BORAL® Spent Fuel Pool Coupon Testing at the University of Texas, Austin

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Overview

- Nuclear Power Plant Spent Fuel & BORAL
- OPPD, FCNS Testing
- Process Overview
- Testing at NETL
- Results & Conclusions

Spent Fuel & Nuclear Industry

- Spent fuel reprocessing option eliminated in 1970's
- Nuclear Waste Policy Act of 1982
  - USDOE contracted to remove spent fuel
  - Utilities pay about 2 cents/rated-kW per quarter
  - National repository scheduled for 1998
- Absence of national repository spurred
  - Development of on-site storage
  - Cooling in spent fuel pools followed by dry storage
  - Modification of SFPs to improve capacity during cooling

NRC Guidance

- April 1978: Review and Acceptance of Spent Fuel Storage and Handling Applications (NRC)

"Prior to 1975, low density spent fuel storage racks were designed with a large pitch, to prevent pool criticality ...."

for modifications to increase capacity by decreasing pitch "Credit may be taken for the neutron absorption in structural materials and in solid materials added specifically for neutron absorption, provided a means of inspection is established."

"...coupon or other type of surveillance testing shall be performed on a statistically acceptable sample size on a periodic basis throughout the life of the racks to verify the continued presence of a sufficient amount of neutron absorber in the racks..."

BORAL®

- Precision, hot-rolled, plate composite
  - Al cladding (1100 series)
  - Core of mixed Al and B_4C particles
- Within practical limits, can be machined & welded
- 35 years production history
- Used at 70 power plants & 11 RRs worldwide

History with NRC Licensees

- Various LERs from surveillances & inspections
- Generic Safety Issue 196: Boral Degradation
- IN 2009-26: Degradation of Neutron-Absorbing Materials in the Spent Fuel Pool

- ASTM C 1187-91 (1999) **Standard Guide for Establishing Surveillance Test Program for Boron-Based Neutron Absorbing Material Systems for Use in Nuclear Spent Fuel Storage Racks**

Surveillance Testing with Neutrons

- Measure neutron transmission
- Analyze attenuation coefficient
- 'First principles' approach problematic
  - Composition
  - Scattering
  - Detector & Measurement geometry
- Comparative Analysis
  - Ratios of measurements of attenuation
  - Comparison of reference, standard, or archive coupons to in-service samples

Calculations

- Exponential attenuation $$I_x = I_0 \cdot e^{-\rho_A \cdot \sigma \cdot \frac{N_A}{AMU}}$$

- Leads to an expression of areal density as a linear function of log of transmission ratio $$\rho_A = -ln\left\{\frac{I_x}{I_0}\right\} \cdot \frac{AMU}{\sigma \cdot N_A}$$

Simple Approximation

- Approximating (ρ_A,I_x:I_0) as a function allows development of a linear response function

$$m = \frac{\rho_{A,2} - \rho_{A,1}}{-ln\left\{\frac{I_{x,2}}{I_0}\right\} + ln\left\{\frac{I_{x,1}}{I_0}\right\}}$$

$$b = \rho_A - ln\left\{\frac{I_x}{I_0}\right\} \cdot m$$

- With error propagation

$$\sigma_m = \left(\rho_{A,2} - \rho_{A,1}\right) \cdot \left[\sigma_{\ln(RATIO),ARC01}{}^2 + \sigma_{\ln(RATIO),ARC02}{}^2\right]^{½}$$

$$\sigma_b = \left(ln\left\{\frac{I_{x,2}}{I_0}\right\} \cdot m\right) \cdot \left(\left(\frac{\sigma_{ln\left\{\frac{I_{x,2}}{I_0}\right\}}}{ln\left\{\frac{I_{x,2}}{I_0}\right\}}\right)^2 + \left(\frac{\sigma_m}{m}\right)^2\right)^{½}$$

