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**SCIENTIFIC PROGRAMME
OF THE FRANK LABORATORY
OF NEUTRON PHYSICS:**

Report for 2006 and Prospects for 2007

Report to the 101st Session
of the JINR Scientific Council,
January 18–19, 2007

Dubna 2006

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БИБЛИОТЕКА

INTRODUCTION

In 2006, the FLNP scientific program was realized under five research themes of the JINR Plan for Scientific Research and International Scientific and Technical Cooperation (PSRISTC) and it was aimed at obtaining new results in condensed matter physics (theme 07-4-1031-99/2008 "Neutron Investigations of Structure and Dynamics of Condensed Matter", headed by V.L.Aksenov and A.M.Balagurov) and neutron nuclear physics (theme 06-4-1036-2001/2007 "Nuclear Physics with Neutrons – Fundamental and Applied Investigations", headed by V.N.Shvetsov and Yu.N.Kopatch). To effect scientific research, work to develop, modernize, and construct the FLNP basic facilities, IBR-2 (theme 07-4-0851-87/2007 "Upgrade of the IBR-2 Complex", headed by V.D.Ananiev and E.P.Shabalin) and IREN (theme 06-4-0993-94/2006 "IREN Project", headed by V.N.Shvetsov, I.N.Meshkov and V.G.Pyataev) as well as the IBR-2 spectrometry and computation complex (theme 07-4-1052-2004/2008 "Development and Creation of Elements of Neutron Spectrometers for Condensed Matter Investigations", headed by A.V.Belushkin and V.I.Prikhodko) continued. Also, FLNP took part in the JINR themes: «ATLAS. General-Purpose pp Experiment at CERN's Large Hadron Collider» (theme 02-0-1007-94/2008, headed by N.A.Russakovich).

This report contains a brief account of 2006 scientific results and outlines the 2007 year plans of the Laboratory reflected in the JINR Plan for Scientific Research (PSRISTC) submitted for approval to the present session of the JINR Scientific Council. The FLNP annual report for 2006 will give a more detail account of 2006 results.

1. 2006 SCIENTIFIC RESULTS

1.1. Condensed Matter Physics

In addition to the complex manganese oxides (manganites), whose main peculiarity is the effect of colossal magnetoresistance, growing interest is being shown in the complex cobalt oxides (cobaltites) of the $\text{Ln}_{1-x}\text{M}_x\text{CoO}_3$ type, where Ln – lanthanide, M – alkaline-earth element. From the scientific point of view, cobaltites are interesting due to strong correlations between lattice, charge, spin and orbital degrees of freedom. Cobalt oxides are important in practice since they are used as electrodes in current power supplies. The peculiarities of phase transitions in cobaltites are connected with the imbalance between the intra-atomic Hund energy and the energy of crystal field corresponding to the configuration of octahedrons of CoO_6 . As a result, the Co^{3+} ion may be in three different spin states: low-spin (LS, $t_{2g}^6 e_g^0$), intermediate (IS, $t_{2g}^5 e_g^1$) and high-spin (HS, $t_{2g}^4 e_g^2$) state.

At the IBR-2 reactor the investigations of atomic and magnetic structure of cobaltites are carried out (including experiments at high external pressures). At the HRFD diffractometer the composition of $\text{Pr}_{0.5}\text{Sr}_{0.5}\text{CoO}_3$ has been studied, in which

several magneto-structural phase transitions had been observed earlier. The diffraction spectra have been measured in a wide range of temperatures (10 – 780 K) mainly in the mode of sample heating. In this range two phase transitions ($T_1 \approx 120$ K and $T_2 \approx 300$ K) have been detected, in the course of which magnetic and crystalline structures of the sample change. On heating the symmetry sequentially varies from triclinic to rhombic and then to rhombohedral one. The transitions are greatly spread over temperature, and between 120 K and 300 K the phases coexist. The magnetic measurements confirm that the structural transition at 300 K coincides with the Curie ferromagnetic point. The nature of the magnetic transition at 120 K remains unknown so far.

At the DN-12 diffractometer the investigation of the crystalline and magnetic structure of hexagonal frustrated manganites RMnO_3 ($\text{R}=\text{Y}, \text{Lu}$) has been performed at high pressures of up to 6 GPa. The obtained experimental data, along with the results of the previous investigations of other hexagonal manganites, have made it possible to relate the symmetry of triangular AFM state with the parameter of distortion of triangular lattice s formed by Mn and O atoms. The obtained generalized magnetic phase diagram allows one to explain the observed changes of the symmetry of magnetic state at chemical substitution (change in the ion radius R of the element) and application of high pressure due to variation of s .

