Russian RERTR Program: Advanced LEU Fuel Development for Research Reactors.

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ABSTRACT

Pin-type fuel elements of new generation have been developed for conversion of Russian-built research reactors to LEU. This paper contains the main results of out-of-pile investigations during manufacturing of experimental batches of mini- and full size fuel elements for irradiation tests in "MIR" (Dmitrovgrad) and VVR-M (Gatchina) reactor respectively. U-Mo LEU fuel granules have been manufactured both by centrifugal atomization and by hydride-dehydride process. Loading of mini-fuel elements made 4 and 6 g U/cm^3, whereas full size ones were loaded to 5.3 g U/cm^3. All fuel elements went through quality control of cladding thickness and uniformity of fuel granules distribution through the length of each one.

1.Introduction.

During recent years new types of fuel assemblies for research reactors on the base of pin-type fuel elements with LEU fuel have been developed in Russia. Computational and experimental researchers to substantiate applicability of these fuel assemblies in the main types of Russian-built research reactors (including VVR-M one) had been performed earlier [1].

Two experimental VVR-M2 type fuel assemblies for irradiation tests have been manufactured by the present time.

Investigations of high density U-Mo fuel are being proceeded now. In the frames of this researches mini-fuel elements with a number of various fuel compositions on the basis of U-Mo fuel granules have been manufactured for irradiation tests in "MIR" reactor [2].

This paper contains information on technical characteristics and parameters of fuel elements and fuel assemblies manufactured. Description of results of FE quality control is given also.

2. Design and fuel element parameters.

The design of fuel element constitutes pin of square cross section with spacers as fins at the corners twisted with pitch 320 mm (figure 1).

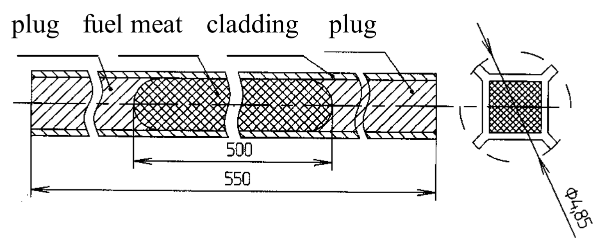


Fig.1 Pin type fuel element

FE has cladding of aluminum alloy SAV-1 and fuel meat made of disperse composition. One of fuel assemblies contains fuel granules of U-9.2Mo alloy, another – uranium dioxide (table 1) [3].

Table 1

Parameters of fuel granules.

Material	Size of fuel granules (mcm)	Uranium concentration (%)	Enrichment (%)	Density (g/cm^3)
U-Mo alloy with 9,2% Mo	160÷60	90,8	19,7±0,3	17,23
Uranium dioxide	100÷60	87,13	19,7±0,3	10

Real parameters of fuel elements are given in tables 2 and 3.

Table 2

Dimensional parameters of fuel element

Circumscribing diameter (mm)	Thickness of fin (mm)	Thickness of cladding (mm)	The side of cross-sectional square (mm)	Length of FE (mm)
$4{,}85_{-0{,}05}$	0,4	0,3 min	$2{,}93_{-0{,}05}$	550,5-1

Table 3

Technical parameters of fuel element

№	Fuel composition	U-235 loading per FE (g)	U concentration in fuel meat, (g/cm^3)	Length of fuel meat (mm)
1	(U-Mo) + Al	2,62±0,13	5,3	500±20
2	UO_2 + Al	1,27±0,06	2,7	500±20

3.FE quality control

Following FE main parameters were being controlled while manufacturing:

- overall dimensions;
- fuel meat length;
- thickness of cladding;
- uniformity of fuel granules distribution through FE length;
- mass of uranium-235 in the fuel meat.

The length of fuel meat has been determined with X-ray installation RUP-200.

