NEI 12-16, "Guidance for Performing Criticality Analyses of Fuel Storage at Light-Water Reactor Power Plants"

NRC/NEI Meeting on SFP Criticality Guidance

Oct. 31st 2013 • Rockville, MD

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Introduction and Meeting Objectives

Kristopher Cummings
Senior Project Manager, Used Fuel

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Agenda

Time	Subject	Presenter
9:00 am	Welcome, Introductions and Meeting Purpose	Kris Cummings, NEI
9:15 am	Overview of EPRI Sensitivity Studies	Hatice Akkurt, EPRI
9:45 am	NFV/SFP Rack Model	Stefan Anton, Holtec
10:15 am	Rack Manufacturing Tolerances	Stefan Anton, Holtec
10:45 am	**Break**	
11:00 am	Fuel Assembly in the Storage Rack	Dale Lancaster, Nuclearconsultants.com
11:30 am	NFV/SFP Operating Conditions	Dale Lancaster Nuclearconsultants.com
12:00 pm	**Lunch**	
1:00 pm	Scenarios/Storage Configuration	Robin Jones, Southern Company

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Agenda (cont.)

Time	Subject	Presenter
1:30 pm	Neutron Absorbers	Matt Eyre, NETCO
2:15 pm	Neutron Absorber Survey	Kris Cummings, NEI
2:45 pm	**Break**	
3:00 pm	Neutron Absorber Testing Programs	Zita Martin, TVA
4:15 pm	Rack Interfaces	Kris Cummings, NEI
4:45 pm	Summary of Actions Captured	Kris Cummings, NEI

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Meeting Purpose

- Reach resolution on methods to be used in spent fuel pool criticality analysis
- Focus on issues around modeling of the fuel storage rack and neutron absorbers.
- Identify areas needing additional description, justification or explanation in NEI 12-16.

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Overview of EPRI Sensitivity Studies

Hatice Akkurt[1] and Albert Machiels[2]
[1]Senior Project Manager
[2]Senior Technical Executive

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Background and Objectives

- A set of sensitivity computations will be performed to determine the impact of certain parameters on the criticality analysis of spent fuel pools in support of NEI12-16 Guidance document.
- The parameters, based on the discussion from the 1st Public Meeting, include
    1. PWR manufacturing tolerances
    2. PWR borated cases
    3. In-core detector tube impact
    4. Burnable absorbers

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General Specifications for Sensitivity Analysis Computations

- Scale 6.1 with ENDF/B-VII 238-group cross-section library
- TRITON (t5-depl) module for depletion
- Depletion Parameters
  - Soluble Boron Concentration: 900 ppm
  - Fuel temperature: 1050 K
  - Moderator Temperature: 616 K
  - Moderator density: 0.60208 g/cm^3
- Analysis will be performed for
  - Westinghouse 17x17: Guide tube in fuel rod locations
  - CE 16x16: Large guide tubes, each replaces 4 fuel rods
- All the analysis will be performed at a single cooling time (100 hrs)
- Axially uniform burnup

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1. PWR Fuel Manufacturing Tolerances

- Analysis will be performed to show the effect of manufacturing tolerances on **guide tubes** and **instrumentation tube** on reactivity
  - **Expected result: insignificant effect on reactivity of the system after statistical combination of uncertainties**
- Analysis will also be performed to show the effect of manufacturing tolerance on **cladding inner diameter** on reactivity
  - **Expected result: insignificant effect on reactivity of the system after statistical combination of uncertainties**

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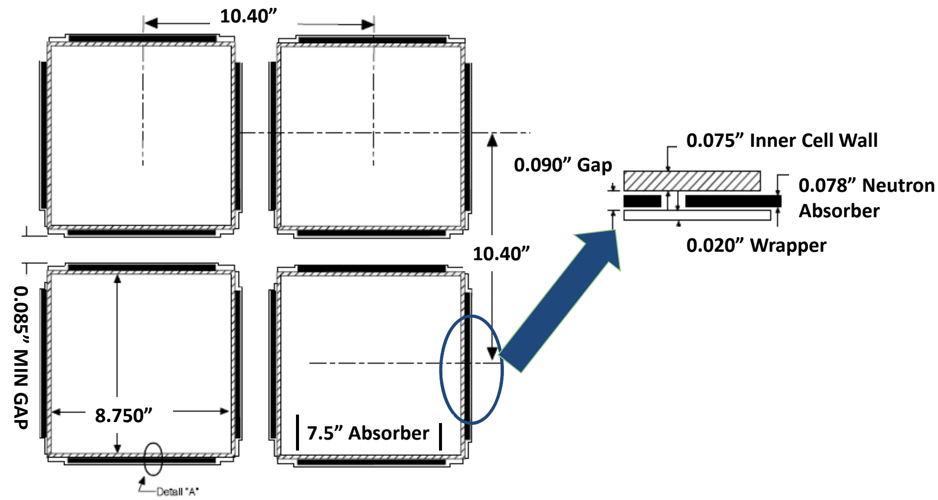
1. PWR Fuel Manufacturing Tolerances

- Reactivity from **Guide tube tolerance** is from displacing water.
- Reactivity from changes in the fuel rod **cladding OD** are due to displacing water.
  - **Expected result: the reactivity effect of the water around the fuel rod is always greater than or equal to the reactivity effect of the water around a guide tube**

