

# McGuire Nuclear Station New Fuel Vault / Spent Fuel Pool Criticality Safety Analysis Proposed License Amendment Request

Pre-submittal meeting – August 11, 2025



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## Meeting Purpose

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Discuss key aspects of the proposed License Amendment Request (LAR)



Foster a high-quality submittal



Help ensure an efficient, predictable NRC review of the LAR

## Duke Energy Team

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Criticality Safety Team within Nuclear  
Fuels Engineering

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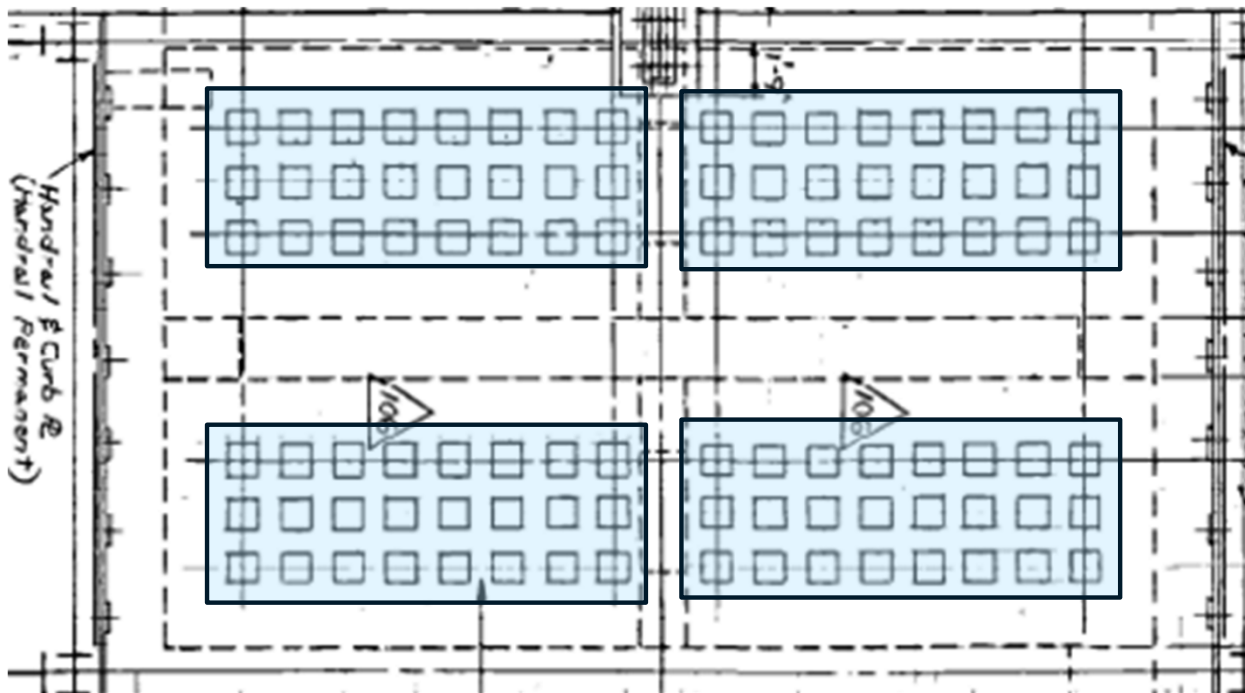
## Topics

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- Purpose and Scope of the License Amendment Request (LAR)
  - New Fuel Vault and Spent Fuel Pool Background
- High-level outline of proposed changes to Technical Specifications (TS)
- Criticality safety analysis (CSA) overview
- NEI 12-16, “Guidance for Performing Criticality Analyses of Fuel Storage at Light-Water Reactor Power Plants,” Revision 4, Appendix C checklist, comparison of anticipated LAR to current guidance
  - Review individual items by request/as time permits
- Potential inclusion of exemption request for enrichment limit in 10 CFR 50.68
- Anticipated timeline for submittal/review/implementation

Note: CSA results described herein are provided to clarify description of the methodology, are preliminary and are subject to change.

