JOINT INSTITUTE FOR NUCLEAR RESEARCH

96-471

V.L.Aksenov

SCIENTIFIC PROGRAM OF THE FRANK LABORATORY OF NEUTRON PHYSICS: Report for 1996 and Prospects for 1997

Report of FLNP Director to the 81st Session
of the Scientific Council of JINR
January 16—17, 1997

Dubna 1996

V.L.Aksenov

SCIENTIFIC PROGRAM OF THE FRANK LABORATORY OF NEUTRON PHYSICS: Report for 1996 and Prospects for 1997

Report of FLNP Director to the 81st Session
of the Scientific Council of JINR
January 16—17, 1997

Dubna 1996

INTRODUCTION

In 1996, the FLNP scientific program was covered by six research themes of the JINR Plan of Scientific Research and International Scientific and Technical Cooperation (PSRISTC), and was aimed at obtaining new results in condensed matter physics (theme 07-4-0864-89/98 "Condensed Matter Investigations Using Neutron Scattering", headed by A.M.Balagurov), and in neutron nuclear physics (theme 06-4-0974-92/99 "Study of the Fundamental Characteristics of Neutrons and Nuclei", headed by W.I.Furman), and in applied investigations (theme 07-4-0975-92/96 "Activation Analysis and Radiation Investigations at IBR-2", headed by V.A.Sarin). To effect scientific research, work to develop, modernize, and construct the FLNP basic facilities, IBR-2 (theme 07-4-0851-87/97 "Development and Upgrading the IBR-2 Complex", headed by V.D.Ananiev) and IREN (theme 06-4-0993-94/96 "IREN Project", headed by W.I.Furman), and the FLNP measurement and computation complex (theme 07-4-1012-96/2000 "Development of the FLNP Measurement and Computation Complex", headed by V.I.Prikhodko) continued.

This report contains a brief account of the 1996 scientific results and plans of the Laboratory for 1997, reflected in the JINR Plan of Scientific Research (PSRISTC) submitted for approval to the present session of the JINR Scientific Council. The 1996 annual report of FLNP activities will present a more detailed review of the 1996 results.

1. THE RESULTS OF SCIENTIFIC INVESTIGATIONS IN 1996

1.1. Condensed Matter Physics

Experimental investigations. In the framework of research theme 0864, investigations of the properties of condensed matter are being conducted at the IBR-2 reactor with the application of the four main techniques: diffraction, small angle scattering, inelastic scattering, and polarized neutron optics. The beam time per an IBR-2 spectrometer is distributed in accordance with experts' recommendations on the basis of submitted proposals and the existing long-term agreements for cooperation.

The 1996 list of the IBR-2 spectrometers operating in the user mode includes 9 instruments: HRFD, DN-2, NSVR, YuMO, SPN, REFLEX-P, KDSOG, NERA, and DIN. The new spectrometer on the list is the REFLEX-P commissioned in the spring. At present, DN-12 is under radical modernization to be completed by spring 1997, adjusting is being carried at REFLEX-N, and the SNIM spectrometer is temporarily excluded from the list in accordance with the recommendations of the Program Advisory Committee.

The main parameters of the included spectrometers and possibilities for creating their sample environments have been formed and are, in the main, on the world level. The number of countries from where applications for beam time arrived has increased to 20. The application for the 1996-II round is 1.6 times larger than for the 1996-I round. This is connected with that the user program is being continually developed, as well as with the increased activity of the spectrometer leaders. The user program can be extended by increasing the number of experiments on DN-2, REFLEX-P, DN-12, SKAT, and DIN-2.

Diffraction. In 1996, the program for investigations of hydrogen-containing superconductors by neutron diffraction continued. In HRFD experiments, precision structural

data were obtained and allowed the temperature dependence of the superconducting transition on the nonstoichiometric oxygen content to be determined. This dependence appeared to be a parabolic one with the maximum at ~0.20 free charge carriers per one CuO_2 layer in agreement with the established notion of the formation process of superconducting properties in layered copper oxides. The data on structural changes in Hg-compounds under the action of high pressure (up to ~50 kbar) have been obtained with the DN-12 diffractometer and confirmed that the "softest" element in the structure of these compounds is the long "apical" bound between copper atoms and oxygen whose reduction under the action of high pressure favors the transition of holes to the superconducting planes in CuO_2 and, as a result, leads to a noticeable increase in T_c ($dT_c/dP \approx 0.2$ K/kbar for optimally doped compounds).

