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

NRC/NEI Meeting on SFP Criticality Guidance

Sept. 24th 2013 • Rockville, MD

Agenda and Meeting Objectives

Kristopher Cummings
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NRC/NEI Meeting on SFP Criticality Guidance
Sept. 24th 2013 • Rockville, MD

Agenda

Time	Subject	Presenter
8:30 am	Welcome, Introductions and Meeting Purpose	Kris Cummings, NEI
9:00 am	Design Basis Fuel Assembly	Kris Cummings, NEI
9:45 am	Fuel Assembly Manufacturing Tolerances	Dan Thomas, AREVA
10:30 am	**BREAK**	
10:45 am	Depletion Parameters	Dale Lancaster, NuclearConsultants.com
12:15 pm	**Lunch**	
1:15 pm	Fuel Assembly Changes with Depletion	Andrew Blanco, Westinghouse
2:15 pm	Axial Burnup Distribution	Kris Cummings, NEI
4:00 pm	**BREAK**	
4:15 pm	Closeout Activities	Kris Cummings, NEI

Background

- Industry identified the need to develop guidance for criticality analysis:
  - Satisfies NRC's Action Plan task to develop regulatory guidance
  - Provides regulatory durability and clarity
  - NRC review of industry guidance to develop Reg. Guide meets fee waiver requirement 10CFR 170.11(a)(1)

History of NEI 12-16

- Pre-submittal draft submitted Dec 2012 for early NRC feedback
- Public meeting in January 2013 for NRC to provide feedback
- Updated guidance submitted in March 2013
- Goal is for NRC endorsement to supercede existing guidance

Scope of NEI 12-16

- Applicable to Part 50 and Part 52 facilities
- Both BWR and PWR pools
- New fuel vaults and spent fuel pools
- Based on fresh fuel assumption or “full burnup credit”.

Industry/NRC Interaction

- A series of public meetings to review/discuss the issues addressed in NEI 12-16
  - 1) Fuel Assembly Modeling
  - 2) Rack Modeling and Neutron Absorbers
  - 3) Criticality Code V&V and Abnormal Conditions
  - 4) Depletion Code V&V and Misc. Topics

Meeting Purpose

- Reach resolution on methods to be used in spent fuel pool criticality analysis
- Focus of issues around modeling of the fuel assembly (both depletion and criticality analysis)
- Identify areas needing additional description, justification or explanation in NEI 12-16.

Path Forward - Schedule

- Industry/NRC Meetings – Sept 2013 to March 2014
- Industry addresses NRC comments - March 2014
- NRC endorsement – March 2015

Design Basis Fuel Assembly

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Design Basis Fuel Assembly

- Criticality analyses rely on a nominal representation of fuel assembly mechanical properties (materials, dimensions, etc.)
- Pools usually contain several types of fuel assemblies
  - PWR (Standard, OFA, Vantage, multiple Mark B fuel generations)
  - BWR (GE-14, ATRIUM, SVEA, Optima)

Design Basis Fuel Assembly

- Most PWR plants have kept the same lattice (i.e., 17x17) over the life of the plant.
- BWR plants have typically increased or modified the fuel lattice array (i.e., 8x8 to 9x9 to 10x10)
- BWR fuel assemblies also introduced partial length rods (rods only extend ~2/3 up the axial length of the fuel assembly)

Design Basis Fuel Assembly - PWR

- Much simpler analysis if a single set of parameters can be used for all calculations.
  - Acceptable to use multiple design-basis fuel assemblies.
- Need to ensure that the selected design is bounding for expected burnup and enrichment combinations.
- A hybrid set of parameters may be selected to result in a bounding, higher reactivity design basis fuel assembly.

Design Basis Fuel Assembly - BWR

- Since calculations performed in 2D code, can analyze each unique lattice type.
- Need to consider lattices with/without fuel rods in partial rod locations.
- Acceptance criteria developed from the limiting lattice array.

Fuel Assembly Manufacturing Tolerances

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Advisory Engineer
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Outline

- Fuel Assembly Manufacturing (FAM) Tolerance Guidance in NEI 12-16
- FAM Tolerance Approaches
- FAM Tolerance Parameters
- FAM Tolerance Parameters Not in NEI 12-16
- Significance of FAM Tolerances Parameters
- Summary
- Open Discussion

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Tolerances in NEI 12-16

- Section 2.2 K_{EFF} Equation, p.5

"... Uncertainties should be determined for the proposed storage facilities and fuel assemblies to account for tolerances in the mechanical and material specifications . An acceptable method for determining the maximum reactivity may be either (1) a worst-case combination with mechanical and material conditions set to maximize k_{eff}, or (2) a sensitivity study of the reactivity effects of variations of parameters within the tolerance limits. ... Combinations of the two methods may also be used. "

