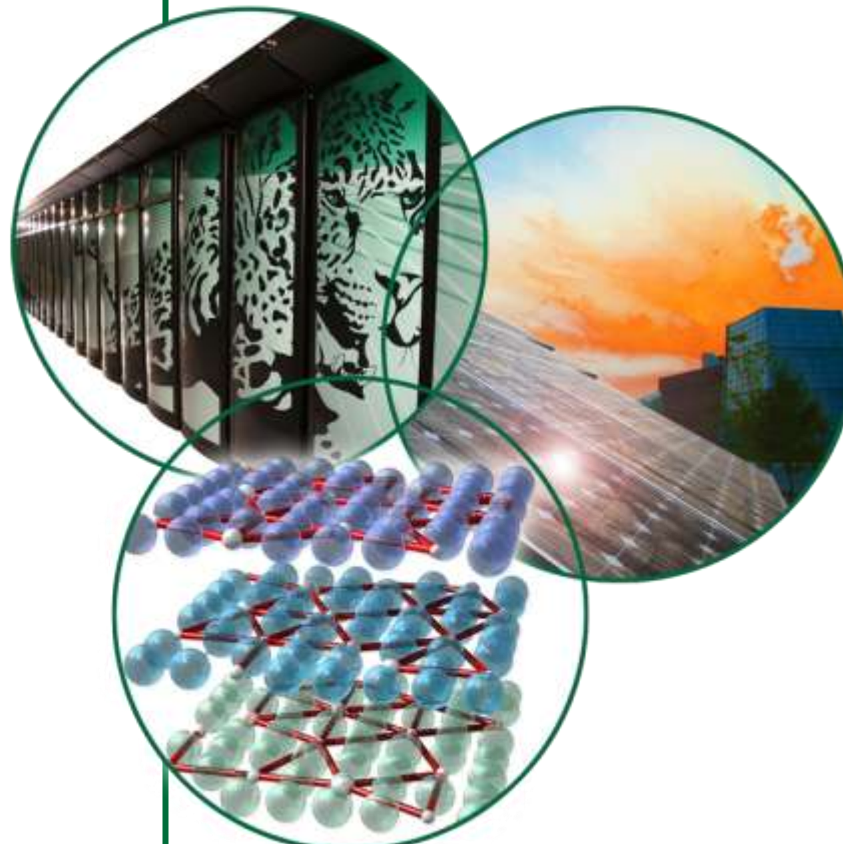
Evaluation of Peak Reactivity Analysis of Boiling-Water Reactor Fuel in Transportation and Storage Casks

