IBR-2 - PULSED SOURCE FOR NEUTRON SCATTERING RESEARCH AT JINR

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Joint Institute for Nuclear Research (JINR), which was established in 1956 by 12 countries, at present is a partnership of eighteen member-countries committed to the goal of collective performance of theoretical studies, building and operating of the world's leading facilities for research in condensed matter physics, nuclear physics and elementary particle physics. Participation of six associated member-countries in JINR activities is based on bilateral agreements signed on the governmental level. The

The IBR-2 fast pulsed reactor is operated by the Frank Laboratory of Neutron Physics (FLNP), one of the seven JINR Laboratories. FLNP provides user access to the 15 modern neutron scattering instruments enabling high level research, based on neutron scattering techniques and complementary methods to investigate the structure, dynamics and microscopic properties of nanosystems and novel materials, which are of great importance for the development of nanotechnologies in the fields of electronics, pharmacology, medicine, chemistry, modern condensed matter physics and interdisciplinary sciences.

Present status of the IBR-2 reactor as well as the complex of it's spectrometers will be presented.

INTRODUCTION

The IBR-2 - a powerful high-flux periodically pulsed reactor was put in operation in 1978-1984 at a mean power of 2 MW [1, 2]. In 2007, the reactor reached the service life limit on fuel burn up and fluence on the reactor vessel and was shut down for modernization and replacement of the primary reactor equipment. The main objectives of the modernization were to increase safety, reliability and experimental possibilities of the reactor for the next 25 years of operation [3].

IBR-2 REACTOR

By 2010 the installation of new equipment was completed and followed by a successful power startup in 2011. The IBR-2 parameters before and after modernization are presented in Table 1 [4]. The main parts of the reactor are shown schematically in Figure 1. The reactor core is an irregular hexahedron composed of fuel element subassemblies. Plutonium dioxide pellets with 95% of ^{239}Pu are used as a reactor fuel. The cooling system has three circuits and two loops. The IBR-2 is a sodium-cooled fast neutron reactor. The core is installed in a double-walled steel vessel and surrounded by several stationary reflectors, control and safety units among them, as well as water moderators serving 14 horizontal beam extraction ports. Water moderators of the reactor thermalize fast neutrons down to a thermal energy range used by experimenters on the extracted neutron beams.

A unique feature of the reactor is the periodic modulation of reactivity, which is accomplished by the rotation of the main moveable reflector and the auxiliary moveable reflector near the core (Figure 2). The rotors of the main and auxiliary movable reflectors rotate in opposite directions with different velocities. At a frequency of 5 Hz the reactor is brought from a deep subcritical state to a prompt supercritical one. A power pulse is generated at the moment when both reflectors approach the core.

Table 1.

IBR-2 Parameters before and after Modernization

Parameter	Before modernization	After modernization
Average power, MW	2	2
Fuel	PuO_2	PuO_2
Number of fuel assemblies	78	69
Maximum burnup, %	6.5	9
Pulse repetition rate, Hz	5, 25	5, 10
Pulse half-width, μs:		
fast neutrons	215	245
thermal neutrons	320	340
Rotation rate, rev/min:		
main reflector	1500	600
auxiliary reflector	300	300
Coolant	Sodium	Sodium
Thermal neutron flux density from moderator surface:		
- time average	~ 10^{13} n/cm$^2\cdot$s	~ 10^{13} n/cm$^2\cdot$s
- burst maximum	~ 10^{16} n/cm$^2\cdot$s	~ 10^{16} n/cm$^2\cdot$s

