FRANK LABORATORY OF NEUTRON PHYSICS

In 2007, 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 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 06-4-1036-2001/2010 «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 07-4-0851-87/2010 «Upgrade of the IBR-2 Complex», headed by A. V. Belushkin and A. V. Vinogradov) and IREN (theme 06-4-0993-94/2008 «IREN Project», headed by V. N. Shvetsov and V. G. Pyataev) as well as the IBR-2 spectrometry and computation complex (theme 07-4-1052-2004/2008 «Development and Construction 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 theme: «ATLAS. General-Purpose pp Experiment at CERN's Large Hadron Collider» (theme 02-0-1007-94/2008, headed by N. A. Russakovich).

The topical problems of investigations carried out in cooperation with the leading nuclear centers were considered at the XV International Seminar on Interaction of Neutrons with Nuclei, the Meeting of the Forum on Cooperation of Regulatory Bodies and Updating Nuclear and Radiation Safety at Research Nuclear Facilities. The participation of FLNP scientists in specific international projects was discussed at the 20th Task Force Meeting of the UNECE ICP Vegetation and Workshop of European Society for New Methods in Agricultural Research (ESNA). New steps in implementation of quality assurance and quality control systems in FLNP were performed during the IAEA TC 1st Workshop «Harmonization of QA/QC Systems According to ISO and International Standards in Nuclear Analytical Laboratories of the Russian Federation». The 2nd Joint Seminar-School JINR–Romania on Neutron Physics for Investigations of Nuclei, Condensed Matter and Life Sciences offered to young scientists from Romania and JINR the possibility to acquaint with applied and theoretical neutron physics, to find out more information about the JINR activities and to create contacts for future collaborations.

CONDENSED MATTER PHYSICS

In view of the IBR-2 reactor shutdown for the next stage of reconstruction, the tasks of the department personnel and work plans under the theme in 2007 differed noticeably from the traditional program of activities. Namely, the scientific activity was transferred to the allied centers in Russia and abroad, and the work on IBR-2 was focused on the realization of the program of modernization of the spectrometers.

Main Scientific Results. The crystal and magnetic structures of the $(La_{1-y}Pr_y)_{0.7}Ca_{0.3}MnO_3$ compounds have been studied as a function of $y = 0.2-1$ across the metal-insulator transition, and of the oxygen mass of ^{16}O and ^{18}O. The quantitative characteristics of the effect of the polaronic narrowing of the bandwidth and the crystal lattice microstrains on the volume fraction of the mesoscopic ferromagnetic and antiferromagnetic clusters have been obtained. A well-defined dip in the temperature of transition to the ordered magnetic state and the suppression of all the types of long-range magnetic ordering near the metal-insulator transition point at $y = 0.9$ indicate a key role of the chemical disorder in the structure for the formation of the phase-separated state at the mesoscopic scale [1].

Structural changes, spin-state transitions of Co^{3+} ions and metal-insulator transitions in lanthanum cobaltite $LaCoO_3$ have been studied in a wide range of temperatures (10–900 K) and pressures (0–20 GPa) [2]. It has been found that pressure induces sharp suppression of magnetic intermediate-spin state ($S = 1$) and stabilization of nonmagnetic low-spin state ($S = 0$) of Co^{3+} ions. The metal-insulator transition temperature significantly increases under pressure.

The possibility of using short chain length monocarboxylic acids ($C_{12}H_{24}O_2$ and $C_{14}H_{28}O_2$) for stabilization of magnetite nanoparticles in magnetic fluids on the basis of nonpolar organic solvents has been studied [3]. It has been demonstrated that they can be used to obtain highly stable magnetic fluids. The new fluids have been compared with magnetic fluids stabilized by unsaturated oleic acid $C_{18}H_{34}O_2$. Magnetic granulometry and small-angle neutron scattering data reveal a great difference in the size distribution function of stabilized magnetite, particularly a decrease in the mean particle radius and polydispersity index when short chain length acids are used instead of oleic acid. It follows from the comparison of effective thickness and density of acid shells about magnetite that the observed size regulation effect is connected with different acid organization on the magnetite surface.

