Neutron Absorber Material Degradation

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October 4, 2012

Opening Remarks

- Questions regarding monitoring of neutron absorber materials
  - Surveillance approach
  - Extent of degradation
  - Predictive and measuring tools (RACKLIFE/BADGER)
- Current safety margins
  - 5% subcriticality margin in TS
  - Conservatism in the nuclear criticality safety analyses

Overview of Spent Fuel Pool Neutron Absorbing Material Degradation

Emma Wong
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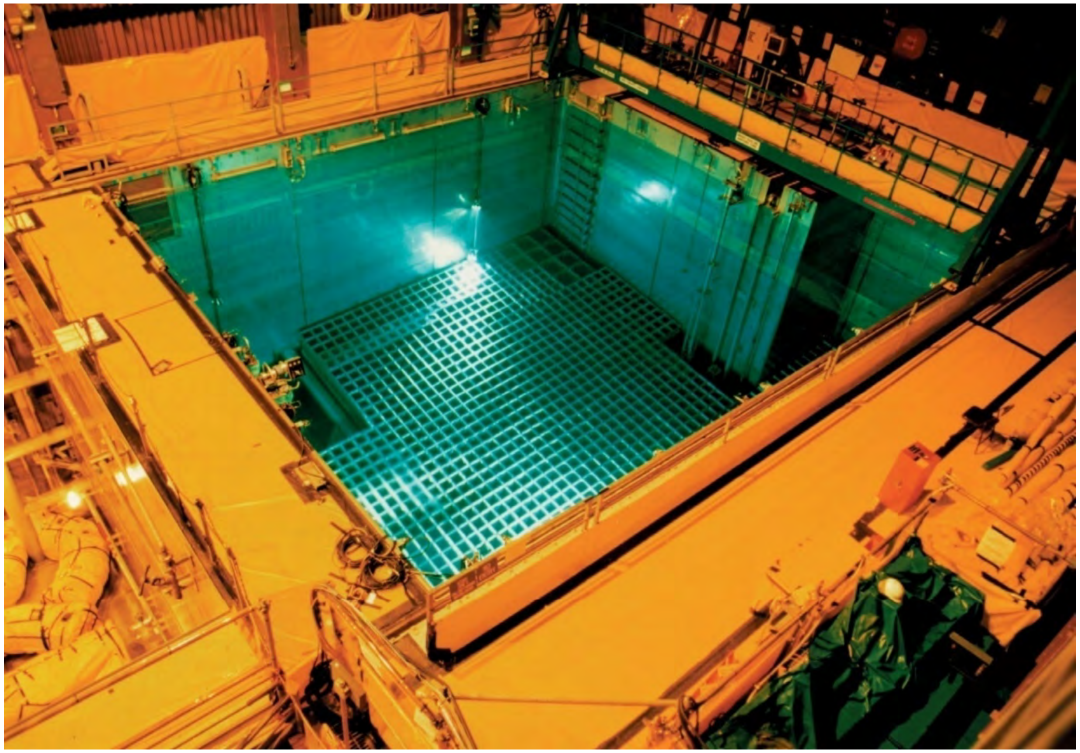
Public Meeting on Neutron Absorbing Material Degradation
October 4, 2012

Overview

- Safety Significance
- Material Types
- Historical Issues
- Recent Events
- Staff Observations
- NRC Questions
- NRC Actions
- Knowledge Base
- Surveillance Methodologies



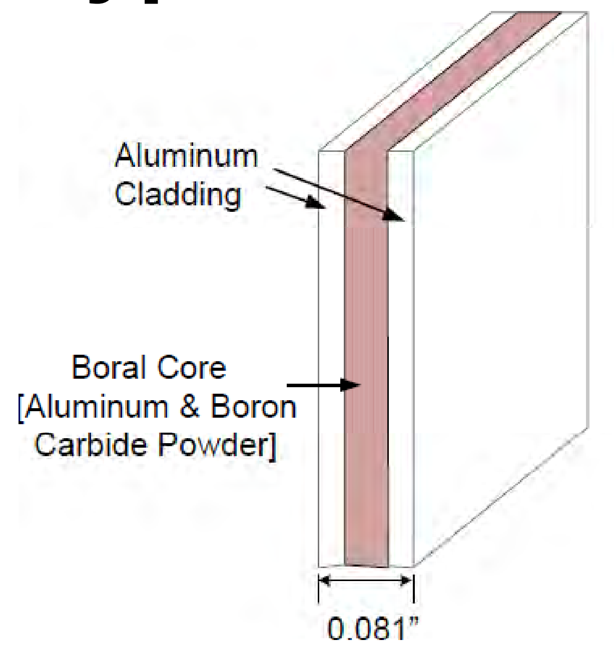
Picture: Spent Fuel Pool

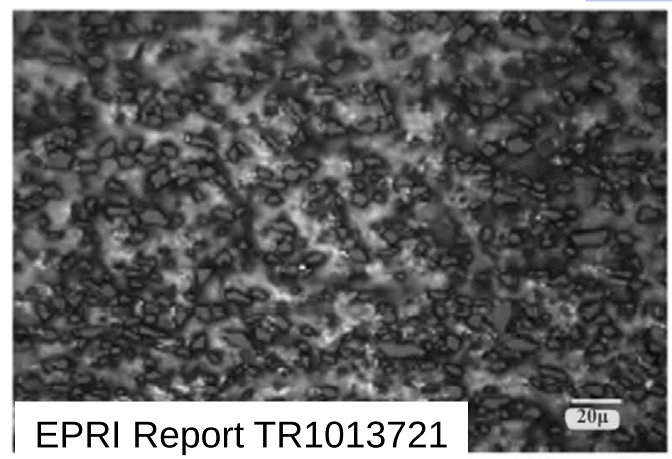
Safety Significance

- Prevent the occurrence of any inadvertent criticality events in the SFP
- Neutron absorbing materials have a direct impact on safety
  - Unidentified and unmitigated degradation poses a criticality and safety concern
  - Challenges compliance with NRC subcriticality requirements: 10 CFR 50.68 and GDC 62
- NRC staff has identified this issue as potentially safety significant

Material Types

- Most popular at US plants
  - Aluminum Boron Carbide Cermet
    - BORAL®
  - Non-metal Matrix Composites
    - Boraflex
    - Carborundum
  - Metal Matrix Composites
    - METAMIC®
- New Metal Matrix Composites
  - Bortec®
  - Alcan Composite





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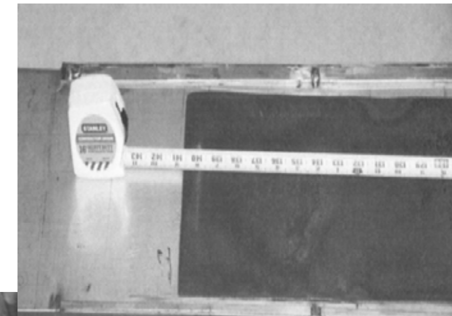
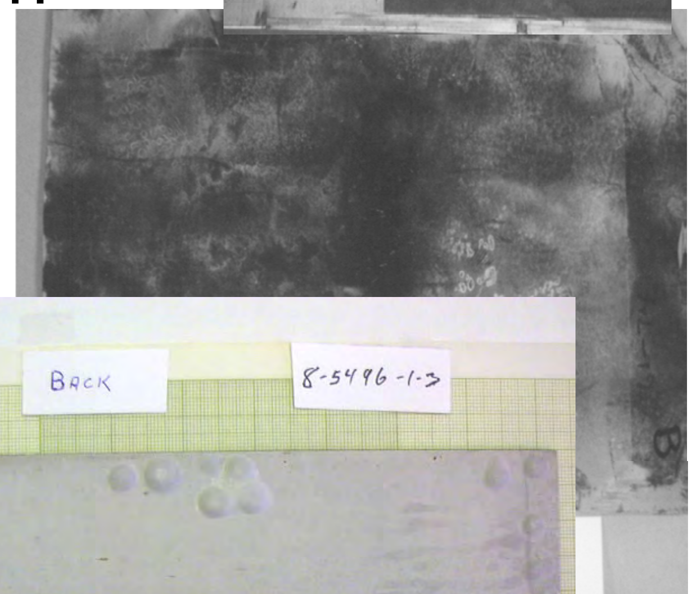
Pictures: BORAL® cross-section and Bortec® micrograph

