EPRI Neutron Absorber Projects – Zion & Accelerated Corrosion Tests

Hatice Akkurt
Used Fuel and High Level Waste Management Program

NRC Public Meeting
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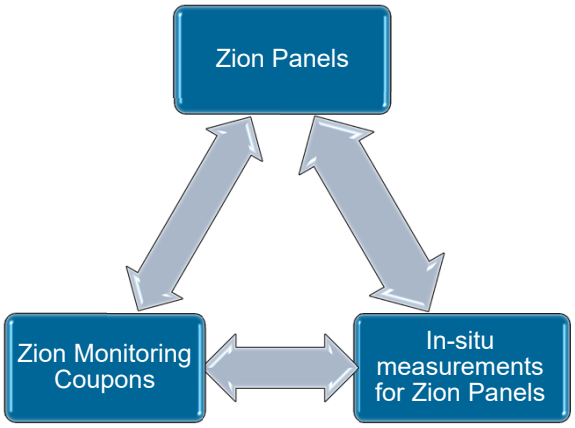
Neutron Absorber Projects

Technical Questions for Neutron Absorber Materials

1. What are the conditions of the neutron absorber panels in SFPs? Is there any gross degradation that could cause potential concern for criticality safety of the pools in the near or long term?
2. Is the coupon monitoring approach adequate for monitoring the conditions of the panels as part of an aging management program?
3. For plants that do not have coupons, do current in situ measurement approaches provide accurate results? Could such in situ approaches be used as an alternative monitoring approach?

Zion Comparative Analysis Project



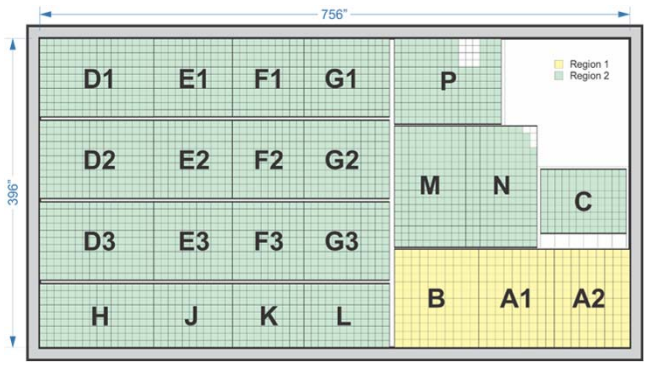
Objectives

- Evaluate the condition of the Boral panels after being in Zion SFP over 22 years
- Verify that the current monitoring approaches provide meaningful results
  - The two monitoring approaches are:
    - Periodic measurements on surveillance coupons
    - In-situ measurement using BADGER

EPRI and NRC signed a MOU for Zion project in October 2014

Zion Power Station & Spent Fuel Pool (SFP)

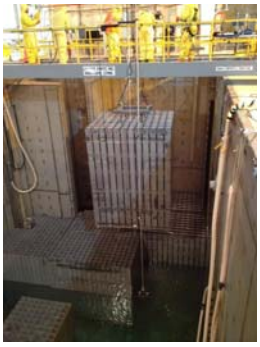
- Westinghouse PWR - operated from 1973 to 1997
  - Fuel in SFP since 1997
- Re-racked using **Boral** panels in **1993**
  - Coupons in the pool
  - Access to previous coupon measurements

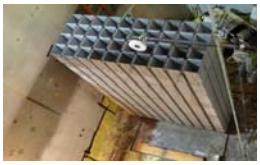


- Fuel off-loading started in December 2013 as part of decommissioning schedule
- 2 regions, Region 1 and 2

Objective I: Evaluate the Condition of Zion Panels

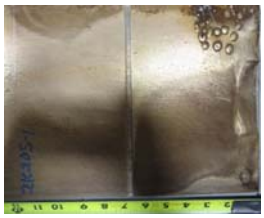
Zion Module Removal & Panel Harvesting





Module B – After 1st cut

- **Two modules** (one from Region1 and one from Region 2) removed from Zion SFP and shipped to Alaron for panel harvesting
- Based on BADGER measurements, 6 panels from Region 1 and 6 panels from region 2 were selected for analyses
- Two of the Region 1 panels were damaged during processing
- Those panels were kept for Areal Density measurements (to compare against BADGER) but two additional panels harvested for full analyses



2K20S
Panel damaged during cutting after removal from Zion SFP

From Panels to Samples

Region 2 panels are being measured, labeled, and marked for sectioning

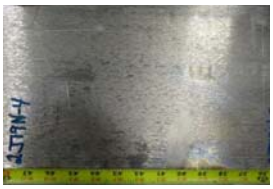
- Each panel (144”) divided into 12 sections
- EPRI & NRC received 6 sections/panel
  - Alternated between odd-even number for different panels
- EPRI panels shipped to PSU for analyses
- NRC panels shipped to SRNL for analyses

Samples packed for shipment

Overview of Condition of Panels

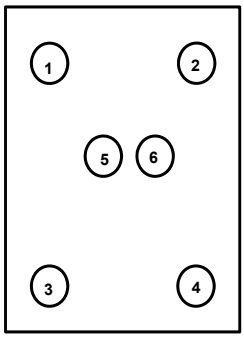
Based on visual inspection, general observations are:

- With the exception of externally damaged panels, both **Region 1** and **Region 2 panels** were in **good condition**
- **Only one very small blister on one of the section of the panels (which was identified under microscope)**
- Externally damaged panels showed blisters but those occurred after removal from the Zion SFP
- Showed general corrosion, flow patterns, some pitting but no evidence of significant degradation
- Overall, Region 1 panels were in much better condition
  - No SS encapsulation allowed a thick oxide layer formation, which acted as protective layer