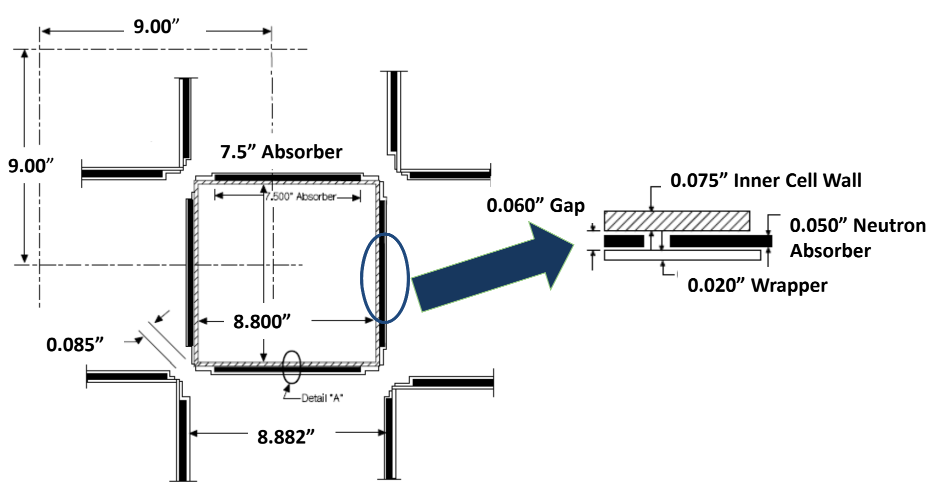
1. PWR Fuel Manufacturing Tolerances

- If uncertainty A is less than 10% of uncertainty B, uncertainty A makes a negligible contribution to the total uncertainty. This result is due to the statistical combination where the total uncertainty is calculated by the square root of the sum of the squares.
- Since the number of guide tubes is less than 10% of the number of pins in the assembly, if the reactivity effect of the guide tube tolerance is similar to that of fuel cladding tolerance, it should be possible to eliminate the requirement for calculation.

Rack Geometries – Region 1



Rack Geometries – Region 2



1. PWR Fuel Manufacturing Tolerances

Region 1

Areal Density (g/cm²)	Enrichment (wt%)	Burnup (GWd/T)
0.030	5	Fresh Fuel
0.015	3.5 and 5	0 and 10
None	2	0 and 20
	3.5 and 5	0; 20; 40

1. PWR Fuel Manufacturing Tolerances

Region 2

Areal Density (g/cm²)	Enrichment (wt%)	Burnup (GWd/T)
0.030	2	0
	3.5	0 and 30
	5	0; 30; 60
0.015	2	0
	3.5	0 and 30
	5	0; 30; 60
None	2	0
	3.5	0 and 30
	5	0; 30; 60

2. PWR Borated Cases

- Determine the amount of soluble boron needed to cover possible changes in reactivity effect of uncertainties under borated conditions rather than unborated conditions.
- Determine the maximum reactivity effect of grids at 2000 ppm.
- Determine the soluble boron needed to offset the reactivity effect of tolerances at 2000 ppm.

3. In-core Detectors in Instrument Tube

- Perform the analysis for a limited set of calculations to determine the reactivity effect of using voided instrument tube depletion compared to non-voided instrument tube
  - With focus on high burnup cases to maximize the reactivity effect of the in-core detector presence
  - Perform the analysis for both small and large guide tubes

4. Burnable Absorbers

- **Gadolinium (Gd),** a limited number of computations will be performed for Gd to confirm that it is conservative to ignore Gd pins.
  - Analysis will be performed for a small number of cases that were not analyzed in previous studies
- **Erbium (Er)** is adequately analyzed in previous studies.
  - Discussion will be provided with no further computations

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Summary

- Sensitivity analysis will be performed to determine the impact of certain parameters on criticality, including
  - Manufacturing tolerances, borated vs. non-borated
  - In-core detectors in instrument tube
  - Burnable absorbers
- The proposed set of analysis was selected based on the discussions during the 1st Public Meeting for NEI Guidance Document
  - Feedback is requested to avoid any disconnect between the NRC and Industry expectations
- The scope of the sensitivity analysis will be expanded based on discussions at the subsequent meetings

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Questions/Comments?

New Fuel Vault and Spent Fuel Pool Storage Rack Models

Stefan Anton
Vice President of Engineering, Holtec International
NRC/NEI Meeting on SFP Criticality Guidance
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Storage Rack Designs

- New Fuel Vaults (NFVs)
  - Typically large cell pitch, no poison, fuel locations may or may not have walls, dry
  - Alternatively, Region 1 Racks may be used (see below)
  - Fully flooded and optimum moderation conditions analyzed (accidents)

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Storage Rack Designs

- Spent Fuel Pool
  - Typically Stainless Steel and Neutron Poison
  - Typically two racks types in the pool, both with solid cell walls with attached neutron absorbers
    - “Region 1”: Larger cells pitch, flux trap (PWR only, fresh fuel)
    - “Region 2”: High density, no flux trap (PWR spent fuel, BWR)
  - Some alternative configurations
    - Single type (Region 2) with fuel configurations for fresh fuel
    - Aluminum
    - No Poison

Important Aspects

- Geometry
- Materials and Material configurations
- Fuel location/configuration
- Accidents
- Convergence

Geometric Models

- Axial
  - Infinite (BWR)
  - Finite (PWR with axial burnup profiles)
    - Everything above and below the active region is modeled as pure water (SFP)
    - Structures outside of the active region partially modeled (e.g. concrete floor in NFV)

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Geometric Models

- Lateral
  - Infinite
    - Single cell, reflective Boundary Condition (BC)
      - May require some model simplification, see further discussion
    - 2x2 array, periodic boundary conditions
      - Non-uniform loading of assemblies (e.g. checkerboard)
      - Avoid model simplifications
  - Finite
    - Defined section (e.g. 5x5 cells); whole rack; whole pool
      - Credit lateral leakage / consider lateral reflection
      - Accidents (e.g. misloading, mislocation)
      - May enable higher reactive assemblies on rack/pool periphery
        - Small rack-to-wall distance may need to be considered

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Geometric Models

- Infinite vs Finite
  - How many cells/rows in a finite model make it equivalent to an infinite model for interface or accident models?

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Geometric Models

- Simplifications
  - Non-symmetric walls (formed and resultant cells)
    - Example 1:
      - Actual 0.1” steel, 0.1” poison, 0.05” steel
      - Model 0.075” steel, 0.1” poison, 0.075” steel
      - Results are expected to match
    - Example 2:
      - Actual 0.5” steel, 0.1” poison, 0.05” steel
      - Model 0.275” steel, 0.1” poison, 0.275” steel
      - Results are not necessarily expected to match

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Geometric Models

- Homogenizing areas with different materials
  - Be careful homogenizing absorber with other materials
- Other simplifications
  - Ignore welds, small structural parts, grid straps
  - How much justification is needed, what can be covered generically to avoid repetition of calcs to prove again and again something does not exist

Materials

- Compositions of standard materials are not critical
  - Standard material compositions (MCNP, SCALE) are acceptable for standard materials such as stainless steel
  - Zirconium Alloys can be modeled as pure zirconium
- Exception for NFV optimum moderation condition
  - Dominating moderator is the hydrogen in the concrete, so the hydrogen concentration in the concrete can be important.