At the REMUR spectrometer the ferromagnetic-superconducting layered structure V (39 nm)/Fe (3.2 nm)/10 × [V (3.2 nm)/Fe (3.2 nm)] consisting of a superconducting layer of vanadium V (39 nm) and periodic structure 10 × [V(3.2 nm)/Fe(3.2 nm)] has been studied by neutron reflectometry using standing waves of polarized neutrons [4]. For the first time, at the transition of a vanadium layer to the superconducting state, the phenomena of formation of a domain structure in the vicinity of vanadium–iron interface and antiferromagnetic ordering in a periodic structure have been observed. Thus, it has been demonstrated that the magnetic state of nanostructures can be controlled using the superconducting transition. This opens up possibilities of designing principally new logic elements for nanoelectronics, in which the state can be encoded both by the magnetic moment value and the resistance.

The magnetic and magnetotransport properties of composite nanogranulated cobalt-based films have been investigated. In nanocomposite alloys $(Co)_x(SiO2)_{1-x}$ near the percolation threshold a magnetic phase transition with the formation of fractal structures has been detected. The obtained experimental data [5] testify that in nanocomposite granulated systems in the range of the structural percolation threshold the magnetic fractal structures are formed, which, in fact, determine the magnetic properties of composites including magnetoresistance.

Neutron diffraction is an exceptionally powerful method for studying structures of biological and model lipid membranes. In particular, by varying the relative content of light and heavy water, it is possible to reliably determine phases of structural factors. One more favourable point is the possibility to carry out *in-situ* experiments in real time. On the DN-2 diffractometer one can follow changes in the membrane structure in the course of hydration with time resolution at a level of 1 min. In 2007, experimental evidences for the phenomenon of reinforcement of the lipid matrix of the outermost layer of mammalian skin, the stratum corneum (SC) by ceramide 6 molecules were obtained. In a series of neutron diffraction experiments [6] it has been found that the extremely strong intermembrane attraction created by ceramide 6 molecules cannot be destroyed either by long-chain ceramides or long-chain fat acids. The small-angle neutron scattering experiments have shown that the interaction created by ceramide 6 molecules is short-range. The stability of the developed SC membrane to variation of biochemical composition of lipids and water solutions has made it possible to begin experiments to study the substances that can increase the permeability of human skin for drug delivery.

Antibiotic amphotericin B (AmB) widely used in medicine has been studied by small-angle neutron scattering, X-ray diffraction and Fourier spectroscopy. The results of the experiments have shown [7] that AmB is located predominantly in the headgroup region of the membrane at concentrations below 1 mol%. At concentrations above 1 mol% the process of AmB aggregation takes place. The effect of association arises and AmB incorporates into the hydrophobic membrane core.

For the first time the existence of open inner cavities in the effective dendrimer volume accessible to a solvent has been demonstrated [8] and their volume fraction has been estimated. It has been shown that the end groups of a dendrimer are located in its surface layer. The small-angle scattering data have made it possible to determine sizes and to restore the external shape of dendrimers of various generations for three and four functional dendrimers. From a new model of dendrimer structure it follows that its inner sphere is permeable to the solvent, and its density decreases by a factor of at least 2.

Complex investigations [9] into the physical properties of synthetic quartz single crystals and quartz powders in the temperature range of the α–β transition with the use of neutron diffraction and mechanical spectroscopy have been carried out. New data on the behaviour of parameters of a unit cell of quartz powders of two fractions with different average sizes of grains at room temperature and in the temperature range of 540–620 °C, as well as atomic coordinates in a unit cell, have been obtained. It has been found that the lattice parameters of the powders that vary in the size of grains by an order of magnitude, differ significantly. The α–β phase transition temperature of a fine-grained powder is higher than that of a coarse-grained one by ≈ 15 °C (lies in the range of 580–585 °C).

Instrument Developments. In 2007, the reconstruction of the neutron guide system of the SCAT, EPSILON and NERA spectrometers on IBR-2 was started. The work is conducted within the framework of the BMBF project in cooperation with the personnel of the Spectrometers Complex Department. According to the approved requirements specification a sketch design of the mechanical and optical units of the neutron guide system has been made and the tie-in of the available constructions of the neutron guide channels located in the ring corridor and the experimental hall has been carried out with reference to real building constructions.

