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Control rod calibration simulation using Monte Carlo code for the IRT-type research reactor

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ABSTRACT

This paper presents the results of the validation of a research reactor calculation using Monte Carlo code against experimental data. Validation efforts are carried out for two university-based research reactors in Russia: the IRT MEPhI reactor at the National Research Nuclear University MEPhI and the IRT-T reactor at the National Research Tomsk Polytechnic University. Calculations were performed using the continuous energy Monte Carlo code MCU-PTR. Full 3-D models for the IRT MEPhI and IRT-T reactors were developed. Measured critical cases during the control rod calibrations are analyzed in benchmarking studies. A procedure for the comparison of the measured and the calculated control rod worth based on the detailed calibration simulation is proposed.

1. Introduction

Many well-established and recently developed Monte Carlo neutron transport codes are currently used for operation and safety analysis of research reactors. To demonstrate the quality of these codes, the validation against experimental data is necessary. If reactor start-up experimental information is available, a set of critical core configurations with the fresh fuel can be used for the validation (Alloni et al., 2014; Wilson et al., 2010; Villarino et al., 1999). If data on the measurements during reactor commissioning are absent or unreliable, the calculated results are compared with current experimental information for the burnt cores. To support the validation need, a formal qualification process was developed in the framework of the IAEA Coordinated Research Project (CRP) entitled "Innovative Methods in Research Reactor Analysis: Benchmark against Experimental Data on Neutronics and Thermalhydraulic Computational Methods and Tools for Operation and Safety Analysis of Research Reactors" (IAEA, 2008). An extended set of neutronics and thermalhydraulic experimental data for benchmarking analysis of the available codes was gathered and presented. 'In most of the cases, neutronics data include the reactor parameters such as core criticality (k_{eff}, k_{inf}), neutron flux level/shape/profile, neutron flux energy distributions, control rod worth, reactivity effects, reactivity coefficient and some kinetics parameters' (IAEA, 2015). An important part of the neutronics experiments is concerned with the criticality and the control rod (CR) worth. Critical cases during the CR calibrations are analyzed in benchmarking studies (Ferraro and Villarino, 2016; Young et al., 2014; Erasmus et al., 2015). The calibration analysis allows for the assessment of a wide range of critical cases with different shadow effects between the control rods.

Some similar benchmarking efforts are carried out for two university-based research reactors in Russia: the IRT MEPhI reactor at the National Research Nuclear University (NRNU) MEPhI and the IRT-T reactor at the National Research Tomsk Polytechnic University.

Both IRT MEPhI and IRT-T reactors are of the open pool type. The reactors are cooled and moderated by light water and reflected by beryllium. The fuel is IRT-3M tube type with UO_2–Al meat and aluminum as cladding. The nominal power levels of the IRT MEPhI reactor and the IRT-T reactor are 2.5 MW and 6 MW, respectively.

An in–house program, TIGRIS, was used as the reference code to support routine operation by IRT MEPhI staff since 1995 (Shurovskaya et al., 1996). Three-dimensional nodal diffusion TIGRIS code was benchmarked against the IRT MEPhI experimental data (Shchurovskaya and Alferov, 2006). These benchmarking efforts are useful for the current validation of Monte Carlo models

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of the reactor because they help select and estimate experimental data and reduce the number of necessary Monte Carlo calculations.

Full 3-D models for the IRT MEPhI and the IRT-T reactors were developed using MCU-PTR code (Alekseev et al., 2012; Kalugin et al., 2015). Some code-to-code benchmark studies have been performed to compare MCU-PTR code with the other Monte Carlo codes (Alferov et al., 2015). The present work contains the results of the calculations using MCU-PTR code of CR calibration experiments performed at the IRT MEPhI and the IRT-T reactors.

2. Reactor description

2.1. The IRT MEPhI research reactor

The IRT MEPhI pool type research reactor (2.5 MW) first reached criticality in May 1967. The current reactor design began operation in 1975. There are 48 in-core positions for fuel assemblies (FA) and reflector blocks (see Fig. 1a). The lattice pitch is 7.15 cm. Each fuel assembly contains 6 or 8 fuel tubes, which consist of 90% enriched dispersed UO_2–Al fuel in aluminum cladding. The fuel meat is 58 cm high and 0.04 cm thick. The thickness of cladding is 0.05 cm. More detailed specifications of FA can be found in Ryazantsev et al. (1998) and in the benchmark specification (Alferov et al., 2015). The reflector consists of 21 beryllium blocks and 7 aluminum blocks. The reactor has 10 horizontal beam tubes, a graphite thermal column, and vertical irradiation channels in the reflector. There are ten control rods: three groups of shim rods (two rods in the group) named KC-1, KC-2 and KC-3; three scram rods named AZ-1, AZ-2 and AZ-3; and one regulating rod named AR. The control rod consists of an absorber rod of boron carbide in cladding of stainless steel and a follower composed of aluminum. The diameter of the absorber is 2.3 cm. The control rod is placed in the channel in the center of 6-tube FA. The burnup map for one of the routine IRT MEPhI operating cycles selected for the analysis (core configuration #120) is shown in Fig. 1a.

