Frank Laboratory of Neutron Physics
Joint Institute for Nuclear Research

ANNUAL REPORT 2003

FRANK LABORATORY OF NEUTRON PHYSICS OF THE JOINT INSTITUTE FOR NUCLEAR RESEARCH

The Joint Institute for Nuclear Research (JINR) is an international centre for experimental and theoretical investigations in the fields of elementary particle physics, nuclear and neutron physics, condensed matter research and related topics.

The JINR structure is determined by the fact that it is governed internationally and has many research specializations. Current scientific and financial affairs of the Institute's Laboratories, common services as well as the work of specialized departments are guided by the Institute Directorate.

The Frank Laboratory of Neutron Physics is one of the eight JINR Laboratories. It was established in 1956, soon after the foundation of JINR.

In 1960 a principally new source of neutrons - the IBR fast pulsed reactor of periodic operation - was created at FLNP under the leadership of Prof. D.I.Blokhintsev (11.01.1908 - 24.01.1979). The birth of this reactor gave rise to a new direction in the development of research neutron sources.

An extended scientific program with this reactor was initiated under the leadership of Nobel Prize Winner and Laboratory Director Prof. I.M.Frank (23.10.1908 - 22.06.1990) and Deputy Director Prof. F.L.Shapiro (06.04.1915 - 30.01.1973). Since 1960, a whole family of unique pulsed neutron sources for nuclear physics and condensed matter physics has been developed and constructed. The latest in the family, the IBR-2 high flux pulsed reactor, was commissioned in February 1984. The Laboratory was named after Prof. I.M.Frank in 1992. In the same year, in JINR the I.M.Frank Prize for Neutron Physics was established.

At present, the scientific activity of the Laboratory focuses on two fields of physics, namely nuclear physics and condensed matter physics. The first involves investigations of the neutron as an elementary particle and studies of compound states in neutron induced reactions. The second investigates pressing problems in the physics and chemistry of solid states, surfaces and liquids, and in molecular biology. Applied investigations are also carried out using nuclear physics methods.

PREFACE

We would like to introduce the report on the scientific activity of the Frank Laboratory of Neutron Physics for 2003. The first part is a brief review of the experimental and theoretical results of investigations achieved in the main scientific directions – condensed matter physics, neutron nuclear physics and applied research. The second part includes reports on the operation of the IBR-2 pulsed reactor and realization of the IREN project. The third part is devoted to the IBR-2 spectrometers complex and computing infrastructure. The fourth part presents the investigations that characterize the main directions of research in greater detail. The report completes with the list of publications for 2003.

In 2003 the IBR-2 reactor operated, as planned, 2 cycles in strict accordance with the approved working schedule. The modernization of the IBR-2 reactor has come to the final stage of the basic equipment manufacturing. The manufacturing of parts of the new movable reflector completed, its control assembling (without jacket) was performed and the start-up was carried out at slow speed on a test-bench. Basically, the manufacturing of fuel elements completed, the manufacturing of new reactor jacket continued. Also, the development of cold moderators for the IBR-2 reactor was conducted.

At the same time, it should be noted, that the deficit financing of the IREN project resulted in a considerable delay of its realization. At the end of 2003 Russian Research Center "Kurchatov Institute" put forward the initiative to consolidate the efforts in order to complete the creation of the IREN facility and to carry out a joint scientific program on it. The preparation of the quadripartite agreement: JINR – RRC KI – MS – MAE, aimed at finding additional sources of funding for the IREN project, was started.

On the neutron spectrometers of the IBR-2 reactor several interesting experiments to investigate magnetic properties of various crystals were carried out. The obtained results are of principal character. In the framework of studying the problem "The physics of seismic foci and physics of rock failure" theoretical and experimental investigations of abnormal physical properties of minerals at high temperatures and pressures were carried out. In the course of the year a considerable modernization of the facility EPSILON was performed. On the spectrometer DIN-2PI the work to complete the creation of experimental basis for neutron-physical experiments of matter in the temperature region up to 3000 K were conducted. This will allow one to stimulate the experimental investigation of atomic structure and dynamics of promising reactor materials under conditions of operating and extreme temperatures.

In 2003 the investigation of nature of the space parity violation in interaction of polarized thermal neutrons with lead nuclei was completed. As a result of the measurements carried out at the IBR-2 reactor, it was conclusively shown that the space parity violating rotation effect of neutron spin is caused by the presence of *p*-resonance in the isotope ^{207}Pb and not in the isotope ^{204}Pb, as was discovered in the previous works by other authors. In 2003 the work to investigate atmospheric depositions of heavy metals was completed using the techniques of biomonitoring, NAA, GIS technologies (project "REGATA") in Central Russia, as well as in a number of European countries. The results of these investigations were published in European Atlas (2003). Similar studies were performed in South Korea, China and European part of Turkey. The data analysis to evaluate the pollution of heavy metals and radionuclides in Chelyabinsk region continued.

The Frank Laboratory of Neutron Physics continues to be one of the leading neutron centers of Europe and develops in spite of all the difficulties connected with severely limited funding.

A.V. Belushkin
Director

March 16, 2004

ПРЕДИСЛОВИЕ

Вашему вниманию предлагается отчёт о научной деятельности Лаборатории нейтронной физики им. И.М. Франка за 2003 год. В первой части представлен краткий обзор экспериментальных и теоретических результатов исследований, достигнутых по основным научным направлениям – физике конденсированных сред, нейтронной ядерной физике и прикладным исследованиям. Вторая часть включает отчёты о работе импульсного реактора ИБР-2 и реализации проекта ИРЕН. Третья часть посвящена комплексу спектрометров ИБР-2 и информационно-вычислительной инфраструктуре. В четвёртой части представлены экспериментальные отчеты, которые более подробно освещают основные направления исследований. Завершает отчёт список публикаций за 2003 год.

В 2003 году ИБР-2 отработал, как и планировалось, 2 цикла в строгом соответствии с утверждённым графиком. Модернизация реактора ИБР-2 вступила в завершающую фазу изготовления основного оборудования. Завершено изготовление узлов нового подвижного отражателя, выполнена его контрольная сборка (без кожуха) и на стенде осуществлен пуск на пониженных оборотах. В основном завершено изготовление ТВЭЛов, продолжалось изготовление нового корпуса реактора. Велась также разработка холодных замедлителей для ИБР-2.

В то же время следует отметить, что недостаточное финансирование проекта ИРЕН привело к значительной задержке в его реализации. В конце 2003 г. РНЦ «Курчатовский институт» выступил с инициативой об объединении усилий для завершения создания установки ИРЕН и осуществления на ней совместной научной программы. Начата работа по подготовке четырехстороннего соглашения ОИЯИ – РНЦ КИ – Миннауки – Минатом с целью изыскания дополнительных источников финансирования по проекту ИРЕН.

На нейтронных спектрометрах ИБР-2 выполнено несколько интересных экспериментов по исследованию магнитных свойств различных кристаллов. Были получены результаты, имеющие принципиальный характер. В рамках исследований проблемы «Физика очага землетрясений и физика разрушения горных пород» проведены теоретические и экспериментальные исследования аномальных физических свойств минералов при высоких температурах и давлениях. В течение года проведена значительная модернизация установки ЭПСИЛОН. На спектрометре ДИН-2ПИ проводились работы по завершению создания экспериментальной базы для нейтронно-физических исследований вещества в области температур до 3000 К, что позволит активизировать экспериментальное изучение атомной структуры и динамики перспективных реакторных материалов в условиях рабочих и экстремальных температур.

В 2003 году было завершено исследование природы эффекта нарушения пространственной четности при взаимодействии поляризованных тепловых нейтронов с ядрами свинца. В результате измерений, проведенных на реакторе ИБР-2, было убедительно показано, что нарушающий пространственную четность эффект вращения спина нейтрона обусловлен наличием *p*- резонанса у изотопа ^{207}Pb, а не у изотопа ^{204}Pb, как было обнаружено в предшествующих работах других авторов. В 2003 году были также завершены работы по изучению атмосферных выпадений тяжелых металлов с применением техники биомониторирования, НАА и ГИС технологий (проект «РЕГАТА») в Центральной России, а также в ряде европейских стран. Результаты этих исследований опубликованы в Европейском Атласе (2003). Аналогичные работы проведены в Южной Корее, Китае и европейской части Турции. Продолжен анализ данных по оценке загрязнений Челябинской области тяжелыми металлами и радионуклидами.

Лаборатория нейтронной физики им. И.М. Франка продолжает оставаться одним из ведущих нейтронных центров Европы и развивается, несмотря на все трудности, связанные с недостаточным финансированием.

16 марта 2004 года

А.В. Белушкин
Директор

1. SCIENTIFIC RESEARCH

1.1. CONDENSED MATTER PHYSICS

Diffraction. On HRFD, new experimental results on the magnetic and nuclear structures of manganites with a colossal magnetic resistance were obtained. In particular, two series of samples of the type $(La_{1-y}Pr_y)_{0.7}Ca_{0.3}MnO_3$ (LPCM) each of which was enriched with the oxygen isotope ^{16}O or ^{18}O were investigated in detail over a wide interval of Pr concentrations. Qualitative coincidence of phase diagrams for the two series, though with a shift in Pr concentration, was established. This means that strong influence of isotopic replacement on LPCM macroscopic properties in the region of mixed metallic and dielectric states, that was observed earlier, is, in the main, a percolation effect but not the result of appearance of some principally new state. Neutron diffraction was used to investigate the oxygen and fluoridated layered manganese oxides $Sr_2GaMnO_{5-x}F_{1+x}$ with a structure of the brownmillerite type. In such compounds, the number of Mn^{3+} and Mn^{4+} ions, that affects the extent the mechanism of “double exchange” demonstrates itself, depends on the concentrations of oxygen and fluorine and can be easily changed. The type of magnetic ordering in brownmillerites depends on the structure of the buffer layer $Ga(O,F)_6$ and on the Mn orbital configuration. The crystalline and the magnetic structures of the compound $Sr_2GaMnO_{4.8}F_{1.2}$, where the Mn mean charge is +3.8, were determined (**Fig. 1**).

On the diffractometer for high pressures DN-12, the structure of the pseudobinar system of mercury chalcogenides $HgSe_{0.7}Se_{0.3}$ was investigated at 9 GPa. A phenomenological model of the phase transition from cubic structure of the blende type to hexagonal structure of the cinnabar type observed in the compound under pressure has been suggested. The effect of high pressures, up to 4 GPa, and low temperatures, from 16 to 300 K, on the MnAs atomic and magnetic structure was investigated (**Fig. 2**). It is found that in MnAs in the region of high pressures and low temperatures there exists a new orthorhombic magnetic phase. Investigations of the atomic and magnetic structure of the manganites $Pr_{1-x}Sr_xMnO_3$ (x = 0.50, 0.56) was conducted at 0 – 5 GPa and 16 – 300 K. It has been discovered that in the region of high pressures and low temperatures a new tetragonal phase, that coexists with the initial orthorhombic phase, arises in $Pr_{0.5}Sr_{0.5}MnO_3$ and $Pr_{0.44}Sr_{0.56}MnO_3$. This pressure-induced tetragonal phase has an antiferromagnetic structure of the C-type in $Pr_{0.44}Sr_{0.56}MnO_3$ and exhibits no sign of magnetic ordering in $Pr_{0.5}Sr_{0.5}MnO_3$.

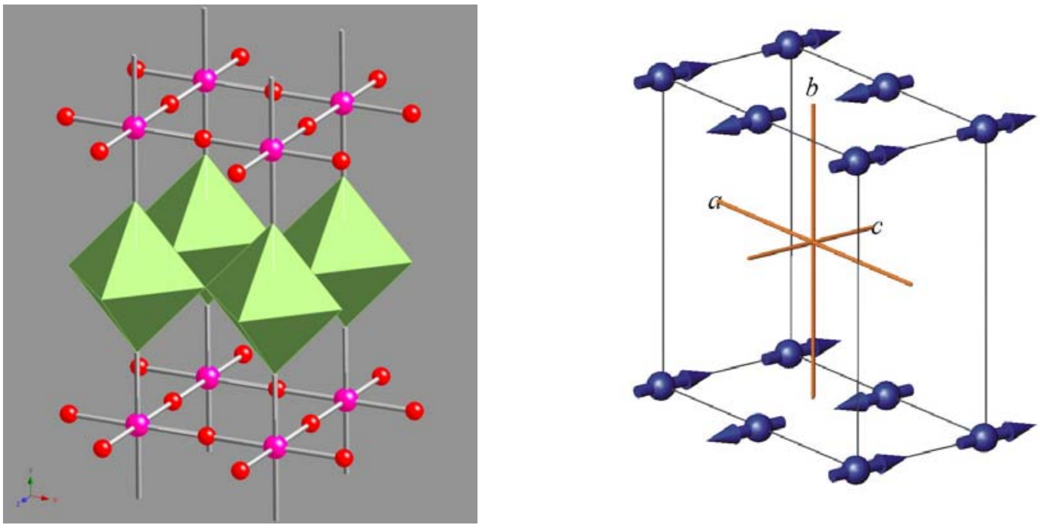


Fig. 1. *The crystalline structure of $Sr_2GaMnO_5F_1$ (left). The MnO_2 planes and the $Ga(O,F)_6$ octahedra are shown. The spin configuration in в $Sr_2GaMn(O,F)_6$ (right). The manganise are only shown.*

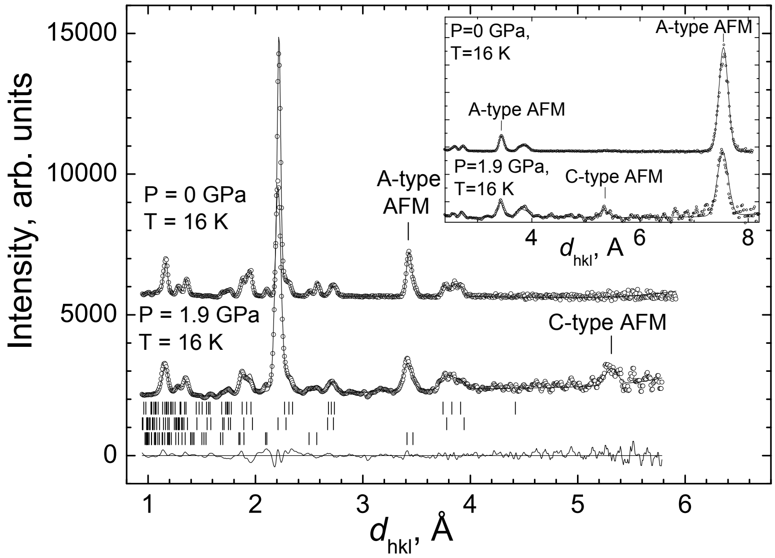


Fig. 2. *Neutron diffraction patterns of $Pr_{0.44}Sr_{0.56}MnO_3$ measured at P = 0 and 1.9 GPa, T = 16 K at scattering angles 2θ = 90° and 45.5° (inset) and processed by the Rietveld method. A coexistence of the initial A-type AFM orthorhombic phase with a pressure-induced C-type AFM tetragonal phase was observed.*

Polarized neutrons and neutron optics. On the reflectometer REMUR**,** a spatial magnetization distribution at the V(650Å)/Cr bilayer interface, where an effective ferromagnetic layer was discovered to exist, was measured. The data from reflectometric measurements of the magnetization profile in periodic Fe/V structures were analyzed to determine the magnetic ordering type of vanadium atoms in the vicinity of the interface (**Fig. 3**). To analyze the experimental data, a program for the calculation of reflection coefficients involving a particular type of gaussian nonideality of the interface structure has been developed.

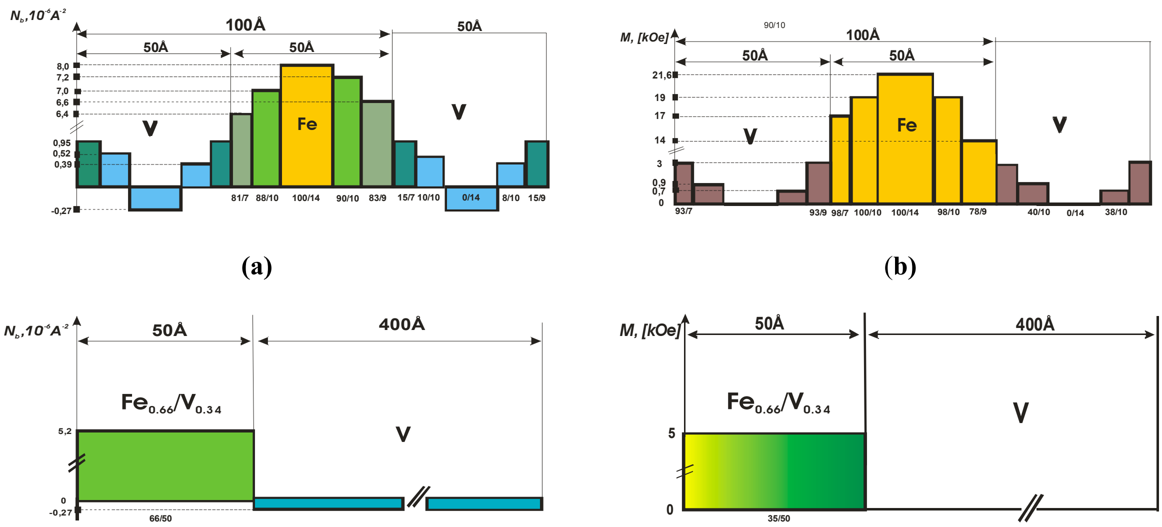


Fig.3. *The nuclear N_b and the magnetic profile M at 3K as revealed by neutron reflectometry for: a) three contiguous layers V(50Å) /Fe(50Å) /V(50 Å) of the periodic layered structure; b) bilayer $Fe_{0.66}V_{0.34}$(50Å)/V(400 Å).*

Inelastic neutron scattering. On the NERA-PR istrument, a series of experiments of neutron diffraction and neutron inelastic scattering was carried out using a setup for the investigation phase transitions and dynamics of solid mesithylene. The obtained results were used to calculate its moderating properties. It is shown that solid mesithylene can occur in the different crystallographic modifications depending on the degree of cooling and thermal processing. The generalized phonon density function of the different mesithylene phases has been obtained and analyzed (**Fig. 4**).

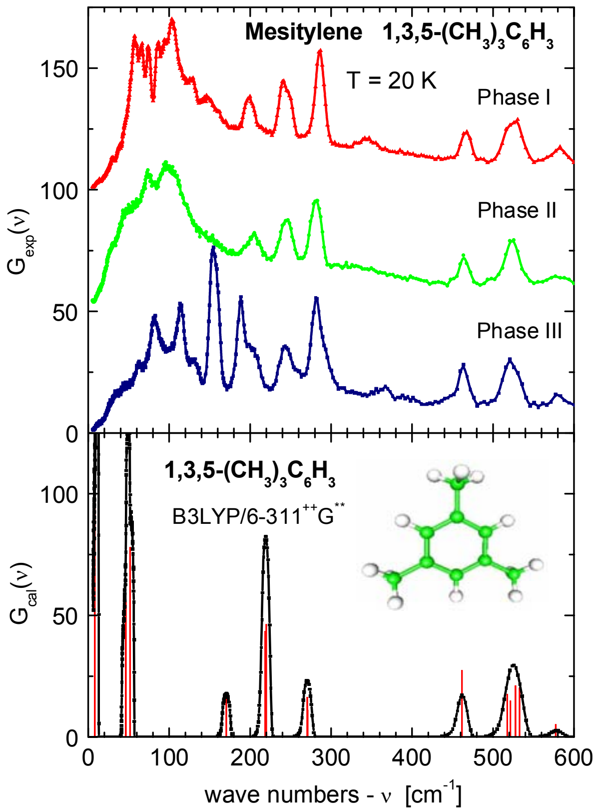


Fig.4. *Vibrational spectra - $G_{exp}(\nu)$ of solid phases of mesitylene and calculated spectra - $G_{cal}(\nu)$ of the internal modes of molecule*

Small-angle scattering. On the YuMO instrument, complex small-angle neutron scattering investigations of a number of nandimensional osystems were carried out. In particular, experiments of the small-angle scattering of neutrons on colloid C60 fullerene water solutions were conducted and analyzed. The specific parameters of colloid particles (size, polydispersivity, density, etc.) and their dependence on the fullerene concentration were determined. A number of models of the particles have been suggested basing on the obtained data and some complimentary methods.

Small-angle neutron scattering experiments on the solution C60/carbon bisulphide were repeated confirming the existence of cluster-like formations in the solution. From the scattering curves size distributions of the formations were obtained and it was determined how the temperature and fullerene concentration affected them. In the framework of nucleation theory, equations for a kinetic formation of clusters in the studied system were investigated. It is shown that a series of simple expressions for the binding energy as a function of the number of particles in the cluster corresponding, in particular, to the drop model of the cluster do not describe the cluster state of fullerene in carbon bisulphide if nucleation theory is used.

In the framework of investigations of ferroliquids a simple method of testing industrial ferroliquid samples, in the basis of which lies an analysis of small angle neutron scattering intensities, has been suggested. The method allows aggregations in ferroliquids to be identified with good confidence and their stability under different magnetic loadings to be judged.

The basic parameters of polycarboxyl dendrimers with different molecular architectures were obtained (**Fig. 5**). At the same time, it was found that the solvent penetrates into the dendrimer structure in the amount reaching up to 30% in volume. Analytical models for the determination of the structural parameters of the protein RecA that forms filament complexes with DNA were investigated. It has been shown that the structure of filaments is formed of two RecA proteins. The effect of the n-decane on the thickness of the lipid bilayer in a unilamellar vesicle was investigated. Precision measurements of small-angle neutron scattering curves have made it possible to discover, in particular, that the bilayer thickness increased by 2.4 angstroms. In addition, the data together with those from differential scanning calorimetry allowed explaining of nonmonotonous temperature dependence of the structural parameters of polyethylenoxide/polypropelenoxide copolymers in water solutions.

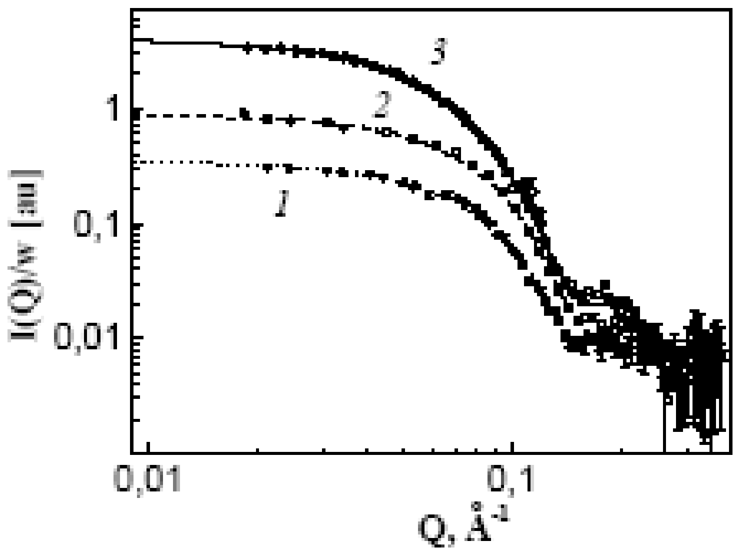


Fig.5. SANS curves for G(3)7 dendrimers in chloroform-d (1) and in benzene-d6 (2), and for G(4)7 dendrimers in benzene-d6 (3). w = 4 wt.% (1,2) and 1 wt.% (3). The fits are made using uniform ellipsoid model.

Applied research. In the framework of studies in "the physics of seismic foci and physics of rock failure", theoretical and experimental investigations of anomalous physical properties of minerals and rocks were conducted at high temperatures and pressures. On the experimental complex SKAT-TKOS**,** measurements of the structure, texture as well as elastic, deformational and thermal properties of polycrystalline quartzite were conducted under simultaneous action of a deforming force and temperatures, from 20 to 620˚ C, making it possible to perform an analysis of the temperature dependence of intra-lattice stresses. To elucidate the nature of the anisotropy of seismic waves at different depths in the lithosphere, there was first conducted a complex investigation of rocks from the different lithosphere depths at high all-round pressures and with an instrument creating triaxial stresses at temperatures up to 600˚C (**Fig. 6**). It is established that the key factor that controls the elastic properties anisotropy of olivine-bearing mantle rocks at high all-round pressures (over 200 MPa) is the crystallographic structure of olivine. The influence of the form texture (oriented microcracks, pores, intergrain boundarier, etc.) on the elastic anisotropy of olivine rocks has been determined.

The research program for EPSILON/SKAT focused on the following directions: investigations of applied and residual stresses in polycrystalline materials (rocks and other materials); texture analysis of materials (mainly geological), and obtaining of anisotropic physical properties of rocks from their crystallographic textures. The investigated samples were dolomite and anhydrite compositions, construction marble materials, rocks from the Eastern Alps, etc.

On the HRFD diffractometer, measurements of residual stresses in bimetallic (hardened steel/zirconium alloy) uses in RBMK neutron reactors continued. The work was carried out together with research institutes of MINATOM, RF. The instrument was also used to study TiNi alloy-based materials under external nonaxial loading at different temperatures. The dependence of the martensite transition temperature on the loading was obtained. The formation and growth of the austenite phase with a characteristic distribution of stresses between the two phases depending on external loading has been observed. A difference between the lattice parameters of the martensite phase in freshly prepared samples and those used has been discovered

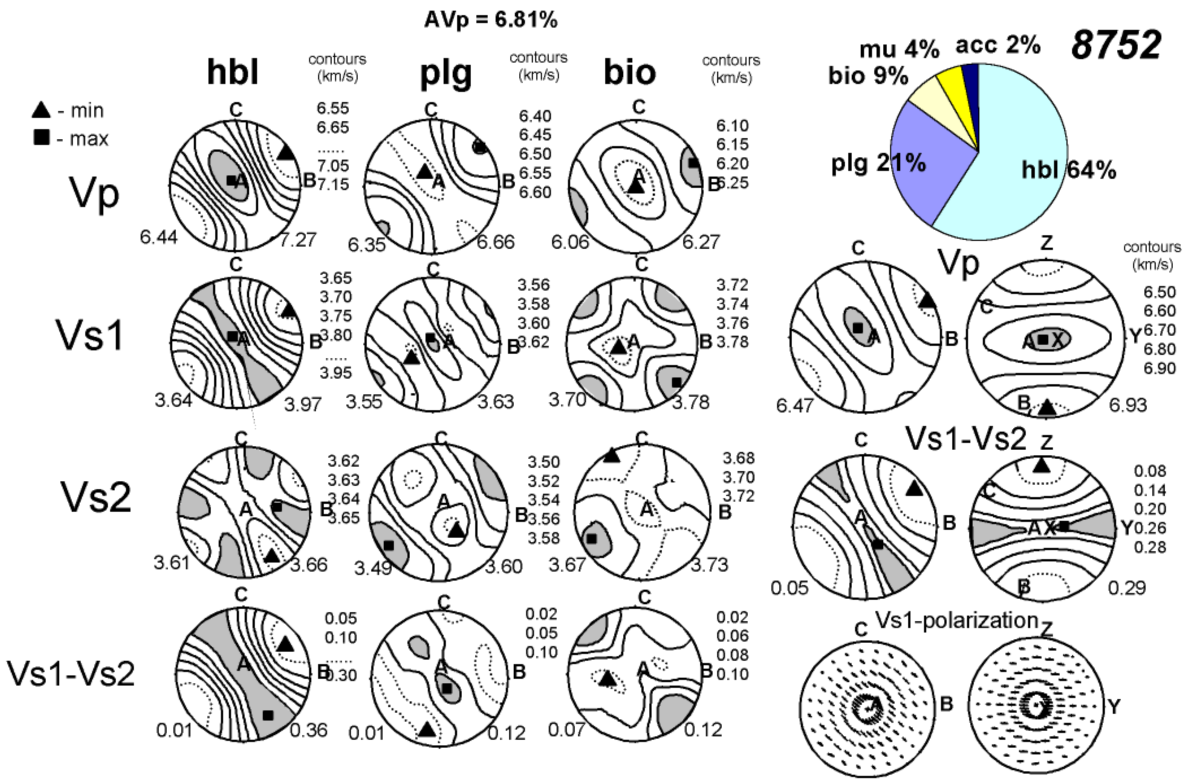


Fig. 6. *Calculated three-dimensional variations of the elastic properties of the amphibolite sample K8752 based on the neutron diffraction measurements. The model composition of the rock sample is displayed by the pie diagram.*

By means of neutron diffraction on the instrument DIN-2PI**,** the structure of liquid lead/potassium alloys was investigated. An analysis of neutronograms as a function of relative lead concentrations points to the absence of specific Zintl clusters in alloys. This means that the investigated alloy has much lower corrosion properties than pure lead and may be looked at as a possible candidate for the role of an effective cooling agent in nuclear power stations.

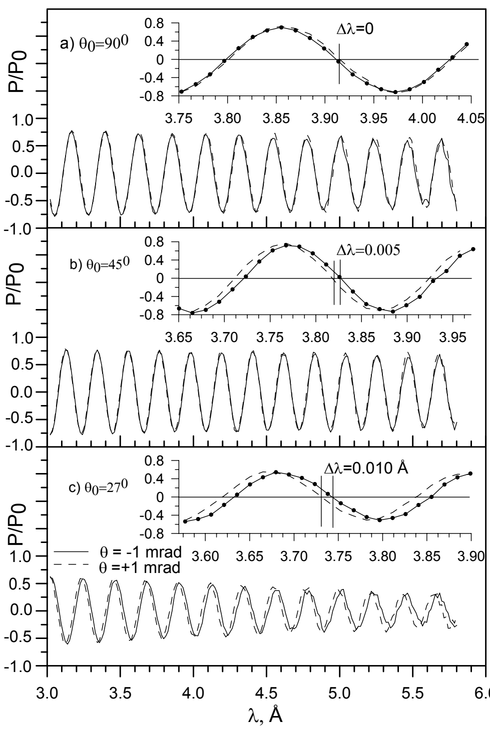


Fig.7. *Beam polarization as a function of neutron wavelength at different angles of current rotators.*

Principal methodological results. Tests of the new head part of the spectrometer REMUR were conducted on the neutron beam. The tests have proved that the choice of a concept of a head part with two different neutron sources is right. Physical and technical proposals for the modernization of the platforms for the polarizers, the shielding of the spectrometer's detector, and the creation of the new movable collimators were developed.

The reflection of neutrons from layered spin-precessors was investigated. The new magnetic system, that allowed the realization of a spin-precessor with rotating current planes, has been created. A two current π/2-rotators-based spin-precessor was investigated. It has been experimentally shown that the neutron spin precession phase changes as a function of beam divergence and rotation angle of the current planes of the rotators (**Fig. 7**). It is obtained that with such a precessor the beam cross section 10×25 cm^2 can be used and objects with a correlation length in the interval $10^2 \div 10^4$ Å can be investigated.

The possibility of the construction and draft project development of a polarized neutron reflectometer with a vertical scattering plane on the second beam of the reflectometer REFLEX was investigated. The instrument is expected to have a resolution of several percent, working wavelength interval 1÷10 Å and a spectrum-averaged polarization of the incident beam on the level not lower that 95%. The main objects of investigation with the new reflectometer will be surface films on liquids.

On the spectrometer REFLEX II**,** a measuring technique using polarized neutrons that employs larmor precession of neutron spin and is based on the use of current foils has been tuned. The techtnique has been developed to use on the time-of-flight reflectometer. The larmor precession technique combined with the time-of-flight method is a new direction that extends essentially the experimental possibilities of the instrument.

On the diffractometer for high pressures DN-12**,** a collimation system for detectors has been developed and tested. The effect to background ratio has been increased three times. A project of a cooled beryllium filter for experiments of inelastic neutron scattering at high pressures has been developed.

On the instrument EPSILON a system of 9 radial collimators each of which can be equipped with nine detectors has been adjusted. A total of 42 new detectors are installed and as a result, the total number of detectors is 78 today. In the course of measurements the diffraction spectra registered by the detectors are added up by means of time focusing based on varying of the channel width in dependence on the detector position. All the necessary calculations (recalculations) are preformed in parallel. To raise the quality of experimental determination of materials' elastic properties, the effect of the number of grains in a polycrystalline sample and of the volume distribution of grains on the accuracy of the obtained elastic property parameters was studied. The new proposed model of calculation of the elastic properties of polycrystals was applied for the investigation of important technological materials, such as copper, graphite, zirconium, etc.

On the instrument YUMO**,** the two-detector system started to operate effectively: sample environment possibilities widened, the project for the creation of a facility with a magnetic field is going on successfully, a number of new experimental data procession programs were written and tested. The project of a small-angle X-ray diffractometer is being developed successfully.

On the spectrometer DIN-2PI, works to complete the experimental base for neutron physics investigations of matter over the temperature region to 3000K were carried out. Heating of the sample and keeping its temperature on the specified level during the course of measurements are executed with the help of the thermostat TS-3000 installed in the vacuum chamber of the spectrometer. The thermostat was designed and produced in Romania in accordance with the technical proposal developed by FLNP and PEI. The thermostat was tested in the working conditions. The new experimental possibilities of neutron physics investigations of matter at temperatures to 3000K allow intensification of research in: atomic structure and dynamics of advanced reactor materials under working or extreme temperatures in nuclear power facilities; superionic conductors with a fluorite structure (of the type CaF_2) in the region of the superionic transition, advanced materials for thermonuclear reactors in the temperature region to 3000K, peculiarities of the structure and dynamics of liquid-metallic systems with admixtures of carbon or carbon modifications in the region of high temperatures, etc.

1.2. NUCLEAR PHYSICS WITH NEUTRONS

1. Introduction

In the course of the year 2003 two base facilities of FLNP, the IBR-30 booster and the IBR-2 reactor, were shut down and FLNP neutron nuclear physics work was, therefore, mainly carried out at EG-5 in FLNP JINR and on neutron beams in other nuclear centers of Russia, Bulgaria, Poland, Czech Republic, Germany Republic of Korea, China, France, USA, and Japan. In the main, the work was of the result processing or methodological type. The studies were in traditional directions, such as the investigation of time and spatial parity violation processes in the interaction of neutrons with nuclei, studying of the quantum-mechanical characteristics and dynamics of the fission process, experimental and theoretical investigations of the electromagnetic properties and beta-decay of the neutron, gamma-spectroscopy of neutron-nuclear interactions, obtaining of the new data for reactor applications and nuclear astrophysics, experiments with ultracold neutrons, and applied investigations.

1. Experimental investigations

1.1. Spatial and time parity violation in the interaction of neutrons with nuclei

1.1.1 Search for and investigation of the structure of subthreshold neutron p-resonances in lead isotopes by the combined correlation gamma spectroscopy method

In 2003 in cooperation with ITEP (Moscow) and Lodz University (Poland) FLNP continued experiments to search for the negative neutron p-resonance in lead isotopes with the aim of explaining of the earlier discovered spatial parity violation effect that demonstrated itself as rotation of spin of polarized thermal neutrons on their transmission through the sample. In the course of the experiments the dependence of the radiative neutron capture cross section on the energy of lead isotopes was studied to discover the expected deviation of the dependence from the law $1/\sqrt{E}$ due to the existence of a negative p-resonance. Over the neutron energy interval 80 meV to 3 eV the gamma spectra of radiative capture were measured for samples of lead enriched with the isotopes ^{204}Pb and ^{207}Pb. The results of the conducted experiments provide evidence of the existence of a strong p-wave resonance below the neutron binding energy in the isotope ^{207}Pb but not in ^{204}Pb as expected from the results of previous works by an ITEP group. Insufficiently high performance of the detecting equipment did not allow obtaining of the data for neutron energies above 3 eV. Additional experiments using improved spectrometric equipment will increase the measuring effectiveness and make it possible to obtain data for a wider neutron energy interval thus justifying the necessity of repeating laborious measurements of the parity violation effect in the nuclei of the isotopes ^{207}Pb and ^{204}Pb to verify the earlier obtained results.

1.1.2 Investigation of neutron spin nuclear precession

During the reported year works to create a polarized nuclear target setup were conducted. The setup is being made on the basis of a 3He-4He dilution cryostat with a superconducting solenoid. The cryostat was manufactured and assembled, nitrogen and helium tests were conducted, the 3He-4He dilution tract was calculated and developed to have the temperature T= 30 mK. The dilution tract with one continuous heat exchanger was tested and the temperature T= 120 mK was obtained. Heat exchangers with a 2 mm copper powder layer (with a grain size of 40 μm) baked on two sides, which corresponds to the calculated 0.75 square meter of the heat exchange working area, and 6 heat exchangers from cintered silver powder were manufactured. The silver powder used had a purity of 99.99 and the grain size 0.12 μm. Heat exchangers with a working area of 5, 8, 10 square meters were produced. The structure of the dilution bath was designed and the one with a sample polarized nuclear target was constructed. A press mold to produce polarized nuclear target plates is designed and built. The plates with a thickness of 0.2 mm and a diameter of 14 mm will be produced by the method of compressing the powder of titanium hydrate and zirconium hydrate at $2x10^6$ g/cm^2.

1.2 Neutron-induced and spontaneous fission

1.2.1 Interference effects in resonance neutron-induced fission of ^{239}Pu

<u>Analysis of even and odd effects in the resonance neutron-induced fission of ^{239}Pu</u>

Within the framework of the new (Barabanov-Furman) approach to the description of induced fission based on the spirality representation and *R*-matrix formalism an analysis of the experimental data on P-even and P-odd angular correlations of fragments in the resonance neutron-induced fission of ^{239}Pu is completed. The approach has allowed the description of interference effects in the differential fission cross section, such as the “forward-backward” anisotropy of fragments separation on the unpolarized neutron beam and their “left-right” anisotropy on the polarized beam, and the spin – opposite spin anisotropy due to nucleon-nucleon weak interaction contribution. Employing the R-matrix formalism it is possible to describe the contribution of interference between s- p-resonances to the observed angular correlations in a more complete and strict manner. At the same time, an important role of inter-resonance interference in the energy structure of the observed effects is indicated. It is what makes the new approach essentially different from the simplified formalism proposed by Sushkov-Flambaum in 1982. In contrast to the Sushkov-Flambaum formalism, the structure of the parity violating cross section $\sigma_{nf}^{PNC}(E)$ is related to s-resonances and correspondingly, the matrix elements of the weak interaction as a superposition enter into the «impurity» fission width of s-resonances. **Figure1** shows the result of fitting of the P-effects «forward-backward» and «left-right», and **Fig.2** presents the results of a P-odd effect analysis.

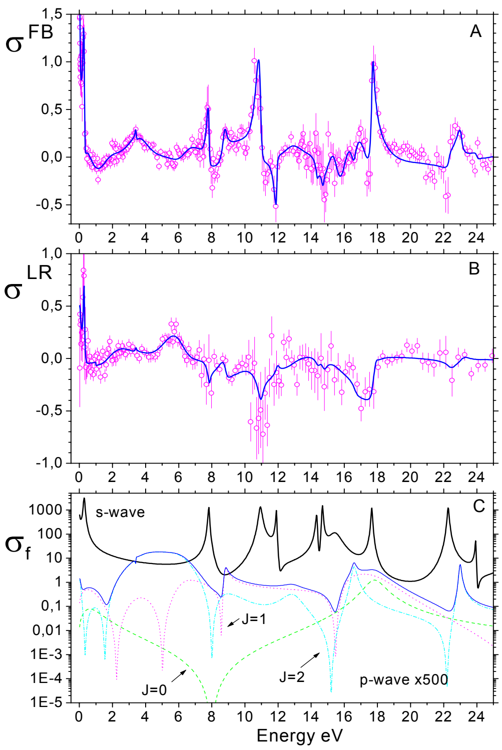


***Fig.1** The fitting results of P-effects «forward-backward» and «left-right»*

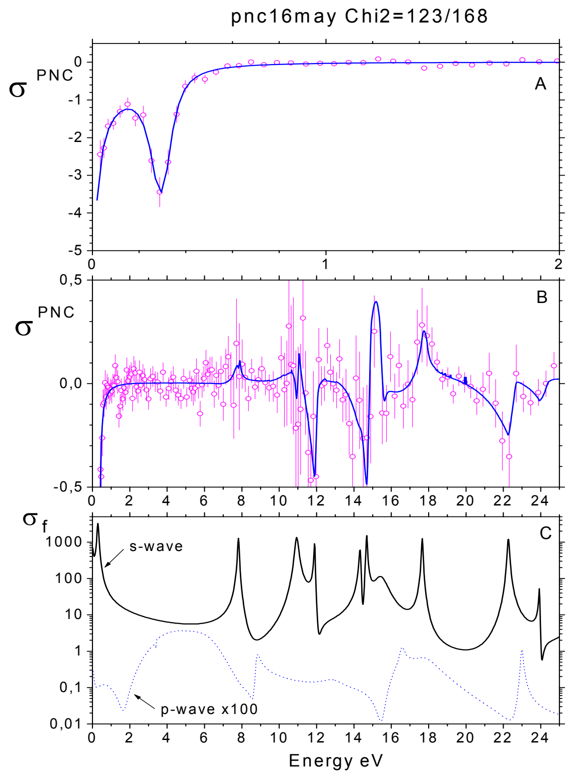


***Fig.2** The results of a P-odd effect analysis*

1.2.2 Experimental investigation of ternary fission

During the year 2003 processing of the results of the experiments of ^{252}Cf ternary fission conducted together with German physicists in Heidelberg and Darmstadt continued.

From the data of experiments with the spectrometer Crystal Ball multiplicities of neutrons emitted from fission fragments were extracted for the different modes of ternary fission. In the case of ^{4}He or ^{6}He emission corrections were made for neutrons emitted from the short-lived unstable nuclei ^{5}He and ^{7}He. This resulted in a characteristic change of the neutron distribution form in dependence on the energy of the light charged particle.

In the experiment employing germanium Super Clover detectors the preliminary results on the anisotropy of γ-quanta obtained for isolated $2^+ – 0^+$ and $4^+ – 2^+$ transitions of separate fragments demonstrate a high degree of alignment of fragments spins comparable with that calculated under assumption of complete alignment..

The use in the experiment of improved ΔE-E telescopes to identify light charged particles has made it possible, for the first time, to carry out the separation in mass of particles heavier than Li in the case of ^{252}Cf spontaneous fission (see **Fig. 3**) and in addition, to investigate mass, energy, and angular correlations of such particles and fission fragments. In 2004 the same telescopes will be used in correlation measurements of ternary neutron-induced fission of ^{235}U on the cold neutron beam in Grenoble.

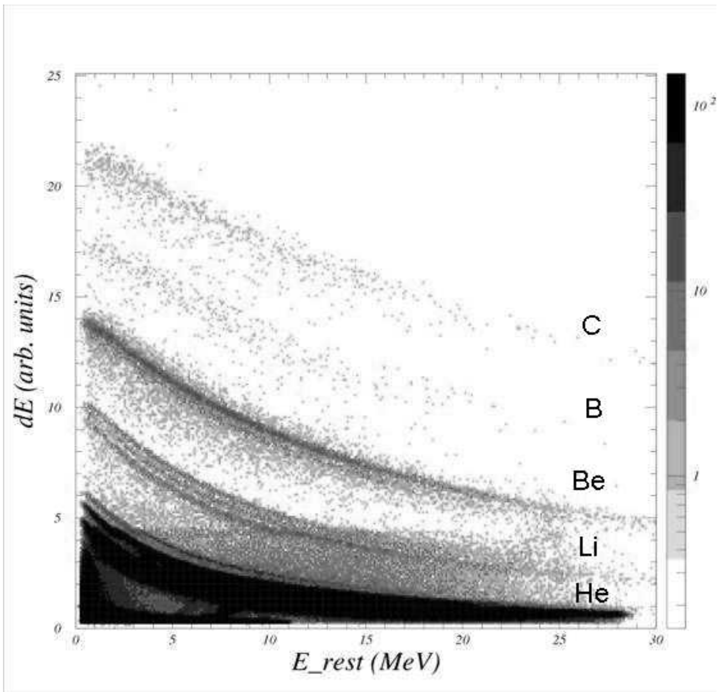


Fig.3 *The identifying* ***ΔE-E*** *plot for the separation of light charged particles.*

1.3 Gamma-spectroscopy of neutron-nuclear interactions

1.3.1 Investigation of two-step gamma-cascades

Processing of the previously obtained experimental data on the cascade gamma-decay of compound states (neutron resonances) of nuclei with a high level density by the method of coinciding pulse amplitude summation continued. By now, under the program most detail and exact data on the properties of excited states of the spherical 118Sn and deformed 185W compound nuclei have been obtained practically down to the neutron binding energy Bn in them.

Information in the form of spectra that are extremely simple and most suitable for the determination of most probable level density and radiative strength function values was obtained for over half total intensity of all possible primary gamma-transitions in the two nuclei. No other experimental method known today can give comparable information about nuclei with analogous parameters for the excitation energy higher than about 1-3 MeV.

Like in earlier studied nuclei the cascade gamma-decay parameters (i.e., nuclear matter properties) in the excitation energy region of about half neutron binding energy either in 118Sn or in 185W cannot be reproduced without taking into account changes in the structure of the nucleus in the indicated excitation energy at least.

The conclusion is prompted not only by the existence of the step-like structure in the dependence of the level density on the excitation energy around 0.5 Bn but also by a considerably large increase in the total cascade populating intensity of levels in a number of nuclei below the indicated excitation energy. In the framework of available developments of model representation of the observed effects by Obninsk theoreticians, the observed effects can be qualitatively explained under assumption of breaking of one or several Cooper pairs of nucleons, if the effective excitation energy of the deformed nucleus is on the order of 3 MeV and somewhat higher in the region of spherical nuclei, A=100, and the associated transition of the nucleus from excitation with dominating vibrational components of the wave functions of its levels to dominance of multiquasiparticle ones.

