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A. V. Belushkin

SCIENTIFIC PROGRAMME OF THE FRANK LABORATORY OF NEUTRON PHYSICS

Report for 2008 and Prospects for 2009–2016

Report to the 105th Session
of the JINR Scientific Council,
February 19–20, 2009

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INTRODUCTION

In 2008, 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 the FLNP basic facility, the IBR-2 (theme 07-4-0851-87/2010 "Upgrade of the IBR-2 Complex", headed by A.V.Belushkin and A.V.Vinogradov) 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. Construction of IREN facility (theme 06-4-0993-94/2008 "IREN Project", headed by V.N.Shvetsov and V.G.Pyataev) reached the stage when the neutrons produced were detected at a distance of 11 m from the target on the floor of the target hall.

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).

This report contains a brief account of 2008 scientific results and outlines the 2009-2016 years 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 2008 will give a more detail account of the results in 2008.

1. 2008 SCIENTIFIC RESULTS

1.1. Condensed Matter Physics

In view of the IBR-2 reactor shutdown for reconstruction, the scientific and experimental work of the personnel of the Department of Neutron Investigations of Condensed Matter was carried out in neutron and synchrotron centers in Russia and abroad under the existing cooperation agreements and in accordance with the accepted beam time application proposals. The work on the IBR-2 reactor was conducted according to the plan of the modernization program for the spectrometers.

I. Scientific results

The crystal and magnetic structures of the $Pb_{2-x}Ba_xFe_2O_5$ solid solution series with $x \approx 1$ have been studied using x-ray and neutron powder diffraction, electron

microscopy and Mössbauer spectroscopy. These compounds belong to the type of anion-deficient perovskites, which are of peculiar interest due to the coexistence of magnetic and ferroelectric properties. In diffraction experiments two structural phases (high- and low-temperature) with a phase transition between them at $T_c \approx 540$ K have been revealed. The phases differ in the configuration of two mirror-related chains of FeO_5 trigonal bipyramids, which become ordered below T_c. It follows from the neutron diffraction data that below $T_N = 625$ K $Pb_{1.08}Ba_{0.92}Fe_2O_5$ transforms into an antiferromagnetically (AFM) ordered state with a propagation vector $k = [0,½,½]$. At the same time the magnetic splitting in Mössbauer spectra occurs below 520 K. This significant difference in the magnetic ordering temperatures has been explained by a specific spin dynamic behavior resulting from essentially different superexchange interactions between the magnetic moments of Fe atoms in FeO_6 octahedra and in FeO_5 trigonal bipyramids.

The studies of high pressure effects on the crystal and magnetic structures of complex magnetic transition metal oxides continued. The experiments with hexagonal frustrated manganite $YMnO_3$ exhibiting multiferroic properties have revealed that the diffuse magnetic scattering gets significantly stronger and the ordered magnetic moments are drastically suppressed with increasing pressure at low temperatures. The interpretation of this phenomenon is based on the assumption implying the stabilization of magnetic liquid state with strong spin fluctuations under pressure. For the $La_{0.33}Ca_{0.67}MnO_3$ compound studied in the temperature range of 10-300 K and at high pressures of up to 5 GPa, the suppression of the "Wigner-crystal" antiferromagnetic ground state and stabilization of the C-type AFM state under high pressure have been observed.

Within the framework of the Helmholtz Association (Germany)-RFBR Joint Research Groups (HRJRG) project «Study of structural aspects of biocompatible ferrofluids by scattering methods: stabilization, properties control and applications» small-angle neutron scattering experiments using the contrast variation method have been carried out with a number of water-based magnetic fluids from various manufacturers including the *Centre* of Fundamental and Advanced Technical Research (*Timisoara* Branch of RAS, Romania), Pierre&Marie *Curie University* (Paris, France), Institute of Experimental Physics of SAS (Kosice, Slovak Republic). Also, in the framework of the study of the mobility of brain cancer cells incorporating magnetic nanoparticles a search for a proper source of magnetic nanoparticles has been conducted among water-based magnetic fluids with sterical stabilization on the basis of double coating of magnetite with various surfactants including citric (CA+CA), oleic (OA+OA), myristic (MA+MA) and lauric (LA+LA) acids. The structure analysis comprising experiments on magnetization, transmission electron microscopy and small-angle neutron scattering has showed that a part of magnetite particles in the fluids under study (size ~7 nm, polydispersity 40 %) forms stable aggregates with a mean size up to 40 nm depending on the type of the surfactant layer. The magnetic fluids were added to the culture medium, where brain

cancer cells of various lines were incubated. The incorporation of nanoparticles into the cells was determined via magnetic cell separation, atomic absorption spectroscopy, fluorimetric measurements, as well as Berliner Blue staining. The cytotoxicity of nanoparticles under study was found to be different for various stabilization layers of the surfactants. The LA+LA stabilized magnetic fluid was demonstrated to be the most preferable source of magnetic nanoparticles. From the viewpoint of structural peculiarities the given fluid has the least aggregation rate, which explains higher absorption of magnetic nanoparticles by the cancer cells in the given case and might also be the reason of their lowest cytotoxicity for the cells.