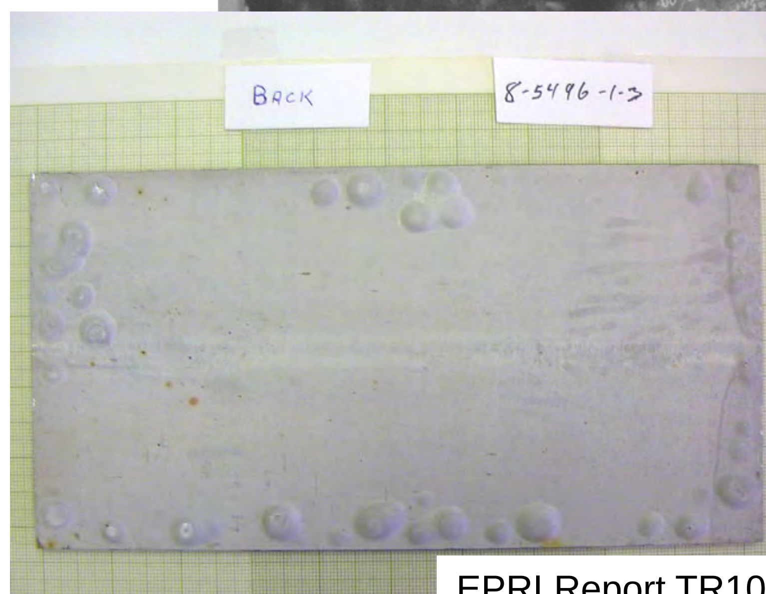
Historical Issues

- Boraflex (1970s-1980s)
  - Silica polymer matrix degradation
  - INs: 87-43, 93-70, 95-38
  - GL 96-04: Maintain 5% margin

- BORAL® (1980's)
  - Blistering & bulging
  - IN 83-29







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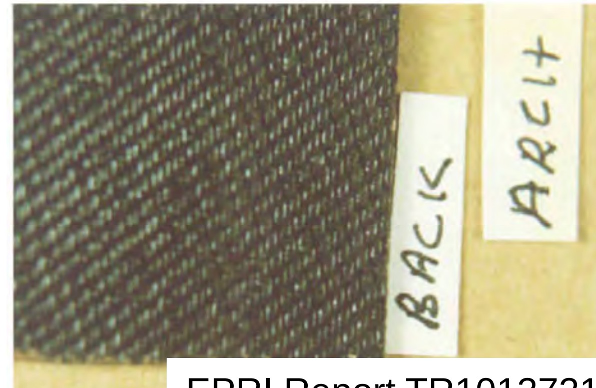
Pictures: In-service shrinkage and Boraflex removed from Spent Fuel Racks and Boral Blistering

Recent Events

- Carborundum, Palisades 2008
  - Stuck fuel assemblies
  - BADGER testing found up to 70% degradation
- BORAL®
  - Blistering
    - Seabrook 2003
    - Beaver Valley 2007
    - TMI 2008
  - Bulging
    - Susquehanna 2009



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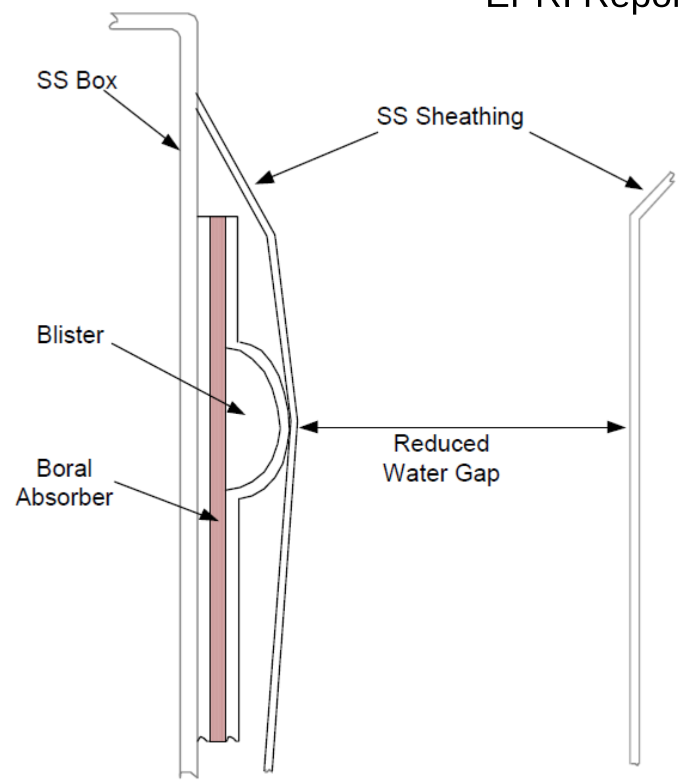

Picture: Carborundum microphotograph and example of Boral blister and bulge

Recent Events (con't)

- Boraflex
  - Turkey Point Unit 3, 2010
    - Areal density was less than the licensing basis
    - Ineffective implementation of corrective actions
    - Ineffective in identifying and mitigating degradation
  - Peach Bottom Unit 2, 2010
    - Panels degraded below the TS requirements
    - Ineffective implementation of corrective actions
    - Monitoring and mitigating the degradation not adequate
  - IN 12-13

Staff Observations

- Surveillance program important to detect onset of degradation
- Effectiveness of surveillance monitoring programs impact management of the SFP
- Effective operating experience evaluation can lead to early identification
- Unknown degradation mechanisms and rates could result in reduced subcriticality margins.

NRC Questions

- Materials in each SFP and monitoring method
- Monitoring and mitigating the material degradation
- Degree of accuracy of in-situ neutron attenuation measurements
- Surveillance intervals to monitor degradation
- Material degradation affect on the criticality analysis

NRC Actions

- IN 09-26, LR-ISG 2009-01, update to GALL (NUREG 1801 Rev 2), and IN 12-13
- NRC evaluating material degradation mechanisms, surveillance techniques, and predictive modeling
  - Literature knowledge base
  - Confirmatory research on the surveillance methodology
  - Confirmatory research on the surveillance interval adequacy

Knowledge Base

- Current NRC state of knowledge
  - Commercial and decommissioned SFPs
  - Lists materials in each SFP
  - Periodically updated
- Issued public
  - Technical Letter Report: ML113550241
  - Spreadsheet: ML121090500

Surveillance Methodologies

- Boraflex methodologies (predictive code and in-situ method) examined
- Reports published
  - TLR on Boraflex, RACKLIFE, and BADGER methodologies: ML12216A307
  - TLR on BADGER tool: ML12254A064
- BADGER report pertains to all neutron absorbing materials

Neutron Absorber Criticality Safety Concern

Jack Davis
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Office of Nuclear Reactor Regulation
October 4, 2012

