Experimental research reactor LVR-15 present status and programs

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Abstract

The reactor LVR-15 is used as a multipurpose facility and its main use is material research carried out on reactor water loops and rigs and horizontal channels beam research.
Advantages of the LVR-15 reactor lay-out are based on flexible diameter of irradiation channels, height of water level above core is only 4 m, there is good access to upper part of the channels, refuelling is done during loops operation and facilities can be operated during time of reactor shut down.

The basic research for materials is carried out using horizontal neutron beams. Neutron activation analysis laboratory is equipped with the pneumatic rabbit facility. Standard irradiation service comprises irradiation of samples, irradiation of samarium for radio-diagnosis purposes and iridium wires for medical treatment as well as iridium discs for technical radiation sources production and silicon neutron doped crystals production.

1. Introduction

LVR-15 special reactor features in the field of material research can be summarized:

- Core and irradiation channel size flexibility
- Irradiation rigs from small (ring, tensile) to large (1CT, 2CT) specimens irradiation
- Five big loops with specialized mechanically loaded or heated irradiation channels
- Water chemistry and dosimetry control

Conditions in testing facilities need to be as close as conditions in power plants. Achieving this high purification rate and high flow rate (>1m/s, Re ~10^5) is needed. For radiation testing complex solution should be proposed involving such items as radiolysis code calculations, ECP in-core measurement, in-situ crack growth measurement etc.

Two new experimental loops for operation in research reactor LVR-15 in ÚJV Rez are recently under preparation: High Temperature Helium Loop (HTHL) and Super Critical Water Loop (SCWL). Pure helium will be used as working medium in HTHL and its main physical parameters are: operating pressure 7 MPa, max. temperature in the test section 900 °C and flow rate 36 kg/h.HTHL will include helium purification system, system for dosage of impurities (e.g. CO_2, H_2, H_2O,O_2, N_2 etc.) and helium sampling. Helium purification experiments and testing of materials in simulated HTR conditions will take place in HTHL in the future.

Main parameters of the second loop SCWL are 25MPa, max. temperature in the test section 600 °C, flow rate max. 200kg/h. SCWL will be used for corrosion tests of candidate materials, studies of water radiolysis at supercritical conditions and for testing of water chemistry suitable for operation. Main objective is to gain and extend knowledge on materials and environment performance under the influence of radiation and coolant chemistry.

2. Research Reactor Description

The LVR-15 research reactor is located in Rez, near Prague, at the Nuclear Research Institute. The reactor was commissioned in 1957; since then it has undergone reconstruction twice, where the last reconstruction took place in 1989, when all reactor components and systems were replaced, including the vessel. The reactor's architecture was created by Russian organizations, and the last reconstruction was performed by the SKODA Company. The LVR-15 reactor is a tank type and currently uses fuel manufactured by the NZCHK Company in Novosibirsk with 36 % enrichment (IRT-2M fuel type). The reactor's systems permit an output up to 18 MW from the standpoint of cooling capacity; due to the fuel type used the output is limited to 10 MW. With new types of fuel that have a greater heat exchange surface area (IRT-3M, IRT-4M), an output of up to 15 MW is under consideration. The thermal neutron flux reached is 1.5 x 10^{18} n/m^2s and the fast neutron flux is 2.5 x 10^{18} n/m^2s. Due to the nature of its usage, the reactor's duty cycle is 21 days, with the number of cycles being 8-10 per year (Fig. 1, 2).

The reactor is used as a multi-purpose facility, with emphasis on material research on loops and rigs. Another area of the reactor's usage is the sphere of neutron physics and neutron activation analysis. These are the two main spheres of usage, which do not compete with each other for space in the active zone. Other, more limited uses are in the areas of medicinal and industrial radioisotope manufacture, production of radiation doped silicon and development of neutron capture therapy.

The reactor is also equipped with hot cells for post-radiation sample manipulation, disassembly and assembly of active channels. Hot cells are equipped with specialized equipment that permit the separation of samples, their cutting and preparation for transport to hot cells for post-radiation evaluation.