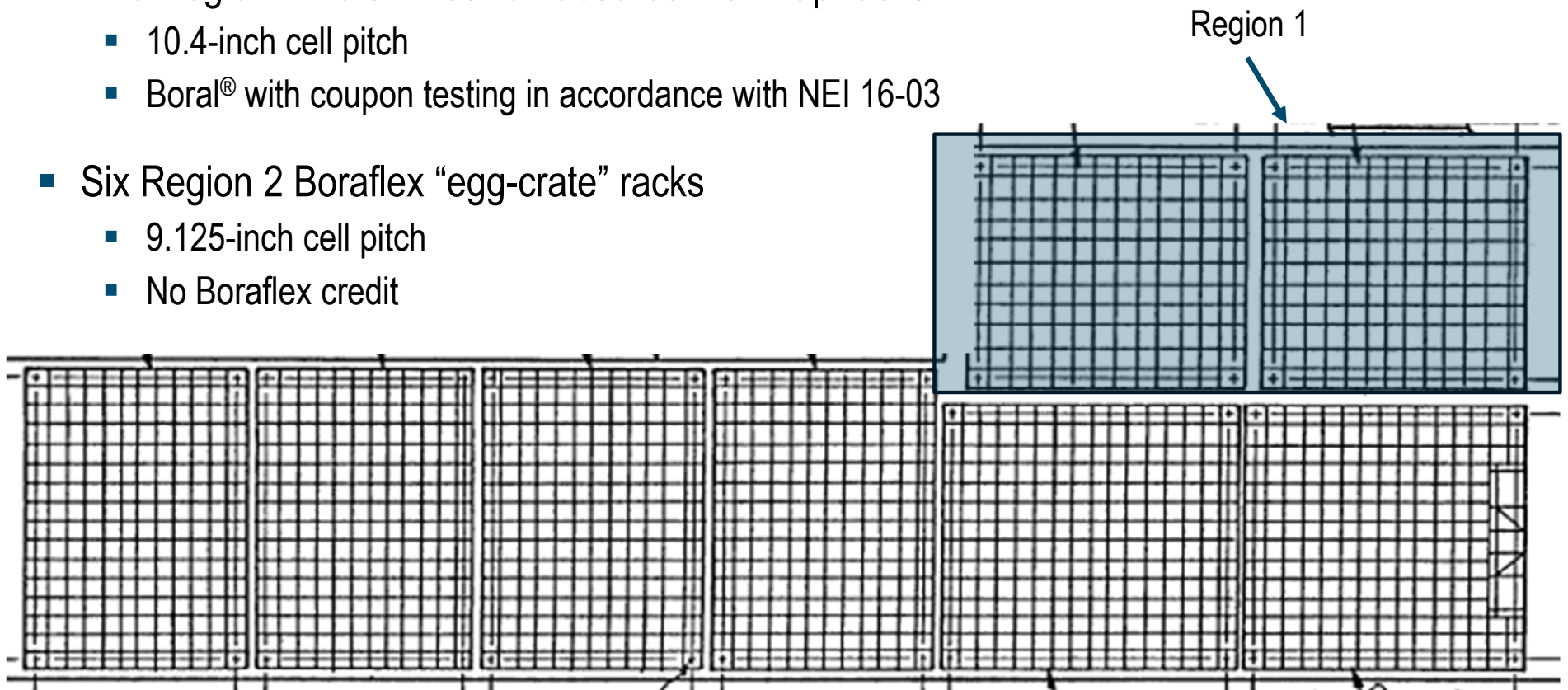
## Background - New Fuel Vault



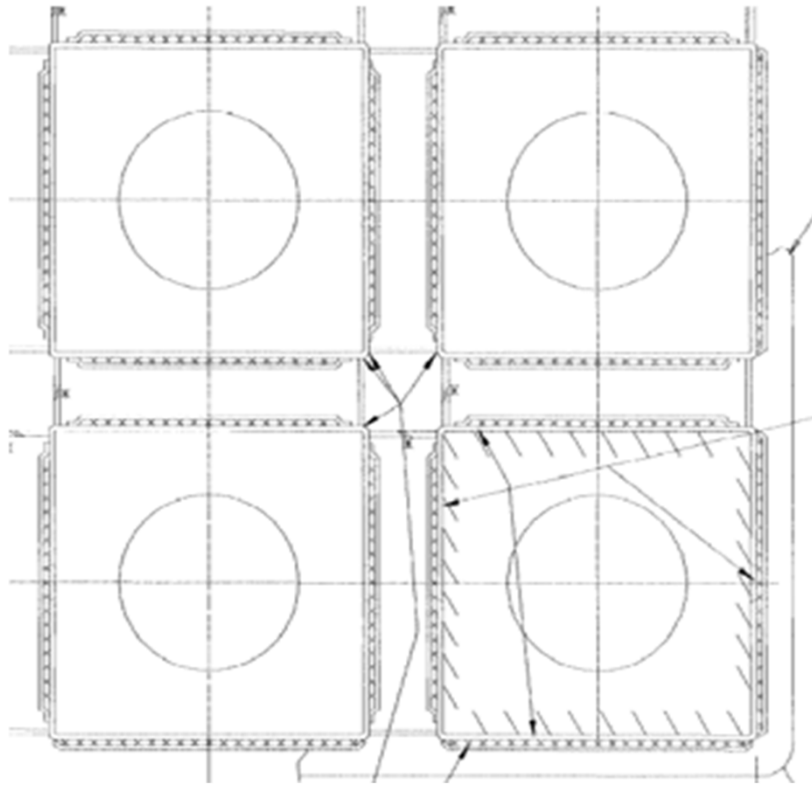
- Four 8x3 modules
- Concrete separators
- Concrete floor, walls and ceiling
- Open rack structure
- Ceiling hatches
- No neutron absorbers

## Background - Spent Fuel Pool

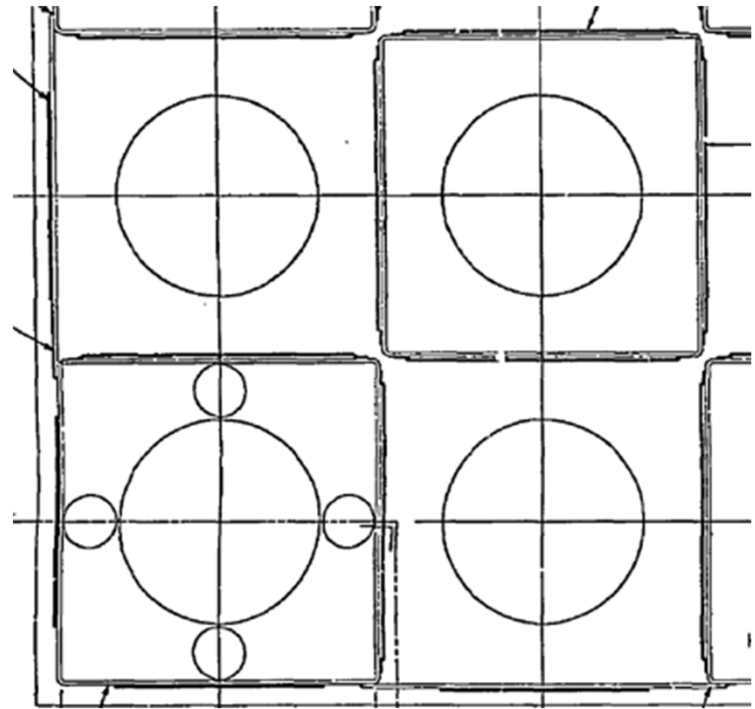
- Two Region 1 Boral<sup>®</sup> neutron absorber flux trap racks
  - 10.4-inch cell pitch
  - Boral<sup>®</sup> with coupon testing in accordance with NEI 16-03
- Six Region 2 Boraflex “egg-crate” racks
  - 9.125-inch cell pitch
  - No Boraflex credit



