LEU experience on the SPARROW training nuclear reactor.

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ABSTRACT

The SPARROW training nuclear reactor was converted from HEU (IRT-3M, 36% of 235U) to LEU (IRT- 4M, 19.7% of 235U) within the RERTR programme scope in autumn 2005. The first criticality with the LEU C1 core was reached on October 18, 2005. During the last year all standard experimental and training tasks as well as validation of the properties of the new fuel were performed with the new LEU core. Subsequently, the reactor was equipped with new experimental devices appropriate for the LEU fuel. In 2006 another LEU core configuration, marked C2, was calculated, approved, and tested in the reactor. Operating the reactor with the new LEU fuel was in agreement with theoretical values; there were exceptions neither in neutronics, nor in daily operation. The paper briefly summarises experience with the new LEU fuel in the last 12 months.

1. Introduction

The operation of the SPARROW reactor was started in 1990 by the Department of Nuclear Reactors of the Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague (CTU). Particularly, the reactor is designed for training the students of Czech universities, preparing the experts for the Czech nuclear programme, as well as for research work, and for information programmes in the area of using the nuclear energy.

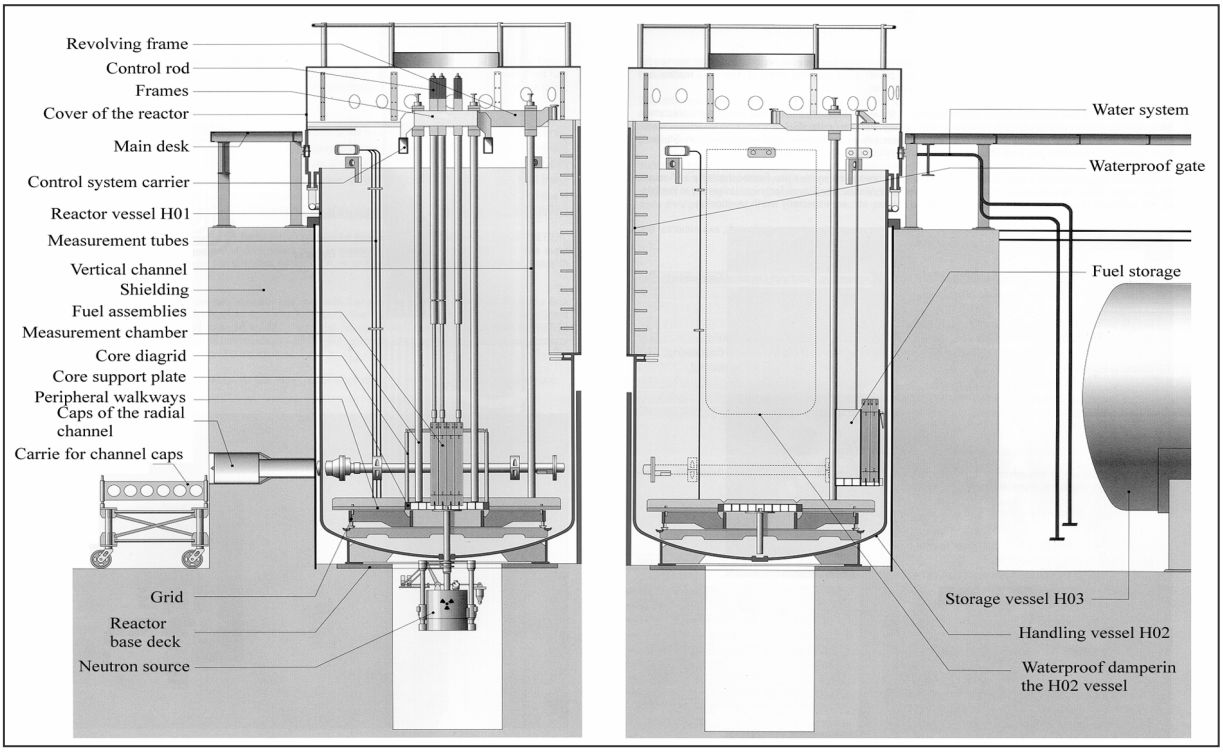

Fig. 1 Cross section of the Training Reactor SPARROW "Sparrow"

The reactor (Fig. 1) is a pool-type light-water reactor based on enriched uranium with maximum thermal power of 1kW [1]. The moderator of neutrons is light demineralised water, which is also used as a reflector, a biological shielding and a coolant. Heat is removed from the core by natural convection. The reactor core contains 17 to 21 fuel assemblies IRT-4M reactor (Fig. 2) [4], depending on the geometric arrangement and kind of experiments to be performed within the reactor.

