FRANK LABORATORY OF NEUTRON PHYSICS

In 2004, the FLNP scientific programme was realized under five research themes of the Topical Plan for JINR Research and International Cooperation 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. Aksenov and A. Balagurov) and neutron nuclear physics (theme 06-4-1036-2001/2004 «Nuclear Physics with Neutrons — Fundamental and Applied Investigations», headed by W. Furman and V. Shvetsov). To effect scientific research, work was continued 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. Ananiev) and IREN (theme 06-4-0993-94/2004 «IREN Project», headed by W. Furman and I. Meshkov), 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. Belushkin and V. Prikhodko).

The topical problems of investigations carried out in cooperation with the leading nuclear centres were considered at the XII International Seminar on Interaction of Neutrons with Nuclei, the III Germany–JINR user meeting «Condensed Matter Physics with Neutrons at the IBR-2 Pulsed Reactor», and the International Meeting on the SAD Project devoted to the 20th anniversary of the IBR-2 reactor.

CONDENSED MATTER PHYSICS

Diffraction. With the help of a combined analysis of X-ray and neutron diffraction data (obtained with HRFD), the crystal structure of the single-phase compound Li_2BeD_4 has been determined [1]. The compound crystallizes into a monoclinic syngony (space group $P2_1/c$) with the lattice parameters $a = 7.06228(9)$ Å, $b = 8.3378(1)$ Å, $c = 8.3465(1)$ Å, $\beta = 93.577(1)°$, $Z = 8$. Its structure contains isolated tetrahedrons with BeD_4 and Li atoms in between (Fig. 1) and remains practically unchanged down to 8 K. The determination of the crystal structure of Li_2BeD_4 is the first real result on trihydrides in the Li–Be–H system. It has demonstrated the capability of the state-of-the-art structural processing programs to directly determine such structures from powder diffraction spectra, as well as the advantages of a complimentary use of the neutron and X-ray diffraction data to obtain structural information on systems consisting of the lightest atoms.

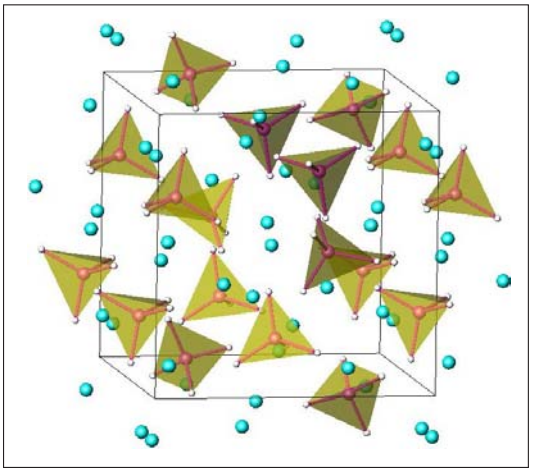

Fig. 1. The crystal structure of the compound Li_2BeD_4, restored from the neutron diffraction data

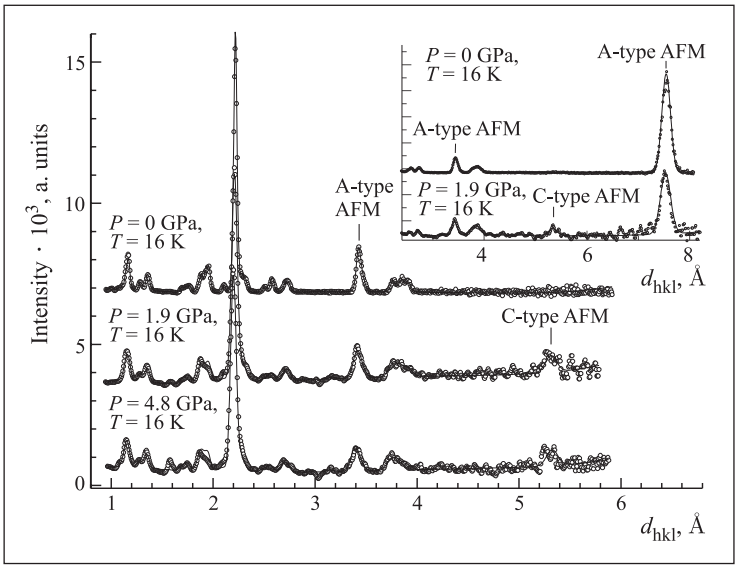

Fig. 2. The sections of the neutron diffraction spectra of $Pr_{0.44}Sr_{0.56}MnO_3$ measured at the pressures $P = 0$, 1.9, 4.8 GPa and the temperature $T = 16$ K and processed by the Rietveld method. As the temperature increases, a rise of the new AFM phase of the C type is observed