The Regulations

- 10CFR50 Appendix A GDC
  - 2: Design Bases for Protection Against Natural Phenomena
  - 4: Environmental and Dynamic Effects Design Bases
  - 5: Sharing of Structures, Systems, and Components
  - 61: Fuel Storage, Handling, & Radioactivity
  - 62: Prevention of Criticality
- 10CFR50.68
  - No Boron; keff ≤ 0.95 at 95/95
  - Boron: keff < 1.0 w/o & ≤ 0.95 w/ at 95/95

The Neutron Absorbers

- Neutron Absorbers
  - Boraflex
    - Silicone rubber matrix with B4C
  - Carborundum
    - Phenolic resin with B4C
  - Boral
    - Al & B4C center in Al clad
  - Metal Matrix Composites
    - Al & B4C composite
  - Borated Stainless Steel

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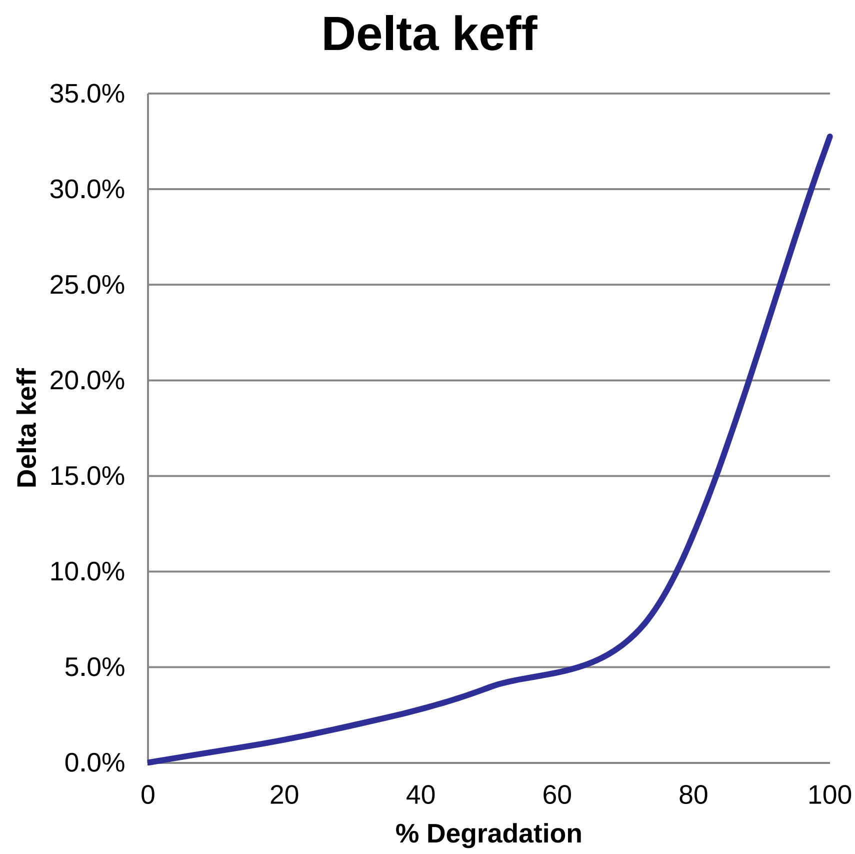
The Effect

- Below ~50% relatively small reactivity change rate
- About 60% reactivity change rate starts increasing
- Above 70% significant reactivity change rate



The NRC Questions

- How well do licensees know the condition of their neutron absorbers?

- To what extent is the condition of the neutron absorber considered in the nuclear criticality safety analysis?

- How well do degraded neutron absorbers perform during accident scenarios?

Context

- One of several related activities currently underway at the NRC

- Must be reviewed with the requisite safety significance and consistent with other agency activities/timelines.

- Welcome and desire stakeholder input on this and related subjects.

The RACKLIFE Methodology

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Public Meeting on Neutron Absorbing Material Degradation

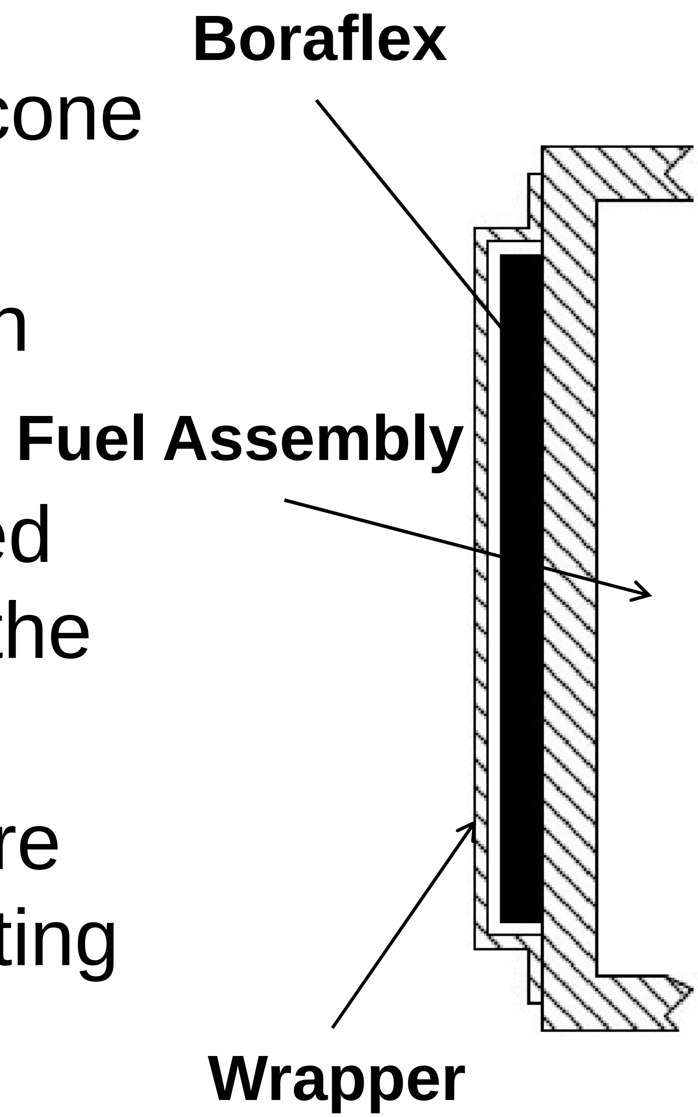
October 4, 2012

Outline

- Boraflex and Boraflex degradation
- Origin of RACKLIFE
- Regulatory history
- NRC main discussion topics
- Summary

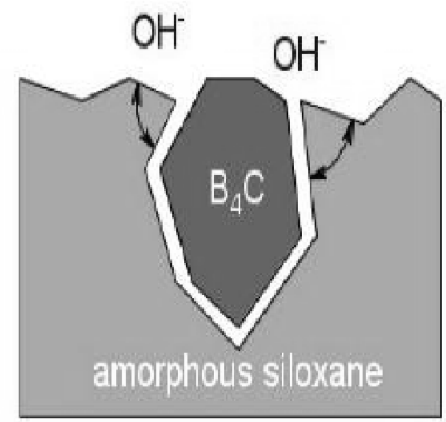
Boraflex

- B_4C particles bound in a silicone polymer matrix
- Cut into panels and placed in spent fuel storage racks
- Absorbs neutrons from stored fuel to assist in maintaining the spent fuel pool subcritical
- RACKLIFE modeling software and the BADGER in-situ testing method were developed by industry



Boraflex Degradation

- Two-step dissolution process:
  - Degradation of the silicone rubber polymer matrix to slightly soluble amorphous silica
  - Slow dissolution of amorphous silica, releasing B_4C from the panel
  - This effect is intensified by erosion
- Shrinkage



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Boraflex Rack Life Extension: RACKLIFE