Within the framework of the study of the coexistence of ferromagnetism (FM) and superconductivity (S) in thin multilayers, data treatment and interpretation of the results obtained for a three-layer system (S)/(FM)/(S), namely, for (Nb)/(Fe)/(Si, Mo) on silicon substrate have been completed. The theoretical analysis has shown that due to the proximity effects between (S) and (FM) layers, various scenarios of their interaction are possible: the formation of domain structure, "flowing" of magnetization from (FM) layer to (S) layer, a change in the direct and indirect exchange interactions of (FM) layers. The practical importance of studying these systems is connected with the prospect of development of devices for recording information simultaneously in electric and magnetic channels. The measurements were carried out under a magnetic field of 500 Oe and in the temperature range of 2-60 K. For the first time the reorganization of the domain structure and the decrease in the saturation magnetization in the domains at the transition of Nb(500 Å) layer and [Si(34 Å)/Mo(34 Å)] structure to the superconducting state have been simultaneously observed. For the first time it has been directly shown that in the three-layer system (S)/(FM)/(S) at the transition of layers to the superconducting state the magnitude of exchange interaction in the ferromagnetic layer decreases.

A new class of polymers produced by regulated synthesis (dendrimers) has been studied. Using small-angle scattering data the spatial distribution of the scattering density for the dendrimer type under study has been obtained. Using the contrast variation method it has been proved that dendrimer molecules in solutions have no closed inner cavities impermeable to a solvent. The partial volume of the dendrimer in solution has been determined and the volume fraction (30-40%) of open inner cavities in the effective dendrimer volume accessible to a solvent has been estimated. The studies of dendrimers with fluorocarbon substitutes of Si atoms in the outer layer of the molecular structure have revealed that the end groups of dendrimers are located in its surface layer. It has been demonstrated that a simple model of dendrimer branch growth fails to explain the anisometry and spatial inhomogeneity of the polymer.

Magnetic elastomers (composite materials consisting of a polymer matrix and highly polydisperse magnetic particles) have been investigated by small-angle neutron scattering and small-angle X-ray scattering. It has been found that the

polymer matrix is fragmented and has a nanophase character, and the geometric sizes of nanophase areas depend on the concentration of doped magnetic particles and the strength of the applied magnetic field during the synthesis of material.

The detailed analysis of experimental data on quasi-elastic neutron scattering by water dispersion of nanodiamonds (concentration of particles ~ 80 mg/ml, average size of particles ~ 8nm, temperature of solution ~ 12°C) has been performed. The data analysis was carried out with the use of the model according to which water in the dispersion was assumed to be a two-component system comprising usual water (bulk water) and water immediately adjacent to the surface of nanoparticles and experiencing their influence on its structural-dynamic properties (hereinafter, hydration water). The relative fraction of this water was estimated to be ~ 3 %, which approximately corresponds to two-three layers of water molecules adjacent to the surface of the nanoparticle. The analysis of diffusion processes in both water components was carried out on the basis of the «stretched exponent» method, which makes it possible to evaluate α-relaxation effects (diffusion processes leading to the distortion of the nearest surrounding of the molecule) in both water components. A clear slowing down in the diffusion mobility of the molecules of hydration water as compared to that of the bulk water was revealed. The intensity of diffusion processes in the hydration water was found to be close to the parameters of the diffusion of supercooled water at a temperature of –(15-20) °C.

Studies have been performed for isomers of dimethylbutanol $C_6H_{13}OH$ (2,2DM-1B, 3,3DM-1B, 2,3DM-2B and 3,3DM-2B) consisting of globular molecules, which in solid state form orientationally disordered crystalline phases. Calorimetric studies of polymorphism of these compounds have revealed significant differences in the melting temperatures, as well as in the kinetics and number of phase transitions observed during cooling and heating. Simultaneous neutron powder diffraction studies and inelastic incoherent neutron scattering (IINS) investigations have made it possible to identify glassy and crystalline phases, which can coexist at low temperatures. The preliminary interpretation of IINS spectra is based on the quantum-chemical calculations of the dynamics of isolated molecules using the B3LYP/6-311G** basis set in the electron density functional theory.

The fluid metamorphogenic (FM) model of seismotectogenesis has been substantiated using the results of neutron and acoustic experiments on mono-crystalline and poly-crystalline quartz samples in the region of polymorphous α-β transition. In this model the reason for destructions in the seismic process is an increase in microstress values and decrease in the strength of solids in the course of the solid-phase transitions. Four types of the crystallographic quartz texture in natural rocks were determined using the quantitative texture analysis. For the first time, the method of preferred orientation description based on ODF-histograms and ODF-spectra has been used for estimating the expected degree of anisotropy of various physical properties.

