Industry View on Neutron Absorber Degradation

Kristopher Cummings
Sr. Project Manager, Used Fuel Programs
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Topics of Discussion

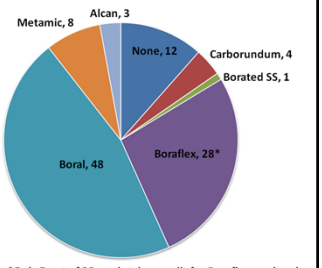
- Neutron Absorber Survey
  - Types of Neutron Absorbers
  - Monitoring Programs
- Neutron Absorber Testing Program
- Is this a Safety Concern?
- What is the Industry Doing?
- Summary/Conclusions

Neutron Absorber Survey

- NEI conducted a survey in 2013 that was distributed to all US nuclear utilities/plants with spent fuel pool storage (operating and shutdown reactors)
- Goal was to gain an understanding of industry actions to measure, test and characterize behavior of neutron absorbers in the spent fuel pool.
- Survey questions:
  - Type of neutron absorbers in pool
  - Type of absorber test program (coupons, in-situ)
  - Observed degradation? Type and extent?
- Results based on a 70% response rate.
  - Multiple plants have more than one type of neutron absorber

Survey - Types of Neutron Absorbers in Use

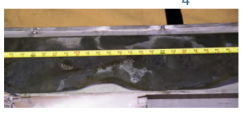
- Carborundum/Tetrabor
- Borated Stainless Steel
- Boraflex
- Boral
- Metamic
- Alcan



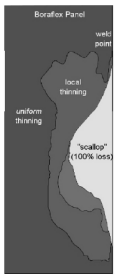
*Only 7 out of 28 pools takes credit for Boraflex as absorber

Boraflex

- Boraflex consists of B_4C particles bound in a silicone rubber matrix
- Degradation mechanism is based on a threshold gamma dose and exposure to pool water (especially flowing water)
- Degradation causes dissolution of silicia into pool water and loss of B_4C from matrix



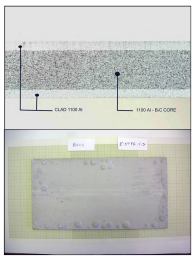
EPRI Report 1003414



T.C. Haley, 2012

Boral

- Boral is an Aluminum Boron Carbide Cerment
- Aging/Degradation issues are:
  - Blistering (seperation of Al clad from core material)
  - Pitting (small, localized)
- No observed loss or redistribution of B_4C.
- No mechanisms identified that could lead to loss of B_4C.
- EPRI Boral database contains data extending over 25 years



EPRI Reports 1019110 and 1011818

Neutron Absorber Survey

- Carborundum/Tetrabor:
  - All plants credit some amount of the neutron absorber and have monitoring programs in place.
- Boraflex:
  - Majority of plants have discontinued credit of neutron absorber:
  - Remainder of plants have LARs for inserts, LARs to remove credit, or monitor via coupons/in-situ testing.
- Boral:
  - Over 50% of the plants have coupon testing programs
  - Those plants without coupons are adding coupons, in-situ testing and/or monitoring fleet/industry results
- Metamic/Alcan: All have coupon monitoring programs

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Neutron Absorber Testing Program

The purpose of a Neutron Absorber Testing Program is to provide ongoing confirmation that:

- The neutron absorber material is not undergoing unanticipated aging effects that would impact reactivity
- Observed material aging effects are observed in coupons in advance of expected degradation in racks and accounted for in the criticality analysis
- The presence of the neutron absorber material provides the criticality control relied upon in the analysis.

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Neutron Absorber Testing (Cont'd)

There are two methods for providing ongoing confirmation of the presence of the neutron absorbers in the racks:

- **Coupon Testing -** Preferred method
- **In-Situ Measurements -** Acceptable method for confirming B-10 used to:
  - Supplement coupon testing
  - In lieu of coupon testing if no coupons available

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Coupon Testing

A Coupon Testing Program should meet the following criteria:

- **Number of Coupons -** Sufficient number of coupons to provide sampling at appropriate frequency for intended life of the material
- **Life of Neutron Absorber -** Based on time the material will be credited in the criticality analysis
- **Sampling Frequency -** Based on expected material performance from qualification testing and operational experience
- **Coupon Location -** Located such that exposure to parameters controlling performance attributes (such as gamma fluence and/or heat) are similar to the in-service neutron absorber material. If possible, coupon exposure should bound 95% of the in-service material.