Zion Panel Areal Density (AD) Measurements

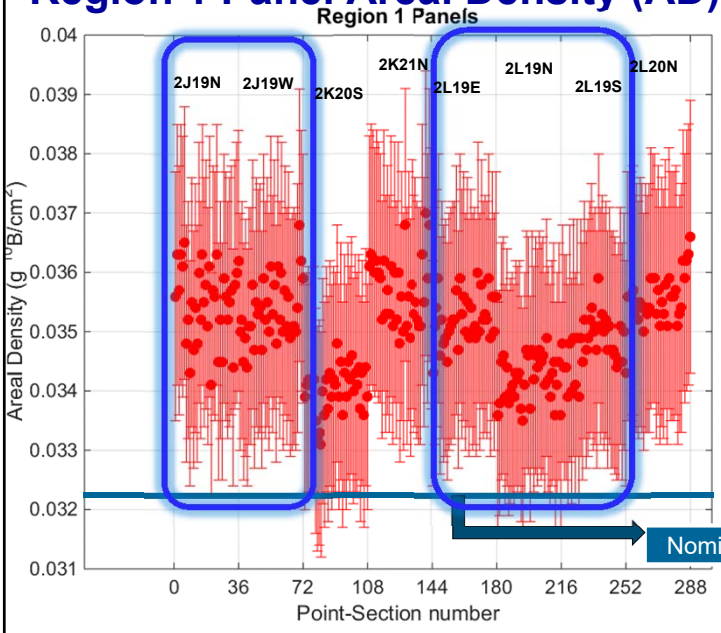
Areal density measurements performed on all EPRI samples



For each sample, areal density measurements performed at 6 locations

- Panel length=144”
- Divided into 12” sections
- Distributed alternating odd/even numbers/panel between NRC & EPRI
  - 6 EPRI sections/panel
  - 6 points for AD measurement/section
- Region 1: 8 Panels ➔ 288 AD measurement points
- Region 2: 6 panels ➔ 216 AD measurement points

Region 1 Panel Areal Density (AD) Measurements



- All of the **measured AD** values are **above minimum certified AD** values
- All of the **measured AD values** are **above nominal AD values** (error bars represent 3sigma)
- There are variations in AD within the same panel
- There are variations in AD for the panels that are in the same cell
  - 2J19N & 2J19W are from the same cell
  - 2L19E, 2L19N, 2L19S are from the same cell
- Panels 2K20S and 2K21 are the damaged panels

Nominal AD=0.0324 g $^{10}B/cm^2$

Minimum certified AD=0.030 g $^{10}B/cm^2$

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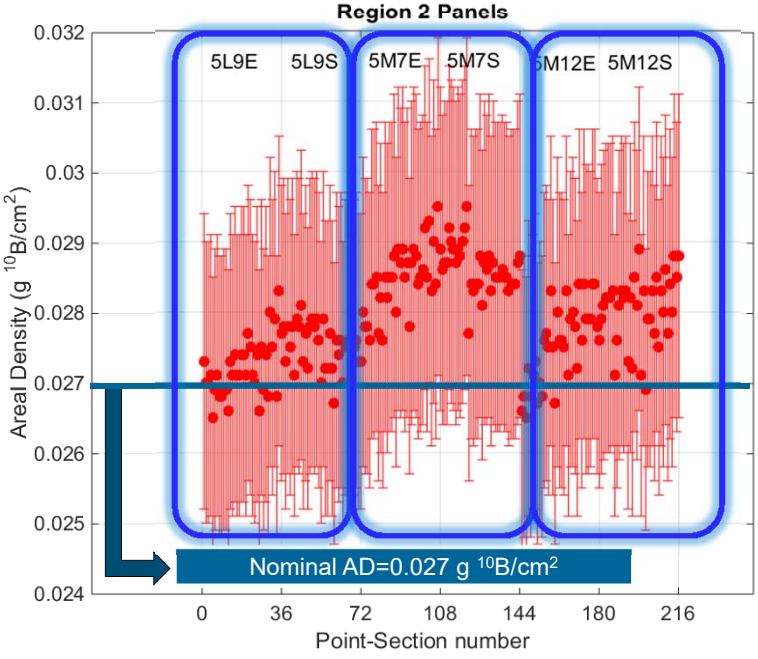
Region 2 Panel Areal Density Measurements



- All of the **measured AD** values are **above minimum certified AD** values
- Few of the **measured AD values** are below **nominal AD values** (error bars represent 3sigma)
- There are variations in AD within the same panel
- There are variations in AD for the panels that are in the same cell
  - 5L9E & 5L9S are from the same cell
  - 5M7E & 5M7S are from the same cell
  - 5M12E & 5M12S are from the same cell

