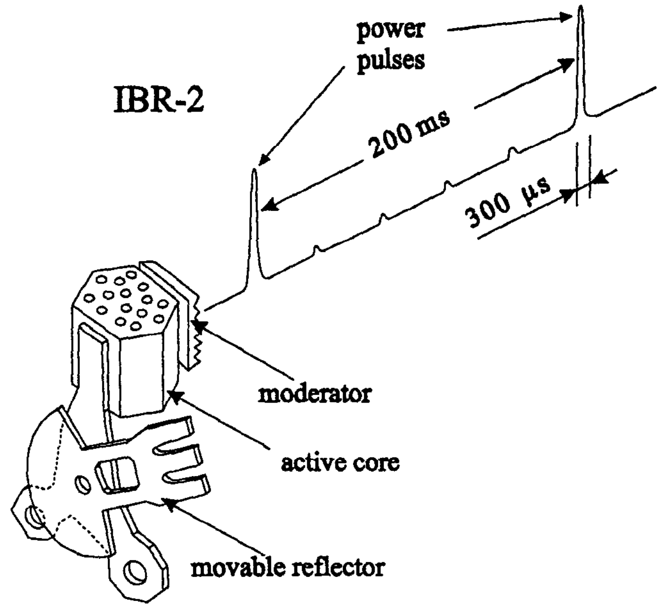
THE IBR-2 FAST PULSED REACTOR: PRESENT AND FUTURE

V.L.Aksenov, V.D.Ananiev, A.V.Belushkin, A.V. Vinogradov
Frank Laboratory of Neutron Physics (FLNP), Joint Institute for Nuclear Research (JINR),
141980, Dubna, Moscow Region, Russia.

1. Introduction

The IBR-2 fast pulsed reactor belongs to and is operating in the Frank Laboratory of Neutron Physics (FLNP) of the Joint Institute for Nuclear Research (JINR) in Dubna, Russia. JINR is an international research centre founded in 1956 and it includes seven laboratories with research programs in nuclear physics, condensed matter research and elementary particle physics.

At present, FLNP with a staff of 500 people has two pulsed neutron sources: the pulsed booster IBR-30 and the fast pulsed reactor IBR-2. The first is mainly used to perform experiments in the field of nuclear physics (physics of the neutron and study of nuclear reactions with neutrons). The second source is used for condensed matter research.



The principle of IBR-2 operation is schematically shown in the figure. The core of the reactor is composed of fuel element subassemblies (plutonium dioxide). The cooling system has three circuits and two loops. In the first and second circuits the coolant is liquid sodium and in the third it is air. The core is contained in a double-wall steel vessel and is surrounded by a stationary reflector with control and safety rods. Around the reactor, water moderators scanned by 14 horizontal channels for neutron extraction are located. Power pulses with a frequency of 5 Hz are generated by a movable reflector whose rotation ensures reactivity modulation of the reactor. When both rotating wheels of the reflector approach the core, a power pulse develops.

Some of the main IBR-2 working parameters are presented in Table 1.

Table 1. IBR-2 working parameters

N	Parameter	As of 01/04/98	Rated
1	Operation for physical experiment, h	33755	
2	Power operation time, MW·h	63358	85000
3	Operation time of movable reflector, h	8172	18000
4	Maximum fluence on reactor vessel in the center of core (10^{22} n/sm^2) for $E_n > 0.1$ MeV	2.79	3.72
5	Maximum fuel burn, %	5.09	6.5
6	Emergency shut-downs	395	550

2. Enhancement of the IBR-2 reactor utilization

The upgraded reactor will be given the name IBR-2M. By the year 2002, the principal parts of the reactor IBR-2 will have their radiation resource exhausted and will have to be replaced. In this connection a possibility appears to improve the characteristics of the reactor. The programme for upgrading the IBR-2 reactor has been elaborated for 10 years (1996-2005) and will be executed in three directions:

- improvement of the reactor parameters,
- increase in nuclear safety and reliability of the reactor,
- updating of the reactor systems.

The main stages of the IBR-2 modernization project:

- designing and manufacturing of the new equipment 1996-1998,
- assembly and tests of equipment,
  replacement of old equipment and fuel reloading 1999-2001,
- physical startup, energy startup 2002-2004,
- startup of IBR-2 for physical experiments 2005.

