RERTR 2009 — 31st INTERNATIONAL MEETING ON
REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS

November 1-5, 2009
Kempinski Hotel Beijing Lufthansa Center
Beijing, China

SAFETY ANALYSIS FOR THE FIRST LOADING OF LEU FUEL INTO THE WWR-M RESEARCH REACTOR IN UKRAINE

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ABSTRACT

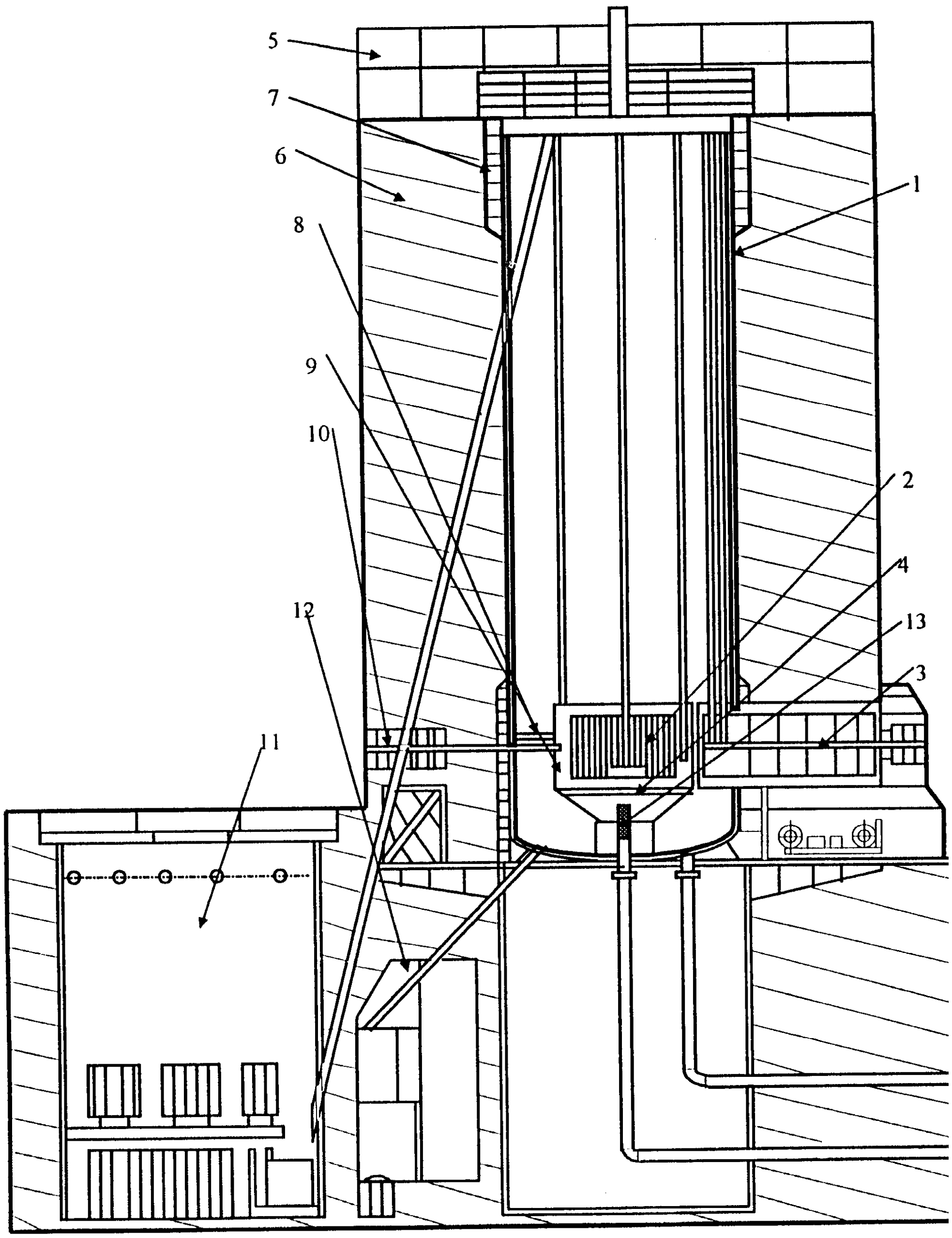
The WWR-M research reactor in Ukraine is converted to the use of LEU fuel. Current HEU (36%) WWR-M2 fuel assemblies (3 tubes, UO2-Al fuel meat with 1.1 gU/cm3 and 37.0 g ^{235}U) are successively replaced by available LEU (19.75%) WWR-M2 fuel assemblies (3 tubes, UO2-Al fuel meat with 2.5 gU/cm3 and 41.7 g ^{235}U). The conversion process begins with the replacement of the most depleted single HEU fuel assembly by a fresh LEU fuel assembly. The safety analysis for the first loading of LEU fuel into the reactor is performed. Neutronics and thermal-hydraulics parameters of the real mixed core containing both LEU and HEU fuel are calculated. In accordance with the requirements of the Nuclear Regulatory Committee of Ukraine, the program of pilot usage of LEU fuel including comparison of calculation and measurement results is developed.