A series of studies on the martensitic transformation and fatigue properties of austenitic stainless steels widely used in industry due to their remarkable mechanical, welding and corrosion-resistant characteristics has been completed. The experimental simulation of fatigue degradation was performed using tension-compression cyclic loading in the plastic deformation region in the frequency range of 0.1-100 Hz. Regions of characteristic frequencies, which have widely different effects on steel, have been revealed. Formation mechanisms of the martensitic phase in an initially one-phase (austenitic) material have been determined. It has been shown that in some cases there is a large variance in elastic constants of phases constituting the material, which significantly influences its strength properties.

II. Instrument developments

A start has been made on the manufacturing of the head part of the mirror vacuum neutron guide within the framework of the realization of the project for construction of the DN-6 diffractometer for neutron diffraction studies of microsamples (beam 6b of IBR-2M).

For the GRAINS reflectometer to be installed on beam 10 of IBR-2M the manufacturing of the head part consisting of a two-beam splitting system encased in a vacuum housing has started. Section design is realized. The collimation system of the reflectometer, which comprises a massive support for housing the setup units is under construction. This system will make it possible to direct the neutron beam at a given angle to the sample surface, to control the incident angle at the sample and to separate thermal and cold neutrons from fast neutrons, which will improve background conditions at the setup.

The technical design of a mirror vacuum neutron guide for the DIN-2PI spectrometer has been completed and work to prepare an installation site for the neutron guide has been carried out. The work on the mirror vacuum neutron guide is conducted in cooperation with PNPI RAS (Gatchina). The mirror neutron guide being constructed will make it possible to increase the intensity of cold neutrons ($E < 5$ meV) at the sample position by a factor of 4-6 and at the same time to reduce the sizes of samples under study by a factor of 2-3, which will mean significant improvement in quality of the DIN-2PI spectrometer and the upgrading of its parameters to the level of the best foreign analogues.

The device for measuring low-temperature magnetoresistance at low temperatures has been constructed. The device is intended for prompt analysis of $La_{1-x}Sr_xMnO_3$ manganites, which are ferromagnetics with a "bad metal" behaviour. The manganites are synthesized using the zole-gel technology. Their magnetoresistance has been successfully measured in a magnetic field $H_{max} = 1.2$ T in the temperature range of 7 – 300 K.

1.2. Neutron Nuclear Physics

Preparation for experiments at the first stage of the IREN neutron source

The modernization of the measuring module of the COCOS gamma spectrometer was performed, which made it possible to essentially increase its operating speed: interface for USB-1 was developed and manufactured and a new program "Lada" to accumulate experimental data was written. Fast time analysis blocks with a channel width of 10-20 ns to carry out neutron time-of-flight (TOF) spectrometry were developed, manufactured and tested. The software for the system with fast time analysis for obtaining four TOF spectra was developed. The system is intended for investigation of beam parameters of the IREN neutron source. In addition, algorithms were developed and included in the given system of the program to carry out precision experiments. Multisection liquid-crystal gamma quantum detector installed on the 60 m path length was prepared and tested. Drawings of the ionization chamber to operate at EG-5 and IREN were prepared.

Investigation of fundamental properties of the neutron

Within the framework of preparation and carrying out of the experiment on the direct measurement of neutron-neutron scattering cross section on the YAGUAR reactor (VNIITF, Snezhinsk), the calibrations using noble gases (Ar, He) were carried out, which demonstrated the operational capability of the facility and measuring technique. The obtained values of scattering cross section for the gases coincide with the tabulated values. In addition, in accordance with the performed measurements it was estimated that the background of fast neutrons does not exceed the calculated value. The first attempt to measure the neutron-neutron scattering showed the presence of high background of thermal neutrons, which exceeds the level of the expected effect by an order of magnitude. This background depends quadratically on the energy of the reactor pulse. At present, the radiation induced desorption of atoms from the surface of walls of the neutron scattering cavity seems to be the most probable source of the background. Further progress of the project should be connected with the study of this phenomenon and efforts to decrease its influence in the experiment.

Within the framework of investigation of neutron interaction with nanoparticles the dependence of angular distribution of neutrons reflected from the surface of diamond nanopowder was measured for various wavelengths of incident neutrons at the angles of incidence of the neutron beam to the surface of 2°, 3° and 4°. As expected, as a result of multiple scattering from nanoparticles the neutrons are reflected from the surface with relatively narrow angular distribution, the maximum of which is close to a specular angle. Thus, for cold neutrons with the wavelength λ ranging from 4 Å to 8 Å the quasi-specular albedo in the scattering plane at small angles of incidence (less than 6-9°) is observed. The probability of such albedo may

reach 30%. For the angles of neutron incidence greater than 6-9° the probability of quasi-elastic reflection becomes commensurate with the probability of scattering at angles much greater than the specular angle. For large angles and large λ (when the lateral velocity of the neutron exceeds ~ 50 m/s) such quasi-specular albedo exceeds the probability of reflection from the available supermirrors (reflection from which at such velocities also has a quasi-specular character).