Small angle scattering. Investigations of DMPC multilayer lipid membranes were conducted with the YuMO small angle scattering spectrometer. These model membranes reflect well the main physical properties of real biological membranes and allow the physical processes going on in a live cell to be investigated. The conducted experiments have clarified why the membrane repetition period increases on heating. It was shown that the effect is mainly connected with an increase in the intermembrane space due to the entropy contribution, i.e., an increase in fluctuations of the membrane surface as the temperature increased. This argues against the previously prevailed opinion of the domination of hydration interaction.

Polarized neutron optics investigations. According to plans for 1996, the first stage of the REFLEX polarized neutron reflectometer was put into operations and the first methodological and physical experiments were conducted. The achieved neutron beam polarization over a wide neutron wavelength range is one of the best in the world for the instruments of that type. One of the first REFLEX experiments was conducted to investigate neutron reflection from self-organizing polymeric films, polysteinsulfonate and polyallilamine, with deuterization of each alternative layer. Neutron reflectometry makes it possible to observe the ordering of this self-assembling, control the effect of salt solutions on the stability of the structure, and to estimate the possibility to control the parameters of the structure. These experiments showed that this effect exists and results in a change in the period of the structure

Inelastic neutron scattering. The main subject-matter of investigations at the NERA-PR spectrometer was the study of dynamics of aluminium and methyl groups. The results obtained for solid -p, -m, and -o-xylene, as well as for $(CH_3)_2C_6H_4$ are used to model the rotation potential of methyl groups in molecular crystals and to check the quantum-chemical calculations of the structure of molecules and their vibrational spectra.

1.2. Neutron Nuclear Physics

According to the recommendations of the 79th Session of the Scientific Council of the Joint Institute for Nuclear Research, disassembly of the IBR-30 reactor was scheduled for the middle of 1997. Therefore, the completion of the research program at IBR-30 was scheduled for the end of 1997.

To realize the recommendations, in the frame of research theme 0974 the following main results were obtained.

Methodological investigations. The first stage of development of the UGRA instrument was completed, test measurements under the specified vacuum were conducted, the methodological capability of the instrument for the determination of the anisotropy of inelastic

neutron scattering was confirmed, and the necessity to increase the number of neutron detectors was realized.

Assembling and tests of the high resolution two-detector gamma-spectrometer with anti-Compton shielding were completed and the first test measurements of prompt-gamma-radiation spectra of the resonance neutron induced fission of ^{235}U were conducted.

The modernization of the multi-detector facility ROMASHKA for the registration of gamma-quanta multiplicity distributions was completed in cooperation with the Base for Development and Application of the Institute of Nuclear Physics and Atomic Energy of the Academy of Sciences of Bulgaria.

Experimental investigations. Essential advances in the completion of a complex program of experiments to study the angular correlation of fragments from the resonance neutron induced fission of ^{235}U nuclei have been made: important data on P-odd correlation (neutron spin – fission fragment momentum) in the region $E_n \leq 20$ eV were obtained, the measurement statistics of P-even angular correlation between the spin orientation of the nucleus and the fission fragment momentum was essentially improved and allowed a multilevel three-channel analysis of the energy dependence of the effect to be performed, as well as to reliably extract, for the first time, the fission $J^{\pi}K$ amplitude (J is the spin, π – parity, and K – the spin projection on the deformation axis of the fissile compound nucleus) for s-wave resonances in the region $E_n \leq 10$ eV. The obtained amplitudes have provided the possibility for the numerical analysis of the FLNP data on P-odd and P-even angular correlation of fission fragments caused by the interference between s- and p-wave neutron resonances.

Isotopic identification of the p-wave neutron resonance at $E_n = 3.2$ eV responsible for the recently discovered P-odd transmission effect in natural xenon was conducted. It appeared that the effect is connected with the ^{131}Xe isotope. This provides principally new possibilities for the creation of a polarized nuclear target necessary for investigations of time invariance in the interaction of neutrons with nuclei.

Measurements of gamma-quanta multiplicities following the capture of resonance neutrons by ^{235}U and ^{239}Pu nuclei were carried out with the multidetector facility ROMASHKA. This allowed recent contradictions between the values of α, the ratio of radiation capture cross section to fission cross section, obtained by different experimental groups for low-lying resonances to be resolved.

The first stage of experiments to test the high density UCN source at the BIGR pulsed reactor in Sarov was completed. The results have demonstrated the possibility for a considerable increase of the obtained UCN density of about 50 n/cm^3 that, even in the preliminary stage, appeared to be close to the UCN density reached at the most powerful UCN source in ILL, Grenoble.