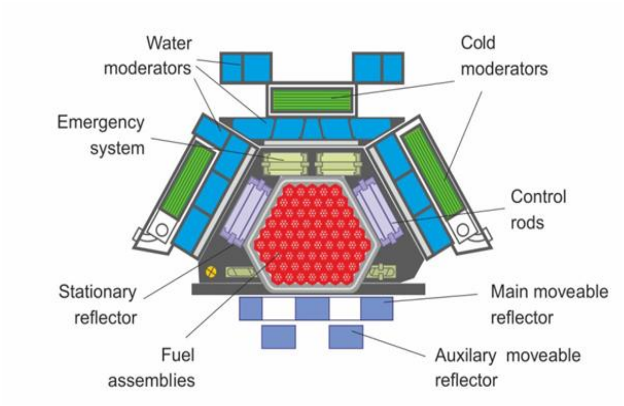

Figure 1 Main parts of the IBR-2 reactor

After modernization of the IBR-2 reactor a pelletized cold neutron moderator based on the solid mixture of aromatic hydrocarbons (benzene derivatives) as the moderating material. was installed [5]. IBR-2 cycles (approximately 8-9, comprising 2500 hours of operation per year) are usually carried out either in the water or cryogenic mode.

By 2015 the number of the instruments accessible within the user program reaches 15, compare to 11 before the modernization, significantly extending the experimental capacities and areas of research carried out [6].

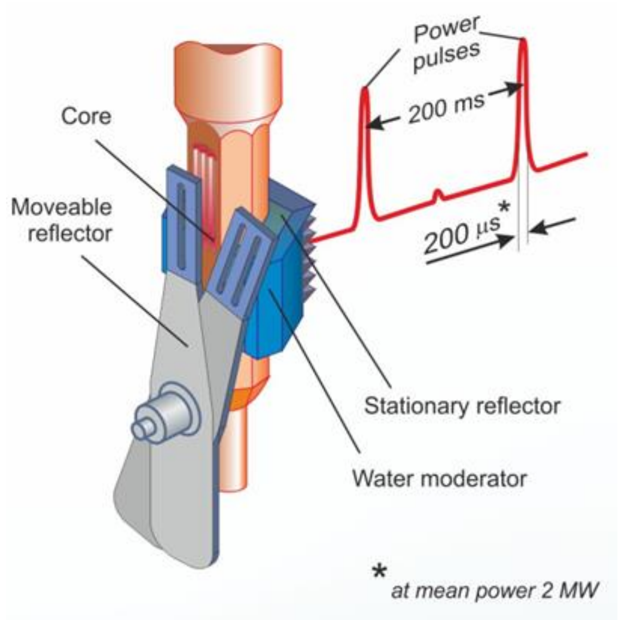

Figure 2 Core of the IBR-2 reactor with a movable and stationary reflector and water grooved moderators

SCIENCE AT THE IBR-2 REACTOR INSTRUMENTS

The main objectives of the research at the IBR-2 reactor instruments are the applications of neutron scattering techniques and complementary methods to investigate the structure, dynamics and microscopic properties of nanosystems and novel materials, which are of great importance for the development of nanotechnologies in the fields of electronics, pharmacology, medicine, chemistry, modern condensed matter physics and interdisciplinary sciences [6].

The list of the main scientific directions, performed at the IBR-2 neutron scattering instruments and other facilities includes:

- ✓ Investigation of the structure and properties of novel functional materials;
- ✓ Investigation of the structure and properties of materials under extreme conditions;
- ✓ Investigation of fundamental regularities of real-time processes in condensed matter;
- ✓ Investigation of atomic dynamics of materials for nuclear power engineering;
- ✓ Computer simulation of physical and chemical properties of novel crystalline and nanostructured materials;
- ✓ Investigation of magnetic properties of layered nanostructures;
- ✓ Investigation of structural characteristics of carbon- and silicon-containing nanomaterials;
- ✓ Investigation of molecular dynamics of nanomaterials;
- ✓ Investigation of magnetic colloidal systems in bulk and at interfaces;
- ✓ Structural analysis of polymer nanodispersed materials;
- ✓ Investigation of supramolecular structure and functional characteristics of biological materials;
- ✓ Investigation of structure and properties of lipid membranes and lipid complexes;
- ✓ Investigation of texture and physical properties of Earth's rocks, minerals and engineering materials;
- ✓ Non-destructive control of internal stresses in industrial products and engineering materials;
- ✓ Introscopy of internal structure and processes in industrial products, rocks and natural heritage objects;
- ✓ Radiation hardness of the semiconductors, polymers and biological objects;
- ✓ Neutron activation analysis in Life Sciences, biotechnology and material science.