Nominal AD=0.027 g $^{10}B/cm^2$

Minimum certified AD=0.024 g $^{10}B/cm^2$

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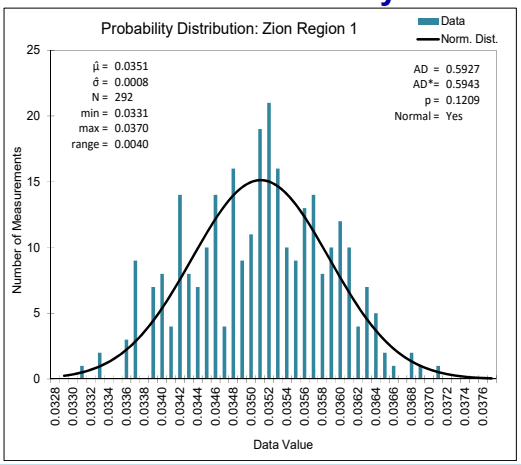
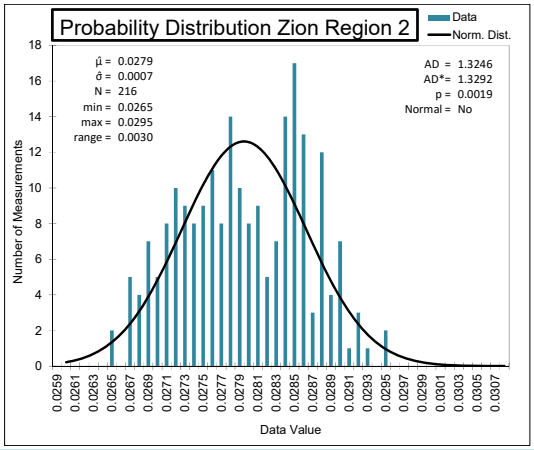
Distribution of Areal Density Measurements for Zion Panels





Region 1 - Tech Spec:

Min. certified AD=0.030 & Nominal AD=0.0324 g $^{10}B/cm^2$

Region 1 – Measured Areal Density values:

Min.=0.0331; Mean=0.0351; Max=0.0370 g$^{10}B/cm^2$

Region 2 - Tech Spec:

Min. certified AD=0.024 & Nominal AD=0.027 g $^{10}B/cm^2$

Region 2 – Measured Areal Density values:

Min.=0.0265; Mean=0.0279; Max=0.0295 g$^{10}B/cm^2$

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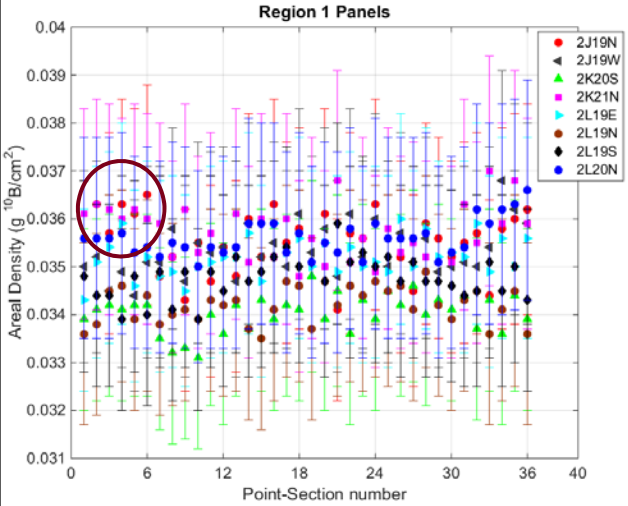
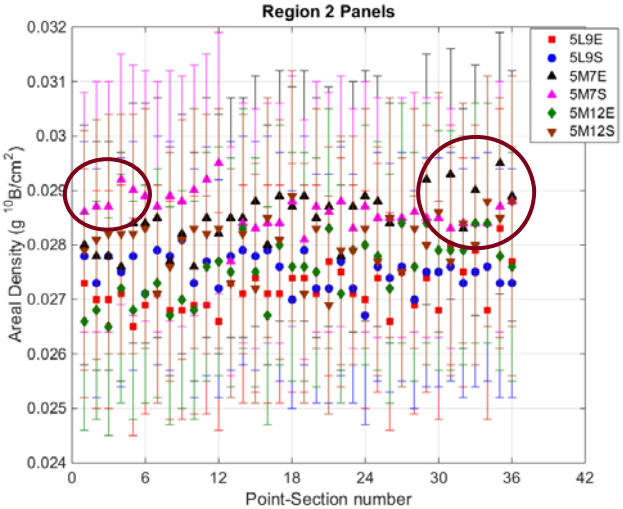
Variations in Areal Density for Zion Panels





Variations in Areal Density

- From panel to panel; for different points in the same panel; for different points within the same section

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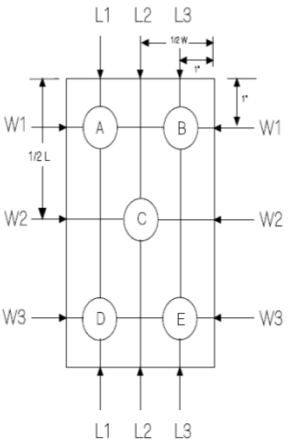
Objective II: Panels vs. Coupons

Zion Panels ⟷ Relation between Coupons & Panels ⟷ Zion Coupons

- Are coupons really representing condition of panels?
- Is coupon monitoring program adequate?

Zion Coupons

- Coupon Tree removed from Zion SFP
- 10 coupons shipped to PSU for analyses
  - Access to previous coupon measurement reports



Coupon Analysis

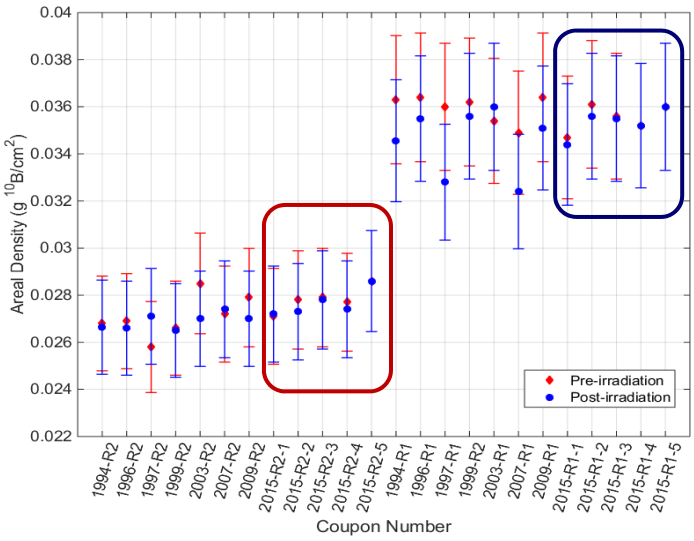
- Length measurements: L1, L2, L3
- Width measurements: W1, W2, w3
- Weight, thickness, density measurements