Improvement of the main parameters of the reactor, including an increase in the thermal neutron flux is connected with the realization of the new reactor core structure and the principally new design of the heterogeneous movable reflector. The expected increase in the thermal neutron flux in pulse is up to $(1.8\text{-}2)\cdot 10^{16}$ n/cm^2/s. The IBR-2 pre- and post-modernization parameters are illustrated in table 2.

Table 2. IBR-2 pre- and post-modernization parameters

N	Parameters	IBR-2	IBR-2M
1.	Average power, MW	2	2
2.	Fuel	PuO_2	PuO_2
3.	Number of fuel assemblies	78	69
4.	Maximum fuel burn, %	6.5	9
5.	Pulse repetition rate, Hz	5; 25	5; 10
6.	Pulse width, μs	215	200
7.	Revolution/minute		
	Main reflector (MR)	1500	600
	Auxiliary reflector (AR)	300	300
8.	MR and AR material	steel	nickel+steel
9.	Service life, h	20000	50000
10.	Background, %	6	7
11.	Number of satellites at 5 Hz	4	1

On a number of IBR-2 beams the flux in the cold neutron part of the spectrum will be essentially increased by using a new cryogenic moderator (CM) to be commissioned in 1999. In parallel with the manufacturing of CM, work to modernize the currently operating neutron moderators will be carried out.

Increasing the nuclear safety and reliability of the reactor involves a number of activities the most important of which are as follows:

1. Improvement of control systems for fuel elements tightness and vibration diagnostics of the movable reflector.
2. Startup of an automated system for measuring and control (ASMC). At present, some of ASMC subsystems are in the process of adjustment and tests are being carried out in order to start the ASMC test operation in 1998-1999. The execution of the ASMC project will provide the IBR-2 reactor with a branched diagnostics system and, thus, essentially increase the safety and reliability of the reactor. This is the PC-based (PC-Lab Standard) Control and Monitoring System. Work has continued to improve the IBR-2 control and monitoring system in a search for higher reliability of the control of the reactor state and the maintenance equipment. At

the same time, the system has been under constant development to increase the information capability on the basis of recent achievements in the field. This helps the staff to get adapted to the system and develop new, more convenient programs for the control of technological parameters, as well as the equipment of the reactor state control system and electronics to execute necessary logic operations of the reactor alerting and monitoring. At present, some ASMC subsystems are in the process of adjustment and resource tests are being carried out in order to start the ASMC test operation in 1998-1999. Unfortunately, the work is delayed due to insufficient financing.

3. Reconstruction of the IBR-2 power supply system. The IBR-2 operation experience showed that a considerable number of IBR-2 emergency shutdowns (about 20%) are connected with different interruptions in power supply caused by malfunctioning of the electric transmission substation. In 1990-1991, the project for switching the IBR-2 high voltage power supply system over to a separate transformer was developed. The reconstruction of the electric substation is to be completed before the year 2000.
4. The IBR-2 reserve control desk. In 1998-1999, in the frame of the project for the construction of the IBR-2 reserve control desk (as required by the State Atomic Inspection of Russian Federation) is to be completed.
5. Substantiation of the technological resource of the reactor. The work is being carried out by design institutes in accordance with the latest requirements of the State Atomic Inspection of Russian Federation.

The modernization of the main systems of the reactor is necessitated by nearly exhausted radiation and mechanical resources of a number of reactor blocks and the fuel burn.

<u>The new movable reflector (PO-2RM).</u> The resource of the currently operating movable reflector PO-2R will be exhausted in 7 years, by the beginning of the year 2002. By this time, the new reactivity modulator PO-2RM will be manufactured. According to the PO-2RM project this involves:

- construction of the main and auxiliary rotors from nickel alloy (nickel content is 70%);
- the main and auxiliary rotors rated speed of rotation is 600 and 300 rpm, respectively. The pulse duration of about 200 μsec is retained. The reactor reliability and the resource of the machine will considerably increase.

By now, the PO-2RM project has got experts approval from the State Atomic Inspection of Russian Federation

In 1998-1999, the first two movable reflectors, PO-1 and PO-2, will have to be removed from a temporary storage room which is 2/3 full at present. Because of high induced radioactivity of these devices, unique technologies will be used to accomplish the task.

