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CHARACTERISTICS OF THE WWR-K TEST CORE AND THE LEU LTAS TO BE PLACED IN THE CENTRAL EXPERIMENTAL BERYLLIUM DEVICE

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ABSTRACT

In 2010 life test of three LEU (19.7%) lead test assemblies (LTA) is expected in the existing WWR-K reactor core with regular WWR-C-type fuel assemblies and a smaller core with a beryllium insert. Preliminary analysis of test safety is to be carried out. It implies reconstruction of the reactor core history for last three years, including burnup calculation for each regular fuel assembly (FA), as well as calculation of characteristics of the test core. For the planned configuration of the test core a number of characteristics have been calculated. The obtained data will be used as input for calculations on LTA test core steady-state thermal hydraulics and on transient analysis.

1. Introduction

Activities related to conversion of the existing Kazakhstan research reactors and critical assembly to low-enriched uranium fuel (19.7 %) are quite important in the nonproliferation program. Up to now only the program of conversion of the WWR-K reactor and the critical assembly has been prepared [1]. Since a new fuel assembly design is required for the conversion, the irradiation of three LTAs in existing WWR-K reactor core is one of the program items . So, arrangements of the core for the irradiation test, needs special attention. Core configuration with 63 FA-1, 6 FA-2 with control rods and 8 FA-2 with experimental beryllium inserts is taken as the core initial state where history of fuel assemblies is traced beginning with the moment of power re-startup in 1998 up to May of 2009.

At present the core state is practically equilibrium, i.e. in reloads amount of newly installed fuel assemblies equals the amount of removed burnt ones. So, last obtained data on parameters of FAs are quite useful for any re-configuration of the core.

2. Core Description

Reconstruction of core history for a period from July of 2006 to May of 2009 has shown that numerous reloading operations in the core have changed the power distribution over the FAs. Three yeas ago the burned FAs of type 2 (control rods) were changed by fresh ones, so their power increased. As a result, the power in LTAs was lower than required in the previously analyzed core with“42+3 +23Be” [2,3]. So, in view of provision of required LTA power for the test and non-increased test duration, the test core configuration has been revised by means of MCU-REA [4], and actual core state, dated 11.05.2009, has been taken as initial one. In revised configuration, four FA-1 have been changed by 4 beryllium blocks, and one more beryllium block was installed into cell 2-5 instead of displacer with water. Thus, the revised core configuration contains a central beryllium carrier with three LTAs, 32 FA-1, 6 FA-2, seven displacers with water and 28 beryllium blocks. Later, as reactivity margin is exhausted, water displacers will be gradually replaced by beryllium blocks.Figure 1 illustrates the revised LTA test core configuration.