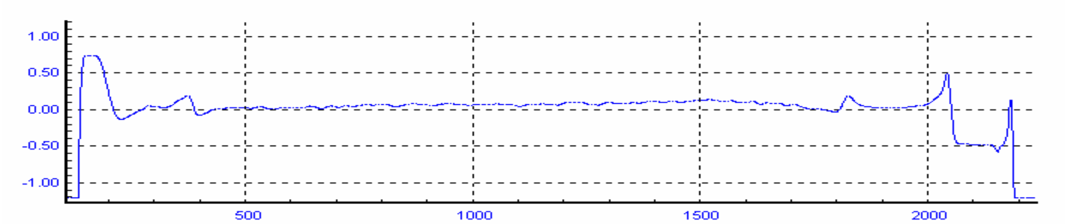
Thickness of cladding has been controlled by the eddy current technique using experimental device (AVK) combined with eddy current transducer (VTP). Three methods of eddy current control were being used [4]:

- absolute method, which permits to determine deviation of parameter under control (thickness of cladding) respectively to reference samples with already known parameters;
- differential method, revealing local defects such as fuel granules inculcated into cladding;
- amplitude-phase method which provides suppression of the influence from disturbing factors, for example alteration of the overall dimensions of fuel element and electric conductivity of fuel meat, and to determine the depth of fuel granules location.

Each fuel element was being controlled 8 times at 4 different modes each corresponding to various depth of eddy current penetration through the cladding.

Typical diagrams of eddy current control are shown in figures 2 (fuel composition – UO_2-Al) and 3 (fuel composition – (U-9.2Mo)-Al) [5].

(FE №5) absolute channel



(FE №5) differential channel

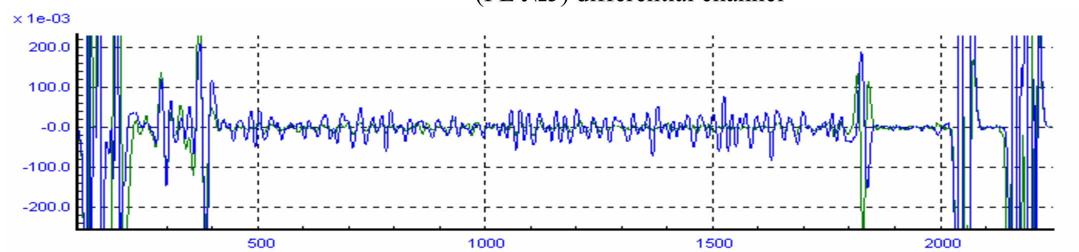
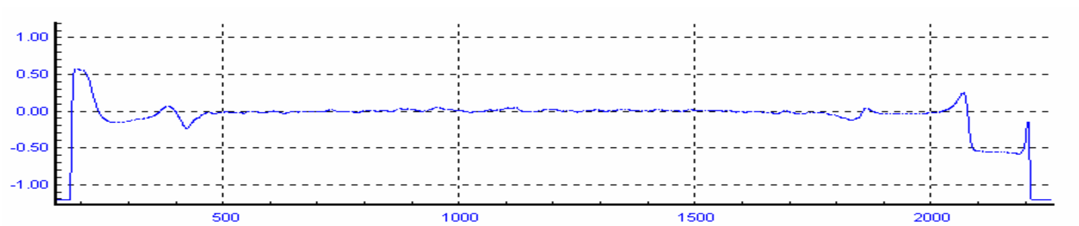


Fig. 2. **Typical diagrams of fuel elements with fuel composition on the base of uranium dioxide**

Fuel elements №5 (suitable for operation)

(FE № 60) absolute channel (ac)



(FE № 60) differential channel (dc)

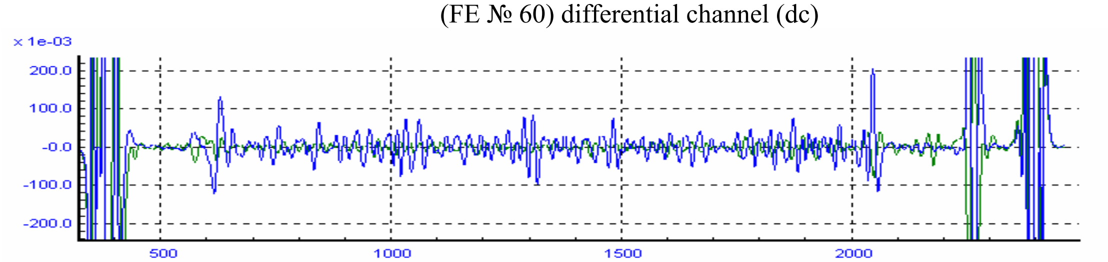


Fig. 3. **Typical diagrams of fuel elements with fuel composition on the base of uranium-molybdenum alloy**

Fuel element №60 (suitable for operation)