- Developed in the 1990's to predict the B^{10} content of Boraflex panels in the spent fuel pool
- Predictive code based on the chemical properties of Boraflex in a spent fuel pool environment
- Specific to Boraflex; cannot be used with another neutron absorbing material

History

- GL 96-04, “Boraflex Degradation in Spent Fuel Storage Racks” (ML031110008)
- IN 2012-13, “Boraflex Degradation and Corrective Actions in the Spent Fuel Pool” (ML121660156)
- Technical Letter Report, “Boraflex, RACKLIFE and BADGER: Description and Uncertainties”(ML12216A307)

Main Discussion Topics

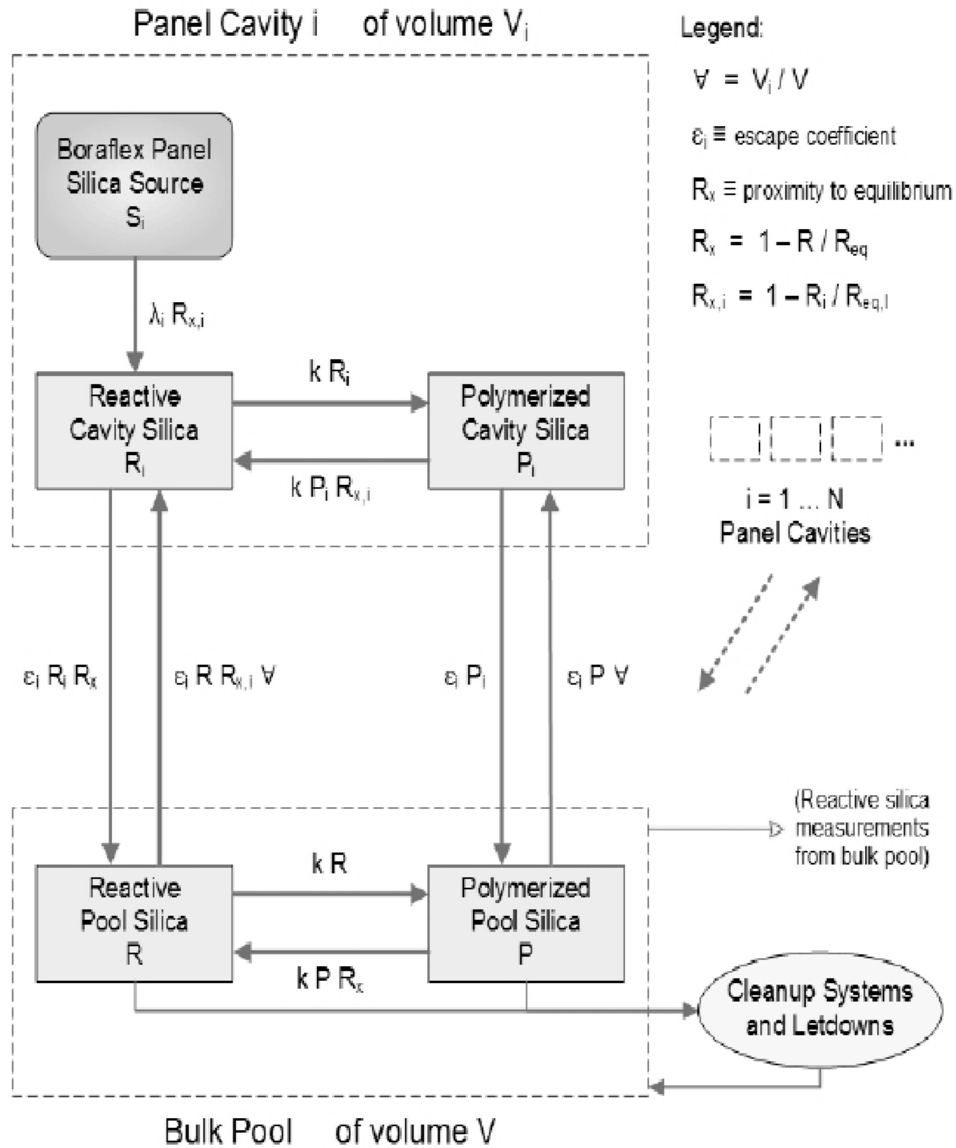
- Silica mass balance
- Escape coefficient
- Localized degradation
- Prediction assumptions
- Confirmatory testing

Silica Mass Balance

- Predicts boron carbide loss through silica mass balance equations

Uncertainties

- Approach uncertainty
- Accuracy of pool sample
- Sample frequency
- Accounting for cleanup system efficiency
- Accounting for letdowns (dilution events)



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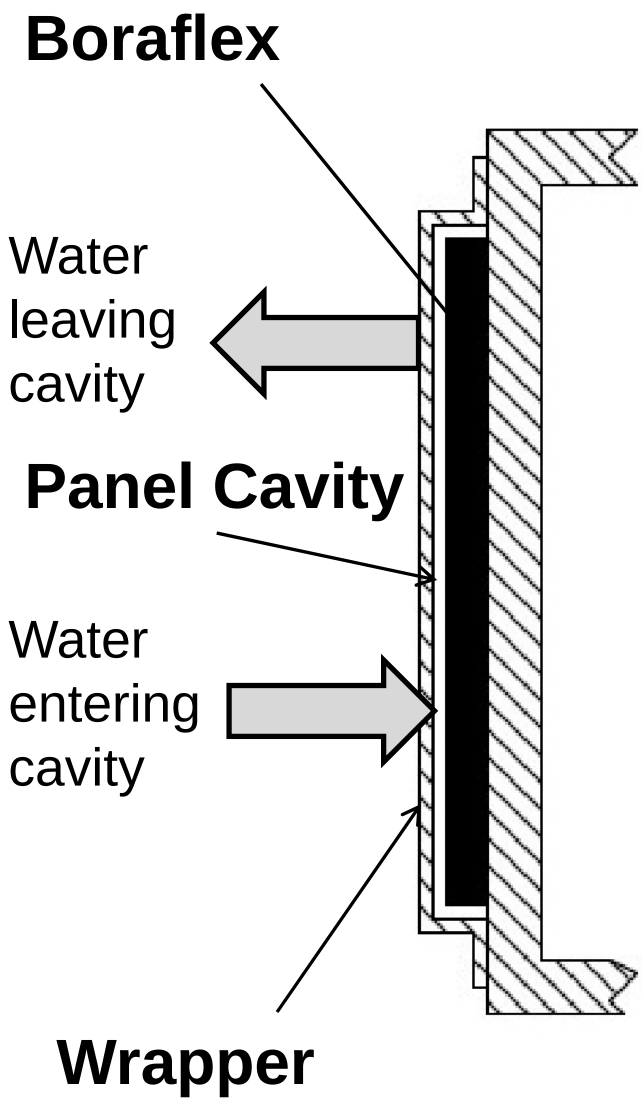
Escape Coefficient

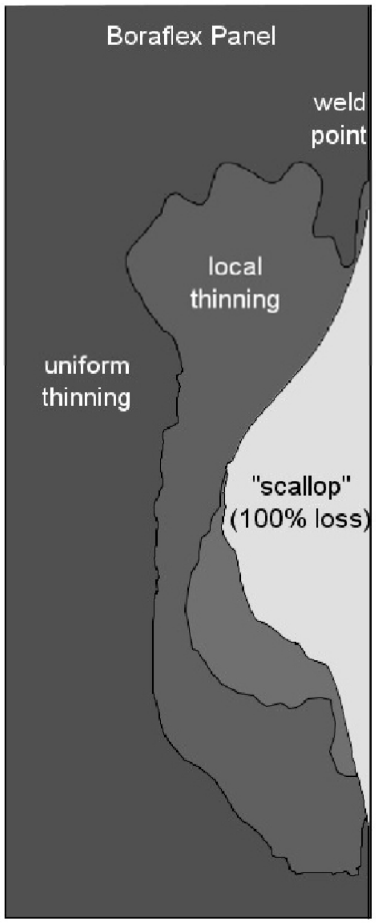
- Rate at which a particular panel cavity exchanges silica-laden water with the bulk pool
- Used to calibrate RACKLIFE to actual measured silica levels