## Background - Spent Fuel Pool



Region 1



Region 2

## License Amendment Purpose and Scope

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- Update criticality safety analysis for new fuel vault (NFV), Region 1 and Region 2 of the spent fuel pools (SFP) for both units at McGuire Nuclear Station (MNS)
  - Enable storage of fuel for future updated core power and 24-month cycles
    - Increase central zone enrichment limit to  $\leq 7$  wt.% U-235
  - Update codes and methods to meet current guidance/expectations
    - CASMO5 and SCALE 6.2.4 KENO-V.a (ENDF/B-VII.1 cross-section data)
    - NEI 12-16 Rev 4 / NRC Regulatory Guide (RG) 1.240
  - Revise Technical Specifications (TS)
    - Require minimum integral poison as a function of enrichment in the NFV
    - Revise storage configurations in the SFP
    - Update SFP loading curves for discharged fuel inventory and current 18-month cycles
    - Add new SFP loading curves for future inventory from updated 24-month cycles
  - No change to existing SFP boron dilution analysis or SFP minimum boron TS

## High-Level Outline of NFV Technical Specification Changes

### ■ **Current NFV** requirements described in TS 4.3.1.2

- All-cell storage of current fuel design
  - Westinghouse RFA-2 with  $\leq 5$  wt.% U-235 enrichment
- Full flooding with water and low-density moderator (water)

RFA – Robust Fuel Assembly

### ■ **Proposed NFV** requirements

- All-cell storage of current fuel design
  - Westinghouse RFA-2 with  $\leq 5$  wt.% U-235 enrichment
- All-cell storage of 24-month cycle fuel design
  - Similar to Westinghouse RFA-2 with 24-month cycle modifications
  - Gadolinia or Integral Fuel Burnable Absorber (IFBA) required for enrichment between 5 and 7 wt.% U-235
- Full flooding with water and low-density moderator (water)

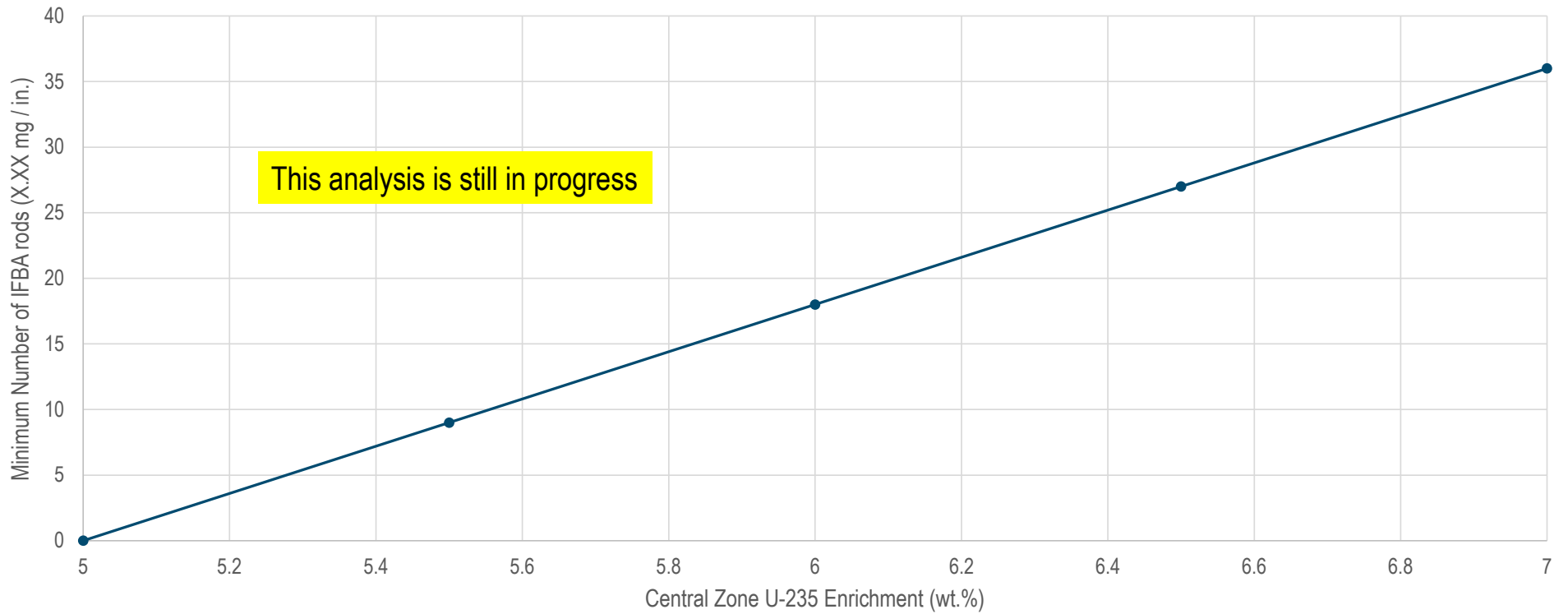
## High-Level Outline of SFP Technical Specification Changes

- **Current Region 1** requirements described in TS 3.7.14, 3.7.15, 4.3
  - All-cell storage of current fuel design
    - Westinghouse RFA-2 with  $\leq 5$  wt.% U-235 enrichment
    - No burnup required

- **Proposed Region 1** requirements
  - All-cell storage of current fuel design
    - Westinghouse RFA-2 with  $\leq 5$  wt.% U-235 enrichment
    - No burnup required
  - All-cell storage of 24-month cycle fuel design
    - Evolution of Westinghouse RFA-2 fuel
    - Gadolinia or IFBA required for enrichment between 5 and 7 wt.% U-235
    - No reactivity increase with burnup based on the expected amount of IFBA credit needed (no burnup required for storage)

## Example of TS Region 1 Burnable Absorber (BA) Requirement

Minimum Burnable Absorber Requirement for SFP Region 1 Storage



## High-Level Outline of SFP Technical Specification Changes (2)

- **Current Region 2** requirements described in TS 3.7.14, 3.7.15, 4.3
  - Separate loading curves for **7** fuel types
    - Initial enrichment, burnup, and decay time
  - **Four** fuel assembly reactivity classifications related to storage patterns
    - Filler (lowest reactivity)
    - Unrestricted
    - Restricted
    - Checkerboard (highest reactivity, 3 out of 4 with one empty cell)
  - **Three** storage patterns
    - Basic pattern is a 2x2 array (“Unrestricted”)
    - “Checkerboard” allows 3 of 4 storage
    - “Restricted/filler” allows 4 of 4 storage
    - Interface effects mitigated with restrictions (empty row or other rules between different configurations)
  - Soluble boron credit (normal and accident conditions)
    - TS minimum SFP boron 2675 ppm