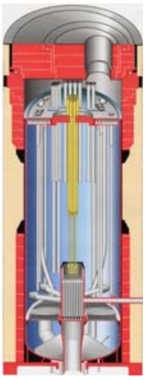

Fig. 1 Research reactor LVR-15

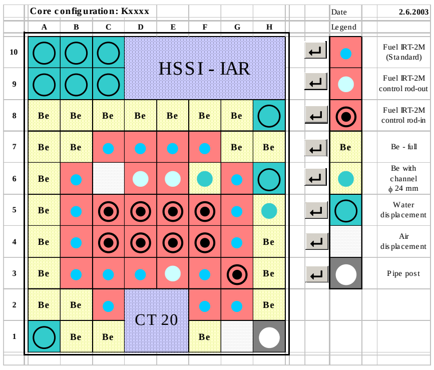

Fig. 2 Example of cross section of LVR-15 active core

3. Reactor Usage For Material Research

The LVR-15 reactor specializes – due to its output and achievable neutron fluxes – in the effect on materials of the interaction of radiation with environment. Neutron fluxes and gamma radiation reach values comparable with the active zone of thermal nuclear systems, which is why the reactor is a suitable tool for the study of these processes. For this usage, the reactor must be equipped with experimental facilities which permit exposure in an environment corresponding to that in power reactors. This environment is generated in facilities such as loops and rigs. The generally utilized procedure is that the material is pre-irradiated in rigs and then is further exposed in loops, which are equipped with additional facilities such us simulation of thermal flux or physical stresses.

The reactor's design and active zones permit the usage of various diameters of irradiation channels and thus flexibility from the standpoint of optimal neutron usage in the zone. The water level height above the active zone is 4 m, which permits the location of the top part of irradiation channels above this surface and thus also good installation and manipulation access. For materials research, when long environmental sample exposures are necessary, the loops are operated and maintained within parameters even during reactor shutdown and nuclear fuel replacement. During shutdown, a maximum of 1-2 elements are replaced, and this operation can be performed with several days. Sample exposure times in loops can thus reach – and this actually happens – up to ca. 5000 hours, which represents a half-year of uninterrupted loop operation.

Irradiation rigs permit the exposure starting with small samples (ring, tensile) up to very large samples (1CT, 2CT). A total of five loops with various irradiation channels and other specialized facilities are in operation in the reactor (Fig. 3).

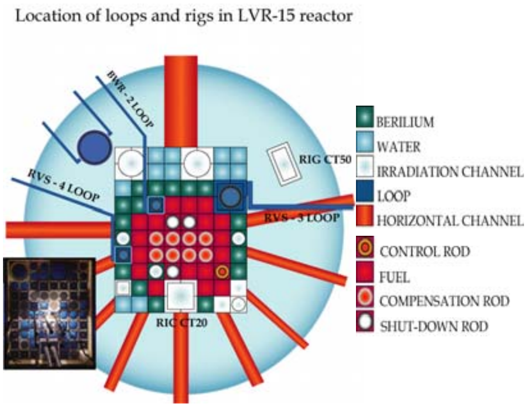

Fig. 3 Location of loops and rigs in LVR-15 reactor

4. Main Experimental Facilities

4.1 Reactor Water Loops

Reactor water loops are used to study the effect of environment on materials in the active zone of power reactors. Phenomena under study include corrosion, the influence of physical and radiation stresses on the rate of crack propagation, the interaction of fuel and coolant coverage, including cladding corrosion and the deposition of corrosion products on the surface of fuel elements, further for the research of water chemistry of PWR, BWR and VVER reactors, including the development and testing of special measurement technology such as for example ECP measurement.

The loops' construction permits the attainment of high flow velocities (>1 m/s, Reynolds number 10^4), which is necessary for a corresponding mass transfer. All loops are equipped with high-efficiency cleaning apparatus in order to achieve the high water purity necessary for tests. For example, water purity achieved in the BWR loop is of conductivity < 0.1 µS/cm. The loops thus permit flexible change of water chemistry, where direct injection of gaseous oxygen or hydrogen according to requirements.

Another important area that is needed for achieving experimental results is instrumentation necessary for the measurement of electrochemical potentials or crack growth rates, for example. Also necessary for such tests are facilities for the calculation and modelling of radiation parameters, thermo hydraulic parameters and water radiolysis, for example.

Currently two loops are used for PWR and VVER reactors, two loops for BWR, and one loop for zinc injection research. Besides this there are also various types of irradiation channels, which are equipped for SSRT (slow strain rate testing), stress corrosion cracking tests (SCC, IASCC) for 1CT and 2CT samples and for cladding corrosion with electrically heated heating rods.

An inseparable part of the loop base is also a reactor dosimetry laboratory, in which neutron and thermo hydraulic calculations are performed, essential mock-up experiments are realized, and which provides measurement of neutron and radiation parameters during experiments. Water chemistry control is secured by a specialized laboratory and inline and online measurements directly on the loops. Included in this measurement circuit is high-pressure gas measurement (oxygen and hydrogen) with the help of an Orbisphere meter, ECP measurement and the use of offline ion-chromatographs.