Fuel Location

- Axial alignment of active region and neutron poison
  - Mostly not a problem, but there are (older) racks that have poison shorter than the active region; needs to be considered
  - “transient” conditions during insertion of an assembly into a cell.

Convergence

- Larger models may require large numbers of generations / particles
- Initial source distribution may be uniform, or already focus on point of interest (e.g. misloaded assembly)
- MCNP5 uses a Shannon Entropy Convergence test
  - Convergence of the source distribution is tracked
  - Considered conservative when utilized as k-eff convergence
- If the “point of interest” is not the area that dominates reactivity, any change at the “point of interest” may have no effect on reactivity.
  - May result in cliff-edge effects.

Questions?

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New Fuel Vault and Spent Fuel Pool Storage Rack Manufacturing Tolerances

Stefan Anton
Vice President of Engineering, Holtec International
NRC/NEI Meeting on SFP Criticality Guidance
October 31st 2013 • Rockville, MD

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New Fuel Vault Storage Rack Manufacturing Tolerances

- Calculations should be performed for both Optimum Moderator Density and Full Moderator Density
- Important Parameters
  - Cell/Storage Location Pitch
  - Storage Cell Wall Thickness (if present)
  - Flux Trap Size (if present)
  - Poison Width (if present)
  - Poison Loading/Density (if present)

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Spent Fuel Pool Storage Rack Manufacturing Tolerances

- Calculations should be performed for all qualified loading configurations in each rack design using the bounding case
- Important Parameters
  - Cell/Storage Location Pitch
  - Storage Cell Wall Thickness
  - Flux Trap Size (if present)
  - Poison Width (if present)
  - Poison Loading/Density (if present)

Questions?

Fuel Assembly in the Storage Rack

Dale Lancaster
NuclearConsultants.com
NRC/NEI Meeting on SFP Criticality Guidance
October 31st 2013 • Rockville, MD

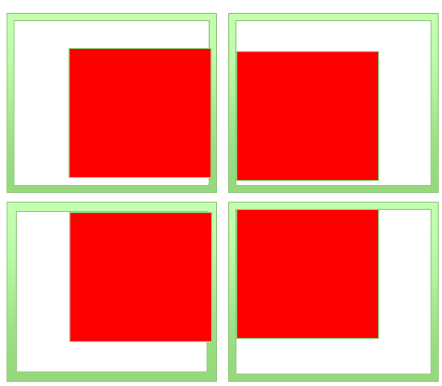
Issues

- Part Length Absorber Panels
- Eccentric Positioning of Assemblies
- Credit for Guide Tube Inserts
- Static/Dynamic Conditions
- Channels in BWR Analysis

Less than Full Length Absorber Panels

- Selection of axial burnup profiles must be performed under rack conditions.
- Historical determinations on limiting axial burnup profiles assumed full length absorber panels.
- The NUREG/CR-6801 burnup profiles do not apply to racks which are not uniform axially.
- Also non-uniform degradation of absorbers requires condition specific ranking of axial burnup profiles.

Eccentric Positioning of Assemblies



Eccentric Positioning of Assemblies

- The location of assemblies in the cell is random within the boundaries of the cell walls.
- This is directly analogous to thickness of clad within the tolerance.
- In order for four assemblies to reach the criticality limits some of the other parameters need to be on the reactive side of the tolerance.
- Each assembly placement is independent of the placement of other assemblies.
- Assume 4 assemblies are eccentrically located and determine the reactivity difference from the reference condition (centered).
- The calculated reactivity should be considered a 2 sigma uncertainty that can be statistically combined with other uncertainties.
- The limiting condition is often with centered assemblies but both conditions shall be analyzed.
- Larger arrangement (greater than 2x2) of assemblies skewed to a central point is unnecessary since the effect is small and we are already counting 4 random events as one.

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Credit for Guide Tube Inserts

- Credit can be taken for:
  - Used control rods (depletion can be ignored)
  - “Moderator displacement only” for used burnable absorbers
  - New burnable absorbers (flux in pool is too small to significantly deplete a burnable absorber)
  - Used Hf inserts (occasionally used for Pressurized Thermal Shock mitigation)

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Static/Dynamic Conditions

- All normal operating conditions should be considered in the analysis.
- Must consider temporary storage positions.
- All places the fuel can be located must be considered in the analysis.
- Most limiting condition is the static condition.

Channels in BWR Analysis

- Analyses of BWR new fuel vaults and spent fuel pools must consider assemblies with and without channels.

Other Issues?

NFV/SFP Operating Conditions

Dale Lancaster
NuclearConsultants.com
NRC/NEI Meeting on SFP Criticality Guidance
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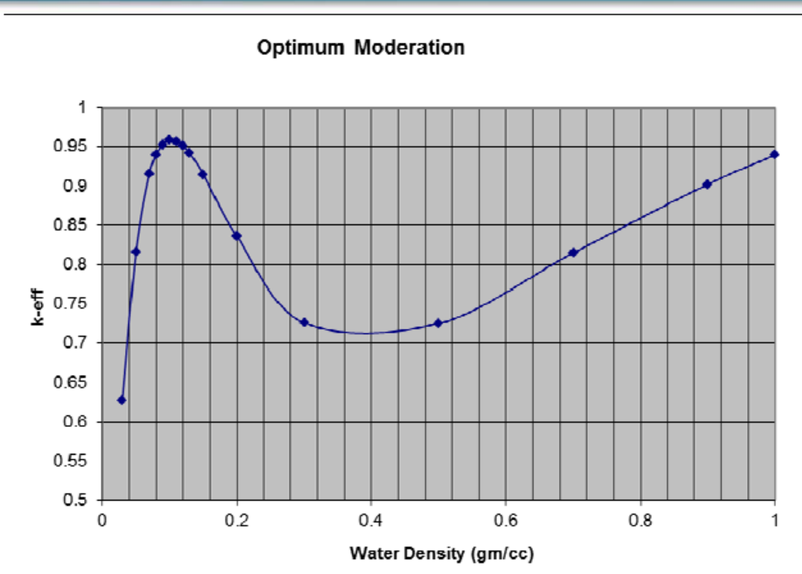
Topics

- New Fuel Vault (NFV) analysis
- SFP temperatures
- SFP soluble boron credit

New Fuel Vault Analysis

- New Fuel Vaults can be open air racks in a large room. For these types of racks full flooding can be shown not to be credible. However, low density moderation (due to fire protection) must be considered.
- Optimum moderation constraint is 0.98 whereas full flooding criteria is 0.95.
- A low density moderation exception is allowable per 10CFR50.68 paragraph 3 using administrative actions such as removal of fire protection sprayers.