Tolerances in NEI 12-16

- Section 4.1 Fresh Fuel Assemblies, p. 14

"The criticality analysis typically relies on a nominal representation of the fuel assembly design (i.e., nominal dimensions, materials, and isotopic concentrations), and applies manufacturing tolerances as uncertainties. ... Alternatively, the analysis could calculate k_{eff} with all tolerance values selected to maximize k_{eff}.
To ensure that the maximum reactivity is being calculated per the requirement of 10CFR50.68 [1], effects of tolerances should be considered for each parameter that may contribute to a significant positive reactivity effect. ... "

Tolerances in NEI 12-16

- Section 4.1, Fresh Fuel Assemblies p. 14

"The following fresh fuel assembly tolerances should be considered for inclusion as uncertainties in the criticality analysis, unless they can be shown to be insignificant. The parameters are listed in descending order of estimated level of significance to k_{eff} uncertainty.

a) Enrichment
b) Channel (BWR only)
c) Pellet Density
d) Rod Pitch
e) Fuel Pellet Outside Diameter
f) Cladding Outside Diameter
g) Cladding Thickness
h) Guide Tube Thickness

… Fuel assembly tolerances should be evaluated in the appropriate rack model. "

Tolerances in NEI 12-16

- Section 7.2 Peak Reactivity Analysis for BWRs, p. 22,

"… A licensee should account for the dependence of the peak reactivity burnup and the magnitude of the peak reactivity for all storage rack calculations that are used to determine the maximum in-rack k_{eff} in the analysis. The following parameters can have a significant impact on reactivity in the storage rack and therefore should be considered: …

- **Non-reactor operating parameters**: …
  - o SFP rack tolerances and uncertainties
  - o BWR fuel lattice tolerances and uncertainties
  - o Other tolerance and uncertainty calculations (e.g., fuel assembly specific parameters, methodology specific items)"

Approaches to FAM Tolerance

- NEI 12-16 includes two approaches for addressing FAM Tolerances for Criticality Analyses
  - Treating the FAM Tolerances as uncertainties
    - Calculate reactive effect (Δk) of each FAM tolerance from the normal configuration, and include in the total uncertainty calculation.
  - Using bounding, with respect to k_{eff}, values
    - Determine which FAM tolerance values result is larger k_{eff} values, and use them in the models.

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NEI 12-16 Δk for FAM Tolerances

- Δk for FAM Tolerances

  Δk = uncertainty $= (k_1 \pm n\cdot\sigma_1) - (k_2 \pm n\cdot\sigma_2)$

  Assuming independence, this equation becomes:

  $$= (k_1 - k_2) \pm [(n\cdot\sigma_1)^2 + (n\cdot\sigma_2)^2]^{(1/2)}$$

  Where:

  k_i = code calculated k_{eff}

  σ_i = Monte Carlo variance in the k_{eff} result

  n = multiplier to achieve a desired confidence level, normally 2

  - The second term is the uncertainty in the reactivity effect of the tolerance.
  - Since the reactivity effect of the tolerance is applied as an uncertainty in the system reactivity, the second term is an uncertainty of an uncertainty.
  - When combined with other uncertainties has a negligible effect.
  - $\Delta k = (k_1 - k_2)$ is appropriate.

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FAM Tolerance Parameters

- The parameters listed in NEI 12-16 are:
  - a) Enrichment
  - b) Channel (BWR only)
  - c) Pellet Density
  - d) Rod Pitch
  - e) Fuel Pellet Outside Diameter
  - f) Cladding Outside Diameter
  - g) Cladding Thickness
  - h) Guide Tube Thickness
- Parameters listed are all inclusive, except for significantly different future FA designs.

Application of Tolerance Calculations

- Tolerances are calculated in the pure water case (non-borated).
- Other situations (borated case), do not significantly impact the effect of the tolerances.
- Acceptable to use pure water tolerances in other situations.

Parameters Not in NEI 12-16

- Some parameters have been shown to not have a significant reactivity effect:
  - tolerances from instrument tube
- If analyzing a similar design, no need to reshow parameters are insignificant (e.g., a new 17x17 design with a new instrument tube thickness, but no other changes)
- For new designs, with substantial differences, the significance of parameters may need to be re-determined

Significance of FAM Tolerances

- A simple test of significance is included in NEI 12-16:
  - FAM tolerances with less than 10% Δk of the total uncertainty
- Section 4.1, Fresh Fuel Assemblies p. 14

"… Significance is determined based upon the overall effect on the total uncertainty, and on the margin to the regulatory limit. Typically, an uncertainty that is less than 10% of the total uncertainty may be considered insignificant. For example, suppose the total uncertainty (defined to be the square root of the sum of the squares of independent uncertainties or RSS) is 0.01 Δk. Using RSS, the effect of an additional independent uncertainty equal to 10% of the total uncertainty (0.001 Δk) can be calculated to increase the total uncertainty from 0.01Δk to only 0.01005 Δk. Unless the margin to the regulatory limit is very small, the 0.001 Δk uncertainty is not significant compared to the total uncertainty. "

