Validation of SCALE and the TRITON Depletion Sequence for Gas Reactor Analysis

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INTRODUCTION

The very-high-temperature reactor (VHTR) is an advanced reactor concept that uses graphite-moderated fuel and helium gas as a coolant. At present there are two primary VHTR reactor designs under consideration for development: in the pebble-bed reactor, a core is loaded with “pebbles” consisting of 6 cm diameter spheres, while in a high-temperature gas-cooled reactor, fuel rods are placed within prismatic graphite blocks. In both systems, fuel elements (spheres or rods) are comprised of tristructural-isotropic (TRISO) fuel particles. The TRISO particles are either dispersed in the matrix of a graphite pebble for the pebble-bed design or molded into compacts/rods that are then inserted into the hexagonal graphite blocks for the prismatic concept.

Two levels of heterogeneity exist in such fuel designs: (1) microspheres of TRISO particles dispersed in a graphite matrix of a cylindrical or spherical shape, and (2) neutron interactions at the rod-to-rod or sphere-to-sphere level. Such double heterogeneity (DH) provides a challenge to multigroup cross-section processing methods, which must treat each level of heterogeneity separately. A new capability to model doubly heterogeneous systems was added to the SCALE system in the release of Version 5.1 [1]. It was included in the control sequences CSAS and CSAS6, which use the Monte Carlo codes KENO V.a and KENO-VI, respectively, for three-dimensional neutron transport analyses and in the TRITON sequence, which uses the two-dimensional lattice physics code NEWT along with both versions of KENO for transport and depletion analyses. However, the SCALE 5.1 version of TRITON did not support the use of the DH approach for depletion.

This deficiency has been addressed, and DH depletion will be available as an option in the upcoming release of SCALE 6. At present Oak Ridge National Laboratory (ORNL) staff are developing a set of calculations that may be used to validate SCALE for DH calculations. This paper discusses the results of calculations completed to date and the direction of future validation work.

APPROACH

Reference 1 describes the methodology for DH cross-section processing, which will not be repeated here. This same paper presented early validation results for a computational benchmark developed for intercomparison of different modeling approaches for gas reactor fuel [2] and provided preliminary results. In this work we seek to identify a more complex and realistic configuration for direct validation against experimental measurements. An extensive list of possible benchmarks has been developed, and analysis is proceeding with a number of different configurations.

The 2008 edition of the *International Handbook of Evaluated Reactor Physics Experiments* [3] provides specifications for reviewed and approved benchmarks for a number of reactor physics configurations and includes specifications for the HTR-10 pebble-bed core (China). ORNL has developed a KENO V.a model for the criticality state within the specification; additional models to calculate control-rod worth are currently under development.

Although an approved benchmark specification has not yet been released for a prismatic-type gas reactor within the International Reactor Physics Evaluation Project, Japan’s high-temperature test reactor (HTTR) has been described in sufficient detail elsewhere [4–5] to allow development of benchmark-quality models. A model of the HTTR is under development at ORNL; however, ongoing work at Texas A&M University has completed calculations of excess reactivity eigenvalue and control-rod worth based on measured data, with excellent agreement. [6]

While calculation of accurate multigroup cross sections for DH fuels presents a challenge, results will show that the two-level homogenization approach employed by SCALE provides excellent agreement with measured data. However, depletion presents an additional challenge within TRITON, as the cross-section-processing method results in effective cross sections for homogenized media; depletion methods based on ORIGEN-S with TRITON [7] explicitly track the discrete fuel-particle compositions within fuel compacts. This approach allows for the depletion of different fuel-particle types within the fuel. This approach relies on the approximation that depletion using an average flux within a fuel sphere or pin is sufficient. Hence, validation of this method by comparison to both measured data and code-to-code comparisons is desirable. Unfortunately, very little such data is publicly available at present. Currently, ORNL staff is developing a depletion model to compare to published calculations for a pebble-bed modular reactor (PBMR) equilibrium core [8]. These calculations are currently underway.

RESULTS

The KENO V.a Monte Carlo transport solver was used in the development of the HTR-10 core model for the critical core. Using the pre-release version of SCALE 6 with ENDF/B-VII data and using the CENTRM continuous energy solver within the DH resonance processing treatment and 238 energy group transport library, a critical eigenvalue was calculated as given in Table I. Although ORNL's HTTR model is still under development, Table 1 also provides the results for two benchmark calculations performed at Texas A&M University and reported in Ref. 6, and results using the same models computed at ORNL with the pre-release version of SCALE 6 and ENDF/B-VII.0 data. ORNL results are more tightly converged, and small differences in results are seen, but all fall within the range of the experimental uncertainty.

TABLE I. Results of Gas Reactor Calculations for Reactor Experimental Measurements.

Reactor	Measurement Type	Calculated k_{eff}	Measured k_{eff}
HTR-10[1]	Critical	1.0008 +/- 0.0009	1.00 +/- 0.04[2]
HTTR (TAMU)[3]	All Rods Out Excess Reactivity	1.1368 +/- 0.0023	1.1363 +/- 0.041
HTTR (ORNL)[1]	"	1.1358 +/- 0.0006	"
HTTR (TAMU)[3]	All Rods in Subcritical	0.6858 +/- 0.0019	0.685 +/- 0.010
HTTR (ORNL)[1]	"	0.6802 +/- 0.0007	"

[1] Calculated using prerelease version of SCALE 6 with ENDF/B-VII.0 data
[2] Measurement uncertainty was not reported and was estimated in Ref. 3
[3] SCALE 5.1/ENDF/B-V based calculations reported in Ref. 6.

CONCLUSIONS

The DH cross-section processing treatment in SCALE is currently being validated for criticality and depletion calculations using TRITON. Eigenvalue calculations completed thus far show excellent agreement with measured data. Validation of the depletion method is currently in progress. Depletion calculations have been successfully performed for the HTR-10 core and show expected behavior, but they do not take into account pebble movement, nor are measured data available for discharged fuel. Calculations are currently being made for comparison to reported calculations performed by PBMR, Ltd. Additionally, efforts are under way to organize the development of a set of simple gas-reactor benchmarks to provide a basic capability for code-to-code comparison. However, measured data will ultimately be available from the radiochemical assay of burned fuel elements, which will provide the best data for depletion physics methods validation.

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