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Optimization of a Monte Carlo Model of the Transient Reactor Test Facility

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INTRODUCTION

The ultimate goal of modeling and simulation is to obtain reasonable answers to problems that don't have representations which can be easily evaluated while minimizing the amount of computational resources. With the advances during the last twenty years of large scale computing centers, researchers have had the ability to create a multitude of tools to minimize the number of approximations necessary when modeling a system. The tremendous power of these centers requires the user to possess an immense amount of knowledge to optimize the models for accuracy and efficiency.

Research reactors require that the neutron flux be well characterized so that the flux in a given location or the power delivered to the target in an experiment center can be accurately determined.

DESCRIPTION OF TREAT

The Transient REActor Test facility (TREAT) at Idaho National Laboratory (INL) was originally intended to allow rapid energy deposition within mock-ups of reactor fuel elements utilizing a short high-energy neutron surge created because of a forced transient in the reactor.[1] The experiments were performed in a highly graphite moderated environment so as not to damage the core itself. The fuel elements in TREAT are 10.0584 cm squared by 122.2375 cm long with 1.5875 cm chamfered corners, as seen in Figure 1 with a larger example in Figure 2, creating a unique octagon shaped element which allows the air coolant to flow around the mostly graphite fuel with highly enriched (93.1%) UO_2 homogeneously dispersed within the element, which has a total length of 247.65 cm. The fuel is encased in a Zircalloy-3 can and capped with graphite reflectors on the top and bottom encased in 6063-aluminum. The fuel elements are shown in red in Figure 1.

The 20 control elements in TREAT are identical in size to the fuel elements except they contain a 4.445 cm outer radius Zircaloy-2 tube that contains the carbon steel tube packed with B_4C powder of length 152.4 cm. These control elements are broken up into three groups: 4 Compensation Rods, 8 Control/Shutdown Rods, 8 Transient Rods. The Control/Shutdown Rods are used at the end of the transient to shut down the reactor and end the experiment. The Compensation Rods are used to maintain the reactivity of the core during transient operation, and the Transient Rods are there to initiate transient conditions during operation through their movement.

TREAT is currently being reactivated after 20 years in fueled standby mode to be able to conduct new transient experiments with the goal of assessing Accident Tolerant Fuel (ATF) for LWR.

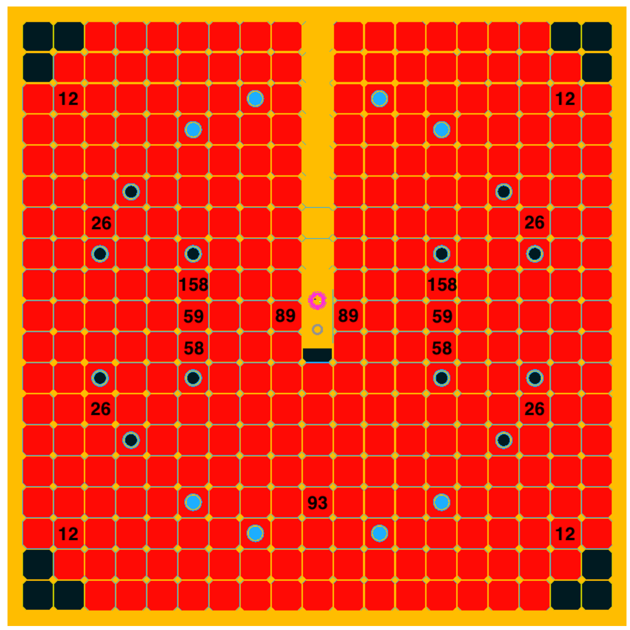

Fig. 1. TREAT Core with Reflector Omitted and the Locations of Evaluated Units Marked with the Unit Number.

FLUX CALCULATIONS

Using a custom-made input generator based on the temperature-limited transients (2855, 2856, and 2857) performed during the M8CAL[2] experiment, TREAT models were created for the 2856 experiment with varying numbers of radial divisions (3, 7, 11, 15, and 19) and a constant number of axial regions (3). These inputs were then run through KENO[3] with 10,000 and 100,000 neutrons per generation with 2,000 active generations being simulated. To assess the importance of number of radial regions and the magnitude of corresponding variation in flux values, various parametric calculations have been performed by varying the number of radial regions per fuel element.

Six fuel elements were selected for analysis from various portions of the reactor including elements close to the control rods, experiment center, and edges as shown in Figure 1. The top-most layer of fuel, equal in height to one-third of the active length, was chosen from each of these elements and examined across all the selected radial divisions to determine when the radial divisions no longer influenced the flux shape. Examples of how the radial divisions of the fuel elements were created can be seen in Figure 2.

