Analysis of Burnup Effects on Reactor Control Strategies T. J. Harrison[1], A. L. Qualls[2], [1]Oak Ridge National Laboratory, 1 Bethel Valley Rd, Oak Ridge, TN 37831 harrisontj1@ornl.gov, [2]Oak Ridge National Laboratory, 1 Bethel Valley Rd, Oak Ridge, TN 37831 quallsal@ornl.gov

Introduction: Reactor control strategy optimization depends on precise calculation of burnup and reflector effects on control element worth. Although most proposed space applications of fission power reactors use small, fast-spectrum cores, the flux profile is not completely flat axially or radially. This affects the fission density and power profile, which in turn affects the relative worth of the control elements.

This paper describes calculational methods to include burnup effects to better optimize the control strategy.

Available Methods: While useful for some transient analyses, point-kinetics models cannot capture the axial and radial variation in fuel composition through lifetime that arises from a non-flat flux profile. Similarly, simple infinite pin-cell models incorrectly assume an infinitely-large reactor.

A static 3-dimensional model of the reactor has significant advantages in that the k_{eff} for a given set of parameters (temperature, boundary conditions, material compositions) can be calculated, and the critical condition can be found by altering any variable parameters, e.g., moving control elements.

Along with calculating the k_{eff} for the configuration, KENO-VI in SCALE 6 [1] can calculate the flux and fission densities in a given volume for a static 3-d model. These are normalized to a single fission neutron; thus, with total fission rate based on a known power, the flux and fission rate in a given volume can be calculated. This can directly show the effects of changing the location or orientation of a control element. Figure 1 shows a KENO-VI model of a sample reactor. In the figure, the core is a hexagonal array of fuel pins with six control drums surrounding it. Each drum has an absorber on the outer surface (green).

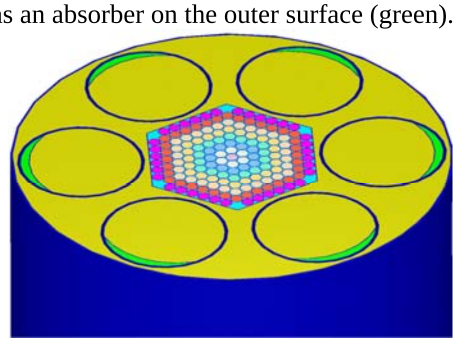

Figure 1 – Sample Reactor with All Drums Out

Note that each ring of fuel pins is a different color; this demonstrates the ability to follow different fuel assignments to see the radial effects of the control drums. While this is useful information, it does not yet capture the effects of burnup. This can be accomplished by using TRITON in SCALE 6 [2].

Using TRITON, a KENO-VI model can be burnt through lifetime with a stated specific power. The radial and axial profiles can be found by using different fuel material assignments.

Proposed Method: The axial and radial profiles can be calculated in several ways. The most straightforward assigns a unique material to each pin at each axial location. For very small reactors, this would be easily managed. However, the sample reactor in Figure 1 has 163 fuel pins; this is a prohibitively large number of materials before assigning any axial definitions.

The next approach assigns a single material to the full length of each fuel pin and assumes a flat axial profile in each pin. Again, this is a large number of materials.

Instead, an alternative approach assigns a single material to the full length of a fuel pin, and then assumes the pins in each ring are identical. This is the method shown in Figure 1. This reactor has 7 rings around a central pin; thus, there are 8 unique materials to follow – a number more manageable than 163.

A similar approach assigns a single material at each axial slice (of a given height) in all pins. This assumes a flat radial profile at each axial location. This is shown in Figure 2. The red on the top and bottom is BeO reflector. The use of a mirror boundary condition at the midplane would allow either the use of half the number of unique materials or greater refinement in the axial direction. However, it is useful to keep the reactor model at full-size for other reasons to be discussed later.

