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REACTOR PRESSURE VESSEL AND INTERNALS STEELS IRRADIATION PERFORMED AT THE LVR-15 RESEARCH REACTOR

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В запропонованій роботі наведено основні характеристики дослідницького реактора LVR-15, а також його використання. Два водяних контури для досліджень в PWR середовищі та два водяних контури для досліджень в BWR середовищі було змонтовано в реакторі. Опромінення зразків в інертному газі виконувалось в реакторних пристроях пластинчастого типу і CNOUCA. Хід експериментів контролювався детекторами різного типу, здійснювалась також дозиметрія реактора. У разі необхідності проводяться модельні експерименти.

В статье представлены основные характеристики исследовательского реактора LVR-15, а также его использование. Два водяных контура для исследований в PWR среде и два водяных контура для исследований в BWR среде установлены в реакторе. Облучение образцов в инертном газе выполнено в реакторных устройствах пластинчатого типа и CNOUCA. Ведение экспериментов контролировалось детекторами различного типа, осуществлялась также дозиметрия реактора. По необходимости выполняются модельные эксперименты.

Main characteristics of the LVR-15 research reactor and its utilisation are presented in the article. Two reactor water loops for the research in the PWR environment and two water loops for the research in the BWR environment are installed at the reactor. The irradiation of specimens in the inert gas is performed in reactor rigs of CHOUCA and slab types. The experiments are controlled with different types of sensors and reactor dosimetry is ensured. If necessary mock-up experiments for specialised experiments are performed.

1. LVR-15 RESEARCH REACTOR

The LVR-15 research reactor is situated in the Nuclear Research Institute Řež plc (further NRI). The reactor power is of 10 MW. The reactor is operated in 21 days irradiation cycle, with 7…8 cycles per year. The fuel assembly consists of 4 concentric tubes or 3 concentric tubes with a control rod inside the assembly. The fuel IRT-2M contains 36 % enriched uranium.

The reactor is used as a multipurpose facility and its main use [1] is in the following areas:

- material research carried out at reactor loops and rigs;
- production of radiation doped silicon;
- production of radioisotopes for the radiopharmaceuticals and technical radiation sources;
- irradiation devices for special irradiation;
- pneumatic rabbit for activation analysis;
- development of boron neutron capture therapy at the thermal column channel;
- neutron physics research at reactor horizontal channels.

The irradiation facilities are complemented with good equipped hot cells for removing irradiated specimens from experimental devices and their post-irradiation examination. More detail post-irradiation examination of irradiated specimens are performed in hot and semi-hot cells situated in another building near the reactor [2].

In-pile irradiation research performed at reactor loops and rigs are the most important activity carried out at the reactor.

2. REACTOR LOOPS

This research is connected with environmental degradation processes (corrosion, mechanical and radiation effect), cladding - coolant interaction (corrosion of zirconium alloys with and without radiation, deposition of corrosion products and effect of water chemistry components). In-pile water chemistry and corrosion monitoring technique (conductivity, pH, redox potential, dissolved hydrogen and oxygen, water impurity content, corrosion potential, contact electrical resistance etc.) is developed and implemented at reactor loops [3]. Description of loops and experiments is presented in [4], research in the field of stress corrosion cracking of ferritic and austenitic steels is presented in [5]

2.1. PWR Loops

Two reactor water loops RVS-3 and RVS-4 are used for the research in the PWR environment.

The RVS-3 loop was put into operation in 1983. At present a project of the loop reconstruction is being prepared in order to:

- simplify the loop primary circuit;
- upgrade or replace principal loop components;
- enable experiments with real fuel elements.

The RVS-4 loop is now under functional and start-up tests.

2.2. BWR Loops

Two reactor water loops BWR-1 and BWR-2 are used for the research in the BWR environment.

The BWR-1 loop is usually used for testing and development of in-pile water chemistry and corrosion monitoring technique and their components [6].

The BWR-2 loop is used for stress corrosion cracking tests of reactor pressure vessel (RPV) and internal steels under simultaneous BWR coolant and irradiation conditions. Its test channels can be used in two modifications:

- a channel situated outside the core (with the possibility to test specimens up to 2T CT) which is connected with a hydrogen peroxide generation channel (situated inside the reactor core);
- a channel situated near the core (with the possibility to test specimens up to 1T CT).

