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KENO CONTINUOUS ENERGY CALCULATIONS FOR A SUITE OF COMPUTATIONAL BENCHMARKS FOR THE DOPPLER REACTIVITY DEFECT

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ABSTRACT

Continuous energy capabilities have been added to development versions of the KENO V.a and KENO VI Monte Carlo packages within the SCALE code system. Recently, continuous-energy cross-section data has been added to SCALE based on ENDF/B-VI evaluations for more than 300 nuclides and a range of temperatures. Ongoing analyses have been able to demonstrate the accuracy of the new continuous energy capabilities. This work describes recently completed calculations for a calculational benchmark developed to assess codes and data for calculation of the Doppler coefficient with a range of UO_2 and MOX fuel types. Results are compared to MCNP calculations for the benchmark, and are found to be in exceptionally good agreement.

Key Words: Continuous Energy, KENO, SCALE, Monte Carlo

1. INTRODUCTION

KENO V.a and KENO-VI are Monte Carlo codes that solve the multigroup form of the Boltzmann transport equation. These codes are part of the SCALE[1] code system and are used for performing criticality calculations for systems with fissionable material. In general, continuous-energy Monte Carlo methods are preferred over multigroup methods because the continuous energy treatment, based evaluated data libraries such as ENDF/B-VI, avoids many of the assumptions inherent in a multigroup treatment. However, continuous-energy treatment is much more demanding in terms of computer storage space for data, memory requirements, and calculation speed.

Continuous-energy versions of both KENO V.a and KENO-VI have been developed at the Oak Ridge National Laboratory and are being extensively tested [2]. These codes utilize continuous energy libraries generated using the latest AMPX cross-section processing system. ENDF/B-VI.7 data for more than 300 nuclides and isotopes have recently been processed through AMPX to generate continuous-energy cross-section data for multiple temperatures. Continuous-energy versions of KENO and these newly generated data have been and are continuing to be tested using various problem sets including sample problems from SCALE and critical benchmark cases.

In this paper, we present results of calculations performed as part of a computational benchmark for the calculation of the Doppler coefficient of reactivity for UO_2 and mixed oxide (MOX) fuel pin cells [3]. The benchmark was established to determine the ability of various code systems, using a variety of data source, to calculate the magnitude of Doppler feedback between hot zero power (HZP) and hot full power (HFP) conditions. In this case, the benchmark is also being used to assess the performance of the KENO codes relative to MCNP calculations.

2. CALCULATIONS

The computational benchmark used in this work sought to determine the Doppler coefficient of reactivity based on eigenvalue calculations performed with fuel temperatures of 600K (HZP) and 900K (HFP). Clad, gap, and moderator temperatures were fixed at 600K for both states for the purpose of this benchmark. The pin cell configuration consisted of a simple infinite-lattice pin-cell with a helium-filled gas gap, zirconium cladding, and borated water as moderator. Three different fuel mixtures were evaluated to assess the impact of plutonium content in MOX fuels relative to UO_2. For the UO_2 pin cell, calculations were performed for ^{235}U enrichments ranging from natural (0.71 wt %) to 5 wt %. Two MOX configurations were also evaluated, for different plutonium vectors. The first set consisted of natural uranium blended with a plutonium vector characteristic of weapons-grade fuel, with plutonium mass fractions varying from 1 to 8 wt %. The second set of MOX fuels were based on a conceptual UO_2 recycle plutonium vector, with plutonium mixed with natural uranium for 1 to 6 wt. % plutonium.

Calculations were set up and run for both KENO V.a and KENO-VI in continuous energy mode, for all benchmark fuel specifications, at both HZP and HFP conditions. Doppler coefficients were calculated from the HZP and HFP eigenvalues as:

$$C_{Doppler} = \frac{\left(\frac{1}{k_{eff,HZP}} - \frac{1}{k_{eff,HFP}} \right)}{\Delta T_{fuel}} \tag{1}$$

For all cases, ΔT_{fuel} was 300K. All calculations were run with 2700 generations, with 2000 neutrons per generation, and the first 200 generations skipped.

