Isotopic Bias and Uncertainty for Burnup Credit Applications

J. M. Scaglione
Bechtel SAIC Company, LLC
1180 Town Center Rd, Las Vegas, NV
(702) 295-5475, John_Scaglione@ymp.gov

Introduction

The application of burnup credit requires calculating the isotopic inventory of the irradiated fuel. The depletion calculation simulates the burnup of the fuel under reactor operating conditions. The result of the depletion analysis is the predicted isotopic composition, which is ultimately input to a criticality analysis to determine the system multiplication factor (k_{eff}). This paper demonstrates an approach for calculating the isotopic bias and uncertainty in k_{eff} for commercial spent nuclear fuel burnup credit. This paper covers 74 different radiochemical assayed spent fuel samples from 22 different fuel assemblies that were irradiated in eight different pressurized water reactors (PWRs). The samples evaluated span an enrichment range of 2.556 wt% U-235 through 4.67 wt% U-235, and burnups from 6.92 GWd/MTU through 55.7 GWd/MTU.

Discussion

Radiochemical assays (RCAs) are conducted as part of the destructive, post-irradiation examination of nuclear fuel. The majority of the RCAs weren't performed for the purpose of determining isotopic compositions for burnup credit but for other reasons including clad performance, fuel pellet performance, and fission gas release rates. Therefore, the majority of the available RCAs focused on the actinide concentrations as a function of burnup. Consequently, many have a limited number of fission products measured, if any at all. An additional complication is that the accompanying operating history information for the samples is relatively coarse.

Investigation shows that using the given reactor operating history information for the simulation of the fuel irradiation in the reactor produces results that are multifarious on an isotope-by-isotope basis. There are compensating effects by the over/under-prediction of different isotopes, and evaluated results thus far

have indicated no direct pattern for a particular isotope. Therefore, when evaluating a code's ability to accurately predict the isotopic composition of irradiated fuel, the end result is what needs to be kept in perspective (effect on k_{eff}).

A summary of the sample characteristics for each of the different assembly designs is presented in Table 1.

Table 1. PWR Radiochemical Assay Information[1]

Reactor	Assembly Design	# of Samples/ assemblies/rods	Sample Burnups (GWd/mtU)	Initial Enrichments (Wt% U-235)
Trino Vercelles	Westinghouse (W), Irregular	14/3/6	12.042	3.897
			11.529-24.548	3.13
Yankee Rowe	W, Irregular	8/1/3	15.95-35.97	3.4
Turkey Point	W 15x15, 20 GT	5/2/5	30.72-31.56	2.556
Mihama	W 15x15, 20 GT	9/3/NA	6.92-8.3	3.208
			14.66-21.29	3.203
			29.5-34.32	3.210
H.B. Robinson	W 15x15, 20 GT, 12 BP	4/1/1	16.02-31.66	2.561
Obrigheim	Siemens 14x14	6/5/special	25.93-29.52	3.13
Calvert Cliffs	Combustion Engineering 14x14 BP present	9/3/3	27.35-44.34	3.038
			18.68-33.17	2.72
			31.40-46.46	2.453
TMI	B&W 15x15, 16 GT	5/1/1	44.8-51.3	4.67
		6/1/1	44.8-55.7	4.67
		4/1/2	23.7-26.7	4.67
		4/1/3	22.8-29.9	4.67

NOTE: BP = Burnable Poison Rods; GT = Guide Tubes

The analytical method employed was the SAS2H control module of the SCALE 4.4a code [2] and MCNP [3]. Based upon fuel assembly design, power history, and operating data for the specific assemblies, a computational representation was developed for use with SAS2H and MCNP. The SAS2H module was used to perform a fuel depletion analysis to predict the isotopic concentrations in localized areas of assembly pins (representative of sample locations). The predicted isotopic concentrations were then used as material input to MCNP in waste package geometry to generate k_{eff} values. These values were then compared with MCNP results using RCA measured concentrations as the fuel material. The isotopes that were assayed are presented in Table 2.

Table 2. RCA Measured Isotopes[1]

Isotope	# of Samples	Isotope	# of Samples	Isotope	# of Samples
U-234	44	Nd-145	31	Eu-155	14
U-235	74	Nd-146	12	Gd-155	22
U-236	74	Nd-148	44	Cm-242	23
U-238	68	Nd-150	12	Cm-243	3
Pu-238	60	Pm-147	3	Cm-244	24
Pu-239	74	Sm-147	22	Am-241	28
Pu-240	74	Sm-148	3	Am-242	6
Pu-241	74	Sm-149	22	Am-242m	8
Pu-242	70	Sm-150	22	Am-243	34
Np-237	31	Sm-151	22	U-232	9
Cs-133	3	Eu-151	3	Pu-236	3
Cs-134	11	Sm-152	22	Ag-109	11
Cs-135	3	Eu-153	22	Mo-95	11
Cs-137	22	Sm-154	3	Tc-99	11
Nd-143	31	Eu-154	3	Ru-101	11
Nd-144	12	Gd-154	3	Rh-103	11

NOTE: Shaded isotopes represent the Principal Isotope set selected for burnup credit applications, which is a subset of all isotopes present in spent nuclear fuel

