Utilization of the LVR-15 Research Reactor at Rez

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Abstract. The LVR-15 research reactor was commenced in 1957 as a multipurpose source of neutrons for basic research at horizontal channels and user-oriented research at mostly vertical loop channels and rigs as well as. The advantage of the reactor layout comes from flexible diameter of irradiation channels, good access to the upper part of the channels, and the fact that the core can be refueled without let-up of operation of the irradiation facility. The main fields of the reactor utilization are neutron beam research including BNCT, fuel and material irradiation tests, and radioisotope and silicon production. Reactor has joined the Russian Research Reactor Fuel Return (RRRFR) initiative to convert from HEU to LEU. At present the transportation of the spent fuel to Russia is being prepared. The paper presents the present status and future plans of LVR-15 utilization.

INTRODUCTION

The LVR-15 research reactor commenced operation in 1957 as a multipurpose source of neutrons for basic research at horizontal channels and user-oriented research at mostly vertical loop channels and rigs as well.

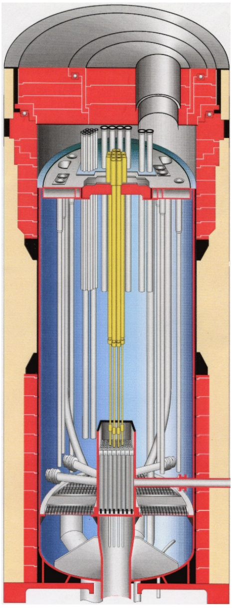


Fig. 1. LVR-15 research reactor

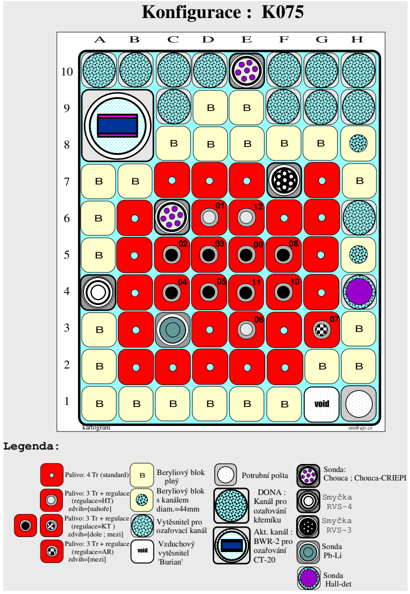


Fig. 2. An example of LVR-15 core (axial cross section)

Since 1957 the reactor has undergone two reconstructions. During the last one in 1989 all the reactor components and systems were replaced, including the reactor vessel. The LVR-15 is a tank type reactor (Fig. 1) and currently uses IRT-2M fuel of 36 wt.% 235U enrichment manufactured by the

NZCHK Company in Novosibirsk, Russia. The fuel features limit the output reactor power to 10 MW. The thermal and fast neutron flux reach up to 1.5 x 1018 n/m2s and 2.5 x 1018 n/m2s, respectively. Due to the nature of the reactor use, the reactor working cycle is 21 days and the number of the cycles is 8-10 per year.

REACTOR USE FOR MATERIAL RESEARCH

The advantage of the reactor arrangement results from the flexible diameter of irradiation channels, good access to the upper parts of the channels, and the fact that the core can be refueled without outage of the irradiation facility. The main fields of the reactor utilization are neutron beam research including BNCT, fuel and material irradiation tests, and radioisotopes and silicon production. LVR-15 special reactor features in the field of material research can be summarized:

- Core and irradiation channel size flexibility
- Irradiation rigs for irradiation of small (ring, tensile) to large (1CT, 2CT) specimens
- Five big loops with specialized mechanically loaded or heated irradiation channels
- Water chemistry and dosimetry control ensuring the conditions in testing facilities to be as close as to the conditions in power plants.

