U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Assessment of the BADGER Methodology

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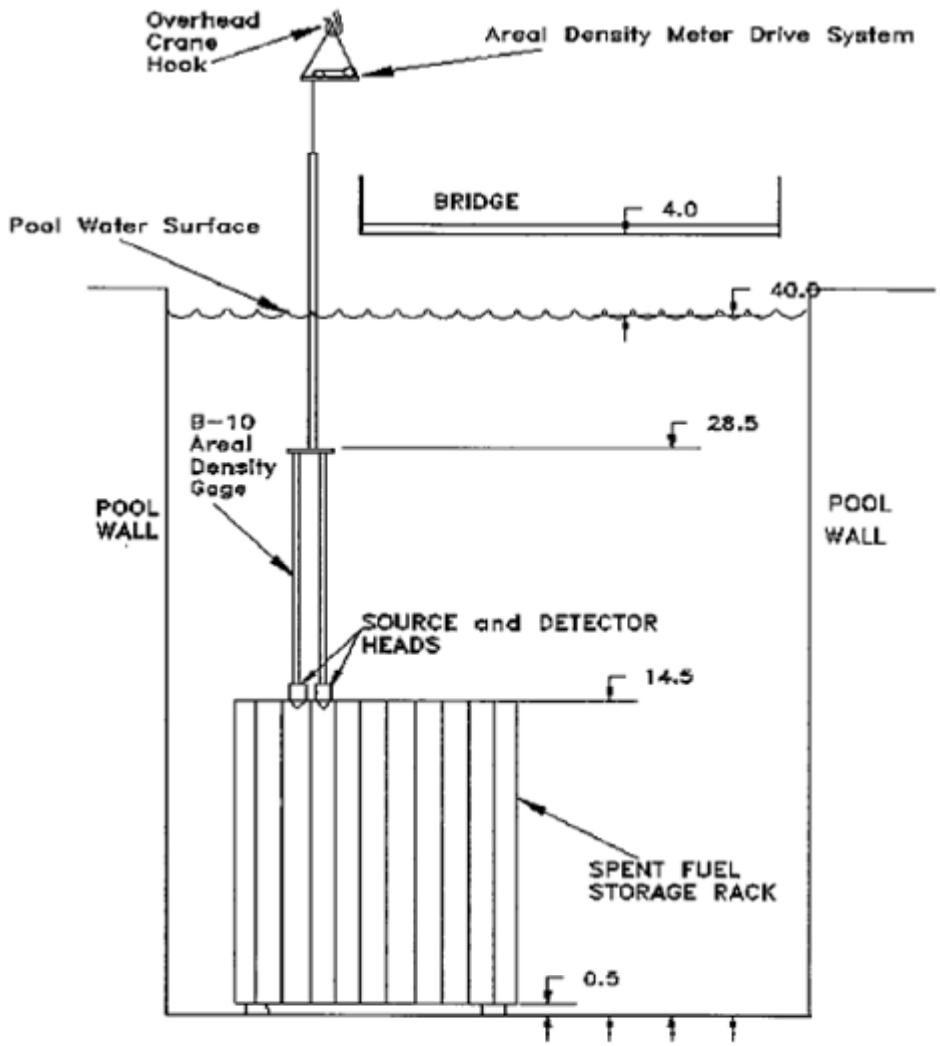
Background

- 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.