On the DN-12 diffractometer the effects of high pressures (up to 5 GPa) and low temperatures (in the range from 15 to 300 K) on the atomic and magnetic structures of the manganites $Pr_{1-x}Sr_xMnO_3$ ($x = 0.5$, 0.56) have been studied [2]. At normal pressure the compounds $Pr_{0.44}Sr_{0.56}MnO_3$ and $Pr_{0.5}Sr_{0.5}MnO_3$ have a tetragonal structure (space group I4/mcm). In $Pr_{0.44}Sr_{0.56}MnO_3$ a phase transition to the A-type antiferromagnetic (AFM) phase (Fig. 2), accompanied by a structural phase transition from tetragonal to orthorhombic structure (space group Fmmm), is observed with decreasing temperature. In $Pr_{0.5}Sr_{0.5}MnO_3$, with decreasing temperature, transitions to the intermediate tetragonal ferromagnetic (FM) and low-temperature orthorhombic A-type AFM phase are noted (Fig. 2). At high pressures, $P \approx 2$ GPa, in $Pr_{0.44}Sr_{0.56}MnO_3$ a new tetragonal C-type AFM phase appears and coexists with the original orthorhombic A-type phase in the region of low temperatures. In $Pr_{0.5}Sr_{0.5}MnO_3$ the effect of high pressures results in a significant increase in the temperature of the phase transition from tetragonal FM phase to orthorhombic AFM phase of the A type. In the low-temperature region the coexistence of the original orthorhombic A-type AFM phase with the tetragonal phase, which does not show evidence of the long-range magnetic order, is observed.

The scientific programme at the EPSILON and SKAT diffractometers was focused on investigations of internal stresses in polycrystalline materials (mainly rocks), texture analysis of rocks and determination of anisotropic physical properties of rocks from crystallographic textures. In particular, the studies of residual stresses in marble-based construction materials aimed at gaining a better understanding of the processes causing deformations in various constructions have been carried out [3].

For the first time the dynamics of the $\alpha-\beta$ transition in a rock sample (quartzite) has been studied by means of neutron diffraction and acoustic emission (AE) [4]. The values of internal stresses were estimated based on the detected changes in interplanar spacings of the crystalline lattice during the $\alpha - \beta$ transition. They were found to be several times higher than the mechanical stresses applied to the sample. Upon completion of the $\alpha-\beta$ transition there appeared flashes of AE with the intensity two orders of magnitude higher than the mean level of AE caused by thermal cracking of the sample on heating. The occurrence of outbreaks of elastic AE vibrations during a phase transition in quartz, a rock-forming mineral of the Earth crust, points to a discrete behaviour of the observed instability. It is not improbable that such phenomena may contribute to the development of an earthquake centre as a consequence of changes in the strained state of the medium or a trigger effect.

Inelastic Neutron Scattering. On the DIN-2PI inelastic scattering spectrometer, a comparison of the experimental data for the system sodium–lead with the calculated spectra has been performed based on the molecular dynamic simulations [5]. It has been concluded that at low concentrations of the admixture, $C_{Pb} \sim 10$ a.w. % and lower, there are no Na_4Pb-type clusters in significant quantities, and dissolved lead is present in the atomic state in the melt. This conclusion makes it possible to estimate the thermodynamical and physicochemical parameters of the melt more correctly.

On the NERA-PR spectrometer the experiments and modeling of the vibration state density function in solid

methanol with different types of deuteration (CH_3OH, CH_3OD, CD_3OH, CD_3OD) have been carried out. It has been demonstrated that solid methanol may be effectively used as a standard to estimate the quality of computer simulations of molecular dynamics both in crystalline and amorphous phases [6].

Reflectometry of Polarized Neutrons. On the REMUR polarized neutron reflectometer, the phenomenon of superconductivity and magnetism on the interface of a superconductor and a ferromagnet has been studied [7]. In particular, layer structures with coexisting periodic structures Fe/V plus bilayers V/Fe and V/$Fe_{0.66}V_{0.34}$ composed of superconducting layers of vanadium and ferromagnetic layers of iron have been investigated. The effect of superconductivity on magnetism has been demonstrated to depend strongly on the composition and structure of the magnetic layer.

Small-Angle Neutron Scattering. On the YuMO small-angle neutron scattering set-up, a number of polymeric systems, dendrimers, as well as mixed solutions of polymers and surfactants, have been studied. The studies of the structure of polycarbosilane dendrimers with different molecular structures have revealed structural peculiarities of stacking of end groups of dendrimers, namely their layered character. This may account for a restraint in the growth of dendrimers with increasing generation degree [8].

Small-angle neutron scattering with contrast variation experiments on highly stable water-based magnetic liquids have been conducted. The parameters of colloidal particles of liquids at various concentrations of dispersed magnetic substance (magnetite) have been obtained. The structure of the given liquids has been compared with less stable water samples that use other surfactants for stabilization, as well as with highly stable magnetic liquids on the basis of nonpolar carriers, such as benzol [9].

The coagulation of water dispersions of fullerenes [10] on addition of various salts has been investigated. Also, the time evolution of the absorption spectra of visible and ultraviolet radiation has been analyzed. The concentration of fullerenes in solutions has been found to decrease monotonically on addition of salt. This confirms the charge character of stabilization of colloidal particles in the given systems. The measured coagulation thresholds differ significantly from the data reported earlier. The experiments and preliminary treatment of the data on small-angle neutron scattering from coagulating water solutions of fullerenes in a real time mode have been carried out. The dynamics of growth of fullerene clusters and their concentration in solutions on coagulation have been estimated.

