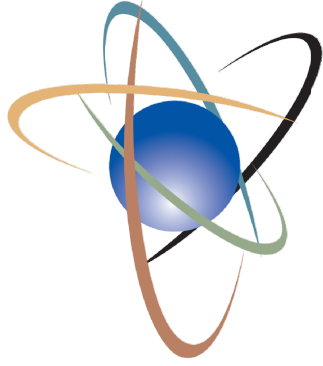




**U.S. NRC**

UNITED STATES NUCLEAR REGULATORY COMMISSION

*Protecting People and the Environment*

# **Assessment of the BADGER Methodology**

**April Pulvirenti**

**Nuclear Regulatory Research/Division of Engineering**

**Public Meeting on Neutron Absorbing Material Degradation**

**October 4, 2012**

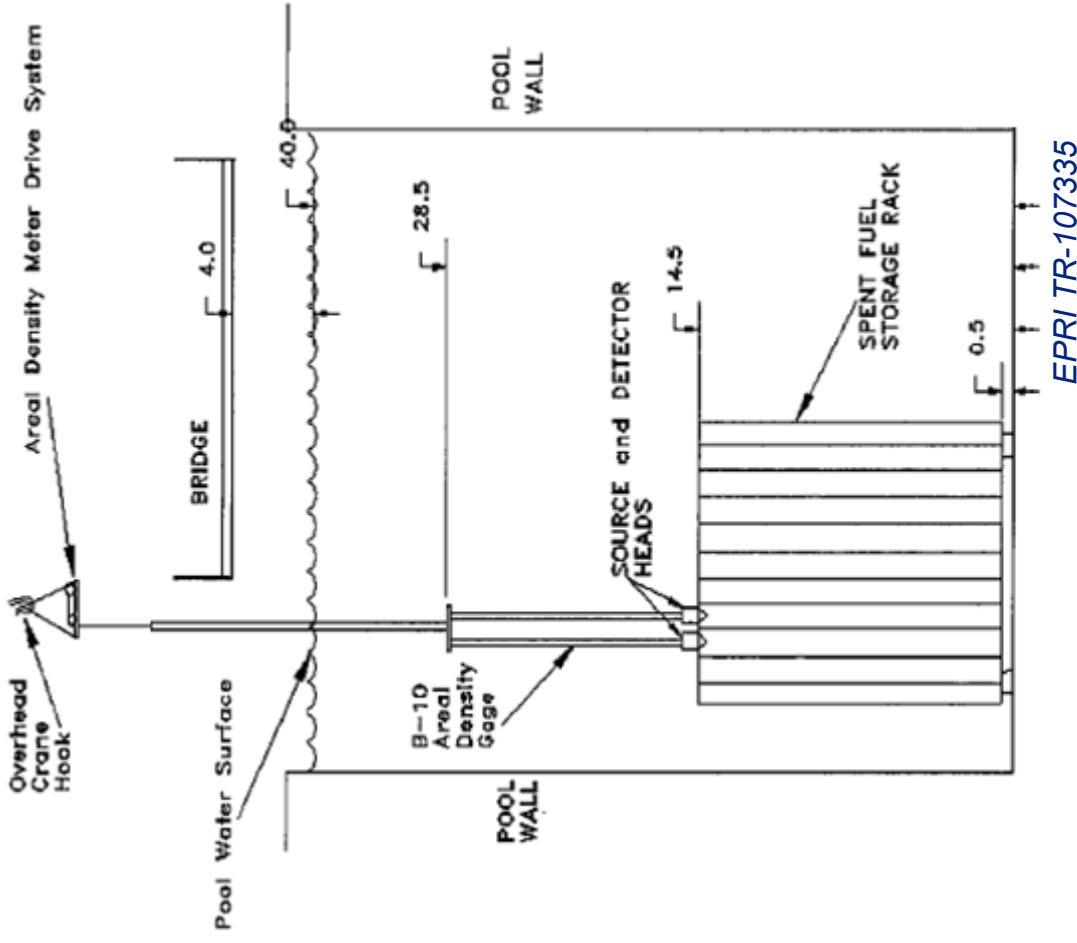


# Background

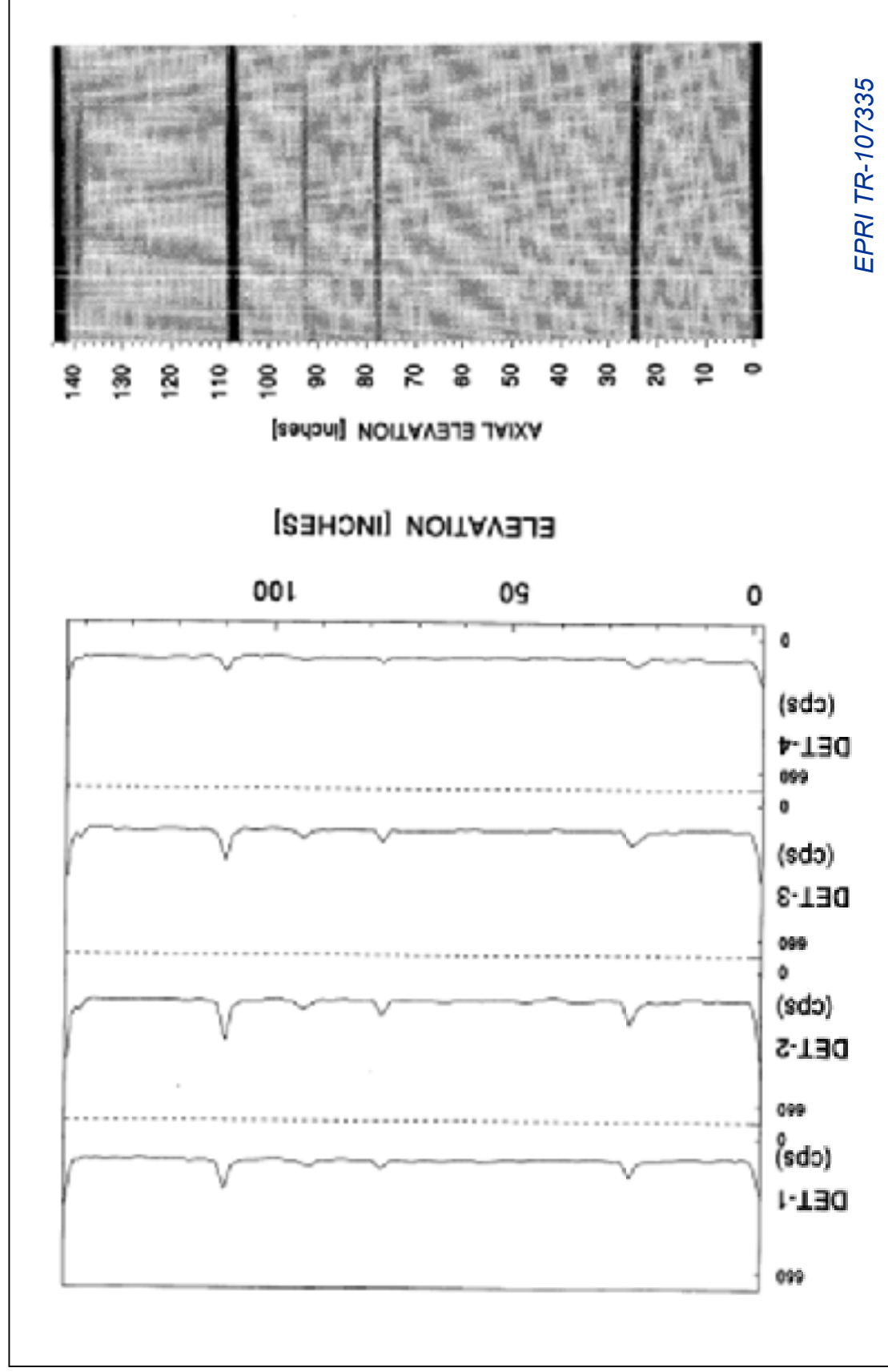
- **Boron Areal Density Gauge for Evaluating Racks was developed in the early 1990's as a result of Boraflex degradation and uncertainty in the RACKLIFE methodology.**
- **Technical Letter Report “Initial Assessment of the Uncertainties Associated with the BADGER Methodology,” September 2012. (ML12254A064)**
- **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  $^{10}\text{B}$  areal density [ $\text{g}(^{10}\text{B})/\text{cm}^2$ ].
- 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.