W.J. Marshall, B.J. Ade, and
S.M. Bowman



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Outline

1. Introduction
2. Codes and Models
3. Results
4. Conclusions
5. Future work

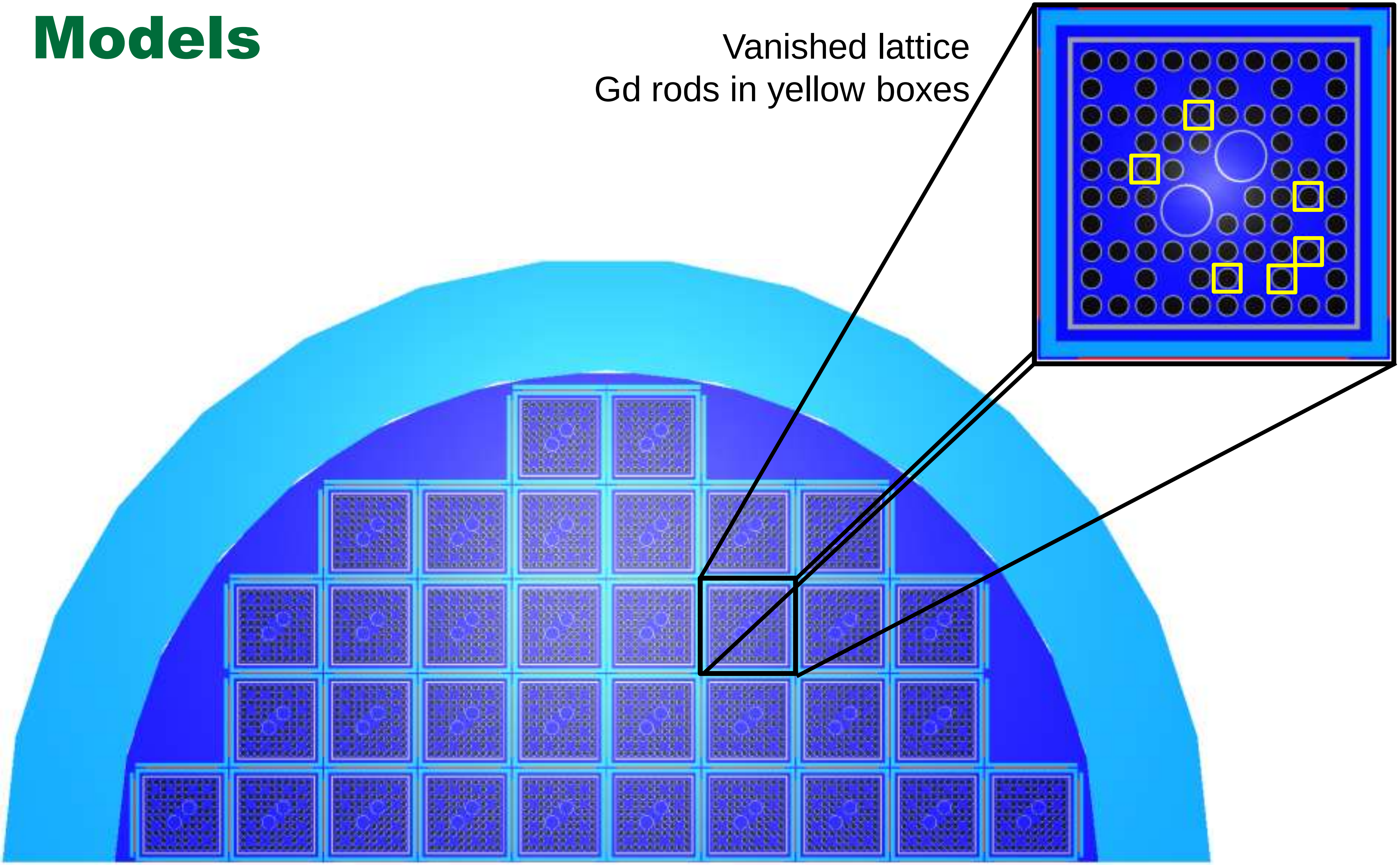
Introduction

- ORNL and NRC have initiated a project to investigate burnup credit for BWR fuel
  - Phase I: Peak reactivity methods applied in casks
  - Phase II: Extended burnup credit
- Phase I contains tasks for evaluating depletion parameters, criticality code validation, and composition validation
  - Depletion parameters presented in this paper
  - Criticality code validation presented later this session
- All Phase I work expected to be published in a future NUREG/CR document by the NRC

Codes and Models

- SCALE 6.1.2 used for all calculations
  - TRITON/NEWT (t-depl) used for depletion
  - SCALE/KENO V.a (csas5) used for cask reactivity determinations
  - SCALE 238-group neutron libraries based on ENDF/B-VII.0
  - Criticality models consider actinide-only (AO) and actinide and fission product (AFP) isotope sets
- GE14 fuel design type only assembly design studied
  - Used both full and vanished lattices, only VAN results presented
- Criticality calculations used GBC-68 computational benchmark model from NUREG/CR-7157
  - 2D slice consistent with peak reactivity methods

