Validating Actinides and Fission Products for Burnup Credit Criticality Safety Analyses – Nuclide Compositions Prediction with Extended Validation Basis

NUREG-7108 Revisited

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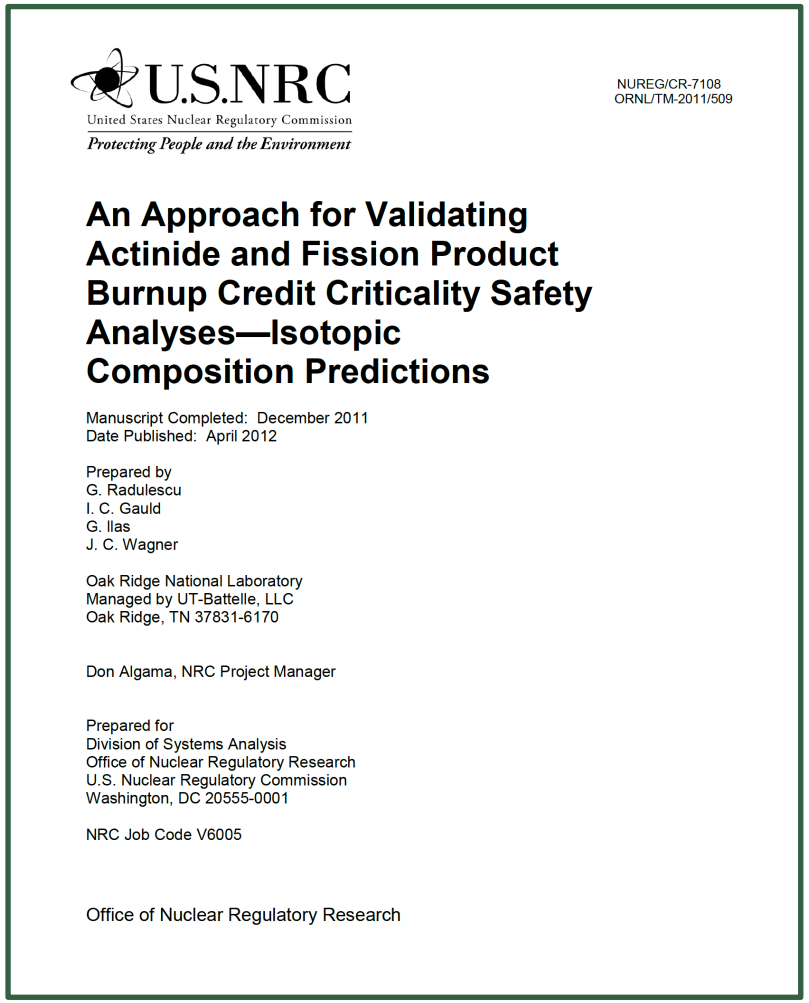
Background: what is NUREG-7108 ?

- Criticality safety evaluations accounting for burnup credit require validation of computational tools and associated nuclear data that are used to perform the fuel depletion and criticality calculations involved in these evaluations
- NUREG-7108 (2012) documented an approach for establishing the bias and bias uncertainty in calculated k_{eff} that is associated to calculated spent nuclear fuel nuclide concentrations
- Approach was demonstrated using as validation basis radiochemical assay (RCA) measurement data for nuclide concentrations



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United States Nuclear Regulatory Commission
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NUREG/CR-7108
ORNL/TM-2011/509

An Approach for Validating Actinide and Fission Product Burnup Credit Criticality Safety Analyses—Isotopic Composition Predictions

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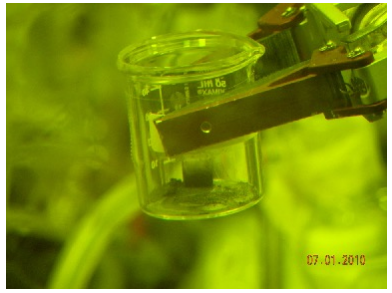
Motivation of recent studies