Spent Fuel Pool Temperature

- Must consider high and low temperature in the operating range (includes maximum density temperature, 4° C).
- In absence of neutron absorbers, most limiting condition can be highest temperature in the operating range.
- Temperatures outside of the operating range are covered by soluble boron.
- Analysis of low moderator density conditions is not required.

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Spent Fuel Pool Soluble Boron Credit

- Limiting condition is the unborated condition (k<1), which determines the burnup/enrichment limits
- Normally, less than half of the Tech Spec soluble boron amount is needed to demonstrate compliance with $k_{eff} < 0.95$
- For accident conditions credit of all the Tech Spec soluble boron is allowed (double contingency principle).

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Other Operating Conditions Topics?

Scenarios/Storage Configuration

Robin D. Jones
Core Analysis Supervisor, Southern Nuclear
NRC/NEI Meeting on SFP Criticality Guidance
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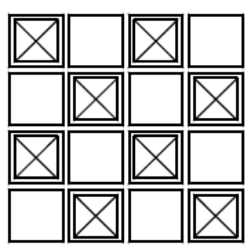
Background

- Storage of nuclear fuel in spent fuel pools was originally quite simple most of the time:
  - Fuel below a certain enrichment could be stored in any cell and in every cell
- Then in the late 80's and early 90's the industry began looking at more complex controls to deal with a couple of issues:
  - The use of higher enrichments approaching the legally allowed 5.0 w/o
  - BORAFLEX degradation

Types of Limits

- The simplest limit was to allow credit for empty storage cells by restricting that there be only two or three assemblies in a designated checkerboard storage pattern using four storage cells
- "Burnup Credit" allowed the industry to take credit for the reduction in reactivity due to fuel burnup
- Additional cooling time allowed industry to take credit for reduction in reactivity with time (actinide decay)
- Credit was taken for various burnable absorbers – primarily in fresh fuel
  - Integral absorbers could be easily credited since they could not be removed
  - Discrete absorbers were used in analyses less frequently

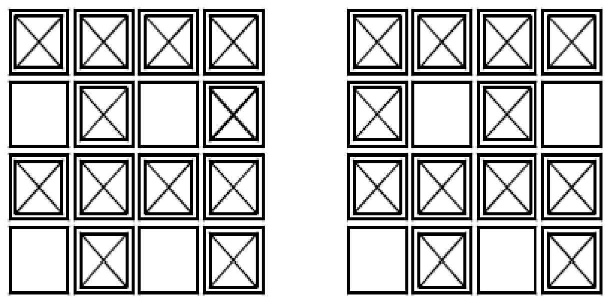
Credit for Empty Cells – 2 of 4



2-out-of-4 Checkerboard Storage (Unit 2)

☐ **Empty Storage Cell** ☒ **Fuel Assembly in Storage Cell**

Credit for Empty Cells – 3 of 4

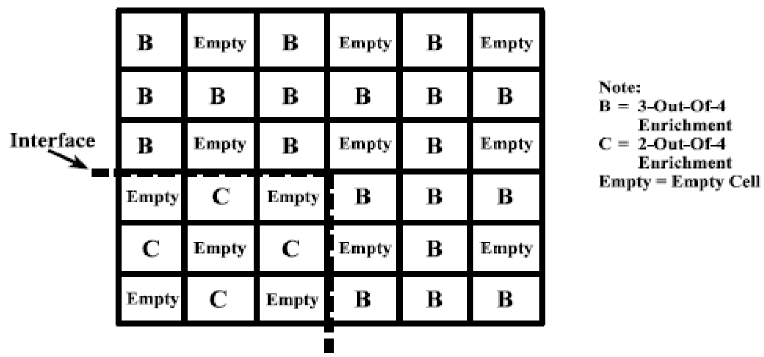


3-out-of-4 Checkerboard Storage (Units 1 and 2)

Interfaces Between Configurations

- An additional complexity is assuring that the “interfaces” between different 2x2 configurations are being implemented appropriately
- Any 2x2 “box” that can be drawn is required to meet the Tech Spec loading patterns

Credit for Empty Cells – Interfaces



Boundary Between 2-out-of-4 Storage and 3-out-of-4 Storage

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Usage of Burnup and BA Credit

- Both burnup and burnable absorbers are normally credited so that each cell can be used
- Some combination of **L**ow reactivity fuel (based upon enrichment/burnup) is stored with **H**igh reactivity fuel (based upon enrichment/# of absorbers) – examples have been provided on the following slides

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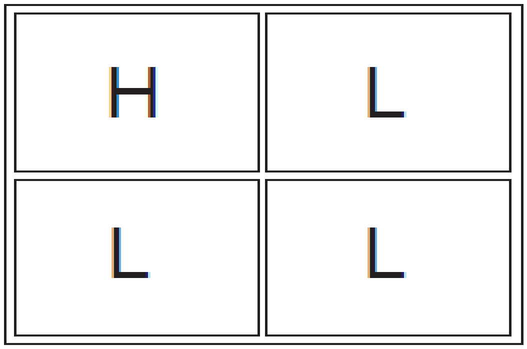
Configuration Using Burnup and BA Credit