On channel 10 of IBR-2 the multifunctional reflectometer GRAINS will soon be constructed in place of the available spectrometer KDSOG. A special feature of the reflectometer, a vertical scattering plane, will make it possible to study reflection from liquid media. The reflectometer will operate in the time-of-flight mode, which will allow the experiments to be conducted at fixed orientations of the incident beam and the sample. Additional modes of the GRAINS reflectometer will comprise off-specular reflection and small-angle polarized neutron scattering. In 2007, a detail scheme of the reflectometer was developed and supported by PAC. Model calculations were made.

In the framework of the Protocol on Cooperation with RRC KI the designing of neutron diffractometer for studying internal stresses in bulk samples on the IR-8 reactor has been started. The concept of the diffractometer supposes the use of modern technologies of forming neutron beams and of detecting scattered neutrons. This diffractometer will provide complementary possibilities as to the available stress-diffractometer FSD on IBR-2.

For further development of the experimental base on IBR-2 and within the framework of cooperation with the NECSA Corporation (Republic of South Africa) a contract for the purchase of an automated materials testing machine has been concluded. The machine allows on-line experiments to be performed with a wide set of loading (stationary or cyclic) modes on any type of neutron diffractometers with bulk samples of metals and alloys.

The first test experiments were carried out on a new multidetector neutron diffractometer at the VVR-M reactor (PNPI, Gatchina) and at the MEDIANA station of the SIBIR-2 synchrotron source in RRC KI. In particular, at the MEDIANA station the possibilities to conduct high pressure experiments with sapphire anvil cells and *in-situ* experiments to study hydrogenation processes of electrolytic deposits in electrochemical cells were explored. It was demonstrated that both types of experiments could produce valuable results.

In the spring of 2007, the physical start-up of the energy-dispersive EXAFS-spectroscopy station at SIBIR-2 was performed and the first results were obtained. Its distinctive feature is the possibility to obtain absorption spectra in a very short time — less than 10^{-3} s as compared to classical EXAFS-stations where it takes $\sim 10^3 \div 10^4$ s. This opens up a possibility to investigate dynamic processes proceeding under the action of external factors. The experimental procedure was optimized in the measurements of X-ray absorption spectra (EXAFS-and XANES-regions) at the Co K-edge in $La_{1-x}Sr_xCoO_3$ ($x = 0$ and 0.5) carried out in the Hamburg Synchrotron Radiation Laboratory HASYLAB (DESY).

NEUTRON NUCLEAR PHYSICS

Investigation of Fundamental Properties of the Neutron. The treatment of the results of the experiment on the measurement of the gravitational force $F_g = m_g a$, experienced by a neutron in the Earth's gravitational field (m_g is the gravitational mass of the neutron, and a is its free fall acceleration), has been completed [10]. The experimental technique is based on the application of quantum devices: moving diffraction grating used as a phase modulator of the neutron wave and neutron Fabry–Perot interferometers. The idea of the experiment consists in comparing a change in the kinetic energy of the neutron $\Delta E = m_g a \Delta H$ in free fall from the altitude ΔH with the energy quantum quantity $E = \hbar\Omega$ taken away from the neutron at the -1 order of diffraction on a moving grating. The value of $m_g a$ obtained in the experiment coincides with mg, where m is the tabulated value of the neutron mass and g is the local value of the free fall acceleration for macroscopic bodies at the experimental site. For the ratio of these quantities $\gamma = mg/m_g a$ describing the degree of validity of the weak equivalence principle for the neutron, the value $1 - \gamma = (1.8 \pm 2.1) \cdot 10^{-3}$ has been obtained.

A new experiment to study the effect of a refracting medium in neutron optics has been carried out. The effect of an accelerating medium consists in a change in the frequency of the wave upon passing through a refracting sample moving with acceleration. The existence of the effect was theoretically predicted for electromagnetic waves in the work by Tanaka in 1982 and for neutron waves in the papers by Kowalski (1993) and by Nosov and Frank (1998). For neutron waves a change in the energy is described by $\Delta E \cong mwd\dfrac{1-n}{n}$. Here m is the neutron mass, w is the sample acceleration directed along the neutron velocity, d is the thickness of the sample, n is the index of refraction of the

sample substance. Though the effect is of quite universal nature, it has been observed, however, only for neutron waves. For the first time it was detected by the JINR–Kurchatov Institute-ILL group in 2005. In the experiment in 2007 new convincing data were obtained, thus allowing us to speak with full confidence that the existence of the effect is proved.

