CONDITIONS AND PRELIMINARY RESULTS OF LOW ENRICHMENT U-Mo PIN TYPE FUEL TESTING IN THE MIR REACTOR

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ABSTRACT

Within the framework of cooperation with ANL under the RERTR program testing of low enrichment U-Mo pin type mini fuel elements manufactured at the Bochvar institute was started in the MIR reactor in August 2003. The cross-section of fuel elements is square, sized 2.93 x 2.93 mm, cladding material is aluminium alloy SAV-1, the length of the fuel part ~200 mm, uranium density 4 and 6 g/cm³. The testing is being performed under the conditions as follows: distilled water with pH~(5,5-6,0) as coolant, coolant pressure ~1,2 MPa, coolant temperature (30-70)ºC, coolant velocity ~2,6 m/s, maximum temperature of fuel elements cladding ~110ºC, maximum heat flux ~ 0,9 MW/m².
The dismountable design of the irradiation device for fuel elements testing makes it possible to perform inspections and replacement of fuel elements during the breaks between the tests.
During the test coolant inlet and outlet temperature, outlet flow rate and pressure are measured in the experimental channel. The thermal power of the tested fuel elements is calculated by the measured thermodynamic coolant parameters. Fuel elements cladding leakage is continuously checked by measuring fission products' delayed neutrons penetrating into the coolant.

1. Introduction

At present all Russian research reactors are operated with high or medium enriched uranium. In the majority of reactors uranium dioxide (UO_2) or uranium intermetallide (UAl_x) dispersed in the aluminum matrix are used as fuel meat. Fuel elements with aluminum alloys claddings have a tube-type design, which have diverse geometry [1].

It is only in the SM reactor and its satellite RBT-type reactors that are used cruciform pin type fuel elements with stainless steel claddings. Fuel meat in these fuel elements is uranium dioxide dispersed in the high temperature copper-beryllium alloy. Usage of fuel elements of that design in the SM reactor becomes reasonable because of the need to obtain very high heat fluxes above 10 $MW \cdot m^{-2}$ [2].

Under the Russian RERTR program in the 90-s of the last century there was carried out a work package on tube-type fuel elements development using low enriched uranium dioxide in the aluminum matrix. In the MIR reactor full-scale fuel assemblies were tested with fuel elements of that type. The test results have shown the principal possibility of manufacturing fuel elements of similar design with low enriched fuel if significant technological updating is provided to improve quality and reliability of fuel elements [3]. Besides, in the recent years tube-type U-Mo fuel elements have been developed and manufactured at Novosibirsk plant. In 2003 in the IVV-2M reactor those fuel elements were tested up to burn-up ~60%.

The other trend of fuel enrichment decreasing for Russian research reactors is the development of pin type fuel elements based on high density U-Mo fuel. The main target of this trend is that pin type fuel elements of that design can be used to complete fuel assemblies of various size and configuration for different reactor types.

Such technology and design of fuel elements were developed by VNIINM in cooperation with ANL [4].

On August 25, 2003 pin type mini fuel elements based on U-Mo fuel were loaded into the MIR reactor. Density of uranium in the fuel meat varies from 4 to 6 g/cm³. The purpose of the tests is to obtain experimental data concerning changing of properties of fuel meat, cladding material and fuel elements integrity on attaining burn-up 20%, 50%, 70%.

This paper presents the design of the irradiation device and conditions of this test.

2. The design of the irradiation device

In order to test mini fuel elements there has been developed and made an irradiation device that is installed in the standard operating channels of the MIR reactor. It has a dismountable design that enables to carry out intermediate inspections or to replace mini fuel elements in the irradiation device in the hot cell.

