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Completed Conversion of the LVR-15 Research Reactor

M. Koleska, V. Broz, J. Ernest, J. Kysela, M. Marek, J. Rychecky
Research Reactors Section
Research Centre Řež, Husinec – Řež 130, 250 68 Řež – Czech Republic

ABSTRACT

The LVR-15 is 10 MW pool-type LWR research reactor situated at Research Centre Řež near Prague, Czech Republic. Starting in February 2010, the reactor had successfully undergone a conversion from HEU IRT-2M fuel to LEU IRT-4M fuel. The conversion had been planned to be finished in March 2012 after 23 cycles (K116 – K138) using mixed cores with both types of fuel. Based on an agreement with US DOE, the conversion plan was changed in spring 2011. The reason of the change was reasonable acceleration of the future return of spent IRT-2M fuel back to Russia. Based on the new plan, the last cycle using HEU fuel was operated in July 2011. After that, during the summer of 2011, the reactor obtained permission from the Czech regulatory body to resume operation after refuelling. Based on this permission, a criticality experiment using both spent and fresh IRT-4M FAs was performed in September 2011 and the first criticality was achieved with a compact configuration on12 September 2011.

1. Introduction

Research Centre Řež (CV Řež) was founded in 2002 as a subsidiary of Nuclear Research Institute Řež plc for the purposes of research and development in the area of natural and engineering sciences related particularly to the utilization of ionizing radiation and nuclear energy. CV Řež is a private non-profit company meeting the definition of a research organization pursuant to 2006/C 323/01. Its research and development activities focus on three areas: basic and applied research of neutron sources in industry and the healthcare sector, participation in the international project Jules Horowitz Reactor designed for development and construction of an experimental reactor at the Cadarache Research Centre in France, and Sustainable Energy project oriented largely on research of Generation IV reactor concepts as well as support for an optimization of the operation of current power facilities.

In 2010, CV Řež started to operate two experimental reactors (LR-0, LVR-15) formerly operated under NRI Řež.

2. LVR-15

The LVR-15 is a pool-type, light water nuclear reactor operated with thermal power of 10 MW (*TABLE 1*).

The reactor was built in 1989 through reconstruction of a VVR-S reactor. During reconstruction, the reactor vessel was replaced (aluminum for stainless steel), as well as core components and reactor instrumentation.

TABLE 1 Main parameters of the LVR-15 reactor

Reactor type	Pool
Pressure [MPa]	Atmospheric
Average temperature [^{o}C]	45
Fuel – HEU	IRT-2M 36% ^{235}U (HEU)
LEU	IRT-4M 19.7% ^{235}U (LEU)
Coolant	demineralized water
Reflector	beryllium
Nominal power	10 MW
Thermal flux	1.5 x 10^{18} n/m^{2}s
Fast flux	2.5 x 10^{18} n/m^{2}s

The reactor is utilized for basic and extended materials research, sample irradiation and isotope production and medical treatment in the BNCT facility. Materials research can be performed either using nine horizontal beams, or through irradiation in rigs and loops under specified conditions (pressure, temperature, flow rate, chemistry). Sample irradiation and isotope production is suitable in several vertical channels including a pneumatic rabbit system and silicon doping facility. The main isotopes produced in the reactor are ^{99}Mo from HEU targets, ^{153}Sm, ^{192}Ir, ^{177}Lu, ^{203}Hg and ^{127}Xe.