Burned/Fresh Storage

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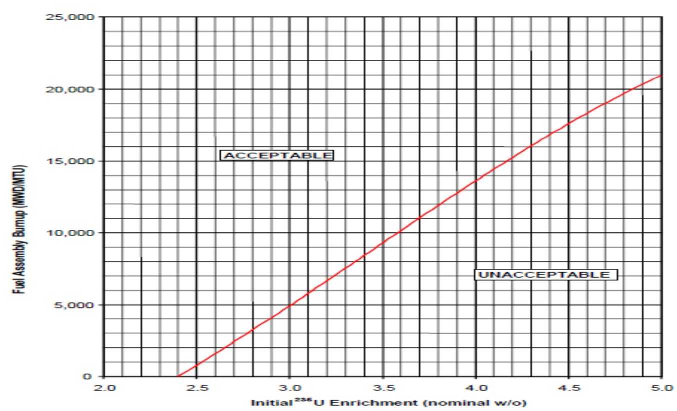
Burnup Credit



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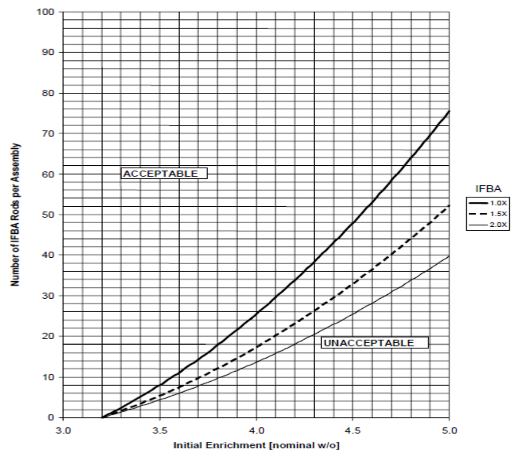
IFBA Credit



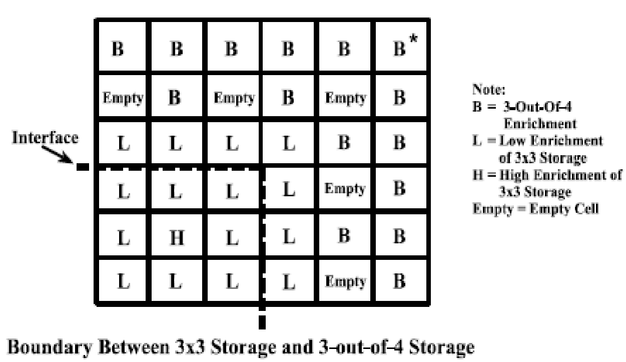
… And When 2 by 2 Configurations Won't Work

- In order to use every cell, sometimes the burnup/BA requirements are so restrictive in a 2x2 configuration, a 3x3 configuration may be needed
- Interface issues tend to be a major consideration when implementing 3x3 configurations

Interfaces Between 3x3 Configurations

- Again, an additional complexity is assuring that the "interfaces" between different 3x3 and 2x2 configurations are being implemented appropriately
- All 3x3 or 2x2 "box" that can be drawn across the inerfaces is required to meet the Tech Spec patterns

Interfaces Between 2X2 and 3X3 Configurations



Other Absorbers

- Though SNC uses IFBA, other burnable absorbers such as Gd and Er can also be used
- “Non-burnable” absorbers can also be used, such as hafnium, used control rods or even unburned WABA’s
  - However, such absorbers are normally placed in GT’s or IT’s (in PWR’s)
  - The inserts can only be removed or inserted when the fuel assembly is in a location where credit for the insert is not required

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Storage Cell Blocking Devices

- Blocking devices are physical hardware installed to prevent inadvertent placement of a fuel assembly in the storage cell.
- Blocking devices provide an additional human performance barrier to misplaced fuel assemblies.
- Presence of the blocking device can be credited to prevent a possible misloading accident.

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QUESTIONS??

Neutron Absorbers

Matt Eyre
Director - NETCO
NRC/NEI Meeting on SFP Criticality Guidance
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Background

- Many different neutron absorbers used/credited in commercial spent fuel storage racks
  - **Boral®**
  - Metamic®
  - Boralcan®
  - Neutronit®
  - **Boraflex**
  - Carborundum
  - Tetrabor®

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Discussion Agenda

- Material description
- Degradation mechanism
- Observation summary
- Other information

Boral®

- Material
  - Aluminum boron carbide cermet
  - 1100 aluminum alloy clad
  - Aluminum, boron carbide core (exposed at edges)
  - B_4C content up to 67 vol.% in the core
- Degradation mechanism
  - General & localized corrosion
- Observations (coupon tests)
  - Blisters: no effect on functionality
  - Pitting: no effect on functionality
- BADGER
  - No unusual or unexpected results
- Other information
  - Boral accelerated corrosion test underway
    - 5-year program

Metamic®

- Material
  - 6061 aluminum boron carbide metal matrix composite (MMC)
  - Produced by powder metallurgy
  - Boron carbide content up to 33 wt.%
- Degradation mechanism
  - General & localized corrosion
- Observations (qualification & surveillance coupon tests)
  - Pitting: no effect on functionality
- Other information
  - First MMC widely used for spent fuel storage racks
  - EPRI qualification report TR-1003137, October 2001
    - No effect of gamma irradiation up to $1.5x10^{11}$ rads
      - No change to dimensions, density or areal density of test coupons

Boralcan®

- Material
  - 1100 aluminum alloy boron carbide MMC
  - Produced by molten metal chill casting
  - Boron carbide content 16-40 vol.%
- Degradation mechanism
  - General & localized corrosion
- Observations (qualification & surveillance coupon tests)
  - Pitting: no effect on functionality
- Other information
  - "Quick Start" performance confirmation at LaSalle

Neutronit®

- Material
  - A887 stainless steel alloy
  - Produced by powder metallugy
  - Boron content up to 1.9 wt.%
- Degradation mechanism
  - General & localized corrosion
- Observations (qualification, surveillance & special tests)
  - Pitting: no effect on functionality
- Other information
  - Very limited US spent fuel pool use
  - Extensive world-wide use
  - Pitting reports from tests associated with pool storage in Spain

Boraflex

- Material
  - Silicone matrix with boron carbide & crystalline silica filler
  - General proportions:
    - 50 wt.% boron carbide,
    - 25 wt.% silicone, 25 wt.% silica
- Degradation mechanisms
  - Irradiation cross-linking
    - Shrinkage/densification (~4%), gaps/cracks
    - No material loss; measured areal density increase
  - Irradiation/water conversion of matrix to amorphous silica
    - Amorphous silica is soluble in water
    - Leads to material loss/relocation
- Observations (coupon monitoring)
  - Shrinkage, gaps, embrittlement, material loss
- BADGER
  - Gaps, general dissolution
- Other information
  - Boraflex is no longer commercially available