Summary

- Reviewed NEI 12-16 text on FAM Tolerances
- Reviewed NEI 12-16 approaches for FAM Tolerances
- Reviewed NEI 12-16 FAM Tolerance Parameters
- Discussed FAM Tolerance Parameters not in NEI 12-16
- Discussed Significance of FAM Tolerance Parameters

Open Discussion

Reactivity Effects of Depletion

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Outline

- Depletion Model
- Power Assumption
  - Moderator Density (and Temperature)
  - Fuel Temperature
- Soluble Boron
- Specific Power
- Operating History
- Integral/Discrete Absorbers and Inserts
- Rodded Operation

Introduction

- Depletion Analysis is needed to determine the isotopic content at the burnups assumed in the criticality analysis
- The Depletion Analysis uses conservative input parameters to cover the range of operating conditions.

Depletion Model

- Depletion Models produce one-group cross sections followed by a solution of the isotopic production and loss equations.
- Historically the group collapse was done using a 1D pin cell or super cell. This produced good results but current and future work is done using 2D lattice models.

Depletion Model

- 3D effects in the pool are modeled by stacking up appropriate 2D models.
- Separate lattice models are used for different enrichment cross-section planes.
- Separate lattice models may also be used for differing burnable absorbers, control rods, or temperature conditions.
- The XY/Z separability is valid for criticality analysis and is used in fuel management analysis.

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Depletion Models

- Depletion models use nominal dimensions as input.
- Dimension changes that produce a harder spectrum and hence more reactive atom densities when in the rack produce a lower k.
- For example, increasing the clad OD hardens the spectrum for the depletion resulting in more reactive atom densities but the reduction of moderation in the pools is a larger negative reactivity. (Borated pool conditions have large margin.)

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Power Assumption

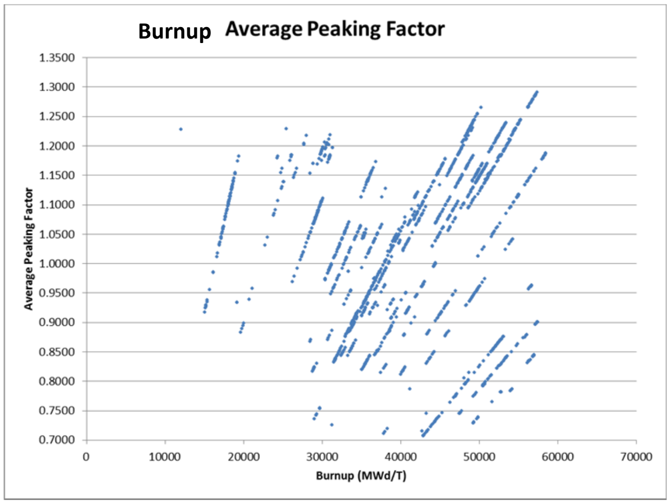
- Higher power produces higher moderator and fuel temperatures which in turn produce more reactive fuel.
- A conservative power is necessary to avoid assembly specific loading curves.
- Studies have shown that the reactivity change with moderator and fuel temperature is linear (NUREG/CR-6665) so using burnup averaged temperatures is appropriate.

Power Assumption

Burnup Average Peaking Factor = Discharge Burnup/(Σ Cycle Burnups)

- The burnup average peaking factor is an assembly averaged value. Tech Specs normally are given for pin values ($F_{\Delta H}$) and are not burnup averaged.
- The maximum assembly radial peaking factor is often part of the reload safety analysis.

Power Assumption



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Moderator Temperature

- With a peaking factor determined, the assembly averaged outlet temperature can be calculated.
- The enthalpy rise across the core (determined by the difference between T_{in} and T_{out}) is multiplied by the peaking factor and the temperature is backed out of the enthalpy at the reactor pressure.
- The nominal T_{in} and T_{out} can be used, since a burnup averaged temperature is desired.

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Moderator Temperature

- Conservative to use the outlet temperature from the peak assembly.
- The use of a constant temperature (the outlet temperature) for all elevations is a small conservatism due to the end effects.

Fuel Temperature

- The higher the fuel temperature the more reactive the fuel.
- The assembly average peaking factor can be used to calculate the fuel temperature.
- The axial peaking factor of 1.0 can be used. This is appropriate due to end effects.
- Fuel management codes determine the fuel temperature as a function of burnup.

