Modeling of operating history of the research nuclear reactor

A Naymushin[1], Yu Chertkov[1], M Shchurovskaya[2], M Anikin[1], I Lebedev[1]
[1]National Research Tomsk Polytechnic University, TPU, 634050 Russia, Tomsk, Lenin avenue 30.
[2]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), NRNU MEPhI, 115409, Russia Moscow, Kashirskoe shosse 31.

E-mail: agn@tpu.ru

Abstract. The results of simulation of the IRT-T reactor operation history from 2012 to 2014 are presented. Calculations are performed using continuous energy Monte Carlo code MCU-PTR. Comparison is made between calculation and experimental data for the critical reactor.

1. Introduction

The major research tool for the processes taking place in the reactor is experiment. However, modern state of computational technology and calculation methods allow completion and partial replacement of experimental methods with simulation of processes using computer codes. Nuclear technologies is a field of increased responsibility, therefore, compliance rationale of calculation data with experimental data is needed so that computational software could be used for the simulation of real prototypes.

MCU-PTR code was chosen for the purpose of IRT-T reactor simulation [1, 2]. This code uses Monte-Carlo method and is oriented on the calculations for research reactors. Created model of the IRT-T reactor core and the reflector simulates material composition and reactor geometry in details and allows neutronics calculations for the different states and operating regimes of the reactor.

2. Simulation of burnup process

The operating regimes of the reactor recorded in the operating logs were used as input data for the computation of the fuel burnup process. Weekly cycles were taken into consideration, as well as control rods movement and reloading of fuel assemblies between the reactor operating cycles. Typical weekly operation of the reactor consists of a 4-day operation at the nominal power level and a 3-day shutdown. Fuel reloading takes place when the excess reactivity is running low.

Initial information about the reactor burnup was obtained from the results of the simulation of the reactor operation history from 1984 to 2012 using diffusion code TIGRIS [3]. The simulation of the simplified operation history of the reactor using MCU-PTR code was used to estimate the poisoning of the beryllium reflector blocks with products of high absorption cross-sections as a result of the interaction with neutrons for the past years.

The detail simulation of the reactor weekly operation with actual control rod positions for the past seven cycles from 2012 to 2014 was carried out using MCU-PTR code. It was assumed that in the horizontal plane, all fuel tubes of one fuel assembly have the same burnup (i.e., they burn as one material). The burnup for six axial layers for each fuel assembly was calculated.

Neutronics characteristics (criticality, reactivity worth of control rods, excess reactivity, shutdown margin) of the investigated operating cycles were determined and analyzed. Thermohydraulic parameters of the reactor cores were also analyzed [3].
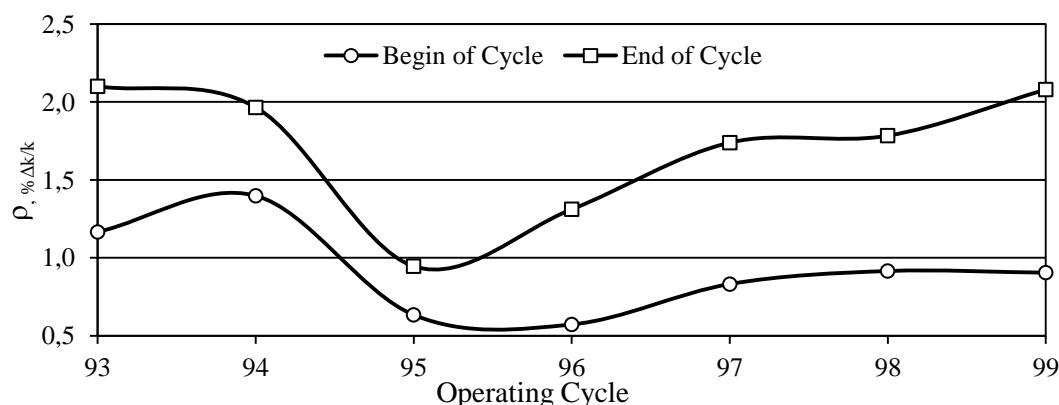
3. Computation of critical states

The reactor critical states corresponding to the beginning and the end of the operating cycle are the most important. Computation of the Xe-free critical states was carried out for the beginning of operating cycle (at IRT-T reactor start-up) and for the end of operating cycle before fuel reloading (Table 1). The value shown in the last column of the Table 1 is the calculated reactivity for the measured critical states (the measured reactivity equals zero for the critical state).

