"TESTS OF PIN-TYPE FUEL ELEMENTS IN THE WWR-M REACTOR"

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ABSTRACT

Pin-type fuel elements loaded with LEU UO_2 and U-Mo in Al matrix are being tested. A detailed description of the tested FEs was previously presented by Y. I. Trifonov (VNIINM) at the RERTR-2002 meeting.

The ~~S~~standard WWR-M5 reactor fuel assemblies and the experimental assemblies substantially differ in their loading, enrichment, hydraulic resistance and specific heat-exchange surface. This report briefly describes the main operations aimed at testing the experimental FEs in the WWR-M reactor.

Experimental data and the evidence that the standard WWR-M5 FEs of the WWR-M reactor and the experimental assemblies can work together are presented.

A test method is described. The results of the tests in the experimental reactor loop before loading into the core are presented. The initial level of FEs' non-integrity is determined .

1. Introduction

The work is being performed within the framework of the Russian program for the development of pin-type FEs intended to replace tube-type FEs for a range of reactors [1]. Pin-type FEs [2] may replace tube-type FEs of WWR-M2. Development of tube-type low enrichment FEs, such as WWR-M2, has been completed [3], and they were accepted for manufacturing. There is a certain hope that the manufacturing of pin-type FEs will be easier [1] than the tube-type FEs. Naturally, reactor tests are a necessary stage of their development.

2. Characteristics of experimental FAs and test modes

The developer and manufacturer of experimental FEs and FAs for the tests, - VNIINM, -

prepared two kinds of dispersion fuel: uranium dioxide in Al matrix and uranium-molybdenium alloy in Al matrix. Characteristics of FEs are presented in tables 1 - 3 and in figure 1.

Table 1

Parameters of fuel granules

	Uranium - molybdenium alloy	Uranium dioxide
Granules size, μ	160÷60	100÷60
Uranium content of, %	90.8	87.13
Enrichment, %	19.7	19.6
Density, g/cm^3	17.23	10

Table 2

Geometrical characteristics of FE

Circumscribed diameter, mm	4.85
Thickness of fin, mm	0.4
Cladding thickness, mm	0.3 min
Quadrate side, mm	2.93
Length , mm	550.5
Fin curling step, mm	320
Square section , mm^2	9.0
Core section, mm^2	5.12
Perimeter , mm	15.6

Table 3

Features of fuel

No	Fuel composition	Average uranium-235 load per FE (g)	Uranium concentration in fuel, (g/ cm^3)	Length of fuel meat (mm)	Volume share of fuel component, %
1	(U-Mo) + Al	2.54	5.3	500	33.9
2	UO_2 + Al	1.30	2.7	500	31.0

