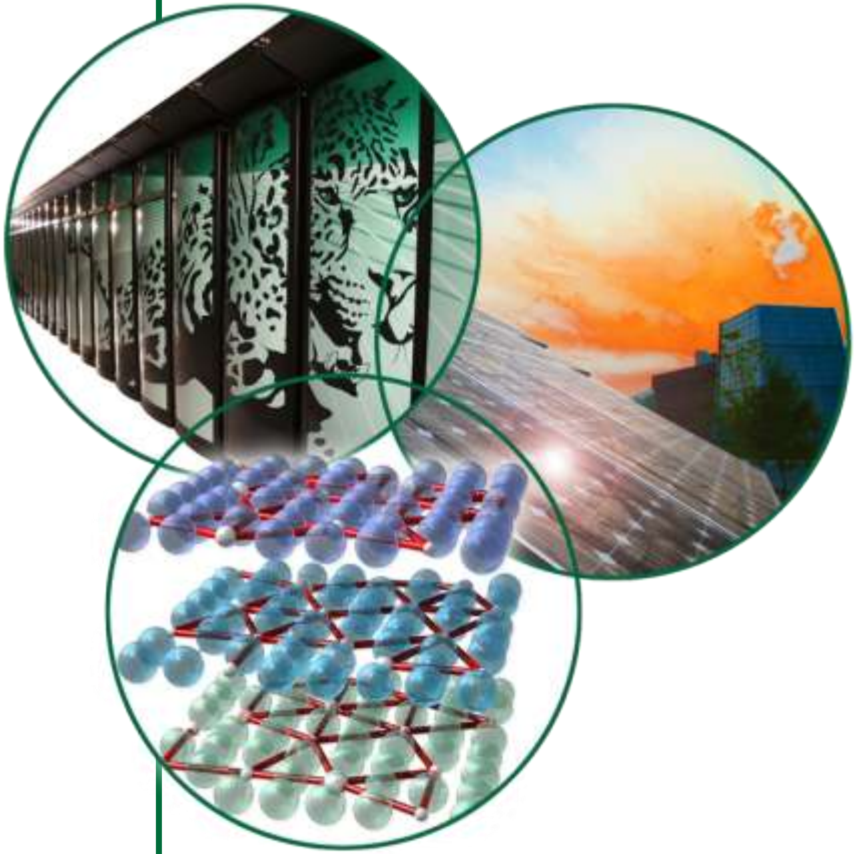
Validation of k_{eff} Calculations for Boiling-Water Reactor Fuel at Peak Reactivity in Transportation and Storage Casks

W.J. Marshall and S.M. Bowman



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Outline

1. Introduction
2. Methodology
3. Sources of sensitivity data
4. Potentially applicable experiments
5. Bias and bias uncertainty
6. Gap analysis
7. Conclusions

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 earlier in this session
  - Criticality code validation presented in this presentation
- All Phase I work expected to be published in a future NUREG/CR document by the NRC

Methodology

- Overall methodology based on that used in NUREG/CR-7109 for validation of PWR BUC
- TSUNAMI-IP used to determine similarity (c_k) between application models and potentially applicable critical experiments
- c_k calculated by dividing covariance by product of application uncertainty and experiment uncertainty

$$\boxed{c_k = \frac{\sigma^2_{\mathrm{AppExp}}}{\sigma_{\mathrm{App}}\sigma_{\mathrm{Exp}}}}$$

- Experiments with a c_k of 0.8 or more are judged to be acceptably similar for validation
- Non-trending, traditional trending, and c_k trending performed with applicable cases to determine bias and uncertainty

Sources of Sensitivity Data

- LEU and MIX systems from International Handbook of Evaluated Criticality Safety Benchmark Experiments (IHECSBE)
- Sensitivity data files (SDFs) generated by SCALE/KENO from:
  - VALID library maintained at ORNL
    - 123 LEU-COMP-THERM and 49 MIX-COMP-THERM
  - OECD/NEA generated, distributed on 2013 IHECSBE
    - 1000+ LEU and 225 MIX systems (solutions, mostly pin arrays)
  - Cases used in NUREG/CR-7109
    - Almost 200 cases, including all 156 HTC experiments
- Total of 1643 unique critical experiments considered

