Updates on EPRI's Research on Neutron Absorber Materials

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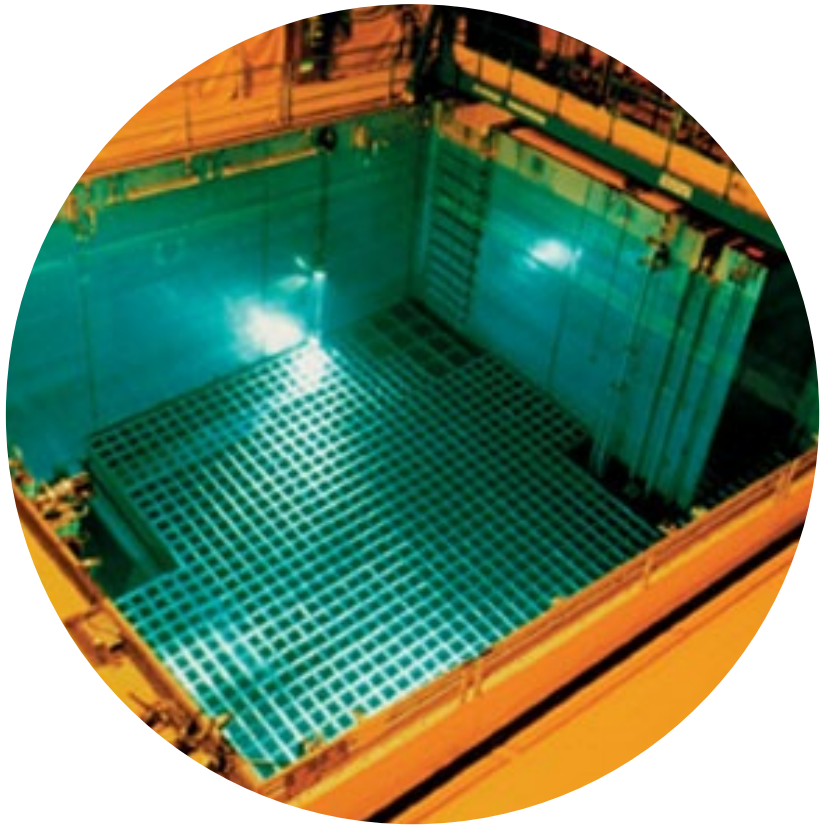
Spent Fuel Pool (SFP) Neutron Absorber Material (NAM) Aging

- **The safety function – maintain subcriticality margin in the SFP**
  - Is the safety function still met?
- **The aging issue – some NAMs have degraded**
  - Boraflex: Severe, up to local total loss of absorber
  - Carborundum: Moderate, gradual washout of absorber
  - BORAL®: Blistering, pitting and surface corrosion
  - Others: Pitting and thinning
- **The regulatory issue – reasonable assurance of safety**
  - If fueled, must have assurance of SFP NAM effectiveness
  - Life of the SFP may be longer than life of the plant

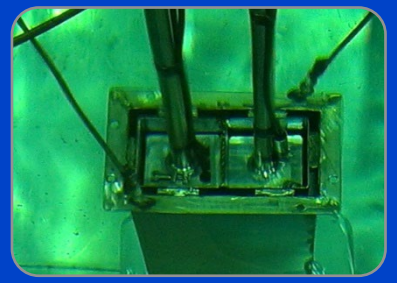


SFPs with neutron absorber materials need a NAM aging management program (AMP)

Spent Fuel Pool (SFP) Neutron Absorber Material (NAM) Monitoring

1. Coupon Monitoring

- Many SFPs have no coupons
- Many SFPs have few coupons left



2. In situ Measurements (Existing tool: BADGER)

- Expensive
- SFP logistic issues and dose
- Can be inaccurate and lead to false degradation*

3. Cutting NAM panels from rack modules

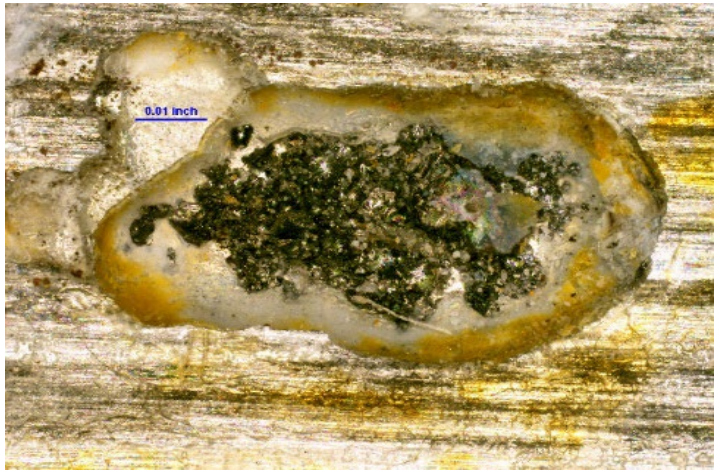
- Very expensive
- May lead to rack module damage (left with cells that can't be used)
- Plant and SFP logistic issues and dose