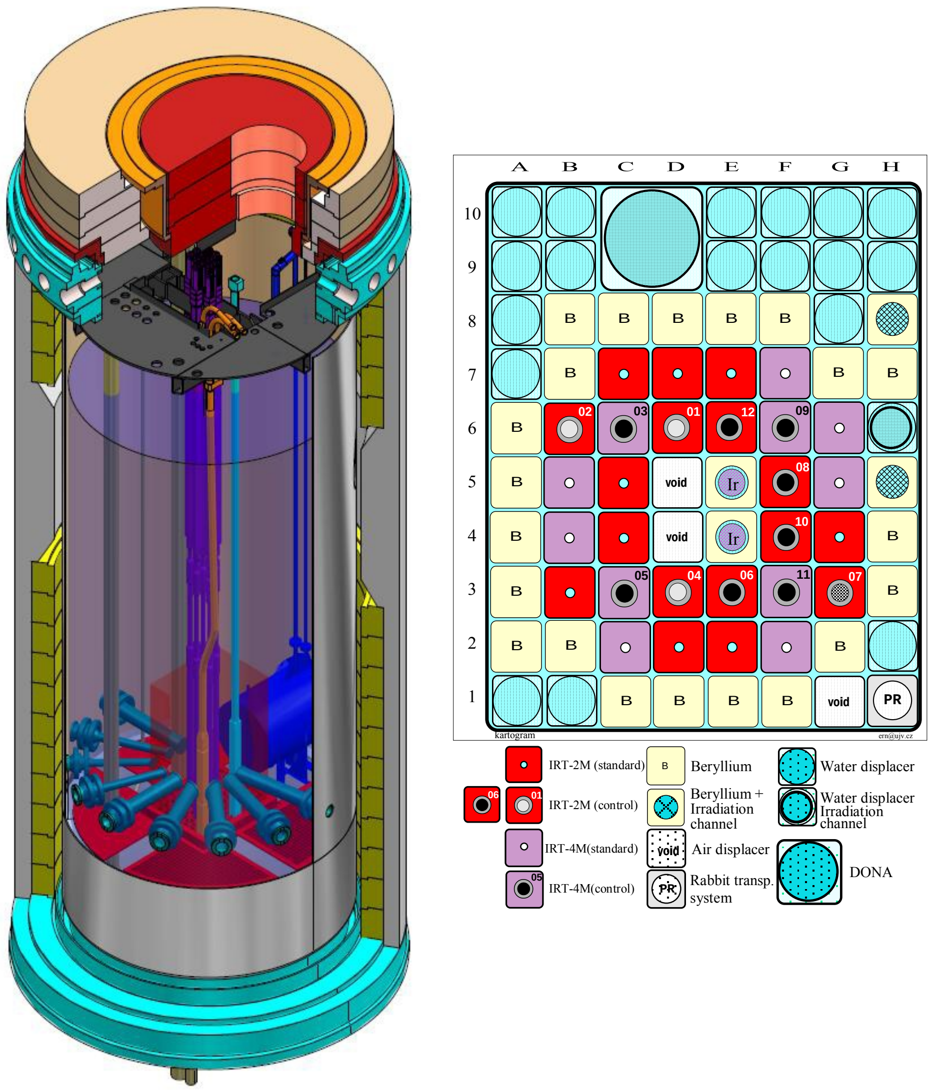

FIG. 1 LVR-15 design and core layout

The core contains 28 – 32 fuel assemblies surrounded by a beryllium reflector (*FIG. 1*). Since its reconstruction, the reactor had been using HEU IRT-2M fuel with 36 wt.% ^{235}U. In September 2011 was successfully converted to LEU IRT-4M with 19.7% ^{235}U (*TABLE 2*).

TABLE 2 Characteristics of HEU and LEU fuel

	IRT-2M	IRT-4M
Enrichment	36% ^{235}U	19,7% ^{235}U
Total length	882 mm	882 mm
Active length	580 mm	600 mm
Section square – head	71.5x 71.5 mm	71.5x 71.5 mm
Section square	67 x 67 mm	69.6 x 69.6 mm
Total mass of the assembly 4/8 tubes	3.7 kg	6 kg
3/6 tubes	3.2 kg	5.2 kg
Mass of ^{235}U 4/8 tubes	230 g	300 g
3/6 tubes	198 g	263.8 g
Tube wall thickness	2 mm	1.6 mm
Cladding thickness	2 x min.0.4 mm	2 x 0.3 mm
Fuel material	UO_2-Al	UO_2-Al
Fuel plate thickness	0.64 mm	0.7 mm

3. Conversion plan

The conversion was planned to be performed using mixed cores. In the first part of the process, the irradiation of 3 IRT-4M FAs for 6 full power and length cycles was planned. During this period, HEU fuel had to be loaded.

The second part was planned so that only LEU fuel would be loaded until the core was fully LEU. This period should be 17 cycles long.

Later on, the conversion plan was changed due to reasonable acceleration of the future return of spent IRT-2M fuel to Russia. The third (and the last) part of the conversion was planned as a criticality experiment using fresh and spent IRT-4M fuel.

During the entire conversion, measurements of water activity, sipping tests and fuel inspections were performed so that the behaviour of the LEU fuel could be tested.

