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**Analysis of a Computational Benchmark for a High-Temperature Reactor Using SCALE**

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# Analysis of a Computational Benchmark for a High-Temperature Reactor Using SCALE

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## Abstract

Several proposed advanced reactor concepts require methods to address effects of double heterogeneity. In doubly heterogeneous systems, heterogeneous fuel particles in a moderator matrix form the fuel region of the fuel element and thus constitute the first level of heterogeneity. Fuel elements themselves are also heterogeneous with fuel and moderator or reflector regions, forming the second level of heterogeneity. The fuel elements may also form regular or irregular lattices. A five-phase computational benchmark for a high-temperature reactor (HTR) fueled with uranium or reactor-grade plutonium has been defined by the Organization for Economic Cooperation and Development, Nuclear Energy Agency (OECD NEA), Nuclear Science Committee, Working Party on the Physics of Plutonium Fuels and Innovative Fuel Cycles. This paper summarizes the analysis results using the latest SCALE code system (to be released in 2006 as SCALE 5.1).

**KEYWORDS:** ***OECD, NEA, HTR, plutonium, uranium, thorium***

## 1. Introduction

Numerous advanced reactor fuel designs have features that enhance the importance of the resonance processing procedure in obtaining accurate results in a system analysis. For example, the fuel for a high-temperature gas-cooled reactor (HTGR) consists of a double-layered geometry with small, tri-isotropic (TRISO) fuel particles uniformly distributed in graphite within a heterogeneous fuel element (or sphere). The fuel particles are closely packed (0.5 mm fissile material surrounded by 0.25 mm-thick moderator shell) so that interactions between the particles as well as the slowing down within the fuel cannot be ignored. The fuel element (or sphere) is small enough that the heterogeneity of the fuel and interstitial moderator is important, and the fuel particles cannot be considered to lie in an infinite medium.

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## 2. Benchmark Definitions

Analyses have been performed using the benchmark definitions [1] provided by the Organization for Economic Cooperation and Development, Nuclear Energy Agency (OECD NEA), Nuclear Science Committee, Working Party on the Physics of Plutonium Fuels and Innovative Fuel Cycles. The computational benchmark has five phases in which infinite arrays of $UO_2$, $PuO_2$ and $ThO_2$-$UO_2$ fueled pebbles as well as $UO_2$ and $PuO_2$ fueled pebbles in a high-temperature reactor are analyzed. Due to differences in available analysis methodologies and corresponding limitations, the infinite array problems have been further divided into two sections: (1) a spherical outer boundary with reflective or white boundary conditions, and (2) a cubic outer boundary with reflective boundary conditions.

## 3. Method

CSAS and CSAS6 sequences of SCALE [2] with the 238-group cross section library, which is based on ENDF/B-VI evaluations and has 148 fast groups and 90 thermal groups (below 3 eV), have been used in the calculations. Deterministic calculations have been performed with the XSDRNPM module of SCALE using the S8 quadrature. Monte Carlo calculations have been performed using KENO V.a and KENO VI modules of SCALE. In all cases, the cross sections have been resonance-corrected using the CENTRM/PMC/CHOPS modules of the SCALE code system. Double heterogeneity has been accounted for by first calculating the flux disadvantage factors for the particles and then using these factors to create the homogenized particle/matrix mixture cross sections. The homogenized cross sections are used on the second pass to create the final resonance-shielded cross sections that represent the fuel pebbles.

For $k_{inf}$ calculations, XSDRNPM calculations used white boundary conditions on a sphere (pebble), whereas KENO V.a and KENO VI calculations used reflected boundary conditions on a cube that contains the sphere (pebble).

## 4. Results and Comparison

Although all phases of the benchmark problems have been calculated, only preliminary results of the calculations for the first phase with $UO_2$-fueled pebbles are listed in Table 1. Analysis of the results shows that the impact of doubly-heterogeneous resonance self-shielding is considerable for the $UO_2$-fueled pebbles, with properly shielded cases, calculating 8% higher than homogenized cases. For all cases, KENO V.a and KENO VI results show excellent agreement. This is expected, since both codes use the same resonance self-shielded cross sections. As shown in Table 2, the $k_{inf}$ values calculated with KENO V.a agree with MONK9 [3] and MCNP [4] results that have been provided by other participants of the benchmark project, with ~0.7% and ~0.0% difference, respectively. Both MONK9 (with JEF2.2-based cross sections) and MCNP (with ENDF/B-VI cross sections) utilize continuous energy representation of the cross sections and therefore do not have to resonance-correct the cross sections. On the other hand, the new capability in SCALE is used in generating resonance-corrected, multigroup cross sections.

**Table 1:** Effect of double heterogeneity

| Definition | Method | KENO V.a | | KENOVI | |
|---|---|---|---|---|---|
| | | $k_{inf}$ | σ | $k_{inf}$ | σ |
| Infinite array of $UO_2$-fueled pebbles | Homogenized | 1.3994 | 0.0004 | 1.3996 | 0.0004 |
| | Doubly heterogeneous | 1.5113 | 0.0004 | 1.5106 | 0.0004 |
| | % difference | 8 | -- | 8 | -- |

**Table 2.** Comparison of $k_{inf}$ values

| Definition | MCNP vs KENO V.a | MONK9 vs KENO V.a |
|---|---|---|
| | % difference in $k_{inf}$ | % difference in $k_{inf}$ |
| Infinite array of $UO_2$-fueled pebbles | 0 | 0.7 |

## 5. Summary

A five-phase computational benchmark problem for an HTR has been modeled with SCALE version 5.1 (to be released) using the automated, user-friendly sequences CSAS and CSAS6. The KENO V.a and KENO VI results agree well. The agreement with other Monte Carlo codes is good for uranium-fueled systems. The differences in the $k_{inf}$ values may be due to the cross section evaluations or to the different methods used (i.e., resonance processing and transport solution).

## References


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