1. Introduction

The WWR-M reactor in Kiev (Ukraine) is a light-water cooled and moderated research reactor with beryllium reflector. Its nominal power is 10 MW. Current HEU fuel assemblies are WWR-M2 (36%) and WWR-M5 (90%). LEU replacement fuel assemblies are LEU WWR-M2 (19.75%), which have been tested successfully in the WWR-M reactor in Gatchina, Russia by irradiation to over 75% burnup [1]. The reactor and fuel assembly parameters and designs are shown in Fig.1-4 and Table 1 [1-3].

The study confirming the feasibility of converting the WWR-M research reactor in Ukraine to the use of LEU fuel was completed in 2002 [4]. The safety analysis to qualify the LEU WWR-M2 fuel assemblies for conversion was performed in 2004-2005 [5-6]. Safety of fresh and depleted LEU fuel storage was analyzed also [6]. The models applied for calculations were validated against measured data, which include critical experiment results for fresh fuel assemblies and measured neutronic distributions in a real WWR-M reactor core [6]. The safety documentation for LEU conversion of the WWR-M reactor was approved officially by the Nuclear Regulatory Committee of Ukraine in 2005.

The Regulatory Committee required developing the program of pilot usage of LEU fuel including comparison of the calculation and measurement results after each core reload. In accordance with this program, which was approved in 2008, current HEU fuel assemblies are successively replaced by available LEU (19.75%) WWR-M2 fuel assemblies, starting with the replacement of the most depleted single HEU fuel assembly by a fresh LEU fuel assembly.



