Calculations and Measurements for the Full-Core Conversion of the WWR-M Research Reactor in Ukraine

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Abstract. To provide safety and sufficient neutronic performance of the full-core conversion of the WWR-M research reactor in Ukraine, computer models were applied. This models were validated against measured data, which included critical experiment results for fresh fuel assemblies and measured neutronic distributions in real WWR-M reactor core.

Key Words: Research reactor, calculation, measurement.

1. Introduction

In accordance with the program of pilot usage of LEU fuel approved by the Ukrainian Regulatory Committee, most burned HEU fuel assemblies of the WWR-M research reactor were successively replaced by fresh LEU fuel. By using this way, neutronic performance of the reactor remained almost the same as with HEU fuel but such the conversion progressed very slowly. Thus, the new full-core conversion program with simultaneous replacement of all remaining HEU fuel by fresh LEU fuel was developed [1].

To provide safety and sufficient neutronic performance of the reactor, computer models were developed. For neutronics calculation, MCNP-4C [2], NJOY-99 [3] and WIMS-ANL [4] codes were used. The models applied for the conversion safety analysis were validated against measured data, which included critical experiment results for fresh fuel assemblies and measured neutronic distributions in real WWR-M reactor core.

2. Critical Experiments

At first, the computer models were validated using the criticality measurement carried out at the WWR-M experimental facility in Gatchina [5]. The experimental parameters are listed in Table I. For all layouts, experimental critical number of fuel assemblies was determined using calibration of control rods in terms of the number of additional fuel assemblies to be loaded to compensate their reactivity.

The results of the measurement and calculation are presented in Table II. Calculated effective multiplication factor for non-integer number of fuel assemblies was determined by the interpolation between neighbor integer numbers. Standard deviation for calculated values was about 0.04%.

TABLE I: EXPERIMENTAL PARAMETERS.

Type of fuel assemblies	WWR-M2
Fuel enrichment, %	36.3
Number of fuel elements in a fuel assembly	3
Average mass of U^{235} in a fuel assembly , g	33.16
Fuel meat composition	U-Al
Pitch/flat-to-flat, mm	35/32
Element/clad/meat, mm	2.5/0.9/0.7
Length of fuel meat, cm	48.9
Moderator and reflector	Light water
Temperature, C	17.5

TABLE I I: RESULTS OF THE MEASUREMENT AND CALCULATION.

Experimental Critical Number of Fuel Assemblies	**Calculated k_{eff}**
94.1±0.2	0.9987
93.5±0.2	0.9982
108.8±0.3	0.9961
146.1±0.5	0.9948
147.8±0.5	0.9960
187.4±0.4	0.9949
225.1±0.4	0.9944

As we can see in Table II, calculation systematically underestimates criticality. Average deviation of the calculated effective multiplication factor from the results of the measurement is –0.38%. Nevertheless, for all the experiments, neutronics calculation is in good agreement with the measurement. Maximum absolute deviation of the calculated effective multiplication factor from the results of the measurement is 0.56%. Root-mean-square deviation is 0.39%.

3. Neutronic distributions in the WWR-M reactor core

Then the computer models were validated using neutronic measurement based on the activation method and carried out at the WWR-M reactor in Kiev [6]. Total number of the measurement data was about one hundred. Standard deviation for calculated values was about 2%. Results of calculation were consistent with the results of the measurement. Maximum relative deviation of the calculation data from the measurements was 15%. Root-mean-square deviation was 7.7%. Core layout and locations of the measurements are shown in Fig.1. Some results of the measurement and calculation of $^{58}Fe(n,\gamma)$ reaction rate are presented in Fig. 2-4.

