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PHYSICAL AND POWER START-UP OF THE MODERNIZED IBR-2M RESEARCH REACTOR

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ABSTRACT

The IBR-2M pulsed research reactor of periodic operation at a power of 2 MW is intended for use as a neutron source for investigations in the field of condensed matter physics, biology, chemistry, materials science. The reactor generates a power pulse of ~1830 MW of 200 μs duration with a frequency of 5 Hz. The IBR-2M is a modernized version of the IBR-2 reactor, which was shut down in 2006 having completed its intended service life period. The physical and power start-up of the IBR-2M reactor was carried out from December 10, 2010 to October 28, 2011. The IBR-2M reactor produces one of the most intense pulse neutron flux at the moderator surface among the world's reactors (~10^{16} n/cm^2/s). The paper covers the main results of the investigation of the modernized IBR-2M reactor carried out within the framework of the program of the power start-up of the reactor operated at a power of up to rated 2 MW.

1. Introduction

The IBR-2 research fast neutron reactor (JINR, Dubna, Moscow region, Russia) was put into operation in 1984 and shut down in 2006 for modernization because of the expiration of its service life [1]. The IBR-2 reactor is intended for carrying out investigations in the field of condensed matter physics by the time-of-flight spectroscopy method. More than 100 experiments are performed on the reactor annually by the researchers from more than 30 countries of the world. Since the beginning of its operation until 2007 the IBR-2 reactor has operated for a total of about 50 000 h providing one of the most intense thermal neutron flux in the world. By 2007 the reactor reached its design service life limits in fuel burn-up and reactor vessel fluence value. In this connection the reactor was shut down to replace its main equipment (first of all reactor vessel, drives and movable operating units of the control and safety system) and fuel loading. The IBR-2M is a modernized version of the IBR-2 reactor.

2. Brief description of the IBR-2 and modernized IBR-2M reactors

IBR-2M is a sodium-cooled fast neutron reactor with a stationary thermal power of 2 MW. A schematic of the reactor core is given in Fig. 1. Plutonium dioxide pellets are used as a reactor fuel. Water moderators of the reactor serve to thermalize fast neutrons down to a thermal energy range used by the 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 two steel blades of a movable reflector near the core. 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 the blades pass simultaneously opposite the core. Such modulation of reactivity (frequency of 5 Hz) results in a pulsed increase in fast neutron flux density of up to 10^{17} cm^{-2}·s^{-1}.

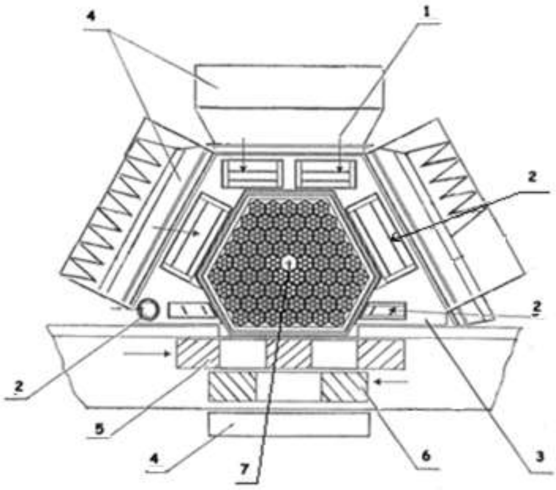

Fig. 1. The IBR-2M core: 1 – emergency system, 2 – control rods, 3 – stationary reflector, 4 – water moderators, 5 – main movable reflector, 6 – auxiliary movable reflector, 7 – neutron source.

Figure 2 presents a photo of rotors of the movable reflectors at a test stand of FLNP JINR. Compared to the IBR-2 reactor the modernized IBR-2M reactor has the following principal features:

- compact core composed of 69 fuel assemblies instead of 78 (in the IBR-2 reactor);
- use of fuel pellets with central holes, which allows an increase in feasible burn-up depth up to 9 %, i.e. almost by a factor of 1.5 as compared to the IBR-2 reactor;
- use of two (instead of four) safety units realizing the function of fast and slow emergency protection systems.
- construction of a complex of cryogenic moderators.

The reactor parameters before and after the modernization are given in Table 1. A considerable part of the reactor main equipment was replaced except for a biological shield, reactivity modulator and technological systems.

Fig. 2. A photo of the reactivity modulator rotors with nickel alloy blades at a test stand.

Table 1. The IBR-2 reactor parameters before and after the modernization.

Parameter	IBR-2 before modernization	IBR-2 after modernization
Average power, MW	2	2
Fuel type	PuO_2	PuO_2
Number of fuel assemblies	78	69
Maximum burn-up, %	6.5	9
Pulse frequency, Hz	5; 25	5; 10
Pulse half-width, µs	215	200
Rotation rate, rev/min: main reactivity modulator auxiliary reactivity modulator	 1500 300	 600 300
Material of main and auxiliary reactivity modulators	steel	nickel
Moveable reflector life, hr	20000	50000
Number of satellites at 5 Hz	4	1
Coolant	Sodium	Sodium
Sodium flow rate through the core, m^3/hr	80-110	80-110

3. Physical and power start-up of the modernized reactor

The loading of the IBR-2 core was started on December 17, 2010 and finished on February 14, 2011. The rated power of 2 MW was achieved on October 12, 2011 [2]. The critical loading of the modernized reactor is 64 fuel assemblies. The remaining uncharged cells will ensure the reactor service life for no less than 20 years. The core loading pattern is presented in Fig. 3.

