RERTR 2011 — 33rd INTERNATIONAL MEETING ON
REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS

October 23-27, 2011
Santiago Marriott Hotel
Santiago, Chile

START OF LOW-ENRICHED FUEL LEAD TEST ASSEMBLIES IN THE WWR-K REACTOR CORE

F. Arinkin, P. Chakrov, L. Chekushina, Sh. Gizatulin, S. Koltochnik, D. Nakipov,
N. Romanova, A. Shaimerdenov, Zh. Zhotabaev,
The Kazakhstan Ministry of Industry and New Technologies
The Institute of Nuclear Physics, 1 Ibragimova str., 050032, Almaty – Kazakhstan

N. Hanan, P. Garner, J. Roglans-Ribas
GTRI Convert Program, Nuclear Engineering Division
Argonne National Laboratory
9700 S. Cass Ave., Argonne, IL 60439-4803 – USA

ABSTRACT

At present the items related to assurance of high-enriched fissile materials nonproliferation are quite urgent. So, conversion of research reactors is a pressing task because they are main consumers of high-enriched uranium in atomic industry. Among a variety of considered FA, the eight-tube thin-walled (1.6mm) design was chosen as the optimum for WWR-K reactor. The calculated neutron-physical characteristics for the core with low-enriched uranium fuel have shown that reactor performance with the chosen fuel composition and FA design would be not only preserved but it would be improved. With application of beryllium side reflector, the performance would be even more improved. In March of 2011 the three LTA life test in the WWR-K reactor core was started. This paper will present the irradiation plan and available results for the irradiation.

Introduction

In a period from 2003 to 2006, the Kazakhstan Institute of Nuclear Physics, which operates the WWR-K research reactor, carried out, under the US financial support (Nuclear Threat Initiative) search of relevant candidates for roles of new LEU fuel assembly composition and design [1-4]. Currently, VVR-C-type fuel assemblies with UO_2 –Al meat, enriched in uranium-235 is to 36% are used in the WWR-K reactor. The fuel compositions on a base of uranium-dioxide of the uranium mass density up to 3.0 g/cm^3 and on a base of uranium-molybdenum alloys of the density up to 5.0 g/cm^3 were analyzed via calculations. Finally, due to a number of technological reasons, the fuel composition on a base of uranium dioxide dispersed in aluminum matrix, having the uranium mass density 2.8 g/cm^3, enriched in U-235 to 19.7% was chosen. The thin-walled (1.6mm) eight-tube fuel assembly (FA) was recognized as the optimum design for the WWR-K reactor. The mass of uranium-235 in the FA is ~250 g; the area of heat-transfer surface reaches 1.34 m^2.

Results of calculations of neutronic characteristics of the core with the chosen LEU fuel composition and FA design are as follows: the reactor new operational characteristics are not worse; we are even capable to improve them, provided beryllium side reflector is installed in the core.

In compliance with relevant regulatory documents which are in force in Kazakhstan, in order to confirm the FA design characteristics, in-reactor test of a pilot batch of new FAs is to be carried out before starting industrial production of new assemblies. A justified program of the test of lead test assemblies (LTA) was developed by specialists from the Kazakhstan Institute of Nuclear Physics, the US Argonne National Laboratory and Russian scientific institutions. Safety of the test in the WWR-K reactor core was proved via calculation analysis of potential transients. The core steady-state analysis and thermal hydraulic calculation of the core were performed. The Kazakhstan Atomic Energy Committee issued permission for the test, and in March of 2011 the three LTA life-test was started in the VVR-K reactor core. In compliance with preliminary calculations, the test will take 2 years before the average burnup in LTA will reach ~ 60%.

LTA test in the WWR-K reactor core

In view of LTA test, the WWR-K reactor core was rearranged such way that the core size was reduced, and, as a result, specific characteristics were improved. So, FAs from the last ring of the core were removed and 28 blocks of side beryllium reflector installed instead. The beryllium irradiation carrier of three LTAs was installed in the core central section instead of removed seven FAs. The LTAs in the carrier are installed in the 68.3-mm-step triangular lattice with the 2-mm gaps left for coolant flow. The core map with 38 regular FAs, 3 LTAs inside the beryllium carrier and 28 block of beryllium reflector is given in Figure 1.