Theoretical analysis and simulation of possible variants of the experiments to measure neutron lifetime in material traps were performed. Additional detailed calculations of the generation of ultracold neutrons in various moderators for the pulsed reactor TRIGA were carried out and on this basis new experiments to measure neutron lifetime in magnetic traps were proposed. New measurements of the generation of ultracold neutrons were performed at the pulsed reactor TRIGA-Mainz (in cooperation with the group from Mainz) in the stationary, pulsed and accumulation modes. The neutrons were generated in a solid deuterium target at the temperature of 6-10 K and were transported through a mirror neutron guide 6 m long. Using the constructed UCN beam, the time-of-flight measurements were carried out to study BN (boron nitride with a cubic crystal structure) properties as a material to construct UCN chambers with high boundary energy.

The results of the activities in recent years in proving the possibility to realize the proposal to extract the n,e-scattering length b_{ne} from the experimental data on diffraction of slow neutrons from noble gases were summed up. It was shown that the performance of dedicated neutron diffraction measurements on gas vapors of $Ar-^{36}Ar$ and $Kr-Xe$ may ensure the extraction of b_{ne} with the accuracy of 2-3 %. This would make it possible to achieve progress in the problem of a wide spread of the existing experimental estimates of b_{ne}, which is beyond the limits of 5 standard errors. The existing experimental b_{ne} values within the limits of $\pm 10\%$ are close to the Foldy length $b_F = -\mu e^2 / Mc^2 = -1.468 \cdot 10^{-3}\ fm$. The intrigue is that if $b_{ne} = b_F$, it would mean that the neutron magnetic moment without the participation of the charge structure is completely responsible for the neutron interaction with an external electromagnetic field.

A facility has been constructed to perform an analogue of the Kron-Ringo experiment to measure the angular anisotropy of slow neutron scattering and to determine b_{ne} from it on the spectrometer in Troitsk. The obtaining of data on the neutron scattering anisotropy depending on the neutron energy will allow one to eliminate the corrections, which were in the Kron-Ringo experiment and to obtain more reliable value of b_{ne}.

Investigations of fission physics and other nuclear reactions

On the beam of the ILL reactor (Grenoble, France) in the framework of the collaboration PNPI (Gatchina) – JINR – Germany – Finland the experiment to observe the rotation of the fissioning nucleus under the action of polarized neutrons (ROT-effect) was carried out. The ^{239}Pu nucleus having spin ½ was chosen as a target. The effect was observed by measuring the angular dependence of the escape of ternary-fission α-particles relative to the rotation axis of the nucleus polarized by incident neutrons. The analysis of the obtained data will be performed in 2009.

In Strasbourg (France) in the framework of the collaboration JINR-France-Germany-Belgium the experiment started to search for correlation of the neutron escape from ^{252}Cf fission fragments with the spins of the fragments. In the experiment the multi-detector facility DEMON to measure neutrons and the ionization chamber CODIS to measure fission fragments are used. The search for angular correlation between two neutrons emitted from one fragment is in progress. The results of the experiment are expected in 2009.

Within the framework of collaboration with FLNR the treatment of the experimental data obtained in 2006 on the IBR-2 reactor using the "Mini-Fobos" facility to search for the ternary collinear decay continued. A new technique of data treatment was proposed, which implies the determination of charges of the detected fission fragments using the time of electron drift in the Bragg chamber. The obtained results agree with the hypothesis on the existence of exotic modes of fissioning nucleus decay.

The analysis and interpretation of the experimental data on intensities of two-step cascades at the capture of thermal neutrons by various nuclei continued. The sums of radiative strength functions of dipole primary γ-transitions were approximated by the semi-phenomenological dependence with high accuracy in the energy region of primary γ-transitions $0.5 < E_\gamma < B_n$-0.5 MeV for 41 nuclei from ^{40}K to ^{200}Hg. It has been found that the shape of radiative strength functions in the studied nuclei is determined by the structure of the decaying and excited levels at least up to the neutron binding energy B_n. The independent confirmation of the presence of considerable stepped structure in the level density was obtained at the reanalysis of the data published by now on the experimental intensities of primary γ-transitions averaged over the neutron resonances in the region of their energies of 2 and 24 keV.

The data treatment of the ^{64}Zn(n,α) reaction at the neutron energy of 2.54, 4.00 and 5.50 MeV as well as of the ^{147}Sm(n, α) reaction at the neutron energy of 5.0 and 6.0 MeV was completed. The measurements of the ^{143}Nd(n,α) reaction were carried out at E_n = 4, 5 and 6 MeV and of the ^{95}Mo(n,α) reaction at E_n = 4, 5 and 6 MeV.

Applied investigations

In 2008 the preparation was carried out for the accreditation of the Neutron Activation Analysis Sector in the framework of the IAEA Technical Cooperation Project "Harmonization of the Quality Control System in Accordance with ISO-17025 and International Standards in the Nuclear Analytical Laboratories of the Russian Federation". Three IAEA Workshops were held and a package of documents was prepared.

The improvement of spectrometric and service equipment of the REGATA facility on the IBR-2 reactor continued. The NAA possibilities on the IREN neutron source were evaluated, a technical project to manufacture pneumatic transport to carry out NAA on this facility was developed.

