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# Current experiments at the irradiation facility of the IBR-2 reactor

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Abstract. Technical details, the principle of work and the distribution of a generated neutron spectrum are presented in the paper. Current experiments at the irradiation facility, as well as investigations at the radiation resistance of various materials, the radiation coloring of minerals, neutron activation analysis, etc. are also described. Conclusions about the high efficiency and the practical relevance of the facility as an instrument for the irradiation of samples with neutrons of various energy (0.25 meV – 10 MeV) with fluence from  $5 \cdot 10^{11}$  n/cm<sup>2</sup> to  $10^{18}$  n/cm<sup>2</sup> are presented as well.

### 1. Introduction

The research pulse reactor IBR-2 (FLNP JINR) is a powerful instrument for the research of radiation resistance and properties after irradiation for a wide range of materials in the most diverse fields of science and technology. Such research allows to solve various science problems such as the upgrade of LHC (HI-LHC), R&D of magnetic field sensors for tokamaks (ITER, DEMO) or colliders (LHC, NICA), neutron activation analysis, the radiation coloring of different minerals, the production of isotopes and others. Currently, an overview of the most important science experiments, carried out at the irradiation facility of the IBR-2 reactor, is represented.

## 2. The irradiation facility of the IBR-2 reactor and its neutron spectrum

The irradiation facility consists of two parts: an aluminum (Al) section and an elbowed (in horizontal plane) stainless steel pipe (Fig. 1). The Al section can be the closest to the surface of water moderator from the side of IBR-2 beamline No3 (Fig. 2). It has a length of 3 m. The elbowed pipe has an internal diameter of 160 mm, a length of 5 m and an elbow's radius of 25 m. The elbowed pipe is located into the cylinder with a diameter of 800 mm, filled with water as a biological shield. Another side of the cylinder is equipped with a dumper. It has a thickness of 1 m and closes off the elbowed pipe for protection from the direct neutron beamline and  $\gamma$ -rays during the irradiation of samples. When the reactor is stopped, dumper is opened and the personnel can install samples into the elbowed pipe. Samples are installed along the length of aluminum section and the elbowed pipe. One of the main advantages of the facility is the possibility of irradiation of large-size samples (180x180 mm<sup>2</sup>). When samples are already installed, the facility begins to move to the surface of the water moderator. Distance from the moderator is chosen depending on the necessary neutron fluences at the surface of the sample. Irradiation lasts for 11 days on the 2 MW of the reactor's power. The differential neutron flux density of the beamline No3 was calculated

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taking into account the experimental data in [1-2]. In addition, it is shown in Fig. 3. The neutron spectrum consists of three main parts: thermal, resonance and fast neutrons. Their proportions are 27% of thermal, 51% of resonance and 22% of fast neutrons.



Fig.1. Irradiation facility of the IBR-2 reactor: 1 – Al section, 2 – railway, 3 – elbowed pipe, 4 –cylinder with water 4, 5 – the dumper



Fig.2. Al section (INP profile) of the irradiation Fig.3. Differential neutron flux density of the facility near the water moderator of the IBR-2 beamline  $N_{23}$ 

#### 3. Current experiments at the irradiation facility

#### The study of changes in the properties of materials after the irradiation

The study of changes in the properties of materials after the irradiation is a basic research field at the irradiation facility of the experimental beamline  $N_{23}$ . Experiments for research at the radiation resistance of different materials (poly- and single crystals of

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diamonds, GaAs, printed circuit board (PCB) of G10, FR4, Arlon 85N, Rogers 4450B, polyimide and the rest) are carried out in the framework of the program to upgrade ATLAS and CMS detectors at LHC [3, 5]. Fast neutrons' fluence ( $E_n$ >0.4 MeV) due to irradiation was near  $4 \cdot 10^{17}$  n/cm<sup>2</sup>. In Fig. 4a,b the photos of PCB after irradiation are shown. The measurements of mechanical and electrical properties (resistant of interlayer isolation and capacitance) and measuring leakage current had been made before, during and after the irradiation.

Experiments in the radiation resistance of semiconductor sensors in radiation conditions close to ITER conditions are carried out in the framework of project for the design of ITER fusion reactor [4], Fig. 4c. During experiments, long-term and stability performance of sensors with neutron fluence of  $10^{20}$  n/cm<sup>2</sup> was demonstrated.



Fig.4. Materials for irradiation: a, b – PCB after irradiation, c – 3D Hall sensors for ITER

In addition, the research of material properties of scintillation detectors (Fig. 6) after the irradiation with small neutron fluence from  $5 \cdot 10^{11}$  n/cm<sup>2</sup> to  $10^{15}$  n/cm<sup>2</sup> were carried out [6].

Currently, experiments assessing the possibility of period extension in sustained operations of the pelletized cold moderator [6-7] based on the mixture of mesitylene and m-xylene are also carried out on the irradiation facility. The radiation resistance of the aromatic hydrocarbons of mesitylene and m-xylene mixture and the new substance – triphenylmethane as different aggregate state was studied in these experiments. Substances with the same mass were put into the cylindrical containers, which were installed at the minimal distance from the thermal moderator of the reactor and were irradiated to the neutron fluence of  $10^{18}$  n/cm<sup>2</sup> (160 MGy). Containers joined with manometers are used as copper tubes for the determination of pressure, which is increased because of the formation of radiolytical hydrogen during the irradiation. The formation of the radiolytical hydrogen from triphenylmethane is 10 times less than from the mixture of mesitylene and m-xylene. This can indicate that the radiation resistance of triphenylmethane is better.

#### Radiation coloring of topazes

Blue topaz is very popular in the world as jewelry. Yet, naturally occurring blue topaz is quite rare. For that reason, on the facility for the radiation research colorless topazes are irradiated up to fast neutron fluence of  $10^{18}$  n/cm<sup>2</sup> to produce a more desired darker blue. The photo of topaz after the irradiation is shown in Fig.5.

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#### Neutron activation analysis

The neutron-activation analysis on the irradiation facility IBR-2 is used for various tasks: for the most part, it's the evaluation of the fast neutron flux density with an energy of E>1MeV (by capture reaction of Ni<sup>57</sup>+n<sup>0</sup> $\rightarrow$  Co<sup>58</sup> + $\gamma$  (811 keV)) and the elementary composition of irradiated samples, such as various kinds of isotopes, archeological or biological materials.

#### 4. Conclusion

Facility for the radiation research at the IBR-2 reactor is efficiently used for carrying out experiments in various fields of science and technology. The irradiation of samples is generally needed for the investigation of radiation resistance of materials and their mechanical, physical, electrical and other properties after the irradiation. Simultaneously, the radiation coloring of topazes, the production of medical isotopes, the irradiation of biological samples and other challenging scientific tasks become getting actual. In addition, the irradiation facility can be used for experiments carried out by external users.

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