JOINT INSTITUTE FOR NUCLEAR RESEARCH

2004-200

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SCIENTIFIC PROGRAMME OF THE FRANK LABORATORY OF NEUTRON PHYSICS:

Report for 2004 and Prospects for 2005

Report to the 97th Session
of the JINR Scientific Council,
January 20–21, 2005

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INTRODUCTION

In 2004, the FLNP scientific program was realized under five research themes of the JINR Plan for Scientific Research and International Scientific and Technical Cooperation (PSRISTC) and it was aimed at obtaining new results in condensed matter physics (theme 07-4-1031-99/2008 "Neutron Investigations of Structure and Dynamics of Condensed Matter", headed by V.L.Aksenov and A.M.Balagurov) and neutron nuclear physics (theme 06-4-1036-2001/2004 "Nuclear Physics with Neutrons – Fundamental and Applied Investigations", headed by W.I.Furman and V.N.Shvetsov). To effect scientific research, work to develop, modernize, and construct the FLNP basic facilities, IBR-2 (theme 07-4-0851-87/2007 "Upgrade of the IBR-2 Complex", headed by V.D.Ananiev) and IREN (theme 06-4-0993-94/2004 "IREN Project", headed by W.I.Furman and I.N.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.V.Belushkin and V.I.Prihodko) continued. Also, FLNP took part in the JINR themes: «ATLAS: General-Purpose pp Experiment at CERN's Large Hadron Collider» (theme 02-0-1007-94/2005, headed by N.A.Russakovich), «Theoretical and Experimental Investigations of the Electronuclear Method of Energy Production and Radioactive Waste Transmutation» (theme 03-0-1008-95/2005, headed by A.N.Sissakian, I.V.Puzynin , S.Taczanowsky, I.A.Shelaev).

This report contains a brief account of 2004 scientific results and outlines the 2004 year plans of the Laboratory reflected in the JINR Plan for Scientific Research (PSRISTC) submitted for approval to the present session of the JINR Scientific Council. The FLNP annual report for 2004 will give a more detail account of 2004 results.

1. 2004 SCIENTIFIC RESULTS

1.1. Condensed Matter Physics

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

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 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). With decreasing temperature in $Pr_{0.44}Sr_{0.56}MnO_3$ a phase transition to the antiferromagnetic (AFM) phase of the A-type accompanied by a structural phase transition from tetragonal to orthorhombic structure (space group Fmmm) is observed. In $Pr_{0.5}Sr_{0.5}MnO_3$ with decreasing temperature transitions to the intermediate tetragonal ferromagnetic (FM) and low-temperature orthorhombic AFM phase of the A-type are noted. At high pressures, $P \approx 2$ Gpa, in $Pr_{0.44}Sr_{0.56}MnO_3$ a new tetragonal AFM phase of the C-type appears and coexists with the original orthorhombic phase of the A-type 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 region of low temperatures the coexistence of the original orthorhombic AFM phase of the A-type with the tetragonal phase, which does not show evidence of the long-range magnetic order, is observed.

The scientific program 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 α-β-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 basing on the detected changes in interplanar spacings of the crystalline lattice during the α-β-transition. They were found to be several times higher than the mechanical stresses applied to the sample. Upon completion of the α-β-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 rockforming mineral of the Earth crust, points to a discrete behavior of the observed instability. It is not improbable that such phenomena may contribute to the development of an earthquake center as a consequence of changes in the strained state of the medium or a trigger effect.

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 basing on the molecular dynamic simulations [5]. It has been concluded that at low concentrations of the admixture, C_{Pb} ~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 physical-chemical 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].

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.

On the YuMO small-angle neutron scattering setup 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 experiments with contrast variation 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 a 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 setup in September-October, 2004 demonstrated that as a result of a shift of the mechanical chopper the working part of the thermal neutron spectra increased from $\Delta\lambda$=5Å to 10Å, 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 more practically executable than alloys based on pure tungsten, has made the construction more convenient for varying the number of screens and their materials 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 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 $1 \div 10^4$ nm.

In the biophysical research group the software to describe the inner membrane structure of lipid vesicles 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 several lipid systems studied experimentally by means of small-angle neutron scattering.

1.2. Neutron Nuclear Physics

In 2004 the FLNP experimental investigation program in neutron nuclear physics included traditional directions of fundamental and applied research carried out on the IBR-2 and EG-5 beams and in collaboration with nuclear centers in Russia, Bulgaria, Poland, Czechia, Germany, Republic of Korea, France, USA, and Japan.