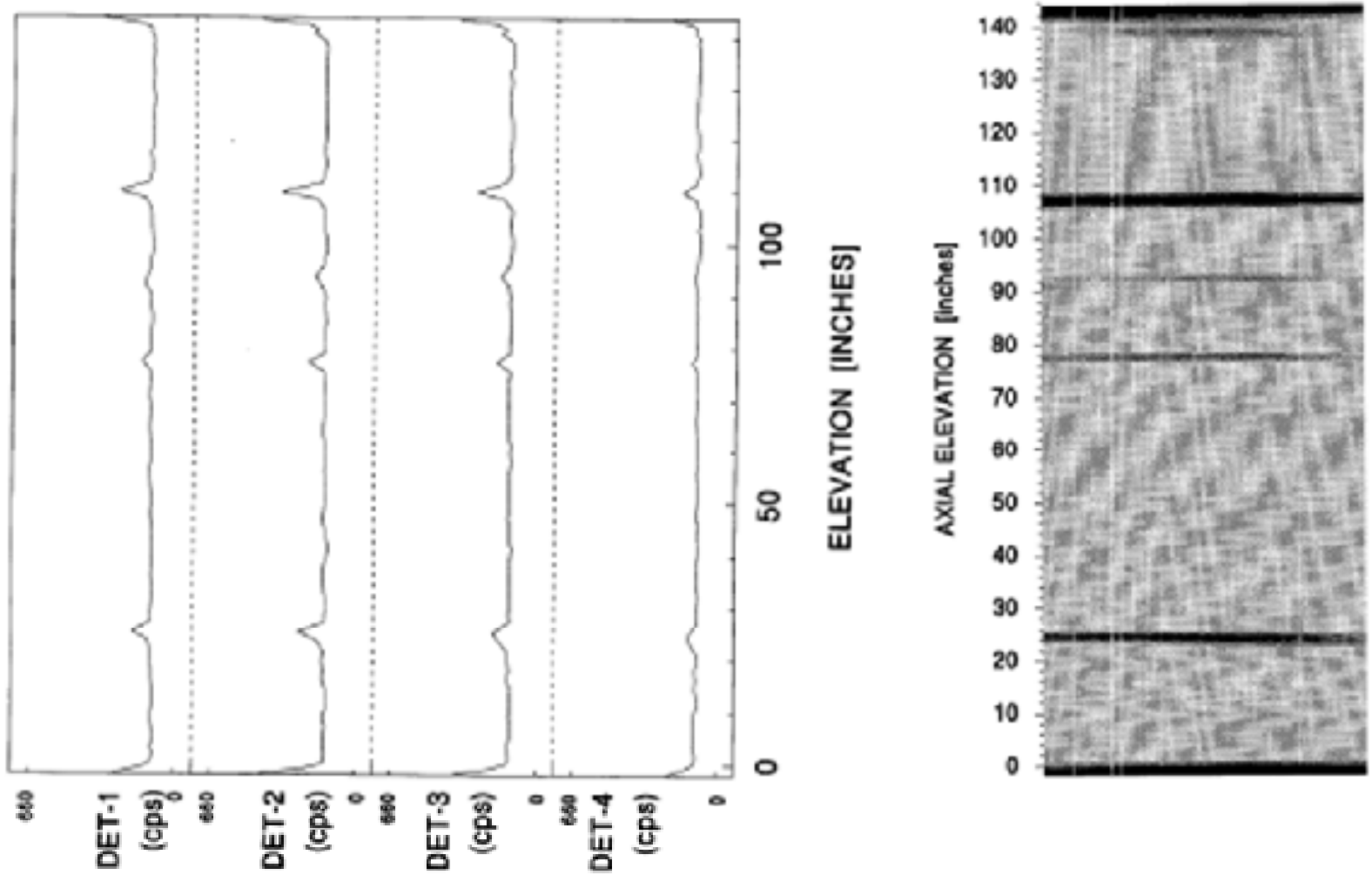
BADGER Instrumentation

- 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

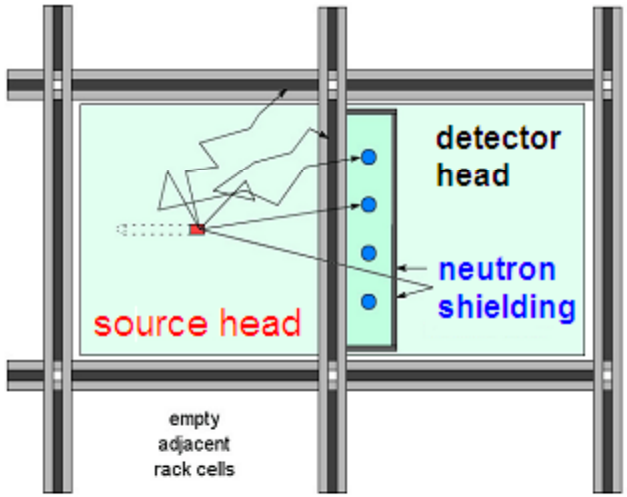
Uncertainty in BADGER

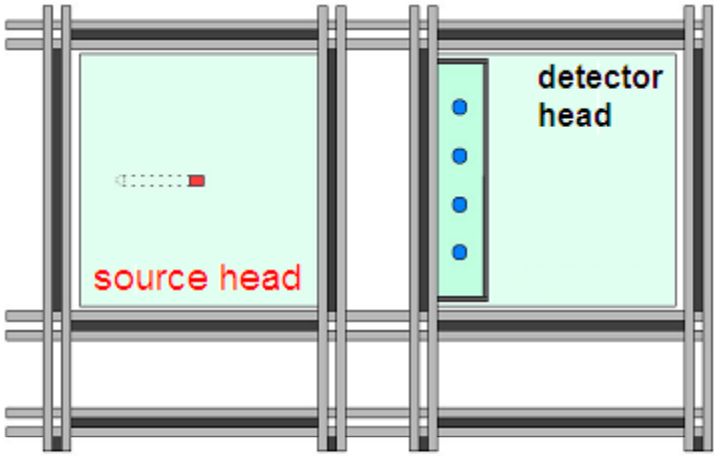
<u>Neutron Source</u>

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

<u>Uncertainties</u>