Results

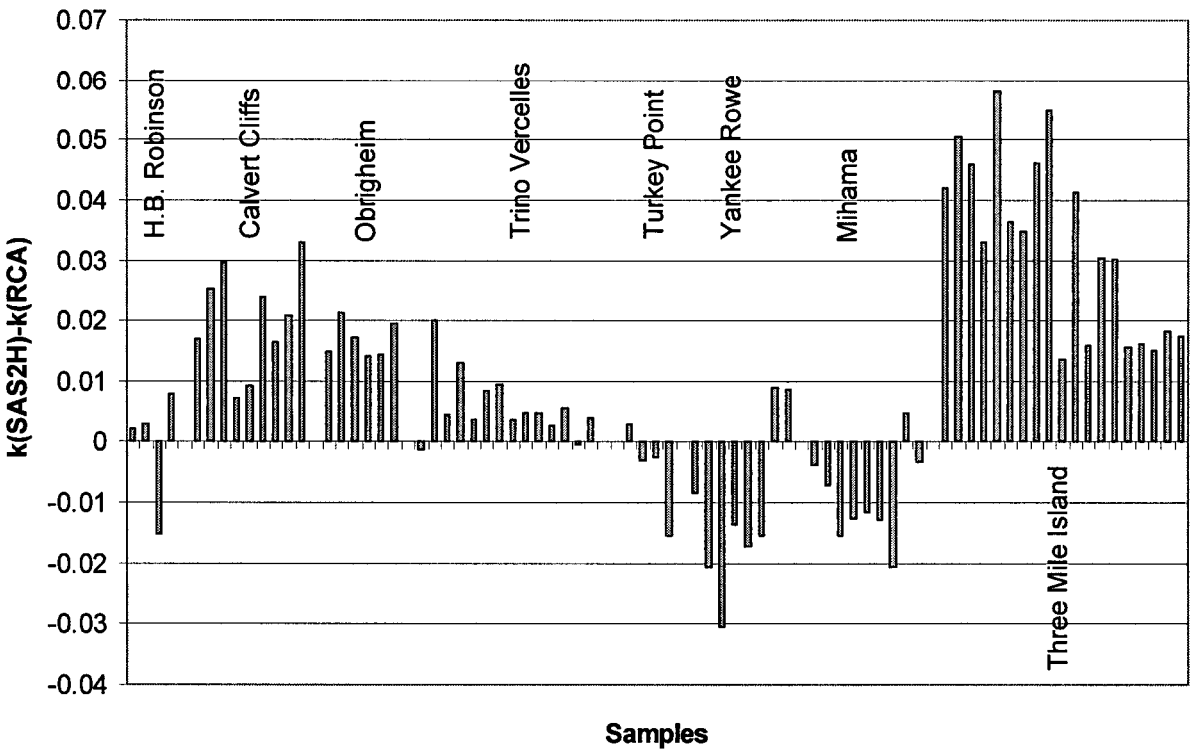
Figure 1 illustrates the Δk_{eff} values from the comparison calculations using the principal isotopes available in each RCA sample. The majority of the results indicate that the isotopic compositions predicted by SAS2H produce conservative (higher) values of k_{eff}. The determination of bias for criticality safety applications should not include positive bias. Therefore, the bias value should only be calculated from samples that show a negative bias. Using this rule the average bias is 0.0115, but high uncertainty arises due to the limited number of negative bias sample results yielding a combined bias and uncertainty of 0.0279 in Δk_{eff}, which was calculated based on a 95% confidence limit. This combined bias and uncertainty is calculated from the statistical analysis of the data shown in Figure 1 and is expected to encompass any computational or measurement uncertainties.

It should be noted that the results presented that pertain to the Mihama and Yankee Rowe reactors (basically all the negative bias results) are somewhat questionable. The operating history information for Mihama was unable to be verified against the original reference source at the time of this write-up and came from a secondary reference source. These results warrant further investigation into the operating history information in order to validate the Mihama results. The operating history information regarding

the control rod movement for Yankee Rowe was unavailable so the simulated irradiation omitted any control rods, which could be a cause of the non-conservative k_{eff} values due to a softer spectrum during the simulated irradiation.

Regardless of the negative bias samples, the results show that SAS2H generally provides conservative isotopic compositions with regards to criticality potential. When using a depletion code in burnup credit applications, operating history parameters will be selected to maximize fissile isotope production in order to ensure that the calculated isotopics for a given initial enrichment and burnup will yield a higher k_{eff} value than any assembly (with similar initial enrichment and burnup) depleted in a reactor. The selected depletion application parameters will need to be confirmed against RCA measured isotopics, and fuel assembly core follow calculated isotopics.

Figure 1. SAS2H and RCA Comparisons Using Principal Isotopes



References

[1] BSC (Bechtel SAIC Company) 2002. *Three Mile Island Unit 1 Radiochemical Assay Comparisons to SAS2H Calculations.* CAL-UDC-NU-000011 REV A. Las Vegas, Nevada: Bechtel SAIC Company.

[2] *SCALE 4.4a, Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation,* NUREG/CR-0200, Rev. 6 (ORNL/NUREG/CSD-2R6) May 2000.

[3] Briesmeister, J. F., Ed., *MCNP™ – A General Monte Carlo N-Particle Transport Code, Version 4B*, LA-12625-M, Los Alamos National Laboratory (LANL), March 1997.