ICANS-XIII
13th Meeting of the International Collaboration on
Advanced Neutron Sources
October 11-14, 1995
Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

NEWS FROM IBR-2

V.L.Aksenov

Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia

ABSTRACT

The IBR-2 nuclear reactor is the most intense pulsed neutron source for condensed matter physics in the world. The present status and trends of reactor development and instrumentation for physical research are described.

1. Introduction

The IBR-2 reactor is the pulsed reactor of periodic operation (pulsing reactor) which has been operating in a regular mode with a mean power of 2 MW and a pulse repetition rate of 5 Hz since 1984. The power in the pulse is 1500 MW and the neutron flux in the pulse is 10^{16} n/cm^2/s. Detailed description of the IBR-2 reactor structure is given in the monography[1]. Later developments of the reactor and its instrumentation are detailed in reviews[2-5].

The main original feature of the IBR-2 reactor consists of the mechanical modulation of reactivity which is accomplished with the help of a movable reflector. Because of a low mean power and as a result, lower activation of equipment and slower burnup of the core the IBR-2 reactor is an extremely economical and relatively inexpensive machine. For 2500 hours of regular operation per year the service life of the core is 20 years and of the movable reflector 5 to 7 years.

On March 27, 1995 the IBR-2 reactor resumed operation with a new movable reflector with a rated service life of 7 years. At the same time, after 2001 the resource of the core currently in use will be exhausted. In this connection, it seems expedient to simultaneously replace the reactor jacket, fuel, stationary reflectors, control and emergency system mechanisms, and water moderators in the period from 2002 to 2004. So, this year we started work to prepare the IBR-2 modernization in the period from 1995 to 2001. In principle, the

Keywords: Pulsed reactor, Instrumentation

new reactor will have the same structure and mean power as the IBR-2, but improving all reactor elements following accumulated experience of reactor operation will, as we hope, help upgrading the reactor characteristics and, in particular, permit a 2 times increase in the neutron flux and a 1.5 to 2 times decrease in the pulse width. More detailed information on the programme of the development of the neutron sources in Dubna is published in[6].

This contribution gives information on the recent main results of upgrading the IBR-2 reactor and development of spectrometers in the period after the last ICANS meeting.

2. Cold moderator for IBR-2

At present, work on upgrading the IBR-2 reactor concentrates on manufacturing the cold methane moderator[7,8].

Over a period of several years work to create a cold neutron moderator for the IBR-2 reactor has been carried out by the Frank Laboratory of Neutron Physics. In 1992, a cold moderator prototype was manufactured and installed in place of the cock water moderator on channels 4 to 6 for short-term investigations of the thermotechnical and physical characteristics of the cold moderator at a reactor power of 1 MW. In December 1992 - January 1993 a long-term investigation of cold methane behavior under irradiation was conducted with the URAM facility at a reactor power of 2 MW.

In February 1994, investigations of the cold moderator prototype completed. The basic possibility of using solid methane as a neutron moderator at a reactor power of 2 MW was demonstrated. A 15 to 25 times increase in the cold neutron flux in comparison with the regular water moderator was obtained. The obtained results formed the basis for creating a regular cold moderator for IBR-2 using solid methane at 20-60 K.

In 1995, work on the creation of a regular cold moderator for IBR-2 continued. Designing of the cryogenic moderator was executed. Development of the project for the technological systems of the cryogenic moderator is approaching its final stage. The project for temporal siting the cold moderator was elaborated. The project of a system for parameter measurements and control and measuring devices is in the stage of realization. A contract for investigating strength characteristics of the cryogenic moderator was concluded. Contracts for manufacturing the cryogenic moderator were concluded and are due to payment by the end of 1995. We hope that the cold methane moderator will be ready for regular operation at the end of 1996.

3. Instruments

At present 13 spectrometers for physical research are operating on the beams of the IBR-2 with 6 of them serving experiments on diffraction studies, 1 - on small-angle scattering, 2 - on reflectometry, and 4 - on elastic scattering. Detailed information about the parameters of these spectrometers is given in[5].

Two new spectrometers were reported on at the last ICANS meeting: the NERA-PR Multicrystal Inverted Geometry Spectrometer[9] and the HRFD High Resolution Fourier Diffractometer[10]. These spectrometers, especially the HRFD, are of significant importance for IBR-2 because they give the same resolution as the ISIS instruments. Recent comparison of parallel measurements with TFXA ISIS and NERA-PR is given in[11]. A special session of this meeting will be devoted to Fourier diffractometers, where detailed information on the HRFD will be presented.

In this contribution I will focuse on the other two new spectrometers which recently started operations.