The first experiments to investigate the heating of UCN with velocities in the range 10–200 m/s were conducted with the MANAGR facility created at the ILL reactor in Grenoble in 1995 in collaboration with PINP, Gatchina. The results initiated the modernization of the facility which will be completed by the beginning of the next series of experiments in the second quarter of 1997.

The first experiments of precision verification of the dispersion law of neutron waves in matter by an original technique based on the application of Fabry-Perot interferometers were carried out at the reactor of ILL, Grenoble, by a JINR – RRC KI – ILL – Melbourne University collaboration. The results confirmed the efficiency of the technique and allowed its real

sensitivity to be estimated. After slight modernization of the facility the experiments will be continued in the first half of 1997.

1.3. Applied Research

Applied investigations at the IBR-2 reactor were carried out in the following directions.

Neutron activation analysis. In 1996, on the IBR-2 irradiation channels the investigations of distributions of rare-earth metals and other elements in environmental objects and in new materials were carried out.

The next stage of work in biomonitoring heavy metals and other elements of the industrial and background territories of Romania in the framework of International European project "Heavy Metal Atmospheric Deposition in Northern Europe" has been completed. A map of technogenic effects of heavy industry centers and gas and oil refining industry on the environment in Romania has been presented.

The analysis of the main contaminants in the region of Warsaw and Krakow has been conducted. It was shown that Krakow is highly polluted from the side of the industrial region in Katovice.

In collaboration with foreign ecologists the monitoring of the regions in Norway and Finland has been performed.

Radiation investigations. Radiation-resistant materials for new detectors and the nature of radiation dyeing centers and other local centers have been investigated. Using the liquid epitaxy method the $TlSe$-$TlInSe_2$ (110) heterojunctions were obtained and their physical properties were studied. It was shown that heterojunctions is rather sensitive to γ and n radiation. A new method of intercalation of anisotropic crystals, which hold much promise as a radiation-resistant semiconducting material for radiation detectors, has been developed, and the application for a patent of the Russian Federation for this method has been awarded a favourable decision. The distribution of admixtures of different elements in a number of minerals (topaz, beryl, olivine) has been studied, and their correlation with the dyeing centers has been established. The experimental data on the structure of defect centers in monocrystals of the ZrO_2 - Y_2O_3 system were obtained (carried out in cooperation with the Scientific Department of Condensed Matter Physics, FLNP).

Scientific and methodological developments. The analysis of the usage of beam 11 of the IBR-2 reactor was carried out to increase its methodical potentialities for studying delayed neutrons and registering instantaneous radiation of nuclei (carried out in cooperation with the Scientific Department of Nuclear Physics, FLNP), and to investigate the processes of strengthening of materials (carried out in cooperation with the Scientific Department of Condensed Matter Physics, FLNP).

Neutron diffraction. In 1996, at the HRFD diffractometer the applied investigations mainly connected with the studies of internal stresses in bulky goods, were conducted. In particular, the experiments to measure stresses in tubes which were strengthened by welding a ferrite layer on the austenitic material, were performed. Large dimensions of the tube (148 mm in outer diameter) and the necessity to determine stresses at a depth of up to 30 mm prevented us from using X-ray diffraction. With the help of high resolution neutron diffraction we succeeded in obtaining reliable data which have been supported by theoretical calculations.

2. NEUTRON SOURCES

2.1. The IBR-2 Pulsed Reactor

In 1996, the IBR-2 reactor operated, for physical experiments, for 2133 hours in 8 cycles.

Active core. The heat-generating assemblies (HGA) were partially reloaded to achieve equal fuel burning for the succeeding years of the reactor operation. Seven central HGAs which reached maximum fuel burn-out, were moved to a periphery of the active zone, two HGAs were taken out of the reactor for investigations in a specialized laboratory.

Modernization project. A technical project for the IBR-2 modernization has been developed. "Agreement on realization of the plan for upgrading the IBR-2 reactor in 1996-2005" has been drawn up and approved. Work to manufacture new fuel loading has started. Deficit financing and delays in funding the IBR-2 modernization project (about 25% of the plan) resulted in the suspension of work in all directions of the modernization project.

Cryogenic moderator. In 1996, work to create a regular cryogenic moderator (CM) for the IBR-2 reactor continued. Unfortunately, delays in financing reduced the pace of work and resulted in lagging behind the initial work schedule.