In 2007, the main result achieved within the framework of activities on the preparation and carrying out of the experiment on the direct measurement of the neutron–neutron scattering cross section at the YAGUAR reactor (RFNC–VNIITF, Snezhinsk) [11] was the construction of a neutron detector meeting all requirements of the experiment. It should be pointed out that these requirements are rather stringent. Never had there existed neutron detectors that could combine high counting rate ($\sim 10^6$ s^{-1}), neutron detection efficiency $\sim 100\%$, high energy resolution (no worse than 10%) and low γ-quantum sensitivity $\sim 10^{-9}$. The detector was installed on the experimental setup and successfully underwent tests in calibration measurements on gases in a pulsed operating mode of the YAGUAR reactor. Thus, at the present time the facility for measuring the nn-scattering is ready for operation.

In 2005, it was experimentally demonstrated that diamond nanoparticles could be used as an effective reflector of very cold neutrons (energy range of $10^{-6} \div 10^{-4}$ eV). In 2007, within the framework of the studies of the possibility to create an effective UCN source of a new type based on the thermalization of very cold neutrons up to the UCN energy, the precision measurements of the albedo of very cold neutrons from a diamond nanoparticle layer were carried out by storing them in a trap with the walls made of nanodiamonds. The numerical estimates show that one can expect the albedo to be at a level of 99% for neutrons with the velocity of 40 m/s, and more than 90% for neutrons with the velocity of 100 m/s from a layer ~ 2 cm thick. To perform these measurements a diamond trap weighing 100000 carats was made.

The measurements and the treatment of the experimental data on ultracold neutron generation at the pulsed reactor TRIGA–Mainz (in cooperation with the groups from Munich and Mainz) were completed. Neutrons were generated in a solid deuterium target at 6–10 K and transported along a mirror neutron guide 6 m in length. In a number of experiments a mesitylene pre-moderator was used at a temperature of 20 K. At a reactor pulse of 10 MJ the number of detected neutrons with an energy below 200 neV exceeded 10^5.

At the IBR-2 reactor the experiments to study dynamical properties of fluorinated polymers at low temperatures were conducted and the results were treated [12]. These substances are used for covering walls of UCN traps. On the basis of the reconstructed excitation spectrum the expected UCN storage loss coefficients were calculated and compared with the experimental data.

On the assumption that the neutron wave function is represented as a wave packet, the question arises as to whether the width of the packet varies with increase in energy or not? To answer this question an experiment to determine the temperature dependence of slow neutron cross section in gas ^{4}He was carried out. From the results of the experiment it follows that with increasing energy the wave packet width decreases in inverse proportion to the neutron velocity.

Investigation of Violations of Fundamental Symmetries in the Interactions of Neutrons with Nuclei. Within the framework of the experiments to search for neutral currents in nucleon–nucleon interactions and to determine weak π-meson coupling constant the measurements (in collaboration with PNPI, ILL and TU of Munich) of P-odd asymmetry of γ-quanta from the reaction $^{10}\mathrm{B}(n,\alpha_1)^7\mathrm{Li}^* \to {}^7\mathrm{Li} + \gamma$ were conducted on the polarized cold neutron beam PF1B (ILL, Grenoble). In the measurement a new system of detection of current signals was applied. The method makes it possible to perform the procedure similar to signal integration in considerably shorter time intervals than the analog integrators do. This allowed us to avoid a low-frequency region where the contribution of the fluctuations of the reactor power and noises is maximal, and to reduce the error in the determination of the effect by more than a factor of 1.5. The asymmetry coefficient averaged over three cycles (preliminary value) is $\alpha_\gamma = (4.5 \pm 2.7) \cdot 10^{-8}$.

The analysis of the results of the test experiments performed in 2005–2006 on beam 1 of the IBR-2 reactor to search for the negative neutron p-resonance in the lead isotopes was completed. The estimation of possible parameters of this resonance was made.

