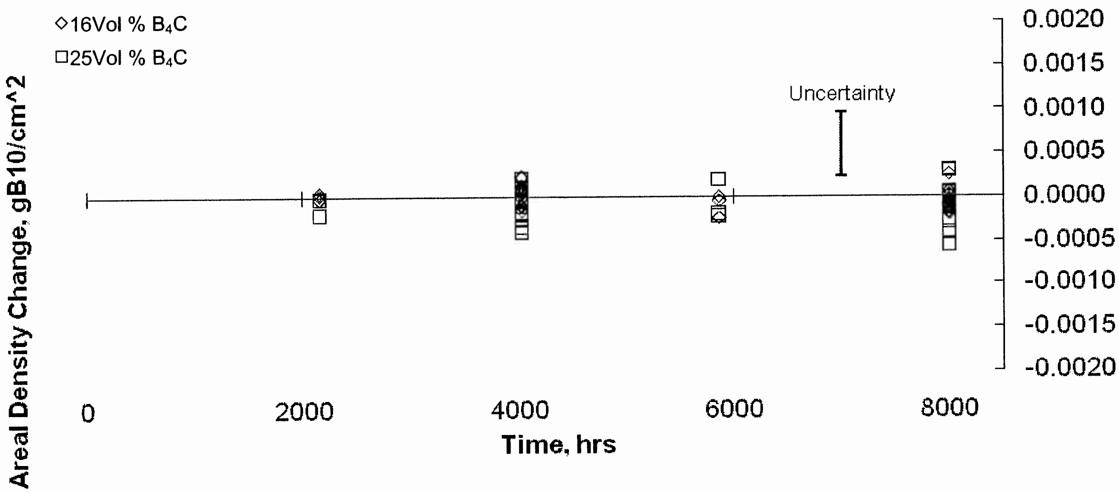

Figure 5-34: PWR Coupon Areal Density Change versus Time

5.5 *Discussion of Test Results and Conclusions*

Following the guidance provided in Reference 1, the post-test coupon weights after acid cleaning can be compared with pre-test weights to compute the test environment corrosion rate (mils/year) of the various coupon types. Using corrosion data in Reference 3 for AA1200 series aluminum in water at 122° F and 392° F, it is possible to compute the corresponding in-service corrosion rates at typical spent fuel pool conditions and water temperature (typically 80° F). These calculations are contained in the Appendix and the so calculated in-service corrosion rates are summarized in Table 5-7. Table 5-8 contains the equivalent in-service exposure times for each of the four test intervals.

Table 5-7: Average Corrosion Rates

	In-Service Corrosion Rates, mils/year				
Coupon Types	**2153-Hour Test**	**4019-Hour Test**	**5871-Hour Test**	**8119-Hour Test**	
BWR General and Bend					4
16 vol % B_4C	-0.01	-0.01	-0.02	-0.01	
25 vol % B_4C	-0.02	-0.02	-0.02	-0.02	
BWR Galvanic					
16 vol % B_4C		0.01		-0.01	
25 vol % B_4C		-0.01		-0.02	
PWR General and Bend					
16 vol % B_4C	-0.01	-0.01	-0.03	-0.01	
25 vol % B_4C	-0.01	-0.02	-0.01	-0.01	
PWR Galvanic					
16 vol % B_4C		-0.02		-0.02	
25 vol % B_4C		-0.04		-0.01	

Table 5-8: Equivalent Exposure Time

Test Hours @ 195° F	**In-Service Hours @ 80° F**
2153	39050
4019	72911
5871	107447
8119	148605

The computed in-service corrosion rates shown in Table 5-7 are extremely low and in
each instance are based on the average weight loss of several coupons. A corrosion
rate of -0.02 mils/year can be interpreted to mean that after 100 years an oxide film 2
mils thick would be expected on all surfaces. The reason for this extremely low
corrosion rate is that once an oxide film forms on all surfaces, the film tends to be self-
passivating; that is, it tends to retard further corrosion. This property of the oxide film
formation leads to the excellent corrosion resistance of AA1100 aluminum alloy and the 5
performance of the Rio-Tinto Alcan material shows similar performance. This has been
observed in other aluminum boron carbide composites tested by NETCO.[4]

It is further noted that for both the 16 vol % and the 25 vol % coupons, there has been
no measurable change in the B-10 areal density, nor has any local corrosion (pitting) or
cracking been detected. Optical microscopy of inside and outside radius of bend
coupons revealed no cracks or anomalistic corrosion behavior. These observations 4
apply to both the BWR and the PWR test environments.

Once installed, the inserts assume a constant strain condition within the rack cell. This
compression leads to internal stresses, especially at the bend, that might make the
inserts susceptible to stress corrosion cracking. An examination of the literature on this
subject[5-5],[5-6], indicates that "In general, high-purity aluminum and low-strength 5
aluminum alloys are not susceptible to SCC."[5-5] However, surveillance bend coupons
to be placed in the pool prior to the installation of the inserts will be maintained under
the same strain conditions to provide indication of any unexpected crack phenomena.

Not withstanding the low measured corrosion rates, corrosion itself does not result in any loss of boron carbide. After the corrosion film forms, the boron carbide remains tightly bound in the corrosion layer. This was confirmed by the neutron attenuation measurements for boron-10 areal density, which were performed prior to acid cleaning to remove corrosion products.

As determined by the testing sequences described herein, the low measured corrosion rates under accelerated corrosion test conditions as well as the constancy of boron-10 areal density, recommends that the AA1100/boron carbide composite produced by Rio Tinto Alcan is a highly suitable neutron absorber material for use in spent fuel storage racks.

References Section 5:

5-1 ASTM G-31-72 (Reapproved 2004), Standard Practice for Laboratory Corrosion Testing of Metals.

5-2 ASTM G-1-03, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

5-3 Godard, Epson, Bothwell and Kane, The Corrosion of Light Metals, John Wiley & Sons, Inc., New York, 1967.

5-4 Qualification of METAMIC® for Spent-Fuel Storage Applications, Electric Power Research Institute Report 1003137 by Northeast Technology Corp., Kingston, NY. October 2001.

5-5 Davis, J.R. Corrosion of Aluminum and Aluminum Alloys. ASM International. November 2000. Pg. 108 4

5-6 Bauccio, Michael. ASM Metals Reference Book, Third Edition. ASM International. April 2003. Pg. 408

6.0 Fast Start Coupon Surveillance Program Description

The fast start coupon surveillance program consists of a series of 24 coupons cut from extra Alcan composite produced for the LaSalle demonstration. These coupons are 2 x 4 inches in width and length and have two 0.25 inch diameter holes along the top and bottom edge as shown in Figure 6-1. Their thickness is nominally 0.065 inch and each coupon contains 16 vol% boron carbide. The purpose of the fast start program is to provide early performance data on the Alcan composite in the LaSalle Unit 2 pool environment.

Each of the coupons will be connected to the next coupon with a stainless steel link clip. The string of 24 coupons will be attached to a short piece of stainless steel chain, which in turn will be attached to a head assembly (See Figure 6-2). The head assembly contains a hook so that it can be remotely lowered into a rack storage cell in the LaSalle Unit 2 pool. When in place the head piece will rest on top of a storage cell with the string of coupons suspended in the cell below. The length of the connecting chain between the head piece and the string of coupons was adjusted so that all 24 coupons are within the active fuel region of the eight surrounding fuel assemblies.

At each refueling outage the fast start coupons will be in a cell surrounded in all eight locations with freshly discharged fuel. In this manner the gamma energy disposition and temperatures of the coupons will be maximized. Two coupons will be removed every six months from the string and sent to a qualified laboratory for testing and inspection. The coupons have been subjected to pre characterization and will be post test characterized. Table 6-1 contains the pre and post test inspections and measurements.

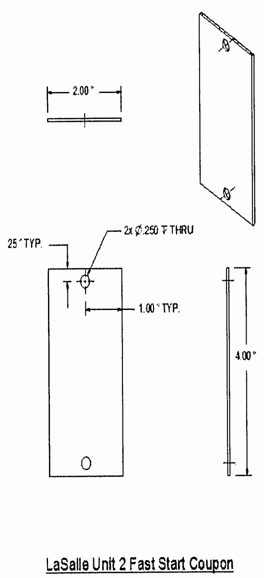

Figure 6-1: Fast Start Surveillance Coupon

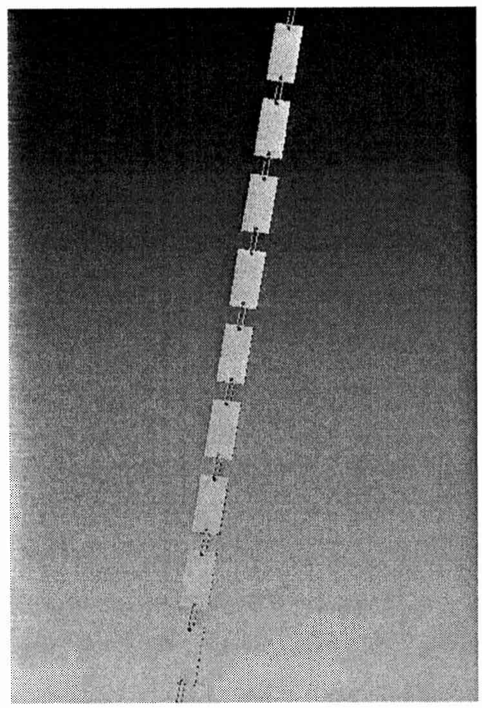

Figure 6-2: Fast Start Coupons String

Table 6-1

Pre and Post Test Coupon Characterization

Test	Pre Characterization	Post Characterization
Visual (Hi resolution digital photo)	√	√
Dimension	√	√
Dry Weight	√	√
Density	√	√
Areal Density	√+	√
Acid Cleaning		√
Weight Loss		√
Corrosion Rate		√
Microscopy		√*

+ On select coupons *as-required

A prime objective of this fast start program is to provide some early data as to the actual corrosion rates anticipated under actual LaSalle spent fuel pool conditions.

7.0 Long-Term Surveillance Program

The long-term surveillance program will consist of a specially designed surveillance tree to which a series of surveillance coupons are attached. The long-term surveillance tree will be placed within the pool as part of the first installation campaign of NETCO-SNAP-INs® and will reside there as long as the fuel racks continue to be used. Periodically, coupons will be removed and sent to a qualified laboratory for testing.

7.1 Tree and Coupon Description

The surveillance tree will be a four-sided structure with 18 - 2" x 4" coupons attached to each side and 12 – 2" bend coupons abutting adjacent faces. The bend coupons will be 3
maintained under a fixed strain in the fixture. They will be manufactured at the same 4
initial angle as the inserts and bent to the square angle of the rack cells. All coupons will contain 17 vol% boron carbide. The types and numbers of coupons included in the program are shown in Table 7-1.

Table 7-1

Long-Term Surveillance Coupons

Coupon Type	Number	Objective	
General	48	Quantify long-term corrosion	
Bend	24	Track effects along bend radii including stress relaxation and stress corrosion cracking	4
Galvanic (bi-metallic)	24	Trend galvanic corrosion with 304SS, In and Zirc coupons	

7.2 Coupon Inspection and Testing

Specific coupons will be removed from tree on a frequency schedule as described subsequently. The general coupons will be subject to pre and post examination according to Table 7-2.

Table 7-2

Long-Term Surveillance General Coupon Characterization

Test	Pre Characterization	Post Characterization	
Visual (Hi resolution digital photo)	√	√	
Dimension	√	√	
Dry Weight	√	√	4
Areal Density	√+	√	
Acid Cleaning		√	
Weight Loss		√	
Corrosion Rate		√	
Microscopy		√*	

+ On select coupons *as-required

The bend and galvanic coupons will be subject to the tests in Table 7-3.

