PREFACE

We would like to offer the readers the scientific activity report of the Frank Laboratory of Neutron Physics for 2013. The first part of the report presents a brief review of the experimental and theoretical results achieved in the main scientific directions – condensed matter physics, neutron nuclear physics, applied research and development and creation of elements of neutron spectrometers for condensed matter investigations. The second part includes the reports on the operation of the modernized IBR-2 pulsed reactor, the development of the IREN neutron source and researches carried out on EG-5 facility. A list of publications for 2013, the information regarding the seminars and conferences organized in FLNP and a statistical view on the FLNP personnel structure are presented as well.

In 2013 the main achievements of the Laboratory were resumption of the user program at the modernized IBR-2 spectrometers as well as development of the IREN facility. In 2013 the IBR-2 reactor operated for physical experiments for 2578 hours and the IREN facility about 1050 hours.

In 2013 the Laboratory celebrated the 105th anniversary of I.M. Frank, the founder and first director of FLNP.

FLNP has cooperation agreements in the field of neutron investigations with almost 200 scientific institutes and universities from 39 countries from all over the world. A significant contribution to this cooperation is made by the JINR Member States.

The FLNP staff consists of more than 450 employees. The scientific staff includes 79 Ph.D. and 17 D.Sci. researchers and 70 researchers and specialists from the JINR Member States (besides the Russian Federation) with more than two thirds of them under 35 years of age.

The organization of annual conferences and schools covering all FLNP research fields helps to recruit young specialists — one of the top priority tasks of the FLNP Directorate.

All these facts confirm that the Laboratory continues to develop successfully and dynamically, carrying out investigations in the interests of the JINR Member States.

V.N. Shvetsov

Director

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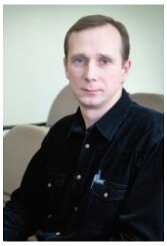

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1. SCIENTIFIC RESEARCH

1.1. CONDENSED MATTER PHYSICS

The main objectives of research in the framework of the theme involved the application of neutron scattering techniques and complementary methods to investigate the structure, dynamics and microscopic properties of nanosystems and novel materials, which are of great importance for the development of nanotechnologies in the fields of electronics, pharmacology, medicine, chemistry, modern condensed matter physics and interdisciplinary sciences.

The greater part of experimental research was carried out on spectrometers of the modernized IBR-2 reactor in accordance with the *Topical Plan* for *JINR* Research and International Cooperation and FLNP User Program. A number of scientific experiments were performed in neutron and synchrotron centers in Russia and abroad under the existing cooperation agreements and accepted beam time application proposals. Also, the activities on the modernization of the available spectrometers and the development of new instruments were carried out in accordance with the development program plan for the IBR-2 spectrometers. Most attention was given to the realization of the top-priority projects (construction of a new DN-6 diffractometer for studying microsamples and a multipurpose GRAINS reflectometer).

Within the framework of investigations under the theme the employees of the FLNP Department of Neutron Investigations of Condensed Matter (NICM) maintained broad cooperation with many scientific organizations in Russia and abroad. The cooperation, as a rule, was documented by joint protocols or agreements. In Russia, especially active collaboration was with the thematically-close organizations, such as RRC KI, PNPI, SSC RF IPPE, MSU, IMP UB RAS, IC RAS, INR RAS and others.

A list of the main scientific topics studied by the employees of the NICM Department includes:

- Investigation of structure and properties of novel crystal materials and nanosystems by neutron diffraction;
- Investigation of magnetic colloidal systems in bulk and at interfaces;
- Investigation of structure of carbon nanomaterials;
- Magnetism of layer nanostructures;
- Investigation of nano-scale structure and functional characteristics of biological, colloidal and polymeric nanodispersed materials;
- Investigation of nanostructure and properties of lipid membranes and lipid complexes;
- Investigation of atomic dynamics of nanosystems and materials by neutron inelastic scattering;
- Investigation of texture and properties of minerals and rocks;
- Analysis of internal stresses in bulky materials and factory-made goods.

1.1.1. Scientific results

1.1.1.1. Structure investigations of novel oxide, intermetallic and nanostructured materials

The crystal and magnetic structure of multiferroic $RbFe(MoO_4)_2$ has been studied by means of neutron and x-ray diffraction, as well as magnetic susceptibility measurements at pressures up to 10 GPa in a temperature range from 1.5 to 300 K [1] (**Fig. 1**). In this compound a spontaneous electric polarization occurs due to the fact that the inversion symmetry of the crystal structure is broken because of the occurrence of noncollinear antiferromagnetic ordering. In addition, Fe magnetic moments in the trigonal structure of $RbFe(MoO_4)_2$ (space group P-3m1) form a two-dimensional magnetic triangular lattice, where magnetic coupling between the magnetic planes is 25 times weaker than the in-plane coupling. With increasing pressure a structural phase transition to the monoclinic *C*2/*c* phase with a phase coexistence in a wide pressure range (residual fraction of the trigonal phase was present up to 10 GPa) was observed. The antiferromagnetic (AFM) symmetry for the trigonal phase is characterized by a propagation vector q = (1/3, 0, k_z). With a rise in pressure an increase in the k_z value from 0.45 to 0.48 and in the Néel temperature with a pressure coefficient of 0.09 GPa^{-1} was observed. No evidence of the formation of the magnetic ordering in the high-pressure monoclinic phase was found down to the temperature of 1.5 K.

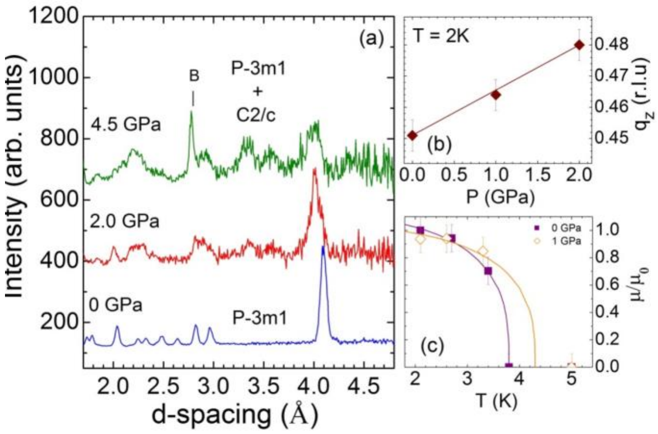


Fig. 1. Neutron diffraction patterns (DN-12 diffractometer, IBR-2) illustrating a structural phase transition in $RbFe(MoO_4)_2$ at high pressures (a). The sign "B" marks a peak from the anvils of a high-pressure cell. Pressure dependence of the k_z component of the propagation vector of the AFM structure (corresponding to the trigonal phase of $RbFe(MoO_4)_2$) determined at T = 2 K (b). Temperature dependences of the ordered Fe magnetic moment for the trigonal phase at various pressures, which are normalized to the value obtained at T = 2 K (c).

The studies of structural and magnetic phase transitions in $CuFe_2O_4$ copper ferrite have continued [2], **Fig. 2**. Additional neutron diffraction experiments have been carried out on a high-resolution powder diffractometer HRPT (SINQ, PSI, Switzerland). Copper ferrite crystallizes into a classical spinel structure and may exist in two symmetry modifications, cubic (sp. gr. *Fd*3*m*) at $T >$ 700 K and tetragonal (sp. gr. *I*41/*amd*) below this temperature. The character of temperature changes in the interatomic spacing indicates that the structural transition is based on the Jahn–Teller distortion of CuO_6 octahedra rather than the mutual migration of copper and iron atoms. It has been established that cubic-to-tetragonal phase transitions are characterized by the equilibrium coexistence of both structural phases in a rather wide temperature range (~40°C). The characteristic sizes of the domains of coexisting phases are large (~1000 Å, mesoscopic phase separation). One of the reasons for stabilization of this phase is long-range internal stresses inside the crystallites, which develop during the structural phase transition and are reflected in a significant anisotropic broadening of diffraction peaks. The temperature of the formation of the ferromagnetic order is much higher (by ~50 K) than the temperature of the structural transition. This is an indication of a weak interaction between lattice (orbital) and magnetic (spin) subsystems. Lack of the relationship between structural and magnetic transitions in $CuFe_2O_4$ is one of the major differences of this spinel from normal spinels with magnetic cations only in B-sites, in which due to the formation of a "pyrochlore lattice" by magnetic atoms the long-range magnetic order is formed only because of the weakening of frustrations in the structural phase transition.

On the HRFD diffractometer the investigations of electrodes in lithium-ion accumulators [3] have continued. In-situ neutron diffraction experiments have been carried out to study charging-discharging processes of commercial lithium accumulators with $LiFePO_4$ (LFP) and graphite electrodes in real time. The experimental data have made it possible to follow more closely the stages of Li intercalation into graphite with the successive formation of several LiC_n phases and a reversible transition $LiFePO_4 \leftrightarrow FePO_4$. The comparison of charging/discharging processes in batteries with a cathode of pure LFP and LFP containing ~ 1% vanadium (LFPV) has demonstrated that in the latter case significantly greater fraction of the anode material undergoes a transition into a final LiC_6 phase because of a smaller relative mass of graphite as compared to fluorine ferrophosphate. The analysis of changes in the microstructure of a vanadium-doped cathode has shown a significant increase in the degree of structure imperfection, which correlates with the best electrochemical properties of LFPV as compared to LFP.

