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Investigation of BWR Depletion Calculations With SAS2H

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1 Introduction

The SAS2H sequence¹ of SCALE² has historically been used to characterize isotopics, radiation sources, and decay heat for spent nuclear fuel. However, there has been little work performed to investigate the viability of the SAS2H modeling limitations in application to the geometric complexities of boiling-water-reactor (BWR) fuel. Thus, ORNL has initiated a study to investigate the use of SAS2H for calculating spent BWR fuel isotopics for criticality analyses and assess the adequacy of SAS2H for this task. This summary discusses comparisons between 1-D SAS2H and detailed 2-D HELIOS³ assembly calculations. The work described in this summary is a small part of this larger project to assess BWR modeling for spent fuel characterization.

2 Analysis

Depletion calculations for this study were performed based on a GE 8×8 assembly design, as illustrated in Figure 1a. Assembly and operating history data applied in these analyses are based on actual neutronic and thermal-hydraulic data for a fuel assembly burned in Quad

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Cities Unit 2. The non-proprietary data supplied to ORNL represent operational data for a real BWR assembly. For identification purposes, this assembly has been designated as “Assembly ZZ”.

Assembly ZZ, with an average enrichment of 3.2 wt % ^{235}U , contains 60 fuel rods with 11 different enrichments, including 9 rods containing 3 wt % Gd_2O_3 . The various initial enrichments and rod locations of the fuel are indicated in Figure 1a. This assembly design also contains a large central water hole and an outer channel. The non-uniform and asymmetric fuel loading of this assembly provide a severe test of the modeling limitations of the SAS2H sequence.

To assess the depletion ability of SAS2H for this heterogeneous BWR fuel assembly, calculations were performed using both SAS2H and the HELIOS computer code package. SAS2H calculations used the SCALE 44-group (ENDF/B-V) library, while HELIOS calculations used a 34-group library based on ENDF/B-VI. Comparisons between these two codes, in tandem with variations in the HELIOS assembly model, were performed to assess the effect of assembly heterogeneity. HELIOS is a widely used tool for reactor fuel management analysis and has been validated for a number of reactor types, including many BWR fuel designs.⁴ While SAS2H is limited to simple, 1-D transport analysis assuming a single fuel type (i.e., rod dimensions and enrichment), HELIOS can perform pin-by-pin depletion calculations based on a 2-D transport solution. Although a code-to-code comparison lacks the quantification of a direct comparison to measured spent fuel data, such a comparison does enable a study of the relative behavior of the two codes. In addition, the code-to-code comparison can provide a valuable understanding of the effect and magnitude of the assumptions required for the SAS2H analysis.

The SAS2H modeling approach used here is illustrated in Figure 1b. This model assumes a single $\text{UO}_2/\text{Gd}_2\text{O}_3$ rod in the center, surrounded by a smeared fuel (at the assembly-average enrichment) and moderator region that represents part of the assembly fuel volume, bounded by corresponding volumes of the assembly channel and bypass moderator materials. In order to preserve the fuel-to- Gd_2O_3 ratio, the assembly fuel volume, as well as the corresponding volumes of the assembly channel and bypass moderator materials, are reduced by the inverse of the number of gadolinium bearing rods.

Percent differences for selected nuclides important to criticality safety analyses are given in Figure 2 for assembly-averaged isotopic concentrations calculated by HELIOS and SAS2H. The listed results correspond to an accumulated burnup of 40 GWD/MTU and a subsequent 5-year cooling-time. In spite of the considerable approximations associated with the SAS2H model, the SAS2H isotopic results are generally within 10% of the HELIOS predictions for the important actinides and fission products. However, considerable differences (>15%) are observed for some of the less important (to reactivity) nuclides. In general, SAS2H over-predicts nuclide concentrations relative to HELIOS, with the significant exception of ^{235}U . The fact that ^{235}U is under-predicted and ^{238}U is over-predicted in the SAS2H calculation seems to indicate a softer spectrum in the SAS2H model. However, this is contradicted by the higher Pu concentrations predicted by the SAS2H model. Therefore, additional analyses were performed in an attempt to understand these differences.

SAS2H is limited to a single fuel enrichment. In contrast, the spatial distribution of fuel pin enrichments may be explicitly represented with HELIOS. To investigate the effect of this

modeling difference, HELIOS calculations were performed with the assembly-average enrichment in all rods to more closely emulate the SAS2H model. The results show that the use of the assembly-average enrichment results in generally lower calculated actinide densities, with the effect diminishing as burnup increases, and very minor reduction in the fission products. The results suggest that the observed difference in ^{235}U between HELIOS and SAS2H is related to the assembly-average enrichment approximation in SAS2H. Further, the underestimation in ^{235}U increases with burnup. Thus, it was postulated that the average enrichment approximation, which artificially increases the enrichment on the assembly periphery where the neutron spectrum is softer, results in an increase in ^{235}U depletion. Additional HELIOS calculations were performed to verify that this effect was not related to the presence of the Gd rods and confirm that the observed differences in ^{235}U between HELIOS and SAS2H are attributed to the assembly-average enrichment approximation in SAS2H.⁵

SAS2H has been compared to HELIOS in earlier validation work for radiochemical assay data from UO_2 fuel samples obtained from a MOX assembly design.⁶ It is worth noting that the differences between actinides in the earlier work are consistent with those shown in Figure 2. Additionally, for several actinides (^{238}Pu , ^{240}Pu , and ^{237}Np), SAS2H was in better agreement with experimental measurement than HELIOS. Thus, code-to-code differences shown in Figure 2 do not necessarily indicate limitations in the SAS2H approach for BWR spent fuel characterization.