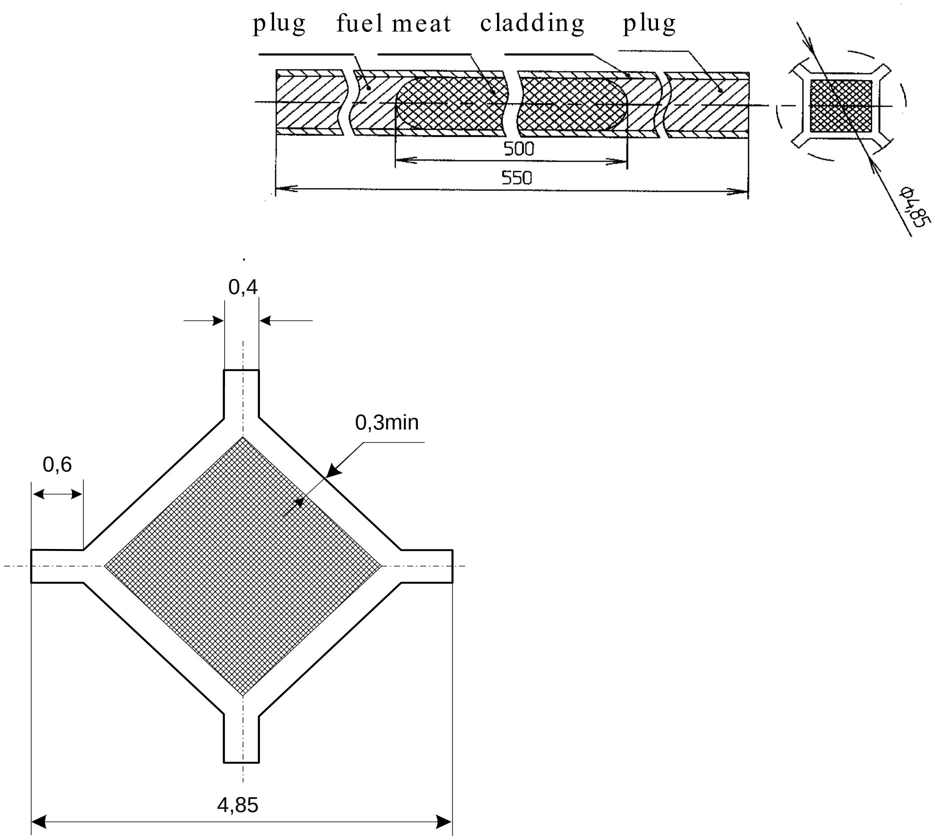

Fig.1. Pin-type fuel element

FEs are combined into two assemblies for the test. Their characteristics are presented in table 4 and in figure 2.

Table 4 Fuel assembly

Characteristics of FA	Fuel UO_2+Al	Fuel (U-9%Mo) +Al
Quantity of FEs in a FA	37	37
U-235 Content in a FA, g	48.0	93.8
Water flow area, mm^2	467.3	467.3
Cooling surface, m^2	0.288	0.288
Hydraulic diameter, mm	2.74	2.74
Volume of fuel, cm^3	94.8	94.8
Volume share of water	0.523	0.523
Total length of FA, mm	748.5	748.5
Size on a "turn-key" basis, mm	32	32

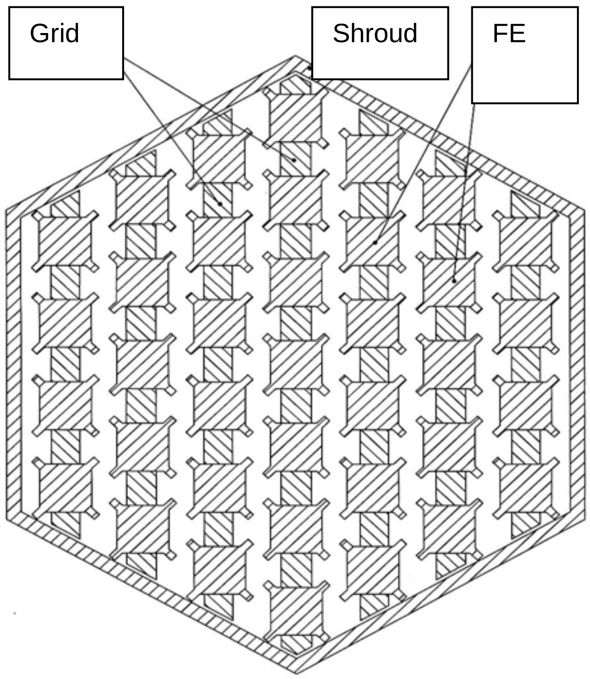

Fig. 2 Arrangement of FEs in the assembly.

The developed FAs do not affect the cooling conditions of serial (standard) FAs of the WWR-M reactor, and allow their combined operation in the core. Meanwhile, it is necessary to ensure sufficient power of experimental assemblies in order to achieve high burnup, and to ensure sufficient reserve prior to crisis. The comparison of the FEs characteristics is given in table 5, and gives an idea of the peculiarities of neutron-physical and heat-hydraulic calculations of each load. Figure 3 shows a combined load of standard WWR-M5 and experimental fuel assemblies.