Areal density measurements:

- After irradiation areal density measurements at 5 locations, A, B, C, D, E
- Pre-irradiation areal density measurements at 3 locations, A, C, E

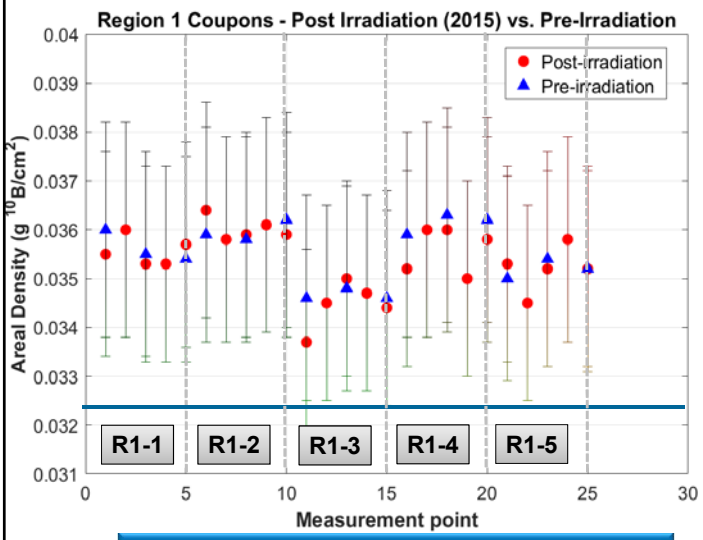
- Coupon L = 15" +/- 0.063“; W = 7.5" +/- 0.063“
- All coupons were encapsulated using SS
- **Thickness:**
  - Region 1: 0.101“
  - Region 2: 0.085".

Zion Coupon Areal Density Measurements



- Between 1994 and 2009, one coupon from each region was analyzed
- The areal density measurements from 2015 are compared to the previous coupons measurements, performed between 1994 and 2009
- **The areal density measurements from 2015 are in excellent agreement with the pre-characterized values**

Zion Coupon Areal Density Measurements — Region 1

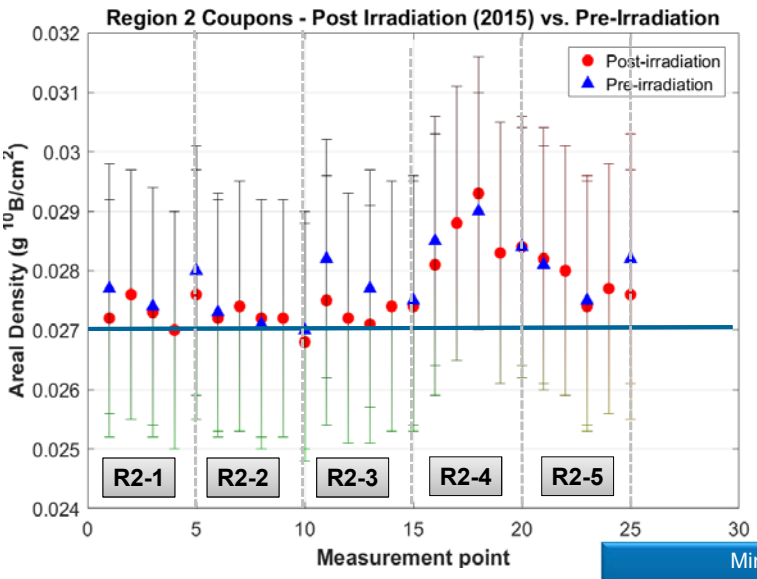


Minimum certified AD=0.030 g ^{10}B/cm^2

Nominal AD=0.0324 g ^{10}B/cm^2

- Pre-irradiation & post-irradiation values are significantly higher than minimum certified AD (~18%)
- Coupon-to-coupon and point-to-point variations within the same coupon are observed in both pre-and post-irradiation values
  - Boral is manufactured via rolling process, non-uniformities are reasonable
  - Pre-irradiation values indicate that additional margins for boron carbide are placed during manufacturing

Zion Coupon Areal Density Measurements — Region 2

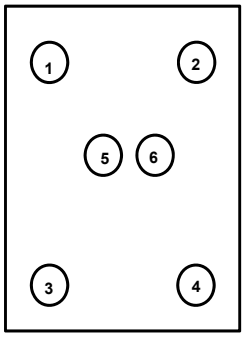


- Pre-irradiation & post-irradiation values are higher than minimum certified AD (~10%)
- Coupon-to-coupon and point-to-point variations within the same coupon are observed in both pre- and post-irradiation values in coupons from this region too

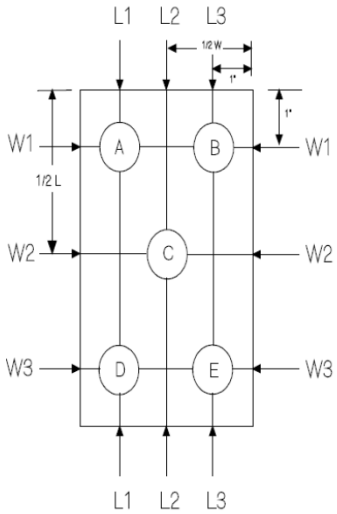
Minimum certified AD=0.024 g $^{10}B/cm^2$