Table 1. Calculated reactivity for the measured critical states at the beginning and at the end of operating cycles (standard deviation 0.00015)

Date	Energy generation, MW·h	Position of control rods, cm			k_{eff}	$\rho,\%\Delta k/k$
		CR-1	CR-2	AR		
01.10.2012	0	42	42	34	1,0118	1,17
12.11.2012	2496	33	33	32	1,0284	2,10
12.11.2012	0	54	53	33	1,0142	1,30
20.02.2013	5390	34	34	33	1,0201	1,97
20.02.2013	0	54	54	31	1,0086	0,85
22.04.2013	4328	36	36	23	1,0096	0,95
24.04.2013	0	50	50	41	1,0058	0,57
17.06.2013	3372	36	36	22	1,0133	1,31
17.06.2013	0	60	57	32	1,0084	0,83
26.09.2013	1588	10	12	60	1,0177	1,74
26.09.2013	0	32	31	60	1,0092	0,92
13.01.2014	7558	38	38	24	1,0182	1,78
14.01.2014	0	55	56	31	1,0091	0,90
24.03.2014	3722	32	33	25	1,0212	2,08

Calculated reactivity for the critical states ranges from 0.6 to 1.3 %Δk/k and from 0.95 to 2.1 %Δk/k for the beginning and for the end of the cycles, respectively. Comparing critical states for the beginning and the end of operating cycles, it can be seen (Figure 1) that at the beginning of operating cycles the calculated reactivity is always less. For example, the calculated reactivity during the cycle #99 increased from ~1% Δk/k to ~2% Δk/k.

Figure 1. Calculated reactivity for the measured critical states at the beginning and at the end of operating cycle (line connecting calculated points serves as an eye-guide only

The average calculated reactivity for the measured critical states is 0.93 %Δk/k and 1.7 %Δk/k for the beginning and for the end of the cycles respectively. After the replacement of the spent fuel assemblies with the fresh ones, the calculated reactivity decreases. It can be explained by the fact that the actual energy generation is larger than the energy generation used in the computation.

4. Control rods reactivity worth

Automatic regulator rod (AR) is calibrated using the asymptotic period method. According to this procedure, the reactor is brought to critical state at power level of 5 kW with specified position of AR control rod (in the beginning of calibration AR is fully inserted). After that, AR is partially withdrawn, leading to input of positive reactivity. Asymptotic period can be defined by measuring time needed for doubling the power. Inserted reactivity is calculated using in-hour equation. After measuring the reactivity worth of inserted part of AR rod, the reactor is brought to critical state by means of shim rods, then, the next part of AR rod is calibrated. Shim rods (CR-1 CR-2 and CR-3) are calibrated using method of compensation with AR rod of known efficiency (rods swap method).
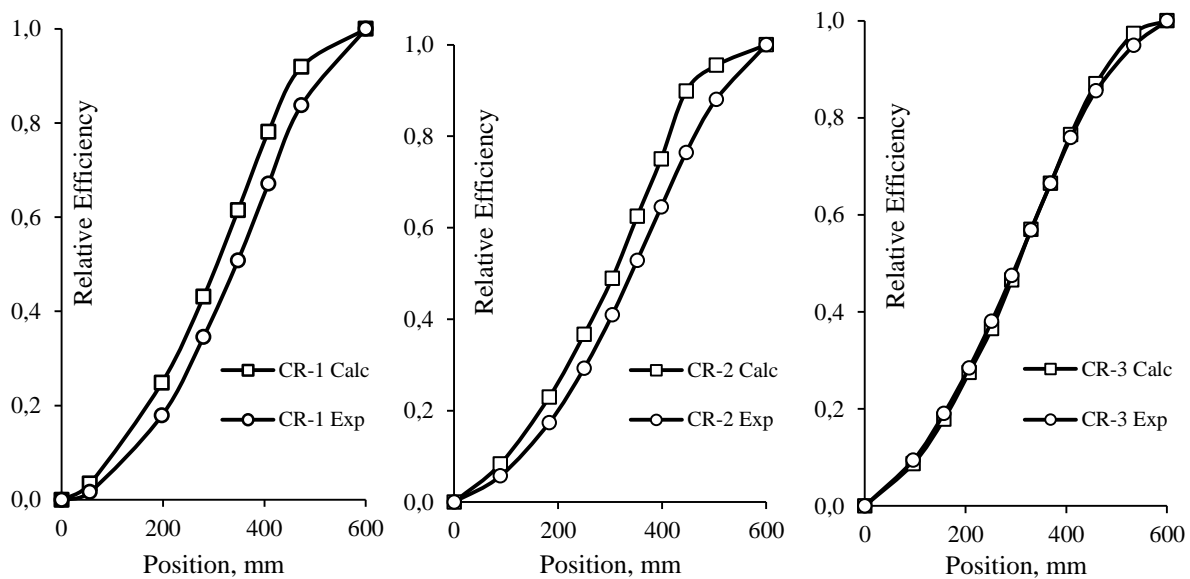
Simulation of calibration procedure was carried out for the beginning of the cycle #100 to determine calculated reactivity worth of control rods. States with experimental critical position of the shim rods during calibration by the compensation method were calculated. Positions of AR rod herewith were averaged. Table 2 shows the results of calculation of states during calibration of CR-1 rods (analogous calculations were made for CR-2 and CR-3 rods). The measured and the calculated reactivity worth of the calibrated parts of CR-1 (Δρ) is presented. Calculated differential reactivity worth was defined as reactivity (ρ) difference between the state №15 and №14, №13 and №12, etc.