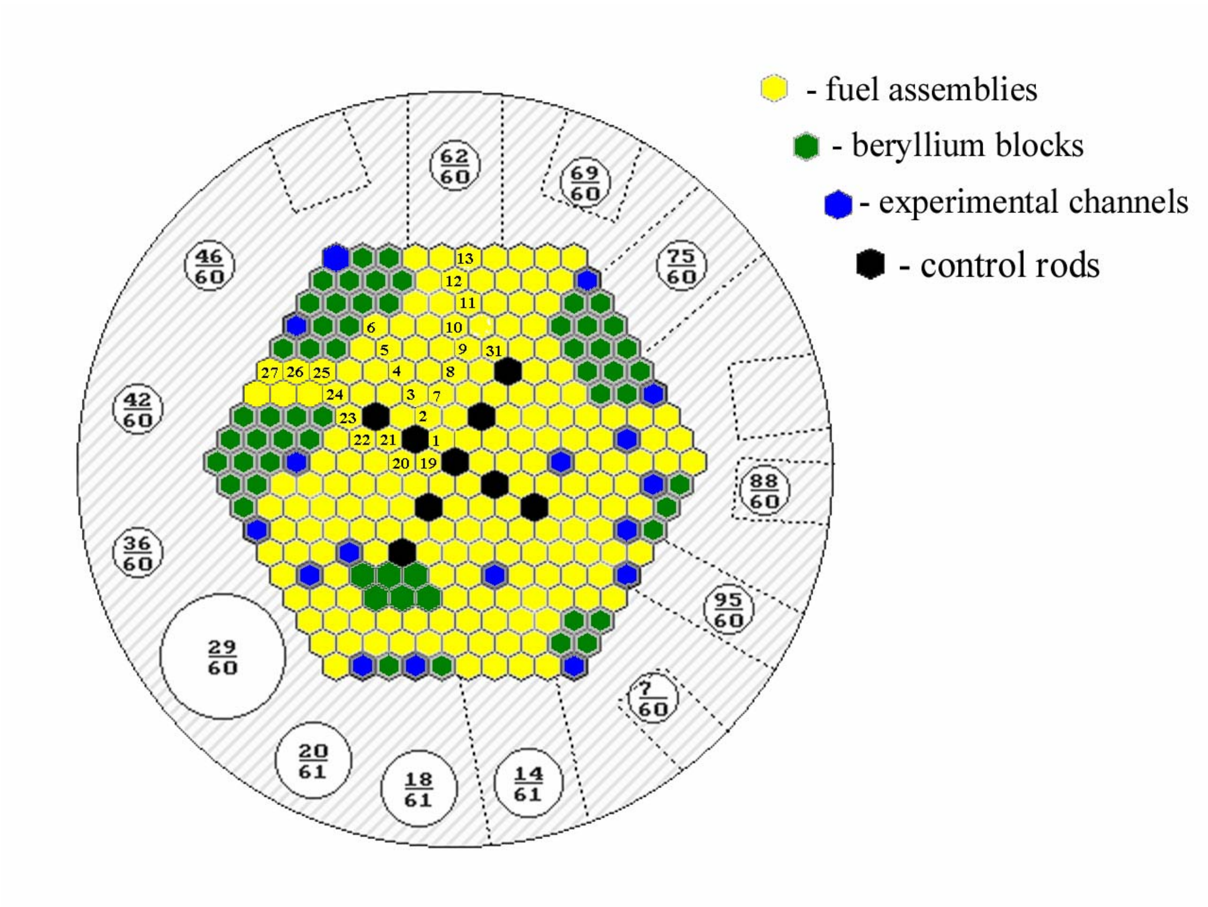

FIG.1. Core layout and location of the measurements

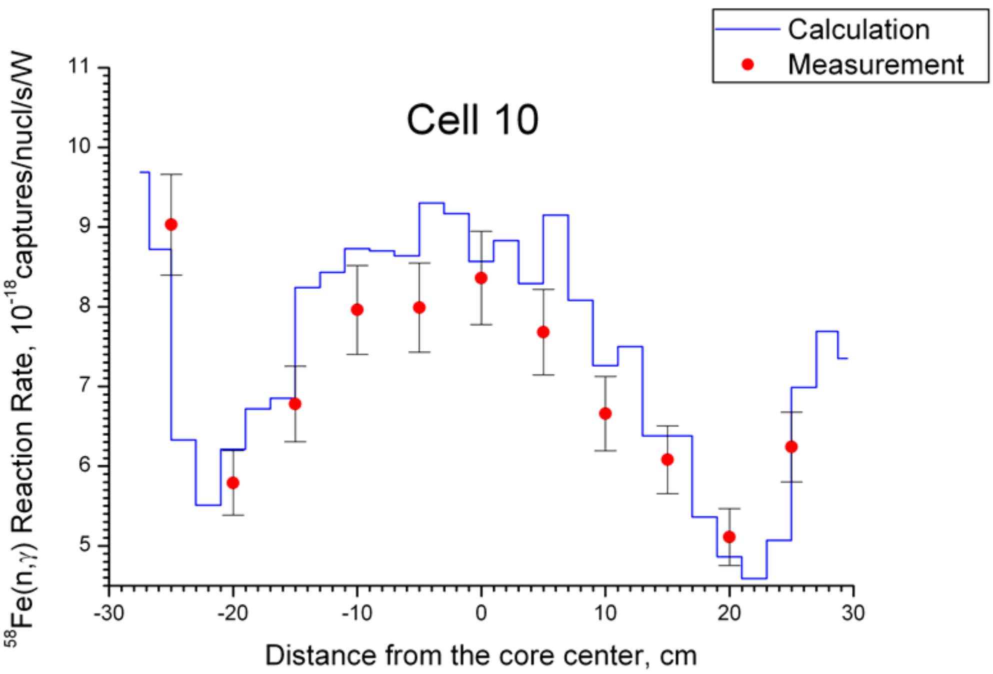

FIG.2. Axial distribution of ^{58}Fe(n,γ) reaction rate in cell 10

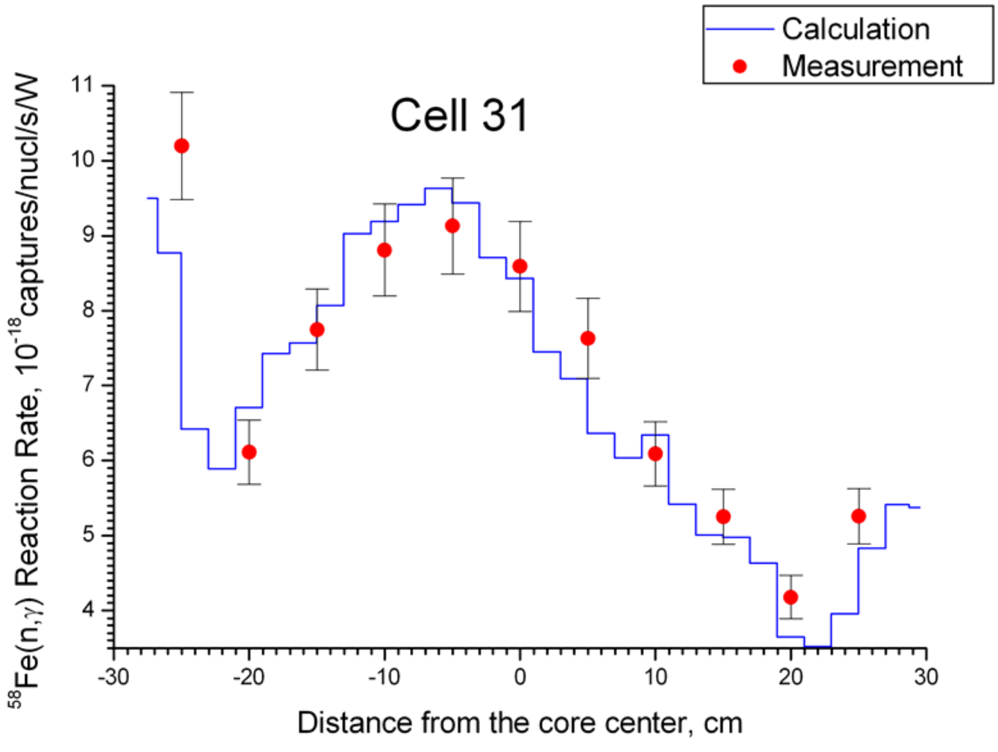

FIG.3. Axial distribution of $^{58}Fe(n,\gamma)$ reaction rate in cell 31

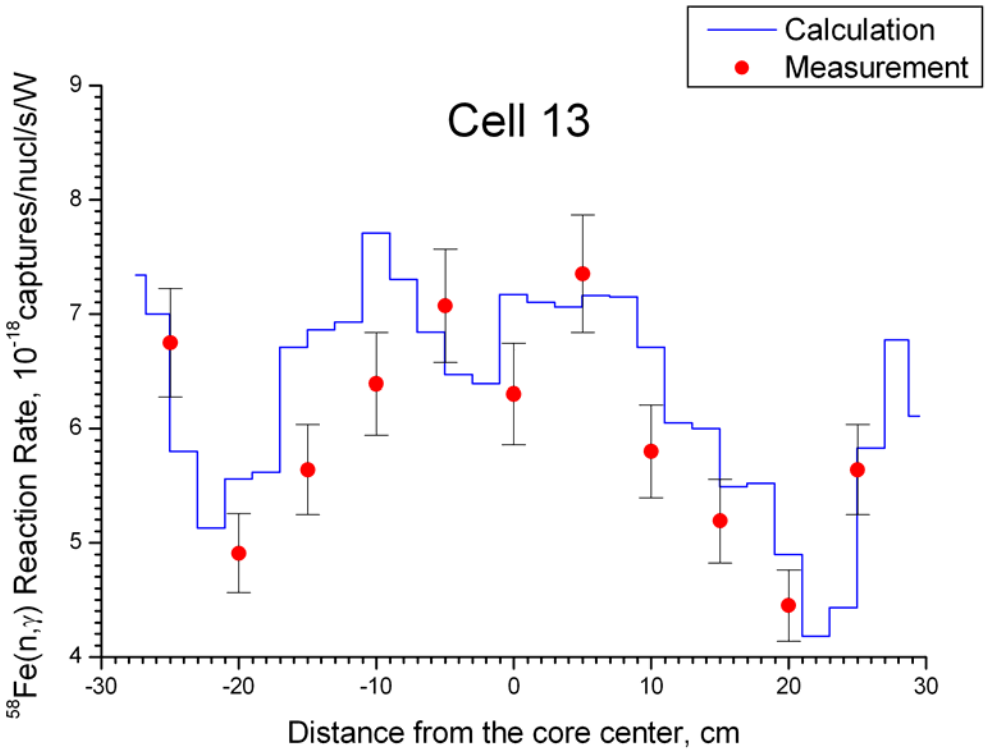

FIG.4. Axial distribution of $^{58}Fe(n,\gamma)$ reaction rate in cell 13

4. Loading of the LEU core

Because of decrease of the number of fuel assemblies in the core from 210 to 72, a lot of beryllium blocks had to be loaded. Most of these blocks were not used more than 40 years and information of their irradiation history was not available. Thus, excess reactivity for the new LEU core was difficult to calculate accurately because of unknown He-3 poisoning. To provide safety of the new core loading, conservative approach was used. Irradiated beryllium blocks with unknown He-3 poisoning were assumed to be fresh, and 15 aluminum blocks were loaded for the nonce instead of beryllium to decrease excess reactivity. Moreover, neutron flux was being monitored all the time during the core loading to estimate subcriticality and worth of the control and safety rods.