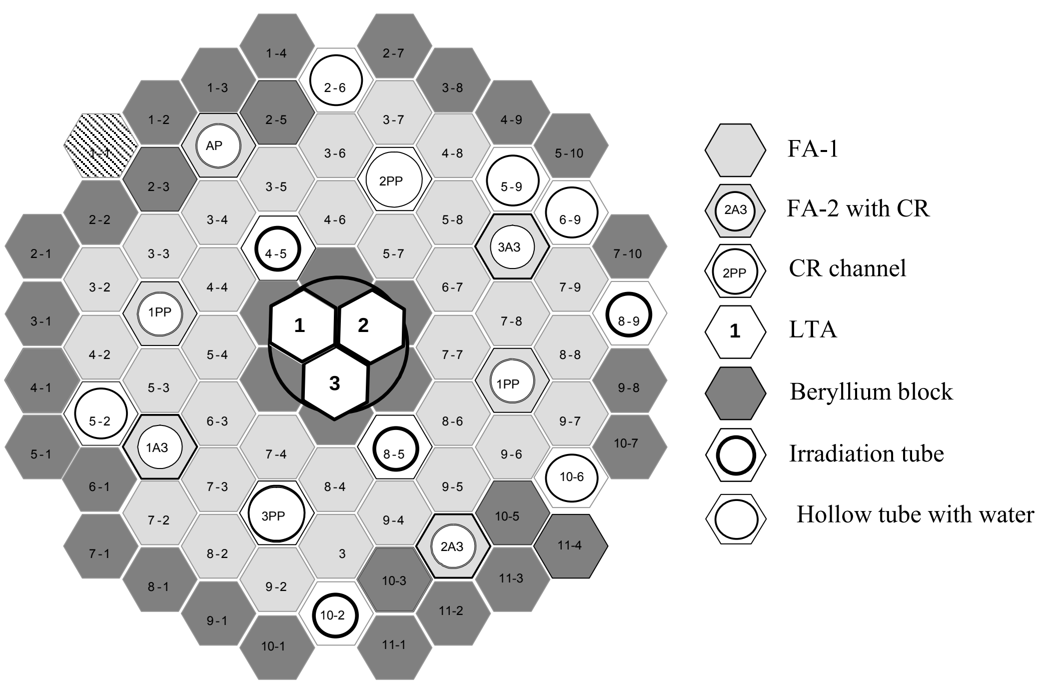
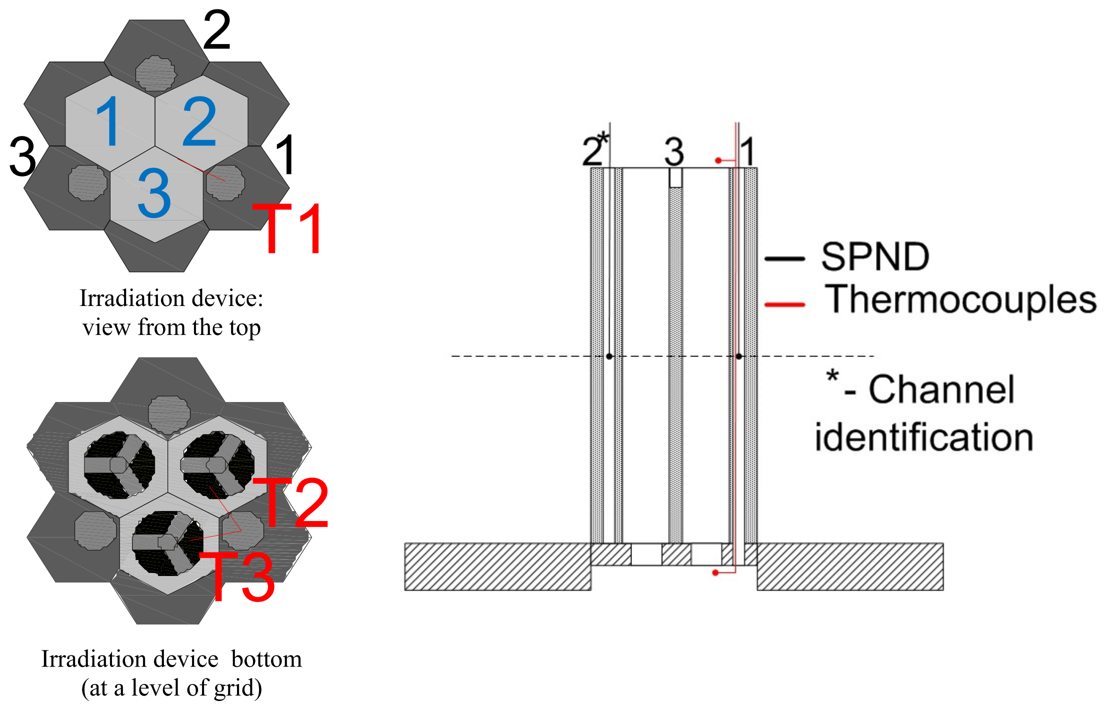