1.3.2 Measurement of partial capture cross sections for the nuclei Fe, Yb, and Gd

In 2003 experiments to study the reactions ^{56}Fe(n,$\gamma\gamma$)^{57}Fe, ^{56}Fe(n,γ)^{57}Fe ^{171}Yb(n, γ)^{172}Yb, ^{155}Gd(n, γ)^{156}Gd were conducted on the cold neutron beam in Budapest Neutron Center. Today, the processing of the measurement results is under way. It is expected to obtain absolute partial capture cross sections for the isotopes Fe, Yb, and Gd. The spectra of two-step cascades from the reaction ^{56}Fe(n,$\gamma\gamma$)^{57}Fe allow assessing of the radiative strength function in the region of soft (<2 MeV) primary gamma-transitions. Work to process the data from previous experiments with silicon, iron, and molybdenum nuclei conducted in the University of Oslo is completed. The level densities and radiative strength functions of the nuclei were obtained. An unusual enhancement of the radiative strength function was discovered for molybdenum and iron nuclei in the region of soft gamma-transitions. Processing of the results of the experiment to study the reaction ^{171}Yb(n,$\gamma\gamma$)^{172}Yb carried out on the thermal neutron beam in the Los-Alamos National Laboratory in 2001 is completed. The experiment has helped to confirm the magnetic nature of the observed pigmi resonance in the radiative function of the nucleus ^{172}Yb around $E_\gamma \approx 3$ MeV.

1.4 Astrophysical aspects of neutron physics

1.4.1 Analysis of alpha-width properties for the reaction ^{147}Sm(n,a).

The properties of alpha-widths obtained by P Keller et al. (ORNL) by measuring the cross section for the reaction ^{147}Sm(n,α) were analyzed. Of surprise is their result that in the energy interval 300 – 700 eV, the mean values of the total alpha-widths of resonances with spin 4^- appear to be larger than those of resonances with spin 3^-. Apparently, this is explained by mistaken identification of the neutron resonances' spin because in resonances with spin 4^- alpha-decay to the ground state (most intense) is forbidden by the parity conservation law and the ratio of mean alpha-widths must therefore be inverse as it is the case for energies below 300 eV as demonstrated in Dubna works 30 years ago. Otherwise, to explain the result we will have to state that in the discussed reaction spatial parity violation occurs and the contribution of the parity violating interaction is close to 100%.

1.5 Nuclear data program

1.5.1 Investigation of resonance structure of fission-fragment and fissionable materials

In 2003 measurements with a chopper of Mo, Pb, Ti, W and Zr sample filters were conducted on beam 6 of the IBR-2 reactor to extract neutron energies from the time-of-flight spectra of cross sections in the thermal neutron energy range.

The time-of-flight spectra over the range 0.1-200 keV of Mo, Rh, Ho and W were analyzed and total capture cross sections and transmissions were obtained with an accuracy of 0.2-0.5 % for transmission and 2-10 % for cross sections. In the same energy region, the blocking coefficients of capture and scattering cross sections were determined for Nb, Mo, and Pb.

The creation of SNM-30, a 4-π neutron detector on the basis of a battery of ^{3}He counters, to investigate delay neutrons, total cross sections in the thermal neutron energy range and to determine the value of υ, started.

1.6 Fundamental properties of the neutron

1.6.1 Investigation of neutron diffraction on argon

At IBR-2, the experiment on the anisotropy of neutron scattering on argon gas at 50 atm and on metallic vanadium or cadmium plates was completed. The scattering intensity ratio $R = I(30^0)/I(150^0)$ for neutrons with energies $E = 0{,}002 \div 0{,}07$ eV was measured. For argon, a clear diffraction pattern in good agreement with the data on its structural factor in the literature was observed. The pattern reduced 50 times leads to two important conclusions 1) even at low pressures, diffraction is a serious obstacle to reliable measurements of the n,e-scattering length b_{ne}; 2) the situation is much better at $E > 0{,}1$ eV, where it is recommended to do such measurements. Vanadium, which is frequently used as an isotropic scatterer, has first demonstrated a slight anisotropy $(R = 0{,}97 \div 1{,}06)$ as predicted by J.Mayers in Nucl. Instr. Meth. 221(1984)609. The measurements with cadmium show that it has an appreciable reflectivity that is well described by the obtained simple formula. The value of *R* is of the order of 0.02 – 0.03.

The new method for obtaining b_{ne}, that bases on known (nearly linear) dependence of the diffraction intensity on the atom density in gas n, was developed. The method allows obtaining of an n-independent b_{ne} contribution per gas atom from the scattering data obtained with $\lambda \sim 2$ Å neutrons at several scattering angles in the interval $5^0 - 100^0$ and several Ar, Kr or Xe pressures in the interval 10 – 200 atm.

An experimental setup similar to that by Krohn and Ringo in the experiment of the 1960's was developed. The improved procedure consists in obtaining of the ratio R as a function of *E* and extending of the E -range to 0.5 – 1.0 eV.

1.6.2 Experiments of the direct measurement of the neutron-neutron scattering length at the pulsed reactor JAGUAR in the town of Snezhinsk, Russia

The background for the lower part of the channel (from reactor to detector) in the n-n scattering experiment was calculated. The calculation yielded the geometry of the channel, collimators and of the under-reactor shielding that satisfies the condition: the number of the registered background events per pulse does not exceed 1% of the registered useful events. It is established that the main contribution to the background is made by fast neutrons with energies from 100 KeV to 5 MeV. To verify the calculation, test measurements at JAGUAR will be conducted in the first quarter of 2004. The geometry of the testing channel is essentially simplified compared to the regular channel while shielding and collimation of fast neutrons are in full correspondence with the regular geometry. The calculation for the testing channel shows that the fast neutron flux in the testing channel does not practically differ from that in the regular channel.

1.7 Ultracold neutron physics, Neutron optics

1.7.1 Neutron optics

In 2003 preparation work to carry out a new cycle of measurements of UCN time focusing was conducted. In particular, the new block of the UCN gravitational spectrometer was designed and constructed in the main, the program for control of experiments with the spectrometer was modified and the new diffraction gratings were calculated. Photomasks for the production of gratings by the lithographic method were made. The experiments will be performed in the firs quarter of 2004.

The scheme of the future experiment of the observation of the new neutron optical effect – changes in the UCN energy at transmission through an accelerated material plate, was determined. The performed estimation work provides evidence of the feasibility of the experiment. The experiment will be done with the UCN gravitational spectrometer. Work to calculate the magnetic field of the spin-echo precession coil in the UCN spectrometer started

1.7.2 Investigation of the temperature dependence of the total cross section of neutron scattering on a 4He atomic gas

A scattering theory study has shown that the scattering cross section is a product of the dimensionless scattering probability and the cross section area of the scattered packet. If the dimension of the packet does not depend on the incident neutron energy, the total neutron scattering cross section on an atomic gas must depend on the temperature T by the law $T^{3/2}$ but not $T^{1/2}$ as in the standard theory of scattering. To examine the dependence, an experiment of transmission of low-energy neutrons through ^{4}He gas was carried out at the reactor in ILL (Grenoble, France). By measuring the temperature dependence it is shown that it obeys the law $T^{1/2}$. This means that the dimensions of the wave packet must depend on the neutron energy. Investigations in the direction continue.

1.7.3 Development of high resolution UCN differential spectrometry

In ILL works devoted to the development of high resolution differential spectrometry of superlow energy neutrons using, in particular, nonmechanical modulation of the neutron flux by thin ferromagnetic shutters, continued. Work to prepare precision measurements of the UCN cross section of liquid fluorine-polymers at 80-300 K was carried out.

2. Theoretical investigations

2.1 Theoretical investigations in reflectometry and Goos-Haenchen effect

It is shown that at total reflection the neutron exit point displaces relative to the neutron entrance point in correspondence with known Goos-Haenchen displacement in light optics. The displacement can only be determined for a neutron wave function limited in space or for a wave packet. At total reflection the reflected particle diverts from the specular direction. The scheme of an experiment to measure the diversion was discussed and it was shown how the wave packet width could be determined from the measured diversion. The question of the measurement of the neutron coherence length in the reflectometry of thin films was also investigated.

2.2 Optical potential and neutron stars

The optical potential of neutron with matter interaction is generated by the coherent scattering length, which is positive for most nuclei. The scattering length itself is the result of a strong interaction of the short-range type. Nevertheless, because of the extension of the free neutron wave function, the optical potential is of the long-range type, which exhibits itself in such effects as Bragg scattering ant total reflection. Since the optical potential is proportional to the density of matter, for ordinary substances in terrestrial conditions it has a value of the order of 10^{-7} eV and demonstrates a repulsion behavior at positive scattering lengths. Rather a small number of substances have a negative scattering length. To them the potential exhibits an attraction behavior. The neutron-neutron scattering has a negative length and since in neutron stars the density of matter is many orders of magnitude larger than in ordinary matter, the neutron star is a deep potential well for all neutrons. It is shown that the total energy of the neutron-neutron interaction due to the optical potential may exceed the gravitational one. So, in some cases it can be conceived that the neutron star will remain compact if the gravitation is switched off. A model of such a star is presented and investigated.

2.3 Theoretical investigations of neutron β-decay

During 2003, the Standard Model treatment of radiative corrections to neutron beta-decay has been set forward. Electroweak interactions have been consistently taken into consideration amenably to the Weinberg-Salam theory. The effect of strong quark-quark interactions is parameterized by introducing the nucleon electromagnetic form factors and the nucleon weak transition current specified by the weak form factors g_V , g_A , ... Besides the lifetime and the electron and proton momentum distributions, the T-odd, P-even triple correlation of electrons and antineutrinos in the beta-decay of polarized neutrons were investigated.

2.4 Calculation of the cross section for the formation of exotic neutron-excess Λ-hypernuclei

The calculation of the cross section for the formation of the neutron-excess hypernuclei $^{12}{}_{\Lambda}$Be , $^{16}{}_{\Lambda}$C, and $^{10}{}_{\Lambda}$Li in the reactions (π^-,K^+) and (K^-,π^+) in flight points to sizeable dominance of the two-step process with recharging (e.g., $\pi^- p \rightarrow \pi^0 n$, $\pi^0 p \rightarrow K^+\Lambda$ and $\pi^- p \rightarrow K^0\Lambda$, $K^0 p \rightarrow K^+ n$). The second, less productive but possible, mechanism of the reaction is the one-step process $\pi^- p \rightarrow K^+\Sigma^-$ through the formation of a virtual Σ^- hyperon admixture in the Λ-hypernucleus as an input state. The first results on the formation of ^{12}C(π^-,K^+)$^{12}{}_{\Lambda}$Be and ^{10}B(π^-,K^+) $^{10}{}_{\Lambda}$Li obtained in KEK (Tsukuba, Japan) evidence in favor of the correctness of our estimate of the ratio between the cross section of the reaction (π^-,K^+) and that of the corresponding ordinary process (π^+,K^+) on carbon equal to 10^{-3}. Our calculations of the differential cross section for the two-step process of the reaction ^{10}B(π^-,K^+) $^{10}{}_{\Lambda}$Li give extremely large values (cross section per zero angle – on the order 70 nb/sr). Also, in the experiment a considerable increase in the cross section of $^{10}{}_{\Lambda}$Li is obtained.

In view of the start of experiments at the ϕ-Factory DAΦNE (Frascatti, Italy) estimates were made of yields from the formation reaction of $^{12}{}_{\Lambda}$Be and $^{16}{}_{\Lambda}$C on remaining kaons taking into consideration two possible formation processes. The calculation shows that in the given reaction the contributions of the two mechanisms are comparable, which is why the reaction (K^-,π^+) on remaining kaons is of special interest from the viewpoint of studies of the virtual Σ^- hyperon admixture in Λ-nuclei.

3. Methodological developments towards expansion of spectrometers software

In 2003 the following was done in the direction of the spectrometers software development:
- possibilities of internet-aided access to the experimental data from a user PC were widened;

- a WMonitor program version that writes log files and sends warning messages to PC users was developed to control the experimental data acquisition process;

- a WMonitor program version that will send warning messages as SMS to the mobile or as vocal messages to the usual phone of the user started to be developed,

- a version of the program for reading count characteristics of helium counters (for the spectrometer EPSILON) with a variant of high voltage source control via serial (COM) port was developed;

- programs for high voltage source control via network were being developed;

- methods for remote control of applied programs continued to be developed in cooperation with LIT.

With the aim of the development of the experiment automation systems (EAS) software the working out of the unified program for sample environment control SetVector continued. This program is a structure over the driving layer of the program. The use of it will allow the minimization of the functions of the driving programs, shortening essentially of the time of EAS development thanks to automation of EAS assembling from modules in .exe format, expansion of EAS service for users, and raising of the reactor time use coefficient due to concurrent control of the instruments operation.

4. Analytical investigations at the IBR-2 reactor

4.1 Modernization of the pneumatic facility REGATA

During the preventive maintenance of the IBR-2 reactor in 2003 a number of blocks and devices in the pneumatic facility REGATA were modernized.

To raise the REGATA radiation safety, a system for emergency unloading of the irradiation channels that makes it possible to unload high activity containers into one of the “hot” chambers in the pneumatic facility was designed and constructed.

For the irradiation channels, a device for temporary storage of radioactive containers in the ring corridor of the reactor has been designed and is presently under construction.

An automatic device for replacement of samples in the detectors has been developed. It will be produced in 2004.

The development of the program for control of the spectrometric equipment, that involves automatic certification of samples including all the parameters necessary for the calculation of the concentration of elements and producing of tables of final results, completed. A number of service programs of spectrometric data processing were improved.

4.2 Ecology

In 2003 works to study atmospheric depositions of heavy metals in central Russia (Tulskaia, Tverskaia, Iaroslavskaia regions and north of Moscow region) and in a number of European countries (Bulgaria, Slovakia, Romania, Ukraine, Poland, Serbia, Bosnia, Macedonia) using the techniques of biomonitoring, NAA, and GIS (project REGATA), completed. The results are published in the European Atlas (2003). Similar investigations were carried out in South Korea, China and European part of Turkey. Analysis of the data on heavy metal and radionuclide pollution in the Cheliabinsk region continued. A cycle of 17 publications on biomonitoring of atmospheric deposition of heavy metals is submitted to the 2003 JINR Best Publication Competition.

Investigations of soil pollution with heavy metals or other toxic elements due to toad transport (Minnesota, USA) completed.

A comparative analysis of the element content of a number of food products grown in the condition of strong antropogenic impact was carried out in cooperation with the Geological Institute of the Russian Academy of Sciences under the IAEA Coordination Program and Technical Cooperation with IAEA.

In 2003 the final stage of the Project «Monitoring of workplaces and health of personnel at some phosphate fertilizers production plants in Russia, Uzbekistan, Poland, Romania (European program 5 Copernicus) was completed.

4.3 Materials science

Epithermal neutron activation analysis (ENAA) of synthetic fine-grained diamonds grown in the Institute of Solid State Physics and Semiconductors of the National Academy of Sciences of Belorussia was completed. The results were presented at the 5th International Conference on the Interaction of Radiation with Solid Matter (October 6-9, 2003, Minsk) and are submitted as an article to the Journal *Diamond and Related Materials*.

4.4 Biotechnologies

In cooperation with a group of biophysicists from the Institute of Physics of the Academy of Sciences, Georgia, studies in the biotechnology of the green-blue algae *Spirulina platensis* used in pharmaceutical industry and in the new biological methods of water purification in water bodies contaminated by toxic metals, continued. The ability of the *spirulina* biomass to adsorb and accumulate such a high toxicity metal as mercury was investigated by the ENAA method. The results of the investigation will be presented at the 7th International Conference on Mercury as a Global pollutant (June 2004, Slovenia). In 2003, a second patent for the production method of a chrome-containing pharmaceutical on the basis of the green-blue algae *Spirulina platensis* was received.

1. НАУЧНЫЕ ИССЛЕДОВАНИЯ

1.1. ФИЗИКА КОНДЕНСИРОВАННЫХ СРЕД

Дифракция. На ФДВР получены новые экспериментальные результаты по магнитной и ядерной структурам манганитов с колоссальным магнетосопротивлением. В частности, детально были изучены две серии образцов $(La_{1-y}Pr_y)_{0.7}Ca_{0.3}MnO_3$ (LPCM) в широком интервале концентраций Pr, каждый из которых был обогащен изотопом кислорода ^{16}O или ^{18}O. Было выявлено качественное совпадение фазовых диаграмм этих серий, но со сдвигом по концентрации Pr. Это означает, что наблюдавшееся ранее сильное влияние изотопического замещения на макроскопические свойства LPCM в области смешанного металлического и диэлектрического состояний, является в основном перколяционным эффектом, а не следствием появления принципиально нового состояния. С помощью дифракции нейтронов исследованы кислородные и фторированные слоистые оксиды марганца $Sr_2GaMnO_{5-x}F_{1+x}$ со структурой типа браунмиллерита. В этих соединениях количество ионов Mn^{3+} и Mn^{4+}, влияющее на степень проявления механизма “двойного обмена”, зависит от содержания кислорода и фтора и может быть легко изменено. Тип магнитного упорядочения в браунмиллеритах определяется как структурой немагнитного буферного слоя $Ga(O,F)_6$, так и орбитальной конфигурацией Mn. Определены кристаллическая и магнитная структуры соединения $Sr_2GaMnO_{4.8}F_{1.2}$, в котором средний заряд Mn составляет +3.8 (**рис.1**).

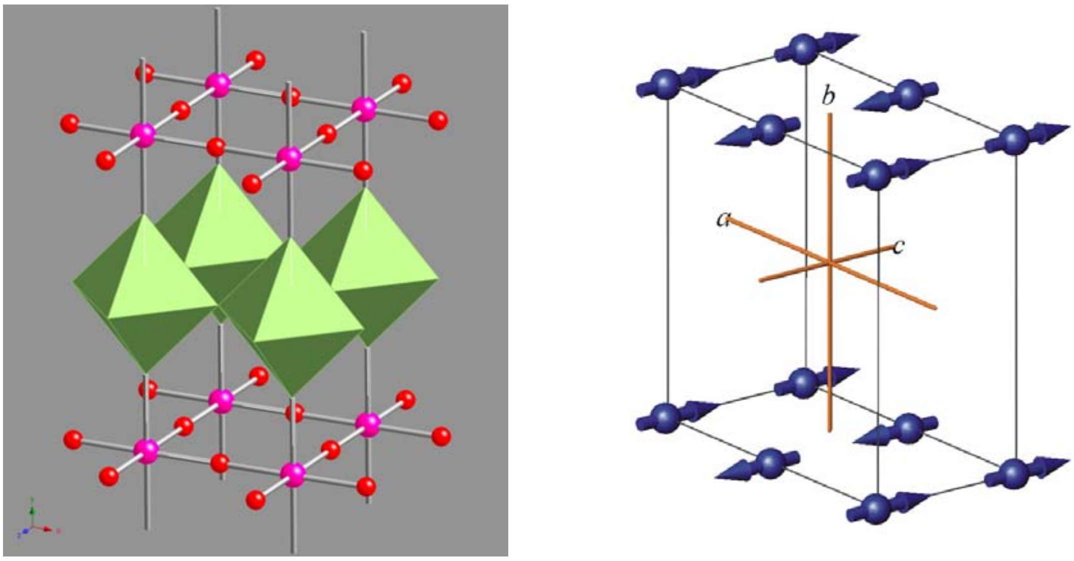


Рис.1. *Кристаллическая структура $Sr_2GaMnO_5F_1$ (слева). Показаны плоскости MnO_2 и октаэдры $Ga(O,F)_6$. Спиновая конфигурация в $Sr_2GaMn(O,F)_6$ (справа). Показаны только ионы марганца.*

На дифрактометре для высоких давлений ДН-12 проведено исследование структуры псевдобинарной системы халькогенидов ртути $HgSe_{0.7}Se_{0.3}$ при давлениях до 9 ГПа. Предложена феноменологическая модель структурного фазового перехода из кубической структуры типа сфалерита в гексагональную структуру типа киновари, который наблюдается в данном соединении под давлением. Проведено исследование влияния высоких давлений в диапазоне до 4 ГПа и низких температур в диапазоне 16 – 300 К на атомную и магнитную структуру MnAs. Установлено существование новой орторомбической магнитной фазы MnAs в области высоких давлений и низких температур. Проведено исследование атомной и магнитной структуры манганитов $Pr_{1-x}Sr_xMnO_3$ (x = 0.50, 0.56) в диапазоне давлений 0 – 5

ГПа и температур 16 – 300 К (**рис.2**). В области высоких давлений и низких температур в $Pr_{0.5}Sr_{0.5}MnO_3$ и $Pr_{0.44}Sr_{0.56}MnO_3$ обнаружено возникновение новой тетрагональной фазы, которая сосуществует с исходной ромбической фазой. В индуцированной давлением тетрагональной фазе $Pr_{0.44}Sr_{0.56}MnO_3$ при низкой температуре возникает антиферромагнитный порядок С-типа, тогда как в $Pr_{0.5}Sr_{0.5}MnO_3$ признаков магнитного порядка не обнаружено.

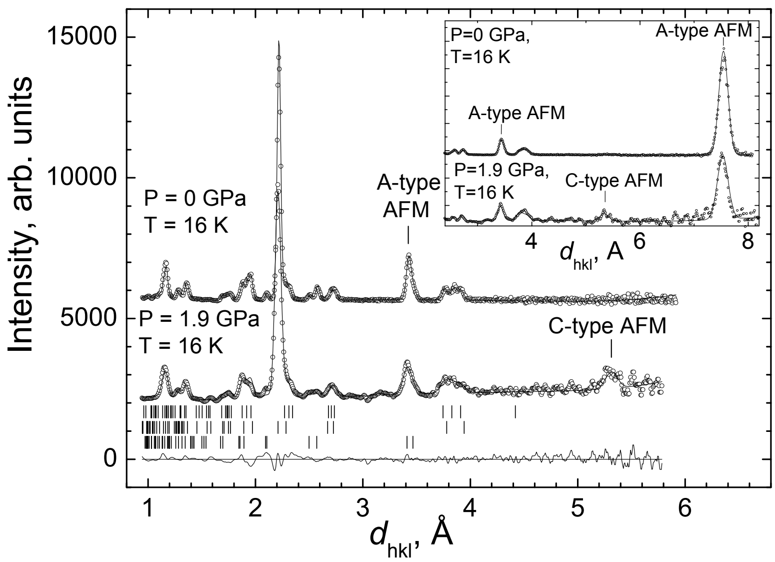


Рис. 2. *Нейтронограммы $Pr_{0.44}Sr_{0.56}MnO_3$, полученные при P=0 и 1.9 GPa, T=16 K. Данные обработаны с помощью метода Ритвельда. Наблюдается сосуществование начальной АФМ ромбической фазы (тип A) с индуцированной давлением АФМ тетрагональной фазы (тип C).*

Поляризованные нейтроны и нейтронная оптика. На рефлектометре РЕМУР измерено пространственное распределение намагниченности на границе бислоя V(650Å)/Cr, где обнаружено наличие эффективного ферромагнитного слоя. Проанализированы данные рефлектометрических измерений профиля намагниченности в периодических Fe/V структурах для определения типа магнитного упорядочения атомов ванадия вблизи границ раздела (**рис.3**). Для анализа экспериментальных данных разработана программа расчёта коэффициентов отражения с включением конкретного типа гауссовой неидеальности структуры границ раздела.

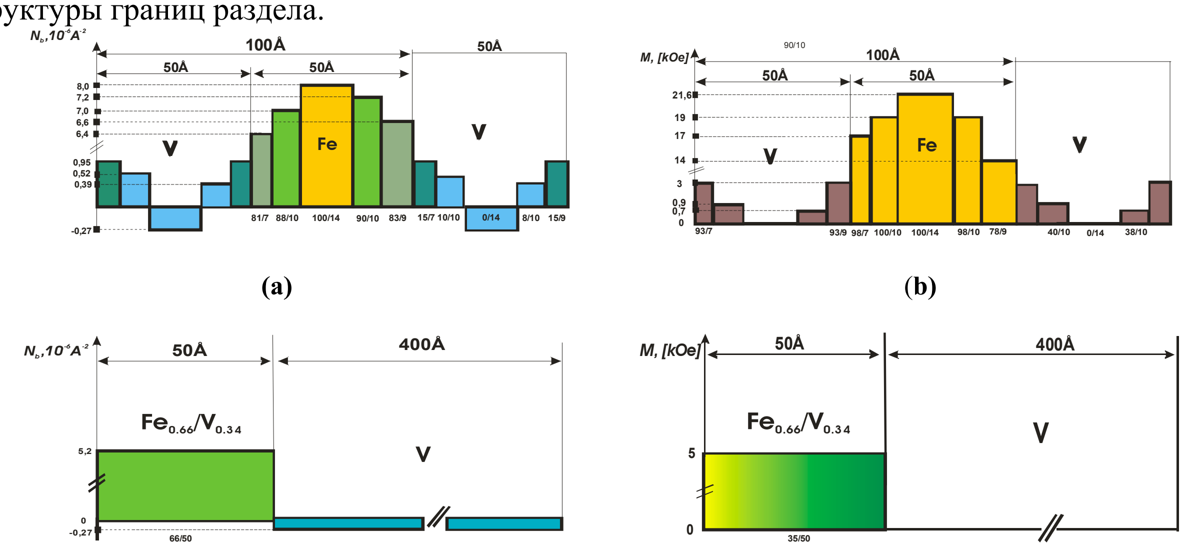


Рис.3. *Ядерный (N_b) и магнитный (M) профили при 3K, полученные в экспериментах по нейтронной рефлектометрии: (a) три последоватльных слоя V(50Å) /Fe(50Å) /V(50 Å) периодической слоистой структуры; (b) двойной слой $Fe_{0.66}V_{0.34}$(50Å)/V(400 Å).*

Неупругое рассеяние нейтронов. На установке НЕРА-ПР проведена серия экспериментов по дифракции и неупругому рассеянию нейтронов по исследованию структурных фазовых переходов и динамики атомов твердого мезитилена. На основе полученных результатов выполнены теоретические расчеты его замедляющих свойств. Показано, что твердый мезитилен может существовать в разных кристаллографических модификациях в зависимости от степени охлаждения и термической обработки. Получена и проанализирована обобщенная функция плотности фононных состояний различных фаз мезитилена (**рис.4**).

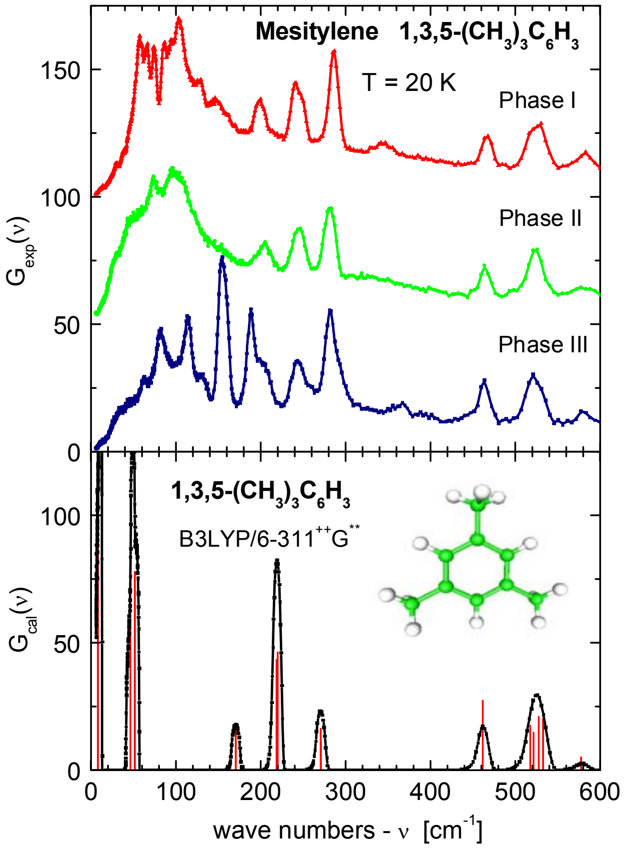


Рис.4. *Спектры $G_{exp}(\nu)$ колебаний в твердых фазах мезитилена и расчитанные спектры $G_{cal}(\nu)$ для внутренних мод молекулы.*

Малоугловое рассеяние нейтронов. На установке ЮМО проведены комплексные исследования ряда наноразмерных систем с использованием малоуглового рассеяния нейтронов. В частности, проведены и проанализированы эксперименты по малоугловому рассеянию нейтронов на коллоидных растворах фуллерена С60 в воде. Определены характерные параметры коллоидных частиц (размер, полидисперсность, плотность и др.) и их зависимость от концентрации фуллерена. На основании полученных результатов и данных дополняющих методов предложен ряд моделей частиц.

Повторены эксперименты по малоугловому рассеянию нейтронов на растворе С60/сероуглерод, которые подтвердили присутствие кластерных образований в растворе. Из кривых рассеяния получены функции распределения кластеров по размерам и влияние на них температуры и концентрации фуллерена. В рамках теории нуклеации рассмотрены уравнения кинетического образования кластеров в данной системе. Показано, что ряд простых выражений для энергии связи от числа частиц в кластере, в частности, отвечающих капельной модели кластера, не могут описать кластерное состояние фуллерена в сероуглероде при использовании теории нуклеации.

В рамках исследования феррожидкостей предложен простой метод тестирования промышленных образцов феррожидкостей на основе анализа интенсивности малоуглового рассеяния нейтронов. Метод позволяет с хорошей достоверностью выявлять агрегацию в феррожидкостях и судить об их стабильности при различных магнитных нагрузках.

Получены основные параметры поликарбоксилановых дендримеров с различной молекулярной архитектурой (**рис.5**). При этом установлено, что растворитель проникает внутрь дендримерной структуры и его количество доходит до 30% по объему. Изучены аналитические модели для определения параметров структуры белка RecA, образующего с ДНК филаментные комплексы. Показано, что структура филаментов формируется двумя RecA белками. Исследовано влияние н-декана на толщину липидного бислоя в униламеллярной везикуле. Прецизионные измерения кривых малоуглового рассеяния нейтронов позволили, в частности, обнаружить, что толщина бислоя возрастает на 2.4 ангстрема. Кроме того, эти данные в совокупности с результатами экспериментов по дифференциальной сканирующей калориметрии позволили объяснить немонотонную температурную зависимость структурных параметров полиэтиленоксид/ полипропиленоксидных сополимеров в водных растворах.

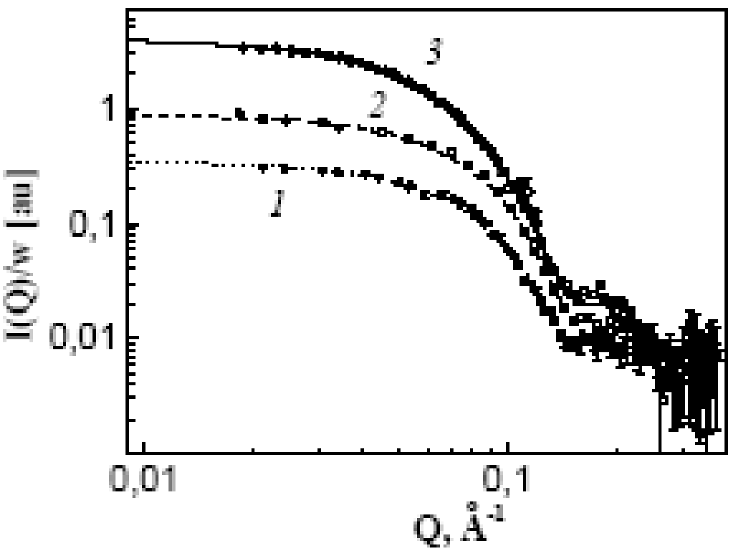


Рис.5. *Кривые малоуглового рассеяния для дендримеров G(3)7 в хлороформе-d (1) и бензоле-d6 (2), и для дендримеров G(4)7 бензоле-d6 (3). w = 4 весовых % (1,2) и 1 весовой % (3).*

Прикладные исследования. В рамках исследований проблемы “Физика очага землетрясений и физика разрушения горных пород” проведены теоретические и экспериментальные исследования аномальных физических свойств минералов и горных пород при высоких температурах и давлениях. На экспериментальном комплексе СКАТ-ТКОС проведены измерения структуры, текстуры, а также упругих, деформационных и тепловых свойств поликристаллического кварцита при одновременном воздействии деформирующего усилия и температуры от 20 до 620˚С, позволившие проанализировать температурную зависимость внутренних решеточных напряжений. Для выяснения природы анизотропии сейсмических волн на разных глубинах литосферы впервые проведено комплексное исследование пород с разных глубин литосферы как при высоких всесторонних давлениях, так и на установке трехосного сжатия с температурой до 600˚С (**рис.6**). Установлено, что основным фактором, контролирующим анизотропию упругих свойств оливиносодержащих мантийных пород при высоких всесторонних давлениях (выше 200 МПа), является кристаллографическая текстура оливина. Определено влияние текстуры формы (ориентированные микротрещины, поры, межзеренные границы и т.п.) на упругую анизотропию оливиновой породы.

Научная программа на установке ЭПСИЛОН/СКАТ была сконцентрирована на следующих направлениях: исследование приложенных и остаточных напряжений в поликристаллических материалах (горные породы и другие материалы), текстурный анализ материалов (в основном геологических) и получение анизотропных физических свойств горных пород по кристаллографическим текстурам. Исследуемыми объектами являлись композиции доломита и ангидрида, мраморные строительные материалов, горные породы из Восточных Альп и др.

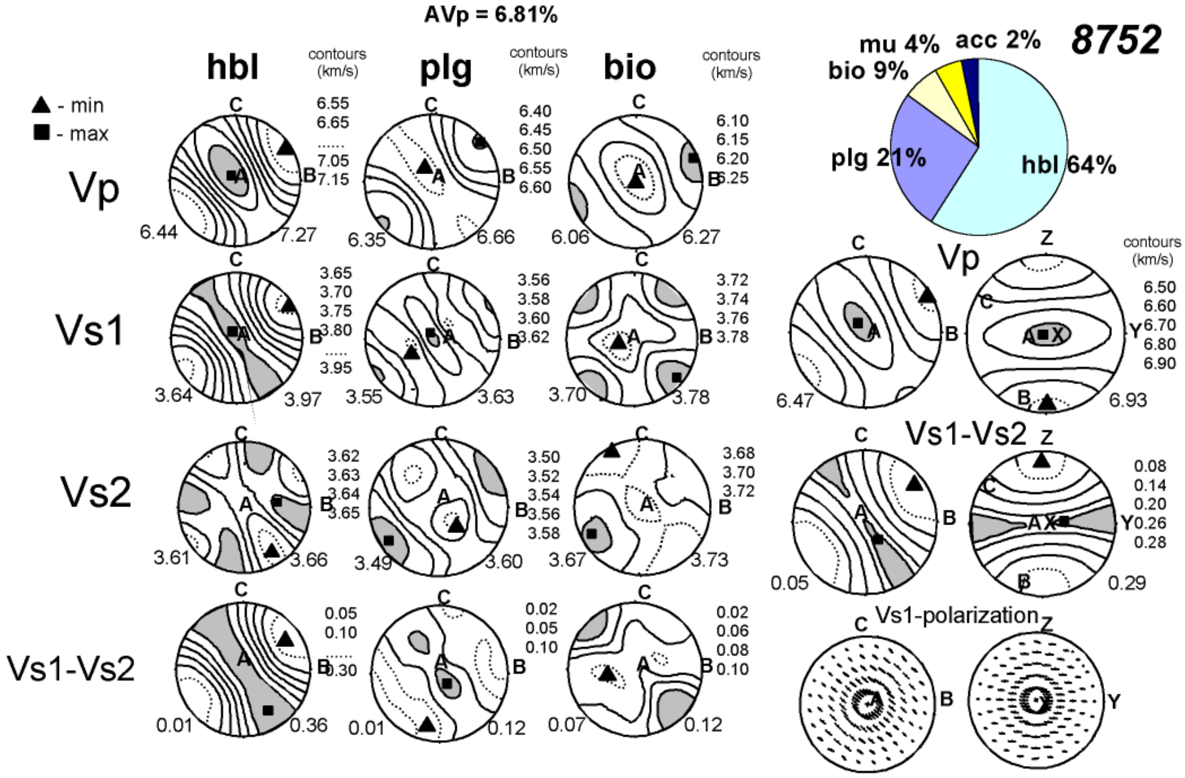


Рис.6. *Рассчитанные трехмерные изменения упругих свойств образцов амфоболита K8752 на основе данных по нейтронной дифракции.*

На дифрактометре ФДВР продолжались измерения остаточных напряжений в биметаллических (закаленная сталь / сплав циркония) конструкциях, использующихся в нейтронных реакторах РБМК. Работа выполнялась совместно с исследовательскими институтами Минатома РФ. На этой же установке изучались материалы на основе сплава TiNi при внешней неаксиальной нагрузке и разной температуре. Получена зависимость температур мартенситного перехода от величины нагрузки. Наблюдалось образование и рост аустенитной фазы с соответствующим распределением напряжений между двумя фазами, которое зависело от внешней нагрузки. Обнаружена разность между параметрами решетки мартенситной фазы в свежеприготовленных и эксплуатируемых образцах.

Посредством дифракции нейтронов на установке ДИН-2ПИ исследована структура жидких сплавов свинец / калий. Анализ нейтронограмм в зависимости от относительной концентрации свинца указал на отсутствие специфических “Zintl” кластеров в сплавах. Это означает, что изучаемый сплав обладает значительно меньшими коррозийными свойствами, чем чистый свинец и может рассматриваться как возможный кандидат на высокоэффективное охлаждающее вещество для атомных электростанций.

Главные методические результаты. Проведены испытания новой головной части спектрометра РЕМУР на нейтронном пучке. Испытания подтвердили правильность выбранной концепции новой головной части с двумя различными источниками нейтронов. Разработаны физические обоснования и технические проекты модернизации платформ поляризаторов и защиты детектора спектрометра и создания новых подвижных коллиматоров.

Исследовано отражение нейтронов от слоистых спин-прецессоров. Создана новая магнитная система, которая позволила реализовать спин-прецессор с вращающимися токовыми плоскостями. Исследован спин-прецессор на основе двух токовых $\pi/2$-ротаторов.

Экспериментально показано, что фаза прецессии спина нейтронов изменяется в зависимости от угла расходимости пучка и угла поворота токовых плоскостей ротаторов (**рис.7**). Получено, что с этим прецессором можно использовать сечение пучка нейтронов 10×25 см^2 и исследовать объекты с корреляционной длиной в интервале $10^2 \div 10^4$ Å.

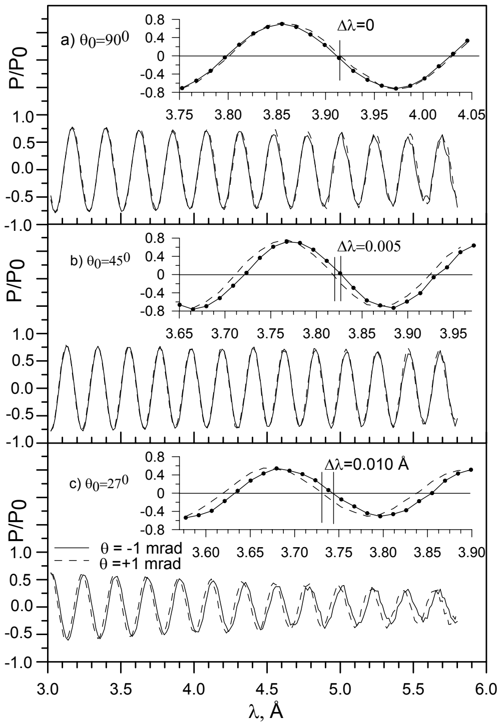


Рис.7. *Зависимость поляризации пучка от длины волны нейтрона при разных углах установки токовых ротаторов.*

Проработана возможность создания и разработан эскизный проект рефлектометра поляризованных нейтронов с вертикальной плоскостью рассеяния на втором пучке спектрометра РЕФЛЕКС. Предполагается, что разрешение установки должно составлять несколько процентов; рабочий интервал длин волн 1÷10 Å; средняя по спектру поляризация падающего пучка на уровне не ниже 95%. Основными объектами исследований для нового рефлектометра являются пленки на поверхности жидкостей.

На спектрометре РЕФЛЕКС II проведена отладка методики измерений с поляризованными нейтронами с использованием ларморовской прецессии спина нейтрона, основанной на использовании токовых фольг. Осуществлено развитие этой методики на спектрометре по времени пролета. Ларморовская прецессия в комбинации с методом времени пролета является новым направлением, которое существенно расширяет экспериментальные возможности установки.

На дифрактометре для высоких давлений ДН-12 разработана и испытана коллимационная система для детекторов. При этом отношение эффект – фон увеличилось в три раза. Разработан проект охлаждаемого бериллиевого фильтра для проведения экспериментов по неупругому рассеянию нейтронов при высоких давлениях.

На установке ЭПСИЛОН отъюстирована система из 9 радиальных коллиматоров, каждый из которых может быть оснащен девятью детекторами. Установлены 42 новых детектора, таким образом, полное число детекторов доведено до 78. В ходе измерений дифракционные спектры, регистрируемые детекторами, суммируются посредством временной фокусировки, которая основана на вариациях ширины канала в зависимости от позиции детектора. Все необходимые вычисления выполняются в параллельном режиме. Для улучшения качества экспериментального определения упругих свойств материалов исследовано влияние количества зерен в поликристаллическом образце и распределения зерен по объемам на точность получаемых параметров упругих свойств. Предложенная новая модель расчета упругих свойств поликристаллов применена в исследованиях важных технологических материалов: меди, графита, циркония и др.

На установке ЮМО начала эффективно действовать двухдетекторная система, расширены возможности систем окружения образца, успешно выполняется проект по созданию установки с магнитным полем, создан ряд новых программ обработки экспериментальных данных. Успешно развивается проект по созданию малоуглового рентгеновского дифрактометра.

На спектрометре ДИН-2ПИ проводились работы по завершению создания экспериментальной базы для нейтронно-физических исследований вещества в области температур до 3000 К. Нагрев образца до нужной температуры и поддержание ее на заданном уровне в процессе измерения осуществляется с помощью термостата TS-3000, устанавливаемого в вакуумной камере спектрометра. Термостат спроектирован и изготовлен в Румынии по техническому заданию ЛНФ и ФЭИ. Проведены испытания термостата в рабочих условиях. Новые экспериментальные возможности для нейтронно-физического исследования вещества при температуре до 3000 К позволят активизировать изучение атомной структуры и динамики перспективных реакторных материалов в условиях рабочих и экстремальных температур ядерных энергетических установок, суперионных проводников с флюоритной структурой (типа CaF_2) в области суперионного перехода, перспективных материалов для термоядерных реакторов в области температур до 3000 К, особенностей атомной структуры и динамики жидкометаллических систем с примесями углерода и его модификаций в области высоких температур и др.

1.2. НЕЙТРОННАЯ ЯДЕРНАЯ ФИЗИКА

1. Введение

В течение 2003 года обе базовые установки ЛНФ – бустер ИБР-30 и реактор ИБР-2 были остановлены, в связи с чем основные работы в области нейтронной ядерной физики в ЛНФ им. И.М. Франка проводились на установке ЭГ-5, на нейтронных пучках других ядерных центров России, Болгарии, Польши, Чехии, Германии, Республики Корея, Китая, Франции, США, и Японии. Большая часть работ носила обработочный или методический характер. Исследования проводились по традиционным направлениям: изучение процессов нарушения пространственной и временной четности при взаимодействии нейтронов с ядрами; изучение квантово-механических характеристик и динамики процесса деления; экспериментальное и теоретическое исследование электромагнитных свойств нейтрона и его бета-распада; гамма-спектроскопия нейтронно-ядерных взаимодействий; получение новых данных для реакторных приложений и для ядерной астрофизики; эксперименты с ультрахолодными нейтронами; прикладные исследования.

1. Экспериментальные исследования

1.1. Нарушение пространственной и временной четности при взаимодействии нейтронов с ядрами

1.1.1 Поиск и исследование структуры подпороговых нейтронных p-резонансов на изотопах свинца методом комбинированной корреляционной гамма-спектроскопии

В течение 2003 года совместно с сотрудниками ИТЭФ (г. Москва) и Лодзинского университета (Польша) были продолжены эксперименты по поиску отрицательного нейтронного p-резонанса у изотопов свинца с целью объяснения обнаруженного ранее эффекта нарушения пространственной чётности, проявившегося во вращении спина поляризованных тепловых нейтронов при прохождении их через образец. В ходе экспериментов изучалась зависимость сечения радиационного захвата нейтрона от энергии изотопами свинца для обнаружения ожидаемого отклонения этой зависимости от закона $1/\sqrt{E}$, связанного с существованием отрицательного p-резонанса. Для интервала энергий нейтронов от 80 мэВ до 3 эВ измерялись гамма-спектры радиационного захвата на образцах свинца, обогащённых изотопами ^{204}Pb и ^{207}Pb. Результаты проведенных экспериментов свидетельствуют о наличии сильного p-волнового резонанса ниже энергии связи нейтрона у изотопа ^{207}Pb, а не у ^{204}Pb, как ожидалось на основании данных предшествующих работ группы ИТЭФ. В связи с недостаточным быстродействием регистрирующей аппаратуры в этих измерениях не удалось получить данных для области энергий нейтронов выше 3 эВ. Проведение дополнительных экспериментов с использованием усовершенствованного спектрометрического оборудования позволит увеличить эффективность измерений и получить данные для более широкого диапазона энергий нейтронов и, тем самым, в полной мере обосновать необходимость повторения трудоёмких измерений эффекта нарушения чётности в ядрах изотопов ^{207}Pb и ^{204}Pb с целью проверки ранее полученных результатов.