Although the effect is assumed to be minor for this study, it is important to note that SAS2H and HELIOS are not using the same cross-sections. To enable a more direct comparison for future studies, a 2-D capability (SAS2D) is currently being developed at ORNL. SAS2D is being developed as part of the SCALE system, but will use the special 2-D lattice capabilities of

NEWT⁷ to allow a more rigorous 2-D model of radiation transport in place of the simple 1-D model of SAS2H.

3 Conclusion

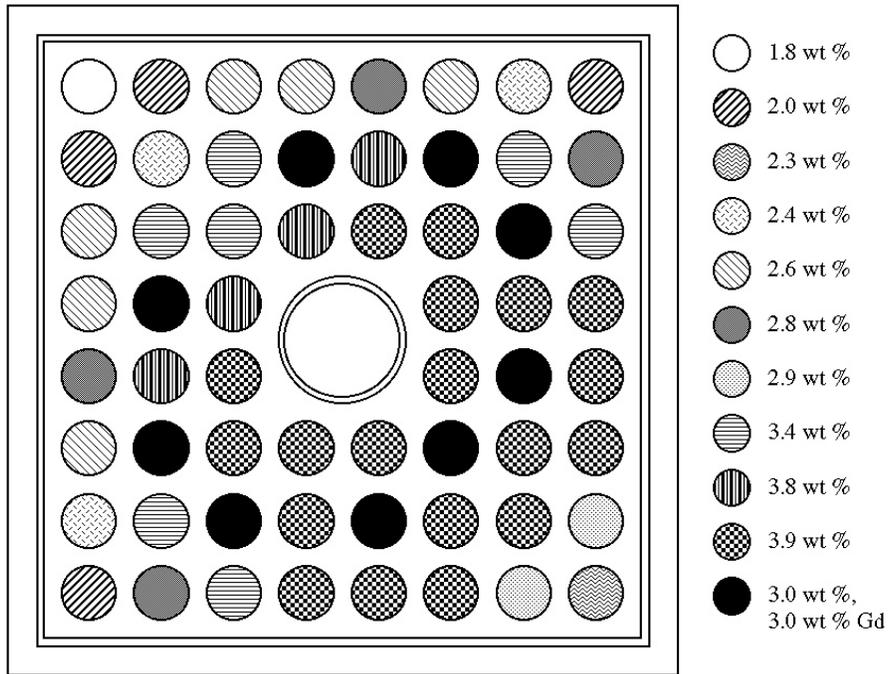
The analyses documented in this summary represent an attempt to gain greater physical understanding of BWR fuel depletion calculations, assess the adequacy of SAS2H for this task, and subsequently refine the calculational methodology. In general, SAS2H is over-predicting nuclide concentrations relative to HELIOS, with the significant exception of ²³⁵U. The under-estimation of ²³⁵U was found to be associated with the limitation of a single fuel enrichment in SAS2H and was shown to increase as a function of burnup. Alternative geometric modeling approaches were also investigated and assessed based on comparisons to HELIOS results. While minor improvements (relative to HELIOS) over the reference model for some of the nuclides were observed, none of the SAS2H modeling approaches considered represented a significant improvement over the reference model shown in Fig.1b.

Based on the calculated results, the indication is that the approximations in the 1-D SAS2H model provide an adequate representation of depletion dynamics for a heterogeneous 2-D BWR assembly. Although not as accurate as an explicit model, the 1-D approximation appears to yield consistent results such that a reasonable bias and uncertainty could be determined in the prediction of assembly-averaged isotopic concentrations. The simplicity and relative speed of the SAS2H approach for modeling complicated systems are clear advantages over more rigorous approaches.

