THE FIRST CRITICAL EXPERIMENT WITH A LEU RUSSIAN FUEL IRT-4M AT THE TRAINING REACTOR VR-1

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ABSTRACT

A critical experiment is a standard part of training of students at the Training Reactor VR-1 operated within the Faculty of Nuclear Sciences and Physical Engineering at the Czech Technical University in Prague. In autumn 2005 the HEU fuel IRT-3M with enrichment 36 % ^{235}U was replaced by the LEU fuel IRT-4M with enrichment 19.7 % ^{235}U. The fuel replacement at the VR-1 Reactor is a part of an international program RERTR. This Paper presents basic information about preparation for the fuel replacement and approaching of the first critical state with the new zone configuration C1 which replaced B1 core with the old IRT-3M fuel. The whole process was carried out according to the Czech law and the relevant international recommendations. The experience with the VR-1 operation confirms the assumption that the C1 core configuration will be suitable from the point of view of the reactivity balance for the long term safe operation of the Training Reactor VR-1.

1. Reactor VR-1

The operation of the training reactor VR-1 was started in 1990. It is an important facility for the Department of Nuclear reactors of the Faculty on Nuclear Engineering, Czech Technical University in Prague (CTU). The reactor is particularly designed for training of students of Czech universities, preparing experts for the Czech nuclear program, as well as for research work, and for information of the public.

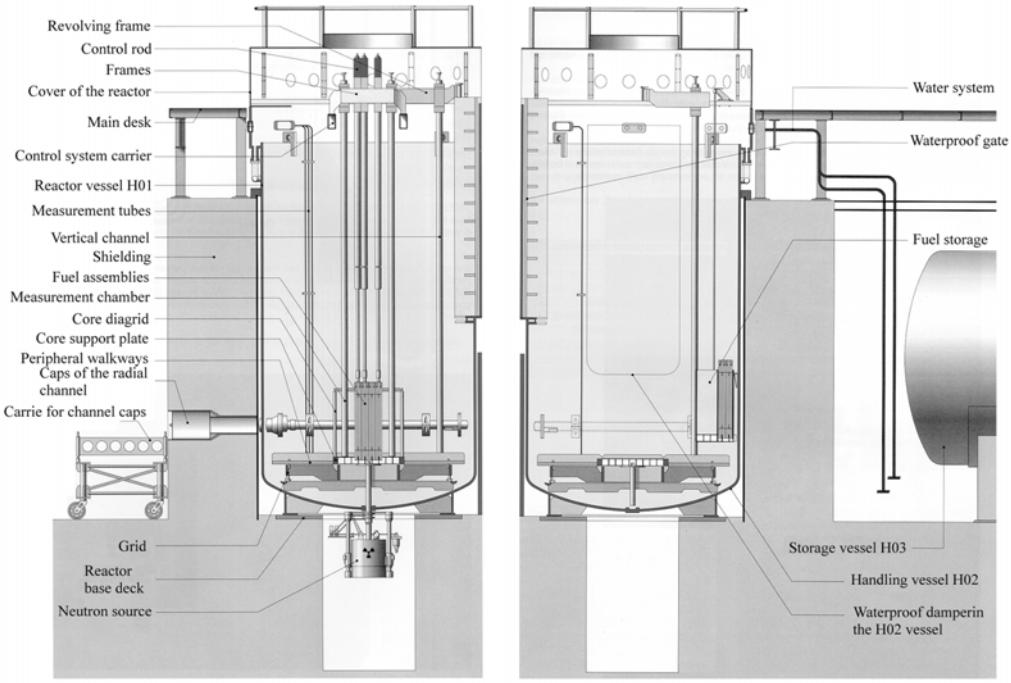

Fig. 1: Cross section of the reactor VR-1

The reactor (Fig. 1) is a pool-type light water-reactor with enriched uranium with maximum thermal power 1 kW. Heat is removed by natural convection. Neutrons are moderated by demineralized water which is also used as a reflector, a biological shielding, and a coolant. The active zone currently contains 17–21 fuel assemblies IRT-4M (Fig. 2) [1]. The core configuration can be flexibly adjusted to specific needs of individual training or research activities.
The IRT-4M fuel is the third type of fuel utilized in the VR-1 reactor. It was preceded by IRT-2M and IRT-3M types, both with 36 % enrichment.