Fuel Temperature

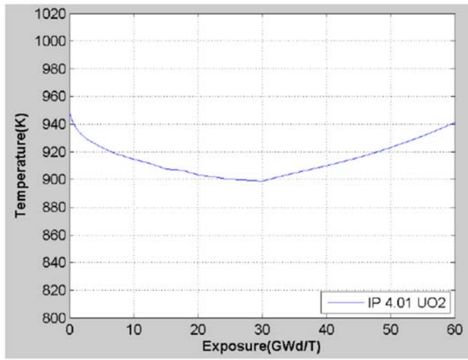

Figure 8-1
Typical INTERPIN-4 Fuel Temperature Change With Burnup

From EPRI Technical Report 1022909

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Fuel Temperature

- Fuel temperature models in fuel management tools are sufficient.
- For tools not used in fuel management such as SCALE the fuel temperatures need to be conservatively matched to fuel management tools or other models.

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Soluble Boron

- The higher the soluble boron during depletion the more reactive the fuel.
- It has been shown that the reactivity effect is about the same (even a little conservative) when using a burnup averaged ppm as using a letdown curve. (NUREG/CR-6665)
- Beginning of cycle ppm is limited due to the Moderator Temperature Coefficient (MTC)
- Due to MTC limits a reasonable maximum average ppm can be determined.

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Soluble Boron

- The soluble boron limit can be confirmed as part of the reload licensing analysis.
- Administrative procedures can be used to confirm the ppm assumption if shutdown outside the design burnup window occurs.
- If the maximum average ppm is not met the fuel can be treated as fresh fuel (or credited for burnup to the point where the average ppm is violated) until analysis of compensating reactivity is performed.

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Specific Power

- Specific power (w/gU) controls the production and loss rate due to neutron interaction versus decay.
- For example as specific power increases, the Xe-135 increases since the production rate increases and the decay rate is the same.
- This increase in Xe-135 hardens the spectrum and therefore if spectrum hardening is the only impact the highest specific power is more limiting (but only slightly)

Specific Power

- Gd-155 is a key absorbing fission product in used fuel.
- Eu-155 decays to Gd-155 with a 5 year half life.
- Low specific power allows more of the Eu-155 to decay to Gd-155 during plant operation.
- Due to the large Gd-155 absorption cross section much of the Gd-155 produced in the reactor is destroyed.
- Since at low specific power more of the Gd-155 is removed depletion with low specific power is more limiting when all isotopes are used in the analysis.
- The effect is small.

Specific Power

- The specific power clearly also effects fuel and moderator temperatures during depletion.
- Since the fuel and moderator temperature effect is much larger than the Gd-155 content effect, the highest specific power is used.

Operating History

- Operating history addresses the order of power with time.
- Most effects are approximately linear so there is little difference on the time ordering of power.
- Burnup average conditions apply.
- Studied in ORNL/TM-12973

Operating History Study ORNL/TM-12973

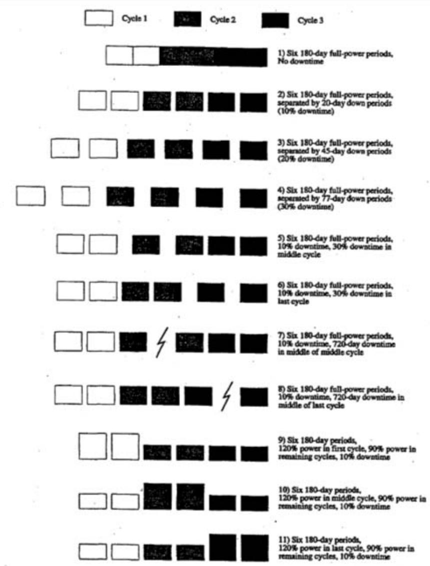

Fig. 20. Three-cycle operating histories for sensitivity analyses.

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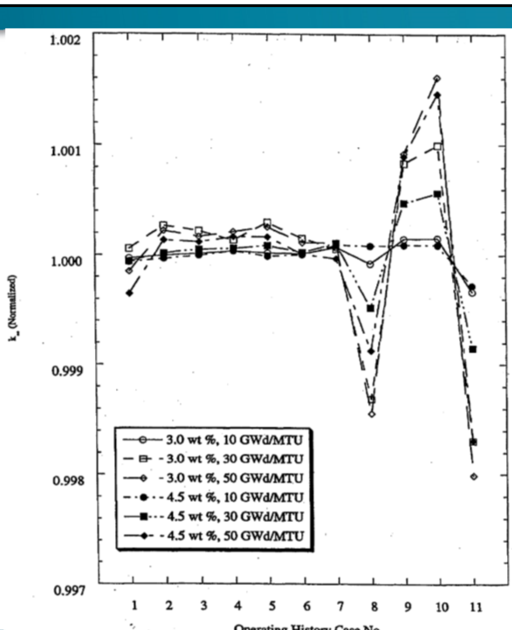
Operating History Study ORNL/TM-12973



