Industry Comments on Draft NRC Safety Evaluation: NEI 16-03, Revision 1,“Guidance for Monitoring of Fixed Neutron Absorbers in Spent Fuel Pools”

December 14, 2023

NUCLEAR ENERGY INSTITUTE

Industry Objectives for NEI 16-03, Rev. 1

- Establish an industry-wide program (i-LAMP) that provides reasonable confidence that any future degradation of BORAL neutron absorber materials is reliably detected and addressed, thereby providing continued assurance of public health and safety.
- Bridge the gap between licensees who currently retain a BORAL coupon surveillance program and those that do not.
- Provide the technical basis for a regulatory framework that encourages adoption of and ongoing participation in i-LAMP by all licensees utilizing BORAL.

Objective for Today's Meeting

- Propose wording for the NRC's draft safety evaluation for NEI 16-03, Rev. 1 that:
  - Requires licensees without a Boral coupon surveillance program to establish participation in i-LAMP.
  - Maximizes the value of the i-LAMP program by associating each spent fuel pool that does not have a coupon surveillance program with every other spent fuel pool that does.

Draft Safety Evaluation Report

Current language in "Limitations and Conditions:

"The NRC staff approves the NEI 16-03, Rev. 1, methodology for employing i-LAMP as an alternative monitoring strategy *only if* the i-LAMP program provides for the licensee to perform a detailed analysis of its SFP and BORAL material considering the parameters described in NEI 16-03 Rev 1. The i-LAMP alternative strategy is unacceptable unless a plant-specific analysis verifies that SFP conditions and BORAL parameters are consistent with those of a sibling SFP or are bounded by those of an older SFP's BORAL. This limitation is imposed to address the discussion in NEI 16-03 Rev.1 of a "2-bin" system in which plants without coupons are assumed to be bounded by those with coupons."

Draft Safety Evaluation Report

Proposed Wording for Limitations and Conditions:

The NRC staff approves the NEI 16-03, Rev. 1, methodology for employing i-LAMP as an alternative monitoring strategy *if* a plant-specific licensee analysis demonstrates that its SFP conditions and BORAL parameters are represented in the i-LAMP database and that there are no degradation trends identified by the i-LAMP program that are relevant to the licensee's BORAL. If a relevant trend is identified, the licensee shall identify one or more siblings with consistent parameters and will monitor the sibling(s) BORAL performance trends within its corrective action program.

Basis for Revised Wording

- After several decades of service in spent fuel pools, no degradation in the neutron absorbing safety function of BORAL has been identified to date. This effectively diminishes the meaning of the term “bounded by” in this case, with respect to age.
- No correlation between service time or age has been established as relevant to any potential degradation mechanism. Other service parameters such as water chemistry, BORAL fabrication lot, or rack design could ultimately be the primary of cause of any future signs of degradation. Thus, establishment of sibling relationships is possible but not currently warranted.
- i-LAMP will equip the industry with the tools to identify appropriate siblings if and when degradation is detected.

Implementation Language in Draft SE

Section 1.0: "…the NRC staff is not proposing to issue a regulatory guide to endorse NEI 16-03. Instead, as stated in this Safety Evaluation (SE), the NRC staff is treating NEI 16-03, Rev. 1, as a topical report, and as described below, the NRC staff has determined that NEI 16-03, Rev. 1 is acceptable, with the limitation described below, for referencing in a license amendment request (LAR) that includes the information described below in Section 4.0 of this SE."

Section 3.6: "Based on the foregoing, the NRC staff has determined that NEI 16-03, Rev.1 is acceptable for referencing in a LAR requesting approval of a NAM monitoring program."

Section 5.0 (paragraph 2): "The NRC staff finds that the requirements… would be satisfied with respect to NAMs and the NAM monitoring program if referenced in an LAR requesting use of the program…"

Section 5.0 (paragraph 3): "Each licensee adopting NEI 16-03, Rev. 1 will need to implement it in accordance with its plant-specific processes and licensing basis. This will involve review under the plant commitment control process and 10 CFR 50.59. Either of these processes could result in the need for a plant-specific license amendment request. Each licensee will need to make its own evaluation in this regard under its site-specific change control program."

Section 1.0, Section 3.6, and paragraph 2 of Section 5.0 should be updated to allow for i-LAMP implementation via plant-specific processes per individual plant licensing bases and to eliminate confusion with paragraph 3 of Section 5.0.

Discussion Items - Other questions/comments

Section 3.3.2: “With respect to the concept of a “2 bin” approach, the staff finds that NEI 16-03 Rev. 1 represents an overly simplistic approach.”

- Simple may be more appropriate for implementation and will enable population trending approach.
- Suggestion: “…**represents a generic approach**.”

Throughout document, consider using “**consistent with**” rather than “bounding,” given no observed trends in any of the parameters described in NEI 16-03 Rev 1.

Guidance for Monitoring of Fixed Neutron Absorbers in Spent Fuel Pools

Hatice Akkurt

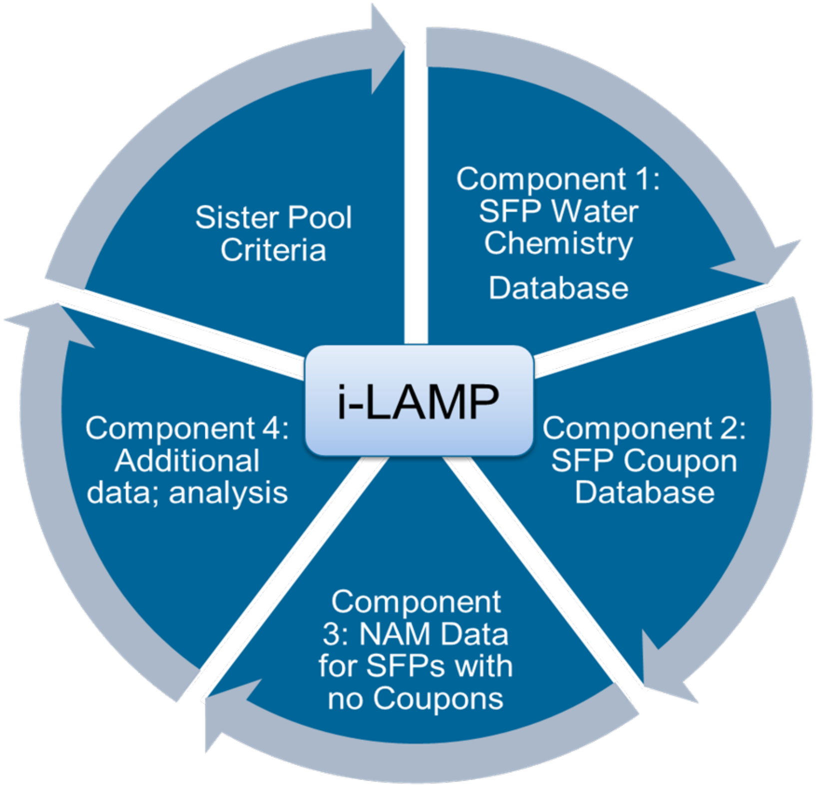
Used Fuel and High-Level Waste Management Program, EPRI

NRC Public Meeting

December 14, 2023

Draft SE: i-LAMP Components

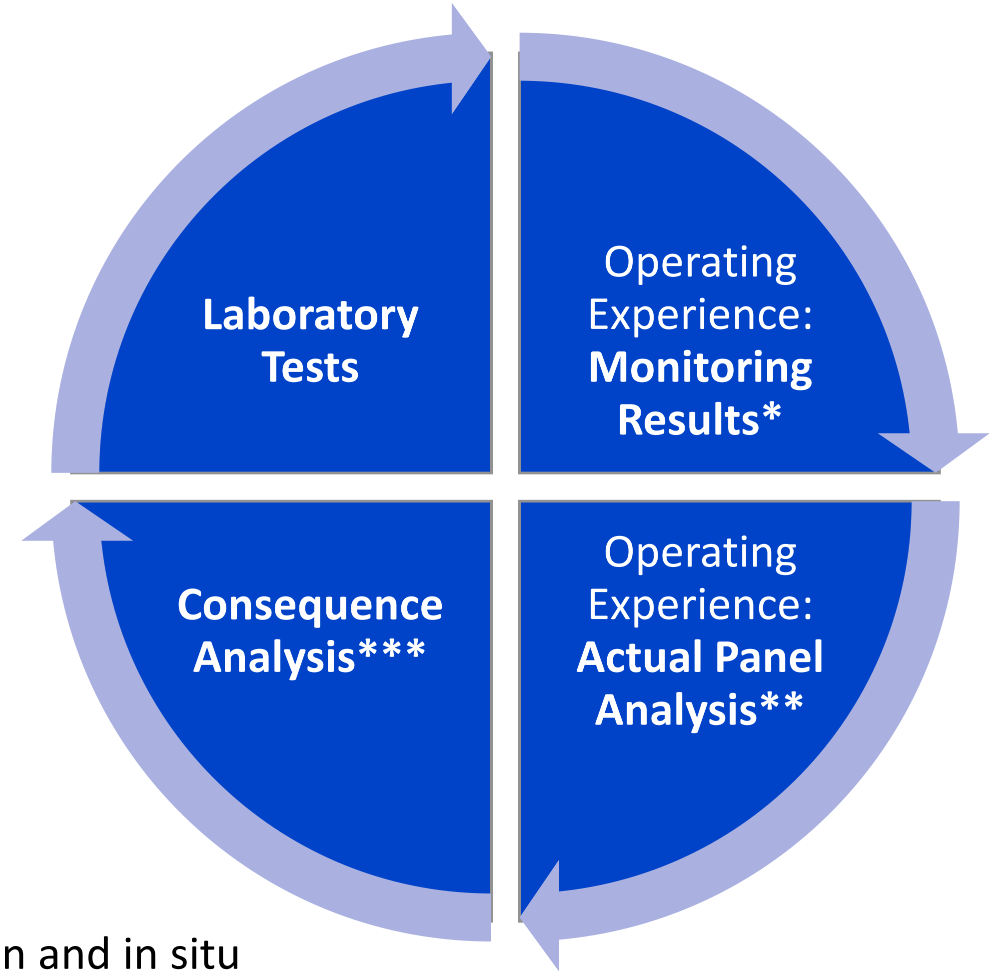
Section 3.3.1, page 7, line 31: “*The core of i-LAMP is an SFP coupon database*”



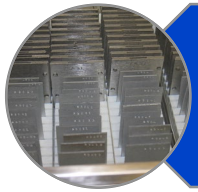
i-LAMP general layout

i-LAMP not only relies on coupon database but also has other vital components to be considered an effective monitoring program

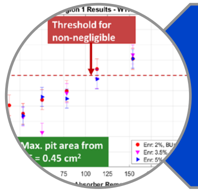
Technical Basis for an Effective Aging Management Program



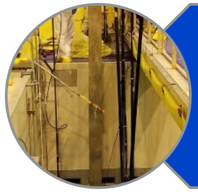
*Coupon and in situ
**Panels from Zion & Operating SFP
***Evaluation of impact of blister and pits on SFP reactivity