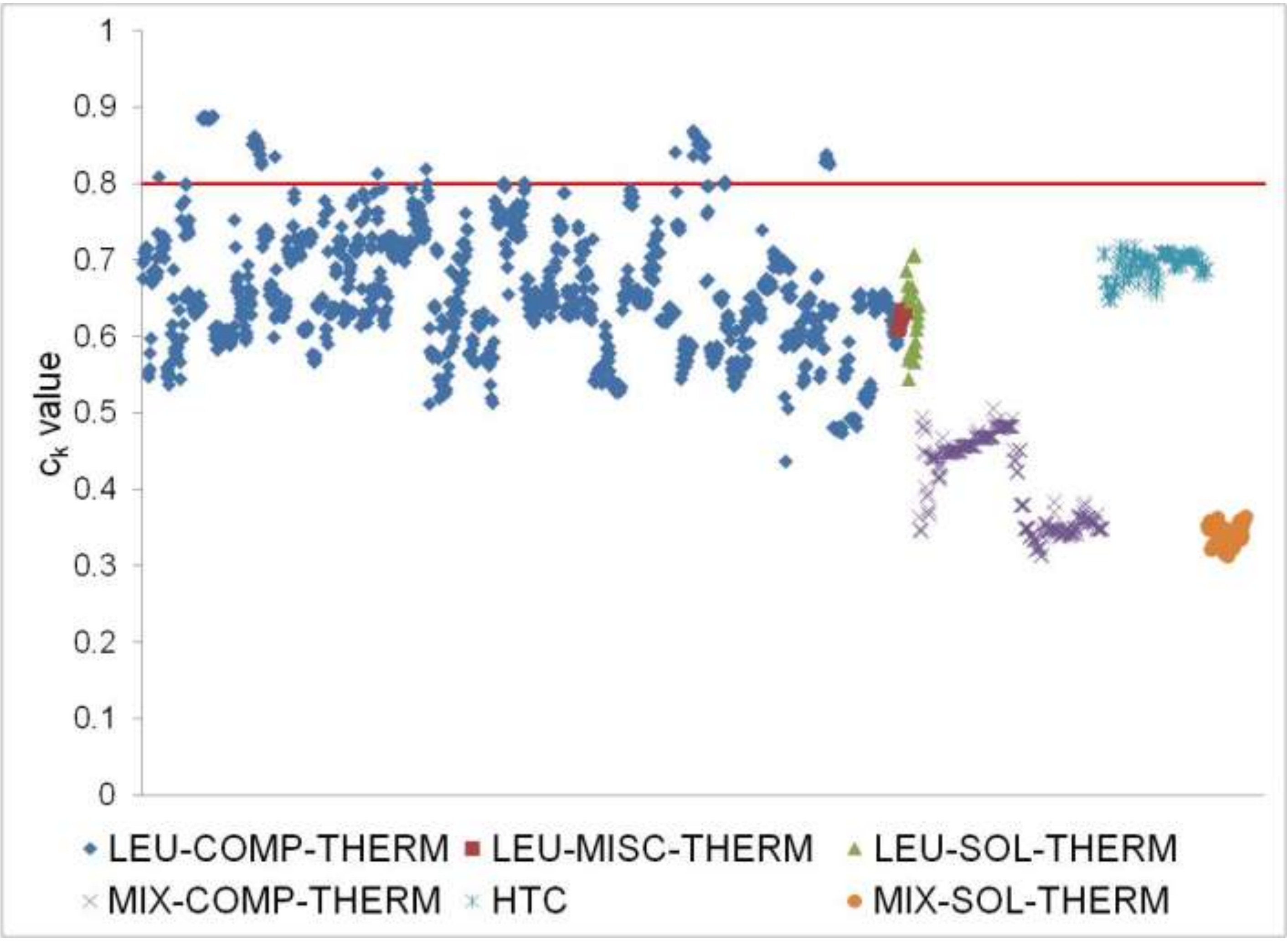
Potentially Applicable Experiments

- 3 application models considered, all GBC-68 with GE14 fuel
  - Vanished lattice, actinide-only fuel compositions
  - Vanished lattice, actinide and fission product fuel compositions
  - Full lattice, actinide and fission product fuel compositions
- All models at ~7.5 GWd/MTU (AFP peak reactivity)
- Table showing cases with $c_k \geq 0.8$ presented in paper
  - 71 experiments for VAN AO lattice
  - 62 experiments for VAN AFP lattice
  - 51 experiments for FULL AFP lattice

Potentially Applicable Experiments

- All high similarity experiments are B&W critical experiments
- IHECSBE evaluations LCT-008, LCT-011, and LCT-051
- Highest 44 c_k cases for VAN lattices from these experiments
- Potential impact of experimental correlations on validation not investigated in this work

