RESULTS OF IRT-4M TYPE FA's TESTING IN THE WWR-CM REACTOR (TASHKENT)

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ABSTRACT

According to the Russian RERTR Program the life time testing of 4 the IRT-4M type FA (two 8-tube and two 6-tube) with LEU (19.7%) UO_2-Al fuel in the WWR-CM reactor (Tashkent, Uzbekistan) were carried out. Uranium density in the Fuel Elements (FE) meat – 3.0 g/cm^3. These FA were fabricated by "Novosibirsk Chemical Concentrates Plant" (NZHK). In the end November 2000 the IRT-4M type FA testing were begun. At the beginning FA were located in central cells of the WWR-CM reactor core. After completion of sixth cycle of IRT-4M type FA testing FA were reloaded in peripheral cells of the core. Testing of IRT-4M type FA was ended in March 2002, after completion of sixteenth cycle testing. The average fuel burnup in FA reached of 60.0–66.5%, and maximum fuel burnup – 83–92.6%. Calculated heat fluxes at fuel element surface reached more 600 kW/m^2, clad temperature – 85˚C. Results of continuous monitoring of gas activity in air under reactor cover and daily monitoring of water activity in primary circuit give basis to consider that under testing of IRT-4M type FA clad failure of fuel elements was not.

INTRODUCTION

The development of the IRT-4M type FA was performed with the purpose of a possibility of conversion on LEU fuel of research reactors, in which FA of the IRT-2M or IRT-3M type with fuel 90, 80 or 36% enrichment are used, but without change of the fuel composition of FE meats (UO_2-Al), using in Russia. The first variant of the IRT-4M type FA, differing from IRT-3M type FA by FE thickness (1.6 instead of 1.4 mm), meat thickness of FE (0.7 instead of 0.4-0.5 mm) and thickness of gaps between FE (1.85 instead of 2.05 mm), was developed with use of FE with the density of uranium in meats equal 3.85 g/cm^3 [1].The necessity of use in the IRT-4M type

FA of FE with such density of uranium in their meats was confirmed also by calculation executed in ANL [2].

FE of two sizes for the IRT-4M type FA (second and third, considering outside) with meats from UO_2-Al with the density of uranium in them 3.85 g/cm^3 were made by JSC NZHK in 1995. The testing of these FE within experimental (combined) FA (the IRT-3M type FA with two FE of IRT-4M type) was begun in May 1996 in the IR-8 reactor in RRC “Kurchatov Institute” [1].

The testing was interrupted in middle of 1998 in connection with a shutdown of the IR-8 reactor for replacement aluminium heat exchangers of the reactor cooling system operated since 1957. To the IR-8 reactor shutdown the average burnup of fuel in FE of the IRT-4M type achieved 33-34%, maximum burnup – up to 53%.

Three full size the IRT-4M type FA were fabricated by JSC NZHK in 1996. The testing of these FA in the IR-8 reactor was begun in February 1997. In connection with cladding failure of some FE in these FA their testing was stopped.

To taking account of results of the IRT-4M type FA testing with the density of uranium in FE meats 3.85 g/cm^3, it was decided to develop the second variant of this type FA with the density of uranium in meats 3.0 g/cm^3. It is obvious, that the use of this variant FA of the IRT-4M type will not allow keeping the cycle length of reactor operation achieved with FA of the IRT-3M type. However for the certain period, before development of FE with fuel on a base of UMo alloy, which will allow to make FE with the density of uranium in the meats ~5.4 g/cm^3 at its thickness of 0.5 mm, it will ensure an opportunity to deliver FA with LEU fuel for the Russian designed research reactors currently operating with HEU fuels.

In 1999 JSC NZHK has fabricated four the experimental IRT-4M type FA: two 8-tube and two 6-tube. These FA were transferred in Tashkent only in November 2000.

Before, neutronic and thermal-hydraulic calculations for choice of the WWR-CM reactor core cells, in which it is necessary to accommodate the experimental IRT-4M type FA, and for a substantiation of testing safety of IRT-4M FA, were performed [3].

In the end November 2000 the IRT-4M type FA testing were begun. Providing the IRT-4M type FA testing to the beginning March 2002 the WWR-CM reactor worked 16 cycles.