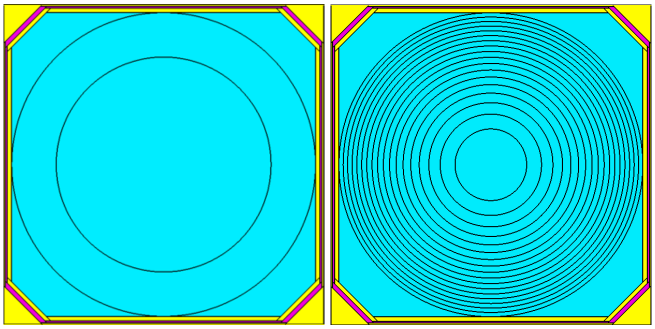

Fig. 2. Example of Chamfered Corner Fuel Element Divided into 3 and 19 Equal Volume Radial Regions.

The point when the flux stopped changing as a function of the number of radial divisions was determined by normalizing the flux per unit volume. These normalized fluxes were then plotted against radial distance from the center and examined by inspection and polynomial trend lines to determine when there was no longer a perceptible change.

RESULTS

As can be seen in Figures 3 – 9, the flux profile with 100,000 simulated neutrons per generation has very good agreement across the varying radial divisions, but does become more resolved as the number of radial divisions increases up to a point, as expected. Across all the divisions, the percentage change in the flux from the center of the fuel element to the outermost edge is nearly identical. On average, there is a less than 0.15% difference between the percent changes seen with 3 and 19 radial regions. This low percentage is a testament to the agreement seen in the shape of the flux profile.

Another parameter used by KENO that affects the accuracy of flux profiles is the number of generations as well as the number skipped at the beginning of the simulation. To evaluate these parameters' effects on the flux profile, simulations were conducted using 100,000 neutrons with 2,500 generations with the first 500 skipped and 5,000 generations with the first 3,000 skipped keeping the number of active generations at 2,000. When looking at the percent difference, at an individual region level, the average difference between the two simulations is 0.034%. The simulation with a total of 5,000 generations is not statistically different than the case with 2,500 generations; therefore, it can be concluded that 2,500 total simulated generations produces a very good approximation of the flux profile.

Figures 10 – 15 show the precision of the calculated flux also depends on the number of simulated neutrons per generation, which also stop affecting the flux profile after a certain number since the flux values become sufficiently converged. In Figure 10, there is very little deviation between the curves for 10,000 vs. 100,000 neutrons for 3 radial divisions, but as the number of radial divisions increases in Figures 11 and 12, the uncertainties in the flux values begin to manifest themselves. Figures 13 - 15 show the various flux curves created in three different fuel elements as a function of the number of simulated neutrons. While significant differences can be seen in the flux curves up until 100,000 simulated neutrons, there is very little deviation in the curve after that point, especially in comparison to 1,000,000 simulated neutrons. Thus, the optimum number of radial regions is not a stagnant number but can be seen to have a direct correlation to the number of simulated neutrons, as expected. Therefore, it is concluded that 11 regions with a total of 200 million active histories created by 100,000 simulated neutrons per generation would be needed to capture the "expected" actual flux profile.

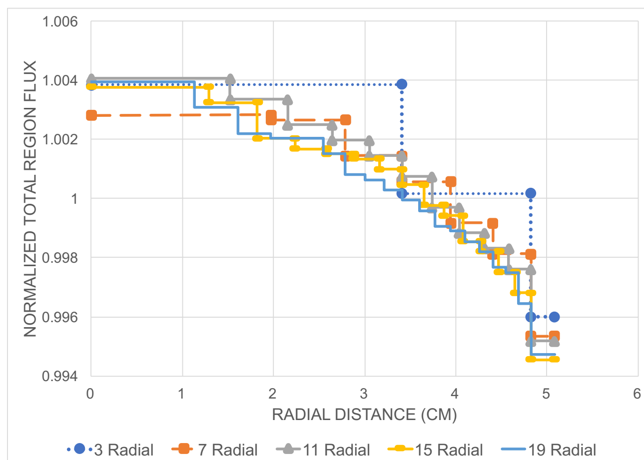

Fig. 3. Normalized Total Region Flux for Unit 12 with 100,000 Neutrons per Generation