1 – Reactor Vessel

2 – Reactor Core

3 – Thermal Column

4 – Supporting Grid

5 – Cover

6 – Shield

7 – Cast Iron

8 – Grid for Water Flow Alignment

9 – Beryllium Reflector

10 – A Beam Tube

11 – Spent Fuel Storage

12 – Hot Cell

13 – Filter

Fig. 1. WWR-M reactor

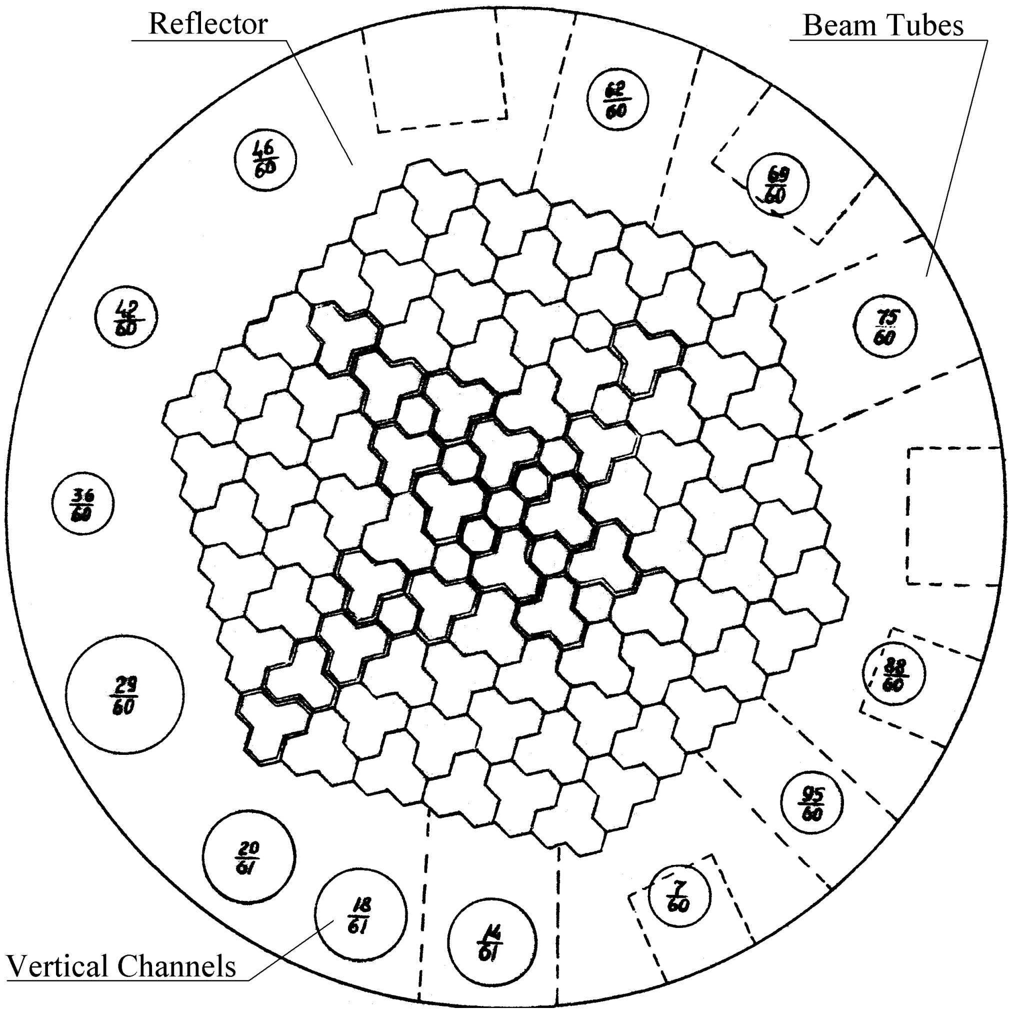


Fig. 2. Reactor Core and Beryllium Reflector

Table 1. Fuel Assembly Parameters

	WWR-M5	WWR-M2	LEU WWR-M2
Enrichment, %	90	36	19.75
Number of fuel elements	6	3	3
Mass of ^{235}U, g	66	37	41.7
Fuel meat composition	UO_2-Al 1.2 gU/cm^3	UO_2-Al 1.1 gU/cm^3	UO_2-Al 2.5 gU/cm^3
Length of fueled region, cm	50	50	50
Pitch/flat-to-flat, mm	35/33.5	35/32	35/32
Element/clad/meat, mm	1.25/0.43/0.39	2.5/0.76/0.98	2.5/0.78/0.94
Specific heat transfer surface, cm^2/cm^3	6.6	3.67	3.67
Hydraulic resistance coefficient	6.5	4.35	4.35
Relative coolant velocities between fuel elements (starting from the center)	0.90; 1.01; 1.08; 0.98; 1.06; 0.88	1.18; 0.89; 1.05; 0.86	1.18; 0.89; 1.05; 0.86