Table 7-3

Long-Term Surveillance Bend and Galvanic Coupon Characterization

Test	Pre Characterization	Post Characterization	
Visual (High Resolution Digital Photo)	√	√	
Thickness	√	√	4
Dry Weight	√	√	
Bending Stress (Bend Coupons Only)	√	√	
Acid Cleaning		√	
Weight Loss and Corrosion Rate		√	
Microscopy		√*	

*as-required

7.3 *Frequency for Coupon Inspection*

The frequency for coupon inspection will depend on the coupon type and results of previous inspections. The frequency for inspection is shown in Table 7-4.

Table 7-4

Frequency for Coupon Testing

Coupon Type	**First Ten Years**	**After 10 Years with Acceptable Performance**
General	2 coupons every 2 years	2 coupons every 4 years
Bend	1 coupon every 2 years	1 coupon every 4 years
Galvanic Couples 304 Stainless Zirc In	1 couple every 6 years " "	

2

ATTACHMENT 7

"Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Rack Inserts," Global Nuclear Fuel, NEDO-33672, September 2011, Revision 0 (Non-Proprietary Version)

Global Nuclear Fuel

A Joint Venture of GE, Toshiba, & Hitachi

Global Nuclear Fuel

NEDO-33672
Revision 0
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September 2011

Non- Proprietary Information - Class I (Public)

Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Rack Inserts

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Revision Status

Revision Number	Date	Description of Change
0	September 2011	Initial revision

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1.0 Introduction

This report describes the criticality analysis and results for the Peach Bottom Atomic Power Station (PBAPS) spent fuel racks assuming complete Boraflex degradation and the use of neutron absorbing inserts in each accessible cell. It includes sufficient detail on the methodology and analytical models utilized in the criticality analysis to verify that the storage rack systems have been accurately and conservatively represented.

The racks are analyzed using the MCNP-05P Monte Carlo neutron transport program and the k_∞ criterion methodology. A maximum cold, uncontrolled peak in-core eigenvalue (k_∞) of 1.27 as defined by the lattice physics code TGBLA06 is specified as the rack design limit for GNF2 fuel in the spent fuel racks. As demonstrated in Table 1, the analysis resulted in a storage rack maximum k-effective (K(95/95)) less than 0.95 for normal and credible abnormal operation with tolerances and uncertainties taken into account.

Table 1 – Summary K-95/95 Result

Region	$K_{max(95/95)}$
Spent Fuel Rack with Inserts	[[ ]]

2.0 Requirements

Title 10 of the Code of Federal Regulations (10 CFR) Part 50 defines the requirements for the prevention of criticality in fuel storage and handling at Nuclear Power Plants. 10 CFR 50.68 details specifically that the storage rack eigenvalue for both new and spent fuel storage racks must be demonstrated to be ≤ 0.95 for normal and credible abnormal operation with tolerances and computational uncertainties taken into account. Reference 1 outlines the standards that must be met for these analyses. These requirements are supplemented by GDC 62 and IN 2011-03. All necessary requirements are met in this analysis.

3.0 Method of Analysis

In this evaluation, in-core k_∞ values and exposure dependent, pin-by-pin isotopic specifications are generated using the GEH/GNF lattice physics production code TGBLA06. TGBLA06 solves 2D diffusion equations with diffusion parameters corrected by transport theory to provide system multiplication factors and perform burnup calculations.

The fuel storage criticality calculations are then performed using MCNP-05P, the GEH/GNF Proprietary version of MCNP5 (Reference 2). MCNP-05P is a Monte Carlo program for solving the linear neutron transport equation for a fixed source or an eigenvalue problem. The code implements the Monte Carlo process for neutron, photon, electron, or coupled transport involving all these particles, and can compute the eigenvalue for neutron-multiplying systems. For the present application, only neutron transport was considered.

3.1 Cross Sections

TGBLA06 uses ENDF/B-V cross-section data to perform coarse-mesh, broad-group, diffusion theory calculations. It includes thermal neutron scattering with hydrogen using an $S(\alpha,\beta)$ light water thermal scattering kernel.

MCNP-05P uses point-wise (i.e., continuous) cross section data, and all reactions in a given cross section evaluation (e.g., ENDF/B-VII.0) are considered. For the present work, thermal neutron scattering with hydrogen was described using an $S(\alpha,\beta)$ light water thermal scattering kernel. The cross section tables include all details of the ENDF representations for neutron data. The code requires that all the cross sections be given on a single union energy grid suitable for linear interpolation; however, the cross section energy grid varies from isotope to isotope. The libraries include very little data thinning and utilize resonance integral reconstruction error tolerances of 0.001%.

3.2 Geometry Treatment

TGBLA06 is a two-dimensional lattice design computer program for BWR fuel bundle analysis. It assumes that a lattice is uniform and infinite along the axial direction and that the lattice geometry and material are reflecting with respect to the lattice boundary along the transverse directions.

MCNP-05P implements a robust geometry representation that can correctly model complex components in three dimensions. An arbitrary three-dimensional configuration is treated as geometric cells bounded by first and second-degree surfaces and some special fourth-degree elliptical tori. The cells are described in a Cartesian coordinate system and are defined by the intersections, unions and complements of the regions bounded by the surfaces. Surfaces are defined by supplying coefficients to the analytic surface equations or, for certain types of surfaces, known points on the surfaces. Rather than combining several pre-defined geometrical bodies in a combinatorial geometry scheme, MCNP-05P has the flexibility of defining geometrical shapes from all the first and second-degree surfaces of analytical geometry and elliptical tori and then combining them with Boolean operators. The code performs extensive checking for geometry errors and provides a plotting feature for examining the geometry and material assignments.

3.3 Validation and Computational Basis

[[

]]

Table 2 – Summary of the Critical Benchmark Experiments

Experiment	Experiments	Year	Where
[[			
			]]

Table 3 – Area of Applicability Covered by Code Validation

[[		
		]]

[[

]]

3.4 In-Core K_∞ Methodology

The design of the fuel storage racks provides for a subcritical multiplication factor for both normal and credible abnormal storage conditions. In all cases, the storage rack eigenvalue must be ≤ 0.95 (Reference 1). To demonstrate compliance with this limit, the in-core k_∞ method is utilized.

The in-core k_∞ criterion method relies on a well-characterized relationship between infinite lattice k_∞ (in-core) for a given fuel design and a specific fuel storage rack k_∞ (in-rack) containing that fuel. The use of an infinite lattice k_∞ criterion for demonstrating compliance to fuel storage criticality criteria has been used for all GE-supplied storage racks and is currently used for re-rack designs at a number of plants. This report demonstrates that the methodology is also appropriate for use at the PBAPS by presenting the following:

- A well-characterized, linear relationship between infinite lattice k_∞ (in-core) and fuel storage rack k_∞ (in-rack)
- The use of a design basis lattice with a conservative rack efficiency and in-core k_∞ for all criticality analyses

The analysis performed to calculate the lattice k_∞ to confirm compliance with the above criterion uses the NRC-approved lattice physics methods encoded into the TGBLA06 Engineering Computer Program (ECP). One of the outputs of TGBLA06 solution is the lattice k_∞ of a specific nuclear design for a given set of input state parameters (void fraction, control state, fuel temperature, etc.).

Compliance of fuel with specified k_∞ limits will be confirmed for each new lattice as part of the bundle design process. Documentation that this has been met will be contained in the fuel design information report, which defines the maximum lattice k_∞ for each assembly nuclear design. The process for validating that specific assembly designs are acceptable for storage in the PBAPS fuel storage racks is provided below.

1. [[

]]

Documentation that all legacy fuel types currently in the PBAPS comply with this in-core limit is found in Appendix B.

3.5 Definitions

Fuel Assembly – is a complete fuel unit consisting of a basic fuel rod structure that may include large central water rods. Several shorter rods may be included in the assembly. These are called "part length rods". A fuel assembly includes the fuel channel.

Gadolinia – The compound Gd2O3. The gadolinium content in integral burnable absorber fuel rods is usually expressed in weight percentage Gadolinia.

Lattice – An axial zone of a fuel assembly within which the nuclear characteristics of the individual rods are unchanged.

Dominant Lattice – An axial zone of a fuel assembly typically located in the bottom half of the bundle within which all possible fuel rod locations for a given fuel design are occupied.

Vanished Lattice – An axial zone of a fuel assembly typically in the upper half of the bundle within which a number of possible fuel rod locations are unoccupied.

Rack Efficiency – the ratio of a particular lattice statepoint in-rack eigenvalue (k_∞) to its associated lattice nominal in-core eigenvalue (k_∞). This value allows for a straightforward comparison of a rack's criticality response to varying lattice designs within a particular fuel product line. A lower rack efficiency implies increased reactivity suppression capability relative to an alternate design with a higher rack efficiency.

Design Basis Lattice – The lattice geometry, exposure history, and corresponding fuel isotopics for a fuel product line that result in the highest rack efficiency in a sensitivity study of reasonable fuel parameters at the desired in-core reactivity. This lattice is used for all normal, abnormal, and tolerance evaluations in the fuel rack analysis.

3.6 Assumptions and Conservatisms

The fuel storage rack criticality calculations are performed with the following assumptions to ensure the true system reactivity is always less than the calculated reactivity:

- [[

  ]]
- For conservatism, only positive reactivity differences from nominal conditions determined from depletion sensitivity and abnormal configuration, analyses are added as biases to the final storage rack maximum K(95/95).
- Neutron absorption in spacer grids, concrete, activated corrosion and wear products (CRUD) and axial blankets is ignored to limit parasitic losses in non-fuel materials.
- TGBLA06 defined "lumped fission products" and Xe-135 are both conservatively ignored for MCNP-05P in-rack k_∞ calculations.
- [[

  ]]
- The chevron shaped rack inserts are installed with multiple wing lengths to allow for improved fitting within the rack structure. In this analysis, all inserts are modeled with the minimum wing length that will be installed. Modeling the inserts in this way minimizes thermal neutron absorptions in the inserts.

- Only B^{10} is modeled in the rack inserts. Each insert is assumed to contain the minimum areal density of 0.0102 g B^{10}/cm^2. All other material is ignored. Ignoring the other materials conservatively limits neutron absorption in the insert.
- No credit is taken for the Boraflex in the storage racks in the analysis, and all material between the inner cell wall and outer wrapper of the fuel rack is modeled as water. Modeling this material as water is reasonable, as the outer wrapper does not provide a water tight seal between the Boraflex and pool environment, and therefore any significant gap formations within the poison material will be filled with water.

4.0 Fuel Design Basis

4.1 GNF2 Fuel Description

Criticality safety analyses to determine storage system reactivity are performed using the GNF2 fuel design. The GNF2 fuel lattice configuration is a 10x10 fuel rod array minus eight fuel rods that have been replaced with two large water rods, as shown in Figure 1 with corresponding dimensions in Table 4. Figure 1 also demonstrates the part-length rod locations, which cannot be changed for this fuel design. Fuel channel dimensions are provided in Figure 2 and Table 5. [[

]]

[[

]]

Figure 1 – GNF2 Fuel Lattice Configuration

Table 4 – Nominal Dimensions for GNF2 Fuel Lattice

Features	Ref.	(mm)	(inches)
[[			
			]]

[[

]]

Figure 2 – Channel Dimensions

Table 5 – Nominal Channel Dimensions for GNF2 Lattice

Dimension	mm	inches
[[		
		]]

[[

]]

4.2 Fuel Model Description

The fuel models considered include two-dimensional geometric modeling of all fuel material, cladding, water rods, and channels. [[

]] An example of a GNF2 vanished zone lattice model in MCNP-05P is depicted in Figure 3.