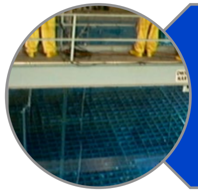

Laboratory: Accelerated Corrosion Test (to be published soon 3002023975)


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)

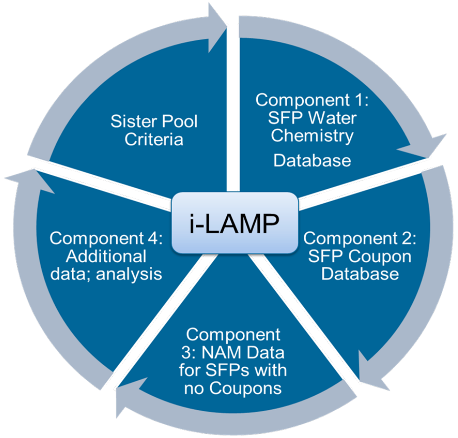

Evaluation of Panels from an Operating SFP (3002018497)


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

Work has been published in 7 EPRI reports and > 25 papers
To date, no significant degradation; no dependence on one parameter or parameters

EPRI

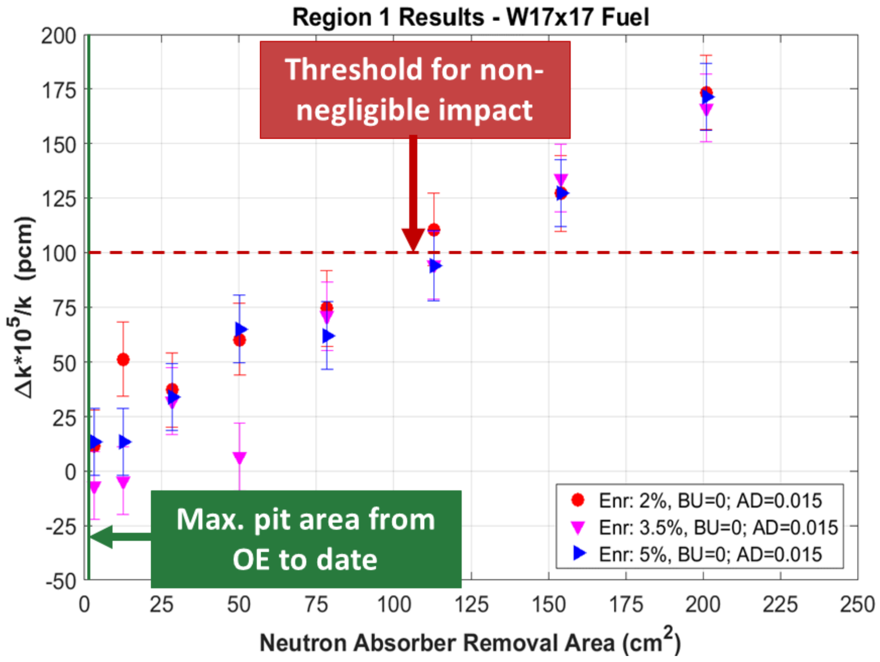
Draft SE: i-LAMP Components



Section 3.3.1, page 7, line 31: "*The core of i-LAMP is an SFP coupon database*"

Suggested change:

Key components of i-LAMP are SFP coupon database, water chemistry, and analysis. Analysis not only includes data analysis for coupons and water chemistry but also impact on reactivity.



Sister/Sibling pool criteria will depend on the analysis when/if trends are established since i-LAMP is a learning program

Draft SE – Section 4.1: Limitations and Conditions

4.1. Limitations and Conditions

Based on the staff review of NEI 16-03, Rev. 1, described above, the NRC staff has identified the following limitation on the use of the methodology shown below:

The NRC staff approves the NEI 16-03, Rev. 1, methodology for employing i-LAMP as an alternative monitoring strategy *only if* the i-LAMP program provides for the licensee to perform a **detailed analysis of its SFP** and BORAL material considering the parameters described in NEI 16-03 Rev 1. The i-LAMP alternative strategy is unacceptable **unless a plant-specific analysis verifies that** SFP conditions and BORAL parameters are consistent with those **of a sibling SFP** or are bounded by those of an **older SFP's BORAL**. This limitation is imposed to address the discussion in NEI 16-03 Rev.1 of a "2-bin" system in which plants without coupons are assumed to be bounded by those with coupons.

Emphasis is on detailed plant specific analysis and age of the BORAL. As written, draft SE diminishes the industrywide and learning components of the program.

Draft SE implementation reads like

SFP A – NO Coupon

Identify sibling via plant specific detailed analysis

SFP B – With Coupon

Uncertainty in degree of similarity? How similar is consistent?

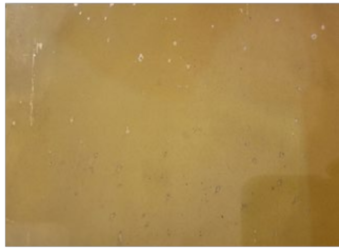
Three observations:

1) Not tied to general i-LAMP's industrywide umbrella

2) To date, no trend is identified for informed sibling identification based on relative importance of different parameters,

3) Trend will be identified by the learning component of i-LAMP

Age of the BORAL – Is that a limiting factor?



Panels from Operating SFP

(~40 years service time and resided in two SFPs with storage in warehouse in between)

Panels from Zion SFP (~20 years service time)

EPRI and NRC independent analysis under MOU

To date, age alone in the absence of other degradation drivers is not associated with degradation.

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

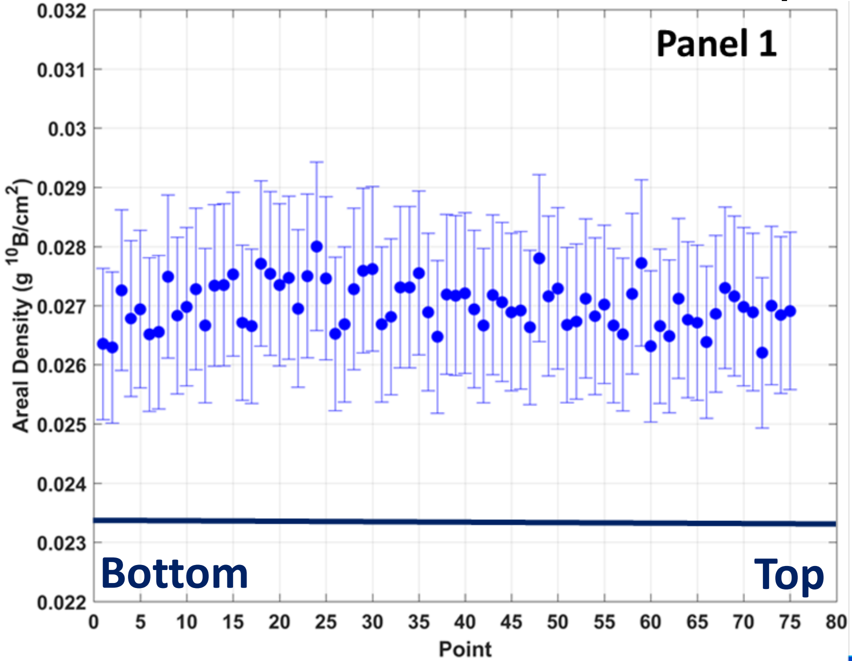
Comparison of Panels from Zion SFP vs. SFP-2

	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

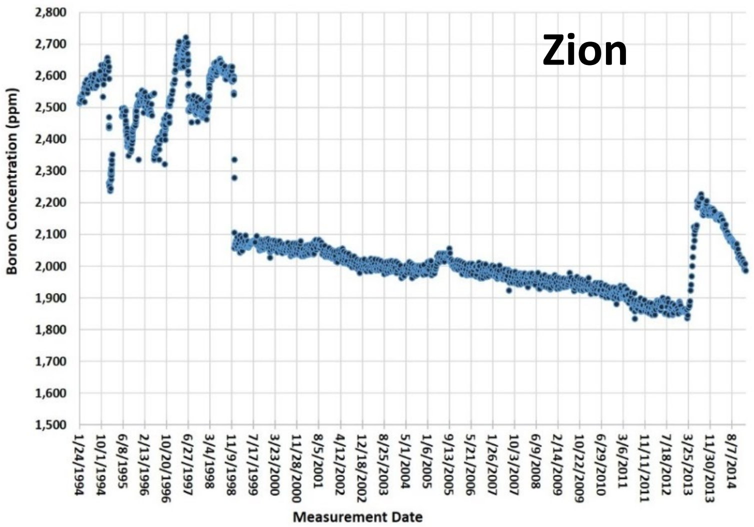
Example sample from SFP-2 panels

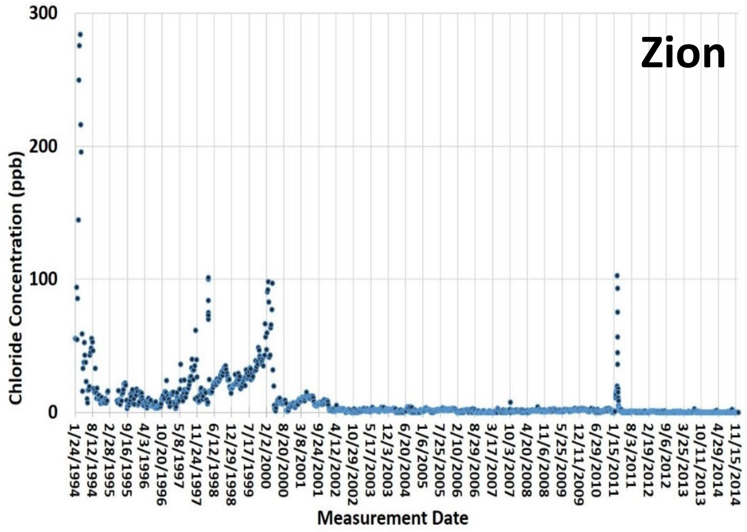


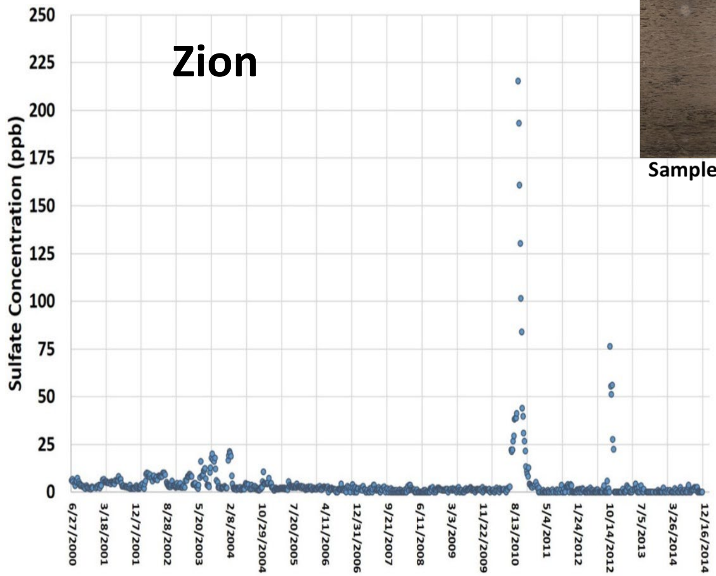
Dose and temperature vary with axial location; no trend in actual measured data from panel with 40 years service time