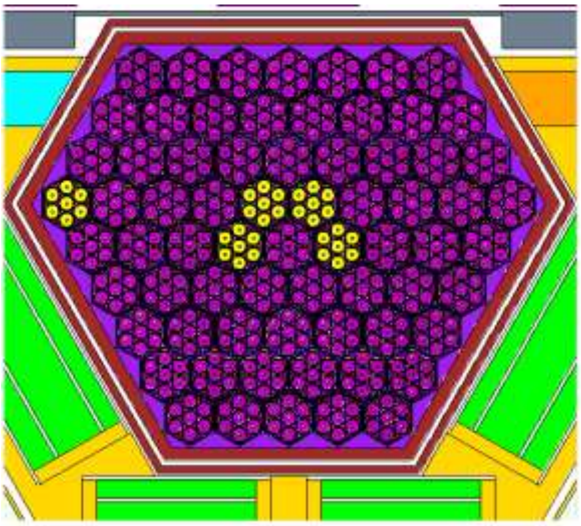

Fig. 3. Final core loading pattern of the IBR-2 modernized reactor with 64 fuel assemblies.

Two safety system units are intended for fast emergency power cutback. In 0.1 s each of the safety system units reduces reactivity by 0.12%, which reliably brings the reactor below prompt criticality and suppresses neutron generation. The response of the reactor to external reactivity perturbations due to a change in the operation mode or a failure of various technological systems that ensure normal functioning of the reactor has been studied. All main reactivity effects are negative. As the power increases, various power feedback effect components start to develop. Numerous experiments in the power range from 500 to 2 MW and at a sodium flow rate through the core from 60 to 100 m^3/hr have demonstrated that power, flow rate and temperature effects are negative. The power pulse shape is the most important characteristic of IBR-2M both for the reactor personnel and the neutron beam users in neutron time-of-flight experiments. The IBR-2M pulse shape is close to a truncated Gaussian distribution with a half-width at half-maximum of 200 ± 4 μs. A pulse shape over a full dynamic range is given in Fig. 4.

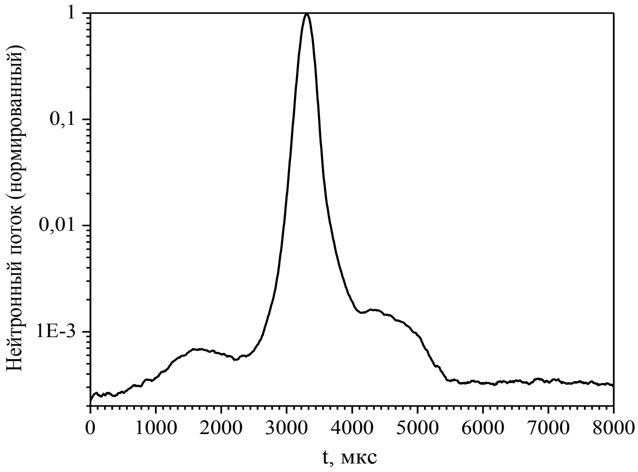

Fig. 4. IBR-2M power pulse shape. The data are normalized to the pulse maximum.

A distinctive feature of IBR-2M as compared with steady-state reactors is a high sensitivity of IBR-2M to external reactivity fluctuations: about 40 times higher than that of steady-state reactors with uranium fuel. A normal operation of IBR-2 requires minimization of all reactivity noise sources. Relative root-mean-square deviations of pulse energy versus a power level are presented in Fig. 5.

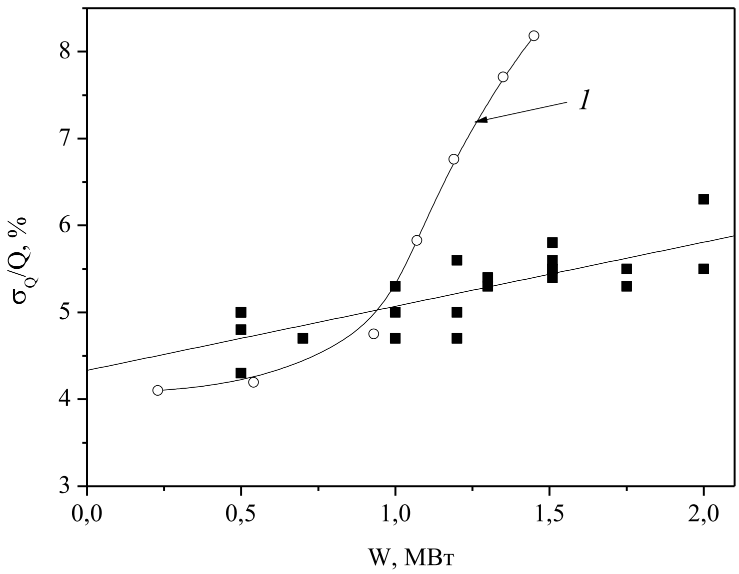

Fig. 5. A dependence of relative root-mean-square fluctuations of pulse energy (σ_Q/Q) on mean power (W) at a sodium flow rate through the core from 40 to 100 m^3/hr. 1 – a change in the pulse energy fluctuations in the course of the IBR-2 start-up in 2004 with a movable reflector of the heterogeneous type [3].