During of the IRT-4M type FA testing the continuous monitoring of main parameters of the reactor operation, of primary circuit water parameters, of specific activities of primary circuit water and gases in air under reactor cover, which enough well characterize of fuel elements state (clad leaktightness).

Below data about conditions of IRT-4M type FA testing and results of testing are presented.

DESCRIPTION OF THE EXPERIMENTAL IRT-4M TYPE FA

The basic parameters of the FA are shown in the table 1 [3].

Table 1. The basic parameters of the IRT-4M type FA

№ FA	Thickness, mm			Meat length, mm	Density of uranium in the meat, g/cm^3	Material		Fuel enrich-ment, %	The content of U^{235}, g
	FE	Meat	Clad			Meat	Clad		
4	1.6	0.7	≥0.3	600	3.0	UO_2-Al	САВ-1	19.7	297.8
5	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	АМг2	- “ -	299.5
6	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	САВ-1	- “ -	260.3
7	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	АМг2	- “ -	264.6

Cross sections of the IRT-4M type FA are presented on Figure 1.

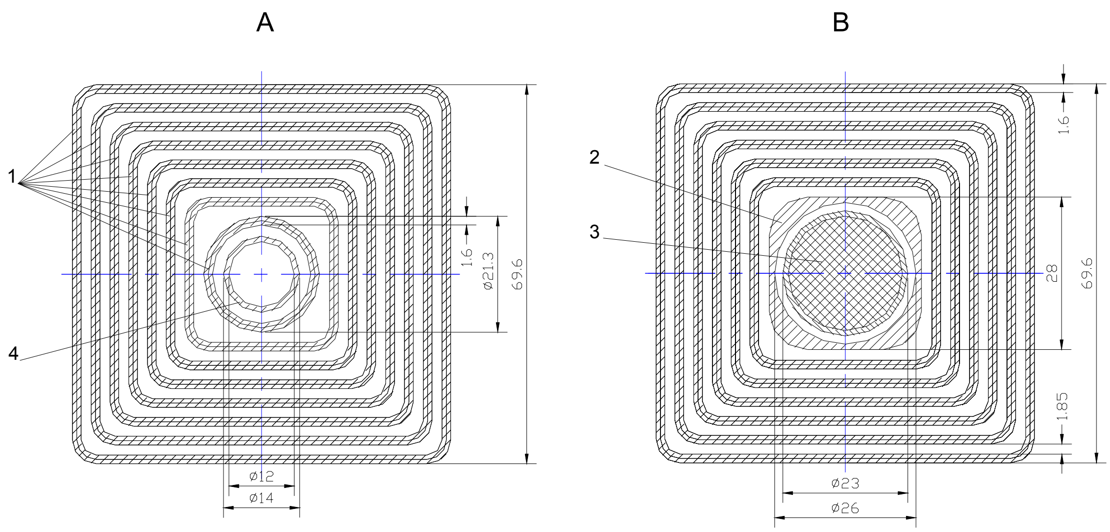

Figure 1. The IRT-4M type FA cross section
A – 8-tube FA B – 6-tube FA
1 – fuel elements; 2 – channel of control rod; 3 - control rod; 4 – central displacement tube

RESULTS OF THE FIRST STAGE OF THE IRT-4M TYPE FA’s TESTING

By choose of cells of the core of the WWR-CM reactor for testing of the IRT-4M type FA the following reasons were allowed. In FA , arranged in central cells of the core, the power peaking factor in 1.3-1.4 times is less, than in peripheral cells. With burnup of fuel during testing the FA power will decrease. Accordingly the maximum density of a heat flux will be reduced. Therefore, the IRT-4M type FA at the first stage of testing should be located in central cells of the core. After achievement in them of fuel burnup ~30% the reloading of the IRT-4M type FA in peripheral cells of the core will allow to compensate a decrease of a heat flux density at the second stage of testing.

The core configuration of the WWR-CM reactor during of the first cycle of the IRT-4M type FA testing, which began 24 November 2000 is shown in Figure 2. As it is seen from Figure 2, the IRT 4M type FA (№ 4, 5, 6 and 7) were loaded in 5-5, 4-4, 4-5 and 5-4 cells.