Location of loops and rigs in LVR-15 reactor

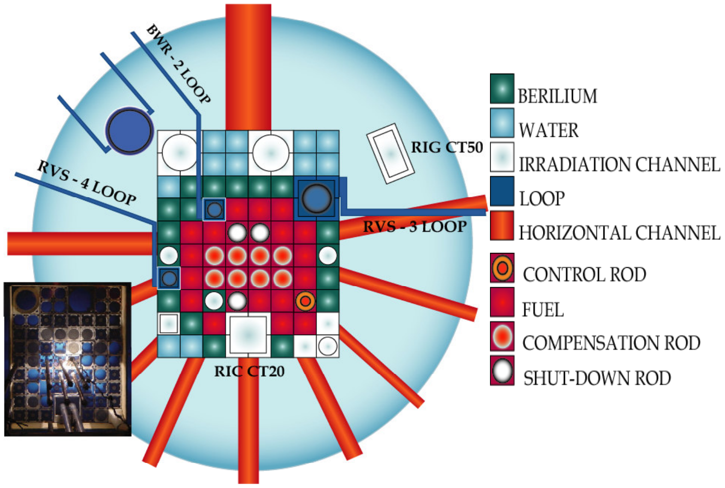


Fig. 3. Location of loops and rigs in LVR-15 reactor

Other, more limited uses are in the areas of medicinal and industrial radioisotope manufacturing, production of radiation doped silicon and development of boron neutron capture therapy.

The reactor is equipped with hot cells for a post-irradiation sample manipulation, disassembling and assembling core channels.

The LVR-15 reactor specializes – due to its output and achievable neutron fluxes – in the study of combined effects of radiation and ambient media on materials. The reactor is equipped with experimental facilities such as loops and rigs, which permit an exposure under conditions corresponding to those in power reactors. The generally utilized procedure is that the material is pre-irradiated in rigs and then is further exposed in loops enabling also the simulation of the thermal flux or physical stresses.

Fig. 4. Instrumentation of a side loop irradiation channel with CT samples

Irradiation rigs permit the exposure starting from small samples (ring, tensile) up to very large samples (1CT, 2CT). Total five loops simulating either PWR or BWR conditions in various irradiation channels and other specialized facilities are in the operation at the reactor:

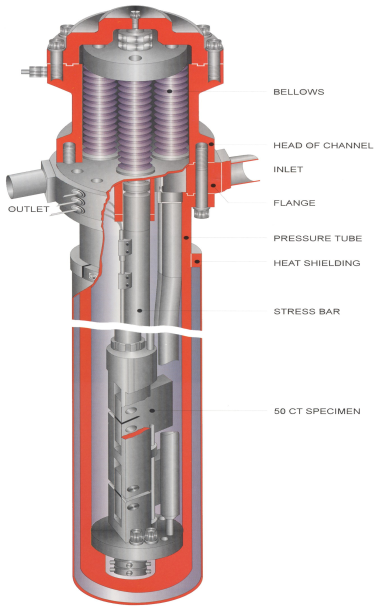
- Reactor rigs –
  - Chouca for Charpy V, tensile, 0.5 CT specimens, and
  - flat rig for 1-2 CT specimens;
- Reactor loops –
  - BWR –1 for structural material testing,
  - BWR-2 for reactor pressure vessel (RPV) and internals steels testing (Fig.5),
  - Zinc loop for radioactive material transport and water chemistry testing,
  - RVS-4 for testing of fuel cladding corrosion ;
  - Irradiation channels - in-pile channel for RPV steel, in-pile channel for austenitic steel, and in-pile channel for slow strain rate tests (SSRT) (Fig.5),
  - Pb-Li loop and primary first wall (PFW) materials of the fusion program.