Potentially Applicable Experiments



c_k results by experiment class, GBC-68 VAN lattice, AFP

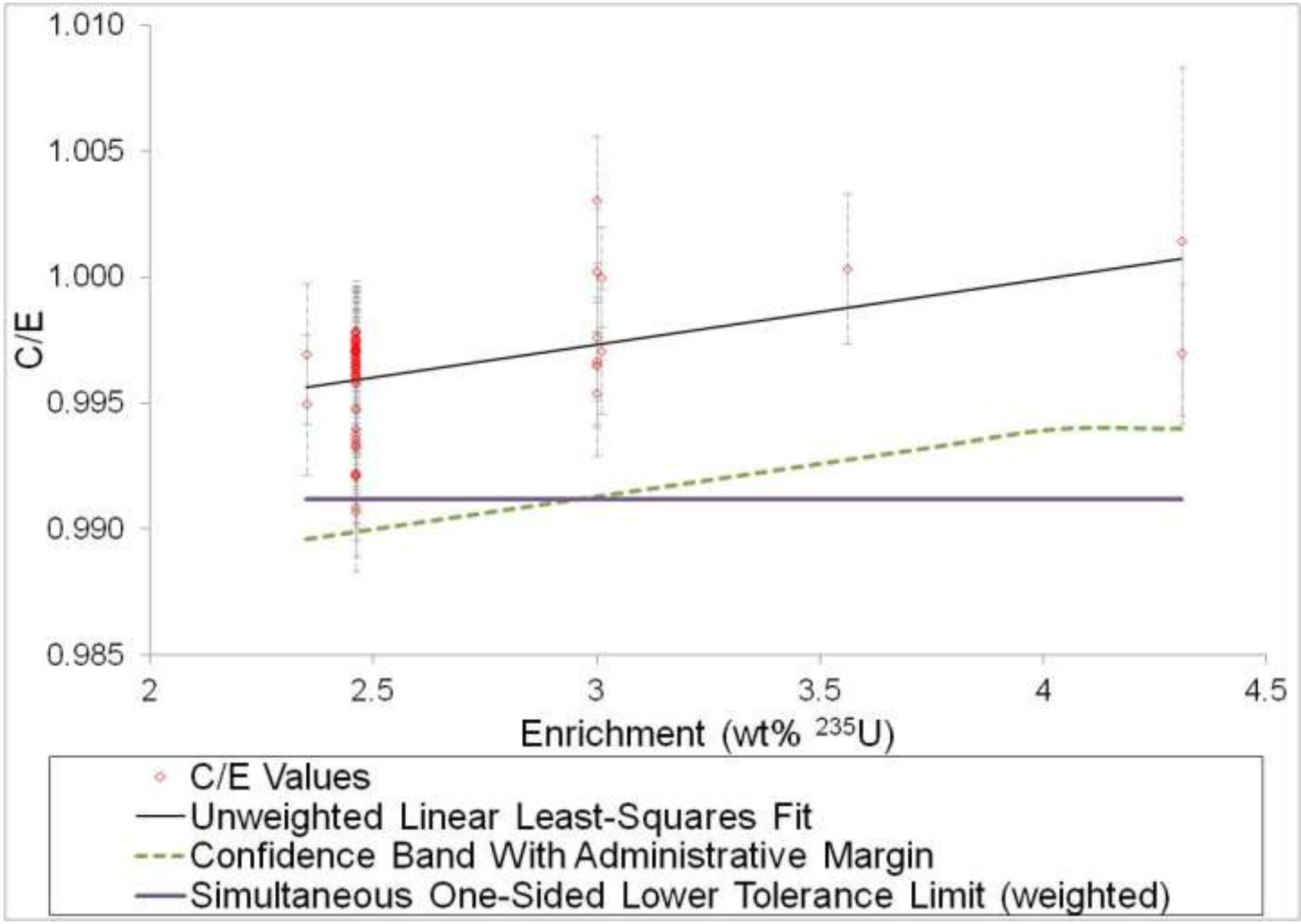
Bias and Bias Uncertainty

- Bias and bias uncertainty determined for vanished lattice with AFP isotope set
  - Vanished lattice is limiting compared to full
  - AFP allows for an assessment of Gd and fission products
- Considered 62 acceptably similar cases with 3 techniques

Validation Technique	Bias	Bias Uncertainty	Combined Total
Non-trending	-0.00354	0.00526	-0.00880
Enrichment trending (3.51 w/o ^{235}U)	-0.00136	0.00604	-0.00740
c_k trending (c_k = 1.0)	-0.00275	0.00695	-0.00970