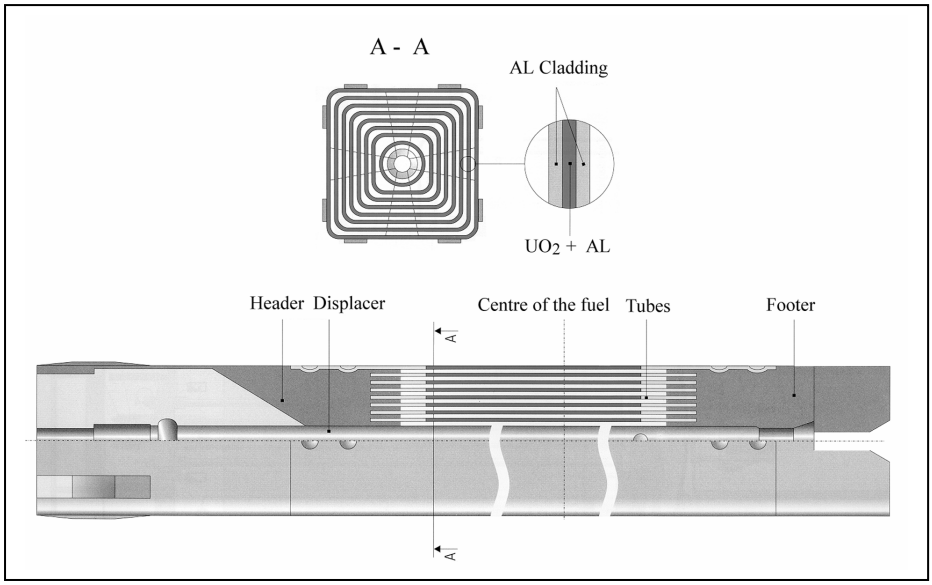

Fig. 2 Eight-tube fuel element IRT-4M

The reactor is used in education of technical university students, in scientific research, in the education and training of specialists in the power industry, and finally in promotional activities in the field of nuclear power.

The education and training is oriented to the reactor and neutron physics, dosimetry, nuclear safety, and control of nuclear installations. Scientific research has to respect reactor parameters and requirements of the so-called clean reactor core (free from a major effect of the fission products). Research at the reactor is mainly aimed at the preparation and testing of new educational methodologies, investigation of reactor lattice parameters, reactor dynamics study, research in the field of control equipment, neutron detector calibration, etc.

2. Preparing the reactor for operating with the LEU fuel IRT-4M.

During the autumn of 2005 CTU successfully converted the reactor from the Russian made IRT-3M fuel containing highly-enriched uranium (HEU, enrichment: 36 % ^{235}U) to the Russian IRT-4M fuel containing low enriched uranium (LEU, enrichment: 19.7 % ^{235}U). This task was completed within the scope of the Reduced Enrichment for Research and Test Reactors (RERTR) programme, that was initiated by the United States Department of Energy (DOE), consistent with the global non-proliferation policy goal of minimizing the use of highly-enriched uranium in civil programmes worldwide. Until the fuel swap, the reactor was operating with the fuel IRT-3M, enrichment 36 % ^{235}U. After the fuel swap, with the new fuel IRT-4M with enrichment of 19.7 % ^{235}U, the limit for LEU of 20 % is fulfilled. The fuel swap involved a direct cooperation of DOE and National Nuclear Security Administration (NNSA) from the RERTR programme, a Russian fuel supplier NZCHK, the Czech regulator (SONS), Euratom, International Atomic Energy Agency (IAEA), and a Russian company SOSNY,

which was repatriating the HEU fuel IRT-3M. Since CTU expertise is in education and not transport or logistic, several other subcontractors were also involved.