*Zion comparative analysis performed blind comparison of in-situ and actual panels, which showed false degradation predicted by in-situ measurements

NAM Degradation Mechanisms and Potential Concerns

1. Pitting

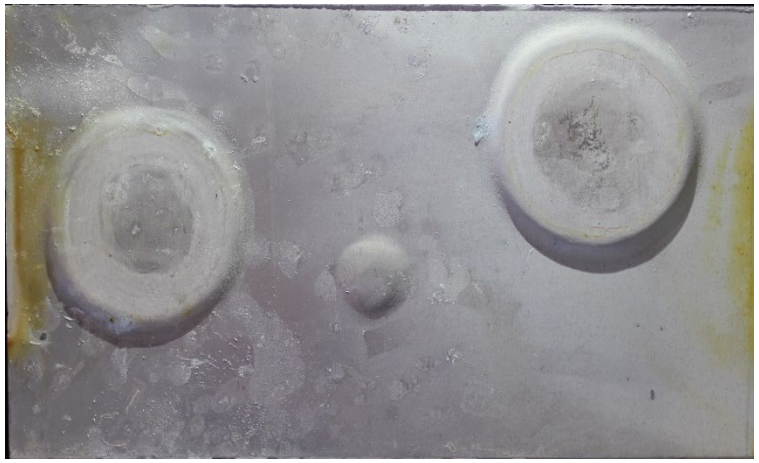
Significant pitting → Significant **absorber** loss → Potential concern for criticality



Pit picture with 100x magnification; pit reached absorber material

2. Blistering

Significant growth of blisters → Significant **moderator** loss → Potential concern for criticality



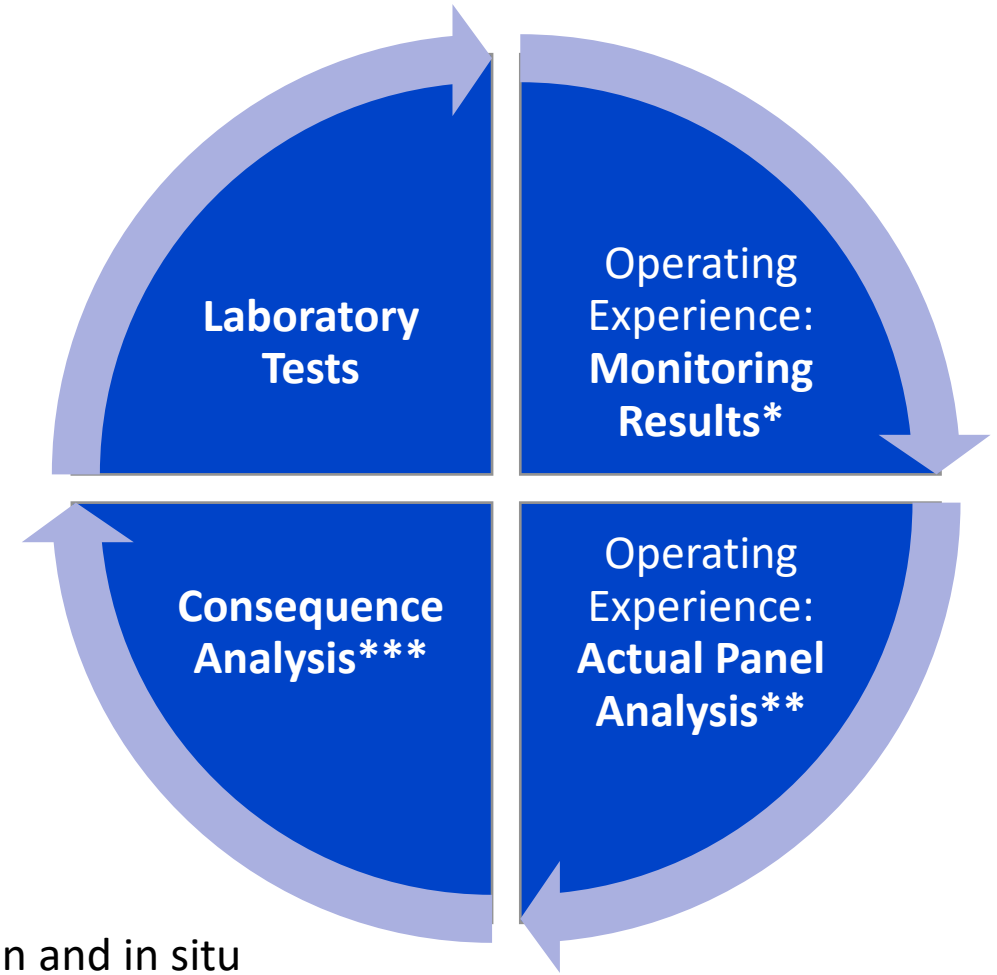
Blistering is only **applicable to absorber materials with cladding** (i.e., Boral, Maxus, etc.)