Nominal AD=0.027 g $^{10}B/cm^2$

Panel vs. Coupon Areal Density Measurement Locations



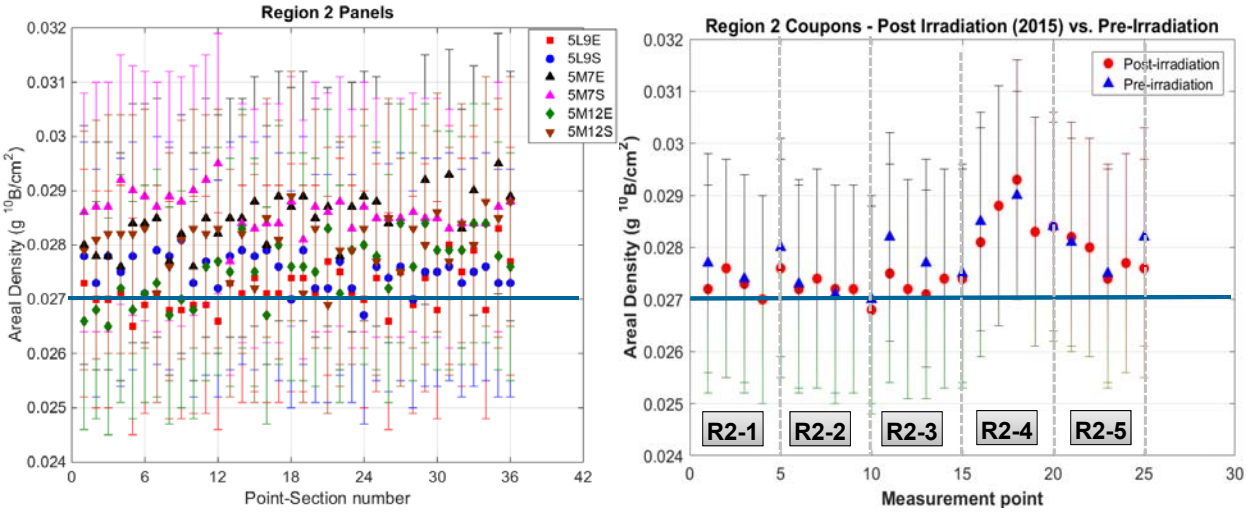
Panel Sample Areal Density measurement locations



Coupon Areal density measurements:

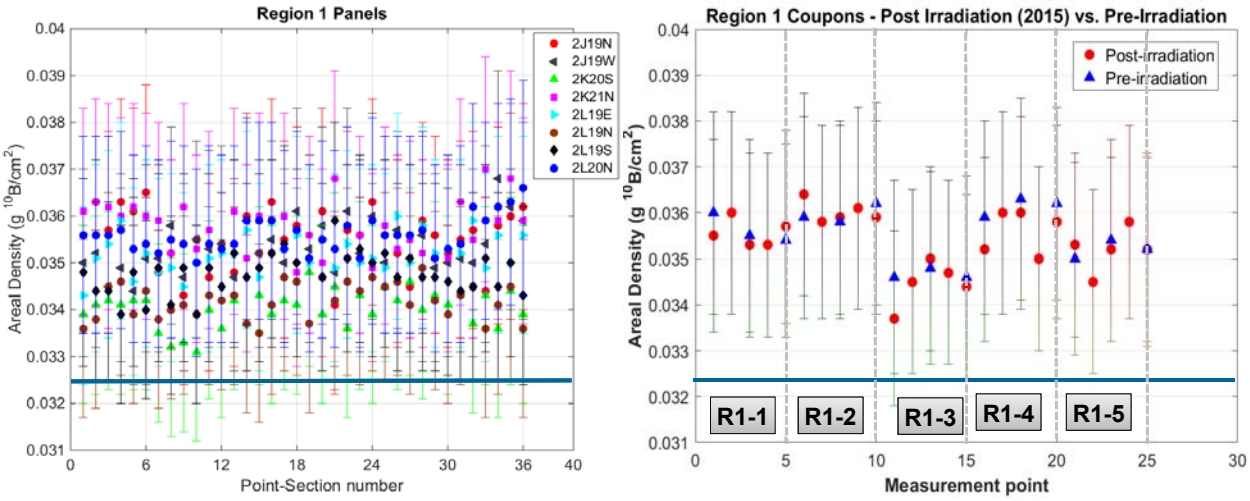
- After Irradiation areal density measurements at 5 locations, A, B, C, D, E
- **Pre-irradiation areal density measurements at 3 locations, A, C, E**

Areal Density Measurements – Zion Panel vs. Coupon – Region 2



1. Very good agreement between panel and coupon areal density values for Region 2
2. All of the areal density measurements are above the minimum certified areal density for both coupons & panels
3. There are variation in Areal Density inboth panels and coupons