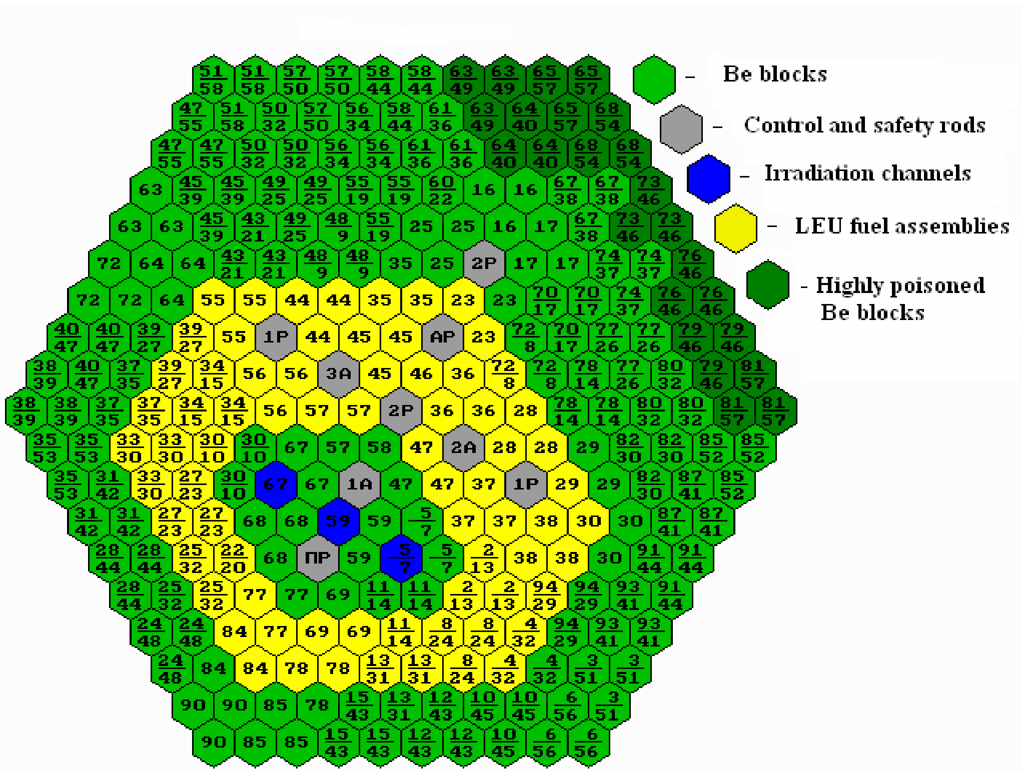

FIG.5. The new LEU core layout

When criticality was reached, He-3 poisoning of beryllium blocks with unknown irradiation history was estimated. It was about $7. Since excess reactivity was small because of high He-3 poisoning, the temporary aluminum blocks were replaced by beryllium ones. Due to this replacement, increase of excess reactivity was $3.6. Then, by using comparative reactivity measurements, beryllium blocks with highest poisoning were detected and moved far away from the fuel to diminish their influence on the neutronics and thermal-hydraulics parameters of the core, as shown in Fig.5. Due to such beryllium shuffling, increase of excess reactivity was $1.5 and He-3 poisoning of beryllium blocks with unknown irradiation history became about $5.5.

Then worth of the rods was measured. As shown in Table III and Fig.6-8, it was in good agreement with calculation.

TABLE III: REACTIVITY WORTH OF THE CONTROL AND SAFETY RODS, $.

Rods	**Calculation**	**Measurement**
1P	7.55	7.71
2P	5.95	6.15
ПР	3.88	3.97
AP	0.70	0.73
1A	4.61	4.9
2A	4.26	4.0
3A	4.57	4.9