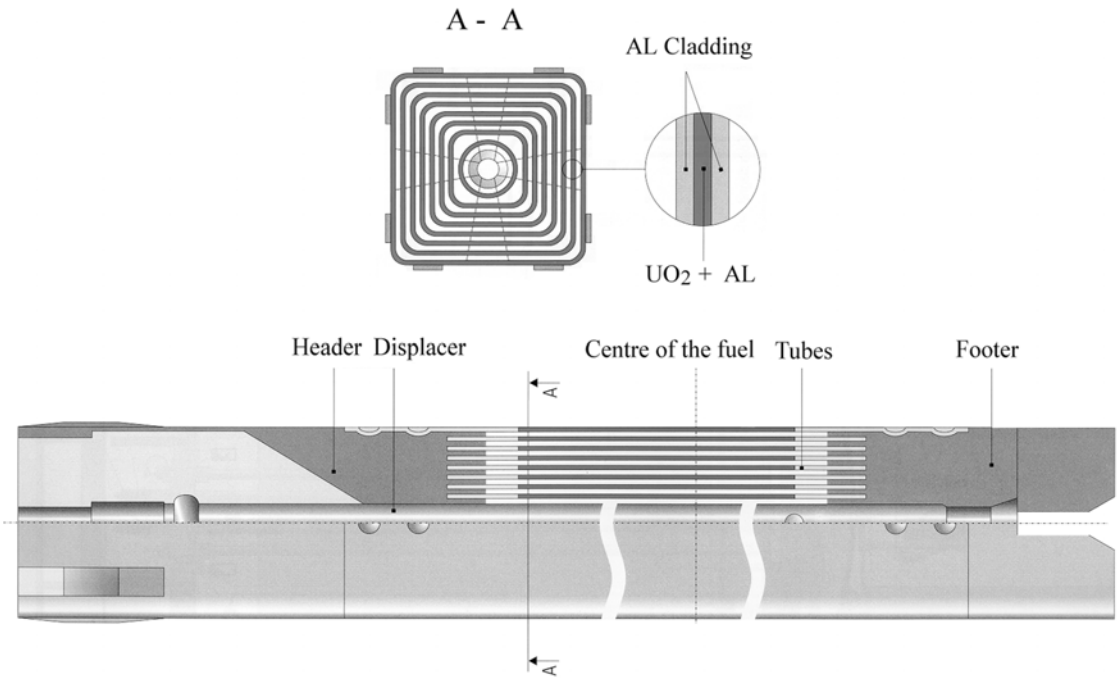

Fig. 2: 8-tube fuel element IRT-4M

2. RERTR program in the Czech Republic

During autumn 2005 the Russian made IRT-3M fuel utilized at the VR-1 reactor was replaced with IRT-4M fuel. This conversion was completed within the scope of the Reduced Enrichment for Research and Test Reactors (RERTR) program 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 programs worldwide.
IRT-3M is a HEU fuel witch 36 % enrichment. LEU fuel IRT-4M containing 19.7 % ^{235}U complies with the requirement to reduce the enrichment below 20 %.
The change of fuel required a direct cooperation of several institutions including DOE and National Nuclear Security Administration (NNSA) from the RERTR program, a Russian fuel supplier NZCHK, the Czech regulator (State Office for Nuclear Safety, SONS), Euroatom, International Atomic Energy Agency (IAEA), and a Russian company SOSNY, which was responsible for repatriating the HEU fuel IRT-3M. Several other contractors were involved in transport and logistics.

3. Critical experiment at the VR-1 reactor

A critical experiment is performed every year as a standard part of students training. An opportunity is given to the students to get acquainted with manipulation with fuel assemblies,

control rods, and other elements of the active zone, like experimental vertical channels, Students have full control and responsibility for the process. They design the zone configuration, unless the zone is meant for some special purpose, carry out all necessary calculation and prepare documentation for the State Office of Nuclear Safety which must approve the prepared program of the critical experiment.
The whole experiment is performed by students under the surveillance of the reactor staff. After successful completion of the program – when the critical state is achieved with standard procedures and parameters of the new configuration are measured and compared with preceding calculations – a final report is prepared and submitted to SONS. This report must reflect all the manipulations and possible changes compared with the originally submitted program.

4. The first critical experiment with the IRT-4M fuel

There were several goals for the first critical experiment with the LEU IRT-4M fuel:

- verification of manipulations with the IRT-4M fuel assemblies
- experimental determination of an unknown critical state (it was the first active zone with fresh fuel IRT-4M in the world)
- determination of worth of control rods
- verification of calculated parameters in individual steps of approaching the critical state
- obtaining fundamental neutronic characteristics of the IRT-4M fuel

The prepared zone configuration is depicted in Fig. 3. The name is derived from the convention of starting the name with a letter. The letter C refers to the third type of fuel.