For a given neutron absorber material, aging effects in SFPs may be a function of:

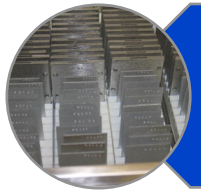
1. Type and vintage of the material
2. Time in the SFP
3. SFP water chemistry
4. Temperature
5. Cumulative neutron dose
6. Cumulative gamma dose

For different materials, significance of parameters vary (i.e., effect of gamma dose for Boral versus Boraflex).

Path to Establishment of Technical Basis for Effective Aging Management Programs

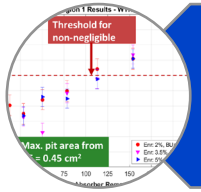


*Coupon and in situ
**Panels from Zion & Operating SFP
***Evaluation of impact of blister and pits on SFP reactivity

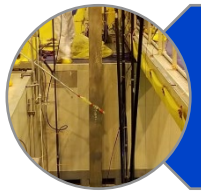


Laboratory: Accelerated Corrosion Test (to be published soon 3002023975)

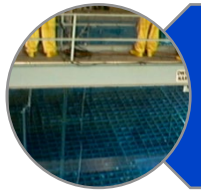
Actual panels, coupons, and in-situ measurements from SFP: Zion comparative analysis (3002008196 and 3002008195)



Modeling and Simulation: Evaluation of Impact of Blister and Pits (3002013119)



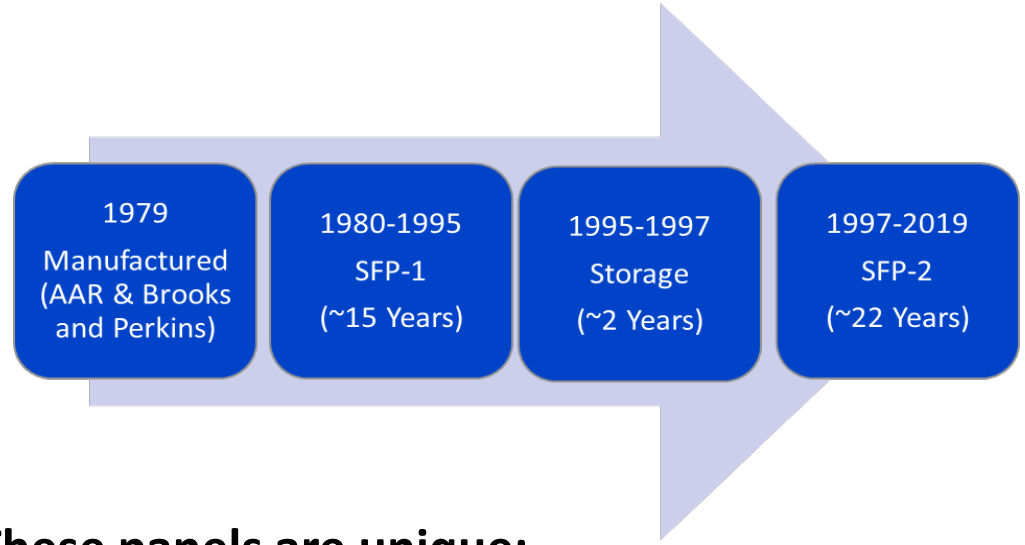
Evaluation of Panels from an Operating SFP (3002018497)



i-LAMP proposal (3002013122) and i-LAMP final report (3002018497)

To date, work has been published in 7 EPRI reports and >30 papers, including 2 journal articles.
To date, Boral did not show significant degradation based on lab test results and OE.