Important experimental projects were/are aimed at:

- Material degradation studies (RPV and core internals for VGB, in-pile and out-of-pile studies for EPRI, irradiation of RPV steels for JAPEIC, studies of pre-irradiated austenitic specimens for Czech Electric Company);
- Study of Zr alloys cladding corrosion in PWR and VVER conditions, with electrically heated fuel rod imitators;
- Water chemistry influence on radioactivity transport and build-up in primary circuit, ammonia, hydrogen, zinc addition chemistry effects, high pH and hydrazine chemistry;
- Fusion reactors materials and technology (PFW and Test Blanket Module for ITER).
- Irradiation test certificates for RPV materials of VVER-440, VVER-1000 reactors,
- European projects - MTR-I3, RAPHAEL, EFDA, HPWLWR, ITSR, ELSY, FRAME, CASTOC, PISA, PERFECT, REDOS, …

Experience based on long-term research in material, water chemistry and radiolysis tests for PWR, VVER and BWR is used in research supporting development of the new generation of reactors (G IV). The following facilities has been designed at the reactor

- Super Critical Water Reactor (SCWR) Loop for Water Chemistry and Radiolysis Study – with parameters 600o C, 30 MPa in the active core and 350-400oC in the main pipelines with flow rate of 1000kg/h for the study of in-core radiolysis for in-flux behavior of materials;
- High Temperature Reactor loop cooled with helium (Fig.6) – the loop comprises an irradiation part, an electric heating part, a regenerative heating exchanger, a cooler and a compressor. The irradiated part will have an outer diameter of 57 mm and core height of 580 mm. The irradiation temperature range is supposed at 500-1000oC, with a flow rate of 20g/s and He pressure of 7Mpa;
- Fusion Reactor Structural Material – research and development and irradiation services for primary first wall and European test blanket module concepts (HCLL, HCPB).



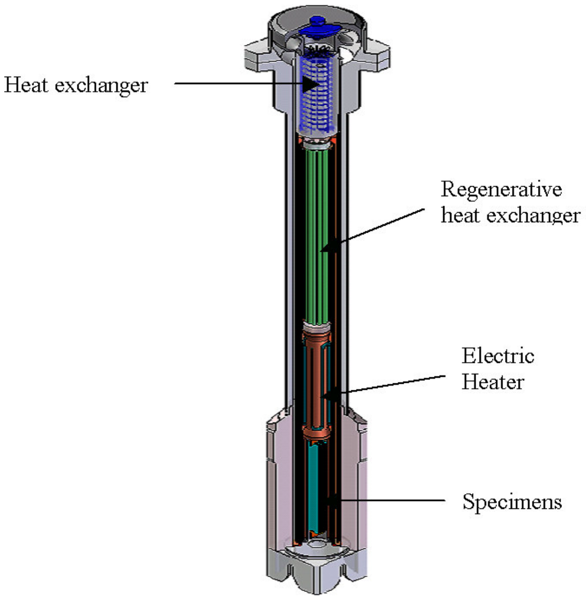


Fig. 5. Active channel of the BWR-2 loop

Fig. 6. Design of a Helium loop

POST-RADIATION EVALUATION

At NRI Rez, there are several hot cells laboratories, which are used in the area of materials research. Hot cells on the reactor serve for the extraction of samples from rigs and loops, and their preparation before transport to hot cells outside the reactor building, where post-radiation work is carried out. In these hot cells the following procedures, among others, can be performed: static tensile tests, impact instrumented Charpy V-notch type tests on standard and sub size specimens, static fracture toughness tests on standard and sub size specimens, crack growth rate in air, vacuum and BWR/PWR environments, stress corrosion tests in BWR/PWR environments, slow rate stress corrosion tests.