<u>Fuel reloading.</u> By the year 2001 the existing active zone will exhaust its resource. Maintaining the current reactor operation schedule (2500 h a year at the power 2 MW) the energy generated by the end of the year 2001 will be 85000 MW-h and the maximum burn of fuel elements will be 6.5%.

In the period up to the year 2001 the operational reactivity resource, as well as replacement of separate fuel cassettes, if such a necessity appears, will be provided from the reserve. At the same time, the new plutonium dioxide fuel elements have to be created. To do this, it is necessary:

- to develop a technical project for fuel elements in a specialized institute,
- to conclude a contract for manufacturing with an appropriate Russian plant,
- in 1999, to start an investigation of two fuel cassettes currently working under greatest strain in the laboratory of the Ministry of Atomic Energy of Russian Federation to obtain necesseary data for designing the new core,
- to assemble the new core at FLNP.

<u>The reactor jacket.</u> By the end of the year 2001 the maximum fast neutron fluence will be $2.3 \cdot 10^{22}$ n/cm^2 for neutrons with an energy $E > 0.5$ MeV and $3.72 \cdot 10^{22}$ n/cm^2 for neutrons with an energy $E > 0.1$ MeV, and the number of emergency shutdowns will be 550, i.e., these parameters will reach the rated limiting values established by the new requirements for reactor safety and the calculation of the reactor jacket durability performed by the designer in 1994. In this connection, it seems expedient to simultaneously replace the reactor jacket, fuel, stationary reflectors, control and emergency system (CES) mechanisms and water moderators in the period from the year 2002 to the year 2004. The estimated IBR-2 modernization expenditures are summarized in table 3.

Table 3. Enhancement of the IBR-2 reactor utilization (estimated cost, k$)

	Stage 1 (designing, manufacturing, assembly and tests of new equipment)					Stage 2 (equipment replacement, physical startup, beginning work for physical experiments)				
Year	1998	1999	2000	2001	Total	2002	2003	2004	2005	Total
k$	1450	1700	1730	1150	6030	750	550	400	300	2000

Remark

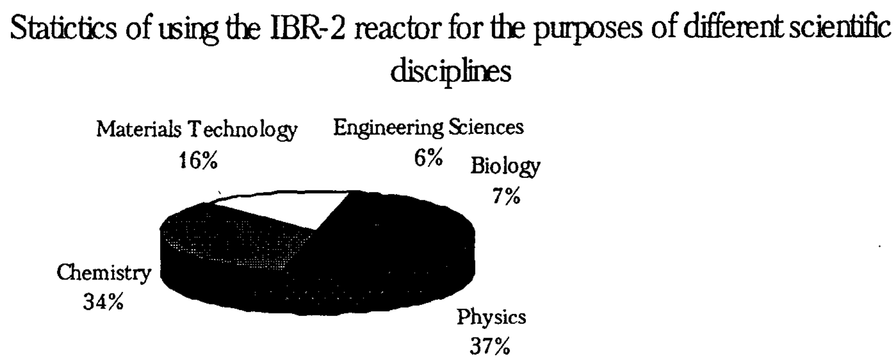
1) Total for the period 1998-2005 - 8.03 k$.

2) Expenses for the period 1995-1997 - 0.7 k$.

3) Salary fund and business trip expenses are not included.

3. Scientific programme at IBR-2

A wide program of scientific investigations in different disciplines has been developed on the reactor beams. The following figure illustrates the distribution of beam time among scientific directions.



At present, the general trend in neutron scattering is the expansion of research in the fields of biology and engineering sciences. This tendency is also pursued at IBR-2. At the same time, other scientific directions develop very actively as well.

IBR-2 as a pulsed neutron source has some specific features. These are a low repetition rate and a very high neutron peak flux with a relatively large pulse duration. The first two were always considered as advantages because they allow one to investigate a broad Q range, study weakly scattering samples, and use very tight collimation to improve spatial resolution. Due to these, a lot of very interesting results were obtained during the last years.

Reflectometry with polarised neutrons is used to measure the magnetic field penetration depth in thin films of type-II superconductors and high-T_c superconductors. Very important results were obtained in the study of the magnetic properties of thin magnetic films and multilayer structures, polymer composites, thin films, etc.