# BADGER Output



# 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*

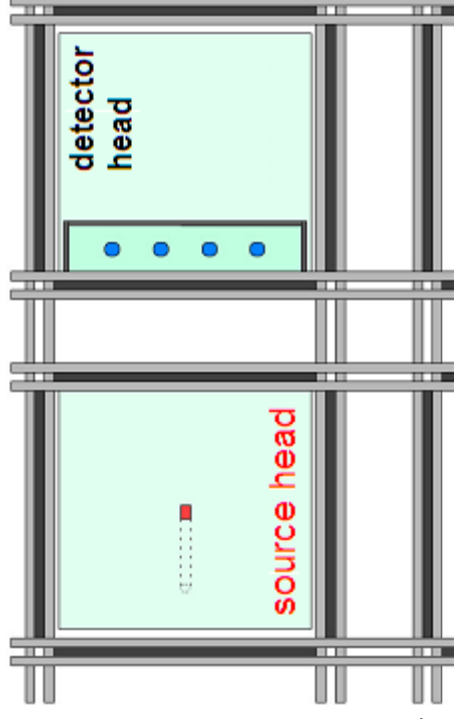
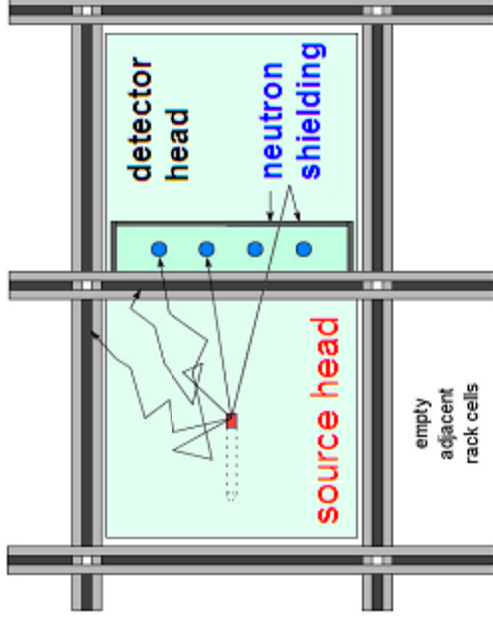
# Uncertainty in BADGER