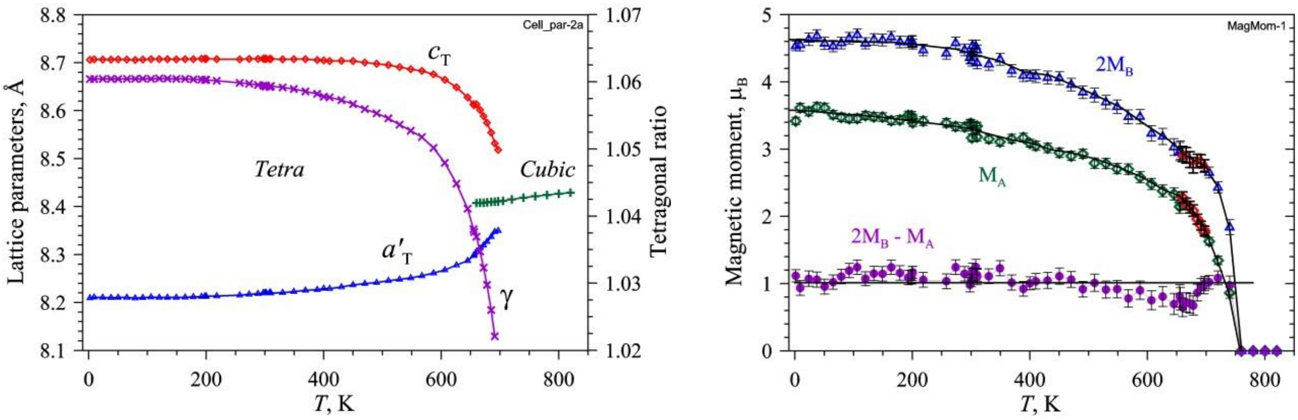


Fig. 2. Left: Temperature dependences of the unit-cell parameters of the cubic and tetragonal phase (left scale) and the tetragonal ratio (γ, right scale). The parameter $a'_T = \sqrt{2} \cdot a_T$ in the tetragonal phase is shown for the sake of visual convenience. Some temperature points were measured twice. The statistical errors are smaller than the symbol sizes. Right: Temperature dependences (data were obtained on heating) of the ordered magnetic moment in octahedral (doubled value, $2M_B$) and tetrahedral (M_A) sites and their difference ($2M_B$ - M_A). The statistical errors are given. The lines through $2M_B$ and M_A points are drawn for visual convenience. The line drawn through their difference is an average (1.01 μ_B) of all points in the range from 1.5 to 750 K.

On the DN-12 diffractometer the crystal and magnetic structure of intermetallic cobalt compounds RCo_2 (R = Tb, Ho) has been studied in a pressure range of up to 5 GPa [4], **Fig. 3**. In these compounds, unusual physical phenomena have been found, among which is a transition from nonmagnetic to a magnetically ordered state of the cobalt sublattice under changes of ionic radius and magnetic moment of R-cation. It has been established that in $TbCo_2$ under pressure there is a sharp linear decrease in the Curie temperature with a pressure coefficient of –9 K/GPa and in the ordered magnetic moment with a coefficient of –0.1 μ_B/GPa.

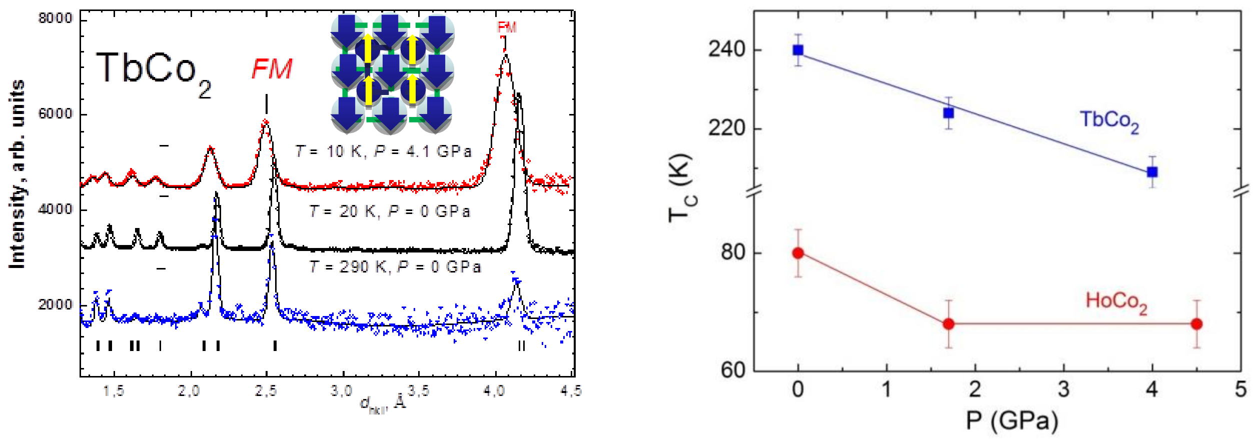


Fig. 3. Left: Neutron diffraction spectra of $TbCo_2$ obtained at various pressures and temperatures on the DN-12 diffractometer. The "FM" signs indicate peaks with the largest magnetic contribution from the ferrimagnetic ordering of Tb and Co sublattices. Right: Pressure dependences of the Curie temperature in $TbCo_2$ and $HoCo_2$.

At the same time the Tb ordered magnetic moment does not vary with pressure. In $HoCo_2$ the change in the Curie temperature has a nonlinear character; in the range of 0-1.7 GPa its decrease is characterized by a pressure coefficient of –6 K/GPa, at higher pressures it weakly depends on pressure. The ordered magnetic moment in this compound decreases under pressure with approximately the same coefficient as in $TbCo_2$ (–0.1 μ_B/GPa).

On the DN-6 diffractometer the crystal structure of a double perovskite antiferroelectric Pb_2MgWO_6 has been studied under high pressures up to 5.4 GPa and at room temperature (**Fig. 4**). A structural phase transition from an orthorhombic antiferroelectric phase with *Pnma* symmetry to a cubic paraelectric phase with *Fm-3m* symmetry has been observed at $P \sim 1$ GPa. Structural parameters of both phases and their pressure dependences have been determined.

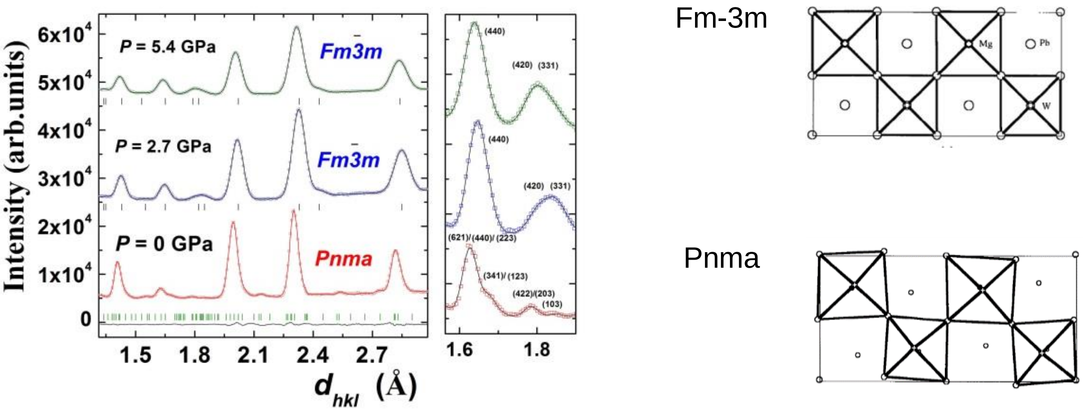


Fig. 4. Left: Neutron diffraction spectra of Pb_2MgWO_6 obtained at different pressures. Right: Schematic representation of the crystal structure of the orthorhombic antiferroelectric phase with *Pnma* symmetry and cubic paraelectric phase with *Fm-3m* symmetry.

The investigations of structural features and luminescent properties of crystal phosphors based on lutetium aluminum garnets $Lu_3Al_5O_{12}:Ce^{3+}$ doped with Lu_2O_3 nanoparticles have continued. It has been found that in the process of heat treatment no new structural phases are formed in this system, however the formation of a stable defect region occurs at the phase interface between LuAG:Ce and Lu_2O_3, which is evidenced by a change in all structural characteristics of LuAG:Ce after doping with lutetium oxide.

