A Summary of the Recent BWR BUC Project at ORNL

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Outline

- Review of project structure, history, and accomplishments to date
- Review of peak reactivity results (NUREG/CR-7194)
- Review of Significant Tasks 3-5 Results (NUREG/CR-7224)
- Summary of Tasks 6 and 7 results (NUREG/CR-7240)
- Summary of Task 8 (NUREG/CR pending)
- Summary of Task 9 (NUREG/CR pending)

Project structure

Phase 1

Application of Peak Reactivity Methods to Casks

1. Evaluate peak reactivity analysis in transportation and storage casks
    - Modeling approaches
    - Gd_2O_3 loading and pattern effects
    - Void fraction, control blades, operating parameters
2. Evaluate validation of peak reactivity k_{eff} and burned fuel composition calculations
    - Crit experiments for validation
    - Isotopic validation via RCA samples

Phase 2

Extended BWR BUC (beyond peak reactivity)

3. Axial moderator distributions
4. Control blades during depletion
5. Axial burnup profiles
6. Reactor operating parameters
7. Correlated operating parameters
8. Burned fuel composition validation
9. Validation of k_{eff} calculations
10. BWR BUC guidance

Project history/accomplishments

- Results of Tasks 1 and 2 summarized in NUREG/CR-7194
  – Published April 2015
- Results of Tasks 3 – 5 summarized in NUREG/CR-7224
  – Published August 2016
- Results of Tasks 6 and 7 summarized in NUREG/CR-7240
  – Published January 2018
- Draft NUREG/CR for Task 8 under review, publication expected soon
- Draft NUREG/CR for Task 9 under review, publication expected soon
- Several conference papers also presented at ICNC, PHYSOR, PATRAM, and ANS conferences

Peak Reactivity (Task 1) Summary

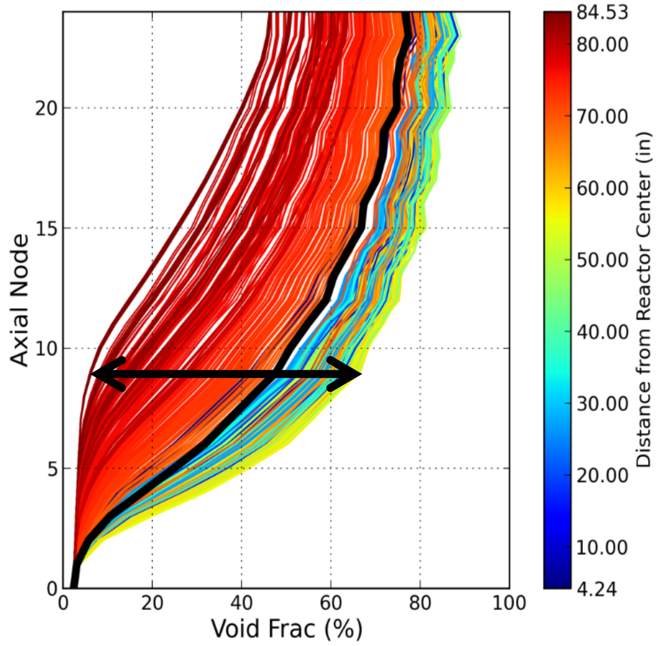
- Factors effecting peak reactivity examined
  - Isotopic modeling during depletion
  - Gadolinia loading and pattern
  - Void fraction
  - Control blade insertion
  - Operating history
- Four isotope sets considered
  - Actinide-only
  - Actinide and major fission products
  - Actinide and major fission products exclude ^{155}Gd
  - All isotopes (addnux=2)
- Tables summarizing effects published in NUREG/CR-7194

Peak Reactivity Validation (Task 2) Summary

- Validation of isotopic composition predictions
  - Challenging due to limiting number of applicable RCA samples
  - No applicable measurements of Gd isotopes in open literature
- Validation of k_{eff} calculations
  - Sufficient applicable benchmarks are available to perform validation
  - Applicable benchmarks lack some isotopes, so modest penalty factors are needed for lack of validation
    - Pu/Am and fission products