Carborundum

- Material
  - Boron carbide in phenol formaldehyde resin matrix (plate)
  - Boron carbide in resin matrix with fiberglass reinforcement (sheet)
- Degradation mechanism
  - Gamma irradiation damage to resin matrix
  - Water interaction with resin matrix
- Observations
  - Coupon monitoring shows acceptable performance
  - Recent BADGER test noted no loss of functionality
  - At one unit, swelling of rack inner walls (plate)
    - BADGER test identified areal density reduction
- Other information
  - Carborundum is no longer commercially available

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Tetrabor

- Material
  - Phenolic resin binder with boron carbide & graphite filler
  - Up to 50% boron carbide
- Degradation mechanism
  - Similar to Carborundum
- Observations (coupon monitoring)
  - No significant dimensional or weight change
  - No significant change to areal density
- Other information
  - Tetrabor is no longer commercially available

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Summary/Conclusion

- Majority of neutron absorber materials have not seen degradation/corrosion that effect the safety function of the material.
- Continue to monitor and test neutron absorbers to assess long term performance.
- Boraflex has a significantly different degradation process that is not applicable to more modern neutron absorbers.

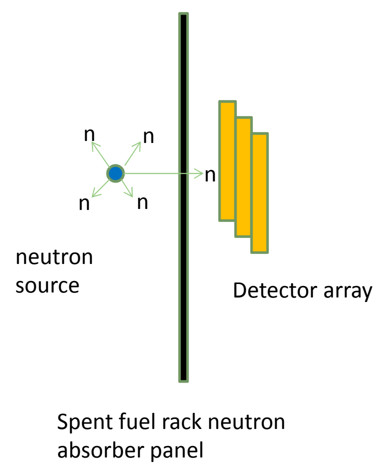
BADGER

Matt Eyre
Director - NETCO
NRC/NEI Meeting on SFP Criticality Guidance
October 31st 2013 • Rockville, MD

BADGER

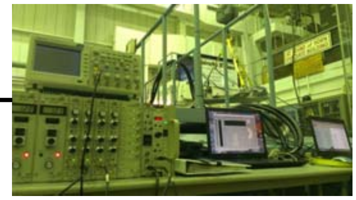
Boron-10 Areal Density Gage for Evaluating Racks

- The BADGER system was developed by NETCO for the Electric Power Research Institute (EPRI).
- BADGER is a device which performs in-situ measurements of boron-10 areal density of the neutron absorber material installed in spent fuel racks for the purpose of reactivity control.
- BADGER utilizes a neutron source and detector array to measure neutron transmission through the spent fuel rack absorber panel.
- The neutron source is enclosed in the BADGER source head.
- The detector array is enclosed in the BADGER detector head.



BADGER System Overview

Drive Mechanism
The drive mechanism hangs from a fuel handling system hoist. It houses the drive motor, cable drum, position encoder & signal pre-amps.



Positioning tool and heads
The positioning tool is suspended from the drive mechanism. It consists of suspension poles attached to the source and detector heads.

Data acquisition and drive control station
The BADGER test director uses this station to control the BADGER detector and source head position in the spent fuel storage rack and review and record BADGER data.

Incentives for BADGER Change

- System reliability shortfalls in 2011/2012 test campaigns
- GALL Report (NUREG-1801) aging management plans require in-situ testing for life extension
  - Increased reliance on BADGER for "Functionality Assessment"
  - BADGER is no longer viewed as a "Management Tool"
- Limitations of use for high areal density absorbers (i.e., Carborundum)
- NRC issuance of BADGER related Technical Letter Reports
  - "Boraflex, RACKLIFE and BADGER: Description and Uncertainties"
  - "Initial Assessment of Uncertainties Associated with the BADGER Methodology"

Super BADGER Design

- Improved cable connectors
- Improved cable to detector seals
- Improved cables
- Improved source and detector heads
- Improved drive mechanism
- Updated electronics
- Updated software

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Cable-Detector

- Key issue regarding BADGER reliability
  - Water tightness of the detector to cable connection at the detector head.
- Improved sealing process ensures a water tight connection and electrical isolation of detector.
- Cable, detector & electronics have improved impedance matching

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Source & Detector Heads

- Control of BADGER source/detector geometry.
  - New source & detector heads fit snugly in the fuel storage cell & chamfered to reduce interference with the cell.
  - Ball bearings keep the detector array and source head against the neutron absorber wrapper plate being scanned.
- Reduction of neutron in-scatter
  - Detector head shielded with boron carbide powder

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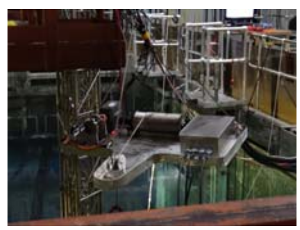
Drive Mechanism

- Drive cable and reel improves positioning
- Pre-amps matched to cable and detector
- Equipment mounting and kick plate address foreign material exclusion



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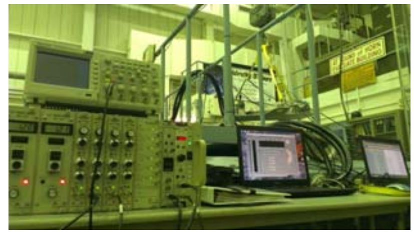
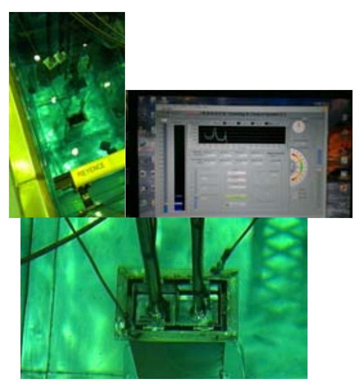
Data Acquisition Hardware & Software

- Hardware upgrades
  - Oscilloscope
  - Power supplies
  - Test computer
- Software
  - Commercially available



System Tests & Operation

- Penn State Prototype Test
  - April 2013
  - Dominion and NextEra observed
- 2013 BADGER deployment
  - Duane Arnold (Boral)
  - Millstone (Carborundum)
  - Grand Gulf (Boraflex)
  - Fermi (Boraflex)
  - Peach Bottom (Boraflex)



2014 Activities

- BADGER tests at utility sites (3)
- Draft Topical Report on Super BADGER accuracy & repeatability
- Further improvements
  - Fission chambers
  - Voltage stability

Industry Neutron Absorber Survey

Kristopher Cummings
Senior Project Manager, Used Fuel
NRC/NEI Meeting on SFP Criticality Guidance
October 31st 2013 • Rockville, MD

Neutron Absorber Survey

- Survey distributed to all US nuclear utilities/plants with spent fuel pool storage (operating and shutdown reactors)
- Update to a previous survey performed in 2011 (not published).
- Goal was to gain an understanding of industry actions to measure, test and characterize behavior of neutron absorbers in the spent fuel pool.