## 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



*T.C. Haley ,2012*

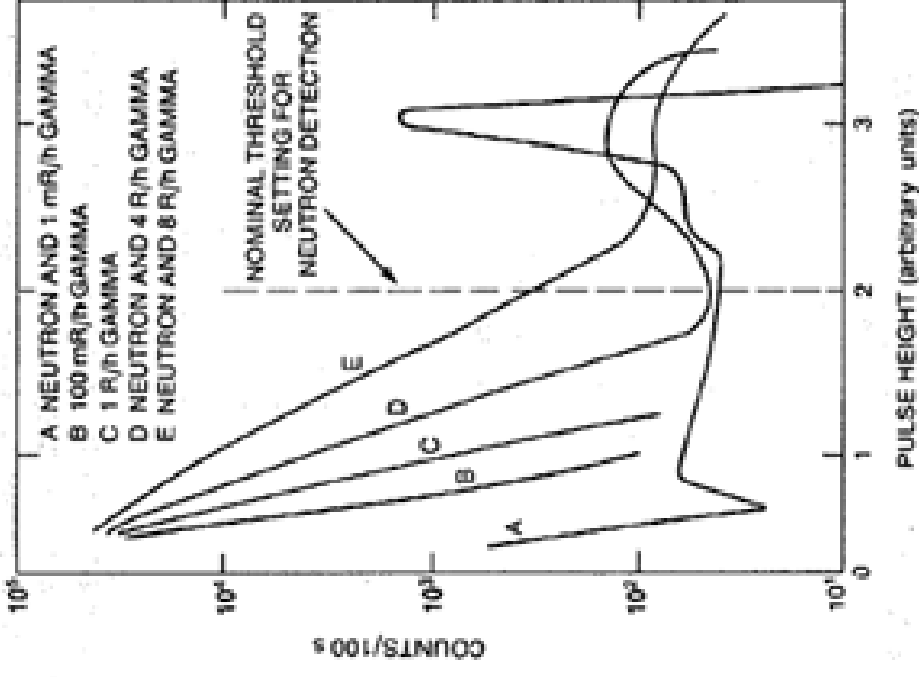
# Uncertainty in BADGER

## 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 <sup>3</sup>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