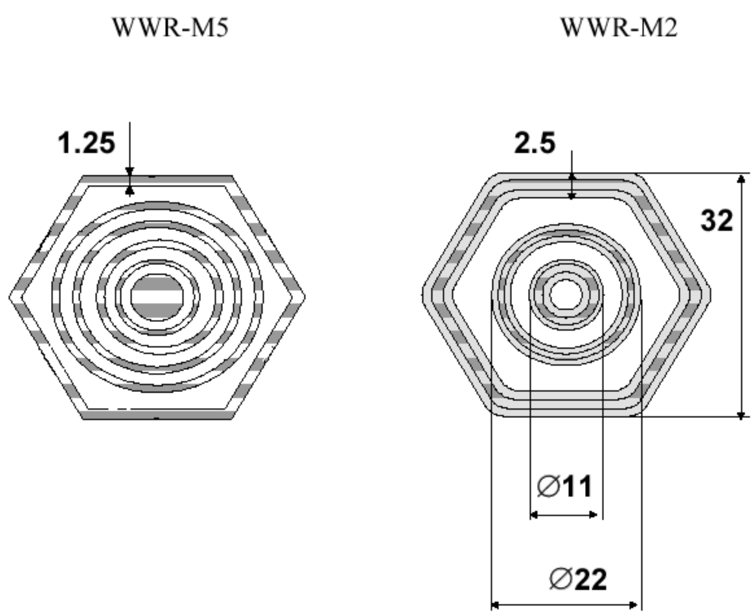
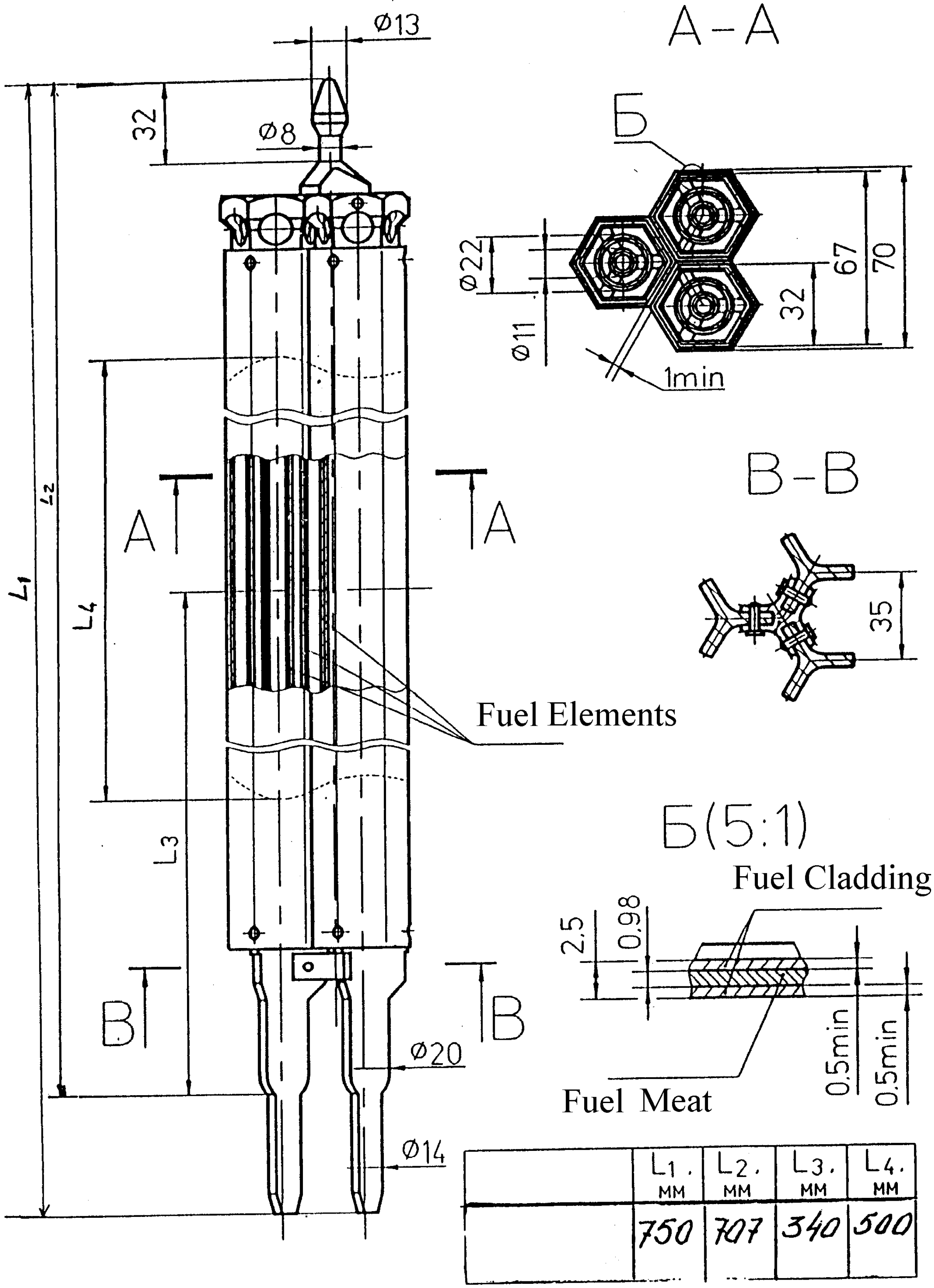


