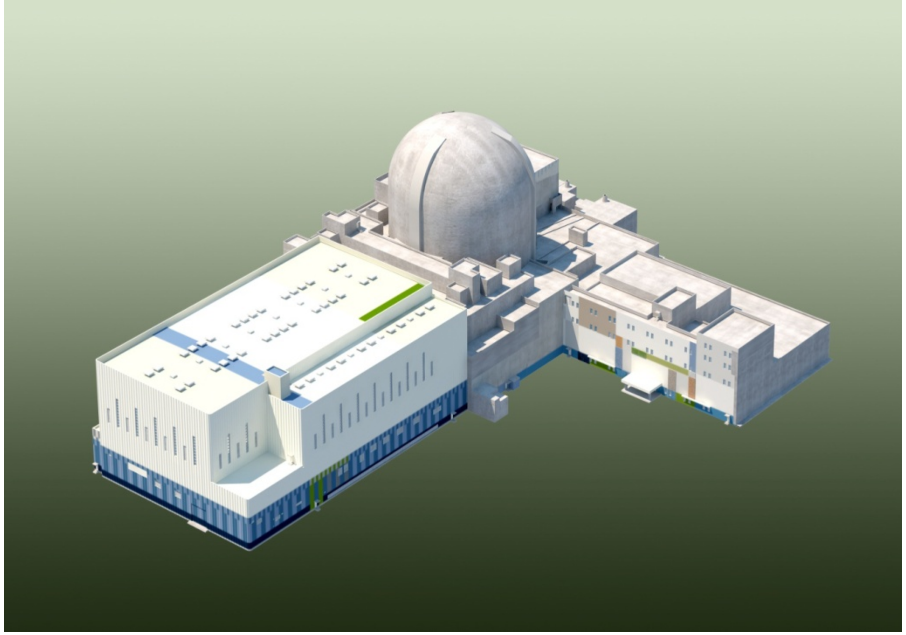
Burnup Credit Analysis Methodology



KEPCO/KHNP
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Introduction

- **Major Guidance**
  - DSS-ISG-2010-01 : Staff Guidance Regarding the Nuclear Criticality Safety Analysis for SFPs
  - NEI 12-16, Rev. 1 : Guidance for Performing Criticality Analyses of Fuel Storage at Light Water Reactor Power Plants
  - Relevant NUREG's
  - NRC memorandum from L. Kopp to T. Collins (Kopp Memo)

Introduction

- **Computer Code & Cross Section Library**
  - Depletion Calculation : ORIGEN-ARP (SCALE 6.1.2)
  - Cross Section Generation : TRITON/NEWT (SCALE 6.1.2)

    - Fuel Name : PLUS7

    - Assembly Lattice : 16x16

    - Enrichment Range: 1.5 ~ 6.0* wt% U-235

    - Burnup Range: 0 ~ 72* GWd/MTU

    - Burnup Step: 2.25 GWd/MTU (Total 33 steps)

    - Cross Section Library: ENDF/B-VII 238-group

* The maximum initial enrichment and burnup were 5.0 wt% U-235 and 62 GWd/MTU, respectively. However, enrichment and burnup beyond the maximum value were considered to generate cross section library for the purpose of sensitivity studies.

Introduction

Cross Section Generation

- The TRITON sequence is used to generate libraries for the PLUS7 16x16 fuel assembly.
- To generate cross section libraries for the PLUS7 16x16 fuel assembly, the following steps are performed for each fuel enrichment value (1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, and 6.0 wt% of U-235):

1. Creating a 2-D reactor physics model considering the PLUS7 fuel assembly design.
2. The depletion calculation is performed up to the maximum burnup (72 GWd/MTU). 32 burnup steps are used with intervals of 2.25 GWd/MTU, and one library is generated for each steps. The library generated by this analysis contains 33 sets of cross sections: fresh fuel cross sections and 32 burnup-dependent cross sections.
3. The above procedure is repeated for each enrichment value.

Introduction

- Parameters used in cross section generation consist of composition mixture data, cell data, moderator data and burnup history data.
- Summary of parameters used in this calculation are listed in the table.