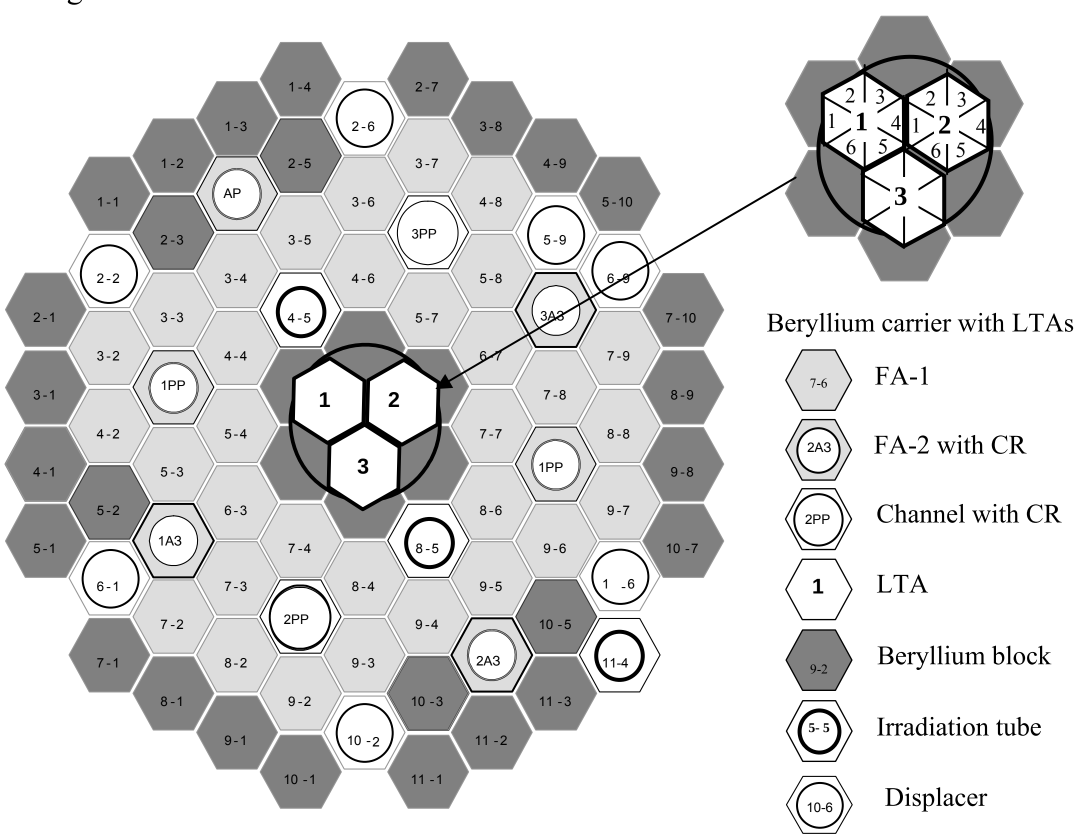

Fig. 1 WWR-K LTA test core configuration (38 FAs + 3 LTAs + 28 beryllium blocks). (Beryllium blocks have hexagonal cross-sections with a flat-to-flat size 65.3 mm.)

In contrast to previous publications [2,3], in these calculations stiffening ribs at LTA fuel element surface are explicitly taken into account. The shape of ribs is trapezium. In the exterior fuel element the sides are 1.7 and 1.9 mm and height 0.7 mm, whereas for the rest fuel elements the sides are 1.1 and 1.3 mm and height is 1.5 mm. For the core configuration presented in Fig. 1 value of K_{eff} = 1.0563; for comparison: in the version without ribs K_{eff} comprises 1.0609.

3. Characteristics of the Power Generated in LTAs and Regular FAs

Values of the power generated in the FAs and LTAs of the core are presented in Table 1.

Table 1. Power generated in FAs and LTAs of the core "38 FA + 3LTA + 28 Be blocks"

Core Cell	Power, kW	Burnup, %	Core Cell	Power, kW	Burnup, %
2-4 (AP)	70.9	33.5	4-6	164.5	24.0
4-3 (1PP)	99.5	19.9	5-3	160.1	18.2
8-7 (1PP)	92.1	20.1	5-8	123.5	27.2
6-2 (1AZ)	132.6	20.1	7-2	119.8	22.6
6-8 (3AZ)	116.3	20.2	7-3	142.5	17.2
10-4 (2AZ)	110.6	17.6	7-8	141.4	16.4
4-4	181.9	25.4	8-2	108.0	19.5
4-8	95.5	26.6	8-4	162.4	29.2
5-4	176.1	31.0	8-8	107.0	23.2
5-7	155.9	27.0	9-2	100.7	24.9
6-7	148.8	32.5	9-3	122.1	24.4
6-3	166.2	32.5	9-4	148.1	28.5
7-4	167.8	25.7	9-5	156.6	22.6
7-7	155.6	36.8	9-6	110.1	39.9
8-6	169.7	31.6	3-2	104.7	34.3
3-3	132.6	24.6	7-9	97.9	36.0
3-4	156.3	20.2	9-7	99.3	30.6
3-5	146.2	21.3	LTA1	352.5	0
3-6	105.6	30.3	LTA2	334.8	0
3-7	85.9	28.0	LTA3	352.7	0
4-2	124.9	25.4	Total:	6000.0	

In calculations of distributions of the generated power and burnup over FAs of the core, a regular FA was homogenized within the core cell (cell's flat-to flat size is 68.3 mm) minus structural tube with water.
Data in all tables and figures of the paper imply the reactor power 6 MW and shim elements (PP-AP) immersed to the core by 300 mm (to the mid of the core).
As a result of the core volume reduction and rearrangement, values of the generated power in fuel assembles have redistributed. Among regular assemblies, the FA in cell 4-4 has the highest fuel rating. Actually, in all LTAs the anticipated design power has been reached. Distribution of power density in LTA1 over its fuel elements and 6 sectors (see Fig.1) is presented in Table 2.