Coolant Density (Task 3) Significant Results

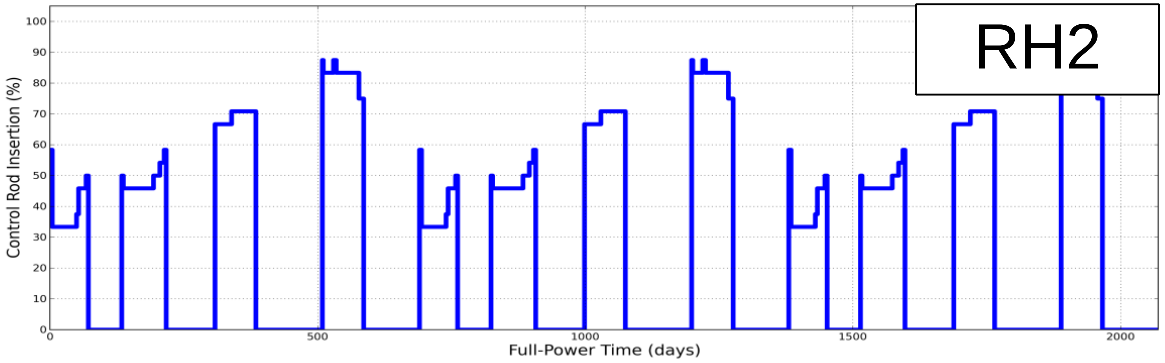
- Cycle-average nodal coolant density can be used with a small penalty
  - Calculated = 0.1% Δk_{eff}
  - Recommended Penalty = 0.25 % Δk_{eff}
- 40% void fraction in all nodes is up to 10% Δk_{eff} non-conservative
- Core-average coolant density profile is up to 4% Δk_{eff} non-conservative
- Axial top portion of the coolant density profile has significant impact on cask reactivity
- 10 actual profiles tested, as well as other limiting profiles documented in NUREG/CR-7224