[[

]]

Figure 3 – GNF2 Lattice in MCNP-05P

[[

]] The lattice type and exposure history that results in the worst-case rack efficiency for an in-core k_∞ greater than the proposed limit is then used to define the design basis lattice. This lattice is assumed to be stored in every location in the rack being analyzed. Details on the determination of the design basis lattice using the process outlined above is presented in Section 5.3.

5.0 Criticality Analysis of Spent Fuel Storage Racks

5.1 Description of Spent Fuel Storage Racks

The PBAPS Boraflex storage racks manufactured by Westinghouse consist of a 304 stainless steel structure composed of a series of square vertical tubes (cells). These tubes contain 0.081" thick Boraflex panels sandwiched between a 0.075" SS inner cell wall and a 0.020" SS outer wrapper. The Boraflex containing cells are arranged in a checkerboard pattern with the space between a 4-cell group forming a fifth bundle storage location with a center-to-center cell pitch of 6.280 inches. Rack array sizes ranging from 9x14 up to 19x20 are placed adjacent to one another in the spent fuel pools of both PBAPS Units 2 and 3. A schematic of a single storage rack unit-cell without inserts installed is shown in Figure 4.

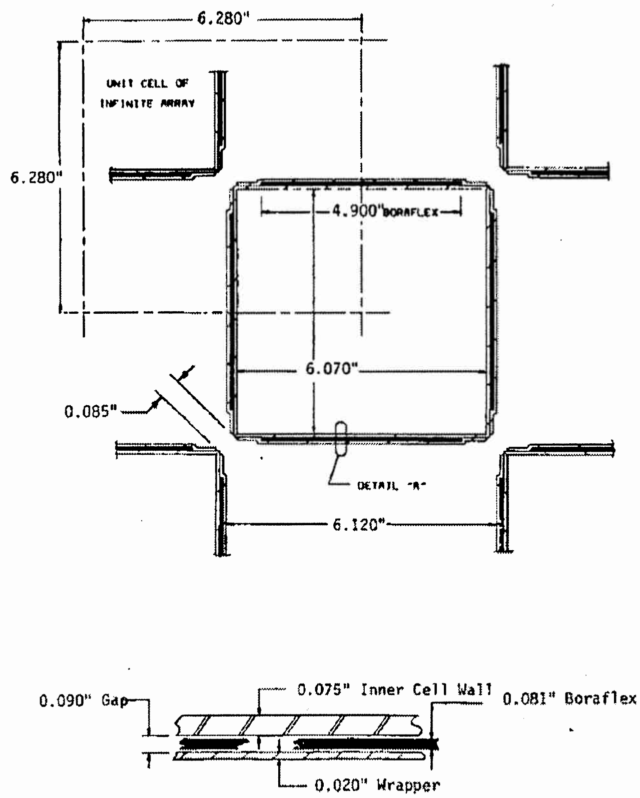

Figure 4 – Boraflex Spent Fuel Storage Rack Cell

Originally, the racks employed thermal neutron absorption in the B-10 of the Boraflex as the primary mechanism of reactivity control; however, the Boraflex has been demonstrated to be degrading over time. Because of this, no credit is taken for the Boraflex in the analysis, and all material between the inner cell wall and outer wrapper is modeled as water. Modeling this material as water is reasonable, as the outer wrapper does not provide a water tight seal between the Boraflex and pool environment, and therefore any significant gap formations within the poison material will be filled with water.

To supplement the reactivity suppression capability of the rack, chevron shaped neutron absorbing inserts (NETCO-SNAP-IN) are installed in each of the storage cells in a storage rack module. These inserts extend over the full length of the active fuel region of the storage assemblies. The inserts are manufactured from Alcan W1100N.19B Aluminum 1100/Boron Carbide metal matrix composite with a minimum areal density of 0.0102 g B10/cm^2. The minimum designed wing length for these inserts is 6 inches, and each insert is modeled with this wing length to conservatively represent all inserts in the rack. Each insert is installed with the same orientation. In this way, one leg of an insert exists between each bundle in the storage rack assembly. The impact of insert orientation within the storage assembly is evaluated by studying bundle rotation effects in Section 5.4. A general schematic demonstrating this layout is provided in Figure 5.

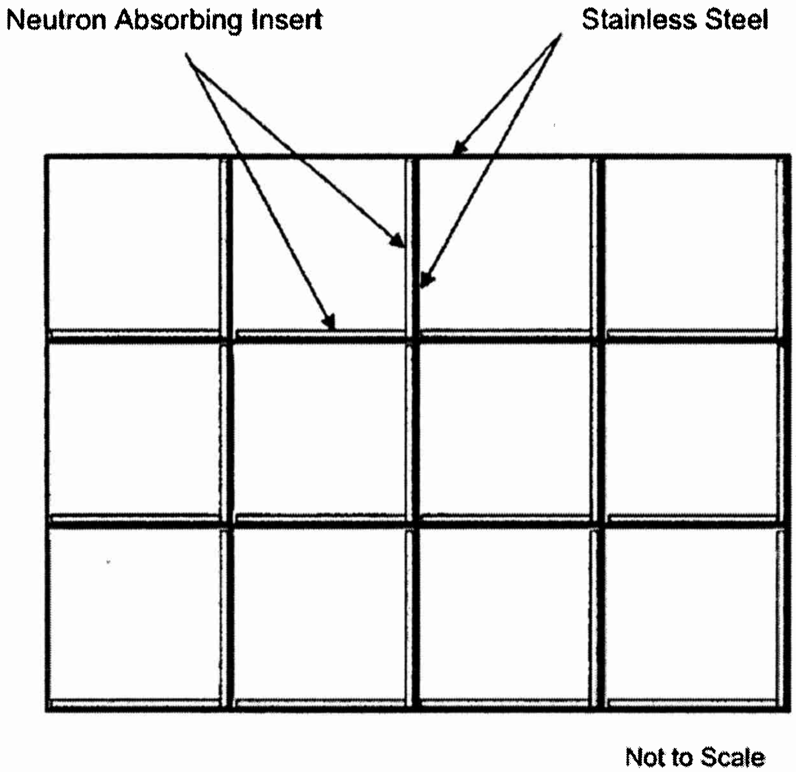

Figure 5 – Storage Rack Array with Inserts

Based on the insert configuration, peripheral storage cells on two sides of the storage pools will not be completely surrounded by four wings of the absorbing insert. There are also a number of inaccessible locations in the storage pool that will not contain either an insert or a bundle. The reactivity impact of these storage limitations will be assessed in Section 5.5.

5.2 Spent Fuel Storage Rack Models

A two-dimensional, infinite storage array with periodic boundary conditions is modeled to conservatively represent the nominal spent fuel pool configuration. An image of a single element of the model is provided in Figure 6, with dimensions and tolerances presented in Table 6.

[[

]]

Figure 6 – Storage Rack Model Schematic

Table 6 – Storage Rack Model Dimensions

		Tolerances	
	Nominal	**Plus**	**Minus**
	(inches)	***(inches)***	***(inches)***
Rack Pitch	**6.280**	**0.025**	**0.025**
Inner Cell Wall Thickness	**0.075**	**0.025**[1]	**0.025**[1]
Outer Wrapper Thickness	**0.020**	*	*
Water Gap in Wrapper	**0.090**	*	*
Primary Fuel Box Width	**6.070**	*	*
Resultant Fuel Box Width	**6.120**	*	*
Rack Insert Wing Length	**6.000**	**0.03**	**0.03**
Rack Insert Thickness	**0.075**	**0.005**	**0.005**

*Important reactivity impacts of these tolerances are covered by studying rack pitch and inner cell wall thickness tolerances
[1] Conservatively assumed values

This single element is used to define a 10x10 rack array with periodic boundary conditions. This array is used in the design basis bundle selection process in Section 5.3.

5.3 Design Basis Lattice Selection

Table 7 defines the lattice designs and exposure histories that were explicitly studied in the spent fuel storage rack to determine the geometric configuration and isotopic composition that results in the worst rack efficiency. Note that void state is not a relevant parameter for zero exposure peak reactivity cases, and, therefore, only a single result is presented for these fuel loadings. Figure 7 presents a graph that demonstrates the linear nature of the in-core to in-rack results over all rack efficiency cases studied in the rack system. [[

]] The highest rack efficiency with an in-core k_∞ greater than the proposed limit of 1.27 is found to result from the parameters defined in Case 8. The geometry and isotopics defined for this case are used to define all bundles in the remaining spent fuel rack analyses.

Table 7 – Fuel Parameter Ranges Studied in Spent Fuel Rack

Case	Lattice Type	Void	Average Lattice Enrichment (U235 wt%)	Number of Gad Rods*	Gad Enrichment (Gd wt %)*	Peak-Reactivity Exposure (GWd/ST)	TGBLA06 Defined In-Core k_∞	MCNP-05P Defined In-Rack k_∞	Rack Efficiency
[[									
									]]

[[
]]

[[

]]

Figure 7 – Spent Fuel In-Core vs. In-Rack Eigenvalues

5.4 Normal Configuration Analysis

5.4.1 Analytical Models

The most reactive normal configuration was determined by studying the reactivity impact of the following credible normal scenarios:

- [[

]]

5.4.2 Results

The results of the study are provided in Table 8. [[

]] The in-rack k_∞ associated with this nominal combination of conditions is [[ ]], and is hereafter referred to as K_{Normal}. This configuration will be used for all abnormal and tolerance studies that are performed on an infinite basis. Any small, positive reactivity differences from this nominal condition are included in the calculation of the system bias in Section 5.5.2.

Table 8 – Spent Fuel Storage Rack In-Rack K_∞ Results – Normal Configurations

Term	Configuration	In-Rack k_∞	Error (1σ)
[[			
			]]

* Largest positive reactivity increase from nominal case for each term is included in roll-up of ΔK_{Bias}

[[

]]

Figure 8 – Nominal 10x10 Array

5.5 Accident/Abnormal Configuration Analysis

5.5.1 Analytic Models

The following abnormal configurations related to the depletion conditions of the stored bundles were explicitly considered, where each description defines an abnormal condition all bundles in storage experience over their entire exposure histories.

- [[

]]

Additionally, perturbations of the normal spent fuel rack configuration were considered for credible accident scenarios. The scenarios considered are presented in the bulleted lists that follow, with explanations of the abnormal condition provided below each listing of similar configurations.

- Missing Rack Insert

  A missing insert from the 10x10 infinite array was analyzed. The relative reactivity increase from this abnormal condition is included in the final ΔK bias term, as demonstrated in Table 12.

- Dropped/Damaged Fuel

  [[

  ]]

- No Inserts on Rack Periphery

  [[

]]

Table 9 – Rack Periphery Study Results

Description	K_{eff}	Error (1σ)	ΔK
[[			
			]]

- Abnormal Positioning of a Fuel Assembly Outside the Fuel Storage Rack

[[

]]

[[

]]

Figure 9 – Finite Corner Model Example

Table 10 – Misplaced Assembly Results

Description	K_{eff}	Error (1σ)	ΔK
[[			
			]]

The following abnormal configurations are also considered bounded, with the justification provided:

- Dropped Bundle on Rack

  Justification – For a drop on the rack, the fuel assembly will come to rest horizontally on top of the rack with a minimum separation distance from the fuel in the rack of more than 12 inches. At this separation distance the fissile material will be separated by enough neutron mean free paths to preclude neutron interactions that increase k_{eff}, and the overall effect on reactivity will be insignificant.