In the framework of structural investigations of the factors influencing the stabilization of ferrofluids a planned study of the effect of surfactant excess in ferrofluids on their stability has started. As the first system the classical ferrofluid based on magnetite dispersed into benzene and covered by a single layer of oleic acid has been chosen. It is known that this system shows the most stability if the whole surfactant is adsorbed on the magnetite surface, i.e. in the absence of free surfactants in solution. In this connection, the solutions of oleic acid ($\text{C}_{17}\text{H}_{33}\text{COOH}$) in deuterated benzene (C_6D_6) have been studied by small-angle neutron scattering. The aim of the study has been to determine the character of interaction between molecules of the acid, and also to clarify the possibility of their clusterization. On the whole, scattering curves in the Guinier approximation point to the repulsion between the surfactant molecules. However, the value of the second virial coefficient $B = -0.02$ determined from these data is significantly larger than that for the system of hard spheres ($B = -8$). This suggests that the attraction component is essential in the pair potential of interaction between molecules. The volume of molecule of oleic acid, 657 \AA^3 , determined from the SANS data differs considerably from its Van der Waals volume, 523 \AA^3 , and, at the same time, practically coincides with the specific volume of the pure oleic acid in its liquid state. In order to clarify the given observation the simulation of the studied system by molecular dynamics methods has started.

At the REMUR spectrometer the investigation of the magnetic ordering and domain structure in the layers $20 \times [\text{Fe}(1.993\text{nm})/\text{Cr}(1.2\text{nm})/\text{MgO}]$ has been carried out. In this structure the magnetizations of neighboring iron layers are directed antiparallel. In the plane of layers there exist domains, which are also ordered antiferromagnetically. The type of interlayer ordering depends on the thickness of chromium layer. It has been proposed to change the thickness of chromium layer by pressing and stretching it using a

sound wave of megahertz range. The effects of change in diffused neutron scattering from the domain structure and of occurrence of inelastic neutron scattering due to the onset of oscillations of the magnetic moments of layers have been observed in reflectometric experiments with polarized neutrons. The dependence of polarization ability on the Q_x component of momentum transfer (along the neutron beam) has been determined at various values of the sound frequency $f_0 = 50$ MHz and $3f_0 = 150$ MHz. It has been shown that it is possible to control the magnetic structure of the antiferromagnetic-ordered structure $20 \times [\text{Fe}(1.993\text{nm})/\text{Cr}(1.2\text{nm})/\text{MgO}]$ by changing the level or frequency of the sound wave. This opens a new possibility to control the magnetic structure, which is characterized by a high speed of response.

At the DN-2 diffractometer the decay of hydrated clathrate with deuterium (composition $32\text{D}_2:136\text{D}_2\text{O}$) has been studied at heating up to 250 K with the fixation of stages of its decomposition. Short-term (15 min) heating of the sample with the subsequent hardening down to the temperature of liquid nitrogen (95 K) has made it possible to carry out a graded removal of hydrogen from clathrate pores at the same conditions of long-term survey to study interaction of the matrix with the molecules of interstitial deuterium. It turned out that the lattice parameter under these conditions does not depend on the deuterium concentration, i.e. no signs of increase of its interaction with the lattice have been shown. In order to solve the question on the nature of deuterium extraction, the intensities of individual reflexes have been analyzed. Thus, the compositions of hydrides at annealing have been determined graphically by imposing the column of experimental intensities on the calculated raster. The calculation of initial scattering by the Rietveld method gave the best agreement at the concentration of 32 molecules of D_2 per cell, where 16 molecules are in a large pore (8b, 2 mol. each) and 16 molecules – in a small pore (16c, 1 mol. each). After a short-term (15 min) heating up to the temperature of 145 K changes in the clathrate structure are minimal. Gradual removal of hydrogen is possible up to the temperature of 195 K, when the growth of impurity phase of ice starts and the composition reaches the minimal value $x = 16_{8b} + 16 \cdot 0.7_{16c} = 27.2 \pm 0.5\text{D}_2$. After the warming up to 220 K the clathrate decomposition is observed and along with the intensive lines of crystalline phases of ice (1h, 1c) with a noticeable portion of amorphous ice of low density.

Complex investigations of physical properties of the synthetic single-crystal quartz and quartz powder in the temperature range of α - β transition have been conducted by neutron diffraction and mechanical spectroscopy. The crystal structure of quartz powders with various average sizes of grains has been determined in the temperature interval up to 620°C and at a temperature of α - β phase transition. Temperature dependences of the value of internal friction and resonance frequency in quartz samples have been obtained in the vicinity of the phase transition temperature at the excitation of oscillations in the planes parallel and perpendicular to the Z axis of quartz. Different values of temperatures of the points of maximum of internal friction lying in the interval of 560 - 620°C have been registered. Possible reasons for the displacement of transition temperature have been suggested. The maximum of internal friction, which is not related to the structural transformations in quartz, has been

revealed in the vicinity of 350°C. The aim of further studies – search for the reasons for the displacement of the point of phase α - β transition in quartz and the nature of the peak of internal friction at 350°C.