In 2008 a series of studies within the framework of the International program "Atmospheric depositions of heavy metals in Europe – estimations based on the analysis of moss-biomonitors" was completed. Within the framework of the project "Geochronology and investigation of retrospective pollution of non-solidified bottom sediments from oxygen-containing and oxygen-free basins of the western part of the Black sea" the assessment of retrospective pollution of this region was performed. The studies on the project "Development of the system of integrated monitoring of heavy metals and radionuclides in Mongolia using nuclear physical analytical methods" were carried out. Within the framework of the IAEA coordinated program "The influence of toxic and potentially toxic elements on women of reproductive age in developing countries" in cooperation with the Russian State Medical University (Moscow), the Analytical Centre of Geological Institute of RAS and I.P.Sechenov Medical Academy in 2008 the study to determine multielement analysis of blood samples of specially selected patients from one of the industrial Moscow districts was completed. For the first time on the territory of Belarus the moss-biomonitor technique was applied to assess atmospheric depositions of radionuclides 20 years after the Chernobyl accident. The measurements of long-lived radionuclides – fission products of nuclear fuel – were carried out in 2008 in cooperation with the Slovak specialists in the low-background laboratory of Comenius University (Bratislava). A number of samples were analyzed by the specialists from NECSA in the Republic of South Africa.

On the charged particle beams of the EG-5 accelerator the analytical investigations were carried out using non-destructive nuclear physical techniques.

The effect of implantation of nitrogen ions with the energy of 125 keV and doses of $1\cdot10^{17}$-$1\cdot10^{18}$ cm^{-2} was studied for tribological characteristics of the AISI316L stainless steel. The composition of surface layers of the steel was studied by the RBS, XRD (GXRD), SEM and EDX methods. The coefficient of friction and abrasion resistance were measured in the air, in oxygen, in argon and in vacuum. An increase in abrasion resistance was found to be different for various environments.

The investigations of the dependence of electrical characteristics of SiCN-films on silicon substrate on their chemical composition were carried out. The concentration of silicon, nitrogen and carbon in the films was measured using the Rutherford backscattering technique. The concentration of hydrogen in the films was determined by recoil proton technique on the ion beam. Similar investigations were conducted with a-C:H films, in which the content of hydrogen was up to 20 at.%. The possibility of accurate determination of concentration of all elements in the three-element film was realized at the simultaneous measurement of the Rutherford backscattering and recoil proton spectra.

Both techniques were used to study depth profiles of elements in the samples of porous silicon. Aged samples of p^+-type of porous silicon of low and medium degrees of porosity were studied. It has been found that the near-surface layers several hundred nanometers thick have different elemental compositions in the films of low and medium porosity.

2. NEUTRON SOURCES

2.1. The IBR-2 Pulsed Reactor

In 2008 the following works on the IBR-2 modernization were performed:

1. Dismantling of all replaced equipment of the IBR-2 was completed:

1.1. In accordance with the project of NIKIMT (Research and Development Institute of Construction Technology) two rolling shieldings (RS), which house stationary reflectors (SR) with control and emergency protection blocks, water moderators and pneumatic rabbit systems (overall weight of each RS is about 10 t) were moved one after another to a ring corridor. The dismantling of RS was complicated by a high level of induced activity (~ 1000 R/h) and space-limited working conditions. Special protection devices manufactured in JINR EW and FLNP were used to reduce the level of radiation. In January-February, 2008, both RS were successfully moved to a storage by the personnel of the FLNP Mechanical and Technological Department (MTD).

1.2. In the first quarter of 2008 the equipment in the reactor control room (control panel and cabinets for electronic safety control system equipment) was dismantled.

2. Installation of new equipment of the IBR-2M reactor:

2.1. After the RS of IBR-2 were removed (see 1.1.), new RS-1M and RS-2M of the IBR-2M reactor with new stationary reflectors SR-1 and SR-2 were installed. This work, which lasted from January till June, 2008, demanded significant operational development of the equipment to meet the specifications of the design documentation (DD) and under hazardous radiation conditions called for efficient organization of work. Upon installation, the operation of RS-1M and RS-2M was tested and the mating of SR-1 and SR-2 with each other as well as of shutters 1 and 9

with RS-1M and RS-2M, respectively, was checked. The work was conducted by the MTD personnel.

2.2. The preparatory work on the installation of the reactor vessel was performed: necessary installation devices as well as components for the Na-collector jacket were manufactured; a contract with the specialized organization "Energospetsmontazh" on welding the vessel with the sodium collector was concluded.

2.3. The preparation of a reserve control room was completed and the installation of equipment started.

3. Manufacturing of new equipment for IBR-2M:

3.1. In the middle of November, 2008 the manufacturing of the reactor vessel in NIKIET (N.A.Dollezhal Research and Design Institute of Power Engineering) was completed and on 17.11.2008 it was delivered to JINR. The delay in delivery of the vessel for 6 months made it impossible to complete welding operations for the vessel and sodium collectors by the end of 2008.

3.2. Manufacturing of 3 grooved water moderators was completed. The inclined moderator (beams 4-6) underwent geometrical try-on tests in its regular place in the central part of the reactor biological shielding. The mating of the moderator with the stationary reflector was tested showing positive results.