The same figure also presents a curve showing a change in the pulse energy fluctuations in the course of the IBR-2 start-up in 2004 with a movable reflector of the heterogeneous type [3]. The investigations have shown that the main source of pulse energy fluctuations are axial (towards the core) vibrations of the blades of the movable reflectors. Other effects, for instance, fluctuations of the temperature and flow rate of sodium passing through the core in a turbulent flow manifest themselves to a much lesser degree and their influence on the fluctuations of power may be neglected. Table 2 presents some nuclear-physical parameters of IBR-2M characterizing the reactor both as a nuclear-physical facility and a pulsed neutron source. Figure 6 shows the place that IBR-2M occupies among the modern neutron sources.

Table 2. The IBR-2M nuclear-physical characteristics.

Parameter	Parameter notation	Value
Half-width at half-maximum	$\Theta_{1/2}$, μs	200±4
Pulse power	W, MW	1830
Power in background (between pulses)	W_b, MW W_b, %W_{aver}	0.2 8.6
Average peak fast neutron flux density in safety system	Φ_f, n/(cm^2/s)	$2.26 \cdot 10^{17}$
Average thermal neutron flux density on grooved water moderator surface	Φ_t, n/(cm^2/s)	$\sim \cdot 10^{13}$

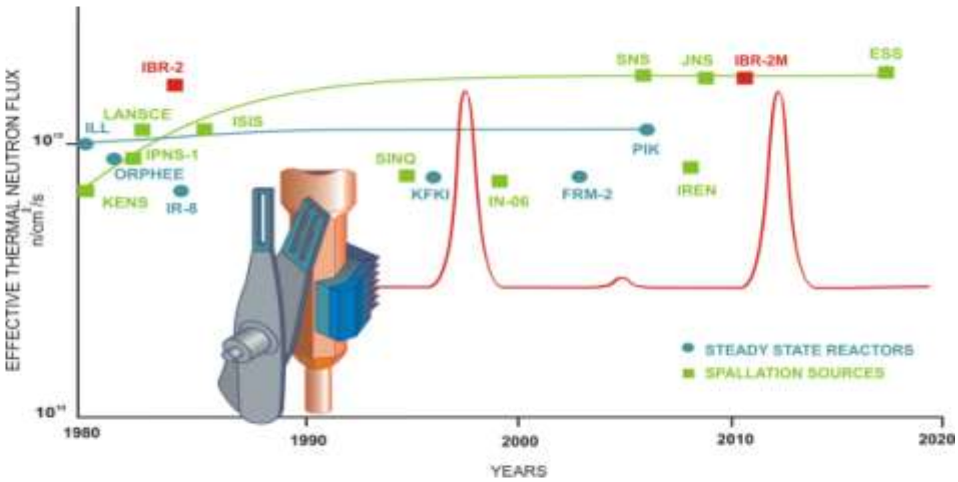

Fig. 6. The intensity of modern pulsed neutron sources.

4. Conclusion

The realization of a ten-year IBR-2 modernization project that involved the participation of a large number of specialized institutes and organizations of nuclear industry including JINR, NIKIET (N.A.Dollezhal Research and Design Institute of Power Engineering), VNIINM (A.A.Bochvar All-Russia Research Institute of Inorganic Materials), Federal State Unitary Enterprise “Mayak Plant”, JSC “SNIIP-SYSTEMATOM” has been successfully completed. The completion of the IBR-2 equipment modernization project has made it possible to extend the service life of this unique pulsed research reactor until at least 2037 and to preserve and develop its scientific and research programs. The results of the start-up activities have revealed good agreement between the analytical calculations and the experimental data obtained after the modernization of the IBR-2 reactor. The operating experience of the reactor has shown that IBR-2 is a very effective neutron source that compares well with the best proton-accelerator-based sources. The IBR-2 reactor is mainly used for beam investigations across a diverse range of science areas encompassing condensed matter physics, biology, chemistry, materials science and Earth sciences. In recent years the number of investigations at the IBR-2 reactor, which are of interest for nuclear science and technology, has increased considerably. These investigations are concerned with the study of the structure and properties of constructions and constructional materials for reactor engineering, new superconductors, bioactive compounds and deal with the obtaining of nuclear data and data on heavy elements in the environment surrounding nuclear objects [4].

5. References

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