Fig.3. Fuel Assembly Designs



	L1, мм	L2, мм	L3, мм	L4, мм
	750	707	340	500

Fig. 4. WWR-M2 Fuel Assembly

2. The first loading of LEU fuel into the reactor core

The conversion process begins with the replacement of the most depleted single HEU WWR-M2 fuel assembly by a fresh LEU WWR-M2 fuel assembly. The first mixed core containing both LEU and HEU fuel is depicted in Fig. 5.

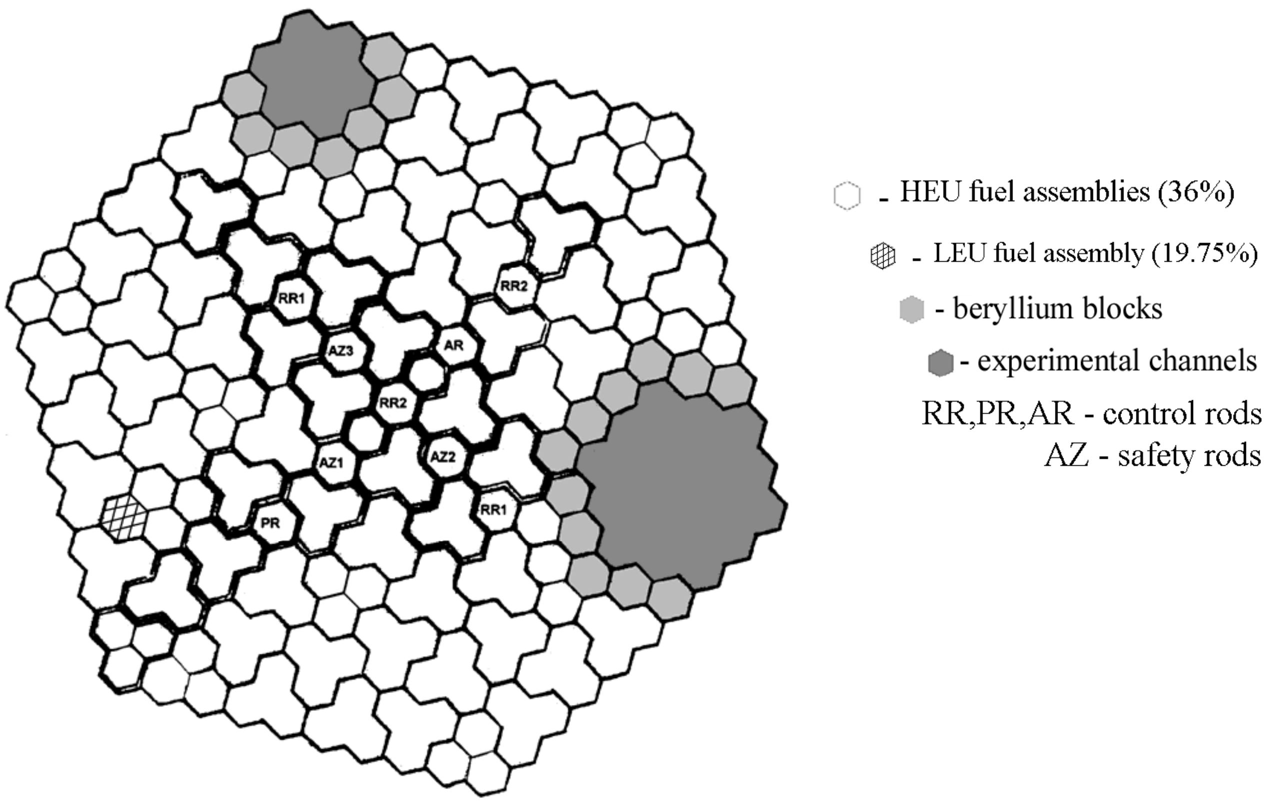


Fig. 5. The first mixed core containing both LEU and HEU fuel (layout No. 393)