- Rack Sliding Which Causes Water Gap Between Racks to Close

  Justification – The racks modeled in this analysis are infinite in extent with no inter-module water gaps. This essentially assumes all racks are close-fitting and bounds possible reactivity effects of rack sliding.

- Loss of Spent Fuel Pool Cooling

  [[

  ]]

- Inaccessible Storage Locations

  Justification – There are fuel storage locations at the edges of the PBAPS storage pools which are physically inaccessible due to crane interferences. These locations will not contain an insert or a fuel assembly. Several scenarios were analyzed using similar finite models as were applied in the "No inserts on the rack periphery" evaluation. In all cases, the array reactivity was found to be bounded by the base case where all cells contained both an assembly and a rack insert; therefore, it can be stated that empty cell locations without an assembly and without an insert do not increase the storage array reactivity. Example ΔK results from two of these studies are provided in Table 11. Because the normal configuration analysis has been performed on an infinite basis and has been shown to be limiting, if at a future date the currently inaccessible cells become accessible they will be allowable for storage with the same restrictions as all other cells in the storage module in which they reside.

Table 11 – Inaccessible Location Sensitivity Results

Description	K_{eff}	Error (1σ)	ΔK
Base Case - Finite Array Model	[[		
Inaccessible Locations - All periphery			
Inaccessible Locations - Some Periphery and 1 in array			]]

5.5.2 Results

The results of the abnormal studies are provided in Table 12. [[

]] The total contribution from these independent conditions to the maximum K(95/95) of the spent fuel rack is found to be [[ ]] using Equation 1. In this equation, a ΔK_{Bi} value must be both positive and the largest for its respective term to be considered.

$$\Delta K_{Bias} = \sum_{i=1}^{n} \Delta K_{Bi} \qquad (1)$$

Table 12 – Spent Fuel Storage Rack Bias Summary

Term	Description	K_{eff}	Error (1σ)	ΔK	ΔK Uncertainty (2σ)+
[[					
					]]

[[

]]

5.6 Tolerance Analysis

5.6.1 Analytic Models

The following tolerance study configurations were explicitly considered for the spent fuel rack:

- [[

]]

All of the tolerances used in these analyses are at least 2σ design limits. The models developed for these studies were all based off the normal configuration presented in Section 5.4.

5.6.2 Results

The results of the tolerance studies are provided in Table 13. The ΔK term in this table represents the difference between the system reactivity with the specified tolerance perturbation and K_{Normal}. The total contribution from these independent tolerances to the maximum K(95/95) of the spent fuel rack is found to be [[ ]] using Equation 2. In this equation, a ΔK_{Ti} value must be both positive and the largest for its respective term to be considered.

$$\Delta K_{Tolerances} = \sqrt{\sum_{i=1}^{n} \Delta K_{Ti}^{2}} \quad (2)$$

Table 13 – Spent Fuel Storage Rack Tolerance Configuration ΔK Results

Term	Description	K_{eff}	Error (1σ)	ΔK	ΔK Uncertainty (2σ)*
[[					
					]]

* Independent ΔK uncertainties combined using square root of the sum of the squares for applicable terms.

5.7 Uncertainty Values

The total contribution to the maximum K(95/95) of the spent fuel rack from the problem and code specific uncertainties is found to be [[ ]] using Equation 3 and the values in Table 14.

$$\Delta K_{Uncertainty} = \sqrt{\sum_{i=1}^{n} \Delta K_{Ui}^{2}} \quad (3)$$

Table 14 – Spent Fuel Storage Rack Uncertainty ΔK Values

Term	Description	Value
[[		
		]]

[[

]]

5.8 Maximum Reactivity

The maximum reactivity of the spent fuel rack without crediting Boraflex and with rack inserts installed, considering all biases, tolerances, and uncertainties, is calculated using Equation 4. The final values are presented in Table 15.

$$K_{max(95/95)} = K_{Normal\,/\,Nominal} + \Delta K_{Bias} + \Delta K_{Tolerance} + \Delta K_{Uncertainty} \quad (4)$$

Table 15 – Spent Fuel Storage Rack Results Summary

Term	Value
[[	
	]]

6.0 Interfaces Between Areas With Different Storage Conditions

As the inserts are installed, the storage pool will become a mixture of degraded Boraflex regions and insert regions. The criticality safety evaluations for each of these loading configurations has demonstrated that, on an independent (or single region) basis, the storage pool multiplication factor is less than the 0.95 regulatory limit. The multiplication factor for a mixture of these regions would be expected to also remain below 0.95 if the net transfer of neutrons from one region to another does not increase significantly.

In order to ensure this net transfer of neutrons between regions is limited, it can be assumed that inserts are installed in one row and one column of regions adjacent to modules with rack inserts installed, as necessary, to completely surround all non-peripheral assemblies that are part of the insert region with four wings of the NETCO-SNAP-IN inserts. As addressed in Section 3.4, the reactivity of future GNF2 fuel assemblies will not exceed the reference bounding assembly of this analysis. Appendix B provides evidence that all assemblies currently in the spent fuel pool also meet the reactivity requirements of Section 3.4. With these restrictions in place, the system k_{eff} of a pool comprised of insert regions mixed with degraded Boraflex regions will be lower than the maximum reported single region value. This occurs because replacement of a large portion of the storage area with another that has a lower multiplication factor decreases the multiplication factor of the entire storage area. MCNP evaluations have demonstrated that the resulting k_{eff} for a system composed of two regions is between that of the individual systems composed of single regions.

The overall conclusion from this multi-region analysis is that the spent fuel pool will have a K(95/95) value less than or equal to 0.95. This conclusion is reached without crediting residual boron in the Boraflex within the insert region.

7.0 Conclusions

The PBAPS spent fuel racks have been analyzed for the storage of GNF2 fuel using the MCNP-05P Monte Carlo neutron transport program and the k_∞ criterion methodology. A maximum cold, uncontrolled peak in-core eigenvalue (k_∞) of 1.27 as defined by TGBLA06 is specified as the rack design limit for GNF2 fuel in the spent fuel racks with rack inserts installed. Documentation that all legacy fuel types currently in the PBAPS comply with this in-core limit is found in Appendix B. The analyses resulted in a storage rack maximum k-effective (K(95/95)) less than 0.95 for normal and credible abnormal operation with tolerances and computational uncertainties taken into account.

8.0 References

1. SRP 9.1.1 "Criticality Safety of Fresh and Spent Fuel Storage and Handling," USNRC, Revision 3, March 2007.
2. LA-UR-03-1987, "MCNP – A General Monte Carlo N-Particle Transport Code, Version 5," April 2003.
3. NUREG/CR-6698, "Guide for Validation of Nuclear Criticality Safety Calculational Methodology," USNRC, January 2001.

Appendix A - MCNP-05P Code Validation

[[

Table
16

]]

Table 16 – MCNP-05P Results for the Benchmark Calculations

#	Experiment	Expt. #	Benchmark Eigenvalue	Experimental Uncertainty	MCNP-05P	MCNP-05P Uncertainty	Bias	Bias Uncertainty
[[								

#	Experiment	Expt. #	Benchmark Eigenvalue	Experimental Uncertainty	MCNP-05P	MCNP-05P Uncertainty	Bias	Bias Uncertainty

#	Experiment	Expt. #	Benchmark Eigenvalue	Experimental Uncertainty	MCNP-05P	MCNP-05P Uncertainty	Bias	Bias Uncertainty
								]]

Figure 10 shows the bias results of Table 16 when all the results are treated as a single population. The top plot in the figure is a histogram plot of the results with an overlaying Normal curve fit. The resulting P-value of this Normal curve fit is 0.341 thus the data passes the normality tests (P-value>0.05). The remaining plots and data in Figure 10 show the simple mean, median, and sample standard deviation of this data, and their corresponding 95% confidence intervals.

[[

]]

Figure 10 – Statistical Analysis of the Benchmark Results

In order to account for the uncertainty in the experimental values, the weighted sample mean and standard deviation were calculated using the following equations:

$$B = Benchmark - MCNP05P$$

$$\overline{B} = \frac{\sum_{i=1}^{n} \frac{B_i}{\sigma_i^2}}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}}$$

$$S_P = \sqrt{s^2 + \overline{\sigma}^2}$$

$$\overline{\sigma}^2 = \frac{n}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}}$$

$$s^2 = \frac{\left(\frac{1}{n-1}\right)\sum_{i=1}^{n}\frac{1}{\sigma_i^2}\left(B_i - \overline{B}\right)^2}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{\sigma_i^2}}$$

$$Bias\ Uncertainty = U \cdot S_p$$

Where:

$\overline{B}$ = Average weighted bias

σ_i = Uncertainty in bias Bi

S_P = Pooled standard deviation

s^2 = Variance about the mean

$\overline{\sigma}^2$ = Average total variance

U = one-sided tolerance factor for n data points at (95/95 confidence/probability level)

n = number of data points (=[[ ]])

Table 17 summarizes the results of these calculations.

Using the average weighted bias and pooled standard deviation; the upper one-sided 95/95-tolerance limit was calculated for use in criticality calculations, in accordance with NUREG-6698 guidance (Reference 3). [[

]] Table 18 summarizes the recommended bias and bias uncertainty to be used in criticality calculations.

Table 17 – Bias and Bias Uncertainty for MCNP-05P with ENDF/B-VII

Bias (weighted)	[[
Variance About the Mean	
Average Total variance	
Pooled Standard Deviation (1σ)	
One-Sided Tolerance Factor	]]

Table 18 – Recommended Bias and Bias Uncertainty in Criticality Analyses for MCNP-05P with ENDF/B-VII

Bias	[[
Bias Uncertainty (95/95 confidence level)	]]

Appendix B - Legacy Fuel Storage Justification

Exposure dependent, maximum, uncontrolled in-core k∞ results have been calculated for each fuel assembly in the Unit 2 and Unit 3 spent fuel pools. Maximum values for each fuel type (e.g. 7x7, 8x8, 9x9, and 10x10) are presented in Table 19. These values have been calculated using the process for validating that specific assembly designs are acceptable for storage in the PBAPS fuel storage racks, as outlined in Section 3.4. Table 20 provides the name of the bundle, the name of the lattice, the lattice exposure and the corresponding void fraction that are associated with the peak reactivity legacy fuel lattice. This information demonstrates that all fuel assemblies currently in the PBAPS spent fuel pools have considerable margin to the reactivity of the GNF2 design basis bundle used in this analysis. The margin to safety was also confirmed to exist in the storage rack by analyzing the peak reactivity legacy fuel lattice (in-core [[ ]]) under normal conditions of storage, as outlined in Section 5.4. [[
]]

Because the GNF2 design basis bundle with an in-core k_{inf} value of 1.27 has been shown to be below the 0.95 in-rack limit when analyzed in the storage racks, and because the legacy fuel types are significantly less reactive than this design basis bundle both in-core and in-rack, it is confirmed that all legacy fuel types are safe for storage in the PBAPS spent fuel storage racks with rack inserts installed.