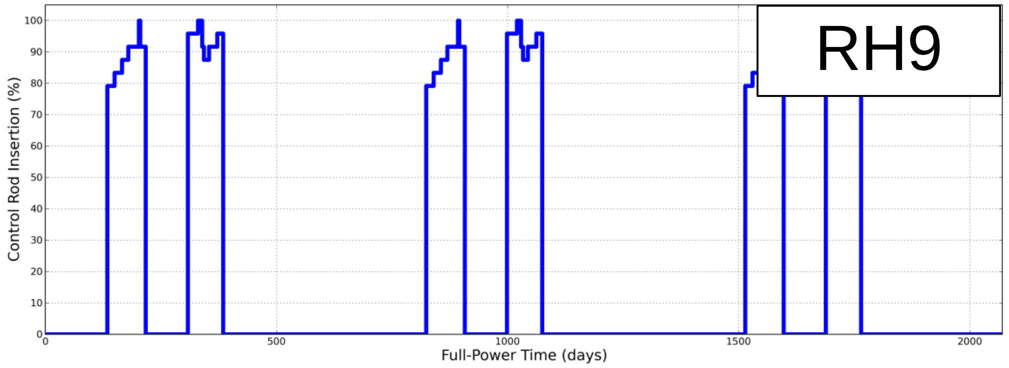


Cycle-average coolant density profiles for every assembly in the core

Control Blade (Task 4) Significant Results

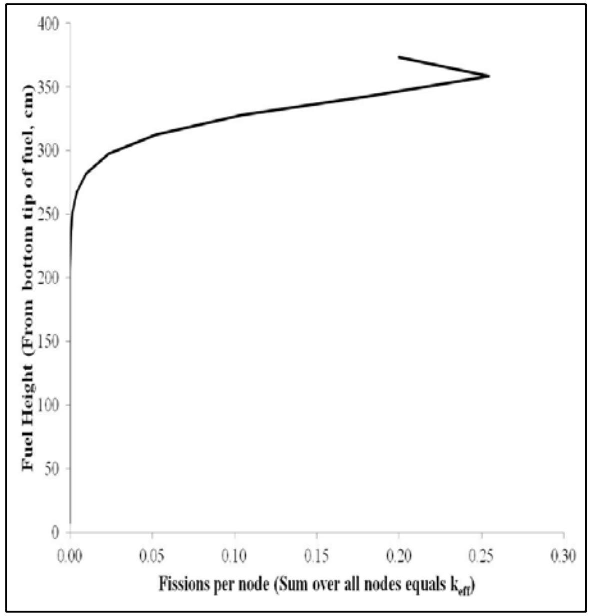
- Control blades inserted to near full-depths, for long duration, and near discharge time result in more limiting cask reactivity.
- Control blade insertion less than 50% of the active fuel height have almost no impact on cask reactivity.
- Modeling the control blades as fully-inserted for the entire irradiation may be overly-limiting.
- The tested realistic control blade histories result in an increase in cask reactivity of 0.6% Δk_{eff} compared to blades-out conditions.
  - 0.6 - 1.2 % Δk_{eff} penalty recommended for a blades-out assumption

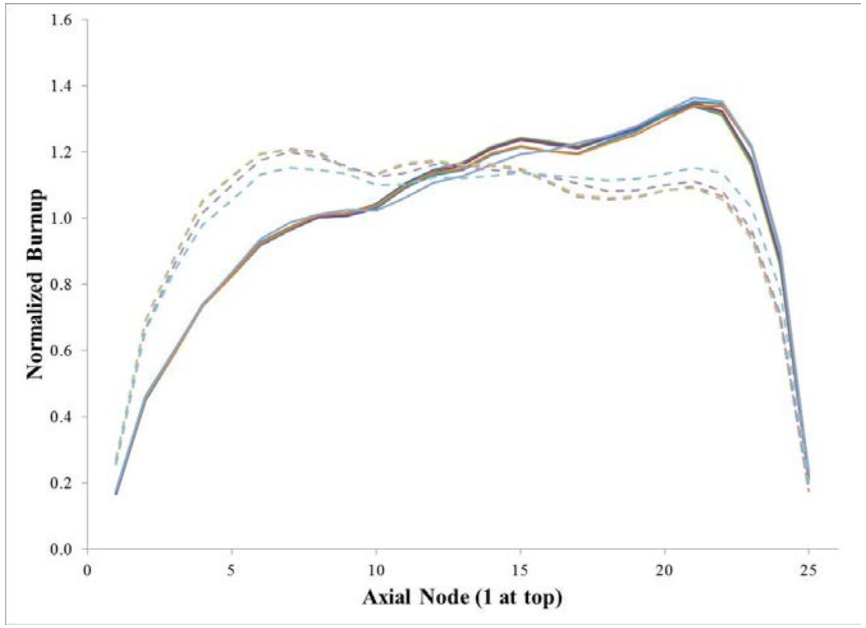




Burnup Profile (Task 5) Significant Results

- Usage of an axially-uniform burnup profile is unacceptable
  - "End effect" – difference between uniform and distributed burnup profiles in terms of cask k_{eff}
  - End effects of up to 12.7% Δk_{eff} were observed
- Selection of a distributed axial burnup profile has a significant impact on cask reactivity
  - Biases up to 7.6% Δk_{eff} between the least and most reactive profiles in the 624 tested burnup profiles