Models



2D Slice of GBC-68 Cask with Vanished Lattice from GE14 Fuel Assembly

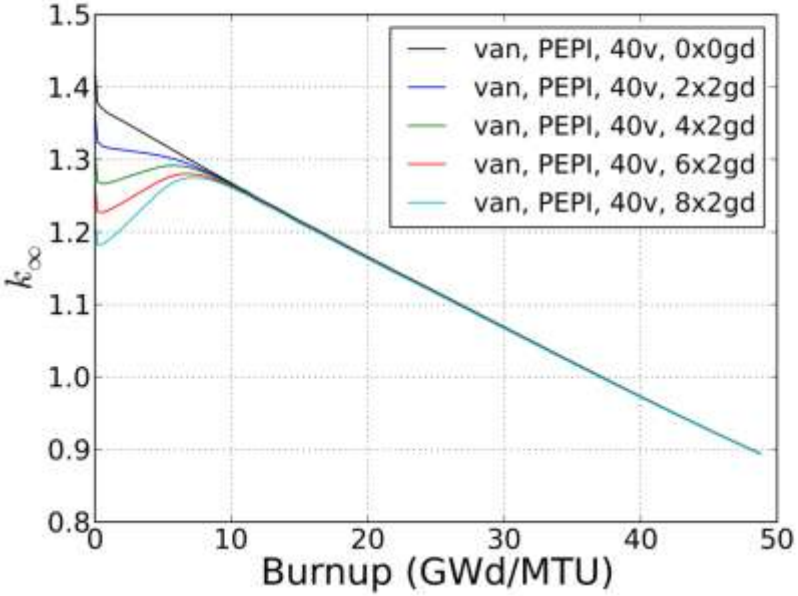
Results – Modeling Approach

- Fresh model of assembly in core could model pin-wise enrichment (PE) or average enrichment (AE)
- Depletion tracking could track pin-wise isotopics (PI) or average isotopics (AI)
  - AI cases have separate averages for UO_2 and UO_2-Gd_2O_3 pins
- PEPI is most detailed and complicated, AEAI is simplest
- AEAI is conservative (and significantly simpler)
  - About 0.3% Δk for AO and 0.5% Δk for AFP at peak reactivity
  - Primarily due to increasing enrichment of pins at assembly periphery in higher thermal flux region, thus increased reactivity

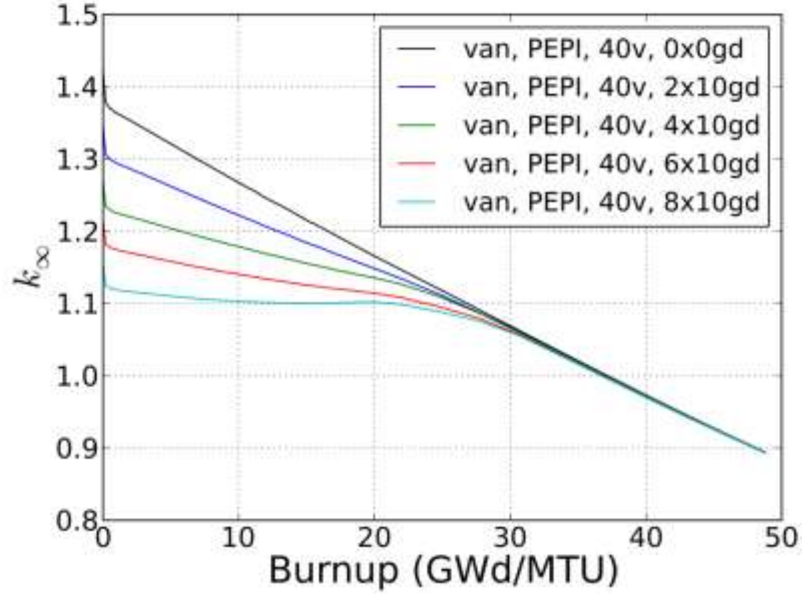
Results – Gd_2O_3 Loading and Pattern

- Gadolinium loading is a primary driver in peak reactivity methods
  - AO does not have a peak since Gd is not credited
- Burnup of the peak is primarily controlled by loading per pin
- Reactivity of the peak primarily controlled by number of pins
- More gadolinium leads to a lower reactivity peak at higher burnup
  - For AO, more gadolinium leads to more spectral hardening
- Pattern appears to have only a small effect ($\leq 0.25\%\ \Delta k$)
  - Study considered 14 realistic alternative patterns