1.1.1.2. Investigation of magnetic fluids and nanoparticles

The experimental aspects of the observation of particle interaction effects in polydisperse magnetic fluids by means of small-angle neutron and X-ray scattering have been considered [5]. Various interaction regimes predicted by the theory of dipolar fluids with respect to the analysis of the scattering structure-factor under different conditions (with and without external magnetic fields) have been studied. It has been found that for adequate verification of the theory the corresponding experimental studies should be focused on a detailed analysis of the low-coupling regime (low dipole interaction constant, high particle concentration) in the case of magnetic fluids with hard and soft stabilizing shells. From this viewpoint the comparison of the experimental scattering data for magnetic fluids stabilized with various methods has shown that classical magnetic fluids based on non-polar organic solvents with magnetite nanoparticles (characteristic size 8 - 10 nm) stabilized by oleic acid are the most informative systems. The chain-formation regime (high dipole interaction constant, low particle concentration) has been discussed as well. Its analysis by small-angle scattering is significantly easier than the low-coupling regime. Actually, any magnetic fluid in this regime can be represented as a two-phase solution comprising non-interacting aggregates and separate particles. However, this regime seems to be difficult to realize in practice because of the accompanying non-equilibrium aggregation of strongly interacting magnetic nanoparticles during the preparation of magnetic fluids. Additionally, magnetic correlations of a specific type have been experimentally found in polydisperse magnetic fluids. They correspond to a rather strong effective repulsion in concentrated systems (volume fraction of magnetic material ~ 10 %) and, in contrast to the correlations in particle locations, also take place in diluted solutions (volume fraction of magnetic material ~ 1 %).

A detailed study of aqueous solutions of magnetoferritin (artificial biological complex based on apoferritin with various content of magnetic materials in the protein cavity) which are of current interest from a biomedical viewpoint has continued. Using the data of small-angle scattering of synchrotron radiation and neutrons (including the contrast variation) it has been found that even for relatively low loading factors of magnetic material (magnetite with 100-200 atoms of iron per apoferritin molecule) a partial destruction of the protein shell takes place (**Fig. 5**). It has been shown that this effect is stronger for higher loading factors. Additionally some aggregation of the complexes has been observed for high (> 500) loading factors.

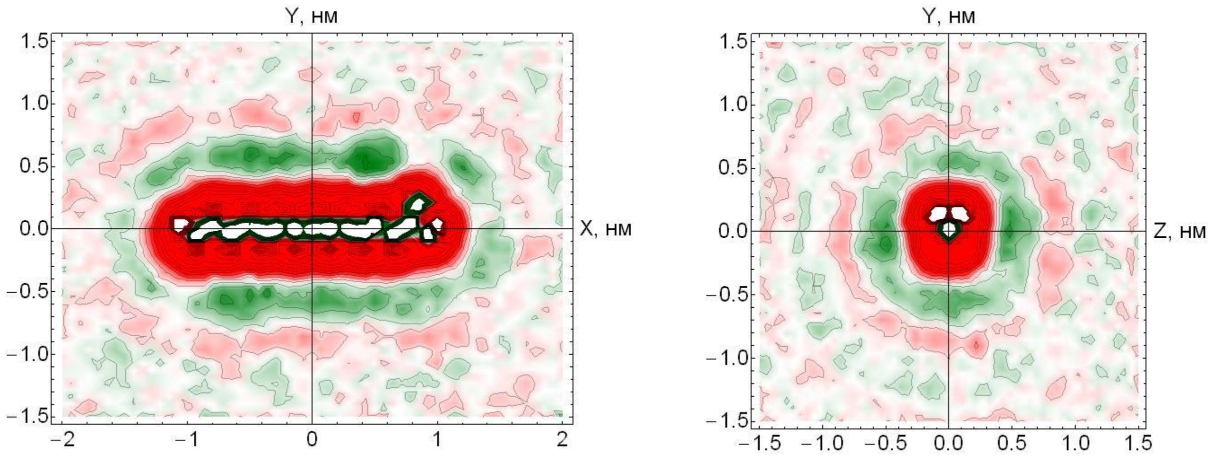
(a) *(b)* *(c)*

Fig. 5. Results of modelling based on experimental data of small-angle scattering from apoferritin (a); protein component in magnetoferritin with the loading factor LF = 156 (*b*) and comparison with the crystallographic data of apoferritin (*c*).

Small-angle neutron scattering has been applied along with the molecular dynamic simulations to study the interaction between solvents and saturated mono-carboxylic acids used in the stabilization of magnetic nanoparticles in ferrofluids based on non-polar organic solvents [6]. The scattering length density (SLD) distributions around acid molecules have been obtained with the help of molecular dynamics. The found modulation of these distributions depending on the acid length is consistent with the data of small-angle scattering from low-concentrated solutions on deuterated solvents. In particular, the use of the calculated SLD distributions makes it possible to describe fully the experimental scattering curves including residual incoherent background (**Fig. 6**).

The analysis of the neutron reflectometry data for the interface between a magnetic fluid (magnetite/sodium oleate/D_2O) and silicon has been performed. A strong contribution of the background diffuse scattering caused mainly by small-angle scattering from nanoparticles in the magnetic fluid adsorbed on the silicon surface has been observed. Several ways to take the background into account during the extraction of the specular reflection curve from experimental data have been studied [7]. From the comparison of the structural features of the magnetic fluid at the interface and in the bulk (small-angle scattering data) it has been concluded that separate particles are preferentially adsorbed on the silicon surface compared to their aggregates.

The behavior of polyethylene glycol (polymer introduced into the structure of aqueous magnetic fluids for increasing their biocompatibility) of low molecular mass (M_w = 400, 1000) in heavy water has been investigated using small-angle neutron scattering [8]. It has been shown that in concentrated solutions the polymeric molecules are partially associated into aggregates with the size of above 30 nm. The scattering from low concentrated solutions (< 3%) is indicative of the "Gaussian coil" conformation of the polymer; the corresponding form-factor (calculated by the Debye formula) has been used in the analysis of the scattering from concentrated solutions, which is well described by the model of "interacting Gaussian coils".



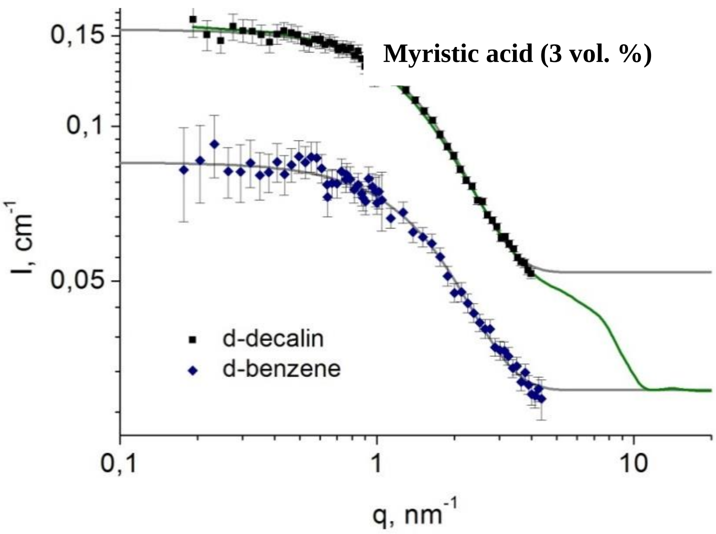


Fig. 6. Maps of the contrast distribution (longitudinal and cross sections) around a molecule of myristic acid in deuterated decaline according to the data of molecular dynamic simulations are shown together with the corresponding calculated small-angle neutron scattering curve (green solid line) and fit to the experimental data. The only varied parameter—non-coherent background—agrees well with the results obtained for the same acid in deuterated benzene. Black solid lines correspond to the Guinier approximation with the constant background.

1.1.1.3. Investigations of carbon nanomaterials

On the basis of the small-angle neutron scattering analysis (including the contrast variation) from liquid dispersions of detonation nanodiamonds (DND) a continuous spatial transition of the carbon state from crystalline diamond (sp^3-hibridization) inside the particle to a graphite-like state (sp^2-hibridization) at DND surface has been suggested (**Fig. 7**).

Such a transition makes it possible to combine the experimentally observed shift in the mean scattering length density of DND as compared to pure diamond (which is indicative of the presence of a non-diamond component in the DND structure) and the diffusive character of the particle surface, which can be deduced from the deviation from Porod's law [9]. The proposed profile is of a simple power-law type and due to a number of specific features explains a homogeneous decrease in the total scattering intensity at the contrast variation. A spherical 'core-shell' representation of DND particles used previously, which gives a reasonable thickness of a non-diamond shell of about 0.5 nm, can be considered as an approximation to the continuous density profile reflecting naturally the diamond-graphite transition in terms of the averaged scattering length density. Along with it, this profile naturally suggests that non-diamond transitional bonds (presumably sp^{2+x}-bonds) are mainly concentrated close to the particle surface. It also allows one to directly determine the parameters of the particle size distribution function.