Table 2. Generated power density [kW/cm^3] over LTA1

FE #	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	K_{irr}
1	0.9848	1.1480	1.0188	0.5184	0.5189	0.9035	1.35
2	0.8995	1.0078	0.9215	0.6940	0.6920	0.8411	1.19
3	0.8352	0.8905	0.8252	0.6755	0.6745	0.7743	1.14
4	0.7838	0.8401	0.7843	0.6795	0.6765	0.7523	1.12
5	0.7633	0.7947	0.7663	0.6795	0.6880	0.7344	1.08
6	0.7598	0.7833	0.7538	0.7114	0.7139	0.7439	1.05
7	0.7858	0.7543	0.7718	0.7533	0.7469	0.7563	1.03
8	0.7635						

The highest power density is observed in the LTA1 in sector 2 (see Fig.1), namely, in the sector faced to cell 4-5 with irradiation tube. A «hot» point (1.148 kW/cm^3) in sector 2 is located in the outer fuel element. Last column of Table 2 presents values of the azimuthal irregularity factor (maximum/average power in FE, K_{irr}). One may observe that the irregularity factor maximum value is in the outer fuel element too. This fact has been taken into account in irradiation test program, where it is prescribed to turn 2 LTAs (in our case, LTA1 and LTA3) by 60 ^{o} every two operation cycles. LTA2 stays in the same place in order to simulate the conditions of LEU core for the fuel assemblies adjacent to side beryllium reflector.

Figure 2 shows distributions of generated power density over 8 fuel elements in the hottest sector of LTA1.

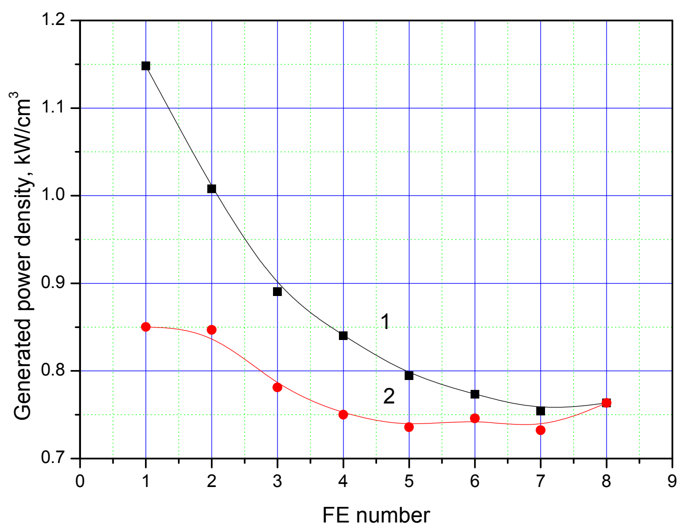

Fig. 2. Distribution of generated power density over the LTA1 fuel elements in the sector faced to cell 4-5 with irradiation tube

Curves 1 and 2 illustrate the power density distribution in sector 2 of LTA1 as well as the similar sector-averaged distribution. Values of the radial irregularity factor for curves 1 and 2 comprise 1.32 and 1.10 respectively.

Figure 3 shows detailed distribution of the power density in the sector 2. The axial irregularity factor has comprised 1.32. The figure demonstrates typical power overshoots at LTA end sections, caused by the end water reflectors. The peak value of the power density is taken as unity.

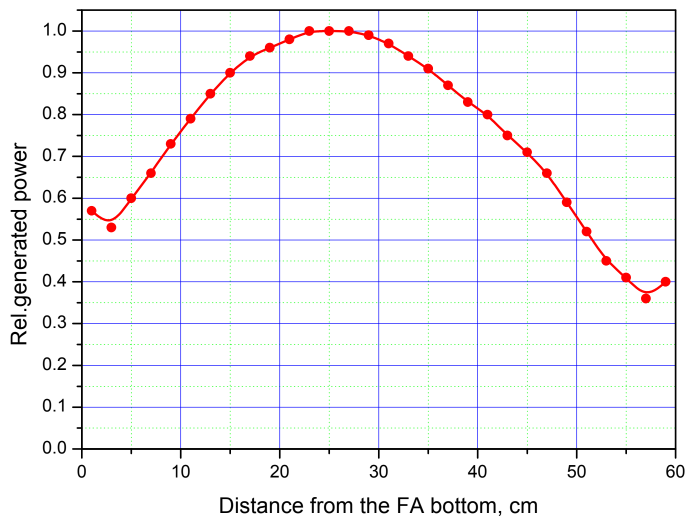

Fig. 3. Generated power density versus height in the LTA1 sector 2, faced to cell 4-5

With all these data taken into account, the peak value of generated power density in LTA1 is 1.515 kW/cm^3.