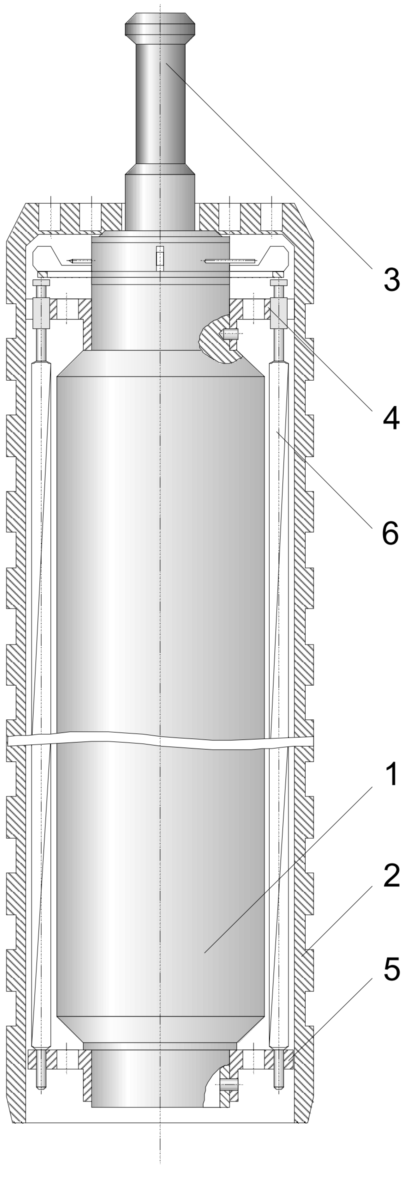


Figure 1 shows the schematic drawing of the irradiation device. The device consists of a cylindrical aluminum body (1) and a casing (2). The body has a special head (3) for the gripping tool, an upper spacer grid (4) and the low grid (5) to hang the fuel element on. The mini fuel elements are placed in the annular gap between the body and the casing. Up to 36 mini fuel elements (6) can be mounted into the device. If necessary, the mini fuel elements could be replaced by displacers. Two irradiation devices are loaded in the reactor channel at a time.

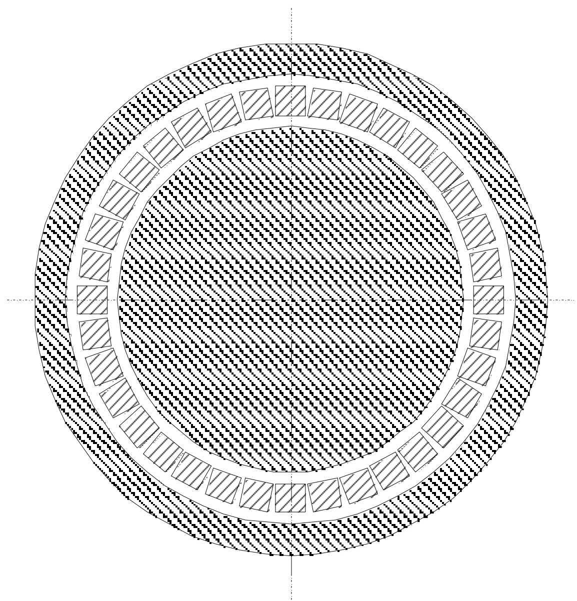


Figure 1. Irradiation device

Figure 2 gives the photograph of the device at its final stage of assembly before mounting into the reactor.