## High-Level Outline of SFP Technical Specification Changes (3)

- **Proposed revised Region 2 requirements**
  - Separate loading curves for **6** fuel types
    - Initial enrichment, burnup, and decay time (three variants consolidated and bounded, 24-month cycle added)
  - **Five** fuel assembly reactivity classifications related to storage patterns
    - Category 1 (lowest reactivity) through Category 5 (highest reactivity)
  - **Five** storage patterns
    - Basic pattern is a 3x3 array with at least one empty cell (“8 of 9”) and no Rod Cluster Control Assembly (RCCA) credit
      - Basic empty cell pattern is fixed in Region 2 racks
    - Three patterns have RCCA credit (8 of 9 1 RCCA, 8 of 9 2 RCCA, 7 of 9 1 RCCA)
    - Lowest density storage pattern is 6 of 9 with no RCCA credit
    - Interface effects mitigated with storage pattern reactivity penalty and restrictions if needed
  - Soluble boron credit (normal and accident conditions)
    - TS minimum SFP boron 2675 ppm
  - Storage rack edge row credit (neutron leakage)
    - Vary rack distance from SFP wall

## High-Level Outline of SFP Technical Specification Changes (4)

- Five storage configurations
- Five reactivity categories
- Empty cells (black)
- RCCA credit (blue)

8 of 9

1		1
1	1	1
1	1	1

8 of 9, 1 RCCA

2		2
1	2	2,R
1	2	2

8 of 9, 2 RCCA

3		3
3	3	4,R
4,R	3	3

7 of 9, 1 RCCA

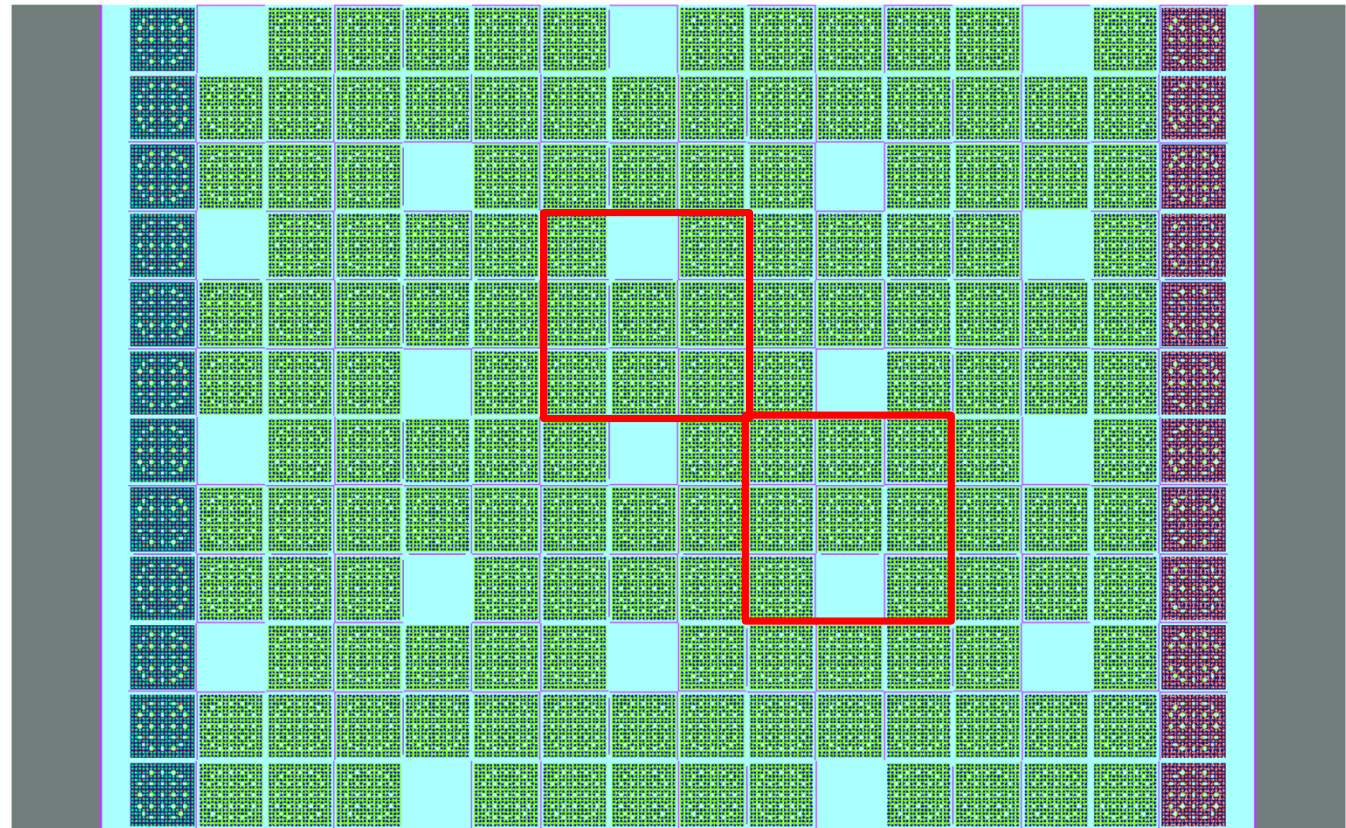
4		4
2	5	
5,R	4	5

6 of 9

4		5
5	5	
	5	5

## High-Level Outline of SFP Technical Specification Changes (5)

- Region 2
- Full rack
- Fixed minimum empty cell pattern
- Pattern extends across rack boundaries
  - Increased pitch
- Seismic event evaluation performed to address rack shifting