The power density distributions on the section and on the height of 6-tube FA of the IRT-4M type in the 5-4 cell at the beginning of the first cycle testing are shown in Figure 3 and 4.

Following two cycles of the IRT-4M type FA testing (the second and the third) also were carried out in the core configuration from 16 of FA. Maximum heat fluxes at the FE surface of the IRT-4M type FA reached of 520-530 kW/m^2. Maximum temperatures at the clad surface – 82˚C.

At the end of the third cycle average burnup of fuel of the IRT-3M type FA did not reach of 40%. So far as in forming of a previous core configurations the IRT-3M type FA were unloaded from the core with average burnup not less 45%, it was decided to increase number of FA in the core configuration up to 18. The increase of the reactor excess reactivity, obtained at it, permitted to increase average fuel burnup in unloaded of IRT-3M type FA up to ~49%.

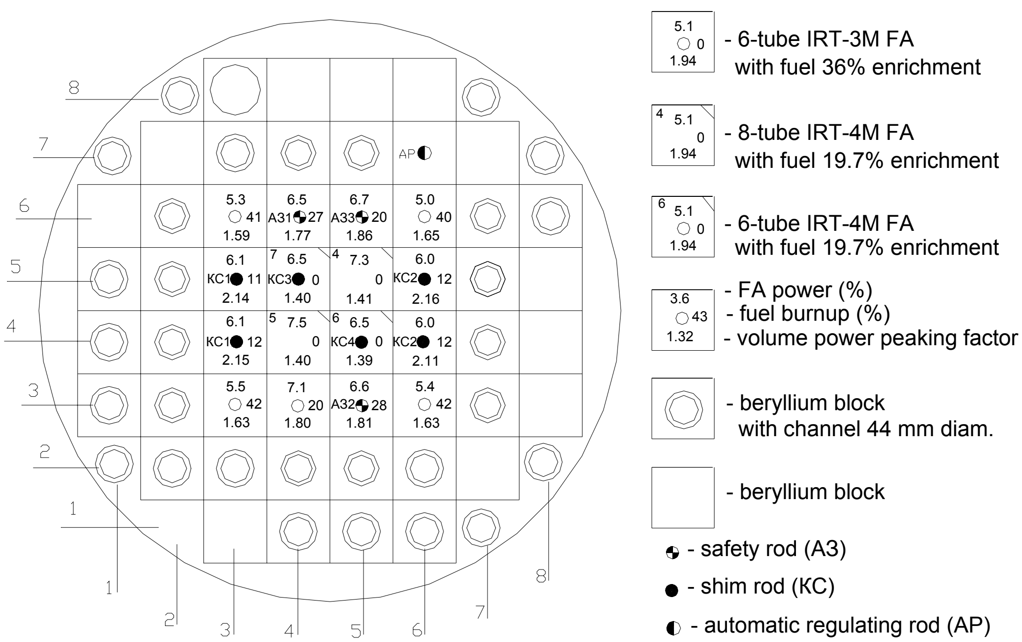

Figure 2. The core configuration of the WWR-CM reactor at the beginning
of the first cycle of the IRT-4M type FA testing
(insertion of KC-1 and KC-2 – 38 cm, KC-3 and KC-4 – 0 cm, AP – 30 cm).

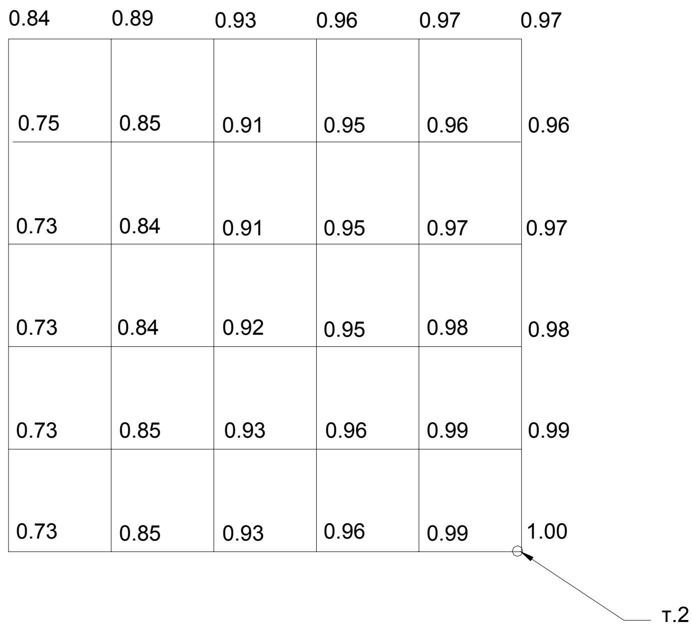

Figure 3. Power density distribution on the section of the FA №7 (beginning of the 1-st cycle , insertion of KC-1 and KC-2 – 38 cm).