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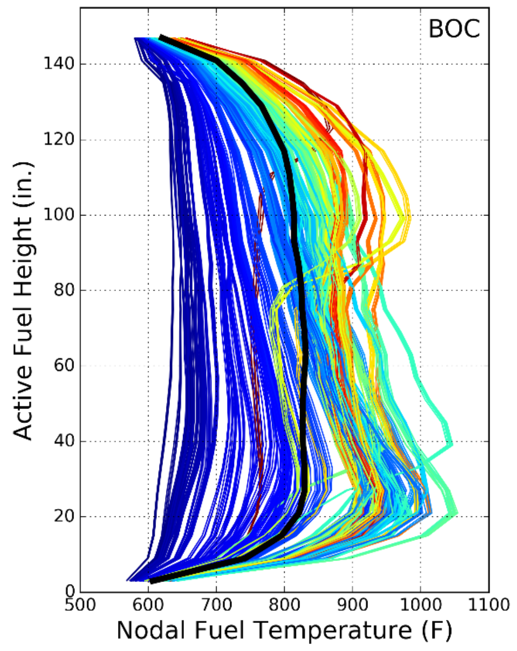
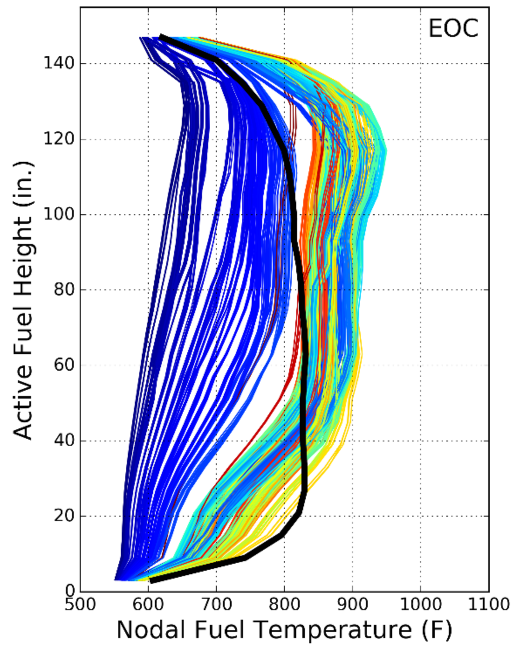
Operating Parameters (Task 6) Results

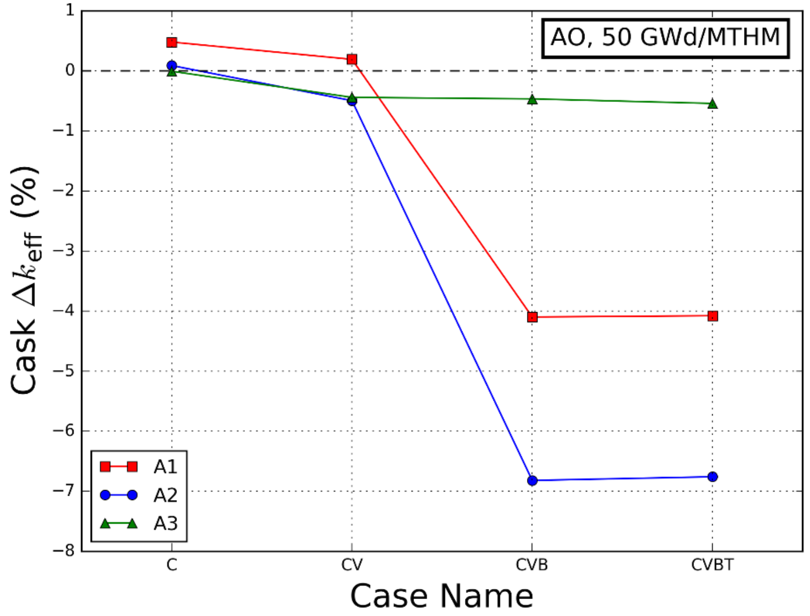
- Fuel temperature
  - Higher temperatures are more limiting due to increased plutonium production
  - ~0.1% Δk_{eff} increase per 100 K
- Bypass water density
  - <0.1% Δk_{eff} increase for every 1% reduction in bypass density
- Specific power almost no impact
- Operating history
  - Downtime between cycles and last cycle power have negligible impacts
  - No significant overall impact based on available data
- Impacts to cask reactivity small compared to those observed in Tasks 3-5