Centerline of diagram (zero value of AVK signal) corresponds to rated thickness of cladding - 0,3 mm.
As a result of measurements of fuel element parameters with non-destructive eddy current technique it has been shown that minimal cladding thickness for majority of fuel elements was not less than 0.3 mm and was uniform throughout the FE length. Several fuel elements were shown to have the areas (not longer than 0,15 mm) where the thickness of cladding made 0,25 - 0,2 mm. Such fuel elements have been excluded from the experimental batch of fuel elements intended for irradiation tests.
Control of uniformity of fuel granules distribution (K_T) has been performed with equipment for gamma absorption radiometric control of mass and distribution of fissile material in fuel elements [6].
Typical diagram for uniformity of fuel distribution through the length of fuel element suitable for operation is shown in figure 4.

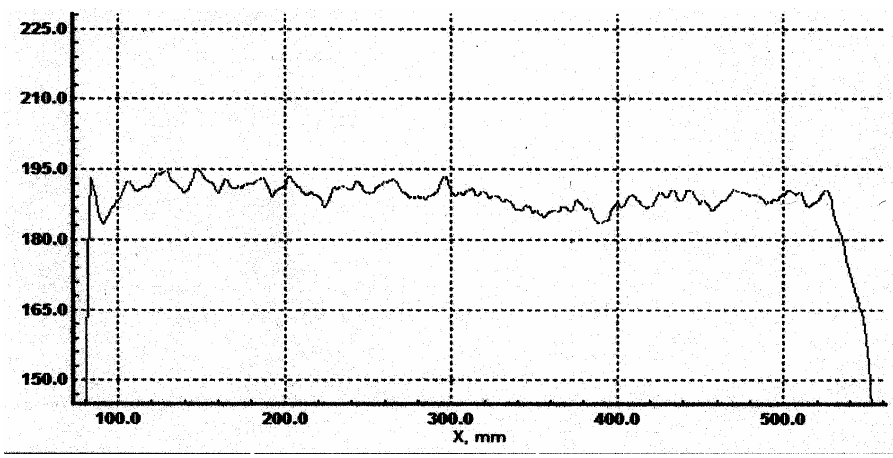


Fig.4 Typical diagram of fuel distribution through the length of fuel element

Measured value of K_T for all fuel elements suitable for operation didn't exceed 1.15.
To confirm the results of non-destructive testing several fuel elements have been cut and their cross sections have been examined with metallography microscope. Typical polished sections of suitable fuel elements are shown in figure 5.

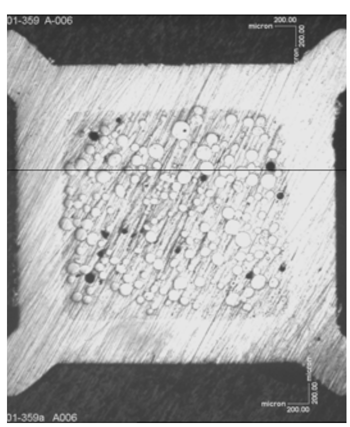


Fig. 5 Cross section of pin type fuel element

4.Design and parameters of fuel assembly.

Design of experimental fuel assembly (fig. 6) has the same overall dimensions and end parts as VVR-M2 does and as well matches the main parameters. FA consists of shroud with 37 fined pin-type fuel elements, spacers as upper and bottom grids, head and tail piece. Shroud represents a pipe with hexahedral cross section, which is connected with head and tail piece by forcing it into the dimples on the ribs of end parts. Thickness of shroud made 0,80 ± 0,05 mm. Parameters of FA manufactured are given in table 4.

Table 4

Parameters of VVR-M2

FA №	Type or fuel	Number of fuel elements in FA	Weight of U-235 per FA (g)	Total length of FA (mm)	Size of shroud (mm)
11	UO_2+Al	37	48,0	748,5	32,0-32,2
22	(U+9%Mo)+Al	37	93,8	748,9	32,0-32,2

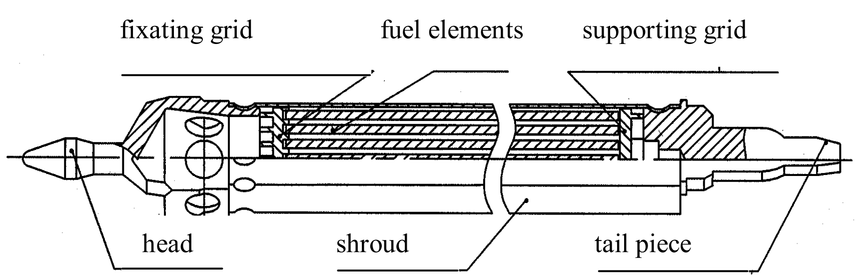


Fig.6 Design of fuel assembly

Upper separating grid fixates fuel elements in definite position respectively to each other. Rightness of design solutions had been demonstrated earlier with hydraulic tests of dummy fuel assembly [7].