3.3. Manufacturing of all executive mechanisms of the safety and control system (SCS) was completed.

3.4. For the most part the manufacturing of equipment of automatic safety and control system (ASCS) and a new control panel was completed.

3.5. In INEUM (I.S.Bruk Institute for Electronic Control Machines) the equipment of the technological parameters control system (TPCS) was manufactured and passed factory acceptance tests. The equipment was delivered to FLNP and its installation started.

4. Complex of cryogenic moderators (CM) of IBR-2M:

4.1. In 2008 the design documentation for CM 202 for beams 7-11 was worked out. A contract with the NPO "Atom" (Research and Production Association "Atom") on manufacturing CM 202 was concluded.

4.2. In NIKIET the development of design documentation for CM 203 for beams 2-3 started.

4.3.The GSPI (State Specialized Design Institute) completed the technological project (1st stage) for the CM complex.

4.4. The design documentation on mesitylene supply pipelines for CM 202 and CM 203 was completed in the FLNP Design Bureau and forwarded to the NPO "Atom" for production.

4.5. In the NPO "Atom" the manufacturing of rolling shieldings for the installation of CM 202 and CM 203 was completed.

4.6. The NPO "Geliymash" (Research and Production Association of Helium

Engineering) delivered the equipment for cryogenic helium refrigerator KGU-700/15. The metal constructions for the installation of KGU-700/15 are being assembled. A contract with "Energospetsmontazh" on assembling of cryogenic pipelines for CM 202 and CM 203 was concluded. In NPO "Geliymash" the manufacturing of cryogenic pipelines and two cryostats is nearing completion.

5. Building and construction activities:

5.1. Preparation of the reactor reserve control room was completed.

5.2. The main construction work in rooms of reliable power supply system was carried out.

5.3. The most part of the planned activities in the reactor control room was performed.

2.2. The IREN Project

The main tasks of the Frank Laboratory of Neutron Physics and the Laboratory of Particle Physics in 2008 were the completion of installation, testing and commissioning of the equipment of the first stage of the LUE-200 accelerator. By June, 2008 work on the installation of the equipment in the accelerator halls was completed. Starting at the end of June, 2008 work to transport the beam and to train various systems of the accelerator was in progress. On June 17, 2008 an electron beam with the specified parameters was obtained at the exit of the electron source whereupon work to adjust the klystron and the modulator of the first accelerating section began.

By the end of November, 2008 the adjustment of HF systems of the accelerator was completed and an accelerated electron beam was transported through the first section. For independent verification of the results, a prototype tungsten target was manufactured and placed in the diagnostic box chamber at the exit of the first accelerating section. On December 5, 2008 the accelerated electron beam was transported to the prototype target and at the same time, in the time windows synchronized with the start of the accelerator the measuring module developed by the specialists from the FLNP Nuclear Physics Department detected high-energy gamma-quanta and neutrons. The presence of hard gamma-quanta and neutrons was independently confirmed by the data from the radiation monitoring equipment.

As a control experiment the measurements of gamma-quanta and neutrons were carried out by placing a diagnostic fluorescent screen in the electron beam at the exit of the source. During the experiment there were no gamma-quantum and neutron counts in the corresponding detection channels as compared to the case when electrons from the source were injected to the accelerating section.

By December 15, 2008 the stage of transportation of the accelerated electron beam to the prototype tungsten target located in the ceiling between the lower

accelerating hall and the target hall of the facility was completed. Using the focal length of quadrupole lenses and the measured value of the displacement of the beam center of gravity depending on the current in the correcting magnets, the average energy of the accelerated electron beam was estimated to be 20 MeV. On December 15, 2008 the accelerated electron beam with a pulse current of 300-400 mA at a frequency of up to 5 Hz was transported to the prototype target. Neutrons produced as a result of interaction of bremsstrahlung gamma-quanta with the substance of the target, were detected by a gas proportional neutron counter placed at a distance of 11 m from the target on the floor of the target hall. The duration of fast neutron burst was estimated and time-of-flight spectra with time channel widths from 20 ns to 8 μs were accumulated. For half an hour of the measurements at a frequency of 5 Hz the statistics of detector counts in the time channels amounted to two hundred counts in the resonance neutron energy region.

At present, the installation of electron guide and focusing elements in the target hall has been completed and work to transport the beam to a regular non-multiplying target has started.

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

In 2008 within the framework of the theme the following main results were obtained:

Neutron beam-forming systems

In cooperation with the German Institutes and PNPI (Gatchina) within the framework of the project aimed at constructing curved mirror neutron guides for the EPSILON and SKAT spectrometers on beam 7a of the IBR-2 reactor the work to design and manufacture mechanical and optical units of neutron guides continued. In particular, additional vacuum housings, supporting platform and installation-loading mechanism for a single-volume demountable vacuum housing of the head part of the neutron guide system (splitter) for beam 7 of IBR-2M were developed and manufactured. In PNPI optical elements for the head and curved parts of the neutron guide were produced as well.