During the reported year 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. With the purpose of refining of the obtained results the gamma-spectrometer COCOS is 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» setup at IBR-2 was carried out. The first measurements of U-235 were performed with the modernized setup. A fission chamber was constructed making it possible to measure delay neutrons for ^{245}Cm.

At the EG-5 generator of FLNP JINR experiments to measure the energy dependence of the angular distribution coefficients in the reaction ^{14}N(n,p)^{14}C for the neutron energy interval ~ 10 keV ~ 1 MeV started. 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 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 so 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 $\alpha_{fb} = (4.2 \pm 4.0)\cdot 10^{-2}$ not accounting for the background was obtained.

The final measurements under the program for collaboration nTOF, 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. Using the detector FIC1 measurements of neutron-induced fission cross sections were performed with the targets of the 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}U(n,f) in the vicinity of the fission threshold. It was the first attempt to investigate interference effects in vibrational resonances.

On the beam PF1 of the reactor in ILL (Grenoble) an experiment to investigate mass-energy correlations in the neutron-induced triple fission of ^{235}U was conducted. 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 by their charge and mass ranging from the isotopes of carbon to beryllium 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 program for the preparation of experiments to verify possible violation of time invariance using an optically polarized gaseous target (in cooperation with KEK, Japan) the setup for the measurement of ^{3}He polarization by the neutron transmission method was modernized. The modification was made for the purpose of the measurement of 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.

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, continued. 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 ~50% can be achieved by cooling the iodine monocrystal to ~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 the 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 last year and published in the JINR Communications E3-2003-183 and P3-2003-232 was applied for the processing of the literature data on the structural factor $S(q)$ of gaseous krypton at various pressures. The result is the 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) the fluxes of fast, epithermal and thermal neutrons over the total depth (~ 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. 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). In FLNP JINR a vacuum over-reactor channel was manufactured and shipped to Snezhinsk.

At the reactor in ILL (Grenoble) a UCN storage experiment was conducted. As a result, the existence of an anomalous UCN leakage channel from vessels with perfect walls made from monocrystalline sapphire was demonstrated 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 deficiency of the effectiveness 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 comparison with theory to be conducted and are in good agreement with the calculated. 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 and discharging dipole electric and magnetic gamma-transitions at excitation energies around the neutron binding energy was solved. 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 energies. Within the framework of the existing models of level density the observed effect may be related to break down 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 can, in principle, be applied for 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 to study atmospheric deposition of heavy metals by means of biomonitoring, NAA and GIS technologies (REGATA Project) over the territory of Central Russia (Tulskaia, Tverskaia, Yaroslavskai reagions and south-east of Moskovskaia region) as well as in Armenia (Sevan) and Vietnam, continued. Organizational and methodological work 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 (Belorussia, Ukraine, Bulgaria, Bosnia, Macedonia, Poland, Romania, Serbia, Slovakia, Turkey (European part)) was done.

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 Program (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 production of phosphate fertilizers at plants in Russia, Uzbekistan, Poland and Romania» (European Program 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 in 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 the production of the *Spirulina* biomass containing chrome was granted.

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

2. NEUTRON SOURCES

2.1. The IBR-2 Pulsed Reactor

In 2004 the IBR-2 reactor operated in accordance with the approved working schedule. It has operated ~ 100 hours in 3 cycles with the power W=1.5 MW.
Main results of the IBR-2 modernization in 2004:

1. 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 program 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 assembling was carried out at the regular place near the reactor, tests were conducted, MR-3 was approved to be put into service by Gosatomnadzor.

   From 16.06.2004 to 23.07.2004 the Program 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, efficiencies of the adjustment units were measured, the efficient reactivity margin was determined, an additional load of the reactor by one fuel assembly was carried out, pulse shape and pulse fluctuations up to 1,5 MWt 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 13.09.2004 an operation for physical experiment in accordance with the working schedule started.

2. Manufacturing of fuel elements was completed at the industrial enterprise «Maiak». In April, 2004, the fuel elements were delivered to JINR. The works to prepare a working floor for the assembling of the fuel elements into a fuel assembly are under way.
3. Works on the development of design documentation for stationary reflectors and rolling shieldings were completed.
4. Manufacturing of a new reactor jacket continued in NIKIET. Manufacturing of rolling shieldings and stationary reflectors started in JINR EW.
5. Development of design documentation (DD) on CSS of the IBR-2 continued.
6. Development of DD on the moderator complex for the IBR-2M reactor started, manufacturing of CHF continued.

