Designing Critical Experiments in Support of Full Burnup Credit

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INTRODUCTION

Burnup credit is the process of accounting for the negative reactivity due to fuel burnup and generation of parasitic absorbers over fuel assembly lifetime. For years, the *fresh fuel assumption* was used as a simple bound in criticality work for used fuel storage and transportation. More recently, major actinides have been included [1]. However, even this yields a highly conservative estimate in criticality calculations. Because of the numerous economical benefits including all available negative reactivity (i.e., full burnup credit) could provide [2], it is advantageous to work toward full burnup credit.

Unfortunately, comparatively little work has been done to include non-major actinides and other fission products (FP) in burnup credit analyses due in part to insufficient experimental data for validation of codes and nuclear data. The Burnup Credit Criticality Experiment (BUCCX) at Sandia National Laboratory was a set of experiments with ^{103}Rh that have relevance for burnup credit [3].

This work uses TSUNAMI-3D to investigate and adjust a BUCCX model to match isotope-specific, energy-dependent k_{eff} sensitivity profiles to those of a representative high-capacity transport cask model (GBC-32) [4] for each FP of interest. The isotopes considered are ^{149}Sm, ^{143}Nd, ^{103}Rh, ^{133}Cs, ^{155}Gd, ^{152}Sm, ^{99}Tc, ^{145}Nd, ^{153}Eu, ^{147}Sm, ^{109}Ag, ^{95}Mo, ^{150}Sm, ^{101}Ru, and ^{151}Eu. The goal is to understand the biases and bias uncertainties inherent in nuclear data, and ultimately, to apply these in support of full burnup credit.

DESCRIPTION OF THE ACTUAL WORK

The BUCCX experiments used 4.306% enriched UO_2 fuel and were intended to produce neutron spectra typical of light water reactors (LWRs). Pitches of 2.0 cm and 2.8 cm were used, corresponding to a typical LWR water-to-fissionable fuel ratio and optimal moderation, respectively.

Several modifications to BUCCX were examined, including different rod designs and pitches, in addition to FP's dissolved in a moderator. For each FP, a worth of approximately 2% Δk was desired to ensure any significant computational bias would be statistically meaningful. Additionally, close qualitative similarity between the energy-dependent sensitivities of k_{eff} in the cask model and the experiment was desired.

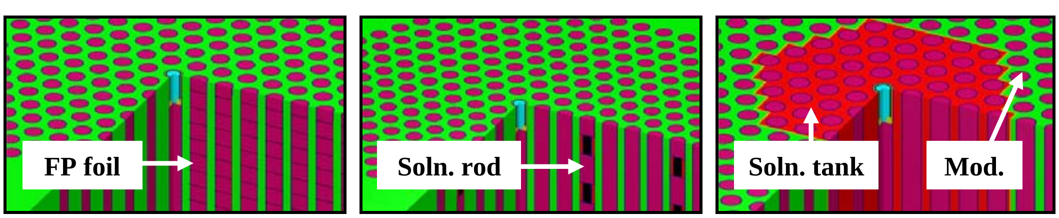
RESULTS

Cases employing foils (see Fig. 1a) of a FP (^{149}Sm, ^{103}Rh, or ^{143}Nd) placed in between fuel pellets met the desired worth only for ^{149}Sm while maintaining reasonable qualitative similarity. However, the desired worth for ^{103}Rh and ^{143}Nd required thicker foils, and due to greater self-shielding, such cases exhibited poor qualitative similarity.

Configurations using rods (see Fig. 1b) containing a FP (^{149}Sm, ^{143}Nd, ^{103}Rh, ^{133}Cs, or ^{155}Gd) solution showed better qualitative similarity. However, in some cases the desired worth required too many experimental rods, which prevented criticality due to reduced fuel.

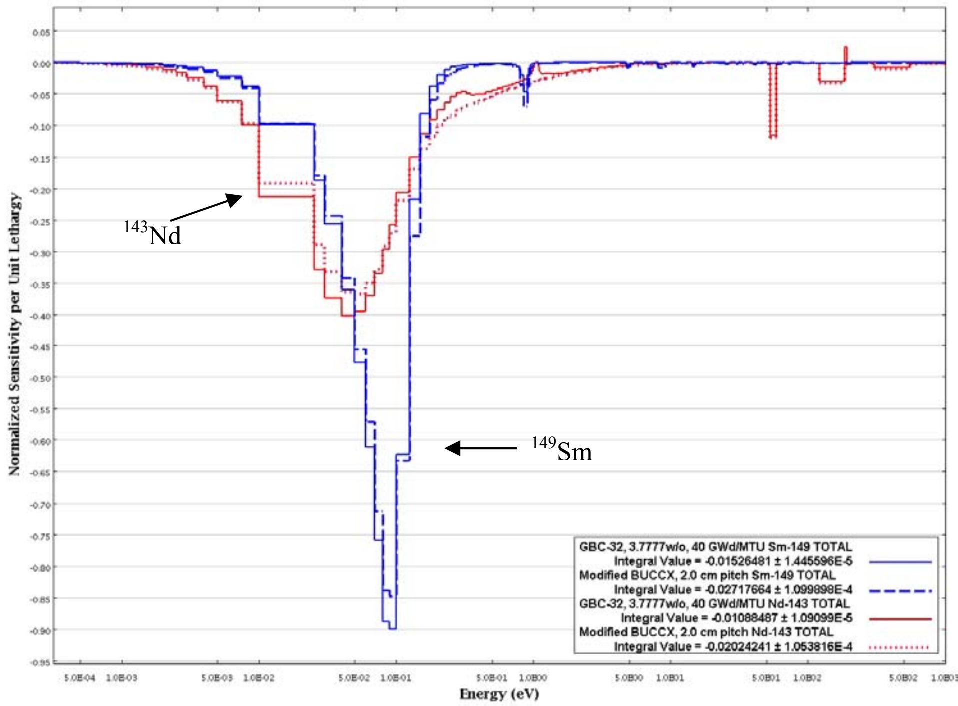
Finally, a solution tank was modeled to encompass central rods within the assembly (see Fig. 1c). This tank was filled with a dissolved FP. This method yielded both the best qualitative similarities overall and the desired worth for all but ^{95}Mo, a relatively unimportant nuclide with respect to burnup credit.