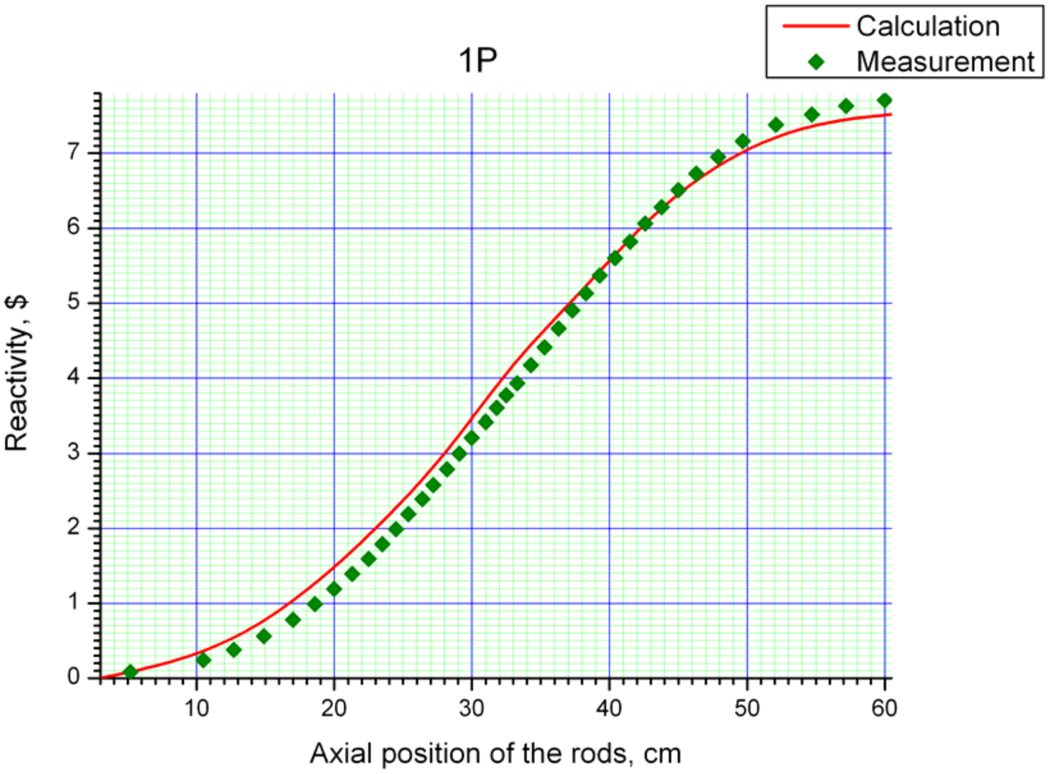

FIG.6. Reactivity worth of the 1P rods

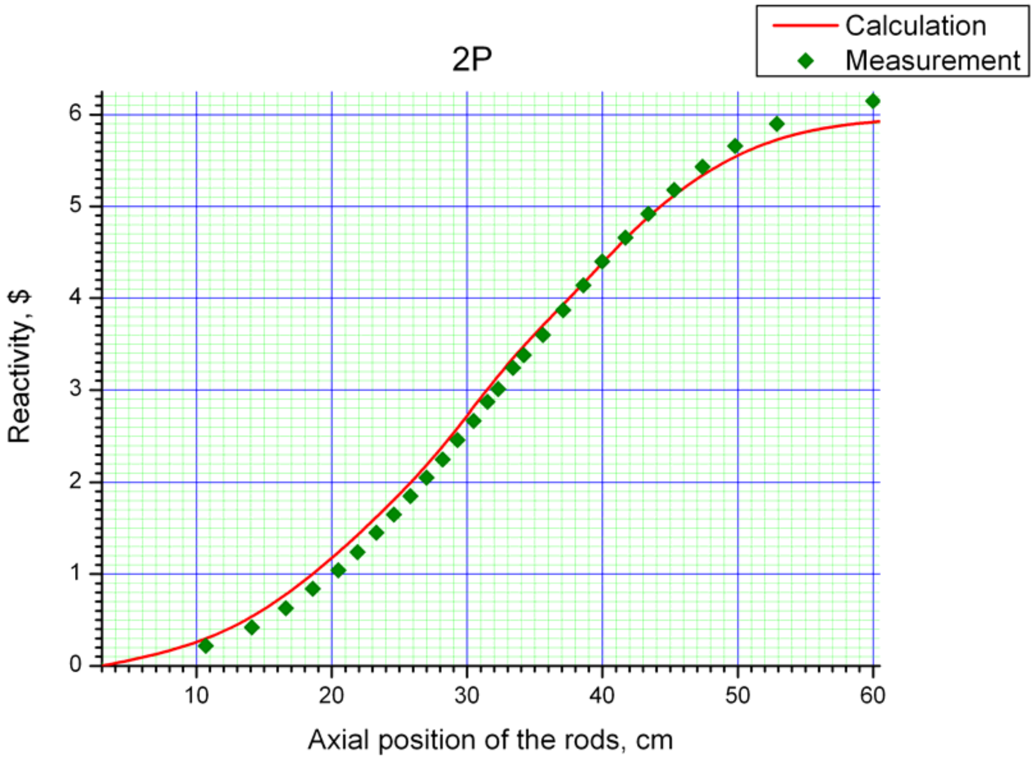

FIG.7. Reactivity worth of the 2P rods

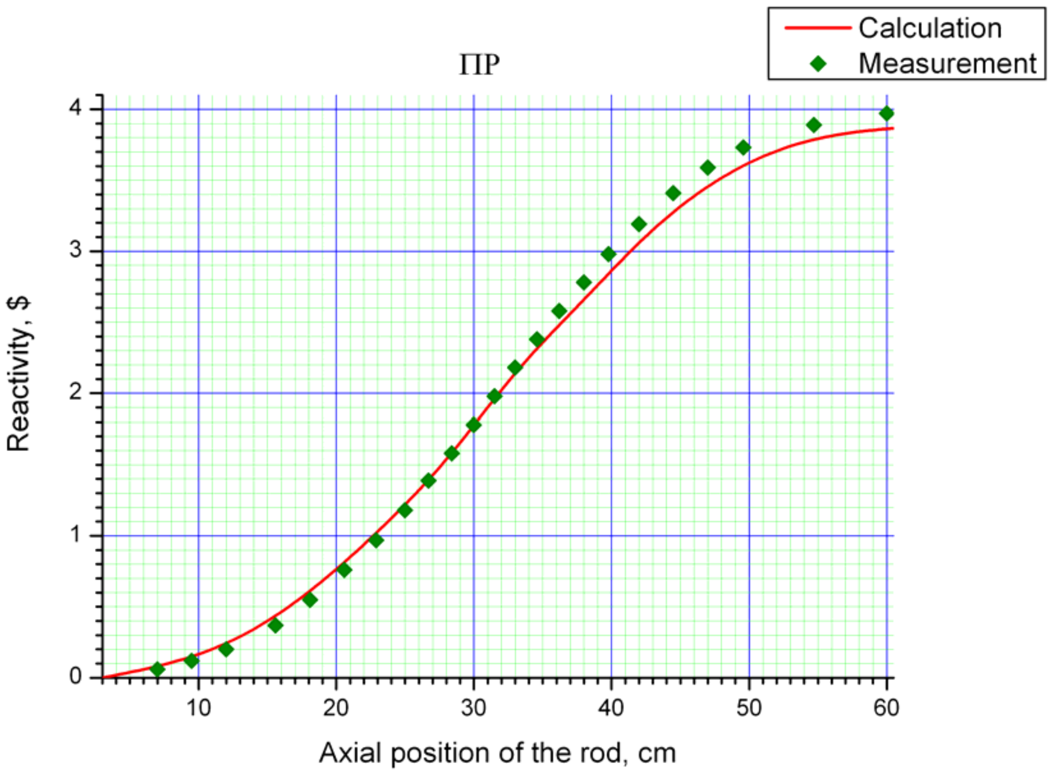

FIG8. Reactivity worth of the ΠP rods

5. Conclusion

To provide safety and sufficient neutronic performance of the full-core conversion of the WWR-M research reactor in Ukraine, computer models were applied. This models were validated against measured data, which included critical experiment results for fresh fuel assemblies and measured neutronic distributions in real WWR-M reactor core.

Because of essential decrease of the number of fuel assemblies in the new LEU core, a lot of beryllium blocks had to be loaded into the reactor core. Most of these blocks were not used more than 40 years and information of their irradiation history was not available. Thus, excess reactivity for the new LEU core was difficult to calculate accurately because of unknown He-3 poisoning.

To provide safety of the new core loading, conservative approach was used. Irradiated beryllium blocks with unknown He-3 poisoning were assumed to be fresh, and 15 aluminum blocks were loaded for the nonce instead of beryllium to decrease excess reactivity. Moreover, neutron flux was being monitored all the time during the core loading to estimate subcriticality and worth of the control and safety rods.

When criticality was reached, excess reactivity and He-3 poisoning were estimated. Since He-3 poisoning was estimated to be high, the 15 temporary aluminum blocks were replaced by beryllium ones. Then worth of the rods and excess reactivity were measured. By using comparative reactivity measurements, the beryllium blocks with the highest poisoning were detected and moved far away from the fuel to diminish their influence on the neutronics and thermal-hydraulics parameters of the core. Since such beryllium shuffling changed the worth of the rods and excess reactivity essentially, they were measured again. This measurement was in good agreement with calculation, so the computer models were validated for the new LEU core.

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