Table 2. Simulation results of calibration of CR-1 rods (standard deviation 0.00015)

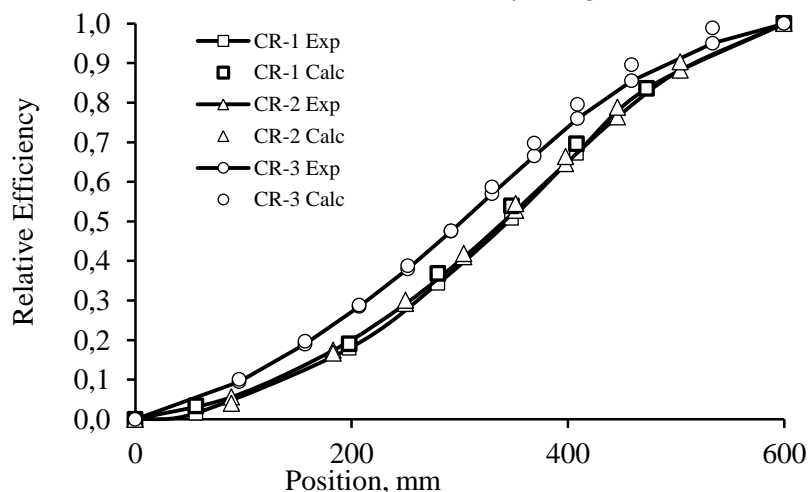| №	Position of control rods, mm				ρ, %Δk/k	Δρ, %Δk/k	
	AR	CR-1	CR-2	CR-3		Calculated	Experimental
1	355	600	333	0	1.06		
2	355	600	333	97	0.71		
3	355	473	333	97	0.96	0.26	0.394
4	355	473	333	169	0.47		
5	355	408	333	169	0.91	0.44	0.394
6	355	408	333	224	0.45		
7	355	348	333	224	0.98	0.53	0.394
8	355	348	333	269	0.51		
9	355	280	333	269	1.09	0.58	0.394
10	355	280	333	308	0.68		
11	355	198	333	308	1.26	0.58	0.394
12	355	198	333	346	0.82		
13	355	56	333	346	1.51	0.68	0.394
14	145	56	333	385	1.33		
15	145	0	333	385	1.44	0.11	0.037

According to Table 2, the largest deviation of calculated differential worth (Δρ) from experimental one takes place at the insertion depth of CR-1 ranging from zero to ~200 mm.

Calibration curves of CR-1, CR-2 and CR-3 were obtained by using the results from Table 2 and analogous calculations for the remaining control rods. Figure 4 shows experimental and calculated curves of integral worth of CR-1, CR-2 and CR-3 rods, normalized to unity.

Figure 4. Calculated and experimental calibration curves of CR-1, CR-2 and CR-3 rods.