3. REACTOR RIGS

The irradiation of specimens from reactor pressure vessels and internals steels is being performed in reactor rigs either of CHOUCA or slab types.

3.1. CHOUCA Irradiation Rig

The reactor rigs CHOUCA (of French production) are used for irradiation of reactor pressure vessel materials for the research of their material properties degradation under radiation. a rig specimens holder enables to irradiate, e.g.:

- Charpy V-impact specimens;
- tensile specimens of different types up to 12 mm in diameter;
- slow strain rate test specimens;
- fracture toughness 0.5T CT specimens.

The specimen holder consists of six sections and is inserted in the rig heating channel (6 heating sections are situated along the rig height and each section has its own thermocouples) which ensures irradiation temperature range from 200±10 °C to 350±10 °C in inert gas [7]. The specimen temperatures are measured in the specimens holder with thermocouples, and control chain keeps the temperature distribution in the required range.

Between each holder section a carrier with neutron monitors is situated for neutron flux and fluence determination.

In Fig. 1[*] a schematic drawing of the rig holder with specimens and neutron monitors positions is presented.

3.2. Slab Rigs

Due to requirements to irradiate larger specimens a new type of rig has been developed in NRI. Several modifications of the rig enable the irradiation e.g.:

- up to six 1T CT specimens;
- four 2T CT specimens;
- batch of different specimens of lower dimensions which volume lies between above mentioned volumes.

Rigs are designed and produced for the irradiation in the inert atmosphere of samples situated in the irradiation volume of width up to approximately 50 mm. There is no restriction to adapt the design and production of the rig to the desired irradiation volume, except that the rig length cannot exceed a limit of 510 mm, for PIE handling reasons.

The rig has 6…8 heating sections which ensure the irradiation temperature range from 250±10ºC to 350±10ºC in inert gas. The specimen temperatures are measured in the specimens holder and rig slabs with 20…30 thermocouples. 6…8 of them (one for each heating section) are used for the heat sections control. Ar, mixture Ar and He or He can be used as an inert gas [8].

Examples of horizontal and longitudinal cross section of rigs are presented in Fig.2 and 3, the record of temperature values from some thermocouples during an irradiation cycle are presented in Fig. 4.

3.2.1. Design and production. The rig is composed of the rig irradiation part and a overhanging part.

In the irradiation part the specimens are situated between two slabs, which create an irradiation cassette. The cassette is situated in the vacuum tight box filled with an inert gas. The box is connected with an overhanging part with flanges. The slabs of the cassette fulfil two functions. On the one side they serve as a specimens carrier, on the other side the thermocouples and the heating cables are situated in the slabs notches. 20…30 thermocouples are used for the temperature measurement and control. The heating cables create three or four independent heating sections in each slab. The thermal barrier and insulation is created with $ZrSiO_4$ ceramic coating made by the plasma spraying. Two solid slabs are situated at the each side of the irradiation cassette. They are tightly taken together with screws in order to ensure a good contact of the cassette layers and specimens. Ni is used as an insulation material for this type of connection.

The overhanging part is formed by the holder tube with heating elements and thermocouples leading and inert gas inlet. It is connected with the irradiation part with flanges. Heating cables leading go through The vacuum tight connection box from the irradiation port and are then led at the outer part of the holder tube above the surface of reactor pool water. There they are connected to the Cu leading wires which go to the connector of the temperature measurement and control system. Thermocouples are led inside the holder tube above the surface of reactor pool water. There they are connected to the connector of the temperature measurement and control system. The inert gas inlet valve is situated at the holder tube above the surface of the reactor pool water.

3.2.2. Out-of-pile tests. Before situating the rig in reactor, the rig situated in the special test equipment undergoes several test to ensure a good rig operation. These tests include helium tightness tests, stiffness test with the gas pressure higher than the functional one, gradual increase to maximum and then gradual decrease of heating elements power cycles with the measurement of thermocouple responses to the individual heating sections power and tests of reliability, tests of

[*] All figures are placed in the Appendix.

thermocouples and heating elements circuit integrity and insulation resistance.