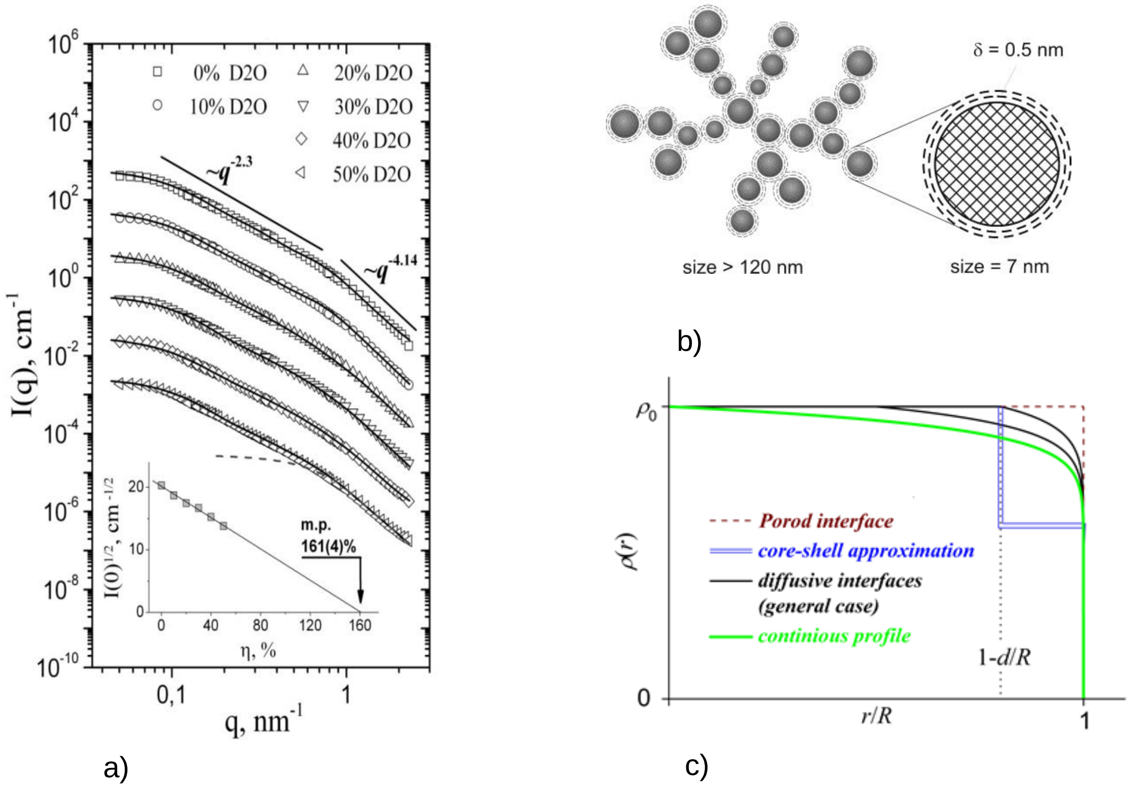


Fig. 7. Experimental curves of small-angle neutron scattering from liquid dispersions of detonation nanodiamonds (DNA) measured with the contrast variation (a). A schematic view of a DNS cluster in liquid dispersions with an enlarged schematic representation of its basic structural unit—a particle composed of crystalline diamond and graphene shell (b). Various approximations to this shell are considered. A continuous diffusive profile (green solid line) gives the best fits to the experimental curves (c).

A comparative structural characterization of fullerene C_{60} and C_{70} clusters in water and mixed solvent NMP/H_2O has been performed using small-angle neutron scattering. The aqueous solutions were synthesized by the solvent substitution method. To prepare the aqueous-organic system C_{60}/NMP/H_2O, fullerenes were initially dissolved in the organic solvent followed by the addition of water in such a proportion that the final volume fraction of NMP in the solutions did not exceed 0.005%. The size distribution function of the clusters was found for all samples. The possibilities for using NMP/H_2O-based fullerene solutions in biomedical applications were studied from the viewpoint of toxicity. In particular, the dependence of cytotoxicity of the solutions on the fullerene cluster size in them was of special interest [10].

1.1.1.4. Investigations of magnetic nanostructures

At the REMUR spectrometer the magnetic state of the layer nanostructure Ta(10nm)/V(150nm)/$Fe_{0.7}V_{0.3}$(1nm)/V(1.2nm)/$Fe_{0.7}V_{0.3}$/Nb(150nm)/Si composed of ferromagnetic and superconducting layers has been studied by polarized neutron reflectometry (**Fig. 8**). Three phenomena were supposed to take place in this nanostructure. The first one was assumed to be an antiferromagnetic ordering of the pair of $Fe_{0.7}V_{0.3}$(1 nm) layers in an external magnetic field. It must have been accompanied by an increase in the degree of antiferromagnetism during the superconducting transition of niobium (T_c=8.5K) and vanadium (4.8K) layers. The second effect was supposed to concern the magnetization of the superconducting pair by ferromagnetic layers, which would result in magnetization of the superconducting layer. Finally, the third phenomenon was presumed to be the formation of a domain structure with small domain sizes and zero mean magnetization.

During the measurements the temperature and magnetic field strength were varied in the ranges of 1.3-110 K and 30 Oe - 9.5 кOe, respectively. The neutron scattering with a maximum at a temperature of 8K (which is below the temperature of superconducting transition in the niobium layer) was observed in the range of 1.3-10 K. The scattering was detected by a decrease in the neutron intensities of the specular reflected and refracted beams and by an increase in the neutron intensities at certain angles in a vertical plane (modes of small-angle scattering and grazing incidence small-angle scattering (**Fig. 8**)).

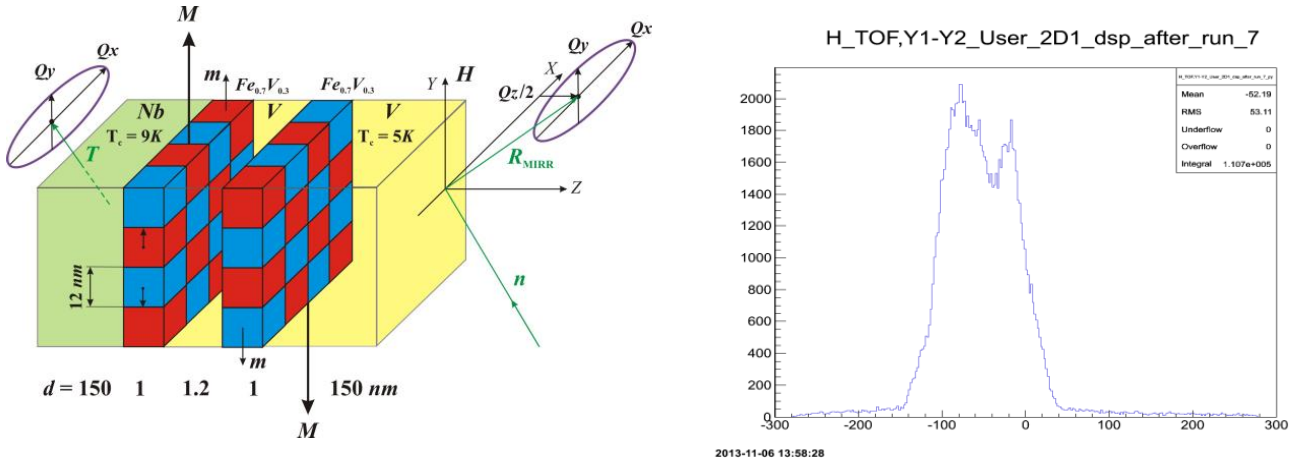


Fig. 8. At the left: Schematic representation of a cryptoferromagnetic state. At the right: Intensity of the beam of polarized neutrons (wavelength 1.29 ± 0.01 Å, incident grazing angle 5.4 mrad) transmitted through a sample as a function of the detector channel (vertical direction). Neutron diffraction peaks from a domain lattice (interplanar distance 50 nm) with a linear domain size of 12 nm are seen.

For the magnetic domain size the value of d = 12 nm was obtained at 8 K. The direction of the domain magnetic moments was varied periodically at the linear scale of L_1 = 43 nm (the scale of antiferromagnetic ordering) and L_2 = 87 nm. With lowering temperature L_1 decreased, while L_2 increased. At the magnetic field of 2.5 кOe, i.e. in the presence of magnetic anisotropy, the antiferromagnetic ordering occurred in pairs of nearest-neighbor domains (d = 11 nm, L_1 = 22 nm).

The obtained experimental data are indicative of the existence (in a certain temperature range below the superconducting transition temperature) of a domain lattice phase where a rotation of the magnetization vector takes place and which is characterized by two directions. The latter is testified by a strong scattering, which cannot be explained only by the scattering in the vertical direction. The absence of neutron scattering in the second direction suggests that the lattice constant in this direction lies in the range below one thousand angstroms.