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

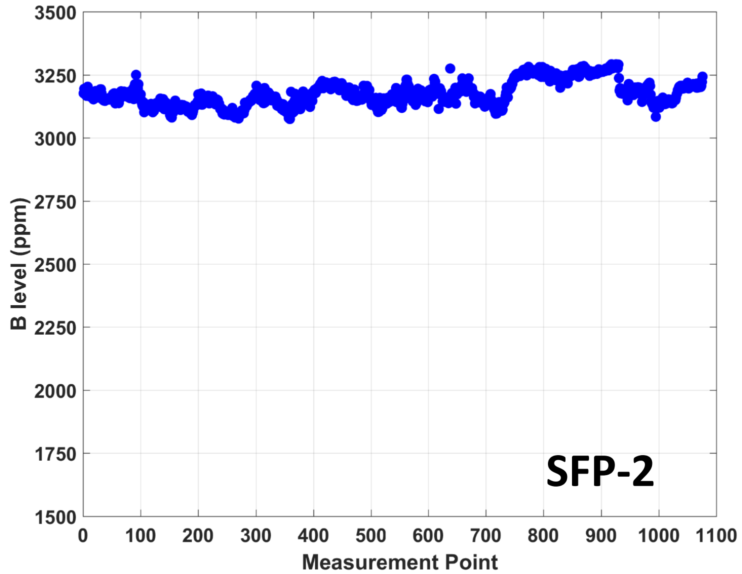
Water Chemistry Parameters - Limiting factor for BORAL?

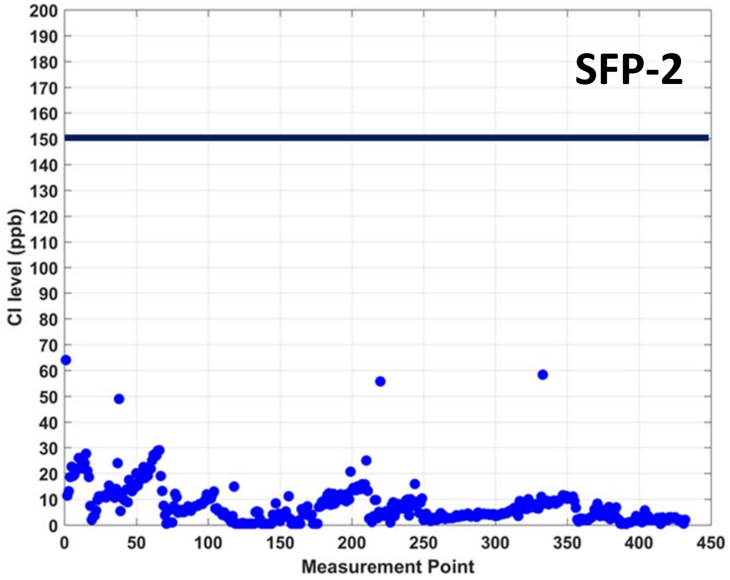


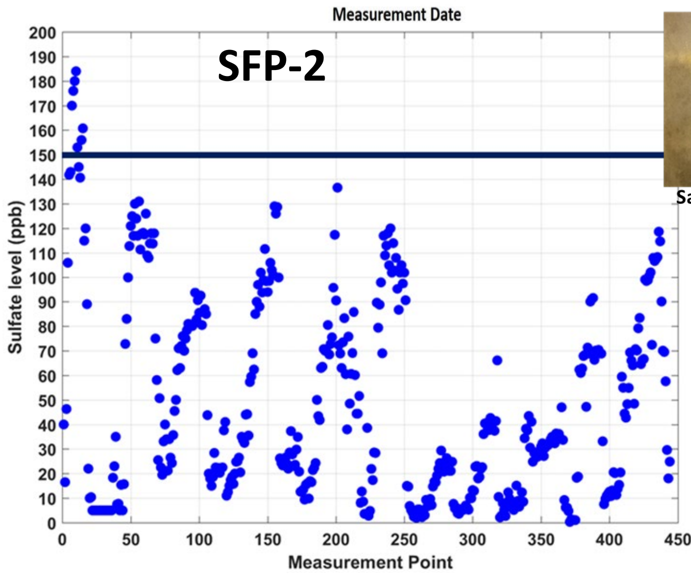




Sample from Zion



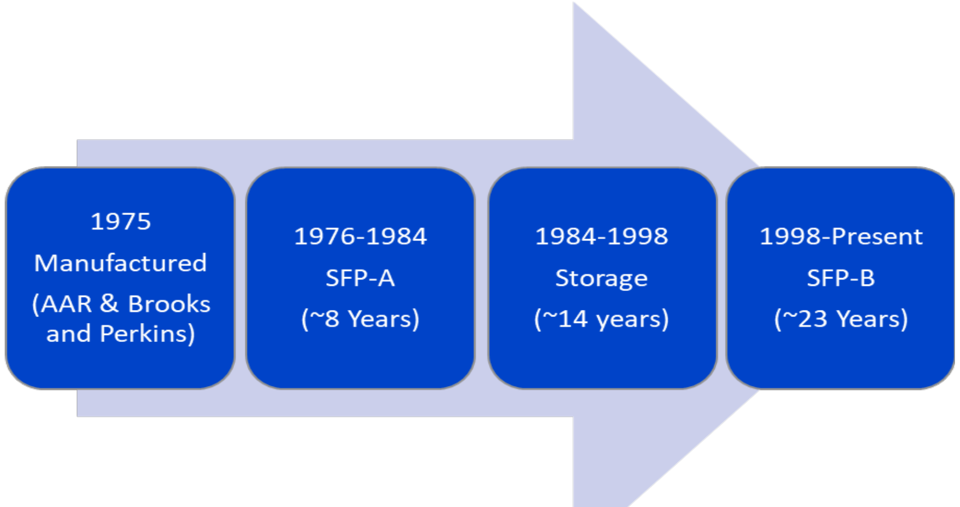




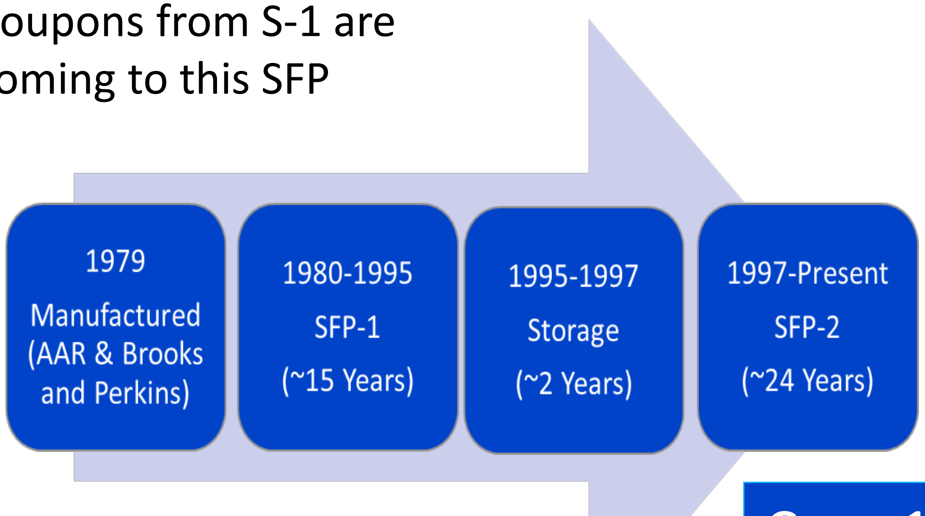
Sample from SFP-2

Zion versus SFP-2 Panels: Despite variations in age, service time, water chemistry (especially for B), no significant degradation or difference in material condition. For panels from SFP-2, water chemistry from previous pool is not retrieved – since panels were almost pristine

How similar is similar enough? Panel Histories: Case-1 (C-1) versus Sibling-1 (S-1)