To get permission of the Regulatory Committee, safety analysis for the first loading of LEU fuel into the reactor core was performed. For neutronics and thermal-hydraulics calculation, the codes MCNP-4C [7], WIMS-ANL [8] and PLTEMP 2.1 [9] were used. Maximum excess reactivity and minimum sub-criticalities were calculated at beginning of cycle for cold core, no xenon, and equilibrium concentration of samarium. The results are as follows:

- Maximum excess reactivity: 5,6 β_{eff}
- Minimum sub-criticality when RR1, RR2, PR and AR are fully in and AZ1, AZ2 and AZ3 are fully out: 3.3%

- Minimum sub-criticality when RR2, AR, AZ2 and AZ3 are fully in and RR1, PR and AZ1 are fully out: 1.7%

- Power peaking factor: 2.14

- Maximum power density: 193 W/cm3

- Maximum fuel element surface temperature: <93C

- Range of reactivity worth of control and safety rods for various positions of RR1, RR2 and PR, β_{eff}:

RR1	3.6÷3.9
RR2	3.3÷3.6
PR	2.3÷2.5
AR	0.3÷0.5
AZ1	1,8 ÷ 2,6
AZ2	1,4 ÷ 2,0
AZ3	1,8 ÷ 2,6

Rods	Positions of RR1, RR2 and PR, for which the rods worth is minimal		
	Position of RR1, cm	Position of RR2, cm	Position of PR, cm
RR1	-	60	0
RR2	60	-	0
PR	0	0	-
AR	60	60	0
AZ1	60	60	60
AZ2	60	60	60
AZ3	60	60	60

Rods	Positions of RR1, RR2 and PR, for which the rods worth is maximal		
	Position of RR1, cm	Position of RR2, cm	Position of PR, cm
RR1	-	0	60
RR2	0	-	60
PR	60	60	-
AR	0	0	60
AZ1	0	0	0
AZ2	0	0	0
AZ3	0	0	0

The reactor’s safety margin criteria and limiting conditions for operation are as follows:

- When all control rods (RR1, RR2, PR and AR) are fully inserted and safety rods (AZ1, AZ2 and AZ3) are fully withdrawn from the core, minimum sub-criticality should be great than 1.2%.
- When the most effective bank of control rods, the slowest control rod (PR) and the most effective safety rod are fully out the core, and the other rods are fully in the core, maximum effective multiplication factor should be less than unity.
- Maximum excess reactivity should be less than 7,0 β_{eff}
- Maximum fuel clad surface temperature should be less than 95C.
- Range of reactivity worth of control and safety rods, β_{eff}:

RR1	3.0 ÷ 4.5
RR2	3.2 ÷ 4.8
PR	1.5 ÷ 2.5
AR	0.2 ÷ 0.6
AZ1	1.3 ÷ 3.0
AZ2	1.2 ÷ 2.8
AZ3	1.4 ÷ 3.1

As we can see, all the parameters of the first mixed core satisfy the reactor’s safety margin criteria and limiting conditions for operation.

3. Conclusions

The WWR-M research reactor in Ukraine is being converted to the use of LEU fuel. In accordance with the requirements of the Nuclear Regulatory Committee of Ukraine, the program of pilot usage of LEU fuel was developed. Current HEU fuel assemblies are successively replaced by available LEU (19.75%) WWR-M2 fuel assemblies, starting with the replacement of the most depleted single HEU fuel assembly by a fresh LEU fuel assembly. The safety analysis for the first loading of LEU fuel into the reactor was performed. Neutronics and thermal-hydraulics parameters of the first mixed core containing both LEU and HEU fuel were calculated. All the parameters satisfy the reactor’s safety margin criteria and limiting conditions for operation. Permission of the Nuclear Regulatory Committee of Ukraine for the first loading of LEU fuel into the reactor core was obtained.

4. References

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