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Using the SCALE 5 TSUNAMI-3D Sequence in Critical Experiment Design

Donald E. Mueller[1] and Gary A. Harms[2]

[1]Oak Ridge National Laboratory[*]
P.O. Box 2008, Bldg. 5700, MS-6170
Oak Ridge, TN 37831-6170, USA
Telephone: (865) 576-4121
FAX: (865) 576-3513
Email: MuellerDE@ornl.gov

[2]Sandia National Laboratories[†]
P.O. Box 5800
Albuquerque, NM 87185-1146, USA
Email: GAHarms@sandia.gov

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Donald E. Mueller

Oak Ridge National Laboratory:[*] P.O. Box 2008, Oak Ridge, TN 37831-6170, USA, MuellerDE@ornl.gov

Gary A. Harms

Sandia National Laboratories :[†] P.O. Box 5800, Albuquerque, NM 87185-1146 USA, GAHarms@sandia.gov

INTRODUCTION

The TSUNAMI-3D sensitivity and uncertainty calculation sequence, first publicly available in SCALE 5, facilitates detailed comparison of critical experiment calculations with criticality safety evaluation calculations. This SCALE sequence may be used as a tool in the design of critical experiments that are intended to support a specific application. An after-the-fact example, involving a critical experiment with the fission product ^{103}Rh that is relevant to burnup credit, is described in this paper for illustrative purposes.

BACKGROUND

A series of critical experiments [1] with ^{103}Rh were performed at Sandia National Laboratories (SNL) in 2002 to support taking credit for the presence of this fission product in spent commercial pressurized-water-reactor (PWR) fuel during transport and storage in casks. The experiments involved placement of one of three thicknesses of ^{103}Rh foils between low-enrichment fuel pellets in selected fuel rods in a roughly cylindrical, water-moderated and water-reflected triangular-pitched array. This set of critical experiments is currently scheduled for inclusion in the 2005 edition of the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, to be published by the Nuclear Energy Agency.

A generic burnup credit cask model is described in NUREG/CR-6747 [2] for use in analytical studies. This model, referred to in the reference and in this paper as the GBC-32, has a 32 PWR fuel assembly capacity. Each fuel assembly rests in a stainless steel basket with a Boral® panel between each assembly and on the external sides of peripheral locations. The cask body, constructed of stainless steel, has inner and outer diameters of 175 and 215 cm, respectively, a cavity height of 411 cm, and 30-cm top and bottom thicknesses.

The TSUNAMI-3D SCALE sequence, described in the SCALE 5 manual [3], uses linear perturbation theory to estimate the neutron energy group-dependent sensitivity of system $k_{effective}$ to changes in the reaction-specific macroscopic cross sections of modeled nuclides. TSUNAMI-3D produces energy-dependent sensitivity coefficient profiles and total sensitivity coefficients integrated over energy. The sensitivity coefficients from critical experiment models may be compared with sensitivity coefficients from criticality safety evaluation calculations to establish similarity.

METHOD

CSAS25 models were created for the SNL ^{103}Rh critical experiments and provided to Oak Ridge National Laboratory (ORNL) by SNL. ORNL used the SCALE 5 TSUNAMI-3D sequence to generate sensitivity coefficients for each of the SNL ^{103}Rh critical experiments.

The SCALE 5 STARBUCS [3] sequence was used to create a CSAS25 model for the GBC-32 loaded with 32 Westinghouse 17 × 17 fuel assemblies having axially varying average burnups of 40 GWd/MTU. A special development version of the TSUNAMI-3D sequence was used to generate the sensitivity coefficients for the GBC-32. The special version was required because the version distributed with SCALE 5 is limited to no more than 50 resonance nuclides. This limitation will be removed in the SCALE 5.1 version, scheduled to be released in 2005. JAVAPENO [3], a data display tool distributed with SCALE 5, was used to compare sensitivity coefficients and to prepare the figures provided in this paper. This modeling and sensitivity analysis effort is described in work [4] to be reported at the 2005 NCSD Topical Meeting, to be held in Knoxville, Tennessee.

RESULTS

Figure 1 presents the total and energy-dependent sensitivity of system $k_{effective}$ to changes in the ^{103}Rh total macroscopic cross sections. The sensitivity is defined as $(\delta k/k)/(\delta\Sigma/\Sigma)$ and is thus unitless. A ^{103}Rh sensitivity