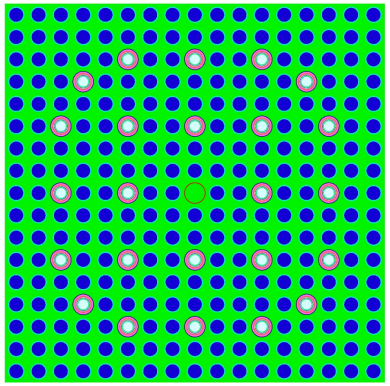
- Provide an updated technical basis to support future updates of current NRC guidance for criticality safety analyses with burnup credit of PWR spent fuel for transportation and storage casks, the Interim Staff Guidance (ISG)-8, Rev 3 (2012)
- Benefit from an improved validation basis that:
  - Extends the covered burnup range from 60 GWd/t to 80 GWd/t
  - Fills data gaps at higher burnups for nuclides that are important to burnup credit (12 actinides + 16 fission products)
  - Includes recent high-quality RCA measurements performed at ORNL under an experimental program jointly funded by the NRC and the DOE



Preamble: terminology and computational tools

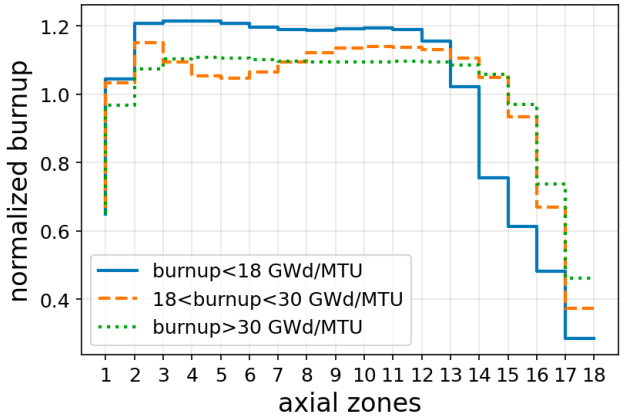
- **k_{eff} bias**: the average change in calculated k_{eff} of the considered criticality safety model resulting from bias and bias uncertainty in calculated nuclide concentrations in fuel
- **k_{eff} bias uncertainty:** the variance of the change in calculated k_{eff} of the considered safety model, at a 95% probability and 95% confidence level, which results from bias and bias uncertainty in calculated nuclide concentrations for that model
- SCALE simulations with version 6.2.4 and 252-group ENDF/B-VII.1 data
  - TRITON: lattice depletion to generate burnup-dependent ORIGEN libraries
  - ORIGAMI: fast depletion to generate burnup-dependent fuel compositions
  - CSAS6: criticality calculations with KENO-VI

GBC-32: criticality safety model used as basis for assessment



TRITON
2D assembly model

ORIGEN libraries
(function of enrichment and burnup)

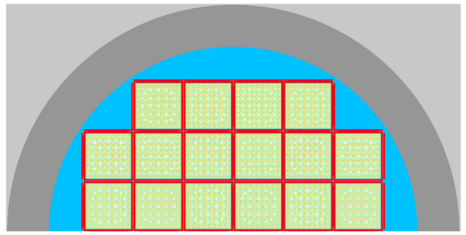


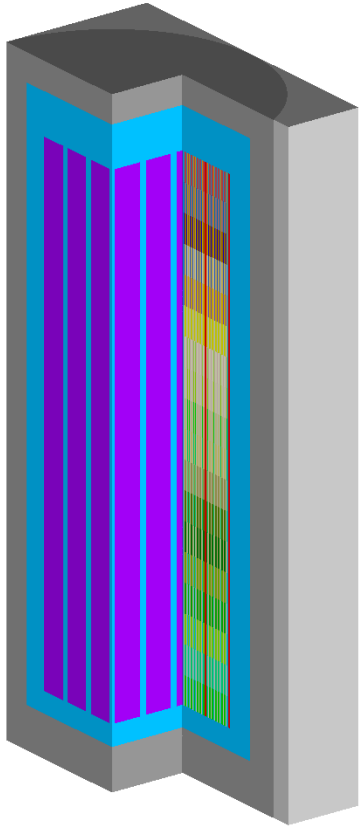
Assembly axial profile

ORIGAMI

(ORIGEN)

axially varying (burnup dependent) fuel compositions





3D Cask model

Python script automates the generation of burnup-dependent fuel compositions and CSAS inputs