Analysis of Removed Panels from an Operation Spent Fuel Pool

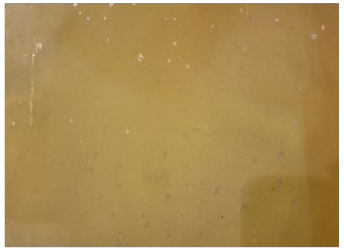


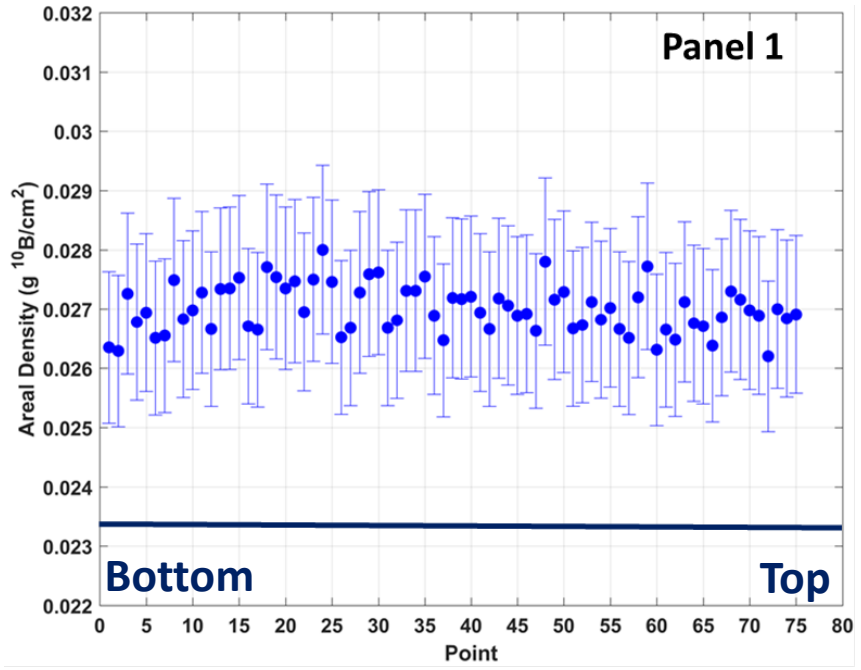
Panels are in very good condition

- **No blisters**
  - Despite being considered most susceptible to blisters due to age
- General flow patterns, scratches but no gross degradation

These panels are unique:

1. Age and vintage (considered most susceptible for blistering)
2. Used in two SFPs
3. Storage time in between two pools (dry)
4. Long service time (~40 years)





1. No loss of absorber material
2. Areal density (AD) values higher than minimum certified (AD)
3. No clear dependence to variation in axial height➔ No impact of temperature and radiation variations

Age, vintage, and cumulative neutron and gamma radiation dose – Are these limiting factors for BORAL?

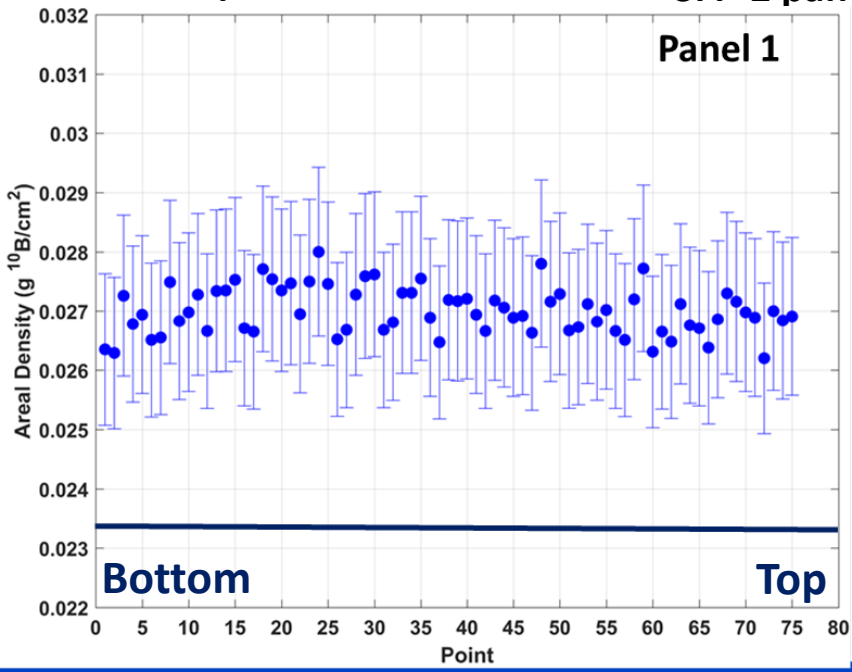
Comparison of Panels from Zion SFP vs. SFP-2

	Zion Region 1	Zion Region 2	SFP-2
Installation Year	1994	1994	1997*
Service time (years)	**~20**	**~20**	**~40****
# of panels removed	8	6	2
Blisters	1***	N	N
Gross Degradation	N	N	N
Thickness (in.)	0.101	0.085	0.085
Min. Cert. AD (g $^{10}B/cm^2$)	**0.03**	**0.023**	**0.023**