3.1. Irradiation of three IRT-4M FAs

Irradiation of first three IRT-4M FAs started with cycle K116 in February 2010, finished with cycle K125 in December 2010, and lasted a total of nine cycles. This period has one significant milestone: 9 February 2010 was the first time when was LEU IRT-4M fuel operated in LVR-15 reactor. The main goal of the first part of the conversion (*TABLE 3*) was to experimentally determine the influence of LEU fuel on neutron spectra and to gain long-term operation experience for IRT-4M fuel.

TABLE 3 Overview of the trial irradiation of 3 FAs IRT-4M

No.	**CYCLE**	**START**	**END**	**WORK (MWD)**	**HEU FAs**	**LEU FAs**	**FINALBURNUP (MWD/kg)**	
							LEU	**HEU**
0	K116 – exp. IRT-4M	9.2.2010	9.2.2010	0.8	25	3		
1	MIX 01.01 – K116	12.2.2010	5.3.2010	199	25	3	6.43	122.73
2	MIX 01.02 – K117	12.3.2010	23.3.2010	105	25	3	12.4	127.08
3	MIX 01.03 – K118	8.4.2010	24.4.2010	140	25	3	15.63	125.37
4	MIX 01.04 – K119	4.5.2010	22.5.2010	156	29	3	18.67	95.27
5	MIX 01.05 – K120	8.6.2010	21.6.2010	124	25	3	21.26	99.15
6	MIX 01.06 – K121	29.6.2010	20.7.2010	152	25	3	26.33	95.44
7	MIX 01.07 – K122	31.8.2010	25.9.2010	211	25	3	31.1	103.49
8	MIX 01.08 – K123	5.10.2010	21.10.2011	156	25	3	36.01	99.47
9	MIX 01.09 – K124	2.11.2010	24.11.2010	198	25	3	41.13	105.04
10	MIX 01.10 – K125	04.12.2010	21.12.2010	151	25	3	44.93	94.14

Variation of neutron spectra was evaluated for cycle K116. Prior to standard operation, two modifications to the K116 layout were made. While in the first modification, fresh IRT-2M fuel in positions B6, C6 and C7 was present, in the second modification, it was replaced with fresh IRT-4M FAs (*FIG. 2*). Neutron spectra were evaluated by activation detectors placed in beryllium (positions A8, B7), in fuel (C6) and in the water displacer (C8). The results were also compared with neutron spectra calculated with MCNPX and NODER [1]. The most significant result of the experiment was the decrease of the thermal neutron fluence rate inside the IRT-4M fuel assembly (*FIG. 3*). In positions more distant from the core, no important differences between IRT-2M and IRT-4M were found (*FIG. 4*).

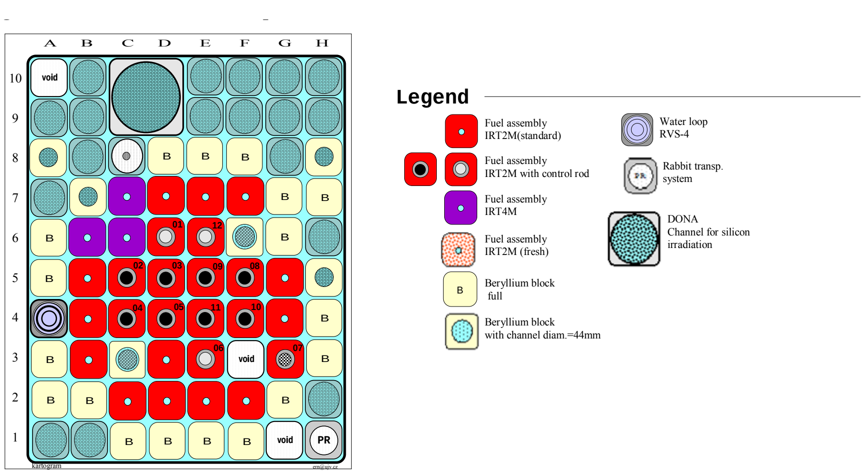

FIG. 2 Experimental layout for determination of neutron spectra (K116 – exp. IRT-4M)

