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Validation of WIMS-AECL/3DDT Code Package Using the IAEA 10 MW Benchmark Problem for the McMaster Nuclear Reactor Fuel Conversion Analysis

By

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Reactor physics calculations were performed to validate the WIMS-AECL/3DDT reactor physics code package using the IAEA 10 MW benchmark reactor. The objective of this work was to determine suitability of this code package for use in connverting the McMaster Nuclear Reactor from using high enriched uranium (HEU) fuel to low enriched uranium (LEU) fuel. The IAEA 10 MW benchmark reactor was chosen for this work because it is very similar to the MNR and also becasue it was analyzed by several international nuclear laboratories including Argonne National Laboratories (ANL). Also, at our request ANL re-analyzed this reactor using the latest reactor physics codes and cross-section libraries. This enabled us to not only validate the codes but also to validate and fine-tune the methodology used to model the MNR.

WIMS-AECL is a reactor lattice code that is used to generate cell-averaged cross-sections, whereas 3DDT is a three-dimensional diffusion theory code used to calculate reactor parameters such as k_{eff}, flux and power profiles. The IAEA benchmark reactor is a 10 MW MTR type reactor that exists on paper only. The reactor consists of 21 standard fuel assemblies and four control assemblies (control rods were assumed to be fully withdrawn). The core is surrounded by graphite on two sides and water on the other two sides. The IAEA defined all the parameters needed to perform the calculations required to convert the reactor from the use of HEU fuel to LEU fuel. The IAEA recommended that two-dimensional diffusion calculations be performed using a three-group energy structure ($E_1 \geq$ 5.531 keV, 0.625 eV $\leq E_2 <$ 5.531 keV, $E_3 <$ 0.625 eV). In this work three-dimensional diffusion calculations were performed based on the IAEA 3-group energy structure and two other group structures, 10-group and 7-group. The 10-group structure was used to estimate the accuracy of the 3-group structure, and the 7-group structure was used in this work because it was used in the MNR calculations. The 3DDT calculations were performed for a fresh, beginning-of-life (BOL), and end-of-life (EOL) cores for both an HEU core and an LEU core. The LEU BOL and EOL cores were modeled using the equivalent burnup in MWDs of the corresponding HEU cores.

Several WIMS-AECL models were developed to explicitly represent the various regions in the reactor. The active fuel lattice was modeled using a three-region unit cell, which consisted of fuel meat, clad, and water coolant. This fuel representation was used to model the fuel in both the standard and control fuel assemblies. WIMS-AECL models were also developed to represent the control regions, the graphite and water regions. The volume fractions of the cell constituents were preserved in all the WIMS-AECL models. The WIMS-AECL calculations were performed using the full energy-group structure (89-group) of the main cross-section library. The cell-averaged cross-sections were then collapsed to the 3-group, 7-group, and 10-group energy structures used in the global diffusion calculations. The 3DDT reactor model was obtained by dividing the core into 42 x-meshes, 46 y-meshes, and 40 z-meshes (20 meshes in the active core region and axial symmetry was assumed). The average mesh size in the active core region was 1.35 cm in the x-direction, 1.575 cm in the y-direction, and 1.53 cm in the z-direction.

The 3DDT calculated k_{eff} for the HEU core compared very well against those calculated by ANL for the fresh, BOL, and EOL cores with the difference being on average about 0.6 %Δk/k. In the case of the LEU core, the 3DDT calculated k_{eff} for the fresh core, BOL core with equivalent burnup, and EOL core with equivalent burnup were within 1.1 % Δk/k of those reported by ANL.

The 3DDT calculated neutron flux and bundle power for the HEU core as well as the LEU core were within 5% of those reported by ANL. The ANL results were based on ANL79-DIF2D, ANL79-VIM, ANL98-DIF3D, and ANL98-MCNP calculations. The overall results of this work show that the tools and methodology used are sufficiently adequate for performing fuel conversion calculations for pool-type, light-water moderated research reactors which use MTR-type fuel such as the MNR.