## Criticality Code Validation/Benchmark

- SCALE 6.2.4 (KENO-V.a) benchmark analysis
  - Follows NUREG/CR-6698, *Guide for Validation of Nuclear Criticality Safety Computational Methodology* (ADAMS Accession No. ML010870155)
  - Includes additional critical experiments with enrichments between 5 and 7 wt.% U-235 (LEU+)
  - Includes Mixed-Oxide (MOX) and Haut Taux de Combustion (HTC) critical experiments
  - Covers expected area of applicability in the SFP environment
    - Rack cell structure materials
    - Installed neutron absorbers (e.g., Boral®)
    - Soluble boron
    - RCCA components (Ag-In-Cd, B<sub>4</sub>C)
    - Neutron spectrum (EALF)
  - No significant trends on U-235 enrichment, Pu/Pu-239 enrichment, EALF, BA B-10 areal density
  - Conservative approach taken to bound all trended parameters in the benchmark results

EALF – energy of the average lethargy of neutrons causing fission

## CSA Overview - Fuel Changes/Codes

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- New fuel product will be implemented with the transition to power uprate, 24-month fuel cycles
- Modest CSA-related fuel changes as compared to current fuel design
  - Axial blanket and annular blanket specifications
    - Length and enrichment cutback
  - Doped fuel pellets
    - Pellet density will be bounded in the CSA
  - Gadolinia and IFBA burnable absorber (BA) combinations will be used
    - No removable BA use is anticipated
- Computer codes updated
  - CASMO5 for fuel depletion (will be used consistent with topical report)
  - KENO-V.a / SCALE 6.2.4 / ENDF/B-VII.1 cross section data

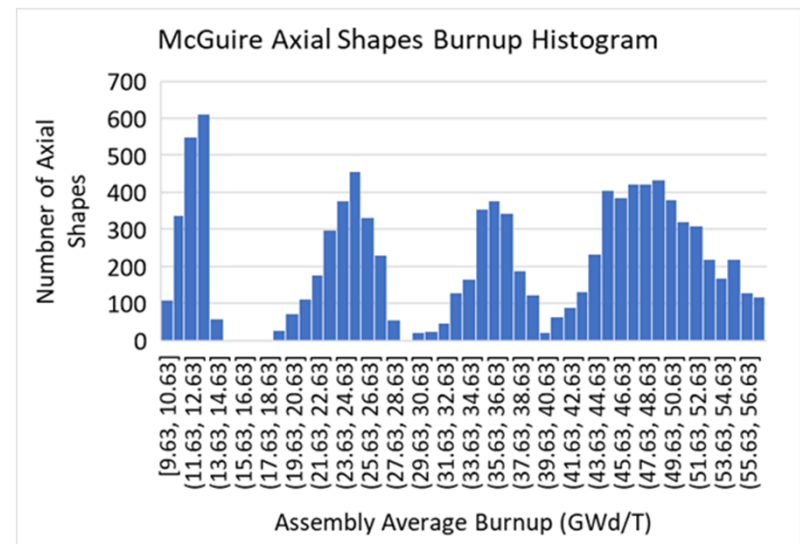
## CSA Overview – Bounding Depletion Conditions

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- Separate sets of bounding conditions selected for each unique fuel design
  - Fuel density
  - BA history
  - RCCA history
  - Cycle average soluble boron
  - Maximum depletion average power (burnup dependent)
    - Maximum fuel and moderator temperature
    - Nodal values determined in combination with axial burnup profile
  - Minimum decay time for legacy populations (isotopic data calculated with CASMO5)
  - Axial blanket credit for RFA; under review for 24-month cycle fuel
    - No axial blanket credit for legacy fuel

## CSA Overview – Axial Burnup Profiles

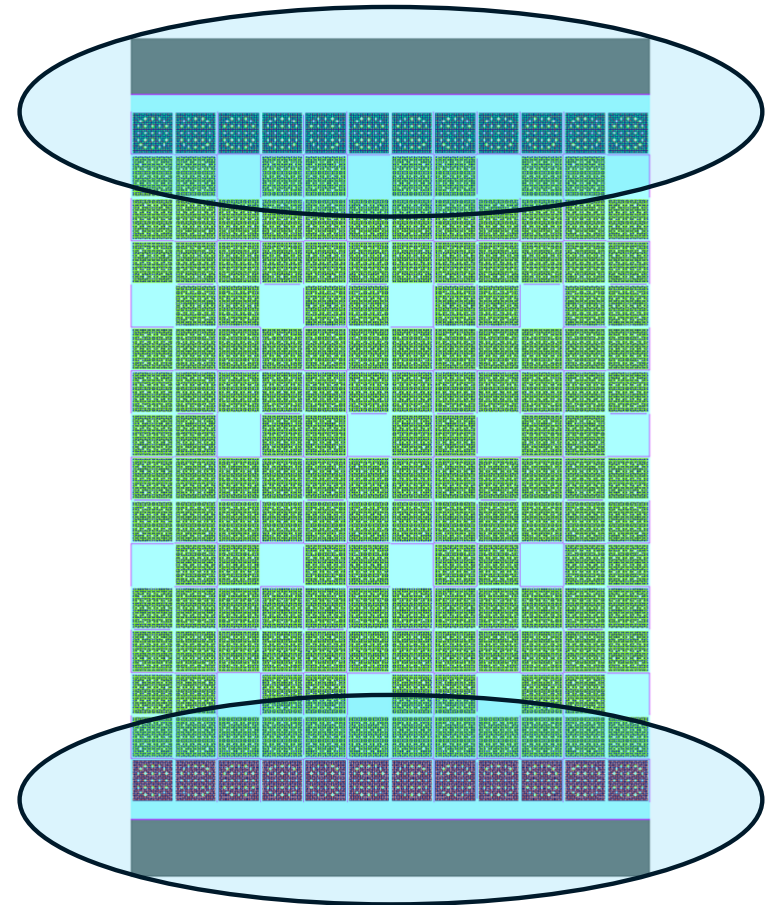
- McGuire-specific 24-node profiles for RFA, RFA-2
  - Over 10,000 18-month cycle, 2.6 wt.% axial blanket shapes
  - Binned in  $\pm 5$  GWd/T bins (15, 25, 35, 45, 55 GWd/T nominal)
  - Sorted by lowest top 1/6 and 1/4 assembly relative burnup (essentially the same limiting profiles)
- NUREG/CR-6801 18-node profiles for legacy fuel
- Expect McGuire 18-month profiles will bound 24-month profiles
  - Transition and equilibrium 24-month cycle profiles currently in development