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Operating History

- Modeling shutdowns allow for more Eu-155 to decay (5 year half life) which results in burnout of some Gd-155. It is conservative (very small) to ignore shutdowns.
- ORNL/TM-12973 concluded that the **operating history effect is small and continuous burn is appropriate.**

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Integral/Discrete Absorbers

- PWRs add burnable absorbers (BA) to
  1. Reduce the Beginning of Cycle (BOC) ppm in order to assure a negative MTC.
  2. Help in power distribution control.
- BAs harden the spectrum due to
  1. Absorber material
  2. Water displacement

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Integral/Discrete Absorbers

- Criticality analysis must maximize reactivity effects of both the water displacement and absorber material.
- For example, Pyrex (also called standard BP) displaces more water than WABAs.
- Varied number of fingers in BA designs.
- Care must be taken to review the history of BA usage.

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Integral/Discrete Absorbers

- Integral and discrete absorbers can be used in the same assembly. The depletion analysis must include both.
- Long cycle lengths can lead to use of the maximum integral absorbers combined with discrete absorbers; in order to cover future designs, high BA content is recommended in the analysis.

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Integral/Discrete Absorbers

- Gadolinia and Erbia contain even isotopes that do not burn out.
- The even isotopes cause an equilibrium content of high absorbing odd isotopes.
- The net effect is that Gadolinia and Erbia absorption outweighs the spectrum hardening effect for all burnups.
- Gadolinia and Erbia can be ignored.
- Ignoring Gd or Er pins includes ignoring other common features of these pins.

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Integral/Discrete Absorbers

- The water displacement effect of a removable burnable absorber may be reduced by removing the burnable absorber from the depletion analysis at some burnup.
- Care must be taken to assure that the burnable absorber is not in the assembly longer than the assumed removal burnup.
- If fresh BAs are placed in assemblies for a second cycle the depletion analysis must model this effect since it adds reactivity.

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Flux Suppression Inserts

- Flux suppression inserts have been used to lower the fluence at vessel welds (PTS concerns)
- These inserts harden the spectrum and must be covered in the depletion analysis.
- The additional burnup of the assemblies while under the flux suppression inserts is generally low.

Other In-Core Inserts

- Neutron source inserts displace some water but generally would be covered by burnable absorber assumptions.
- Incore detector systems displace some water but not significant to criticality.

Integral/Discrete Absorbers and Inserts

- Burnable absorber and insert assumptions need to be verified for each cycle.
- The verification can be part of the fuel management design.

Rodded Operation

- Control rods harden the spectrum and need to be included in the depletion analysis if rodded operation occurs at the plant.
- For most plants at full power a small fraction of assemblies (less than 10%) are allowed to contain a control rod.
- Historically the lead control bank was placed at the bite position.
- Separate loading criteria may be used for assemblies that had rodded operation.

Example of Depletion Assumptions To Cover BAs/Inserts and Control Rods

- For the top node deplete for all burnups with control rods – this covers the bite position burnable absorbers and inserts
- For the rest of the nodes deplete 2 GWd/T with control rods followed by 33 GWd/T with discrete absorber – This covers 35 GWd/T of discrete absorber operation if not rodded or no inserts. It covers 2 GWd/T of flux suppression rods and 33 GWd/T of discrete absorbers.

Rodded Operation

- The depletion assumptions for rodded operations must be clearly presented and confirmed prior to taking burnup credit.
- Confirmation of the assumptions can be done as part of the reload design safety analysis checklist.

Open Discussion

Fuel Assembly Changes With Depletion

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Westinghouse

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Overview

- Background
- Analysis Description
  - Fuel Rod Analysis
  - Depletion
- Individual Parameter Results
- Holistic Results
- Conclusions

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STORED HISTORY BRIGHT FUTURE

Background

- During depletion within the core, there are physical changes to the fuel rods and pellets which may impact fuel assembly reactivity
- Westinghouse has performed an analysis to quantify different physical fuel changes associated with fuel depletion

Analysis Outline

- Westinghouse Study Considered:
  - Study based on 15x15 Westinghouse Fuel Design
  - IFBA and non-IFBA fuel pins
  - Pellets from Center and Top of fuel assembly reviewed

Fuel Rod Analysis

- PAD 4 analysis was performed based on Westinghouse FRD fuel temperature analysis methods:
  - Limiting axial power shapes and power histories
  - Burnups from 0 – 62 GWd/MTU examined

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Fuel Rod Analysis

- PAD 4 used to determine inputs to the depletion calculations:
  - Min/max fuel density
  - Min/max fuel pellet diameter
  - Min/max clad diameter
  - Min/max clad thickness

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Depletion Analysis

- Depletions performed in PARAGON based on PAD data to determine isotopic inventory:
  - Fuel data was modified to reflect PAD results
  - Assume changed parameter over full depletion
  - Uniform moderator temperature profile assumed
  - Fuel temperature a function of burnup & power
  - Limiting plant-specific axial profile used