Results – Gd_2O_3 Loading and Pattern



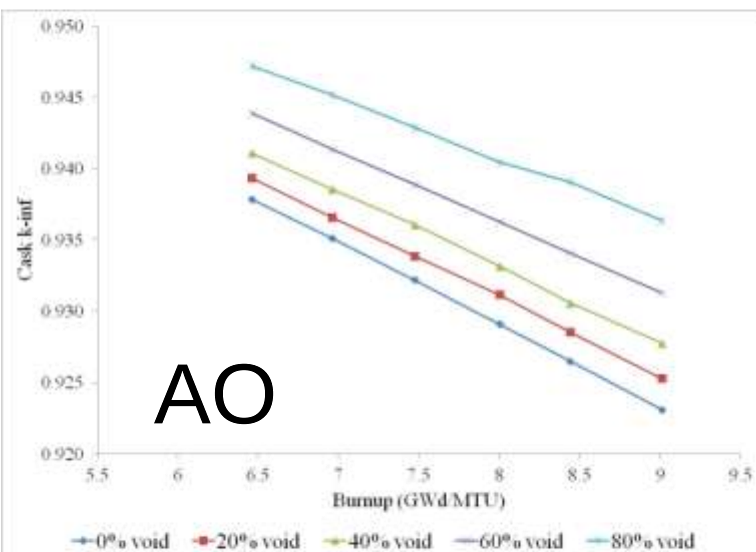
k-infinity vs. burnup, 2 w/o Gd_2O_3

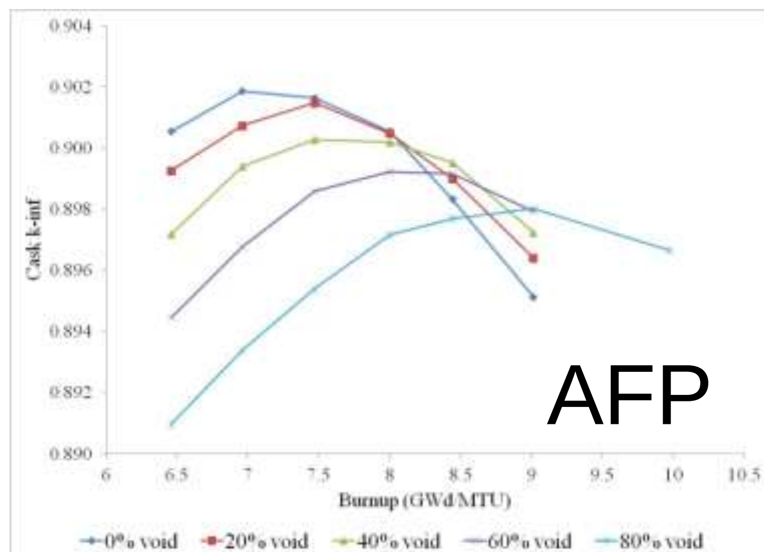


k-infinity vs. burnup, 10 w/o Gd_2O_3

Results – Void Fraction

- Void fraction impact >1% Δk from 0% - 80% void for AO
  - High void fraction conservative due to ^{239}Pu generation
- Smaller, <u>opposite</u> impact (~0.4% Δk) for AFP
  - 0 void fraction conservative due to faster Gd depletion
  - Peak reached earlier with higher fuel reactivity