The shape of the relative calibration curves allows assumption that CR-1 and CR-2 rods are situated 4-5 cm higher than defined in the geometric model used in the calculation, while the CR-3 position over the height in the geometric model is approximately the same as actual CR-3 position over the height. In the initial geometric model at zero insertion depth of control rod, the lower end of the absorber is leveled to the top edge of the active part of the fuel assembly. The geometric model was corrected by using the results of comparison of calculated and experimental relative calibration curves. Specifically, CR-1 and CR-2 rods were shifted upwards by 5 cm and 4 cm respectively. Simulation of calibration was carried out again using the corrected geometric model. The relative calibration curves of CR-1, CR-2 and CR-3 rods obtained by using this model are shown in Figure 5.

Figure 5. Calculated and experimental calibration curves of CR-1, CR-2 and CR-3 rods (corrected geometrical model)

The selected shift made it possible to achieve satisfactory agreement between the calculated and experimental calibration curves of CR-1, CR-2 and CR-3 rods.

Table 3 shows calculated and experimental integral reactivity worth of IRT-T reactor control rods.

Table 3. Comparison of calculated and experimental integral reactivity worth of control rods.

	Reactivity worth, %Δk/k			
	AR	CR-1	CR-2	CR-3
Calculated	0.530	2.96	4.04	4.45
Experimental	0.394	2.40	3.69	4.15

The discrepancy between the calculated and measured integral reactivity worth of CR-2 and CR-3 is less than 10% (relative). For the group of CR-1 rods the discrepancy is 23%. To reveal the reasons of CR-1 integral reactivity worth overestimation in the simulation additional investigations are required. It should be noted that the absorber depletion cannot be such reason. The estimation of the absorber depletion for the IRT-T was made on the basis of the irradiation history of the rods [5, 6]. The reactivity worth loss because of the absorber depletion was found to be ~3% for the CR-1 and CR-2 rods and ~0% for CR-3 rods. Thus, estimated CR-1 and CR-2 worth loss connected with the depletion is not enough to compensate the overestimation. Also it should be noted that CR-1 and CR-2 rods are used similar during the reactor operation while CR-3 group is usually withdrawn, hence the worth overestimation of CR-1 and CR-2 rods because of the absorber depletion would be the same, while the integral worth of CR-1 rods only is overestimated in the simulation. In addition, the uncertainty of location of horizontal experimental channels (HEC) relative to the housing of the reactor core may influence the value of efficiency of CR-1. According to operating data, the gap between bottoms of HECs and housing of the reactor core ranges from 0.5 cm to 2.5 cm. In the calculation model this gap is 2.5 cm for all HECs. Moving all HECs closely to the housing of the reactor core leads to CR-1 efficiency decreasing by 2.3% (relative). Thus, the error of calculated integral reactivity worth of CR-1 rods equals ~20 %.

5. Conclusion

Simulation of the operating history of IRT-T reactor enabled to obtain the extensive material for verification and validation of MCU-PTR code. The results of the presented research were used for development of verification report for MCU-PTR code [6]. The verification report was approved by Rostekhnadzor.

Further studies are planned to identify and eliminate the causes of differences between calculated and experimental data on criticality and reactivity worth of control rods, which would make the developed calculation model more precise.

References

[1]   Alekseev, N. I., et al. "MCU-PTR program for high-precision calculations of pool and tank type research reactors." Atomic energy 109.3 (2011): 149-156.
[2]   Alekseev, N. I., et al. "The status of MCU-5." Physics of Atomic Nuclei 75.14 (2012): 1634-1646.
[3]   Shchurovskaya, M. V., and Alferov, V. P. "Calculation and experiment to determine the operational characteristics of a research reactor." Atomic Energy 101.4 (2006): 706-713.
[4]   Naymushin, A., et al. "Thermal analysis of IRT-T reactor fuel elements." IOP Conference Series: Materials Science and Engineering. Vol. 93. No. 1. IOP Publishing, 2015.
[5]   Lebedev I. I., et al. "Calculations of IRT-T control rods resource". Physical-technical problems of nuclear science, energy and industry. 2014. p.64
[6]   Naymushin A. G., Shchurovskaya M. V., Alferov V. P., Chertkov Yu. B., Anikin M. N., Lebedev I. I., Verification of MCU-PTR code with MDBPT50 evaluated nuclear data for calculation of IRT-T and IRT MEPhI research reactors neutronics characteristics.TPU report.   2015. Tomsk.