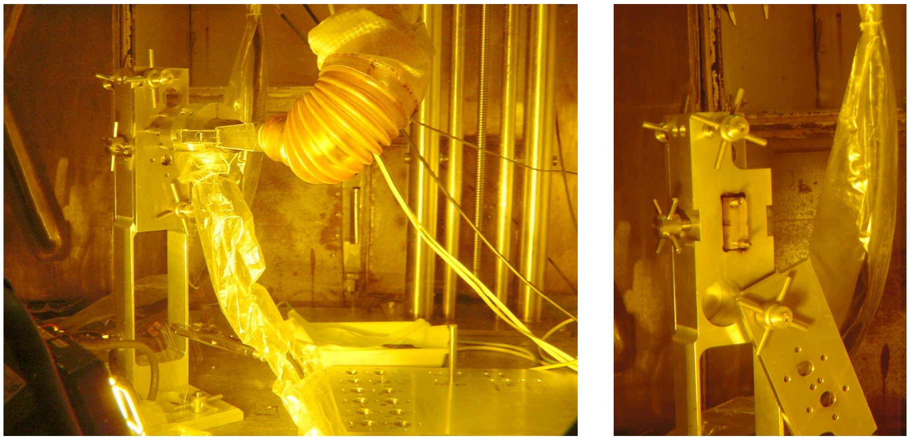


Fig. 7. Equipment for samples welding in hot cells

HEU TO LEU CONVERSION

Reactor LVR-15 is operated with the IRT-2M 36% fuel and has sufficient fuel reserve till 2010, nevertheless, first studies about the HEU to LEU conversion had started as was already reported. The prospective type of fuel assembly design that could be potentially used is IRT-4M with UO2-Al fuel, which is compatible with the current LVR-15 core lattice and control rods system. This oxide fuel design is commercially available. However, the new FA type will require a more challenging licensing of mixed cores during gradual conversion for the LVR-15 reactor environment as 235U content and the geometry of FAare substantially different. Basic advantage of the IRT-4M design is that the FA could be used at 15 MW. They have been tested in Uzbekistan and are used at the Vrabec VR-1 reactor at Prague Technical University.

So far performed analyses have been oriented to how the summary rods worth is bound to the total reactivity excess, fuel depletion, and neutron spectrum change assessment.

The value of ratio of the total rods worth and the total reactivity excess is a key parameter deciding if the given core pattern can be utilized. Based on the performed calculations and operational experience this criterion could be fulfilled only up to 235U content of about 300 - 325g in IRT-4M (8 tubes) fuel assembly. The exploitation of the proposed LEU fuel could reduce the annual consumption of FAs more than 30% comparing with the IRT-2M (36%) currently used.

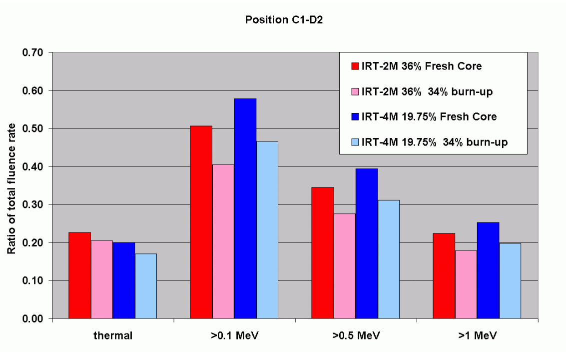


Fig.8. Ratio of total fluence rate by neutron energy averaged over the stainless steel samples irradiated in the large flat rig at the core periphery

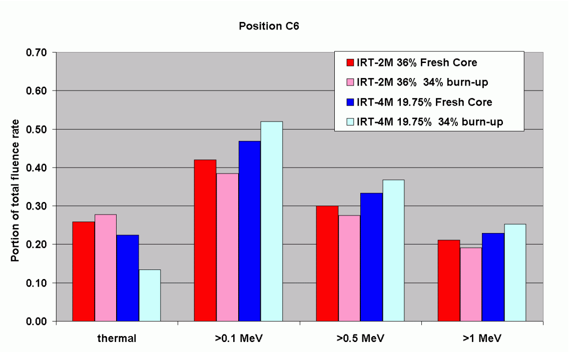


Fig.9. Ratio of total fluence rate by neutron energy averaged over the stainless steel samples irradiated in the core

Results of calculations for in-core positions and close to the core periphery confirmed the known fact that neutron spectrum shifts towards higher energies when enrichment decreases (Fig.8, Fig.9). The increase of the fast neutron fluxes varies from 32% to 35% for the half burnt fuel while the thermal neutron flux decreases up to –52% under the same conditions. The increase of the fast neutron fluxes is a beneficial consequence of the conversion regarding the prevalence of the commercially important irradiations based on material studies that are realized at the reactor.