Neutron diffraction studies of the structure of *Stratum Corneum* model membranes have been carried out [11]. The structure of the mixed four-component system ceramide 6/cholesterol/ palmitic acid/cholesterol sulfate with various weight ratios of components and a low level of hydration has been investigated. The position of cholesterol in a lipid bilayer has been determined. The distribution function of water in the bilayer has been measured. It has been established that *Stratum Corneum* model membranes have low hydration of the intermembranous space as compared to phospholipids.

Main Methodological Results. The modernization of the REMUR reflectometer at the IBR-2 pulsed reactor has been carried out. As a result, the radiation background in the spectrometer has been reduced and the intensity of the neutron beam upon leaving a multichannel polarizer has increased. In the spectrometer the design of two mirror-polarizers is realized, which makes it possible to considerably increase the neutron beam polarization. The new software for the spectrometer based on the use of a VME-PSI adapter has been designed to enhance the performance reliability.

The modernization of the REFLEX reflectometer has been performed. Test measurements on the set-up in September–October 2004 demonstrated that as a result of a shift of the mechanical chopper the working area of the thermal neutron spectra increased from $\Delta\lambda = 5$ to 10 Å, which considerably extended the range of the detected values of momentum transfer of the scattered neutrons.

In accordance with the plan, on the DIN-2PI spectrometer the designing of a new case of the TS-3000M thermostat has been completed. The design drawings for the modernized variant of a shell for the thermostat case have been worked out. The unit of the radiation screens has been reconstructed. The application of new materials, specifically tungsten–rhenium alloys, that are easier prepared in practice than alloys based on pure tungsten, has made the construction more convenient for varying the number of screens and their material and thickness depending on the parameters of experiments.

On the REMUR reflectometer a new algorithm for the implementation of the different theoretical approaches to calculate diffusion scattering in neutron reflectometry experiments has been developed. The computer software packages for model calculations and fitting of the experimental data on neutron scattering from magnetic multilayered nanostructures have been designed. New programs allow one to process the experimental data more correctly and to study proximity effects in the scale interval of 1–10^4 nm.

In the biophysical research group, the software to describe the inner membrane structure of lipid vesicles by using small-angle neutron scattering data has been designed. The computer programs are based on the hydrophobic-hydrophilic model of bilayers with a linear function of water distribution and on the model of separated form factors. The work of the software has been demonstrated on the example of several lipid systems studied experimentally by means of small-angle neutron scattering.

Experimental Investigations. In 2004 the FLNP experimental investigation programme 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 centres in Russia, Bulgaria, Poland, Czechia, Germany, the Republic of Korea, France, the USA, and Japan.

During the reported year, the analysis of the data obtained in the experiments conducted in 2002–2003 to search for the negative neutron p resonance in lead isotopes was completed [12]. With the purpose of refining the obtained results, the gamma spectrometer COCOS has been prepared for reconstruction to increase its effectiveness and processing speed.

To develop works aimed at obtaining data on the outputs and decay constants of groups of delay neutrons in the fission of minor actinides, the modernization of the Izomer set-up at IBR-2 was carried out. The first measurements of ^{235}U were performed with the modernized set-up. A fission chamber was constructed, making it possible to measure delay neutrons for ^{245}Cm.

At the EG-5 generator of FLNP, experiments to measure the energy dependence of the angular distribution coefficients in the reaction $^{14}\mathrm{N}(n,p)^{14}\mathrm{C}$ for the neutron energy interval from $\sim$ 10 keV to $\sim$ 1 MeV started [13]. Investigations of the interference effects of s and p resonances in the reaction (n,p) are of interest from the viewpoint of obtaining more complete spectroscopic information about p resonances and having a more precise interpretation of the measurement results of P-odd effects. The angular distribution data for such spectra are also of importance for the understanding of what causes such strong discrepancies (by a factor of 2–3) in the Maxwellian spectrum–averaged cross section values at stellar temperatures obtained in a number of works. The forward–backward correlation $\alpha_{\mathrm{fb}} = (4.2 \pm 4.0) \cdot 10^{-2}$ not accounting for the background was obtained.

The final measurements under the nTOF collaboration programme, the investigations of the nature of vibrational resonances in neutron-induced fission and obtaining of fission cross-section data for the solution of ADS system–related and nuclear waste burning problems were completed. By using the detector FIC1, measurements of neutron-induced fission cross sections were performed with the target isotopes ^{233}U, ^{235}U, ^{238}U, ^{241}Am, ^{243}Am, ^{245}Cm with a record energy resolution in the neutron energy range 0.01 eV–200 MeV. In addition, the new ionization chamber made it possible to measure, at the same time, the forward–backward asymmetry of fission fragments from the reaction $^{236}\mathrm{U}(n,f)$ in the vicinity of the fission threshold. It was a first attempt to investigate interference effects in vibrational resonances.