Areal Density Measurements – Zion Panel vs. Coupon – Region 1

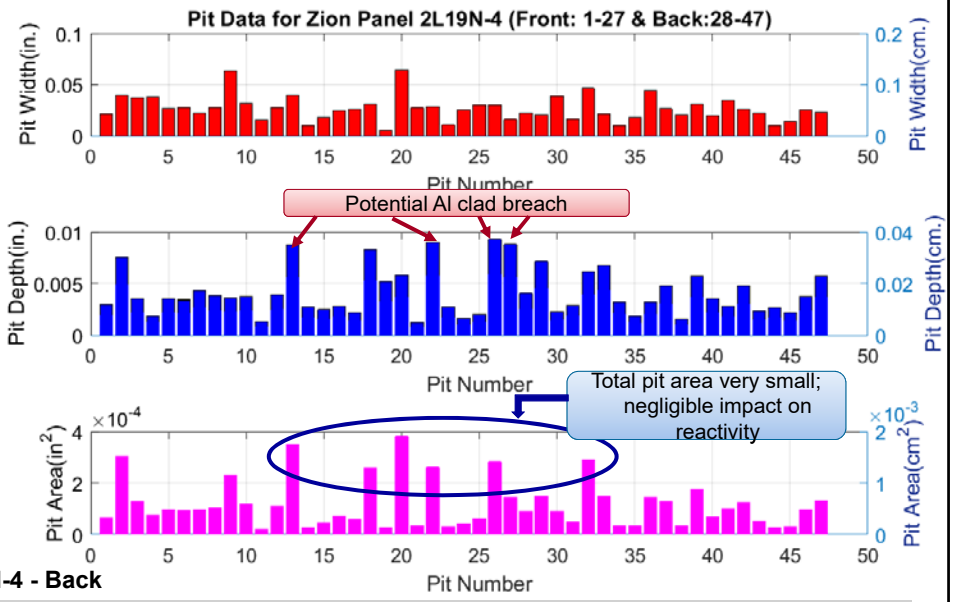


1. Very good agreement between panel and coupon areal density values for Region 1
2. All of the areal density measurements are above the minimum and nominal certified areal density for both coupons & panels
3. There are variation in Areal Density in both panels and coupons

Zion Panel Pit Measurements

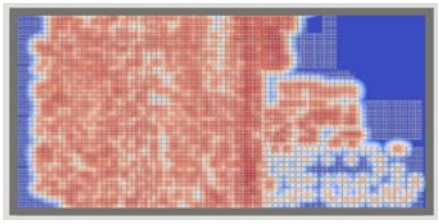
2L19N-4 - Front

2L19N-4 - Back



Objective III: Panels vs. In Situ Measurements

Zion In-Situ Measurements



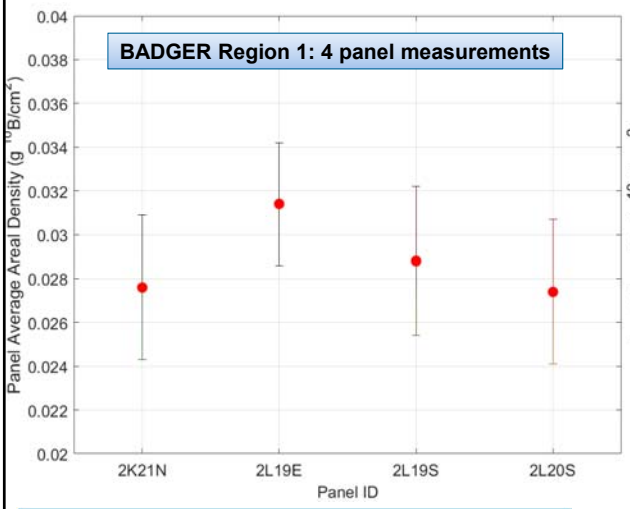
In-situ measurements performed for 25 panels

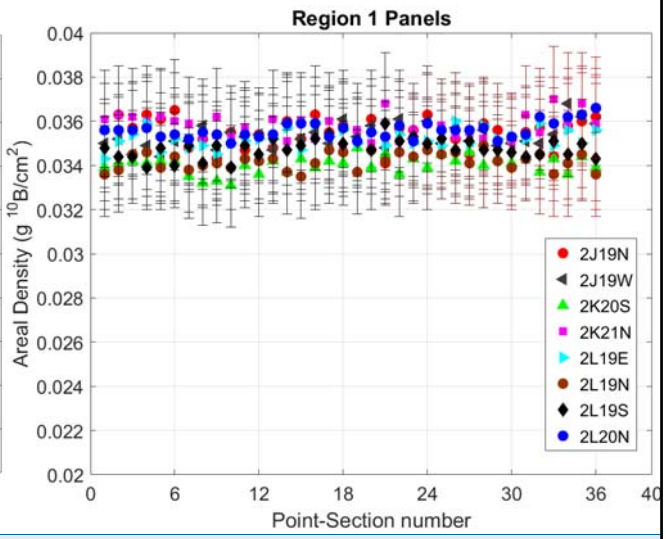
- **Region 2:** 21 panels (ranking from 1 to 99); **Region 1:** 4 panels (ranking from 15 to 95)
- Performed repeat measurements to determine repeatability
- Performed measurements close to coupon tree
- Performed measurements close to fuel assembly to address background contribution concerns

Panel Selection for In-Situ Measurements

- Performed extensive analysis for panel selection for in-situ measurements and panel harvesting. Selection based on:
  - Gamma dose rates
  - Neutron dose rates
  - Decay heat values
- Obtained normalized values for each panel for entire panel (1 to 99)

Panel Averaged Areal Density Values: Preliminary BADGER Results





Minimum certified AD=0.030 g ^{10}B/cm^2

Nominal AD=0.0324 g ^{10}B/cm^2

The in-situ measured areal density values for Region 1 panels are up to 35% lower than pre-characterized areal density values and significantly lower than measured panel AD values