These observations are the first direct experimental evidence of a cryptoferromagnetic phase in superconducting ferromagnetics, which is the appearance of an antiferromagnetic ordering at the scale of superconducting coherent length (size of a superconducting pair). At the same time, the magnetic period of the cryptoferromagnetic state was found to be an order of 1000 times less than the size of usual domains in ferromagnetics (microns).

At the REMUR spectrometer a layer structure 12×[Fe(35Å)Cr(4.4Å)/Gd(50Å)] where the exchange coupling between RE and PM ferromagnetics was regulated by a chromium layer, has been studied. It has been found that at room temperature (above the Curie temperature of bulk gadolinium) there is a magnetic moment in gadolinium in the near-surface region close to interlayer boundaries and the magnetic moments of gadolinium and iron layers have opposite signs with respect to the direction of the magnetic field.

The ferromagnetic multilayer nanostructures of the Fe/MgO/Fe type, where magnetic layers are separated from each other by nonmagnetic layers, have been studied. These systems characterized by the giant magnetoresistance (GMR) effect are of current interest from the technological and scientific viewpoints, since they can be used as elements of spintronic devices. The GMR effect is provided by the tunneling of electrons between Fe-layers through a dielectric MgO-layer. The thickness of the latter influences the tunneling of electrons, which are involved in the exchange coupling between ferromagnetic layers, and thus changes the magnetic properties of the structure. The so-called spin valves based on a thin film structure MgO//Fe(200Å)/MgO(15Å)/Fe(50Å)/Ta(50Å) have been investigated. Principal characteristics of these systems are specific features in the hysteresis loop in the form of ledges (**Fig. 9**). The reflectivity has been measured in the fields corresponding to the specific points in the hysteresis curve. The measurements have shown good quality of the prepared samples and revealed an interesting magnetic behavior as a result of competition between Zeeman interaction, layer exchange coupling and magnetic anisotropy inside the iron layers.

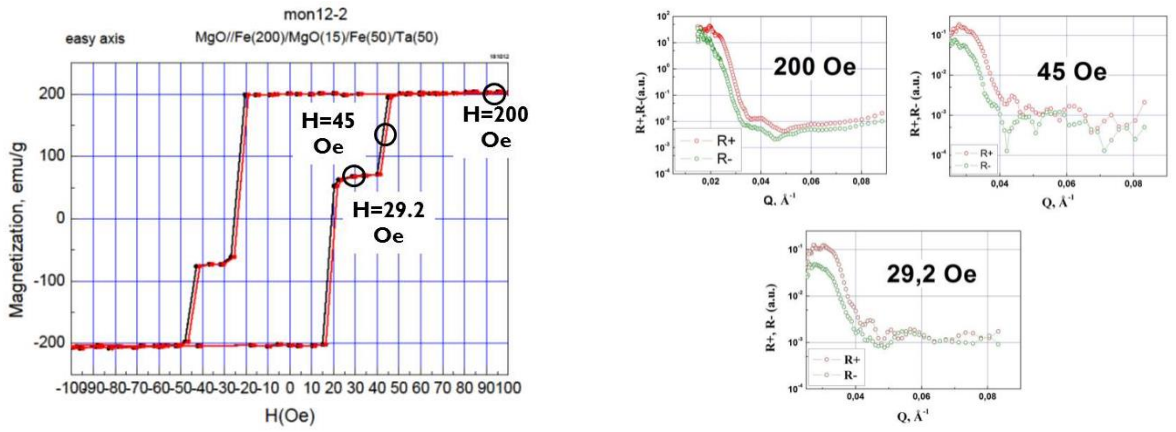


Fig. 9. Left: magnetization curve for the structure MgO//Fe(200Å)/MgO(15Å)/Fe(50Å)/Ta(50Å) in the external magnetic field directed along the easy axis. The open circles are the points where reflectivity has been measured. Right: obtained reflectivity curves.

1.1.1.5. Biological nanosystems, lipid membranes and complexes

A process of spontaneous phospholipid vesicle formation in the presence of calcium ions has been studied by small-angle neutron scattering (**Fig. 10**). For the first time, the behavior of intermembrane distance in the transition region has been considered in detail for the membranes in both liquid and gel phases. It has been shown that the transition of the system from the bound to the unbound state in both phases has a continuous character, which is rather unusual for gel phases. The earlier theoretical studies on gel phases suggested that on addition of calcium ions to lipid multilayer membranes there should be a sharp transition of membranes from the bound to the unbound state, since there are no undulations in the gel phase (membranes are ‘harder’ than in the liquid phase). The investigations performed have shown that there is a significant contribution of undulation forces into membrane interactions. The critical calcium ion concentrations at which the studied transition takes place in gel (0.3 mM) and liquid (0.4 mM) phases have been obtained together with the direct determination of the affinity constants for calcium ions with respect to lipid membranes (22 M-1 and 24 M-1 in gel and liquid phases, respectively).

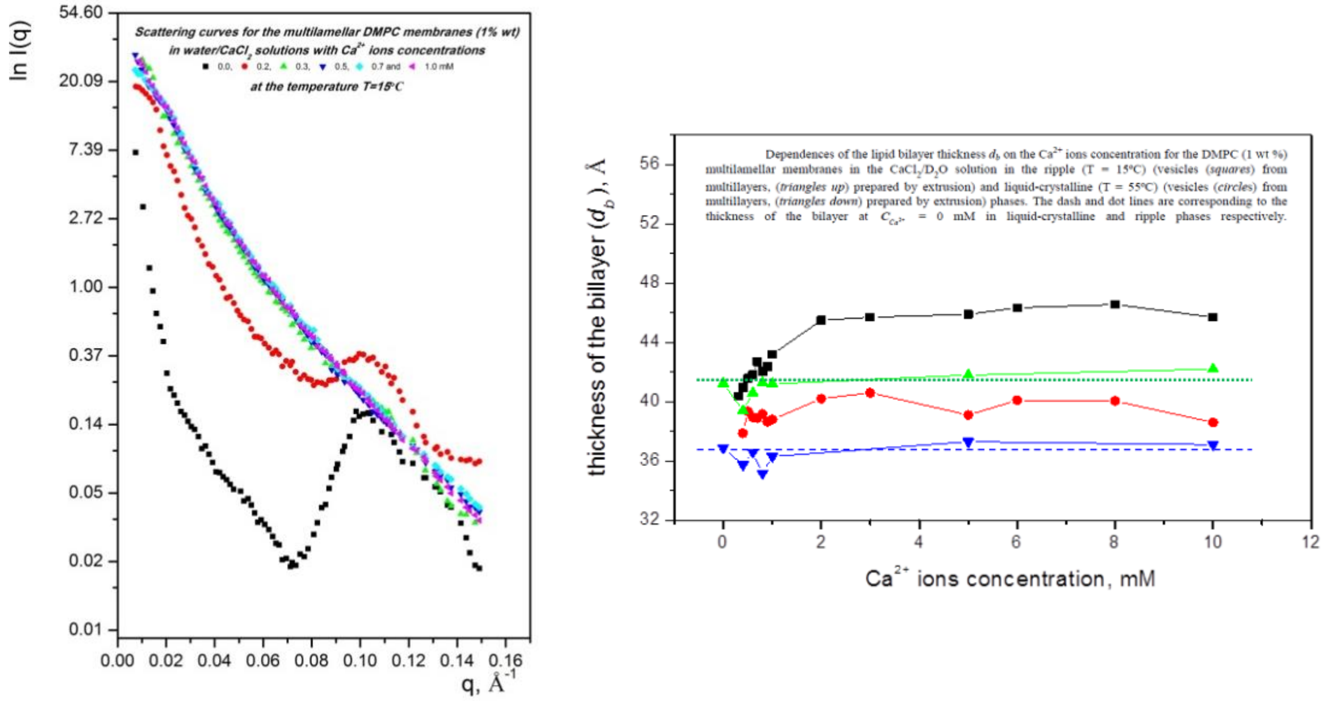


Fig. 10. Left: small-angle neutron scattering curves from multilayer membranes DMPC (1% wt) in the solution water/$CaCl_2$ for molar concentrations of Ca2+ ions: 0.0, 0.2, 0.3, 0.5, 0.7 1.0 mM. Right: concentration dependence of the bilayer thickness in different phases.

The packing of inner membranes (crista) from rat heart mitochondria has been investigated. This type of mitochondria is exposed to greater loads and has larger area of inner membrane as compared with mitochondria from liver studied previously. The diffraction peaks have been observed in the scattering curves, which can be related to the regular positioning of the inner mitochondrial membrane (structure parameter 200 Å). The osmotic shock applied to mitochondria and a priori destroying their structure has resulted in the suppression of the observed peaks. This supports the connection between diffraction peaks and the packing of the inner membrane. Using contrast variation the scattering curves have been obtained separately for protein and lipid components of mitochondria. It has been shown that the peaks appear mainly due to lipid bilayers. Also, it has been found that the inner membrane organization is sensitive to the tonicity of the environment and the presence of calcium ions. Calcium and tonicity of the environment play important roles in mitochondrial and cell signaling.

