Validation of deterministic and Monte Carlo codes for neutronics calculation of the IRT-type research reactor

M V Shchurovskaya, V P Alferov, N I Geraskin and A I Radaev

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), 31 Kashirskoe shosse, 115409 Moscow, Russia

E-mail: mvshchurovskaya@mephi.ru

Abstract. The results of the validation of a research reactor calculation using Monte Carlo and deterministic codes against experimental data and based on code-to-code comparison are presented. The continuous energy Monte Carlo code MCU-PTR and the nodal diffusion-based deterministic code TIGRIS were used for full 3-D calculation of the IRT MEPhI research reactor. The validation included the investigations for the reactor with existing high enriched uranium (HEU, 90 w/o) fuel and low enriched uranium (LEU, 19.7 w/o, U-9%Mo) fuel.

1. Introduction

Monte Carlo neutron transport codes are currently widely used for the operation and safety analysis of research reactors. Diffusion codes are also used, especially for routine core follow calculations. To demonstrate the quality of these codes, the validation against experimental data is necessary. If the special qualification process is developed including detailed description of the experimental data and the test problems, this process can be used simultaneously for the validation of Monte Carlo and diffusion codes. Such approach allows carrying out code-to-code comparison and gives additional information for the analysis. We have developed the validation process for the IRT-type research reactor. The continuous energy Monte Carlo code MCU-PTR [1] and the nodal diffusion-based deterministic code TIGRIS [2] were validated against experimental data of the IRT MEPhI research reactor and on the basis of the comparison with the calculated results obtained using different codes for test problems and real core configurations. The validation included the investigations for the reactor with existing high enriched uranium (HEU, 90 w/o) fuel and low enriched uranium (LEU, 19.7 w/o, U-9%Mo) fuel [3].

2. Validation methodology

MCU-PTR code and TIGRIS code validation included: comparison with the results of the test problems calculation obtained using the other codes; comparison with the results of IRT MEPhI reactor reference cores calculation obtained using the other codes; comparison with the operational measured data of the IRT MEPhI reactor and the results of the calculation of these experiments obtained using the other codes.

The test problems consider simplified configuration of the core and the reflector, only fuel assembly (FA) is described in detail. The test problems have not the IRT MEPhI reactor specific features.

Three reference cores with real geometry of the reflector and experimental channels were considered. The first reference core is IRT MEPhI current core, the other reference cores are the cores with IRT MEPhI current reflector but HEU fuel is replaced with LEU fuel (fresh or with typical burnup). The reference cores and the test problems were used for the comparison with the results calculated using different codes. The calculated results comparison was carried out for the identical fuel isotopic composition.

The comparison with the operational measured data of the IRT MEPhI reactor was based on the modeling of the reactor operation history (burnup process, reloadings, control rod calibrations).

The calculations for the code validation were performed for real and model cores with existing IRT-3M fuel assemblies with HEU fuel as well as for model cores with IRT-3M fuel assemblies with LEU U-9%Mo-Al fuel. Calculated results for both types of fuel show that HEU and LEU FA have similar neutronics parameters and the conclusions made for one type of fuel are correct for another. In the test problems with depletion in the most cases LEU fuel was considered since due to higher plutonium buildup the isotope inventory vs. burnup is more complicated for LEU fuel. In the test problems concerned with control rod (CR) absorber burnup HEU fuel was considered since these test problems simulate the real reactor operation. In the test problems with fresh cores performed for the comparison of the calculations conducted by Monte Carlo codes with different cross-section libraries and diffusion code both HEU and LEU fuel were considered.

3. Models and codes

Full 3-D model for the IRT MEPhI reactor was developed using MCU-PTR code, including fuel assemblies, reflector blocks, control rods, main structural components, horizontal beam tubes and vertical irradiation channels. Investigations to prove the choice of spatial nodalization for the power density and the burnup distribution calculation were carried out [4].

The TIGRIS code is intended for steady-state neutronics calculation and for the burnup calculation of pool-type research reactors using three-dimensional (x-y-z geometry) few group diffusion approximation. Spatial neutron distribution is resolved by means of polynomial nodal method.

4. Calculated results

4.1. Test problems

The calculation of the set of the test problems for the IRT-type research reactor with a tube-type LEU (U-Mo) and HEU fuel, a light water moderator and a beryllium reflector was performed using MCU-PTR and two other continuous-energy Monte Carlo codes. The results of the test problems calculation are presented in [5]. For the fresh cores the discrepancy in neutron multiplication factor between the results of MCNP with ENDF/B-VII cross section library and the results of MCU-PTR with the ACE/MCU library is from 0.03%Δk/k to -0.34%Δk/k for HEU and LEU fuel. A good agreement among the MCU-PTR and the other Monte Carlo codes results was observed for the test problem with burnup. The increase in the discrepancy among the codes in neutron multiplication factor after the first burnup cycle with LEU fuel was found to be less than 0.2%Δk/k.

The calculation of the set of static test problems using TIGRIS code showed that the deviation in neutron multiplication factor from MCU-PTR results is ~-1%Δk/k. The maximum deviation from the precision codes in FA power is less than 16%. The calculation of the depletion test problem showed that reactivity calculated using TIGRIS code has approximately constant bias from MCU-PTR results. So, reactivity vs. time modeling during burnup using TIGRIS code is satisfactory.

4.2. Reference cores

Calculation was performed for three reference cores. Table 1 presents three cases with different CR (regulating rod AR and 3 shim rods KC) positions for the reference HEU and LEU cores. The calculation of these cases enables to estimate criticality, excess reactivity and shutdown margin.