At the EG-5 accelerator, FLNP, the experiments to measure P-even angular correlations in the reaction $^{14}\mathrm{N}\,(n,p)^{14}\mathrm{C}$ in the neutron energy region of up to 1 MeV continued [13]. For spectrometry of quasimonoenergetic neutrons with an energy from ~ 100 keV to 1 MeV produced in the reaction $^7\mathrm{Li}\,(p,n)^7\mathrm{Be}$ on thin lithium targets, a special ionization ^{3}He chamber was constructed. Its tests are in progress.

Investigations of Fission Physics and Other Nuclear Reactions. The first results of the experiment to study the reaction $^{235}\mathrm{U}\,(n_{\mathrm{th}},f)$ conducted in 2006 at the IBR-2 reactor using the two-arm time-of-flight heavy-ion spectrometer mini-FOBOS were obtained. In the «mass–mass» distribution of fission fragments various peculiarities were revealed, which can be interpreted as the existence of a new channel of many-body decay similar to that observed earlier in ^{252}Cf(sf). In the distribution «total kinetic energy–fragment mass» fine structures similar to those found earlier for other fissioning systems were revealed as well.

From the experimental data obtained earlier, the energy distributions and light charged particle yields (from ^{3}H up to carbon isotopes) were determined for spontaneous fission of ^{252}Cf(sf) and neutron-induced fission

of $^{235}\mathrm{U}\,(n_{\mathrm{th}}, f)$. For isotopes heavier than lithium such data were obtained for the first time.

At the reactor in ILL, Grenoble, the experiment to study the recently discovered effect of rotation of fissioning nuclei under the action of cold polarized neutrons (ROT-effect) was carried out. The effect manifests itself in the shifts in the angular distributions of α-particles emitted in ternary fission depending on the direction of polarization of incident neutrons. The change in the angular distributions of α-particles is assumed to be determined by the component of rotation of the fissioning system around the vector of total angular momentum of the compound nucleus contributed by the incident neutron spin. In the experiment the data obtained earlier in the pioneer experiments were confirmed.

The treatment of the experimental data obtained on beam 11 of the IBR-2 reactor in the framework of continuation of the studies on characteristics of delayed neutrons from fission of major and minor reactor isotopes was completed [14]. The obtained value of the total delayed neutron yield from ^{245}Cm fission induced by thermal neutrons $\nu_d = (0.64 \pm 0.02)\%$ is the second known experimental result, which differs from the first one by higher accuracy (by a factor of 2). The comparison of this result with the global systematics of delayed neutron yields shows that it coincides with the value obtained within the framework of the simplified variant of this systematics.

In the framework of the program for studying nuclear reaction mechanisms and obtaining data for nuclear power engineering on the EG-4.5 accelerator of the Institute of Heavy-Ion Physics, Peking University, China, the investigations of the reactions $^{6}\mathrm{Li}\,(n,\alpha)^{3}\mathrm{H}$ at $E_n = 1.23$, 1.70, 2.05, 2.47 MeV and $^{64}\mathrm{Zn}\,(n,\alpha)^{61}\mathrm{Ni}$ at $E_n = 2.5$ MeV were carried out. The energy spectra and angular distributions of α-particles were obtained; the data treatment is in progress. The work is conducted in cooperation with Peking University (China), the University of Lodz (Poland) and the National University of Mongolia (Mongolia).

The complex analysis of experimental data on cascade γ-decay of neutron resonances was continued. The earlier made approximation of the data obtained in FLNP JINR on the level density in a fixed spin window showed that the properties of this parameter of any nucleus below neutron binding energy are completely determined by breaking of from 3 to 5 cooper pairs of nucleons. The approximation of experimental data on partial widths of primary dipole γ-transitions in the same energy interval substantiated this conclusion: the properties of the nucleus are determined by the coexistence and interaction of excitations of fermion and boson types in the nucleus. Thus, the possibility and necessity of direct experimental and theoretical investigations of superfluidity of the heated nucleus up to its temperature of no lower than 0.5 MeV have been demonstrated.