The development of methods for studying the structure of membrane proteins using small-angle neutron scattering has been started. The solutions of bicelles with a 'built-in' protein (bacteriorhodopsin) have been chosen as a system. At the moment a procedure for preparing becelles and incorporating the membrane protein in them has been developed. The information on the structure and behavior of bicelles in various conditions (temperature, concentration, lipid composition, presence of protein) has been obtained with the help of small-angle scattering.

The investigations of the structural features of connexin (protein) have been started using small-angle neutron and X-ray scattering from the solutions of different parts of the protein. Connexins are selective channels, which play a central role in cell communication. Structural anomalies of the given protein cause serious heart diseases. Connexins are composed of membrane and water-soluble parts. The experiments have demonstrated that the water-soluble part of connexin is a dimer with an elongated shape. A linear polymer is used to stabilize solutions of the membrane part of connexin. Using small-angle X-ray scattering data it has been revealed that the polymer forms a massive “coat” around the protein, which makes it rather difficult to obtain information only about the protein (without the polymer). The application of neutron scattering with contrast variation has turned out to be difficult, since the protein aggregates in the presence of heavy water.

The study of model systems for drug delivery continued [11]. Different aggregation states in the system 1,2-dipalmitoyl-sn-glycero-3-phosphatidylcholine/deoxycholate (DPPC/NaDC) have been investigated by small-angle neutron scattering and dynamic light scattering. It has been found that depending on the concentration of NaDC this system shows a wide spectra of supramolecular formations including ellipsoidal vesicles (1.5 mM NaDC), ribbon-like structures (3.5 mM NaDC), spherical mixed micelles (10 mM NaDC).

1.1.1.6. Polymeric materials

The structural features of new polymeric composite materials with iron nanoparticles (size from 10 to 100 nm) have been studied by atomic force microscopy and small-angle neutron scattering [12] (**Fig. 11**). These materials show unique mechanical and rheological properties, which vary significantly under magnetic fields. Thus, in the case of a homogeneous external magnetic field with the strength of 0.4 T the compression modulus changes by a factor of 100. Under sufficiently strong magnetic fields the samples behave as elastoplastic materials.

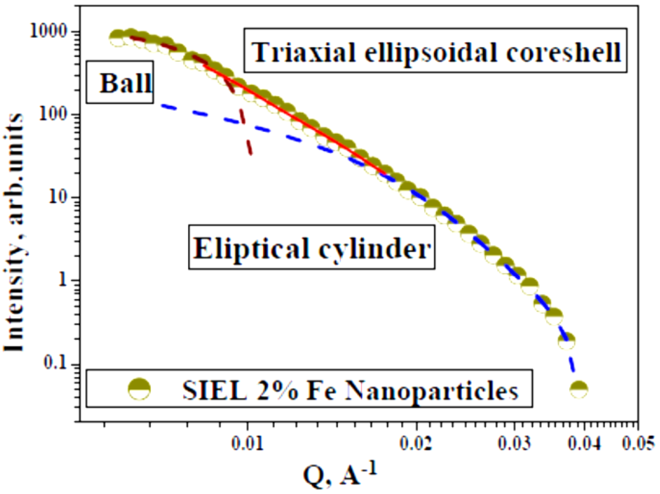


Fig. 11. Small-angle neutron scattering curve from a new polymeric composite material with iron nanoparticles.

In the framework of the study of the glass-transition kinetics in polymers the modeling of polystyrene vitrification has been performed in a wide range of cooling rates (10^{-4} - 2 K/s). The aim of the investigations was to determine the best model, which could describe experimental dependences of isobaric heat capacity in a temperature range of 90 - 130˚C. The Tool-Narayanaswami and Schmeltzer-Gutzov methods have been used as basic approaches. It has been shown that all existing approaches require a wide variation in the modeling parameters (as a minimum, parameter of non-exponentiality β) at different cooling rates. It has been concluded that the Schmeltzer-Gutzov method with an original expression for the relaxation time of the system, τ, is as good as other methods for describing qualitatively the experimental data of differential scanning calorimetry [10].

1.1.1.7. Atomic and molecular dynamics

An experimental and theoretical study of molecular dynamics and structure of derivative compounds alkylcoumarin-hexafluorophosphate (ESP-PF6) and tosylate (ESP-TOS) has been carried out (**Fig. 12**). The experimental investigation has been performed using infrared absorption spectroscopy, Raman scattering, inelastic neutron scattering and terahertz radiation.

The density functional theory approximation and software packages CASTEP and GAUSSIAN09 were used for theoretical modeling of molecular dynamics. The experimental data show good agreement with the results of theoretical modeling.

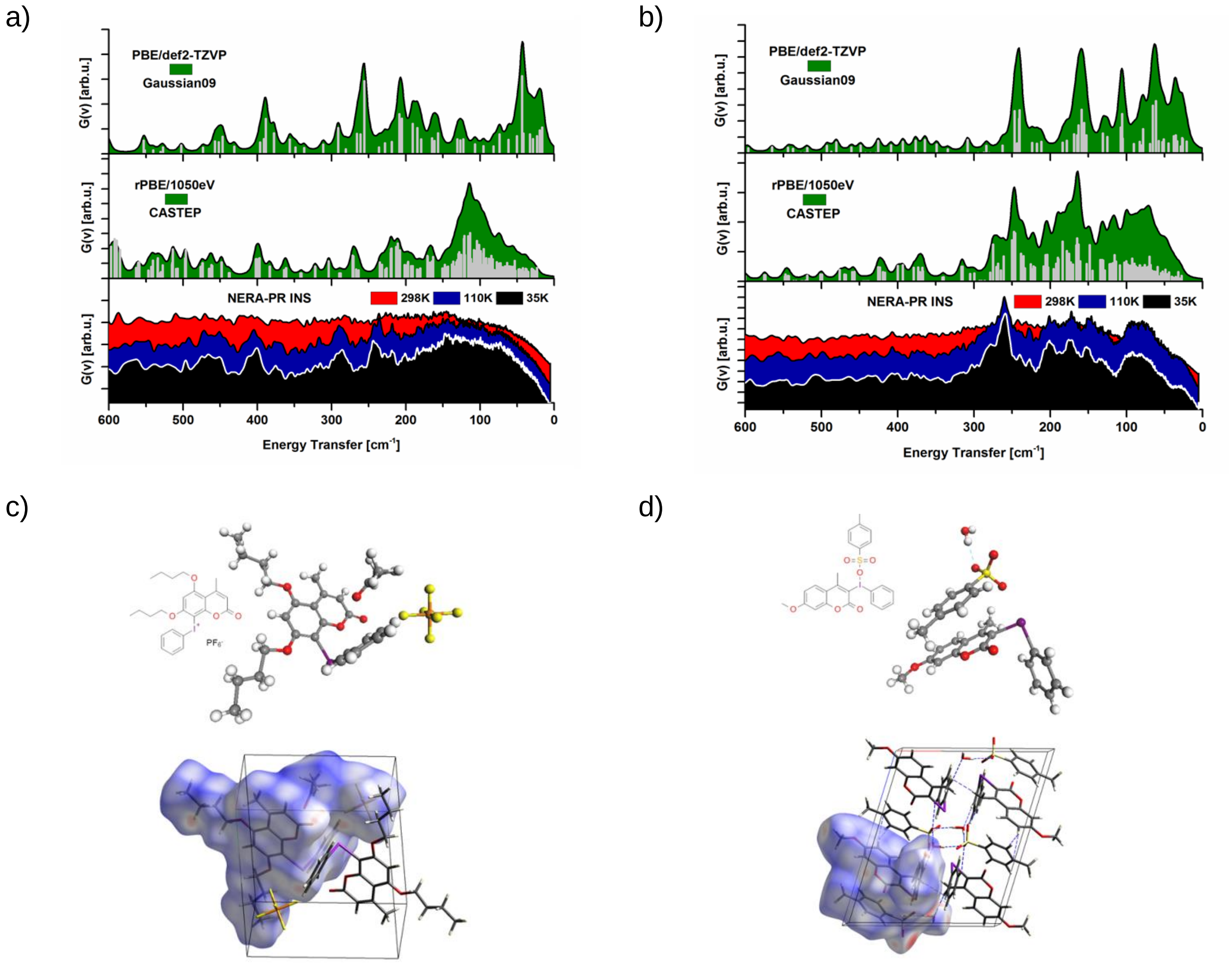


Fig. 12. Inelastic neutron scattering spectra; results of their theoretical modeling in the framework of various approximations and the crystal structure of ESP-PF6 (a,c) and ESP-TOS (b,d).