Uncertainties

- – Use of average escape coefficient



Localized Degradation



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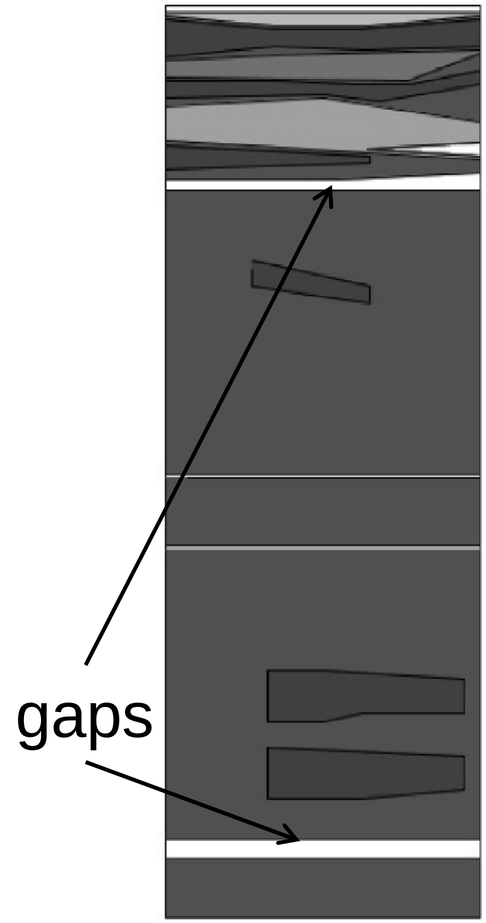
- Degradation of Boraflex panels in the spent fuel pool is not uniform

Uncertainties

- Use of average panel degradation
- Spatial effects not accounted for



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Prediction Assumptions

- Exchange rate kinetics are estimated as linear
- Approach appears consistent for moderate levels of Boraflex loss when compared to in-situ testing data

Uncertainties

– Linear kinetics model may not be as accurate at higher levels of degradation

Confirmatory Testing

- RACKLIFE uses confirmatory testing to tune the predicted model to match actual pool conditions

Uncertainties

- Accuracy of confirmatory testing
- Frequency of confirmatory testing
- Number of panels scanned

Summary

- The uncertainties associated with RACKLIFE may impact the monitoring programs used to manage Boraflex and need to be understood and managed.
- The NRC staff is working with industry to gain more information on how these uncertainties are being addressed in order to assess the adequacy of monitoring programs.
- The NRC staff is considering a path forward, including the possibility of follow up action, based on the information gained through interaction with the industry and the Technical Letter Reports recently released.

Assessment of the BADGER Methodology

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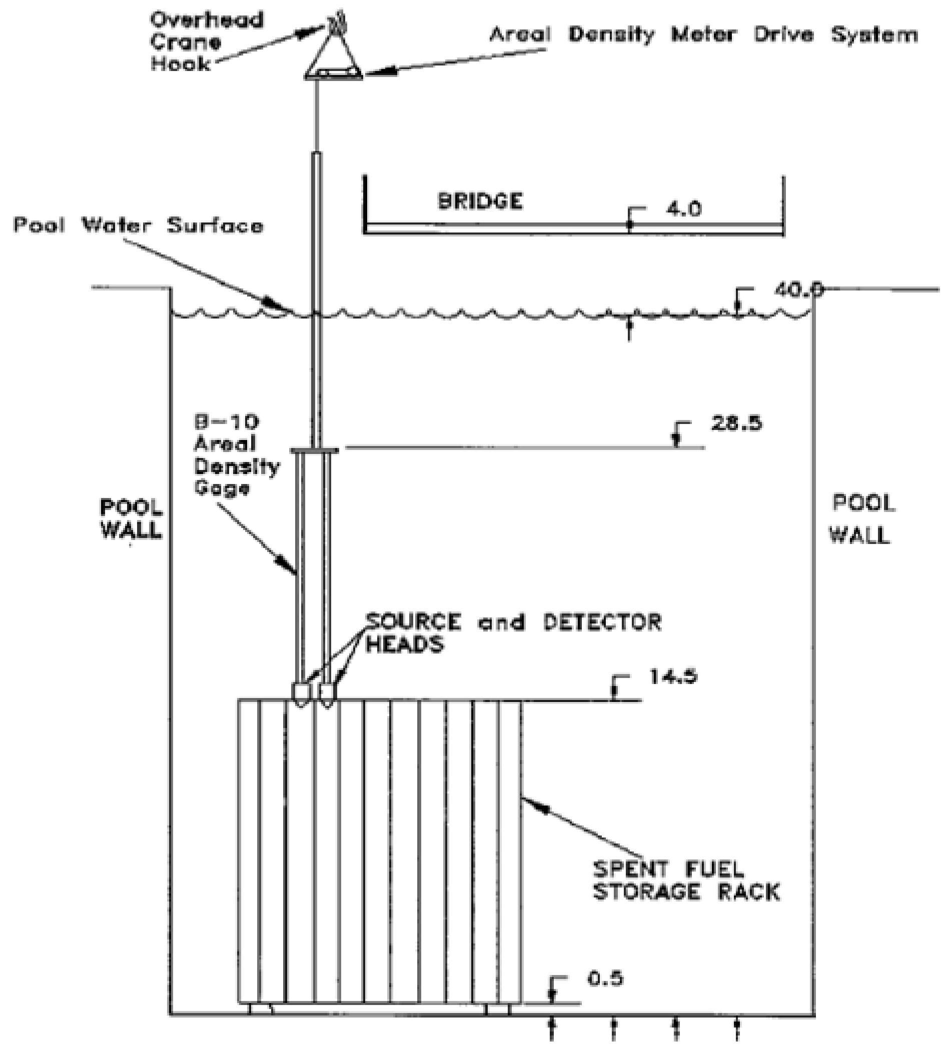
Public Meeting on Neutron Absorbing Material Degradation
October 4, 2012

Background

- **Boron Areal Density Gauge for Evaluating Racks was developed in the early 1990's as a result of Boraflex degradation and uncertainty in the RACKLIFE methodology.**
- **Technical Letter Report "Initial Assessment of the Uncertainties Associated with the BADGER Methodology," September 2012. (ML12254A064)**
- **NRC has identified questions and knowledge gaps about the execution of BADGER and the accuracy of results.**