Table 5 Comparative characteristics of standard and experimental FAs

FE type	Enrichment, ^{235}U %	Specific heat-exchange surface cm^2/cm^3	Uranium density in fuel g/cm^3	Concentration of ^{235}U in core g/l	Hydraulic diameter, Mm
WWR-M	90	6.6	1.2	125	3.1
Experimental UO_2	19.7	5.43/4.56*	2.7	90.5	2.74
Experimental U-Mo	19.7	5.43/4.56*	5.3	177	2.74

* Effective data in denominator present unevenness of heat flux on the FE perimeter.

Calculated parameters in the test are presented in table 6.

Table 6. Supposed parameters of FEs during tests

Type	Water velocity, m/s	Hydraulic diameter, mm	$q_{s\ max}$. MW/m^2	Max. power of FA, kW	$q_{V\ max}$, MW/m^3 (in the size of a cell)
WWR-M5	3	3,1	0,74	214	485
Experimental	2,72	2,74	0,67	135	306

In the calculation of the maximum temperature of FE's wall we took into account a previously fixed coefficient of heat flux density unevenness in the perimeter of fuel element. Profile coefficient is equal to 1,19 for the experimental FE’s and for axial 1.2 for both FEs.

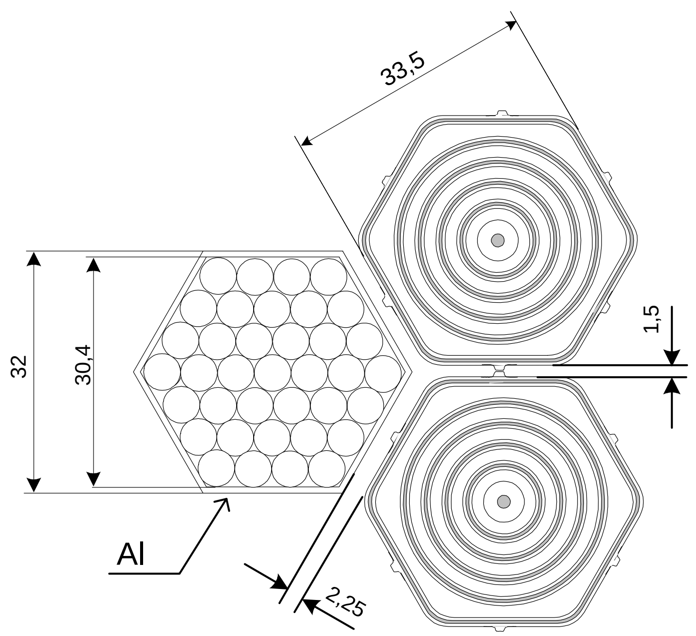

Fig. 3 Combination of experimental and standard FAs

Data in table 6 are considered as the maximum. In real position in the core power is less namely 95-100 kW per FA. An example of loading is given in figure 4.