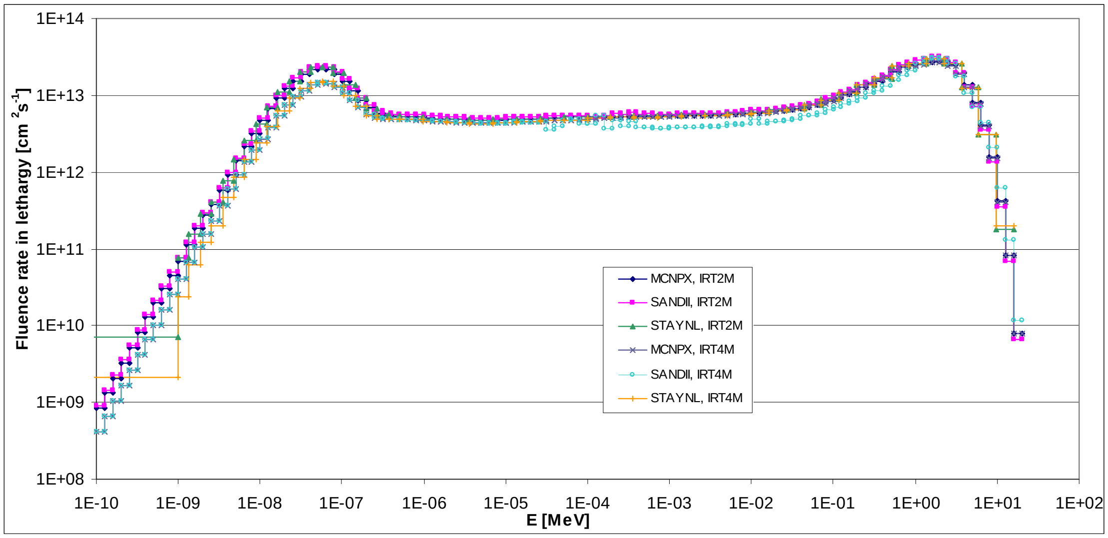

FIG. 3 Results of neutron spectrum adjustment/deconvolution at the position C6 [1]

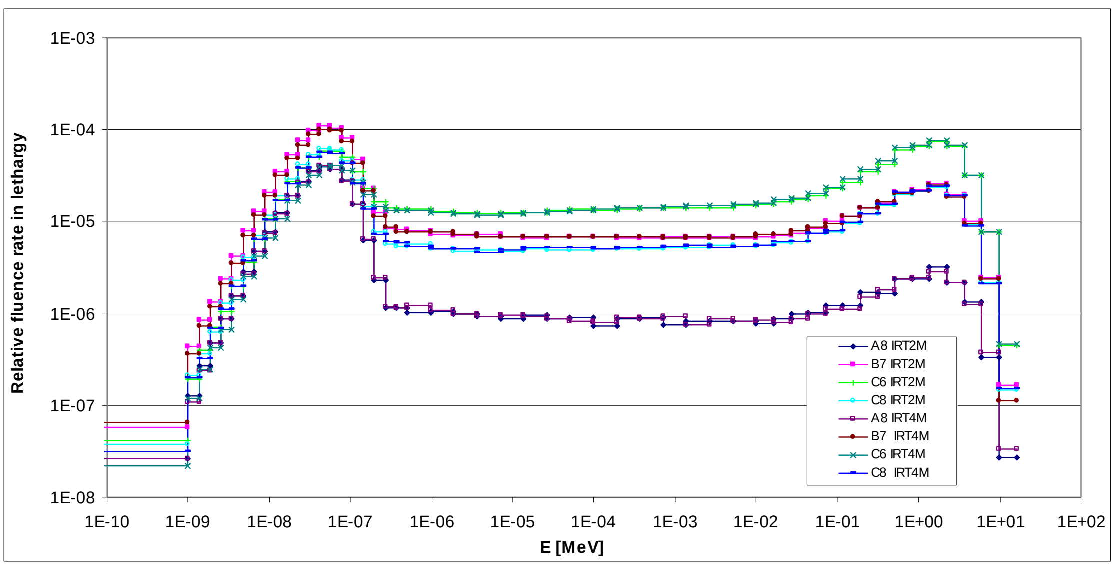

FIG. 4 Results of MCNPX calculation for all positions [1]

Fuel condition and tightness during the trial irradiation was monitored via regular measurement of primary water samples, sipping tests and inspection with underwater camera. Primary water samples were taken three times per week while the reactor was in operation and once a week during shutdown. During operation with three FAs, no leakage of fission products was detected. The sipping tests and visual inspections also revealed no significant defects.