3.1. Time-of-flight neutron spectrometer for micro-sample studies under high pressures (DN-12 spectrometer)

The DN-12 spectrometer is placed in channel 12 of the IBR-2 reactor and consists of the following main systems: neutron beam chopper phased with the power pulse of the reactor, beam collimating system, multicounter circular detector system, information management, and a registration and processing system.

The DN-12 spectrometer is specifically intended for work with high-pressure cells based on sapphire anvils. A well collimated neutron beam passes through the sapphire single crystals, between which a sample is placed. Scattered neutrons are registered by the detector consisting of small counters positioned around the circle of a vertically standing ring. The ring as a whole can be moved relative to the sample along the beam direction, providing scattering angles from 45° to 135°.

In Table 1 the essential parameters of the DN-12 spectrometer are given.

Table 1. The main characteristics of DN-12

	1994	1997
1. Thermal neutron flux at the sample position	$1 \cdot 10^6$ n/cm²/s	$2 \cdot 10^6$
2. Distances: moderator-sample sample-detector	31.8 m 0.4 m	27.0 m 0.4 m
3. Range of: wavelength scattering angle d_{hkl}	 1 - 4 Å 45° - 135° 0.8 - 5.2 Å	 0.8 - 10 Å 45° - 135° 0.6 - 13 Å
4. Resolution (Δd/d, d=2 E): for 2θ=90° for 2θ=135°	 0.022 0.012	 0.022 0.012
5. Solid angle of the detector system	0.125 sr	1.0 sr
6. Pressure range: with sapphire anvils with diamond anvils	 10 GPa 20 GPa	 25 GPa 50 GPa

Table 2 gives the list of some experiments performed with DN-12 since the start of its operations.

Table 2. Experiments performed with DN-12 from November 1993.
Pressure is given in GPa, sample volume in mm²

Sample	Pressure	Volume	Anvils	Main result
Hg-1212	3.6	1	sapphire	equation of state, struct. changes
DyD_3	10.0	0.01	diamond	equation of state
ND_4Cl	2.5	2	sapphire	structural changes
NH_4Cl	4.0	2	sapphire	libration and lattice mode changes
Fe_2O_3	4.7	1	sapphire	new magnetic phase above 3 GPa

Results of the investigations of the vibrational spectrum and structure variations in NH_4Cl are published in[13], the results of the structural studies of high-temperature superconductors are published in[14].

Several experiments have been carried out to determine the minimal quantity of substance from which it would be possible to obtain a diffraction pattern with DN-12 within a reasonable amount of time (not more than 50-100 hours). For this purpose, a $^{164}DyD_3$ sample with a maximal coherent scattering cross-section was used ($\sigma_{coh}\approx 250$ b). This sample was placed in the diamond anvil cell. The sample volume was 0.027 mm^3, the pressure was about 10 GPa, and it was possible to increase the pressure up to 20 GPa. One can see in Fig.1 the clear diffraction pattern, which was obtained in 24 hours.