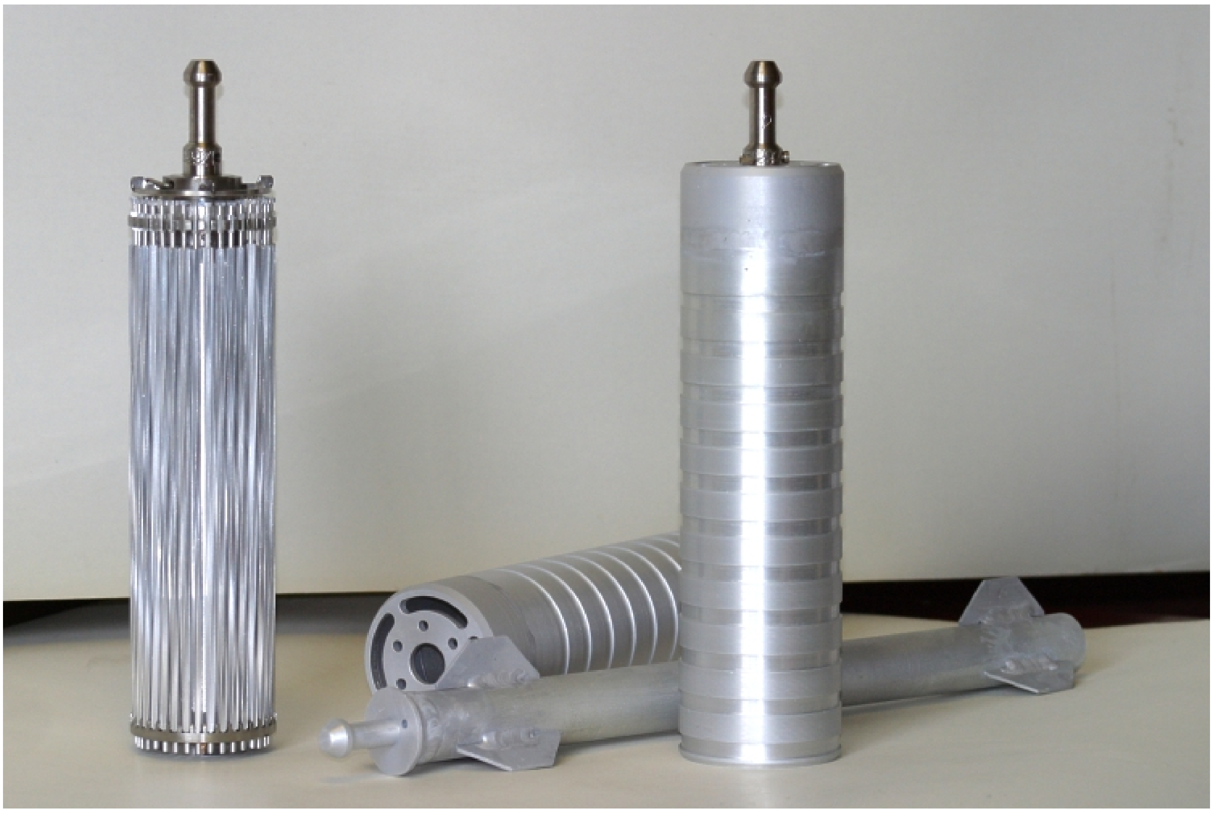


Figure 2. The photograph of the irradiation device

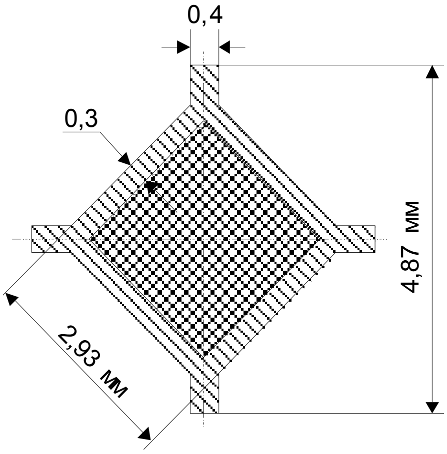
Table 1 shows basic characteristics of the mini fuel elements.

Characteristic	Value	
Cladding material	Aluminum alloy	
Fuel meat	UMo + Al	
U-235 isotope enrichment, %	19,7 ± 0,3	
Uranium density in the fuel meat, g/cm³	4	6
Loading ^{235}U, g	0.60 ± 0.12	0.85 ± 0.12
U-Mo volume fraction, %	23 – 25	34 – 38
Fuel meat length, mm	200 ± 20	200 ± 20

Table1. Characteristics of mini fuel elements.