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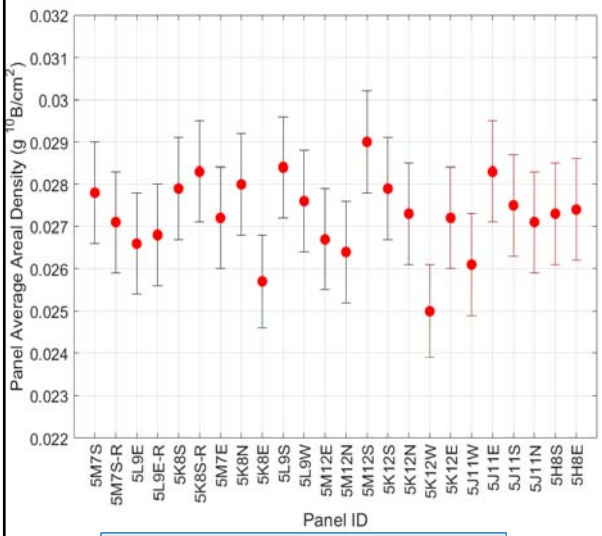
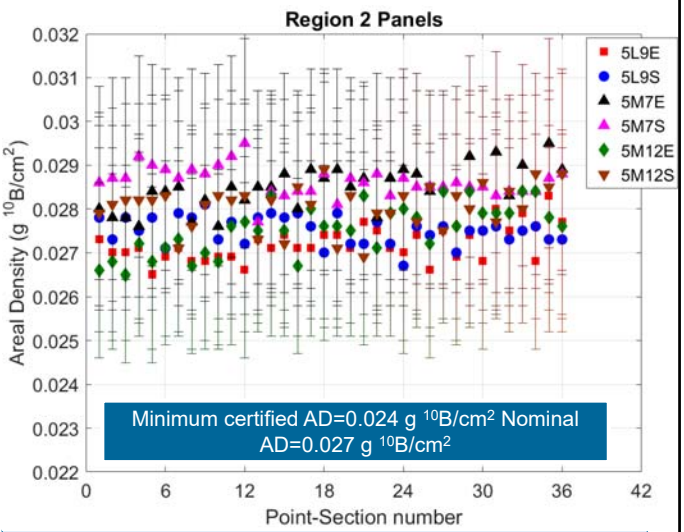
Panel Averaged Areal Density Values: Preliminary BADGER Results





Minimum certified AD=0.024 g ^{10}B/cm^2 Nominal AD=0.027 g ^{10}B/cm^2

BADGER Region 2 Measurements : 21 panels and 4 repeat measurements

Although in general, there seem to be good agreement between panel averaged AD values and pre-characterized values; they are lower than measured panel AD values

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Zion Comparative Analysis Project - Summary

- 14 panels harvested (2 were damaged out of pool). **Panels are in very good condition**.
  - Out of 168 sections, only one section had one very small blister.
  - There are some pits but no significant degradation.
- **Very good agreement between panel and coupon areal density values**.
- BADGER analysis ongoing. NRC is also conducting independent analysis.
  - Reasons behind discrepancies between BADGER and panel results are not clear yet.
  - Discrepancy between BADGER and panel results are more significant, compared to reported certified values.
- Several EPRI reports are under preparation.
  - Coupon and panel analysis reports will be published in 2016.
  - BADGER and final report, comparing panel vs. coupon vs. BADGER measurements, will be published in 2017.

Neutron Absorber Projects

Accelerated Corrosion Test Project

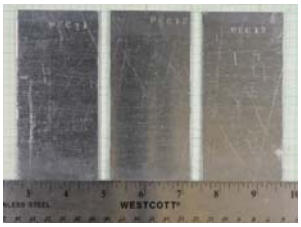
Accelerated Corrosion Test

Objectives

- Evaluate/demonstrate Boral in-pool performance for an extended service life
- Determine long-term corrosion rate of Boral

Approach

- Place pre-characterized Boral coupons in test baths representing
  - **PWR and BWR water chemistry**
    - Water chemistry measured regularly
  - **At elevated temperatures (196°F)**
    - Compared to typical pool temperature: 80–100°F
    - Evaluate changes in coupon attributes after exposure to accelerated environmental conditions.
  - **Five year test (2013-2018)**



Accelerated Corrosion Test – Coupon Types and Analyses

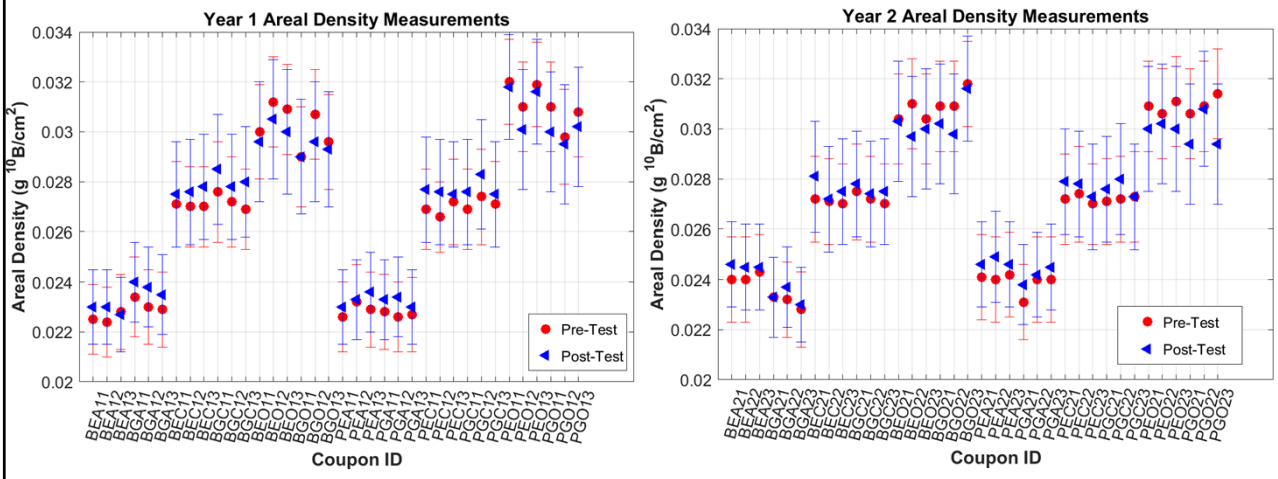
- Encapsulated, using SS jacket, and un-encapsulated (bare) coupons to determine impact of encapsulation.
- Boral manufacturer and manufacturing process changed over time. To determine impact of vintage on performance, used coupons from different manufacturing processes
  - AAR
  - Ceradyne-AAR
  - Ceradyne-Ceradyne
- Encapsulated Utility Archives (12)
- Clad removed coupons