Omaha Public Power District, Fort Calhoun Station Unit 1

RE-ST-RX-004 Surveillance test

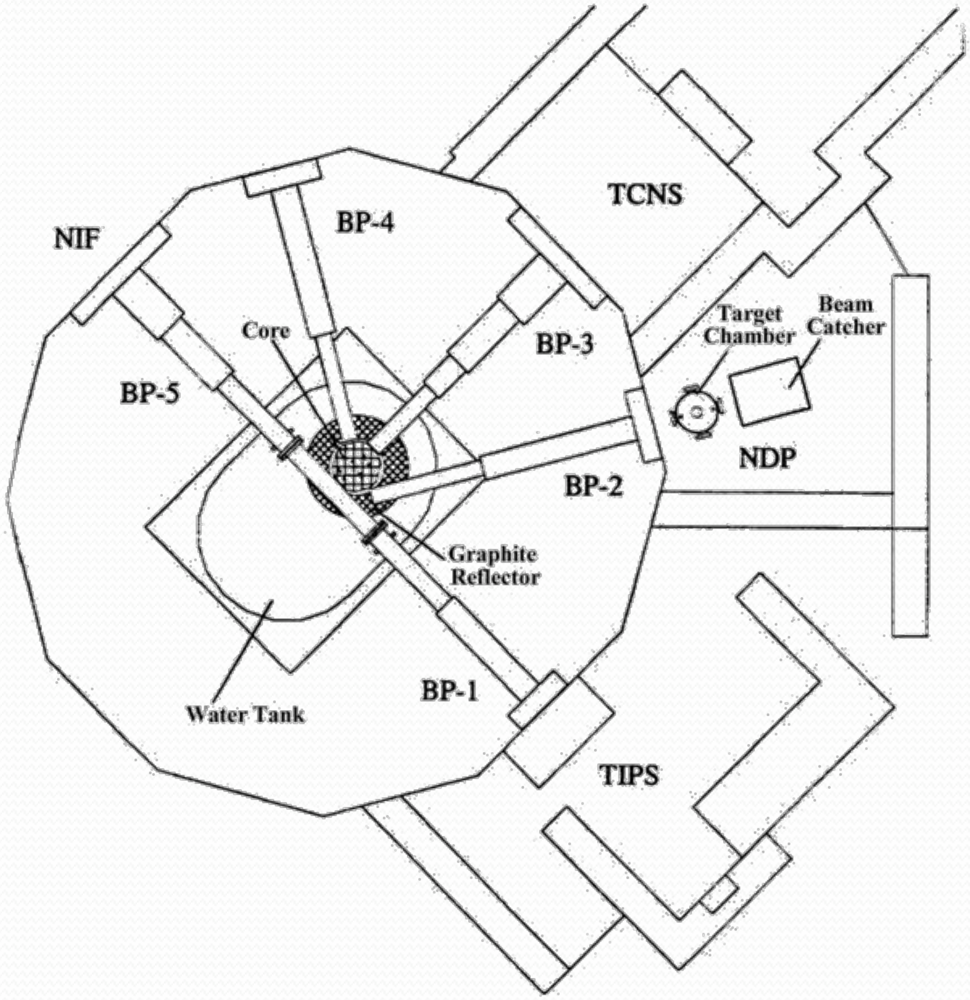
BORAL Sample Coupon Retrieval and Testing

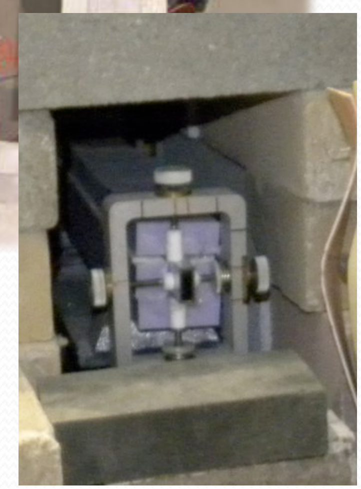
- Technical Specification 3.2: *five-year test interval*
- Neutron Attenuation Tests - An instrumental method of chemical analysis for Boron-10 content using a non-destructive technique in which the percentage of thermal neutrons transmitted through the panel is measured and compared with pre-determined calibration data.
- 7.23 The irradiated and archive coupons are sent to a qualified independent laboratory to obtain for the irradiated coupon, neutron attenuation measurements, specific gravity measurements, and, if required, detailed photographic documentation…