The atomic dynamics of liquid gallium has been studied at high temperatures using inelastic neutron scattering. A quasi-elastic part including both coherent and incoherent components was found from experimental double-differential scattering cross-sections of liquid gallium obtained at temperatures of 313, 433, 553 and 673 K. In the case of coherent scattering the analysis of the spectra was performed in the Q-range in the vicinity of the first structure factor maximum ($Q \sim Q_o$). A modified hard-sphere fluid model was used and a temperature dependence of self-diffusion coefficient for liquid gallium was obtained in the range of 313-673 K. For incoherent scattering the quasi-elastic data were analyzed in a wider Q-range and the obtained results were described by a simple diffusion model. The results of two methods of analysis are in good agreement with respect to both the diffusion coefficient value and its temperature dependence and are roughly described by the Arrhenius law with a constant energy of activation of ~ 6 kJ/mol. From the analysis of the shape of coherent and incoherent quasi-elastic scattering peaks it has also been found that the decay of density fluctuations of the immediate surrounding in liquid gallium follows a simple exponential law.

1.1.1.8. Applied research

Among traditional applied investigations in the NICM Department are the experimental studies of internal stresses and texture of rocks and minerals, determination of internal stresses in bulk materials and products, including engineering materials and components of machines and devices. For the most part, these investigations are carried out using neutron diffraction.

Control over a condition of metal of a reactor vessel during its service life and a guarantee of its integrity under normal operation conditions as well as in case of any design accidents is one of the key problems of the present-day nuclear power engineering. When operating nuclear facilities a surveillance program of witness specimens positioned at the inner wall of a reactor cavity serves as an important source of information on changes in properties of vessel steels, which tend to worsen as a result of neutron irradiation. To increase the number of irradiated samples of reactor vessel steel for validation of its design service life or for its extension, the technology of reconstitution of witness specimens after their mechanical tests using different types of welding (electric-arc, electron-beam, laser-beam, etc.) is used. This requires the level of residual stresses to be controlled after welding in the reconstituted witness specimens.

On the FSD diffractometer the experiments have been carried out to study the distribution of residual stresses in witness specimens that develop after electron-beam welding (EBW) and laser beam welding (LBW). The experimental results (**Fig. 13**) have shown that the level of residual stresses for an LBW sample is much higher than for an EBW sample and ranges to 550 MPa in the weld region.

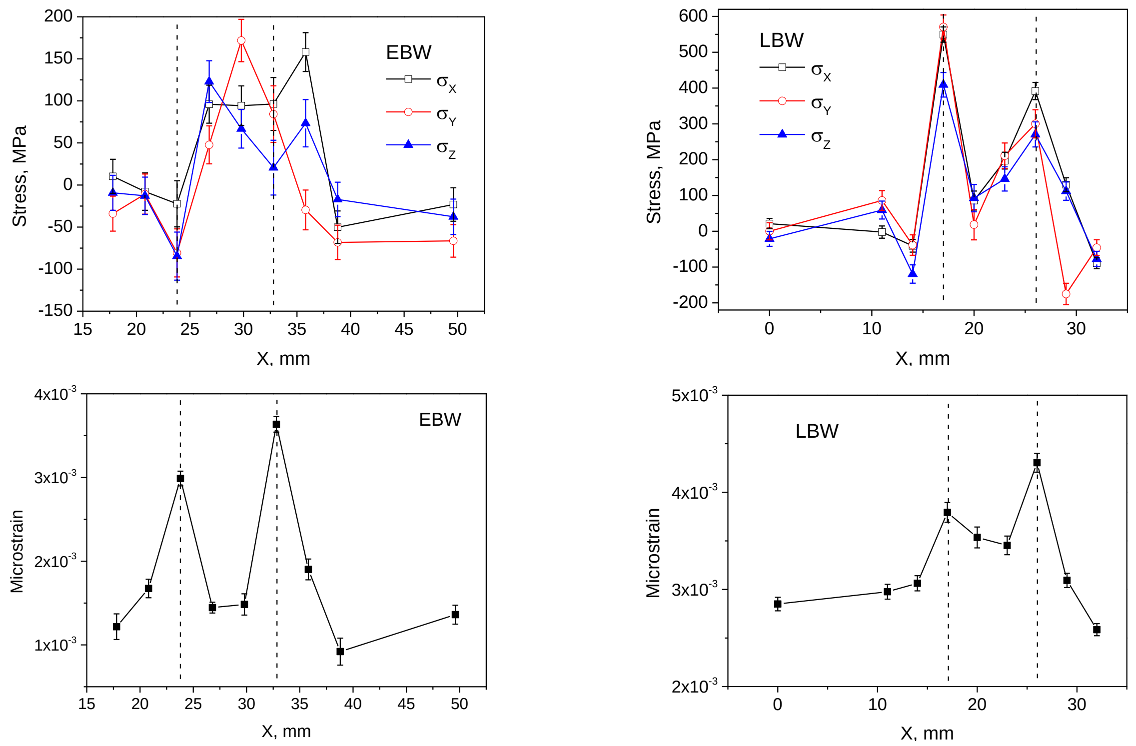


Fig. 13. Distribution of residual stresses (top) and microstrains (bottom) in samples reconstituted by electron- and laser-beam welding.

This supports the well-known fact that among all methods the application of electron-beam welding results in the lowest level of residual stresses in welds. This is most probably due to a low heat input of the EBW process (4-5 times lower than, for example, in arc welding) which significantly reduces the deformation of a final product. In addition, the diffraction peak broadening was used to determine the level of residual microstrains, which directly characterizes the density of dislocations in a material being studied. The microstrain in the EBW specimen amounts to $3.5 \cdot 10^{-3}$ and is slightly higher in the LBW specimen – $4.5 \cdot 10^{-3}$. This effect is accompanied by a considerable (~ 2.5 times) increase in microhardness in weld seam regions. The observed increase in microhardness is likely to be the result of the formation of martensite (or martensite-bainite) structure in welds and heat-affected zones.

The investigation of residual stresses in calcite-based rock samples, which are induced by the presence of magnetic pyrrhotite has been conducted on the Epsilon diffractometer. The distribution of internal stresses in the calcite phase has been determined as a function of the angle of rotation of the sample in the XY plane around the Z axis.

The texture of a number of ferritic-pearlitic steel samples has been investigated with the aim of studying the effect of treatment, chemical composition and texture on the strength properties of railway car wheels made of this steel. On the basis of the measurement of pole figures (200), (110), (211) for α-Fe performed on the SKAT diffractometer it has been concluded that heat treatment destroys texture. Doping of the alloy results in the reorientation of weak preferred orientation.

The experiments have been carried out to study thermal internal stresses in marbles that are induced by seasonal temperature variations [15].

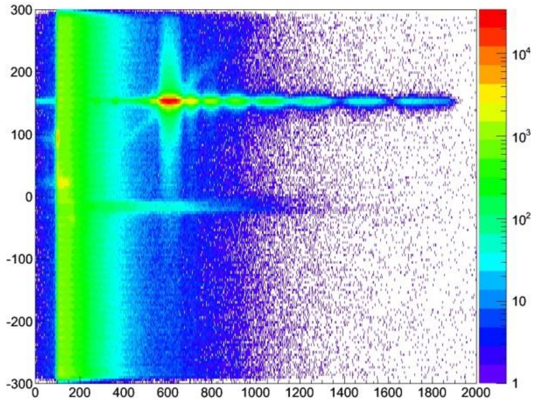
1.1.2. Instrument development

Work to develop and test sample environment devices for the new DN-6 diffractometer has been carried out. A cryostat for experiments with high-pressure cells has been constructed and tested. High-pressure cells with diamond anvils with an operating range up to 15 GPa (culet diameter of 0.8 mm) and 50 GPA (culet diameter of 0.5 mm) have been purchased. The first experiments have demonstrated a possibility of their successful application in experiments on DN-6. An advanced detector system has been designed for obtaining spectra at a scattering angle of 90° on the basis of 96 separate gas counters. The implementation of this system will allow a 3-4-fold increase in the neutron flux at the instrument.

The operation of the first-stage of the GRAINS reflectometer has started. Beam profiles have been measured and optimized for different configurations of the reflectometer elements. The experimental estimations of the total flux of non-polarized thermal neutrons (wavelength above 0.05 nm) after deflector have been made in thermal (2×10^6 cm^{-2} s^{-1}) and cold (1×10^6 cm^{-2} s^{-1}) operating modes of the moderator. Time-of-flight spectra have been optimized over the fast neutron background. The first reflectivity curves for standard systems have been obtained in two operating modes of the moderator (**Fig. 14**). During the start-up the first experiment to study the oxidation effect on the structure of thin titanium films on a glass substrate has been carried out in the framework of the development of new coatings for neutron optical devices.