Depletion Analysis

- The following cases were performed for both IFBA/Non-IFBA Fuel:
  - Base Case
  - Maximum Fuel Density
  - Maximum Clad Outer Diameter
  - Maximum Clad Thickness
  - Minimum Clad Outer Diameter Pre-Condition
  - Minimum Clad Outer Diameter
  - Minimum Fuel Density Pre-Condition
  - Minimum Fuel Density
  - Minimum Clad Thickness

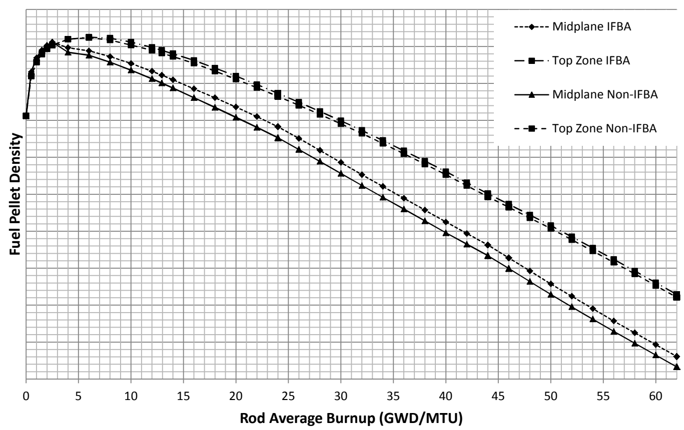
Criticality Analysis

- The isotopics generated in the depletion calculations are imported to KENO V.a
- KENO V.a Models:
  - 26 Axial Nodes
  - All-Cell Model
  - Developed-Cell Style Rack
  - Calculations done at 5.0 wt%, 62 GWd/MTU

Fuel Pellet Diameter & Density Changes

- The density and outer diameter of fuel pellets change with fuel burnup as the pellet goes through densification and then swelling
- The reactivity associated with conservatively modeling each phenomena was reviewed together
  - Minimum pellet diameter + maximum density
  - Maximum pellet diameter + minimum density

Fuel Density with Depletion



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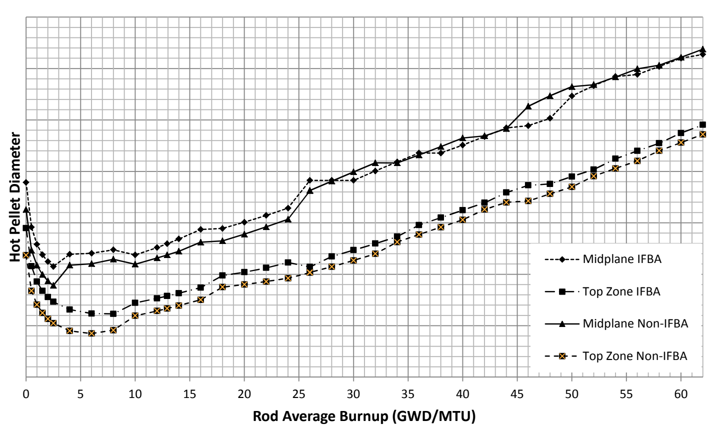
Fuel Pellet Diameter with Depletion



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Fuel Pellet Density Change Results

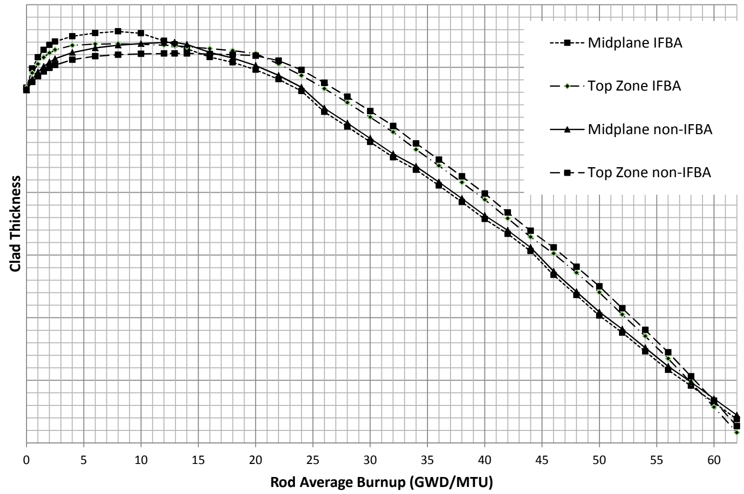
non-IFBA Fuel Results	
Case Name	**Δk**
maximum pellet density	0.00223
minimum pellet density	-0.00375

IFBA Fuel Results	
Case Name	**Δk**
maximum pellet density	0.00165
minimum pellet density	-0.00321