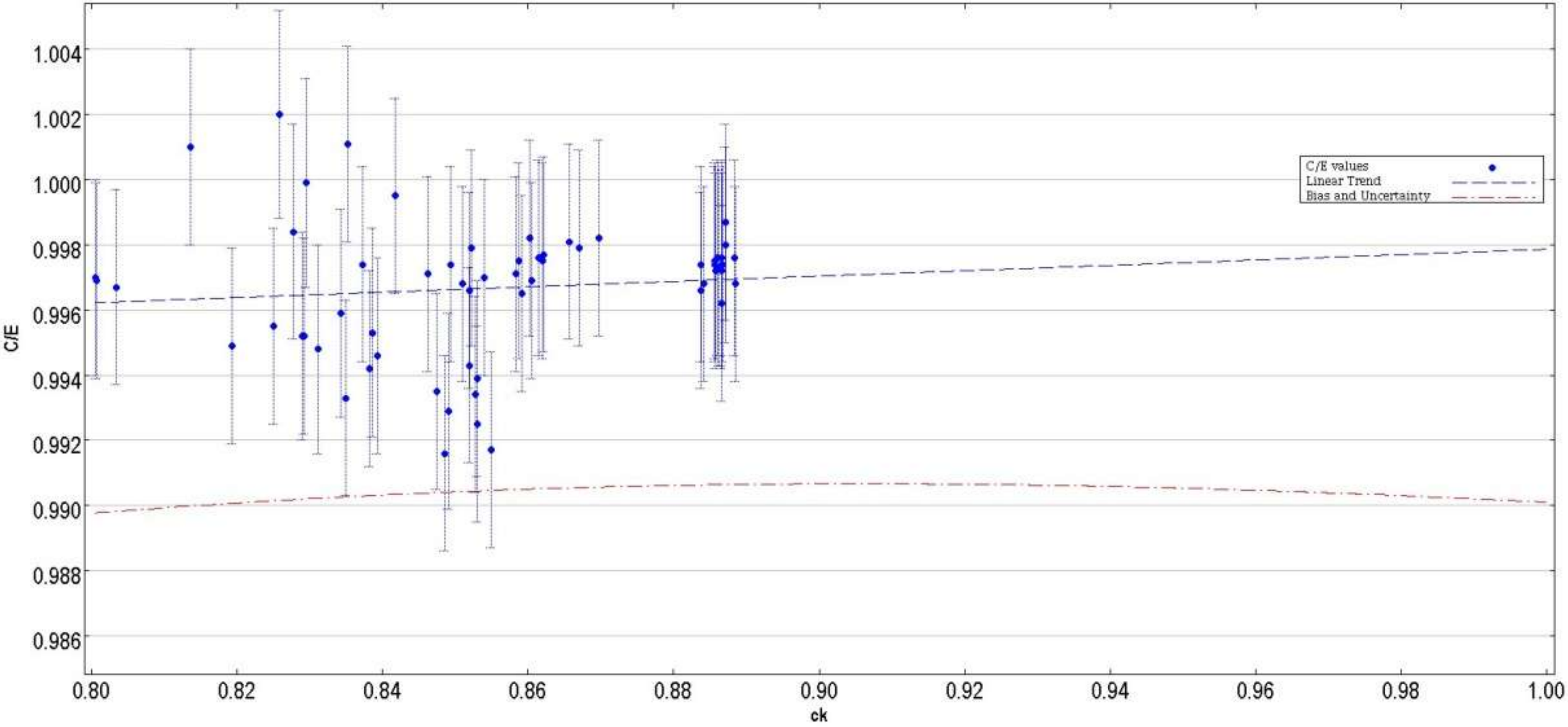
Bias and Bias Uncertainty

Enrichment trend



Bias and Bias Uncertainty

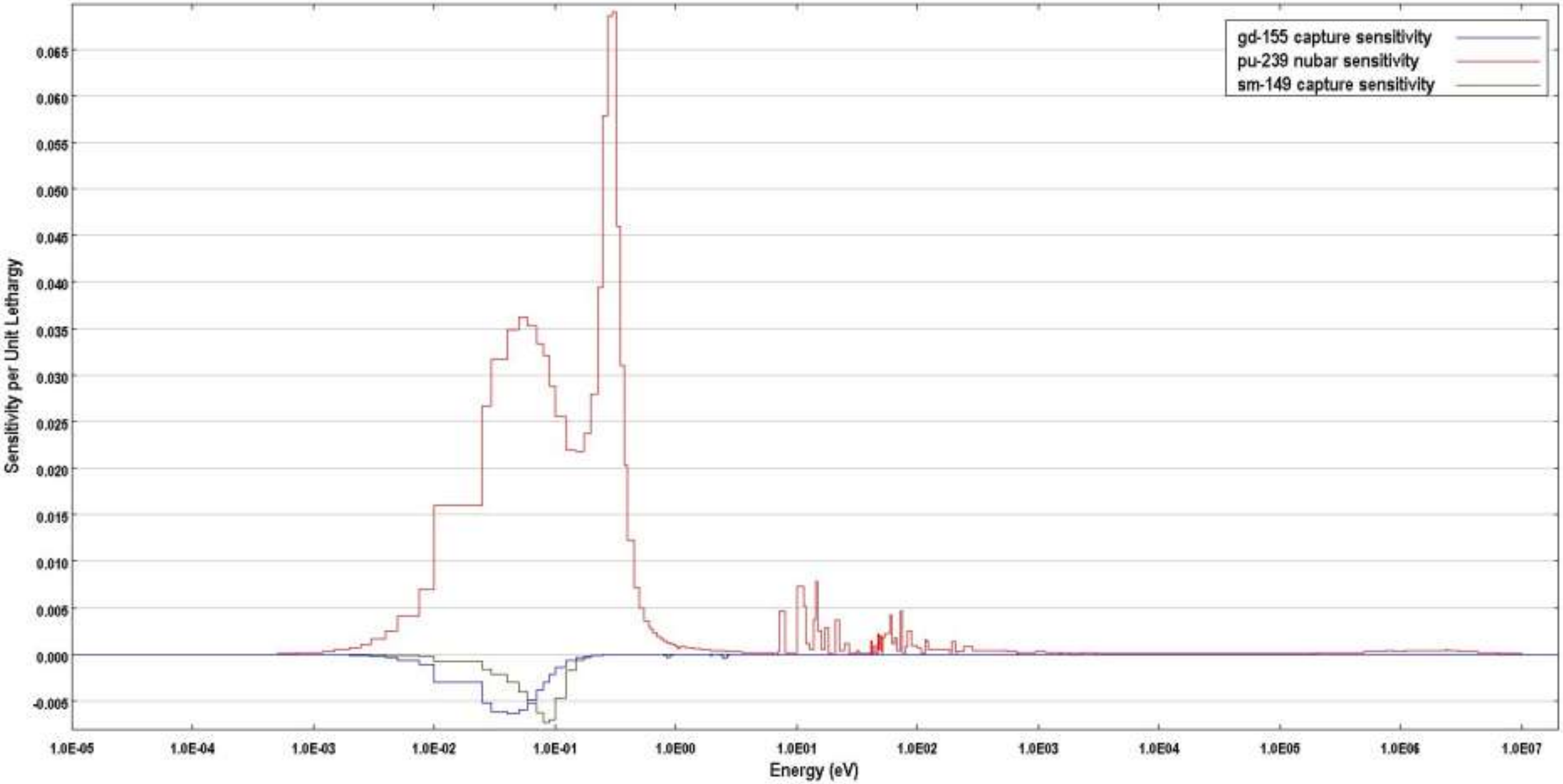
c_k trend



Gap Analysis

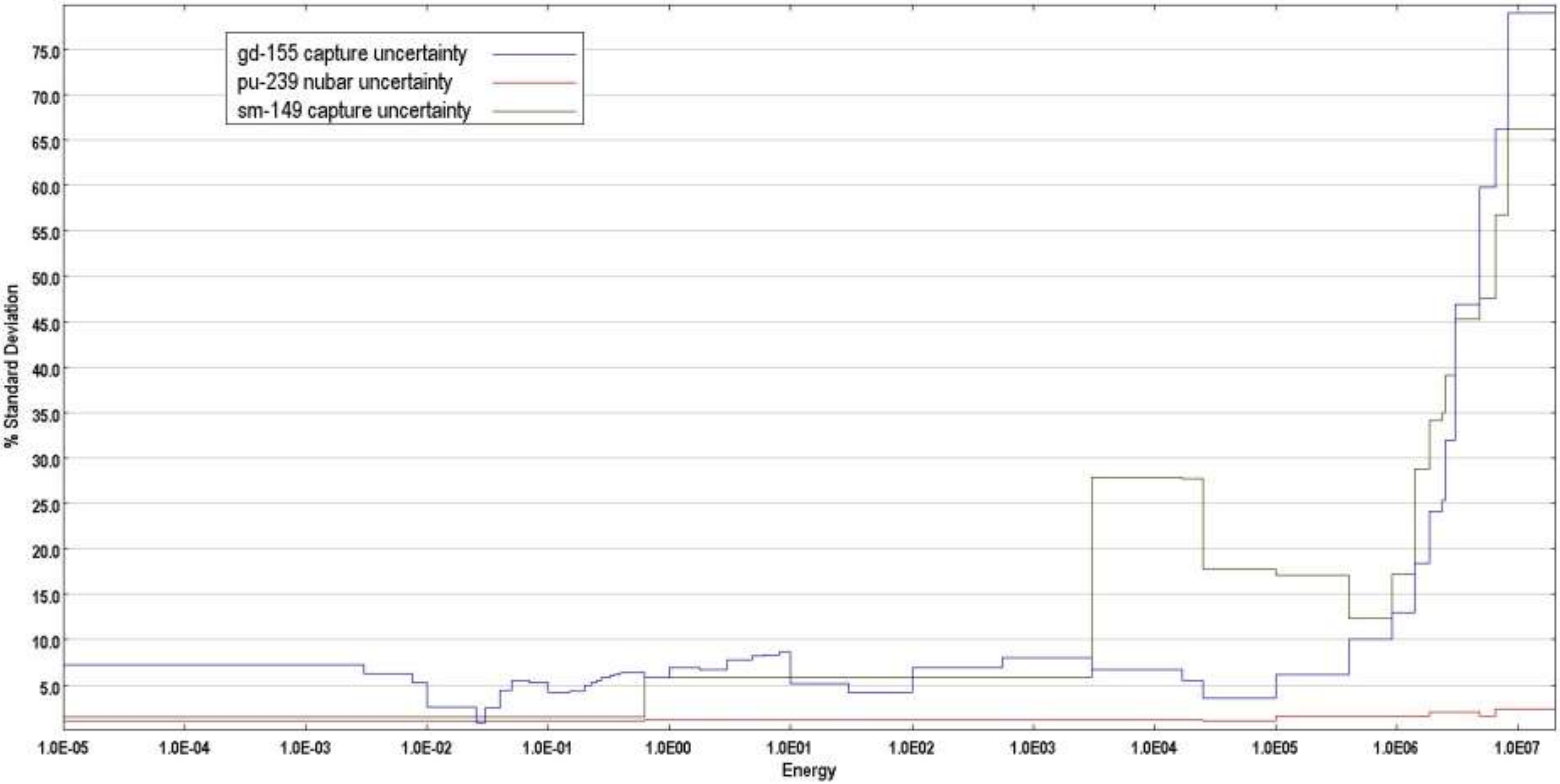
- Identified potential experiments are all LCT cases
- BWR fuel at peak reactivity also contains plutonium, residual gadolinium, and fission products
- These are unvalidated in the proposed suite
- Sensitivity/uncertainty analysis can be used to determine penalty factors, using methods similar to those used in NUREG/CR-7109 for fission products and minor actinides