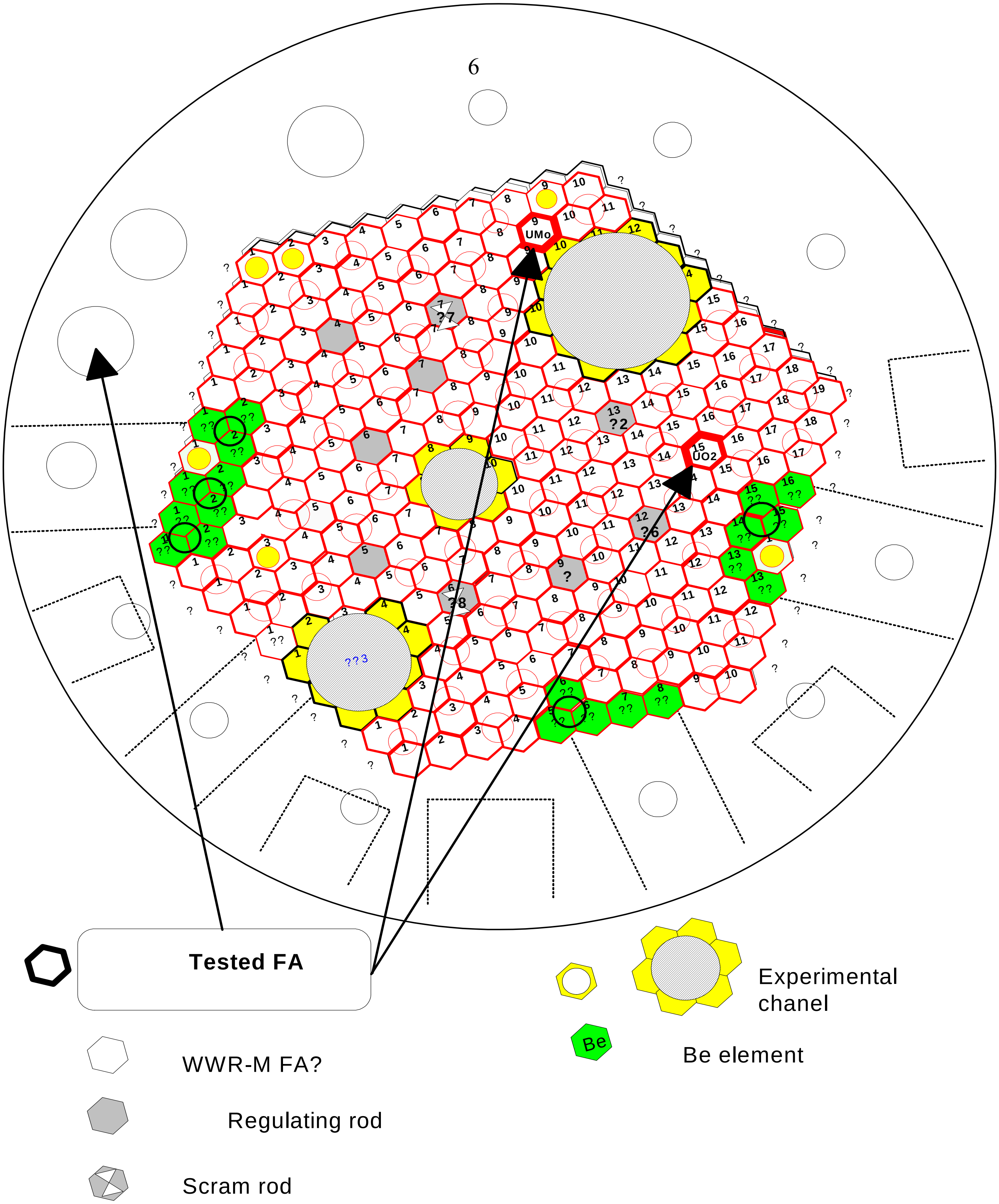

Fig. 4 Map of the designed first load of experimental FAs

Uranium - 235 load of experimental FAs with UO2 and U-Mo fuel differs approximately in 2 times. The WWR-M reactor core ensures simultaneous tests of such assemblies with similar operational parameters (maximal specific power in hot spots). The said conditions for initial installation of FAs correspond to the values of maximal and minimal energy release irregularity coefficients K_r which differ by approximately 4 times, which allows to cover the difference in energy release caused by difference in loads of uranium - 235. As uranium - 235 burns up, a FA with U-Mo fuel may be moved to an area with higher neutron fluxes. If necessary, energy release profiling in the core is ensured by rearrangement of serial FAs with different burnup, use of additional poisons, or with submergence of one of the standard regulation rods. Following its burnup tested FA will be replaced in another cells and will be surrounded with WWR-M5 FA with another burnup to provide requested power.

The expected maximal energy release q_v in the case of putting FA with UO2 fuel in an area with maximal energy release will be a little bit lower as shown in table 6. An area with minimum energy release is chosen for the beginning of tests of FAs with U-Mo fuel.

Energy release of FAs in the core is calculated according to the HEXA two-dimensional diffusive program, MCU-3 and MCNP-4C. Burnup of 60% will be achieved in approximately 280 effective days for UO_2 FEs, and 560 days for U-Mo FEs.