To provide for the works 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 01.12.2004 .

2.2. 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 250k$. In fact, in March about half requested amount with guaranteed financing of the first two stages only was assigned. In addition, a considerable sum (about 50 k$) 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 in JINR. However, on 19.08.04 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 the activities in the field of atomic energy use was enforced. The decision has delayed considerably granting of a license for putting into operation of the storage of IBR-30 radioactive

elements, 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 next summer. It is important to note, that the works 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 the current year.

Due to practical absence of financing, works to mount the equipment for the linac LUE-200 were 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 a 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 scheduled completion of mounting of the main equipment of the linac LUE-200.

Manufacturing of the elements for the magnetic focusing system in LPP and VBLHE was 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 21-st 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:

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

The realization requires financing which does 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.

3. DEVELOPMENT OF THE IBR-2 SPECTROMETERS COMPLEX AND COMPUTING INFRASTRUCTURE

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.

3.1. 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 in 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) 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 last year. 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.1,2. Figure 1 illustrates the result of uniform irradiation of the detector for 1 coordinate. In Fig.2 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.

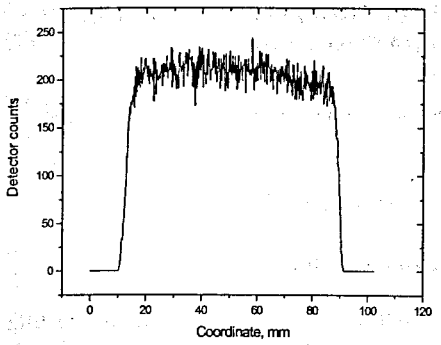

Fig.1. Uniform distribution for 1 coordinate

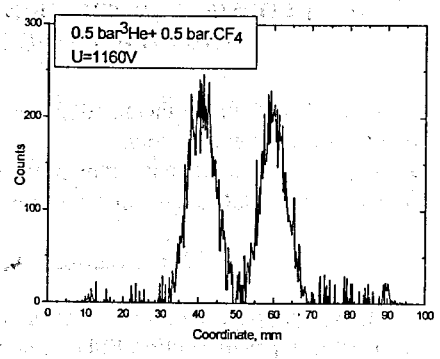

Fig.2. One coordinate image of two slits in the collimation mask

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.

Table 1. 1D neutron PSD characteristics

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

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

Position-sensitive monitor detector. Within collaboration between FLNP and Technical University of Munich the specifications on an in-beam position-sensitive monitor have been prepared. 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.

Table 2. In-beam monitor characteristics

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

At present the manufacturing of the detector main units is being completed at the central JINR workshops. 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.

3.2. 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 in NPI Rez, Czech Republic for the DSD spectrometer of the IVV-2M reactor of Sverdlovsk branch of A.N.Dollezhal Research and Development Institute of Power Engineering) a goniometric device with 5 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 4-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 3 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 250-3 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 RAS (Moscow) and the Institute of Applied Physics RAS (Nizhni Novgorod).

3.3. Development of data acquisition systems and computing infrastructure

In 2004 in the frame of works to integrate PC into DAQ systems the creation of the new unified instrument control software Sonix+ was completed. 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 simple 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 readout PCI DAQ board (FPGA, DSP and PC components) for MWPC detectors has been tested and optimized to enhance reliability and 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 been 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.

In 2004 under the theme fifteen papers were published.

4. SCIENTIFIC RESEARCH PLAN FOR 2005

The 2005 FLNP Scientific Research Plan contains 5 first priority themes.

Theme	Leader	Priority	Code
Neutron investigations of the structure and dynamics of condensed matter	V.L.Aksenov A.M.Balagurov	1	07-4-1031-99/2008
Nuclear physics with neutrons - fundamental and applied investigations	Yu.N.Copatch V.N.Shvetsov	1	06-4-1036-01/2007
Upgrading of the IBR-2 complex	V.D.Ananiev E.P.Shabalin	1	07-4-0851-87/2007
Construction of the IREN facility (Project IREN)	I.N.Meshkov W.I.Furman	1	06-4-0993-94/2005
Development and creation of elements of neutron spectrometers for condensed matter investigations	A.V.Belushkin V.I.Prikhodko	1	07-4-1052-04/2008

In the year 2005, in the framework of theme **1031** investigations in condensed matter will be carried out in the following directions:

Neutron diffraction investigations of the structure and properties of new crystalline materials.