Preparation of the reactor for the new LEU fuel is well described in [1], and was done in the following ten stages:

1. Agree the legal contract framework for the entire fuel swap.
2. Create a new computational model of the reactor core to calculate and validate the C1 and C2 core configurations.
3. Conduct thermo hydraulic, safety and transient analysis for the new core configurations.
4. Adjust the reactor's control system.
5. Update operational and safety documentation, obtain necessary licenses.
6. Inspect the fuel manufacturer; check the new fuel properties, new fuel delivery.
7. Conduct a basic criticality experiment with the new C1 core configuration following the SONS approved programme.
8. Measure the standard neutronics properties of the C1 core, completion of the LEU core license.
9. Operate the reactor in a testing regime; preparation for education.
10. Evaluate the testing regime's results; switch to the standard operation.

As the steps 1 up to 8 were described in detail in [2], [3], and [5], only the remaining steps will be expanded here.

3. Operating the reactor in a testing regime; preparation for education.

The testing regime of the reactor was conducted between October 24, 2005 and January 15, 2006. All remaining neutronics characteristics of the C1 core were measured; hence the necessary conditions to license the core were fulfilled. Then the other reactor's operational characteristics were measured, such as thermal neutron flux at different positions in the core or reflector. Also the reactor's dynamics was studied, namely responses to positive, periodic and negative reactivity changes.

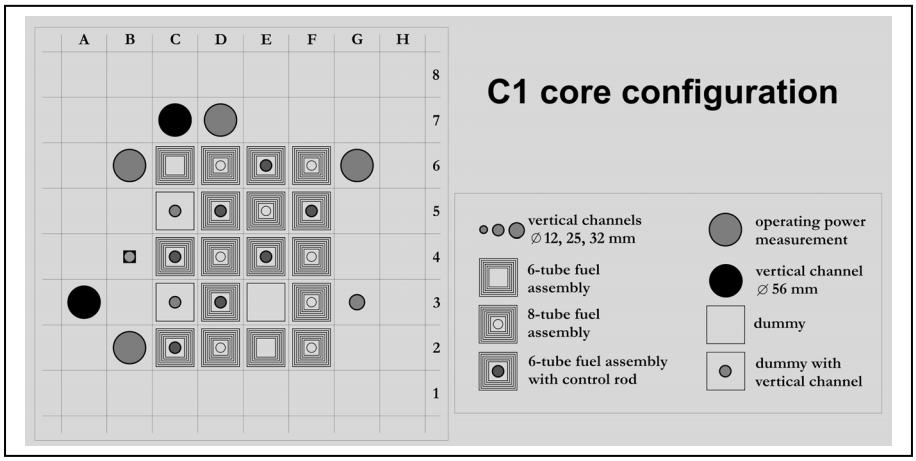

Fig. 3 C1 core configuration with IRT-4M fuel

All the results confirm our theoretical calculations when we expected that the reactor would behave with the new LEU fuel practically in a same way as with the HEU fuel. The measurements confirmed the difference, that was expected in the calculations, of a lower neutron flux density with the LEU fuel compared with the HEU fuel. Training and teaching

was already started during the testing regime for the undergraduate and graduate students. All standards experiments were implemented and the effects of the new LEU fuel were closely watched.

4. Study of reactor dynamics with LEU fuel

For the safety operation of the nuclear reactor it is necessary to have a good knowledge about its dynamics in various operating modes. Among others experiments reactor dynamics with LEU fuel and its comparison with HEU fuel was studied very closely. The reactor is a low power reactor (or zero power) without measurable feedback in standard operational regimes, negative feedback is important in potential emergency states of the reactor only during power excursion.