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





T.C. Haley ,2012

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

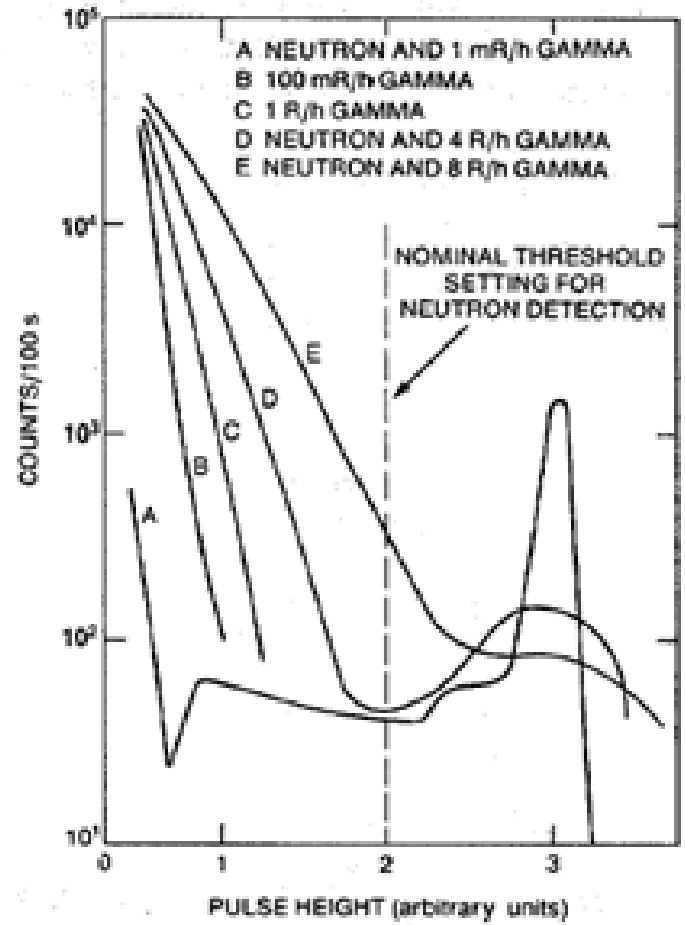


Fig. 13.8 Gamma-ray pile-up effects for a ^3He proportional counter tube 2.54 cm in diameter and 50.8 cm in length.

NUREG/CR-5550, 1991 p390.