As it was already mentioned above, the FA located in cell 4-4 is the hottest among regular (HEU) FAs. Detailed distribution of the generated power density over the FA sectors and fuel elements (FE) has been obtained with the FA heterogeneous representation and the fuel nuclide concentrations associated with 25-% burnup, in compliance with Table 1. Table 3 below presents distribution of the generated power density over the FA sectors and fuel elements.

Table 3. Distribution of the generated power density [kW/cm^3] in the regular FA fuel meat (cell 4-4) over sectors and fuel elements

FE #	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	K_{irr}
1	0.5562	0.6669	1.0125	0.8820	0.6993	0.576	1.38
2	0.5742	0.6678	0.8982	0.8370	0.6984	0.5922	1.26
3	0.6048	0.6822	0.8235	0.8001	0.6975	0.6084	1.17
4	0.6372	0.7020	0.7938	0.7893	0.7191	0.6453	1.11
5	0.7281						

The peak power density is observed in the sector 3 faced to cell 4-5. A «hot» point in sector 3 is located in the outer fuel element. Last column of Table 3 presents maximum values of the azimuth irregularity factors (K_{irr}). One may observe that the maximum value of K_{irr} is in the outer fuel element.

Figure 4 shows detailed distribution of the power density in the sector 3 versus height in sector 3 of the regular FA located in cell 4-4 faced to cell 4-5 with irradiation tube. Distances are counted from the FA bottom.

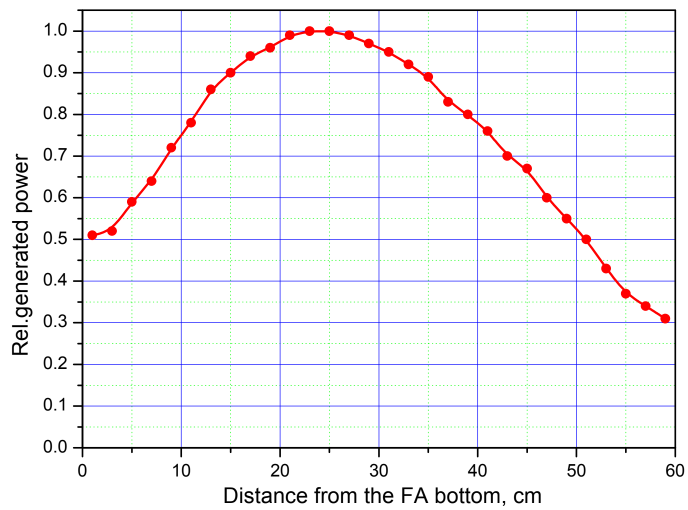

Figure 4. Generated power density versus height in the FA located in cell 4-4

The axial irregularity factor is equal to 1.366. The generated power peak density in regular FA, located in cell 4-4, is 1.383 kW/cm^3.

4. Characteristics of Shim Elements and Protection Rods

Table 4 presents values of the worth of the control rods. Initial reactivity margin is 5.33 %(ΔK/K), and subcriticality is -2.12%(ΔK/K), when all shim elements (1PP, 2PP, 3PP and AP) are immersed to the core by 600 mm, and protection rods are outside the core.

Table 4. Control Rod Efficiencies

Control rod	Efficiency, % $^{\Delta K}/_{K}$	Remarks
1AZ	1.04	
2AZ	0.70	
3AZ	0.80	
ΣAZ	2.64	Protection rods (AZ) are immersed simultaneously
1PP	2.74	
2PP	1.58	
3PP	1.87	
AP	0.20	
ΣPP+AP	7.36	All shim elements (PP) and automate rod (AP) are immersed simultaneously

In compliance with regulatory requirements, potential accident with spontaneous withdrawal of the most efficient control rod 1PP (two shim elements PP per drive) is to be analyzed. So, Fig. 5 presents the 1PP differential worth characteristics (see Table 4).