*Panels had previous history, in SFP-1
**Wet storage time, does not include dry storage time in between SFPs
***Only one panel showed a very small blister at the corner

Example samples from Zion panel

Example sample from SFP-2 panels



Dose and temperature vary with axial location; no trend in actual measured data from panel with 40 years service time

For Boral, to date, no variation with service time (age; neutron and gamma dose); type (varying areal densities and thicknesses)

Industrywide Learning Aging Management program (i-LAMP)

i-LAMP: Industrywide Global Learning Aging Management Program

Global program – Initial focus is on BORAL®

- NAM specifications (type, vintage)
- NAM history (installation and manufacturing years)
- SFP water chemistry history
- NAM performance (coupon monitoring)

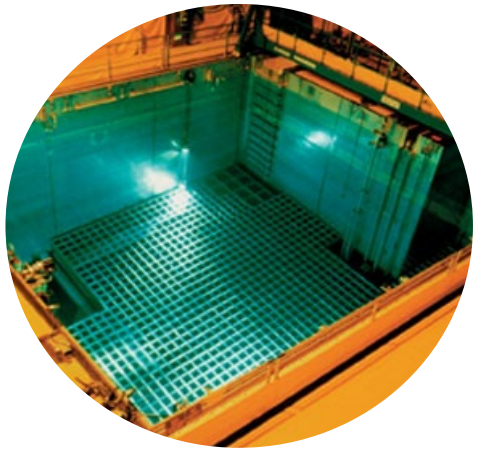
Sibling Pool Process – If No Coupons

- Identify sibling(s)
- Commitment to i-LAMP for AMP
- Periodic data updates (“learning”)
- Periodic sibling performance update

SFP With Coupons

Siblings

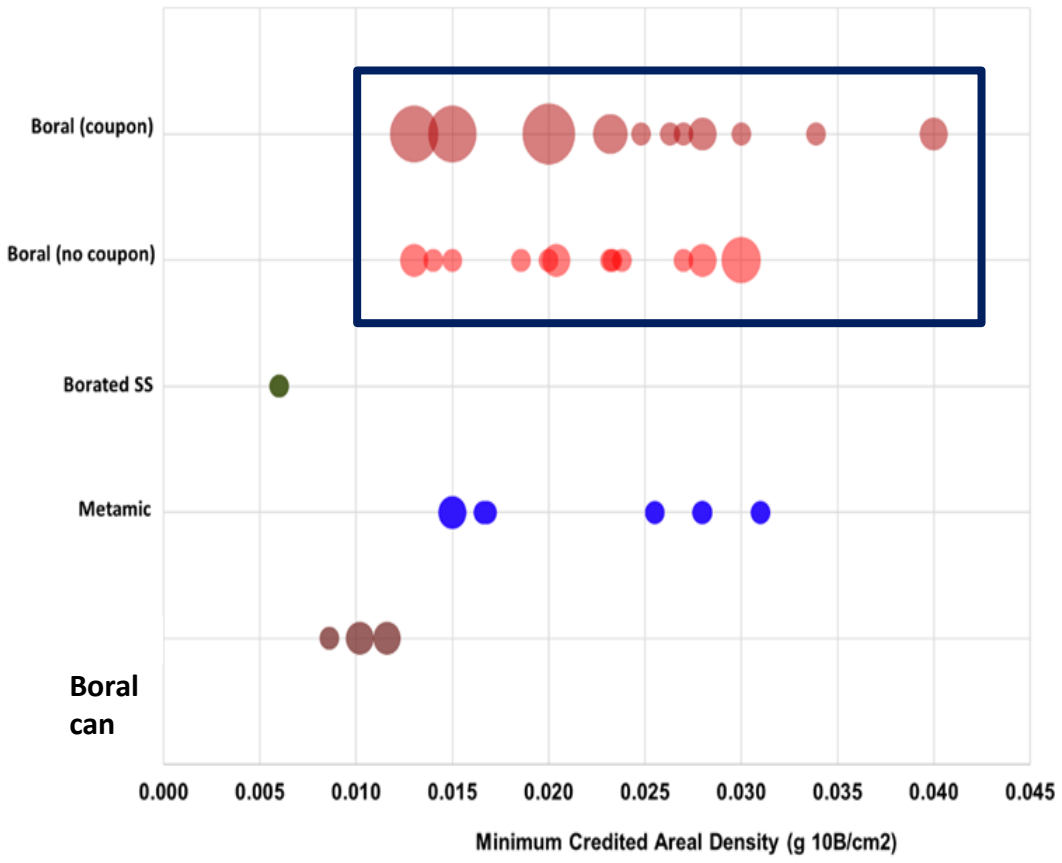
Similar NAM Specifications
Similar Water Chemistry
Similar NAM Vintage