3.2.3. In-pile test before the irradiation. These tests include the rig tightness tests, tests of thermocouples and heating elements circuits connected to the measurement and control system integrity and insulation resistance, function of the measurement and control system.

4. REACTOR DOSIMETRY AND TEMPERATURE DISTRIBUTION MODEL FOR IRRADIATION EXPERIMENTS

According to the type of experiment, different demands on reactor dosimetry are required, ranging from neutron spectrum, thermal and fast neutron fluxes densities and their behaviour during the irradiation, demanded are also final fluences and gamma radiation heating and absorbed doses. To fulfil these demands, several measures are taken.

– neutron flux distribution and neutron transport calculations;
– neutron fluence monitoring with activation monitors or self-powered neutron detectors;
– gamma heating calculations;
– gamma heating monitoring with reactor calorimeters;
– mock-up experiments.

4.1. Neutron Fluence Monitoring

Neutron flux monitors are situated in different parts of the rig irradiation volume to determine the target neutron fluence values.

For a long term irradiation two carriers with neutron flux monitors situated in tubes (see Fig.3) outside the rig are used for neutron fluence monitoring. After certain period of irradiation the carriers are withdrawn, and replaced by new carriers with fresh neutron fluence monitors. From irradiated neutron fluence monitors a received fluence is determined and plan for further irradiation is elaborated. For CHOUCA rigs self-powered neutron monitors situated near the rig are used for the neutron fluence monitoring.

The following materials ad interactions can be used for the neutron irradiation parameters determination: $^{54}Fe(n,p)^{54}Mn$, $^{58}Fe(n,\gamma)^{59}Fe$, $^{46}Ti(n,p)^{46}Sc$, $^{63}Cu(n,\alpha)^{60}Co$, $^{58}Ni(n,p)^{58}Co$, $^{59}Co(n,\gamma)^{60}Co$, $^{93}Nb(n,\gamma)^{94}Nb$, $^{93}Nb(n,n')^{93}Nb$.

The monitors are used in the form of foils or wires and delivered by JRCM-IRMM, Geel, Belgium, or sets of monitors encapsulated from NRG Petten, The Netherlands.

4.2. Calculation codes

The power and neutron group flux densities distribution in the core are calculated with the NODER 4 groups diffusion code developed in the NRI. The macroscopic constants for this code are prepared with the use of WIMSD4 and WIMSD4-M codes. The WIMS code is also used for the calculation of the flux density detail distributions in the irradiation devices.

Fast neutron spectra, neutron flux densities and gamma heating are determined using the ANISN, DORT transport computer codes with the BUGLE-96 coupled cross section library of 47 neutron and 20 gamma groups, MCNP and KENO V, a Monte Carlo codes with ENDF/B VI cross section library.

For temperature distribution across the rig a computer code was developed in NRI. The code solve the Laplacean heat conduction equation together with the boundary conditions by the finite differences method. Boundary conditions take also into account the resistances between rig outer slabs and the reactor cooling water as well as heat resistances rig slabs and the $ZrSiO_4$ insulation layers.

4.3. Mock-up Experiments

When a new type of irradiation experiment should be carried out, or when the irradiation equipment position in the reactor core could be quite different then those used during the preceding experiments, a mock up experiment is carried out. For this experiment a model of irradiation assembly with dummy samples is produced and it contains an appropriate amount of activation monitors and thermocouples are situated in the places of interest. In this experiment the calculated neutron spectrum is verified, neutron flux densities distribution in the irradiation assembly are determined and also relations to the neutron monitors situated outside the irradiation equipment are determined.

From thermodynamical measurements the data are generated concerning the gamma heating and temperature distribution across the rig as well as final design of the insulation layers profile along the reactor core height in order to keep the required irradiation temperature.

When an outer calorimeter string is used for the gamma radiation absorbed dose rate monitoring, the mock up experiment includes also the measurement with a calorimeters inside the irradiation channel.

5. CONCLUSION

Reactor rigs in NRI enable irradiation in inert gas batches of samples with dimension up to 2T CT with the irradiation temperature range from 250±10°C to 350 ±10 °C. Reactor loops can be used for the material studies both in PWR and BWR environment.