NUREG/CR-6801, *Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analyses* (ADAMS Accession No. ML031110292)

## CSA Overview – Reactivity Credits

- NFV
  - Minimum integral absorber
- SFP Region 1
  - Boral<sup>®</sup> neutron absorber
- SFP Region 2
  - Empty cells
  - Axial blankets (RFA)
  - BA axial cutback (RFA)
  - RCCA (3 storage configurations)
  - Decay time
  - Edge row neutron leakage (shaded ovals)



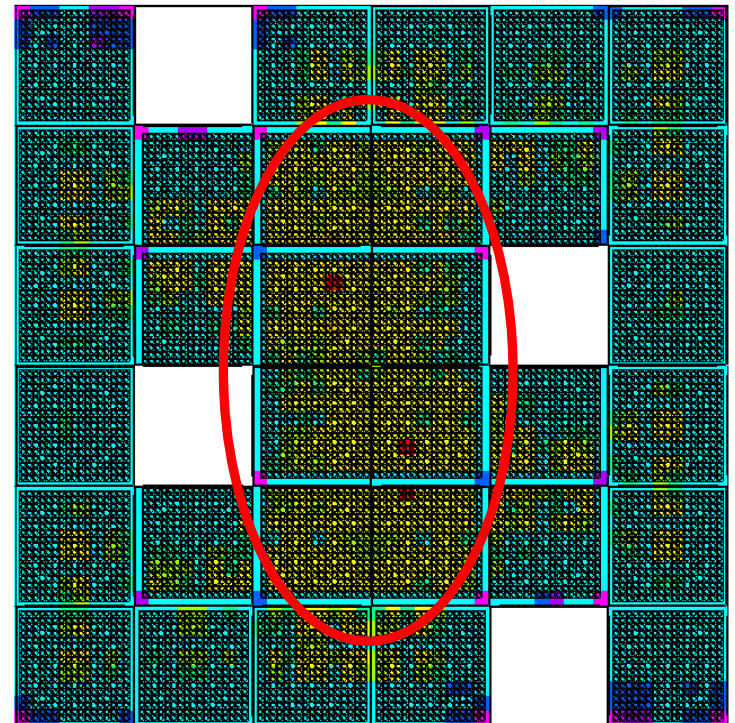
## CSA Overview - Eccentric Positioning

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- New Fuel Vault
  - Shift assemblies toward center and away from center of 3x8 module
  - Shift assemblies in separate modules toward each other (center of vault)
- Region 1
  - Base case: fuel assemblies centered in storage cells in a 6x6 model
  - Case 1: shift the central 4x4 set of assemblies inward
  - Case 2: shift the central 4x4 set of assemblies outward
  - Full flooding and low-density moderator
- Result in each case is applied as a bias

## CSA Overview – Region 2 Eccentric Positioning – Method 1

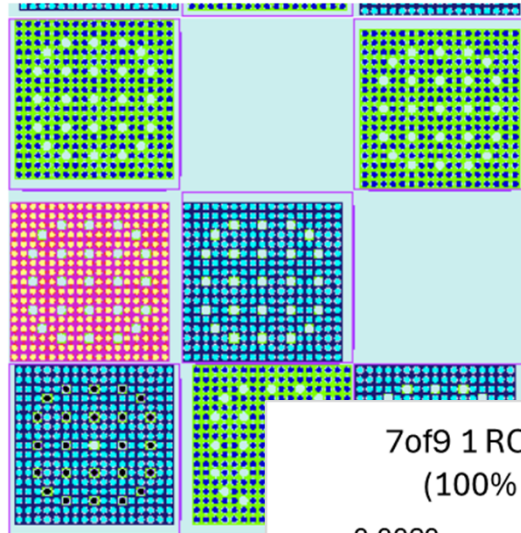
- Configurations for each storage pattern
  - Base case: fuel assemblies (FAs) centered in storage cellsNext, shift the central 4x4 FAs...
  - Toward the model center
  - Away from the model center
  - Toward empty cells
  - Away from empty cells
  - Diagonally toward storage cell corner 1
  - Diagonally toward storage cell corner 2
  - Diagonally toward storage cell corner 3
  - Diagonally toward storage cell corner 4
- Preliminary results show a small effect
  - Maximum: 150 pcm



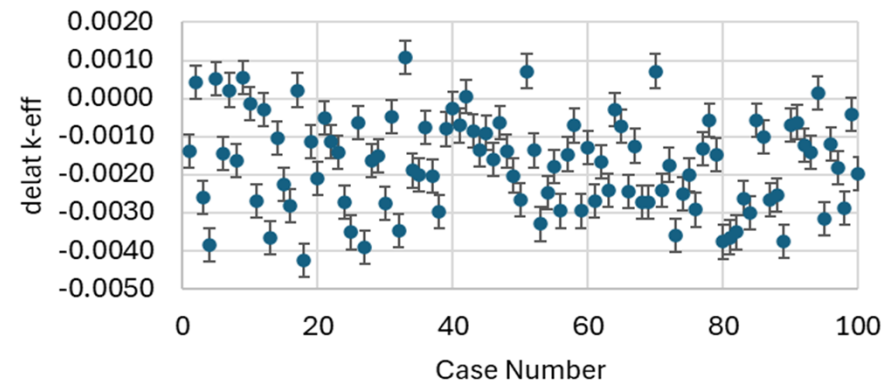
8 of 9 (no RCCA) fission density map with central assemblies moved toward model center