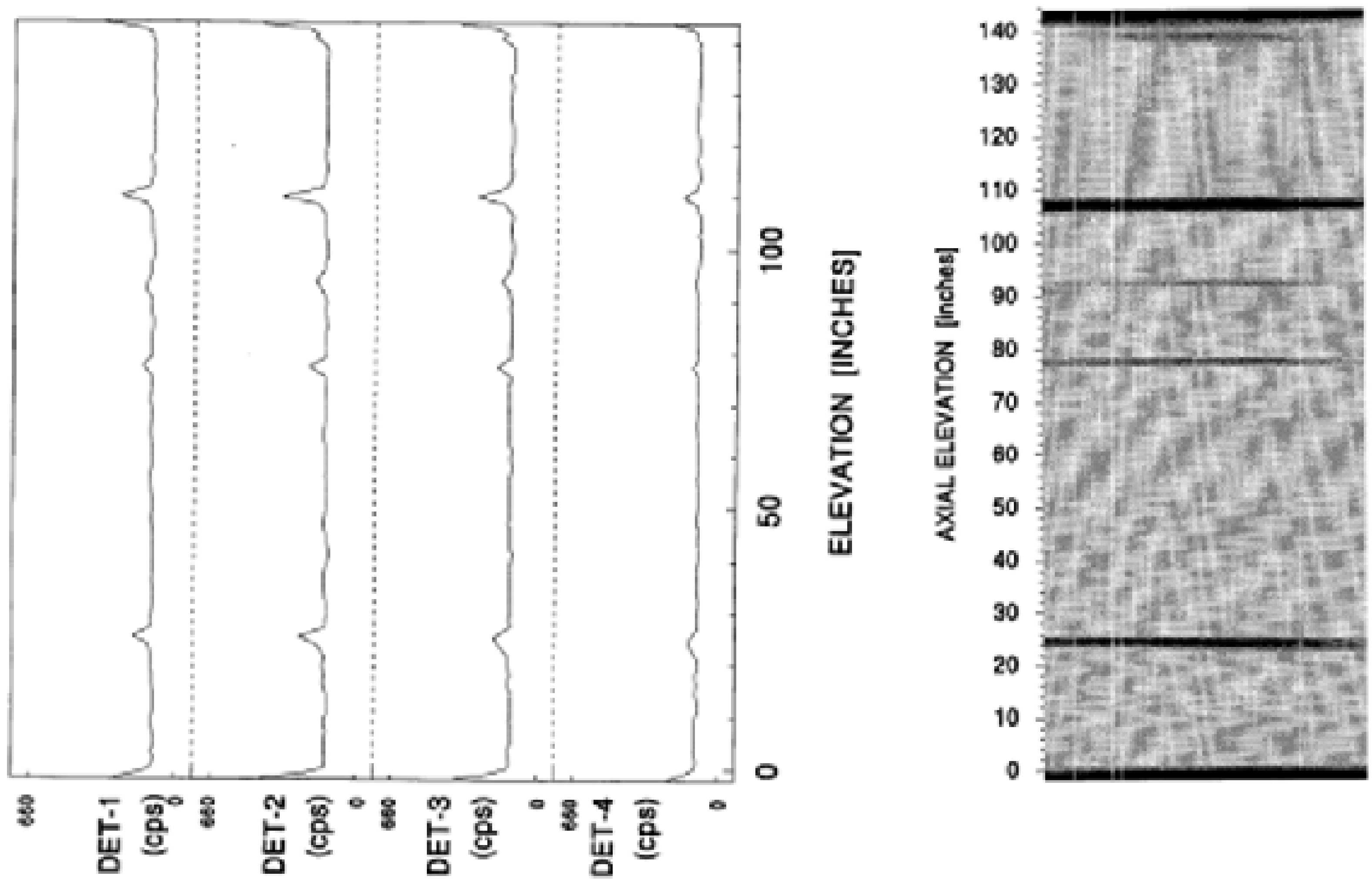
BADGER Instrumentation

- Developed from a one-head go/no-go blackness testing system to a quantitative determination of ^{10}B areal density [g(^{10}B) /cm^2].
- Source and detector heads are lowered into adjacent cells to scan the panel(s) in the intervening rack wall(s).
- BADGER returns 2-D information about neutron absorbing capability of the panel.



EPRI TR-107335

BADGER Output



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Uncertainty in BADGER

Main Topics of Discussion

- Neutron source
- Interference
- Head misalignment
- Calibration method
- Calibration material
- Data processing
- Panel selection and campaign frequency

Curtiss-Wright file photo

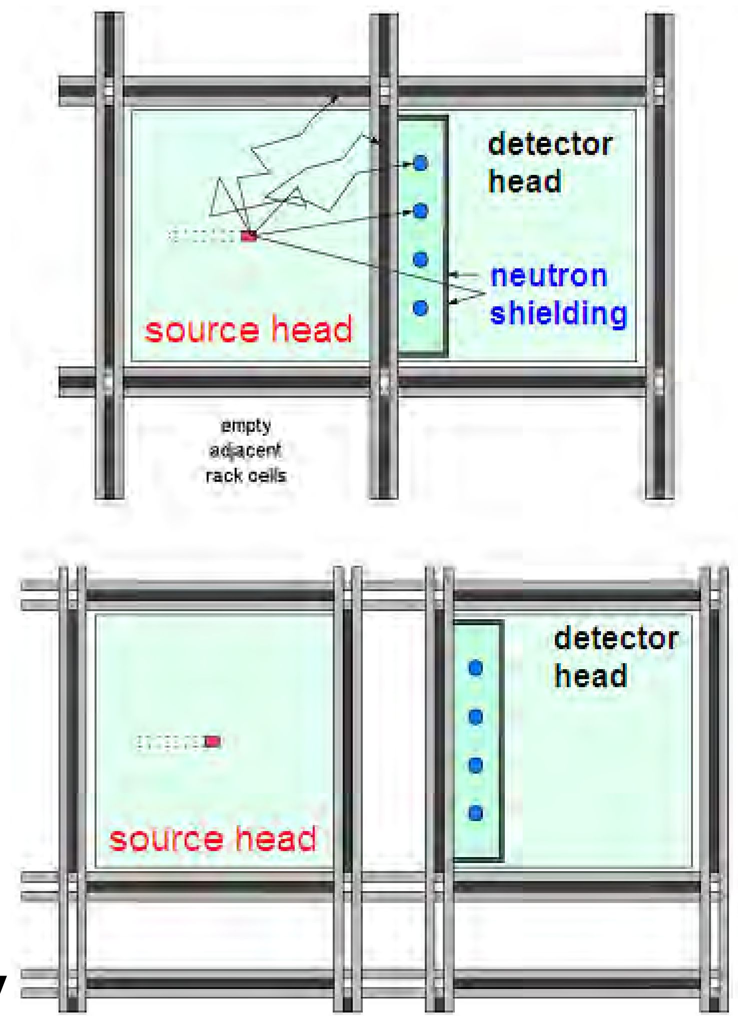
Uncertainty in BADGER

Neutron Source

- CF-252 neutron source
- Count times of ~10 seconds

Uncertainties

- Low neutron counts
- Neutron scatter
- Source head moderator
- Effect of pool conditions
- Effect of flux trap panels
- Effect of CF-252 source decay



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Uncertainty in BADGER

Interference

- In-situ conditions
- Exposed to gamma radiation from nearby fuel assemblies
- Small detectors