Applied Research. In the Neutron Activation Analysis (NAA) sector in collaboration with the Andronikashvili Institute of Physics (Tbilisi, Georgia) and Lawrence Berkeley National Laboratory, USA, studies on new biotechnologies using various microorganisms to clean up contaminated environment from toxic metals are carried out. In 2007, the studies onto the possibility of application of blue–green microalgae *Spirulina platensis* and *Arthrobacter* species isolated from natural basalts to reduce toxic Cr(VI) to stable nontoxic Cr(III) using epithermal NAA at the IBR-2 reactor (FLNP, JINR) were continued [15].

On charged particle beams of the EG-5 accelerator (FLNP) analytical investigations using nondestructive nuclear-physical techniques RBS (Rutherford Back Scattering Method) and ERD (Elastic Recoil Detection Method) were conducted. Depth profiles of various elements from hydrogen and deuterium to gadolinium and tungsten were measured, metal nanolayers deposited on silicon substrates, samples of layered structures with layers 1–2 μm thick, silicon samples saturated with hydrogen and deuterium, samples of modified constructional materials were analyzed [16, 17]. The studies were carried out in cooperation with Voronezh State University, Sumy Institute for Surface Modification (Sumy, Ukraine), Institute of Electrical Engineering of SAS (Bratislava, Slovak Republic), Institute of Physics of the Marie Curie-Sklodowska University and Lublin University of Technology (Lublin, Poland).

NEUTRON SOURCES

The IBR-2 Pulsed Reactor. Starting in December 2006 after the reactor shutdown, the works on the modernization of IBR-2 were conducted in accordance with the «Program of Activities on the IBR-2 Reactor during its Temporary Shutdown (2007–2010)» in compliance with the quarterly plans approved by the FLNP chief engineer.

By now the work on the moving reflector PO-3, fuel elements and design documentation for all reactor equipment for the IBR-2M reactor has been completed.

1. Works to dismantle IBR-2:

1.1. The main task in 2007 according to the schedule of works on modernization is the defueling of the IBR-2 reactor core and the removal of sodium from the extracted fuel assemblies (FA). The work after thorough preparations was started on March 12, 2007 and on June 22, 2007 it was successfully completed.

1.2. On July 6, 2007, sodium was drained from the 1st and 2nd contours. The equipment and pipelines of sodium contours were filled with argon.

1.3. The actuating mechanisms of the safety control system (SCS) and ionization chambers were dismantled and placed in a storehouse.

1.4. The rolling shielding was moved away from the reactor.

1.5. The moving reflector was moved away from the reactor. Temporary service lines were laid for feeding helium and oil to PO-3, thus providing a temporary laying-up mode.

1.6. Fixation of the reactor vessel was done prior to its removal in the top and bottom parts.

1.7. Water moderator and inclined moderator were dismantled.

1.8. Cooling pipes of stationary reflectors were dismantled.

1.9. The tail part of the channel of the target and the fixation gripper of the reactor vessel were dismantled.

1.10. The sodium cooling pipelines (pressure and outlet collectors) were cut off from the reactor vessel. A package of measures to remove the IBR-2 reactor vessel was carried out.

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

2.1. The manufacturing of a standard ASCS, reactor control panel (SNIIP–SYSTEMATOM) and CM system (INEUM) continued.

2.2. In JINR EW standard actuating mechanisms (AM) for control units of compensating regulators and manual regulators and a prototype model of AM of emergency shutdown system (ESS) were manufactured. The manufacturing of standard AM of ESS and AP is in progress.

2.3. On the FLNP test-bench the longevity tests of the prototype model of AM of CO and ESS were carried out.

3. In NIKIET the manufacturing of a new reactor vessel continued. The in-vessel FA reloading device was delivered to FLNP.

4. In JINR EW the manufacturing of rolling shielding, stationary reflectors and blocks of regulation for the stationary reflector was completed. The check assembly of this equipment complex was conducted. The specified equipment was accepted by the Commission with participation of NIKIET and Rostekhnadzor (Federal Service for Supervision of Environment, Technology and Nuclear Management).

5. Complex of cryogenic moderators (CM):

• CHF-700 (Heliymash) was manufactured;

• detail design of CM (NIKIET) was completed;

• the manufacturing of cryogenic pipelines in Heliymash is in progress;

• in NIKIET the design documentation for CM 202 (beams $7 \div 11$) is being worked out;

• in JINR EW the manufacturing of water moderators was started.