1.1.2 Исследование ядерной прецессии спина нейтронов

В течение года велись работы по созданию установки поляризованной ядерной мишени. Установка создается на базе криостата растворения 3He-4He со сверхпроводящим соленоидом. Были завершены изготовление и сборка криостата, проведены азотное и гелиевое испытания, рассчитан и разработан тракт растворения 3He-4He для получения температуры Т= 30 мК. Был испытан тракт растворения с одним непрерывным теплообменником и получена температура Т= 120 мК. Изготовлены теплообменники, в которых с двух сторон напечен слой медного порошка (размер зерна 40 мкм) толщиной 2 мм, что соответствует расчетной площади теплообмена 0,75 $м^2$, а также 6 теплообменников из спеченного серебряного порошка. Использован серебряный порошок чистоты 99,99 с размерами зерен 0, 12 мкм. Изготовлены теплообменники с площадями теплообмена 5, 8, 10 $м^2$. Разработана конструкция и создана ванна растворения с образцом поляризованной ядерной мишени. Разработана конструкция и создана пресс-форма для изготовления пластинок поляризованной ядерной мишени. Пластинки толщиной 0,2 мм и диаметром 14 мм будут получены методом прессовки порошков гидридов титана и циркония под давлением 2×10^6 $г/см^2$.

1.2 Нейтронно-индуцированное и спонтанное деление

1.2.1 Интерференционные явления в делении ^{239}Pu резонансными нейтронами

<u>Анализ четных и нечетных эффектов в делении ^{239}Pu резонансными нейтронами</u>

В рамках нового (Барабанова-Фурмана) подхода к описанию вынужденного деления, основанного на представлении спиральности и R-матричного формализма, завершен анализ экспериментальных данных о Р-четных и Р-нечетных угловых корреляциях осколков при делении ^{239}Pu резонансными нейтронами. Этот подход позволил описать интерференционные эффекты в дифференциальном сечении деления такие, как анизотропию разлета осколков «вперед- назад» на неполяризованном пучке нейтронов и их анизотропию «лево – право» на поляризованном пучке, а также анизотропию по спину – против спина, обусловленную вкладом нуклон-нуклонного слабого взаимодействия. Использование R-матричного формализма позволяет более полно и строго описывать вклад интерференции s-p-резонансов в наблюдаемые угловые корреляции. При этом показана важная роль межрезонансной интерференции в энергетической структуре наблюдаемых эффектов. Это существенно отличает новый подход от упрощенного формализма Сушкова-Фламбаума, предложенного еще в 1982 г. В отличие от подхода Сушкова-Фламбаума структура не сохраняющего четность сечения $\sigma_{nf}^{PNC}(E)$ привязана к s-резонансам, соответственно и матричные элементы слабого взаимодействия своей суперпозицией входят в «примесную» делительную ширину s-резонансов. На **рис.1** представлен результат фитирования Р-эффектов «вперед – назад» и «лево – право», а на **рис.2** представлены результаты анализа Р-нечетного эффекта.

1.2.2 Экспериментальные исследования тройного деления

В течение 2003 г. продолжалась обработка результатов экспериментов по изучению спонтанного тройного деления ^{252}Cf, проведенных в Гейдельберге и Дармштадте совместно с немецкими физиками.

Из данных эксперимента с использованием спектрометра Crystal Ball были извлечены значения множественности нейтронов, испускаемых из осколков деления, для различных мод тройного деления. В случае вылета ^{4}He и ^{6}He была сделана поправка на нейтроны, которые испускались из короткоживущих нестабильных ядер ^{5}He и ^{7}He. Это привело к характерному изменению формы нейтронного распределения в зависимости от энергии легкой заряженной частицы.

В эксперименте с использованием германиевых Super Clover детекторов предварительные результаты по анизотропии γ-квантов, полученные для изолированных 2^+ – 0^+ и 4^+ – 2^+ переходов отдельных осколков, демонстрируют большую выстроенность спинов осколков, сравнимую с теоретическими расчетами, проведенными в предположении полной выстроенности.

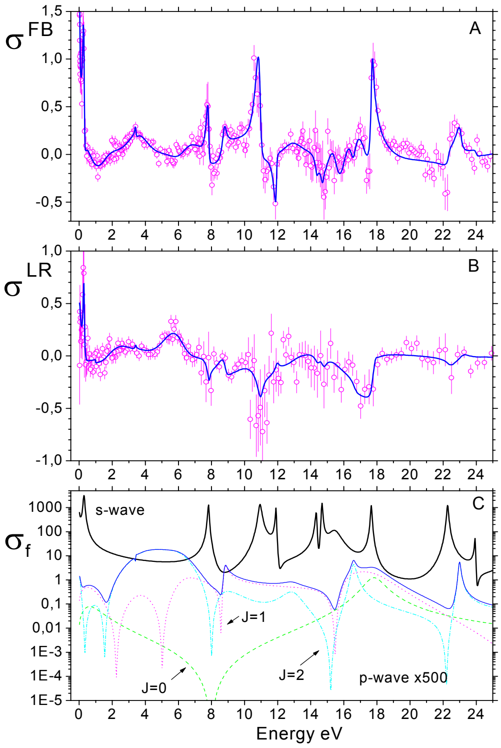


Рис.1. *Результаты фитирования Р-эффектов «вперед – назад» и «лево – право»*

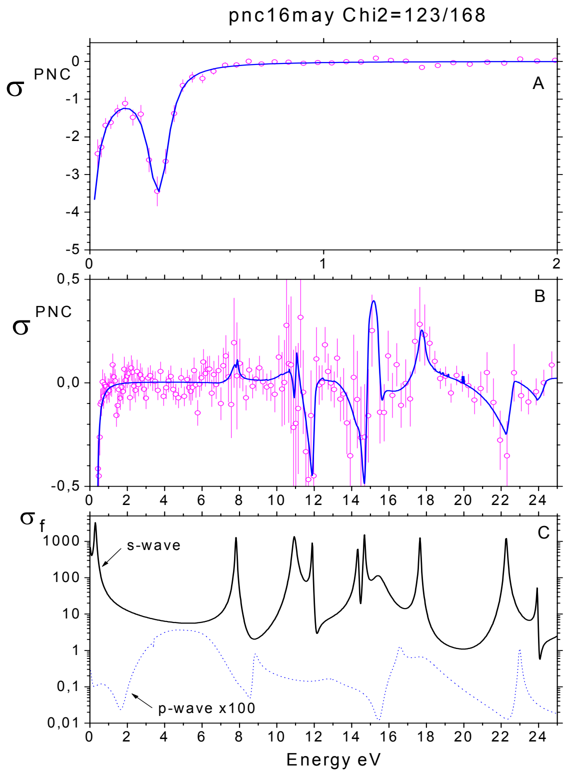


Рис.2. *Результаты анализа Р-нечетного эффекта*

Применение в данном эксперименте усовершенствованных ΔE-E телескопов для идентификации легких заряженных частиц позволит впервые провести разделение по массе частиц, тяжелее Li, для случая спонтанного деления ^{252}Cf (см. **рис. 3**), а также исследовать массовые, энергетические и угловые корреляции этих частиц и осколков деления. В 2004 г. планируется использование этих же телескопов для корреляционного измерения тройного нейтроно-индуцированного деления ^{235}U на пучке холодных нейтронов в Гренобле.

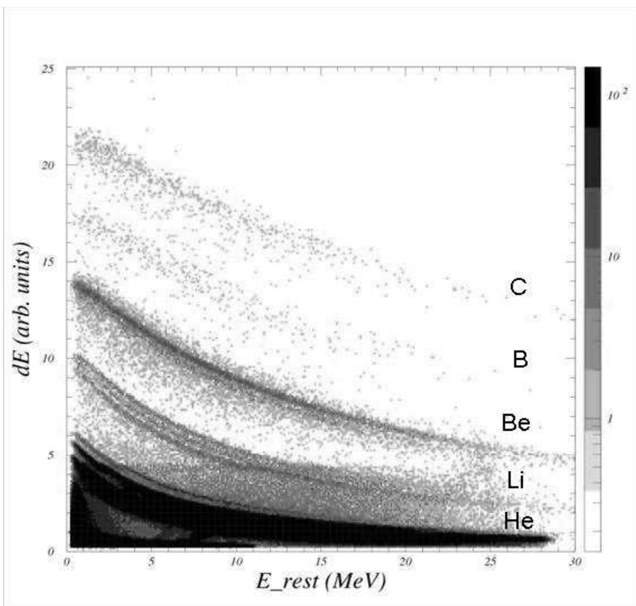


Рис.3. *Идентификационный **ΔE-E** плот для разделения легких заряженных частиц.*

1.3 Гамма-спектроскопия нейтронно-ядерных взаимодействий

1.3.1 Исследование двухквантовых гамма – каскадов

Продолжалась обработка полученной ранее экспериментальной информации о процессе каскадного γ-распада компаунд состояний (нейтронных резонансов) ядер с высокой плотностью уровней с помощью метода суммирования амплитуд совпадающих импульсов. В рамках этой программы к настоящему времени получены наиболее детальные и точные данные о свойствах возбужденных состояний сферического ^{118}Sn и деформированного ^{185}W составных ядер практически до энергии связи нейтрона B_n.

Получена информация для более, чем половины суммарной интенсивности всех возможных первичных γ-переходов для обоих ядер в форме простых спектров, подходящих для определения наиболее вероятных значений плотности уровней и радиационных силовых функций. Никакая иная методика эксперимента, известная в настоящее время, не может дать сопоставимой информации о подобных ядрах выше энергии возбуждения 1-3 МэВ.

Как и в ранее изученных ядрах, параметры каскадного γ-распада (то есть свойства ядерной материи) в области энергии возбуждения около половины энергии связи нейтрона как в ^{118}Sn, так и ^{185}W не могут быть воспроизведены в расчете без учета резкого изменения структуры ядра в указанной области возбуждения.

К такому выводу приводит не только наличие ступенчатой структуры в зависимости плотности уровней от энергии возбуждения около 0.5Bn, но и весьма значительное увеличение суммарной каскадной заселяемости уровней ряда ядер ниже этой энергии. В рамках имеющихся разработок модельного описания плотности уровней теоретиками Обнинска качественное объяснение наблюдаемых эффектов может быть получено в предположении о разрыве одной или нескольких куперовских пар нуклонов при эффективной энергии возбуждения около 3 МэВ в деформированном ядре и несколько большей в сферических ядрах из области A=100. С этим связан переход ядра от возбуждения состояний с доминирующими вибрационными компонентами волновых функций к доминированию состояний с многоквазичастичными компонентами.

1.3.2 Измерение парциальных сечений захвата для ядер Fe, Yb и Gd

В 2003 г. были проведены эксперименты по изучению реакций ^{56}Fe(n,γγ)^{57}Fe, ^{56}Fe(n,γ)^{57}Fe ^{171}Yb(n, γ)^{172}Yb, ^{155}Gd(n, γ)^{156}Gd на пучке холодных нейтронов Будапештского нейтронного центра. В настоящее время идёт обработка результатов измерений. Планируется получить абсолютные парциальные сечения захвата на изотопах Fe, Yb и Gd. Спектры двухквановых каскадов из реакции ^{56}Fe(n,γγ)^{57}Fe позволят оценить значение радиационной силовой функции в области мягких (<2 МэВ) первичных гамма-переходов. Завершена работа по обработке данных из предыдущих экспериментов проведённых, в университете г.Осло на ядрах кремния, железа и молибдена. Получены плотности уровней для этих ядер и радиационные силовые функции. Обнаружено необычное усиление радиационной силовой функции в области мягких гамма-переходов для ядер молибдена и железа. Закончена обработка результатов эксперимента ^{171}Yb(n,γγ)^{172}Yb, выполненного на пучке тепловых нейтронов Лос-Аламосской национальной лаборатории в 2001 г. С помощью этого эксперимента удалось подтвердить магнитную природу наблюдаемого пигми резонанса в радиационной силовой функции для ядра ^{172}Yb в области $E_\gamma \approx 3$ МэВ.

1.4 Астрофизические аспекты нейтронной физики

1.4.1 Анализ свойств альфа-ширин в реакции ^{147}Sm(n,a)

Были проанализированы свойства альфа-ширин, полученные П.Кёллером и др. (ORNL) в измерениях сечения реакции ^{147}Sm(n,α). Удивление вызвал результат авторов, состоящий в том, что в интервале энергий 300 – 700 эВ средние значения полных альфа-ширин для резонансов со спином 4^- оказались большими, чем в резонансах со спином 3^-. По-видимому, это объясняется ошибочной спиновой идентификацией нейтронных резонансов, так как в резонансах со спином 4^- альфа распад в основное состояние (наиболее интенсивный) запрещен законом сохранения четности и поэтому отношение средних альфа-ширин должно быть обратным, как это имеет место для энергий ниже 300 эВ, что было продемонстрировано в дубненских работах 30 лет назад. В противном случае, для объяснения этого результата придётся констатировать, что в этой реакции зафиксировано нарушение пространственной чётности, причем вклад взаимодействия, нарушающего четность, близок к 100%.

1.5 Программа ядерных данных

1.5.1 Исследование резонансной структуры нейтронных сечений осколочных и делительных материалов.

В 2003 г. были проведены измерения с прерывателем образцов-фильтров Mo, Pb, Ti, W и Zr на $6^{б}$ пучке реактора ИБР-2 для извлечения из времяпролётных спектров сечений рассеяния в тепловой области энергий нейтронов.

Проведён анализ времяпролётных спектров в области 0.1-200 кэВ Mo, Rh, Ho и W и получены полные, захватные сечения и пропускания с точностью 0.2-0.5 % (в пропусканиях) и 2-10 % (в сечениях). Для Nb, Mo и Pb в той же энергетической области определены коэффициенты резонансной блокировки в захватных сечениях и сечениях рассеяния.

Начато создание 4-π нейтронного детектора на основе батареи ^{3}He счётчиков (SNM-30) для исследования запаздывающих нейтронов, полных сечений в тепловой области нейтронов и определения величины υ.

1.6 Фундаментальные свойства нейтрона

1.6.1 Исследования дифракции нейтронов на аргоне

На ИБР-2 был завершен эксперимент по анизотропии рассеяния нейтронов газообразным аргоном при 50 атм., а также металлическими пластинами ванадия и кадмия. Измерялось отношение интенсивностей рассеяния $R = I(30^0)/I(150^0)$ для нейтронов с энергиями $E = 0{,}002 \div 0{,}07$ эВ. Для аргона наблюдалась отчетливая дифракционная картина, хорошо совпадающая с литературными данными по его структурному фактору. Ослабленная в 50 раз, эта картина привела к двум важным выводам: 1) даже при низком давлении дифракция – серьезное препятствие для надежного измерения длины n,e-рассеяния b_{ne}; 2) ситуация с дифракцией много лучше при $E > 0{,}1$ эВ, где и следует делать измерения. Часто используемый в качестве изотропного рассеивателя ванадий впервые проявил небольшую $(R = 0{,}97 \div 1{,}06)$ анизотропию, которая предсказывалась в работе J.Mayers. Nucl. Instr. Meth. 221(1984)609. Измерения с кадмием показали его заметную $(\sim 10^{-3})$ отражательную способность, которая хорошо описывается полученной простой формулой. Величина R порядка 0,02 – 0,03.

Был развит новый метод получения b_{ne}, основанный на известной (почти линейной) зависимости интенсивности дифракции от плотности атомов газа n. Этот метод позволяет выделить независящий от n относительный вклад b_{ne} на один атом газа из данных по рассеянию, измеренных на нейтронах с длиной волны $\lambda \sim 2$ Å при нескольких углах рассеяния из интервала $5^0 - 100^0$ и нескольких давлениях Ar, Kr или Xe из интервала 10 – 200 атм.

Разработана установка, подобная установке Крона и Ринго из известного эксперимента 60-х годов. Усовершенствование методики состоит в получении отношения R как функции от E и расширении диапазона E до 0.5 – 1.0 эВ.

1.6.2 Эксперимент по прямому измерению длины рассеяния нейтрона на нейтроне на импульсном реакторе ЯГУАР (Снежинск)

Проведены расчеты фонов для нижней части канала (от реактора до детектора) эксперимента по n-n рассеянию. В результате расчетов получена геометрия канала, коллиматоров и защиты под реактором, удовлетворяющая условию: число регистрируемых фоновых событий за вспышку не превышает 1% от числа регистрируемых полезных событий. Установлено, что основной вклад в фон вносят быстрые нейтроны с энергиями от 100 кэВ до 5 МэВ. Для проверки правильности расчетов в первом квартале 2004 г. планируется проведение тестового измерения на реакторе ЯГУАР. Геометрия тестового канала значительно упрощена по сравнению со штатным каналом, но защита и коллимация для быстрых нейтронов полностью соответствуют штатной геометрии. Проведенные расчеты для тестового канала показали, что поток быстрых нейтронов в тестовом канале практически не отличается от штатного канала.

1.7 Физика ультрахолодных нейтронов, нейтронная оптика

1.7.1 Нейтронная оптика

В течение 2003 г. проводилась подготовка к новому циклу измерений по временной фокусировке УХН. В частности, был сконструирован и в основном изготовлен новый узел гравитационного спектрометра УХН, модифицирована программа, управляющая экспериментами со спектрометром, рассчитаны новые дифракционные решетки. Изготовлены фотошаблоны для проведения литографических работ по изготовлению решеток. Проведение эксперимента планируется в первой половине 2004г.

Определена схема будущего эксперимента по наблюдению нового нейтронно-оптического эффекта – изменение энергии УХН при прохождении через ускоренную пластинку вещества. Сделанные оценки свидетельствуют о возможности осуществления опыта. Эксперимент будет проводиться с гравитационным спектрометром УХН. Начата работа по расчету магнитных полей в катушке прецессии спин-эхо спектрометра на УХН.

1.7.2 Исследование температурной зависимости полного сечения рассеяния нейтронов на атомарном газе 4He

При исследовании теории рассеяния было показано, что сечение рассеяния представляет собой произведение безразмерной вероятности рассеяния на поперечную площадь рассеиваемого пакета. В случае, если размеры пакета не зависят от энергии падающего нейтрона, полное сечение рассеяния нейтрона на одноатомном газе должно зависеть от температуры Т по закону $T^{3/2}$, а не $T^{1/2}$, как это следует из стандартной теории рассеяния. Чтобы проверить зависимость на реакторе в ИЛЛ (Гренобль, Франция) был проведен эксперимент по пропусканию нейтронов низких энергий газом ^{4}He. Измерение температурной зависимости показало, что она следует закону $T^{1/2}$. Это означает, что размеры волнового пакета должны зависеть от энергии нейтрона. Исследования в этом направлении продолжаются.

1.7.3 Разработка дифференциальной спектрометрии УХН высокого разрешения

Продолжались работы в ILL по развитию дифференциальной спектрометрии высокого разрешения нейтронов сверхнизких энергий, в частности, с применением немеханической модуляции потока нейтронов с использованием тонких ферромагнитных затворов. Проведены приготовления для прецизионных измерений сечений УХН для жидких фтор-полимеров при 80-300 К.

2. Теоретические исследования

2.1 Теоретические исследования по рефлектометрии и эффекту Гооса-Хенхен

Показано, что при полном отражении точка выхода нейтрона смещена относительно точки входа в соответствии с известным смещением Гооса-Хенхен в световой оптике. Смещение может быть определено только для ограниченной в пространстве волновой функции нейтрона или для волнового пакета. При неполном отражении происходит отклонение отраженной частицы от зеркального направления. Рассмотрена схема эксперимента по измерению отклонения и показано, как по измеренному отклонению определить ширину волнового пакета. Исследован также вопрос об измерении длины когерентности нейтрона при рефлектометрии тонких пленок.

2.2 Оптический потенциал и нейтронные звезды

Оптический потенциал взаимодействия нейтрона с веществом порожден когерентной длиной рассеяния, которая для большинства ядер имеет положительную величину. Сама длина рассеяния есть результат сильного взаимодействия, которое имеет короткодействующий характер. Тем не менее, сам оптический потенциал в силу протяженности волновой функции свободного нейтрона имеет дальнодействующий характер, что проявляется в таких эффектах как брэгговское и полное отражение. Поскольку оптический потенциал пропорционален плотности вещества, то для нормальных веществ в земных условиях он имеет величину порядка 10^{-7} эВ, и при положительной длине рассеяния имеет характер отталкивания. Лишь небольшое число веществ имеет отрицательную длину рассеяния. Для них потенциал имеет характер притяжения. Нейтрон-нейтронное рассеяние характеризуется отрицательной длиной, и поскольку в нейтронной звезде плотность вещества на много порядков превосходит обычное вещество, то нейтронная звезда представляет собой глубокую потенциальную яму для всех нейтронов. Показано, что полная энергия взаимодействия нейтронов за счет оптического потенциала может превосходить гравитационную. Значит в некоторых случаях мы можем представить себе, что нейтронная звезда останется компактной даже при выключении гравитации. Рассмотрена модель такой звезды и ее свойства.

2.3 Теоретические исследования β-распада нейтрона

В течение 2003 года продолжались исследования радиационных поправок к бета-распаду нейтрона в соответствии со Стандартной Моделью. Электрослабые взаимодействия последовательно учтены согласно модели Вайнберга-Салама. Влияние сильных кварк-кварковых взаимодействий параметризуется путем введения электромагнитных формфакторов нуклонов и нуклонного слабого тока перехода, который определяется слабыми форм-факторами g_V , g_A ... Наряду со временем жизни нейтрона и импульсным распределением электронов и протонов в бета-распаде нейтрона, исследовались T-нечетные, P-четные тройные корреляции элетронов и антинейтрино в бета-распаде поляризованного нейтрона.

2.4 Расчеты сечений образования экзотических нейтрон-избыточных Λ-гиперядер

Расчеты сечений образования гиперядер с нейтронным избытком $^{12}{}_{\Lambda}$Be , $^{16}{}_{\Lambda}$C, и $^{10}{}_{\Lambda}$Li реакциях (π^-,K^+) и (K^-,π^+) на лету показали значительное доминирование двухступенчатый процесса с перезарядкой (например, $\pi^- p \to \pi^0 n$, $\pi^0 p \to K^+\Lambda$ и $\pi^- p \to K^0\Lambda$, $K^0 p \to K^+ n$). Второй, менее продуктивный, возможный механизм реакции - одноступенчатый процесс $\pi^- p \to K^+\Sigma^-$ через образование примеси виртуального Σ^- гиперона в Λ-гиперядре в качестве входного состояния. Первые результаты эксперимента в КЕК (Цукуба, Япония) по образованию ^{12}C(π^-,K^+)$^{12}{}_{\Lambda}$Be и ^{10}B(π^-,K^+) $^{10}{}_{\Lambda}$Li подтверждают нашу оценку отношения сечения реакции (π^-,K^+) к сечению соответствующего обычного процесса (π^+,K^+) на углероде – 10^{-3}. Наши расчеты дифференциального сечения двухступенчатого процесса реакции ^{10}B(π^-,K^+) $^{10}{}_{\Lambda}$Li дали экстремально большое значение (сечение на нулевой угол порядка 70 nb/sr). В эксперименте также получено значительное увеличение сечения для $^{10}{}_{\Lambda}$Li.

В связи с началом экспериментов на ϕ-фабрике DAΦNE (Фраскати, Италия) сделаны оценки выходов в реакции образования $^{12}{}_{\Lambda}$Be и $^{16}{}_{\Lambda}$C на остановившихся каонах с учетом двух возможных процессов образования. Расчеты показывают, что в данной реакции оба механизма дают сравнимый вклад, что делает реакцию (K^-,π^+) на остановившихся каонах особенно интересной с точки зрения изучения примеси виртуального Σ^- гиперона в Λ-гиперядрах.

3. Методические разработки по развитию программного обеспечения спектрометров

В 2003 г. проводились следующие работы по развитию программного обеспечения спектрометров:

- расширены возможности сетевого доступа к экспериментальным данным с PC пользователя;
- для контроля процесса накопления экспериментальных данных разработана версия программы WMonitor, ведущей протокол и выдающей предупреждающие сообщения на PC пользователя;
- начата разработка версии программы Wmonitor с передачей тревожных сообщений в виде СМС на мобильный телефон и голосовых сообщений на обычный телефон пользователя,
- разработана версия программы снятия счетных характеристик гелиевых счетчиков (для спектрометра EPSILON) с вариантом управления высоковольтным источником через последовательный (COM) порт;
- разрабатывалась программа управления высоковольтным источником по сети;
- совместно с ЛИТ продолжена разработка методов дистанционного управления работой прикладных программ.

С целью развития программного обеспечения систем автоматизации экспериментов (САЭ) продолжалась разработка унифицированной программы управления окружением образца SetVector. Данная программа является надстройкой над драйверным слоем программ. Её применение позволит минимизировать функции драйверных программ, существенно сократить сроки разработки САЭ благодаря автоматизации процесса сборки САЭ из модулей в формате .exe, увеличить предоставляемый пользователям САЭ сервис, повысить коэффициент использования реакторного времени за счет параллельного выполнения операций управления устройствами.

4. Аналитические исследования на реакторе ИБР-2

4.1 Модернизация пневматического транспортного устройства РЕГАТА

Во время планово-предупредительного ремонта реактора ИБР-2 в 2003 году была проведена модернизация ряда узлов и устройств ПТУ РЕГАТА.

С целью повышения радиационной безопасности установки РЕГАТА разработана и создана система аварийной выгрузки из каналов облучения, позволяющая осуществлять выгрузку контейнеров с повышенной активностью в одну из «горячих» камер ПТУ.

Для каналов облучения разработано и находится в стадии изготовления устройство для временного хранения активных контейнеров в кольцевом коридоре реактора.

Разработано устройство для автоматической смены образцов на детекторах. Изготовление планируется в 2004 году.

Завершена разработка программ управления спектрометрической аппаратурой с автоматической паспортизацией образцов, включающей в себя все необходимые параметры для расчета концентраций элементов с выдачей таблиц окончательных результатов. Усовершенствован ряд сервисных программ для обработки спектрометрической информации.

4.2 Экология

В 2003 году были завершены работы по изучению атмосферных выпадений тяжелых металлов с применением техники биомониторирования, НАА и ГИС технологий (проект «РЕГАТА») в Центральной России (Тульская, Тверская, Ярославская и Север Московской области), а также в ряде европейских стран (Болгария, Словакия, Румыния, Украина, Польша, Сербия, Босния, Македония). Результаты этих исследований опубликованы в Европейском Атласе (2003). Аналогичные работы проведены в Южной Корее, Китае и европейской части Турции. Продолжен анализ данных по оценке загрязнения Челябинской области тяжелыми металлами и радионуклидами. Цикл из 17 опубликованных работ по биомониторингу атмосферных выпадений тяжелых металлов представлен на конкурс научных работ ОИЯИ 2003 года.

Завершено исследование загрязнения почв тяжелыми металлами и другими токсичными элементами под воздействием автодорожного транспорта (Миннесота, США).
Совместно с Геологическим институтом РАН в рамках Координационной программы МАГАТЭ и Технической кооперации с МАГАТЭ проведен сравнительный анализ элементного состава ряда продуктов питания, выращенных в условиях сильного антропогенного воздействия.

В 2003 году выполнен заключительный этап работ по проекту «Мониторинг на рабочих местах и здоровье персонала, занятого в производстве фосфорных удобрений на ряде заводов России, Узбекистана, Польши и Румынии» (Европейская Программа 5 Коперникус).

4.3 Материаловедение

Завершен эпитепловой нейтронный активационный анализ синтетических мелкокристаллических алмазов, выращенных в Институте физики твердого тела и полупроводников НАН Беларуси. Результаты доложены на 5ой Международной конференция по взаимодействию излучения с твердым телом (Минск, 6-9 октября , 2003 г.) и направлена статья в журнал *Diamond and Related Materials*.

__4.4 Биотехнологии__

Продолжены совместные работы с группой биофизиков Института физики АН Грузии по биотехнологии сине-зеленой водоросли *Spirulina platensis,* используемой в фармацевтической промышленности и в разработке новых способов биологической очистки водоемов, загрязненных токсичными металлами. С помощью ЭНАА исследовалась способность биомассы спирулины аккумулировать и адсорбировать такой высокотоксичный металл, как ртуть. Результаты этих исследований будут доложены на 7ой Международной конференции по ртути как глобальному поллютанту (Словения, июнь, 2004). В 2003 году получен второй патент на способ получения фармацевтического хромсодержащего препарата на основе сине-зеленой водоросли *Spirulina platensis.*

2. NEUTRON SOURCES
2.1. The IBR-2 Pulsed Reactor

Modernization. In 2003.the IBR-2 reactor operated for physical experiment ~ 681 hours. 2003 main IBR-2 modernization results:

1) MR-3 – chief goal of the year
   - Manufacturing of the MR-3 elements is completed
   - Test assembling of MR-3 without a jacket on the FLNP testing stand is performed
   - MR-3 startup in the air at a rate of up to 360 rot/min (60% of nominal rate) is conducted. The testing results are positive.
   - Test assembling of MR-3 with a jacket is under way (see **Figs. 1 and 2**).

Fig. 1. *The new movable reflector MR-3 for the IBR-2 reactor (main and auxiliary reactivity modulators).*

Fig. 2. *The IBR-2 reactor personnel at work to assemble the MR-reflector with a jacket on the testing stand in FLNP JINR.*

2) New fuel loading
- Manufacturing of TVELs is completed by the industrial enterprise “Maiak”.
- The components of the fuel element assemblies (TVS) are manufactured and site-delivered.
- The project of TVELs assembling into TVS is under way in GSPI.

3) Basic reactor equipment
- Manufacturing of the new reactor jacket continued.
- Work to execute design plans and documentation for roll-away shieldings and stationary reflectors continued.

4) Control and emergency system (SUZ)
- Agreement with SNIIP SYSTEMATOM for the development and manufacturing of SUZ electronic equipment is signed.
- Development of SUZ executive mechanisms continued in NIKIET.

5) Helium facility
- Development of the new Cold Helium Facility (CHF) for future cold moderators of the reactor is completed.

In 2003, to execute the reported works a sum of 617 k$ (JINR – 285 k$, MAE – 332 k$) was spent. The total sum invested in the IBR-2 modernization amounts to 39% of the total project cost (see Table 1).

Table 1

IBR-2 modernization financing schedule

		1995-1999	2000	2001	2002	2003	Total
JINR	scheduled (k$)	550	190	700	250	250	**1940**
	factual (k$)	602	193	233	130	285	**1443**
	implement.. percent	109	102	33	52	114	**74**
MAE	scheduled (k$)	–	300	300	450	450	**1500**
	factual (k$)	–	342	301	423	332	**1398**
	implement, percent	–	114	100	94	74	**93**
Total:	scheduled (k$)	550	490	1000	700	700	**3440**
	factual (k$)	602	535	534	553	617	**2841**
	implement. percent	109	109	53	79	88	**83**

No	Work	2003			2004					
		10	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**
1.	Jacket shipment from NIKIET	■								
2.	MR-3 with jacket assembling on testing stand		■	■	■					
3.	Stand testing					■				
4.	MR-3 dismantling to move to bldg. 117					■				
5.	MR-3 assembling at standard site by reactor						■	■		
6.	MR-3 testing								■	
7.	Reactor startup in stationary mode and pulsed mode									■

Fig. 3. *2003-2004 working schedule to realize MR-3.*

2004 Plans

1. After finalizing the assembly of MR-3, its stand testing will be performed, then MR-3 will be assembled at a standard site by the reactor, and the IBR-2 startup with the new reflector will take place in mid-2004 (see **Fig. 3**).
2. Shipment of a new fuel loading from "Maiak" and organization of a working area for assembling of TVELs into fuel cassettes in JINR.
3. Continuing of works to manufacture the new IBR-2M reactor jacket and other basic equipment of the reactor.
4. Development of executive mechanisms and SUZ electronic equipment for IBR-2M.
5. Development of the technical proposal for new moderators and start of their designing.
6. Manufacturing of CHF.

Development of a complex of wide spectrum neutron moderators («combi-moderators») for the IBR-2M reactor under modernization. In the current year the investigation of radiation properties of hydrogen-bearing materials (methane, methane hydrate, aromatic hydrocarbons, water ice and ice with admixtures of atomic hydrogen acceptors) at the URAM-2 installation at low temperatures (20-40K) completed and the analysis of experimental data was performed. Of the main results there should be noted two phenomena nobody had observed before:

- spontaneous chain reaction of radicals recombination (RRR) in irradiated water ice (**Fig.4**),
- and a sharp decrease in the thermal conductivity of ice under irradiation (**Fig.5**).

Spontaneous heating of ice to 150-200K was at radiation dose 2-8 MGy (5-20 hours of irradiation by fast neutron flux 3 10^{12} n/cm^2/s). Introduction of certain hydrogen acceptors did not influence much the conditions of the RRR development. It was shown for the first time that the RRR phenomenon is typical for numerous frozen compounds, in which one of the products of radiolysis are radicals. Of the studied materials RRR are not possible only in aromatic hydrocarbons. Accumulation of energy of radical recombination occurs with the rate 20-24 J/g/hr in water ice

(5.4%±0.4% from the absorbed dose) and 12-14 J/g/hr in solid methane (1.6%±0.2% from the absorbed dose). The important result for practice is that in aromatic hydrocarbons (mesithylene C_9H_{12} etc.) radicals accumulate by a factor of 100 slower and the generation rate of radiolytic hydrogen is smaller by a factor of 10-20, than in methane.
стабильным.

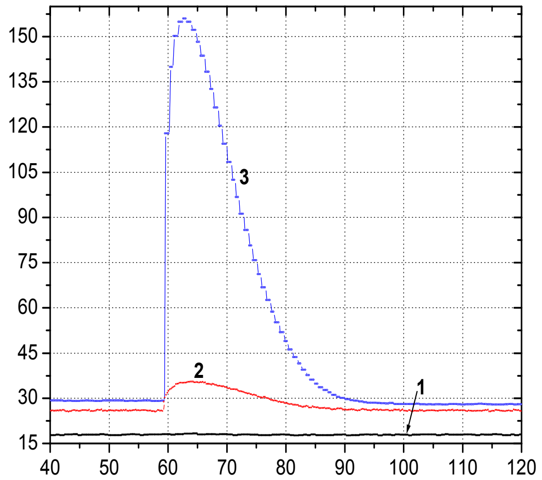


Fig. 4. *Time dependence of temperature at spontaneous energy release in irradiated water ice. 1 - temperature of cooling helium, 2 – temperature of copper wall of capsule, 3 – temperature of methane. Abscisssa axis – time in sec, ordinate axis - temperature in Kelvins.*

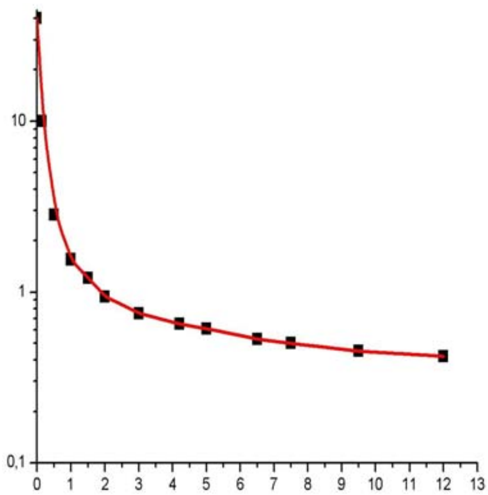


Fig. 5. *Change of ice thermal conductivity (ordinate axis, Wt/m/K) at irradiation by fast neutrons; abscissa axis – absorbed dose in units 0.4 MGy).*

An analysis of the effectiveness of cold neutron producing and the possibility of realization of cold moderators with various moderating materials was carried out. The conclusion was made that, from the practical point of view, mesithylene mixtures with other aromatic hydrocarbons are preferable. Taking into account real working conditions, the yield of cold neutrons from such moderator will not be less than that from the solid methane moderator and at the same time it will be stable.

The earlier proposed concept of combi-moderators for the IBR-2M reactor, which provide a necessary spectrum of neutrons for each of the spectrometers using this moderator, was confirmed by way of calculation. The combi-moderator for beams: 7, 8, 10 and 11 (**Fig. 6**) of the IBR-2M rector was optimized. The mesithylene-based cold moderator with the size of approximately 20×15×3 cm (with 3 cm water premoderator) is planned to be installed higher than the median plane of the reactor and with a shift in horizontal direction relative to the axis of the 8-th beam. This will provide a free «view» from the 7-th beam to the cock-like water moderator. For the 11-th beam a tangent cock-like moderator with a density of neutron flux of about 50% of this value for the 7-th beam will be installed.

The density of cold neutron flux from the mesithylene-based moderator is expected to be equal to 2 10^{13} n/cm^2/s/eV/sr at λ = 4 A and 0.5 10^{13} n/cm^2/s/eV/sr at λ = 9 A, which is three times higher than the flux from a liquid hydrogen moderator ISIS (England).

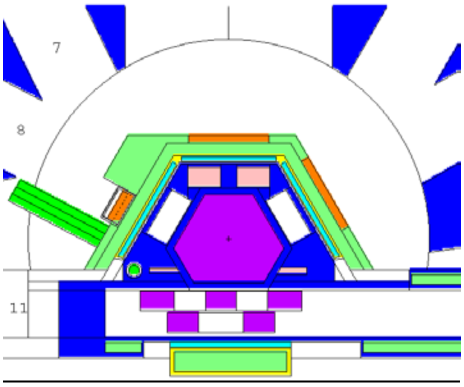


Fig. 6. *The combi-moderator for beam 7 (cock-like water), 8 (cold), 10 (wide-spectrum) and 11 (hole water).*

As a result of works in 2003 a basis for designing the moderator complex at the IBR-2M reactor, providing a maximum effectiveness of the spectrometers, was created.

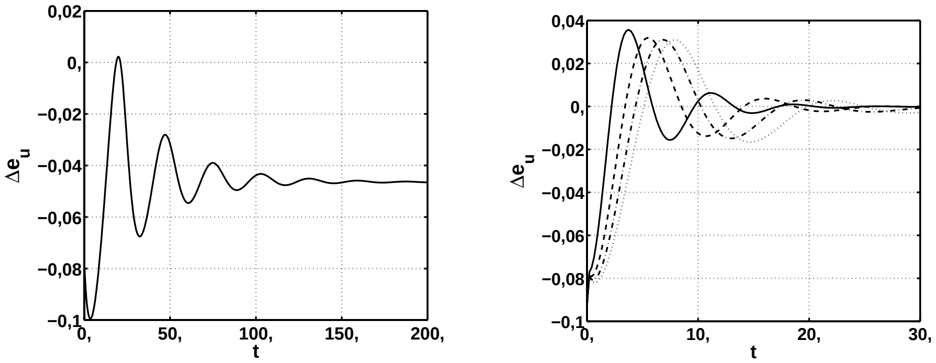
Investigation and diagnostics of reactor state. In 2003 the works devoted to the investigation and diagnostics of the reactor went in the following main directions:

Monitoring of the primary parameters of the reactor during its operation at power transmitting part of the data onto the neutron beam users' WEB page.

Monitoring of the reactor noise state and experimental investigation of reactor stability with the help of neutron noises. It is noted that the dynamics of the reactor have not practically changed compared with that from detail investigations of the dynamical characteristics of the reactor in 2002.

Works were carried out to improve the algorithms and software of the new methods for data analysis based on neutron networks and of image recognition methods. It is shown to be possible to predict slow changes of the degradation type (with a period of over a month) occurring in the movable reflectors in the vibrational state and correspondingly, in power pulse energy noises using neutron networks.

Reactor dynamics models were being improved. Calculations in the modeling of power transitional processes for the different external reactivity perturbations taking place in the process of regular operation of the reactor for a power of 1450 kW were done. It is shown that the presently chosen parameters of the system for automatic power regulation (AR) are not optimal (**Fig. 7**). The investigations show that the AR system is, at present, a basic link in the reactor feedback chain providing for stable operation of the reactor at nominal power as well as during routine operations of increasing or decreasing the power.



a) AR off b) AR on, q = 8

Fig. 7. *The power transitional processes in IBR-2 for the reactivity jump 0.1 β_u, the mean reactor power 1.450 MW and the cooling agent consumption 90 m³/h; t is time in seconds.*

—— Δ=0.05 - - - - Δ=0.10- · - · - - Δ=0.15 · · · · Δ=0.20. The values of q = 8 and Δ=0.20 are regular.

A variant of the dynamics model of powerful pulsed subcritical systems with an electron or proton accelerator as an advanced pulsed neutron source has been developed. A physically realizable variant of a hypothetical source combining a source based on a nonmultiplying target of the ISIN- (Great Britain, Chilton) or MLNSC-type (USA, Los Alamos) and a subcritical multiplying assembly with parameters similar to those of the IBR-2 reactor zone is shown. Such a combination gives a 20 times increase in the power of the source retaining the neutron pulse duration.

Preliminary calculations of the specifics of fuel burning in IBR-2 were conducted taking into account its actual cyclic character of operation. The results reveal dependence of the buildup of some actinides on the reactor operation mode.

Theoretical investigations of the time resolution of vacuum fission chambers as an advanced detector for the measurement of the form of short neutron pulses completed.

8. Works are being carried out to develop a block for the measuring of axial vibrations of movable reflectors using several reflector blade position sensors. It should be noted that axial vibrations of the reflectors contribute considerably to power pulse energy fluctuations and stable operation of the reactor depends greatly on the MR vibration level.

Works are being conducted to prepare IBR-2 startup operations.

2.2. The IREN Project

The main task of the IREN project in 2003 was a decommissioning of the reactor IBR-30. It is a mandatory condition to get a license for construction of the IREN facility. JINR directorate assigned nominally the special grant (80 K$) for decommissioning of the IBR-30 reactor and the separate grant (50K$) for the project itself.

The first one allowed fulfilling of the task in principle. But, actually, in spite of many efforts to realize the special JINR director order and the respective time-table the decommissioning of IBR-30 has not been finished in 2003. Meanwhile, most of items of this time-table were realized (bld. 117/6 for storing of activated constructions of the reactor is completed and technically equipped, all devices necessary for dismantling of the reactor are manufactured and tested, all containers intended for transportation and storing of reactor fuel load are manufactured and obtained, the first stage of personnel training is completed), the absence of some dosimetric equipment and debts for construction of bld. 117/6 did not permit us to get license for exploitation of this storage and for its use for some operation with fuel load. So the dismantling of IBR-30 will be able to start only next summer if dosimetric equipment is paid, delivered and installed in the first quarter of 2004 and before starting of the works the license for storage is received. The work for dismantling of the reactor is permitted to carry out only at warm time. It is essential to note that the present license for decommissioning of the IBR-30 will expire on 31/12/2003 so now we have sent an application to get a new license from Russian GOSATOMNADZOR.

The second main task of the IREN project was to complete a working out of a first part of the technological project of the facility. It was fulfilled with large delay by the Moscow design institute GSPI. We have obtained very recently the part of the general project necessary for approving in the respective Russian authorities. The activity aimed at getting permission for siting of the IREN source at JINR is started on the basis of the obtained project. But we did not obtain from NIKIET, Moscow, the technological drawings of the multiplying target necessary to claim a tender for manufacture of the hardware of this target. This documentation is practically ready but it could not be delivered to JINR without of the respective payments. Very similar situation is with the technical project of the control system of the IREN source. It is completed by a special Moscow organization OKSAT NIKIET on credit but up to now JINR has not paid for it.

The third main task defined for current year, namely a startup of LUE-200 assembling, has large delay due to very insufficient and irregular funding. But as in the case with the IBR-30 some progress based mainly on internal resources is achieved. Many efforts have been made to create the first variant of the electron source. Now this device is being tested at a special full- scale test-bench. Some elements of LUE-200 magnetic focusing system were manufactured during last months at

JINR. The measurements of their technical characteristics confirmed their matching with the designed ones. But completion of manufacture of the whole system is impeded by lack of financing. A cosmetic repair of the accelerator halls in bld. 43, FLNP, and modernization were completed in June including installation of a new lifting device and creation of the additional hole into the floor of higher hall. All constructions of the girder have been obtained at last. Its assembling was started in November 2003 in bld. 43 with large delay after completion of precise geodesic measurements at the site of the linac. A design work of most elements of the accelerator has been finished and many of them are actually manufactured at JINR workshops. But due to permanent and deep under-financing manufacturing and assembling of the linac goes with large delay.

2. НЕЙТРОННЫЕ ИСТОЧНИКИ

2.1. Импульсный реактор ИБР-2

Модернизация. В 2003 г. ИБР-2 отработал на физический эксперимент ~ 681 час.

Основные результаты по модернизации ИБР-2 в 2003 г.:

1) ПО-3 – главная задача года
   - Полностью завершено изготовление узлов ПО-3.
   - На стенде ЛНФ выполнена контрольная сборка ПО-3 без кожуха.
   - Осуществлен пуск ПО-3 на воздухе до 360 об/мин (60% от номинальных оборотов), результаты испытаний положительные.
   - Ведется контрольная сборка ПО-3 с кожухом (см. **рис. 1 и 2**).