SFP Without Coupons

EPRI’s research over the past ~8 years informed establishment of technical basis and implementation plan for i-LAMP

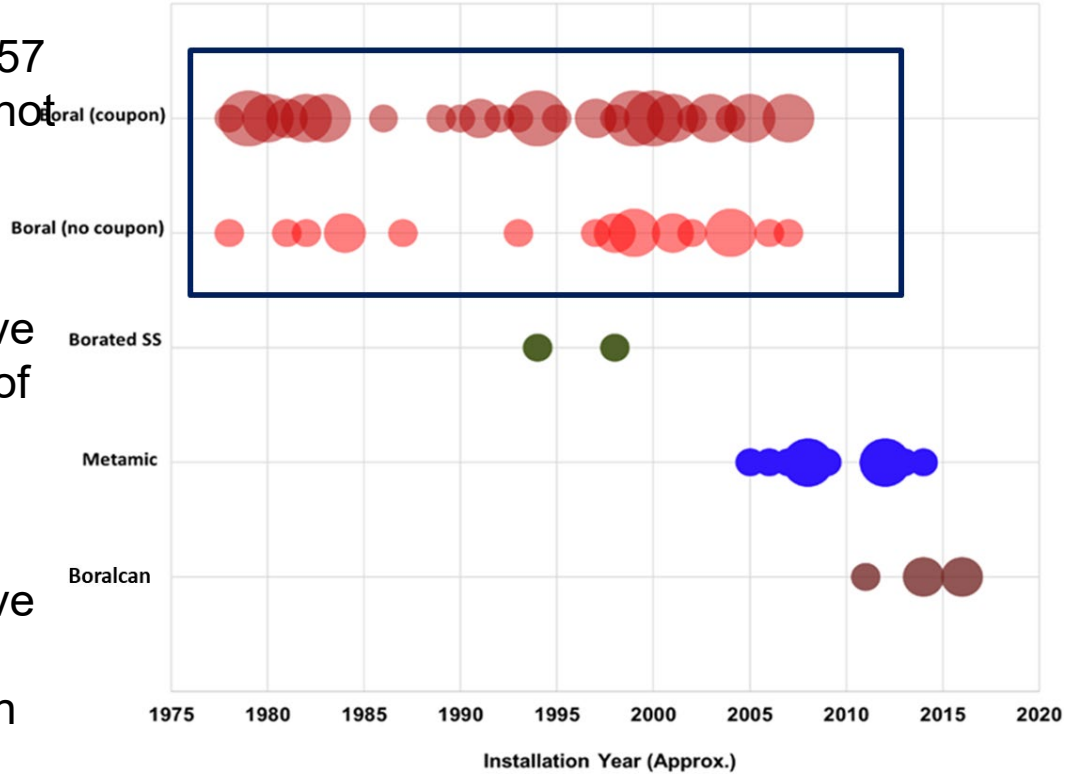
SFP Neutron Absorber Material (NAM) Status (US)



Areal Density: For Boral, all SFPs without coupons are bounded by SFPs with coupons

Boral:

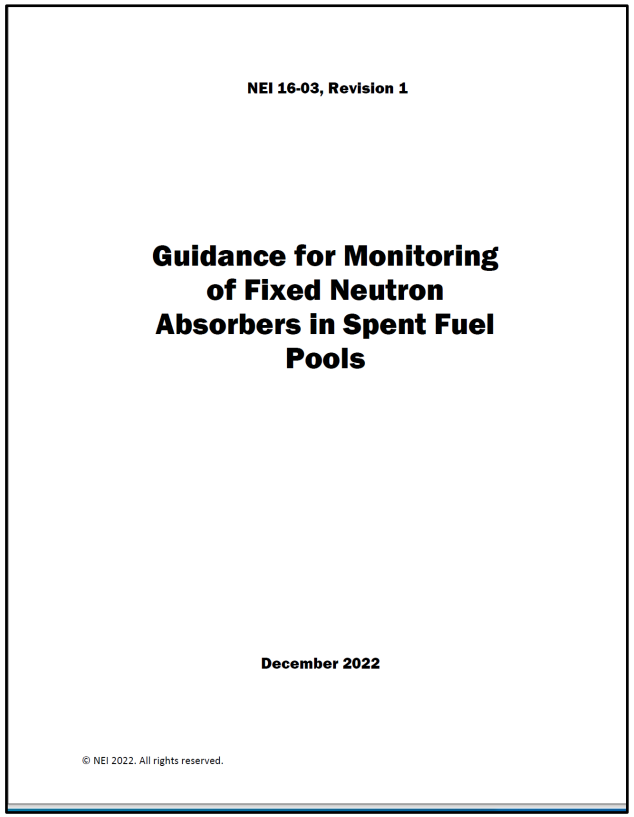
1. 24 SFPs out of 57 SFPs in US do not have coupon monitoring program
2. Some SFPs have limited number of coupons left – coupon re-insertion
3. Some SFPs have multiple NAMs
4. Some SFPs with Boral have multiple installation dates (same AD) and/or varying AD