2.2. The IREN Project

The project status. Following the recommendations of the JINR Plenipotentiary Committee (March 1993) the JINR Directorate adopted the decision, approved at the 76th Session of the JINR Scientific Council June 1994), to construct the new modern source of resonance neutrons for investigations in fundamental nuclear physics. The completion date (physical startup date) is the end of 1997 - the beginning of 1998. The IBR-30 analogous scheme, i.e., the combination of a powerful linear electron accelerator and a subcritical multiplying target, was chosen for the new neutron source. The new IREN facility will permit the neutron energy resolution to be increased by an order of magnitude at a double increase in luminosity.

In 1996, because of deficit financing, a considerable delay in fulfilment of the IREN project has to be noted. Nevertheless,

- manufacture of TVELs was started at the MAJAK Industrial Enterprise – the cores have been made and worked with a high degree of precision from metallic plutonium, the VNIINM produced 25% of inserts from tungsten diboride;
- project of the IBR-30 disassembly has been completed for the most part;
- design specification for the LUE-200 equipment complex has been drawn up and agreed to with GSPI;

- progress has been achieved in creating a full-scale stand of the LUE-200 accelerator, – the M-350 modulator created on the basis of the OLIVIN station has been assembled, the first signals from the modulator to a load simulator were obtained (July 1996); further work was suspended because of the shortage of funds on electric energy;

- at the LUE-40 accelerator the elements of the beam diagnostics and thermostatic control systems for the LUE-200 accelerator were tested;

- general scheme of the LUE-200 vacuum system and a full-scale stand has been developed in collaboration with VAKUUM (Prague, Czech Republic); the manufacture of the vacuum equipment for the electron gun and the LUE-200 stand, which is to be shipped to FLNP in February 1997 on account of the Czech dues to JINR, has been agreed to and started;

- in the FLNP Design Bureau the drawings of a draft arrangement of LUE-200 including the first section with a buncher, an intermediate segment and the second section have been elaborated;

- the 6th Session of the Program Advisory Committee on Nuclear Physics recommended to prolong theme 06-4-0993-94/96 till 1999 and to adjust the work schedule of the IREN project to the completion date at the end of 1999.

3. THE FLNP MEASUREMENT AND COMPUTATION COMPLEX

The network and computer infrastructure. In 1996, the main efforts of the FLNP specialists and financial resources in 1996 were directed toward developing the FLNP local computing network (LCN). The network equipment and software to switch over to data-transfer rates of up to 100 Mbit/s in the main LCN segments, and primarily in the segment of the IBR-2 experimental setups, were purchased. Six X-terminals were purchased in addition to the available ones, to significantly increase the efficiency of using the servers and workstations of the SUN-cluster.

Development of electronic equipment. Main works to design, construct and put into operation the VME measuring systems at the NERA-PR, HRFD and NSVR spectrometers, have been performed. At several spectrometers the standard equipment to regulate temperature at the samples under study, was put into operation. The development of the detector electronics and the unified electronics of the data acquisition and accumulation systems for the position-sensitive detectors at the YuMO and DN-2 spectrometers has been completed. At present, the equipment is being constructed and adjusted. Financial difficulties, however, seriously slow down the pace of executing work.

4. SCIENTIFIC RESEARCH PLAN FOR 1997

The 1997 FLNP Scientific Research Plan will contain 5 first priority themes and 1 second priority theme.

Theme	Leader	Priority	Code
Neutron scattering investigations of condensed matter	A.M.Balagurov	1	07-4-0864-89/98
Study of the fundamental properties of neutrons and nuclei	W.I.Furman	1	06-4-0974-92/99
Development and modernization of the IBR-2 complex	V.D.Ananiev, V.L.Aksenov	1	07-4-0851-87/97
Realization of the IREN project	W.I.Furman	1	06-4-0993-94/99
Development of the information and computation infrastructure of FLNP and creation of the new generation of experiment automation systems	V.I.Prikhodko	1	07-4-1012-96/2000
Activation analysis and radiation investigations at IBR-2	V.A.Sarin	2	07-4-0975-92/97

In 1997, in the framework of theme 0864 investigations will be carried out in condensed matter physics in the following directions:

structural investigations in a wide range of external conditions (temperature, pressure, and magnetic field) with four diffractometers at the IBR-2 reactor: HRFD, DN-2, DN-12, and NSVR;

investigations of large-scale inhomogeneities in solid matter and solutions, including biochemical inhomogeneities, by small-angle scattering on the YuMO spectrometer;

investigations with polarized thermal neutrons on the SPN-1 spectrometer in two operation modes: depolarization and reflectometry, to study ferromagnetic and HTSC materials. In 1997, the new reflectometric complex REFLEX will start to operate in the framework of the user policy;

investigations of the atomic and molecular dynamics of matter with the inelastic scattering spectrometers, NERA-PR, KDSOG, and DIN-2;

investigations of thin films and multilayer structures with the spectrometers on ion beams using the RBS, PIXE, and ERD methods.