Fig.1. The LTA tests core map of the WWR-K reactor core

The irradiation device is equipped with extra systems of the LTA irradiation condition diagnostics. Two self-powered neutron detectors (SPND) with rhodium emitter were used to control the neutron flux density. Three (chromel-alumel) thermocouples were used to measure the coolant temperature at the irradiation device inlet (T_1) and outlet (T_2 and T_3). Figure 2 illustrates layout of LTAs, temperature sensors and SPND inside the irradiation device. Three thermocouples and a SPND are in the channel 1, whereas only SPND is in the channel 2.



(a) Horizontal section (b) Vertical section

Fig. 2. Irradiation device layout

The information measuring system (IMS) accompanies permanently the LTA test. IMS provides operators and experimentalists by on-line data, recording every minute the test main parameters: temperature at the irradiation device inlet/outlet and SPND readings.

Prior to the first operational cycle, the pressure differential across the core was measures versus the flow rate (which is provided by the operating primary circuit circulation pumps) in order to confirms the calculated values which were used in heat-hydraulic calculations of the core. Table 1 and Figure 2 show results of the measurements.

Table 1. Flow rate in LTA versus pressure differential across the core

Quantity of primary circuit pumps	ΔP, MPa	Flow rate in LTA, m^3/h	Flow rate in the core, m^3/h
1	0.0020	5.8	340±24
2	0.0076	12.1	662±24
3	0.0160	18.2	996±24

Hydraulic calculation for LTA was carried out by the formulas given below [5-7].

- The local resistance coefficient ξ for jet compression in transition from wide section (S_w) to narrow one (S_n) was determined as $\xi=0.5\ (1- S_n/S_w)$.
- The local resistance coefficient ξ for jet expansion in transition from narrow section to wide one was calculated by the Bordo formula: $\xi=(1- S_n/S_w)^2$.

- The local resistance coefficient ξ for friction in gaps between neighboring fuel elements was determined as $\lambda \cdot L/D$, where L and D are, respectively, the gap length and hydraulic diameter, λ is the hydraulic friction coefficient.
- The hydraulic friction coefficient was calculated by the Altshull formula for turbulent flow:
  $\lambda = 0.11\ (\Delta/D + 68/Re)^{0.25}$, where Δ is roughness dimension (set equal to 0.001 mm), Re is the Reynolds number, which was calculated by the formula $Re=wD/\nu$, where w is the coolant velocity, ν - is kinematical viscosity.
- Pressure differential was determined by the Darcy-Weisbach formula (in MPa): $\Delta p = \xi \cdot \rho \cdot w^2 / 2$.

By results of hydraulic calculation and performed hydraulic measurements, the experimental dependence of the pressure differential across the core on the flow rate was obtained. Later it was used in determination of the LTA thermal power.

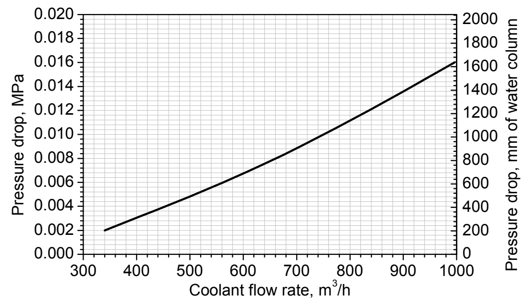


Fig.3. Pressure differential as function of the coolant flow rate in the core

Due to large amount of beryllium in the core (side reflector, irradiation device) photo-neutrons from reaction (γ,n) and neutrons from reaction (n,2n) have changed considerably indications of neutron control devices. So, the first transition to the 6-MW power level was carried out by 100-kW steps with 1-hour staying between the steps for establishing thermal equilibrium in the primary circuit. The reactor thermal power was estimated after reaching the 1.0-°C difference between values of the coolant inlet and outlet temperature; then indications of regular neutron sensors (ionization chambers) were corrected by values of the thermal power.