3. Test method

Experimental pin-type FEs are combined into assemblies which have the same configuration as standard WWR-M5 tube-type FAs and are loaded in the core of the WWR-M reactor. Periodically, as burning up goes on, experimental FAs will be extracted from the core and put into a water loop for the purpose of measuring their integrity. This method was used for research for the WWR-M2 low enrichment FEs and is described in [3]. Non- integrity level is estimated proceeding from leakage of several fission-fragments Kr-85m, Kr-87, Kr-88, Xe-135, Xe-138 into the loop water and into gas volume of the loop.

An experimental loop for tests is equipped with an independent cooling circuit and is provided with: necessary instrumentation; delayed neutrons permanent fuel non- integrity monitoring system; coolant (water) and gas (air) sampling system for measuring fission products leakage.

The non- integrity criteria are assumed as the estimate of efficiency of fuel assemblies. The quantitative parameter of non- integrity level $\beta = V/Q$ is calculated as a ratio of the rate of arrival of fission fragments into heat-transfer medium **V** to the rate of generation of fission fragments in fuel **Q** [3].

Generation of fragments is calculated proceeding from energy release, which is fixed according to readings of heat monitoring devices in an experimental loop. Together with testing experimental FAs, non- integrity of serial assemblies is monitored, which allows us to take into account possible deviations of the non- integrity parameter in the case of deterioration of the state of the core, as a whole.

The test method provides for:

- monitoring non-integrity of fuel elements prior to their loading into the core. In an experimental loop, sampling of water is carried out, and the quantitative non- integrity parameter β is fixed. Such preliminary tests help to reveal possible workmanship defects early on.
- Loading experimental FAs into the core and their operation in the mode of serial assemblies.

During this time, non- integrity of the core, as a whole, is monitored.

- Periodic checks of non- integrity of FAs in an experimental loop upon achievement of rated burnup. Usually 3 to 5 measurements are carried out in an experimental loop during tests.

Control measurements of energy release prior to the beginning of tests of fresh FAs are carried out by measuring activity of ^{140}La in fuel and by Au monitors [3].

4. Safety

To ensure safe tests, operational parameters of experimental FAs are additionally limited in comparison with serial WWR-M5 items.

Tests shall be stopped, if the non- integrity parameter β exceeds $2 \cdot 10^{-5}$, in order to prevent contamination of the water loop. This parameter ensures the warranted limits of rates and fixed quotas for radionuclide emission. If more considerable damages are revealed, in connection with direct contact of fuel with heat-transfer medium, FAs shall be removed to a hermetic case for storage of defective assemblies. In the case of favorable non-integrity parameters, tests of FAs shall be continued until 60% of burnup, on average, is achieved per assembly.

5. Results of non- integrity test before loading

Both FA were tested in the water loop. Results are presented in table 8

Tab.8

FA	Reactor Power, Mw	FA power, kW	Non-integrity β, 10^{-7}
U-Mo	11.7	30	4±1
UO_2	13	25	6±2

A some higher level of heat-transfer a medium level of activity in the loop was observed. The calculated parameter β was approximately in 2 times higher than usually in standard WWR-M5 FAs. Nevertheless, after additional washing activity fell up to the normal level. This effect may be explained as contamination of the surface with uranium.

Compare with standard WWR-M5 fuel some higher level of cooling water activity in a loop was observed. Parameter β was approximately in 2-4 times higher than usually for WWR-M5 standard FAs. Calculated surface contamination was about 10^{-8} g ^{235}U/cm^2 and this is at least 2 times lower than allowed specification level. During the tests the noticeable drop of the instrument readings of delayed neutrons leak tightness control was observed instead of the expected slow rise. This is evidence for the existence of a layer of surface contamination that was washed off over the course of the experiment.

Based on the results of the preliminary tests, both assembles were allowed to be used in the next testing phase in the reactor core.

Acknowledgments

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