  - Propagate cross section uncertainty and sensitivity coefficients to determine potential reactivity effect of cross section uncertainties
  - Fundamental theorem of TSUNAMI: Biases are a result of nuclear data errors, and the errors are bounded by the uncertainties.

Gap Analysis – Sensitivities



k_{eff} sensitivities for ^{239}Pu, ^{155}Gd and ^{149}Sm

Gap Analysis – Uncertainties



Cross section uncertainties for ^{239}Pu, ^{155}Gd and ^{149}Sm

Gap Analysis – Penalty Factors

- TSUNAMI-IP calculates 1-sigma uncertainty in k_{eff} caused by uncertainty in each reaction cross section
- RSS multiple reactions together to determine total uncertainty associated with each nuclide
- Doubled resulting uncertainty to determine 2-sigma penalty

Nuclide Group	Validation Gap Penalty (%Δk_{eff})
Pu and Am	0.3
Gd	0.05
Major Fission Products and Minor Actinides	0.06

Gap Analysis – Penalty Factors

- Peak reactivity for 3 models considered was 7.5 GWd/MTU
  - GBC-68 models discussed earlier
- Peak reactivity for other model was 11 GWd/MTU
  - BWR application model in NUREG/CR-7109
- Reported factors bound both models
  - Pu and fission products increase with burnup
  - Residual Gd drops with burnup, but also sensitive to loading
- Large Pu sensitivity more important in determining penalty than larger uncertainties in fission product cross sections

Conclusions

- Validation of k_{eff} calculations involving BWR fuel at peak reactivity is possible using experiments from the IHECSBE
- Experiments with acceptable similarity identified so far are all LCT systems, lacking Pu, Gd, and fission products
- S/U methods can be used to determine a penalty to account for unvalidated isotopes
  - Penalties are not prohibitively large
  - Fission product penalty is smaller than 1.5% of worth proposed in NUREG/CR-7109