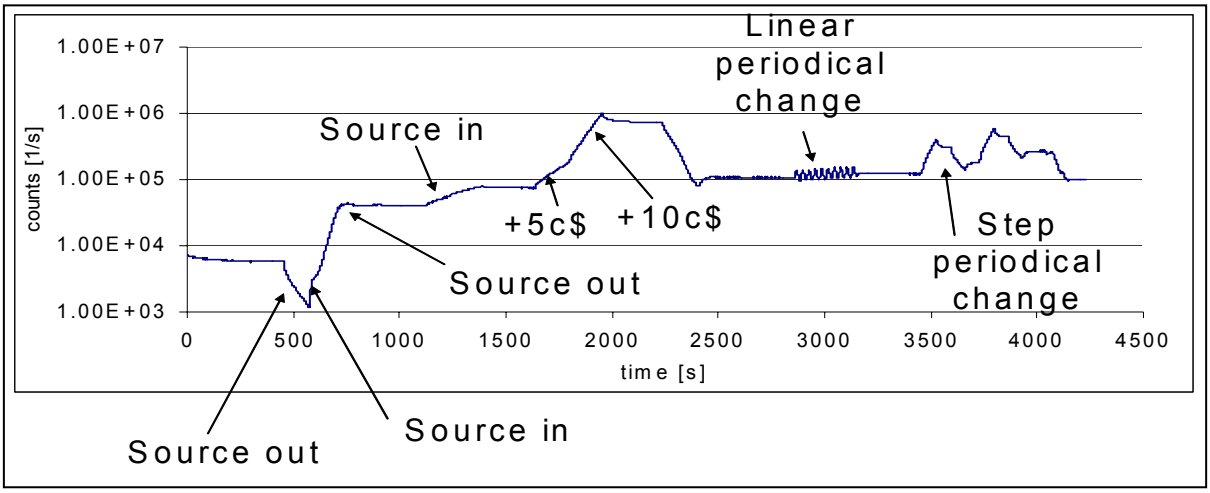

Fig. 4 Study of reactor dynamics with LEU fuel IRT-4M fuel [6]

Dynamic behaviour of the reactor in subcritical, critical, and supercritical states were studied. Reactor responses to the negative, positive, and periodic reactivity changes with and without external neutron source in all states were measured and compared with theoretical calculations. Measurements were performed by reactor physicists and staff only and later as a part of educational and training courses with students. The following results of dynamics studies were performed during Eugene Wigner course on Reactor Physics Experiments 2006 which was held in September 2006. Response of the reactor to the various reactivity changes

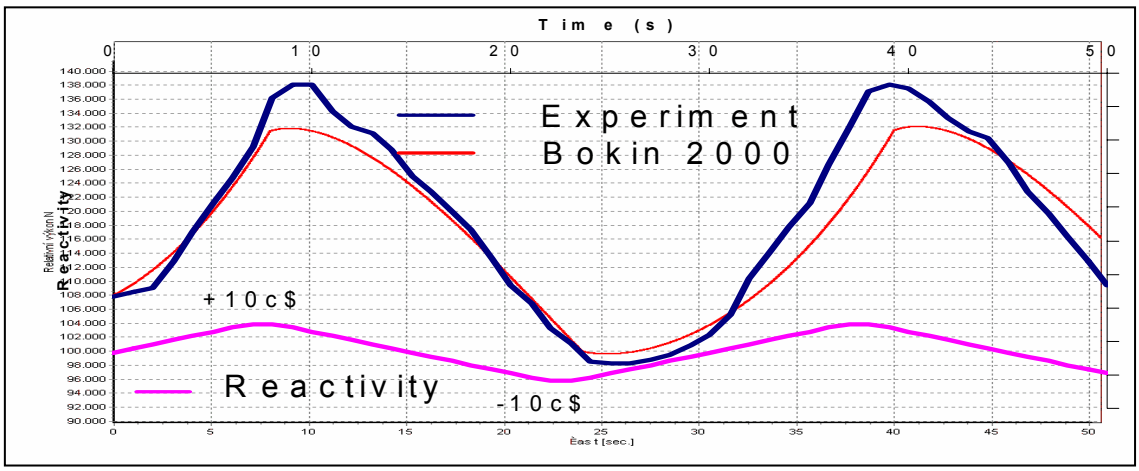

Fig. 5 Study of linear periodical change of reactivity with LEU fuel IRT-4M fuel [6]

is shows in (Fig. 4) and detailed comparison with theory for linear periodical change of reactivity is shows in (Fig. 5) and for step periodical changes of reactivity is shows in (Fig. 6). The results of the dynamics studies were compared with the same experiments using the HEU IRT-3M fuel and do not show any important changes in the dynamic behaviour of the reactor.