3.2. Cycles with mixed cores

Because test cycles with three FAs completed successfully, the second part of the conversion was started by adding two fresh LEU FAs in cycle K126 (milestone: 7 January 2011). The amount of LEU fuel was increased in each cycle up to 14 FAs in cycle K131 (*TABLE 4*). During operation, several tests to prove fuel cladding integrity were performed. These tests included the regular primary water measurement, sipping tests and visual inspection of the fuel. During these tests were no significant defects observed.

TABLE 4 Overview of mixed cycles

No.	CYCLE	START	END	WORK (MWD)	HEU FAs	LEU FAs	FINAL BURNUP (MWD/kg)	
							LEU	LEU
0	MIX 01.10 – K125	04.12.2010	21.12.2010	151	25	3	44.93	94.14
1	MIX 02.11 – K126	07.01.2011	29.01.2011	182	23	5	33.74	98.85
2	MIX 03.12 – K127	08.02.2011	02.03.2011	188	22	6	33.72	107.90
3	MIX 04.13 – K128	16.03.2011	06.04.2011	167	21	7	33.07	106.81
4	MIX 05.14 – K129	19.04.2011	09.05.2011	174	20	8	34.29	114.75
5	MIX 06.15 – K130, Part I + II	25.05.2011	09.06.2011	139	18	10		
	MIX 06.15 – K130, Part III + IV	10.06.2011	29.06.2011	155	18	10	30.49	117.10
6	MIX 07.16 – K131	11.07.2011	24.07.2011	121	16	14	28.58	123.96

Due to reasonable acceleration of the future return of spent IRT-2M fuel to Russia, the mixed core operation was ended after cycle K131 in July 2011. After this cycle, the entire batch was transported to the spent fuel storage pool and the reactor was prepared for accelerated conversion through the criticality experiment. The end of cycle K131 on 24 July 2011 is one of the important milestones of the conversion. This date was the last time when IRT-2M HEU fuel was operated in the LVR-15 reactor.

3.3. Accelerated conversion

The accelerated conversion was planned for September 2011 as a criticality experiment using both fresh and spent LEU fuel. The experiment was planned in two steps. In the first step, the construction of a compact configuration with 19 FAs (6 spent, 13 fresh) was planned. The second step was then a configuration with a central irradiation trap containing 28 FAs (14 spent, 14 fresh).

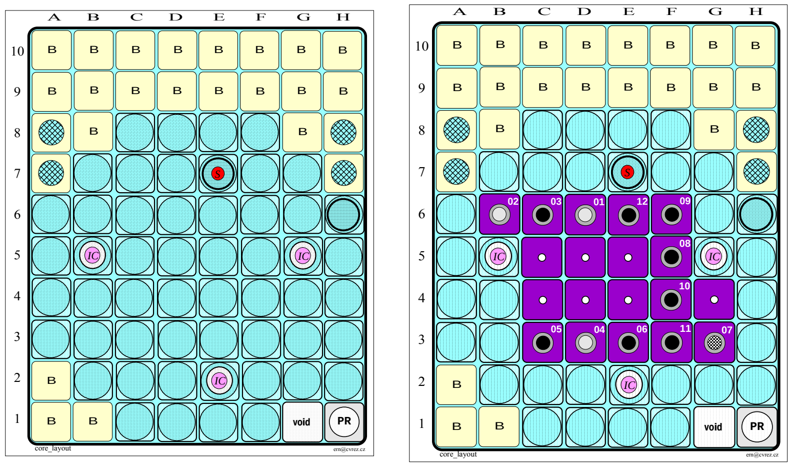

FIG. 5 Accelerated conversion, step I – initial and final configuration

The first step of the accelerated conversion started with a fully unloaded core. Beryllium blocks were placed in peripheral positions as shown in the *FIG. 5*. In the first two steps, six-tube FAs with control rods were added. In the next 6 steps, seven standard FAs were added. Criticality was achieved during step 8 with 19 FAs loaded (*TABLE 5*). Criticality with a fully LEU core was first achieved on 12 September 2011.

TABLE 5 Overview accelerated conversion, step I

No.	FAs	calculated Kef	measured Kef
1	8	0.6705	0.630
2	12	0.7425	0.673
3	14	0.8626	0.842
4	15	0.9122	0.880
5	16	0.9503	0.950
6	17	0.978	0.964
7	18	1.0025	0.986
8	19	1.0162	reactor critical

The second step of the accelerated conversion started by rearranging the compact configuration and creating the central irradiation trap (*FIG. 6*, *TABLE 6*). In the second step, only standard FAs were added. The minimum configuration with a central trap was completed by adding the 28th FA on 20 September 2011.