Figure 4 shows results of monitoring of the neutron flux density for the first cycle of reactor operation (21 days).

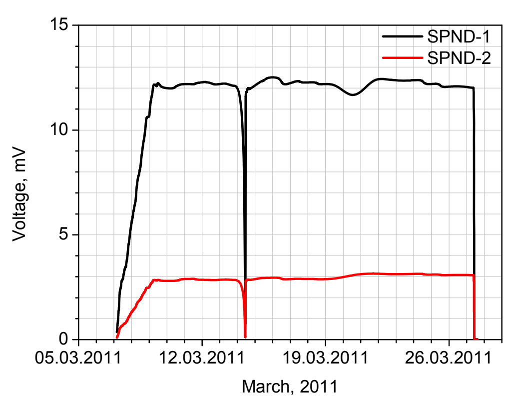


Fig. 4. SPND indications during the first cycle

Abrupt fall in SPND indications is a result of scram. The figure demonstrates clearly a process of transition to 6-MW level for 2 days. Difference in indication of SPND-1 and SPND-2 is caused by differing load resistances.

Tables 2 and 3 present levels of the burnup in fuel assemblies to moments of start of the first and second cycles of reactor operation.

Table 2. Burnup in the core FAs to moments of start of the first and second cycles

Cell	Burnup, %		Cell	Burnup, %		Cell	Burnup, %	
	Cycle 1	Cycle 2		Cycle 1	Cycle 2		Cycle 1	Cycle 2
2-4 AP	1.23	5.00	8-6	6.8	11.23	8-4	28.36	0.00*
4-3 1PP	27.46	30.82	3-3	29.02	32.13	8-8	34.02	36.07
8-7 1PP	27.30	30.33	3-4	25.74	29.18	9-2	29.75	32.13
6-2 AZ1	27.70	31.23	3-5	31.97	35.08	9-3	37.05	32.05
6-8 AZ3	27.54	30.66	3-6	37.95	31.39	9-4	42.13	0.00*
10-4 AZ2	23.93	26.89	3-7	35.08	37.21	9-5	25.08	28.28
4-4	3.69	8.44	4-2	22.21	33.03	9-6	21.31	38.28
4-8	31.97	34.34	4-6	27.62	31.23	3-2	31.64	34.26
5-4	5.98	10.66	5-3	23.85	27.21	7-9	34.75	36.89
5-7	2.62	7.05	5-8	29.02	31.89	9-7	33.28	35.41
6-7	27.87	22.54	7-2	30.33	32.87	LTA1	*0.00	3.44
6-3	29.34	25.25	7-3	31.15	34.10	LTA 2	*0.00	3.39
7-4	34.75	24.10	7-8	35.98	*0.00	LTA 3	*0.00	3.51
7-7	20.41	24.34	8-2	27.46	30.33			

*fresh FA in the cell

On a base of thermocouple indications and values of the coolant flow rate in LTAs (Table 1), the net maximum power of three LTAs at start of the first cycle was 1054 kW; inaccuracy in determination of the power is 8%. Figure 5 shows variation in the net power of three LTA for the cycle; loss of power for a very short period of time was explained earlier.

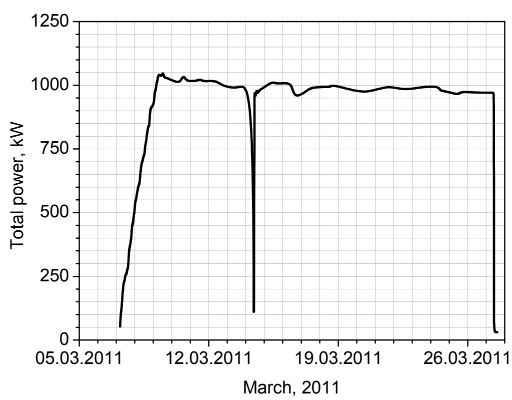


Fig. 5. The net power of three LTAs during Cycle 1

For today, five cycle of irradiation have passed; the net duration of irradiation is 96 days. Figure 6 shows variation in the core excess reactivity for these cycles of irradiation.