Total Number of Coupons: 216

- **108 coupon/bath**

Test	Pre-Test Characterization	Post-Test Characterization
Visual Inspection	√	√
High Resolution Photography	√	√
Dimensions	√	√
Dry Weight	√	√
Density	√	√
Neutron Attenuation	√	√
Surface Characterization via Metallography for:		
Blister Characterization		√*
Oxide Film		√*
Pit Size and Depth		√*

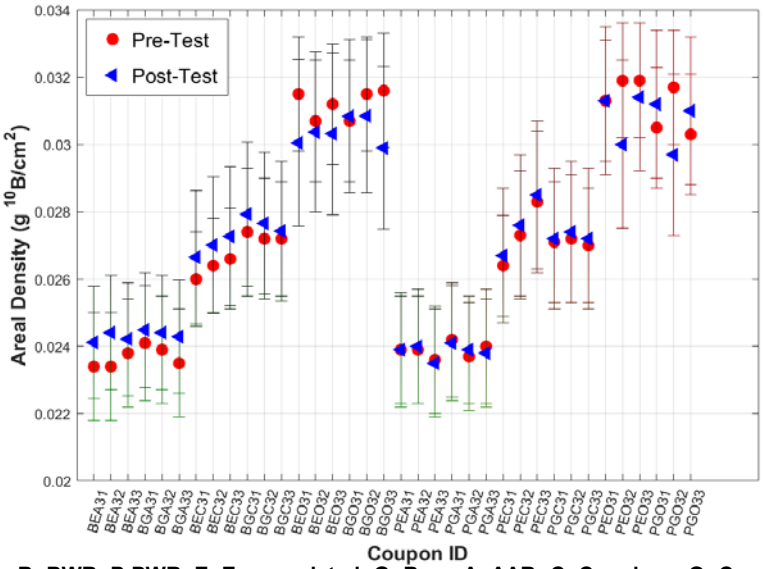
Year 1 & 2 Areal Density Values



B: BWR; P:PWR; E: Encapsulated; G: Bare; A: AAR; C: Ceradyne; O: Ceradyne-Oil

No statistically significant change in Areal Density Values for Year 1-3 coupons

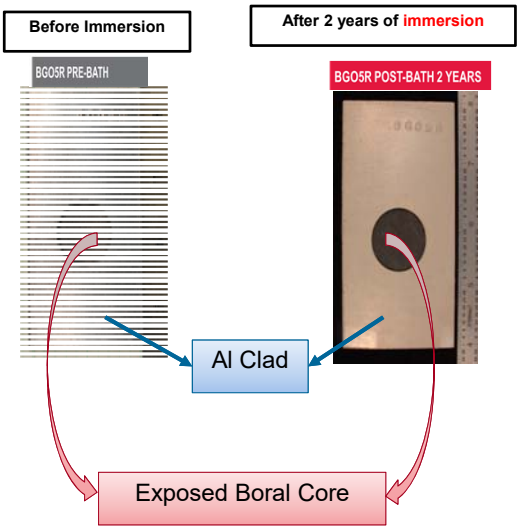
Areal Density Values – Year 3

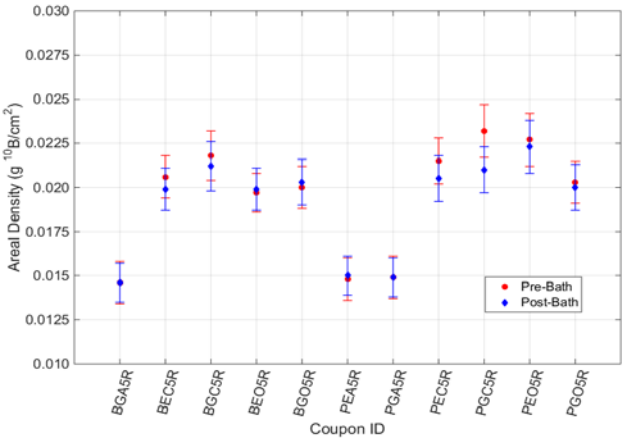


- No statistically significant change in areal density after 3 years in test baths!

B: BWR; P:PWR; E: Encapsulated; G: Bare; A: AAR; C: Ceradyne; O: Ceradyne-Oil

Key Result: Coupons with Core Directly Exposed to Water





No statistically significant change in areal density after 2 years of exposure!

Accelerated Corrosion Test Summary

- Year 1-3 results did not show any significant degradation
- The most significant key result is for the clad removed coupons, which showed no statistically significant change in areal density after 2 year at elevated temperatures

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