Table 19 – Peak Cold Uncontrolled In-Core Reactivity for Legacy Fuel Types

Plant: Peach Bottom 2	Lattice type	In-core K-infinity
[[		
		]]
Plant: Peach Bottom 3		
[[		
		]]

Table 20 – Peak Reactivity Legacy Fuel Lattice Information

Plant	Peach Bottom 2	Peach Bottom 3
[[		
		]]

ATTACHMENT 8

"Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Boraflex," Global Nuclear Fuel, NEDO-33686, September 2011, Revision 0 (Non-Proprietary Version)

Global Nuclear Fuel

A Joint Venture of GE, Toshiba, & Hitachi

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Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Boraflex

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Revision Status

Revision Number	Date	Description of Change
0	September 2011	Initial revision

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1.0 Introduction

This report describes the criticality analysis and results for the Peach Bottom Atomic Power Station (PBAPS) spent fuel racks with credit taken for Boraflex. It includes sufficient detail on the methodology and analytical models utilized in the criticality analysis to verify that the storage rack systems have been accurately and conservatively represented.

The racks are analyzed using the MCNP-05P Monte Carlo neutron transport program and the k_∞ criterion methodology. A maximum cold, uncontrolled peak in-core eigenvalue (k_∞) of 1.235 as defined by the lattice physics code TGBLA06 is specified as the rack design limit for GNF2 fuel in the spent fuel racks. As demonstrated in Table 1, the analysis resulted in a storage rack maximum k-effective (K(95/95)) less than 0.95 for normal and credible abnormal operation with tolerances and uncertainties taken into account.

Table 1 – Summary K-95/95 Result

Region	$K_{max(95/95)}$
Spent Fuel Rack with Boraflex	[[ ]]

2.0 Requirements

Title 10 of the Code of Federal Regulations (10 CFR) Part 50 defines the requirements for the prevention of criticality in fuel storage and handling at nuclear power plants. 10 CFR 50.68 details specifically that the storage rack eigenvalue for both new and spent fuel storage racks must be demonstrated to be ≤ 0.95 for normal and credible abnormal operation with tolerances and computational uncertainties taken into account. Reference 1 outlines the standards that must be met for these analyses. These requirements are supplemented by General Design Criteria (GDC) 62 and Information Notice (IN) 2011-03. All necessary requirements are met in this analysis.

3.0 Method of Analysis

In this evaluation, in-core k_∞ values and exposure dependent, pin-by-pin isotopic specifications are generated using the GE Hitachi Nuclear Energy (GEH) / Global Nuclear Fuel (GNF) lattice physics production code TGBLA06. TGBLA06 solves two-dimensional (2D) diffusion equations with diffusion parameters corrected by transport theory to provide system multiplication factors and perform burnup calculations.

The fuel storage criticality calculations are then performed using MCNP-05P, the GEH/GNF proprietary version of MCNP5 (Reference 2). MCNP-05P is a Monte Carlo program for solving the linear neutron transport equation for a fixed source or an eigenvalue problem. The code implements the Monte Carlo process for neutron, photon, electron, or coupled transport involving all these particles, and can compute the eigenvalue for neutron-multiplying systems. For the present application, only neutron transport was considered.

3.1 Cross Sections

TGBLA06 uses ENDF/B-V cross-section data to perform coarse-mesh, broad-group, diffusion theory calculations. It includes thermal neutron scattering with hydrogen using an $S(\alpha,\beta)$ light water thermal scattering kernel.

MCNP-05P uses point-wise (i.e., continuous) cross section data, and all reactions in a given cross section evaluation (e.g., ENDF/B-VII.0) are considered. For the present work, thermal neutron scattering with hydrogen was described using an $S(\alpha,\beta)$ light water thermal scattering kernel. The cross section tables include all details of the ENDF representations for neutron data. The code requires that all the cross sections be given on a single union energy grid suitable for linear interpolation; however, the cross section energy grid varies from isotope to isotope. The libraries include very little data thinning and utilize resonance integral reconstruction error tolerances of 0.001%.

3.2 Geometry Treatment

TGBLA06 is a two-dimensional lattice design computer program for Boiling Water Reactor (BWR) fuel bundle analysis. It assumes that a lattice is uniform and infinite along the axial direction and that the lattice geometry and material are reflecting with respect to the lattice boundary along the transverse directions.

MCNP-05P implements a robust geometry representation that can correctly model complex components in three dimensions. An arbitrary three-dimensional (3D) configuration is treated as geometric cells bounded by first and second-degree surfaces and some special fourth-degree elliptical tori. The cells are described in a Cartesian coordinate system and are defined by the intersections, unions and complements of the regions bounded by the surfaces. Surfaces are defined by supplying coefficients to the analytic surface equations or, for certain types of surfaces, known points on the surfaces. Rather than combining several pre-defined geometrical bodies in a combinatorial geometry scheme, MCNP-05P has the flexibility of defining geometrical shapes from all the first and second-degree surfaces of analytical geometry and elliptical tori and then combining them with Boolean operators. The code performs extensive checking for geometry errors and provides a plotting feature for examining the geometry and material assignments.

3.3 Validation and Computational Basis

[[

]]

Table 2 – Summary of the Critical Benchmark Experiments

Experiment		Experiments	Year	Where
[[				
				]]

Table 3 – Area of Applicability Covered by Code Validation

[[		
		]]

[[

]]

- BADGER/RACKLIFE uncertainty

  An additional uncertainty was also added to account for the measurement and calculational uncertainty in BADGER and RACKLIFE usage. The uncertainty was given in terms of percentage of B-10 areal density. A study was performed that assessed the in-rack reactivity difference between the design basis spent fuel bundle at nominal B-10 areal density (0.0140 g B-10/cm^2) and at a 33.2% reduction in B-10 areal density (0.00935 g B-10/cm^2). This uncertainty is applied to the spent fuel rack's maximum K(95/95) value in Table 13 to cover uncertainty in the BADGER measurements and RACKLIFE analysis.

3.4 In-Core K_∞ Methodology

The design of the fuel storage racks provides for a subcritical multiplication factor for both normal and credible abnormal storage conditions. In all cases, the storage rack eigenvalue must be ≤ 0.95 (Reference 1). To demonstrate compliance with this limit, the in-core k_∞ method is utilized.

The in-core k_∞ criterion method relies on a well-characterized relationship between infinite lattice k_∞ (in-core) for a given fuel design and a specific fuel storage rack k_∞ (in-rack) containing that fuel. The use of an infinite lattice k_∞ criterion for demonstrating compliance to fuel storage criticality criteria has been used for all GEH-supplied storage racks and is currently used for re-rack designs at a number of plants. This report demonstrates that the methodology is also appropriate for use at the PBAPS by presenting the following:

- A well-characterized, linear relationship between infinite lattice k_∞ (in-core) and fuel storage rack k_∞ (in-rack)
- The use of a design basis lattice with a conservative rack efficiency and in-core k_∞ for all criticality analyses

The analysis performed to calculate the lattice k_∞ to confirm compliance with the above criterion uses the Nuclear Regulatory Commission (NRC)-approved lattice physics methods encoded into the TGBLA06 Engineering Computer Program (ECP). One of the outputs of TGBLA06 solution is the lattice k_∞ of a specific nuclear design for a given set of input state parameters (e.g., void fraction, control state, fuel temperature).

Compliance of fuel with specified k_∞ limits will be confirmed for each new lattice as part of the bundle design process. Documentation that this has been met will be contained in the fuel design information report, which defines the maximum lattice k_∞ for each assembly nuclear design. The process for validating that specific assembly designs are acceptable for storage in the PBAPS fuel storage racks is provided below.

1. [[

]]

Documentation that all legacy fuel types currently in the PBAPS comply with this in-core limit is found in Appendix B.

3.5 Definitions

Fuel Assembly – A complete fuel unit consisting of a basic fuel rod structure that may include large central water rods. Several shorter rods may be included in the assembly. These are called "part length rods." A fuel assembly includes the fuel channel.

Gadolinia – The compound Gd_2O_3. The gadolinium content in integral burnable absorber fuel rods is usually expressed in weight percentage Gadolinia.

Lattice – An axial zone of a fuel assembly within which the nuclear characteristics of the individual rods are unchanged.

Dominant Lattice – An axial zone of a fuel assembly typically located in the bottom half of the bundle within which all possible fuel rod locations for a given fuel design are occupied.

Vanished Lattice – An axial zone of a fuel assembly typically in the upper half of the bundle within which a number of possible fuel rod locations are unoccupied.

Rack Efficiency – The ratio of a particular lattice statepoint in-rack eigenvalue (k_∞) to its associated lattice nominal in-core eigenvalue (k_∞). This value allows for a straightforward comparison of a rack's criticality response to varying lattice designs within a particular fuel product line. A lower rack efficiency implies increased reactivity suppression capability relative to an alternate design with a higher rack efficiency.

Design Basis Lattice – The lattice geometry, exposure history, and corresponding fuel isotopics for a fuel product line that result in the highest rack efficiency in a sensitivity study of reasonable fuel parameters at the desired in-core reactivity. This lattice is used for all normal, abnormal, and tolerance evaluations in the fuel rack analysis.

3.6 Assumptions and Conservatisms

The fuel storage rack criticality calculations are performed with the following assumptions to ensure the true system reactivity is always less than the calculated reactivity:

- [[

]]

- For conservatism, only positive reactivity differences from nominal conditions determined from depletion sensitivity and abnormal configuration, analyses are added as biases to the final storage rack maximum K(95/95).
- Neutron absorption in spacer grids, concrete, activated corrosion and wear products (CRUD) and axial blankets is ignored to limit parasitic losses in non-fuel materials.
- TGBLA06 defined "lumped fission products" and Xe-135 are both conservatively ignored for MCNP-05P in-rack k_∞ calculations.
- [[

  ]]
- All Boraflex panels are assumed to contain an areal density of 0.0140 g B-10/cm^2.
- All Boraflex panels are assumed to be 142 inches long centered relative to active fuel height and 4.9 inches wide.
- A 3-inch gap is assumed to exist in the middle of all Boraflex panels. The gap is placed in the middle of the Boraflex panel to minimize leakage and maximize streaming between storage cells. The gaps are modeled as co-located in all panels.
- All the material in the Boraflex panels are modeled with typical Boraflex elemental compositions (Boron: 31.5 wt%, Carbon: 19 wt%, Silicon: 24.5 wt%, Oxygen: 22 wt%, Hydrogen: 3 wt%)
- The space between the inner cell wall and outer wrapper of the fuel rack which does not contain Boraflex is modeled as water. Modeling this material as water is reasonable, as the outer wrapper does not provide a water tight seal between the Boraflex and pool environment, and therefore any significant gap formations or degradation within the poison material will be filled with water.

4.0 Fuel Design Basis

4.1 GNF2 Fuel Description

Criticality safety analyses to determine storage system reactivity are performed using the GNF2 fuel design. The GNF2 fuel lattice configuration is a 10x10 fuel rod array minus eight fuel rods that have been replaced with two large water rods, as shown in Figure 1 with corresponding dimensions in Table 4. Figure 1 also demonstrates the part-length rod locations, which cannot be changed for this fuel design. Fuel channel dimensions are provided in Figure 2 and Table 5. [[

]]

[[

]]

Figure 1 – GNF2 Fuel Lattice Configuration

Table 4 – Nominal Dimensions for GNF2 Fuel Lattice

[[			
			]]

[[

]]

Figure 2 – Channel Dimensions

Table 5 – Nominal Channel Dimensions for GNF2 Lattice

Dimension	mm	inches
[[		
		]]

[[

]]

4.2 Fuel Model Description

The fuel models considered include three-dimensional geometric modeling of all fuel material, cladding, water rods, and channels. [[

]] An example of a GNF2 vanished zone lattice model in MCNP-05P is depicted in Figure 3.

[[

]]

Figure 3 – GNF2 Lattice in MCNP-05P

[[

]] The lattice type and exposure history that results in the worst-case rack efficiency for an in-core k_∞ greater than the proposed limit is then used to define the design basis lattice. This lattice is assumed to be stored in every location in the rack being analyzed. Details on the determination of the design basis lattice using the process outlined above are presented in Section 5.3.