At the inverted geometry spectrometer NERA the vibration spectra of hexane isomers have been studied accompanied by the calculations in the framework of the DFT method. Inelastic scattering spectra have been measured for the isomers: 2- or 3-methyl-pentane and 2,2- or 2,3-dimethyl-butane with a general formula C_6H_{14} . Simultaneously, the diffraction spectra of these samples were measured, which allowed us to control the structure of solid phases. DFT calculations of the structure and dynamics of molecules of the studied isomers have been made for the interpretation of a low-frequency part of the internal vibration spectrum, which is clearly seen in the experimental spectra measured at a low temperature. Special interest in these calculations has been related to the fact that the inelastic scattering spectra of diisopropyl measured in the glassy and crystalline phases differ from each other. The comparison of the calculated and measured spectra shows that internal vibrations in the orientation glass state corresponds to the vibrations in a *gauche*-form of a molecule. This implies low potential barriers for internal rotations of molecular groups $CH(CH_3)_2$, which has also been confirmed by the DFT calculations.

At the DIN-2PI spectrometer the investigation of atomic dynamics in superionic and non-superionic phases of AgCuSe has been carried out for the first time using the slow neutron scattering technique. The analysis of the dynamic structural factor $S(Q, \omega)$ points to the presence of low-energy modes in the energy region of 3-4 MeV in the ordered state of AgCuSe, which presumably correspond to the acoustic phonon modes. A correlation has been established between the transition of AgCuSe into the superionic state and the changes in the dynamics of crystalline lattice, which lies in the abrupt change of spectra of the dynamic structural factor, generalized density of phonon states, thermodynamic properties. An increase in thermal oscillation amplitude, a change in heat capacity at the transition into the superionic state are indicative of a considerable softening of the phonon spectrum in α -AgCuSe. The phonon state density $G(\epsilon)$ in α - and β -AgCuSe is characterized by the non-Debye behavior in the small energy region and by two clearly defined maxima at $\epsilon \sim 10$ and 20 meV. The reason for deviation $G(\epsilon)$ from the Debye dependence is the presence of mode of low-energy excitations. At the transition from β to α phase the smearing of maxima is observed at $\epsilon \sim 10$ and 20 meV, as a result of the change of many factors in the atomic dynamics of the studied system.

1.2. Neutron Nuclear Physics

In 2006 the FLNP investigation program in neutron nuclear physics included traditional directions of fundamental and applied research carried out on the IBR-2 and EG-5 beams and in collaboration with nuclear centers in Russia, Bulgaria, Poland, Czechia, Germany, Republic of Korea, France, USA, and Japan.

Study of fundamental properties of the neutron

In 2006 the manufacturing of the full-scale facility to measure the cross section of neutron-neutron scattering on the YAGUAR reactor was completed. The facility was successfully tested and delivered to Snezhinsk, mounted and positioned at the YAGUAR reactor.

In order to check the working capacity of all systems of the facility under conditions of real measurements at the reactor and as well as to check the reliability of the obtained results, first calibration measurements on rare gases with the well-known cross-sections have been carried out. As a result of the measurements we managed to show that the main systems of the facility operated normally, the channel was adjusted correctly and when there was no detector overload, the data acquisition system also operated correctly. The measured cross-section of thermal neutron scattering by ^4He conducted at a constant reactor power was 0.87 ± 0.13 barn (tabulated value of this cross section – 0.760 barn). However, during the measurements in a pulsed mode it was found that the detector was subjected to overloads due to a high level of γ -background from the reactor. The works to modernize the electronics of the data acquisition system and the protection system of the detector aimed at decreasing the recovery time in case of overloads are under way.

On the UCN source in ILL (Grenoble) the experiment to measure the gravitational acceleration of the neutron has been carried out. In the experiment a change of neutron gravitational energy $mg\Delta H$ has been compared with the energy transmitted to the

neutron by means of quantum at the diffraction on the moving grating $2\pi\hbar \frac{\varphi}{\Omega}$, where φ

- angular period of the grating, and Ω - its angular velocity. The experiment has been conducted using the UCN gravitational spectrometer with the Fabry-Perot interferometer. Now processing of the experimental data is under way. The preliminary result is that within the accuracy on the order of 0.2% the gravitational acceleration of a neutron is the same as for macroscopic bodies.

The data of an experiment to observe a change of the neutron energy at passing through an accelerated matter have been processed. Existence of the effect follows from the validity of the equivalence principle and detailed neutron-optical calculations. A change of the neutron energy recorded in the experiment has been on the order of 2×10^{-10} eV. Simultaneously, the sample – silicon wafer, was moving with alternating acceleration reaching the value of 7.5g. The corresponding change of neutron energy has been recorded by the UCN spectrometer with interference filters in phase with the sample motion. The obtained results undoubtedly testify to the existence of this effect observed in an experiment for the first time. Value of the effect corresponds to the theoretical predictions with the accuracy on the order of 15%. It has been realized that although the effect of accelerated matter had been observed only in the neutron-optical experiment so far, it is of quite universal nature and should also exist for particles of different nature.