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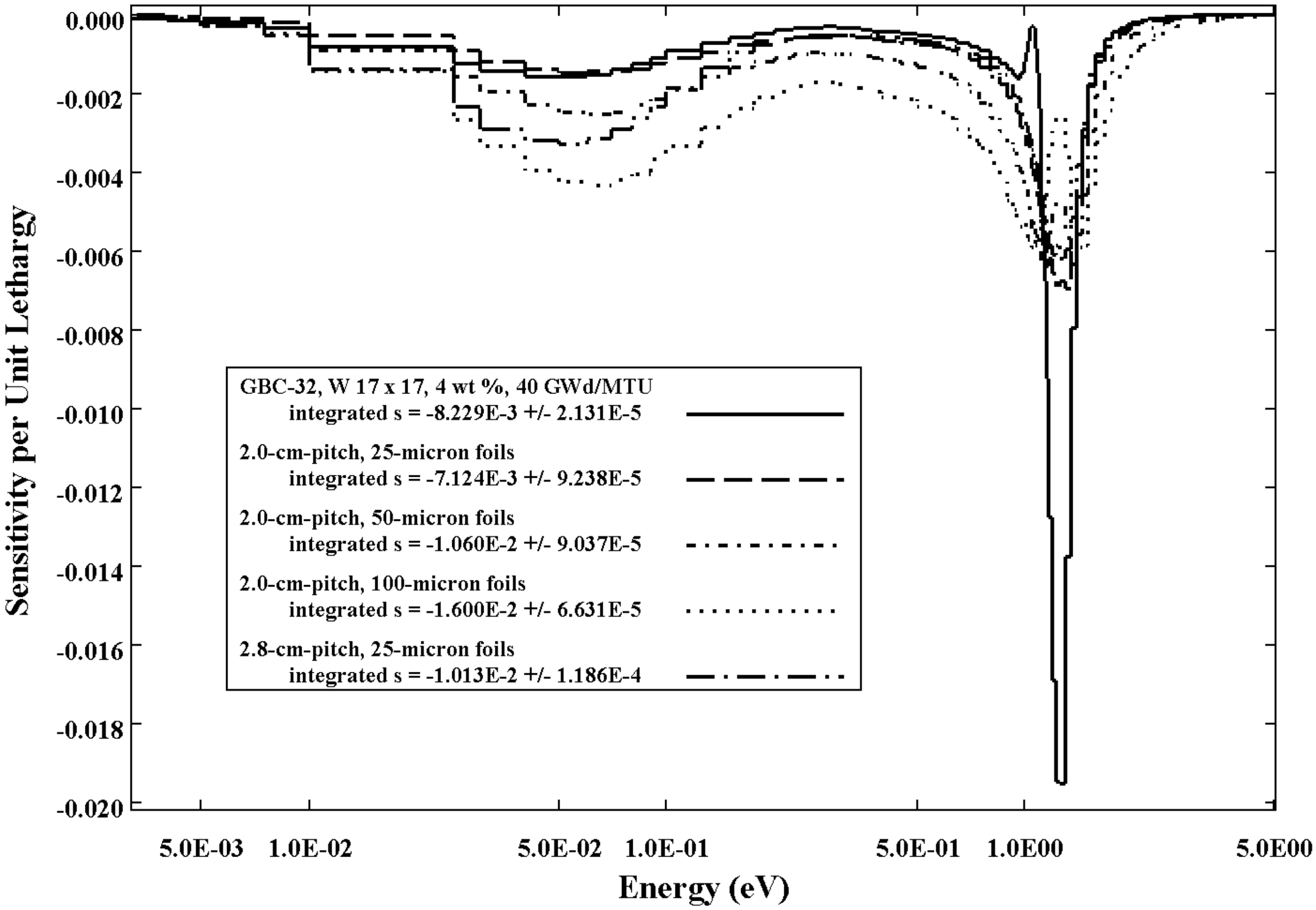

Fig. 1. Comparison of ^{103}Rh sensitivities versus neutron energy for a GBC-32 cask model and the SNL ^{103}Rh critical experiments.

profile is provided for flooded GBC-32 shipping casks, each loaded with 32 Westinghouse 17 × 17 fuel assemblies that had an initial enrichment of 4 wt % ^{235}U and have assembly-average burnups of 40 GWd/MTU. Also presented in Fig. 1 are sensitivity profiles for four of the SNL ^{103}Rh critical experiments. Of the six experimental configurations with ^{103}Rh, the critical experiment with a 2.0-cm hexagonal lattice pitch and 25-μm-thick foils produced the sensitivity profile closest to the GBC-32 profile. However, the GBC-32 model exhibits a sensitivity peak (in terms of negative reactivity) between 1 and 2 eV that is significantly different from that of the critical experiments.

A review of the ^{103}Rh sensitivity profiles from the critical experiments showed that the thinner ^{103}Rh foils produced higher sensitivity peaks in the 1- to 2-eV range. Based on this information, the critical experiment models were modified to include 10- and 5-μm-thick ^{103}Rh foils. The number of rods containing ^{103}Rh foils was increased to compensate for the use of thinner foils. Figure 2 includes the sensitivity profile for a fictitious critical experiment containing 5-μm ^{103}Rh foils. The figure also includes the GBC-32 ^{103}Rh profile and the best profile from the SNL ^{103}Rh critical experiments. Note the improvement in the comparison of the GBC-32 and the case with the 5-μm-thick foil in the 1- to 2-eV range.