The test on strength of fastening between shroud and end parts has been realized using dummy FA. The result of test showed that the force of tearing away the end parts from the shroud made more than 400 kg.

Fuel assemblies manufactured are intended for irradiation tests in Gatchina's research reactor VVR-M2 [2].

5.Mini-fuel elements for irradiation tests of fuel compositions

To evaluate serviceability and select fuel composition with suitable irradiation behavior the in-pile tests of the set of mini-fuel elements with various fuel compositions (table 5) [8, 9] shall be conducted in test facility of "MIR" reactor. More than 72 such mini-fuel elements have been manufactured which also underwent full-scale quality control of the main parameters. The design of mini-fuel elements is drawn in figure 7.

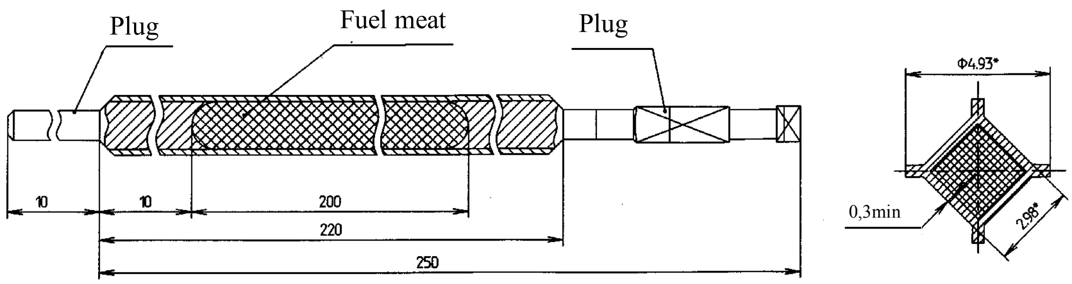


Fig.7. Design of mini-fuel element.

Table 5.

Characteristics of fuel meats of mini-fuel elements.

Designation	Alloy	Characteristics of fuel elements				
UM-9,2	U+(9,2)%Mo	Method of manufacturing fuel granules	Atomization			
		Phase composition	Single phase (γ)		Two phase (α+γ)	
		U concentration	6 g/cm^3	4 g/cm^3	4 g/cm^3	
UM-7,3	U+7,3%Mo	Method of manufacturing fuel granules	Atomization			
		Phase composition	Single phase (γ)		Two phase (α+γ)	
		U concentration	6 g/cm^3	4 g/cm^3	4 g/cm^3	
UM-7,3 L1	U+7,3%Mo+ $(0,1^{-0,05})$%Al	Method of manufacturing fuel granules	Atomization			H-D processing
		Phase composition	Single phase (γ)			Single phase (γ)
		U concentration	4 g/cm^3			4 g/cm^3
UM-7,3 L2	U+7,3%Mo+ $(0,2^{-0,05})$%Al	Method of manufacturing fuel granules	Atomization			
		Phase composition	Single phase (γ)			
		U concentration	4 g/cm^3			
UM-7,3 L3	U+7,3%Mo+ 0,2%Al+ 0,2%Sn	Method of manufacturing fuel granules	Atomization			H-D processing
		Phase composition	Single phase (γ)			Single phase (γ)
		U concentration	4 g/cm^3			4 g/cm^3
UM-1,5L	U+1,5%Mo+ (0,2)%Al+ (0,2)%Sn	Method of manufacturing fuel granules	Atomization			
		Phase composition	Two phase (α+γ)			
		U concentration	4 g/cm^3			

6.Conclusions.

Experimental fuel assembly with pin-type fuel elements on the base of LEU fuel has been manufactured for full-scale irradiation tests. Parameters and characteristics of fuel assembly meet all necessary requirements.
Mini-fuel elements with low enriched U-Mo fuel varying on fuel compositions used have been manufactured for irradiation tests in "MIR" reactor.

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