# Evaluation of Applicability of CRC Models for Burnup Credit Validation

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## INTRODUCTION

Previous studies on the applicability of commercial reactor criticals (CRCs) to validation of burnup credit criticality calculations have focused on general characteristics comparisons between the CRCs and spent nuclear fuel (SNF) storage/transport/disposal systems.[1, 2] Recent work at Oak Ridge National Laboratory [3] has thoroughly evaluated the similarities between the two types of systems using the Tools for Sensitivity and Uncertainty Analysis Methodology Implementation (TSUNAMI) in the SCALE code system.[4] This paper summarizes the results of the sensitivity and uncertainty (S/U) analysis.

## S/U ANALYSIS METHOD

S/U analysis methods can be used to demonstrate that systems with similar physical characteristics exhibit similar sensitivities of the effective neutron multiplication factor, $k_{eff}$, to perturbations in cross-section data on an energy-dependent, nuclide-reaction specific level. TSUNAMI facilitates the application of such S/U analysis methods to the validation of benchmark data sets for use in criticality safety calculations.

### Generic SNF Cask and CRC Models

A generic SNF cask containing typical spent fuel assemblies was compared with 40 CRC models representing 37 hot zero-power (HZP) and three hot full-power (HFP) reactor critical conditions attained from five pressurized water reactors. The generic cask model, referred to as the GBC-32 cask, has been proposed as a reference configuration for burnup credit studies.[5] The CRC models are comprised of beginning-of-cycle (BOC), middle-of-cycle (MOC) or end-of-cycle (EOC) configurations that have been documented for Crystal River Unit 3 (CR3) Cycles 1 through 10, Sequoyah Unit 2 HZP and HFP BOC-3 and HFP MOC-3, Surry Unit 1 BOC-2 and HFP EOC-2, Three Mile Island (TMI) Unit 1 BOC-5, and North Anna Unit 1 BOC-5.[6, 7] CR3 provided 33 CRCs, referred to as state-points 1 through 33, where state-points 1, 4, 5, 8, 11, 13, 16, 22, 28, and 32 were BOC-1 through -10 configurations, and state-points 3, 7, 10, 12, 15, 21, 27, 31, and 33 were EOC-1 and -3 through -10 configurations. The reactor downtime before a startup was less than a year for all CRCs except TMI BOC-5 and Sequoyah MOC-3. These two configurations correspond to downtimes of 6.63 and 2.73 years, respectively.

### Calculations

CSAS25/KENO V.a modeling of the CRCs for TSUNAMI-3D calculations was validated through comparison with the criticality calculation results of previous studies obtained with either MCNP or CSASN/KENO V.a.[6, 7] The CSAS25 $k_{eff}$ results are in very good agreement with the $k_{eff}$ results obtained in the previous studies, except for the two CR3 Cycle 10 configurations. Sensitivity profiles in the SCALE 238-energy group structure were computed with the TSUNAMI-3D version for SCALE 5.1 and used in a TSUNAMI-IP calculation to determine system correlation coefficients. A sensitivity profile is the energy-dependent ratio of the relative change in $k_{eff}$ due to perturbations in the cross section of a nuclide-reaction pair to the relative change in the cross section. The correlation coefficient ($c_k$) provides a measure of similarity of two systems in terms of their common components of uncertainty in $k_{eff}$ due to cross-section uncertainties and is normalized to produce a correlation coefficient of 1.0 for identical systems.[8]

## RESULTS

The TSUNAMI-IP results indicate that, except for the CR3 fresh fuel core configuration, all analyzed CRC configurations are either highly similar ($c_k \geq 0.95$), similar ($0.95 > c_k \geq 0.9$), or marginally similar ($0.9 > c_k \geq 0.8$) to the GBC-32 cask loaded with SNF, where the highly similar configurations were attained at or near the end of reactor cycles. A grouping of the CRC state-points based on the degree of similarity, core average burnup, soluble boron concentration, and energy of average lethargy causing fission (EALF) is presented in Table I. The following trends were observed: $c_k$ increases with increasing burnup within a reactor cycle, and $c_k$ increases with increasing burnup for CRCs with similar soluble boron concentrations, regardless of reactor cycle.

Comparison of the sensitivity profiles from the GBC-32 cask and the CRCs indicates that the sensitivities are quite similar between the cask model and many of the CRC state-points for the fission products and actinides relevant to burnup credit. As expected, the CRC state-points with higher average burnup tend to have greater sensitivity to the relevant fission products, and thus better consistency with the sensitivities in the cask model. Further, the sensitivity profiles of CRCs attained at or near the end of reactor cycles provide better coverage for a specific nuclide-reaction pair than the other CRCs. For nuclides that build in after fuel discharge, notably $^{155}$Gd, TMI Unit 1 BOC-5 and Sequoyah Unit 2 MOC-3 provide significantly better coverage than all the other CRCs. Comparisons of the $k_{eff}$ sensitivities to $^{149}$Sm and $^{143}$Nd total cross sections for the GBC-32 cask and two CR3 state-points are shown in Figures 1 and 2, respectively. For some nuclides, including $^{143}$Nd, the CRC sensitivity profiles show a slight shift toward higher energies as compared to the sensitivity profile of the GBC-32 cask. Detailed comparisons for relevant nuclides are provided in Reference 3.