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APPENDIX

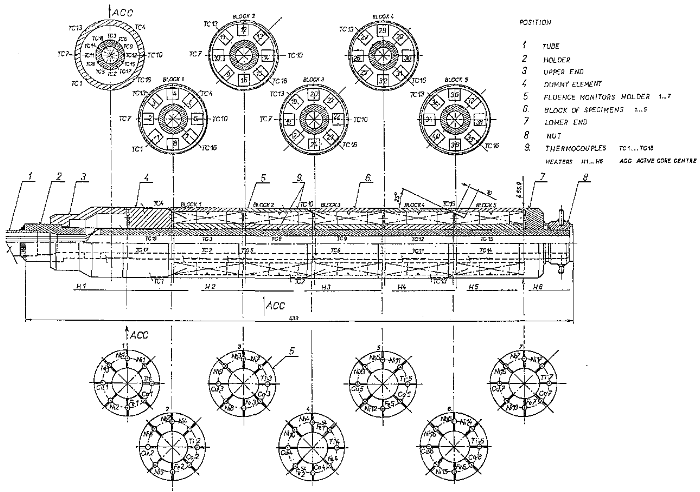

Fig.1. CHOUCA MT samples and neutron fluence monitors carrier

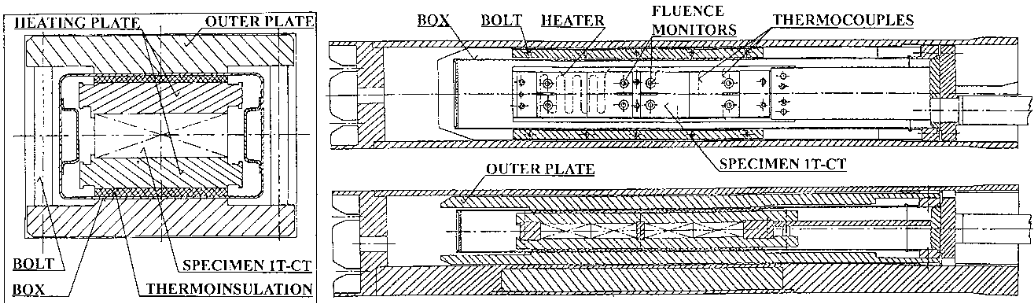

Fig. 2. Irradiation rig 1T CT crossections

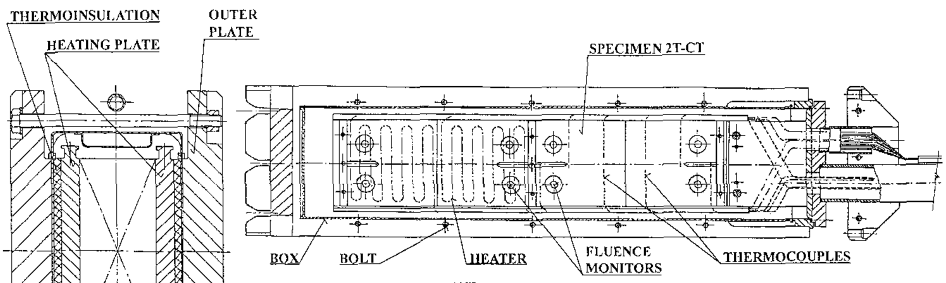

Fig.3. Irradiation rig 2T CT crossections

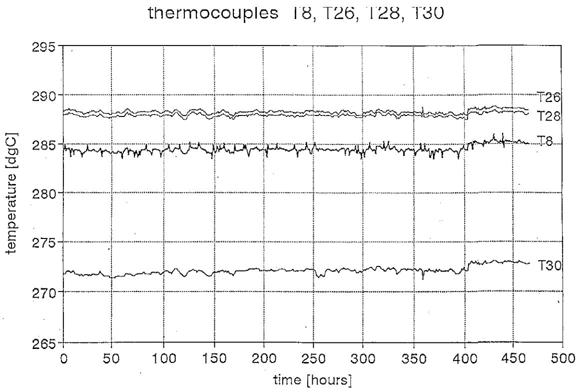

Fig. 4. Record of temperature values from some thermocouples during an irradiation cycle