Case-1 (C-1) Panel History – Coupons from S-1 are coming to this SFP



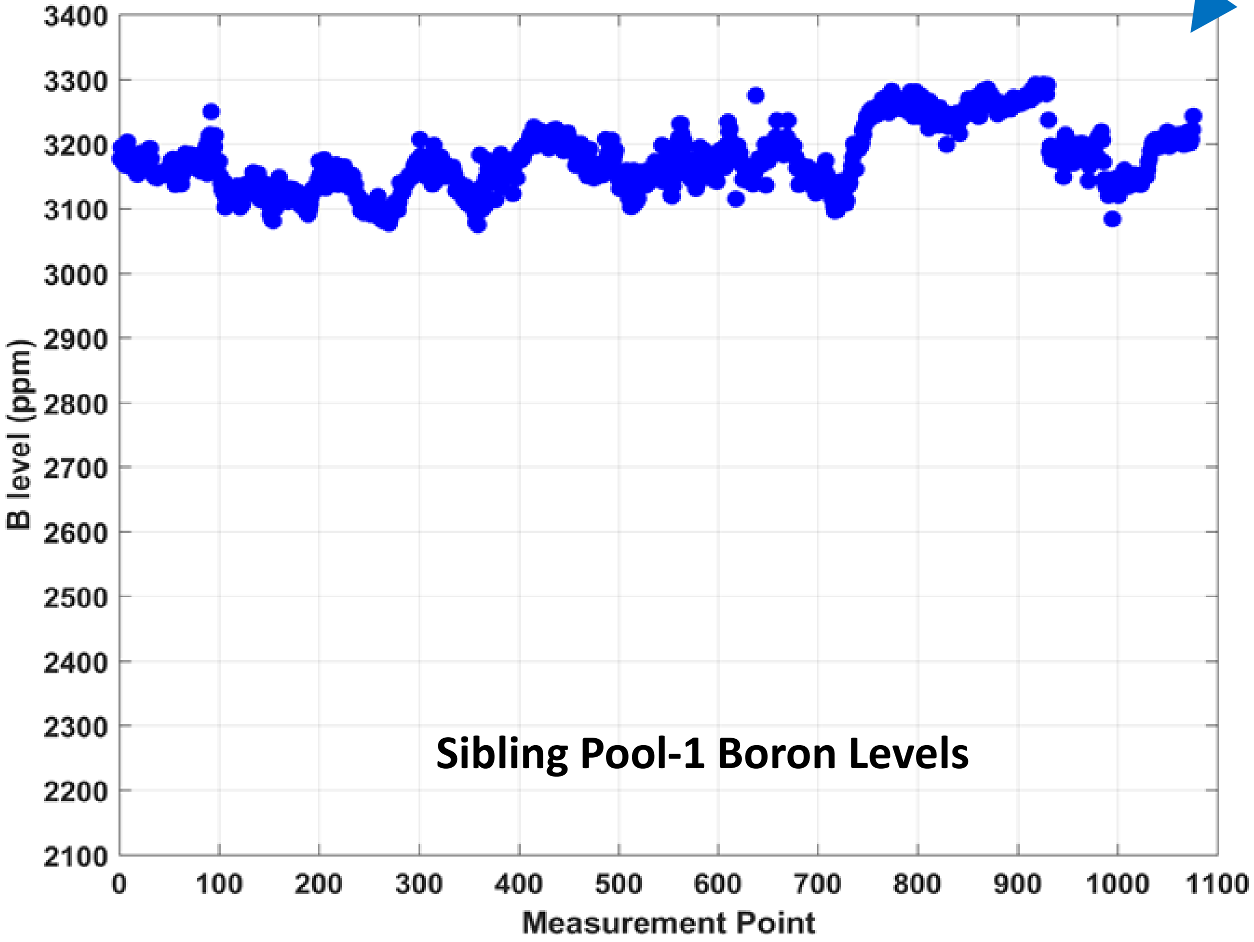
Sibling-1 (S-1) Panel History

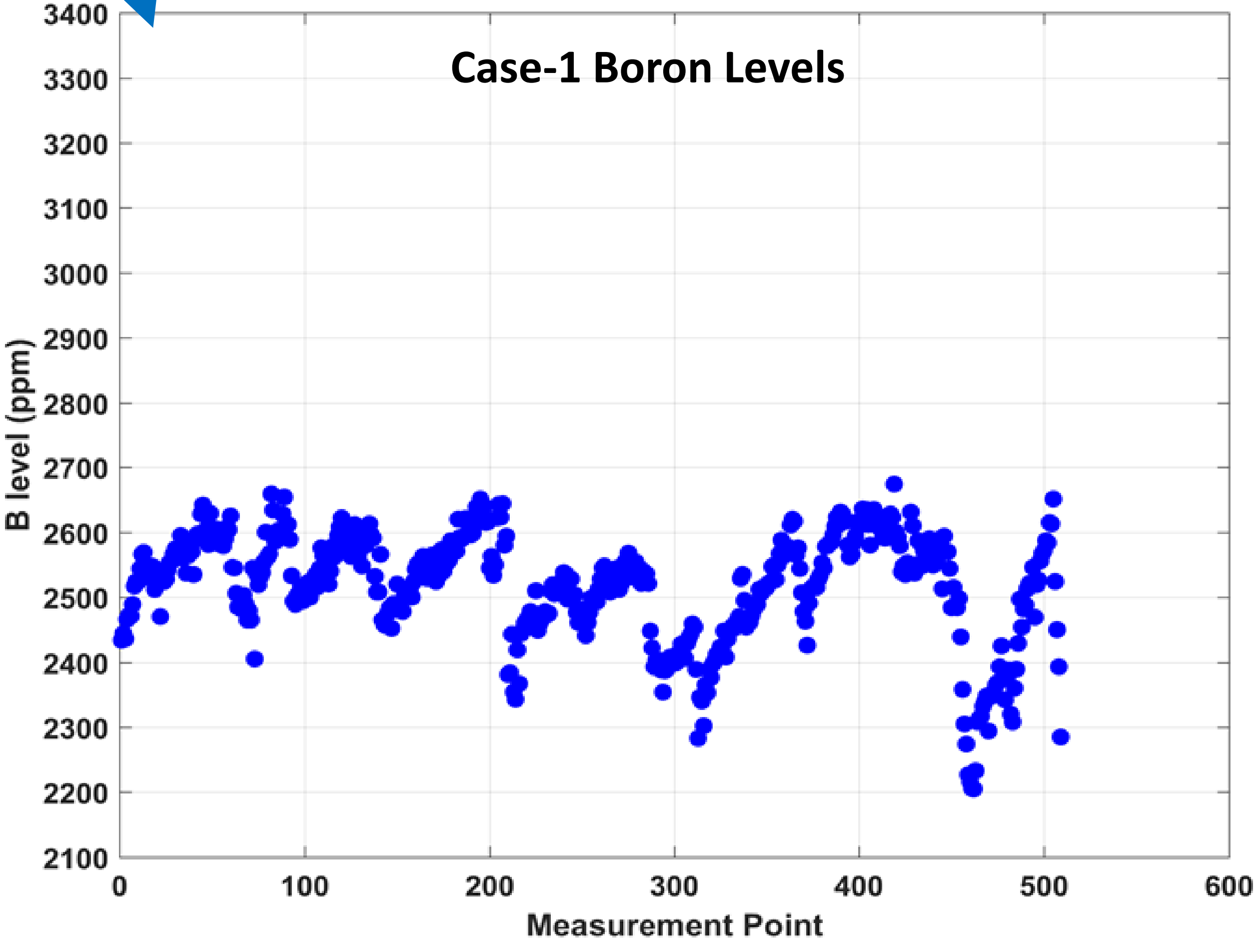
- Unique panel history – very similar to panel history residing in SFP-2, described in previous presentation
  - Wet-Dry-Wet
  - Old BORAL panels
- **Case-1:** ~30 years in-pool service history
- **Sibling-1:** ~40 years in-pool service history
  - One BORAL type
- **Case-1:** Two boral types
  - Old BORAL (reclaimed from SFP-A), installed in SFP-B in 1997
  - New BORAL, installed in 1998
    - New BORAL has higher AD but uses the same AD (lower value based on old BORAL) in CSA

Case 1 has OLDER BORAL but less service time? Can they still use coupons from Sibling 1 based on draft SE language?

How similar is similar enough: Water Chemistry for Sibling Pool-1 versus Case - Boron Levels

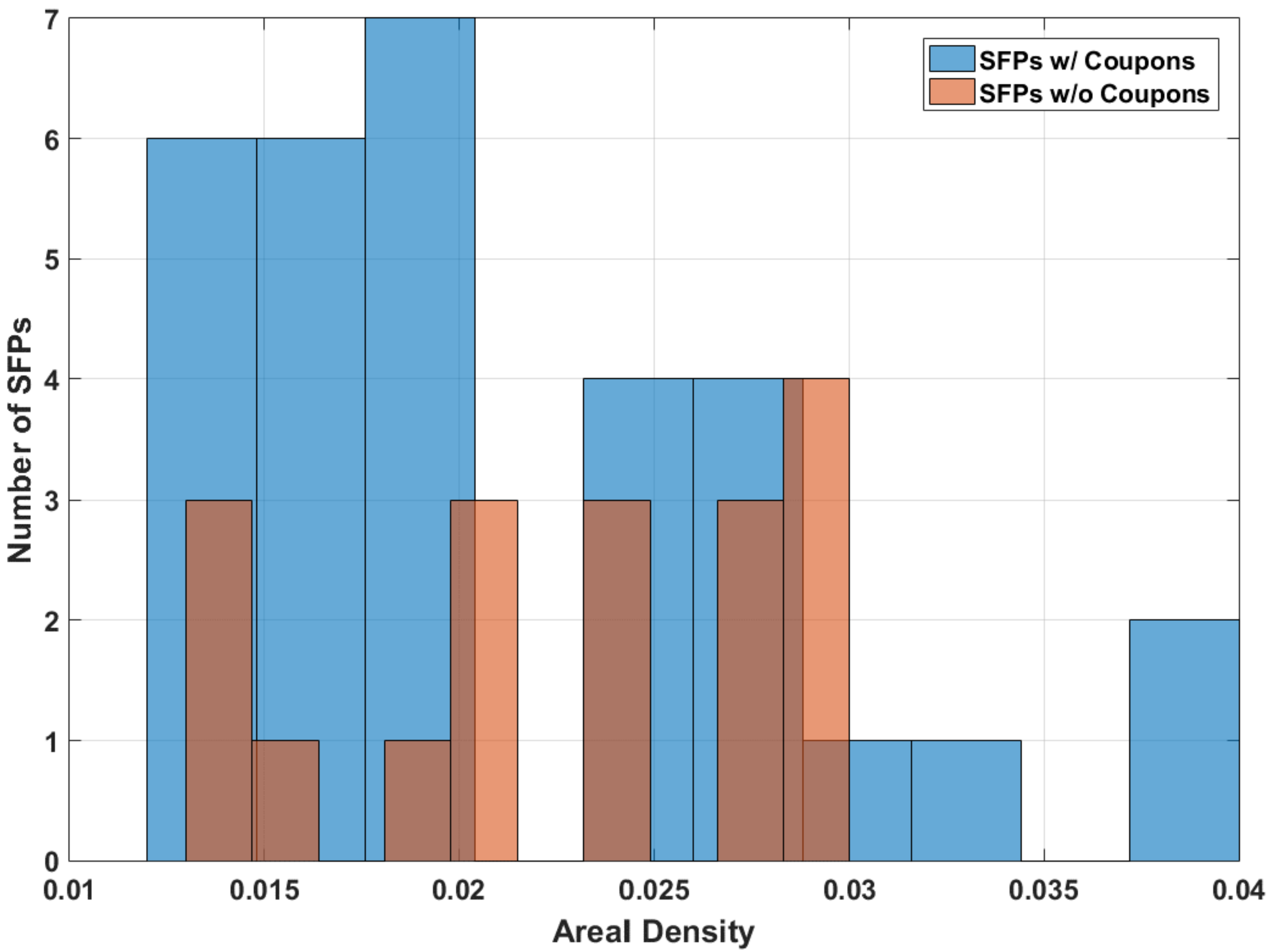
Are these similar enough?