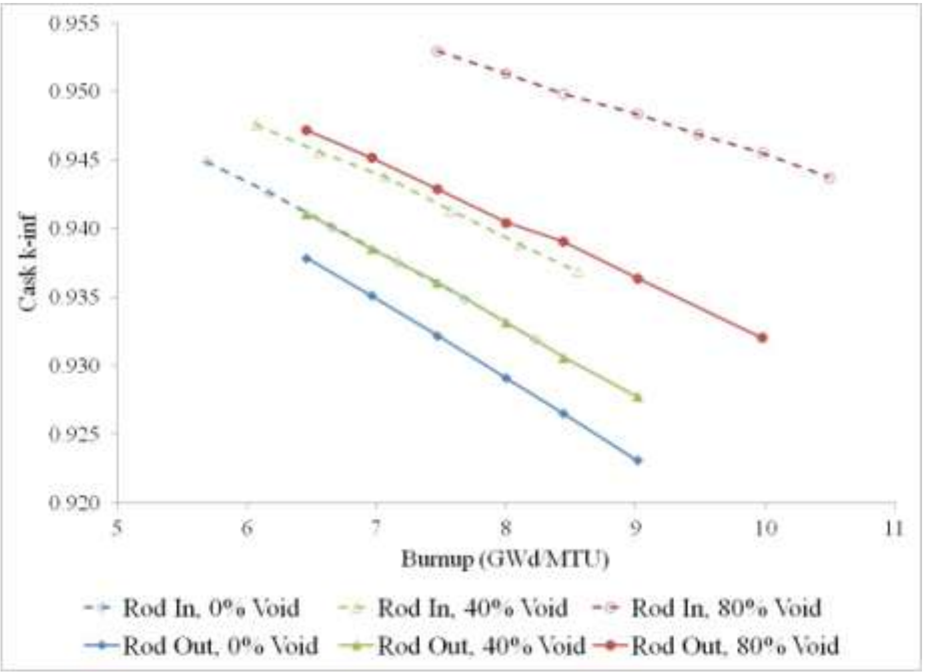




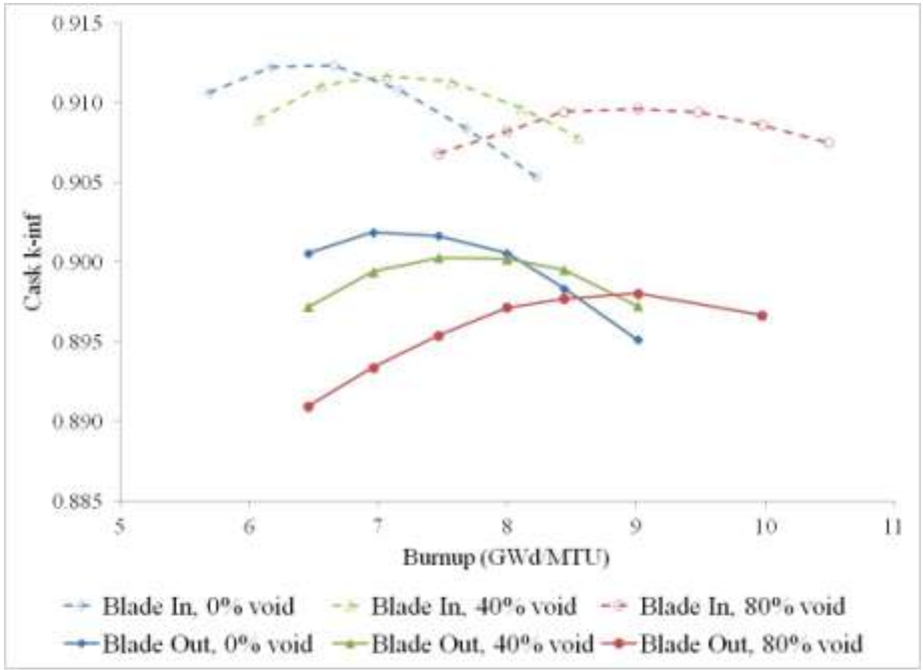
Results – Control Blade Insertion

- Control blade active material B_4C, which hardens spectrum
  - Expected to increase reactivity for AO analysis (it does)
    - More reactivity increase at higher void fraction (1% Δk increase for 80% void)
    - ^{239}Pu content increased by more than 10% at 7.5 GWd/MTU
  - Expected to decrease reactivity for AFP analysis by delaying Gd depletion – but it doesn't!
- Power shift induced within assembly by control blade insertion away from rodded corner
- 4 of 6 Gd pins are in quadrant opposite blade, so the average Gd content is depleted more quickly
  - Reactivity *increase* dependent on Gd_2O_3 pattern