NAM Age: Not all but majority of SFPs without coupons are bounded – due to histories of two SFPs that are considered exceptions

i-LAMP and Regulatory Review

EPRI report **3002018497 –** *Published in August 2022 and publicly available*



i-LAMP is included in NEI 16-03 Revision 1 as 3rd monitoring option (besides coupon and *in situ* measurements)

- Received 9 RAIs in April 2023
- RAI responses submitted on May 25, 2023
- Draft SE received November 30, 2023
  - Required plant specific analysis
  - Required to be bounded by older plant to be considered sibling
- NRC public meeting: December 14, 2023
- **Final SE received January 30, 2024**
  - **Removed requirement to be bounded by older plant for siblings**

Regulatory review, under NEI 16-03 Revision 1, is complete.

i-LAMP Implementation

i-LAMP Implementation Paths

1. **If possible, use coupons from another site. If not, use surrogate approach after identification of siblings.**
   - For a BWR pool, if not other BWR sibling pool is not available, a sibling from PWR can be used. However, PWR pool can not solely depend on a BWR as pool surrogate
2. **Develop and agree standardized approach** (each plant decides licensing actions via LAR, 50.59, or other)
3. **Close actions to generic letter** (impacts all US SFPs)
4. **Develop EPRI databases** and **add other absorbers into database (Metamic and Boralcan)**

Order of the implementation is coordinated with the global utility members and it is determined by the timelines/urgency of the commitment dates

i-LAMP Databases

SFP Water Chemistry

- pH
- Conductivity
- Chloride (Cl) concentration
- Fluoride (F) concentration
- Sulfate (SO4) concentration

Additionally, for PWRs

- Boron (B) concentration
- Sodium (Na) concentration

Few SFPs measure Al; in future may recommend all SFPs to measure Al

SFPs with Coupon

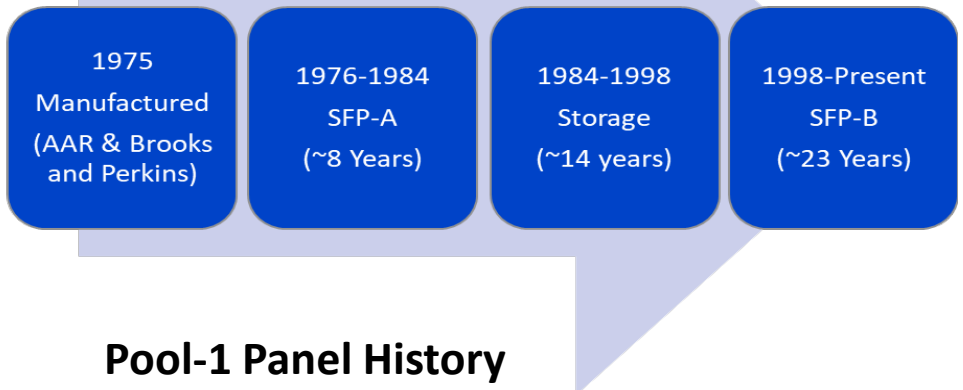
- Pool name
- Rack installation year
- Rack type (egg crate versus flux trap)
- Stainless steel encapsulation or not
- Coupon unique ID number
- Coupon analysis year(s), if the same coupon is analyzed multiple times
- Dimension data (pre-characterization and post-irradiation)
  - Height, width, thickness
  - Weight
- Areal density values (pre-characterization and post-irradiation)
- Pit and blister data
- Pictures

SFPs w/o Coupon

- Pool name
- Rack installation year
- Rack type (egg crate versus flux trap)
- Stainless steel encapsulation or not
- Dimension data
  - Height, width, thickness
- Weight
- Areal density values

EPRI is the owner of these databases. Databases are live and updated as new data comes

i-LAMP Implementation – Path 1



Pool-1 Panel History

Surrogate Panel History

- **Instead of simply proposing to use surrogate data, proposed to take some of the remaining coupons from surrogate and transfer to Pool-1**
  1. Pool-1 built a coupon tree
  2. Keep half of coupons bare and encapsulate half of the coupons
  3. Place them on coupon tree and install in Pool-1
  4. Develop an aging management program based on coupons