Рис. 1. *Новый подвижный отражатель ПО-3 реактора ИБР-2 (основной и дополнительный модуляторы реактивности).*

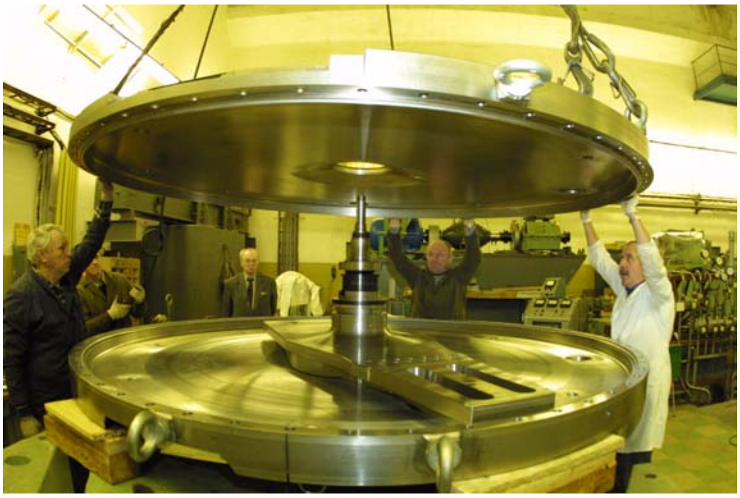


Рис. 2. *Персонал реактора ИБР-2 выполняет сборку подвижного отражателя с кожухом ПО-3 на испытательном стенде ЛНФ ОИЯИ.*

2) Новая топливная загрузка
   - На ПО «Маяк» завершено изготовление ТВЭЛов.
   - Изготовлены и получены комплектующие детали для тепловыделяющих сборок (ТВС).
   - Ведется в ГСПИ проект участка сборки ТВЭЛ в ТВС.
3) Основное оборудование реактора
   - Продолжалось изготовление нового корпуса реактора.
   - Продолжалась работа по выпуску конструкторской документации на откатные защиты, стационарные отражатели.
4) СУЗ
   - Заключен договор со СНИИП-СИСТЕМАТОМом на разработку и изготовление электронной аппаратуры СУЗ.
   - Продолжалась разработка исполнительных механизмов СУЗ в НИКИЭТ.
5) Гелиевая установка
   - Завершена разработка новой ХГУ для будущих холодных замедлителей реактора.

На обеспечение перечисленных выше работ в 2003 было израсходовано 617 k$. (ОИЯИ – 285 k$, МАЭ – 332 k$). Всего в модернизацию ИБР-2 вложено около 39 % от полной стоимости проекта (см. табл. 1).

Таблица 1

График финансирования модернизации ИБР-2

		1995-1999	2000	2001	2002	2003	Всего
ОИЯИ	план (k$)	550	190	700	250	250	**1940**
	факт (k$)	602	193	233	130	285	**1443**
	процент выполнения	109	102	33	52	114	**74**
МАЭ	план (k$)	–	300	300	450	450	**1500**
	факт (k$)	–	342	301	423	332	**1398**
	процент выполнения	–	114	100	94	74	**93**
Всего:	план (k$)	550	490	1000	700	700	**3440**
	факт (k$)	602	535	534	553	617	**2841**
	процент выполнения	109	109	53	79	88	**83**

Планы на 2004 г.

1. После окончательной сборки ПО-3 провести стендовые испытания, выполнить монтаж ПО-3 на штатном месте около реактора и осуществить пуск ИБР-2 с новым ПО-3 в середине 2004 г. (см. **рис. 3**).

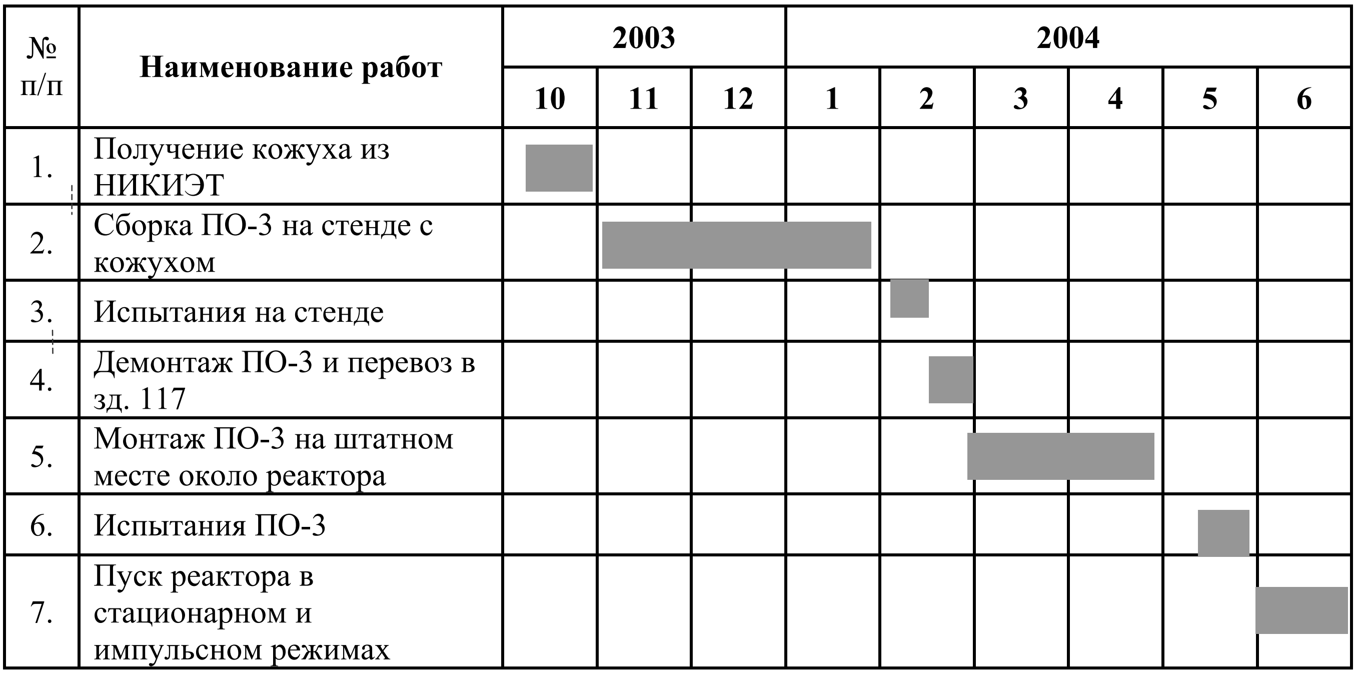


Рис. 3. *План работ по ПО-3 на 2003-2004 гг.*

2. Получение новой топливной загрузки с ПО «МАЯК» и организация в ОИЯИ участка по сборке ТВЭЛов в тепловыделяющие кассеты.
3. Продолжение работ по изготовлению нового корпуса реактора ИБР-2М и другого основного оборудования реактора.
4. Разработка исполнительных механизмов и электронной аппаратуры СУЗ ИБР-2М.
5. Разработка технического задания на новые замедлители и начало их проектирования.
6. Изготовление ХГУ.

Разработка комплекса замедлителей нейтронов широкого спектра для ИБР-2М. В текущем году завершено исследование радиационных свойств водородосодержащих материалов (метан, гидрат метана, ароматические углеводороды, водяной лед и лед с добавками акцепторов атомарного водорода) на установке УРАМ-2 при низких температурах (20-40К) и сделан анализ экспериментальных данных. Из главных результатов можно отметить два явления, ранее никем не наблюдавшиеся:

- спонтанную цепную реакцию рекомбинации радикалов (РРР) в облучаемом водяном льде (**рис.4**),
- и резкое снижение теплопроводности льда под облучением (**рис.5**).

Спонтанный нагрев льда до 150-200К возникал при дозе облучения 2-8 МГр (5-20 часов облучения потоком быстрых нейтронов 3 10^{12} н/см^2/с). Введение некоторых акцепторов водорода мало влияло на условия развития РРР. Впервые было показано, что явление РРР характерно для многих замороженных соединений, в которых одним из продуктов радиолиза являются радикалы. Из изученных веществ РРР не возможны только в ароматических углеводородах. Накопление энергии рекомбинации радикалов идет со скоростью 20-24 Дж/г/час в водяном льду (5.4%±0.4% от поглощенной дозы) и 12-14 Дж/г/час в твердом метане (1.6%±0.2% от поглощенной дозы). Практически важен тот результат, что в ароматических углеводородах (мезитилен C_9H_{12} и др.) радикалы накапливаются в сотню раз медленнее, а скорость генерации радиолитического водорода в 10-20 раз меньше, чем в метане.

Проведен анализ эффективности производства холодных нейтронов и возможности реализации холодных замедлителей с разными замедляющими веществами и сделан вывод, что с практической точки зрения предпочтительным является смесь мезитилена с другими ароматическими углеводородами. При учете реальных условий работы, выход холодных нейтронов из такого замедлителя не будет уступать твердо-метановому и в то же время будет стабильным.

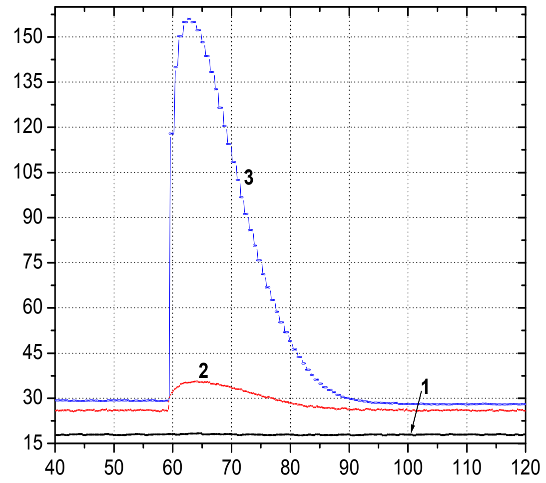


Рис. 4. Временной ход температур при спонтанном выделении энергии в облучаемом водяном льду. 1- температура охлаждающего гелия, 2 – температура медной стенки капсулы. 3 – температура метана. Ось абсцисс – время в секундах, ось ординат - температура в абсолютных градусах Кельвина.

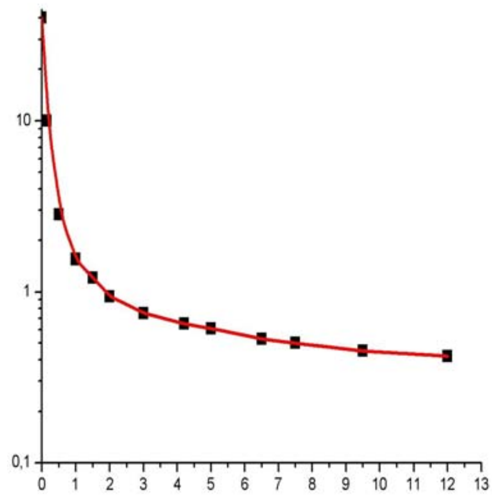


Рис. 5. Изменение теплопроводности льда (ось ординат, Вт/м/К) при облучении быстрыми нейтронами; по оси абсцисс – поглощенная доза в ед. 0.4 МГр).

Расчетным путем подтверждена предложенная ранее концепция комби-замедлителей для ИБР2-М, которые обеспечивают необходимый спектр нейтронов для каждого из спектрометров, использующих этот замедлитель; оптимизирован комби-замедлитель для пучков реактора ИБР-2М: 7-го, 8-го, 10-го и 11-го (**рис.6**). Холодный замедлитель из мезитилена размером примерно 20×15×3 см (с 3-х сантиметровым водяным предзамедлителем) предполагается установить выше медианной плоскости реактора, а также со сдвигом в горизонтальном направлении относительно оси 8-го пучка. Тем самым обеспечивается свободный «просмотр» от 7-го пучка на гребенчатый водяной замедлитель. Для 11-го пучка будет установлен касательный гребенчатый замедлитель с плотностью потока нейтронов около 50% от этой величины для 7-го пучка. Плотность потока холодных нейтронов из мезителенового замедлителя ожидается равной $2\ 10^{13}$ н/см^2/с/эВ/ср при $\lambda = 4$ А и $0.5\ 10^{13}$ н/см^2/с/эВ/ср при $\lambda = 9$ А, что в 3 раза выше потока из жидководородного замедлителя ISIS (Англия).

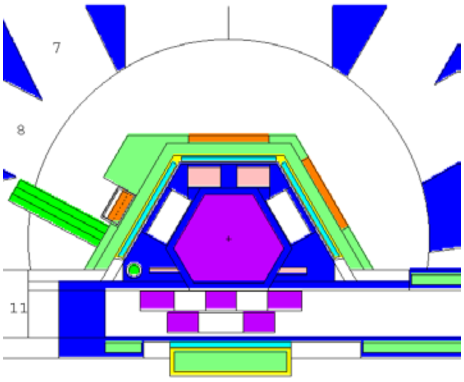


***Рис.6**. Комби-замедлитель для пучков: 7-го (гребенчатый водяной), 8-го (холодный), 10-го (широкого спектра) и 11-го (дырочный водяной).*

В результате работ 2003 года создана база для проектирования комплекса замедлителей на ИБР-2М, обеспечивающего максимальную эффективность спектрометров.

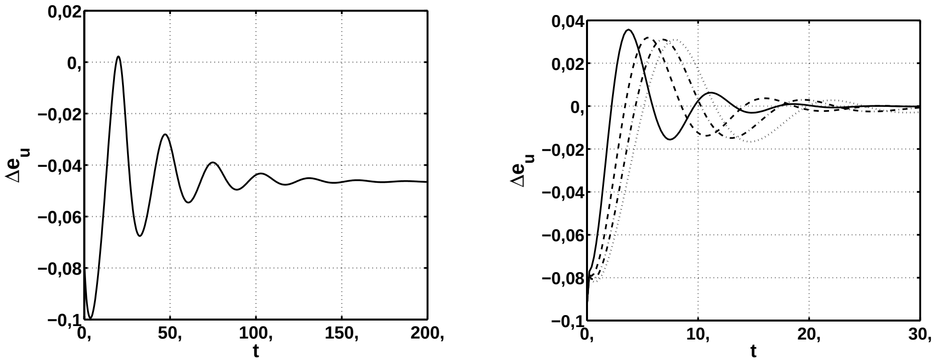
<u>Исследование и диагностика состояния реактора</u>. Работы по исследованию и диагностике реактора в 2003-м году в велись в следующих основных направлениях:

Мониторирование основных параметров реактора при его работе на мощности с выдачей части информации на WEB-страницу для пользователей нейтронных пучков;

Мониторирование шумового состояния реактора и экспериментальное исследование стабильности реактора с помощью нейтронных шумов. Отмечено, что динамика реактора практически не изменилась по сравнению с результатами подробных исследований динамических характеристик реактора, проведенных в 2002 г.;

Проводились работы по совершенствованию алгоритмов и программного обеспечения новых методов анализа данных на основе нейронных сетей и методов распознавания образов. Показана возможность предсказания медленных изменений деградационного типа (с периодом более месяца), происходящих в вибрационном состоянии подвижных отражателей и, соответственно, в шумах энергии импульсов мощности с помощью нейронных сетей;

Совершенствовались модели динамики реактора. Проведены расчеты по моделированию переходных процессов мощности при различных возмущениях внешней реактивности, имеющих место при нормальной работе реактора на мощности 1450 кВт. Показано, что выбранные в настоящее время параметры системы автоматического регулирования мощности (АР) не являются полностью оптимальными (**рис. 7**). Исследования показывают, что система АР в настоящее время является основным звеном в цепи обратной связи реактора, обеспечивающая стабильную работу реактора как на номинальной мощности, так и в штатных операциях подъема и снижения мощности;



а) АР отключен б) АР включен, q = 8

***Рис. 7.** Переходные процессы мощности ИБР-2 при скачке реактивности - 0,1 β_u при средней мощности реактора 1,450 МВт и расходе теплоносителя 90 м³/ч; t – время в секундах.*
—— Δ=0,05 - - - - Δ=0,10- · - · - - Δ=0,15 · · · · Δ=0,20. Значения q = 8 и Δ=0,20 – штатные.

Разработан вариант модели динамики мощных импульсных подкритических систем с электронным или протонным ускорителем как одного из перспективных импульсных источников нейтронов. Показан физически реализуемый вариант гипотетического источника, объединяющего источник на основе неразмножающей мишени типа ISIS (Великобритания, Чилтон) и MLNSC (США, Лос-Аламос) и подкритической размножающей сборкой с параметрами активной зоны реактора ИБР-2. В такой комбинации мощность источника возрастает в 20 раз при сохранении длительности нейтронного импульса.

Проведены предварительные расчеты по особенностям выгорания топлива ИБР-2 с учетом реального циклического характера его работы. Результаты расчетов показывают зависимость накопления некоторых актинидов от режима работы реактора.

Закончены теоретические исследования по временному разрешению вакуумных камер деления как одного из перспективных детекторов для точного измерения формы коротких нейтронных импульсов.

Ведутся работы по разработке блока измерения осевых колебаний подвижных отражателей с использованием нескольких датчиков положения лопастей отражателей. Отметим, что осевые колебания отражателей вносят значительный вклад в колебания энергии импульсов мощности и стабильная работа реактора во многом зависит от уровня вибраций ПО.

Ведутся работы по подготовке к проведению пусковых работ на ИБР-2.

2.2. Проект ИРЕН

Основной задачей проекта ИРЕН в 2003 году был демонтаж реактора ИБР-30, что является обязательным условием для получения разрешения на строительство установки ИРЕН. Дирекция ОИЯИ номинально выделила специальный грант (80 к$) на демонтаж реактора ИБР-30 и отдельный грант (50 к$) на сам проект.

Первый грант позволял в принципе выполнить данную задачу. Но, фактически, несмотря на большие усилия реализовать специальный приказ директора ОИЯИ и соответствующий план-график, демонтаж ИБРа-30 не был закончен в 2003 году. Между тем, большинство пунктов плана-графика были выполнены (строительство здания 117/6 для хранения активированных элементов реактора завершено и проведено его техническое оснащение, всё специальное оборудование, необходимое для демонтажа реактора изготовлено и испытано, все контейнеры, предназначенные для транспортировки и хранения топливной загрузки реактора изготовлены и получены, первый этап тренировки персонала завершён). Отсутствие некоторого дозиметрического оборудования и долги за строительство здания 117/6 не позволили нам получить лицензию на эксплуатацию этого хранилища и его использование для некоторых операций с топливной загрузкой. Таким образом, демонтаж ИБРа-30 может быть начат только следующим летом, если дозиметрическое оборудование будет оплачено, доставлено и установлено в первом квартале 2004 года и до начала работ будет получена лицензия на хранилище. Работы по демонтажу реактора разрешено проводить только в тёплое время года. Важно отметить, что существующая лицензия на демонтаж ИБРа-30 истекает 31/12/2003, поэтому сейчас мы отослали заявление на получение новой лицензии ГОСАТОМНАДЗОРа РФ.

Второй основной задачей проекта ИРЕН было завершение разработки утверждаемой части рабочего проекта установки. Она была выполнена с большой задержкой ГСПИ, Москва. Совсем недавно мы получили эту часть рабочего проекта, который необходимо согласовывать в соответствующих российских инстанциях. Начата деятельность по получению разрешения на размещение источника ИРЕН в ОИЯИ на базе полученного проекта. Но мы до сих пор не получили из НИКИЭТа, Москва, конструкторской документации по размножающей мишени, необходимой для объявления тендера на изготовление корпуса этой мишени. Указанная документация практически готова, но она до сих пор не получена ОИЯИ из-за долгов по соответствующему контракту. Очень похожа ситуация и с техническим проектом АСКУ источника ИРЕН. Проект выполнен специальной

Московской организацией ОКСАТ НИКИЭТ в кредит, но до сих пор ОИЯИ за него не заплатил.

Третья основная задача, определённая на текущий год, а именно запуск линака ЛУЭ-200, выполнялась с большой задержкой из-за недостаточного и нерегулярного финансирования. Но, как и в случае с реактором ИБР-30, некоторый прогресс достигнут в основном за счёт внутренних ресурсов. Было потрачено много усилий на то, чтобы создать первый вариант источника электронов. Сейчас это устройство испытывается на специальном полномасштабном стенде. Некоторые элементы магнитной фокусирующей системы ЛУЭ-200 были изготовлены в течение последних месяцев в ОИЯИ. Измерения их технических характеристик подтвердили соответствие проектным параметрам. Но завершение изготовления всей системы затрудняется недостатком финансирования. В июне был завершён косметический ремонт и модернизация залов ускорителя в здании 43, ЛНФ, включая установку нового подъёмного устройства и создание дополнительного проёма в полу верхнего зала. Все конструкции фермы линака были наконец получены. Её сборка была начата в ноябре 2003 года в здании 43 с большой задержкой после завершения точных геодезических измерений на месте установки ЛУЭ-200. Конструкторская разработка большинства элементов ускорителя к настоящему моменту завершена, и они изготавливаются в ОП ОИЯИ. Но ввиду постоянного и серьёзного недостатка финансирования, изготовление и монтаж линака идут с большой задержкой.

3. THE IBR-2 SPECTROMETERS COMPLEX AND COMPUTING INFRASTRUCTURE

In 2003, work under theme 1012 was carried out in the following main directions:

- creation of neutron detectors;
- development of sample environment systems;
- development of data acquisition systems and network infrastructure;
- current modernization and routine maintenance of the IBR-2 spectrometers complex.

1. Creation of neutron detectors

1.1 Gas detectors

1.1.1. Infrastructure

A large amount of work to create technological and electronic infrastructure for manufacturing and testing detectors has been performed:

- Preparation for the commissioning of a clean room is being completed. Some works on the assembling of detector elements are already being carried out in it (**Fig. 1**).

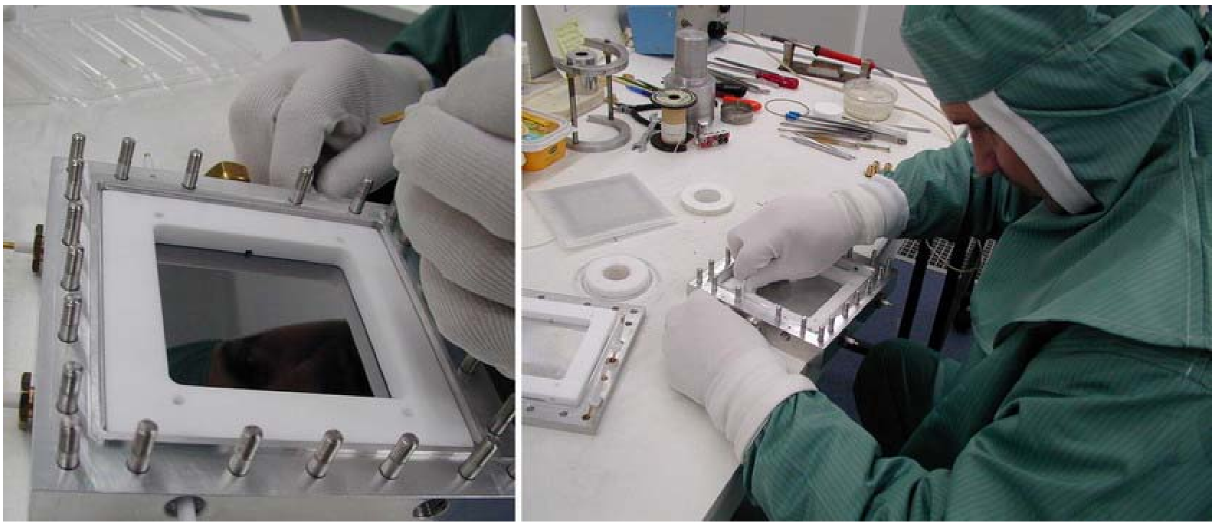


Fig.1. *Assembly of MSGC detector in a clean room*

- Stand for creating anode and cathode planes for neutron detectors on the basis of multiwire proportional chambers (MWPC) was created and the manufacturing of electrodes for MWPC detectors with individual signal readout from each wire and with delay line data readout was started.
- Electronic stand for testing two-coordinate detectors with delay line data readout was assembled. It includes an amplitude analyzer and NIM crate with 5-channel constant fraction discriminator, blocks of controlled delays and a high-voltage power supply. The structure of the stand also comprises a personal computer with a built-in data acquisition (DAQ) and accumulation card developed in cooperation with HMI, Berlin. All mentioned equipment was adjusted and first test measurements with ^{252}Cf source on a real detector manufactured in ILL, Grenoble were performed.

1.1.2. Development and manufacturing of detectors

1. An original design of MSGC detector with a "virtual" cathode was developed and the prototype of the detector (**Fig. 2**) was manufactured; readout electronics was adjusted and measurements were carried out. At present, the stability of detector operation is being checked. Electronics for a coordinate microstrip detector with determination of coordinates by the charge division method was assembled and prepared for testing.

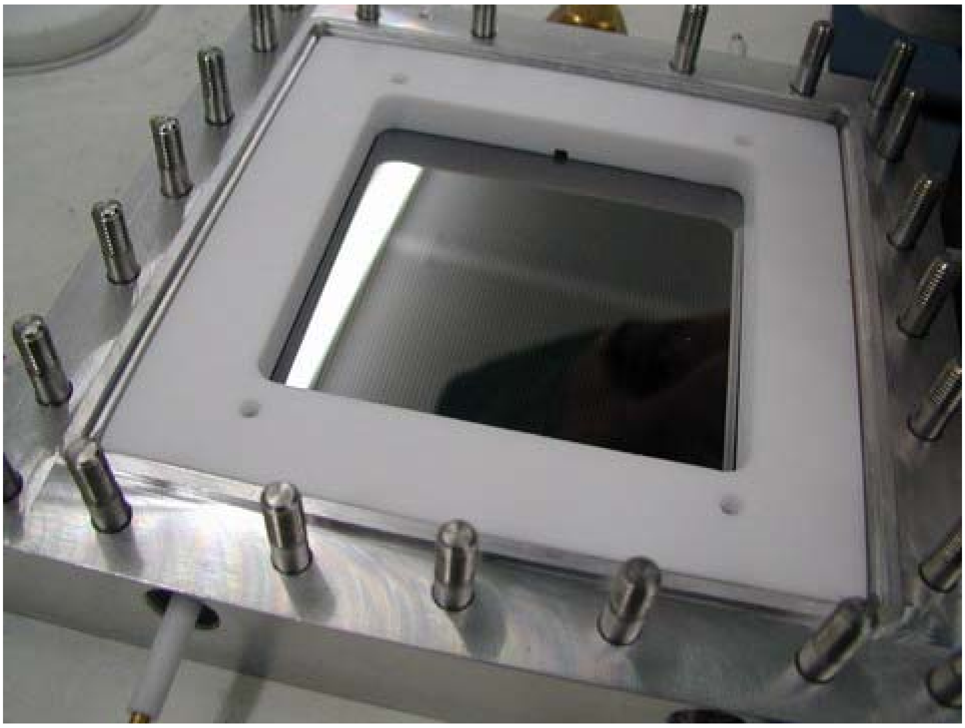


Fig.2. *MSGC detector with a "virtual" cathode*

2. MWPC detector with a sensitive area of 20×20см^2 and planned coordinate resolution of 2.5 mm (**Fig. 3**) was developed and manufactured. Determination of coordinates is realized by wire number coding. Together with the University of Magdeburg, a principal electric circuit of the block for calculation of the center of mass of the event cluster in the detector space
(64×64 wires) was developed and simulated in FPGA environment. The accuracy of determination of the center of mass is 0.5 pixels. A simplified version of the encoding block (24×24 pixels) was developed and manufactured.

3. The same casing will be used for creation of a two-coordinate detector of 20×20 cm^2 with delay line data readout. Cathode planes with delay lines, anode planes and preamplifiers are in the manufacturing stage. The manufacturing of the casing and assembling of the detector, as well as the beginning of test trials with DAQ electronics are planned for I-II quarters of 2004.

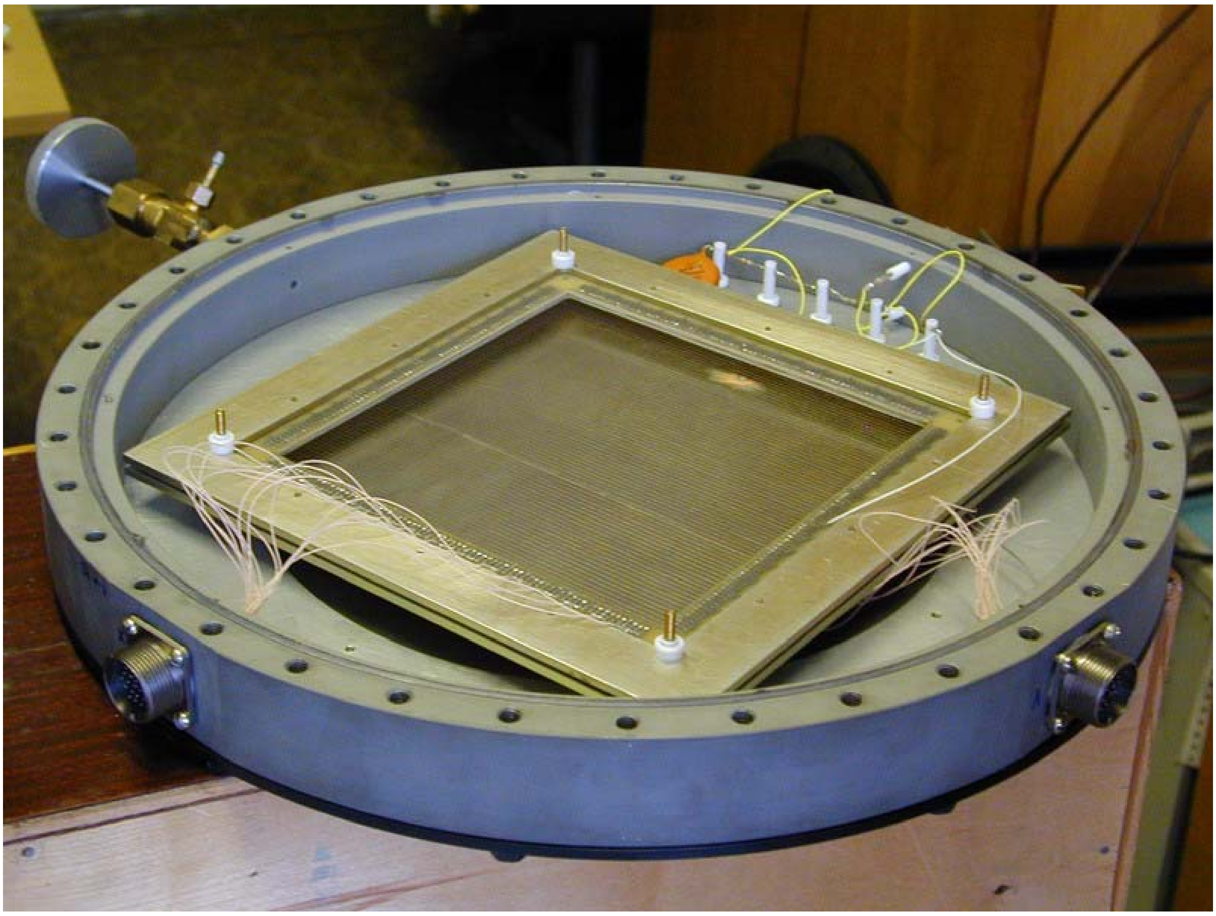


Fig.3. *Two-coordinate MWPC detector (20×20 cm²)*

2.1. Scintillation detectors

Work in this direction has been successfully carried out for several years. In 2004 the following results were obtained:

- At the FSD diffractometer to reduce the cost of detectors, investigations were conducted and the construction of scintillation counters was elaborated permitting a changeover to domestic photomultipliers. The main elements and units (**Fig. 4**) of 2 sections (16 working modules) of the ASTRA wide-aperture scintillation (ZnS) 90°-detector with time focusing were manufactured. In cooperation with the State Optical Institute (St.-Petersburg) the first stage of investigations of new scintillation ZnS-based materials was completed. These materials will make it possible to improve characteristics of scintillation ZnS-screens, as well as to abandon expensive purchases of ZnS-screens abroad.
- A prototype of the module (**Fig. 5**) for the scintillation (ZnS) 90°-detector of the DN-12 spectrometer was manufactured and tested on channel 12 of the IBR-2 reactor. The prototype was designed on the basis of the "rough" time focusing method, which allows a considerable increase in a solid observation angle, using scintillation plates of small area. The tests demonstrated a complete compliance of the detector parameters with the calculated values. According to the results of the tests, the 90°-detector assembled entirely of modules of a new type (ring of 16 modules) will provide an 8-fold increase in statistics gathering rate as compared to the available ring 90°-detector on helium counters working on channel 12.

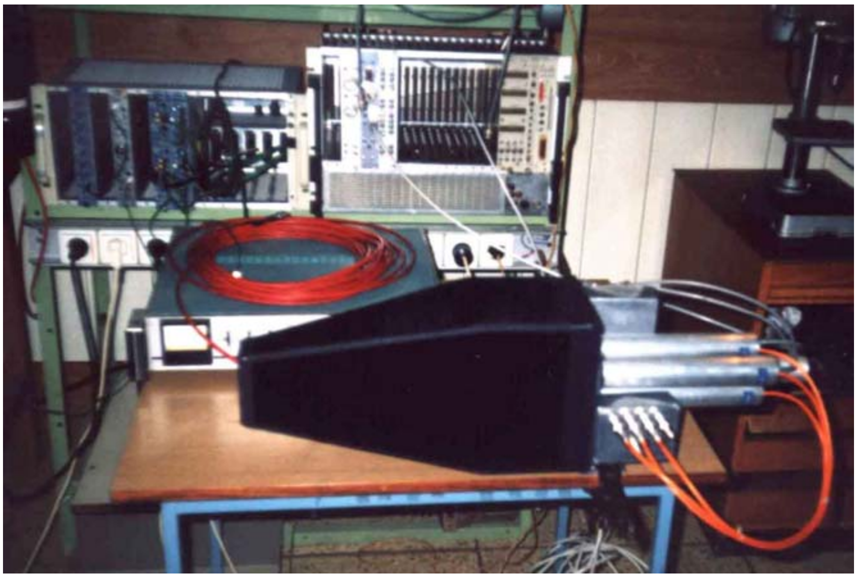


Fig.4. *Section of the ASTRA scintillation 90°-detector with time focusing and the measuring equipment*

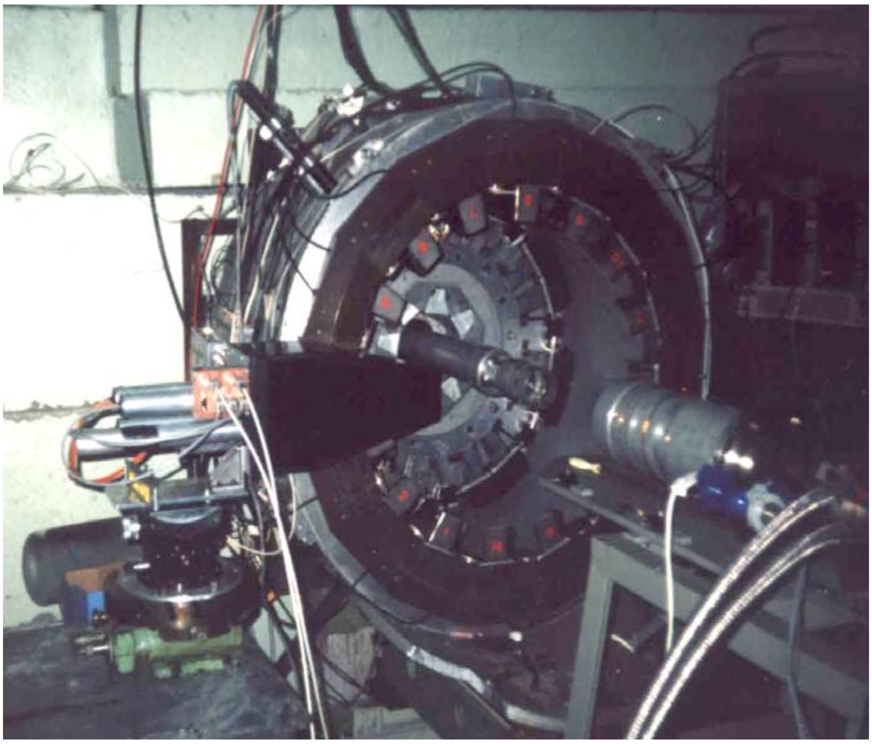


Fig.5*. A prototype of the module for the scintillation (ZnS) 90°-detector of the DN-12 spectrometer*

2. Development of sample environment systems

A microcontroller block for controlling step motors was developed to create multichannel control systems of actuating mechanisms of spectrometers on the basis of PC. The system comprises: controller, commutators-amplifiers of step motors SMD-D2A and a power supply unit for motors 32B*2A. Communication with PC is carried out using RS232 protocol.

For the DSD spectrometer of the IVV-2M reactor (Sverdlovsk branch of NIKIET) a central platform of stress-diffractometer with a linear scanner (Fig. 6) was manufactured. The central platform provides rotation of the linear scanner as a single whole around a vertical axis and rotation of a rotary platform with the detector around the same axis. All control systems are constructed on the basis of step motors and controlled by the experimental program.

Fig.6. *Control system of sample position on the basis of a scanner and platform with a rotary "arm" for placing the detector at the DSD spectrometer*

Fig.7. *Top loaded closed cycle cryostat on the basis of two-stage cryogenerator CoolPower 100T*

A top loaded cryostat was developed for carrying out diffraction experiments on thermal neutron beams in the temperature range from 8 to 300 K (**Fig. 7**). In the cryostat the closed cycle refrigerator of Leybold firm is used on the basis of cold head CoolPower 5/100T and compressor CoolPak 6000. The replacement of a sample does not demand the removal of the cryostat casing or disassembly of the cryostat. The shaft, whose bottom end is connected by means of a heat exchanger to the second stage of the refrigerator, is intended for sample changing. The sample volume – a vanadium glass is shunted by a copper heat conductor, which equalizes temperature across its volume. A drift diameter of the shaft is 19.2 mm, however at the level of the heat exchanger it is tapered to 18.1 mm. The greatest possible diameter of a sample is limited to the diameter of 17 mm.

A self-contained sorption refrigerator for working at a temperature of 0.3 K was developed. The refrigerator is designed as an insert 80 mm in diameter, which is submerged in a helium cryostat. It keeps the temperature of a sample at 0.31 K for 20 hours after condensation of ^{3}He at a useful heat load of 10 μW. Recondensation time is 0.5 hours.

Work to modernize the microcontroller-based control systems of choppers for the NERA-PR, SKAT and DIN-2 spectrometers (three choppers) was conducted. The software of chopper control systems was significantly modernized.

3. Development of data acquisition systems and network infrastructure

In the FLNP local area network Access Control Module Catalist 8510 for controlling and analyzing traffic, as well as a new mail server based on two Intel compatible processor with OS Solaris were installed and put into operation.

Work to develop FLNP Web-server and information system HIPNS (hypertext information system on neutron sources and neutron instruments) continued. HIPNS provides users with data about neutron sources and spectrometers, as well as about investigations carried out on these sources. The XML-version of the HIPNS system using the Apache Cocoon technology was realized. Required pages are automatically generated from the database, which was created for several IBR-2 spectrometers. In 2003 a new two-processor PC Web-server was purchased and installed.

In cooperation with HMI, Berlin, testing of DAQ electronics for MWPC detector with delay lines was completed. The changes improving speed of operation and time resolution were made in the electric circuit, and 10 boards for JINR and HMI were manufactured in ILFA firm, Hamburg. The first version of software for the board was developed. It includes event selection algorithms (realized in FPGA), programs for controlling data flows in various operating modes of the board (these programs are run by a digital signal processor installed on the board), program driver of the board, programs of preliminary processing and user programs on PC. Electronics and software were successfully tested with a real detector using a source (in HMI and in FLNP) and on the BER-II reactor in HMI. The analysis and visualization of data were carried out using ROOT and PV-WAVE packages. At present, works on optimization of the programs are conducted.

The combined control system of the NERA-PR spectrometer (graphic interface on PC with retention of control programs in VME) was given to users for operation testing from the end of October 2002 till February 2003. This operation testing has demonstrated stable work of the hardware, operating system Windows XP and the created software. Work to adapt all control programs to Windows is in the completion stage. Simultaneously at the SPN (REMUR) spectrometer a similar problem of changing over to a new control system on the basis of VME-PCI adapter is being solved. The scheduled completion date of works is the end of I quarter, 2004.

The SONIX software complex was adapted for work at the FSD spectrometer, installed, tested and put into operation. Works to install the adapted SONIX software complex at the HRFD spectrometer were started as well.

During the reported year a number of digital and analog electronic blocks for the IBR-2 spectrometers (spin-flippers for the SPN spectrometer, preamplifiers, spectrometric amplifier, etc.) were developed and manufactured. On demands of users works on current modernization and repair of the equipment, as well as on optimization and routine maintenance of the software, were carried out.

The maintenance of trouble-free operation of the spectrometers during the IBR-2 cycles and preventive servicing during the reactor shutdown also required great efforts.

Within the framework of main directions of works under theme 1012 (detectors, sample environment systems, data acquisition systems, local area network) long-term development projects for 2004-2008 were prepared.

3. КОМПЛЕКС СПЕКТРОМЕТРОВ ИБР-2
И ИНФОРМАЦИОННО-ВЫЧИСЛИТЕЛЬНАЯ ИНФРАСТРУКТУРА

Работы по теме в 2003 г. велись по следующим основным направлениям:

- создание нейтронных детекторов;
- развитие систем окружения образца;
- развитие систем сбора данных и сетевой инфраструктуры;
- текущая модернизация и эксплуатация комплекса спектрометров ИБР-2.

1. Создание нейтронных детекторов

1.1 Газовые детекторы

1.1.1. Инфраструктура.

Выполнен большой объем работ по созданию технологической и электронной инфраструктуры для изготовления и тестирования детекторов:

- Завершается подготовка к сдаче в эксплуатацию чистого помещения. В нем уже ведутся некоторые работы по сборке элементов детекторов (**рис.1**).

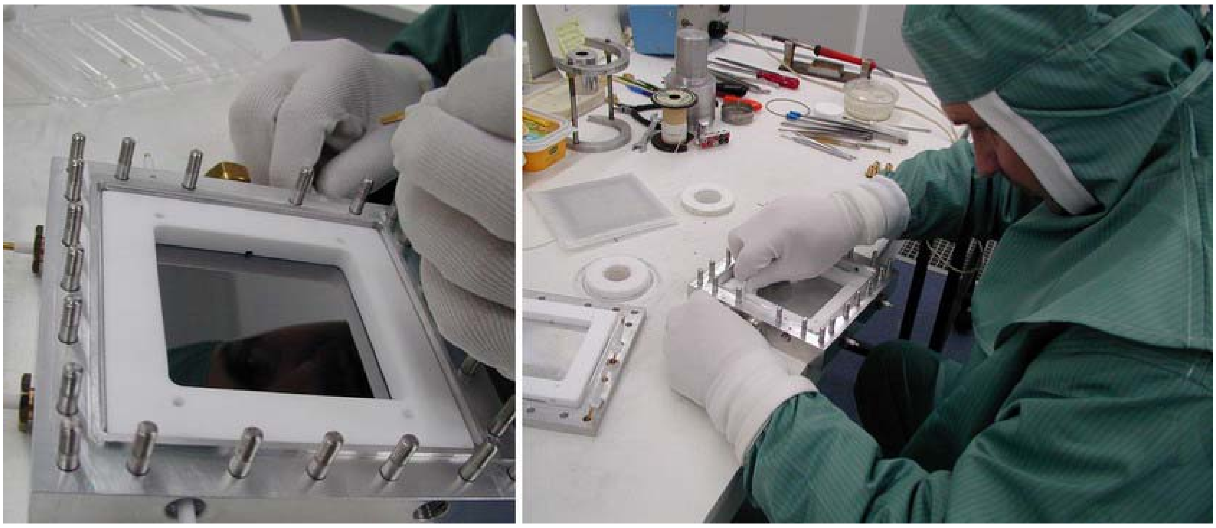


Рис. 1. *Сборка MSGC детектора в чистом помещении*

- Создан стенд для намотки анодных и катодных плоскостей нейтронных детекторов на основе многопроволочных пропорциональных камер (MWPC) и начато изготовление электродов для MWPC детекторов с индивидуальным съемом информации с каждой нити и со считыванием информации с линий задержки.
- Собран электронный стенд для испытания двухкоординатных детекторов с линиями задержки. Он включает в себя амплитудный анализатор и NIM крейт с 5-канальным дискриминатором с точной временной привязкой, блоками управляемых задержек и высоковольтным источником питания. В состав стенда входит также персональный компьютер со встроенной платой сбора и накопления данных (DAQ), разработанной в сотрудничестве с ИГМ, Берлин. Вся указанная аппаратура отлажена и проведены первые тестовые измерения с источником ^{252}Cf на реальном детекторе, изготовленном в ИЛЛ, Гренобль.

1.1.2.Разработка и изготовление детекторов

1. Выполнена оригинальная разработка MSGC детектора с “виртуальным” катодом и изготовлен прототип детектора (**рис.2**), настроена электроника считывания сигналов и проведены измерения. В настоящее время проверяется стабильность работы детектора.

Собрана и подготовлена к тестированию электроника для определения координат событий в этом детекторе методом деления заряда.