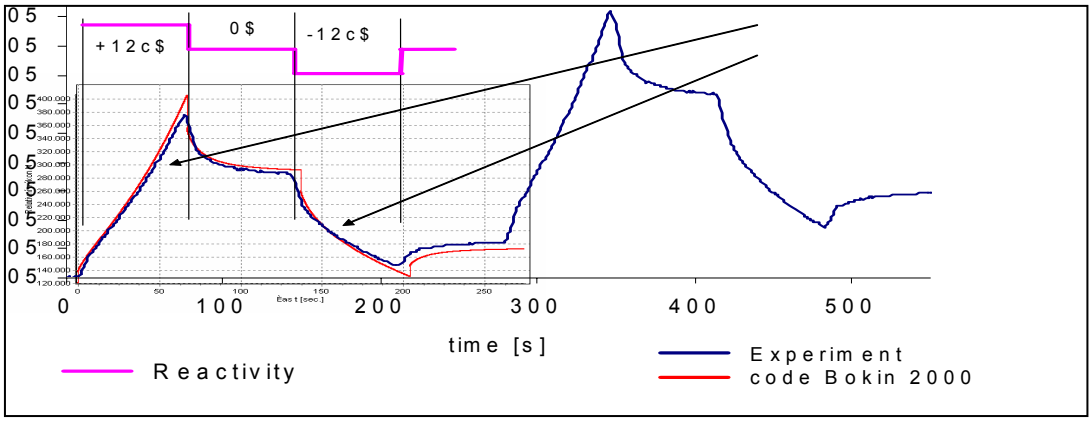

Fig. 6 Study of step periodical changes of reactivity with LEU fuel IRT-4M fuel [6]

Void coefficient of reactivity for LEU fuel loaded in the core of the reactor was studied. The core as a whole is submoderated and thus, the void reactivity coefficient is negative. In the place of the neutron trap, the core is locally overmoderated and „overabsorbed“ and the void reactivity coefficient can be locally positive in the certain range of the moderator dilution. For the study of void coefficient of reactivity, the boiling of the moderator (thus, the coolant, as well) is simulated in the reactor by forming the air bubbles that are equivalent to the steam bubbles in terms of the effects to the reactivity. One difference between the steam bubbles and the air bubbles is the fact that during forming the air bubbles the temperature changes do not occur during the experiment. During forming of the air bubbles, it is necessary to observe the bubbles must be sufficiently small not to be connected mutually and the bubble stream must be homogeneous and stationary. New instrumentation for studying the void coefficient of reactivity was developed by the Czech Technical University and Skoda Nuclear machinery Pilsen (Fig. 7) and was successfully used in education.