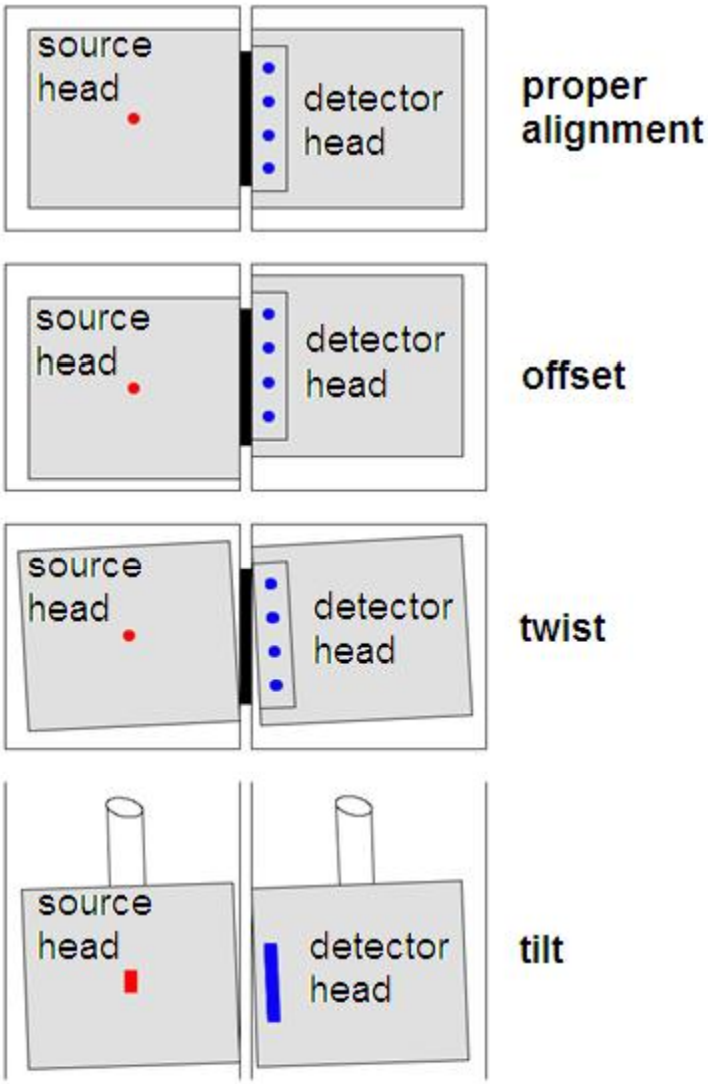
Uncertainty in BADGER

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

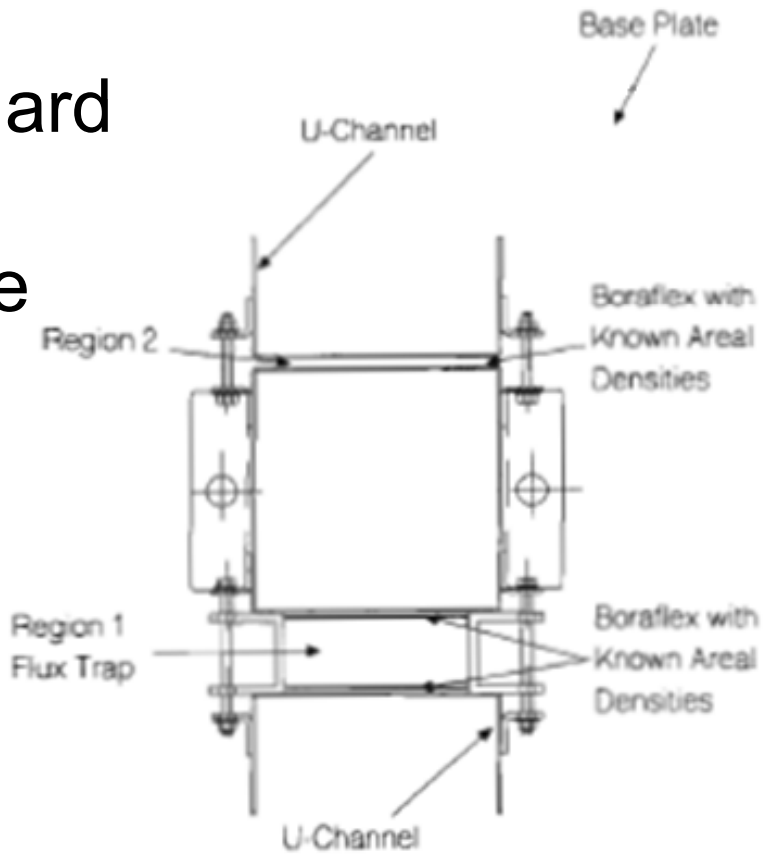


T.C. Haley, 2012

Uncertainty in BADGER

Calibration Method

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



EPRI GC-110539

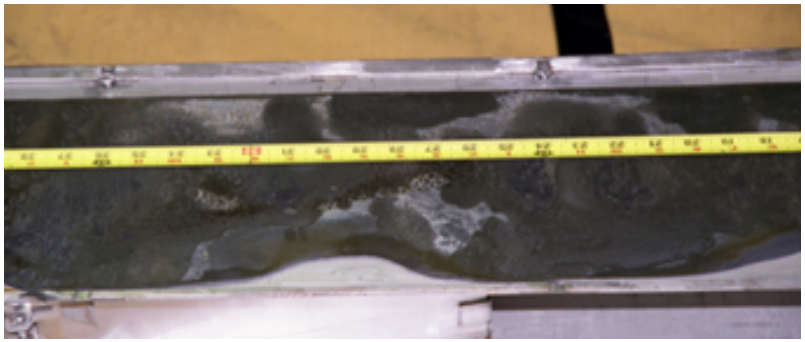
Uncertainties

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

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

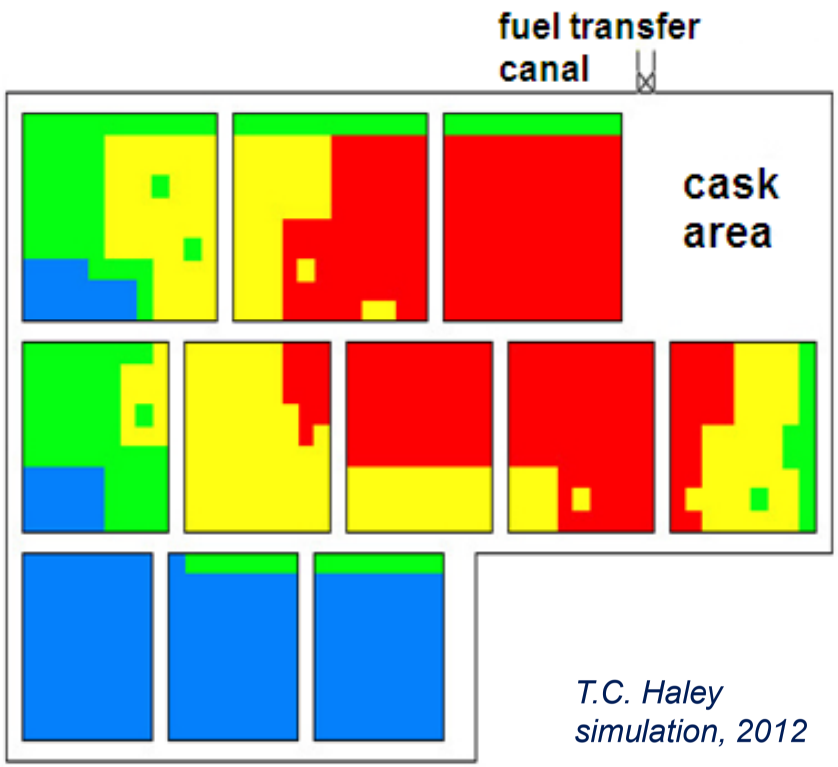
Elevation [inches]	Detector 1	Detector 2	Detector 3	Detector 4
143	3	3	3	3
141		30%	30%	
139				
137				
135				
133	10%	10%	10%	10%
131			10%	
129				
127	15%	25%	5%	
125	30%	30%	30%	10%
123		25%	1	1
121				20%
119			1	1
117	4	4	4	4
115				
113				
111				