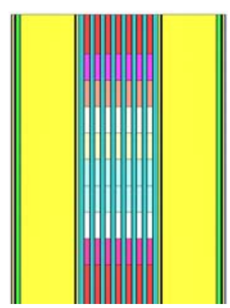

Figure 2 – Axial Slices

This model was burnt for 8 years at 2.0263 MWt/MTHM (approximately 185 kWt for this reactor) [3] with the drums rotated out (see Figure 1). Table 1 shows the comparison between the beginning-of-life (BOL) and end-of-life (EOL) nuclide number densities of fuel for the center pin and outer ring; Table 2 shows the comparison between the BOL and EOL number densities for the mid-plane and top.

Table 1 – Radial Compositions (#/b*cm)

	BOL	EOL Center	EOL Outer
U-235	2.16095E-02	2.14578E-02	2.13520E-02
U-238	1.44538E-03	1.44355E-03	1.44196E-03
U-236	0	2.12441E-05	5.34907E-05
Pu-239	0	8.60829E-07	2.65204E-06

The table shows that the center fuel pin burned or converted 0.71% of its U-235 and 0.13% of its U-238, while the outer ring burned or converted 1.2% of its U-235 and 0.24% of its U-238. Further, the outer ring produced 3x the Pu-239 and 2.5x the U-236 as the center pin. This demonstrates a significant radial effect.

Table 2 – Axial Compositions (#/b*cm)

	BOL	EOL Center	EOL Top
U-235	2.16095E-02	2.13970E-02	2.14736E-02
U-238	1.44538E-03	1.44270E-03	1.44362E-03
U-236	0	3.67313E-05	2.53438E-05
Pu-239	0	1.65253E-06	1.19249E-06

The table shows that the center slice burned or converted 0.99% of its U-235 and 0.19% of its U-238, while the top slice burned or converted 0.63% of its U-235 and 0.12% of its U-238. Further, the center slice produced 1.39x the Pu-239 and 1.45x the U-236. This demonstrates a significant axial effect.

This approach is taken further in the analysis below. Figures 3 and 4 show configurations with one drum in (Figure 3) and one drum out (Figure 4). The first represents a control strategy: single drum motion. The second represents accident analysis: single drum stuck out.

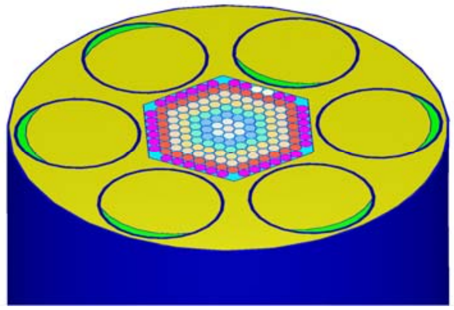

Figure 3 – Sample Reactor with One Drum In

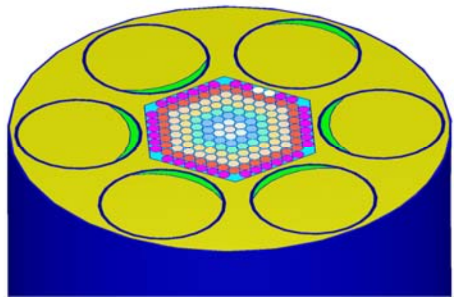

Figure 4 – Sample Reactor with One Drum Out

Both scenarios can depend on burnup-dependent material definitions within the fuel pins. This work is currently in progress.

Future Work: Future work will generate a "wrapper" script written around the TRITON inputs and outputs. This script will move control drums to maintain criticality through burnup and analyze temperature effects of decreasing reactivity. This is the main driver for maintaining a full-core model.

References:

[1] Hollenbach, D. F., et al. (2009) *KENO-VI: A General Quadratic Version of the KENO Program*

[2] DeHart, D. M., (2009) *TRITON: A Two-dimensional Transport and Depletion Module for Characterization of Spent Nuclear Fuel*

[3] Poston, D. I., et al. (2009) *Reference Reactor Module Design for NASA's Lunar Fission Surface Power System*