A new method of obtaining the experimental value of neutron-electron scattering length b_{ne} from the data on structural factors $S(q)$ (q - transmitted wave number), describing the neutron diffraction in gases and liquids, has been applied for the results of diffraction experiments at the reactor in Grenoble by the international group of physicists. The $S(q)$ processing for gaseous isotope ^{36}Ar , whose relative contribution of the n,e-scattering to the total scattering is approximately by an order less than in natural Ar, Kr and Xe, has showed a quite modest result but has displayed effectiveness of the proposed method: $b_{ne} = -(1.33 \pm 0.28 \pm 0.57) \cdot 10^{-3}$ Fm, where the second error is systematic. The data processing of liquid Kr diffraction has given much better result. Three different variants of the data processing have resulted in very close values of b_{ne} , the most accurate of them is $b_{ne} = -(1.38 \pm 0.04) \cdot 10^{-3}$ Fm.

Investigation of violations of fundamental symmetries in neutron-nuclear interactions

An experiment aimed at verification of the effectiveness of control of the polarization of thermal and epithermal neutrons using the radio-frequency field has been carried out. The experiment has been conducted on beam H8 of the KENS pulsed neutron source (KEK, Japan). The polarization of neutrons and analysis of their polarization have been carried out by devices on the basis of polarized ^3He with optical pumping created by the KEK-FLNP JINR collaboration in 2003-2005. Results of the experiment are in good line with the calculations and have showed high effectiveness of the proposed method. The developed technique will be used to control the neutron polarization in the experiment to verify T-invariance in interaction of polarized neutrons with polarized nuclei. The experiment is planned to be carried out on the JSNS source under construction.

On beam PF1B of cold polarized neutrons of the ILL reactor (Grenoble) a «zero» experiment has been performed to determine the background asymmetry for a series of experiment to measure P-odd asymmetry of triton emission in the reaction $^6\text{Li}(n,\alpha)^3\text{H}$. The value of $\alpha_0 = (0.0 \pm 0.5) \cdot 10^{-8}$ has been obtained. Comparison of this result with the result of the main experiment: $\alpha = -(8.6 \pm 2.0) \cdot 10^{-8}$ shows that the observed effect is caused by P-odd asymmetry of tritons from the reaction $^6\text{Li}(n,\alpha)^3\text{H}$. The aim of investigations is to determine the weak π -meson coupling constant f_π corresponding to the interaction of neutral currents in nucleon-nucleon processes. The restrictions: $f_\pi = (0.4 \pm 0.4) \cdot 10^{-7}$ follow from the obtained asymmetry on the assumption that other constants are equal to the Desplanques «best values», etc., and $-1.2 \cdot 10^{-7} \leq f_\pi \leq 1.6 \cdot 10^{-7}$ taking into account theoretical and experimental uncertainties of other constants. This confirms the results of the experiment on ^{18}F and the conclusion that f_π is significantly smaller than the Desplanques «best value», etc., ($4.6 \cdot 10^{-7}$). The works are carried out in common with PNPI (Gatchina), ILL (Grenoble, France), TU of Munich (Germany).

At the EG-5 accelerator, FLNP, experiments to measure angular correlations in the reaction $^{14}\text{N}(n,p)^{14}\text{C}$ in the region of neutron energies up to 1 MeV are carried out. The

aim of the studies is to determine partial neutron and proton resonance widths for spins of the channels $j = 1/2$ and $3/2$ and using these data to estimate the weak matrix element from the results of polarization experiments obtained earlier. By now, preliminary values of the forward-backward correlation are obtained for 10 values of the energies of quasihomoeenergetic neutrons in the studied region.

Experiments to search for the negative neutron p-resonance in the lead isotope continued. Two series of measurements with samples enriched by Pb-207 and Pb-204 isotopes were carried out.

Investigations of fission physics and other nuclear reactions

On the IBR-2 reactor within the FLNP-FLNR collaboration a series of measurements of the mass-energy distributions of ^{235}U fission fragments under the action of thermal neutrons is carried out using the «Mini-Fobos» facility. In the study a search for events, in which the nucleus decays into three fragments comparable in mass, is performed. At present, the statistics on the order of $3 \cdot 10^6$ events is accumulated, which is comparable with a similar experiment conducted on the spontaneous fission source ^{252}Cf , where certain indications on the existence of such effects have been observed. First results are expected at the beginning of 2007.

Within the collaboration Jyväskylä-Darmstadt-Dubna-Gatchina in JYFL (Finland) a series of experiments to study fission using two mosaics of semiconductor detectors has been carried out. In the first experiment angular and mass-energy correlations of fission fragments in the reaction $^{238}\text{U} + ^4\text{He}$ (40 MeV) have been investigated. Angular resolution of the facility has made it possible to conduct a direct search for the events of triple collinear decay. Preliminary analysis of the obtained data have not revealed such events. A series of other effects, which point indirectly to the existence of exotic fission mode, has been discovered. In the second experiment a precision measurement of energy distributions of α -particles and nuclei of ^6He emitted in the process of the ^{252}Cf triple spontaneous fission has been carried out. A significant deviation of spectra from the Gaussian form in the low-energy region has been observed.