The RVS-3 loop simulates a pressurized water reactor environment and was commissioned in 1983. The loop serves for research into fuel element cladding corrosion and the deposition of corrosion products in the loop. The RVS-4 loop (Fig. 4) as commissioned in 1998, and is used for research into VVER reactor water chemistry. Currently it is being used for experiments for the study of the influence of corrosion product deposition on the surface of fuel elements and the surface of steam generator tubes after circuit decontamination. The loop with zinc (Fig. 5) doping is a specialized facility which fully models primary circuit parameters, not only with regards to temperature, heat transfer and flux, but also with regards to the ratio of surface and coolant volume to the surface of zirconium and stainless steel. The loop has been used to study the effect of zinc on the deposition, transport and release of corrosion products in the primary circuit, with a goal of lowering the radiation dosage to operational personnel and the minimizing of corrosion.

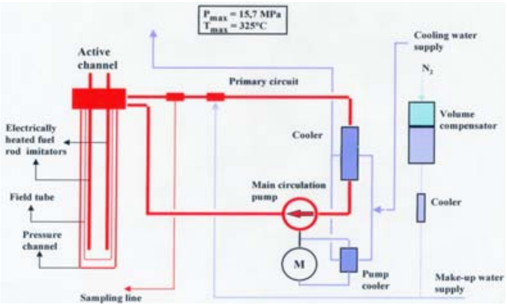

Fig. 4 Primary circuit of loop RVS-4

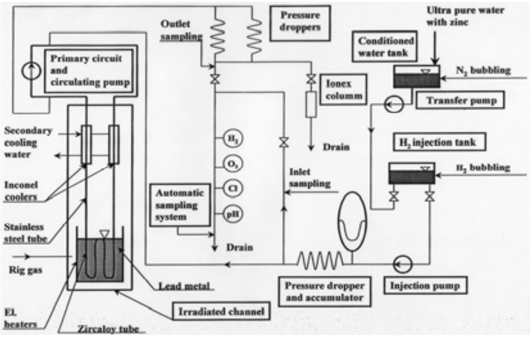

Fig. 5 Zinc injection loop

Two BWR-1 and BWR-2 (Fig. 6) boiling water reactor loops are used for the study of material behavior in BWR and RBMK reactor environment and conditions. The BWR-1 loop has been used for tests of ceramic construction materials that are used in the construction of high-temperature sensors (electrodes).

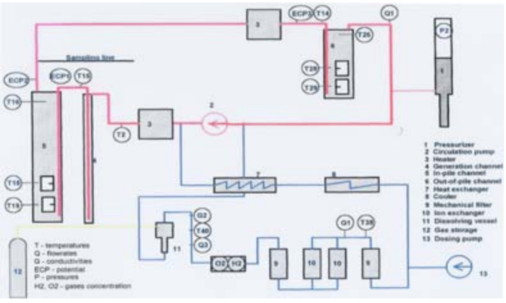

Fig. 6 Boiling reactor water loop BWR-2

These sensors are necessary for the measurement of electrochemical and reduction potentials necessary for the determination of content of oxidizing substances (oxygen, hydrogen peroxide) in the reactor's active zone. The BWR-2 loop is being used for long-term research into corrosion materials of internal boiling water reactor assemblies. Pressure vessel SCC material tests and internal assembly IASCC material tests have been realized. The velocity of crack propagation in materials in the heat affected zone, i.e. the material region between weld metal and substrate, that is in the region most affected by the occurrence of IASCC, have been realized (Fig. 7, 8).

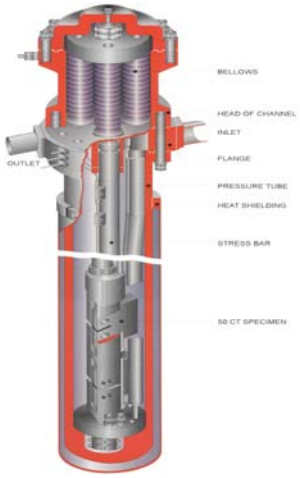

Fig. 7 BWR-2 loop irradiation channel

Fig. 8 Instrumentation with CT samples in side loop irradiation channel

A significant part of corrosion studies via BWR and RMBK boiling water reactors is the behaviour of peroxide and other oxidizing substances that are created in water during its radiolysis.
A numerical radiolysis model, which calculates the development of peroxide and oxygen on the basis of loop parameters, has been verified on both BWR-1 and BWR-2 loops.