Qualified Independent Laboratories

- University of Michigan Ford Nuclear Reactor (diffracted beam station)
- Kansas State University (tangential thermal beam)
- University of Texas at Austin
  Nuclear Engineering Teaching Laboratory
  - Beam Port 3
  - 6 m curved guide (three 2 m sections)
    - 300 meter radius of curvature
    - 1000 Å ^{58}Ni coating,
    - characteristic wavelength 2.7 Å, 11 meV cutoff
  - 80 cm capillary focusing assembly (gain from 3 to max 4)
  - Neutron energy 0.008-0.0085 eV (94-98°K)
  - Intensity $5x10^6$ n/cm^2-s (Cd ratio 81,000)

NETL Beam Ports

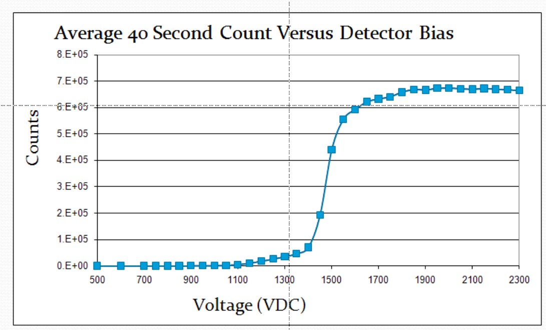




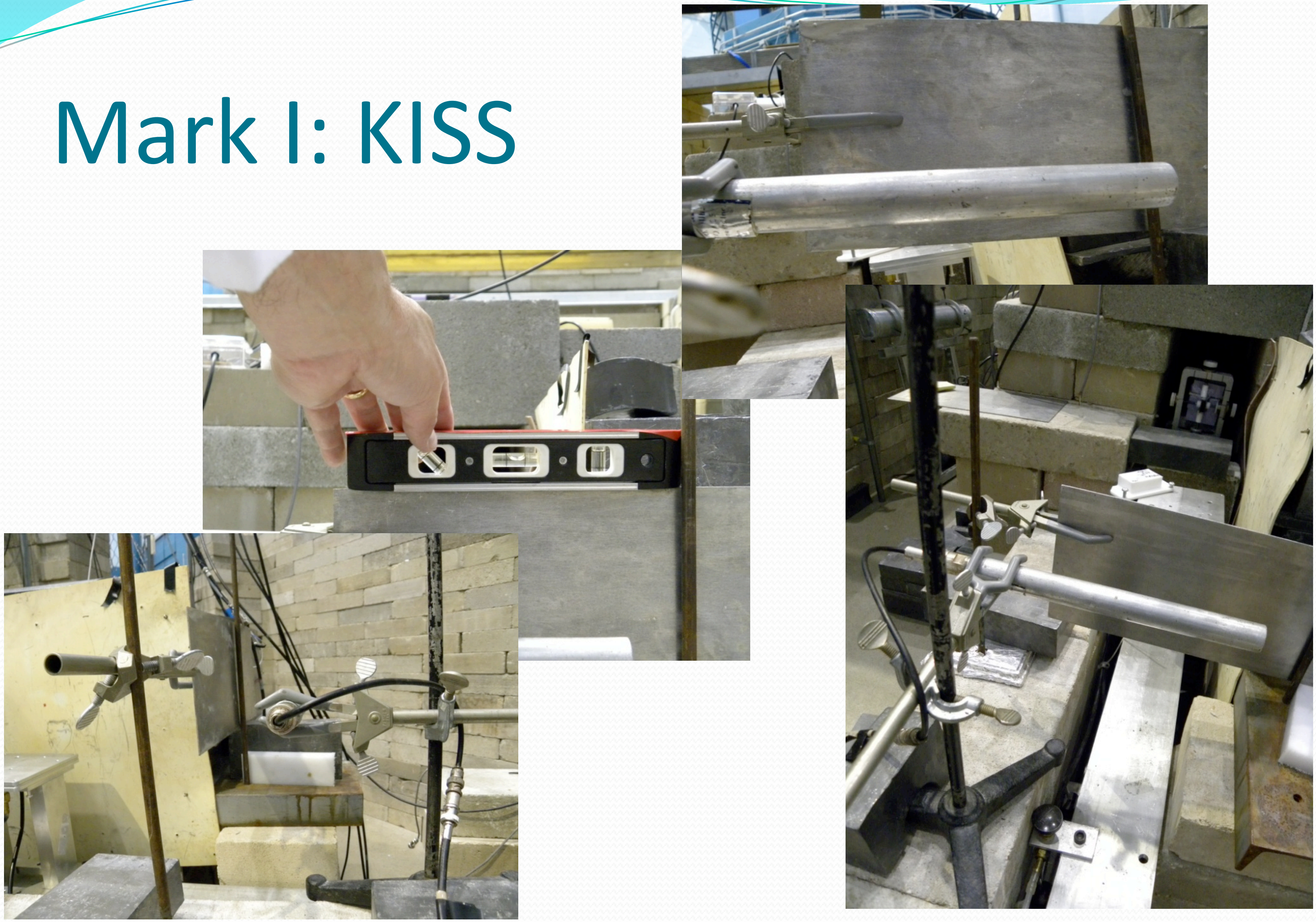
Preparation & Setup

- Coupons received (no data, certification, or procedure)
- System optically aligned
- Detector plateau performed
- Calibration for response versus power level
  - 20 kW did not saturate detector in bare beam
  - Shielded count times of 40 sec provided >10K events