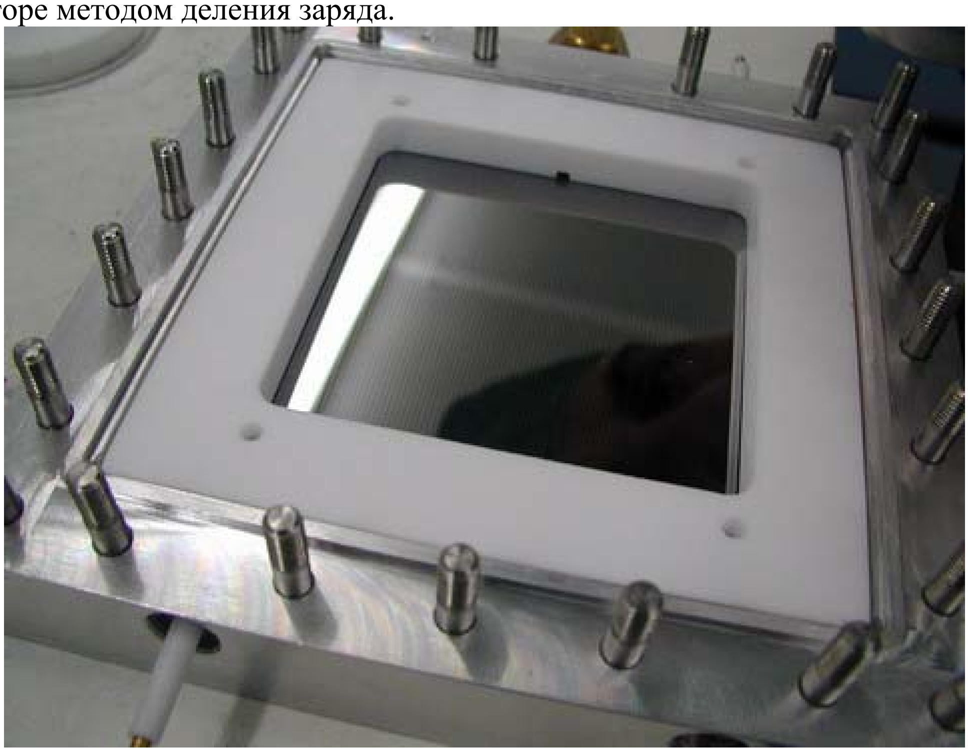


Рис. 2. *MSGC детектор с виртуальным катодом*

2. Разработан и изготовлен MWPC детектор с чувствительной областью 20×20см² и планируемым координатным разрешением 2.5.мм (**рис.3**). Определение координат реализуется путем кодирования номера «сработавшей» проволочки. Совместно с Университетом, Магдебург разработана принципиальная схема блока для вычисления центра масс кластера события в пространстве детектора (64×64нити) и проведено ее моделирование в FPGA. Точность определения центра масс составляет 0.5 пиксела. Разработана и изготовлена упрощенная версия блока кодирования (24×24пиксела).

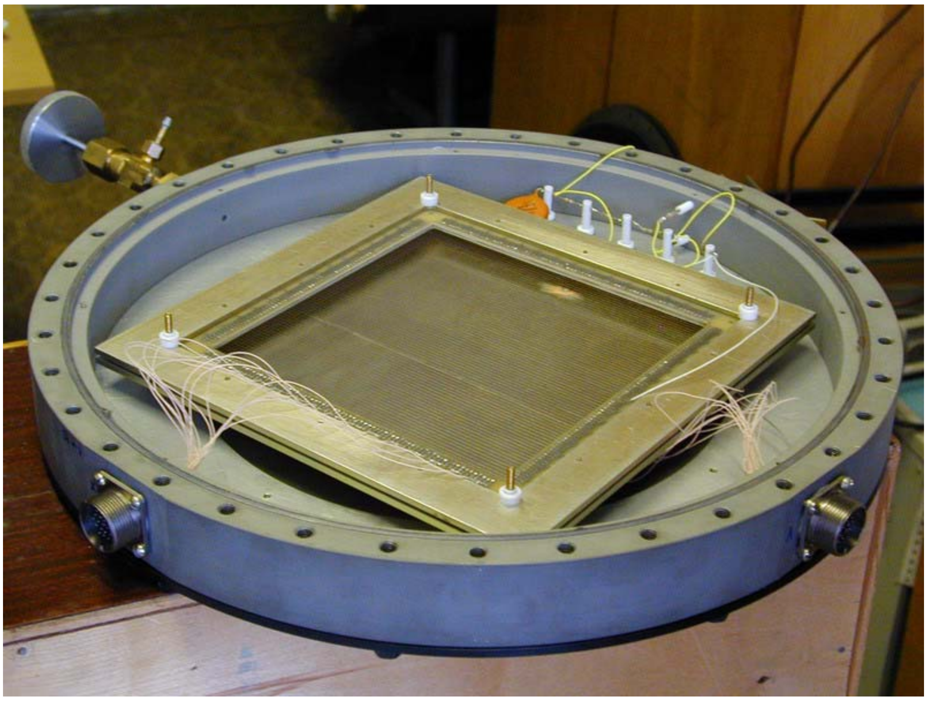


Рис. 3*. Двухкоординатный MWPC детектор 20x20 см²*

3. Точно такой же корпус будет использоваться для создания двухкоординатного детектора площадью 20×20см² со считыванием информации с линий задержки. Катодные плоскости с линиями задержки, анодная плоскость и предусилители находятся в стадии изготовления. Изготовление корпуса и сборка детектора, а также начало тестовых испытаний с DAQ электроникой планируются на I-II кв. 2004г.

2.1. Сцинтилляционные детекторы

Работы в этом направлении успешно ведутся в течение нескольких лет. В 2003г. получены следующие результаты:

- Для дифрактометра ФСД с целью снижения себестоимости детекторов выполнены исследования и доработка конструкции сцинтилляционных счетчиков, обеспечившие переход на отечественные фотоумножители. Изготовлены основные детали и узлы (**рис.4**) 2-х секций (16 рабочих модулей) широкоапертурного 90^0 сцинтилляционного (ZnS) детектора с временной фокусировкой ASTRA. Совместно с ГОИ (Санкт-Петербург) выполнен первый этап исследований новых сцинтилляционных материалов на основе ZnS. Данные материалы позволят улучшить характеристики сцинтилляционных ZnS-экранов, а также отказаться от дорогостоящих закупок ZnS-экранов за рубежом.
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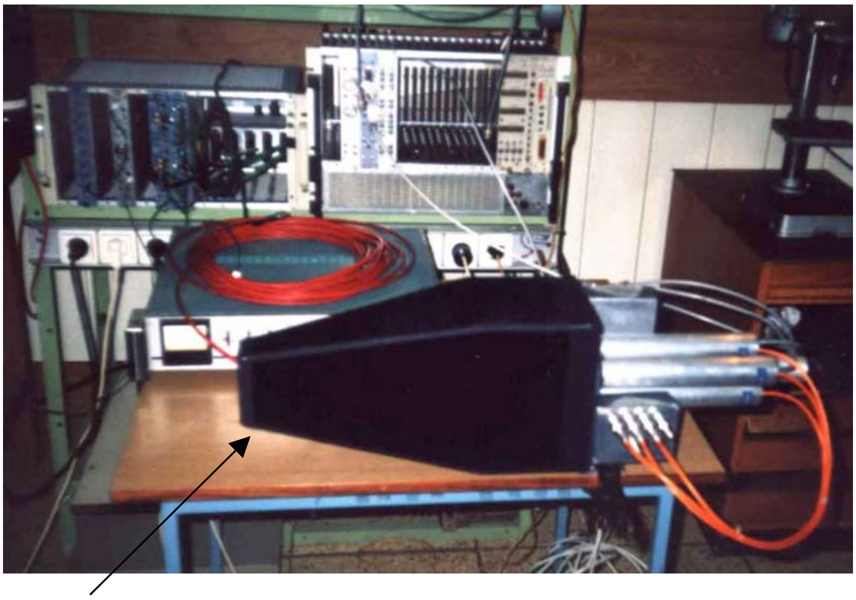

***Рис.4.** Секция 90^0 сцинтилляционного детектора с временной фокусировкой ASTRA с измерительной аппаратурой для снятия характеристик*

- Изготовлен и испытан на 12-м канале реактора ИБР-2 опытный образец модуля **(рис.5)** для 90^0 сцинтилляционного (ZnS) детектора спектрометра ДН-12. Образец был спроектирован на основе метода «грубой» временной фокусировки, позволяющий значительно увеличить телесный угол наблюдения, используя сцинтилляционные пластины малой площади. Испытания продемонстрировали соответствие параметров детектора расчетным значениям. Согласно результатам испытаний, полностью собранный из модулей нового типа 90^0 детектор (кольцо из 16-и модулей), обеспечит 8-кратное увеличение скорости набора статистики по сравнению с действующим на 12-м канале кольцевым 90^0 детектором на гелиевых счетчиках.

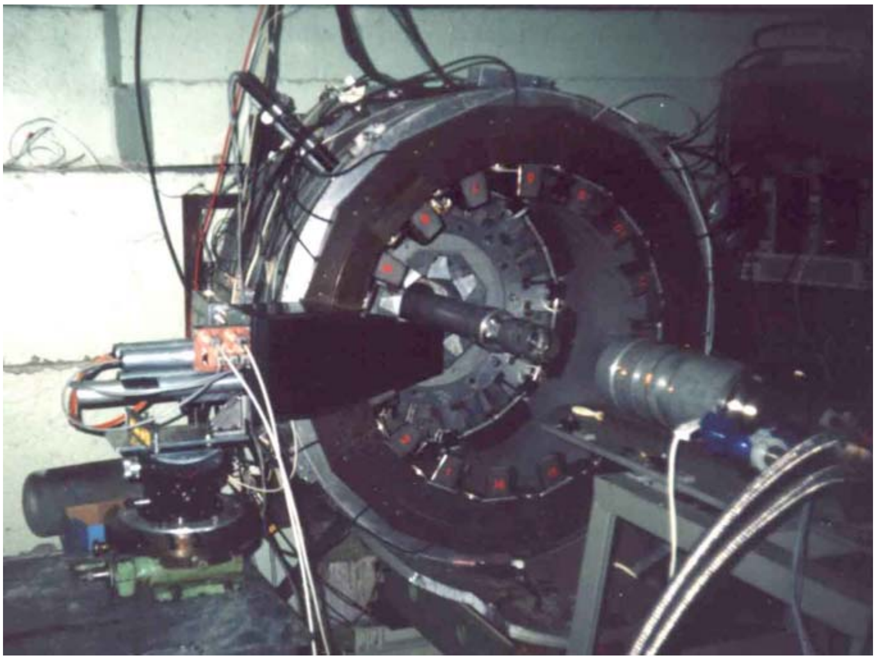

Рис.5*. Опытный образец модуля для 90^0 сцинтилляционного (ZnS) детектора спектрометра ДН-12*

2. Развитие систем окружения образца

Разработан микроконтроллерный блок управления шаговыми двигателями для создания многоканальных систем управления исполнительными механизмами спектрометров на базе ПК. В состав системы входят: контроллер управления, коммутаторы-усилители шаговых двигателей SMD-D2A и блок питания для двигателей 32В*2А. Связь с ПК осуществляется по протоколу RS232.

Для спектрометра ДСД реактора ИВВ-2М Свердловского филиала НИКИЭТ изготовлена центральная платформа стресс-дифрактометра с линейным сканером (**рис.6**). Центральная платформа обеспечивает вращение линейного сканера, как целого, вокруг вертикальной оси и вращение поворотной платформы с детектором вокруг этой же оси. Все системы управления выполнены на базе шаговых двигателей под управлением программы эксперимента.

Рис.6*. Система управления положением образца на базе сканера и платформы с поворотным «плечом» для размещения детектора на спектрометре ДСД*

Разработан шахтный криостат для проведения экспериментов по дифракции на пучках тепловых нейтронов в диапазоне температур 8 – 300 К (**рис.7**). В криостате использован рефрижератор замкнутого цикла фирмы Leybold на основе холодной головки CoolPower 5/100T и компрессора CoolPak 6000. Замена образца не требует снятия кожуха криостата и какой-либо другой разборки криостата. Для смены образца предназначен канал – шахта, нижний конец которой соединен посредством теплообменника со второй ступенью рефрижератора. Объем образца – ванадиевый стакан зашунтирован медным теплопроводом, который выравнивает температуру по его объему. Проходной диаметр шахты равен 19.2мм, однако на уровне теплообменника имеется коническое усечение до диаметра 18.1мм. Максимально возможный диаметр образца ограничивается диаметром в 17мм.

Рис.7. *Шахтный криостат замкнутого цикла на базе двухступенчатого криогенератора CoolPower 100T*

Разработан автономный сорбционный рефрижератор для работы при температуре 0,3 К [15]. Рефрижератор выполнен в виде вставки диаметром 80 мм, погружаемой в гелиевый криостат. Он обеспечивает температуру образца 0.31 К в течение 20 часов после конденсации ^{3}He при полезной тепловой нагрузке 10 мкВт. Время реконденсации 0,5 часов.

Выполнены работы по модернизации систем управления прерывателями на базе микроконтроллеров для спектрометров: НЕРА-ПР, СКАТ и ДИН-2 (три прерывателя). Существенно модернизировано программное обеспечение систем управления прерывателей.

3. Развитие систем сбора данных и сетевой инфраструктуры

В локальной сети ЛНФ установлены и введены в эксплуатацию модуль Catalyst 8510 для контроля и анализа трафика, а также новый mail-сервер на базе двух процессоров Intel с операционной системой Solaris.

Продолжались работы по развитию Web сервера ЛНФ и информационной системы HIPNS (hypertext information system on neutron sources and neutron instruments), предоставляющей пользователям сведения о нейтронных источниках и спектрометрах, а также о выполняемых на них исследованиях. Реализована XML версия системы HIPNS с использованием технологии Apache Cocoon. Запрашиваемые страницы автоматически генерируются из содержимого базы данных, которая создана для нескольких спектрометров ИБР-2. В 2003г. приобретен и установлен новый двухпроцессорный Web сервер.

В сотрудничестве с ГМИ, Берлин завершено тестирование электроники сбора данных с MWPC детектора с линиями задержки. В документацию внесены изменения, улучшающие быстродействие и временное разрешение, и на фирме ILFA, Гамбург, изготовлено 10 плат для ОИЯИ и ГМИ. Разработана первая версия программного обеспечения платы, включающего в себя алгоритмы отбора событий (реализованные в FPGA), программы управления потоками данных в различных режимах работы платы (эти программы выполняются цифровым сигнальным процессором, установленном на плате), программный драйвер платы, программы предварительной обработки и пользовательские программы на ПК. Электроника и программное обеспечение успешно протестированы с реальным детектором при работе с источником (в ИГМ и в ЛНФ) и на реакторе BER-II в ИГМ. Анализ и визуализация данных осуществлялись с использованием пакетов ROOT и PV-WAVE. В настоящее время ведутся работы по оптимизации программ.

Комбинированная система управления спектрометром НЕРА-ПР (графический интерфейс на PC с сохранением управляющих программ на VME) была предоставлена пользователям в опытную эксплуатацию с конца октября 2002 до февраля 2003 года. Эта эксплуатация показала стабильную работу, как аппаратной части, так и операционной системы Windows XP и созданного программного обеспечения. Работы по полному переводу программ управления на платформу Windows находятся в стадии завершения. Одновременно решается аналогичная задача по переводу спектрометра СПН (РЕМУР) на новую систему управления на основе VME-PCI адаптера. Планируемые сроки завершения работ – конец I квартала 2004 года.

Программный комплекс Sonix адаптирован для работы на спектрометре ФСД, установлен, испытан и передан в эксплуатацию. Начаты также работы по переносу адаптированного комплекса SONIX на спектрометр ФДВР.

В течение года разработан и изготовлен ряд цифровых и аналоговых электронных блоков для спектрометров ИБР-2 (спин-флипперы для спектрометра СПН, предусилители, спектрометрический усилитель и др.). По запросам пользователей проводились работы по текущей модернизации и ремонту аппаратуры, а также по оптимизации и сопровождению программного обеспечения.

Много усилий потребовало обеспечение бесперебойной работы спектрометров во время сеансов ИБР-2 и проведение профилактических работ в период остановки реактора.

По основным направлениям работ по теме (детекторы, системы окружения образца, системы сбора данных, локальная сеть) подготовлены долгосрочные проекты развития на период 2004/8 г.г.

4. EXPERIMENTAL REPORTS

4.1. CONDENSED MATTER PHYSICS

Diffraction

Neutron Research of the High- and Low-Temperature Phases in Rb_2KfeF_6 Elpasolite
A.V.Belushkin, A.I.Beskrovnyi, S.G.Vasilovsky, V.V.Sikolenko, K.S.Aleksandrov, I.N.Flerov, A.Tressaud

Structural Study of the Lithium Orthogermanates in the Superionic State
S.N.Bushmeleva, A.M.Balagurov, R.V.Shpanchenko, V.I.Voronin, G.Sh.Shekhtman, D.V.Sheptyakov

Atomic and Magnetic Structures of $Sr_2GaMnO_{5.41}$ and $Sr_2GaMn(O,F)_6$
V.Pomjakushin, D.Sheptyakov, P.Fischer, A.Balagurov, A.Abakumov, M.Alekseeva, M.Rozova, E.Antipov

High Pressure Effects on the Crystal and Magnetic Structure of $Pr_{1-x}Sr_xMnO_3$ Manganites (x=0.5-0.56)
D.P.Kozlenko, V.P.Glazkov, Z.Jirak, B.N.Savenko

Residual Strain Investigations Using Neutron-TOF-Diffraction on Marble Building Stone
Ch.Scheffzuek, S.Siegesmund, A.Koch, A.Frischbutter, K.Walther

Seismic Properties and Anisotropy of Rock Samples from the Kola Superdeep Well Based on Neutron Diffraction and Seismic Velocity Laboratory Measurements
T.I.Ivankina, A.N.Nikitin, H.M.Kern

Small-Angle Scattering

Changes in Mitochondrial Structure Induced by Swelling
T.N.Murugova, V.I.Gordeliy, A.Kh.Islamov, A.I.Kuklin, A.Nuernberg, L.S.Yaguzhinsky

Small-Angle Neutron Scattering Study of Structural Change of the Coal Tar Pitch Additived with Nanocarbon under Heat Treatment
I.Ion, M.V.Avdeev, A.Kuklin, Y.Kovalev, M.Balasoiu, A.M.Bondara, C.Banciu, I.Pasuk

On the Possibility of Cluster Formation in Molecular Solutions of Fullerenes
T.V.Tropin, M.V.Avdeev, V.B.Priezzhev, J.W.P.Schmelzer, V.L.Aksenov

Inelastic Scattering

Neutron Scattering Studies of Methyl Derivatives of Benzene Selected as Potential Materials for Cold Neutron Moderators
I.Natkaniec, K.Holderna-Natkaniec, J.Kalus

Partial Structure Features of Pb-K Melt
N.M.Blagoveshchenski, V.A.Morozov, A.G.Novikov, V.V.Savostin, A.L.Shimkevich, I.Yu.Shimkevich

Neutron Optics

First Physical Results from REMUR
V.L.Aksenov, K.N.Zhernenkov, Yu.V.Nikitenko, A.V.Petrenko

4.2. NEUTRON NUCLEAR PHYSICS

Violation of Fundamental Symmetries

Nature of the Parity Violation in Interaction of Neutrons with Lead
J.Andrzejewski, N.A.Gundorin, I.L.Karpikhin, L.Lason, G.A.Lobov, D.V.Matveev, L.B.Pikelner, K.V.Zhdanova

Development of Neutron Polarizer-Analyzer System for T-Invariance Experiment
V.R.Skoy, Y.Masuda, S.Muto, T.Ino, G.N.Kim

Nuclear Astrophysics

Stellar Neutron Capture of Promethium: Implications for the s-Process Neutron Density
R.Reifarth, C.Arlandini, M.Heil, F.Kappeler, P.V.Sedyshev, A.Mengoni, M.Herman, T.Rausher, R.Gallino, C.Travaglio

Applied Research

Active Biomonitoring with Moss-Bags Applied to an Industrial Site in Romania
O.A.Culicov, R.Mocanu, M.V.Frontasyeva, L.Yurukova, E.Steinnes

Neutron Activation Analysis for Development of Mercury Sorbent Based on Blue-Green Alga *Spirulina Platensis*
L.M.Mosilishvili, A.I.Belokobylsky, A.I.Khizanishvili, M.V.Frontasyeva, E.I.Kirkesali, N.G.Aksenova

Neutron research of the high- and low- temperature phases in Rb_2KFeF_6 elpasolite.

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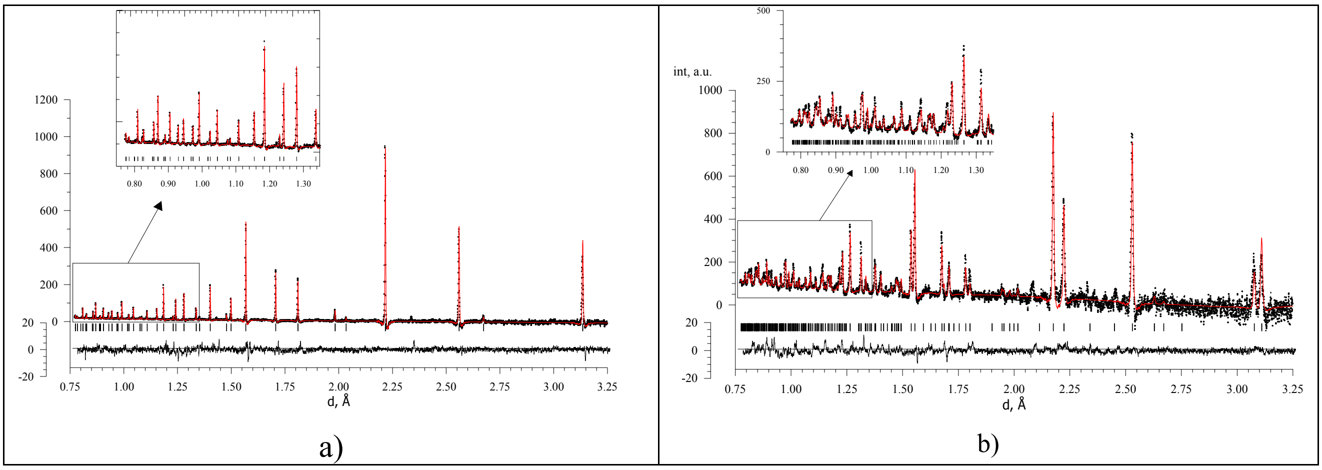
Fluorides with general formula Rb_2KMF_6 belong to family of K_2NaAlF_6 elpasolite. Crystals of elpasolite type at high temperatures have cubic structure and belong to sp. gr. Fm3m. At decrease of temperature in family of crystals Rb_2KMF_6 there are structural phase transitions. Exception is Rb_2KAlF_6 for which structural changes it was not observed, and it remains cubic down to temperature 77K. Temperatures of transitions and sequences low temperatures phases essentially depend on the size of a trivalent ion in M^{3+}.

The recently neutron study of the elpasolite with large of ion radius M^{3+} of Rb_2KBiF_6 have shown, that the crystal has two changes of crystal structure. At 360 K there is a transition in tetragonal phase $P4_2/mnm$, and at room temperature in the monoclinic structure with sp. gr. P21/n. At diminution of the size of ion M^{3+} (Tb, Ho, Y, Er) in crystals there is a trigger change of phase in monoclinic phase Fm3m→$P2_1/n$ which is connected to rotational displacements of octahedrons KF_6 and MF_6. In crystals with the smaller sizes of ion M^{3+} (Sc, In, Lu), at depression of temperature the sequence from two transitions is observed Fm3m→I4/m→$P2_1/n$. The structure of crystals with smaller radius of ion M^{3+} (M^{3+} = Cr, Ga, Fe) is insufficiently studied.

For investigation of the mechanism of the phase transition and definition of structure in a low temperature phase, powder composition of Rb_2KFeF_6 has been synthesized and his study with neutron diffraction is lead. The temperature of structural phase transition is equal 170 K. The entropy change and size of temperature shift of this transition under pressure much more surpass analogous performances for trigger transitions. Symmetry of the low-temperature phase of compounds with small cations M^{3+} till now does not set, however it is supposed, that the change of phase in them has other mechanism.

Structure of the cubic phase.

The previous investigations of Rb_2KFeF_6 by X-ray powder diffraction have shown [1] that structure is cubic with space group Fm3m at room temperature. A cell parameter is equal 8.865 Å. The atom were found on their special position: Rb (8c) (¼, ¼, ¼), Fe (4a) (0, 0, 0), K (4b) (½, ½, ½), F (24e) (x=0.24, 0, 0). The refinement of the crystal structure carries out with several alternative models. In a first step of the refinement atom coordinates are fixed in they special position. In a second step, F atoms have been distributed on rings lying in the planes orthogonal to the K-F-Fe direction. After position refinement with anisotropic thermal vibration consideration, F has taken position 96k. In this position F atoms are displacement to 4 equivalent states. For Rb three types of displacement have been tested: along [100], [110] and [111] directions, leading to 6, 12 and 4 local disordered position respectively. The difference between three types of displacement is very weak and we can not choose from it.



Neutron diffraction pattern of Rb_2KFeF_6 and the Rietveld refinement profiles at 290 K (a) and 10 K (b). The observed diffraction data are shown at point, and the calculated profile as a solid line. Tick marks below the profile mark the positions of allowed reflections. Difference between the observed and the calculated intensities, normalized on a root-mean-square deviation in a point, are shown at the bottom.

Structure of the orthorhombic phase

The carried out Raman scattering researches in [2] have shown, that candidates for space group of the low-temperature phase are P4/m, P/m, $P112_1/n$ or P1, but they are not necessary that only ones. Hence, low-temperature phase symmetry was unknown.

We were the carried out indexing which has shown, that position of observably diffraction peaks it is described as tetragonal space group P4/m (a=b=6.1534(1), c=8.8939(1) Å), as orthorhombic space group Pmnn (a=6.1567(3), b=6.1508(3), c=8.8942(3) Å). The model of atoms position in structure for these groups was selected. The structure's refinement was carried out. For P4/m group the parameters of the refinement are: χ^2=6.5, R_W=15 %; χ^2=3.2, R_W=13 for Pmnn group. A great difference of χ^2 value (more than twice), allows choosing the space group for low-temperatures phase as Pmnn.

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STRUCTURAL STUDY OF THE LITHIUM ORTHOGERMANATES IN THE SUPERIONIC STATE

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The solid solution based on lithium orthogermanates in the Li_4GeO_4-$Li_3A^VO_4$ (A^V=P,V) and Li_4GeO_4-$Li_2B^{VI}O_4$ (B^{VI}=S, Cr, Se, Mo, W) systems are considered as perspective solid electrolytes with lithium-cation conductivity [1]. The electric conductivity of these compositions assumes 10^{-4} S*cm^{-1} at room temperature while in the superionic state region (about 870 K) it exceeds 1 S*cm^{-1}. $Li_{3.75}Ge_{0.75}V_{0.25}O_4$ and $Li_{3.70}Ge_{0.85}W_{0.15}O_4$ are the typical specimens of these compounds. At room temperature the V-containing compound has lower conductivity than W-based one, however at the temperature above 500 °C the situation is changed to opposite one (Fig.1). At the present time there is no complete understanding of the nature of superionic state in these compounds. This situation is a result of a lack of detailed information about thermal behavior and structural features of these phases at high temperature.

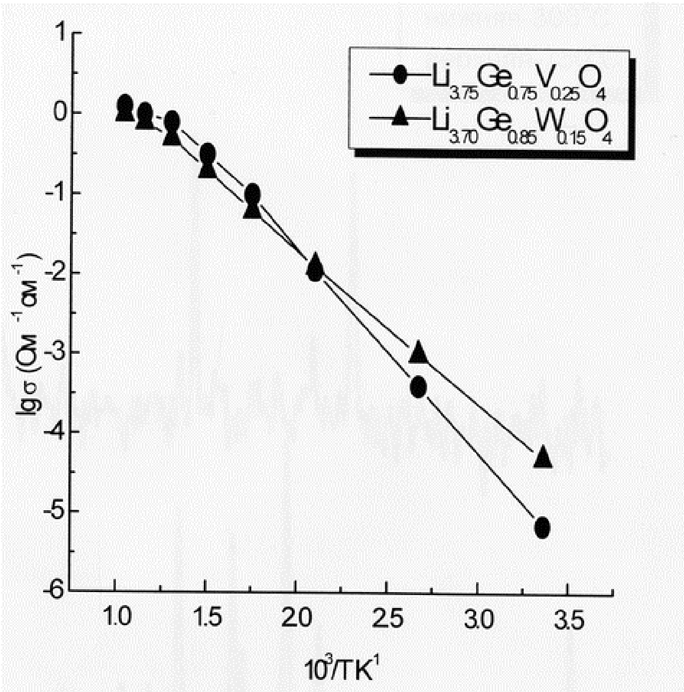


Fig. 1. Conductivity for orthogermanates.

The powder samples for neutron diffraction investigation were synthesized at the High Temperature Electrochemistry Institute, Ural Branch of the Russian academy of sciences. X-ray diffraction data at room temperature were collected at the Department of Chemistry Moscow State University, neutron diffraction experiments – were carried out at Frank Laboratory of Neutron Physics at IBR-2 reactor. The diffraction spectra were measured in the heating regime at room temperature, 350 and 600 °C. The MRIA and GSAS programs were used for structure refinement by Rietveld method. At room temperature both diffraction patterns were indexed in the orthorhombic symmetry (S.G. *Pnma*). This is in agreement with early studies of similar compounds [2]. The neutron diffraction spectra of the $Li_{3.7}Ge_{0.7}V_{0.3}O_4$ compound measured at room temperature is shown in Fig. 2.

Simultaneous fitting of X-ray and neutron diffraction spectra collected at room temperature allowed to refine element distribution in studied samples. It was found that the vanadium content is slightly higher than proposed one: about 30 % (instead of 25 %), and lithium content decreases from 3.75 to 3.67. Thus our data revealed that the first sample has composition $Li_{3.67}Ge_{0.7}V_{0.3}O_4$. A valence balance calculation using experimental ratio Ge/V (0.7:0.3): w(O)V(O)+w(Ge)V(Ge)+w(V)v(V)+w(Li)V(Li)=0, where w(x) and V(x) content and valence x element and results to lithium content of 3.7. This value is in a good agreement with experimental data.

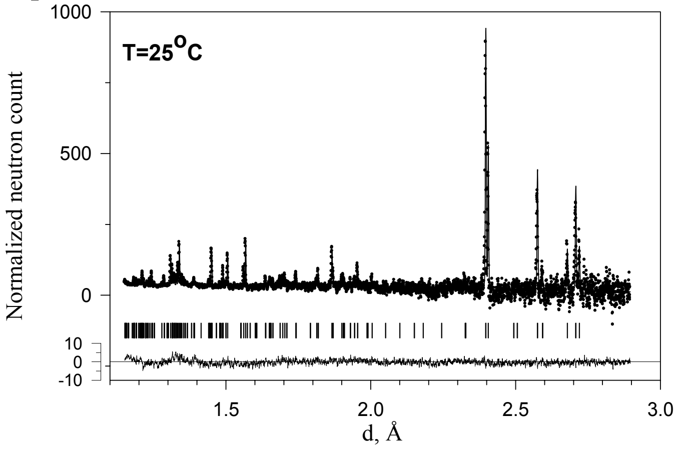


Fig. 2. Experimental, calculated and difference neutron spectra for $Li_{3.7}Ge_{0.7}V_{0.3}O_4$ at room temperature.

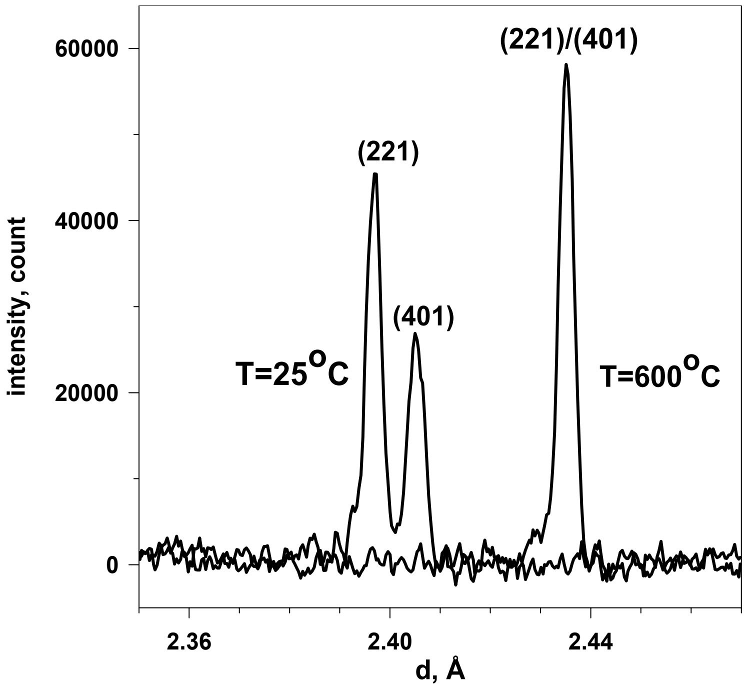


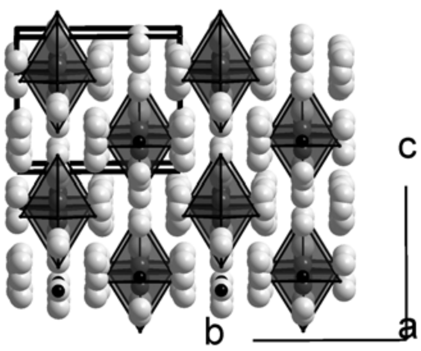
Fig. 3. Diffraction spectra of the $Li_{3.7}Ge_{0.7}V_{0.3}O_4$ sample measured at different temperatures.

Increasing temperature up to 600 °C results in a noticeable change of the neutron diffraction pattern. (221) and (401) peaks coincide each with other (Fig. 3) and all peaks on the diffraction pattern may be indexed in hexagonal unit cell. However both DTA and electric conductivity measurements for this sample do not confirm a presence of the phase transition. Except this the 3-fold axis is absent in the positional relationship of the atoms in orthorhombic unit cell (i.e. there is no hexagonal supergroups for *Pnma* space group). Therefore we concluded that at high temperatures the $Li_{3.7}Ge_{0.7}V_{0.3}O_4$ compound has pronounced pseudosymmetry. Further structural refinement was carried out in *Pnma* space group.

The lattice parameters for both compounds under investigation linearly increase with rising temperature. However an increase of the temperature does not affect on the heavy atom (germanium, wolfram, oxygen) positions inside the unit cell, whereas coordinates of the lithium atoms are essentially changed.

Based on results of structure refinement one may suppose that a conductivity of the V-contained phase at room temperature for the most part is due to movement of lithium atoms along the *c*-axis of the unit cell (Fig. 4). In the $Li_{3.7}Ge_{0.82}W_{0.15}O_4$ structure lithium atoms are uniformly distributed inside the unit cell and preferred direction is absent.

The difference in the transfer mechanism can explain a higher electric conductivity in $Li_{3.7}Ge_{0.82}W_{0.15}O_4$ at the room temperature in comparison with that for $Li_{3.7}Ge_{0.7}V_{0.3}O_4$. At higher temperatures lithium atoms in both structures are lined up along the <010> direction of the unit cell (Fig. 5). This results in a close values of electric conductivity (Fig. 1). However in the $Li_{3.7}Ge_{0.7}V_{0.3}O_4$ structure lithium atoms are less ordered that is probably a reason for higher conductivity value.



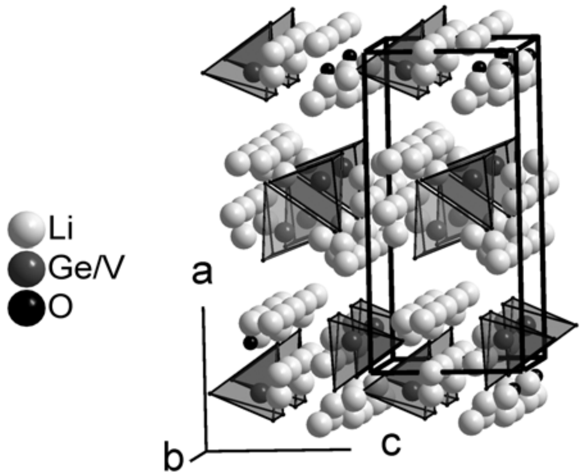


Fig. 4. Crystal structure of $Li_{0.7}Ge_{0.7}V_{0.3}O_4$ at room temperature.

Fig. 5. Crystal structure of $Li_{0.7}Ge_{0.7}V_{0.3}O_4$ at 600 °C.

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ATOMIC AND MAGNETIC STRUCTURES OF $Sr_2GaMnO_{5.41}$ AND $Sr_2GaMn(O,F)_6$

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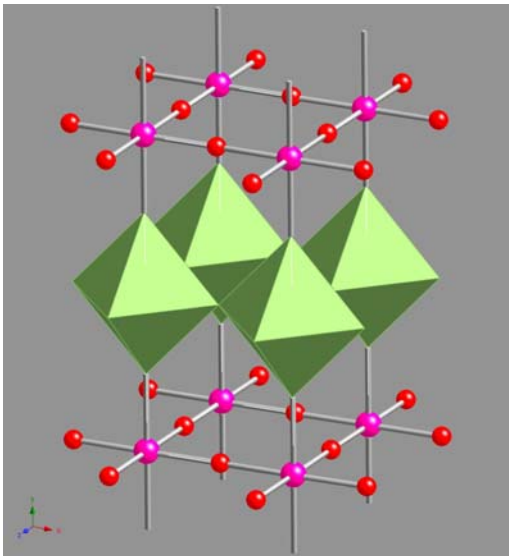
Layered complex manganese oxides, A_2GaMnO_{5+x} (A=Ca, Sr) with the brownmillerite-type structure, represent a new family of manganites with possible CMR effect. These compounds contain single MnO_2 layers separated by 3 cation-oxygen layers (AO)(GaO)(AO) rather than the more usual 2, as in the Ruddlesden-Popper system. The oxygen content can be adjusted in the range from 5.0 to 5.5, corresponding to a nominal Mn oxidation state between +3 and +4, respectively. For the end members, the magnetic moments of Mn are coupled antiferromagnetically (AFM) in the MnO_2 plane, but either anti- (G-type, T_{NG}=180 K) or ferromagnetically (C-type, T_{NC}=100 K) between planes for x=0 or x=0.5, respectively. The change in the magnetic ordering type from G to C is driven by the strong diagonal 180° superexchange AFM interaction between Mn^{4+}-ions (t^3_{2g}) in adjacent layers through additional oxygen atoms in the GaO_{1+x} layer (coordinating Ga-ions octahedrally). In the oxidized composition (x=0.5) there is a contribution of short-range G-type antiferromagnetic correlations, which develops below T_{NG} and which is partially suppressed below the transition to the AFM state at T_{NC}. A detailed report on the end-member properties is given in [1].

The intermediate valence of Mn^{3+2x} can lead to the activation of double exchange, producing a FM metallic state. However, the oxygen index x cannot be continuously varied from 0 to 0.5 in single-phase compositions, owing to the presence of a miscibility gap. One of the intermediate Mn-valence single-phase compositions, which we were able to synthesize has x=0.41, which corresponds to $Mn^{+3.82}$. Its crystal structure can be satisfactorily refined in the *Ammm* SG with lattice parameters a=8.00, b=5.40, c=5.36 Å at T=300 K. In this case, the (8p)-oxygen position in the GaO_{1+x} layer is partially filled and disordered. This disorder implies a statistical distribution of GaO_4-tetrahedra and GaO_6-octahedra. An important feature of the diffraction pattern is an anisotropic broadening of the Bragg peaks along the [100] direction, which is clearly seen in high resolution neutron-diffraction data. This broadening is well modelled by anisotropic micro strains along [100]. The reason for the strains is probably a distribution of octahedra and tetrahedra in Ga-layers, since the Mn-Mn distance along the ***a*** axis is larger for Mn^{3+}, which corresponds to the local tetrahedral Ga coordination.

The magnetic structure has a G-type AF-component below 140 K, and a C-type one below 110 K. This behaviour is similar to the one observed for x=0.5, but the G-type correlations for x=0.41 are long-ranged. Whether these G- and C-type magnetic structures are spatially separated remains open question.

Three fluorinated compounds $Sr_2GaMnO_{5-x}F_{1+x}$ with x>0 were prepared. A nominal oxidation state of manganese determined by iodometric titration for one of the samples amounted to +3.8 (x=0.2). The low temperature crystal structure (Fig. 1) has an orthorhombic SG *Pmmm* ($a<c<b$, y-axis is perpendicular to the MnO_2-planes), however for one of the samples the structure can be also represented as a pseudo-tetragonal similar to the oxygenated x=0.5 composition



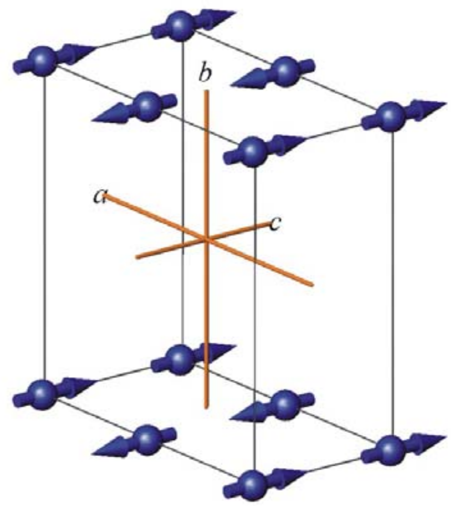


Fig. 1. Crystal structure of $Sr_2GaMnO_5F_1$. The MnO_2 planes and $Ga(O,F)_6$ octahedra are shown.

Fig. 2. Spin configuration in $Sr_2GaMn(O,F)_6$. Only Mn-ions are shown.

(*P4/mmm*). The longest Mn-O distance is along *z*-axis, implying that the e_g-orbitals of Mn^{3+} are directed along *z*. The Mn-moments are AFM-ordered below $T_N \approx 70$ K with $\mu(15\text{ K})=1.5(1)\ \mu_B$. Mn-spins are FM-coupled between planes, as expected for “diagonal” superexchange through completely filled $Ga(O,F)_2$ layers [1], but in-plane the Mn-spins form FM-rods along *z*-axis coupled AFM to each other along *x*-axis, as shown in Fig. 2. This type of magnetic structure can be well understood in frame of standard superexchange theory. The z^2-orbitals are orientation ordered, but there is no translational ordering of the orbitals due to the random distribution of the Mn^{3+}. Having this orientation of the orbitals the suprexchange interaction along x-direction is always AFM, while along the z-direction it can be both FM and AFM giving the average structure, which is shown in Fig. 2.

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HIGH PRESSURE EFFECTS ON THE CRYSTAL AND MAGNETIC STRUCTURE OF $Pr_{1-x}Sr_xMnO_3$ MANGANITES (x = 0.5 - 0.56)

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Manganites of perovskite type $A_{1-x}A'_xMnO_3$ (A - rare earth, A' - alkali earth elements) exhibit rich magnetic and electronic phase diagrams depending on the A (A') - site elements and show an extreme sensitivity of magnetic, structural, electronic and transport properties to variation of temperature, external high pressures and magnetic fields [1]. These systems have attracted considerable interest with respect to the recently discovered colossal magnetoresistance (CMR) effect.

The crystal and magnetic structures of the manganites $Pr_{1-x}Sr_xMnO_3$ (x = 0.5, 0.56) have been studied by means of powder neutron diffraction at high external pressures up to 4.8 GPa at the DN-12 diffractometer. At ambient pressure, both compounds have a tetragonal structure (sp. gr. *I4/mcm*). At $T_N \approx 215$ K in $Pr_{0.44}Sr_{0.56}MnO_3$ a onset of A-type antiferromagnetic (AFM) state accompanied by the structural phase transformation from the tetragonal to the orthorhombic structure with *Fmmm* symmetry occurs. $Pr_{0.5}Sr_{0.5}MnO_3$ exhibits an intermediate ferromagnetic (FM) state with a tetragonal structure at $T < T_C = 265$ K and transforms to the A-type AFM state with the orthorhombic *Fmmm* structure at $T_N \approx 175$ K. Under high pressure, in originally pure A-type AFM $Pr_{0.44}Sr_{0.56}MnO_3$ a phase separated state is formed, consisting of the mixture of the A-type AFM phase with the orthorhombic *Fmmm* structure ($T_N \approx 220$ K) and C-type AFM phase with the tetragonal *I4/mcm* structure ($T_N \approx 125$ K). In $Pr_{0.5}Sr_{0.5}MnO_3$ the application of high pressure leads to the noticeable increase of transition temperature from FM to the A-type AFM state up to $T_N \approx 230$ K and the formation of the phase separated state below ≈ 150 K, consisting of the mixture of the A-type AFM phase with the orthorhombic *Fmmm* structure and the tetragonal *I4/mcm* phase without long range magnetic order. Anisotropy of the lattice compression leads to the marked apical elongation of the MnO_6 octahedra in the tetragonal phase and creates favorable conditions for appearance of the $d(3z^2-r^2)$ orbital polarization, prerequisite for the C-type AFM order.