NEW DUBNA SOURCE FOR NEUTRON SCATTERING

The Frank Laboratory of Neutron Physics proposes a project of a new fourth-generation neutron source with record parameters, which is to be put into operation after expiration of the service life of the IBR-2 research nuclear facility in 2032-2037 (depending on the operating mode). The working title of the project is Dubna fourth-generation neutron source: DIN-IV. The scientific rationale for the project was presented at the meeting of the Program Advisory Committee for Condensed Matter Physics on January 19, 2017 [7]. The need for a next-generation neutron source is driven not only by the development of neutron research in JINR, but also by a growing interest in these investigations against the background of a steadily decreasing number of neutron sources in the world, as evidenced by the analysis of a specially established

ESFRI Physical Sciences and Engineering Strategy Working Group [8].

The DIN-IV is a subcritical assembly with mechanical modulation of reactivity driven by a superconducting linear proton accelerator with an energy of about 1.0 GeV and an average current of about 0.1 mA with a variable pulse duration from 10 to 200 μs. The principal difference between the DIN-IV and the world's existing and projected pulsed neutron sources is the use of a subcritical core with an internal neutron-producing target with the total neutron multiplication at a level of several tens, which ensures nuclear-safe operation of this facility. The proton beam power on the target is only about 0.1 MW, which is 50 times less than the declared power of the ESS accelerator. Calculations show that the average thermal neutron flux density of this source can be higher than $5 \cdot 10^{14}$ n/cm^{2}s, which is comparable to the calculated estimate of the European Spallation Source (ESS) being constructed in Lund, Sweden and other projects. The DIN-IV is designed to operate in two neutron pulse duration modes: short pulses of 20 ÷ 30 μs and long pulses of 200 ÷ 300 μs, which will make it possible to study the structure and dynamics of condensed matter with optimum spatial and energy resolution.

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[1] *V. L. Aksenov, V. D. Ananyiev, and E. P. Shabalin*, "Repetitively pulsed research reactor IBR-2: 10 years of operation," in Proceedings of the Topical Meeting on Physics, Safety and Applications of Pulse Reactors, Washington, D.C.,Nov. 13–17, 1994, p. 111

[2] *A.V. Belushkin*, IBR-2 – the fast pulsed reactor in Dubna. Neutron News 1991, 2, 14-18

[3] *V.D Ananiev, A.V. Vinogradov, A.V.Dolgikh, Yu. N. Pepelyshev* Physical and power start-up of the modernized IBR-2M research reactor. Proceedings of the European Research Reactor Conference, Saint-Petersburg, Russia, 21-25 April, 2013, p. 4-10

[4] *V.N. Shvetsov*, Neutron Sources at the Frank Laboratory of Neutron Physics of the Joint Institute for Nuclear Research. Quantum Beam Sci.2017,1, 6

[5] *V. Ananiev, A. Belyakov, M. Bulavin, E. Kulagin, S. Kulikov, K. Mukhin, T. Petukhova, A. Sirotin, D. Shabalin, E. Shabalin, V. Shirokov, A. Verhoglyadov*, The world's first pelletized cold neutron moderator at a neutron scattering facility. Nuclear Instruments and Methods in Physics Research B 320 (2014) 70–74

[6] *V.L. Aksenov, A.M. Balagurov, D.P. Kozlenko* Condensed matter research at the modernized IBR-2 reactor: from functional materials to nanobiotechnologies. PEPAN 2016, 47, 627–646

[7] *V.L. Aksenov* JINR Communications E3-2017-12, JINR, Dubna, 2017

[8] Neutron scattering facilities in Europe. Present status and future perspectives, ESFRI PSE Strategy Working Group, Neutron Landscape Group, ESFRI Scripta Vol. I, 2016