In the framework of the program to study mechanisms of nuclear reactions and to obtain data for nuclear power engineering on the EG-4.5 accelerator of the Institute of Heavy Ion Physics, Peking University, China, investigations of the reaction $^{64}\text{Zn}(n,\alpha)^{61}\text{Ni}$ for neutrons with the energies 2.6 and 4.0 MeV have been carried out. Energy spectra and angular distributions of α -particles have been obtained, the data are being processed. Data processing of the previous measurements at $E_n = 5$ and 6 MeV has completed, values of the total and differential cross section of the reaction $^{64}\text{Zn}(n,\alpha)^{61}\text{Ni}$ for these energies have been obtained. The works are performed in common with Peking University (China) and the University of Lodz (Poland).

On channel №11 of the IBR-2 reactor using the «Isomer-M» facility the experiments were carried out, and the data on the delayed neutron yield at fission of the ^{245}Cm isotope by thermal neutrons were obtained.

Applied investigations

In the framework of collaboration with SRI RAS calculations of the angular dependence of effectiveness of the LEND laboratory instrument being a part of the NASA orbital vehicle Lunar Reconnaissance Orbiter 2008 intended to analyze the neutron radiation in the Lunar orbit were performed by specialists from FLNP and LRB. Also, experimental calibrations of the laboratory prototype of the instrument were carried out.

On the EG-5 accelerator the experiments to investigate the properties of GaAs implanted by In ions with the energy 250 keV and the dose $3 \times 10^{16} \text{ cm}^{-2}$ were conducted. Also, optical parameters (n, k) of the GaAs implanted surfaces were investigated using the ellipsometric technique. With the purpose of developing the implantation technology, the mechanism of generation of ions in plasma sources, their extraction and ion beam shaping was investigated. Experiments to study the structure of elements of the electronics were carried out. Using the methods PIXE and RBS experiments to determine concentrations of Ca, Cr, Cu, Fe, Zn and other heavy elements in the enamel of human teeth were conducted, and also experiments to determine concentrations of Fe and Cr in Fe-Cu alloys depending on their working were conducted.

In the framework of international program «Atmospheric depositions of heavy metals (HM) in Europe – assessments based on the analysis of moss-biomonitoring» a large series of studies has completed, which is related to the simultaneous collection of samples in 2005–2006 in a number of regions in Central Russia, Southern Urals, Belarus, Bulgaria, Slovakia, Poland, Romania, Serbia, Macedonia, Croatia and Greece to perform multielement activation analysis at the IBR-2 reactor. Results of the analysis on 13 elements: Al, As, Cd, Cr, Cu, Fe, Hg, Ni, Pb, Sb, Ti, V and Zn will be submitted to the European Atlas of atmospheric depositions of HM. Similar studies have been carried out in Mongolia and Vietnam.

The study to determine chromium in bacterial samples *Arthrobacter oxidans* granted by biochemists from the Institute of Physics of Georgian AS was published in the prestigious journal Analytical Chemistry (USA) in 2006 and was highly evaluated by the IAEA specialists.

An analysis of rubidium-containing compounds used in experiments of the Condensed Matter Department on the X-ray and neutron diffraction was carried out.

2. NEUTRON SOURCES

2.1. The IBR-2 Pulsed Reactor

In the year 2006 the IBR-2 reactor operated for physical experiments for ~ 2022 hours as of 01.12.2006.

The main results of IBR-2 modernization in 2006:

- 1) The main task of the year – manufacturing of fuel assemblies (FA) for the IBR-2M reactor – has been successfully fulfilled. In July the license for manufacturing FA

in JINR was obtained, and on 12.07.2006 the first FA was made in the presence of a special commission. On 16.11.2006 the work was completed: 89 FA were manufactured, which provided an initial charge of the new reactor (63 FA) and burn up margin (~ 40 %). The FLNP specialists have performed the work with a high quality.

2) In JINR EW:

- manufacturing of rolling shielding was completed, its check assembly and tests were carried out;
- control systems of the reactor were manufactured (emergency system, compensating regulators, manual regulator).

3) Safety Control System (SCS) of IBR-2M:

- prototype model of ASCS (SNIIP-SYSTEMATOM) was manufactured and tested at the IBR-2 reactor;
- in SNIIP-SYSTEMATOM the work on standard ASCS (including a new control panel) was started;
- in INEUM the work to develop CM system was continued;
- in JINR EW a prototype model of KO drive was manufactured, work on a prototype model of emergency shutdown system drive is in progress.

4) Moderator complex for IBR-2M.

In December, 2006, the following work is to be completed:

- manufacturing of CHF-700/15 in “Heliymash”;
- detail design of moderators for 3 directions: beams 2-3, beams 4-6, beams 7-11 (NIKIET);
- engineering design of moderators (SSDI);
- detail design of cryogenic pipeline and intermediate heat exchanger (Heliymash);

In FLNP calculations and experimental work on transportation of C_9H_{12} pellets were performed; design documentation on pellet generator was worked out.

- 5) “The program of works at the IBR-2 reactor during temporary shutdown (2007-2010)” as well as the schedule of works on modernization of IBR-2 in this period were developed, agreed upon and approved.

As of 01.12.2006 the expenses on IBR-2 modernization amounted to about 900 k\$ (JINR – 550 k\$, Rusatom – 350 k\$).

