SCALE Continuous-Energy Monte Carlo Depletion with Parallel KENO in TRITON*

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INTRODUCTION

The TRITON sequence of the SCALE code system[1] is a powerful and robust tool for performing multigroup (MG) reactor physics analysis using either the 2-D deterministic solver NEWT or the 3-D Monte Carlo transport code KENO. However, as with all MG codes, the accuracy of the results depends on the accuracy of the MG cross sections that are generated and/or used. While SCALE resonance self-shielding modules provide rigorous resonance self-shielding, they are based on 1-D models and therefore 2-D or 3-D effects such as heterogeneity of the lattice structures may render final MG cross sections inaccurate. Another potential drawback to MG Monte Carlo depletion is the need to perform resonance self-shielding calculations at each depletion step for each fuel segment that is being depleted. The CPU time and memory required for self-shielding calculations can often eclipse the resources needed for the Monte Carlo transport. This summary presents the results of the new continuous-energy (CE) calculation mode in TRITON. With the new capability, accurate reactor physics analyses can be performed for all types of systems using the SCALE Monte Carlo code KENO as the CE transport solver. In addition, transport calculations can be performed in parallel mode on multiple processors.

METHOD

When TRITON is executed in the MG mode, KENO is used to compute the fluxes, which are then folded with the cross sections to compute the reaction rates. In the CE mode, KENO is used to compute the fluxes as well as the cross sections by tallying the reaction rates and then dividing by the computed fluxes. The few-group (MG) cross sections that are computed this way are more accurate than those calculated using resonance self-shielding tools in SCALE. Level of accuracy, of course, depends on the number of histories that are used in the Monte Carlo simulations. The computed few-group cross sections and fluxes are used in the ORIGEN depletion module.

For systems with complicated geometry or many nuclides, the time needed to accurately compute the fluxes and nuclide cross sections could be prohibitively long. Therefore, a parallel version of KENO has been adapted and used in the TRITON calculations.

MAGNOX REACTOR

The CE mode TRITON depletion capability has been tested against the measured values from the Magnox Reactor.[2] The Magnox (an alloy of magnesium) gas-cooled reactor model that was used in this study is based on the Calder Hall Magnox Reactor. The Calder Hall design has 112 square graphite blocks in a horizontal plane forming a rough circular prism that measures approximately 1077 cm across the corners. The structure is surrounded by additional graphite as a reflector. The design parameters for the Calder Hall Reactor are listed in Table I. In the KENO model, the reactor has been simplified to contain an infinite array of cuboidal blocks with cylindrical fuel rods. Fuel, Magnox cladding, and void radii are 1.461 cm, 2.040 cm, and 4.849 cm, respectively. Each block is 20.32 cm wide and modeled to be infinitely long. This approximation is not expected to have any effect on the depletion results as performed for this study. Note that ideally one would divide the reactor into axial regions to capture the axial power distribution. However, since the axial location of the measured sample data is not known, there is no need for such detail in the model.

Table I. Design Parameters for Magnox Reactor

Parameter	**Calder Hall**
Fuel density	17.98 g/cc
Fuel radius	1.461 cm
Clad radius	2.04 cm
Coolant channel radius	4.849 cm
Coolant temperature	650 K
Fuel material	Natural U metal
Control rod hole radius	8.25 cm
Clad material	Mg (1% Al, 0.05% Be)
Clad density	1.65 g/cc
Moderator density	1.628 g/cc
Moderator temperature	650 K
Fuel pin pitch	20.32 cm
Coolant material	CO_2
Coolant pressure	10–27 bar
Typical power rating	1.5–2.0 MW(th)/t
Typical fuel burnup	4500 MW (th)d/t
Maximum fuel burnup	9000 MW (th)d/t

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CROSS-SECTION LIBRARY

The CE cross-section libraries that are distributed with SCALE do not contain cross sections for reactions such as (n,p), (n,d), (n,α), etc., as they are not used for Monte Carlo transport nor are they used in processing with CENTRM/PMC to generate a problem-dependent MG library. However, some of these reactions contribute significantly to the capture reaction rates. Examples are (n,α) reaction cross sections for ^{16}O and ^{10}B. Therefore, a new CE cross-section library with all available reactions has been generated for testing and use with TRITON in CE mode. CE mode calculations are triggered by specifying a CE cross-section library. The results presented in this paper are obtained using the newly generated library that is based on the ENDF/B-VII Release 0 evaluations.