## CSA Overview – Region 2 Eccentric Positioning – Method 2

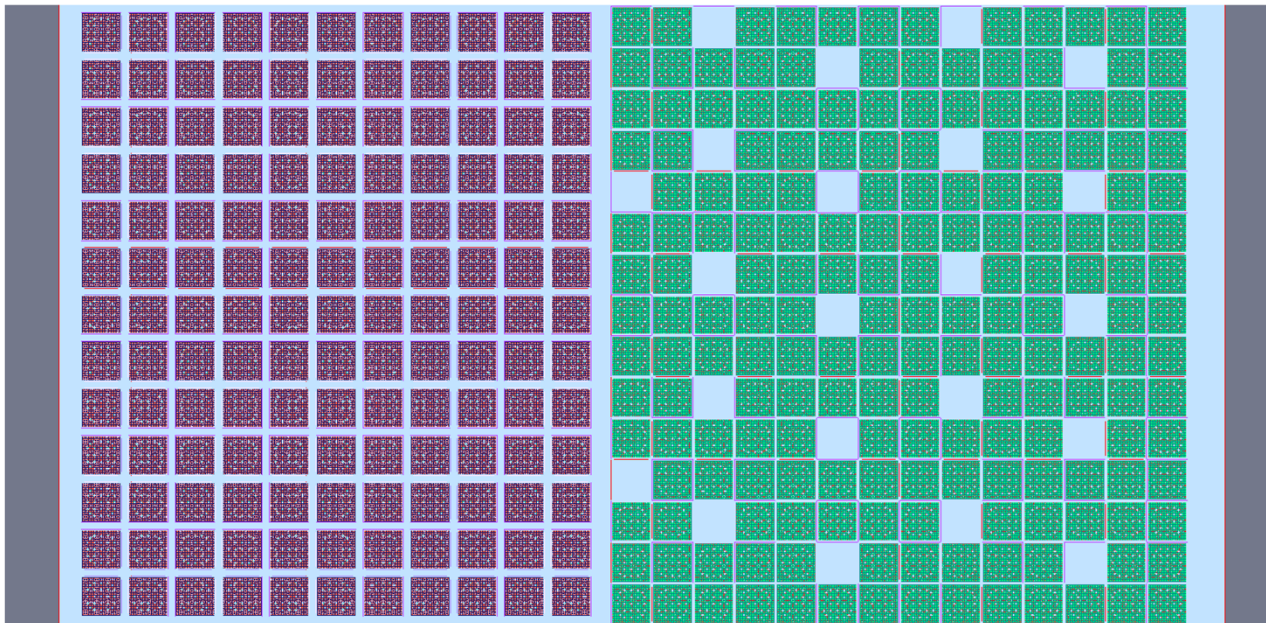
- Random Positioning Method
  - Centered,  $\pm$  max. shift X,  $\pm$  max. shift Y
  - 6x6 model
  - 9 possible positions for each fuel assembly
  - Single and mixed storage configurations
- Generate 100 sets of random placements
  - Evaluate statistically
  - Assume normality and non-parametric
  - Results to date bounded by method 1



7of9 1 RCCA Random Eccentric Position Cases  
(100% of Maximum Eccentricity, Discrete)

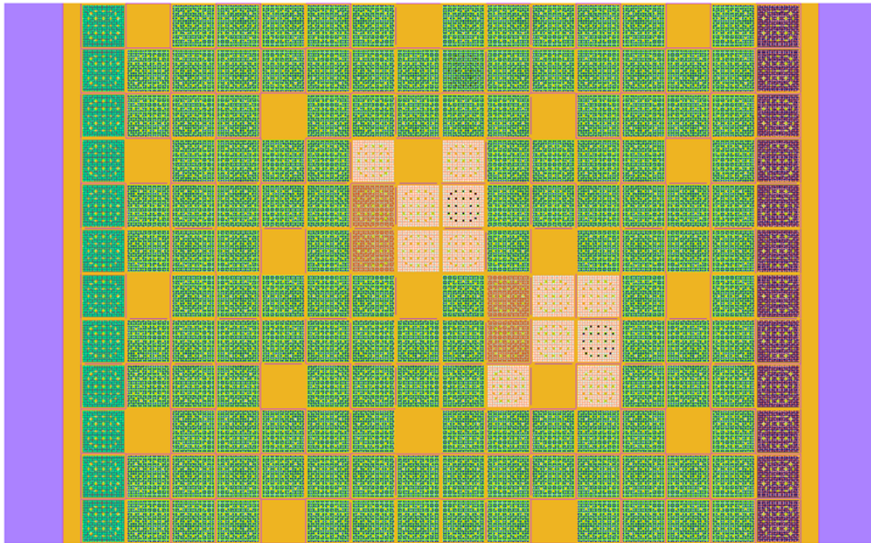


## CSA Overview – Interface Effects (Region 1 to Region 2)

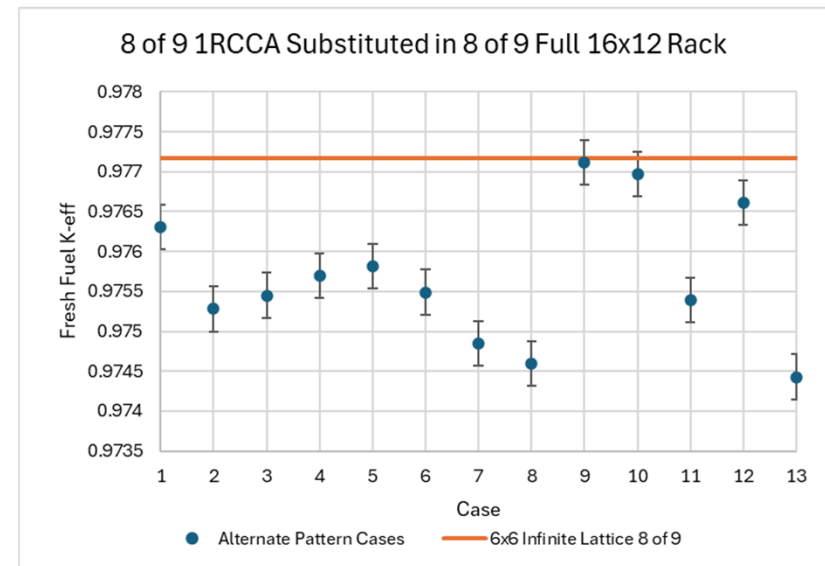


- Determine equal reactivity in infinite lattice models
  - Region 1
  - Region 2
- Load into 2 rack model
  - Actual size X direction
  - Infinite Y direction
- 2 racks
- Change rack-to-rack spacing
- $K\text{-effective} \leq K\text{-infinite}$ 
  - **2 empty cells added**