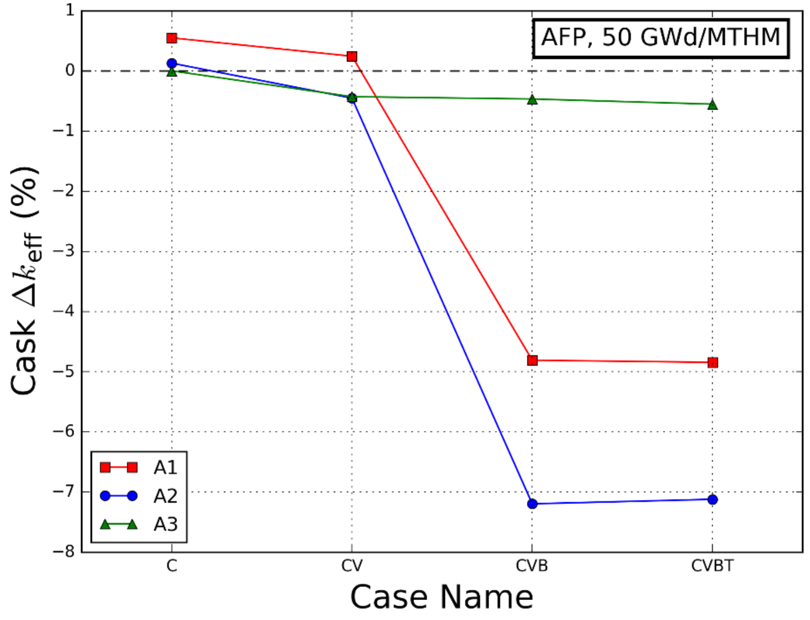




Correlated Parameters (Task 7) Results

- Criticality margin can be gained by using assembly-specific conditions for all assemblies tested
- Magnitude of the margin gained heavily depends on the assembly chosen: 0.5 – 7.0% Δk_{eff}
- Using the assembly-specific burnup profile has the most significant impact on cask reactivity
- Fuel assemblies that undergo control blade insertion result in less limiting cask reactivity due to the effect the control blade has on the coolant density and axial burnup profile





Extended BWR BUC Isotopic Validation (Task 8) Summary

- Analysis based on 77 BWR RCA samples from a number of fuel assembly design types in Polaris
  - Burnup range from 7-68 GWd/MTU
  - Void fraction range from 0-74%
- Margin developed based on bias and single-sided 95% lower tolerance limit
  - Bias: 253 pcm (AO) and 161 pcm (AFP)
  - Uncertainty: 2166 pcm (AO) and 2390 pcm (AFP)
  - Total margin (no positive bias): 2419 pcm (AO) and 2551 pcm (AFP)
- Margin similar to PWR BUC results (NUREG/CR-7108)

Extended BWR BUC k_{eff} Validation (Task 9) Summary

- Sufficient critical benchmarks exist to support validation
- Changes in covariance data can impact the applicable benchmarks and therefore the validation results
- BWR BUC validation can be accomplished with HTC experiments (AFP) or HTC and LCT experiments (AO)
- Bias ~0.2% Δk and bias uncertainty ~0.6% Δk, depending on method
  - Results similar to PWR BUC validation (NUREG/CR-7109)
- Reactivity margins needed for unvalidated isotopes
  - 1-1.5% of minor actinide and fission product worth

Summary

- A wide range of analyses have been performed to investigate factors affecting BWR BUC analyses
- No significant technical barriers identified for analysis
- Isotopic validation of peak reactivity methods is challenging
- Additional considerations may be necessary for implementation of these methods in pool and/or cask loading
  - Cask loading/misload analysis
  - Combining peak reactivity and extended BUC methods