In the JINR Experimental Workshops (JINR EW) 44 beam-positioning support pillars for curved neutron guides were manufactured. Also, the drawings of posts and beam-positioning support pillars of the head part were forwarded to JINR EW and put into production. The head part of the neutron guide on beam 7b (NERA-PR spectrometer) was dismantled and the shielding of the chopper in the reactor ring corridor was partially disassembled. The technical project of reconstruction of the supporting column in bldg. 117 was prepared.

It has been suggested that a test beam for testing neutron detectors and other

elements of spectrometers be positioned on IBR-2M channel 13. The parameters and infrastructure of the test beam were determined and the preparation of the technical project started. The design parameters of beam 13 are: neutron guide cross-section – 314 cm^2; neutron flux on the moderator surface – ~ 2×10^{12} n/ cm^2 /s, at a distance of 10 m – up to 10^8 n/ cm^2 /s.

Cryogenic investigations

Under the contract with the RRC «Kurchatov Institute» a bore cryostat for cooling high-pressure sapphire anvil cells for working in the temperature range of 6.5-300 K was designed and manufactured. The diameter of the cryostat orifice opening for loading high-pressure cells is 120 mm, which corresponds to the cell sizes and makes it possible to place them in either a vertical or horizontal position. The temperature is measured and controlled by ***Scientific Instruments*** Model ***9700*** temperature ***controller*** and silicon diodes DT470. The cryostat also uses SUMITOMO SRP-062B cryocooler.

Work on the FLNP cryogenic test stand continued. In 2008 the basic element of the test stand – CRYOMECH PT403 cryocooler – was purchased and installed. The main components of the cryostat, which makes it possible to carry out tests in the temperature range of 2.5 – 300 K, were designed and manufactured as well.

Control systems of actuating mechanisms

The software was upgraded and the SMC-32-CAN controller developed in FLNP for the control systems of actuating mechanisms on the IBR-2M spectrometers was tested:

- The control module with controlled parameters (current pulse duration and pause duration) for direct-current motors was embedded into the Sonix + software package;
- To improve the accuracy of actuating mechanisms, the encoder installed on the step motor shaft was incorporated in their design, which significantly enhances the resolution.

The investigations demonstrating the possibility of using TOSHIBA VFAS1-4370PL drives for phasing the rotation of motors with power up to 500W were carried out. Corresponding recommendations to replace obsolete and worn-out drives EKT2 used in beam choppers on the IBR-2 spectrometers were made. A stand to test characteristics of choppers was assembled. Work to introduce control systems of actuating mechanisms on the spectrometers of the IR-8 reactor in the RRC «Kurchatov Institute» was performed.

Gas detectors

The prototype of a position-sensitive neutron detector based on a multi-wire proportional chamber with individual data readout from each wire was constructed.

The detector uses 36(X)*18(Y) cathode wires spaced 1mm apart. Signals are read out via 8-channel current preamplifiers and discriminators; there are also analog outputs. Amplitude spectra of signals from the wires were obtained. Pulse width is about 200 ns. The prototype of the detector was prepared for stand tests.

In cooperation with INRNE BAS (Sofia) a curved PSD intended for x-ray and neutron diffraction studies was designed and constructed. It is a curved 1D gas-filled position-sensitive detector based on a multiwire proportional chamber with delay line data readout.

The detector is housed in a steel case. A panel with a system of electrodes is fixed to its front wall. Signals are output via BNC connectors; high voltage is supplied via SHV connectors. There are two Swagelok connectors on the detector case, which makes it possible to use it in a continuous-flow mode of operation. The front wall is detachable, and when the device is used as an x-ray detector the entrance window is an aluminum plate 0.1 mm thick, when detecting neutrons the thickness of the entrance window is 7 mm. For greater rigidity the entrance window is buried in the detector case. The cathode and anode wires are spaced 1 mm apart.

As well as the 1D and 2D PSD developed earlier in FLNP, the given detector uses unified electronic blocks:

- NIM crate with Phillips Scientific PS715 constant-fraction discriminator, Iseg NHQ206L 2-channel HV power supply and fast charge-sensitive preamplifiers;
- Personal computer with a built-in PCI DAQ board.

At present, the prototype of the detector is being tested at the stand.

In 2008 two MWPC position-sensitive detectors were manufactured: for the GRAINS spectrometer (financed by the grant of the Hungarian Academy of Sciences) and for the monitoring system of the IBR-2M reactor cold moderators (financed by the grant of the Federal Agency for Science and Innovations of the RF Ministry of Science and Education).

Development of LAN, DAQ electronics and software

Work to lay and install fiber-optic communication lines between bldg. 119 and experimental halls 1,2 and the IBR-2M control room was completed. The installation of the corresponding communication equipment in 2009/10 will allow 1-10 Gbit/s data transfer rate in the given segment of the network. An optical cable was laid in the IREN network segment as well and a 100 Mbit/s switch was put into service; access to the Internet was provided to the first top-priority users. Lower level network switches in buildings 42 and 42a were upgraded.