Schematic drawings and cross-section of mini fuel element are illustrated in figure 3.

Figure 3. Schematic drawings and cross-section of mini fuel element



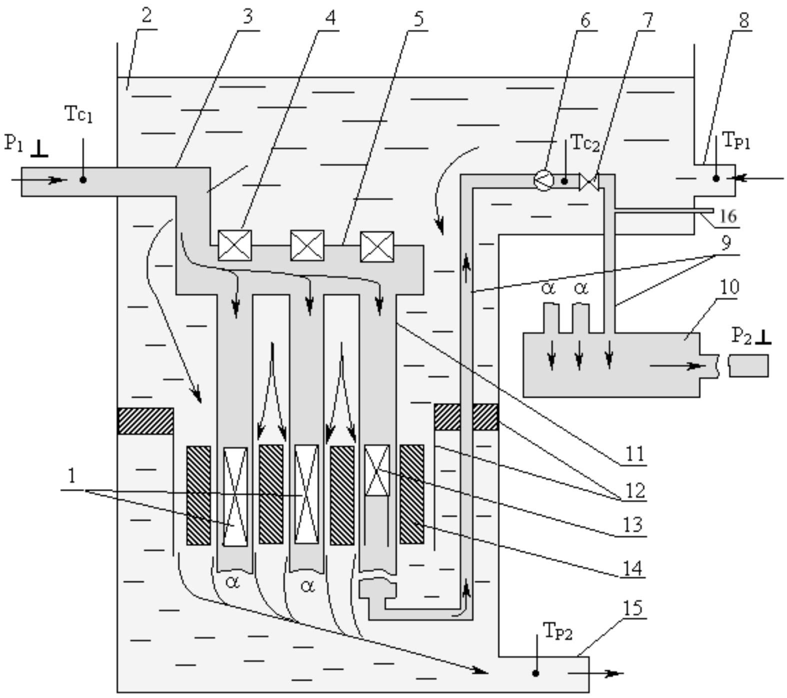
3. Means and methods of test parameters control

Figure 4 shows the layout of the instrumentation to measure coolant parameters at the test channel inlet and outlet. The coolant pressure and temperature at the test channel inlet are determined by the results of the measurement of the cited parameters at the distributing manifold input. The coolant temperature and flow rate are measured directly in the channel outlet pipeline. The corrective amendments to stipulate the coolant temperature and pressure at the inlet and outlet of the irradiation device are attained by means of calculation and test while processing the results of the specially prepared experiments. After each channel the coolant is sent to cladding leakage detector. The method of determination is based on measurement of fission products' delayed neutrons.

In order to determine the total energy release power in the mini fuel elements the procedure as follows is used:

$$N = k_1 \cdot C_P \cdot G(T_{C2} - T_{C1}) + k_2(T_{C2} - T_{P1}) - k_3 N_{PFA},$$

where: G, T_{C1}, T_{C2}, T_{P1} are parameters to be measured;
k_1 is an energy carry-over coefficient of n-, γ- irradiation beyond the channel ,
k_2 is the heat-transfer coefficient from the channel pipeline into the reactor pool water;
k_3 is the heating coefficient of the experimental channel by the reactor irradiation.
Coefficients k_1, k_2, k_3 are determined in special verification experiments using irradiation device fragments.



T_{C1}, T_{C2}; T_{P1}, T_{P2} – thermometers; P_1; P_2 – pressure transducer.

1 – operating FA; 2 – reactor pool; 3 – primary coolant inlet; 4 – channel plug; 5 – inlet collector; 6 – flow meter; 7 – adjustable valve; 8 – coolant inlet to the pool; 9 – RC outlet pipe; 10 – outlet collector; 11 – reactor channel; 12 – reactor casing; 13 – irradiation rig; 14 – beryllium block; 15 – coolant outlet from the pool; 16 – coolant sampling to cladding leakage detector.