Method for stochastic uncertainty sampling – Brief summary

- Objective: propagate the bias and bias uncertainty in calculated nuclide concentrations to bias and bias uncertainty in the k_{eff} of a criticality model
- Validation of the depletion method used to calculate nuclide concentrations for the criticality model can be performed by comparing measured nuclide concentrations to corresponding calculated values determined using the considered depletion method
- In the context, ***depletion method*** refers to the computational tool and the associated nuclear data used to simulate the fuel depletion during irradiation and decay

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Method for stochastic uncertainty sampling – Steps

- Establish the expected bias and bias uncertainty in calculated nuclide concentration

$$\overline{X}_i = \frac{1}{N_i}\sum_{j=1}^{N_i} X_i^j = \frac{1}{N_i}\sum_{j=1}^{N_i} \frac{M_i^j}{C_i^j}, \qquad s_i = \sqrt{\frac{\sum_{j=1}^{N_i}\left(X_i^j - \overline{X}_i\right)^2}{N_i - 1}}.$$

- Randomly sample the calculated nuclide concentrations within the range of their estimated uncertainties and probability distributions
- Calculate k_{eff} for the criticality model using the values of nuclide concentrations and repeat multiple times for multiple random realizations
- Analyze distribution of k_{eff} values -> bias and bias uncertainty in k_{eff}

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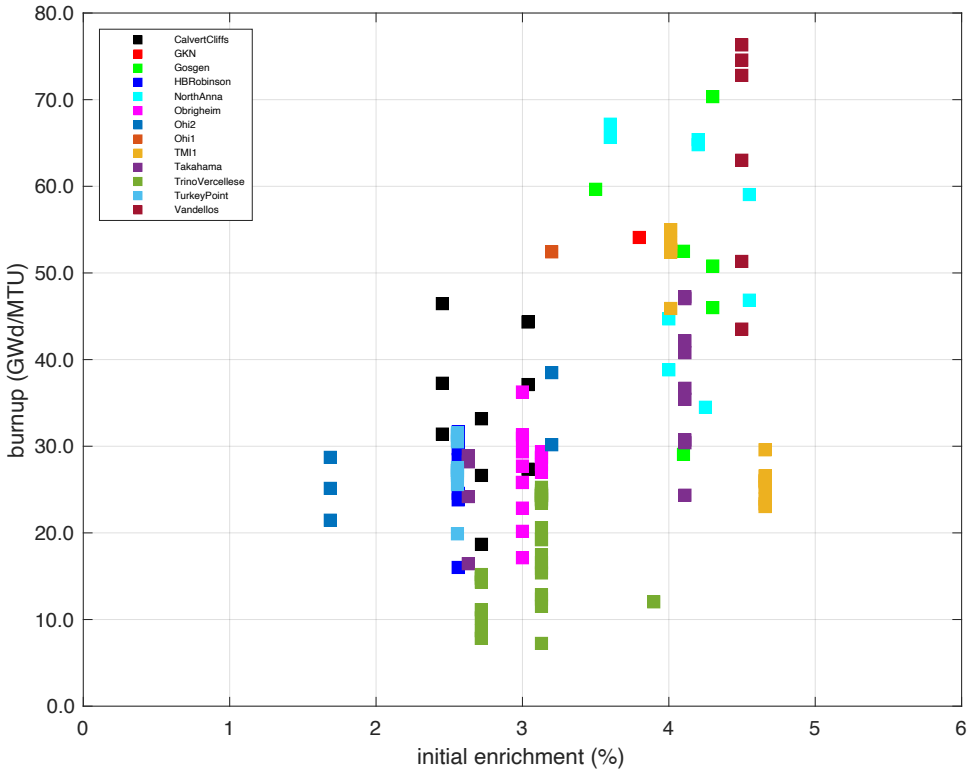
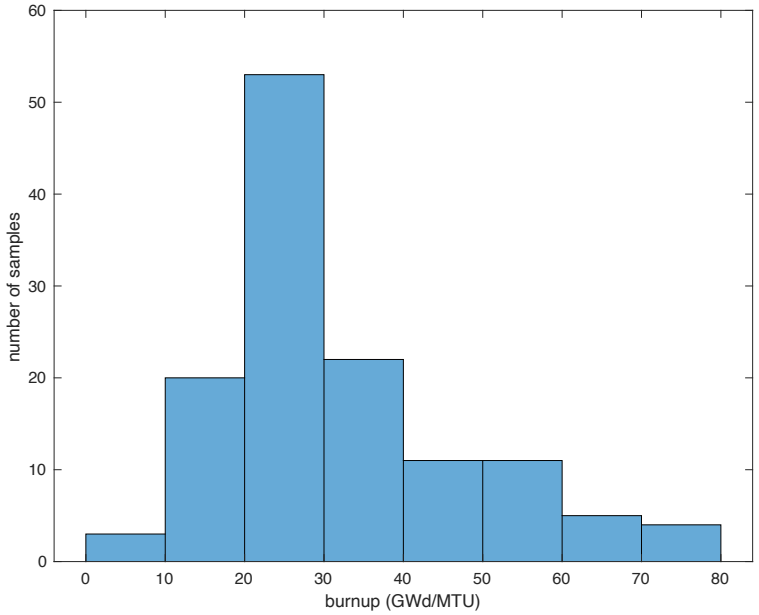
RCA validation basis for PWR spent fuel burnup and enrichment for measured fuel samples