## CONCLUSIONS

CRC configurations attained at or near the end of a reactor cycle are highly similar neutronically to a representative burnup credit cask (i.e., the GBC-32 cask loaded with SNF) and therefore applicable to validation of burnup credit criticality calculations. Based on the recommended applicability criterion in Reference 8 (i.e., $c_k>0.9$ indicates applicability), 28 of the 40 CRC state-points are applicable for validation of burnup credit in the GBC-32 cask. However, the CRC state-points are complex configurations that include considerable uncertainty (e.g., isotopic compositions of the burned fuel, operating history, data). Therefore, a thorough evaluation and understanding of the uncertainties in the CRC configurations are needed prior to the use of CRCs for code validation (i.e., bias determination).

## REFERENCES

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Table I. CRC State-point Grouping Based on the Degree of Similarity with the GBC-32 Cask Containing SNF of 3.78-wt% $^{235}$U Initial Enrichment, 40-GWd/MTU Burnup, 5-year Cooling Time.

| Correlation Coefficient | Number of CRCs | CRC Configurations | Core Average Burnup (GWd/MTU) | Soluble B Concentration (ppm) | EALF[a] (eV) |
|---|---|---|---|---|---|
| 0.95−0.9726 | 18 | CR3 state-points 3, 6, 7, 9, 10, 12, 15, 17, 18, 19, 20, 21, 25, 26, 27, 31, 33. Surry Unit 1 EOC-2. | 12.34−33.00 | 123−1223 | 0.61−0.88 |
| 0.90−0.95 | 10 | CR3 state-points 2, 4, 5, 14, 23, 24, 29, 30. Sequoyah Unit 2 MOC-2. TMI Unit 1 BOC-5. | 7.50−20.96 | 475−1751 | 0.63−0.95 |
| 0.85−0.90 | 5 | CR3 state-points 8 and 13. Sequoyah Unit 2 HZP and HFP BOC-3. Surry Unit 1 BOC-2. | 6.92−12.01 | 1030−1685 | 0.66−0.96 |
| 0.80−0.85 | 6 | CR3 state-points 11, 16, 22, 28, and 32. North Anna Unit 1 BOC-5. | 7.08−15.24 | 1540−2326 | 0.72−1.04 |
| 0.6124 | 1 | CR3 state-point 1. | 0 | 1403 | 0.56 |

[a] EALF of GBC-32 cask model is 0.28 eV.

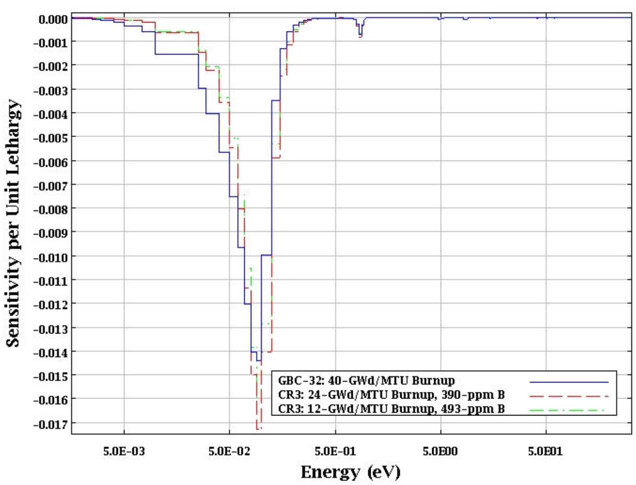


Fig. 1. Comparison of $k_{eff}$ Sensitivities to $^{149}$Sm Total Cross Section for GBC-32 Cask and CR3 State-points 15 and 3.

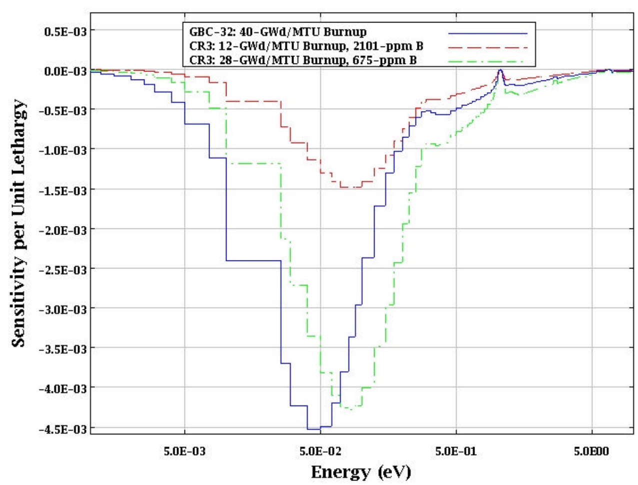


Fig. 2. Comparison of $k_{eff}$ Sensitivities to $^{143}$Nd Total Cross Section for GBC-32 Cask and CR3 State-points 22 and 27.