Results – Control Blade Insertion

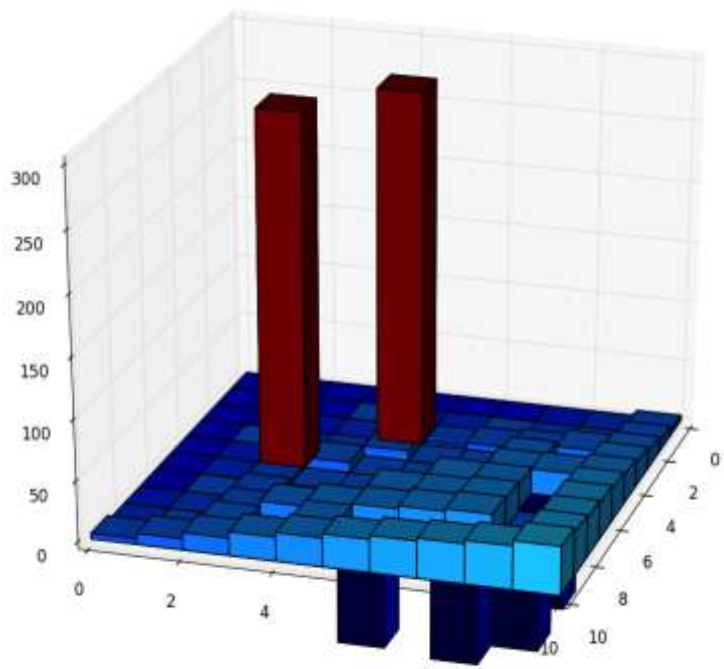


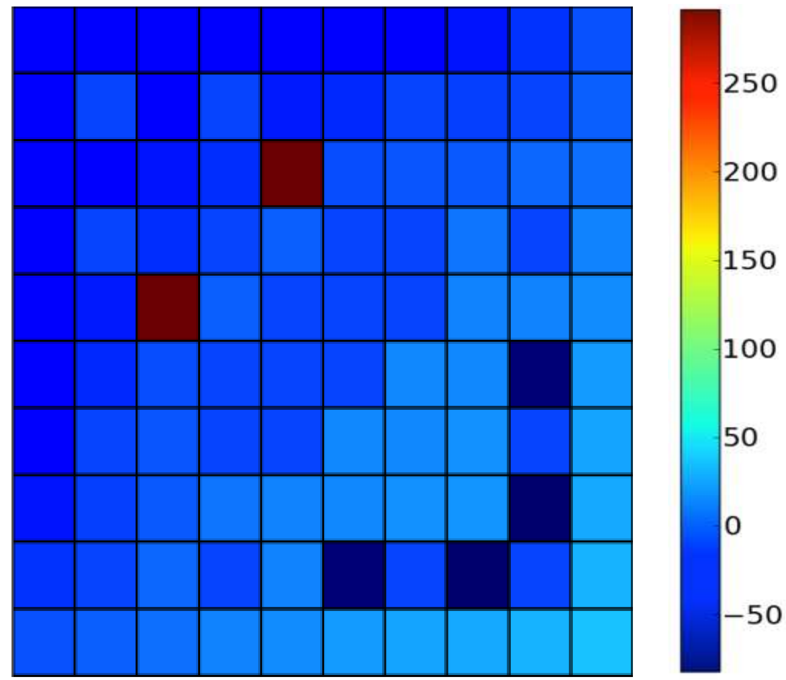
AO



AFP

Results – Control Blade Insertion





^{155}Gd content ratio: rodded depletion divided by unrodded depletion – overall effect is to lower residual Gd (~50% lower at 7.5 GWd/MTU)

6 Gd_2O_3 pins are evident, smaller positive changes show fission product difference driven by higher power fraction in (10,10) corner

(PEPI results shown for demonstration purposes)

Results – Reactor Operating Conditions

- Tested 3 fuel temperatures, 3 specific powers, and 4 operating histories
- Possibly a very small trend for increasing reactivity with increasing fuel temperature for AO
  - Sensitivity ~0.02% Δk per 100 K of fuel temperature
- Small effect of specific power
  - 0.1% Δk increase for AO at 35 and 45 W/g compared to 25 W/g
  - 0.1% Δk decrease for AFP at 45 W/g compared to 25 W/g
- AFP appears to have a small sensitivity such that low constant power is conservative

Conclusions

- Physics of BWR fuel depletion are well understood, reliable and predictable
- Conservative analysis conditions identified to allow peak reactivity analyses in casks
- Significant differences in conservative parameters depending on isotope set selected
  - Effects may also be dependent on gadolinium rod pattern

Future work

- Working to complete NUREG/CR document for NRC publication
- Work on extended BWR BUC (Phase II) has begun
- Foci for this year are axial moderator and burnup profile and control blade effects
  - Data collection
  - Development of modeling and depletion approaches
- Future years include validation of extended BUC and treatment of correlated parameters