Next step should provide a complex conversion study of the transition from MEU to LEU core via mixed cores. Work will cover the assessment of neutronic and thermo-hydraulic aspects of the LVR-15 reactor. Decision what type of fuel is the most appropriate for the LVR-15 will be based on a detailed analysis of physical and economical aspects of the conversion.

FUEL CYCLE

Reactor has joined the Russian Research Reactor Fuel Return (RRRFR) initiative to be converted from HEU to LEU. Together 32 FAs are in the reactore core and the present fresh fuel stock consists of 73 fuel assemblies that are sufficient for the reactor operation till the end of 2010 year. The spent fuel FAs are stored either at the reactor site in the reactor pools (28 FAs) or in the NRI HLWSF interim storage.

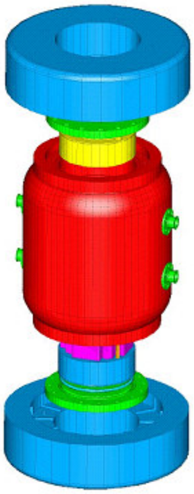


Fig. 10. VPVR/M cask for storage and transport of SF from Russian origin research reactors

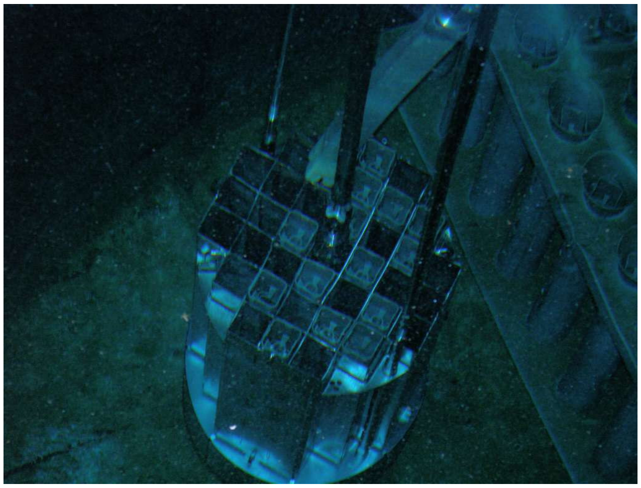


Fig. 11. Loading the SNF from the HLWSF pool

Fig. 12. VPVR/M cask being moved into the storage area

Fig. 13 Interior of the ISO container with one VPVR/M cask

Spent fuel will be shipped to Russia in autumn 2007 in the VPVR casks (Fig.10) that were designed for all the Russian fuel types used in the LVR-15 similar research reactors of the Russian origin round the world. The cask is licensed in the Czech Republic and Russia as well. Technical acceptability of the VPVR/M cask, handling it and loading spent fuel at the research reactor facilities, as well as its receipt and unloading at the Mayak facilities in Russian Federationhave been demonstrated. Three demonstrations were organized at the SKODA manufacturer, at LVR-15 research reactor at NRI Rez, and in Mayak facilities in Russia.

At present the shipment of the spent fuel to Russia is being finalized. All the FAs have been loaded into 16 VPVR/M casks. At first three casks were loaded at the LVR-15 reactor site with 91 IRT-2M (36 %) FAs and 10 IRT-2M (80 %) FAs in March and May 2007 and then transported to the HLWSF facility at NRI.

In May-August 2007 six casks were loaded with 206 EK-10 FAs from the HLWSF hot cell by manual and robotic manipulators. Seven additional casks were loaded with 242 IRT-2M (80 %) (235 FAs from the HLWSF pool and 7 repacked FAs from hot cell). All the 16 casks were loaded into ISO containers. In autumn 2007 the containers will be transported to a railroad station on trucks and then on railroad carriages to Russian Federation.

CONCLUSIONS

The LVR-15 reactor is an important facility, which supports and contributes to research of nuclear materials and water chemistry. Experience that has been achieved operating the reactor during the last 50 years can be now transferred to the new irradiation facility designs including those which performs the research for Generation IV reactors, e.g. such as reactors cooled by high-temperature helium or water with supercritical parameters.

ACKNOWLEDGEMENTS

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