Detector Voltage



Mark I: KISS

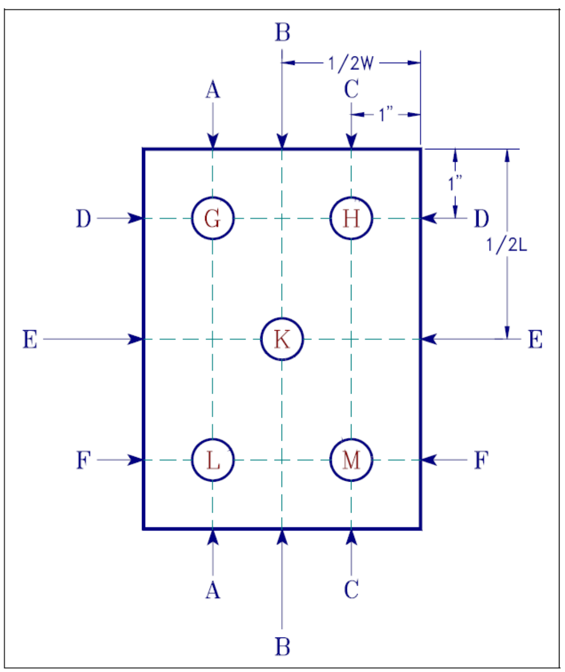


Measurement (Mark I)

- Transmission testing completed with data:
  - Three elevations for each sample/coupon
  - Five positions at each elevation
  - Three times for each measurement location
- Observations
  - Bare beam extremely stable across 60 measurements
    - Average 101173, max 1011858, min 1011521 events
    - Standard deviation 0.007%
  - Standard deviations 2.9% for both archive samples
  - Coupon sample attenuation not bracketed by archive sample attenuation values
  - More variability in 54 coupon sample measurements
    - Average 20293, max 22284, min 18390 events
    - Standard deviation 4%

Received Procedure

- Reference data
- Acceptance criteria
- Initial assay



Initial/Reference Data

	G	K	M	Reference
ARC 01	0.0177	0.0177	0.0177	0.0174
ARC 02	0.0169	0.0166	0.0167	0.0168
Coupon	0.0161	0.0165	0.0163	0.0163