Development of the complex of broad spectrum neutron moderators («combi-moderators») for the modernized research reactor IBR-2M

1. The technical project of the complex of neutron moderators for IBR-2M has been worked out.

2. The contract (with SSDI and "Heliymash") on the project of engineering design of the cooling system for cold moderators and the contract with the Barber-Nichols firm on the supply of helium coolant circulator have been signed.
3. The project of tracing of helium tubes has been fulfilled.
4. The calculations of spectral characteristics of neutron beams have been completed, taking into account the real geometry of the moderators determined by the technical project.
5. The experiments to obtain spectra of cold neutrons from the moderator composed of a mixture of mesitylene and m-xylene in the temperature range from 10 K to 50 K have been conducted. The results of preliminary processing have been obtained.
6. The experiments to transport pellets in a gas flow both in a straight tube and in smooth bends of the tube in the range of gas rate of 5 – 12 m/s, as well as the experiments to fill the pellets into a prototype of the moderator chamber have been completed.
7. The work on mathematical computer simulation of gas-dynamic forces and pulses influencing a pellet moving in the tube has been performed; resistance coefficients as functions of the pellet and gas rate have been obtained.
8. The concept has been experimentally substantiated and the engineering documentation has been worked out in order to manufacture a "pilot" copy of a device for the dosed feed of pellets.
9. The manufacturing of a "pilot" copy of the device for mass production of solid pellets of the mixture of mesitylene and m-xylene has been started.

In 2006 the research and design works, which are necessary to issue the working documentation of the whole moderator complex and its technological part were completed.

2.2. The IREN Project

The main tasks of the Frank Laboratory of Neutron Physics and the Laboratory of Particle Physics in 2006 were the completion of disassembling of the IBR-30 reactor and assembling of the available equipment of the first stage of the LUE-200 linac.

Decommissioning of IBR-30

In accordance with the approved working schedule of the decommissioning the following works were carried out:

- «The report on the estimation of condition of the nuclear and radiation safety of the Research Pulsed Reactor IBR-30 in 2005» was prepared and submitted to the Rostehnadzor of RF.
- All the equipment from the reactor hall except for beam shutters, which will be used for the first stage of IREN, was dismantled and moved to building 117/b.
- All rooms of building 43 adjacent to the reactor hall were cleared.
- The inspection and repair of the entrance into the reactor hall were performed.

- The decontamination and preparation to the repair of the reactor hall were carried out.

Works on the LUE-200 linac

- The theoretical substantiation of a possibility to obtain the necessary parameters of the electron beam at the first stage of the linac completed.
- The MK1 klystron modulator was dismounted at the regular place and adjusted.
- The modulator was mounted at the regular place and also the pulsed transformer for the electron gun.
- Test assembling of the SHF path of the first section was carried out.
- Power frame of the vacuum pump system of the LUE-200 first section was completed. The test assembling was carried out.
- Test assembling and certification of the buncher coil were carried out.
- In building 43 mounting of the focusing solenoid of the first accelerating section was performed with geodetic tie.
- The electron gun was mounted at the regular place.
- By the end of the year pipeline laying-out of the water supply for the system of water-cooling and thermostabilization of LUE-200 will be completed.

3. DEVELOPMENT AND CREATION OF ELEMENTS OF NEUTRON SPECTROMETERS FOR CONDENSED MATTER INVESTIGATIONS

In 2006 work in the framework of the theme was focused on the following main activities:

- Creation of gas and scintillation neutron detectors;
- development of sample environment systems;
- development of data acquisition systems and computing infrastructure.

Creation of neutron detectors

a) Gas detectors

In 2006 1-D position-sensitive detector based on multiwire proportional chamber was put into operation at the HRFD diffractometer. The software for acquisition and accumulation of data from this detector is integrated into the control software package Sonix.

A similar detector system was constructed for the REFLEX spectrometer. The detector was tested on a test bench with a ^{252}Cf source and on beam 9. At present, it is used in current measurements.

Using the same technology, 2D PSD with a sensitive area of $225 \times 225 \text{ mm}^2$ was developed. On the basis of experience gained in the process of development and tests of

1D PSD and 2D monitor, the following characteristics of 2D detector (Table 1) were specified:

Table 1

Gas mixture	2000 mbar He ³ +2000mbar CF ₄
Efficiency	60%
Sensitive area	225×225 mm ²
Coordinate resolution X,Y	2-3 mm
Count rate	Up to 10 ⁶ events/s
Differential nonlinearity	<10%
Readout	Delay lines, start from anode

The design and engineering documentation of the detector case, anode and cathode electrodes was worked out. All mechanical units were manufactured in JINR EW.

The detector is a multiwire proportional chamber with delay line data readout. Overall dimensions of the chamber are 342×342×54 mm, the entrance window is 7 mm thick, which only minimally weakens an incident neutron flux and makes it possible to withstand mechanical loads that arise when filling the detector with a gas mixture. To detect neutrons, the internal volume of the chamber is filled with a mixture consisting of neutron gas-converter He³ and quenching gas CF₄. The total pressure of the gas mixture is 4000 mbar. The detector was tested at a pressure of up to 6 atm.