- **This proposed approach has benefits for i-LAMP, Surrogate-1, and Pool-1**
  1. One less SFP without coupon monitoring program
  2. Increased number of coupons across industry – beneficial for the health of i-LAMP
  3. Opportunity to evaluate impact of coupon size on formation of blisters in two SFPs
  4. Opportunity to evaluate impact of SS encapsulation versus bare coupons

This implementation is now complete

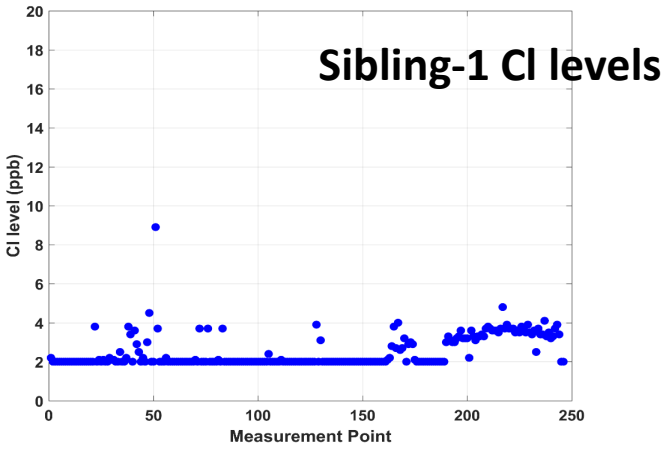
i-LAMP Implementation: Path-2: Surrogate Approach

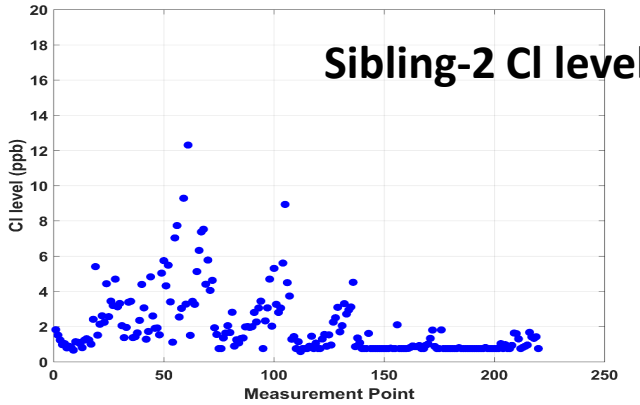
	Pool-2*	Sibling-1	Sibling-2
Installation Year	1999	1993	2003
Thickness (in.)	0.101	0.101	0.101
Min. Cert. AD (g $^{10}B/cm^2$)	0.03	0.03	0.03
Coupons	N	Y**	Y***

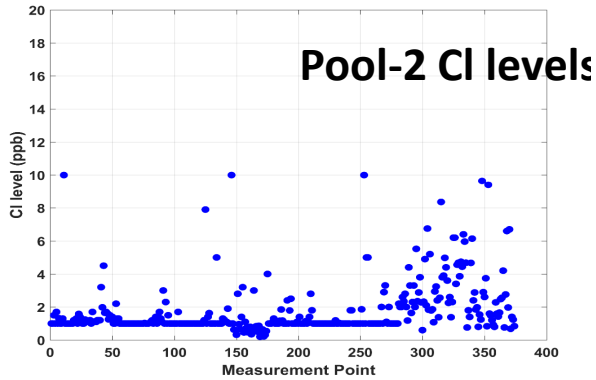
*Pilot-2 characteristics are very similar to Zion panels, installed in 1994, and Pilot-1 New Boral, installed in 1998.

** No blisters. No gross degradation or decrease in areal density.

***Observed pitting, several blisters on some coupons. No gross degradation or decrease in areal density.







Cl, F, Sulfate levels well below recommended levels (150 ppb) for Pool-2 and Siblings

This implementation is now complete

Summary: i-LAMP Implementation and Long-Term Success

EPRI report **3002018497,** published in August 2022. Report is publicly available

- **i-LAMP implementation is ongoing across global industry via different paths**
  - Order of the implementation is determined by existing commitment timelines
- **i-LAMP data, need, and commitment is global**
  - Maintain existing coupon inventory
    - **Return coupons to SFP after periodic testing**
      - Prior typical utility practice was to discard
    - **Transfer coupons to a sibling SFP after decommissioning**
  - Update coupon monitoring data
    - **Provided by utilities to EPRI after periodic testing**
    - EPRI identification of adverse trends, if any
  - Maintain and update water chemistry data (**sent by utilities to EPRI**)
- **Extend to other neutron absorbers, Metamic and Boralcan**

Multiple utilities (2 US, one in Europe and one in Asia) received EPRI's Technology Transfer Award (TTA) for being first implementers in February 2025. Implementation will continue in 2026

Questions/Comments?

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