5.0 Criticality Analysis of Spent Fuel Storage Racks

5.1 Description of Spent Fuel Storage Racks

The PBAPS Boraflex storage racks manufactured by Westinghouse consist of a 304 stainless steel structure composed of a series of square vertical tubes (cells). These tubes contain 0.081-inch thick Boraflex panels sandwiched between a 0.075-inch stainless steel (SS) inner cell wall and a 0.020-inch SS outer wrapper. The Boraflex containing cells are arranged in a checkerboard pattern with the space between a 4-cell group forming a fifth bundle storage location with a center-to-center cell pitch of 6.280 inches. Rack array sizes ranging from 9x14 up to 19x20 are placed adjacent to one another in the spent fuel pools of both PBAPS Units 2 and 3. A schematic of a single storage rack unit-cell as installed is shown in Figure 4.

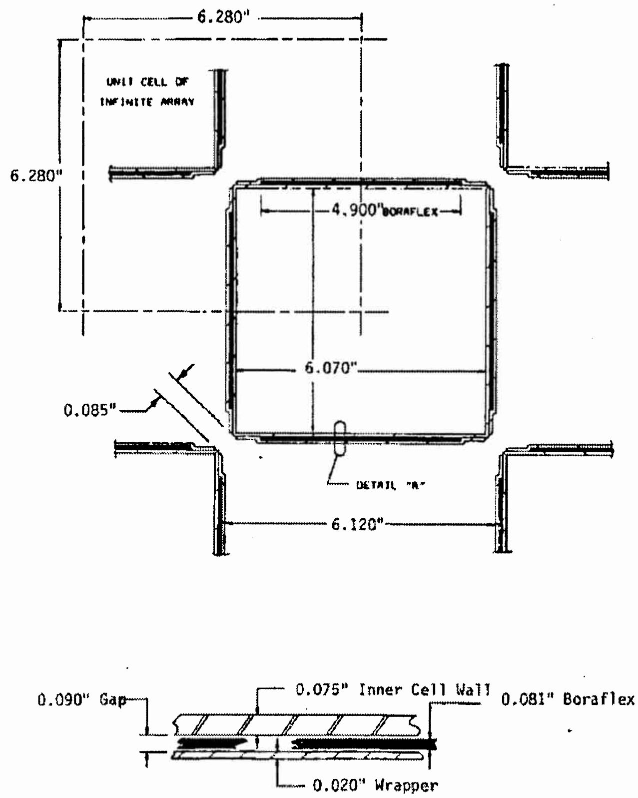

Figure 4 – Boraflex Spent Fuel Storage Rack Cell

The racks employ thermal neutron absorption in the B-10 of the Boraflex as the primary mechanism of reactivity control. Originally, the minimum certified B-10 areal density was 0.021 g B-10/cm^2; however, the Boraflex has degraded over time. Because of this, a minimum areal density of 0.0140 g B-10/cm^2 is assumed to account for partial degradation of the Boraflex in the analysis. All material between the inner cell wall and outer wrapper excluding the Boraflex is modeled as water. Modeling this material as water is reasonable, as the outer wrapper does not provide a water tight seal between the Boraflex and pool environment, and therefore any significant gap formations within the poison material will be filled with water.

Based on the Boraflex configuration, peripheral storage cells will not be completely surrounded by four panels of Boraflex. The reactivity effect of these storage limitations is assessed in Section 5.5.

5.2 Spent Fuel Storage Rack Models

A three-dimensional, semi-infinite storage array is modeled to conservatively represent the nominal spent fuel pool configuration. The array is represented as infinite in the X-Y plane by modeling a 10x10 array with periodic boundary conditions. The model is 174 inches in the axial direction, with 150 inches of active fuel and 12 inches of water on the top and bottom of active fuel for full water reflection. It is more conservative to model water than actual materials such as upper and lower tie plates because water will prevent leakage and increase k_{eff}. In addition, many of the components above and below active fuel contain SS which is an absorber of neutrons, thus it is more conservative to ignore the presence of these materials. An image of a 2x2 section of the array in the X-Y plane is provided in Figure 5 with dimensions and tolerances presented in Table 6. A representation of the X-Z direction is shown in Figure 6.

[[

]]

Figure 5 – Storage Rack Model Schematic X-Y Plane

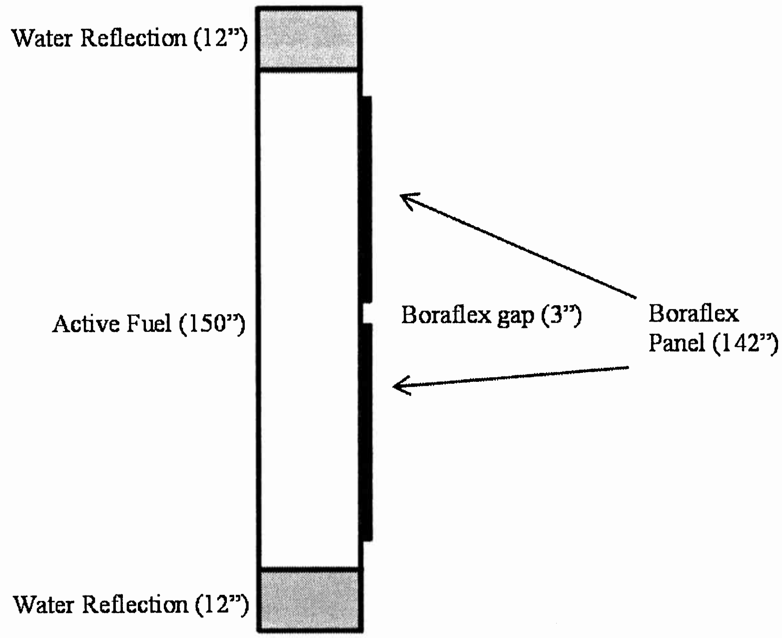

Figure 6 – Storage Rack Model Schematic X-Z Plane

Table 6 – Storage Rack Model Dimensions

		Tolerances	
	Nominal	Plus	Minus
	(inches)	*(inches)*	*(inches)*
Rack Pitch	6.280	0.025	0.025
Inner Cell Wall Thickness	0.075	0.025[1]	0.025[1]
Outer Wrapper Thickness	0.020	*	*
Primary Fuel Box Width	6.070	*	*
Resultant Fuel Box Width	6.120	*	*
Boraflex Panel Length	142.000	0.250	0.250
Boraflex Panel Width	4.900	0.075	0.075

* Important reactivity effects of these tolerances are covered by studying rack pitch and inner cell wall thickness tolerances

[1] Conservatively assumed values

5.3 Design Basis Lattice Selection

Table 7 defines the lattice designs and exposure histories that were explicitly studied in the spent fuel storage rack to determine the geometric configuration and isotopic composition that results in the worst rack efficiency. Note that void state is not a relevant parameter for zero exposure peak reactivity cases, and, therefore, only a single result is presented for these fuel loadings. Figure 7 presents a graph that demonstrates the linear nature of the in-core to in-rack results over all rack efficiency cases studied in the rack system. [[

]] The highest rack efficiency with an in-core k_∞ greater than the proposed limit of 1.235 is found to result from the parameters defined in Case 8. The geometry and isotopics defined for this case are used to define all bundles in the remaining spent fuel rack analyses.

Table 7 – Fuel Parameter Ranges Studied in Spent Fuel Rack

Case	Lattice Type	Void	Average Lattice Enrichment (U235 wt%)	Number of Gad Rods*	Gad Enrichment (Gd wt %)*	Peak-Reactivity Exposure (GWd/ST)	TGBLA06 Defined In-Core k_∞	MCNP-05P Defined In-Rack k_∞	Rack Efficiency
[[									
									]]

[[

]]

[[

]]

Figure 7 – Spent Fuel In-Core vs. In-Rack Eigenvalues

5.4 Normal Configuration Analysis

5.4.1 Analytical Models

The most reactive normal configuration was determined by studying the reactivity effect of the following credible normal scenarios:

- [[

]]

5.4.2 Results

The results of the study are provided in Table 8. [[

]] The in-rack k_∞ associated with this nominal combination of conditions is [[ ]], and is hereafter referred to as K_{Normal}. This configuration will be used for all abnormal and tolerance studies that are performed on an infinite basis. Any small, positive reactivity differences from this nominal condition are included in the calculation of the system bias in Section 5.5.2.

Table 8 – Spent Fuel Storage Rack In-Rack K_∞ Results – Normal Configurations

Term	Configuration	In-Rack k_∞	Error (1σ)
[[			
			]]

* Largest positive reactivity increase from nominal case for each term is included in roll-up of ΔK_{Bias}

[[

]]

Figure 8 – Nominal 10x10 Array

5.5 Accident/Abnormal Configuration Analysis

5.5.1 Analytic Models

The following abnormal configurations related to the depletion conditions of the stored bundles were explicitly considered, where each description defines an abnormal condition that all bundles in storage experience over their entire exposure histories.

- [[

]]

Finally, perturbations of the normal spent fuel rack configuration were considered for credible accident scenarios. The scenarios considered are presented in the bulleted lists that follow, with explanations of the abnormal condition provided below each listing of similar configurations.

- Dropped/Damaged Fuel

  [[

  ]]

- Misplaced 1.27 Bundle in 1.235 Region

  The in-core limit for the regions of the spent fuel rack with only Boraflex is 1.235. The regions with rack inserts can contain a bundle with an in-core limit of 1.27. Thus, there needed to be an evaluation of the effect of placing a bundle with a cold, uncontrolled in-core reactivity of 1.27 in the region of the rack system with the limit of 1.235. [[

  ]]

- No Boraflex Panels on Rack Periphery

  [[

]]

Table 9 – Rack Periphery Study Results

Description	K_{eff}	Error (1σ)	ΔK
[[			
			]]

- Abnormal Positioning of a Fuel Assembly Outside the Fuel Storage Rack

  [[

  ]]

[[

]]

Figure 9 – Finite Corner Model Example

Table 10 – Misplaced Assembly Results

Description	K_{eff}	Error (1σ)	ΔK
[[			
			]]

The following abnormal configurations are also considered bounded, with the justification provided:

- Dropped Bundle on Rack

  Justification – For a drop on the rack, the fuel assembly will come to rest horizontally on top of the rack with a minimum separation distance from the fuel in the rack of more than 12 inches. At this separation distance the fissile material will be separated by enough neutron mean free paths to preclude neutron interactions that increase k_{eff}, and the overall effect on reactivity will be insignificant.

- Rack Sliding Which Causes Water Gap Between Racks too Close

  Justification – The racks modeled in this analysis are infinite in extent with no inter-module water gaps. This essentially assumes all racks are close-fitting and bounds possible reactivity effects of rack sliding.

- Loss of Spent Fuel Pool Cooling

  [[

  ]]

To account for partial Boraflex degradation, additional biases were considered in this analysis as described below:

- Undetected Boraflex Cracking

  Justification – The NETCO Monte Carlo analysis (Reference 5) shows that a bias of 0.004 ΔK is appropriate to apply for the effects of undetected Boraflex cracking.

- Boraflex Shrinkage and Edge Dissolution

  Justification – A 5% reduction in the Boraflex panel width was assessed and the reactivity difference between that case and the nominal case was applied as a bias to account for physical shrinkage of the Boraflex panel and edge dissolution. PBAPS BADGER results show that 5% width reduction is conservative. The relative reactivity increase from this bias (0.00703 ΔK) is included in the final ΔK bias term, as demonstrated in Table 11.