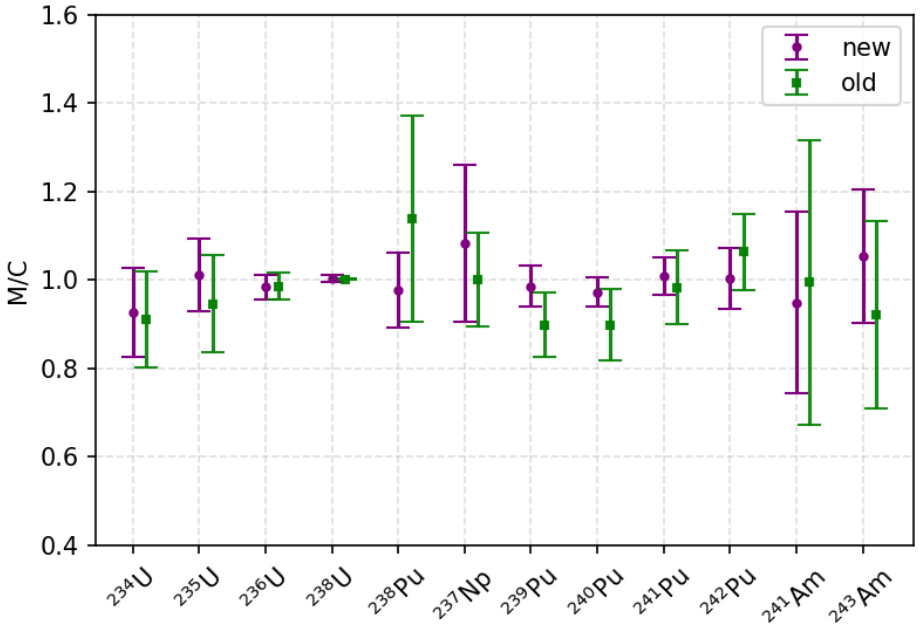


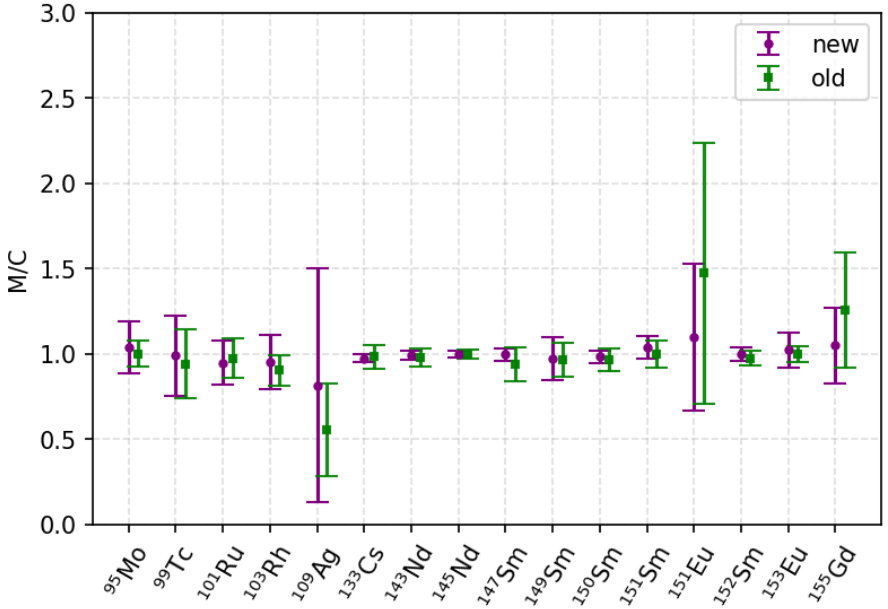


Total = 129 fuel samples

Bias and uncertainty for burnup credit nuclides

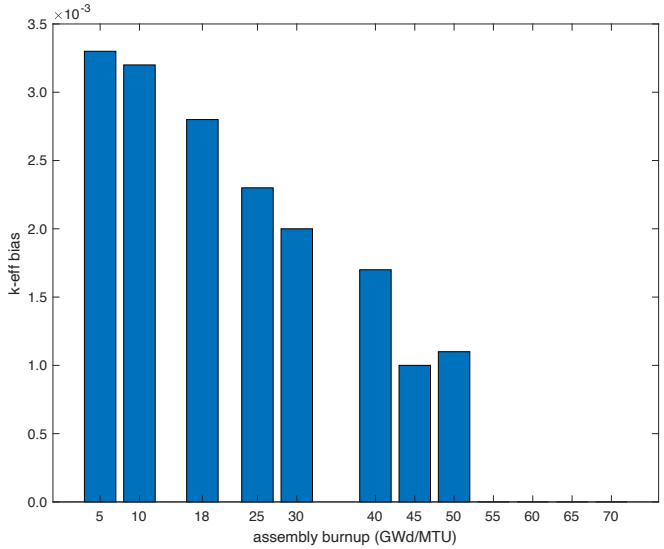
comparison of current data with that in NUREG-7108 for burnups > 40 GWd/t