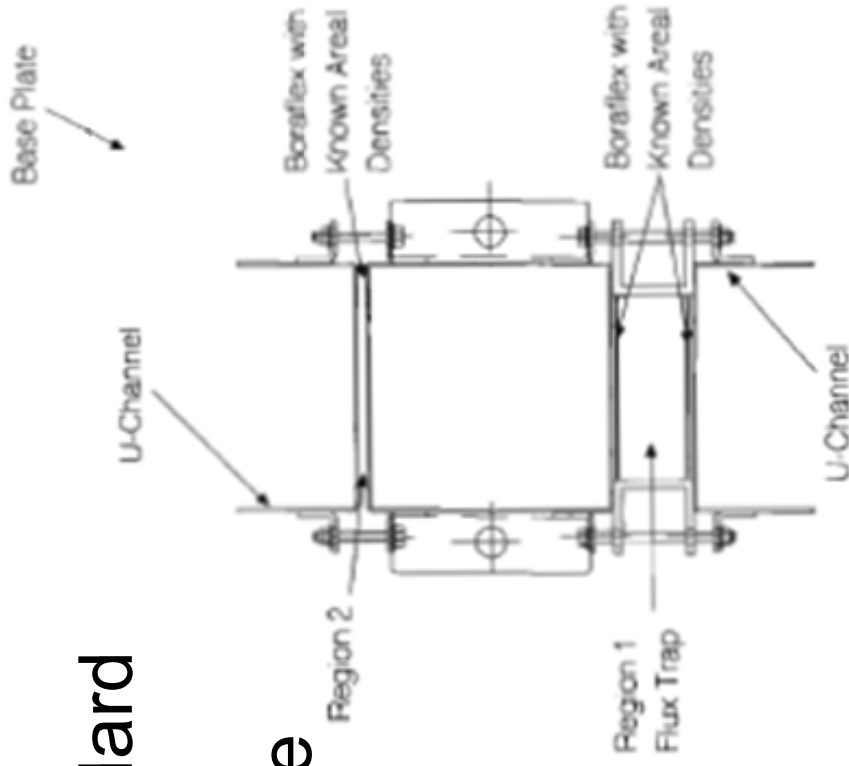
## Uncertainties

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

# Uncertainty in BADGER

## Calibration Method

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



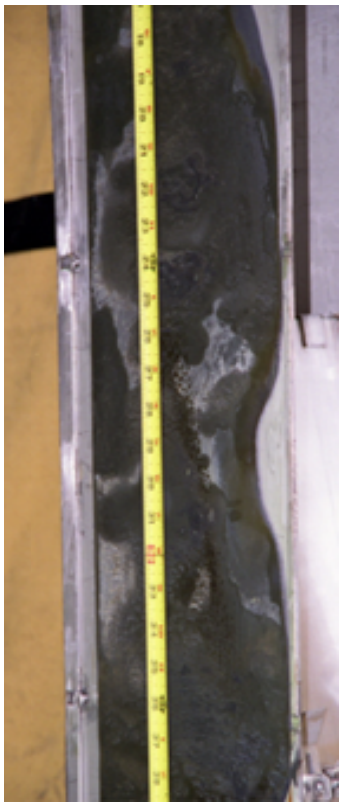
## Uncertainties

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

# 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<br>[inches] | Detector<br>1 | Detector<br>2 | Detector<br>3 | Detector<br>4 |
|-----------------------|---------------|---------------|---------------|---------------|
| 143                   | 3             | 3             | 3             | 3             |
| 141                   |               | 30%           | 30%           |               |
| 139                   |               |               |               |               |
| 137                   |               |               |               |               |
| 135                   |               |               |               |               |
| 133                   | 10%           | 10%           | 10%           | 10%           |
| 131                   |               |               |               |               |
| 129                   |               |               |               |               |
| 127                   | 15%           | 25%           | 5%            |               |
| 125                   | 30%           | 30%           | 30%           | 10%           |
| 123                   |               | 25%           | 1             | 1             |
| 121                   |               |               |               | 20%           |
| 119                   | 4             | 4             | 1             | 1             |
| 117                   |               |               | 4             | 4             |
| 115                   |               |               |               |               |
| 113                   |               |               |               |               |
| 111                   |               |               |               |               |
| 109                   |               |               |               |               |
| 107                   |               |               |               |               |
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| 23                    |               |               |               |               |
| 21                    |               |               |               |               |
| 19                    |               |               |               |               |
| 17                    |               |               |               |               |
| 15                    |               |               |               |               |
| 13                    |               |               |               |               |
| 11                    |               |               |               |               |
| 9                     |               |               |               |               |
| 7                     |               |               |               |               |
| 5                     |               |               |               |               |
| 3                     |               |               |               |               |
| 1                     |               |               |               |               |

# Uncertainty in BADGER

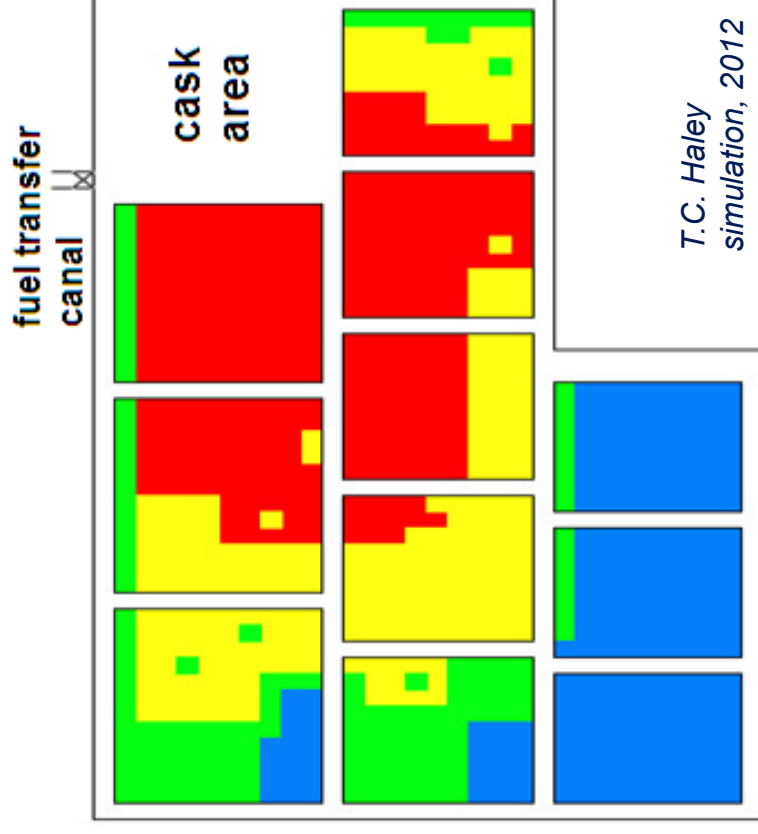
## Panel Selection and

### 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



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



EPRI