- Boraflex Particle Self-Shielding

  Justification – A bias of 0.00253 ΔK is applied for Boraflex particle self-shielding. This bias is a result of KENO studies performed by NETCO that explicitly modeled varying particle sizes.

- Gaps in Boraflex

  Justification – The rack model was developed with a 3-inch gap co-located in all Boraflex panels axially centered in the rack. The largest cumulative gap detected in the PBAPS BADGER reports was 2.7 inches. A 3-inch gap conservatively bounds current and projected gap growth. Co-locating the gaps is more conservative than randomly distributing them throughout the rack panels because it maximizes the effect of neutron streaming.

- Non-Uniform Thinning in Boraflex

  Justification – This analysis assumes a uniform B-10 areal density of 0.0140 g B-10/cm^2; therefore, the potential for non-uniform thinning must be addressed. BADGER testing results are reported as panel average areal densities, but distributions of local dissolutions are also provided in the analysis summary. The BADGER results for PBAPS Unit 2 and

Unit 3 show that local dissolution occurs most often at the axial ends of the Boraflex panel. Having losses at the ends of the panels reduces the effect of the local dissolution due to increased neutron leakage relative to leakage associated with losses in the central axial region of the rack system. Additionally, if non-uniform thinning beyond 0.0140 g B-10/cm^2 is observed at the ends of the panels, it must be offset by areas of increased panel density to achieve the same average panel density result as is assumed in the uniform areal density approach. Having a higher areal density than is assumed in the analysis in the central axial region of the rack system will tend to result in an overall lower system reactivity. This analysis also includes a large delta K uncertainty term for the BADGER and RACKLIFE measurement uncertainties of B-10 areal density. This uncertainty term can also account for local thinning effects in the statistical rollup up. The majority of remaining, centrally located dissolutions are shown to occur near gaps in the panels. This analysis conservatively bounds current and projected gaps sizes, and thus bounds the effects of local dissolution immediately around gaps.

- Effects of a Seismic Event on Degraded Boraflex Rack

  Justification – In a seismic event, it is possible the Boraflex panels could slide together such that all the interspersed gaps accumulate at the top. The largest cumulative gap observed in either PBAPS Unit 2 or 3 was 2.7 inches. This analysis modeled 3-inch gaps to represent the accumulation of gaps in all panels co-located in the middle of the rack. This is more conservative than modeling all the gaps at the top of the panels because there is more leakage at the top of the bundle.

5.5.2 Results

The results of the abnormal studies are provided in Table 11. [[

]] The total contribution from these independent conditions to the maximum K(95/95) of the spent fuel rack is found to be [[ ]] using Equation 1. In this equation, a ΔK_{Bi} value must be both positive and the largest for its respective term to be considered.

$$\Delta K_{Bias} = \sum_{i=1}^{n} \Delta K_{Bi} \qquad (1)$$

Table 11 – Spent Fuel Storage Rack Bias Summary

Term	Description	K_{eff}	Error (1σ)	ΔK	ΔK Uncertainty (2σ)[+]
[[					
					]]

[[

]]

5.6 Tolerance Analysis

5.6.1 Analytic Models

The following tolerance study configurations were explicitly considered for the spent fuel rack:

- [[

]]

All of the tolerances used in these analyses are at least 2σ design limits. The models developed for these studies were all based off the normal configuration presented in Section 5.4.

5.6.2 Results

The results of the tolerance studies are provided in Table 12. The ΔK term in this table represents the difference between the system reactivity with the specified tolerance perturbation and K_{Normal}. The total contribution from these independent tolerances to the maximum K(95/95) of the spent fuel rack is found to be [[ ]] using Equation 2. In this equation, a ΔK_{Ti} value must be both positive and the largest for its respective term to be considered.

$$\Delta K_{Tolerances} = \sqrt{\sum_{i=1}^{n} \Delta K_{Ti}^{2}} \qquad (2)$$

Table 12 – Spent Fuel Storage Rack Tolerance Configuration ΔK Results

Term	Description	K_{eff}	Error (1σ)	ΔK	ΔK Uncertainty (2σ)*
[[					
					]]

* Independent ΔK uncertainties combined using square root of the sum of the squares for applicable terms.

5.7 Uncertainty Values

The total contribution to the maximum K(95/95) of the spent fuel rack from the problem and code specific uncertainties is found to be [[ ]] using Equation 3 and the values in Table 13. [[

]]

$$\Delta K_{Uncertainty} = \sqrt{\sum_{i=1}^{n} \Delta K_{Ui}^{2}} \quad (3)$$

Table 13 – Spent Fuel Storage Rack Uncertainty ΔK Values

Term	Description	Value
[[		
		]]

[[

]]

5.8 Maximum Reactivity

The maximum reactivity of the spent fuel rack crediting Boraflex and without rack inserts installed, considering all biases, tolerances, and uncertainties, is calculated using Equation 4. The final values are presented in Table 14.

$$K_{max(95/95)} = K_{Normal/Nominal} + \Delta K_{Bias} + \Delta K_{Tolerance} + \Delta K_{Uncertainty} \quad (4)$$

Table 14 – Spent Fuel Storage Rack Results Summary

Term	Value
[[	
	]]

6.0 Interfaces Between Areas with Different Storage Conditions

Rack inserts are being installed in PBAPS spent fuel storage pools to replace the poison material in the Boraflex racks. A prior analysis has demonstrated the storage pool multiplication with rack inserts is less than 0.95 for bundles with an in-core limit of 1.27 (Reference 4).

As the inserts are installed, the storage pool will become a mixture of degraded Boraflex regions and insert regions. The criticality safety evaluations for each of these loading configurations have demonstrated that, on an independent (or single region) basis, the storage pool multiplication factor is less than the 0.95 regulatory limit. The multiplication factor for a mixture of these regions would be expected to also remain below 0.95 if the net transfer of neutrons from one region to another does not increase significantly.

In order to ensure this net transfer of neutrons between regions is limited, it can be assumed that inserts are installed in one row and one column of regions adjacent to modules with rack inserts installed, as necessary, to completely surround all non-peripheral assemblies that are part of the insert region with four wings of the NETCO-SNAP-IN inserts. As addressed in Section 3.4, the reactivity of future GNF2 fuel assemblies will not exceed the reference bounding assembly of this analysis. Appendix B provides evidence that all assemblies currently in the spent fuel pool also meet the reactivity requirements of Section 3.4.

As shown in Section 5.5.1, the effect of misplacing the higher reactivity bundle from the rack insert analysis (in-core reactivity of 1.27) in the Boraflex region was assessed and found to have negligible effect.

The overall conclusion from this multi-region analysis is that the spent fuel pool will have a K(95/95) value less than or equal to 0.95. This conclusion is reached without crediting residual boron in the Boraflex within the insert region and crediting partial degradation of the Boraflex region.

7.0 Conclusions

The PBAPS spent fuel racks have been analyzed for the storage of GNF2 fuel using the MCNP-05P Monte Carlo neutron transport program and the k_∞ criterion methodology. A maximum cold, uncontrolled peak in-core eigenvalue (k_∞) of 1.235 as defined by TGBLA06 is specified as the rack design limit for GNF2 fuel in the spent fuel racks with credit taken for Boraflex panels. Documentation that all legacy fuel types currently in the PBAPS comply with this in-core limit is found in Appendix B. The analyses resulted in a storage rack maximum k-effective (K(95/95)) less than 0.95 for normal and credible abnormal operation with tolerances and computational uncertainties taken into account.

8.0 References

1. NUREG-0800, Standard Review Plan (SRP) 9.1.1 "Criticality Safety of Fresh and Spent Fuel Storage and Handling," USNRC, Revision 3, March 2007.
2. LA-UR-03-1987, "MCNP – A General Monte Carlo N-Particle Transport Code, Version 5," April 2003.
3. NUREG/CR-6698, "Guide for Validation of Nuclear Criticality Safety Calculational Methodology," USNRC, January 2001.
4. Global Nuclear Fuel,"Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Rack Inserts," NEDC-33672P, September 2011.
5. NET-264-02 P, Revision 4, "Criticality Analysis of the Peach Bottom Spent Fuel Racks for GNF2 Fuel with Maximum Boraflex Panel Degradation," December 17, 2009.

Appendix A - MCNP-05P Code Validation

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Table A-1 – MCNP-05P Results for the Benchmark Calculations

#	Experiment	Expt. #	Benchmark Eigenvalue	Experimental Uncertainty	MCNP-05P	MCNP-05P Uncertainty	Bias	Bias Uncertainty
[[								

#	Experiment	Expt. #	Benchmark Eigenvalue	Experimental Uncertainty	MCNP-05P	MCNP-05P Uncertainty	Bias	Bias Uncertainty

#	Experiment	Expt. #	Benchmark Eigenvalue	Experimental Uncertainty	MCNP-05P	MCNP-05P Uncertainty	Bias	Bias Uncertainty
								]]

Figure A-1 shows the bias results of Table A-1 when all the results are treated as a single population. The top plot in the figure is a histogram plot of the results with an overlaying Normal curve fit. The resulting P-value of this Normal curve fit is 0.341 thus the data passes the normality tests (P-value>0.05). The remaining plots and data in Figure A-1 show the simple mean, median, and sample standard deviation of this data, and their corresponding 95% confidence intervals.

[[

]]

Figure A-1 – Statistical Analysis of the Benchmark Results

In order to account for the uncertainty in the experimental values, the weighted sample mean and standard deviation were calculated using the following equations:

$$B = Benchmark - MCNP05P$$

$$\overline{B} = \frac{\sum_{i=1}^{n} \frac{B_i}{\sigma_i^2}}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}}$$

$$S_P = \sqrt{s^2 + \overline{\sigma}^2}$$

$$\overline{\sigma}^2 = \frac{n}{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}}$$

$$s^2 = \frac{\left(\frac{1}{n-1}\right)\sum_{i=1}^{n}\frac{1}{\sigma_i^2}\left(B_i - \overline{B}\right)^2}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{\sigma_i^2}}$$

$$Bias\ Uncertainty = U \cdot S_p$$

Where:

$\overline{B}$ = Average weighted bias

σ_i = Uncertainty in bias Bi

S_P = Pooled standard deviation

s^2 = Variance about the mean

$\overline{\sigma}^2$ = Average total variance

U = one-sided tolerance factor for n data points at (95/95 confidence/probability level)

n = number of data points ([[ ]])

Table A-2 summarizes the results of these calculations.

Using the average weighted bias and pooled standard deviation; the upper one-sided 95/95-tolerance limit was calculated for use in criticality calculations, in accordance with NUREG-6698 guidance (Reference 3). [[

]] Table A-3 summarizes the recommended bias and bias uncertainty to be used in criticality calculations.