Uncertainties

- Pile-up pulse
- Wall effect
  - Efficiency
- Calibration

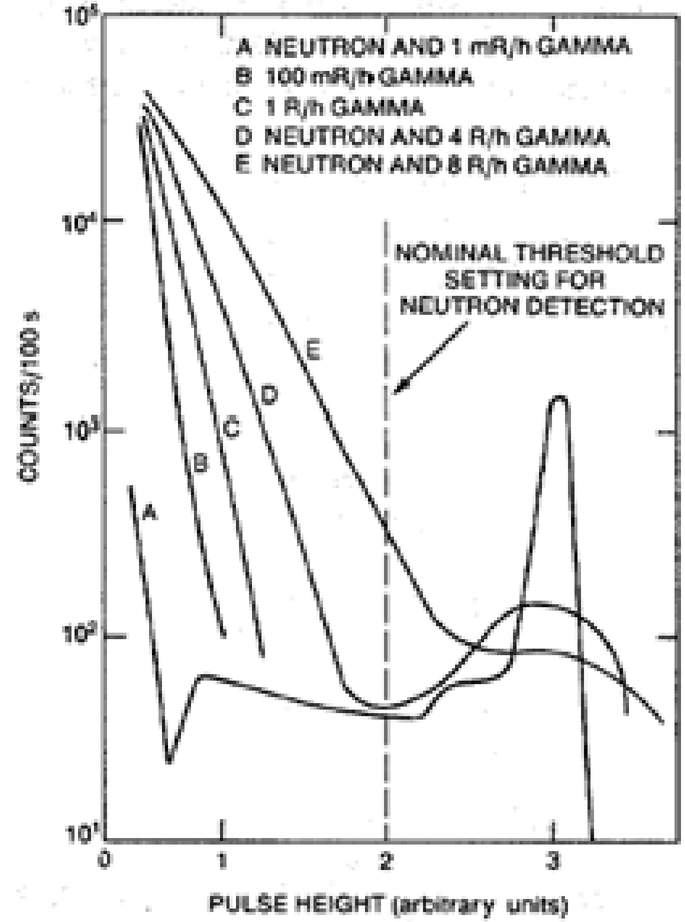


***Fig. 13.8** Gamma-ray pile-up effects for a ^{3}He proportional counter tube 2.54 cm in diameter and 50.8 cm in length.*

NUREG/CR-5550, 1991 p390.

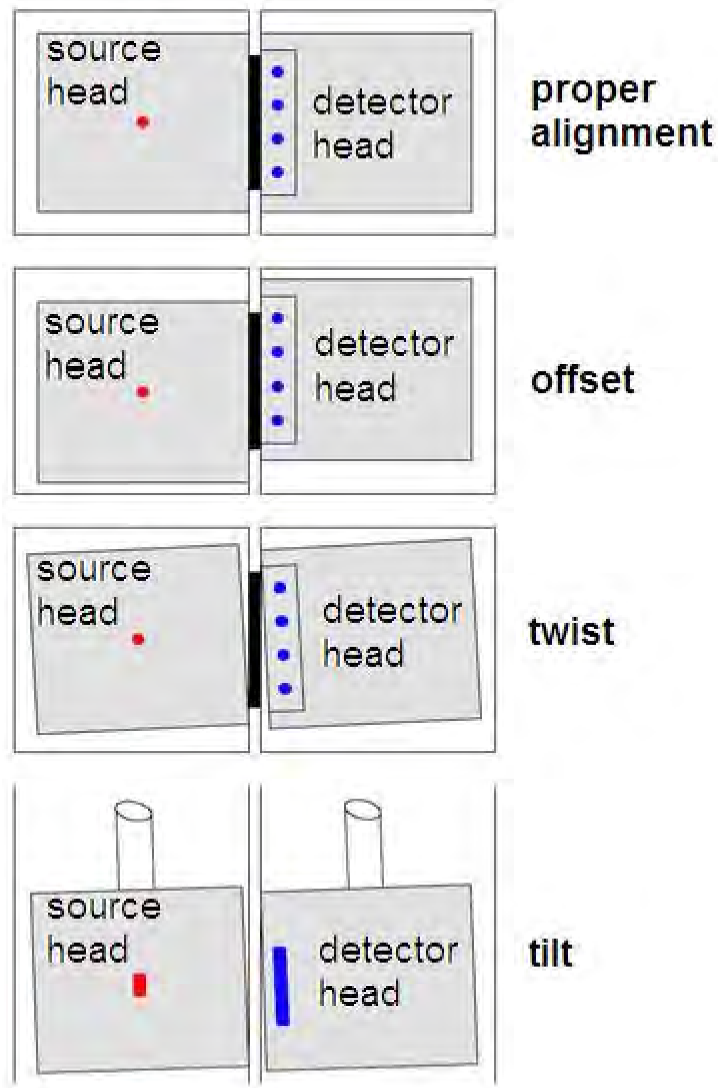
Uncertainty in BADGER

Head Misalignment

- Neutron source and detector heads in close proximity, i.e. 2-3 inches apart
- Types of misalignment

Uncertainties

- Misalignment errors
- Detection of misalignment
- Remedies for prevention of misalignment



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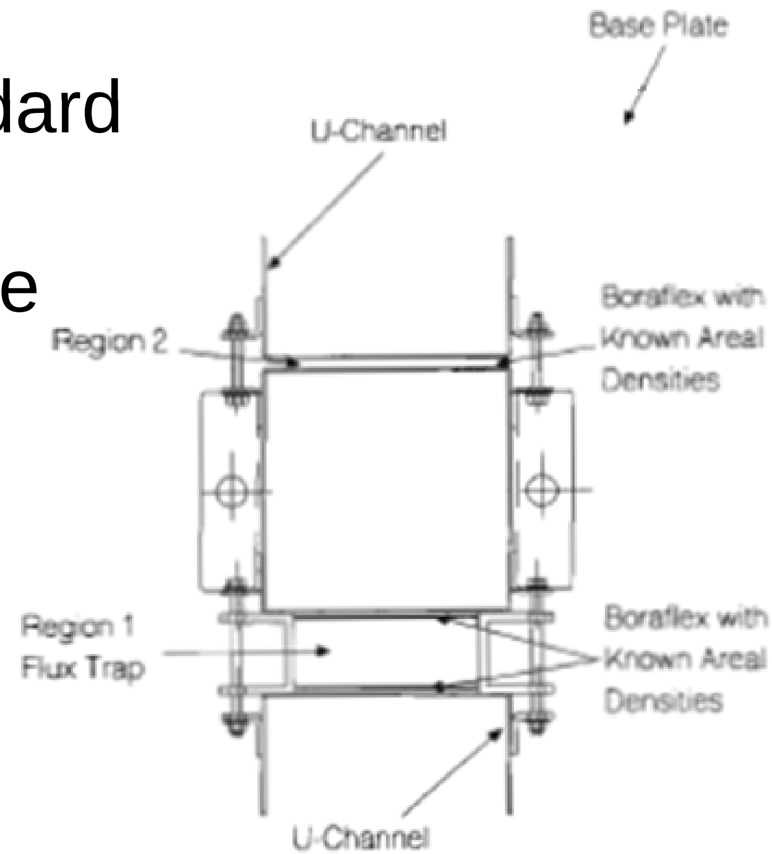
Uncertainty in BADGER

Calibration Method

- Calibration curve from a standard calibration assembly
- Uses a pool-specific zero-dose panel as a nominal reference

Uncertainties

- Number of calibration points
- Effect of flux trap rack
- Zero-dose panel
- Effect of non-uniform degradation
- Pool characteristics
- Frequency of calibration

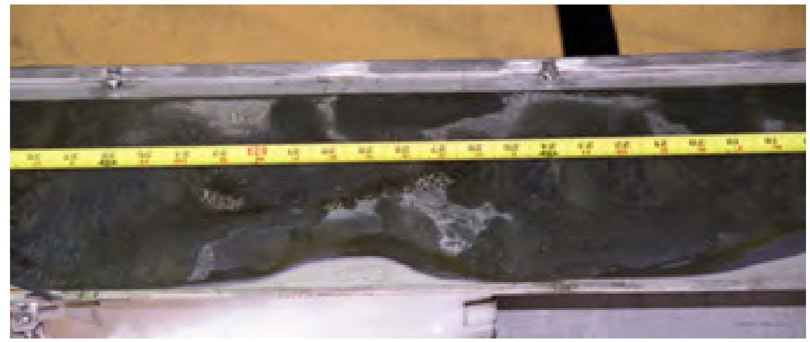


EPRI GC-110539

Uncertainty in BADGER

Calibration Material

- Calibration materials have been tailored to Boraflex
- Other materials may exhibit different degradation modes



scalloped Boraflex face
EPRI TR-1003414

Uncertainties

- Degradation characteristics
- Use of different calibration materials vs. panel materials