2.2. The IRT-T research reactor

The IRT-T pool type research reactor (6 MW) first reached criticality in July 1967. The current reactor design began operation in 1984. There are 56 in-core positions for fuel assemblies and reflector blocks (see Fig. 1b). The fuel assemblies and control rods are the same as for the IRT MEPhI reactor. The reflector consists of beryllium blocks. The reactor has 10 horizontal beam tubes, a beryllium thermal column, and vertical irradiation channels in the reflector. There are nine control rods: three groups of shim rods (two rods in the group) named KC-1, KC-2 and KC-3; two scram rods named AZ-1 and AZ-2; and one regulating rod named AR. The control rods are placed in the center of 6-tube fuel assemblies except for the regulating rod, which is placed in the center of the beryllium block. The burnup map for the routine IRT-T operating cycle selected for the analysis is shown in Fig. 1b.

3. MCU-PTR models of the IRT MEPhI and the IRT-T

The detailed geometrical models of the IRT MEPhI and the IRT-T reactors were developed using MCU-PTR code (Figs. 2 and 3), including fuel assemblies, reflector blocks, control rods, main structural components, horizontal beam tubes and vertical irradiation channels. Each FA was modeled independently. It was assumed that in the horizontal plane, all fuel tubes of one FA have the same burnup (i.e., they burn as one material). We did not consider the question on the necessity to calculate the burnup for each fuel tube because the fuel assembly orientation in the horizontal plane during reactor refueling is uncontrolled. The sufficient number of axial layers for the burnup calculation was found to be 6 (Radaev and Schurovskaya, 2015).

Beryllium blocks are described as parallelepipeds with dimensions of $69 \times 69 \times 660$ mm. In each beryllium block individual He-3 and Li-6 concentrations are specified. End details of the FA and the reflector blocks are described as a homogeneous mixture of aluminum and water. The control rod is described as a cylinder of boron carbide in the cladding of stainless steel.

Investigations to prove the choice of spatial nodalization for the power density and the burnup distribution calculation were carried out (Radaev and Schurovskaya, 2015).

The burnup distributions for the calculations presented in this paper were obtained from the simulation of the last 7 cycles of operation of the reactors using MCU-PTR code. The initial burnup distributions and He-3 and Li-6 concentrations in the beryllium blocks for these calculations were taken from the previous calculations of the reactors operation history using the diffusion code TIGRIS.

The estimation of the absorber depletion for the IRT MEPhI and the IRT-T was based of the irradiation history of the rod. The loss in reactivity worth due to the absorber depletion was found to be

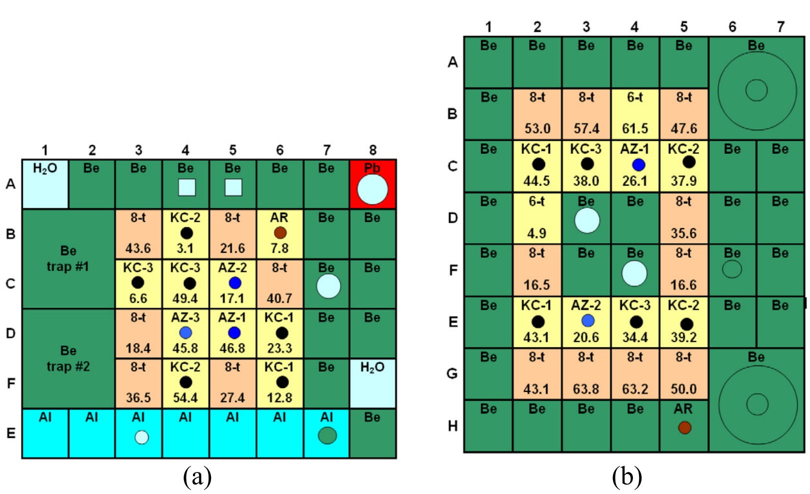

Fig. 1. Reference core diagrams: (a) – IRT MEPhI; (b) – IRT-T. 8-t—8-tube fuel assembly; 6-t—6-tube fuel assembly without CR; AR—6-tube fuel assembly with regulating rod for the IRT MEPhI or beryllium block with regulating rod for the IRT-T; KC-1, KC-2 KC-3—6-tube fuel assembly with the shim rod; AZ-1, AZ-2, AZ-3—6-tube fuel assembly with safety rod; Be—beryllium block; Al—aluminum block; Pb—lead block; H_2O—water. The numbers in the fuel assembly cells are the ^{235}U burnup in %.