Clad Thickness Changes

- Clad thickness changes with depletion:
  - BOC clad thickens with oxide buildup
  - Clad starts to ‘thin’ after ~15 GWd/MTU
  - Calculations based on minimum clad thickness

Clad Thickness Changes with Depletion



Fuel Clad Thickness Change Results

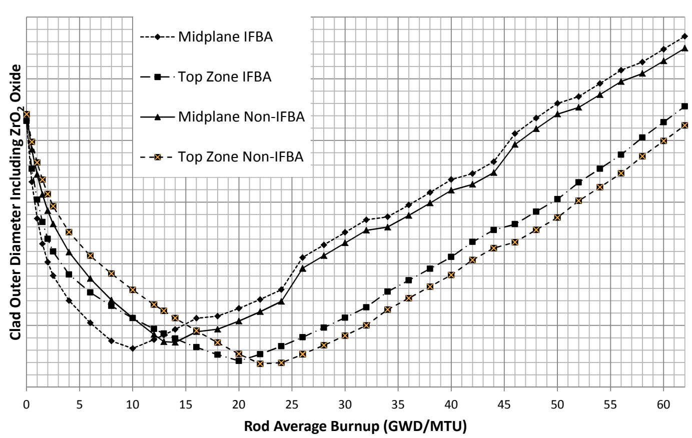
non-IFBA Fuel Results	
Case Name	**Δk**
maximum clad thickness	0.00032
minimum clad thickness	0.00223

IFBA Fuel Results	
Case Name	**Δk**
maximum clad thickness	0.00021
minimum clad thickness	0.00237

Clad OD Changes

- Fuel Clad Outer Diameter changes based on pellet thickness
  - Fuel Clad OD decreases BOC due to pellet densification
  - Fuel Clad OD increases from ~15 GWd/MTU due to pellet swelling

Clad Diameter Changes with Depletion



Fuel Clad OD Change Results

non-IFBA Fuel Results	
Case Name	**Δk**
maximum clad OD	0.00129
minimum clad OD	-0.00506

IFBA Fuel Results	
Case Name	**Δk**
maximum clad OD	0.00124
minimum clad OD	-0.00554

Holistic Impact

- Each effect discussed above was isolated to the extent practicable but these impacts are directly related
- To provide a better estimate of the true reactivity impact
  - Calculations were performed assuming the fuel pin geometry associated with peak fuel density and end of life conditions (62 GWd/MTU)

Overall Reactivity Impact of Fuel Changes

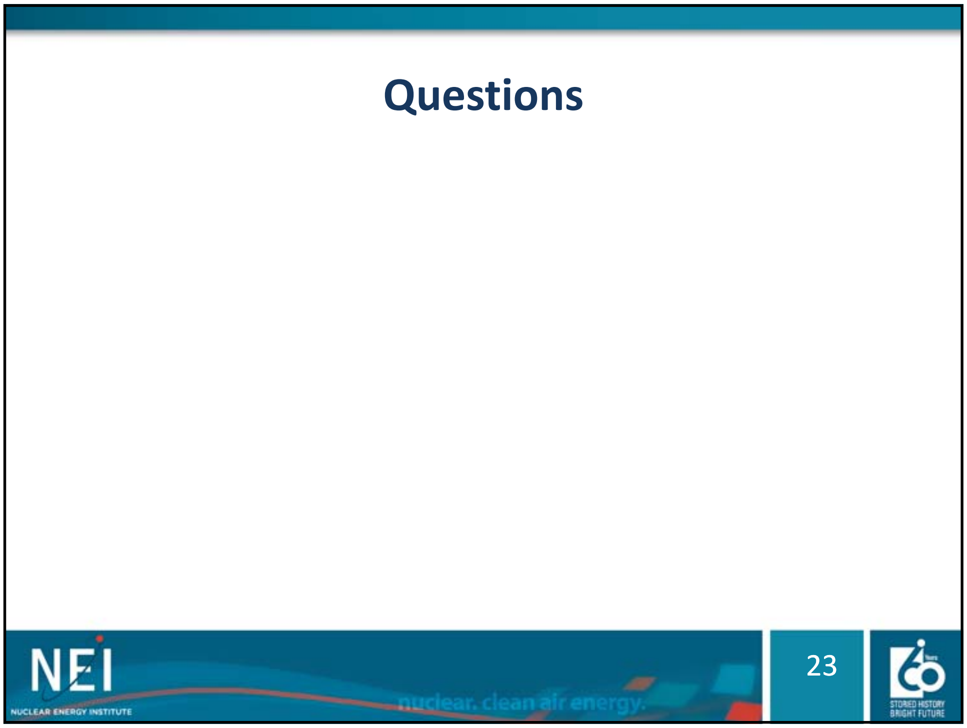
- Reactivity delta: $k_{perturbed} - k_{nominal}$
  - $k_{perturbed}$: Reactivity with geometry changes
  - $k_{nominal}$: Reactivity without geometry changes

non-IFBA Fuel Results	
Case Name	**Δk**
EOL Case	-0.00093
Maximum Density Case	-0.00123