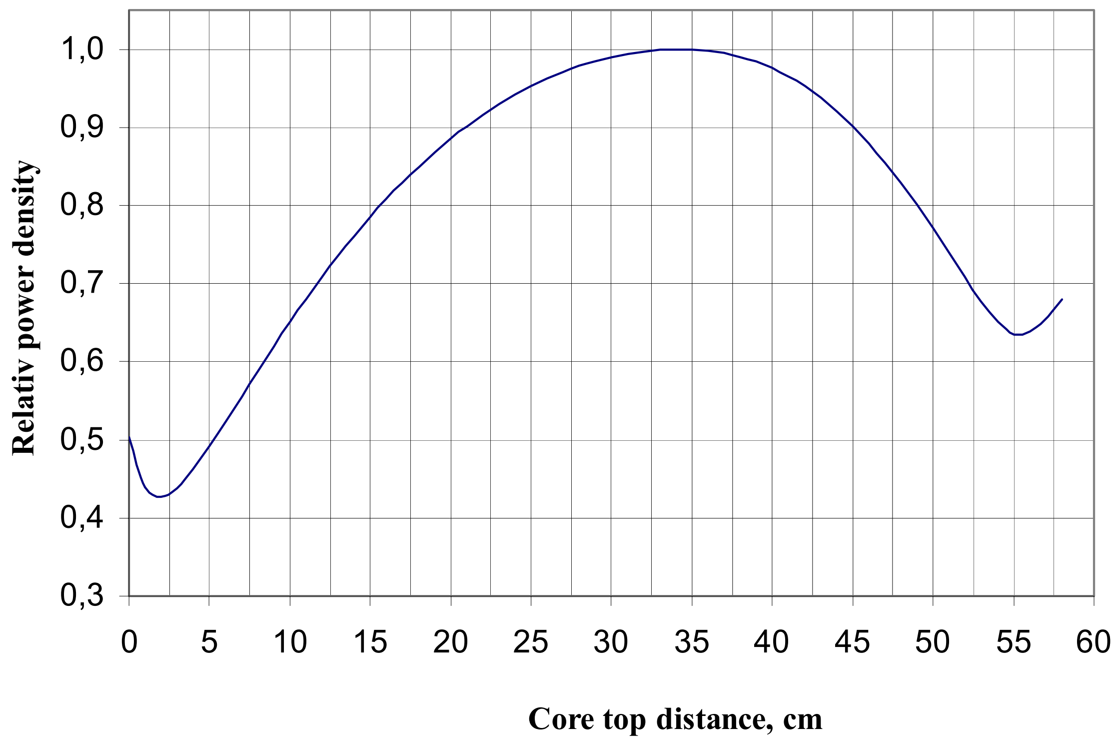

Figure 4. Power density distribution on the height of FA №7
(beginning of the1-st cycle, insertion of KC-1 and KC-2 - 38 cm).

The core configuration of the WWR-CM reactor at the beginning of the fourth cycle of the IRT-4M type FA testing is shown in Figure 5.
The power density distributions on the section and on the height of 6-tube FA of the IRT-4M type in the 5-4 cell at the beginning of the fourth cycle testing are shown in Figure 6 and 7.
With shown in Figure 5 the core configuration the WWR-CM reactor operated yet 2 cycles (the fifth and the sixth). Maximum heat fluxes in fuel elements of the IRT-4M type FA reached of 470-490 kW/m^2. Maximum temperatures of the FE clad surface – 80˚C. At the end of the sixth cycle the uranium-235 average burnup in the IRT-4M type FA reached:

- in 8-tube FA: №4 – 27%; №5 – 27.3%;
- in 6-tube FA: №6 – 27.1%; №7 – 26.7%.