Delay line signals and anode signal through preamplifiers come to a constant fraction timing five-channel discriminator and are registered in data acquisition and accumulation block (DAAB). This block contains signal level converter NIM-TTL, 8-channel integrated time-to-code converter (TDC-GPX) with time resolution of 80 ps and count rate of 10M events/s; programmable logic array (FPGA), containing about 6K of logic elements; 1 Gbyte histogram memory, which makes it possible to accumulate three-dimensional spectra X-Y-TOF of up to 512×512×1024 32-bit words; and high-speed interface with optical communication link to a personal computer. The main distinctive feature of DAAB software as compared to that of PCI DAQ block now in use is that DAAB has no digital signal processor (DSP), which essentially limits data accumulation rate (down to 100K events/s). In the new version of the block the functions of DSP (filtering, histogramming, data formatting, etc.) are performed by FPGA.

Logic and time simulation of block operation was performed using Quartus II package by ALTERA firm. It was shown that the rate of reception, filtering and acquisition of events in the block may amount to 2 million events/s. Real registration rate (taking into account data transfer and recording to a computer) is no less than 1 million events/s. The detector was tested on a test bench.

Electronics and software of the microstrip detector were debugged and its tests were conducted on an IBR-2 beam.

b) Scintillation detectors

The 4-th and 3-rd sections of the FSD diffractometer were designed.

The design of detector system for the DN-6 diffractometer was developed. It has provision for using 2 groups of detectors located in the region of scattering angle of 90° and scattering angle of 45° (laboratory system).

In cooperation with the Institute of Metal Physics RAS (Yekaterinburg) 100-channel scintillation thermal neutron detector for the D7A spectrometer located at the IVV-2M reactor of Sverdlovsk branch of NIKIET was developed, manufactured and put into operation. The detector is constructed on the modular principle, which makes it possible to arrange channel sensitive areas on a cylindrical surface of arbitrary radius. The channel sensitive volume is a multilayer composition of plates of scintillation screen ND and spectrum-shifting fibers. Dimensions of entrance aperture of channel sensitive area are $S = 3 \times 120$ mm. Average detection efficiency in channels for neutrons with a wavelength of $\lambda = 1.53$ Å is $\eta = 70$ %. Gamma sensitivity of detector channels does not exceed $\xi \leq 1 \cdot 10^{-7}$. Maximum count rate of a single channel is no less than $\nu \geq 1 \cdot 10^5$ n/s. Each module of the detector is an independent device and contains 10 neutron detection channels, signal processing electronics, high-voltage power supply system and computer communication electronics. Data acquisition from modules, setting of detection parameters and control over modules are carried out via interface CAN.

Development of sample environment systems

In 2006 a device for placing a scatterer into a neutron beam in front of PSD of a spectrometer was included into the structure of control system of spectrometer actuators.

Controller SMC-32-CAN for control systems of spectrometer actuators was developed and tested.

On beam 9 the modernization of the chopper control system was carried out on the basis of direct-current electric drive. More stable amplifiers of the electric drive were included into the structure of the system. The control system software was renewed.

In 2006 a closed-cycle cryostat with cryocooler PT-405 with pulse tubes was manufactured for operation in a temperature range of 8-300K. Its construction allows it to be installed in the shaft of the DN-2 spectrometer. The cryostat was used to obtain spectra of scattered neutrons from mesitylene, which is considered to be the most promising material for cold moderators of the modernized reactor IBR-2M.

Development of data acquisition systems and computing infrastructure

A new central server *Sun Fire X4200* (AMD-64 platform) with the operating system *OS Solaris 2.10* and bulk storage device *Storage Array* (6.4 T byte) were put into

service. The replacement of the basic server of the FLNP computer cluster (*Enterprise 3000*) by the modern system on the basis of AMD Opteron 64 and the use of bulk storage device made it possible to significantly enhance computing power of the cluster and to increase the shared disk space. At present, the former central server is used for work with applications written for the old operating system.

The first stage of work to create a new architecture of the FLNP computer cluster and to optimize network communication lines was fulfilled. A change-over of the available switches of the central network core to routing switches Cisco 3750, the installation of 1Gbit/s interface to switch Cisco 8510 CSR and the application of high-speed communication in the main FLNP LAN links made it possible to enhance the reliability of network operation and to provide connection with the JINR network and other networks at Gigabit rates. Reorganization of the FLNP Web server was carried as well.

A large amount of work to design and manufacture electronic blocks of data acquisition systems, as well as to develop and support control software package Sonix + for IBR-2 spectrometers was carried out.

Electronic and software support was constantly provided during the IBR-2 reactor cycles.

4. SCIENTIFIC RESEARCH PLAN FOR 2007

The 2007 FLNP Scientific Research Plan contains 5 first priority themes.