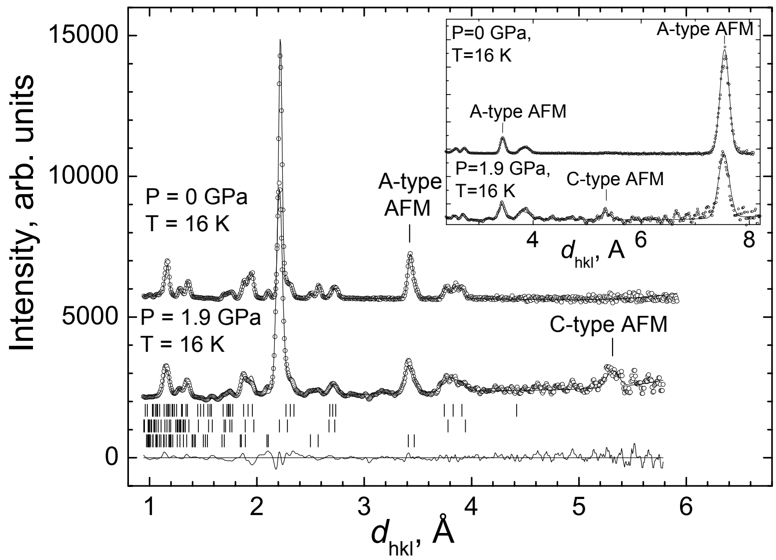

***Fig. 1.** Neutron diffraction patterns of $Pr_{0.44}Sr_{0.56}MnO_3$ measured at P = 0 and 1.9 GPa, T = 16 K at scattering angles 2θ = 90° and 45.5° (inset) and processed by the Rietveld method. A coexistence of the initial A-type AFM orthorhombic phase with a pressure-induced C-type AFM tetragonal phase was observed.*

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RESIDUAL STRAIN INVESTIGATIONS USING NEUTRON-TOF-DIFFRACTION ON MARBLE BUILDING STONE

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Abstract
To describe and explain the effects of bowing on marble facade panels neutron time-of-flight diffraction was applied for residual macro-and microstrain determination on the mineral calcite. The results were supplemented by the determination of the crystallographic preferred orientation (texture) of calcite by neutron diffraction as well as studies on microfabric features of the specimens using optic microscopy.

Experimental: Microstructure, Texture and Residual strain
Durability is an important property to characterize natural rocks for exterior use. Marbles for instance frequently show a bowing of facade panels after a short time of exposure. This bowing is generally accompanied with a reduction of strength properties [1]. For a better understanding of the observed effect, three samples of marble (calcite $CaCO_3$) were investigated: a fresh broken marble (P1), a good conditioned facade panel (P2) and a strong deformed facade panel (P3). The studied samples are characterised by a wide grain size distribution, from medium to coarse grained: the medium grain size is between 1 and 2 mm with a maximum of up to 6 mm. Domains with a coarser grain size exhibit a polygonal to interlobate shape, and straight to slightly curved grain boundaries (Fig. 1a). Evidence of crystal-plastic deformation is documented by deformation twins and undulatory extinction. Furthermore, the fabric is characterised by a preferred grain boundary orientation more or less parallel to the foliation (Fig. 1b).

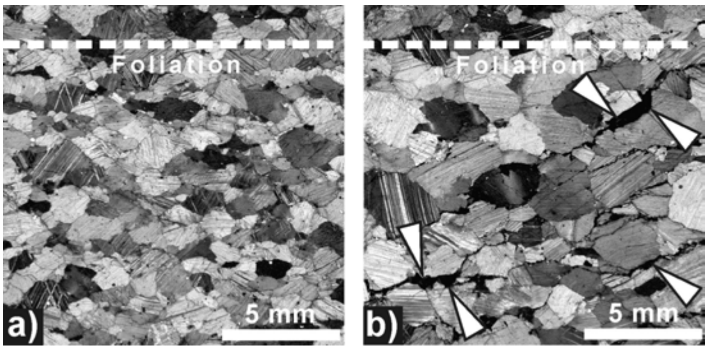

Fig. 1: Thin section images from demounted panels: (a) section vertical to the foliation (weak bowing of a good conditioned panel P2); (b) section vertical to the foliation (strong bowing of a strong deformed panel P3): the open grain boundaries are clearly visible (arrows).

In thin sections from strongly bowed panels, open grain boundaries, which are connected to intergranular microcracks, can be observed. The observed cracks are opened up to 0.5 mm with a length up to 5 mm (Fig. 1b). Intracrystalline cracks along twin planes are more rare. Apparently there is a correlation between the presence of microcracks and bowing. In contrast to the strong deformed sample, the fresh broken, undeformed sample does not show any evidence of open grain boundaries. For P2 a warping of 0.2 mm/m was measured while for sample P3 17.1 mm/m was observed.

The fresh broken Peccia marble sample (P1) was measured using neutron time-of-flight diffraction at the texture diffractometer SKAT. The sample exhibits a strong crystallographic preferred orientation. The (0006) pole figure of calcite shows an maximum normal to the macroscopic foliation with a weak tendency to form a girdle distribution around a maximum of the *a*-axis distribution in the foliation plane, while the ($11\bar{2}0$) poles are arranged on a great circle around the (0006) pole maximum (Fig. 2). The crystallographic *a*-axes corresponding to the ($11\bar{2}0$) poles are oriented within the foliation plane. The importance of calcite textures to the contribution of physical weathering has been widely discussed. A general observation is that the maximum deterioration is closely linked to the *c*-axis maximum. Only the texture of the fresh broken sample (P1) is shown, because the texture of the good conditioned plate (P2) and the strong deformed facade plate (sample P3) is similar.

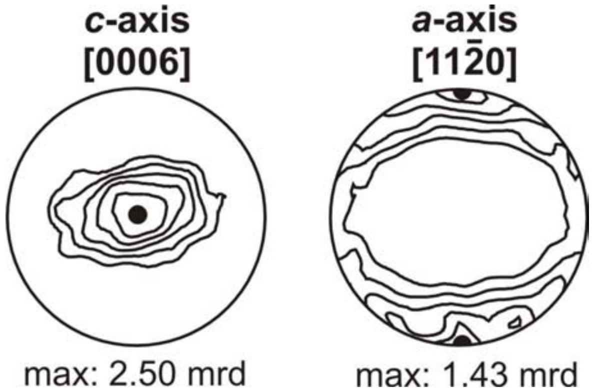

Fig. 2: Crystallographic preferred orientation (texture) of the fresh broken Peccia marble (P1), measured by neutron-TOF-diffraction at SKAT, projection into the foliation plane.

The strain measurements were carried out at the diffractometer EPSILON-MDS at beam line 7A [2, 3]. Six Bragg reflections of calcite ($01\bar{1}2$), ($10\bar{1}4$), (0006), ($11\bar{2}0$), ($11\bar{2}3$), and ($01\bar{1}8$) were investigated. Macroscopic internal strains ($\varepsilon = \Delta d/d$) at all samples in relation to the stress free state were determined by analysing the position of the Bragg peaks (Fig. 7). The stress free state as the reference value were determined by measuring rock powder, prepared by grinding up and annealing. Microscopic internal stresses, caused by dislocations and other microscopic defects, could be observed by peak broadening (Fig. 7). The figures show the dependence of macroscopic and microscopic strain in dependence on the detected six Bragg reflections.

Macro- and microstrain data for the acquired direction perpendicular to the foliation plane are shown in Figure 3. The ($01\bar{1}2$) Bragg reflections for all samples are characterized by a positive strain. The microscopic strain shows no significant differences between the three investigated samples. Only the good conditioned and the strong deformed facade panel show positive strain at the ($10\bar{1}4$)-Bragg reflection, whereas the fresh broken facade panel shows a negative strain. The good conditioned sample shows a positive strain of $\varepsilon = +(720\pm150)\text{x}10^{-6}$, the strong deformed facade panel a lower tensional strain of $\varepsilon = +(380\pm140)\text{x}10^{-6}$. All three panels show comparable macroscopic positive strain values for the *c*-axis [0006]. The microscopic strain is characterized by a lower FWHM for the fresh broken sample in contrast to a little larger FWHM for good conditioned and the strong deformed sample. The *a*-[$11\bar{2}0$]-axes are characterized by the highest positive strain value at the strong deformed facade panel with $\varepsilon = +(980 \pm 170) \mathrm{x}10^{-6}$, the fresh broken sample shows a tensional strain of $\varepsilon = (200 \pm 140) \mathrm{x}10^{-6}$, whereas the good conditioned facade panel shows a negative compressive strain of $\varepsilon = -(420 \pm 180) \mathrm{x}10^{-6}$.

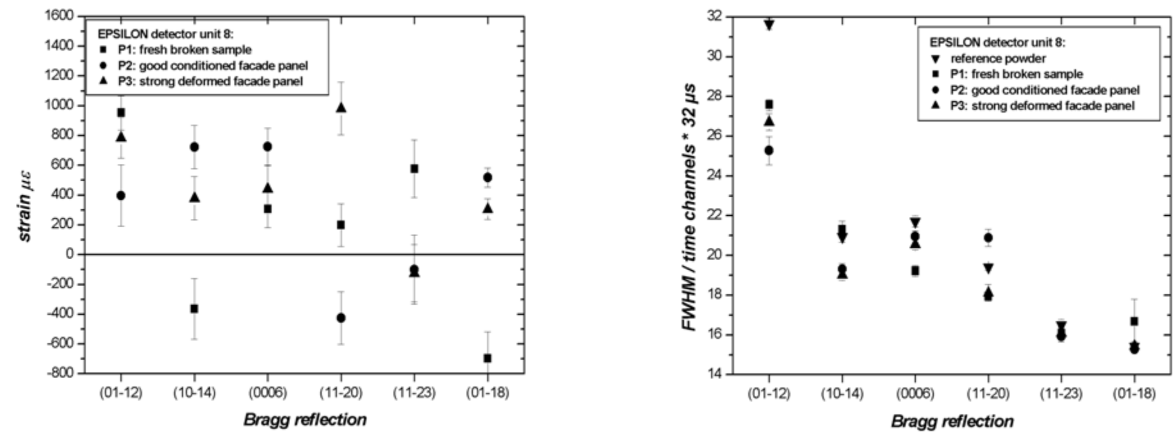

Fig. 3: Macrostresses (left) and microstresses (right), measured by neutron time-of-flight diffraction at EPSILON-MDS, perpendicular to the foliation plane.

In the acquired direction parallel to the foliation plane, also all three samples show comparable macroscopic strain values for the *c*-[0006]-axis, the *a*-[$11\bar{2}0$]-axis, the lattice planes ($11\bar{2}3$) and ($01\bar{1}8$), but with a tendency to compression in the strong deformed facade panel. Microscopic strain by peak broadening were found at the strong deformed facade panel (P3) on the *a*-[$11\bar{2}0$]-axis with a full width at half maximum (FWHM) of (21.8 ± 1.0) time channels*32 µs in relation to a FWHM of (17.8 ± 0.3) time channels * 32 µs for the fresh broken sample and the good conditioned facade panel.

The measured residual strain values acquired perpendicular to the foliation plane are higher than in the direction parallel to the foliation plane. A dependence on the bowing process of the plates may be concluded, because the samples are mainly bowed either concave or convex in relation to the foliation plane. The observed texture is mainly characterized by a preferred orientation of the basal (0006)-planes perpendicular to the foliation plane. The strong texture of the Peccia marble is a significant evidence for plastic deformation.

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SEISMIC PROPERTIES AND ANISOTROPY OF ROCK SAMPLES FROM THE KOLA SUPERDEEP WELL BASED ON NEUTRON DIFFRACTION AND SEISMIC VELOCITY LABORATORY MEASUREMENTS

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The neutron diffraction texture analysis of multiphase rocks from deep levels of the lithosphere in a combination with traditional geophysical and geological methods is applicable widely to study of different physical properties of rocks [1].

The results of experimental and theoretical investigations on two fine-to medium- grained foliated biotite plagioclase gneisses (K8802, K9002) and two fine-grained amphibolites (K8752, K11345) recovered from the Archean basement of the Kola superdeep well (SG-3) are presented. In this investigation, the sample reference frame A, B, C is used which is basically related to the borehole axis: [C] is parallel to the borehole, and [B] and [A] normal to it, with a rough relationship of [A] to lineation. Two different methods are using to determine the seismic aisoptropy and to discriminate between the contribution of oriented cracks and lattice preferred orientation (LPO) of the minerals to bulk anisotropy, and to elucidate the relationship between the crystallographic fabric and the elastic properties such as velocity anisotropy, shear wave splitting and shear wave polarisation. First, P- and S-wave velocities in three orthogonal directions were measured as a function of pressure and temperature, and second, 3D-velocities were calculated from measured LPO (texture) and the known single-crystal properties. The LPO of the rock-forming minerals was measured by TOF (Time Of Flight) neutron diffraction.

The measurements of compressional (Vp) and shear wave velocities (Vs) at pressure and temperature were performed on oven-dried (120°C) cube-shaped specimens (43 mm edge length) in a multi-anvil pressure apparatus using the ultrasonic pulse transmission technique with transducers (lead zirconium titanate) operating at 2 MHz. The special arrangement of the apparatus allows simultaneous measurements of compressional and orthogonally polarised shear wave velocities (S1,S2) in three perpendicular directions. A detailed description of the experimental technique is given by Kern *et al*.[2].

Measurements were done over a range of pressures up to 600 MPa at room temperature and from room temperature up to 600°C at 600 MPa confining pressure. Each set of experimentally determined data comprises three P-wave velocities, six S-wave velocities, and the pressure (and temperature) dependent linear (and volumetric) strain.

As an example, Figure 1 shows the directional dependencies of P-velocities for the amphibolite sample K8752. In all samples, the velocity versus pressure relations for P-waves show typical slopes: a steep, non-linear velocity increase up to about 200 MPa, giving way for linear behaviour at higher pressures. Anisotropy is almost highest at low pressures resulting from a constructive interference of the effects caused by effective oriented microcracks (shape texture) and by lattice preferred orientation (mathematically expressed by the orientation distribution function ODF) of the major minerals. Increasing pressure reduces the effect of cracks in a non-linear slope approaching nearly constant values at high pressures. The pressure-dependent part of velocity anisotropy must be attributed to oriented cracks and their progressive closure, and the residual, almost pressure-independent part of seismic anisotropy is mainly due the ODFs of major minerals.

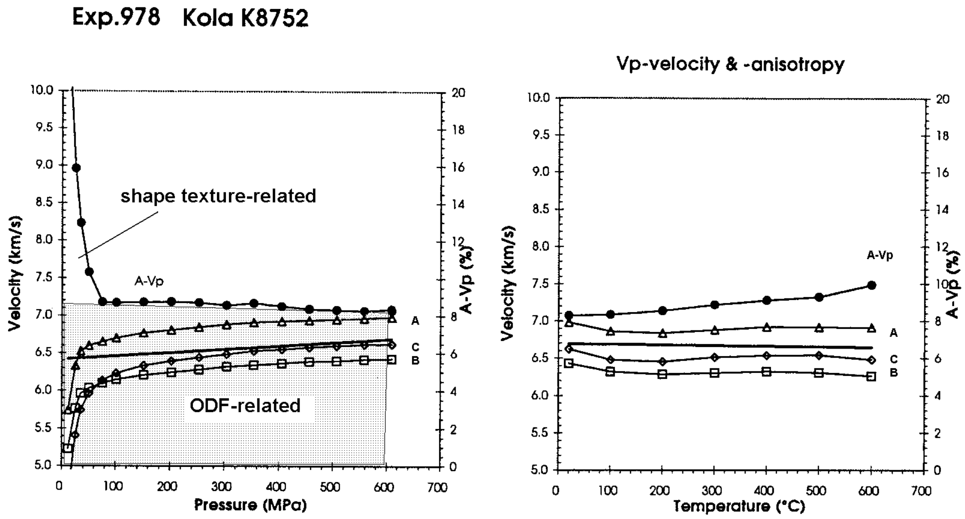

Fig.1. P-wave velocities and anisotropy A-Vp of a) as a function of pressure at room temperature; b) as a function of temperature at 600 MPa confining pressure.

Neutron diffraction was applied for the determination of lattice preferred orientation (LPO) of the major rock-forming minerals. The measurements were carried out at the texture diffractometer SKAT of the pulsed reactor IBR-2 (Dubna, Russia), using TOF method which is, in particular, appropriate for the investigation of materials composed of low-symmetry minerals such as samples under the investigation, because several pole figures can be measured simultaneously. From the experimental pole figures the orientation distribution functions (ODFs) for the predominant mineral phases were recalculated applying the WIMV method and the computer program BEATREX [3]. The spatial distributions of P- and S-wave velocities for the mineral phases were calculated from the ODFs and the corresponding single crystal elastic constants, and the averaged bulk sample velocity distributions were determined by summarizing the velocity distribution of the aggregates according to the volume fractions of the constituent minerals.

The calculated three-dimensional variations of Vp, Vs1 and Vs2 and shear wave splitting Vs1-Vs2 of the prevailing rock forming minerals (hornblende, plagioclase and biotite) and the corresponding averaged data of the bulk amphibolite sample K8752 are shown in Figure 2. The stereoplot coordinate system corresponds to the reference frame A, B, C of the sample cube and the experimental pole figures. In Fig.2 (right) we have rotated the diagrams along with the sample reference frame A, B, C to bring them in accordance with the standard setting used in structural geology: Z (top) = normal to foliation; Y (center) = parallel to foliation and normal to lineation, X (E-W) = parallel to lineation. It is clear from the diagrams, that the Vp distribution of amphibolite K8752 exhibits an overall rhombic symmetry. The marked Vp-anisotropy (6.81 %) calculated for the amphibolite sample K8752 is mostly caused by the strong LPO of the anisotropic hornblende minerals (Fig.2) and their high volume percentage. Interestingly, the Vp velocity distribution calculated from the LPO of the constituent plagioclase minerals give hints for a dissolution of the bulk Vp-anisotropy because it superimposes the hornblende pattern in a deconstructive way.

P-wave velocities are highest subparallel to lineation within the foliation and lowest normal to foliation. On the Vs1-Vs2 diagram of the amphibolite sample, an overall rhombic symmetry is also apparent. The foliated amphibolite exhibits market shear wave splitting (Vs1-Vs2) within the foliation plane with the fast split shear wave (see on the orientation of the Vs1-polarization plane) parallel to foliation. Normal to foliation (parallel to Z), a second shear wave will practically not be generated.

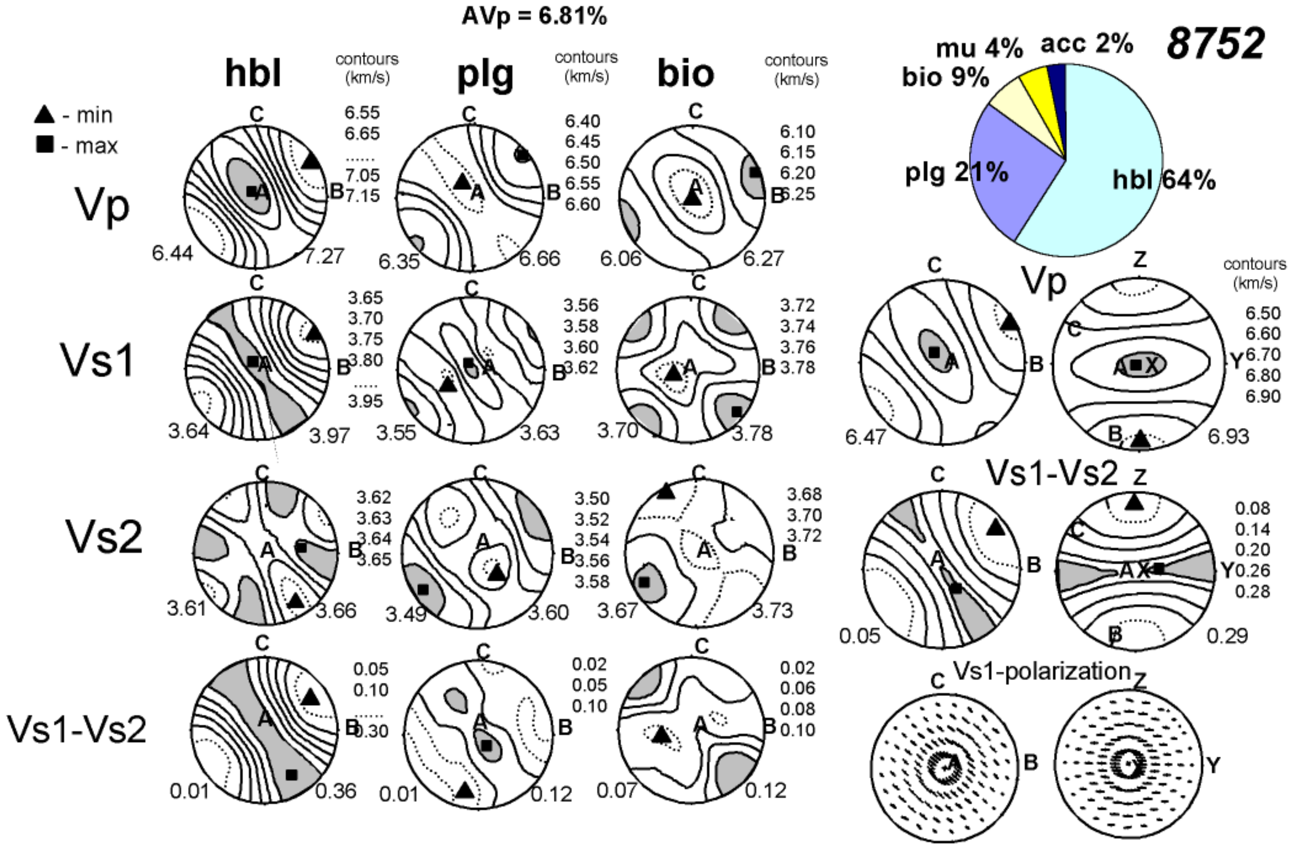

Fig. 2. Calculated three-dimensional variations of the elastic properties of the amphibolite sample K8752 based on the neutron diffraction measurements. The model composition of the rock sample is displayed by the pie diagram.

The numerical calculations based on the TOF-method give important information on the different contribution of the various rock-forming minerals to bulk elastic anisotropy and on the relationship between the crystallographic fabric (LPO) and the seismic properties of the rocks such as velocity anisotropy, shear wave splitting and shear wave polarisation.

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CHANGES IN MITOCHONDRIAL STRUCTURE INDUCED BY SWELLING

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The mitochondria are organelles of the cell, which produce the energy by oxidative phosphorylation. The oxidative phosphorylation is one of the major processes providing living organisms with energy. It has been established that swelling of mitochondria is coupled with functional changes in them. These changes are accompanied by reorganization of mitochondrial membrane [1]. Earlier the influence of uncoupler on mitochondrial structure has been investigated by method of small angle x-ray scattering [2]. In our experiments small angle neutron scattering (SANS) was used to study structural changes of mitochondria in two types of medium - isotonic and hypotonic.

SANS experiments with intact rat liver mitochondria were carried out on the YUMO spectrometer (reactor IBR-2, Dubna) [3, 4]. Measurements were made using the method of contrast variation, when the mixture of various ratio of H_2O and D_2O was in the media. The method of contrast variation allows one to separate the scattering curves from protein and lipidic components of mitochondrial membrane.

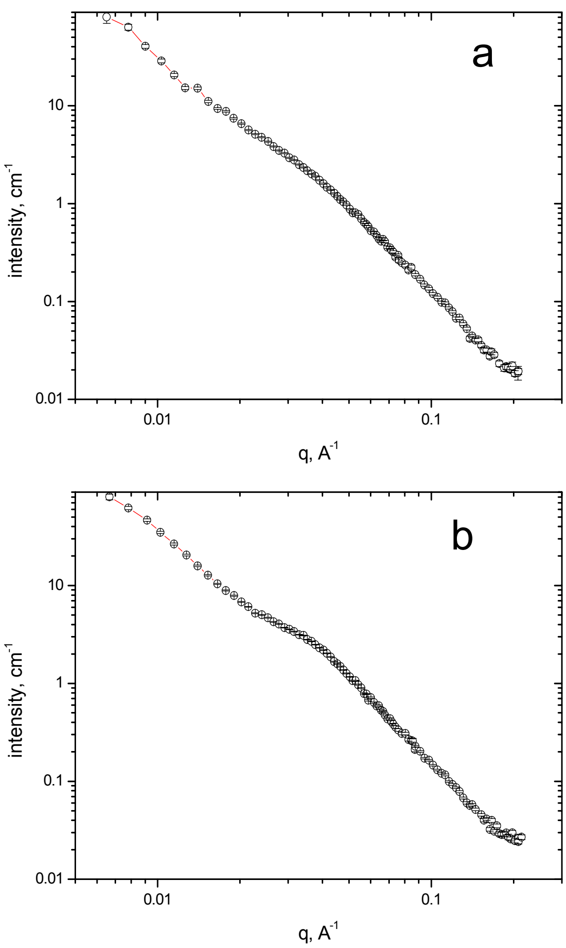

Figure 1 - Small angle scattering curve for mitochondria placed in isotonic (a) and hypotonic (b) solutions.

Determined scattering curves are presented in Figure 1. In logarithmic coordinates the scattering curves have linear sites both for initial and swelling mitochondria. The slope of these sites is about –2, which can be evidence of a fractal structure of the mitochondrial membrane. In the case of hypotonic D_2O-medium the scattering curve has a structural maximum at $\boldsymbol{q} = 0.045$ $Å^{-1}$ (Fig. 1b), which corresponds to the distance of about 140 Å in real space. In the case of isotonic medium scattering curve has not this particular feature (fig. 1a). The appearance of this maximum correlates with the adjacency of outer mitochondrial membrane to inner one and with the cristea adhesion, that have been discovered in our previous experiments on electron microscopy [1].

Data of electron microscopy and small angle neutron scattering enable to calculate the distance between membranes of adhering cristea. This distance composes approximately 65 *Å*. With the help of the contrast variation method it was shown that the appearance of the maximum was determined by neutron scattering from lipidic component of the mitochondrial membrane, while membrane proteins gather on the membrane surface in groups. The location of the groups, in its turns, in cristea is disordered.

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SMALL-ANGLE NEUTRON SCATTERING STUDY OF STRUCTURAL CHANGE OF THE COAL TAR PITCH ADDITIVED WITH NANOCARBON UNDER HEAT TREATMENT

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Introduction. The carbon composite materials are now one of the major structural materials for many industrial applications due to a lot of advantages. Among them are the following: at high-temperature the mechanical properties don't change too much; they posses a low density, a low coefficient of thermal expansion, as well as a good electrical conductivity, etc. The coal tar pitch is a suitable precursor for preparation the advanced carbon material with controlled properties.

The sample preparation. The coal tar pitch (CTP), was processed for QI removal using a modified Soxhlet. Characteristics of selected CTP and fractionated coal tar pitch (FCTP). FCTP was mixed with nanocarbon powder in amounts of: 0.1%(wt). The mixtures were heat-treated (HT) at 440°C and 900°C, with a heating rate of 1°C in controlled atmosphere (3h soak time for each final temperature).

Results and discussions. The aim of research was to investigate the influence of additive, nanocarbon, and high temperature (HT) on the fractionated coal tar pitch at the nanoscale by means of small-angle neutron scattering (SANS). The nanocarbon composites materials (NC), coke and semi-coke were investigated. SANS measurements were performed at the YuMO spectrometer at the IBR-2 pulsed reactor, Dubna.

The linear relationship for large q-values in double logarithmic plot of the obtained scattering curves (Fig.1) indicates to the fractal structure of material. The fractal structure has a surface fractal dimension. A smoothness effect of the additive and HT is observed. It is quite large for HT resulting in about 20 % increase in surface fractal dimension D_S both for CTP and NC, while the effect of the additive to D_S does not exceed 2%. The smoothness effect because of the HT treatment can be explained by the volatile releasing process during carbonization. The HT treatment also results in an increase in the absolute scattering intensity at small q-values for both types of the studied materials, which reflects an increase in pores and staked arrangements of the graphene layers with the temperature. Vice verse, the incoherent background at large q-values decreases at HT, which corresponds to a lost of some amount of hydrogen and to an increase in crystalline order.

The appearance of the scattering nonhomogeneities at nanoscale in the studied materials is be due to the incomplete crystallization, the absorption of amorphous mater or of same molecule of the graphene sheets or/and the variation in size of the interlayer spacing, the diameters of basal planes and the number of the stacked layers inside the crystalline clusters.

Conclusions: first results of the present study shows the importance of the nanoscale for the carbon materials in their production and control over the properties. In particular, one can see that the temperature formation of MS is higher in NC, which acts as an active site during the formation of mesophase following an increase in the number of crystalline microdomains. In this way new materials are more suitable for electrical purpose.

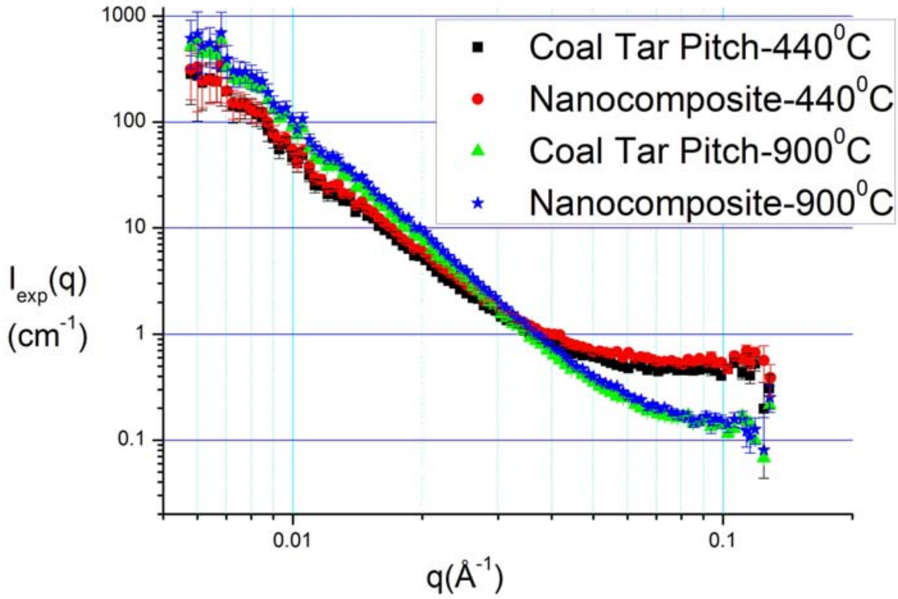

Fig.1. Obtained SANS curves.

Table 1. Results of fit of function $Aq^{-S} + B$ to scattering curves in double logarithmic plot

Sample/THT(°C)	Slope S	Fractal dimension D_S	Parameter A	Parameter B	Bulk density (g/cm^3)
FCTP/440	3.55±0.3	2.45±0.3	1.67	0.13	1.076
NC/440	3.57±0.02	2.43±0.02	1.66	0.16	1.026
FCTP/900	3.76±0.02	2.23±0.02	2.35	0.07	1.166
NC/900	3.78±0.02	2.22±0.02	2.70	0.08	1.165

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ON THE POSSIBILITY OF CLUSTER FORMATION IN MOLECULAR SOLUTIONS OF FULLERENES

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First order phase transitions, condensation and cluster growth in matter play a major role in various scientific and technological problems. The study of possible ways to describe the time evolution of systems where aggregation processes take place, lead to the basics of the kinetic theory. One of the modern approaches, which develop the description of such systems, is the nucleation theory [1]. Solutions of C_{60} are an example of a system, where the problem to describe cluster growth processes arises. Fullerene clusters are detected in a number of "C_{60}/organic solvent" systems, as well as in triple systems "C_{60}/organic solvent/polar solvent". Also, a variety of ways were developed to produce dispersions of C_{60} in water.

Solutions of fullerene molecules in organic non-polar solvents inhibit a variety of unique properties, including solvatochromism and non-monotonous temperature dependence of the solubility [2]. The latter was assumed [2] to be the result of the cluster state of C_{60} molecules in solutions. A phenomenological theory [2] based on this assumption and used the liquid droplet model of clusters is in partial agreement with experimental observations. In particular, previous [3] and recent [4] experiments on small-angle neutron scattering from molecular solution of C_{60} fullerene in carbon disulfide (CS_2) do not show clusters with the size distribution function predicted by this theory.

The aim of the present work was to use the nucleation theory approach and to check out whether simple models for cluster growth (in particular, the liquid drop model) may result in a cluster state of fullerenes in molecular solutions of C_{60}.

The nucleation theory describes the formation and growth of clusters in solutions. Using different forms for the work of cluster formation $\Delta G(n)$, a set of kinetic equations is obtained, which describes the time evolution of the cluster size distribution function $f(n, t)$. An important parameter, which determines the evolution is the ratio $c_0(t)/c_{eq}^{\infty}$, where $c_0(t)$ is the monomer concentration in solution and c_{eq}^{∞} is the concentration of segregating particles of the ambient phase needed for equilibrium coexistence of both phases with a planar interface. The cases when $c_0(t)/c_{eq}^{\infty} < 1$ and $c_0(t)/c_{eq}^{\infty} > 1$ correspond to homophase and heterophase fluctuations, respectively, and should be treated separately.

The following expressions of $\Delta G(n)$ were considered:

(i) liquid droplet model: $\Delta G(n) = -n\Delta\mu + \alpha_2 n^{2/3}$;

(ii) limited cluster growth: $\Delta G(n) = -\Delta\mu n + \alpha_2 n^{2/3} + kn^{\beta}$;

(iii) charged cluster model: $\Delta G = -n\Delta\mu + \alpha_2 n^{2/3} + \dfrac{1}{4\pi\varepsilon\varepsilon_0}\dfrac{Q^2}{r}\left(n^{5/3} - n\right)$.

The typical thermodynamical parameters of C_{60} fullerene organic solutions (carbon disulfide, benzene and toluene) were used when modeling the evolution of the $f(n, t)$ function. One example of such evolution obtained for model (ii) is given in Fig.1.

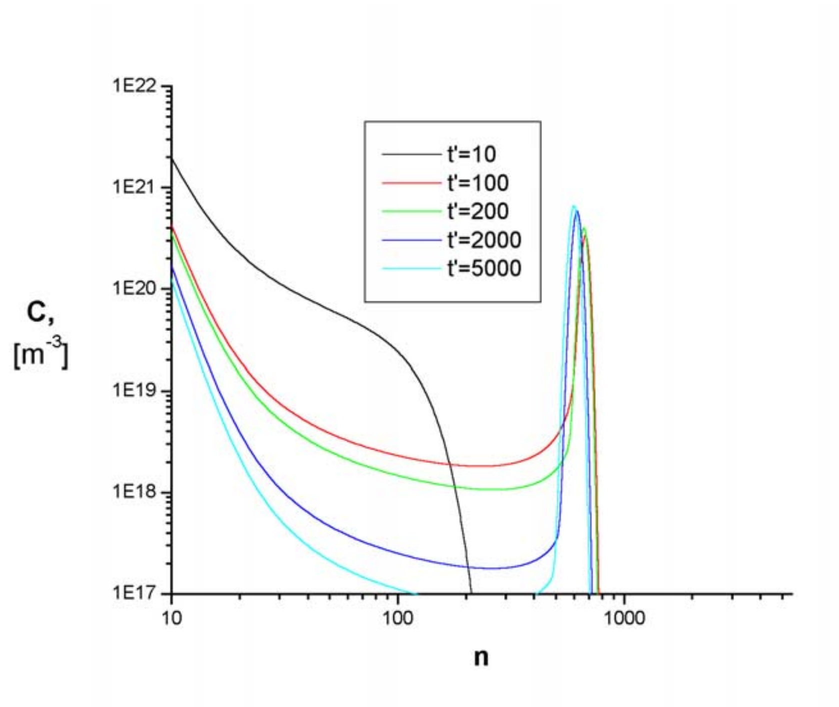

Fig. 1. Evolution of the cluster size distribution in time (in specific time units) obtained numerically for model (ii) in the case of homophase fluctuations.

A special respect was given to the liquid droplet model (i). Both analytical and numerical treatment of the corresponding kinetic equations results in the following conclusions. In the case of homophase fluctuations a stable cluster size distribution in the system is obtained in the form:

$$f(n,t) = Ae^{-\frac{\Delta G(n)}{k_B T}} .$$

The maximal mean cluster size that can be obtained in the system does not exceed $\langle n \rangle \approx 1.6$. In the case of heterophase fluctuations the system takes a long-time evolution, the final state being one big cluster in equilibrium with c_{eq}^{∞} monomers around it. The size of this cluster depends on the initial supersaturation in respect with c_{eq}^{∞} (Fig.3). The obtained conclusions again are in disagreement of the SANS from solutions C_{60}/CS_2, which shows that liquid droplet model cannot describe the observed clusters.

The modified liquid droplet model (ii) uses the potential arising in systems where the cluster growth is strictly limited by some kind of interaction described by the additional term with parameters k and β. The corresponding evolution of the $f(n, t)$ function (Fig. 1) show that in equilibrium the final cluster size distribution consists of a Gaussian peak of large clusters and an exponential decay distribution of monomers, dimers, trimers and so on,. The position of Gaussian peak, as well as the average cluster size does not depend on the initial value of c_0. The analytical expression for the mean cluster size obtained for this model:

$$\langle n \rangle = w_s^{\frac{3\beta}{3\beta-2}} \left(\frac{\alpha_2}{3k(\beta-1)} \right)^{-\frac{3}{3\beta-2}},$$

where w_s – is the volume of a monomer (fullerene), is in agreement with numerical solutions. This is in a qualitative agreement with the situation in the system C_{60}/CS_2, the quantitative comparison is in progress.

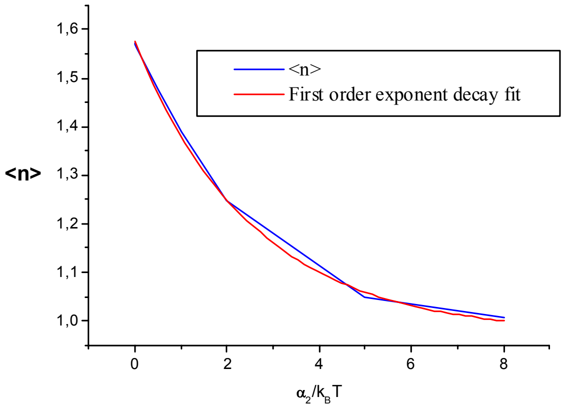

Fig.2. Dependence of average cluster size on system parameters in model (i) in the case of homophase fluctuations.

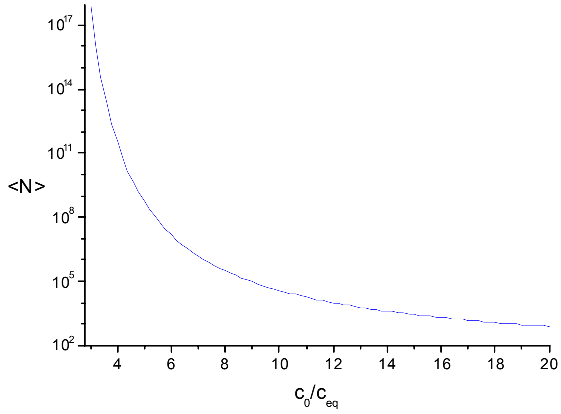

Fig.3. Dependence of average cluster size on initial supersaturation in model (i) in the case of heterophase fluctuations.

The last model (iii) takes into account the charge of monomers, *Q*, suggested for molecular solutions in [5]. This kind of potential can be brought to the form of $\Delta G(n)$ for model (ii), and all the conclusions obtained above stay true for it.

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NEUTRON SCATTERING STUDIES OF METHYL DERIVATIVES OF BENZENE SELECTED AS POTENTIAL MATERIALS FOR COLD NEUTRON MODERATORS

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Methyl derivatives of benzene, such as toluene – $CH_3C_6H_5$, *m*-xylene – $(CH_3)_2C_6H_4$, and mesitylene – $(CH_3)_3C_6H_3$, are commonly known as organic solvents with relatively low melting points: 180K, 225K and 227K, respectively. Melting point of *p*-xylene, equal to 286 K, is close to this value of benzene, equal to 278 K. For all these molecules internal barriers for rotation of CH_3 groups with regard to C-C bound is very low. The librational modes of methyls in solid *p*-xylene are mixed with the high wave-number optical phonons at the cut-off spectrum of lattice modes at about 120 cm^{-1} [1]. In the solid state of toluene [2] and m-xylene [3], methyl librations are mixed with the low wave-number acoustic phonon branches and form the librational band at about 50 cm^{-1}, which suggests low external barriers for rotation of CH_3 groups in the solid state of these compounds. Mesitylene was assumed to behave similarly, therefore, it has been proposed as a cold moderator at pulsed neutron sources [4]. However, our recent neutron scattering investigation of this compound indicated three crystalline phases of mesitylene [5].

The vibrational spectra of crystalline toluene, *m*-xylene and mesitylene are characterized by continuous phonon density of states with the parabolic dependence on the wave-number up to about 50 cm^{-1}, and the phonon cut-off energy at about 120 cm^{-1}. Except for the phase III of mesitylene, methyl librational modes in solid toluene, *m*-xylene and phase I and II of mesitylene are mixed with the lattice vibrations and increase the number of the low energy modes, which can effectively slow down neutrons to low energies. In the disordered phase of toluene and mesitylene the bands at 50 cm^{-1} are smeared out and cause a non-parabolic dependence of the G(ν) below this wave-number. Such behavior of these bands, as well as the disappearing of the strong bands seen at phase III of mesitylene at 155 and 193 cm^{-1}, allows one to assign these bands as corresponding to methyl librations. Other internal modes form discrete spectra in the range of wave-numbers from about 200 to 1800 cm^{-1}, except for the C-H stretching modes, which form a narrow band at about 3200 cm^{-1}.

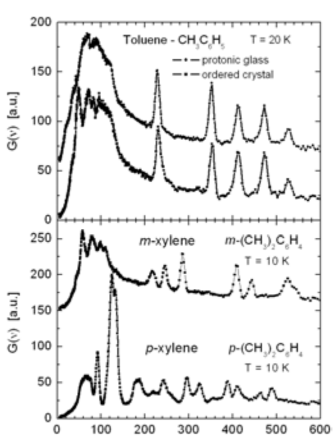

Fig. 1. The amplitude weighted vibrational density of states – G(ν) obtained from the IINS spectra measured at 20K for solid toluene, m- and p-xylenes.

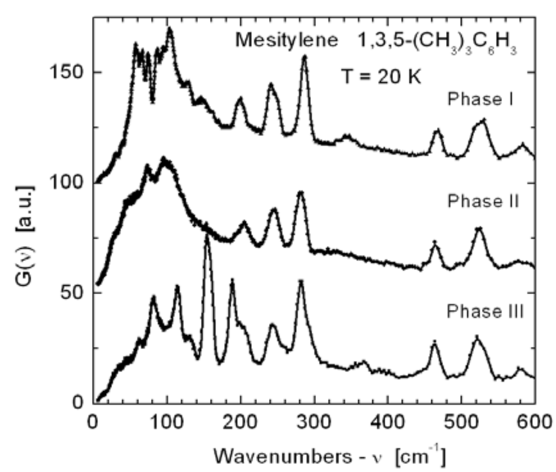

Fig. 2. The G(ν) spectra of different solid phases of mesitylene at 20K.

The additional density of states, over the parabolic dependence of the G(ν) of ordered crystals, called "boson peak", is typical for all disordered or glassy substances. The orientational disorder of methyl groups in solid toluene and mesitylene caused so-called protonic glass phase in solid state of these substances. However, these glassy phases are not stable in all temperature range of solid phase of these compounds.

The disordered solid phase II of mesitylene can be obtained when overcooled liquid is freezing at slow cooling rate. This phase is not stable at low temperatures but at about 90K it passes the structural phase transition to the low temperature phase III. This transition is reversible until phase II is not heated over 180K. At about 190K phase II starts a transformation to the high temperature ordered phase I. The growth rate of nucleations of phase I increases with temperature and at about 220K full transformation of phase II to phase I need only some minutes. This transformation is not reversible and the structure of phase I is stable from its melting point at 227K, down to the liquid helium temperatures. Phase II, in presence of nucleations of the phase I, can be also overcooled to the liquid helium temperatures.

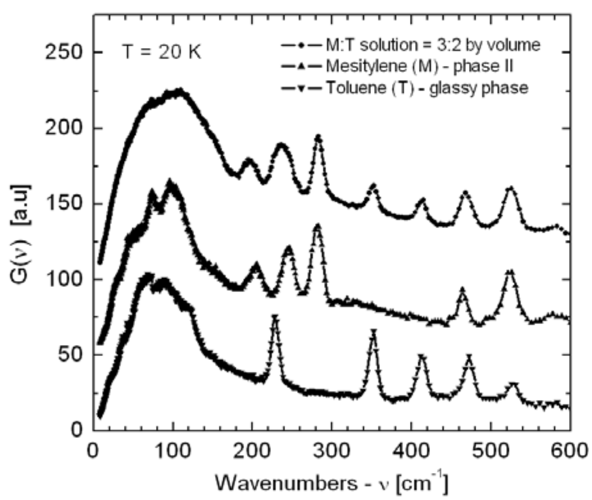

Fig. 3. Comparison of the G(ν) spectra of disordered phases of toluene and mesitylene with its 3:2 volume solution measured at 20K.

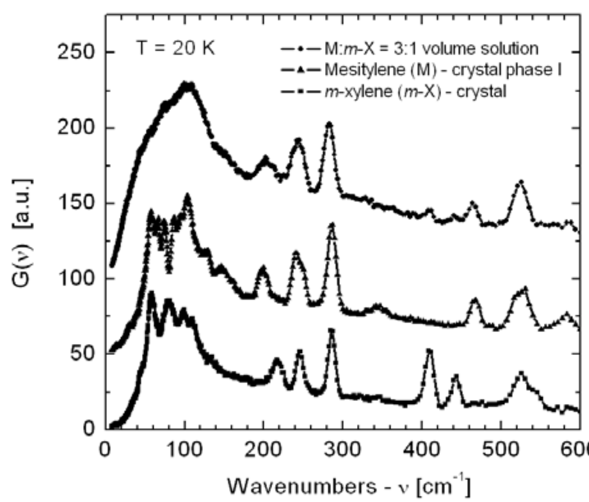

Fig. 4. Comparison of the G(ν) spectra of ordered crystalline phases of m-xylene and mesitylene with its 3:1 volume solution measured at 20K.