4.2 Rigs

Reactor rigs are intended for the irradiation of materials in an inert environment with a goal of studying the behaviour of materials after irradiation. Rigs function at temperatures between 250 – 350 °C. These temperatures are achieved by a combination of radiation heating and electrical heat boosting, with the fact that the samples are thermally insulated from the surrounding reactor coolant environment. The rigs are used to irradiate various sample types, from the smallest to the largest, for example of type 2CT. An important part of the rig design and its configuration is also the achievement of a desired temperature profile in the irradiated sample. A combination of rig design and its method of insulation, the types of gases used and the location of the rig in the reactor's active zone achieve this. At UJV we use a CHOUCA rig type for smaller samples, while for larger samples, special rigs have been developed for sample irradiation (Fig. 9, 10).

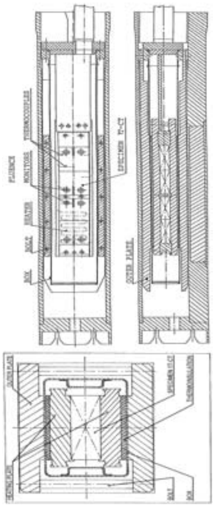

Fig. 9 Irradiation rig 1T-CT cross section

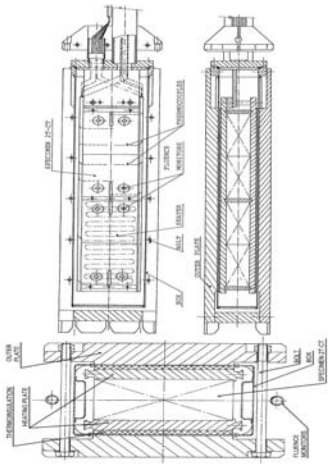

Fig. 10 Irradiation rig 2T-CT cross section

5. Post-Radiation Evaluation

At ÚJV Rez, there is a number of hot cells, 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 essential 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.

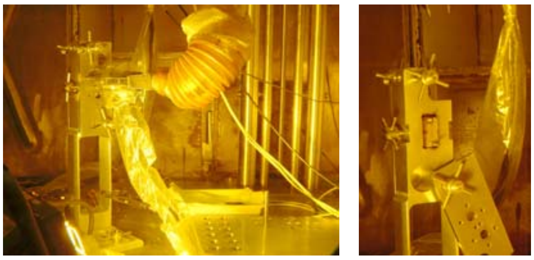

Fig. 11 Equipment for samples welding in hot cells

6. Irradiation services

The LVR-15 reactor, aside from research on horizontal channels and irradiation in loops and probes, also provides production services, though these services represent a smaller share (10 % of the reactor's activity). This is given primarily by the reactor's output (10 MW), which is not sufficiently high to permit greater production. The reactor is used regularly to irradiate silicon up to 3 inches in size for an electrical equipment company in Prague. It also produces iridium for diagnostics and some isotopes for the production of radiopharmaceuticals for hospitals. A number of small users from industry and research also make use of the reactor's irradiation services.

7. Material research carried out by neutron diffraction

The basic research for materials is carried out using horizontal neutron beams. There are six beams facilities used of Academy of sciences and university. The main purpose is to study material [Ref. 4].

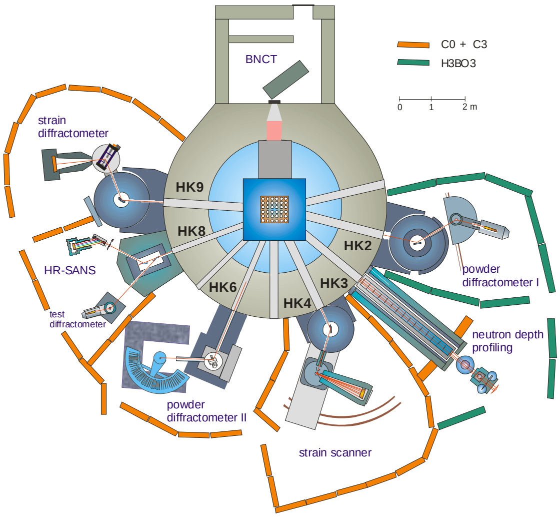

Fig. 12 Horizontal neutron beam facilities

8. Fusion Research

NRI has several projects related to the fusion research programme. They are technical materials research projects for the ITER first wall, and TBM (Test Blanket Module) research. In the case of the first wall, research is focused on the influence of radiation on beryllium tiles and its connection to copper alloys, which are used to transfer heat away from the internal parts of the tokamak.