3. RESULTS

Eigenvalue results for KENO V.a and KENO-VI calculations were found to be statistically identical. Doppler coefficients show some variability, however, those variations are due to the stochastic uncertainty in the eigenvalues. The behavior of the Doppler should in fact be a smoothly varying trend. As an independent check, results were compared to MCNP calculations for the same benchmark [4]. All calculations were performed using ENDF/B-VI data. Figures 1-3 compare the results of the three codes, plotting the Doppler coefficient as a function of ^{235}U enrichment (Fig. 1) and Pu content (Figs 2 and 3). These results show exceptional agreement between the three methods. Note however that a small but clear bias is observed between MCNP and KENO results; this bias is likely due to differences in data but will warrant further study.

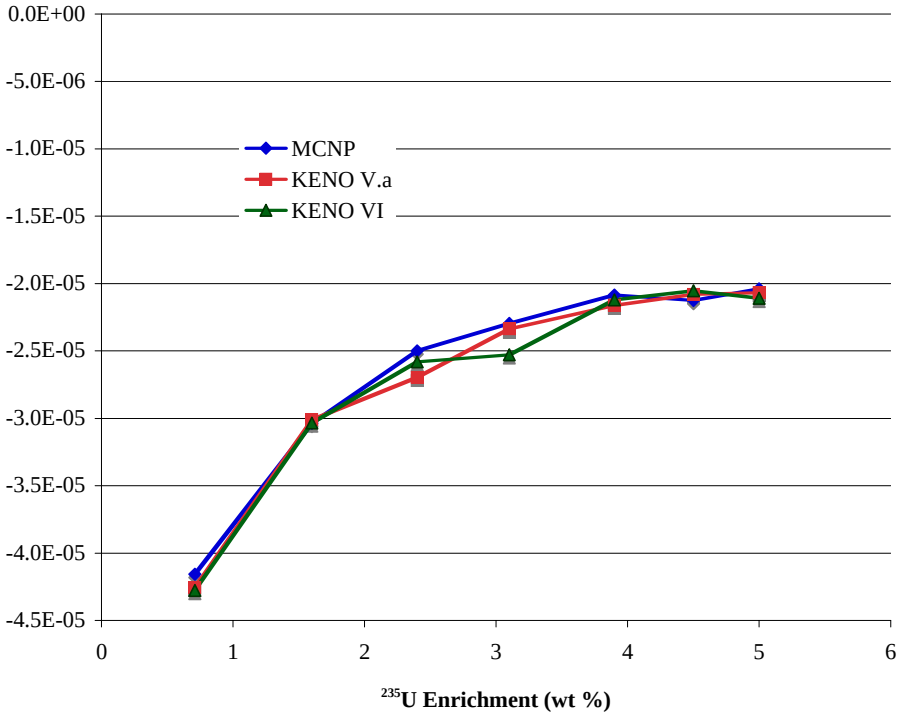

Figure 1. Doppler coefficents calculated for UO_2 fuel.