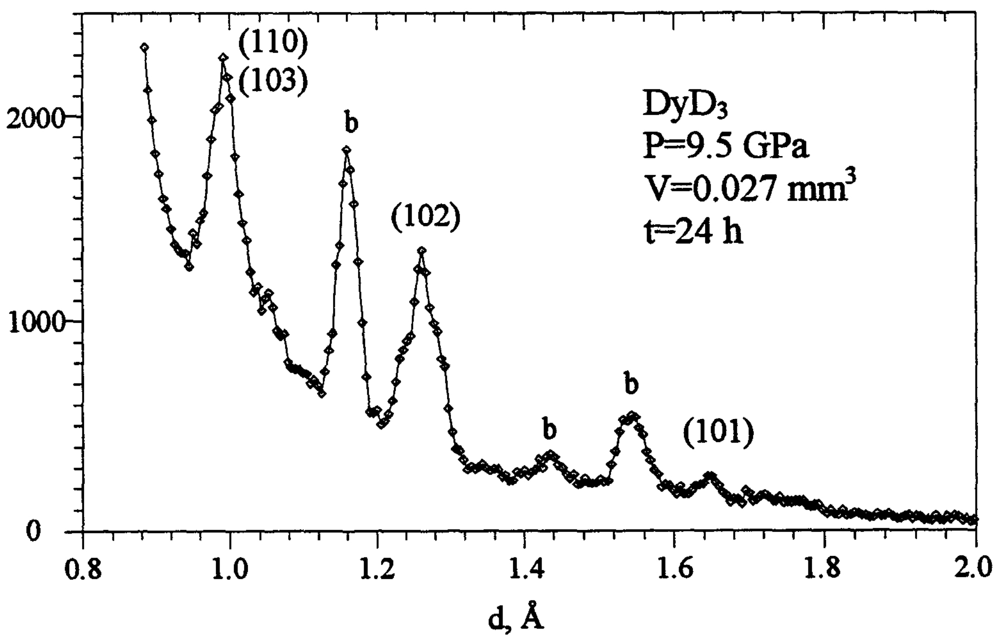

Fig.1 Diffraction pattern of DyD_3 powder (the isotope ^{164}Dy was used) measured in a diamond anvil cell in 24 hours. The sample volume was 0.027 mm^3, the pressure was 9.5 GPa. The Miller indices of diffraction lines from the sample and background lines (b) are shown.

It is planned to develop the DN-12 in the following directions:

- improvement of the detector system, including the creation of a data acquisition system in VME standard;
- substitution of the vacuum neutron guide tube by a mirror neutron guide tube;
- moving of the neutron beam chopper to another position. (It will be placed 4.5 m between the moderator and chopper instead of 8.9 m at this moment);
- creation of special equipment for loading the pressure cell with the optical spectrometer measurement of pressure;
- widening of experimental possibilities (use of new materials for the anvils, getting low and high temperatures at the samples.

The experiments carried out at the DN-12 spectrometer have shown its advantages in comparison with similar devices in such centres as RAL, RRC KI, ANL, LANL. Putting the new detector system into operation, building the mirror neutron guide tube and a beam chopper will improve the device characteristics significantly, increase its efficiency and will make it more attractive and beneficial for users.

3.2. REFLEX complex

This instrument having been designed with account for experience acquired by the neutron laboratories over the world has some original features making it different from the like instruments. The design of the instrument is described in[15]. The incident neutron splits into two beams in the collimator system. Then one of the beams passes through a polarizing and the other through a nonpolarizing mirror systems which focuse neutrons on two samples, where each of the two beams again splits into two. So, the REFLEX complex consists of two independent reflectometers: REFLEX-N with an unpolarized neutron beam and REFLEX-P with a polarized neutron beam and a horizontal geometry arrangement.

In 1994-early 1995, the main units of the REFLEX complex were installed, adjusted and the first test experiments on REFLEX-P were performed. The REFLEX-P uses the unique, highly efficient Korneev spin-flipper with an extended spin-reverse area. The polarization reflectometer also has an original magnetic system: a solenoid with a special electromagnet which can be rotated about the neutron beam axis to create an arbitrary oriented field up to 1 KOe on the sample. The essential parameters of the REFLEX-P spectrometer are given in Table 3.

In Fig.2 the polarization of the incident beam as a function of the wavelength, as measured by the FeCo/TiGd analyzer, is shown.

The detector system for each reflectometer consists of four PC-controlled movable ^{3}He detectors. The REFLEX-P is also equipped with a helium cryostat for 1.5 K, a helium refrigerator for the temperatures above 9 K, and a vacuum furnace for up to 500°C.

Table 3. The main characteristics of the REFLEX-P

Moderator	water at 320 K
Neutron wavelength	1.2-8 Å
Polarizer	two parallel FeCo/TiGd mirrors 1.6 m long adjusted for twofold impindge of neutrons
Incident beam polarization averaged over the spectrum	98%
Q range	0.005-0.1 1/Å
ΔQ/Q (for a grazing angle of 7 mrd)	2%
Spin-flipper efficiency	99.6%

Test experiments with the REFLEX-P reflectometer have demonstrated high efficiency and a ready state of the instrument for the realization of the physical program whose first priority is the study of microscopic magnetic properties of superconductors, inhomogeneities in magnetics, and multilayer polymer structures. It is planned to carry out complete equipping the REFLEX-N in 1996.