Figure 4. Layout of the instrumentation to measure coolant parameters.

4. The main test parameters

The mini fuel elements are cooled by distilled water with pH ~ (5.5-6.0) of primary circuit of the reactor.
The main test parameters are presented in Table 2.

Table 2

Test parameters of mini fuel elements

Parameter	Value
Power of mini fuel element, kW	1.3-1.9
Surface heat-flux density, MW/m^2 - average - maximum	 0.4-0.6 0.9
Inlet coolant pressure, MPa	1.1-1.3
Inlet coolant temperature, º C	30-70
Coolant velocity, m/s	2.3-3.0
Maximum surface temperature of cladding,º C	110
Maximum temperature of fuel meat,º C	125
Maximum neutron flux $E_n > 0.1$ MeV, $cm^{-2} \cdot s^{-1}$	$6 \cdot 10^{13}$

The distribution of the neutron flux, energy release and burn-up in the mini fuel elements are determined by calculations using a three-dimensional code MCU by "Monte-Carlo" method [5]. The results of relative heat power distributions calculations in the mini fuel elements for different means burn-up are shown in figure 5. (Burn-up: 1- 0%; 2- 27,3 %; 3 – 51,6%; 4 – 68.1%).

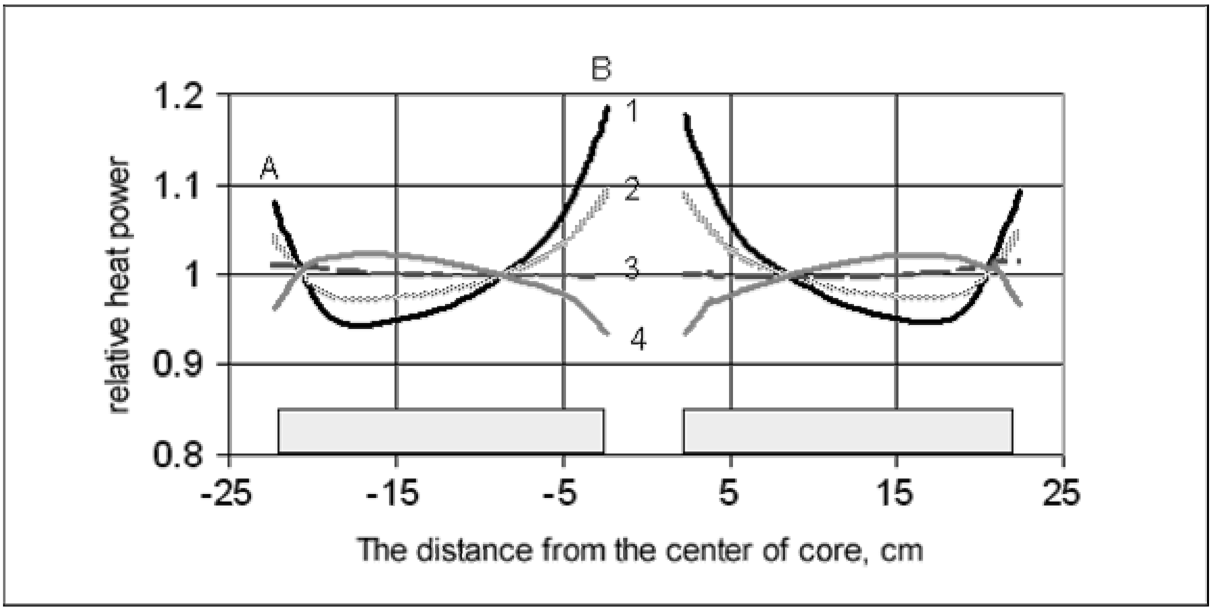


Figure 5. The relative heat power distributions

The azimuth heat power distributions in the mini fuel elements with different loading ^{235}U are presented in figure 6. These calculations are carried out using maximum ununiformity of neutron flux surrounding the experimental channel.