Theme	Leader	Priority	Code
Neutron investigations of the structure and dynamics of condensed matter	V.L.Aksenov A.M.Balagurov	1	07-4-1031-99/2008
Nuclear physics with neutrons - fundamental and applied investigations	Yu.N.Kopatch V.N.Shvetsov	1	06-4-1036-01/2007
Upgrading of the IBR-2 complex	A.V.Belushkin A.V.Vinogradov	1	07-4-0851-87/2007
Construction of the IREN facility (Project IREN)	V.N.Shvetsov V.G.Pyataev	1	06-4-0993-94/2007
Development and creation of elements of neutron spectrometers for condensed matter investigations	A.V.Belushkin V.I.Prikhodko	1	07-4-1052-04/2008

In 2007 in the framework of theme 1031 the investigations in condensed matter will be carried out in the following directions:

Obtaining of new data on equilibrium magnetostructural inhomogeneous states in transition metal oxides.

Obtaining of new data on atomic and magnetic structures of strongly correlated electron systems - complex oxides of manganese, cobalt, etc.

Study of changes in atomic and magnetic structures of complex magneticoxides under high external pressures.

Investigations of large-scale structure of noncrystalline materials: vesicles, polymers, colloidal solutions, etc.

Obtaining of new data on properties of complex surfaces and nanostructures with reduced dimensionality.

Study of relation of texture and properties of rocks.

The following research program will be realized in the framework of theme 1036:

Carrying out of the first in the world experiment on direct measurement of n,n -scattering length at the JAGUAR reactor, Snezhinsk. Start of measurements.

Start of measurements of n,e -scattering length b_{ne} at the neutron source in Troitsk.

Experimental verification of equivalence principle for the neutron.

Preparation of the first in the world experiment to search for neutron-mirror-neutron oscillations.

The following main problems are to be solved in the year 2007 in the framework of theme 1052:

Design of neutron position-sensitive detector based on multi-wire proportional chamber with individual data readout from each wire (design and manufacturing of the detector case and electrodes, design of readout electronics and data acquisition electronics, purchase of materials and components).

Design and manufacturing (in cooperation with INRNE BAS, Sofia) of elements of bent position-sensitive X-ray detector.

Creation of module scintillation detector on the basis of matrix photomultipliers (development of the detector design, design of data accumulation electronics, measurement of characteristics of the assembly – matrix photomultiplier + scintillation screen).

Manufacturing of 8 modules of the ASTRA detector for the FSD diffractometer.

Creation (in cooperation with Germany institutes) of bent reflector neutron guide on beam 7a of the IBR-2 reactor (calculations and selection of a variant of optical channel, design, purchase of materials, manufacturing of optical elements and mechanical constructions of the head part of the neutron guide).

Modeling, manufacturing and testing of electronic blocks for multicounter systems and PSD with delay lines.

Creation of cable infrastructure of the network segment of the IBR-2 experimental halls (Gigabit Ethernet).

Development of control block of actuating mechanisms for the IBR-2 spectrometers on the basis of industrial standard CAN.

Modernization and support of infrastructure of engineer and programmer workplaces.

Creation of vacuum test bench to improve "cryogen free" technology for the IBR-2M spectrometers.

Development of the Sonix+ software package for remote control over experiments.

The following main tasks are to be accomplished in the year 2007 in the framework of theme **0851**:

Defueling of the IBR-2 reactor.

Research and development work to modernize the IBR-2 reactor (manufacturing of reactor vessel and stationary reflectors).

Design and manufacturing of the IBR-2M safety control system (SCS).

Dismantling of the equipment being replaced.

Working out of design documentation for the IBR-2M cryogenic moderators complex and manufacturing of cryogenic equipment.

The following main problems are to be solved in the year 2007 in the framework of theme **0993**:

All the works planned for 2007 are in the framework of the approved budget of theme 0993:

Completion of working drafts of power supply, water supply and automated radiation control (ARC) for LUE-200.

Development of the project documentation for the non-multiplying target.

Manufacturing and mounting of the non-multiplying target.

Complete equipment and mounting of the power supply system, water supply one and ARC.

Completion of repair of the room for the main control panel (MCP) and rooms 204-209, 306 of building 43.

Repair of the hall for the non-multiplying target.

Mounting of equipment for the automated monitoring and control system (AMCS) including MCP.

Completion of mounting of the LUE-200 equipment: 1-st accelerating section, klystron 5045 (SLAC), SHF-feeder, intermediate areas with beam diagnostics devices, simulator of the 2-nd section, quadrupoles, transport channel, vacuum system, power supply system for electromagnets of the focusing system, magnetic spectrometer.

Start-and-adjustment work, testing of the linac equipment.

Complex start-up of the linac.

5. CONFERENCES AND MEETINGS

In 2006, FLNP organized the following meetings:

1. *XIV International Seminar on Interaction of Neutrons with Nuclei ISINN-14, Dubna, May 24-27.*
2. *V Workshop on Investigations at the IBR-2 Pulsed Reactor, Dubna, June 15-17.*
3. *Crystallography at High Pressures, Dubna, September 28 – October 1.*
4. *International Small-Angle Scattering Workshop, Dubna, October 5-8.*

In the year 2007, FLNP will organize the following meetings:

1. *XV International Seminar on Interaction of Neutrons with Nuclei ISINN-15, Dubna. May 16-19.*