Table A-2 – Bias and Bias Uncertainty for MCNP-05P with ENDF/B-VII

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Table A-3 – Recommended Bias and Bias Uncertainty in Criticality Analyses for MCNP-05P with ENDF/B-VII

[[	
	]]

Appendix B - Legacy Fuel Storage Justification

Exposure dependent, maximum, uncontrolled in-core k_∞ results have been calculated for each fuel assembly in the PBAPS Unit 2 and Unit 3 spent fuel pools. Maximum values for each fuel type (e.g., 7x7, 8x8, 9x9, and 10x10) are presented in Table B-1. These values have been calculated using the process for validating that specific assembly designs are acceptable for storage in the PBAPS fuel storage racks, as outlined in Section 3.4. Table B-2 provides the name of the bundle, the name of the lattice, the lattice exposure and the corresponding void fraction that are associated with the peak reactivity legacy fuel lattice. This information demonstrates that all fuel assemblies currently in the PBAPS spent fuel pools have considerable margin to the reactivity of the GNF2 design basis bundle used in this analysis. The margin to safety was also confirmed to exist in the storage rack by analyzing the peak reactivity legacy fuel lattice (in-core [[ ]]) under normal conditions of storage, as outlined in Section 5.4. [[

]]

Because the GNF2 design basis bundle with an in-core k_∞ value of 1.235 has been shown to be below the 0.95 in-rack limit when analyzed in the storage racks, and because the legacy fuel types are less reactive than this design basis bundle both in-core and in-rack, it is confirmed that all legacy fuel types are safe for storage in the PBAPS spent fuel storage racks with credit for degraded Boraflex panels and without rack inserts installed.

Table B-1 – Peak Cold Uncontrolled In-Core Reactivity for Legacy Fuel Types

Plant: Peach Bottom 2	Lattice Type	In-Core K-infinity
[[		
		]]
Plant: Peach Bottom 3		
[[		
		]]

Table B-2 – Peak Reactivity Legacy Fuel Lattice Information

Plant	PBAPS Unit 2	PBAPS Unit 3
[[		
		]]

Appendix C – Alternate In-Core Reactivity Limit for Lower B-10 Areal Density Cells

While the peak in-core reactivity in legacy fuel bundles is 1.2344, PBAPS spent fuel storage racks hold many bundles with peak reactivities less than this value. To allow more flexibility in storage solutions for these lower reactivity bundles, a sensitivity study was performed to determine an alternate minimum B-10 areal density corresponding to a lower in-core limit of 1.2170.

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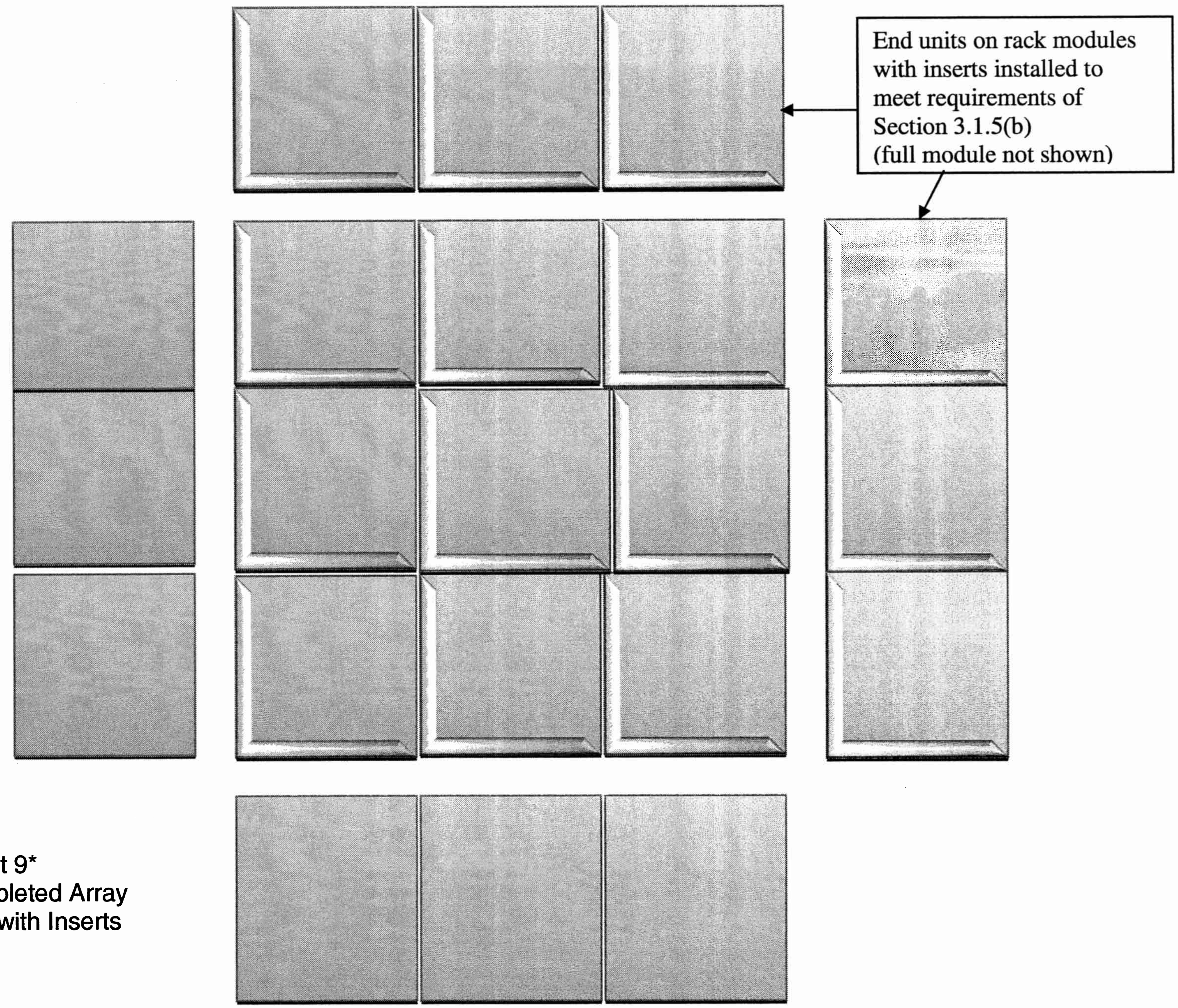
With the lower reactivity design basis bundle established, the storage system reactivity was studied over a range of B-10 areal densities using the same base rack model described in Section 5.2 of the report. The results of the sensitivity study show that a minimum B-10 areal density of 0.01113 g B-10/cm^2 results in an in-rack reactivity less than the nominal in-rack value determined in Table 7 of the report [[ ]].

It is relevant to note that the bundle design and rack model used in this assessment are nearly identical to that presented in the body of this report. Additionally, no new credible accident scenarios or tolerance studies are required to determine a maximum K(95/95) value in this study. Therefore, the reactivity adders for tolerances, biases, and uncertainties determined in Table 14 are appropriate for use in this case. The resulting maximum k-effective (K(95/95)) for the combination of an in-core k_∞ limit of 1.2170 and a minimum B-10 areal density of 0.01113 g B-10/cm^2 is less than 0.95 for normal and credible abnormal operation with tolerances and computational uncertainties taken into account.

ATTACHMENT 9

Example of a Completed Array of a Rack Module with Inserts



Attachment 9*
Example of a Completed Array of a Rack Module with Inserts

*This figure is intended to show the position of the NETCO-SNAP-IN® rack inserts in each spent fuel pool rack cell. The figure does not represent the actual physical dimensions and characteristics of the inserts and is not drawn to scale.

ATTACHMENT 10

Affidavits

Global Nuclear Fuel – Americas, L.L.C.

AFFIDAVIT

I, Russell E. Stachowski, state as follows:

(1) I am Chief Consulting Engineer, Global Nuclear Fuel – Americas, L.L.C. ("GNF-A"), and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in GNF-A proprietary report NEDC-33672P, "Peach Bottom Atomic Power Station: Fuel Storage Criticality Safety Analysis of Spent Fuel Storage Racks with Rack Inserts," Revision 0, dated September 2011. GNF-A proprietary information in NEDC-33672P is identified by a dotted underline placed within double square brackets. [[This sentence is an example.{3}]] GNF-A proprietary information in figures, large equation objects, and some tables is identified with double square brackets before and after the object. In all cases, the superscript notation {3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which GNF-A is the owner or licensee, GNF-A relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for trade secrets (Exemption 4). The material for which exemption from disclosure is here sought also qualifies under the narrower definition of trade secret, within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975 F2d 871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704 F2d 1280 (DC Cir. 1983).

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

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

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

c. Information which reveals aspects of past, present, or future GNF-A customer-funded development plans and programs, resulting in potential products to GNF-A;

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

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a. and (4)b.

(5) To address 10 CFR 2.390(b)(4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GNF-A, and is in fact so held. The initial designation of this information as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in the following paragraphs (6) and (7). The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GNF-A, no public disclosure has been made and it is not available in public sources. All disclosures to third parties, including any required transmittals to the NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary and/or confidentiality agreements that provide for maintaining the information in confidence.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, who is the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge, or who is the person most likely to be subject to the terms under which it was licensed to GNF-A. Access to such documents within GNF-A is limited to a "need to know" basis.

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

(8) The information identified in paragraph (2), above, is classified as proprietary because it contains details of the nuclear fuel criticality licensing methodology for the GEH Boiling Water Reactor (BWR). Development of these methods, techniques, and information and their application for the design, modification, and analyses methodologies and processes was achieved at a significant cost GNF-A.

The development of the evaluation processes along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GNF-A asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GNF-A's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GNF-A's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GNF-A. The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial. GNF-A's competitive advantage will be lost if its competitors are able to use the results of the GNF-A experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

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

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 29th day of September 2011.

Russell E. Stachowski
Chief Consulting Engineer
Global Nuclear Fuel – Americas, L.L.C.
3901 Castle Hayne Rd.
Wilmington, NC 28401

Global Nuclear Fuel – Americas, L.L.C.

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c. Information which reveals aspects of past, present, or future GNF-A customer-funded development plans and programs, resulting in potential products to GNF-A;

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Executed on this 29th day of September 2011.

Russell E. Stachowski
Chief Consulting Engineer
Global Nuclear Fuel – Americas, L.L.C.
3901 Castle Hayne Rd.
Wilmington, NC 28401

ATTACHMENT 11

Summary of Commitments

ATTACHMENT 11
Summary of Commitments

The following table identifies commitments made in this document. (Any other actions discussed in the submittal represent intended or planned actions. They are described to the NRC for the NRC's information and are not regulatory commitments.)

COMMITMENT	COMMITTED DATE OR "OUTAGE"	COMMITMENT TYPE	
		ONE-TIME ACTION (YES/NO)	PROGRAMMATIC (YES/NO)
The Boraflex monitoring program will continue to be maintained for as long as Exelon continues to credit Boraflex for criticality control, until the installation of NETCO-SNAP-IN® rack inserts is complete in both spent fuel pools.	Complete	No	Yes
The rack inserts will be installed in stages as discussed in Section 3.1.5 of Attachment 1.	Prior to crediting the neutron absorption capabilities of the NETCO-SNAP-IN® rack inserts for each individual spent fuel storage rack	Yes	No
Exelon will implement the Rio Tinto Alcan Composite Surveillance Program as described in Section 3.9 of Attachment 1 to ensure that the performance requirements of the Rio Tinto Alcan composite in the NETCO-SNAP-IN® rack inserts are met over the lifetime of the spent fuel storage racks with the rack inserts installed. A description of the program will be added to the PBAPS, Units 2 and 3 UFSAR upon implementation of the proposed change.	Upon implementation of the proposed change	No	Yes
The k-infinity limitations will be incorporated into reload design documents and spent fuel pool criticality compliance procedures. Additionally, the design limitations will be reflected in Section 10.3.4 of the PBAPS, Units 2 and 3 UFSAR.	Upon implementation of the proposed change	No	Yes
Exelon will submit the data and analysis associated with the first 10-year surveillance of the NETCO-SNAP-IN® rack inserts to the U.S. Nuclear Regulatory Commission.	Within 60 days following completion of the analysis	Yes	No
The NETCO-SNAP-IN® rack inserts will be installed in both units by December 31, 2016 as discussed in this license amendment request.	December 31, 2016	Yes	No