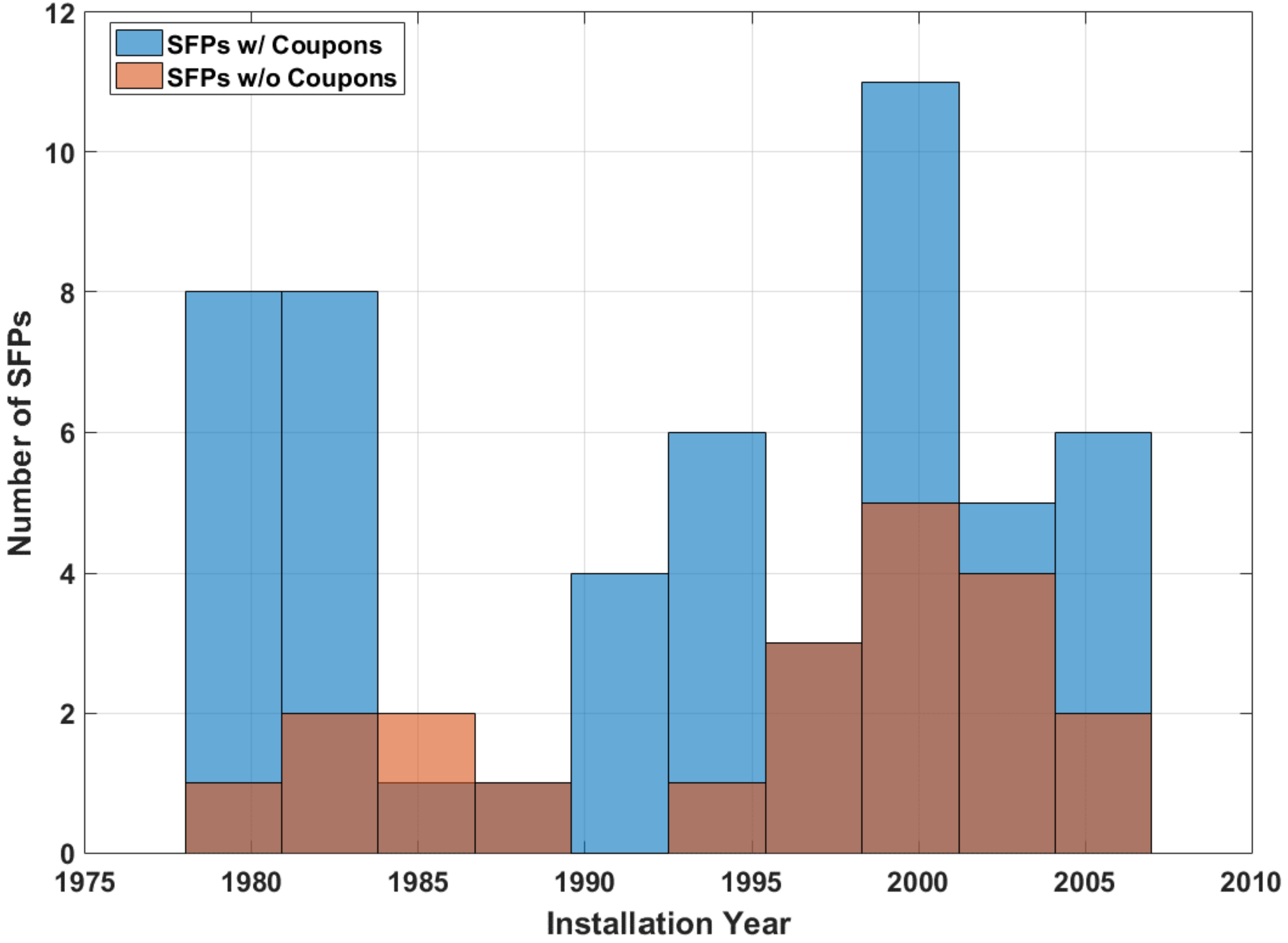
Case-1 Boron levels lower than Sibling Pool-1 Boron levels and more consistent with industry averages – despite differences, can they still use coupons from Sibling-1?

How similar is similar enough? – Variations in Areal Density (AD)



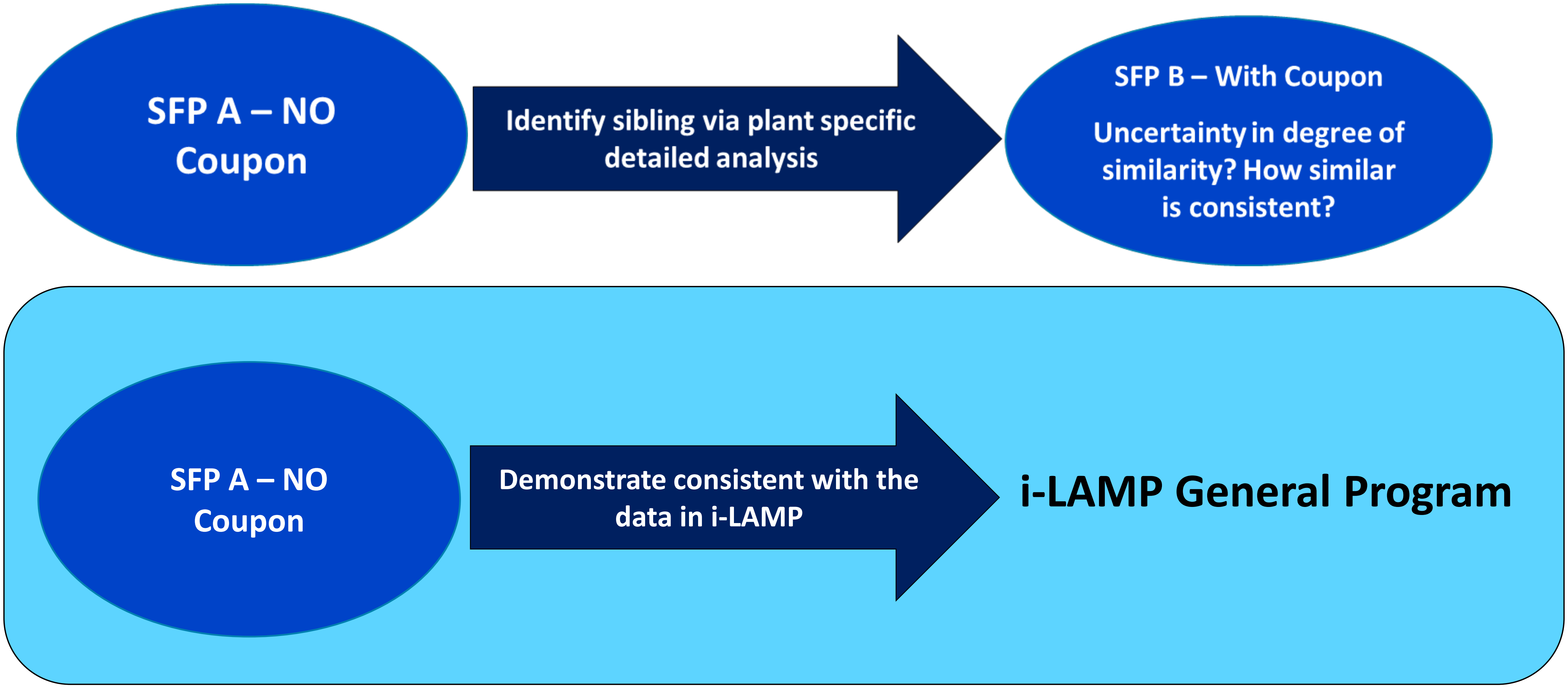
For AD, SFPs without coupons are represented by SFPs with coupons

How similar is similar enough? – Variations in Installation Year



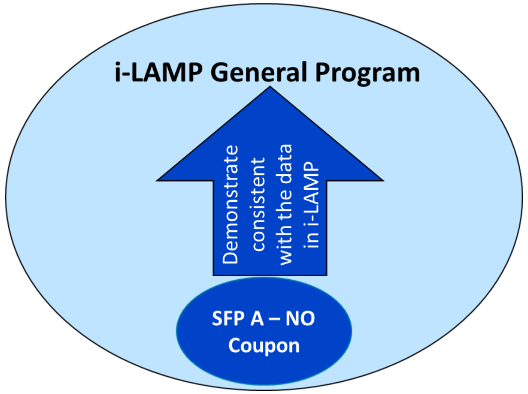
For Installation year, SFPs w/o coupons are represented by SFPs with coupons – two exceptions were discussed separately

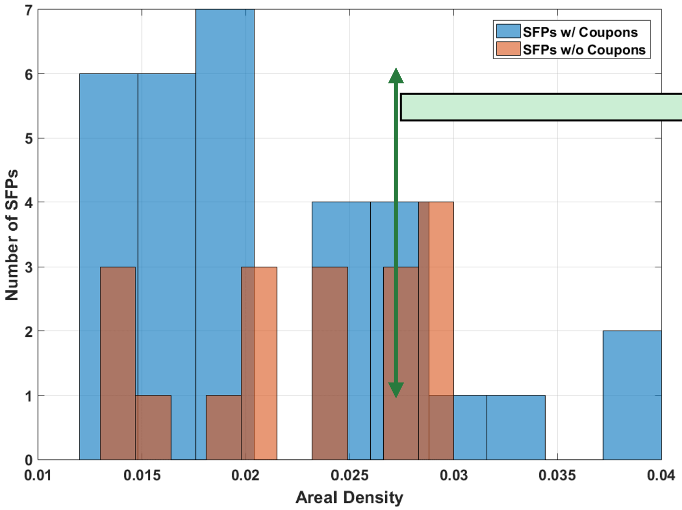
Current Draft SE versus Proposed Change



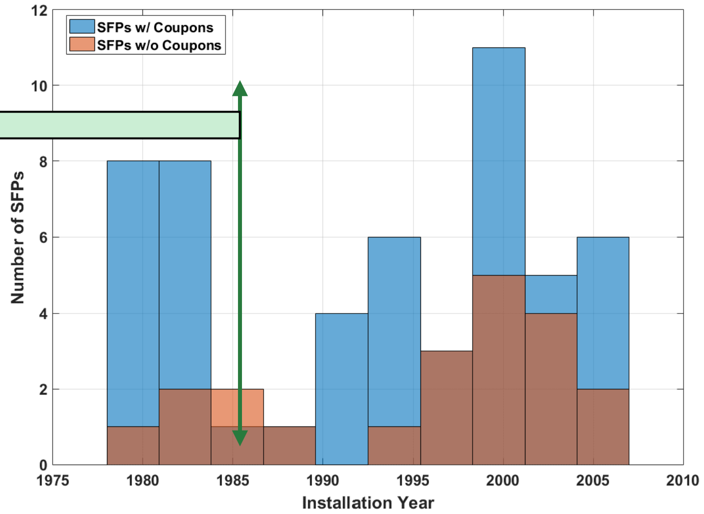
Further binning and sibling determination will be done when/if a trending parameter(s) is established. Proposed approach maintains "industrywide" and "learning" components

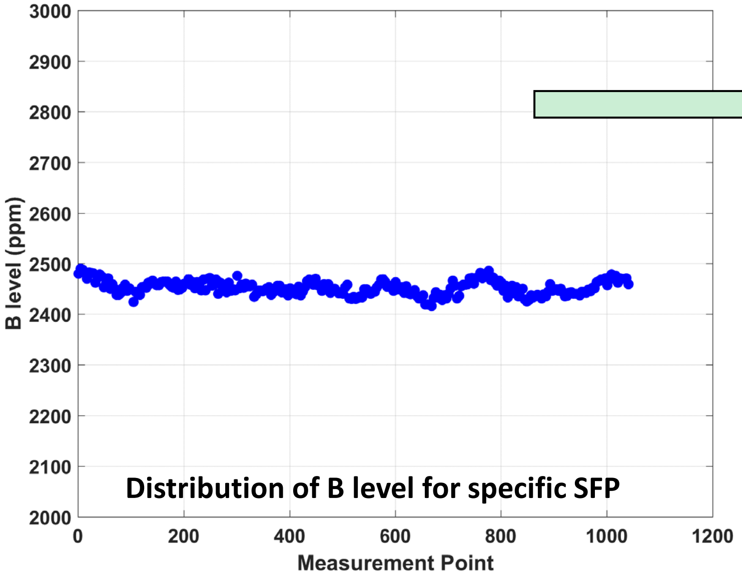
Proposed Change





SFP specific analysis to demonstrate within i-LAMP

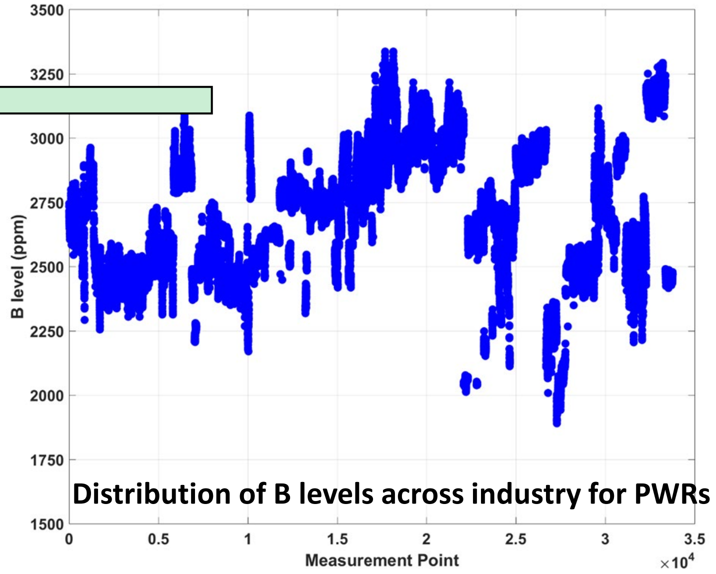




Distribution of B level for specific SFP

SFP specific analysis to demonstrate within i-LAMP for potential key parameters, such as:

- B (PWR)
- Cl
- SO4



Distribution of B levels across industry for PWRs

Plant specific analysis to demonstrate SFP data is consistent with general i-LAMP databases. Further binning and sibling determination will be done when/if a trending parameter is established

Draft SE Section 4.1 (Limitations and Conditions)

Current language:

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Proposed language:

The NRC staff approves the NEI 16-03, Rev. 1, methodology for employing i-LAMP as an alternative monitoring strategy if a plant-specific licensee analysis demonstrates that its SFP conditions and BORAL parameters are represented in the i-LAMP database and that there are no degradation trends identified by the i-LAMP program that are relevant to the licensee's BORAL. If a relevant trend is identified, the licensee shall identify one or more siblings with consistent parameters and will monitor the sibling(s) BORAL performance trends within its corrective action program.

Questions?

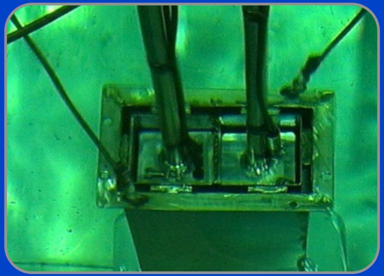

Together...Shaping the Future of Energy®

Backup Slides

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*

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

3. Cutting NAM panels from rack modules

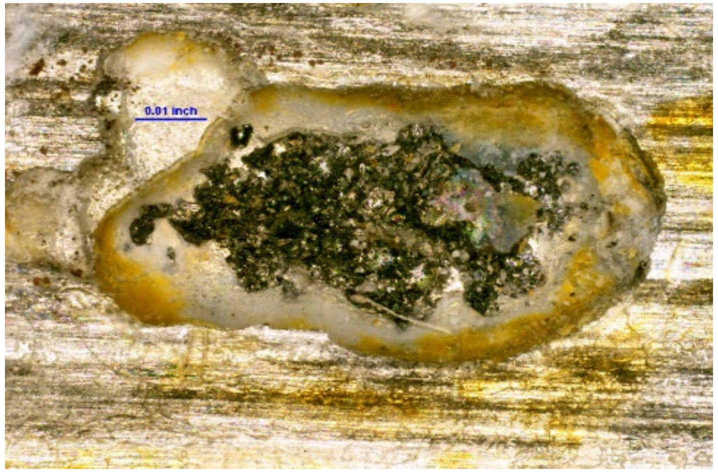
- Very expensive
- May lead to rack module damage (left with cells that can't be used)
- Plant and SFP logistic issues and dose

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

NAM Degradation Mechanisms and Potential Concerns

1. Pitting

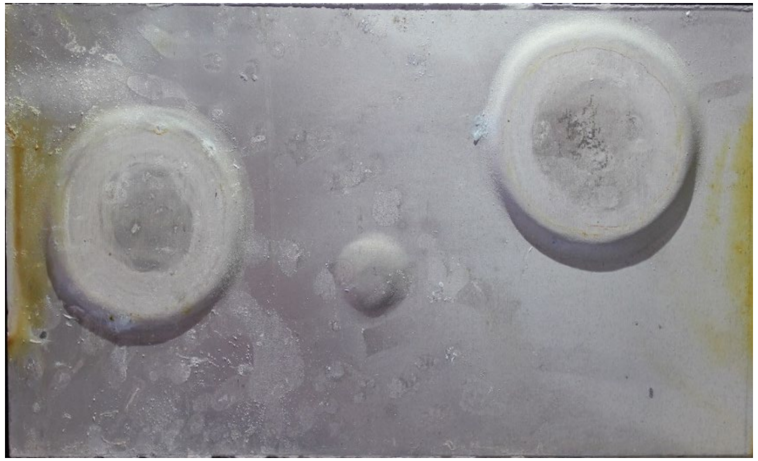
Significant pitting → Significant **absorber** loss → Potential concern for criticality



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 can be a function of:

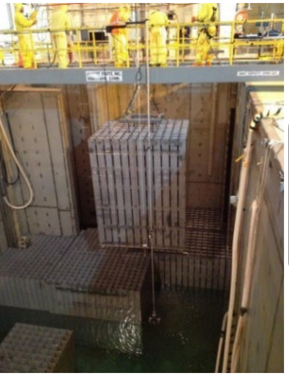
1. Type and vintage of the material
2. Time in the SFP
3. SFP water chemistry
4. Temperature
5. Cumulative neutron dose
6. Cumulative gamma dose

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

For BORAL, based on research and data analysis over the past 10 years and >40 years of OE; no significant degradation observed; therefore, no correlation to a given parameter

Zion Comparative Analysis Project

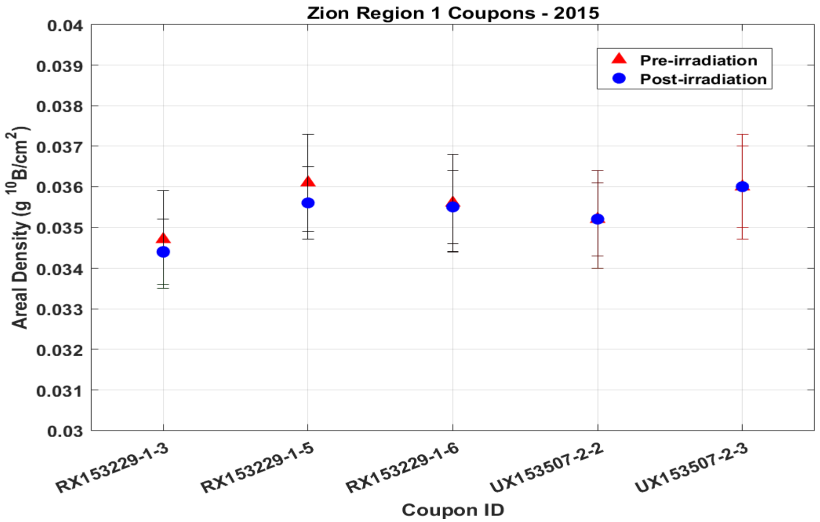
Zion Comparative Analysis project – Key Findings

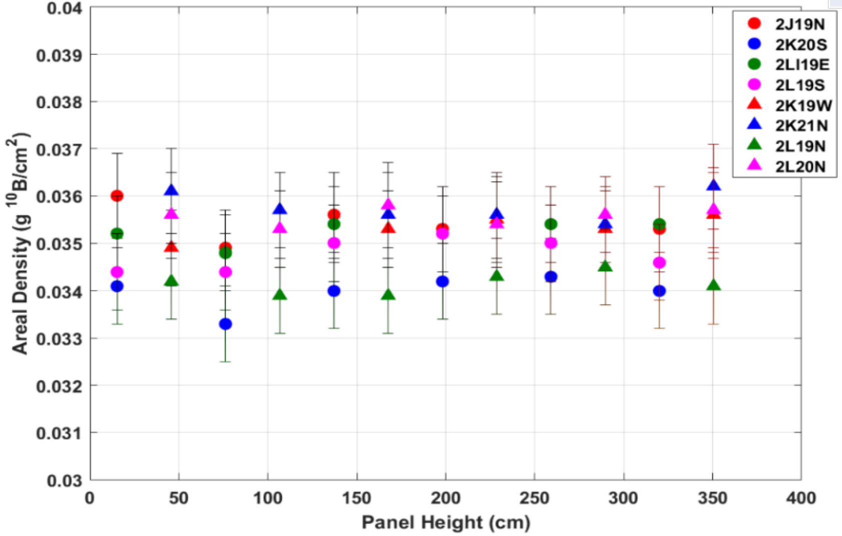


Zion Panels

Zion Coupons

Zion In-situ Measurements



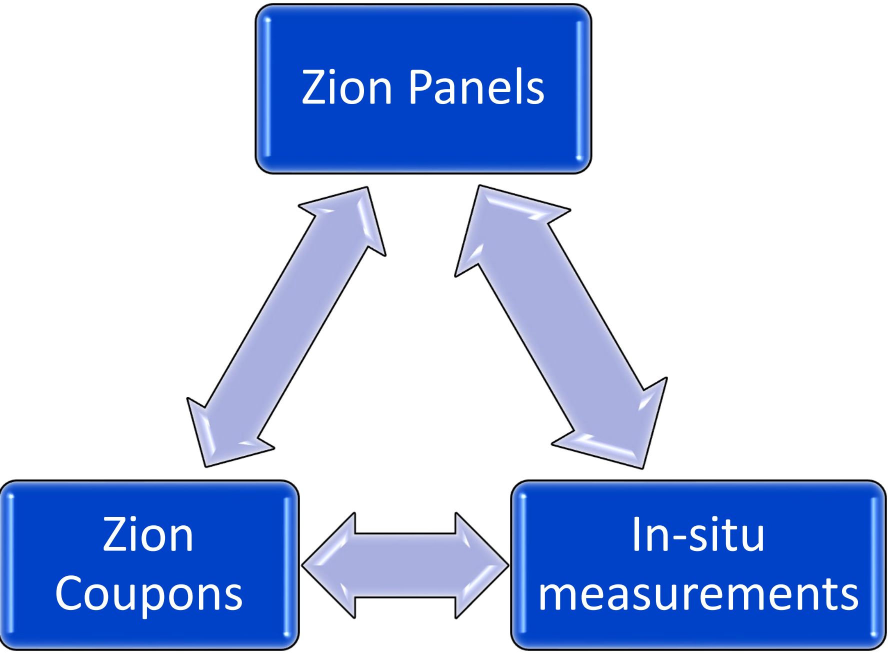


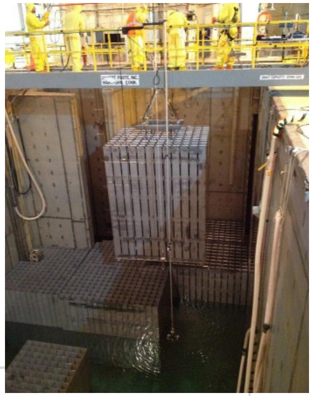
Zion Panel Sample ID	Region	Total Number of Pits	Zion Coupon ID	Region	Total Number of Pits
2J19N-5	1	28	RX153229-1-3	1	182
2L19N-4	1	47	RX153229-1-5	1	255
2L19S-1	1	25	RX153229-1-6	1	131
5L9E-1	2	16	UX153507-2-2	1	176
5L9S-9	2	34	UX153507-2-3	1	155
5L9S-11	2	33	RZ150433-1-3	2	121
5M7E-9	2	10	RZ150433-1-4	2	257
5M7S-12	2	19	RZ150433-1-6	2	203
5M12E-6	2	40	SZ151748-1-4	2	149
2J19N-5	1	28	RX153229-1-3	1	182