The following main tasks are to be solved in 1997 in the framework of theme 1012:

creation of the equipment and software of the VME-based data acquisition systems for three IBR-2 spectrometers;

putting into operation the position-sensitive detectors at the YuMO and DN-2 spectrometers;

installation and mastering of the new network equipment, gradual transition to the radial network structure and twisted pair technology;

replacement of a number of SUN2 workstations with SUN20;

updating the electronic component base and switching over to the surface mounting technology;

current modernization and maintenance of the measuring systems of the spectrometers.

Applied research using instrumental neutron activation analysis, radiation action, and other nuclear physics methods will be continued.

The main task of the IBR-2 reactor personnel will be to ensure the realization of the physical research program on 12 neutron beams of the reactor and execute the reactor maintenance plan in correspondence with the requirements of the State Atomic Inspection (GOSATOMNADZOR). In the frame of theme 0851 the realization of the project for the IBR-2 modernization will be continued. Design and construction works to modernize the IBR-2 reactor are scheduled to be continued next year; the technical project for modernization will be drawn up. Work to manufacture the new fuel loading in accordance with the contract 400/498 is also to be continued. The cryogenic moderator is to be put into operation.

In 1997, the main task of the direction "Neutron nuclear physics" will be the realization of the IREN project:

approval of the work schedule of the IREN project adjusted to the completion date at the end of 1999;

completion of the manufacturing and licensing of TVELs;

development of the working drawings and the technical substantiation for the safety and reliability of the multiplying target;

continuation of the manufacturing of the main systems of the LUE-200 accelerator and the completion of the creation of a full-scale stand;

development and construction of the auxiliary systems of the IREN facility;

The IBR-30+LUE-40 will be used as a working stand to adjust, model and test the IREN systems. Because of the changes in the schedule and the postponement of dismantling IBR-30 to the middle of 1998 in accordance with the corrected work schedule of the IREN project, as well as in view of the fact that the State Atomic Inspection of the Russian Federation has given permission to operate the IBR-30+LUE-40 facility till the end of 1997, it appears to be reasonable and advisable to realize a number of points of the research program in neutron nuclear physics (theme 0974) approved by the 79th Session of the JINR Scientific Council for 1996-1998, concurrently with the tests of the IREN systems. In particular, for 1997 it is scheduled:

to continue the development of the UGRA installation and to obtain the first results in neutron polarizability;

to complete the complex program for investigating the fission of ^{235}U induced by resonance neutrons;

to continue the program for investigating the phase transition in excited nuclei by the $(n, 2\gamma)$ reaction method, and to obtain data for astrophysics;

to start work aimed at creating the installations to study time invariance violation in interactions of neutrons with nuclei for experiments at IREN;

to continue the research program with UCNs at the BIGR (Sarov) and ILL (Grenoble) reactors to study the neutron lifetime, the anomaly in the heating of UCN, and the dispersion law of neutron waves in matter.

5. CONFERENCES AND MEETINGS

In 1996, FLNP organized the following meetings:

1. IV International Seminar on Interaction of Neutrons with Nuclei ISINN-4, April 27-30.

2. International Seminar on Relaxor Ferroelectrics, May 21-23.

3. International Seminar "Polarized Neutrons in Condensed Matter Investigations", June 18-20.

4. IV Russian-French Seminar on the Application of Neutron and Synchrotron Radiation for Condensed Matter Investigations, Novosibirsk-Irkutsk, June 24 - July 2.

In 1997, FLNP will organize the following meetings:

1. International Seminar "Structure and Properties of Crystalline Materials" SPCM, March 4-7.

2. V International Seminar on Interaction of Neutrons with Nuclei ISINN-5, May 14-17.

3. National Conference on X-ray, Synchrotron, and Neutron Investigations RSN-97, May 26-29.

4. International Workshop on Data Acquisition Systems for Neutron Experimental Facilities DANEF'97, June 2-4.

5. International Seminar "Neutron Analysis of Textures and Stresses", NTSA, June 23-27.

Received by Publishing Department
on December 18, 1996.