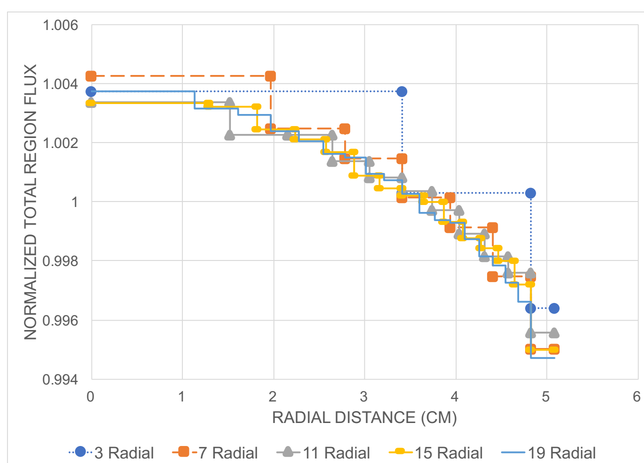

Fig. 4. Normalized Total Region Flux for Unit 26 with 100,000 Neutrons per Generation

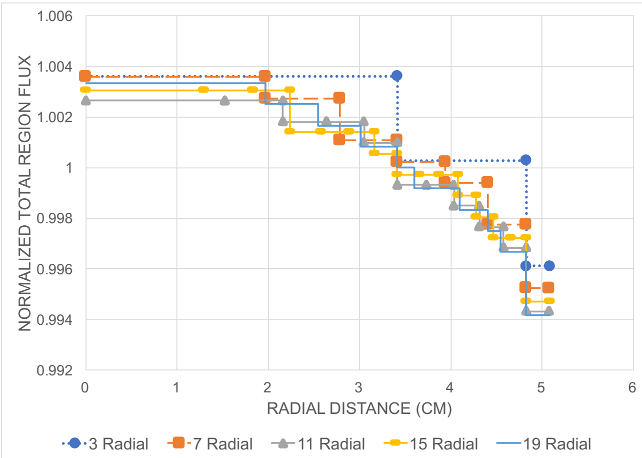

Fig. 5. Normalized Total Region Flux for Unit 58 with 100,000 Neutrons per Generation

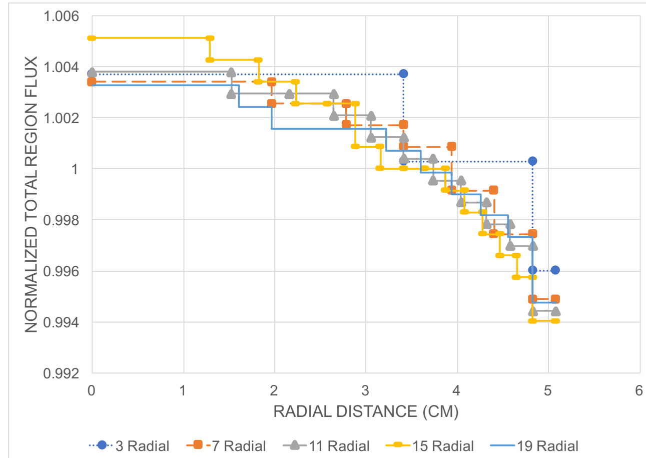

Fig. 6. Normalized Total Region Flux for Unit 59 with 100,000 Neutrons per Generation

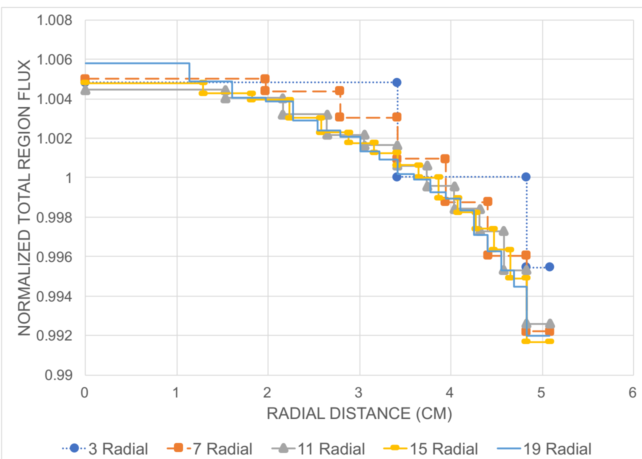

Fig. 7. Normalized Total Region Flux for Unit 89 with 100,000 Neutrons per Generation