Neutron Absorber Survey - Questions

- Type of rack (flux trap, pitch, etc).
- Type of neutron absorber
- Type of absorber test program (coupons, in-situ)
- Coupon testing acceptance criteria:
  - Dimensions
  - Neutron attenuation
  - Weight
  - Visual/microscopy/photography

Neutron Absorber Survey - Questions

- In-situ acceptance criteria:
  - Degradation
  - Shrinkage/Creation of gaps
  - Areal density
- Licensing basis of testing program or voluntary
- Plan or commitments from aging management plans for license renewal

Neutron Absorber Survey - Responses

- Received a 70% response rate.
- Shared pools are treated as a single response
- Multiple plants have more than one type of neutron absorber
- Results are separated by type or presence of neutron absorber

Neutron Absorber Survey - Responses

- Type of neutron absorbers
  - None (12 pools)
  - Carborundum (4 pools)
  - Borated Stainless Steel (1 pool)
  - Boraflex (28 pools)
  - Boral (48 pools)
  - Metamic (8 pools)
  - Alcan (3 pools)

Neutron Absorber Survey – No absorber

- Quantity: 12 pools
- Testing – No coupons or in-situ testing. Rely on spacing or burnup/soluble boron credit.
- Future: Insert installation for expanded loading capability.

Neutron Absorber Survey – Carborundum

- Quantity: 4 pools
- Absorber Credit: All pools continue to credit some percentage of the absorber.
- Testing: 3 use coupons, 1 uses in-situ testing
- Test results: some weight loss (<20%), areal density > than min.
- Future: Continue to monitor through existing test programs to measure areal density.

Neutron Absorber Survey – Boraflex

- Quantity: 28 pools
- Absorber Credit: 21 pools no longer credit absorber, 7 still credit absorber to some extent
- Testing: 5 had coupons, only 1 still tests; 2 had no coupons.
- Test results: Coupons degraded beyond usefulness, in-situ testing show shrinkage, gaps, dissolution (known effects)
- Future: 2 have insert LARs, 3 have LARs to remove credit, 2 monitor (coupons/BADGER)

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Neutron Absorber Survey – Boral

- Quantity: 48 pools
- Absorber Credit: All pools continue to credit absorber
- Testing: 28 have coupon testing program, 20 no coupon testing.
- Test results: Shown blistering on edges, pitting, general corrosion, but no loss of absorber capability that would affect functionality. Includes racks with 35 years in-service life.
- Future: Those plants without coupons are adding coupons, in-situ testing or monitoring fleet/industry results.

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Neutron Absorber Survey – Metamic

- Quantity: 8 pools
- Absorber Credit: All pools continue to credit absorber
- Testing: All pools have coupons. Duration between tests lengthens with time
- Test results: No degradation exhibited. Coupons have short exposure times. (< 10 years)
- Future: Continue to monitor through coupon testing

Neutron Absorber Survey – Boralcan

- Quantity: 3 pools
- Absorber Credit: All pools continue to credit absorber in inserts
- Testing: All pools have coupons. Duration between tests lengthens with time
- Test results: No coupons test results to date
- Future: Continue to monitor through coupon testing

Conclusions

- Response rate gives a good representation of the industry experience with neutron absorbers.
- Pools have moved to eliminating reliance on Boraflex.
- Boral experience shows localized pitting, corrosion or blisters with no loss of function (i.e., no loss of ^{10}B)
- Many licensees that were not required to have a test program have instituted coupon testing or in-situ testing. (Note: Requirement for license renewal).
- License renewal applications is trending toward implementing in-situ testing where coupons were not installed.

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Rack Neutron Absorber Testing Program

Z. I. Martin
Sr. Program Manager, Spent Fuel, TVA
NRC/NEI Meeting on SFP Criticality Guidance
October 31st 2013 • Rockville, MD

Topics

- Neutron Absorber Testing
  - Coupon Testing
  - In-Situ Measurement
  - Evaluation of Testing Results
  - Additional Program Elements
- Regulatory Analysis of Neutron Absorber Tech Spec Requirements

Neutron Absorber Testing

The purpose of a Neutron Absorber Testing Program should be to provide ongoing confirmation that:

- The neutron absorber material is not undergoing unanticipated aging effects that would impact reactivity
- Observed material aging effects are accounted for in the criticality analysis
- The presence of the neutron absorber material provides the criticality control relied upon in the analysis

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Neutron Absorber Testing (Cont'd)

There are two methods for providing ongoing confirmation of the presence of the neutron absorbers in the racks:

- **Coupon Testing -** Preferred method
- **In-Situ Measurements -** Acceptable method for confirming B-10 used to:
  - Supplement coupon testing
  - In lieu of coupon testing if no coupons available

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Coupon Testing

A Coupon Testing Program should meet the following criteria:

- **Number of Coupons -** Sufficient to provide sampling at appropriate frequency for intended life of the material
- **Life of Neutron Absorber -** Based on time the material will be credited in the criticality analysis
- **Sampling Frequency -** Based on expected material performance from qualification testing and operational experience
- **Coupon Location -** Located such that exposure to parameters controlling performance attributes (such as gamma fluence and heat) are similar to the in-service neutron absorber material. If possible, coupon exposure should bound 95% of the in-service material.