IFBA Fuel Results	
Case Name	**Δk**
EOL Case	-0.00040
Maximum Density Case	-0.00409

Conclusions

- Each individual fuel geometry pattern has a small positive or negative impact on fuel reactivity
- Overall impact of fuel geometry changes with depletion is small
- Ignoring the impact of fuel geometry changes with depletion is appropriate
- Aligns with standard fuel management calculations which ignore fuel geometry changes


Questions
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STORIED HISTORY
BRIGHT FUTURE

Axial Burnup Distribution

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Axial Burnup Distribution (ABD)

- The distribution of the burnup along the axial length of the fuel assembly can have a significant impact on reactivity
- Compared to assuming a constant burnup value for the entire assembly
- Determined by multiple factors during reactor operation (power level, core operation, presence of absorbers, axial enrichment zoning, etc).

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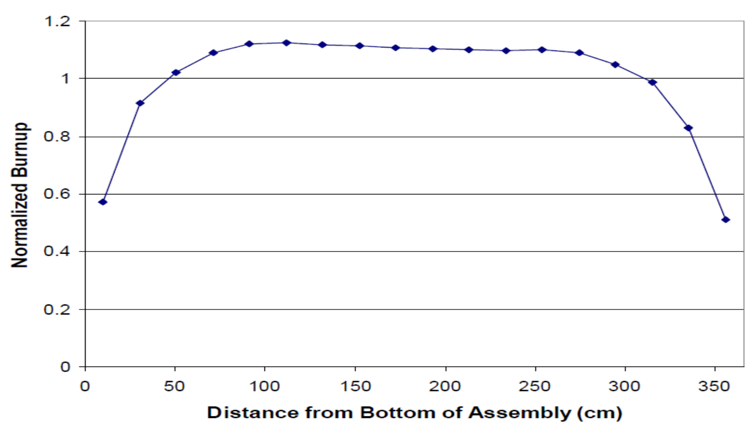
Axial Burnup Distribution

- ABD starts out cosine shaped, and gradually flattens in the middle due to shifting of the neutron flux to the ends.
- Burnup at the top and bottom is reduced due to axial neutron leakage.
- The presence of the low burnup regions near ends of assembly produces a higher reactivity region than center of assembly.

Representative Axial Burnup Distribution[1]



[1]ORNL/TM-1999/246, 1999

Determination of the ABD

- Determining the ABD to use in the fuel assembly model can significantly impact the results.
- Three acceptable approaches are available to model the ABD, depending on the amount of data available.

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Determination of the ABD

1) Use of generic profiles from NUREG/CR-6801

- Bounding for non-blanketed fuel
- Can be used when plant specific profiles are not available
- Sufficiently conservative to eliminate need to explicitly verify that future plant specific profiles are bounded.

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Determination of the ABD

2) Use of plant specific profiles to create a bounding profile(s):

- Take the minimum relative burnup of each node from all plant specific profiles
- Produces an under-normalized (<1.0) profile
- No renormalization of the profile
- Also eliminates need to verify future profiles

Determination of the ABD

3) Evaluate and use most reactive plant specific profile(s):

- Licensee/vendor develops process for determining most reactive profile
- Bounds all past fuel assemblies, and provides reasonable assurance that future profiles will be covered.
- Recommended to verify future profiles are bounded by worst past profile (by admin procedure).

Variation of ABD with Burnup

- NUREG/CR-6801 recognizes that applying a low burnup ABD to higher burnups "overestimates" the reactivity effect.
- Therefore ABDs were developed for 12 "burnup groups"
- It is acceptable to apply this same approach to Options 2 & 3 above and maintain conservative ABDs in the analysis

Axial enrichment distributions - Blankets

- NUREG/CR-6801 only covers non-blanketed fuel.
- Low-enrichment blankets reduce the relative burnup in the top/bottom nodes (but offset by lower enrichment)
- Non-blanketed fuels bound blanketed fuel (evidenced by higher burnup requirements for non-blanketed fuel).

Axial enrichment distributions - Blankets

- Options 2&3 allow for the use of separate ABDs from blanketed fuel to be used for additional operational flexibility.
- Separate acceptance limits would be developed for fuel with blankets.

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Nodalization

- Nodalization of the axial burnup distribution needs to be sufficiently fine to capture low burnups ends.
- NUREG/CR-6801 (Appendix A) concluded 18 equidistant nodes is sufficient.
- Also, 7 nodes (with finer structure on the ends) is sufficient.[1]

[1]ORNL/TM-1999/99

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Questions

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