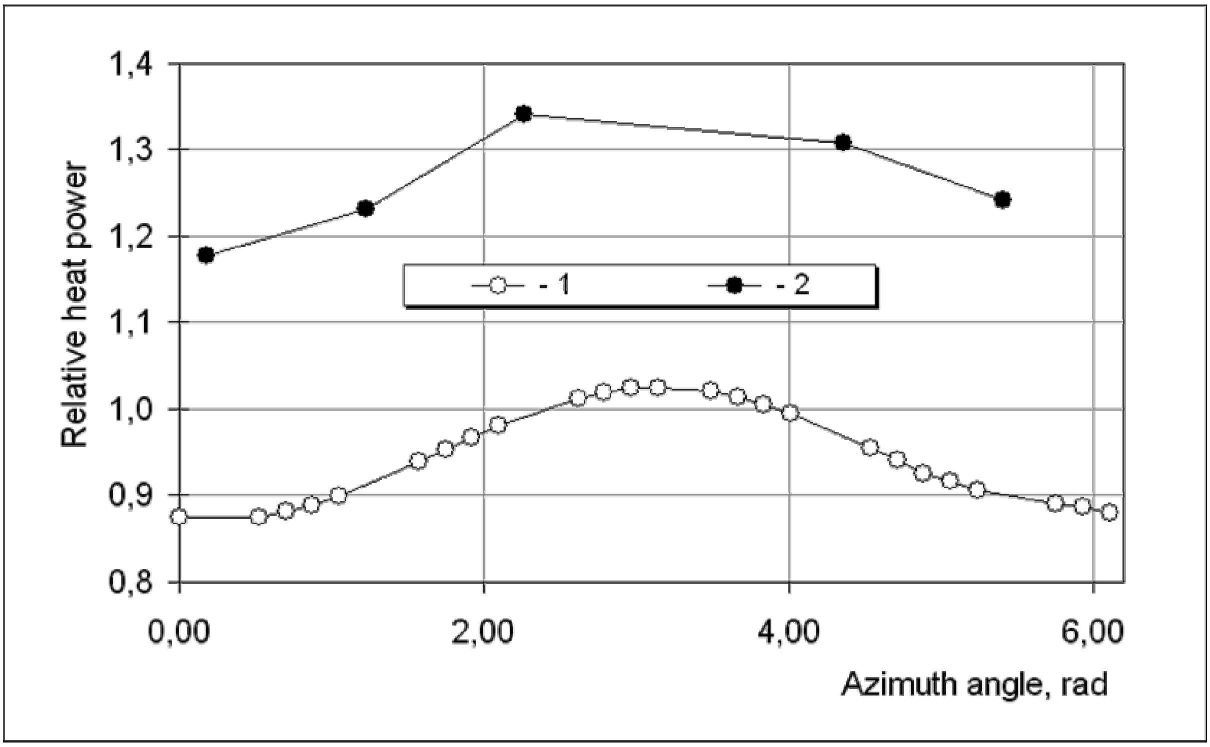


Figure 6. Azimuth distribution of relative heat power in the mini fuel elements:
1 – 4 gU $см^{-3}$; 2 – 6gU $см^{-3}$.

5. Conclusion

Testing of pin type fuel elements with low enriched U-Mo fuel with the uranium density being up to 6 g/cm^3 was started in the MIR reactor on August 27, 2003. The operating parameters are those typical for low and mean power pool reactors.

The testing is supposed to be carried out until uranium-235 burn up attains ~70% with intermediate post irradiation examinations at ~20% and 50% burn up, correspondingly.

As of October 1, the U-235 mean burn up in the fuel elements made up~4.5%. The ~20% burn up should be attained by ~December 15, 2003, when one of the irradiation devices is unloaded from the reactor for the fuel elements cooling and subsequent material structure investigations.

6. References

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