TBM research is oriented towards coolant compatibility (helium, Pb-Li eutectic) with structural materials and neutron radiation. Research also concerns itself with the production of tritium and its subsequent processing for fuel use and for future demo power stations with a fusion reactor.

9. International Cooperation

It would not be possible to use the reactor for materials research for Generation IV reactor systems without broad international cooperation. Our facility participates in work taking place within the scope of European strategic documents such as SRA (Strategic Research Agenda) and SNETP (Sustainable Nuclear Energy Technology Platform). The reactor is being used to prepare two pieces of experimental equipment for SCWR and high-temperature helium-cooled (VHTR, GFR) reactors. Both pieces of equipment have been designed and built in the Czech Republic with the assistance of the local nuclear industry, and are now being tested outside the reactor prior to their placement in the reactor.

10. SWOT Analysis

SWOT analysis is performed on the reactor regularly, and provides information for further strategy and business plans. Each research reactor has certain ties to the history of its construction, national research policy extant at the time of its creation, its participation within the scope of national research and development, and its integration with industry. This mostly defines financial support for reactor operation.

Prior to 1992, the LVR-15 reactor belonged to the Academy of Sciences, and then the Czechoslovak Atomic Commission. During subsequent political and economic changes, NRI was privatized and turned into a joint-stock company, with the majority shareholder being CEZ. Prior to 1992, the reactor was funded by the state; starting in 1993 it lost its institutional support due to the institute's privatization, and its operation is now paid for exclusively through contracts and research projects.

SWOT analyses are listed as examples for primary market segments. Analyses are produced for materials research (GIII, GIV and fusion reactors) and for materials research in horizontal channels. These two areas make up the bulk of the reactor's orders and activity.

Material research for G II (III) reactors

STRENGTH	*WEAKNESSES*
Rigs and loop long term R&D Rigs size variables Several water loops for PWR and BWR Water chemistry R&D, hot cells for PIE Links with plant operators	Very costly and time consumable experiments Long time preparation
OPPORTUNITIES	*THREAT*
Reactor aging, LTO (Long Term Operation), vision of life time prolongation 40-60 years G IV reactors deployments delay Nuclear renaissance has started – large deployment of G IV reactors in the world	No reactor experiments needed. Out-of pile material tests only

Material research for fusion

STRENGTH	*WEAKNESSES*
Rigs and loop long term R&D Liquid metal loop experience	Very costly and time consumable experiments No good neutron spectrum relative to ITER (neutron – 17 MeV)
OPPORTUNITIES	*THREAT*
Material development needed for ITER and DEMO Blanket breeding technology – key issue for fusion reactor operation	Out-of pile material tests only IFMIF or fast reactor irradiation

Material research for G IV reactors

STRENGTH	*WEAKNESSES*
Rigs and loop long term R&D Loops for VHTRand SCWR in preparation hot cells for PIE	Very costly and time consumable experiments Not well define relation between GIV members Frequent changes in national strategy between GIV
OPPORTUNITIES	*THREAT*
Materials R&D needed For some type of reactors materials not yet tested	No reactor experiments needed. G IV reactors deployments delay Large deployment of G IV reactors in the world

Material and basic research on horizontal channels

STRENGTH	*WEAKNESSES*
Basic research for different science branches Good and motivated staff Involved in european R&D network Good facility instrumentation	Very low financial support from Academy budget Other Academy targets than buziness Staff other priorities
OPPORTUNITIES	*THREAT*
Good potential for industrial aplications International cooperation	Staff age on beam research Measurement on other reactors

11. Conclusions

The LVR-15 reactor is an important facility, which serves for research into nuclear generating station materials and water chemistry. The main goal of all the reactor’s facilities is to model conditions that are as close as possible to real conditions, and thus secure the reproducibility and utilization of measured values. Experience that has been gained during the operation of loops and rigs are now exploited for the preparation of the facility for research into new, so-called Generation IV reactors, such as for example reactors cooled by high-temperature helium or water with supercritical parameters. Another direction in the sphere of materials research is the usage of neutron diffraction methods on horizontal channels for the study of the influence of damage in materials exposed in loops and rigs.

The reactor's primary focus is materials technology research for loops and probes, and basic research for horizontal channels. Production represents only a minor part of its activities. The primary focus is given by the need to extend the lifetime of existing nuclear power stations. Research for new systems like GIV and fusion has been delayed as compared to original plans, which in some cases has been especially caused by unavailability of necessary materials that would meet the requirements of equipment designers. This area presents a challenge for the research reactor community, which can help address the situation and ensure sufficient materials qualification and attestation.

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