Determined with calculation of section and axial power peaking factors maximum burnup reached:

- in 8-tube FA: №4 and №5 – 37.2%;
- in 6-tube FA: №6 and №7 – 35.8%.

After completion of the sixth cycle of the IRT-4M type FA testing the 6-tube FA №6 was reloaded from 4-5 cell into 3-5 cell, but the 6-tube FA №7 was reloaded from 5-4 cell into 6-4 cell. Practically the first stage of the IRT-4M type FA testing was completed.

RESULTS OF THE SECOND STAGE OF THE IRT-4M TYPE FA's TESTING

After reloading 6-tube of the IRT-4M type FA from central cells in peripheral (cell 3-5 and 6-4) the reactor has worked two cycles (7-th and 8-th). The maximum heat fluxes at FE surface of the IRT-4M type FA reached 580-600 kW/m^2, and the temperatures at the clad surface reached 83˚C.

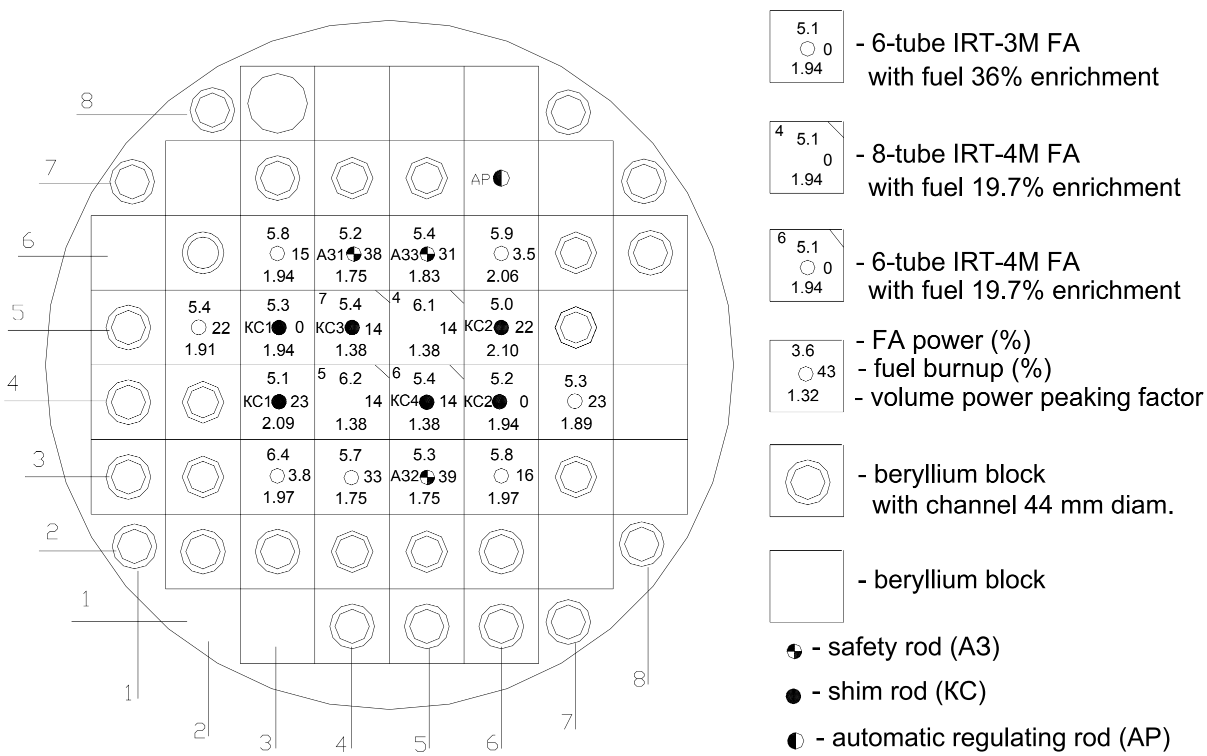

Figure 5. The core configuration of the WWR-CM reactor at the beginning of the fourth cycle of the IRT-4M type FA testing (insertion of KC-1 and KC-2 – 34 cm, KC-3 and KC-4 – 0 cm, AP – 30 cm).