RESULTS

The ratios of $^{236}U/^{235}U$ and $^{240}Pu/^{239}Pu$ at various burnup levels are shown in Fig. 1 and Fig. 2, respectively. The measured values are based on four different samples at 3323, 6714, 7000, and 9154 MWd/t corresponding to complete cross sections of fuel and cladding cut from the center of each fuel element.[2,3] All samples were taken from fuel elements furthest removed from the control rods and were assumed to have been irradiated at a constant rating. However, the rating of the last sample (9154MWd/t) was reduced by 7% after derating of the reactor from which it was taken. CE and MG values for the $^{236}U/^{235}U$ ratio are in excellent agreement with the measured values for all but one sample burnup value. Looking at the trend of measured values, it appears the third sample corresponding to the burnup level of 7000 MWd/MTIHM falls clearly outside of the trend shown by the other three.

For the $^{240}Pu/^{239}Pu$ ratio, CE overestimates the measured values by as much as 5% for the lowest three sample burnups. Again, a visual inspection of the measured values shows the fourth value is outside the apparent trend established by the other three. For that fourth sample value, both CE and MG values deviate considerably from the measured value.

The ratio of total plutonium to uranium (by weight) is shown in Fig. 3 for measured and CE and MG mode calculations. Reported uncertainties for the measured values are on the order of 1%. CE mode TRITON results show excellent agreement with the measured values for all but the third sample, while MG mode TRITON results slightly overestimate the ratio.

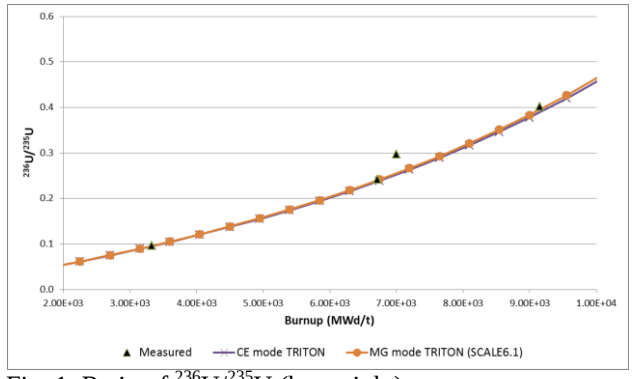

Fig. 1. Ratio of $^{236}U/^{235}U$ (by weight).

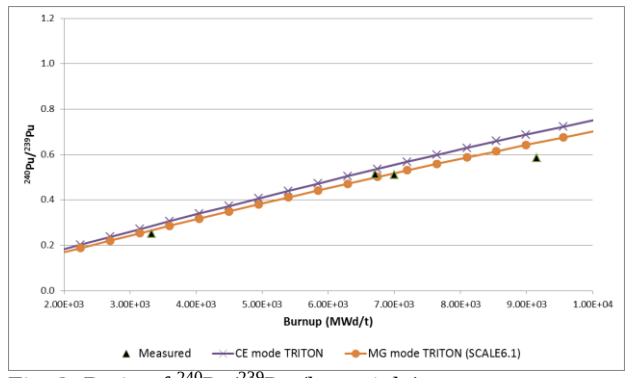

Fig. 2. Ratio of $^{240}Pu/^{239}Pu$ (by weight).