On the beam PF1 of the reactor at ILL (Grenoble), an experiment to investigate mass–energy correlations in the neutron-induced triple fission of ^{235}U was conducted [14]. The fission fragments were measured with a fast double ionization chamber and light charged particles were registered with high-resolution ΔE–E telescopes, which make it possible to identify the particles ranging from carbon to beryllium isotopes by their charge and mass, as well as to measure their energy and angular distributions. There were obtained preliminary results on the output, energy and angular distributions of light charged particles and investigated some properties of quadruple fission with simultaneous emission of two α particles or an α particle and tritium.

Under the programme for the preparation of experiments to verify possible violation of time invariance by using an optically polarized gaseous target (in cooperation with KEK, Japan), the set-up for the measurement of ^{3}He polarization by the neutron transmission method was modernized. The modification was made for the purpose of measuring the pseudomagnetism of the polarized nuclei ^{129}Xe and ^{131}Xe. The pseudomagnetic interaction of polarized neutrons with polarized Xe nuclei must result in the rotation of the polarized beam plane. The resulting experimental effect will then demonstrate itself as a difference in the counts of the detector for the measurements with polarized and unpolarized Xe. In practice, there will be measured the difference in the transmission of the polarized neutron beam in the region 0.02–0.1 eV.

Work continued on the development of the measuring procedures of T-invariance effects in neutron nuclear interactions: three-vector P-odd T-odd and five-vector P-even T-even correlation of the vectors I, k, s. Neutronographic investigations of the structure of a $LaAlO_3$ monocrystal sample were conducted and showed the applicability of the sample for performing trial experiments of the dynamic polarization of ^{139}La nuclei for the purpose of studying the first-type correlations. To investigate the second-type correlations, the alignment of ^{127}I nuclei in a monocrystal of iodine at low temperatures was estimated. It was found that a measurement-suitable alignment of $\sim 50\%$ can be achieved by cooling the iodine monocrystal to $\sim 20{-}50$ mK. To verify the idea of the dynamic alignment of nuclei, a monocrystal of lutetia niobite with a paramagnetic admixture was prepared (together with ITEP), the EPR spectra of the crystal were measured, a trial run of dynamic alignment was performed, which showed the necessity of creation of a more sensitive and a wider range Q meter that would not destroy the alignment.

The new method for the determination of the n,e-scattering length b_{ne} developed in 2003 and published

in the JINR Communications E3-2003-183 and P3-2003-232 was applied for processing the literature data on the structural factor $S(q)$ of gaseous krypton at various pressures. The result is a new value for $b_{ne} = -(1.53 \pm 0.24) \cdot 10^{-3}$ fm.

In the framework of the plan of the preparation of direct measurements of the nn-scattering length at the pulsed reactor JAGUAR (Snezhinsk, Russia), the fluxes of fast, epithermal and thermal neutrons over the total depth ($\sim$ 12 m) of the under-reactor well were measured in satisfactory agreement with the calculated values, which justifies the continuation of work to realize the experiment on neutron–neutron scattering [15]. The effect and background were calculated for the nn-scattering experiment. They are in good agreement with the results of an independent calculation by VNIITF (Snezhinsk, Russia). FLNP manufactured an over-reactor vacuum channel and then shipped it to Snezhinsk.

At the reactor at ILL (Grenoble) the UCN storage experiment was conducted. As a result, an anomalous UCN leakage channel from vessels with perfect walls made from monocrystalline sapphire was demonstrated to exist over a wide temperature range (70–800 K).

The new experiment of UCN time focusing was performed. A focusing effectiveness of about 25% of theoretically feasible 40% for the diffraction lattice used was reached. The effectiveness deficiency is due to an insufficient quality of the lattice. Detail measurements of the UCN spectra of diffraction on a moving lattice were conducted. The results allow a quantitative experiment-to-theory comparison to be conducted and are in good agreement with the calculated data. On the basis of the measurements the transversal coherence length of the free-neutron wave function was estimated. The time-of-flight method was tested. The time resolution $\Delta t/t \approx 3\%$ was achieved. In the process of preparation is the experiment of the observation of changes in the energy as the neutron goes through an accelerated substance. The existence of the effect follows from the principle of equivalence and detail neutron-optical calculations. An experiment of precise measurements of the neutron gravity acceleration was proposed. The aim of the experiment is to verify the principle of equivalence for the neutron.