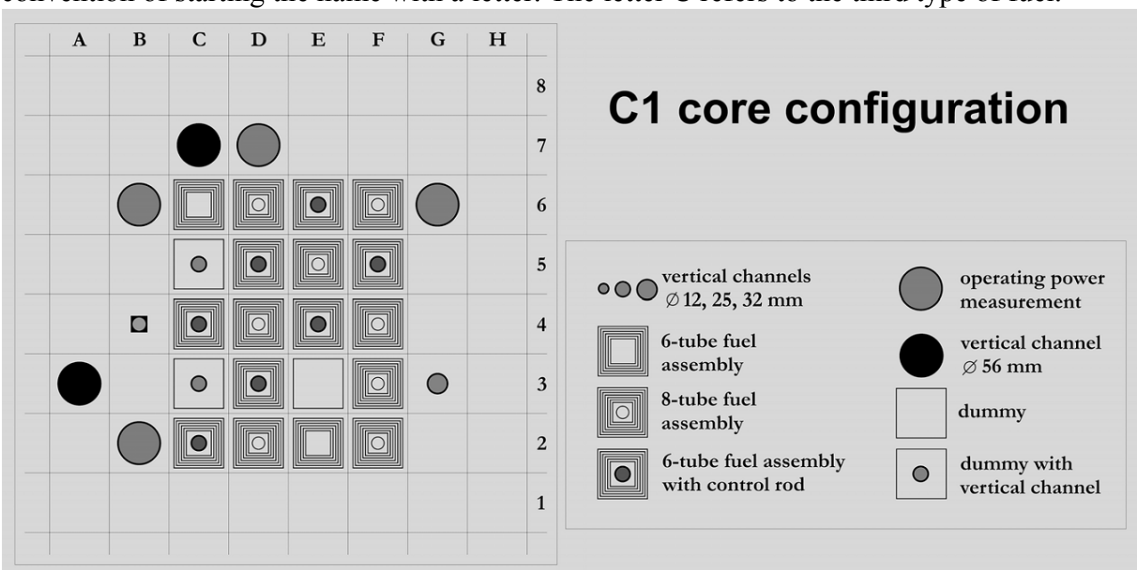

Fig. 3: C1 zone configuration assembled from the IRT-4M fuel

Parameters of the C1 zone configuration are in Tab. 1. The Fig. 3 shows that the fuel is organized in a square lattice 4×5 including 17 fuel assemblies and 3 dummies. Included are also channels for detectors for measurements of power level, other vertical channels, and experimental device for studying of parameters of delayed neutrons.

Tab. 1: Basic parameters of the C1 core configuration

fuel type	IRT-4M, enrichment 19.7% ^{235}U
total number of fuel assemblies	17
number of 8-tube FA	8
number of 6-tube FA	0
number of 4-tube FA	9
total mass of 235U	4774 g
number of control rods	7
number of FA dummies	3
number of experimental vertical channels	2 – Ø 25 mm
	1 – Ø 32 mm

5. Program of the critical experiment

The first critical experiment with the LEU IRT-4M fuel was the fifteenth since the commencement of VR-1 operation, therefore the staff at the Department of Nuclear Reactors was well prepared for experiment.

The actual program [2] consisted of almost 60 individual steps. The procedure started with the fresh fuel in the storage. In successive steps the IRT-4M fuel assemblies were loaded in the reactor. After the moment the power level made reactivity measurements applicable, the actual reactivity value was determined after every step. The actual procedure of determining the reactivity level is stated below. Obtained values were compared with calculations prepared earlier.

An inverse count rate method is the most reliable for prediction of critical state of the reactor. The inverse count rate method is a standard procedure. Application of this method must take into account dependency of inverse count rate curves on geometry of the core and relative positions of active zone components (including the external source of neutrons) and detectors. The count rate is measured using the vertical experimental channels and reactor I&C.

The inverse count rate is extrapolated to predict the reactivity at the following step of the critical experiment. Individual fuel assemblies are added by one at a time and exclusively with all control rods in their lowest positions, therefore, at their maximum effectiveness. The neutron source is always present in the zone.

The precise reactivity values are measured in chosen and in the program of the critical experiment defined steps by a Source Jerk Method. This method is well verified by a long term usage at the VR-1 reactor. Error analyse confirms that the Source Jerk Method accuracy is c. 8 % for reactivity up to -4 βef. The accuracy for lower reactivity is c. 15 % and for reactivity lower than -20 βef the accuracy is c. 30 %.

During the course of the critical experiment, values of reactivity are determined with control rods in their lowest and highest positions (if possible). Based on results, it is always decided about the next step of approaching the critical state.

Each critical experiment ends when reactivity reaches -0.7 βef, after that, the critical state is reached with standard means, i.e. control rods. The first critical state with LEU IRT-4M fuel was reached on October 18, 2005.

6. Requirements for standard operation of VR-1

Successful completion of the critical experiment was only one step on the way to daily reliable operation of the VR-1 reactor. The whole preparation was well described in [3] and was done in the ten following stages:

- agree the legal contract framework for the entire fuel swap
- create new computational model of the reactor core to validate new core configurations (C1 and following)
- conduct thermal-hydraulic, safety, and transient analyses for the new core configuration
- adjust the reactor control system
- update the operational and safety documentation and obtain necessary licenses
- inspect the fuel manufacturer, check the new fuel properties
- conduct the critical experiment following the SONS approved program
- measure the standard neutronic properties of the C1 core, completion of the LEU core licensing
- operate the reactor in a testing regime, preparation for education
- evaluate the testing regime results and switch to the standard operation

7. Conclusions

The CTU successfully replaced the HEU fuel IRT-3M with the LEU fuel IRT-4M at the VR-1 reactor. The results from more than 2 year operation of the reactor are favourable [4].
The first active zone configuration with fresh LEU Russian fuel IRT-4M used during normal education and in terms of safety, reliability, physical properties, and training experiments well proved its capabilities. Its deployment is important not only for CTU but for the entire RERTR program and demonstrated that a Russian made high-enriched fuel can be successfully replaced with a LEU fuel. Completion of following regular critical experiments with the IRT-4M fuel confirmed that utilization of LEU at the training reactor VR-1 can be done on a routine basis.

8. References

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