The IINS and neutron diffraction investigations of selected solutions have confirmed stabilization of disordered solid phase by mixing of mesitylene with other methyl-benzene compounds. Some of these results are presented in figures 3 and 4. It has been shown that solutions of mesitylene with toluene or *m*-xylene form glassy solids, which are stable in the whole temperature range below the melting point. The vibrational spectra of these glassy state solutions indicate that methyl librations are mixed with the lattice vibrations and form the wide band with cut-off at about 120 cm^{-1}.

Additional density of states at low frequencies, over the parabolic dependence of the G(ν) for ordered crystals, typical for disordered solids can be seen in fig. 4. It makes solid solutions of the investigated compounds preferable as potential moderators for cold neutron sources.

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PARTIAL STRUCTURE FEATURES OF PB–K MELT

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The paper is devoted to the extraction of the partial structure factors (PSF) and partial pair correlation functions $g_{ij}(r)$ (PPCF) from the results of the neutron diffraction experiments. For this purpose we use our earlier experimental results on Pb-K melt with various concentrations of components $C_{\mathrm{Pb,\,K}}$ (fig. 1, see [1]).

The structure factor (SF) for Pb-K binary system can be written as:

$$S(Q) = (C_{\mathrm{Pb}}b_{\mathrm{Pb}})^2 S_{\mathrm{PbPb}}(Q) + 2C_{\mathrm{Pb}}C_{\mathrm{K}}b_{\mathrm{Pb}}b_{\mathrm{K}}S_{\mathrm{PbK}}(Q) + (C_{\mathrm{K}}b_{\mathrm{K}})^2 S_{\mathrm{KK}}(Q) \qquad (1)$$

Here b_{Pb} and b_{K} are amplitudes of coherent neutron scattering. In coordinate space

$$g_{ij}(r) = 1 + \frac{1}{(2\pi)^2 n_0 r}\int_0^\infty [S_{ij}(Q) - 1]Q\sin(Qr)dQ \qquad (2)$$

where n_0 is density. To minimize the influence of spurious oscillations at small r arising in the course of the procedure (2) two methods were used: the first, based on the experimental SF correction [2], and the second, based on the maximum entropy approach [3].

The PSF and PPCF, extracted from experiment, were analyzed by the comparison with MD simulations results [1]. In so doing two model of the melt investigated were applied. In the first one the Pb-K melt was assumed as the mixture of free Pb and K atoms (atom-atom (AA) approach). The example of PPCF $g_{ij}(r)$ for the melt with the concentration $Pb_{0.86}K_{0.14}$ obtained in the frame of this model, is shown in fig 2. The second model assumes the melt to be a mixture of Pb-K clusters and free Pb atoms (cluster-atom (CA) approach). It follows from MD results [4], that Pb-K melt along with the clusters of Zintle type Pb_4K_4 (their existence is evident from the presence of the prepeak in SF S(Q) at Q ~ 1 A, [5], see fig. 1) contains as well the Pb-K clusters with variations of components Pb_mK_n . So, besides the Zintle clusters the possible variants of the Pb-K clusters Pb_2K_2, Pb_4K_3, Pb_4K_2, and Pb_6K_4 were considered, the latters being assumed as scattering units with coherent amplitude $b = mb_{\mathrm{Pb}} + nb_{\mathrm{K}}$. The examples of the experimental $g_{ij}(r)$ for this AC approach are shown in fig. 3 ($g_{12}(r)$ – PPCF for free Pb atom – Pb-K cluster correlations) and fig. 4 ($g_{22}(r)$ – PPCF for Pb-K – Pb-K cluster correlations). As in the case of fig. 2, there exists only far resemblance between MD and experimental results. It is desirable to explain the possible origin of the main features demonstrated in these figures. The peak at r ~ 7 A may be connected with the correlations "cluster – free Pb". The peak at (7 – 8) A reflects the correlations between Zintle clusters. The peaks at ~ (2-2.5) A, which are absent in MD results can be understood presumably in the following way. Two Pb atoms and two K atoms are situated at the vertices of tetrahedra. In this case the shortest distance between scattering centers is $\sqrt{2}$ times less than interatomic distance, i.e. 3.4/1.4 ≈ 2.4 Å. If the clusters converge through two neibouring free Pb atoms, this distance can be estimated as twice of this value, i.e. ≈ 5 Å.

In general, one can point out some resemblance only between the positions of the main features in MD data and PPCF curves extracted from experimental results, to say nothing of their shapes.

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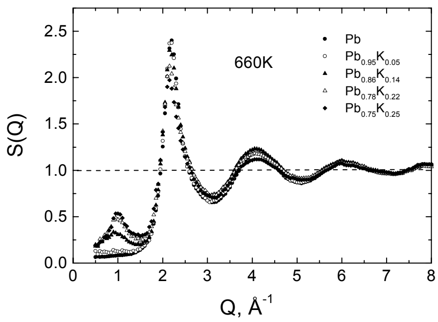

Fig. 1. Structure factor for the Pb–K melts for various concentrations.

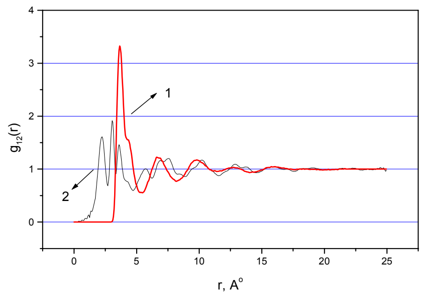

Fig. 2. PPCF $g_{12}(r)$ for the $Pb_{0.86}K_{0.14}$ melt: 1 – MD result, 2 – AA approach.

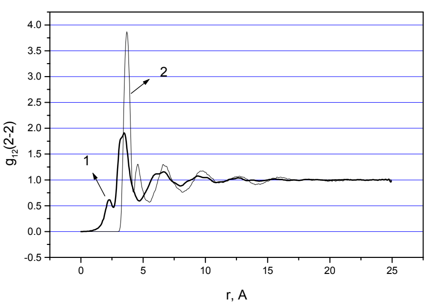

Fig. 3. PPCF $g_{12}(r)$ for the Pb_2K_2 cluster: 1 – AC approach, 2 – MD result.

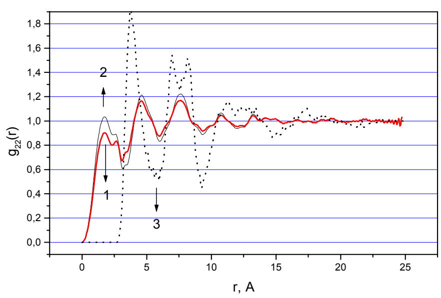

Fig. 4. PPCF $g_{22}(r)$: 1 – for Pb_2K_2 cluster, 2 – for Pb_4K_4 cluster, 3 – MD result.

FIRST PHYSICAL RESULTS FROM REMUR

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This year the first modernization stage of the polarized neutron spectrometer REMUR completed. Today, the spectrometer allows carrying out high-luminosity investigations of neutron reflection from surfaces, layered magnetic structures, and interfaces and experiments of small angle neutron scattering on inhomogeneous magnetics for a wide interval of momentum transfer, $Q = 3\times10^{-3} \div 5\times10^{-1}Å^{-1}$.

The proximity effect at the superconductor-magnetic interface involving simultaneous establishment of the superconducting and the magnetic state in the bilayer or periodic structure has already been studied for a comparatively long time. In 1988, A.I.Buzdin and L.N.Bulaevskii [1] predicted the effect of modification by superconductivity of the ferromagnetic order. Actually, it was noted that in a thin ferromagnetic film a domain structure established. Contrary to [1] article [2] points to that superconductivity leads to the establishment of a modulated magnetic structure. Experimental studies of the effect of superconductivity on the ferromagnetic layer magnetization were first conducted by Mühge and co-authors[3] who determined the effective magnetization in a Nb/Fe crystalline layer by measuring the magnetic resonance. They discovered that the magnetization fell as the temperature decreased below the critical temperature and the thinner the layer the sharper the fall was. For a thinnest iron layer of 14Å the magnetization drop was the largest and amounted to 4%.

To reveal how superconductivity and magnetism co-exist on a nano-level, we have chosen the layered structure $Pd(15Å)/V(400Å)/Fe_{0.66}V_{0.34}(50Å)/$ $[10\times(V(50Å)/Fe(50Å))]/MgO$ where simultaneously exists the periodic structure $10\times[V(50Å)/Fe(50Å)]$, that is composed of superconducting vanadium and ferromagnetic iron layers, and the bilayer $V(400Å)/$ $Fe_{0.66}V_{0.34}(50Å)$. The measurement at different temperatures of the dependence of the neutron reflection coefficients $R^{++}(Q)$ and $R^{--}(Q)$ responsible for the processes without spin-flip has allowed the determination of the spatial dependence of the magnetization (magnetization profile) in the periodic structure and at the interface in the bilayer. At the same time, the given periodic structure is a generator of short-period standing neutron waves [4], which also allows study of spatial variation of the magnetization vector direction using the neutron reflection coefficients $R^{+-}(Q)$ and $R^{-+}(Q)$ responsible for the neutron spin-flip processes.

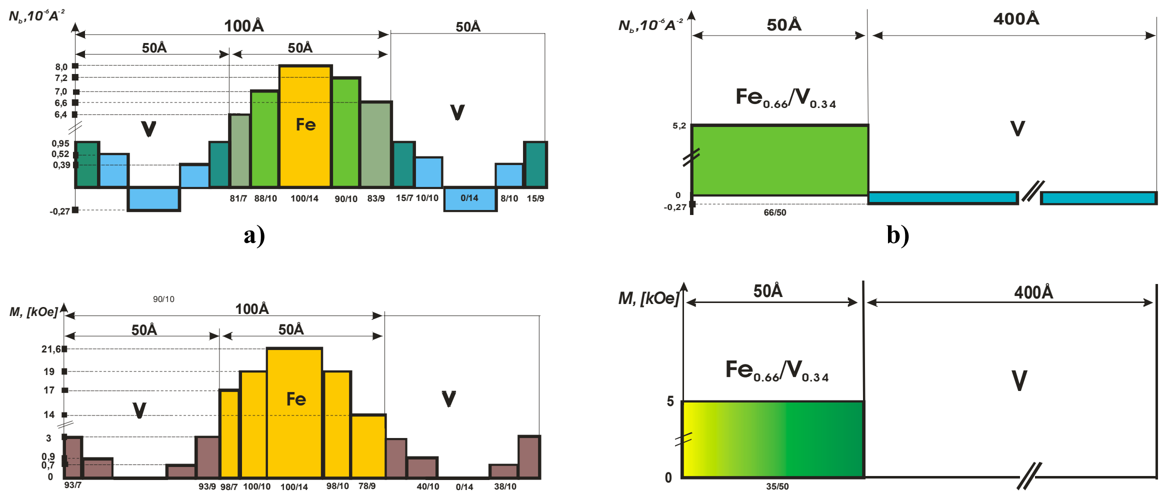

Fig.1. The nuclear N_b and the magnetic profile M at 3K for: a) three contiguous layers

V(50Å) /Fe(50Å) /V(50 Å) of the periodic layered structure; b) bilayer $Fe_{0.66}V_{0.34}$(50Å)/V(400 Å).

Measurements of neutron reflection were carried out at 293K, 7K, 3K, and 1.7K. Basing on the fact that the temperature of superconducting transition in bulk vanadium is known to be 5.3K and that it slightly decreases if in a nano-layer, it is assumed that the temperatures 3K and 1.7K lie below the superconducting transition temperature for vanadium layers and the temperatures 7K and 293K are above it. However, the experimental data on neutron reflection coincide for the temperatures 293K, 7K, and 3K and only differ for 1.7K.

Figure 1 shows the histograms of the spatial dependence of the nuclear scattering density amplitude N_b(nuclear profile) and of the magnetization M (magnetic profile) for the three contiguous layers V/Fe/V of the periodic structure (Fig. 1a) and the bilayer $Fe_{0.66}V_{0.34}$(50Å)/V(400Å) (Fig. 1b) at 3K. In the Figure each separate section (structure sublayer) of the histogram N_b is marked with the C_{Fe} and L values with a slash between standing for the iron percentage in the sublayer C_{Fe} and the sublayer thickness L. It is seen that there are just two sublayers that have 100% iron and 100% vanadium content (C_{Fe}=0). The rest are a mixture of iron and vanadium atoms. Next, from a comparison of the dependence N_b with the dependence M it is seen that in sublayers with a low iron concentration (15%, 10% or 8%) magnetization has a much lower value than that which follows from the assumption of magnetization being proportional to the iron atom concentration. The latter is due to the fact that in such sublayers vanadium atoms are magnetized by iron atoms and get antiferomagnetically ordered with respect to them. For the bilayer (Fig. 1b), we also have a 66% iron atom concentration in a 50Å thickness sublayer while the magnetization is only 35% of the iron atom magnetization, which means that antiferromagnetic ordering is stronger than in the periodic structure sublayers. Thus, in a real Fe/V layered structure we have a more complicated case when together with ferromagnetic ordering in the middle of the iron layer there exists antiferromagnetic ordering at iron-vanadium interface.

Figures 2a,b show the magnetic profile for the temperature 1.7K. In the Figure each sublayer is marked with effective manetization M_{eff} and L values with a slash between their. The M_{eff} is expressed in percentages the ratio of sublayer magnetization M and magnetization of iron atoms in sublayer $C_{Fe}M_{Fe}$, where M_{Fe} is magnetization of iron equal 21.6kOe. It is seen that in the periodic structure sublayers with a low iron atom concentration, 15%, 10%, 8% and 0%, magnetization drops by 1кOe, 0.9кOe, 0.7кOe and 0, respectively. In the sublayers with a high iron atom concentration, 81%, 88%, 100%, 90% and 83%, magnetization changes by –3кOe, -2кOe, 0, 0, +2кOe, respectively. Thus, there is direct evidence of that magnetization tends to decrease, although in separate sublayers it does not change and even increases. It is, however, characteristic of the sublayer with a 100% vanadium atom concentration that in it there is not observed diamagnetism due to establishment of superconductivity. At the same time, in the bilayer (Fig. 2b) the sublayer $Fe_{0.66}V_{0.34}$ loses magnetization completely while the 400 Å vanadium layer becomes diamagnetic.

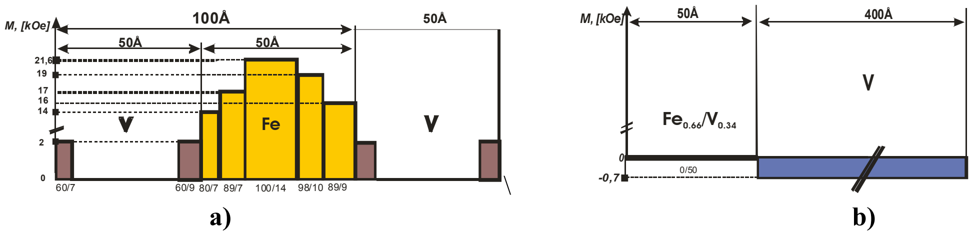

Fig. 2. The magnetic profile at 1.7K for: a) three contiguous levels V(50Å) /Fe(50Å) /V(50 Å) of the periodic layered structure; b) bilayer $Fe_{0.66}V_{0.34}$(50Å)/V(400 Å).

The results of the first neutron investigations are unexpected to some extent, though they can be explained. Unexpected is that in the periodic structure with thin vanadium layers in each of which superconductivity cannot occur [5] (what is seen on the example of the 14Å layer with a 100% vanadium concentration) changes in the magnetic profile are observed. A possible explanation is that there establishes some superconducting state in the entire periodic structure whose sum thickness of vanadium layers is on the order of 500 Å. Unexpected is 100% suppression of a 5кOe magnetization in the $Fe_{0.66}V_{0.34}$ sublayer It may be connected with strong antiferromagnetic ordering that produces a weaker destructive effect on the superconducting pair [6].

So, the obtained results make us sure that the unique possibilities for the measurement of the nuclear and the magnetic profile of layered structures that provide the present polarized neutron spectrometer REMUR will allow us to obtain new data to advance essentially in the solution of the problem of superconductivity-magnetism coexistence.

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Nature of the parity violation in interaction of neutrons with lead

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Introduction

At the beginning 1980's the enhanced parity nonconservation (PNC) effects were predicted [1, 2, 3] and experimentally observed [4, 5] in the processes of interaction of slow neutrons with nuclei. It was shown the structure and properties of the nuclei cause the mechanism of this enhancement. Those effects are mostly expressed close to the p-wave resonances. For example, for ^{139}La total capture cross section of the p-resonance with the energy 0.75 eV differs by 10% for polarized and unpolarized neutrons.

Later on detailed investigation of these effects for a number of nuclei was carried out in Los-Alamos [6], where the dependence of the neutron total cross section vs. neutron helicity was measured. All the results are in agreement with the theory treating PNC-effects as a result of mixing of compound states, having different parity. In the considered case they are s- and p- resonance.

Besides PNC-effect at total cross-section there is another effect - neutron spin rotation, if neutron polarization is perpendicular to the neutron momentum, by neutron flight through the target. Both effects are described in the frameworks of the same theoretical model.

Lead is among those nuclei where neutron spin rotation was measured. The value of rotation angle was obtained in [7]:

$$\Delta\varphi = (2.24 \pm 0.33) \cdot 10^{-6} \text{ rad/cm}$$

The target was a natural lead, which consists of four isotopes. Additional experiment on natural lead [8] confirmed that the effect is present. The obtained value in this experiment was

$$\Delta\varphi = (3.53 \pm 0.79) \cdot 10^{-6} \text{ rad/cm.}$$

The carried out measurement on an isotope ^{207}Pb, which in a natural mix of 22 %, has shown, that this isotope does not respond to this effect [8].

Further measurement was done with an isotope ^{204}Pb [9], which in natural lead only 1.4 %, and the next value of rotation angle was obtained

$$\Delta\varphi = (8 \pm 2) \cdot 10^{-5} \text{ rad/cm}$$

It was somewhat less than needed for interpretation of the effect but approximately, nevertheless, could explain it.

In the frameworks of the simplified two-level model of the s- and p- resonance mixing spin-rotation angle may be written as follows [10]:

$$\Delta\varphi = \frac{4\pi\lambda\!\!\!^{-2}(1eV)\rho W_{sp}\sqrt{\Gamma_n^s(1eV)\Gamma_n^p(1eV)}}{(E-E_s)(E-E_p)} \qquad (1)$$

Here: $\lambda\!\!\!^{-}$ - is the neutron wave length, ρ - is the number of nuclei in cm^3 of target, W_{sp} - is the matrix element of the mixing by the weak interaction between the states with different parity, Γ_n^s и Γ_n^p – neutron widths of s- and p- resonances, E_s и E_p – energy means of this resonances. Symbol (1eV) demonstrates that this value is reduced to 1 eV of energy.

It is assumed in Eq. (1) that the total widths Γ_s и Γ_p << (E - E_s) and (E - E_p), respectively.

Using known values of the parameters of s- and p- resonances of ^{204}Pb [11], one may see that the theoretical estimation of Δφ is several orders less than was experimentally obtained. It is possible, that the compound state corresponding to the p-resonance lies below the binding energy (so-called negative resonance). It is obvious from Eq. (1) that the effect in thermal region at E < 0.1 eV is proportion to $\sqrt{\Gamma_n^s} / E_s$, and $\sqrt{\Gamma_n^p} / E_p$. Taking maximal value of this ratio (E_s = -3 keV и Γ_n^s (1eV) = 1.3 eV) [11] and assuming also that for p-resonance the average width is Γ_n^p (1eV) = $3 \cdot 10^{-7}$ eV and E_p = D/10 =100 eV (where D is the average interval between nuclear levels which is about 1 keV for ^{204}Pb) one obtains Δφ = $9 \cdot 10^{-7}$ rad/cm, i.e. 2 orders less than obtained in the experiment. Here we used $W_{sp} = 5 \cdot 10^{-3}$ eV which is slightly higher in comparison with the average value. The larger effect may be obtained, if Γ_n^p would be essentially larger and E_p smaller, respectively. For instance, if an increase Γ_n^p by an order of magnitude and arranging the resonance below binding energy by 5 eV, we obtained Δφ = $6 \cdot 10^{-5}$ rad/cm. It becomes nearer to the experimental value on ^{204}Pb, while still not enough to explain the measurement on the natural lead. Thus interpretation of the parity violation in lead may be related with the strong p-resonance close to the binding energy. Therefore, observation of the “negative” neutron resonance is a principal importance.

The purpose of experiment and estimation of expected results

We have proposed to investigate the energy dependence of the neutron capture cross-section $\sigma_\gamma(E)$ and such way to carry out search of subthreshold resonance. It is known that $\sigma_\gamma(E)$ is described by the Breit-Wigner relationship. At low neutron energy E << E_0 and Γ << E_0 it may be rewritten as

$$\sigma_\gamma^s(E) = \frac{\pi\lambda\!\!\!^{-2}(1eV)\Gamma_n^0\Gamma_\gamma}{E_S{}^2\sqrt{E}} \qquad (2)$$

in the case of s-wave interaction, and as

$$\sigma_\gamma^p(E) = \frac{\pi\lambda\!\!\!^{-2}(1eV)\Gamma_n^1\Gamma_\gamma}{E_p{}^2\sqrt{E}}V_1 \qquad (3)$$

in the case of p-wave resonance.

In expressions (2) and (3) Γ_n^0 and Γ_n^1 are the reduced widths of s- and p- resonances, which do not depend on the energy of neutrons. An important role in the p-wave cross-section plays centrifugal factor:

$$V_1 = \frac{(kR)^2}{1+(kR)^2} \qquad (4)$$

Here: $k = 1 / \lambda\!\!\!^{-}$ – is the neutron wave number and R – is the radius of a nucleus. For lead the number of $V_1 = 3 \cdot 10^{-6}$ E. It is seen from here that the energy dependencies of the neutron cross-sections for s- and p- waves are different:

$$\sigma_\gamma^s(E) \approx 1/\sqrt{E} \quad \text{and} \quad \sigma_\gamma^p(E) \approx \sqrt{E}$$

It is seen that the p-wave contribution (or its upper limit) may be obtained from the measurements of the energy dependence of the radiation neutron cross-section from thermal energy up to 1-3 eV.

The technique of experiment and results

The experiment carried out on the neutron beam of the pulsed reactor IBR-2 of FLNP JINR in Dubna. The well fulfilled technique of time-of-flight for spectrometry of neutrons was used. As follows from the experimental results above [8,9] the negative resonance most probable could be observed in radiation neutron capture of ^{204}Pb. Thus, we used as a target lead enriched by an isotope ^{204}Pb. It is convenient to measure gamma-ray spectra from two targets simultaneously to decrease various systematic uncertainties during the experiment. The first investigated target is enriched by isotope ^{204}Pb and the second one is a reference target having known 1/√E energy dependence of the capture cross-section.

As soon as an overlap of the gamma-peak from two components of composite target is absent it may be possible to compare the squares under these peaks. So, on the base of this comparison an unambiguous conclusion concerning the deviation of the energy dependence of the neutron radiation cross-section from the 1/√E can be maid. At the initial stage of experiment as a reference target served copper, and further as reference was the isotope ^{207}Pb. This isotope contained in the investigated sample and the lines appropriate to it were intensive enough in a measured gamma-spectrum.

Gamma-ray spectroscopy of radiative neutron capture carried out with the Combined Correlation Spectrometer (COCOS). Its peculiarity consists of the combination of lonely semi-conductor detector (HPGe) with high energy resolution and several scintillation gamma-detectors (BGO) with high registration efficiency. The possibility of registration of two and more coincidence gamma quantums and the correlation analysis of multi-parameter experimental data allows essentially to suppress a background and to improve a ratio “peak-background” in the measured spectrum. The high-energy part of the spectrum from 5 to 8 MeV was analyzed in the carried out experiment. Here, the probability of formation of electron-positron pairs due to gamma-ray interaction with a germanium crystal prevails the probability of a photoeffect and Compton-effect.

This part of spectrum is presented in figure 1. It is a gamma-ray spectrum from radiation capture of neutrons with energy 0.04 eV, registered by HPGe detector in coincidence with BGO registration of the photon with energy 511 keV, accompanying of positron annihilation. The peaks marked on spectrum as S and D, single and double escape, respectively, correspond to the direct transition from the top exited levels on the ground levels for compound-nucleus ^{205}Pb, ^{208}Pb and ^{64}Cu.

Result of experimental data of processing several series of measurements with the enriched isotope ^{204}Pb total duration 575 hours shows, that the ratio of direct transitions intensities of target components (^{205}Pb/^{208}Pb) does not grow with increase of neutron energy, as it was expected, but falls. The similar energy dependence of analogous ratio (^{64}Cu/^{208}Pb) was observed in the control measurement with the enriched sample on an isotope ^{207}Pb and copper as the reference.

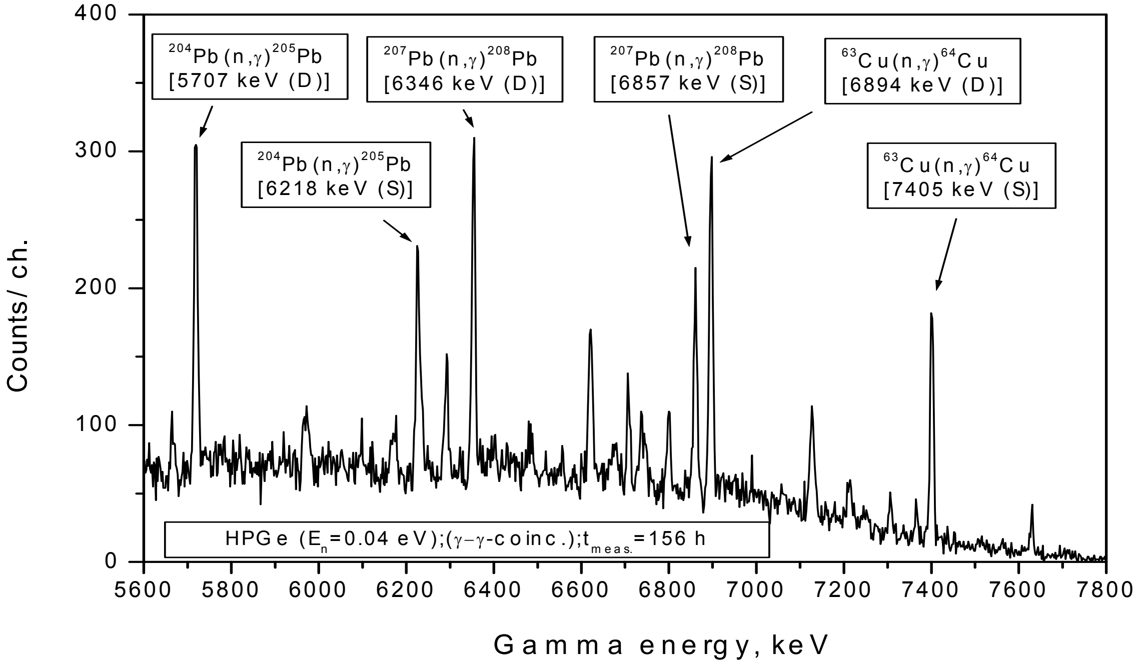

Fig.1. High-energy part of the gamma-ray spectrum of radiative capture of neutron with energy 0.04 eV for an investigated sample.

The experimental data of measurements are presented in figure 2. There are inverse relations K($^{208}Pb/^{205}Pb$) and K ($^{208}Pb/^{64}Cu$) for six group of neutron energy. It is obtained after normalization on the average meaning of these relations for two group neutron energy 8 and 20 meV, where the contribution of a p-wave is negligible. This data are supplemented with the calculated result of neutron capture cross-section ratio $\sigma_\gamma(^{207}Pb)/\ \sigma_\gamma(^{204}Pb)$ as function of neutron energy with the presumable negative resonance parameters satisfying observed effect of parity nonconservation in lead.

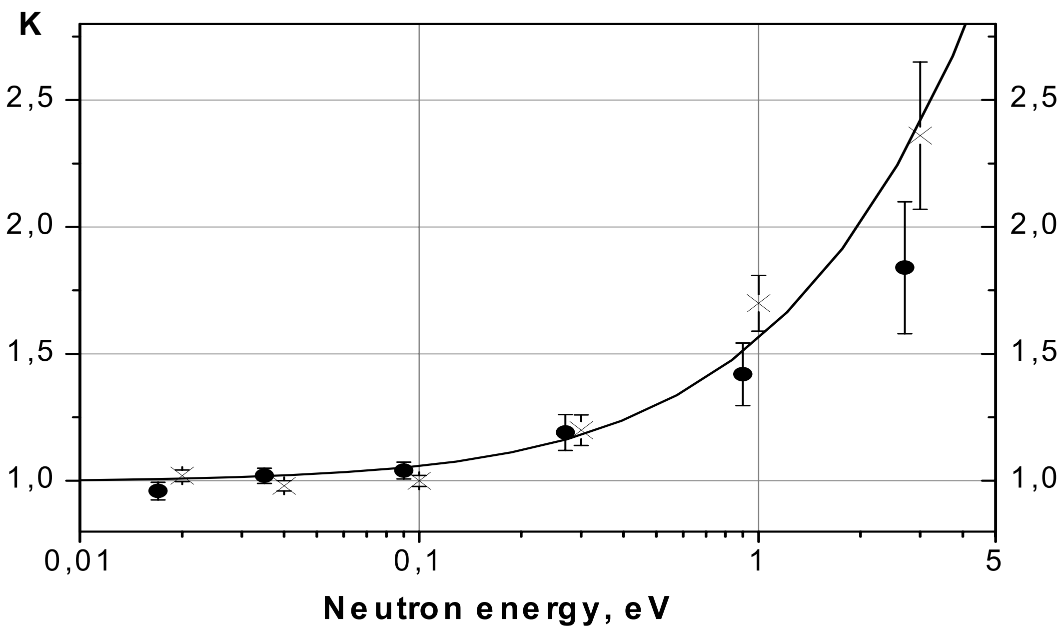

Fig.2. Neutron energy dependence of experimental meanings K. (×) - $^{208}Pb/^{205}Pb$, (•) - $^{208}Pb/^{64}Cu$, curved line – calculated result.

Conclusion

The experimental data of the measurements shown that neutron capture cross-section ratio $\sigma_\gamma(^{207}Pb)/\sigma_\gamma(^{204}Pb)$ increases with the incident neutron energy. This is an indication of the existence of the p-wave capture at an isotope ^{207}Pb. Thus, the result of the carried out experiment gives a possibility to conclude that isotope ^{207}Pb have a "negative" resonance, which could explain parity non-conservation effect in the natural lead. So, it seems very interesting the more detailed study of the nature of the observed PNS-effect in lead.

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Development of Neutron Polarizer-Analyzer System for T-Invariance Experiment

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Introduction:

A polarized ^{3}He neutron spin filters are useful for numerous researches in fundamental physics and applied physics with neutrons [1]. We will apply the polarized ^{3}He neutron spin filter for testing time reversal invariance in the nuclear reaction. The present experiment is a methodological preparation for the T-violation experimental, namely R&D for the experimental apparatus which will be used in the forthcoming full-scale experiment. The experiments were performed on KENS neutron beamline H-8.

Any noble gas nucleus of odd isotope is highly polarized by means of a rubidium optical pumping [2]. In the optical pumping, circularly polarized photons of 795 nm in the wavelength are absorbed at the rubidium D1 resonance. Upon the resonance absorptions, photon circular polarizations are transferred to rubidium atomic electrons, and then rubidium atomic spins are polarized in the direction of photons. Polarized rubidium atoms collide with noble gas nuclei of non-zero spins. Upon the atomic collisions, the rubidium atomic polarization is transferred to the ^{3}He nuclear polarization via hyperfine interactions.

Neutrons are polarized upon transmission through the polarized ^{3}He gas by the optical pumping because of strong spin-dependent neutron absorption by the ^{3}He(n,p)^{3}H reaction. The neutron polarization is represented by the following expression:

$$p_n = \tanh\left(p_{He} n_{He} \sigma_P L\right), \qquad (1)$$

where n_{He} is a ^{3}He nuclear number density, p_{He} is a ^{3}He polarization, and L is a target length. Quantity σ_p is a polarization cross-section of the ^{3}He(n,p)^{3}H reaction, which is a difference between cross sections for the parallel and antiparallel spin states of a neutron and ^{3}He nucleus system. The polarization cross section depends on the neutron energy, E as $\sigma_p(E) \approx 5370\sqrt{0.0253/E}$ barn. The neutron transmission is represented as

$$N = \exp\left(-n_{He}\sigma_0 L\right)\cosh\left(p_{He} n_{He} \sigma_P L\right) = N_0 \cosh\left(p_{He} n_{He} \sigma_P L\right), \qquad (2)$$

where N_0 is a neutron transmission for unpolarized ^{3}He nuclei and σ_0 is the total cross-section of the ^{3}He nucleus. From Eq. (1) and (2), the neutron polarization is obtained as

$$p_n = \sqrt{1-\left(N_0/N\right)^2} \qquad (3)$$

Experimental Installation:

In the test of the time reversal invariance, polarized ^{3}He neutron spin filters are used as a neutron spin polarizer and an analyzer. A prototype set-up for the polarizer and analyzer are shown in Fig. 1. Two ^{3}He cells are placed in two solenoids of 34 G as the polarizer and analyzer. Each cell is irradiated with a laser beam of 795 nm in wavelength. A neutron beam passes through the polarizer and analyzer in the axis of the solenoids. The configuration of the apparatuses can be changed easy and fast enough to fit the particular experiment. In fact, it represents the constructor set of uniform parts. For example, we can place a spin flipper for a neutron spin manipulation experiment as it is shown in Fig. 1. The solenoids are placed on revolving platform, which allows rotate the entire installation around the upright axis and sets the angular position with accuracy ±0.01 deg.

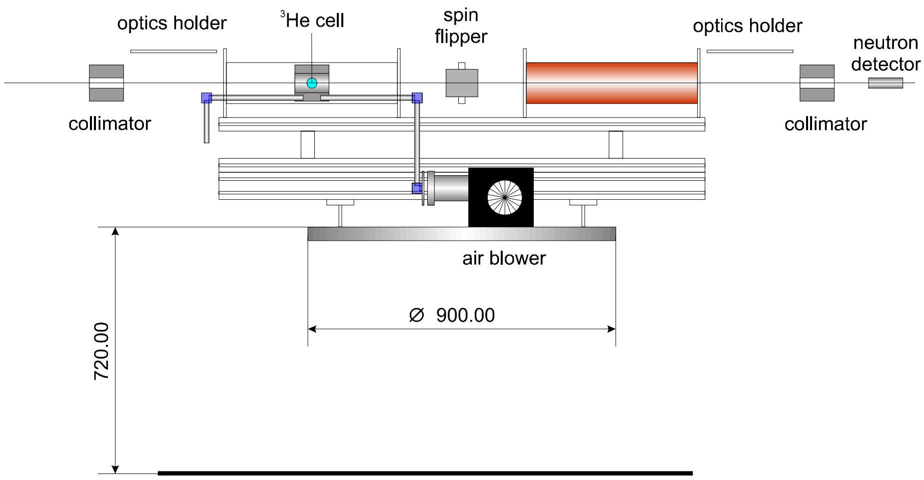

Fig. 1. Installation with the polarized ^{3}He cells in a KENS beam line. Position of the neutron detector is not scaled.

As a container for polarized ^{3}He gas, we used a 3 cm diam and 4.65 cm length cylindrical cell of quartz and a 3.6 cm diam and 4.65 cm length cell of sapphire. The both cells were filled with ^{3}He gas at a pressure of 3 atm. together with small amount of rubidium and nitrogen gas. The cells were placed in the two solenoids aligned along the neutron beam direction. The quartz and sapphire cells have the advantage of clean surface for polarized ^{3}He gas and low neutron absorption. Each cell had its own hot air supply line. The temperature of the cells was kept at about 195±1^{o}C so that an optimal rubidium atomic number density was obtained for the optical pumping.

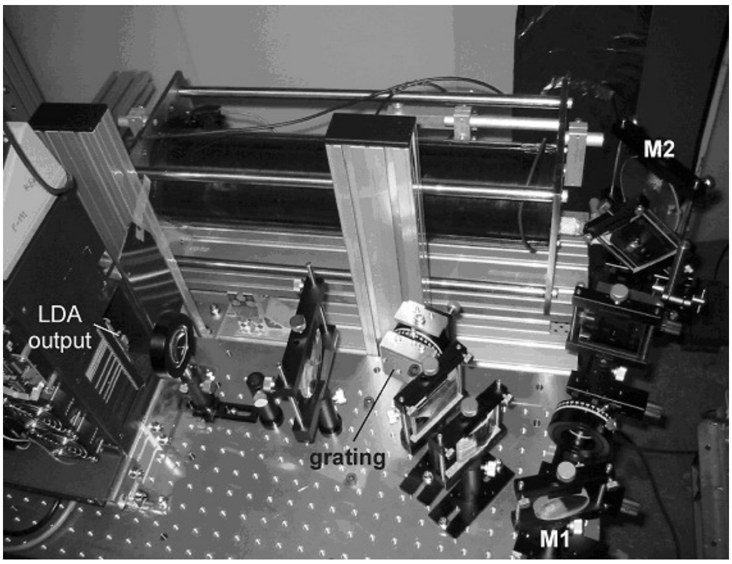

Fig. 2. LDA FWHM narrowing system. Mirror M1 guides zeroth-order reflection from grating to the mirror M2 which reflects the light to a cell inside the solenoid. All lenses are used for shaping of the laser beam profile.

For the optical pumping, we used 17 W laser diode arrays (LDA) of 795 nm in wavelength as shown in Fig. 2. The LDA has a line width of 2~3 nm in FWHM and are much broader than the Rb natural absorption line width. Therefore, a small fraction of the LDA power can be used for the rubidium optical pumping. The effective laser power limits the rubidium atomic polarization and then the ^{3}He nuclear polarization. There are two ways to improve this situation. First one is a brute force, just to increase the laser power. We used two laser systems for single cell. We used almost twice as much laser power. The second one is the application of a frequency narrowing system to the LDA, which allows us to use full laser power [3]. We used an external cavity with a diffraction grating and some optical lenses for the frequency narrowing. The grating has 2400 grooves/mm. The first order diffraction from the grating is reflected back to the LDA and then form a cavity in order to stimulate coherent photon emissions. The 0th-order diffraction is used for the extraction of the laser beam. The result of the frequency narrowing is shown in Fig. 3. As shown in Fig. 3, the width of the LDA is reduced to the rubidium D1 resonance width. The extracted laser beam is guided through an optical lens system for a beam shaping for the ^{3}He cell irradiation.

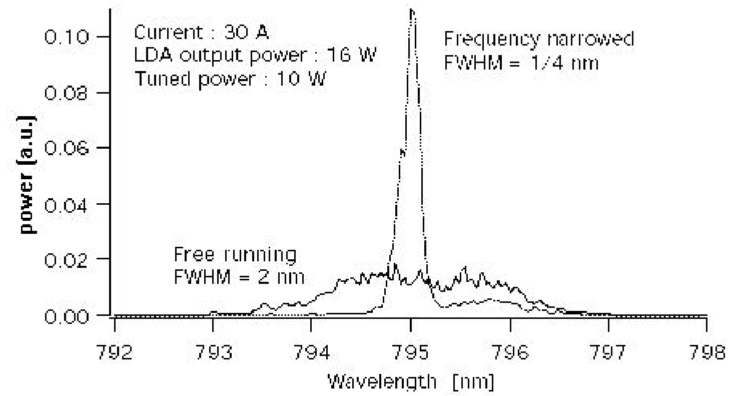

Fig. 3. The result of the frequency narrowing system.

Experimental Results:

The transmission enhancement, N_0/N was measured by a neutron detector of ^{10}B-loaded liquid scintillator, which is placed at 12 m from the pulsed neutron source, as a function of a neutron time of flight. From Eq. (3), the neutron polarization was obtained. The difference of incident neutron intensities between N_0 and N measurements was normalized by using the property of the polarization cross section. The polarization cross section is almost zero, and then the transmission enhancement, N_0/N is almost unit at higher neutron energies above 120 eV. The deviation from unity is less than 0.01. The results of neutron polarization for the quartz and sapphire cells are shown in Fig. 4 and Fig. 5.

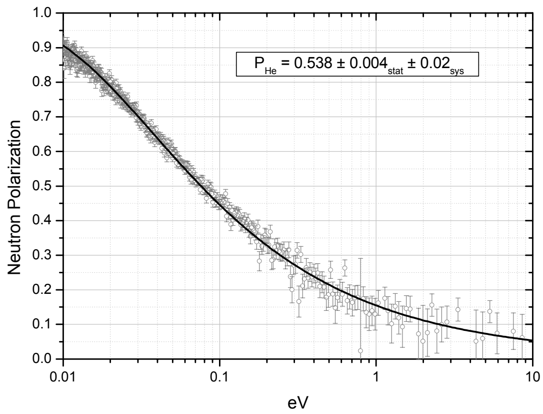

Fig. 4 Neutron polarization with quartz cell.

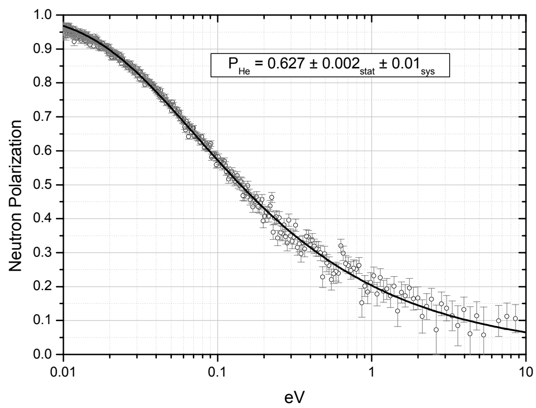

Fig. 5 Neutron polarization with sapphire cell.

A ^{3}He pressure in each cell was extracted from neutron transmissions through each cell and an identical empty cell, and then the 3He nuclear number density was obtained. The ^{3}He polarization was determined by means of Eq. (1). The result of the ^{3}He polarizations are p_{He}

$=0.538 \pm 0.004_{stat} \pm 0.02_{sys}$ for the quartz cell and p_{He} = $0.627 \pm 0.002_{stat} \pm 0.01_{sys}$ for the sapphire cell, respectively. In the both cases the single laser with the narrowing system was applied to the LDA. The double laser pumping for the same quartz cell without the narrowing system provided p_{He} $=0.431 \pm 0.002_{stat} \pm 0.02_{sys}$. The error of the ^{3}He polarization in the quartz cell is bigger than in the sapphire cell. The increase in the error arises from the uncertainty of ^{3}He pressure. The ^{3}He gas diffuses through the cell wall. The ^{3}He pressure decreased at a rate, ~1% per day at 195°C. The leakage was not found for the sapphire cell.

Conclusions:

We have compared different methods of optical pumping for the ^{3}He polarization. The application of the frequency narrowing system to the LDA showed better performance than the direct increase in the laser power. The sapphire cell showed better performance in the ^{3}He polarization than the quartz cell, in addition, the sapphire cell had no ^{3}He gas leakage.

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STELLAR NEUTRON CAPTURE ON PROMETHIUM: IMPLICATIONS FOR THE s-PROCESS NEUTRON DENSITY

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The unstable isotope ^{147}Pm represents an important branch point in the *s*-process reaction path (Fig. 1). The resulting abundance ratio of ^{148}Sm and ^{150}Sm is affected by three branchings at the unstable isotopes ^{147}Nd, ^{147}Pm, ^{148}Pm. In framework of the classical *s*-process, based on the assumption of steady process with constant temperature and neutron density, the strength of branching can be expressed in terms of the rate for β-decay and neutron capture of the branch point nucleus as well as by the $\langle\sigma\rangle N_s$ values of the involved isotopes,

$$f_\beta = \frac{\lambda_\beta}{\lambda_\beta + \lambda_n} \approx \frac{\left(\langle\sigma\rangle N_s\right)_{branched}}{\left(\langle\sigma\rangle N_s\right)_{unbranched}}$$

The effective strength of the combined branchings at A = 147/148 is determined by the branched and unbranched s-only isotopes ^{148}Sm and ^{150}Sm. These isotopes are shielded against β-decays from the *r*-process, hence, $\langle\sigma\rangle N_s = \langle\sigma\rangle N_\odot$. The isotopic ratio is well defined [1], the cross section ratio ^{148}Sm/^{150}Sm was measured with high accuracy [2]. Such a way, the effective branching factor is known - $f_\beta^{eff} = 0.870 \pm 0.009$. Since the β-decay rates of the branch point nuclei ^{147}Nd, ^{147}Pm, ^{148}Pm are practically independent of temperature and electron density during *s*-process [3], the expression can be solved for $\lambda_n = n_n\langle\sigma\rangle v_T$, choosing the neutron density n_n such as to reproduce ^{148}Sm and ^{150}Sm in solar proportions. However, the uncertainties lie evidently in the cross sections of the branch point isotopes, for which only theoretical values existed so far.

The stellar (n,γ) cross section for ^{147}Pm was determined via the activation technique. The quasy-stellar neutron spectrum was obtained by bombarding a thick metallic Li target with protons of 1912 keV at the Karlsruhe Van de Graaff accelerators (Fig. 2). The sample was a graphite pellet 6 mm in diameter and 0.4 mm in thickness, containing a mixture of ^{147}Pm and ^{147}Sm (as a carrier). The sample was sandwiched between gold foils and placed on the lithium target. The experiment was difficult because the relatively short ^{147}Pm half-life of 2.62 yr enforced the sample mass to be restricted to 28 ng or 10^{14} atoms only. By means of a modular, high-efficiency Ge Clover array (Fig. 3) the low induced activity could be identified in spite of considerable backgrounds from various impurities (Figs 4 and 5). Both partial cross sections feeding the 5.37 day ground state and the 41.3 day isomer in ^{148}Pm were determined independently, yielding a total (n,γ) cross section of 709 ± 100 mb at thermal energy of kT = 30 keV. This is clearly smaller and at lest a factor of 2 more accurate than the recommended theoretical value (1290 ± 350 mb) [4].