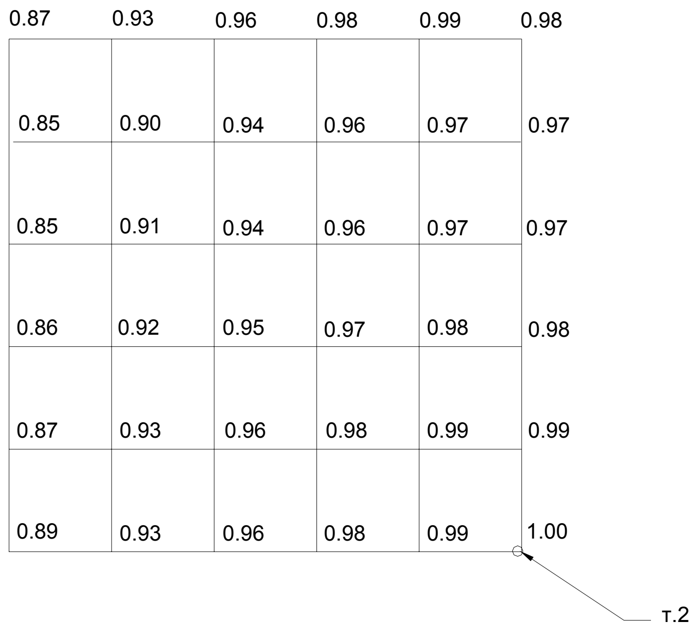

Figure 6. Power density distribution on the section of the FA №7
(beginning of the 4-th cycle , insertion of KC-1 and KC-2 – 34 cm).

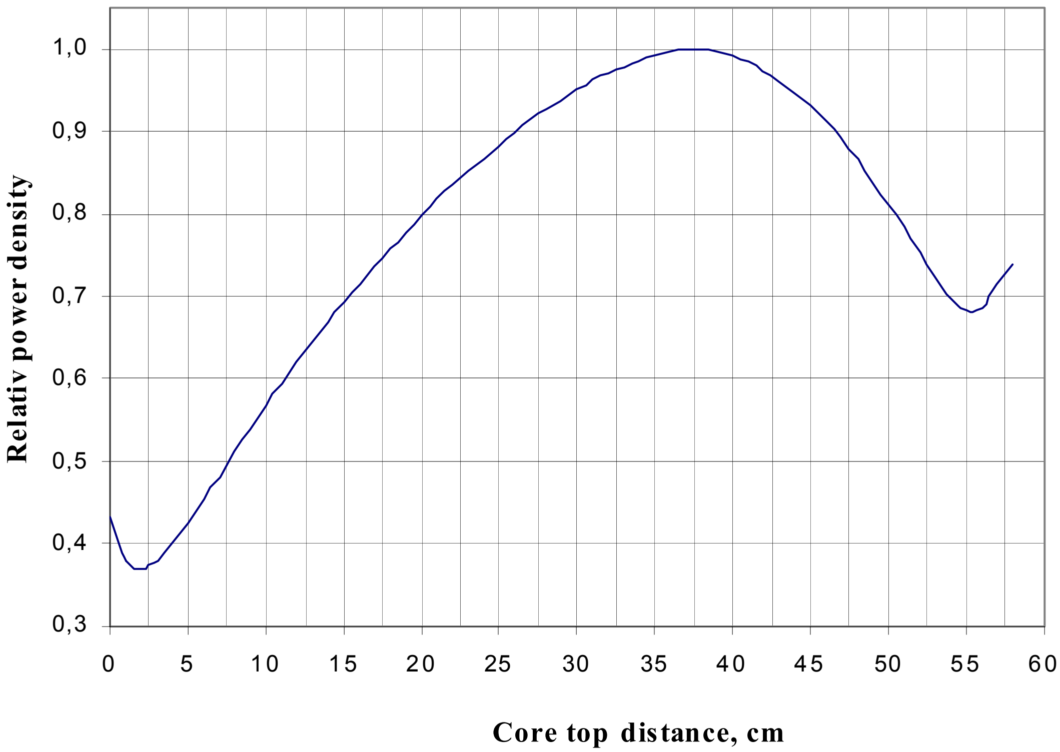

Figure 7. Power density distribution on the height of the FA №7 (beginning of 4- th cycle , insertionof KC-1 and KC-2 -34 cm).