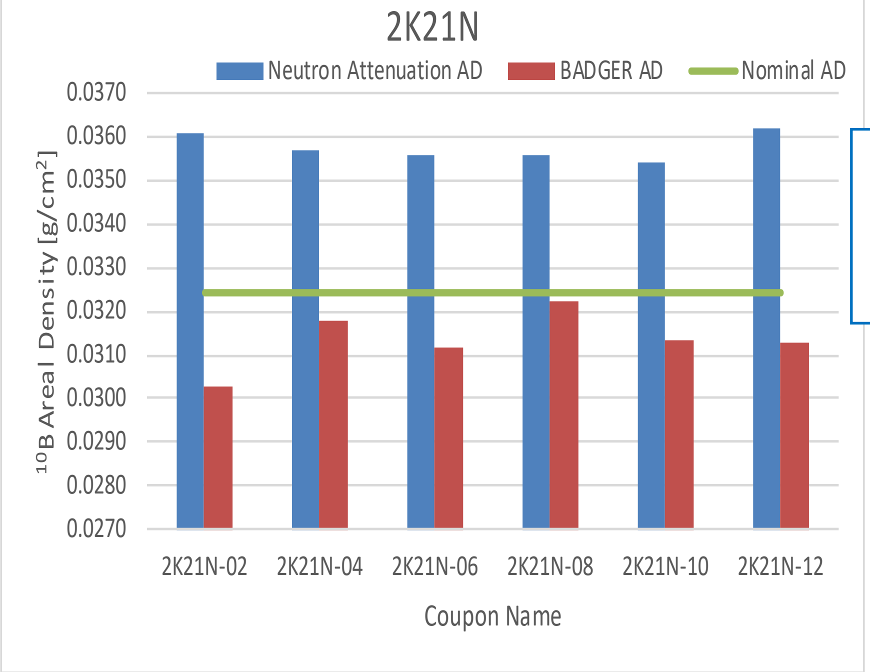
1. Good agreement between panel and coupon areal densities
2. No axial height dependence for areal density for panels (radiation and temperature impacts are minimal)
3. Coupons show more pits compared to panels

Coupons represent panels in a conservative manner

Zion Comparative Analysis project – Key Findings







4. **In situ (BADGER) measurements underpredict Areal Density → Implies false degradation**

One of the key recommendation after Zion was to re-insert coupons into SFP without heat drying to avoid losing remaining coupons across the industry. This approach is now accepted by the NRC and implemented by the industry

Accelerated Corrosion Project

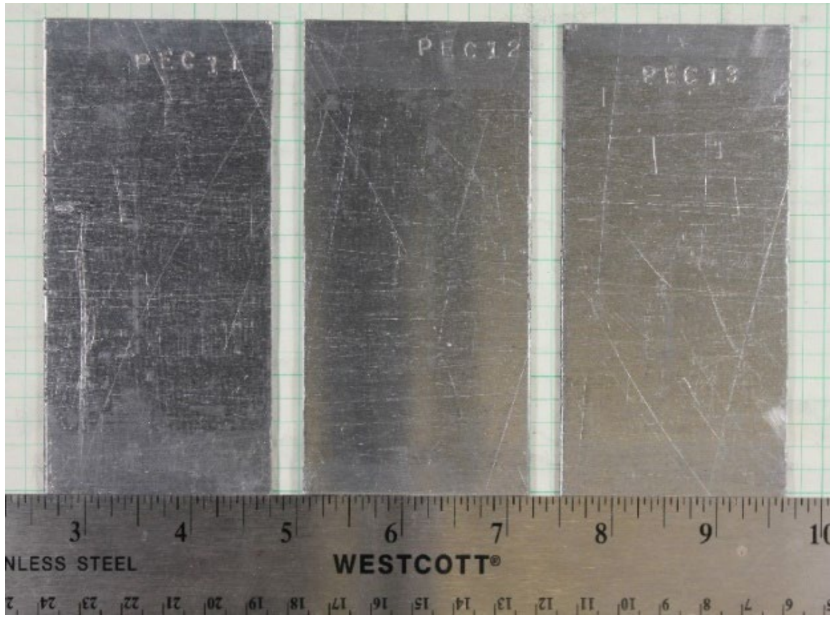
Accelerated Corrosion Test

Objectives

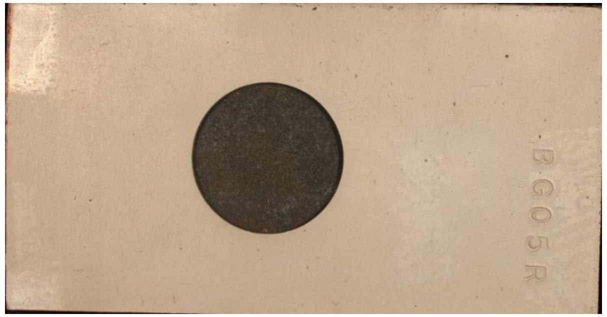
- Evaluate/demonstrate BORAL in-pool performance for an extended service life
- Determine long-term corrosion rate of BORAL

Approach

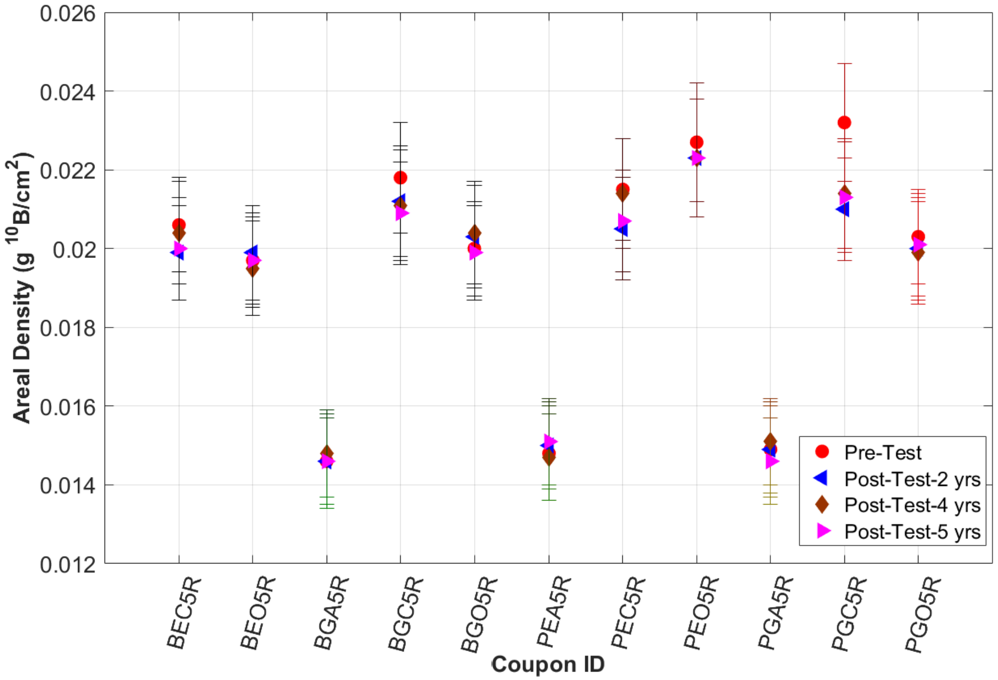
- Place pre-characterized BORAL coupons in test baths representing
  - **PWR and BWR water chemistry**
    - Water chemistry measured regularly
      - **At elevated temperatures (91ºC - 196ºF)**
        - Compared to typical pool temperature: ~27–38°C (80–100°F)
    - Evaluate changes in coupon attributes after exposure to accelerated environmental conditions.
  - **Five year test**