109				
107				
105				
103				
101				
99				
97				
95				
93				
91				
89				
87				
85				
83				
81				
79				
77				
75				
73				
71				
69				
67	1	1	1	1
65				
63				
61				
59				
57	1	1	1	1
55				
53				
51				
49				
47				
45				
43				
41				
39				
37				
35				
33				
31				
29				
27				
25				
23				
21				
19				
17				
15				
13				
11				
9				
7	6	6	6	6
5	1	1	1	1
3				
1				

T.C. Haley simulation, 2012

Uncertainty in BADGER

<u>Panel Selection and Campaign Frequency</u>

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



T.C. Haley simulation, 2012

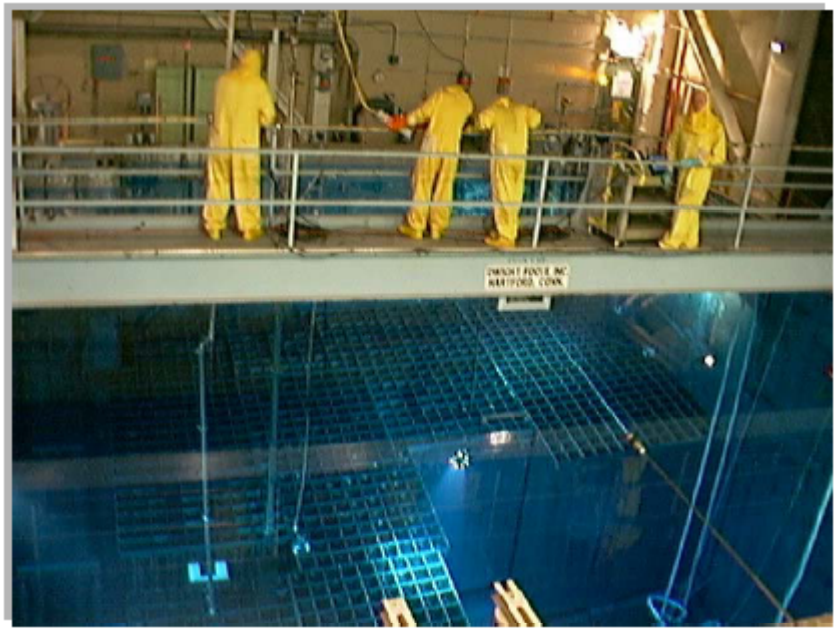
<u>Uncertainties</u>

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

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.