In formation of the core configuration of the reactor for the 9-th cycle of the IRT-4M type FA testing 8-tube FA №5 was reloaded from 4-4 cell in 3-4 cell. FA №4 (8-tube) was reloaded from 5-5 cell in 6-5 cell in formation of the reactor core configuration for 10-th cycle of the IRT-4M type FA testing. During these cycles the maximum heat fluxes at FE surface of the IRT-4M type FA reached 500-540 kW/m^2, and the temperatures at the clad surface reached 80-84˚C.

In formation of the reactor core configuration for the 11-th cycle of the IRT-4M type FA testing number of the FA in the core was reduced up to 16. During this cycle the maximum heat fluxes at FE surface of the IRT-4M type FA reached 620 kW/m^2, and the temperatures at the clad surface reached 80˚C.

In formation of the reactor core configuration for the twelfth cycle of the IRT-4M type FA testing number of the FA in the core was again increased up to 18. During this cycle the maximum heat fluxes at FE surface of the IRT-4M type FA reached ~580 kW/m^2, and the temperatures at the clad surface reached 77˚C.

In formation of the reactor core configuration for the 13-th cycle of the IRT-4M type FA testing number of the FA in the core did not change. During this cycle the maximum heat fluxes at FE surface of the IRT-4M type FA reached ~540 kW/m^2, and the temperatures at the clad surface reached 79˚C.

In formation of the reactor core configuration for the 14-th cycle of the IRT-4M type FA testing number of the FA in the core did not change. During this cycle the maximum heat fluxes at FE surface of the IRT-4M type FA reached ~510 kW/m^2, and the temperatures at the clad surface reached 76˚C.

In formation of the reactor core configuration for the 15-th cycle of the IRT-4M type FA testing number of the FA in the core did not change. During this cycle the maximum heat fluxes at FE surface of the IRT-4M type FA reached ~500 kW/m^2, and the temperatures at the clad surface reached 80˚C.

The average burnup of uranium-235 in the IRT-4M type FA at the end of the 15-th cycle of testing has reached:

– in 8-tube FA: №4 – 60.1%; №5 – 53.3%;
– in 6-tube FA: №6 – 61.4%; №7 – 60%.

The maximum burnup has reached:

– in 8-tube FA: №4 – 87.9%; №5 – 78.2%;
– in 6-tube FA: №6 – 92.6%; №7 – 91.3%.

The distributions of uranium-235 burnup at the end of the 15-th cycle testing on the height 6-tube FA №6 and №7 are shown in Figure 8.

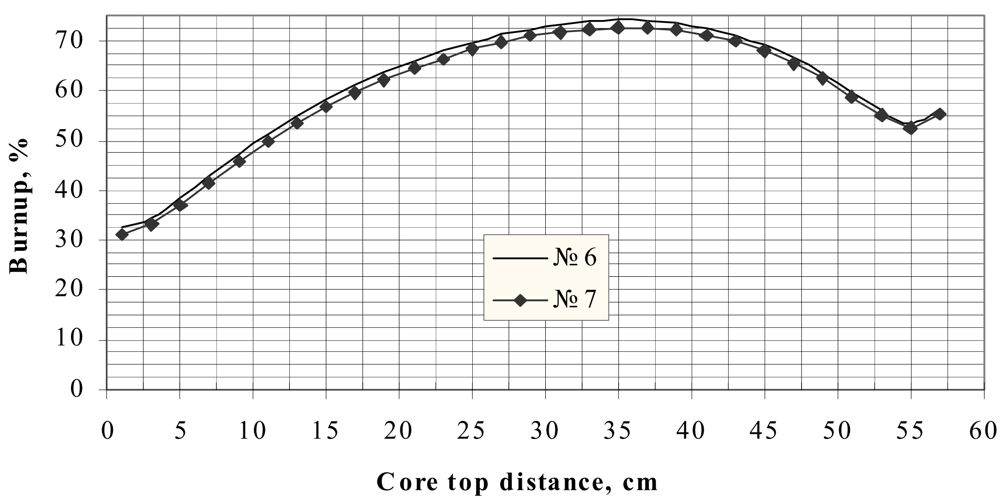

Figure 8. Distribution of uranium-235 burnup on height of 6-tube FA of the IRT-4M type №6 and №7 at the end of 15-th cycle testing (average burnup – 61.4 and 60.0%, maximum burnup – 92.6 and 91.3%).