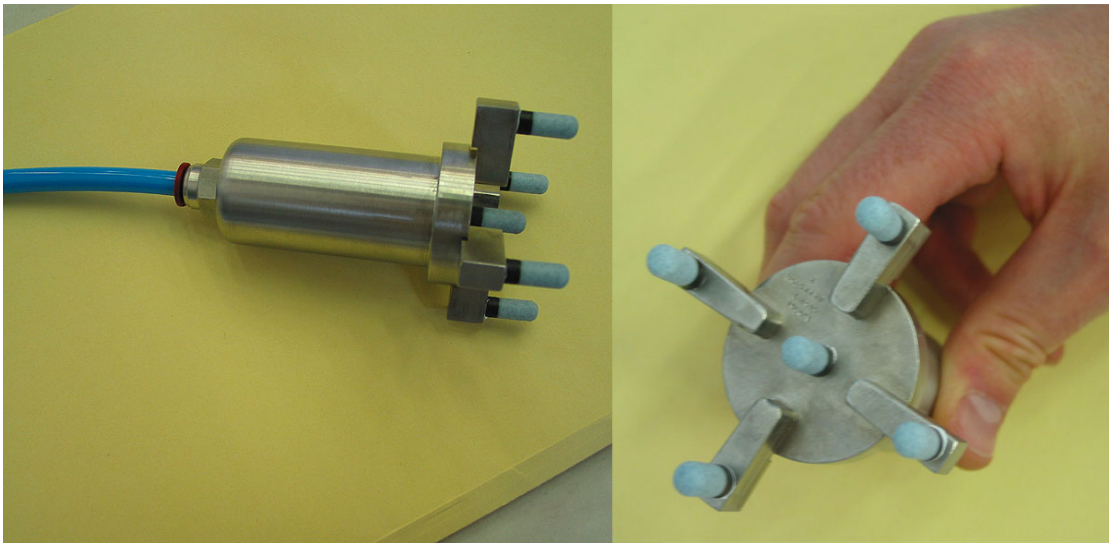

Fig. 7 New instrumentation for studying the void coefficient of reactivity with LEU fuel

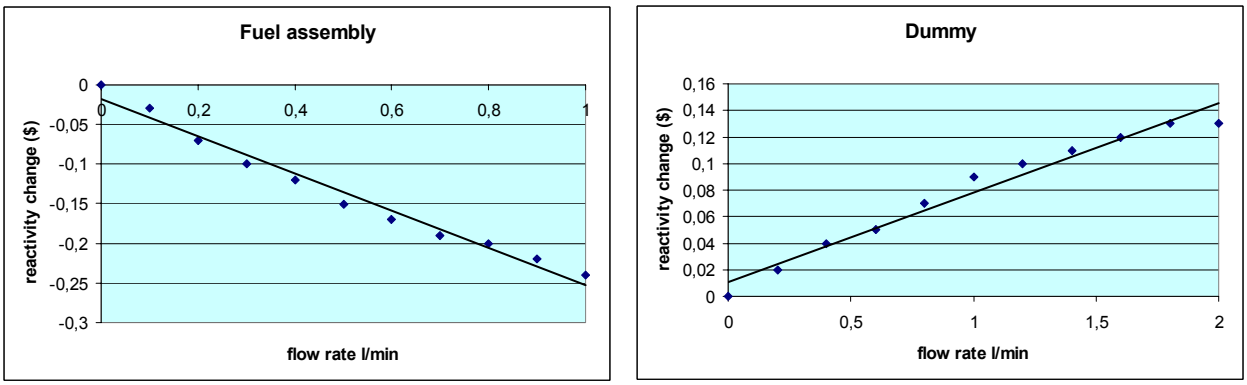

Fig. 8 Studying the void coefficient of reactivity in LEU fuel IRT-4M and in fuel dummy

5. The criticality experiment with the C2 core configuration

Core configuration C2 (Fig. 9) is the second core with the new fuel IRT-4M at the reactor. The basic criticality experiment with the core configuration C2 was carried out in the start of June 2006 [7]. Approaching the critical state with the C2 core configuration was prepared in the usual arrangement, which is typical for the reactor, and is based on the Czech law and the relevant international recommendations. The core was assembled in compliance with valid regulations.

The reason of assembling the C2 core configuration was to validate larger scale core geometry with the new LEU fuel as well as setting up a framework for irradiation experiments. The C2 core contains 20 fuel elements, out of which ten are eight-tube ones, ten are six-tube ones, one large graphite block (its dimension equals the four fuel elements) and seven control rods. Large graphite block is placed in the core centre and it is surrounded by fuel elements. It is assumed that in the future the graphite block will be replaced by an irradiation module.

The first critical state with the C2 configuration was attained (Fig. 10) on June 15, 2006 at 15:41 UTC. The critical state was calculated for all scram rods (B1, B2 and B3) in the top position (680 mm) and experimental rods (E1 and E2), control rods (R1 and R2) in the middle of the core.