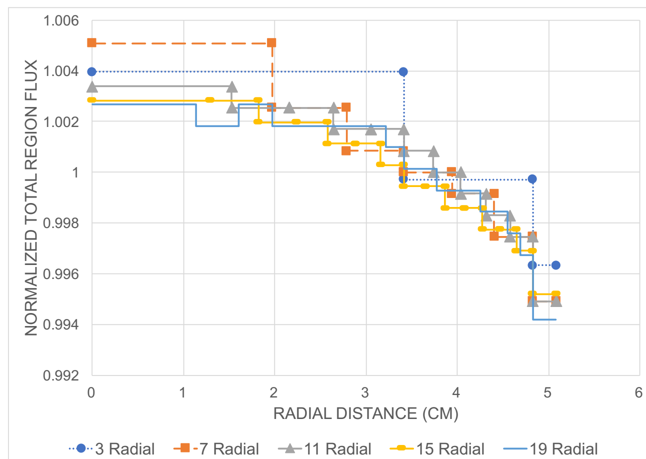

Fig. 8. Normalized Total Region Flux for Unit 93 with 100,000 Neutrons per Generation

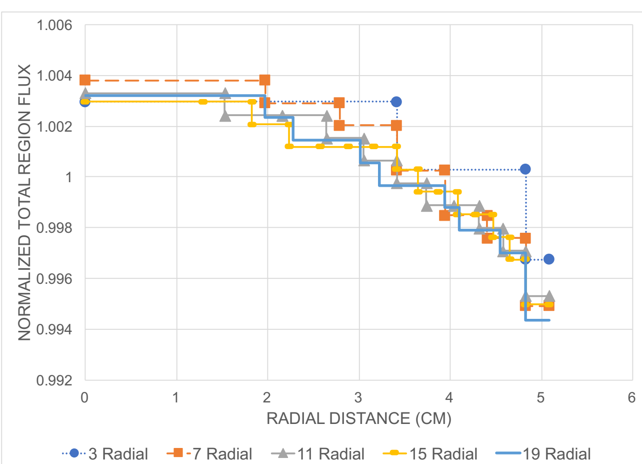

Fig. 9. Normalized Total Region Flux for Unit 158 with 100,000 Neutrons per Generation

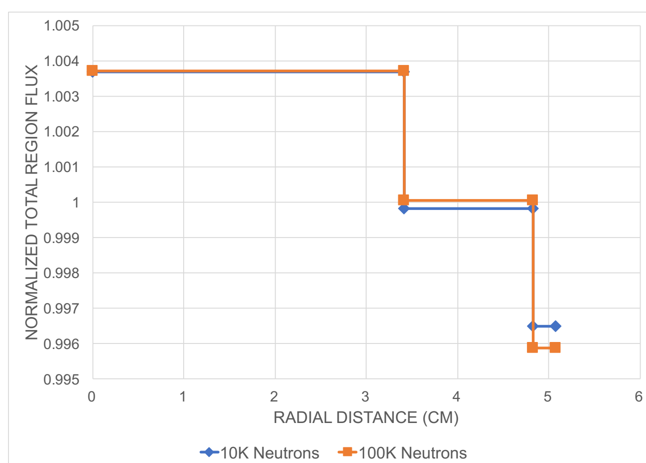

Fig. 10. Normalized Total Region Flux for Unit 12 Comparing 10,000 to 100,000 Neutrons per Generation for 3 Radial Divisions

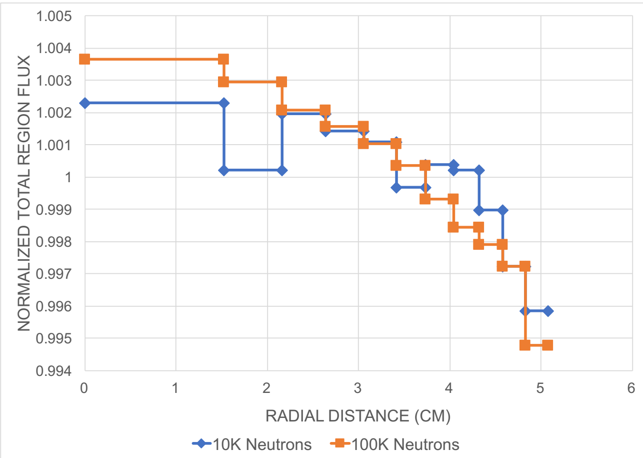

Fig. 11. Normalized Total Region Flux for Unit 12 Comparing 10,000 to 100,000 Neutrons per Generation for 11 Radial Divisions