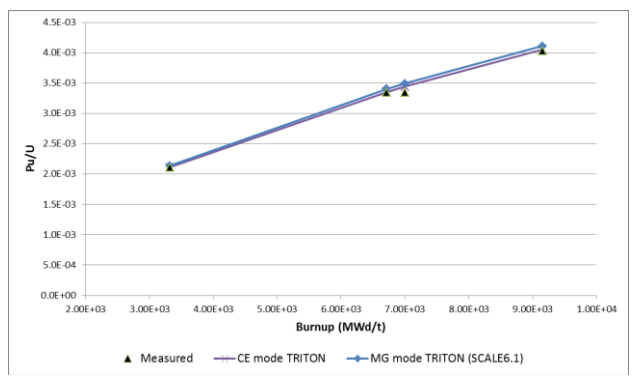

Fig. 3. Ratio of total Pu to total U (by weight).

Figures 4–6 show parallel performance of KENO as used in CE mode TRITON. Here, it can be observed that speedup increases very rapidly as a function of the number of processors. The parallel performance of KENO is very good up to eight processors, greater than 93%. The parallel performance starts diminishing as a function of increased number of processors but is still above 80% when using up to 20 processors.

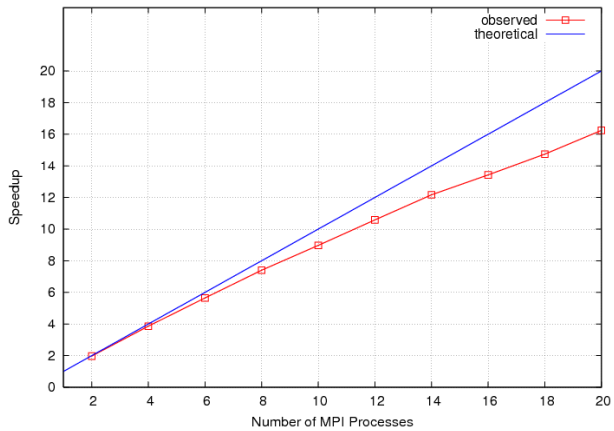

Fig. 4. Speedup for parallel (MPI) KENO calculations.

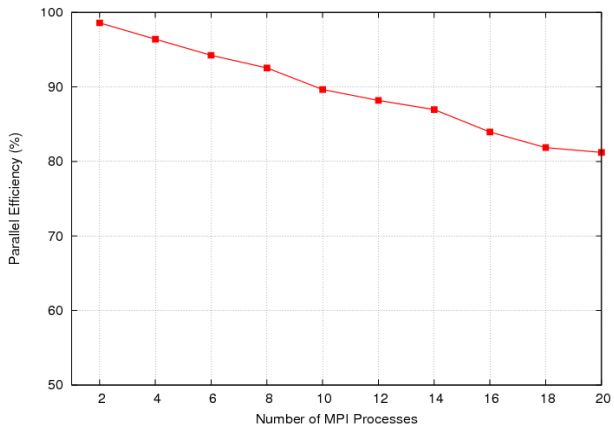

Fig. 5. Parallel efficiency of KENO in CE TRITON.

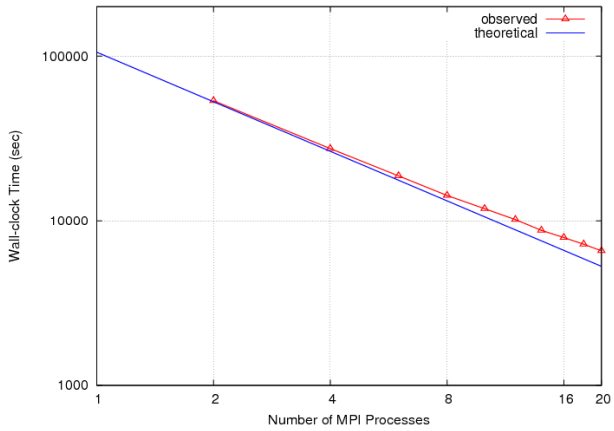

Fig. 6. Computational time as a function of number of processors.

CONCLUSIONS

The SCALE TRITON sequence has been upgraded to allow CE mode calculations. The calculated nuclide concentrations generally show very good agreement with measured data. Parallel mode Monte Carlo transport calculations exhibit very good speedup for the depletion problem shown in this paper. This CE Monte Carlo depletion capability will be released in SCALE 6.2.

REFERENCES

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