Table 1. CR positions for the reference cores calculation (scram rods withdrawn).

Core	Case	CR position (mm)			
		AR	KC-1	KC-2	KC-3
HEU operational	#1	250	0	0	393
	#2	0	0	0	0
	#3	580	580	580	580
LEU fresh	#1	250	0	180	580
	#2	0	0	0	0
	#3	580	580	580	580
LEU operational	#1	250	0	0	390
	#2	0	0	0	0
	#3	580	580	580	580

Table 2 presents the results of the calculation of the reference cores using TIGRIS code and MCU-PTR code with different CR positions (case #1, #2, #3) described in Table 1. The last column of Table 2 shows the total worth of shim rods and regulating rod.

Table 2. Calculated criticality (#1), excess reactivity (#2) and shutdown margin (#3) for the reference cores.

Core	Code	ρ (%Δk/k)			ρ(#2) - ρ(#3) (%Δk/k)
		#1	#2	#3	
HEU operational	MCU-PTR[a]	0.32	5.52	-12.18	17.7
	TIGRIS	-0.2	4.4	-11.8	16.2
LEU fresh	MCU-PTR	0.18	10.11	-5.68	15.8
	TIGRIS	-0.8	9.0	-6.2	15.1
LEU operational	MCU-PTR	0.62	5.13	-10.48	15.6
	TIGRIS	-0.1	4.1	-10.4	14.6

[a] Standard deviation <0.0002.

For the cases #1 and #2 the difference between the reactivities calculated using TIGRIS code and MCU-PTR code is from -1 to -0.5%Δk/k. The total CR worth calculated using TIGRIS code is 4-9% less than that calculated using MCU-PTR code.

4.3. IRT MEPhI operational data

The calculations of the states with measured critical CR positions for Xe-free cores at the Beginning of Cycle (BOC) and at the End of Cycle (EOC) were performed. Table 3 presents critical CR position and calculated reactivity. The calculations using TIGRIS code and MCU-PTR code are presented.

Table 3. Results of criticality calculation for Xe-free cores at BOC and EOC.

Cycle		CR position (mm)				ρ (%Δk/k)		Δ (%Δk/k)
		AR	KC-1	KC-2	KC-3	TIGRIS	MCU-PTR[a]	
#113	EOC	250	0	0	373	-1.44	-0.91	-0.53
#114	BOC	200	0	219	592	-0.35	0.04	-0.39
	EOC	250	0	81	592	-0.65		
#115	BOC	270	0	0	590	-0.61		
	EOC	250	0	0	515	-0.88		
#116	EOC	250	0	0	385	-1.01	-0.45	-0.55
#117	EOC	250	0	0	360	-1.35		
#118	BOC	250	0	155	592	-0.34	0.02	-0.37
	EOC	231	0	93	592	-0.50		
#119	BOC	248	0	0	489	-0.13	0.35	-0.49
#120	BOC	250	0	25	592	-0.14	0.54	-0.67
	EOC	250	0	0	418	0.05	0.75	-0.69
#121	BOC	250	0	0	393	-0.18	0.42	-0.60

[a] Standard deviation is ±0.00014.

The maximum negative discrepancy with the experiment for both codes is observed for the EOC #113 and #116. It could be explained by the fact that the cores at the end of the cycles #113 and #116 are the cores with maximum burnup: EOC #113 – core-averaged burnup is 33%, 4 FA have deep burnup (50.3%, 51.4%, 54.8%, 56.4%), EOC #116 – core-averaged burnup is 31.8%, 4 FA have deep burnup (48%, 52%, 54.9%, 55.3%). The other cycles have core-averaged burnup of 26-29%. For the cores with large burnup the error of the power measurement has the maximum impact on the calculated results. The maximum positive discrepancy is observed for the cycles #119-121. It could be explained by the fact that starting from the cycle #118 the duration of shutdown periods increased and the error in beryllium poisoning calculation has the maximum impact on the calculated results.

It can be seen from Table 3 that the difference between TIGRIS and MCU-PTR results is from -0.4 to -0.7%Δk/k. This difference is approximately the same as for the reference cores and is less than for the test problems due to the error cancellation.

The detailed simulation of CR calibrations was performed [6,7]. For the IRT MEPhI, the discrepancy between the measured and calculated integral reactivity worth was found to be less than 10% for the shim rods and less than 15% for the regulating rod [7].

The brief summary of the results of MCU-PTR code and TIGRIS code validation based on the comparison with IRT MEPhI operational data is presented in Table 4.

Table 4. Comparison of the calculated and measured results for the IRT MEPhI reactor.

Parameter	Deviation from the experiment	
	MCU-PTR	TIGRIS
Criticality (%Δk/k)	-0.9…0.8	-1.4…0.1
Excess reactivity (%Δk/k)	0.1…0.9	-0.3…0.6
Reactivity worth of shim and scram rods (%)	<10	<10
Reactivity worth of regulating rod (%)	<15	<15

5. Conclusion

The continuous energy Monte Carlo code MCU-PTR and the nodal diffusion-based deterministic code TIGRIS were validated for the IRT MEPhI reactor calculation. The validation was based on the calculation of the test problems for model core configuration with HEU and LEU fuel, reference cores with HEU and LEU fuel, and IRT MEPhI cores with HEU fuel. Detailed comparison with the measured data and code-to-code comparisons were performed. The range of the discrepancy between the calculated and measured results was determined. A satisfactory agreement among the considered codes and among the calculated and measured results is observed. The calculated reactivities for the measured critical CR positions are between the ±1%Δk/k range and ±1.5%Δk/k range for MCU-PTR code and TIGRIS code, respectively.

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