The (n,γ) cross sections of the additional branch point isotopes ^{147}Nd and ^{148}Pm as well as the effect of thermally excited states were obtained by detailed statistical model calculations. Three different sets of calculations using the same Hauser-Feshbah statistical model but different parameterizations have been considered: NON-SMOKER, EMPIRE-II, ENEA Code. The calculations lead to different cross sections, however the ratios of these results, ^{148}Pm/^{147}Pm, ^{149}Pm/^{147}Pm are consisted within 8%. In combination with the measured value of ^{147}Pm, this provides a reliable estimation of cross sections for ^{148}Pm and ^{149}Pm. It has a significant impact on the theoretical assessment of another important branch point isotope ^{148}Pm. The uncertainty of this cross section could be reliable reduced to 15%.

The present results allowed considerably refined analyses of the s-process branchings at A = 147/148. The classical analysis yields a neutron density $n_n = \left(4.94^{+0.60}_{-0.50}\right)\times 10^8$ cm^{-3}, what is in conflict with recent studies of the branching at A = 191/192 [5] ($n_n = \left(7^{+0.5}_{-0.2}\right)\times 10^7$). This inconsistency confirms once more that the *s*-process mechanism must include a dynamic component. In agreement with observations, the main s-process component is commonly ascribed to He shell burning in thermally pulsing stars on the asymptotic giant branch (TP-AGB stars) with masses 1.5-3 $M_\odot$ [6]. During the interpulse period of a few times 10^4 yr the dominant ^{13}C(α,n)^{16}O reaction provides a relatively high neutron exposure at comparably low temperature ($kT \approx 8$ keV) and neutron density ($n_n \leq 10^7$ cm^{-3}). At the start of the next convective instability, a sufficiently high temperature is reached at the bottom of the He-burning to marginally activate the ^{22}Ne(α,n)^{25}Mg source. This short burst of ~5 yr reaches peak neutron density of $n_n \leq 10^{10}$ cm^{-3}. Although this second burst represents only a few percent of the total neutron exposure, it suffices to determine the final abundance pattern of the s-process branchings. In this stellar model, the neutron density of ^{13}C(α,n) source is not sufficient for the reaction flow to bypass ^{148}Sm. Only in the second burst of ^{22}Ne(α,n) source, ^{148}Sm is bypassed and even strongly depleted (Fig. 6). However, during the final decline of the neutron density, the branchings to ^{148}Sm are restored, and the final value is established during the freezeout of the abundance pattern. With the new cross sections, these models reproduce the observed abundance ratio ^{148}Sm/^{150}Sm to better than 1%. The effective parameters obtained by the classical analysis have to be considered as local features. This emphasizes the importance of the decline of neutron density, which leads to a stepwise freezeout of the abundance according to the particular cross section situation in each branching.

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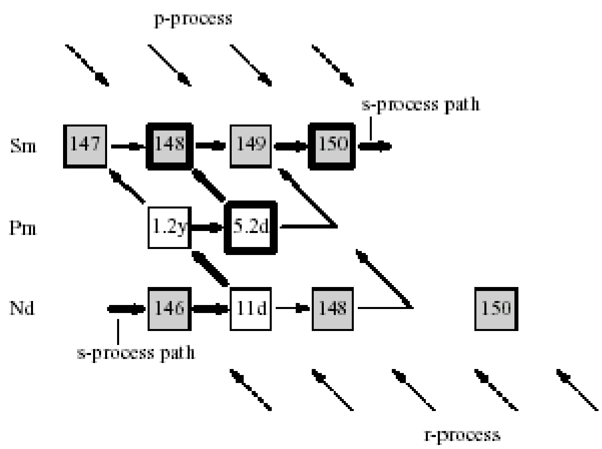

Fig 1. *s*-process path between Nd and Sm partly bypassing ^{148}Sm as a result of the branchings at A = 147/148. The second s-only isotope, ^{150}Sm, experiences the full reaction flow. An additional, very small branching to ^{149}Pm has been omitted for better readability of the figure but was considered in all analyses. The half-lives reflect the stellar values.

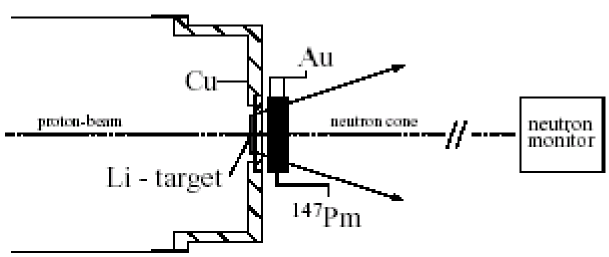

Fig 2. Sketch of the activation setup at the Van de Graaff accelarator.

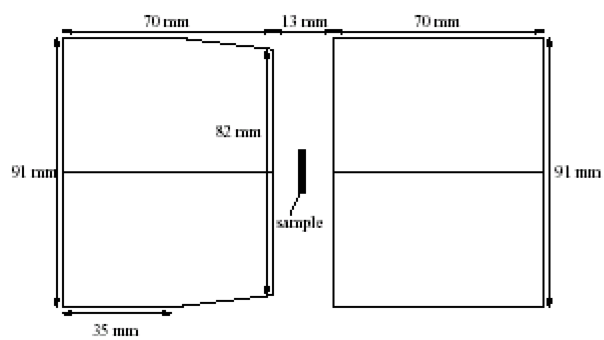

Fig 3. Schematic view of the HP Ge spectrometer consisting of two fourfold Clover-type detectors in close geometry.

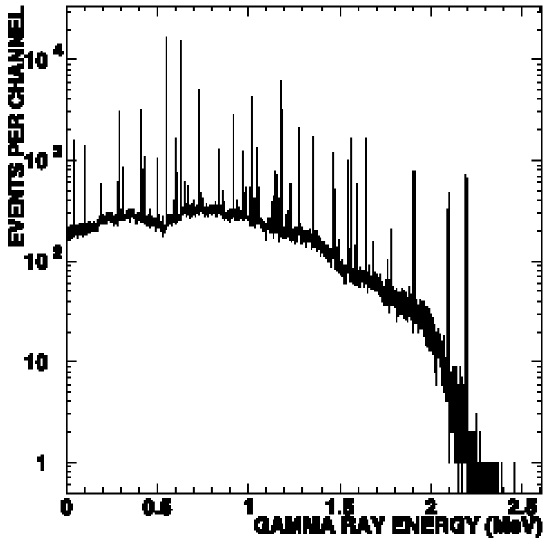

Fig 4. GEANT simulation of the decay of ^{148m}Pm with the Clover system operated in calorimetric mode. The complex response illustrates the need for a detailed simulation, since cascade corrections for summing-in and summing-out effects no longer be handled with codes for single Ge detectors.

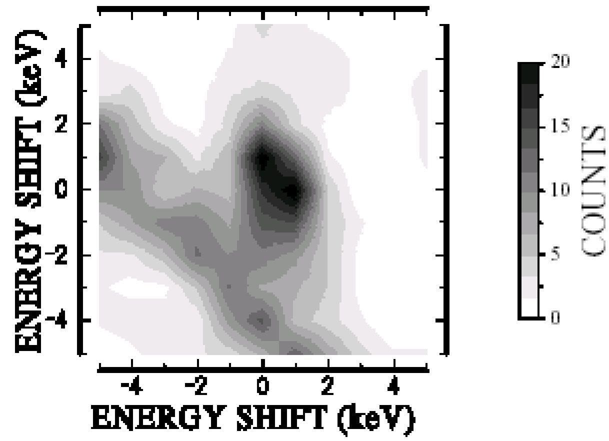

Fig. 5. γ-ray spectrum of coincident events from the activated ^{147}Pm sample. The spectrum was obtained by off-line analysis of the data taken with the Ge Clover array. Events due to cascades from the decay of ^{148g}Pm consisting of the 915 and 550 keV transitions are concentrated in the center, clearly separated from the overall background and from Compton-scattered events of the 1461 keV line from ^{40}K, which appear as the diagonal band in the lower left part.

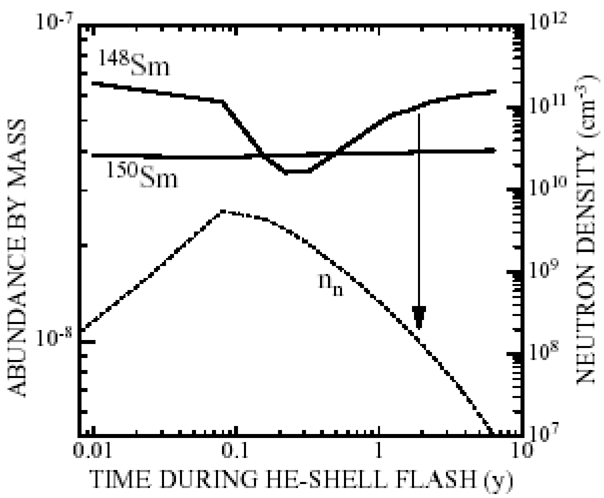

Fig. 6. Evolution of neutron density (right scale) and of the abundances of ^{148}Sm and ^{150}Sm in fractions of mass during the ^{22}Ne neutron release in a typical advanced pulse (pulse 15 of the standard AGB model). The timescale starts at the moment when the bottom temperature reaches 2.5×10^8 K. The arrow indicates the freezeout of the ^{148}Sm abundance according to the criterion $X_{freeze} = 0.9X_{final}$.

ACTIVE BIOMONITORING WITH MOSS-BAGS APPLIED TO AN INDUSTRIAL SITE IN ROMANIA

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The well known ability of mosses to sorb and retain elements from wet and dry deposition (Clymo, 1963) was successfully used during the last 30 years to identify and monitor zones of heavy metal contamination by the collection and analysis of moss samples (Buse et al., 2003). Since the introduction of the method (Rühling and Tyler, 1968), the most popular variant has been passive monitoring, involving only two major steps: collection and analysis of moss samples. This method has the advantage of the extensive character but does not offer information about exposure of the moss to the pollutant agent during periods of less than a year. The active biomonitoring with transplanted bryophytes in moss-bags, introduced by Goodman and Roberts (1971), has the distinct advantage of a well-defined exposure time (Steinnes, 1989).

This work is the first application of the moss-bag technique in Romania. In order to optimize the assessment of atmospheric pollution in an industrial area using active biomonitoring a novel sampling design was introduced, and transplants with two different qualities of the moss *Sphagnum girgensohnii* were deployed in parallel in order to study the uptake of a series of trace elements from the air over a defined time period. The site selected for this experiment was Baia Mare, Romania (47°44' N, 23°20' E, altitude 228 m), characterized by a sub-Mediterranean climate (an exception for a such latitude) and high pollution with heavy metals from non-ferrous ores mining and metallurgy (Figure 1).

Figure 1. Sampling points and place of transplant

Nine moss transplants from each of two background areas (Dubna, Russia and Vitosha Mountain Natural Park, Bulgaria) were deployed in parallel on balconies about 24 m above street level for 4 months (Figure 2).

Figure 2. T system used for deploying moss-bags

Conventional and epithermal neutron activation analyses at IBR-2 pulsed fast reactor FLNP JINR Dubna, Russia (Frontasyeva and Pavlov, 2000), were used to determine the contents of 36 elements in moss. The analytical quality control was ensured by carrying out concurrent analyses of the standard reference materials.

A comparison of the two moss qualities used in the transplant experiment shows that the moss from Russia (RU) was a better choice than those from Bulgaria (BG) because of generally lower content of many elements of interest. Obviously the BG moss had a greater content of soil particles than RU as evident from the markedly higher levels of elements such as Al, Sc, Fe, REE, Ta, Th, and U. Moreover higher contents of V, Zn, As, Cd, and Sb in BG may indicate some exposure of the growing site from the Sofia region, which is only about 25 km away from Vitosha Mountain. Nevertheless, the individuals of moss collected in Bulgaria were drier and weaker than the moss in Russia, with a yellow-green color compared to green of_moss from Russia, indicating a worst development of the Sphagnum in Bulgaria than in Russia.

In order to study the relative uptake of the different elements relative to the initial levels in the transplanted moss an "Increment coefficient" IC_x is introduced:

$$IC_x = \frac{T_x \cdot (T_x - U_x)}{U_x \cdot |S_x|}$$

where: IC_x = increment coefficient for the element X;

T_x = concetration of element X in transplanted moss;

U_x = concetration of element X in unexposed moss

S_x = uncertainty of IC_x

The investigated elements may be grouped in three groups as follows:

1. IC_x has a significant positive value (IC_x >1), indicating a net uptake of element X relative to the initial content.
2. IC_x has a significant negative value (IC_x<0), indicating a net loss relative to the original content of X.
3. IC_x is not significantly different from 0 (0<IC_x<1).

Not surprisingly the group of elements with ICx >2 includes typical exponents of air pollution in surroundings of Pb and Zn smelters (Se, As, Sb) and elements associated to wind blown particles from dumps and ore transport by trucks. The next group (1<IC_x<2) contains elements more likely to be connected with a crustal component absorbed by the moss in the form of windblown soil dust. The group with IC_x not significantly different from 0 most probably represents elements lost from the moss at about the same rate as they are supplied from the atmosphere.

The way IC values come out for RU and BG transplants, respectively is a very strong demonstration of the necessity to start any field work with a “clean” moss.

The elements subject to major loss from the moss during the deployment period are physiologically active elements such as Cl and the alkali elements Rb and Cs, which presumably exhibit a behavior similar to that of K in the moss. These elements were lost in about the same proportion in RU and BG. A similar situation was noticed by Yurukova and Ganeva (1997) for other two *Sphagnum* species, for Ca, Mg, Na and especially K. No previous data on, Rb, and Cs in this respect were found in the literature. In the present case, the mentioned elements were most probably removed from *Sphagnum* tissues due to a combination of two factors: accumulation of heavy metals and desiccation/ hydration cycles.

When dry the *Sphagnum* moss becomes brittle and the small leaf fragments tend to fall off the stem. In this way some of the leaf biomass may be lost and the final sample subjected to analysis may have a different leaf/stem mass ratio than the original moss. It was therefore considered necessary to determine this ratio in the employed mosses for the elements in question. Samples of RU consisting of only leaf biomass were analyzed and compared to the corresponding data for whole moss. The following trends are evident:

leaf content higher than whole moss:	Mg, Al, Sc, Cr, Mn, Ni. Fe, Co, As, Se, Br, Rb, Mo, Ag, Sb, I, Ba, REE, Hf, Ta, Au, Th, U;
no significant difference:	Na, Cl, K, Ca, V, Mn, Zn, Sr, Cd, In, Cs, I, W.

The second group includes elements active in moss physiology and elements with similar chemical behaviour. These elements are mobile and presumably present in all cells in the moss. The first group on the other hand may have been supplied to the leaf surface and fixed there, and is thus transferred to the stem only to a limited extent. Since this group contains most of the elements of interest from the pollution monitoring point of view it is important that the leaf/stem ratio is not significantly changed during the transplant experiment.

In conclusion, the moss-bags using *Sphagnum girgensohnii* demonstrate a good or very good capacity of response to the environmental conditions for a majority of the 36 investigated elements. This capacity depends not only on the moss species as demonstrated in some previous studies, but also on the initial state of the transplanted moss. The higher the element concentrations are in the moss before exposure the lower are the values of the increment coefficient defined in this work. Based on differences in element content between leaves and whole moss it is clearly suggested that the moss samples used in a monitoring campaign should retain a constant leaves-to-stem ratio over the exposure period. The success of the active biomonitoring with moss-bags also depends on the instrumental method used to determine the elements. This method should be able to detect concentrations not only in exposed but also in unexposed moss with as small error as possible. NAA fully demonstrates this capacity for a great number of elements.

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NEUTRON ACTIVATION ANALYSIS FOR DEVELOPMENT OF MERCURY SORBENT BASED ON BLUE-GREEN ALGA *SPIRULINA PLATENSIS*

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INTRODUCTION

Mercury and its compounds are widely used in various branches of industry, agriculture and medicine penetrating the environment in one or another way. A considerable anthropogenic part of the environmental pollution by Hg is contributed by Hg pyrometallurgy, non-ferrous metallurgy, production of chlorine and caustic soda, consumption of fuel, garbage etc.

Mercury holds the first position for toxicity among other heavy metals. Medico-biological studies of the last decades showed the gravity of the «mercury hazard» related to the transition of chronic poisoning by Hg vapor from the professional diseases into the disease of population.

Thus, the necessity to study the peculiarities of Hg interaction with living systems is obvious. A blue-green microalgae *Spirulina platensis (S. platensis)*, which is widely used as a basis for pharmaceuticals and also as a biologically active food additive for humans and animals, is considered as a living system.

Algae are often used in water remediation from heavy metals [1–3]. The processes of accumulation and adsorption of mercury by biomass of the blue-green alga *S. platensis* depending on the Hg concentration in the medium, where the growth of spirulina cells occurs, were studied.

MATERIALS AND METHODS

Experiments:

Cultivation of *S. platensis* was carried out in a standard Zaroukh alkaline water-salt medium, mercury glycinate ($HgNCH_2COOH$) was used as a nutrient loading.

In the first series of experiments to study the Hg accumulation by the *S. platensis* cells the concentrations of nutrient medium loading by mercury constituted 100, 50, 5, 1, 0.1 μg Hg/L. Samples in all the series were taken every 24 hours.

In the second short-term series of experiments to study the Hg adsorption by *S. platensis* concentration of nutrient medium loading was 500 μg Hg/L. Dynamics of the adsorption processes, usually taking place during 1-2 hours, were studied during 1 hour. Samples were obtained in 2, 10, 20, 40 and 60 minutes after the beginning of cultivation.

Analysis:

Mercury content in the samples was determined by epithermal neutron activation analysis (ENAA) at the pulsed fast reactor IBR-2 (FLNP JINR, Dubna). Earlier we used the technique of ENA analysis of *S. platensis* samples both to determine its background elemental content and to study accumulation processes of some trace elements [4,5]. The samples were irradiated for 5 days and their activity was measured twice in 4 and 20 days. The mercury content was determined by γ-line with the energy 279.1 keV of isotope ^{203}Hg. Here the influence of interference lines ^{75}Se and ^{182}Ta was taken into consideration. The ENAA data processing and determination of Hg concentrations were performed with the help of programs used in FLNP JINR.

RESULTS AND DISCUSSION

The results of experiments to study Hg accumulation from nutrient medium by the *Spirulina platensis* biomass at cell cultivation during 6 days at various Hg concentrations are presented in Fig.1. In all the cases the exponential character of decrease of Hg content is observed. The curves are well approximated by the function $y=y_0+Ae^{-x/t}$.

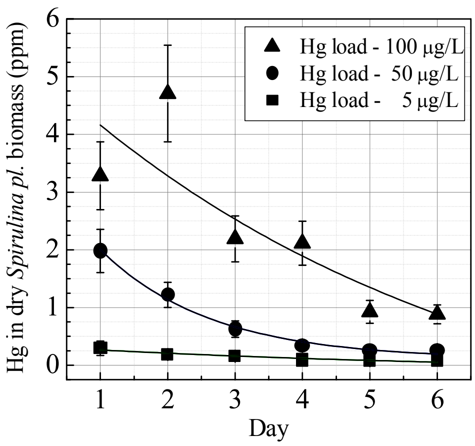

Fig. 1. Hg accumulation from nutrient medium by the *Spirulina platensis* biomass at various loading during 6 days.

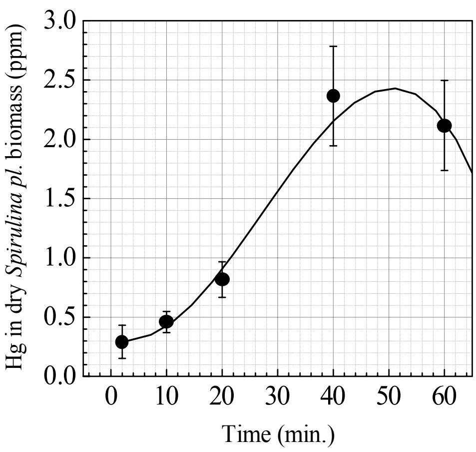

Fig.2 . Hg(II) adsorption by the *Spirulina platensis* cells.

Such character of dependence seems to be clear, as the number of *S. platensis* cells grows exponetially, the number of sites of Hg(II) ion binding surpasses considerably the number of Hg(II) ions in nutrient medium. This results in blocking of toxic Hg ions and their removal from the nutrient medium. Such mechanism may serve as one of the important ways for biosphere to «self-purify» from heavy metals with the help of microorganisms.

The results of investigation of Hg adsorption process by the *S. platensis* cells are presented in Fig. 2. The experimental data obtained by ENAA method approximate well by the polynomial of the third order: $y=0.3586-0.02286x+0.00332x^2-0.0000406482x^3$. As seen from the obtained curve, the maximum Hg content is adsorbed by the *S. platensis* biomass within 50 minutes and then a diminution of concentration is observed. Similar character of dependence of Hg(II) accumulation was also obtained in paper [6].

If we take into account that Hg content in control samples constituted approximately 0.007 ppm, than it turns out to be that in 50 minutes the *S. platensis* biomass accumulates mercury in about 300 times more. Thus, at relatively low Hg concentrations (of the order of 100 µg/L) in the medium *S. platensis* can be used in the remediation of industrial and sewage waters from mercury.

Here, it should be also noted, that the *S. platensis* biomass consisting of long trichoms can be easily gathered (separated) by filtration, which makes the technological process considerably cheaper and simpler.

CONCLUSIONS

1. By the ENAA method it is possible to control the rate of Hg assimilation from nutrient medium by the *S. platensis* biomass in the course of its cultivation in open ponds.
2. At Hg concentrations of the order of 100 μg/L the *S. platensis* biomass in its natural state may be used to accumulate Hg(II) ions for the purpose of their removal from the cultivation medium.
3. The *S. platensis* biomass is suitable for fast remediation of industrial and sewage waters from mercury by way of biosorption and subsequent separation with the help of filtration.

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6. PRIZES

JINR Prizes:

In Experimental Physics Research*:*

Second Prize:

V.LAksenov, A.M.Balagurov, V.Yu.Pomyakushin, D.V.Sheptyakov, N.A.Babushkina, O.Yu.Gorbenko. A.R.Kaul. A series of works "Magnetic and atomic structure of CMR-manganites: phase immiscibility and isotope effects"

Second Prize:

E.P.Shabalin, E.N.Kulagin, S.A.Kulikov, V.V.Melikhov, A.A.Belyakov, V.V.Golikov, A.V.Androsov, L.B.Golovanov, V.G.Ermilov, V.I.Konstantinov. A series of works "Radiation effects in materials of neutron cold moderators"

In Applied Physics Research*:*

First Prize:

M.V.Frontasyeva, S.S.Pavlov, S.F.Gundorina, E.V.Yermakova, O.A.Kulikov, T.M.Ostrovnaya, L.I.Smirnov, L.P.Strelkova, E.N.Cheremisina, V.P.Chinaeva. A series of works "Biomonitoring of atmospheric deposition of heavy metals and other elements with the help of neutron activation analysis at the IBR-2 reactor"

***FLNP Prizes*:**

In Nuclear Physics:

First Prize:

Yu.M.Gledenov, Yu.P.Popov, J.Andrzejewsi, et al. «Measurement of cross-section in the reaction $^{147}Sm(n,\alpha)$ in the energy region of neutrons 3 eV – 500 keV»

Second Prize:

A.M.Sukhovoj, V.A.Khitrov, Ts.Panteleev. «Cascade gamma-decay of ^{118}Sm»

Third Prize:

V.P.Alfimenkov, N.A.Bazhanov, Yu.N.Kopatch, Yu.D.Mareev, L.Lason, V.V.Novitsky, L.B.Pikelner, T.L.Pikelner, A.B.Popov, W.I.Furman, A.N.Chernikov, M.I.Tsulaya et al.

«Measurements and analysis of P-even and P-odd angular correlations of fragments at ^{239}Pu fission by resonance neutrons»

In Condensed Matter Physics:

First Prize:

M.V.Avdeev, V.L.Aksenov, M.Balasoiu. «Investigation of ferrofluids by small-angle neutron scattering (5 articles)»

In Applied and Methodical Physics:

Encouraging Prize:

N.V.Astakhova, A.I.Beskrovnyi, A.A.Bogdzel, P.E.Butorin, S.G.Vasilovsky, N.A.Gundorin, V.B.Zlokazov, S.A.Kutuzov, I.M.Salamatin, V.N.Shvetsov. «Development of a new method to create systems of automation of experiments, as well as development and introduction of programs and methods of local and remote control of experiments»

The JINR young scientists contest and nuclear physics with neutrons:

In Condensed Matter Physics:
First Prize:
D.P.Kozlenko. «Pressure induced magnetic phase transitions in manganites».

I.M.Frank Stipend:

In Nuclear Physics:
Zh.V.Mezentseva

In Condensed Matter Physics:
M.V.Avdeev

In Methodical Investigations:
S.A.Kulikov

7. SEMINARS

Date	Authors	Title
6.02.03	D.Fursaev (BLTP JINR)	Introduction into the physics of black holes
6.03.03	L.I.Ponomarev (RRC KI)	Transmutation of minor actinides in accelerating-blanket systems
20.03.03	L.B.Pikelner E.P.Shabalin (FLNP JINR)	First years of FLNP History of development of the pulsed neutron sources in FLNP
26.06.03	Yu.A.Kamyshkov (Tennesy Univ., USA)	Neutron-antineutron transition (current state of problem and the possibilities of experiment)
31.07.03	M.Klein (TU, Heidelberg, Germany)	Neutron detector CASCADE: position-sensitive gas detector with a GEM-based solid-state converter working at counting rates ~MHz/ piccell
13.10.03	V.M.Maslov (JIENR, Minsk)	Fission cross-sections of actinides by neutrons with the energy 100 keV-200 MeV
12.11.03		Review of the film about I.M.Frank
4.12.03	E.P.Shabalin (FLNP JINR)	Cold neutron moderator: problems and solutions (review of the works made in JINR)

INTERNATIONAL SEMINAR dedicated to 95-th anniversary of I.M.Frank

October 23-24, 2003
Dubna, Russia

Organizing Committee

V.G.Kadyshevsky – Chairman
A.V.Belushkin – Vice-Chairman
V.A.Khitrov – Scientific Secretary
S.V.Kozenkov - Member
V.N.Shvetsov- Member

Program Committee

O.N.Krokhin – Chairman
V.L.Aksenov
A.I.Frank
W.I.Furman
V.I.Lushchikov
L.B.Pikelner
E.P.Shabalin

Local contact

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Fax: +7-09621-65085
E-mail: khitrov@nf.jinr.ru

PROGRAM of international seminar dedicated to 95-th anniversary of I.M.Frank

23 October 2003

11:00 – Opening ceremony (Academician V.G.Kadyshevsky, Academician O.N.Krokhin)
11:20 – 13:00 Participants' presentations devoted to I.M.Frank's scientific activity and life
13:00 – 15:00 Lunch
15:00 – 16:30 Participants' presentations devoted to I.M.Frank's scientific activity and life
16:30 – 17:00 Coffee break
17:00 – 18:30 Participants' presentations devoted to I.M.Frank's scientific activity and life
19:00 – Reception

24 October 2003

9:30 – 11:00 Excursion to FLNP
11:00 – Coffee break
12:00 – Trip to Moscow for laying flowers on the tomb of I.M.Frank

Please, confirm your participation not later than 10 September

I.M.FRANK

The 95th anniversary

Dates of life and activity of I. M. Frank

23.10.1908 – 22.06.1990

1930 – graduated from M.V.Lomonosov Moscow State University (MSU)

1930-1934 – State Optics University (Leningrad)

1934-1970 – Physics Institute of the USSR Academy of Sciences

1935 – Doctor of Sciences (Phys. and Math.)

1936-1937 – I.M.Frank and I.Ye.Tamm gave a theoretical explanation for the Vavilov-Cherenkov radiation

Since **1940** – lectured and conducted research in MSU, **1944** – Professor of MSU

1946-1956 – head of the Laboratory of Radioactive Radiation of the Research Institute of Nuclear Physics at MSU

1946 – Corresponding Member of the USSR Academy of Sciences

1946 – laureate of the State Prize

1953 – laureate of the State Prize

1958 – laureate of the Nobel Prize in physics

1968 – Academician of the USSR Academy of Sciences

1946-1970 – founded and directed the Laboratory of Atomic Nucleus at the Physics Institute of the USSR Academy of Sciences

1957-1988 – organized and headed the Laboratory of Neutron Physics at JINR

1971 – laureate of the State Prize

1990 – emeritus director of the Laboratory of Neutron Physics

Prominent scientist, laureate of the Nobel and State Prizes, Academician I.M.Frank made important contributions to the formation and development of various directions in physics in our country.

In honor of his outstanding achievements, the Laboratory of Neutron Physics was named after I.M.Frank.

The name of I.M.Frank is primarily associated with a new direction in physics – electrodynamics of a moving charged relativistic particle. In 1937 S.I.Vavilov, I.M.Frank's guru, who characterized him as an extremely versatile physicist-experimenter with remarkable theoretical erudition, involved him in the research of the luminescence of liquids (discovered by P.A.Cherenkov) irradiated with radium gamma rays. I.Ye.Tamm and I.M.Frank theoretically explained the observed phenomenon. In 1958 I.Ye.Tamm, I.M.Frank and P.A.Cherenkov were awarded the Nobel Prize in physics as a token of recognition of the great importance of the experimental and theoretical work done. This work became part of the gold fund of world science. I.M.Frank took part in fundamental investigations of electrodynamics of moving sources in refracting media. I.M.Frank together with V.L.Ginzburg opened a new important direction in modern physics connected with transitional radiation. All his life I.M.Frank preserved interest in the research of effect of optical properties of media on radiation of a moving source.

One more field of science, to which I.M.Frank made a fundamental contribution, was nuclear and especially neutron physics. The thirties and forties

were years of rapid development of nuclear physics. In 1933 S.I.Vavilov suggested I.M.Frank start research in this area. In 1946 I.M.Frank organized the Laboratory of Atomic Nucleus in the Physics Institute of the USSR Academy of Sciences, where together with his colleagues he carried out a number of important investigations in the fields of nuclear and neutron physics. Precision measurements of parameters of uranium-graphite lattices were performed, a new pulsed method for studying thermal neutron diffusion was suggested and the phenomenon of diffusion cooling was discovered, reactions on light nuclei with neutron emission, as well as the interaction of fast neutrons with nuclei and fission processes were investigated. I.M.Frank also initiated studies of fission processes induced by mesons and high-energy particles. Investigations in reactor physics were conducted in close contact with I.V.Kurchatov. Most of these works were carried out under a special government project. In 1946 I.M.Frank also participated in the creation of the first Soviet uranium-graphite reactor. Later I.M.Frank noted that his specialization in the field of neutron physics began from investigations in reactor physics. It was under his leadership that in Dubna at the Joint Institute for Nuclear Research the pulsed reactors of periodic operation – IBR, IBR-30 with injector and IBR-2 – were constructed. This allowed the scientists of the Laboratory of Neutron Physics to obtain a number of new results in the investigations in nuclear and condensed matter physics. Of special note is the role of I.M.Frank in the creation of scientific traditions of the Laboratory, which is now one of the leading neutron centers in the world.

8.1. STRUCTURE OF LABORATORY AND SCIENTIFIC DEPARTMENTS

<u>**Directorate:**</u>
Director:
A.V.Belushkin
Deputy Directors:
N.Popa
V.N.Shvetsov
Scientific Secretary:
V.A.Khitrov

<u>**Reactor and Technical Departments**</u>
Chief engineer: V.D.Ananiev
IBR-2 reactor
Chief engineer: A.V.Vinogradov
Department of IREN
Head: V.G.Pyataev
IBR-30 booster + LUE-40 Group
Head: S.A.Kvasnikov
Mechanical maintenance division
Head: A.A.Belyakov
Electrical engineering department
Head: V.P.Popov
Design bureau
Head: A.A.Kustov
Experimental workshops
Head: A.N.Kuznetsov

<u>**Scientific Departments and Sectors**</u>
Condensed matter department
Head: V.L.Aksenov
Nuclear physics department
Head: Yu.N.Kopatch
Department of IBR-2 spectrometers complex
Head: A.V.Belushkin
Nuclear Safety and applied research sector
Head: E.P.Shabalin

<u>**Administrative Services**</u>
Deputy Director: S.V.Kozenkov
Secretariat
Finances
Personnel

<u>**Scientific Secretary Group**</u>
Translation
Graphics
Photography
Artwork

CONDENSED MATTER DEPARTMENT

Sub-Division	Title	Head
Diffraction sector. Head: A.M.Balagurov		
Group No.1	HRFD	V.Yu.Pomjakushin
Group No.2	DN-2	A.I.Beskrovnyi
Group No.3	DN-12	B.N.Savenko
Group No.4	NSVR	A.N.Nikitin
Group No.5	SKAT	Ch.Scheffzük
Small-angle neutron scattering group. Head: V.I.Gordeliy		
Neutron optics sector. Head: V.L.Aksenov		
Group No.1	REMUR	Yu.V.Nikitenko
Group No.2	REFLEX	V.I.Bodnarchuk
Inelastic scattering group. Head: I.Natkaniec		
Biophysics investigations group. Head: I.N.Serdyuk		

NUCLEAR PHYSICS DEPARTMENT

Sub-Division	Title	Head
Sector 1. Correlation γ-spectroscopy and development of experimental installations. Head: N.A.Gundorin		
Sector 2. Polarized neutrons and nuclei. Head: Yu.D.Mareev		
Group No.1	Polarized nuclear targets	Yu.D.Mareev
Group No.2	Thermal polarized neutrons	M.I.Tsulaya
Sector 3. Neutron activation analysis. Head: M.V.Frontasyeva		
Group No.1	Analytical	M.V.Frontasyeva
Group No.2	Experimental	S.S.Pavlov
Group No.2	**Neutron spectroscopy**	**Yu.N.Kopatch**
Group No.3	**Nuclear fission**	**Sh.S.Zeinalov**
Group No.5	**Proton and α-decay**	**Yu.M.Gledenov**
Group No.6	**Properties of γ-quanta**	**A.M.Sukhovoy**
Group No.7	**Neutron structure**	**V.G.Nikolenko**
Group No.8	**Ultra-cold neutrons**	**A.V.Strelkov**
Group No.9	**Neutron optics**	**A.I.Frank**
Group No.11	**Theory**	**V.K.Ignatovich**
Group No.12	**Electrostatic generator-5**	**I.A.Chepurchenko**

DEPARTMENT OF IBR-2 SPECTROMETERS COMPLEX

Sub-Division	Title	Head
Group	Detectors	E.S.Kuzmin
Sector No.1	**Electronics**	**V.I.Prikhodko**
Group No.1	Analogous electronics	A.A.Bogdzel
Group No.2	Digital electronics	V.F.Levchanovsky
Group No.3	Software	A.S.Kirilov
Group No.4	Local networks	G.A.Sukhomlinov
Group No.5	Technology	A.B.Melnichuk
Sector No.2	**Spectrometers**	**A.P.Sirotin**
Group No.1	Development	G.A.Varenik
Group No.2	Samples environment	A.P.Sirotin

8.2. USER POLICY

To accomplish the experimental program the IBR-2 reactor operated in the year 2003 only 2 cycles (681 hrs.) in the intervals 13-24 January and 10-28 February. After that the reactor was stopped for the replacement of the movable reflector and installation of cold moderators.

All experimental facilities of IBR-2 were open to the general scientific community. Most of experiments were performed on the application basis. Commissions formed from independent experts selected the applications. Four expert's commissions were organized as follows:

1. Diffraction, *Chairman* - V.A.Somenkov – Russia,
2. Inelastic scattering, *Chairman* - W.Nawrocik – Poland,
3. Neutron optics, *Chairman* - A.I.Okorokov – Russia, and
4. Small angle scattering, *Chairman* - L.Cser – Hungary.

The schedule of experiments at the IBR-2 beams was done by the Head of the Condensed Matter Department together with instruments scientists on the basis of expert's recommendations and was approved by the FLNP Director or Deputy Director for condensed matter physics.

The experience accumulated in the last year concerning the user policy has revealed the necessity to make some significant modifications in order to make this policy more functional. The new user's program will be posted on the laboratory web site not later than the middle of February 2004.

8.3. MEETINGS AND CONFERENCES

In 2003, FLNP organized the following meetings:

1.	XI International Seminar on Interaction of Neutrons with Nuclei (ISINN-10)	May 28-31	Dubna
2.	XII International Conference on Selected Problems of Modern Physics (organized together with BLTP)	June 8-11	Dubna
3.	International Seminar Dedicated to 95-th Anniversary of I.M.Frank	October 23-24	Dubna

In 2004, FLNP will organize the following meetings:

1.	XII International Seminar on Interaction of Neutrons with Nuclei (ISINN-11)	May 26-29	Dubna
2.	III German-Russian Meeting "Condensed Matter Physics with Neutrons"	June 12-16	Dubna

8.4. COOPERATION

List of Visitors from Non-Member States of JINR in 2003

Name	Organization	Country	Dates
V.Lauter	ILL, Grenoble	France	13.01-24.01
H.-J.Lauter	ILL, Grenoble	France	13.01-24.01
K.Bramnik	TU, Darnstadt	Germany	15.01-21.01
A.Skomorokhov	TU, Darmstadt	Germany	17.01-24.01
Yu.N.Grin'	ICFT, Dresden	Germany	18.02-19.02
E.A.Kravtsov	Univ., Bohum	Germany	19.02-01.03
A.I.Ioffe	FZ Juelich	Germany	24.02-27.02
V.Lauter	ILL, Grenoble	France	27.03-06.04
H.-J.Lauter	ILL, Grenoble	France	27.03-06.04
B.Smodis	IAEA, Vienna	Austria	06.04-10.04
V.Gavrilov	IPE, Riga	Latvia	07.05-15.05
E.Raitman	IPE, Riga	Latvia	07.05-15.05
G.Karr	ENSTA, Paris	France	12.05-12.07
K.Walther	GeoFRZ, Potsdam	Germany	19.05-12.06
A.Frischbutter	GeoFRZ, Potsdam	Germany	26.05-12.06
J.R.Granada	Centro Atomico Bariloche	Argentina	04.06-15.06
M.Koshkun	Istanbul Univ.	Turkey	05.06-22.08
H.-J.Lauter	ILL, Grenoble	France	04.06-12.06
V.Lauter	ILL, Grenoble	France	06.06-12.06
M.-T.Rekveldt	TU, Delft	The Netherlands	07.06-15.06
M.-H.Kern	Kiel Univ.	Germany	16.06-19.06
M.Rudalics	RISC, JK Univ., Linz	Austria	20.07-31.08
H.-J.Sass	FZ Juelich	Germany	21.07-23.07
V.Lauter	ILL, Grenoble	France	21.07-27.07
H.-J.Lauter	ILL, Grenoble	France	21.07-27.07
M.-O.Klein	Univ. Heidelberg	Germany	27.07-01.08
G.Pepy	LLB, Saclay	France	19.10-29.10
V.Nesvizhevsky	ILL, Grenoble	France	28.10-30.10
K.Walther	GeoFRZ, Potsdam	Germany	03.11-14.11
A.Frischbutter	GeoFRZ, Potsdam	Germany	03.11-14.11
H.Tiele	GeoFRZ, Potsdam	Germany	03.11-14.11
J.Wummel	GeoFRZ, Potsdam	Germany	03.11-14.11
E.Steinnes	Univ., Tondheim	Norway	08.11-16.11
P.Geltenbort	ILL, Grenoble	France	12.11-14.11
D.G.Kartashov	INFN, Pisa	Italy	13.11-20.11
V.Gavrilov	IPE, Riga	Latvia	15.11-16.11
E.Raitman	IPE, Riga	Latvia	15.11-16.11
R.Matties		Germany	17.11-21.11
V.Lauter	ILL, Grenoble	France	12.12-17.12

8.5. EDUCATION

The objective of the FLNP educational program is the training of specialists in the field of neutron methods for condensed matter and nuclear physics research. The students of neutron diffraction division of MSU and the students of the MSU Interfaculty Center «Structure of Matter and New Materials» carry out their diploma work in FLNP. In the Center the students from the Chemical Faculty of MSU, Higher College of Materials Sciences under MSU, Tula State University, Tver State University and other universities of Russia and JINR member-states do the course.

8.6. PERSONNEL

Distribution of the Personnel per Department as of 01.01.2004

Theme	Departments	Main staff
-0974-	Nuclear Physics Department	61
-1031-	Condensed Matter Physics Department	41
-1012-	IBR-2 Spectrometers Complex Department	46
-0993-	IREN Department	14
-1007-	Nuclear Safety Sector	15
-0851-	IBR-2 Department	46
	Mechanical and Technical Department	50
	Electric and Technical Department	32
	Central Experimental Workshops	38
	Design Bureau	8
	FLNP infrastructure:	
	Directorate	9
	Services and Management Department	22
	Scientific Secretary Group	5
	Supplies Group	4
Total		**391**

Personnel of the Directorate as of 01.01.2004

Country	People
Armenia	2
Bulgaria	1
Germany	2
Georgia	2
Kazakhstan	1
KPDR	5
Poland	3
Romania	6
Russia	21
Ukraine	2
TOTAL	**45**

8.7. FINANCE

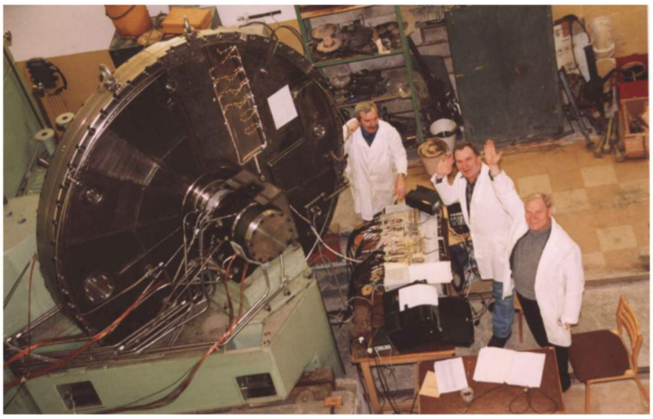
Financing of the FLNP Scientific Research Plan in 2003 (th. USD)

No.	Theme	Financing plan, $ th.	Expenditures for 12 months, $ th.	In % of FLNP budget
I	**Condensed matter physics**	**4002.9**	**2817.6**	**70.4**
	-1031-	2355.3	1482.7	63.0
	-0851-	914.7	960.9	105.0
	-1012-	732.9	374.0	51.0
II	**Neutron nuclear physics**	**1054.7**	**944.1**	**89.5**
	-1036-	653.0	620.2	95.0
	-0993-	401.7	323.9	80.6
III	**Elementary particle physics** -1007-	**6.0**	**5.3**	**88.3**
IV	**Relativistic nuclear physics** -1008-	**40.4**	**10.5**	**26.0**
V	**TOTAL:**	**5104.0**	**3777.5**	**74.0**

Modernization of the IBR-2 reactor

Assembling of a new movable reflector
for the IBR-2 reactor on the test-bench

Testing of MR-3 on the test-bench



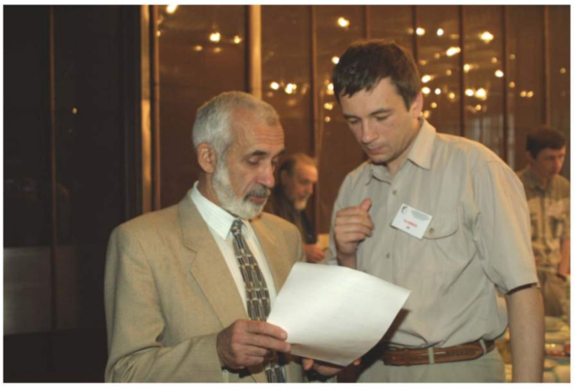
New movable reflector MR-3 in the jacket

XI International Seminar on Interaction of Neutrons with Nuclei

Opening of the Seminar. FLNP Director A.V. Belushkin

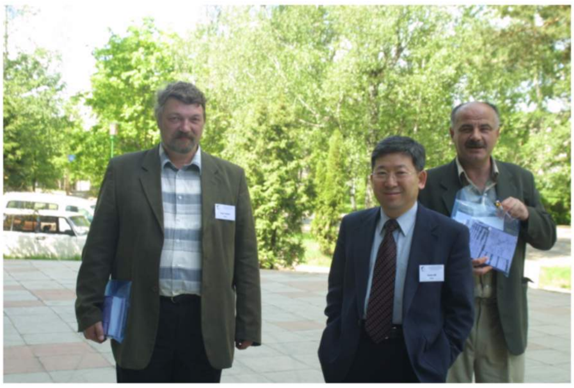
A. Laptev and P. Cennini

N. Yaneva, L.B. Pikelner, Ts. Panteleev



W.I. Furman and Yu.N. Kopatch

Yu.I. Chernukhin, V.A. Teriokhin, A.V. Strelkov



S.G. Yavshits, G. Kim, O.T. Grudzevitch

International Seminar dedicated to 95-th anniversary of I.M. Frank
October, 23-24, 2003

Opening of the Seminar

A.I. Frank. Report “History of one family”

I.M. Frank's relatives in his room

General photo of the Seminar's participants

V.M. Bolotovsky, Yu.N. Vavilov, L.B. Pikelner, A.V. Belushkin