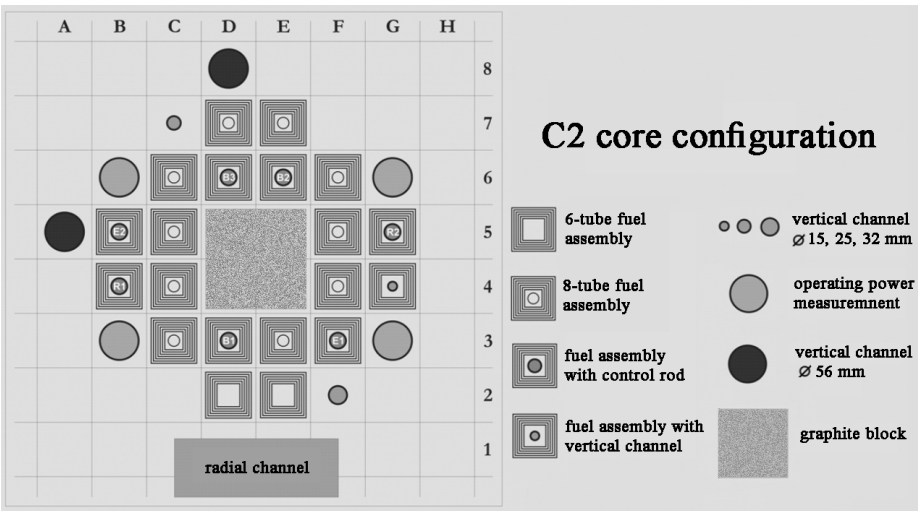

Fig. 9 C2 core configuration with IRT-4M fuel

The measured first critical state was attained with the first control rod R1 in the position 450 mm and the second control rod R2 in the position of 452 mm and all the other rods in the top

position. The deviation of the actual critical state from the calculated values was 0.27 β_{eff} only (Table 1). However, when the critical state was being reached, the deviations of the actual values from the calculated ones were higher, in particular in deeper subcritical states.

Table 1 Calculated and measured critical state of the reactor

rod position	B1	B2	B3	E1	E2	R1	R2
critical state	680	680	680	680	680	450	452

recalculation of the experiment	keff	deviation	reactivity [β_{eff}]	deviation
	1.00186	0.00034	+0.27	0.045

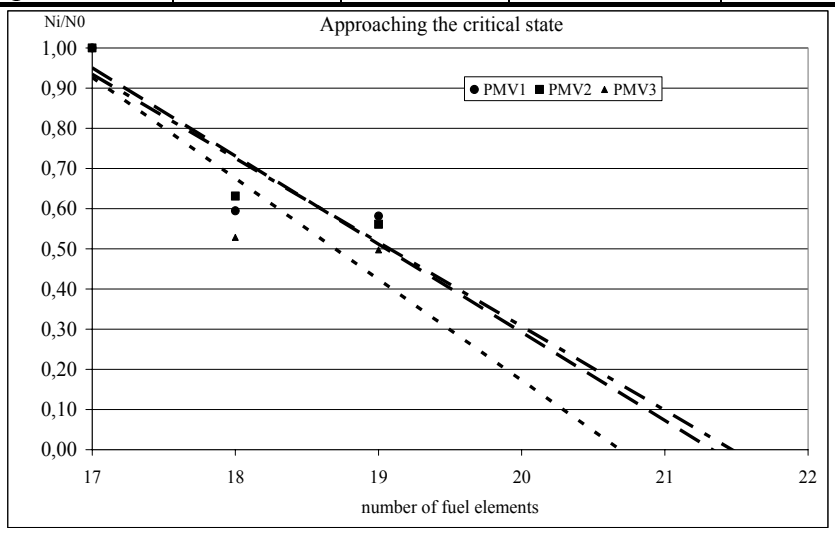

Fig. 10 Approaching the critical state with the core configuration C2

The worth of all the rods was calculated and also measured. The calculated results confirmed the assumption about the worth of the fuel elements and control rods (Fig. 11).