The best configurations and sensitivity profiles for each FP will be provided in the presentation. As examples, Fig. 2 compares the normalized profiles for the best tank-based configurations and the cask model for ^{149}Sm, ^{143}Nd, ^{103}Rh, and ^{133}Cs. The figure legends provide the k_{eff} sensitivity coefficients for each nuclide.

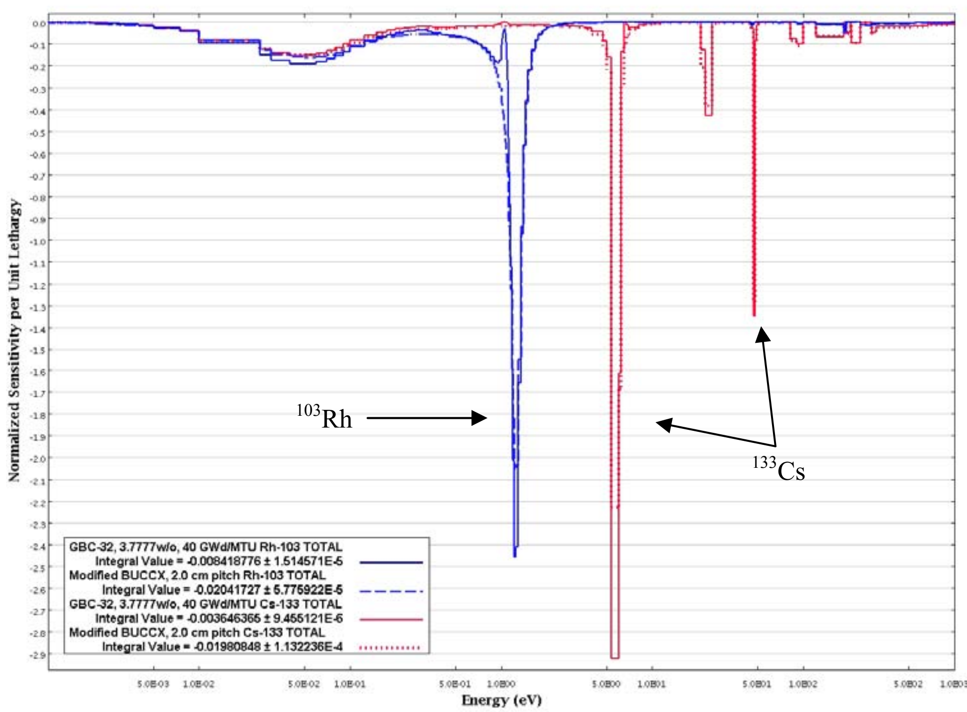


(a) (b) (c)

Fig. 1. Example assembly cutaways: (a) FP foils in between fuel pellets, (b) experimental rods with varying FP solution patterns, and (c) FP solution tank extending the length of the rods.



(a)



(b)

Fig. 2. Sensitivity profiles for (a) ^{149}Sm, ^{143}Nd, (b) ^{133}Cs and ^{103}Rh, each normalized to integrate to -1. The solid lines represent the GBC-32 sensitivities and the dashed lines represent those of the modified BUCCX. Note: the integral values listed in the legend refer to the integral of the *un-normalized* sensitivities. Moreover, these values are similar to total FP worth, consistent with linear perturbation theory.

CONCLUSION

Several modifications to BUCCX were developed and evaluated for the purposes of designing critical experiments that could be used for establishing FP biases for full burnup credit. Many of the ideas explored were shown to be potentially useful in this endeavor. The models employing a tank with a FP dissolved in the moderator exhibited particularly promising results. For each configuration, two criteria were enforced: (1) a FP worth of 2% Δk and (2) close qualitative similarity—judged graphically—between the experiment and application sensitivity profiles. Currently, the methods by which these experiments and criteria may be applied in code validation are being developed.

While the analyses were initially performed using GBC-32 cask model for comparison, further study determined the experiments would also be applicable—using the same criteria—to the Transportation, Aging, and Disposal (TAD) canisters specified for use by the DOE Office of Civilian Waste Management.

REFERENCES

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