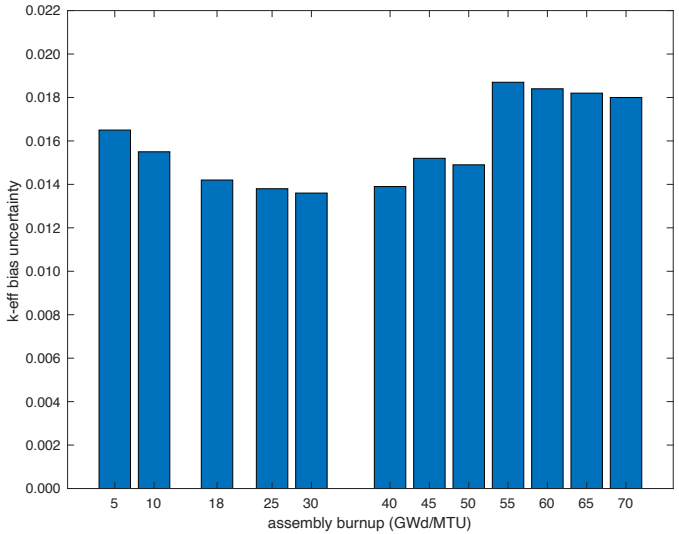




Bias and bias uncertainty in calculated k_{eff}

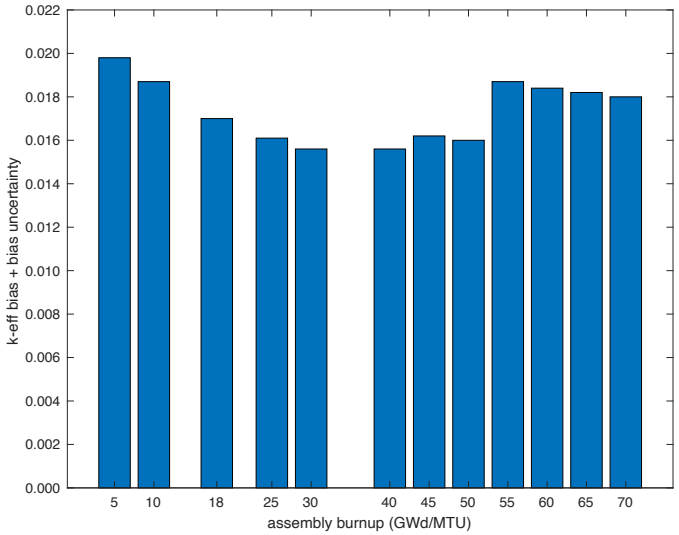
bias



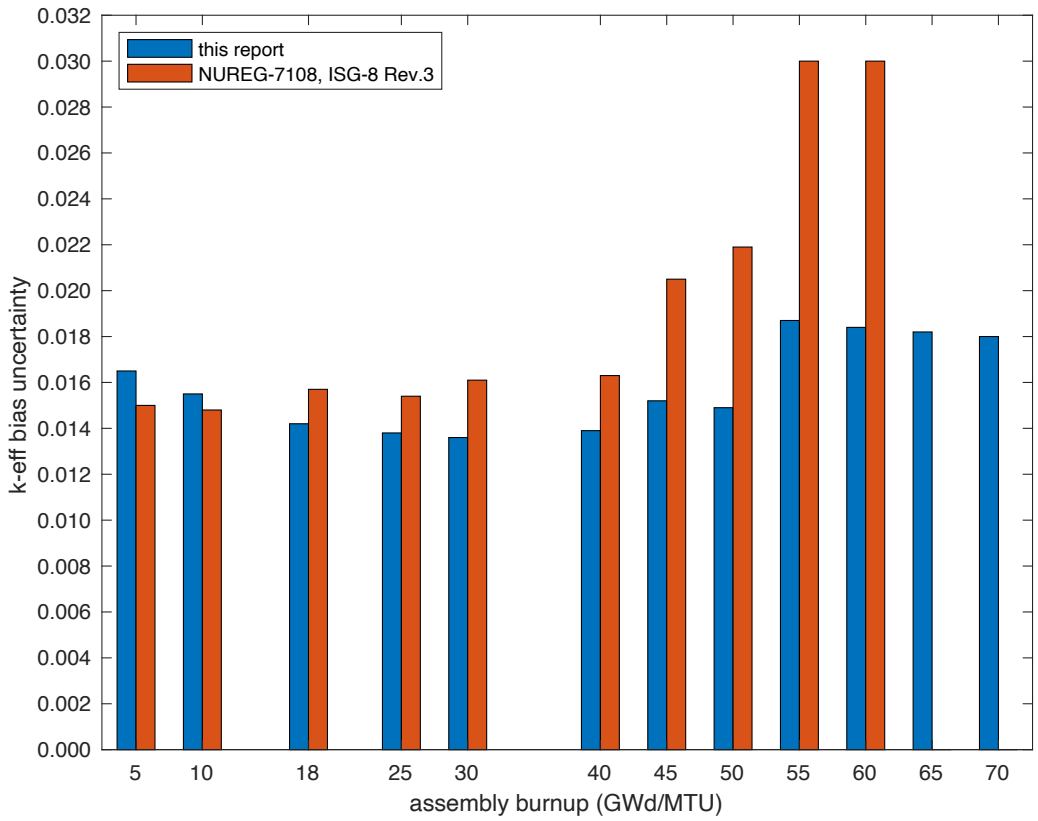


uncertainty

bias + uncertainty



Bias uncertainty in calculated k_{eff} : comparison to ISG-8, Rev. 3



NUREG-7108 includes data up to 45 GWd/t
ISG-8, Rev 3 includes data up to 60 GWd/t

Outcomes

- New studies built upon and complementing the approach presented in NUREG/CR-7108, to estimate k_{eff} bias and bias uncertainty in burnup credit criticality safety analyses that are associated to calculated nuclide concentrations of spent nuclear fuel – draft NUREG under review
- New standardized implementation of the stochastic sampling method, taking advantage of the capabilities in the Sampler uncertainty quantification tool in SCALE
- Improved validation basis for estimating the bias and bias uncertainty in calculated concentrations of burnup credit nuclides
- Filled data gaps for burnup credit nuclides at higher burnups -> uncertainty in the calculated nuclide concentration for most of these nuclides was reduced
- Improvement in the validation basis led to an overall decrease in the k_{eff} bias uncertainty for the considered cask criticality model compared to the corresponding values shown in ISG-8 Rev.3

Acknowledgments

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