The IREN Project. The main tasks of the Frank Laboratory of Neutron Physics and the Laboratory of Particle Physics in 2007 were the development of engineering infrastructure and the installation of the available equipment of the 1st stage of the LUE-200 accelerator.

1. Development of engineering infrastructure.

In 2007, in accordance with the approved plan-schedule the following works on the construction and installation of power supply systems, water-cooling and thermostabilization systems, control and alarm systems of the 1st stage of the IREN facility were performed:

• All electric equipment of the LUE-200 accelerator and auxiliary systems were installed and tested.

• Systems of water-cooling, thermostabilization and of distillate preparation were installed.

• Interlock and alarm systems were installed.

• Repairs to control console and service rooms were done, the installation of equipment of AMCS (automated monitoring and control system) is in progress.

• Work to construct ARCS (automated radiation control system) was started.

• Installation of fire alarm and fire extinguishing systems is nearing completion.

2. The LUE-200 accelerator.

In spite of the delay due to the accident with the klystron SLAC 5045, the installation of the accelerator systems is carried out in accordance with the corrected plan-schedule:

• The gun modulator charging system was started up on its regular place.

• The power supplies of the focusing magnets UM-10, VC-25 (INP), Bruker D1, Bruker D2, Bruker Q1 were installed on their regular place and connected to the mains.

• The high-current power supplies of the focusing solenoids of the 1st accelerating section (Bruker D1) and of the SHF-buncher (Bruker Q1) were tested at real load.

• Magnetic measurements and correction of magnetic field of the focusing solenoid were carried out. Magnetic field nonuniformity Br/Bz in the beam region is no worse than $\pm 5 \cdot 10^{-3}$.

• At a full-scale test-bench of the LUE-200 accelerator the power supply system of the SLAC 5045 klystron was adapted to the TH2129 klystron.

• Correcting coils of the first accelerating segment were installed.

• The first accelerating section was assembled.

• The installation of the SHF feeder was completed, vacuum tests of the accelerator comprising the electron source, the first accelerating segment and the first accelerating section were carried out.

• The installation of the magnetic spectrometer is nearing completion.

• The installation of the AMCS equipment is nearing completion.

DEVELOPMENT AND CONSTRUCTION OF ELEMENTS OF NEUTRON SPECTROMETERS FOR CONDENSED MATTER INVESTIGATIONS

In 2007, work in the framework of the theme was focused on the following main activities: construction of gas and scintillation neutron detectors, development of neutron beam-forming systems and sample environment systems and development of data acquisition systems and computing infrastructure.

Construction of Neutron Detectors. In accordance with the plan the following works on optimization of geometry and working parameters of the MWPC detector with an active area of 225×225 mm and delay line data read-out were carried out:

- Diameter of the anode wire was reduced from 15 to 10 μm.
- Tension and accuracy of positioning of cathode wires were improved.
- Parallelism of anode and cathode wires (spread is less than 2 μm) was provided.
- Length of the delay line was reduced by a factor of 1.5.

All these changes made it possible to improve the spatial resolution down to 2 mm.

Owing to the financial support of the Hungarian Academy of Sciences the development and manufacturing of a similar PSD detector for the GRAINS spectrometer started. In 2007, the design documentation for a PSD casing was worked out and the casing was produced; a high-voltage power supply, NIM crate and a constant fraction timing discriminator were purchased. Preamplifiers for signal read-out from anode and cathode planes of the detector were made as well.

For the period of 2007–2008, a grant from the Federal Agency for Science and Innovations of the RF Ministry of Science and Education was received to design and create a system for monitoring cold moderators of a new type based on a solid frozen mixture of aromatic hydrocarbons in the form of pellets at a temperature of 20–30 K (State Contract No. 02.518.11.7035 of 19.04.07). Within the framework of this contract the project of the monitoring system, whose main element is a 2D PSD with an active area of 200×200 mm, was developed. In 2007, a casing and electrodes of the detector were manufactured and standard electronic blocks were purchased.

In cooperation with INRNE BAS, Sofia, a gas-filled curved position-sensitive detector intended for studies in the area of X-ray structure analysis of solid-state samples is being designed. The drawings of the detector casing were turned over to the workshops for production.