"Reference" is chemical analysis

Acceptable Range: 0.0155 to 0.0163

Evaluation of Results

- Calculated sample areal densities
  - 0.01628 to 0.01668
  - More than ½ of the 9 readings exceeded tolerance
  - Values in the G/M/K positions (2 orientations) 0.01629 (0.01616), 0.01629 (0.01628), 0.01668
- Compared to original transmission data,
  - One orientation matched original assay
  - Center areal density 1% higher than assay
- Original center value assay (0.0165) out of tolerance
- Original measurement indicated non uniform boron

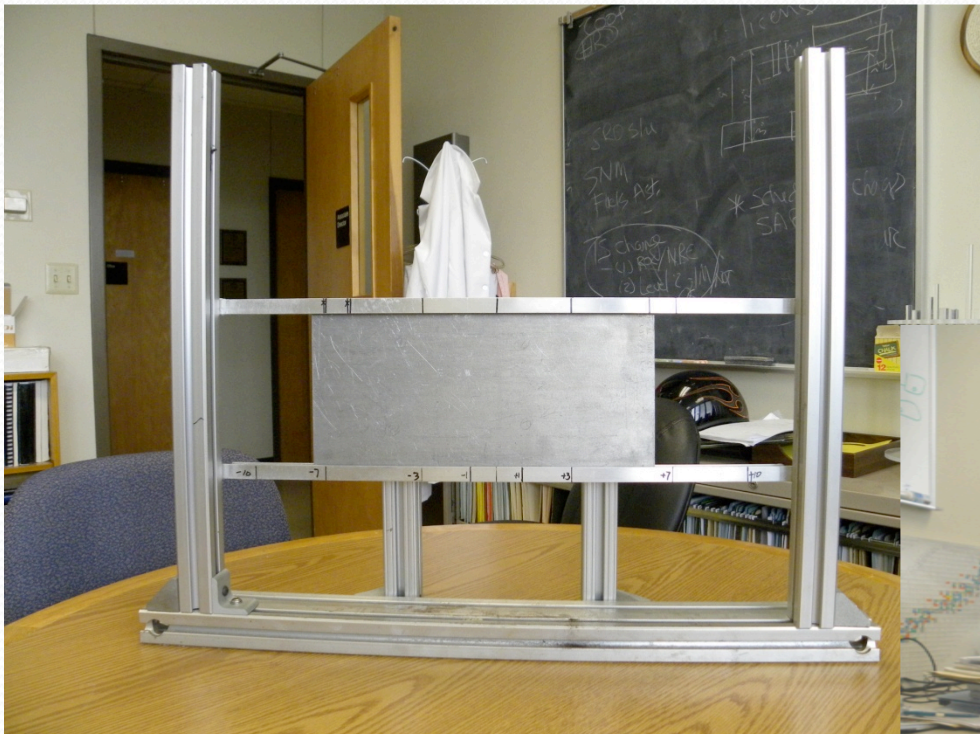
Analysis

- FCNS requested comprehensive error analysis
  - Center areal density outside 1 σ band
- Sample manipulation not overly precise
- Small, divergent beam could lead to
  - Relative position changes between measurements
  - Different optical paths between measurements
  - Variations in scattering contribution between measurements

Mark II

- Developed & used a fixture
  - Detector positioned securely close to sample
  - Sample position precision improved
- Detector aligned to be fully illuminated in beam using neutron radiography camera
- *Detector failure* potentially challenging previous work

Sample Jig



Fixture in Place

Detector Alignment

Results and Conclusions

- Test results were essentially identical
- An out of tolerance condition was observed, but appears to be an artifact of the test specification
- Based on original transmission data, there is strong indication that the boron content of the coupon has not degraded by service conditions
- The NETL BP 3 neutron beam is well suited for spent fuel coupon transmission testing
  - Stability
  - Neutron energy
  - System configuration