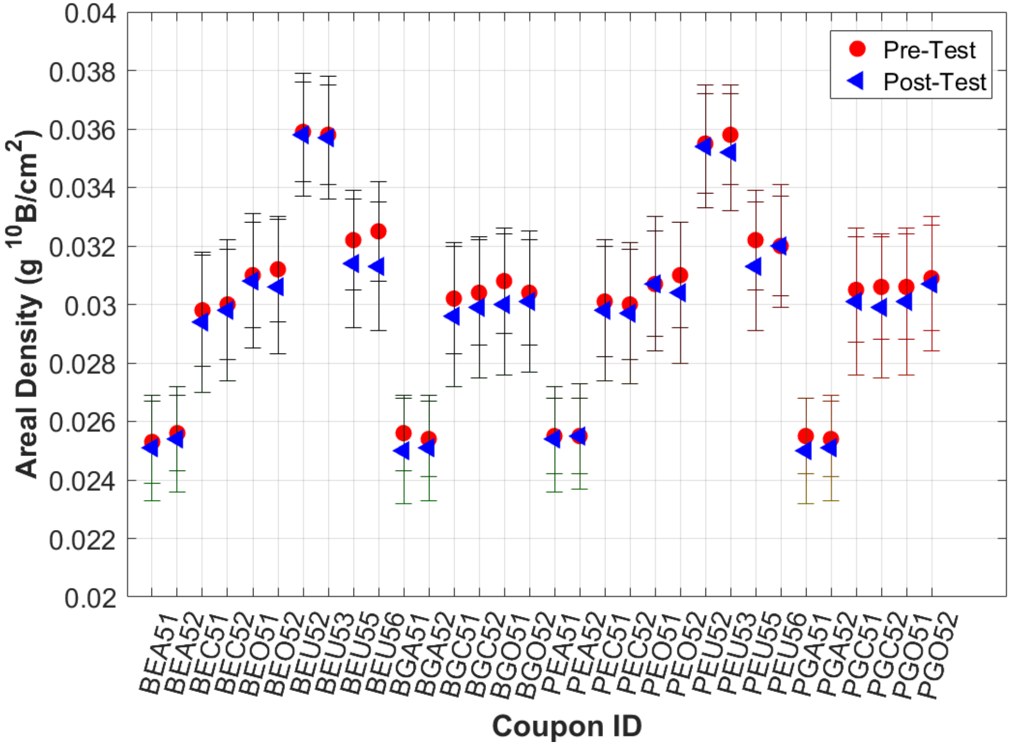


Accelerated Corrosion Tests – Key Findings



Clad removed coupon



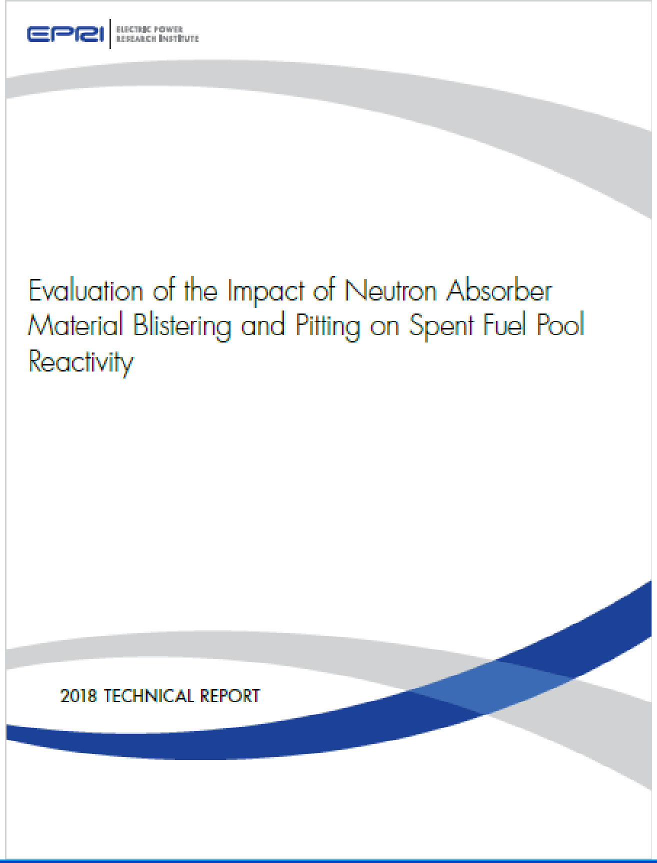


- No statistically significant change in Areal Density values for Year 5 coupons
- No statistically significant change in Areal Density for Year 1-4 coupons either

- Even for clad removed coupons, no statistically significant change in AD over time
- Considered extending the project beyond 5 years, although coupons are in great condition, corrosion test baths degraded

Evaluation of Impact of Blisters and Pits on SFP Reactivity (Consequence Study)

Evaluation of the Impact of NAM Blistering and Pitting on SFP Reactivity – Key Findings



EPRI report, **3002013119**, *Evaluation of the Impact of Neutron Absorber Material Blistering and Pitting on Spent Fuel Pool Reactivity*, May 2018.

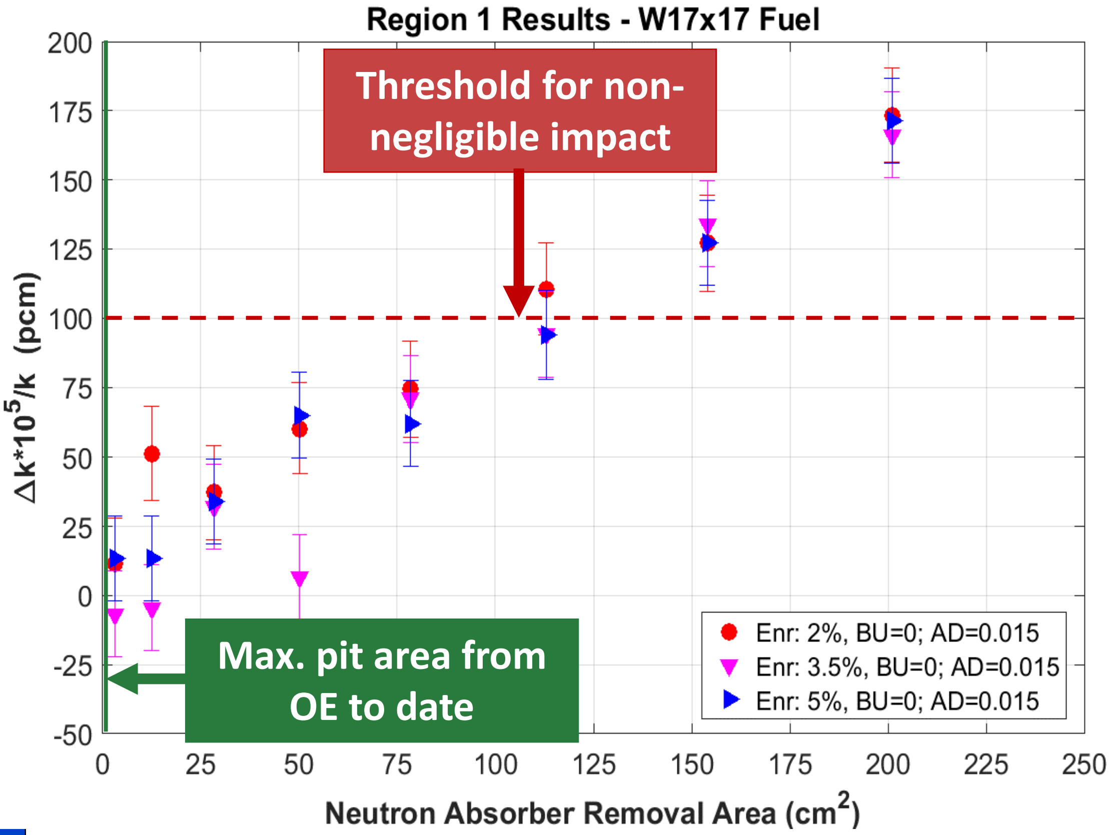
Objectives

Perform simulations and analysis to evaluate

- Impact of pits on reactivity
- Impact of blisters on reactivity

Perform analysis to determine

1. Impact based on operational experience (OE) to date
2. The bounds when impact become non-negligible



Based on extensive simulations, pits observed to date have no statistically significant impact on reactivity (need to be >300X larger and in worst location)

Evaluation of Panels from an Operating SFP – Key Findings

1979
Manufactured (AAR & Brooks and Perkins)

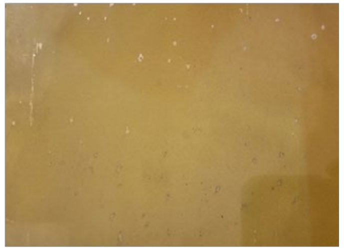
1980-1995
SFP-1
(~15 Years)

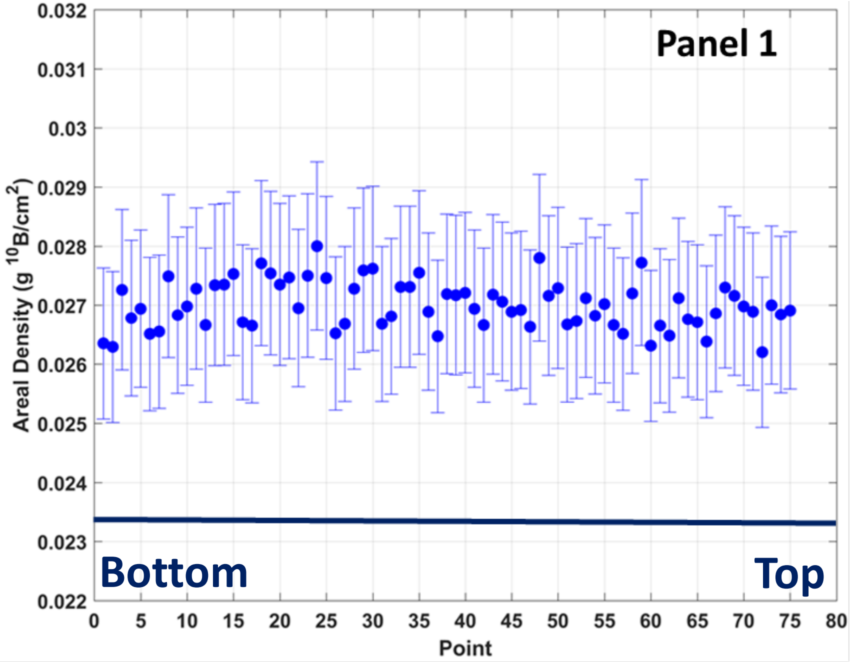
1995-1997
Storage
(~2 Years)

1997-2019
SFP-2
(~22 Years)

Panels are in very good condition
- **<u>No blisters</u>**
  - Despite being considered most susceptible to blisters due to age
- General flow patterns, scratches but no gross degradation

These panels are <u>unique:</u>
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

EPRI

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, as shown in Slide 12
**Wet storage time, does not include dry storage time in between SFPs
***Only one panel showed a very small blister at the corner

Panels removed from Zion and SFP-2 were in very good condition: General flow patterns, scratches but no gross degradation

Example samples from Zion panels

Example sample from SFP-2 panels

Zion Module being removed from pool

Panel being removed from SFP-2

EPRI

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)

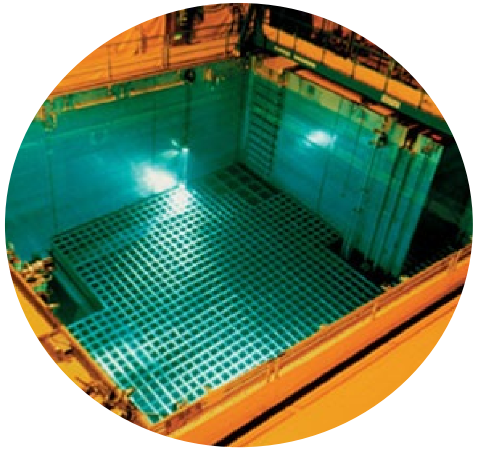
Sibling Pool Process – If No Coupons

- 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

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

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-irradiation 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

Two Pilots for Demonstration as Case Studies – Pilot-1

1979
Manufactured
(AAR & Brooks and Perkins)

1980-1995
SFP-1
(~15 Years)

1995-1997
Storage
(~2 Years)

1997-Present
SFP-2
(~24 Years)

Surrogate Panel History

1975
Manufactured
(AAR & Brooks and Perkins)

1976-1984
SFP-A
(~8 Years)

1984-1998
Storage
(~14 years)

1998-Present
SFP-B
(~23 Years)

Pilot-1 Panel History

Benefits for i-LAMP

1. increased number of coupons across industry
2. Enable comparative analysis for varying parameters (impact of B levels, Silica levels, SS encapsulation)

Benefits for Pilot-1

1. One time opportunity to install coupons that are analogs to the Pilot-1 history
2. Encapsulate half of the coupons with SS encapsulation to evaluate impact of encapsulation

Benefits for Sibling-1

If there are issues due to lack of SS encapsulation, can gather additional data points from Pilot-1

Instead of simply using SFP-2 as surrogate, proposed to install extra samples from Surrogate-1 to Pilot-1, which is beneficial for all stakeholders

Necessary Elements for i-LAMP Long Term Success


EPRI

Industrywide Learning Aging Management Program (i-LAMP): Global Neutron Absorber Material Monitoring Program for Spent Fuel Pools

2022 TECHNICAL REPORT

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

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
- Maintain and update water chemistry data (**sent by utilities to EPRI**)
- Standardization of coupon analysis