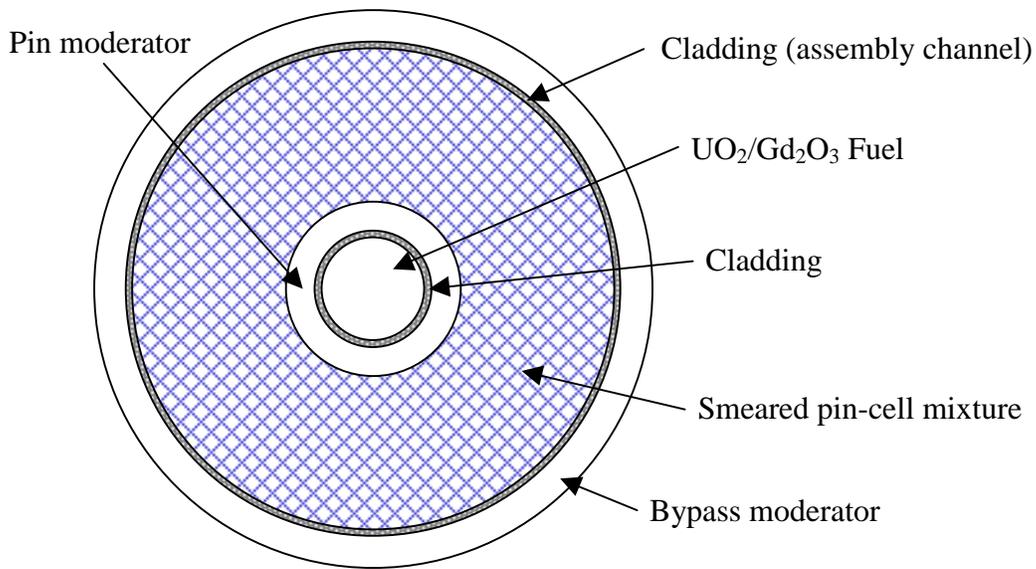
4 References

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(a) Actual Assembly ZZ Design (As Modeled by HELIOS)



(b) SAS2H Model of Assembly ZZ (not drawn to scale)

Figure 1. Representations of Assembly ZZ

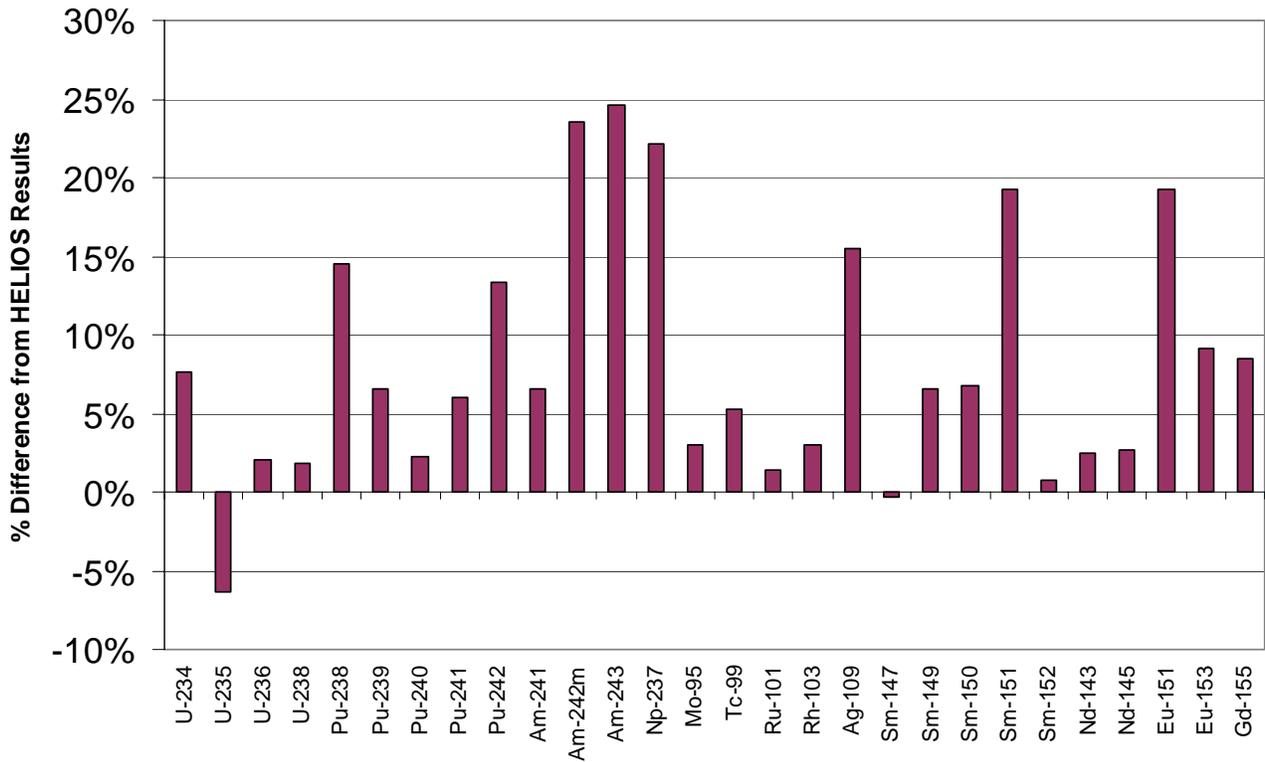


Figure 2. Percent difference (relative to HELIOS) between SAS2H and HELIOS calculated nuclide densities.