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Introduction

- **Related Issues for the Burnup Credit Analysis**
  - Reactor Parameters
  - Depletion Uncertainty
  - Burnup Measurement Uncertainty
  - Minor Actinide and Fission Product Bias
  - Burnable Absorbers
  - Axial Burnup Profile

Reactor Parameters

- DSS-ISG-2010-01 states that "Bounding values should be used, and they should be traceable to other licensee documents."
- Therefore, bounding reactor parameters were applied to depletion analyses.
  - Maximum Fuel Temperature : Higher fuel temperature causes Doppler broadening and it results in increased plutonium production.
  - Maximum Moderator Temperature (Minimum moderator density) : Higher moderator temperature causes less moderation and it results in energy spectrum hardening.
  - Maximum Power Level: Maximum power level was considered in depletion calculation since higher power level results in higher moderation and fuel temperature.
  - Maximum Fuel Density : Maximizes fissile material.
  - Maximum Cycle Average Soluble Boron Concentration : Higher soluble boron concentration causes energy spectrum hardening.

Reactor Parameters

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Depletion Uncertainty

- DSS-ISG-2010-01 states that "Depletion uncertainty as cited in the Kopp memorandum should only be construed as covering the uncertainty in the isotopic number densities generated during the depletion simulations."

- Therefore, the uncertainty due to isotopic number density generation is taken to be 5% of the reactivity difference between the reactivity at the fresh fuel condition and the reactivity at the burned fuel condition of interest.

- EPRI report* titled "Utilization of the EPRI Depletion Benchmarks for Burnup Credit Validation" shows that the use of 5% Δk as an uncertainty is conservative enough.

*The EPRI report is still under NRC review but is only being used to demonstrate the conservatism of the 5% decrement method from the Kopp Memo.

Depletion Uncertainty

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Burnup Measurement Uncertainty

- The burnup measurement uncertainty is calculated by the reactivity difference between exactly burned fuel and 5% less burned fuel.

- 5% change in burnup was based on the NEI 12-16 Rev. 1.

Burnup Measurement Uncertainty

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Bias due to Minor Actinide and Fission Product

- **Nuclides considered in the criticality analysis**
  - 12 actinides and 16 fission products recommend in ISG-8 were considered for the criticality analysis.

9 Major Actinides	U-234, U-235, U-238, Pu-238, Pu-239, Pu-240 Pu-241, Pu-242, Am-241
19 Minor Actinides and Fission Products	Mo-95, Tc-99, Ru-101, Rh-103, Ag-109, Cs-133, Sm-147, Sm-149, Sm-150, Sm-151, Sm-152, Nd-143, Nd-145, Eu-151, Eu-153, Gd-155, U-236, Am-243, Np-237

Bias due to Minor Actinide and Fission Product

- To analyze the bias for minor actinide and fission product, the sensitivity analysis is performed to assess the worth of the minor actinides and fission products.
- The analysis results show that the credited minor actinide and fission product worth is no greater than 0.1 in k_{eff}. (Although the worth of 5.0 wt% and 51.75 GWd/MTU is slightly over the limit, the excess worth is negligible.)
- Therefore, 1.5% of the worth of the minor actinides and fission products conservatively covers the bias due to these isotopes as discussed in the NUREG/CR-7109.

Bias due to Minor Actinide and Fission Product

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Burnable Absorbers

- Burnable absorber effect to the reactivity should be evaluated because it harden the energy spectrum during operation.
- As a result of evaluation, the k_{eff} for the fuel assembly without burnable absorber is greater than the k_{eff} for the fuel assembly with burnable absorber.
- The reason for this result is that residual content of Gadolinium has more negative reactivity worth than the positive worth due to harder spectrum depletion.
- This result was consistent with NUREG/CR-6760.
- Therefore, burnable absorbers were not considered in criticality analysis.