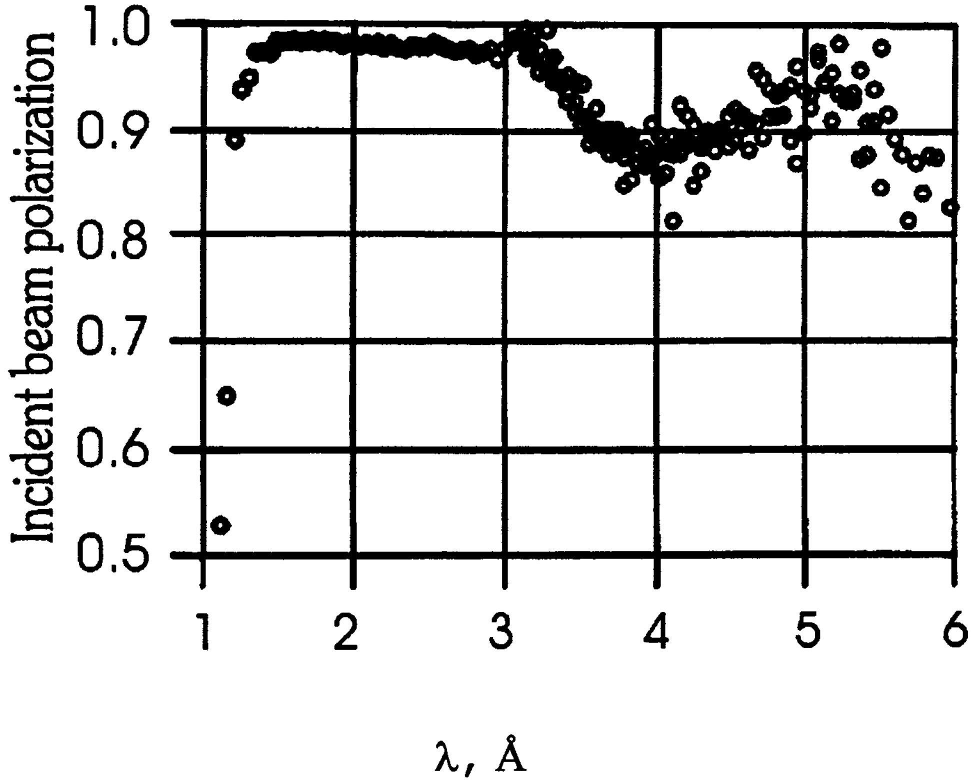

Fig.2. Neutron beam polarization by REFLEX-P as a function of the wavelength

4. Conclusion

The third field of activity around the IBR-2 reactor (besides upgrading the reactor and development of spectrometers) is the development of the experimental infrastructure, including upgrading sample environments and the computational and data acquisition systems of the Laboratory. The major goal of these projects is to create a system for performing experiments which will be user friendly and similar to what scientists find in western or international neutron centers. This system will also allow effective data storage and easy transfer of data between Dubna and other institutions.

So, in the last two years much effort was made by the Laboratory staff to make all IBR-2 experimental facilities open to the world scientific community.

In conclusion, I would like to emphasize that the IBR-2 high flux pulsing reactor with a large neutron pulse duration (~300 μsec) really gives physicists the possibilities which are very close to those provided by spallation sources nowadays. The operational experience with IBR-2 shows that the width of the neutron pulse is not crucial in achieving a good quality source and to have a higher flux is more important. I believe the above conclusion from the IBR-2 experience could be helpful in discussions on the prospects of neutron sources in condensed matter physics.

5. References

[1] E.P.Shabalin, *Fast Pulsed and Burst Reactors* (Pergamon Press, Oxford, 1979)

[2] A.V.Belushkin, *Neutron News* **2** (1991) 14

[3] V.L.Aksenov, *Physica B* **174** (1991) 438
[4] V.L.Aksenov, in *Large Facilities in Physics,* ed. M.Jacob and H.Schopper (World Scientific, Singapore, 1995)
[5] A.M.Balagurov, *Neutron News* (1995) in press
[6] *FLNP - Programme of Research and Development 1996-1998,* ed. V.L.Aksenov and Yu.V.Taran (JINR, Dubna, 1995)
[7] A.A.Belyakov, V.G.Ermilov, V.L.Lomidze et al., in *Proc. of ICANS-XII,* RAL Report 94-025 (1994), vol.II, p.144.
[8] A.A.Belyakov, V.V.Melikhov, Yu.N.Pepyolyshev and E.P.Shabalin, *J. of Neutron Research* (1995) in press
[9] I.Natkaniec, S.I.Bragin, J.Brankowski and J.Nayer, in *Proc. of ICANS XII,* RAL Report 94-025 (1994), vol.1, p.89
[10] V.L.Aksenov, A.M.Balagurov, V.G.Simkin et al., ibid, p.124
[11] R.Baddour-Hadjean et al., Chemical Phys. **197** (1995) 81
[12] V.L.Aksenov, A.M.Balagurov, B.N.Savenko et al., *High Pressure Research* **14** (1995) 181
[13] A.M.Balagurov, B.N.Savenko, A.V.Borman et al., ibid, p.55
[14] V.L.Aksenov, A.M.Balagurov, B.N.Savenko et al., ibid, p.127
[15] V.L.Aksenov, D.A.Korneev, L.P.Chernenko, in *Neutron Optical Devices and Applications,* ed. Charles F.Majkrzak, James L.Wood. *Proc. SPIE,* **1738** (1992) 335