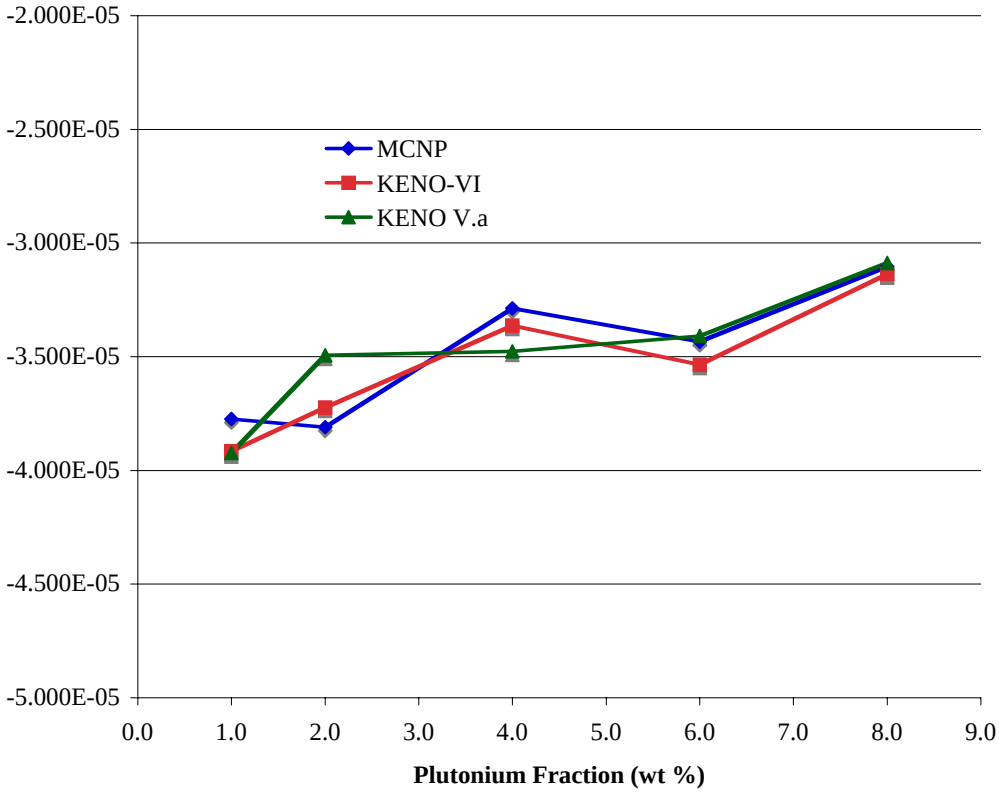

Figure 2. Doppler coefficients calculated for weapons-grade MOX fuel.

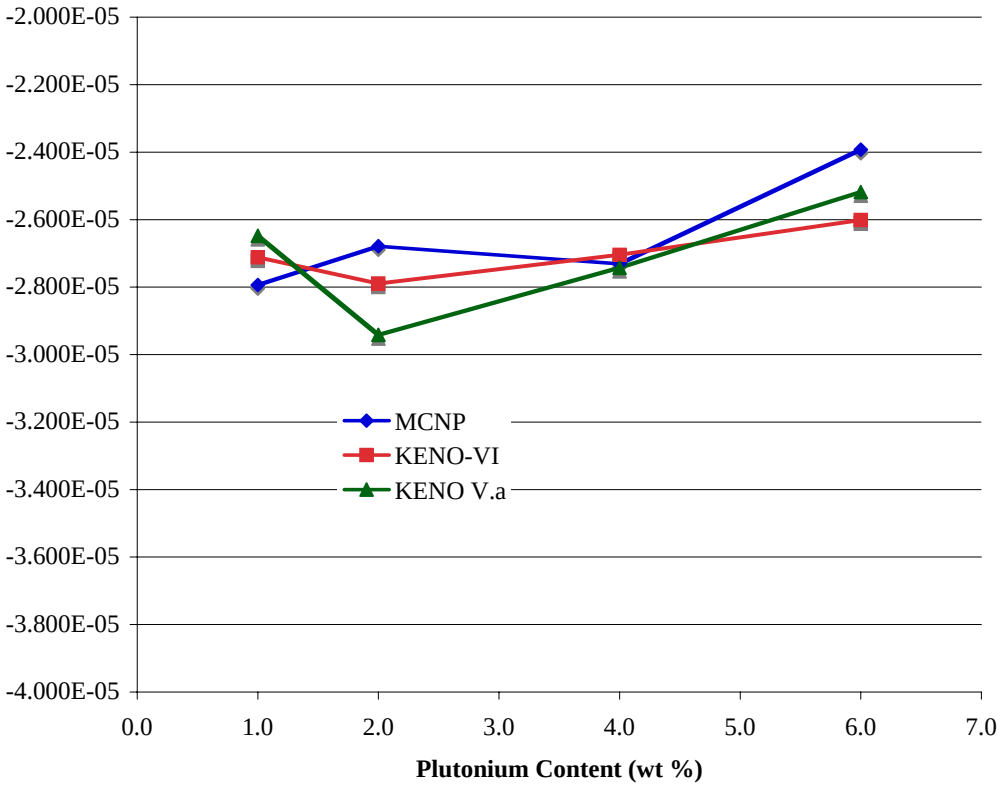

Figure 3. Doppler coefficients calculated for recycle-grade MOX fuel.

4. CONCLUSIONS

Although still under development, both KENO V.a and KENO-VI appear to perform well relative to MCNP for this benchmark suite when run in continuous energy mode. Earlier studies have shown similar behavior for other benchmarks and critical experiments. Completion and publication of the entire set of benchmark results will provide a wider range of results for comparison, from which additional conclusions may be drawn. Future work relative to this benchmark will include results from KENO V.a and KENO-VI in multigroup mode, as well as deterministic results from NEWT calculations.

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