The problem of completely model-absent determination of the density of levels in a fixed interval of their spins and reduced probability of their exciting or discharging dipole electric and magnetic gamma transitions at excitation energies around the neutron binding energy was solved [16]. No analogous experimental data exist in the world. The employed method uses the experimental data on the cascade population of levels excited at thermal neutron capture up to excitation energies not less than 3–5 MeV and the intensities of the earlier measured two-step cascades to the low-lying levels of the nuclei. A comparison of the data makes it possible to estimate experimentally the degree of the difference in the energy dependence of the radiative strength functions of the primary and secondary transitions in the cascade gamma decay of the compound state and, with accounting for the difference, determine, without any additional hypotheses, the interval of probable densities of levels with a minimum systematic error to date. Such data were obtained for 19 nuclei from the region $39 < A < 201$. The main physical conclusion that follows from their analysis is: in the majority of nuclei a quite essential change in the structure of the excited levels is observed in the regions around 20, 50 and 80% of the neutron binding energy. Within the framework of the existing models of level density, the observed effect may be related to breakdown of at least two Cooper pairs of nucleons.

In the **Field of Theoretical Physics** a theoretical investigation of pair correlations of neutrons with small relative momenta formed in the process of fission of atomic nuclei was conducted. It was shown, in particular, that the correlation method is, in principle, possible to be applied to the determination of the portion of pairs of prompt («pre-scission» and «scission») neutrons in the total number of neutron pairs registered at fission (as, in fact, for conventional fission neutrons there are no pair correlations).

Applied Research. In 2004 work continued on the study of the atmospheric deposition of heavy metals by means of biomonitoring, NAA and GIS technologies (REGATA project) in the territory of Central Russia (Tula, Tver, Yaroslavl regions and south-east of Moscow region) [17], as well as in Armenia (Sevan) and Vietnam. Organizational and methodological work was done to get ready for the next European simultaneous collection of moss-biomonitors of heavy-metal atmospheric deposition (moss-survey) to be held in 2005 in a number of JINR Member and non-Member states (Belarus, Ukraine, Bulgaria, Bosnia, Macedonia, Poland, Romania, Serbia, Slovakia, Turkey (European part)).

A comparative analysis of various biomonitors (lichens, tree bark) and of soils from the region of the oil-refining plant in Constance (Romania) was carried out. The possibility of using biomonitors for the assessment of the influence of the plant on the natural environment of the recreational area on the Black Sea coast of Romania was demonstrated.

Neutron activation analysis of over 250 samples of vegetation and animal origin was conducted under the Coordination Programme (2002–2005) and the Project for Technical Cooperation with IAEA (2003–2005) for supervision and quality of food products grown in the conditions of strong antropogenic pollution.

In 2004 the final stage of work under the project «Monitoring of Working Places and Occupational Health of Personnel Engaged in the Production of Phosphate Fertilizers at Plants in Russia, Uzbekistan, Poland and Romania» (European Programme 5, Copernicus) was completed. The results of analysis of ecological

samples (raw materials, soils, sediments, water and air filters) and of human biosubstrates (hair, nails, urine and teeth) were presented at two international conferences and are submitted for publication.

Work to develop new pharmaceuticals and sorbents on the basis of the blue-green alga *Spirulina platensis*, in cooperation with a group of biophysicists at the Institute of Physics of the Georgian Academy of Sciences, continued. Part of the investigations was conducted at the reactor of the University of Texas, USA. In 2004 the patent for the method of production of chrome-containing *Spirulina* biomass was granted.

Analysis of the data from the study of the effect of neutrons lying in the fission spectrum on the physical properties of fine-crystal diamonds created at the Institute of Physics of Solid Matter and Semiconductors of the National Academy of Sciences of Belarus (Minsk) was completed.

NEUTRON SOURCES

The IBR-2 Pulsed Reactor. In 2004 the IBR-2 reactor operated in accordance with the approved working schedule. It has operated ~ 1400 h in 4 cycles with the power $W = 1.5$ MW. The main results of the IBR-2 modernization in 2004 are:

• Movable Reflector (MR-3) — chief task of the year. At the beginning of February 2004, the MR-3 assembling was fully completed on the FLNP test-bench and MR-3 was started up at rated speed. The MR-3 investigation programme to measure vibration characteristics in the modes of 5 and 10 Hz was carried out. All MR-3 parameters corresponded to the engineering requirements. A life test was also carried out and it revealed no deviations in the MR-3 operation; all systems functioned correctly. Later the machine was moved into the reactor building. The MR-3 mounting was carried out at the regular place near the reactor, tests were conducted, MR-3 was commissioned by Gosatomnadzor.

From 16 June to 23 July 2004 the programme to start and investigate the main characteristics of the IBR-2 with a new MR-3 was performed: the efficiency curve of the movable reflector was measured in the stationary mode, the efficiencies of the adjustment units were measured, the efficient reactivity margin was determined, an additional loading of the reactor with one fuel assembly was carried out, the pulse shape and pulse fluctuations up to 1.5 MW were measured. The obtained results are close to the calculated ones.

Thus, a very important stage of the IBR-2 modernization to create a new MR-3 was completed.

On 13 September 2004, operation for physical experiment in accordance with the working schedule started.

• Manufacturing of fuel elements was completed at the industrial enterprise Mayak. In April 2004, the fuel elements were delivered to JINR. The activities to prepare a working floor for the assembling of the fuel elements into a fuel assembly are under way.