So far as in 6-tube of the IRT-4M type FA (№6 and №7) the average burnup of uranium-235 has reached 61.4 and 60%, the testing them were ceased, also they were unloaded from the reactor.

FA number in the core in formation of the core configuration for following of the 16-th cycle the reactor operation did not change. During this cycle the maximum heat fluxes at FE surface of the IRT-4M type FA reached ~480 kW/m^2, and the temperatures at the clad surface reached 77˚C.

The average burnup of uranium-235 in the IRT-4M type FA at the end of the 16-th cycle of testing has reached: №4 – 66.5%, №5 – 60.5%. The maximum burnup has reached: №4 – 92.1%, №5 – 83.1%. The distributions of uranium-235 burnup at the end of the 16-th cycle testing on the height 8-tube FA №4 and №5 are shown in Figure 9.

The water flow rate in the primary circuit of the reactor cooling system for each testing cycle was set by such, that the pressure drop on the core of the reactor was 4 m water column.

During all cycles of the IRT-4M type FA testing there were 29 planning shut down of the reactor and 9 non-planning as a result of actuation of emergency protection (basically because of loss of external electrical power supply).
From results of the monitoring of specific activities of primary circuit water and gases in air under a cover of the reactor follows, that failure of the fuel elements clad in the IRT-4M type FA during testing has not taken place.

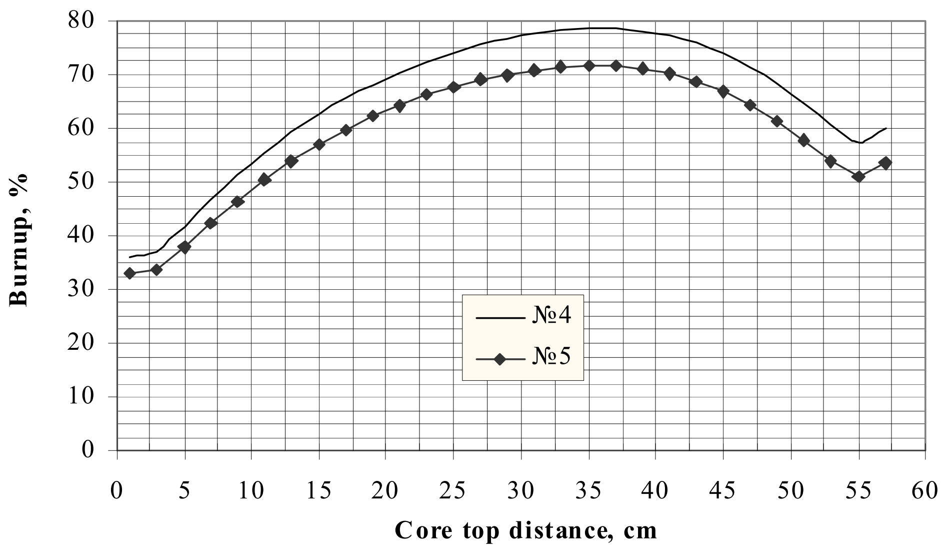

Figure 9. Distribution of uranium-235 burnup on height of 8-tube FA of the IRT-4M type №4 and №5 at the end of 16-th cycle testing (average burnup – 66.5 and 60.5%, maximum burnup – 92.1 and 83.1%).

CONCLUSION

For 15 months of testing in the reactor WWR-CM 4 FA of IRT-4M type with LEU (19.7%) UO_2-Al fuel was reached following average burnup of fuel in FE these FA:

– in 6-tube FA: №6 – 61.4%; №7 – 60%;
– in 8-tube FA: №4 – 66.5%; №5 – 60.5%.

The maximum burnup of fuel with calculation of its irregularity on section and height FA has reached:

– in 6-tube FA: №6 – 92.6%; №7 – 91.3%;
– in 8-tube FA: №4 – 92.1%; №5 – 83.1%.

Maximum heat fluxes at FE surface reached during of testing - 620 kW/m^2. Maximum temperatures at the FE clad surface – 85˚C.

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