Burnable Absorbers

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Burnable Absorbers

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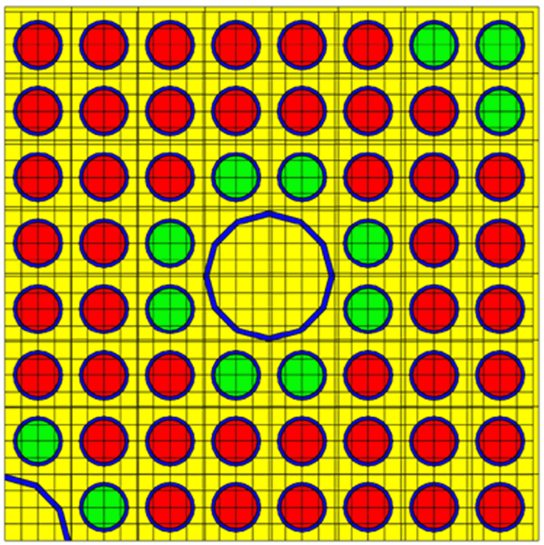
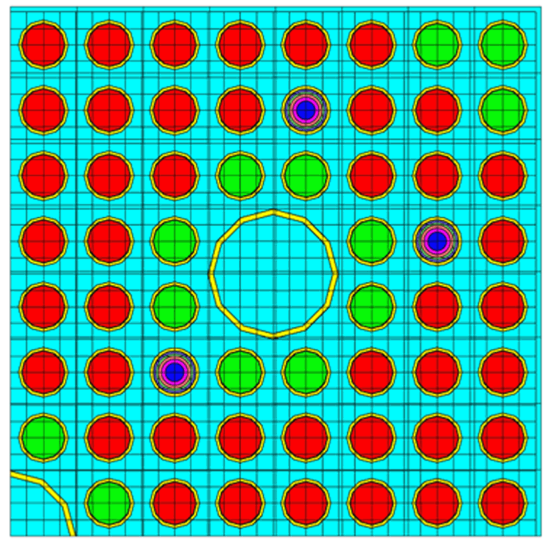
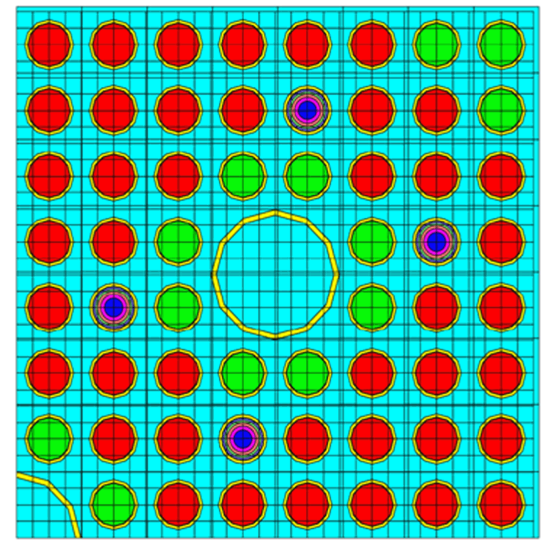
Burnable Absorbers