Neutron diffraction investigations of the structure and properties of strongly correlated electron systems - complex oxides (manganites, vanadates, ruthenates), new superconductors (mercury compounds, bismu\-tha\-tes, etc.).

Neutron diffraction investigations of changes in the atomic and magnetic structure of crystalline materials under the action of high external pressures.

Investigations of internal stresses in voluminous industrial products, gradient, and composite materials.

Investigations of internal stresses in construction materials of nuclear reactors, industrial materials and products - composites, reinforced systems, metal ceramics, shape memory alloys.

Investigations of the structure and vibrational spectra of molecular complexes, verification of quantum-chemical model calculations of physicochemical properties of studied materials and getting an insight into microscopic mechanisms of phase transitions.

Investigations of the structure and dynamics of Pb-based alloys, melts of reactor materials and their oxides in the range of high temperatures up to 3000 K.

Investigations of the structure and dynamics of materials with superionic conductivity.

Determination of the structure and properties of polymeric films with magnetic impurities.

Measurement of parameters of magnons and phonons in low-dimensional systems.

Obtaining of new information on the relationship of the structure, physical properties and functioning of nanostructures in cells, including at high pressures.

Obtaining of new data on the structure of DNA-lipid complexes.

Determination of the structure of lipid complexes for drug transport (liposomes).

Investigations of cluster state of fullerenes in solutions.

Investigations of cluster formation in colloidal solutions.

Description of the structure of aqueous biocompatible magnetic liquids, quantitative description of aggregation processes in these liquids under the action of external magnetic fields.

Studying of biological macromolecular systems and molecular complexes for drug transport.

Determination of the influence of ionic strength on the structure, form of existence and rigidity of micelles in surfactants and colloids, determination of a connection between physicochemical properties and structure of micellar solutions.

Studying of structure of hydrophobic gels.

Neutron diffraction investigations of the structure, texture and physical properties of geological materials in order to get a deeper insight into the structure of lithosphere and the nature of seismic anisotropy.

New experimental data on optical and structural properties of heterogeneous systems with nanostructural clusters.

Creation of EXAFS - a spectrometer on the "Sibir-2" synchrotron radiation source in RSC "Kurchatov Institute" (Moscow).

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

Continuation of the development and construction of nuclear targets polarized by the dynamic pumping method for experiments of time invariance verification in five-fold correlation. Synthesis of monocrystalline samples suitable for polarization of lanthanum-139 nuclei. Investigation of possibility to create an optically polarizable target on the basis of ^{129}Xe and ^{131}Xe with pressures up to 10 atm.

Continuation of measurements of P-odd correlation coefficients in the reactions $^{6}Li(n,\alpha)^{3}H$ and $^{10}B(n,\alpha)^{7}Li^{*}\rightarrow\gamma\rightarrow^{7}Li(g.s.)$ on cold polarized neutrons at the reactor of ILL, Grennoble, France.

Continuation of experiments in the field of optics of cold and ultracold neutrons at the reactor of ILL, Grenoble, France. Investigation of the physics of UCN interaction with trap surfaces at the reactor of ILL.

Design and construction of the facility, preparation and carrying out of test experiments on nn scattering at the JAGUAR reactor, Snezhinsk, Russia.

Modernization of detectors at UGRA facility. Creation of a facility to measure neutron scattering by noble gases. Measurement of the n,e-scattering length by new methods at the neutron source, Troitsk, and at the reactor of ILL, Grenoble and further refinement of limitation on the value of electric polarizability of the neutron. Measurements of σ_{tot} for ^{208}Pb on the filtered beams with the energies from 2 keV to 140 keV at the stationary reactors in Kiev and in Garching.

Measurement of total, partial and differential cross sections of the (n,p) and (n,α) reactions on the different nuclei (^{6}Li, ^{10}B, ^{14}N, ^{35}Cl, ^{64}Zn) in the range of neutron energies from several keV to 6.5 MeV.

Development of an experimental method to extract weak long-range potentials in neutron scattering by nuclei based on the usage of monochromatic neutrons from an electrostatic accelerator.

Commencement of the measurements of neutron spin precession at the passage of polarized neutrons through a polarized target, investigations of nuclear pseudomagnetism.

Continuation of the investigation of parity violation effects in lead. Analysis of the obtained results. Preparation of an experiment to measure the gamma-quantum emission anisotropy in the process of polarized neutron transmission through lead isotopes.