• Work on the development of design documentation for stationary reflectors and rolling shieldings was completed.

• Manufacturing of a new reactor jacket continued in NIKIET. Manufacturing of rolling shieldings and stationary reflectors started in EW JINR.

• Development of design documentation (DD) on CSS of the IBR-2 continued.

• Development of DD on the moderator complex for the IBR-2M reactor started, manufacturing of the Cold Helium Facility (CHF) continued.

To provide for the work on the IBR-2 modernization in 2004, a sum of 626 k$, including JINR — 278 k$, Federal Agency of Atomic Energy — 348 k$, was spent as of 1 December 2004.

The IREN Project. The IREN project working plan for 2004 included:

1) completion of IBR-30 dismantling;

2) shipment of fuel for the multiplying target from the industrial enterprise Mayak to JINR;

3) assembling of the main equipment of the linac LUE-200 in bldg. 43.

The amount of minimal financing to implement the plan is 250 k$. In fact, in March about half the requested amount with guaranteed financing of the first two stages only was assigned. In addition, a considerable sum (about 50 k$) was to be paid to NIKIET for the preparation of design documentation for manufacturing of the IREN multiplying target performed in 2002–2003.

Up to mid-August the implementation of the working schedule for dismantling of the IBR-30 reactor was carried out with insignificant delays in spite of a very difficult financial situation at JINR. However, on 19 August 2004 the decision of the Government of the Russian Federation on the reorganization of some Russian authorities (including Gosatomnadzor and the Ministry of Ecology) responsible for licensing of activities in the field of atomic energy use was enforced. The decision delayed considerably the granting of a license for putting into operation of the storage area for IBR-30 radioactive elements in bldg. 117/6, making it impossible to complete the IBR-30 dismantling in 2004.

Negotiations with representatives of the reorganized Rostekhnadzor, which includes the former Gosatomnadzor, show that the necessary licenses may be granted in the first quarter of 2005 and, correspondingly, the dismantling of the reactor may be performed in the summer of 2005. It is important to note that the activities outlined in the 2004 working plan as to be implemented by the FLNP services were successfully completed.

A large amount of work to prepare the transportation of fuel for the IREN multiplying target was carried out and now everything is ready for fuel transportation from the industrial enterprise Mayak. The fuel is to be delivered to JINR by the end of 2004.

Due to practical absence of financing, work to mount the equipment for the linac LUE-200 was mainly implemented with the help of internal resources. However, certain advances were made in the construction of the electron gun, focusing elements and RF systems. The pulsed electron source was finally adjusted to the designed parameters, which was proved by its successful testing. The main equipment of the RF modulator was installed at a regular place in the accelerator halls of bldg. 43, FLNP. At the full-scale RF test-bench, the system of doubling the klystron power supply was successfully tested. But the absence of funds for purchasing the necessary cables and a number of components led to a delay in the completion of mounting of the main equipment of the linac LUE-200.

The manufacturing of the elements for the magnetic focusing system at LPP and VBLHE stopped in September due to lack of financing. By now about 70% of the whole focusing system has been manufactured. Testing of its elements at the recently created LPP stand for magnetometric measurements shows a good quality of the manufactured coils and quadrupole lenses.

Taking into account the recommendations of the 21st session of PAC for Nuclear Physics, the IREN project leaders proposed to prolong theme 06-4-0993-94/2004 for one year with top priority. The main tasks to be implemented in the course of 2005 are:

- completion of the dismantling of the IBR-30 reactor and receiving the license for the IREN construction;
- receiving the design documentation for the multiplying target from NIKIET and choosing its producers with the aim of real estimation of the final cost of the IREN project;
- detail design of the IREN backup systems in the amount necessary for assembling the equipment of the linac LUE-200;
- completion of the assembly of the equipment of the linac LUE-200 in bldg. 43, FLNP.

The realization requires financing that would not exceed the average annual funding of the IREN project and the total budget of theme 06-4-0993-94/2005. The execution of the stated tasks can be considered as a basis for making strategic decisions on the project future.

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

In 2004 work under theme 1052 was focused on the following main activities:

— creation of neutron detectors;

— development of sample environment systems;

— development of data acquisition systems and computing infrastructure.

Creation of Neutron Detectors. ***Infrastructure.*** To provide necessary conditions for manufacturing and testing of the different types of neutron PSDs, a clean room has been put into service at FLNP. It consists of three parts: a tambour, clean room and a clean box inside the clean room. At present, the air purity in the clean room is better than class 7 according to ISO 14644-1 standard, which is enough to assembly gas MWPC. For assembling microstrip detectors a laminar cabinet will be used (shipped to Dubna in October 2004 and being assembled now).

A gas stand has been put into use, allowing oil-free pumping out of the detector chambers and filling them with various gas mixtures under pressure. The gas stand, together with other technological equipment, is placed in the tambour of the clean room.