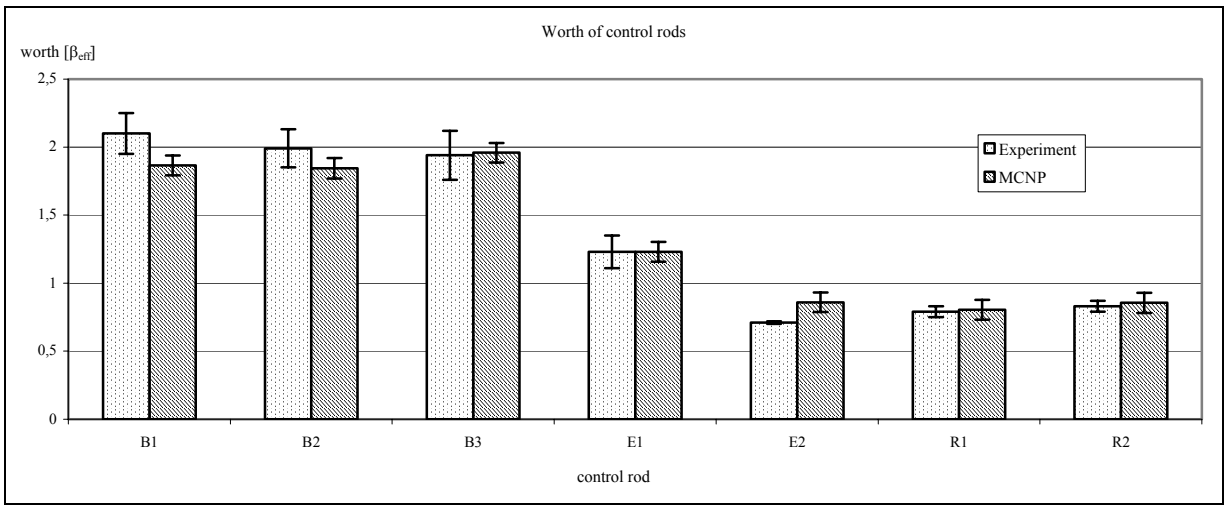

Fig. 11 Calculated and measured worth of the control rods

Conclusions

The Czech Technical University replaced the Russian made fuel containing highly-enriched uranium by the new Russian fuel, IRT-4M, containing low enriched uranium. The reactor has been now operating with the new LEU fuel for just over twelve months; the results from using the new LEU fuel are favourable indeed.

The world-wide first Russian made IRT-4M fully operational core configuration with the LEU fuel, named C1, was used during normal education and in terms of safety, reliability, physical properties, and training experiments well prove its capabilities. Its deployment during the last two semesters was important not only for CTU but for the entire RERTR programme and demonstrated that a Russian made HEU can be successfully replaced by LEU. Reaching criticality with the second core configuration, named C2, confirmed that using LEU at the SPARROW training reactor can be done on a routine basis.

References

[1] Skoda, R.: Sparrow Flies Lower, 2005 International Meeting on Reduced Enrichment for Research and Test Reactors, Boston, Massachusetts, 6-10 November 2005

[2] Rataj, J.: Criticality Calculations and Transient Analyses for the SPARROW Reactor with IRT-4M LEU Fuel Assemblies, 2005 International Meeting on Reduced Enrichment for Research and Test Reactors, Boston, Massachusetts, 6-10 November 2005

[3] Sklenka, L. – Matejka, K.: The First Critical Experiment with a LEU Russian Fuel IRT-4M at the Training Reactor SPARROW, 2005 International Meeting on Reduced Enrichment for Research and Test Reactors, Boston, Massachusetts, 6-10 November 2005

[4] Sborky teplovydelyayuschie IRT-4M, Katalozhnoe opisanie, 0019.20.00.000 DKO, NZCHK, Novosibirsk, Russia, 2004 (in Russian)

[5] Skoda, R.: 1st Full Conversion of Russian-designed HEU Fuel: Sparrow Flies Lower, Minimization of HEU in the Civilian Nuclear Sector, Oslo, 17-20 June 2006

[6] Uyttenhove, W. – Štrubelj, L.: Studying Nuclear Reactor Dynamics, E. Wigner Course on Reactor Physics Experiments 2006, Prague, September 2006

[7] Rataj, J. – Matejka, K.: Program of the approach to the first critical state on the C2 core of the Reactor VR-1, Czech Technical University, Prague, May 2006 (in Czech)