Work to modernize the detector test-bench was carried out and a new winding machine to wind electrode frames of detectors with an area of up to 800×800 mm was constructed.

Neutron Beam-Forming Systems and Sample Environment Systems. In 2007, in the framework of the BMBF–JINR project in cooperation with the German Institutes and PNPI (Gatchina) work to construct curved mirror neutron guides on beam 7a of the IBR-2 reactor and to radically modernize the EPSILON and SKAT spectrometers was started. The calculations and simulation of neutron guide elements were performed; entrance cross sections for neutron guides 7a-1 and 7a-2 were determined; draft and detail designs of vacuum housings, supporting frames and alignment tables were developed; the dismantling of the old neutron guide was completed and the contracts with PNPI to design and construct a three-channel mirror collimator of the entrance section of the neutron guide complex were concluded.

The control block of the spectrometer actuating mechanisms was designed, manufactured and debugged. The block is in the CAN standard; its main element is a programmable controller M167-1. All spectrometers of IBR-2M will be equipped with these unified blocks, each being able to control 32 step motors.

On the basis of the equipment received on account of the Romanian dues, a vacuum test-bench with a helium leak detector L200 (Leybold) intended to test various vacuum and cryogenic systems of the IBR-2 spectrometers was constructed and put into operation. Also, a contract with CRYOMECH (USA) to deliver cryorefrigerator PT 403, which is the main element of the cryogenic test-bench, was concluded [18].

A bore cryostat with a closed-cycle refrigerator SUMITOMO RP-062B was designed to carry out diffraction experiments with samples in high-pressure sapphire anvil cells on thermal neutron beams in the temperature range of 6–300 K [19]. At present, the documentation is being processed in JINR Experimental Workshops.

Development of Data Acquisition Systems, Computing Infrastructure and Software. The development of a DAQ block for multicounter systems (up to 64 channels in one block) was completed. The block was prepared for tests on the neutron source in PNPI (Gatchina). DAQ blocks for the system of acquisition and accumulation of data from 1D and 2D PSD were manufactured. These blocks will be tested at the BER-II reactor (HMI, Berlin) in early 2008. The expected count rate will be no less than 10^6 events/s.

The work on the construction of cable infrastructure of the network segment of the IBR-2 experimental halls (Gigabit Ethernet) was started. A contract to supply component parts was concluded with the «CONTACT» company. The work on the laying and welding of a fiber-optic cable was completed.

In the works on software, particular attention has been given to the development of the Sonix + software package intended to operate at the IBR-2M reactor and to practice tests of the programs at the reactors of outside organizations (IPPE, Obninsk and RRC KI, Moscow). In particular:

• Modules for control systems of actuating mechanisms with CAN interface were developed.

• Spectrum visualization program was improved to operate in on-line and off-line modes.

• Design of software for new electronic DAQ blocks connected to PC via USB-interface was started.

• First version of the system of remote supervision and control of the progress of the experiment at the spectrometers (Web Sonix) was prepared.

In collaboration with HMI, Berlin, a large amount of work to integrate the software (designed in FLNP) for the system of data acquisition from 2D PSD into the program system CARESS and to test its long-term stability was carried out. These activities were successfully completed at several spectrometers of the BER-II reactor and the synchrotron source of HMI.

In 2007, the development of the software package VITESS for simulation of new elements of spectrometers and neutron scattering methods was continued. As before, the Monte-Carlo method (particle motion in three-dimensional space) was used. The following modules for the VITESS package were designed, tested and put into service [20, 21]:

• Module for the refraction lens system with a set of accessory programs (bringing to a focus, etc.).

• Module for simulation of neutron spin precession in pulsed magnetic fields («triangle», «saw» shapes).

• Module for analysis of polarization in time intervals (TIME GATE) for simulation of a spin-echo spectrometer.

• Module for simulation of multichannel polarizers (in the stage of testing and introduction).

Preliminary calculations were made and the following instruments were simulated:

1) spin-echo spectrometer with time-dependent magnetic fields («triangle», «saw» shapes);

2) systems of focusing refraction lenses and their application in the simplest small-angle setup to improve data quality;

3) neutron beam polarizers (of N, V, Double V form).

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