Coupon Testing (cont'd)

A Coupon Testing Program should meet the following criteria: (cont'd)

- **Coupon Testing -** Based on operating history of material as follows:
  - **Basic Testing**
    - Appropriate when testing and operating experience indicates no mechanism resulting in loss of function
    - Consists of visual observations, dimensional measurements, and weight
  - **Full Testing**
    - Appropriate for the first coupon test and when testing and operating experience indicates loss of function
    - Consists of B-10 areal density measurements, microscopic analysis, and characterization of degradation in addition to Basic Testing

In-Situ Measurement

An In-Situ Measurement Testing Program should meet the following criteria:

- **Number of Panels Tested -** Should be an appropriate statistical sample
- **Sampling Frequency -** Based on expected material performance from qualification testing and operational experience
  - If material does not have a long-term industry in-service history – initial frequency should not exceed 5 years
  - If material has a long-term industry in-service history and material stability has been documented – frequency should not exceed 10 years
- **Measurement Uncertainties -** Measurement method should be appropriately justified, including identifying uncertainties.
- **Use of Results –** Should be material dependent as follows:
  - For material with potential performance experience which do not result in loss of function – measurements should be used as confirmatory
  - For material with potential performance experience which may result in loss of function – measurements should be performed to justify functionality

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Evaluation of Testing Results

Results from the neutron absorber testing provide:

- Confirmation that no loss of function is occurring
- Confirmation that anticipated material degradation is occurring at rates less than predicted
- Identification if unanticipated material degradation is occurring (such as a new mechanism or anticipated degradation at accelerated levels). In this event, additional actions may be required, such as:
  - Reporting requirement
  - Technical assessment

Results of the testing should be evaluated against criticality analysis input.

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Additional Program Elements

The licensee Neutron Absorber Testing Program should also identify and evaluate:

- Operating Experience at other plants to be reviewed for applicability
- Material testing and R&D results to be reviewed for applicability

Regulatory Analysis of Neutron Absorber Tech Spec Requirements

- Preventing an inadvertent criticality event (ICE) is a design criteria for the SFP
  - An ICE is precluded by the criticality analysis of record (AOR) therefore is not a design basis accident – there is no consequence analysis. It does not appear in Chapter 15 of the SRP.
- The neutron absorber material is relied upon to provide reasonable assurance that the requirements of 10 CFR 50.68 are met
  - The neutron absorber parameters are verified during rack fabrication and the condition of the material is monitored through the industry neutron absorber testing program.

Regulatory Analysis of Neutron Absorber Tech Spec Requirements (cont'd)

- Neutron absorber density does not satisfy the 10 CFR 50.36(c)(2)(ii) criteria for a Limiting Condition for Operation (LCO)
  - Criteria 2 and 3 only apply to parameters that initiate or mitigate a design basis accident discussed in Chapter 6 or 15 of the FSAR. ICE is not a design basis accident.
  - Criteria 1 and 4 do not apply (RCS leakage instrumentation and PRA risk).

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Regulatory Analysis of Neutron Absorber Tech Spec Requirements (cont'd)

- Neutron absorber areal density does not satisfy 10 CFR 50.36(c)(3) for establishment of Surveillance requirements
  - Surveillance Requirements are only established for parameters that meet the criteria for an LCO. Otherwise, the 10 CFR 50, Appendix B, Quality Assurance Program provides the requirements for ensuring the quality of SSCs.

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Regulatory Analysis of Neutron Absorber Tech Spec Requirements (cont'd)

- 10 CFR 50.36(c)(4) on Design Features appears to apply to neutron absorbers as a material of construction which if altered or modified would have a significant effect on safety.
- Similar parameters (cell pitch, enrichment limits, etc.) are in the Design Features.
- These are features incorporated into the design, not under control of the control room operator. There is no TS required testing of these Design Features parameters, but they must be met (e.g., maximum number of assemblies).
- However, industry is still researching the historical definition of "significant effect on safety"

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Summary

- Neutron absorber density appears to meet the requirements for the Design Features section of the TS, however we are still investigating this issue.
- The licensee testing will be in accordance with the Quality Assurance program and will utilize NEI 12-16
- Reasonable assurance should be material performance dependent:
  - For material with potential performance experience which do not result in loss of function – measurements should be used as confirmatory
  - For material with potential performance experience which may result in loss of function – measurements should be performed to justify functionality

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Neutron Absorber Testing

Questions?

Storage Rack Interfaces

Kristopher Cummings
Senior Project Manager, Used Fuel
NRC/NEI Meeting on SFP Criticality Guidance
October 31st 2013 • Rockville, MD

Definitions

- For submittals that contain multiple storage racks/loading configurations the analysis should consider:
  - *Intrafaces* between adjacent storage configurations in the same rack.
  - *Interfaces* between adjacent storage racks of different types (i.e., flux trap and non-flux trap).
- The adjacent storage configurations may result in a higher k_{eff} than the individual storage patterns.

DSS-ISG-2010-01 Guidance

- Two possible paths for interface calculations:
  - Specific biases and uncertainties for the interface configuration
  - Use of maximum biases and uncertainties from individual storage configurations

Assessment of DSS-ISG-2010-01

- Interface specific biases and uncertainties is calculationally burdensome, depending on the number of interfaces possible.
- Using the maximum biases and uncertainties will always show a k_{eff} greater than both of the individual storage configurations (see Example)

Example of Using DSS-ISG-2010-01

Loading Pattern	Uniform Loading	High/Low Reactivity Checkerboard	Interface
Calculated k_{eff}	0.9740	0.9700	0.9740
Biases	0.0040	0.0050	0.0050
Uncertainties	0.0170	0.0200	0.0200
Maximum k_{eff}	0.9950	0.9950	0.9990

- Using the maximum biases and uncertainties falsely gives the impression that there is an increase in reactivity
- In reality, the reactivity of the interface is dictated by the storage configuration of the maximum reactivity.
- The biases and uncertainties should also be dictated by the storage configuration with the maximum reactivity

Acceptable Interfaces

- The interface is acceptable if calculated k_{eff} is less than or equal to the maximum calculated k_{eff} of the individual storage patterns.
- If the interface model calculated k_{eff} is larger, then interface restrictions should be set to prevent these adjacent storage patterns
- Can credit additional margin (if interface k_{eff} is still below regulatory limit)

Acceptable Interfaces

- Racks that are sufficiently separated (6 inches wall-to-wall) are neutronically decoupled and do not require analysis.

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