Boral edge showing oxidation and delamination
EPRI TR-1013721

Uncertainty in BADGER

Data Processing

- Recognizes non-uniform degradation
- Produces B-10 areal density measurements
- 2-D spatial image for each test panel

Uncertainties

- Original material condition not fully understood
- Algorithms to calculate overall panel loss are non-standardized

Elevation [inches]	Detector 1	Detector 2	Detector 3	Detector 4
143	3	3	3	3
141		30%	30%	
139				
137				
135				
133	10%	10%	10%	10%
131			10%	
129				
127	15%	25%	5%	
125	30%	30%	30%	10%
123		25%	1	1
121				20%
119			1	1
117	4	4	4	4
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11				
9				
7	6	6	6	6
5	1	1	1	1
3				
1				

T.C. Haley simulation, 2012

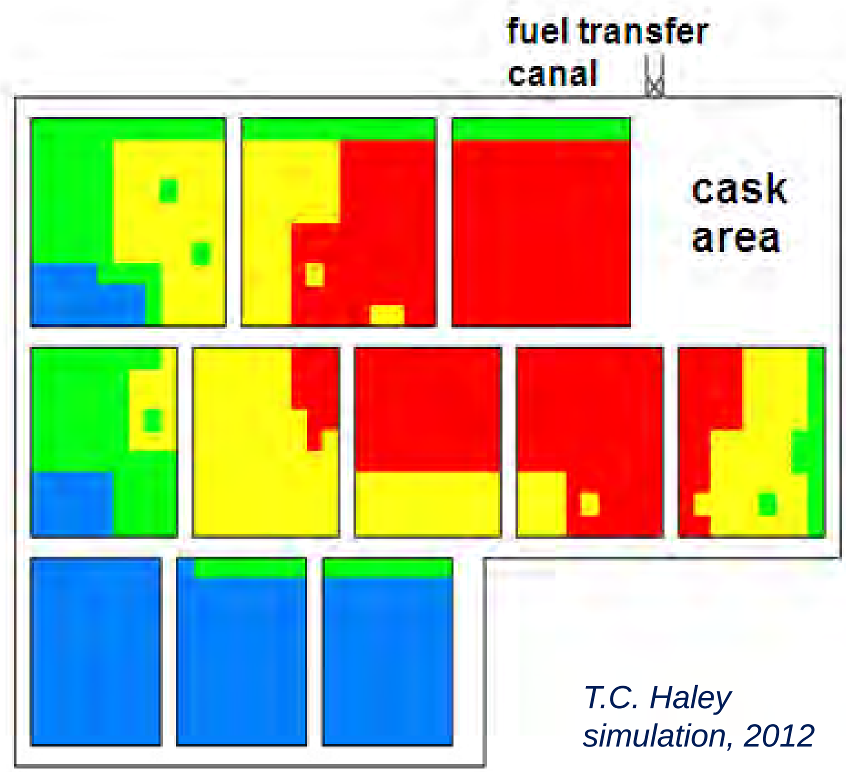
Uncertainty in BADGER

Panel Selection and Campaign Frequency

- Typical pool contains ~3000 – 8000 panels
- Typical campaign tests ~30-60 panels
- Can be informed by degradation prediction modeling

Uncertainties

- Informing test panel selection
- Statistical extrapolation
- Trending and campaign frequency

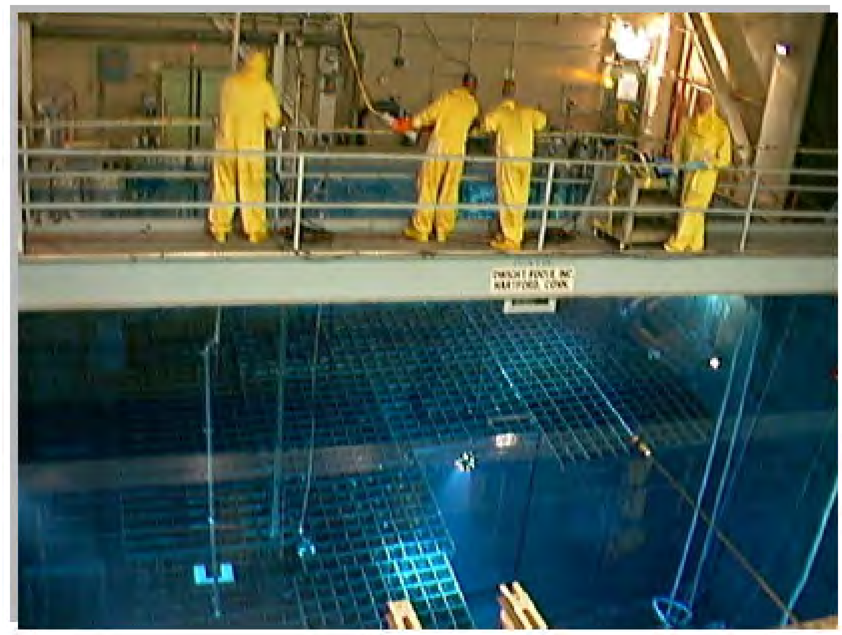


T.C. Haley simulation, 2012

Summary

Questions on the BADGER methodology

- Eroding margins increase dependence on accurate and timely surveillance
- BADGER increasingly used for non-Boraflex materials
- Many sources of uncertainty identified by NRC



EPRI

- NRC to interact with industry to fill knowledge gaps and resolve BADGER questions.

Path Forward on Issues of Spent Fuel Pool Neutron Absorbing Material Degradation

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Overview

- NRC Questions
- Knowledge Base
- Surveillance Methodologies
- Surveillance Frequencies
- Criticality Aspects
- Current Actions
- Timeline
- Summary

NRC Questions

Knowledge Base

- Current NRC state of knowledge
- Issued public
  - Technical Letter Report: ML113550241
  - Spreadsheet: ML121090500
- Many gaps in information
  - Material and configuration in the SFP
  - Use in the criticality analysis of record

Surveillance Methodologies

- Visual inspection
- Coupon monitoring
  - Representative of the rack panel material
  - Test methods/procedures
- Predictive modeling methodology
  - RACKLIFE
- In-situ testing methodology
  - Blackness testing
  - BADGER testing
- Other methods

Surveillance Frequencies

- Material degradation mechanisms and rate
- Frequency acceleration/deceleration
- Indicators of degradation between surveillances

Criticality Aspects

- Degradation of the material's potential affect on the criticality analysis of record
  - Loss of material – neutron absorbing capability
  - Deformation – blistering, bulging, pitting, warping
  - Gaps, cracks, shrinkage, densification
  - Voids
  - Structural integrity
  - Wear/mechanical damage

NRC Actions

- Phenolic resins report
- Cermet research
- Metal matrix composite research
- Borated stainless steel research
- Coupon methodology
- Potential Generic Communication
  – Work in progress
  – May be used to gather information
  – Determine if any additional NRC actions necessary

Timeline

- RACKLIFE and BADGER TLRs released
- Public Meeting - October 4, 2012
- Phenolic Resin TLR – Early 2013
- RIC – March 2013
- NEI Used Fuel Management Conference - May 2013
- Public Comment period on potential generic communication - Mid-2013

Summary

- Gaps in information and questions
- Additional dialogue with industry
- Additional research underway
- Regulatory guidance, as necessary
- Other generic communications, as necessary

Questions