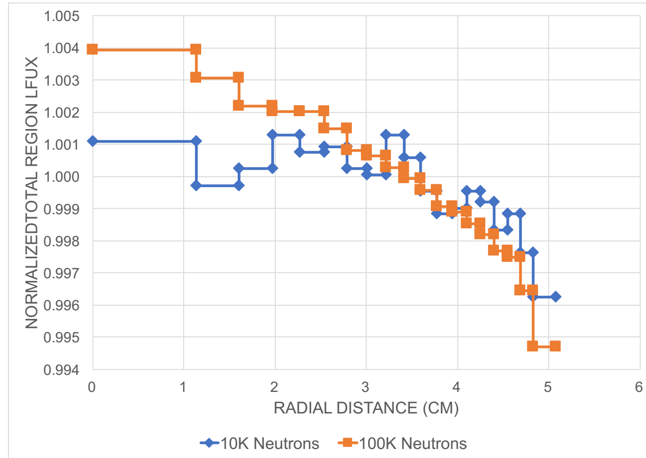

Fig. 12. Normalized Total Region Flux for Unit 12 Comparing 10,000 to 100,000 Neutrons per Generation for 19 Radial Divisions

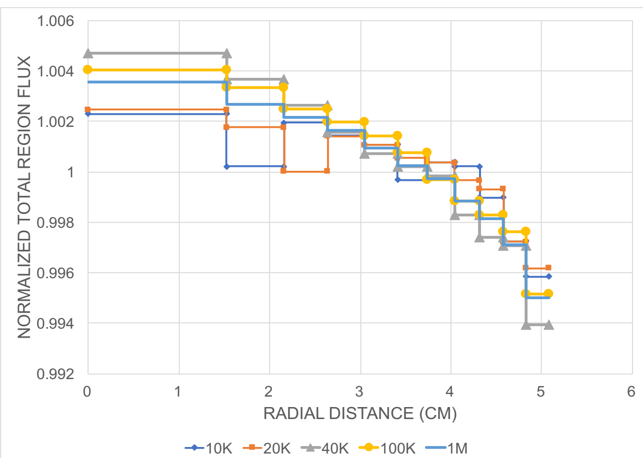

Fig. 13. Normalized Total Region Flux for Unit 12 Comparing 10K, 20K, 40K, 100K, and 1M Neutrons per Generation for 11 Radial Divisions

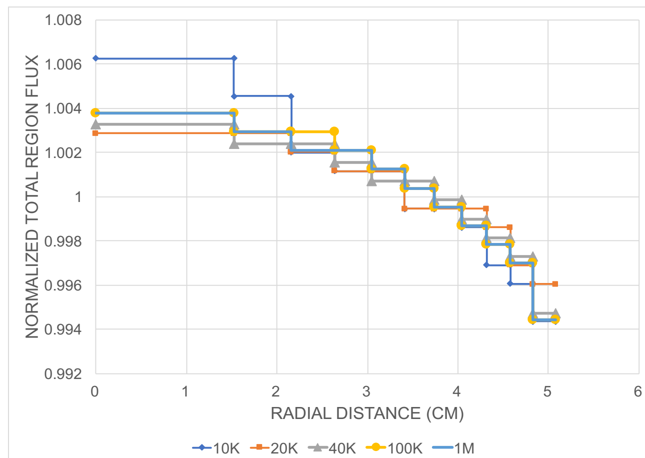

Fig. 14. Normalized Total Region Flux for Unit 59 Comparing 10K, 20K, 40K, 100K, and 1M Neutrons per Generation for 11 Radial Divisions

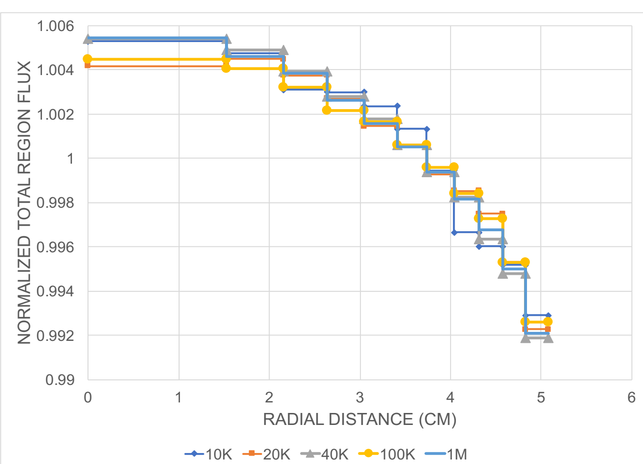

Fig. 15. Normalized Total Region Flux for Unit 89 Comparing 10K, 20K, 40K, 100K, and 1M Neutrons per Generation for 11 Radial Divisions

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