## CSA Overview – Interface Effects (Internal Region 2 storage patterns)



- Substitute alternate 3x3 pattern equal reactivity fresh fuel clusters into full rack base configuration
- 12 cases per substitution, 10 pattern substitutions (120 cases)



- Determine interface reactivity penalty (if any) needed to achieve  $k(\text{substitute}) \leq k(\text{infinite})$
- Interface reactivity penalty is applied to loading curve calculation

## CSA Overview – Horizontal Burnup Gradient

- Conservative generic model developed based on precedents (limit analysis scope)
  - Similar plant LARs, Oak Ridge National Lab study
- Result confirmed bounding by limited set of validation cases
  - 8 to 16 adjacent assemblies in 6x6 model

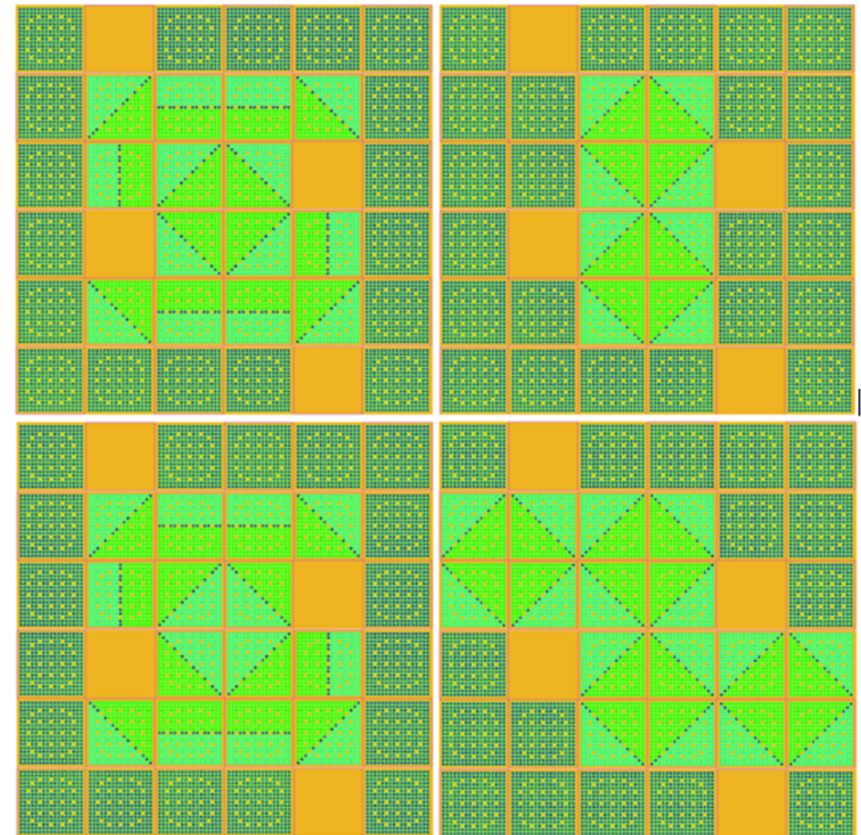
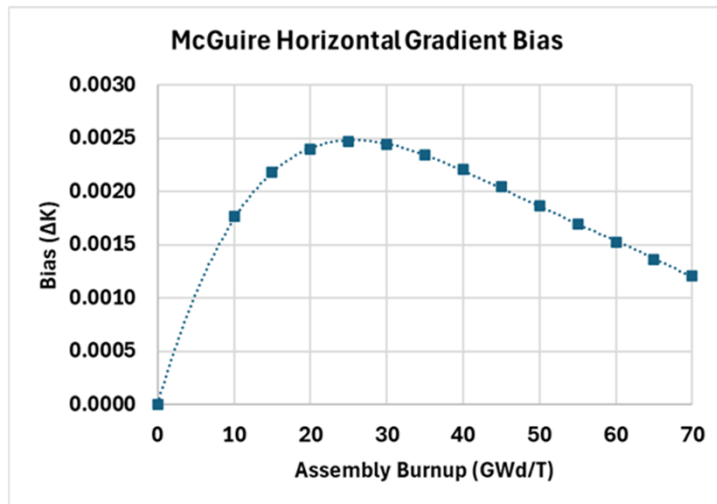


Figure 13.1.2.4-4 Horizontal Gradient Patterns

## CSA Overview - Misload Accident Approach

- Single misloads
  - Mis-manufacture, administrative error, spotting error
- Multiple misload of burned fuel
  - Administrative error
- **No multiple** fresh assembly misloads in Region 2
  - No “shiny” fuel in the “dull” fuel racks (independent 2<sup>nd</sup> barrier) – reinforced through training, independent procedures (move sheet development separate from fuel movement procedure).

Region	Number of Misload FAs	Analysis Model	Model Type	Error
1	1	Single FA	Infinite lattice	No required BA in one fuel assembly (FA)
2	1	6x6	Infinite lattice	Fresh assembly in a Category 1 cell
1-2	1	2 Racks	Finite 2 full racks	Fresh assembly in empty Region 2 cell at interface
2	32	16x12	Finite Region 2 rack	Category 5 assemblies in a Category 1 6x6 pattern

## NEI 12-16 Revision 4 Appendix C Checklist

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- See attached preliminary checklist/review items by request, time permitting

## Exemption Request



Exemption will be requested to the U-235 enrichment limit in 10 CFR 50.68 (b)(7)

Current limit: 5.0 wt.% U-235 enrichment



Seek exemption to allow what is justified by the criticality code benchmark and the criticality safety analysis for the application

For the McGuire Nuclear Station application, this will be up to 7.0 wt.% nominal U-235 enrichment



Exemption would be supported by draft rulemaking materials and other technical materials presented (EPRI workshop, upcoming ANS meetings, etc.)

# Anticipated Timeline for Submittal/Review/Implementation



Analysis completion will depend on availability of final design information for 24-month cycles at uprated power with new fuel product

Finalized fuel design information  
Transition core and equilibrium core cycle depletions



Target LAR submittal → 3<sup>rd</sup> quarter 2026



NRC review → 18 months (or less)



SE issuance → mid-2028



Fuel order → September 2028



Revised TS implementation → refueling outage M1R33 (Fall 2029)



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