- **TRITON/NEWT 2-D Depletion Calculation Model**







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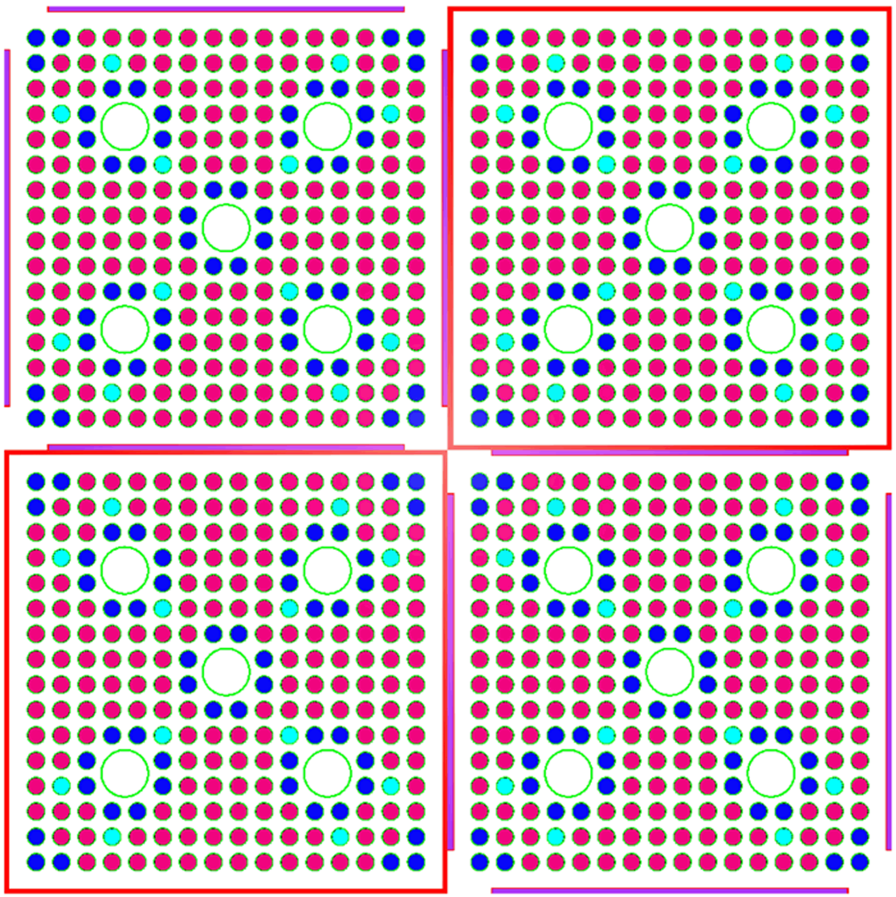
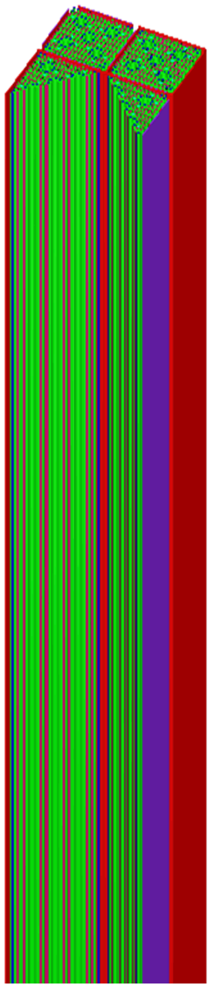
Burnable Absorbers

- Criticality Calculation Model





Burnable Absorbers

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Axial Burnup Profile

- When modeling the fuel assembly in the criticality analysis, the reactivity is affected by the distribution of burnup along the axial length of the fuel assembly.

- Therefore, sensitivity analyses were performed with and without a bounding axial burnup profile, to assess the magnitude of the end effect which is applied as a bias.

Axial Burnup Profile

- **Selection of Bounding Axial Burnup Profile**
  - Survey 304 axial burnup profiles over cycle 1 to 8.
  - Find the axial burnup profile that has a minimum of burnup summed over top 10 axial nodes (33% of active core length).
- **Modeling of Axial Burnup Distribution**
  - Original 26 axial nodes are modified into the 18 nodes by merging flat burnup regions in the middle of fuel assembly.
  - The local powers for each node are assumed by multiplying a normalized burnup distribution by the assembly-averaged power.

Axial Burnup Profile

- **End Effect of Non-Blanketed Fuel and Blanketed Fuel**
  - The PLUS7 16x16 fuel assembly has blankets (6 inches long 2 wt% U-235 pellets) at the top and bottom end of the fuel rod.
  - Sensitivity analyses were performed to assess the magnitude of the blanket effect.
  - By comparing the end effect without blanket and with blanket shows that the non-blanketed fuel is up to 3% Δk_{eff} more reactive.
  - Therefore, axial blankets in the fuel rod are not considered for conservatism.

Axial Burnup Profile

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Axial Burnup Profile

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Summary

- Burnup credit analysis methodology used in criticality analysis of spent fuel storage racks of APR1400 was based on DSS-ISG-2010-01.

- Depletion uncertainty, burnup measurement uncertainty, bias due to minor actinide and fission product, burnable absorber effects and axial burnup profile effects were evaluated.

- The burnup credit analysis overestimates the reactivity of discharge fuel and therefore the burnup requirements developed in technical report titled “Criticality Analysis of New and Spent Fuel Storage Rack” are conservative and ensure the safe storage of fuel in the spent fuel pool.

Thank you for your attention.