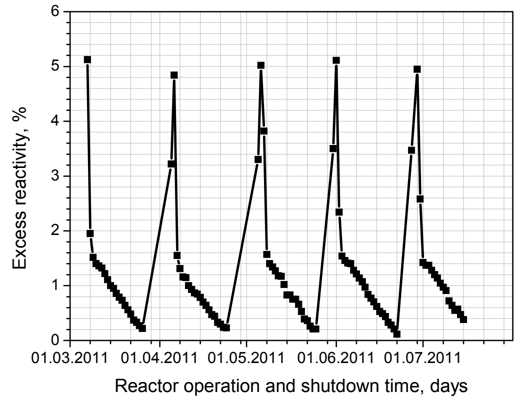


Fig. 6. Excess reactivity as function of time for first five cycles of LTA irradiation

The figure demonstrates clearly abrupt reduction in the excess reactivity during first three days of reactor operation which is a result of poisoning by xenon. Later change in the excess reactivity is caused by fuel burnup, comprising, in average, 0.07% per day. It should be mentioned that the observed pattern of reactivity variation fully coincides with the relevant calculated function.

In parallel to monitoring of the above-mentioned parameters, samples of water from primary circuit were examined against presence of cesium (reference isotope) and other fission products. The content of cesium in coolant did not exceed 500 Bq/l, which is the background value for the WWR-K reactor, proving integrity of the fuel assemblies, including LTAs, in the core.

Conclusion

Re-arrangements in the core have increased levels of the power density, assuring the LTA design operational parameters.

Usage of the diagnostic system has made it possible to provide permanent control of LTA state in course of the test.

As a whole, first five cycles of LTA irradiation have been completed successfully; in the LTA-3 the average burnup ~ 15.2% is reached. Integrity of both regular and lead test assemblies is conserved.

References

[1]. F. Arinkin, Sh. Gizatulin, Zh. Zhotabaev, K. Kadyrzhanov, S. Koltochnik, P. Chakrov, L. Chekushina, “Feasibility Study of the WWR-K Reactor” Proceedings of RERTR-2004 International Meeting on Reduced Enrichment for Research and Test Reactors, Vienna, Austria, November 7-12, 2004 – P.5.

[2]. F. Arinkin, P. Chakrov, L. Chekushina, I. Dobrikova, Sh. Gizatulin, K. Kadyrzhanov, S. Koltochnik, V. Nasonov, A. Taliev, A. Vatulin, Zh. Zhotabaev, N. Hanan, “Feasibility Analysis for Conversion of the WWR-K Reactor Using an Eight-Tube Uranium Dioxide Fuel Assembly,” Abstract. Proceedings of the

RERTR-2005 International Meeting on Reduced Enrichment for Research and Test Reactors, Boston, USA, November 6-10, 2005 - P.117.

[3]. F. Arinkin, P. Chakrov, L. Chekushina, I. Dobrikova, Sh. Gizatulin, K. Kadyrzhanov, S. Koltochnik, V. Nasonov, A. Taliev, A. Vatulin, Zh. Zhotabaev, "Comparative Study of the WWR-K Reactor Using Low-Enriched U-Mo Fuel Pin- and Tube-Type," Abstract. Proceedings of the RERTR-2005 International Meeting on Reduced Enrichment for Research and Test Reactors – Boston, USA, November 6-10, 2005 – P.122.

[4]. F. Arinkin, P. Chakrov, L. Chekushina, Sh. Gizatulin, K. Kadyrzhanov, E. Kartashev, S. Koltochnik, V. Lukichev, V. Nasonov, N. Romanova, A. Taliev, Zh. Zhotabaev, "Characteristics of the WWR-K reactor core with low-enriched uranium dioxide fuel" Proceeding of the RERTR-2006 International Meeting on Reduced Enrichment for Research and Test Reactors – Cape Town, South Africa, October 29, 2006 – P.47.

[5]. Shaimerdenov A.A., Arinkin F. M., Koltochnik S.N., Chekushina L.V. Thermal-Hydraulic steady state analysis of the WWR-K RR core of the LTA test. // Vestnik NNC RK. – Kazakhstan, 2010. – issue 4. – pp. 54-59 - *in Russian*.

[6]. Idelchik I.E. Hand-Book on Hydraulic Resistances. – Moscow: Machinery 1975. – 560 p. –*in Russian*

[7]. Kiselev P.G. Hand-Book on Hydraulic Calculations. – Moscow: Energy, 1972. – 312 p. –*in Russian*