In cooperation with specialists from IPM RAS (Nizhni Novgorod, Russia), the wire winding system (based on comb-like spacers made of siliceous monocrystal) for manufacturing multiwire proportional chambers has been significantly improved. This has been achieved by the use of spacers made of silicon monocrystals, where grooves for laying wires are etched with a high degree of accuracy (several microns). The system will be used to produce anode and cathode planes for a position-sensitive monitor and 1D detectors.

Microstrip neutron detector with «virtual» cathode. In cooperation with the detector group of the Institute Laue-Langevin, a Microstrip Gas Counter (MSGC) has been created using the «virtual» cathode technology. The drawings of the substrate plate were placed at our disposal by ILL, substrate plates were manufactured at IPM RAS (Nizhni Novgorod, Russia) and successfully tested at ILL in 2003. The original design of the detector case was developed and manufactured at FLNP.

The first results of the detector testing with a ^{252}Cf neutron source are shown in Figs. 3 and 4. Figure 3 il-

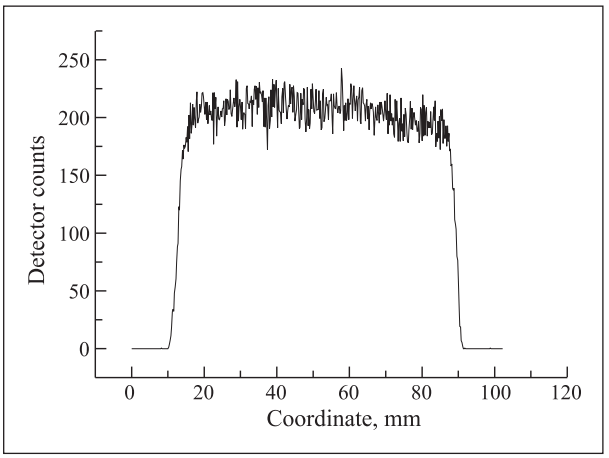

Fig. 3. Uniform distribution for one coordinate

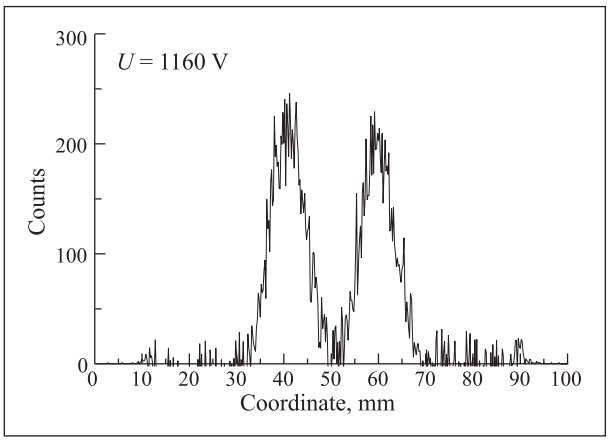

Fig. 4. One-coordinate image of two slits in the collimation mask

lustrates the result of uniform irradiation of the detector for one coordinate. In Fig. 4 the result of irradiation of the detector with a collimation mask made of borated polyethylene (5 cm thick with two 5-mm slits at 10-mm distance) is presented. The geometrical dimensions of the slit images on the detector plane were 10 mm. The gas mixture (1 bar) consisted of ^{3}He (0.5 bar) and CF_4 (0.5 bar), so the coordinate resolution was only 5 mm. At a working pressure of 2 bar of CF_4 the coordinate resolution is expected to be 1.5 mm.

Prototype of one-dimensional PSD for the Fourier Stress Diffractometer. The design of a 1D wide-aperture neutron PSD has been developed at FLNP. The detector parameters are listed in Table 1.

At the present time the manufacturing of the detector case is being completed in the JINR Experimental Workshop. The assembling and beam tests at the IBR-2 reactor are scheduled for the beginning of 2005. A similar detector will be produced in 2005 for the Institute of Metal Physics, of the RAS Ural Branch (Yekaterinburg) under the contract in force.

Position-sensitive monitor detector. Within a collaboration between FLNP and the Technical University

Table 1. 1D neutron PSD characteristics

Aperture, mm^2	200×80
Position resolution (FWHM) Δx, mm	1.5 (centre)
Efficiency (1 Å), %	40–45
Detector count rate R, kHz	up to 100
Readout	Delay line
Gas mixture	^{3}He + 0.25 CF_4 (6 atm)

Table 2. In-beam monitor characteristics

Sensitive area, mm^2	100×100
Position resolution (FWHM), mm	$\Delta x \approx 4$ $\Delta y \approx 4$
Sensitivity to thermal neutrons $S_{\rm th}$	10^{-3}–10^{-6}
Range of neutron wavelengths λ, Å	0.4–12
Detector count rate R, kHz	1–50
Readout	Delay lines

of Munich, the specifications on an in-beam position-sensitive monitor have been prepared [18, 19]. The detector is to be installed on a bent neutron guide outside the reactor hall of the FRM-II reactor. The detector will be a multiwire proportional chamber with a ^{3}He gas mixture. The main features of the detector are listed in Table 2.