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Coupon Testing (cont'd)

A Coupon Testing Program should meet the following criteria: (cont'd)

- **Coupon Testing -** Based on operating history of material as follows:
  - **Basic Testing**
    - Appropriate when testing and operating experience indicates no mechanism resulting in loss of neutron absorbing capability
    - Consists of visual observations, dimensional measurements, and weight.
  - **Full Testing**
    - Appropriate for the first coupon test and when testing and operating experience indicates loss of neutron absorbing capability
    - Consists of ^{10}B areal density measurements, microscopic analysis, and characterization of degradation in addition to Basic Testing

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In-Situ Measurement

An In-Situ Measurement Testing Program should meet the following criteria:

- **Number of Panels Tested -** Should be an appropriate statistical sample
- **Sampling Frequency -** Based on expected material performance from qualification testing and operational experience
  - If material does not have a long-term industry in-service history – initial frequency should not exceed 5 years
  - If material has a long-term industry in-service history and material stability has been documented – frequency should not exceed 10 years
- **Measurement Uncertainties -** Measurement method should be appropriately justified, including identifying uncertainties.
- **Use of Results –** Should be material dependent as follows:
  - For material with potential performance experience which do not result in loss of neutron absorbing capability – measurements should be used as confirmatory
  - For material with potential performance experience which may result in loss of neutron absorbing capability – measurements should be performed to justify credit in analysis

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Is this a Safety Issue?

- Degradation of older neutron absorbers (Boraflex, Carborundum) have largely been addressed by:
  - elimination of absorber credit
  - installation of new neutron absorber inserts
  - Monitoring/reanalysis with conservative treatment and prediction of neutron absorber presence
- Degradation for metallic absorbers is a slow process (decades) that provides advance indication through coupon testing, in-situ measurements and pool chemistry observations.
- Localized degradation (pitting, general corrosion, localized loss of material) has a negligible effect on criticality (< 0.001 Δk). Boral blistering, theoretically could have a small impact (0.01 Δk), in reality is a minimal localized effect (0.001 Δk)

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Is this a Safety Issue?

- Significant amounts of independent reactivity holddown is present in pools:
- PWR Pools:
  - Soluble boron present in pool to offset unexpected conditions (approximately 2000ppm per Tech Spec = ~0.2 Δk)
- BWR Pools:
  - Analysis based on maximum reactivity provides significant conservatism (> 0.10 Δk)
  - Regulatory administrative margin (0.05 Δk)

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What is the Industry Doing?

- EPRI Accelerated Boral Corrosion Testing :
  - BWR & PWR Spent Fuel Pool Conditions
  - Encapsulated and Un-encapsulated Coupons
  - Various fabrication processes
  - Tests are conducted at 195°F to simulate approximately 90 years of service life
- Future EPRI project to remove Boral from in-service racks and compare in-situ test results to in-lab neutron attenuation test results.

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What is the Industry Doing?

- NEI 12-16, "Guidance for Performing Criticality Analysis of Fuel Storage at Light Water Reactor Power Plants":
  - Includes a section on the appropriate monitoring program depending on material and availability of coupons (March 2014)
- Industry continues to share test results, operating experience through the EPRI Neutron Absorbers Users Group (NAUG)

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Summary/Conclusions

- Industry has responded to operating experience and NRC notifications to address significant neutron absorber degradation issues. (Boraflex, Carborundum)
- With 35 years of in-pool exposure, Boral continues to provide the same level of neutron absorption capability as when it was installed.
- Existing monitoring programs and new accelerated tests will provide additional information to ensure that any degradation processes are observed and responded to prior to causing a safety issue.

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