Creation of charged particle detectors for measurements at the lead slowing down spectrometer LSD-100, INR RAS, Troitsk. Experimental investigation of «nonstatic» effects observed in the reaction $^{147}Sm(n,\alpha)^{144}Nd$ at the LSD-100 spectrometer. Creation

of a facility to investigate the (n,p), (n,α)reactions on the resonance neutrons of the pulsed neutron source at INR RAS, Troitsk.

Analysis of the obtained results from measurements of the total, partial and differential cross-sections of the (n,α) reaction on ^{64}Zn in the neutron energy interval from 1 to 8 MeV at the Van-de-Graaf accelerator in the Institute of Heavy Ion Physics of Peking University.

Accumulation of the information on two-step gamma cascades at thermal neutron capture in the target-nuc;lei 152Sm, 171Yb and 119Sn at the spectrometers of gamma-gamma coincidences in Dalata, Vietnam, and in Grenoble, France. Investigation of superfluidity manifestations – Fermi-liquid phase transition in excited compound-nuclei in the spectra of two-step cascade gamma-decays.

Experiments to study quaternary and quinary fission of ^{252}Cf. Analysis of the experimental data on ternary fission of ^{235}U and ^{252}Cf, obtained in 2002-2004. Investigation of the different properties of neutron-induced and spontaneous nuclear fission accompanied with emission of light charged particles.

Preparation of equipment for new measurements at the n_TOF source in CERN and processing of the 2003-2004 data on cross-sections of neutron-induced fission of minor actinides in the neutron energy range up to 250 MeV. Investigation of properties of vibrational fission resonances on the fission barrier.

Completion of modernization of the DRENIZ facility and beginning of measurements of delayed neutron yields from the thermal neutron induced fission of ^{245}Cm nuclei.

Creation of a facility on the basis of a mechanical chopper for neutron monochromatization and shortening of the neutron burst on an IBR-2 flight path.

PROJECT REGATA - investigations of heavy metal pollution in a number of regions in Russia, including Central region and South Ural region, and in some regions in Bulgaria, Vietnam, Greece, Egypt, Macedonia, Mongolia, Poland, Romania, Serbia, Turkey and South Korea. Continuation of investigations in ecology and monitoring of working places. Continuation of investigations in materials science and development of biotechnologies.

The following main problems are to be solved in the year 2005 in the framework of theme **1052:**

Carrying out of physical tests and calibrations of 2D detector prototypes on the IBR-2 beams.

Completion of the improvement of the manufacturing technology of multiwire neutron detectors.

Adaptation of electronics and software for data acquisition board TDC/DSP/DAQ for1D detectors with delay line readout.

Development and manufacturing of two planes (16 modules) of the FSD detector system.

Design and manufacturing of the support for the DN-6 diffractometer detector system.

Modernization of actuating mechanisms of the YuMO spectrometer.

Design and manufacturing of a cryostat with a temperature range from 4 to 200 K for the NERA-PR spectrometer on the basis of a cold head with the pulse tubes PT405.

Modernization of the power drives and control systems of the neutron choppers on the IBR-2 spectrometers.

Development of new electronic blocks with a USB interface.

Putting into operation of the Sonix program package with a PCI-VME adapter on the REMUR spectrometer.

Current maintenance of spectrometers, electronic and software support of experiments on IBR-2.

The following main tasks are to be accomplished in the year 2005 in the framework of theme **0851:**

Assembling of fuel elements into fuel assemblies.

Continuation of works to manufacture the new reactor jacket and other main equipment.

Development of the CSS electronic equipment of the IBR-2M and of the CSS actuating mechanisms.

Development of the engineering design of the moderator complex for the IBR-2M.

Manufacturing of CHF.

5. CONFERENCES AND MEETINGS

In 2004, FLNP organized the following meetings:

1. *SAD International Workshop, January 26-27.*
2. *Seminar dedicated to the 20-th Anniversary of the IBR-2 Reactor, March 25.*
3. *XII International Seminar on Interaction of Neutrons with Nuclei ISINN-12, May 26-29.*
4. *III JINR – Germany User Meeting «Condensed Matter Physics with Neutrons at the IBR-2 Pulsed Reactor», June 12-16.*

In the year 2005, FLNP will organize the following meetings:

1. *XIII International Seminar on Interaction of Neutrons with Nuclei ISINN-13, May 25-28.*
2. *IV JINR – Germany User Meeting «Condensed Matter Physics with Neutrons at the IBR-2 Pulsed Reactor», June 15-17.*