At present the manufacturing of the detector main units is being completed at the JINR Experimental Workshop. Beam tests at IBR-2 and later at FRM-II are scheduled for the beginning of 2005.

Scintillation detectors. For the FSD spectrometer, 16 additional modules of the 90° scintillation detector with the ASTRA time focusing have been developed and manufactured. The detector electronics units have been made. The mechanical units for fixing the detector modules have been manufactured. At present the detectors are being assembled and tested.

Calculations have been made by the method of focusing surfaces of the geometry of detector sensitive layers to detect neutrons at scattering angles of 90 and 45°. For the DN-6 spectrometer it is proposed to produce a detector consisting of two rings. Each ring consists of 16 independent modules. The designs of the detector modules for both rings have been worked out, as well as the support of the detector modules. The project is submitted for approval by experimenters.

Development of Sample Environment Systems. A temperature control system has been developed on the basis of a Eurotherm 902 controller for the equipment of the Epsilon spectrometer.

To adjust the monochromator (Si monocrystal with a bending device, made at NPI (Rez, Czech Republic) for the DSD spectrometer of the IVV-2M reactor of Sverdlovsk branch of the Dollezhal Research and Development Institute of Power Engineering), a goniometric device with five degrees of freedom (two swinging motions and two linear motions in mutually perpendicular directions and rotation around a vertical axis) has been manufactured.

For the DSD spectrometer a control system for mechanical devices has been made as well. The control system is realized in CAMAC standard with a microcontroller control block for SMC step motors on the basis of a 80C167 microprocessor connected to a personal computer via a serial communication line. Four-channel commutators-amplifiers SMD-2A are used as a power drive of four-phase step motors (a total of 18). The system can be extended by connecting SMD-2A additional blocks to the SMC controller.

The range of functions of the control system of the step motors of the SPN spectrometer has been extended (neutron guide platform movement, control over a two-coordinate diaphragm, as well as over rotating actuators).

A positioning device with three degrees of freedom has been manufactured for a variable diaphragm of the neutron beam of the HRFD spectrometer. Control is exercised via the control system of the Huber goniometer.

On the Isomer spectrometer the chopper control system on the basis of the microcontroller control unit CC-11 has been put into operation. The phase equalization accuracy is 25–30 μs. If the phase goes beyond a specified range, the measurement is interrupted by blocking reactor starts in the KOMA spectrometric data accumulation system.

The design documentation for a cryostat with a refrigerator based on the pulse tubes PT405 (Cryomech, USA) for operation in the temperature range of 3–250 K has been worked out. At the present time the cryostat components are being manufactured in the FLNP experimental workshops. Such a cryostat with a refrigerator based on pulse tubes is made for the first time in Russia.

A sorption pumped microrefrigerator to obtain temperatures down to 0.3 K has been designed. The microrefrigerator is mounted on a platform having a temperature of 4.2 K, which can be obtained in an ordinary helium cryostat or by means of an appropriate closed cycle refrigerator. In our case the microrefrigerator is installed at the bottom of a helium optical cryostat. This work has been carried out in cooperation with the Institute of Radioelectronics of RAS (Moscow) and the Institute of Applied Physics of RAS (Nizhni Novgorod).

Development of Data Acquisition Systems and Computing Infrastructure. In 2004 as part of work to integrate PC into DAQ systems, the creation of the new unified instrument control software Sonix+ was completed [20–22]. The VME/OS-9 platform has been replaced with PC/Windows with Python being used as a script language. The use of PC with Windows OS for instrument control reduces the overall cost of the system. The existing VME electronics can be connected to PC via a VME-PCI adapter. Due to the structural changes, the Sonix+ software package has become more powerful, flexible and easier for users and, at the same time, more unified and easily extendable.

At the moment the Sonix+ successfully operates on the NERA-PR spectrometer. The extended version of the Sonix+ for the REMUR and YuMO spectrometers is in the final stage of testing.

The software for a delay line [23] readout PCI DAQ board (FPGA, DSP and PC components) for MWPC detectors has been tested and optimized to enhance reliability and raise the acquisition rate up to 10^6 events per second.

An analysis of engineering solutions for MSGC DAQ electronics with individual strip readout has been performed. As a result, it was decided to order two-coordinate electronics for charge division readout (designed at ILL) from the SYNERGIECONCEPT Company (Grenoble, France). The USB interface for this electronics and corresponding software is to be designed at FLNP.

In the LAN segment of the experimental halls of the IBR-2 reactor, two Switch Catalist 2950C-24, together with Uninterrupted Power Supplies, have been installed and put into operation. The modernization of the power supply system of electronics and computers has been performed for the YuMO and FSD spectrometers as well.

The development of new electronic blocks with USB interfaces for data acquisition systems of point detectors and multiwire PSDs with individual data readout from each wire has started.

A number of detector electronics blocks have been developed, manufactured, tested and put into operation on the IBR-2 spectrometers.

Through the reported year the equipment of the spectrometers has been prepared for operation and serviced during a total of 4 cycles of the IBR-2 reactor.

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