In the field of small-angle neutron scattering intense activity goes in the study of self-organizing systems, model and biological membranes, structure of biological macromolecules.

Considerable progress has been made in the field of texture studies. Due to the startup of a new spectrometer constructed at IBR-2 by the German group for texture studies, investigations of complex multicomponent rock samples have become possible. This opens a new field of research – the study of the relationship between the texture of geological samples and the physical properties of the earth crust and the upper mantle.

During the last years, a very high pulsed neutron flux has made it possible to start a very pressing research program in the study of the structure and dynamics of condensed matter at very high pressures. The results for 9.5 GPa have been obtained and in the future, it is planned to increase the pressure up to 25 GPa or even higher. Very interesting experiments of high-T_c superconductors, metal hydrides and ammonium halides were performed.

The new spectrometer built for such kind of research allows simultaneous measurements of diffraction and inelastic scattering spectra. It can also be used for the study of the structure and dynamics of microsamples.

For many years a relatively large neutron pulse width has been considered as a natural disadvantage of IBR-2, because it limits the resolution of the instruments in the traditional approach. However, the implementation of the reverse time-of-flight Fourier technique and the construction of the high resolution Fourier diffractometer have completely changed the situation. At present, for a very broad range of scientific problems, at IBR-2, one can obtain structural results of the same quality as they can be achieved on the best powder diffractometers in the world. Also, this machine has a very good potential for stress/strain research as it was demonstrated in recent experiments.

Very good possibilities exist at IBR-2 for time-of-flight inelastic neutron spectroscopy. For example, the NERA high resolution inverted geometry neutron spectrometer makes it possible to obtain inelastic scattering data of the quality comparable with the best spectrometer of its type, TFXA, in the Rutherford Appleton Laboratory. The DIN direct geometry time-of-flight inelastic scattering spectrometer has very good parameters to study the dynamics of quantum and normal liquids.

The method of neutron activation analysis is presently applied very effectively to analytical work connected with the protection of the environment: biomonitoring of industrial areas, multielement analysis of aerosols etc.

The new direction in applied research is the testing of radiation hardness of various constituents of detectors for large hadron colliders. After some years of operation such detectors will get the neutron fluence of the order 10^{15} n/cm^2 and the gamma-dose 10 Mrad. The neutron and gamma-spectra, similar to the corresponding spectra from hadron colliders, can be easily formed at the reactor IBR-2 and at present, different electronics and construction elements created in the frame of the project ATLAS CERN are being tested.

At the present time, the cold methane moderator is being installated. The first experiments have shown that such moderator gives the gain of 20 times in the yield of cold neutrons (with E<1meV). In 1999, it is planned to move the cold moderator to its regular site at IBR-2.

4. Conclusion

The reactor has been operated for over 13 years without accidents. The years of continuous operation of IBR-2 have demonstrated that it is reliable in operation and is very effective for studies in condensed matter physics. It supplies neutron spectrometers with neutrons 110 days per year. The initial fuel charge ensures over 15 years of operation without fuel reloading. The liquid sodium loops are working reliably in the non-stop regime. A succesful implementation of the IBR-2 modernization program will extend its service life to the year 2030.

References

1. V.L.Aksenov / Update on pulsed reactor IBR-2 at Dubna, Physica B 174 (1991), 438-442
2. Yu.S.Yazvitskii / The pulsed reactor IBR-2 as a neutron source, (1977), Nuclear Structure Study with Neutrons, Publishing House of the Hungarian Academy of Sciences
3. I.M.Frank and P.Pacher / First experience on the high intensity pulsed reactor IBR-2, Physica 120 B (1983), 37-44
4. E.P.Shabalin / Fast Pulsed and Burst Reactor, Pergamon Press, Oxford, 1979
5. FLNP - Programme of Research and Development 1996-1998, ed. V.L. Aksenov and Yu. V. Taran (JINR, Dubna, 1995)
6. V.I. Luschikov, A.V. Vinogradov / Applied research at the IBR-2 fast pulsed reactor, IAEA International Seminar "Enhancement of the research reactors utilization", Bhabha, India (1996).