University of Michigan adds Depletion Capability to MPACT for VERA-CS

MPACT is a three-dimensional (3-D) whole core transport code being developed by the University of Michigan and ORNL for the CASL VERA toolset. MPACT's integral transport solution is obtained by means of the method of characteristics (MOC) that employs discrete ray tracing for the radial direction and diffusion theory for the axial direction. In order to allow the analysis of commercial power reactors, the radiation transport code must be capable of describing the depletion of the nuclides in the reactor core; thus, a depletion module has been integrated into MPACT by University of Michigan researchers Ben Collins, Ang Zhu, Brendan Kochunas, and Tom Downar.

The numerical methods to implement nuclide point depletion and integrate a time dependent application within MPACT are based on those utilized by SCALE/ORIGEN-S [Ref. 1]. The module uses a hybrid approach that combines the matrix exponential method with Bateman equations for short-lived nuclides to obtain stable numerical solutions for all nuclides. This method eliminates the need to use linearized chains. The depletion of the nuclides is calculated for all regions and material combinations for each state point evaluated, and must therefore be extremely computationally efficient.

The exponential matrix method and the Bateman solutions complement each other in the approach used; the exponential matrix method is quite accurate when the transition coefficients are small but has problems when including large rate constants; conversely the Bateman solution has some numerical difficulties for extremely small rate constants, but is stable and accurate for large rate constants.

The point depletion calculation assumes a constant flux. To correct for this, MPACT adopts two commonly used techniques: the predictor-corrector and sub-step methods. The predictor-corrector method calculates the depletion at t2 using a 1-group flux and cross section at t1, produces a new predicted 1-group flux, cross section, and depletion using the predicted t2 concentration, and then averages the two. Once the t2 nuclides are obtained, a transport calculation is performed to obtain the steady state flux at t2. The sub-step method is applied to perform multiple depletion calculations between transport calculations. Since the depletion calculation typically takes less time than the transport calculation this will often save computational time. Mathematically this is the equivalent of applying a time dependent normalization factor with a constant eigenvector representing the flux distribution to retain constant core power over a time step.

A separate depletion library was developed for MPACT based on the ORIGEN-S library which provides the basic decay constants and fission yields, as well as the 3-group cross-sections which are used for the depletion of the isotopes not contained in the MPACT multi-group transport library.

Prior to releasing the code update, the team ran several international benchmark problems to verify and validate the depletion routines implemented in MPACT. Additionally, the team ran several of CASL's Progression Problems. Figure 1 illustrates the 2D mid-core planar power distribution associated with the initial core loading and the depleted core for Watts Bar unit 1 Cycle 1. Comparisons with continuous energy Monte Carlo [Ref. 2] results indicate that

MPACT provides an accurate result of the 2D power distribution with an eigenvalue difference of 133 pcm, an RMS pin difference of 0.295%, and a maximum pin difference of 0.894%. The 2D core was depleted at the average temperatures and densities used in the 3D model and the rated core thermal power was divided by the axial height of the fuel to obtain the power for the 2D core depletion of 9.33 MW. The expected radial shifts in the power distribution are observed in the depletion of the 2D core; the higher power locations in the core observed at the beginning of the cycle are reduced by the end of the cycle, with the power distribution flattening.

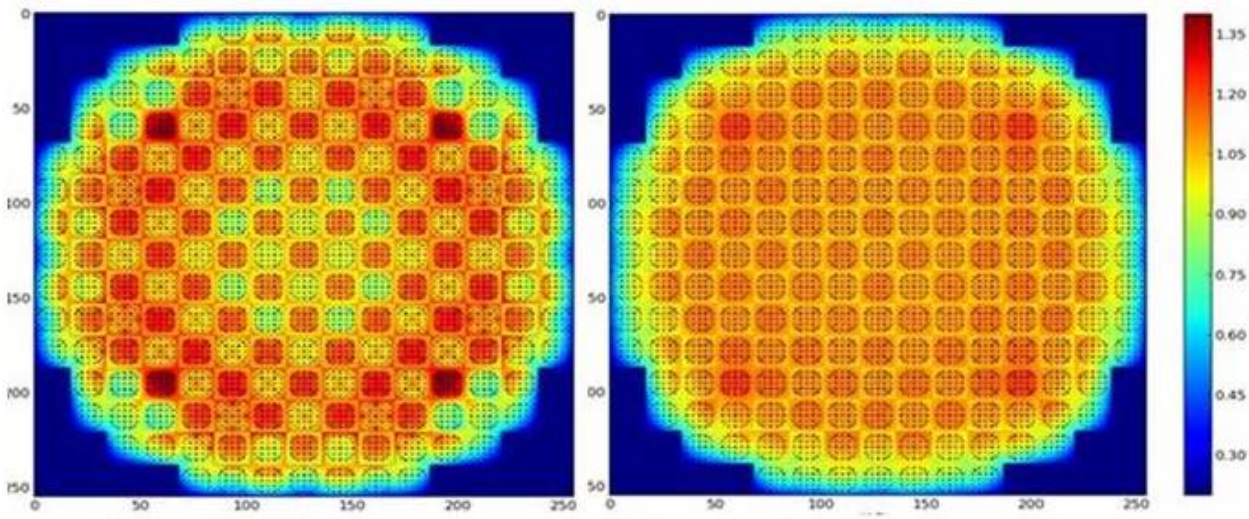

Figure 1 2D Core Power Distribution, Beginning (left_ and End (right of Cycle

Currently, the depletion subroutine in MPACT assumes symmetric radial depletion of a fuel rod. The modification to azimuthally vary the depletion is expected to be relatively simple, but will considerably increase memory requirements. This and other capability enhancements are being considered for the next release of MPACT, scheduled for later this year. For more information on this work, see CASL-U-2013-0276-001.

Several works are referenced in the full CASL report; those works referred to in this article include:

[1] Y. Gokhan, K Clarno, I. Gauld, J. Galloway. *Modular ORIGEN-S for Multi-physics Code Systems*. International Conference on Mathematics and Computational Methods Applied to Nuclear Science and Engineering (M&C 2011), Rio de Janeiro, RJ, Brazil, May 8-12, 2011, American Nuclear Society.

[2] SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, ORNL/TM-2005039, Version 6, Vols. I - III; see also CCC-750, Radiation Safety Information Computational Center, Oak Ridge National Laboratory , Jan. 2009