Firmware programs were developed and two sets of electronic blocks for the

IBR-2M spectrometers were manufactured and debugged with a programmable event generator. Drivers and program interfaces for the Sonix + software package were developed.

The development of the Sonix+ software package proceeded both by including new hardware control modules and by improving the user interface and visualization means. Service possibilities of the WebSonix remote control system were extended.

In cooperation with the Jülich Research Center the development and preliminary testing of the PHASE SPACE TRANSFORMER module for the VITESS software package were performed and work on computer simulation of a backscattering spectrometer started. The parameters of a number of other VITESS modules (SPACE, SPACEWINDOW_MULTIPLE, etc.) were improved and new options (consideration of neutron attenuation by air at various temperatures and humidities, simulation of geometrically non-ideal neutron guides, etc.) were added. Using the above-mentioned modules the simulation and optimization of the beam-forming system for channel 7a of the IBR-2 reactor were performed. Work on simulation and development of neutron spin-echo spectroscopy with rotating/pulsating magnetic fields continued.

4. SCIENTIFIC RESEARCH PLAN FOR 2009

The 2009 FLNP Scientific Research Plan contains 4 first priority themes.

Theme	Leader	Priority	Code
Investigations of Nanosystems and Novel Materials by Neutron Scattering Methods	V.L.Aksenov A.M.Balagurov D.P.Kozlenko	1	04-4-1069-2009/2011
Nuclear physics with neutrons -fundamental and applied investigations	Yu.N.Kopatch V.N.Shvetsov	1	03-4-1036-2001/2010
Upgrade of the IBR-2 complex	A.V.Belushkin F.V.Vinogradov	1	04-4-0851-87/2010
Novel Development and Creation of Equipment for IBR-2M Spectrometers Complex	S.A.Kulikov V.I. Prikhodko	1	04-4-1075-2009/2011

In 2009-2016 the activity within the framework of theme **1069** will be focused on instrument developments at the IBR-2 reactor.

In addition to the modernization of the available spectrometers (HRFD, DN-2, DN-12, SKAT/EPSILON, YuMO, REMUR, REFLEX, DIN-2PI, NERA-PR) aimed at improving their technical parameters, the development and construction of three new spectrometers (DN-6, GRAINS, FSD) are planned, which will make it possible to significantly extend the areas of scientific research. The development of projects for two new spectrometers (small-angle neutron scattering spectrometer and reflectometer with atomic resolution) is planned as well.

Before the completion of the IBR-2 reactor modernization, scientific investigations will be carried out in other neutron centers in Russia and abroad under the existing cooperation agreements and on the basis of accepted beam application proposals. Starting from the end of 2010 planned scientific experiments will be conducted on the available spectrometers of the reactor within four main scientific directions: nanosystems and nanotechnologies, biomedical studies, investigations of novel materials, engineering diagnostics and earth sciences.

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

1. Investigations of fundamental properties of the neutron
2. Fundamental investigations of nuclear reactions under the action of the neutron
3. Applied investigations

To successfully fulfill the modernization and expanding of the IBR-2 spectrometers complex in the framework of theme **1075** the following activities are planned:

1. Calculation and optimization of the IBR-2M spectrometers, development of neutron spectrometry techniques.
2. Commissioning of the complex of moderators of the IBR-2M reactor and optimization of parameters.
3. Development of new types of neutron and x-ray detectors and data acquisition systems, improvement of their application efficiency.
4. Cryogenic investigations.
5. Development of network and computer infrastructure for performing experiments and data processing.

The following main tasks are to be accomplished in the years 2009-2016 in the framework of theme **0851:**

1. Start up and achievement of the IBR-2M reactor design parameters. Study of physical characteristics of the IBR-2M reactor.
2. Reactor operation at design parameters and provision of realization of physics research program on extracted neutron beams.
3. Implementation and operation of the cryogenic moderator complex.
4. Construction of a reserve movable reflector.
5. Upgrade of the reactor equipment with expiring service life.
6. Preparation of the concept of the IBR-2M operation after 2030.

5. CONFERENCES AND MEETINGS

In 2008, FLNP organized the following meetings:

1.International Seminar-School "Pulsed Advanced Neutron Sources" PANS-III dedicated to the centenary of the birth of D.I.Blokhinzev, Dubna, January 29 – February 4.

2. IAEA TC 2nd Workhop "Harmonization of QA/QC Systems According to ISO and International Standards in Nuclear Analytical Laboratories of the Russian Federation", Dubna, May 26-30.

3. XVI International Seminar on Interaction of Neutrons with Nuclei ISINN-16, Dubna, June 11-14.

4. IAEA TC 3nd Workhop "Harmonization of QA/QC Systems According to ISO and International Standards in Nuclear Analytical Laboratories of the Russian Federation", Dubna, October 27-31.

5. International Seminar Dedicated to the centenary of the birth of I.M. Frank, Dubna, October 23-24.

In the year 2009, FLNP will organize:

XVII International Seminar on Interaction of Neutrons with Nuclei ISINN-17, Dubna, May 27-30.