The TSUNAMI-3D sensitivity and uncertainty analyses tool was not available when the SNL critical experiments were designed and performed. This tool has permitted energy-dependent quantification and comparison of how the ^{103}Rh affects the $k_{effective}$ of the GBC-32 loaded with burned fuel and the SNL ^{103}Rh critical experiments. The comparison showed that use of 5-μm foils in the critical experiments would have resulted in critical experiments that better support validation of fission products in burned fuel in a shipping cask. The practicality of using 5-μm foils was not explored by the authors. TSUNAMI-3D can be useful in the design of future critical experiments, especially when such critical experiments are to be performed to support a specific application, such as taking credit for fission products in burned nuclear fuel.

ACKNOWLEDGEMENTS

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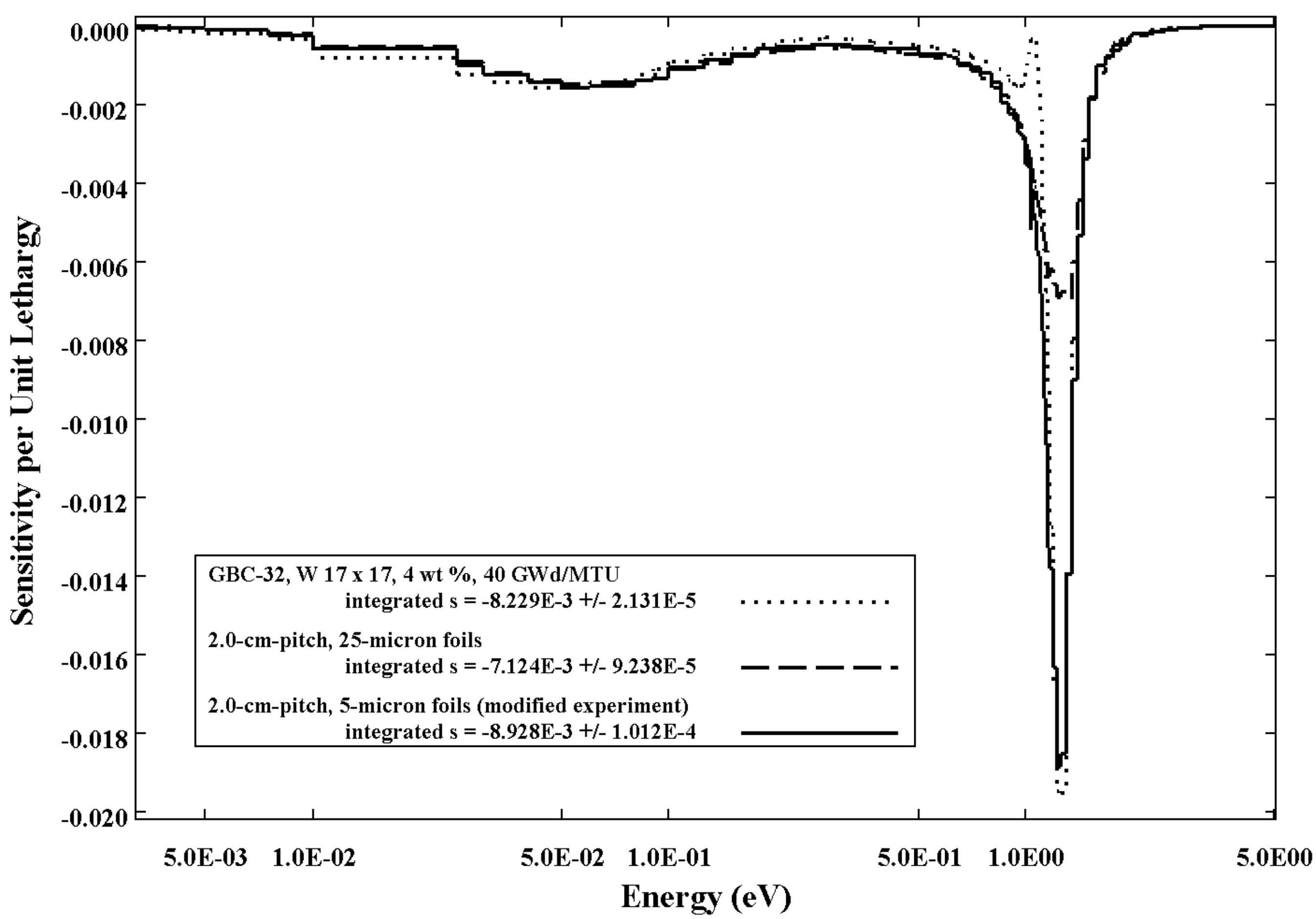

Fig. 2. Comparison of ^{103}Rh sensitivities versus neutron energy for a GBC-32 cask model and a modified ^{103}Rh critical experiment.