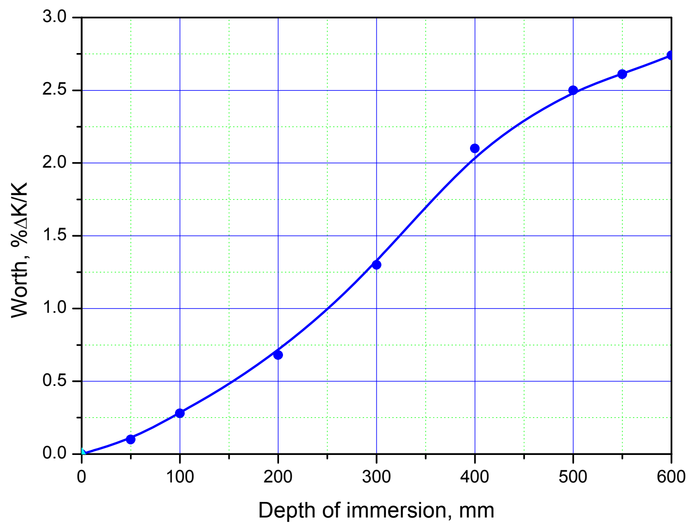

Figure 5. The 1PP shim element worth versus height of its immersion to the core

5. Core Poisoning and Reactivity Coefficients

Fig.6 shows variation in reactivity margin during the 21-day operation cycle with subsequent 6-day shutdown for fuel reloading and restoration of reactivity margin. A dashed line is the reactivity loss due to fuel burning out.

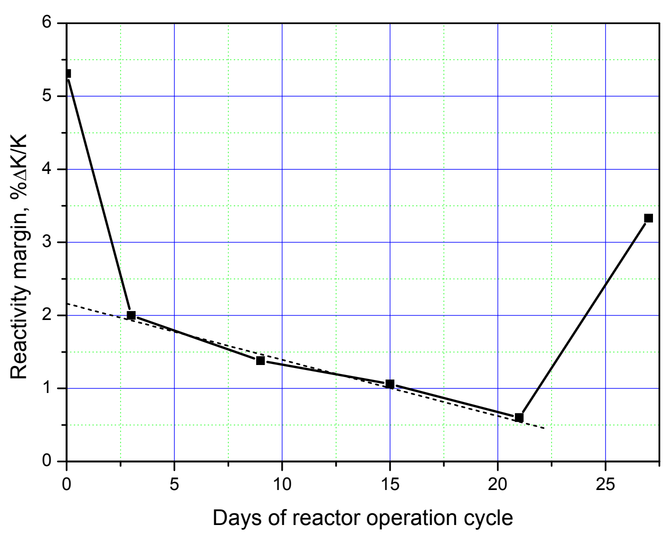

Fig. 6. Variation in the core reactivity in the course of the 21-day operation cycle

The figure shows that reactor poisoning by xenon and samarium comprises ≈3.1% ΔK/K.
Table 5 presents the calculated reactivity feedback factors by changes in temperature (300 ÷ 350 ^{o}K) and water density; temperature range used for evaluation of fuel is 300 ÷ 400 ^{o}K.

Table 5. Calculated reactivity feedback factors

Reactivity feedback coefficients	BOC	EOC
Coolant temperature, %/^{o}C	0.013±0.001	0.013±0.001
Coolant void, %/% of void	0.194±0.003	0.198±0.003
Fuel temperature, %/^{o}C	0.0010±0.0001	0.0010±0.0001

The calculated neutron life-time is 0.98E-04 s, and $ß_{eff}$ is 0. 73 %ΔK/K.

6. Conclusions

1. Configuration of the LTA test core has been determined. In version with ribs in LTA taken into account the effective multiplication factor has been calculated, comprising K_{eff} = 1.0563.
2. For the hottest LTA and hottest regular FA, detailed characteristics (azimuthal, radial and axial distributions) of a field of the generated power have been calculated.
3. Reactivity worth of shim elements (1PP, 2PP, 3PP and AP) and protection rods (AZ) have been determined.
4. Values of the reactivity temperature coefficients have been calculated as well as the value of the reactivity loss related to reactor poisoning by xenon and samarium .

7. References

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