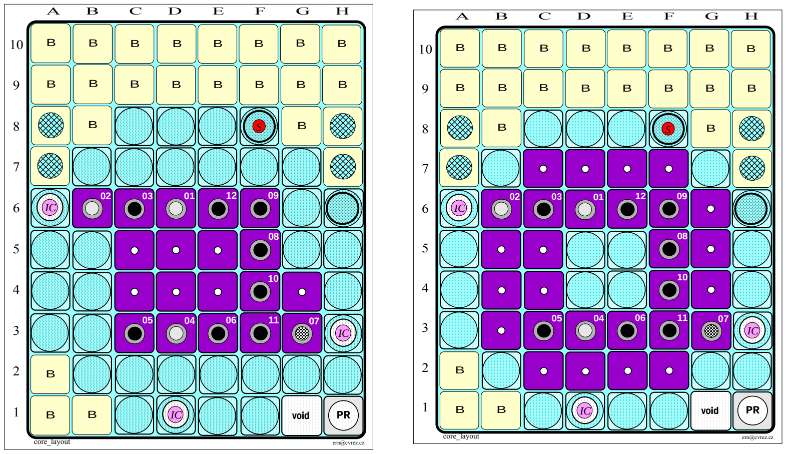

FIG. 6 Accelerated conversion, step II – initial and final configuration

TABLE 6 Overview accelerated conversion, step II

No.	FAs	calculated Kef	measured Kef
1	19	0.8634	0.881
2	22	0.9297	0.951
3	24	0.9644	0.978
4	26	0.9850	0.992
5	27	0.9990	0.999
(6)	28	1.0114	reactor critical

The conversion was then successfully completed by starting the first LEU cycle, K132, on 26 September 2011.

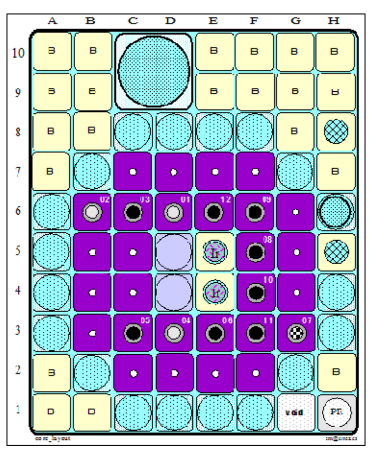

FIG. 7 Cycle K132 (26th September – 11th October 2011)

4. Conclusion

The Czech LVR-15 research reactor, located in Řež, was successfully converted for the use of fuel with low enrichment. IRT-4M fuel was selected as the most suitable fuel type for further operation. The conversion took place in three phases in the years 2010 and 2011. During the process, the concept of the conversion changed slightly due to reasonable acceleration of the future return of HEU fuel to Russia. Due to this conceptual change, the second phase of the conversion (mixed core cycles) was stopped midway and replaced by accelerated conversion in the form of a criticality experiment. During the conversion, the following milestones were achieved:

- 9 February 2010 — 3 IRT-4M FAs in the core, beginning of the conversion, beginning of the first phase of the conversion
- 7 January 2011 — beginning of the second phase of the conversion, 2 more FAs added
- 24 July 2011 — end of the last cycle, K131, using IRT-2M fuel
- 12 September 2011 — first criticality with a fully IRT-4M core
- 26 September 2011 — first fully IRT-4M cycle, end of the conversion

Successful conversion of the LVR-15 meant the end of HEU fuel usage in the entire Czech Republic.

5. Acknowledgement

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6. References

[1]. M. Vins, L. Viererbl, Z. Lahodova, M. Marek, A. Voljanskij, V. Klupak, M. Koleska, ” Comparison of the neutron energy spectrum and neutron fluence rate in the LVR-15 research reactor with fuel with different enrichment”, Journal of Radioanalytical and Nuclear Chemistry, http://dx.doi.org/10.1007/s10967-011-1277-6

[2]. M. Marek,, J. Ernest, V. Broz, J. Kysela, “CONVERSION OF THE LVR-15 REACTOR FROM HEU TO LEU”, ISMTR 3rd International Symposium on Material Test Reactors, Rez, Czech Republic, June 21-23, 2010