The activities on the implementation of the project to develop and construct a new diffractometer on beam 6a for real-time neutron diffraction studies of transient processes have continued. Design drawings of background shielding for a detector system have been prepared. An adjustable neutron beam diaphragm providing linear movement along the horizontal and vertical axes and mounted on an outlet flange of the RTD neutron guide has been manufactured and installed.

a) *b*)



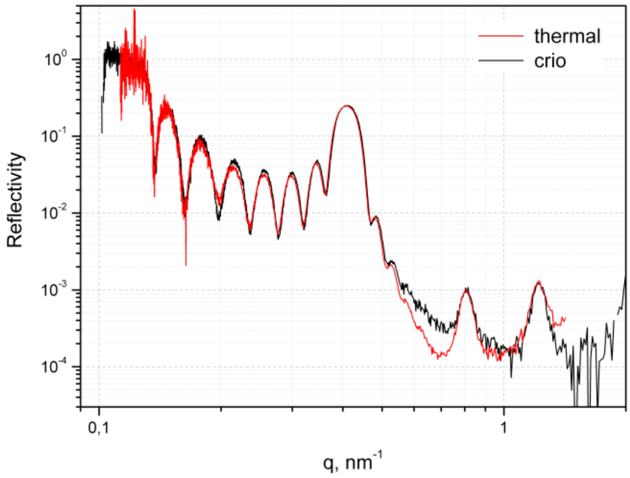


Fig. 14. a) 2D spectrum of non-polarized neutron beam reflected from a layer structure [Ni(8.4nm)Ti(7nm)]×8/Floatglass (MIRROTRON Ltd., Hungary) obtained on the GRAINS reflectometer in a cryogenic operating mode of the moderator; data are represented in coordinates Z (detector channel width 0.35 mm) – Time-Of-Flight (channel width 32 μs). b) Reflectivity curves for the same system measured in thermal and cryogenic operating modes of the moderator.

The development and construction of a prototype of a radiography spectrometer on beam 14 (**Fig. 15**) continued.

a)

b)

Fig. 15. Vacuum collimation system (a) and CCD-camera-based imaging system (b).

A vacuum collimation system has been manufactured and installed on the beam. A CCD-camera-based imaging system has been produced and tested on beam 12. The construction of biological shielding of the channel continued. The test opening of a shutter was performed, during which the neutron flux at a sample position was evaluated and found to be $5 \cdot 10^6$ n/cm^2/s.

On the DN-12 diffractometer in cooperation with the Spectrometers' Complex (SC) Department the replacement of detector counters, electronics and data accumulation system has been done. The use of new detectors has made it possible to increase the neutron flux at the instrument by 30%.

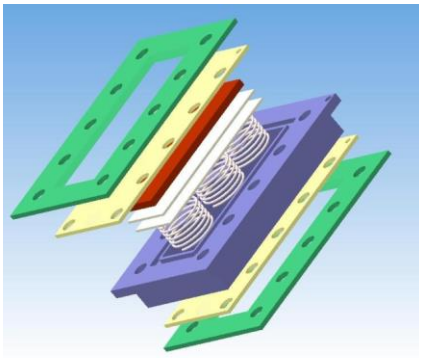
After a long break the construction of ZnS-based modules of the ASTRA detector for FSD has been resumed in the SC Department. In cooperation with the specialists from SC a new scintillation module of the ASTRA detector has been installed and tested in a low-resolution mode on FSD. In the near future this module will be tested in a high-resolution mode. On the FSD diffractometer the tests of a "*List Mode"-analyzer* for accumulation of "raw" data in the list mode continued. The work to develop and improve complex algorithms for recovering high-resolution spectra is in progress.

On the YuMO spectrometer in cooperation with the SC Department the following activities have been carried out: data acquisition electronics of 3 detectors (two ring proportional helium-3 detectors and a direct beam detector) were replaced; gas mixture of the detectors was checked; preamplifiers of ring detectors were replaced, new accumulation electronics were installed, new cables (more than a kilometer in length) from electronics to detectors including vacuum connectors were placed into service. An electronic log and database of experiments were created. The software (including SONIX and SAS) was upgraded.

The technical parameters of the SKAT and EPSILON diffractometers after their modernization have been determined. The values of the neutron flux at a sample position have been estimated using uranium fission chambers and found to be $1.7 \cdot 10^6$ n/cm^2/s for EPSILON and $6.8 \cdot 10^5$ n/cm^2/s for SKAT. Neutron beam profiles have been measured and the resolution function of SKAT has been refined.

To study Li-ion accumulators in real-time diffraction experiments, special model electrochemical cells and temperature control add-on device (**Fig. 16**) which will make it possible to produce temperatures in the range from – 100 to 100 °C (extreme temperature range of operation of accumulators) for a bulky sample have been developed.

a)



b)

Fig. 16. a) 3D model of a new electrochemical cell for testing electrode materials showing a frame made of corrosion-resistant alloy (green), vanadium current collector plates (yellow), electrode materials (cathode and anode) together with a separator and electrolyte (red), second vanadium current collector, boron nitride and springs (gray), fluoroplastic framing (blue). b) A ready-assembled device for creating special temperature conditions on accumulators.

On the REFLEX reflectometer the investigations of reflectivity properties of thin-film multilayer structures prepared according to a special algorithm proposed by V.K.Ignatovich, have continued (**Fig. 17**) [14].

The idea is to use the properties of certain periodical thin-film structures for designing neutron mirrors with enhanced reflectivity in some definite interval of momentum transfer. Each period consists of a bi-layer with sublayers of positive and negative scattering length density (SLD). Such periodical structure gives a Bragg peak with a height and width determined by SLD values of the sublayers. This approach is an alternative to the widely used technique for producing neutron mirrors with aperiodic structures (magnetron evaporation). This technology does not provide clear scientific criteria for the preparation procedure; the processes are regulated by trial-and-error procedures. This makes the existing method to be unreliable to some extent; it is characterized by a comparatively high reject rate and long adjustment operations with the equipment. The development of the technology based on a precise mathematical algorithm for constructing neutron mirrors could simplify their design process and improve their quality. Neutron mirrors with high critical angles of total reflection are of current interest for neutron centers engaged in designing neutron guides. The samples for investigations were produced by Mirrotron Ltd, Budapest.

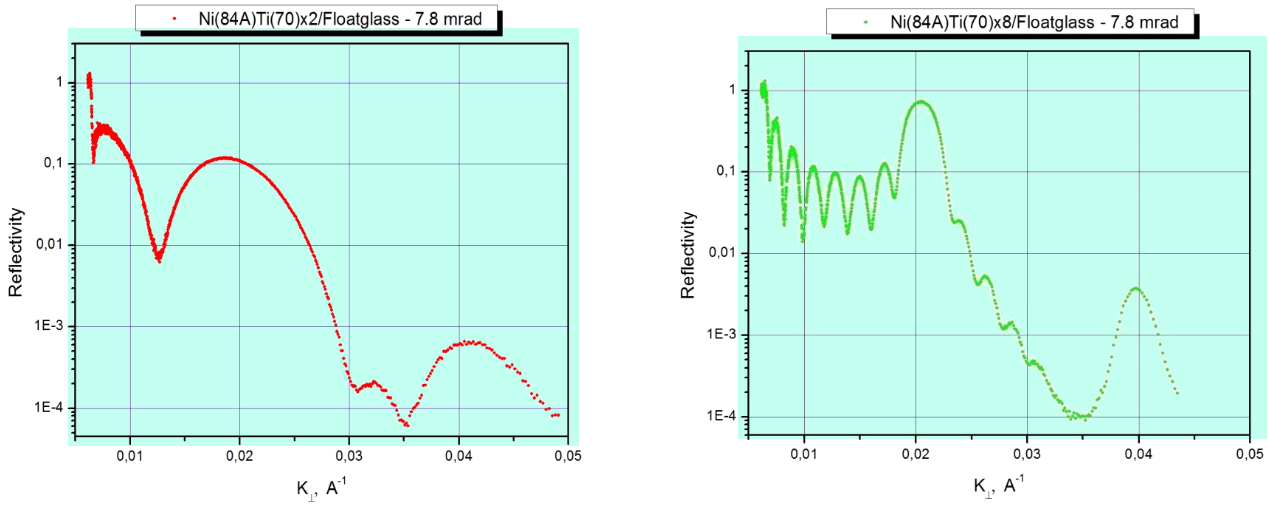


Fig. 17. Reflectivity from periodical structures formed by Ni-Ti bilayers. A scheme at the bottom illustrates the principle of enhanced reflectivity in a wide interval of momentum transfer: sets of bi-layers of various periods form Bragg peaks in a reciprocal space; bi-layer periods are chosen in such a way that peaks overlap and produce a wide interval with high reflectivity.

A technique has been developed for calculating the behavior of the polarization vector of a neutron beam as it passes through magnetic fields of arbitrary spatial configuration. This method allows high-accuracy estimation of losses in the polarization vector value as neutrons pass any spectrometer element, which creates magnetic fields, and thus makes it possible to optimize the instrument. Three-dimensional distributions of magnetic fields from individual elements used on the REFLEX polarized neutron spectrometer on beam 9 of the IBR-2 reactor have been calculated using the MagNet software package. The obtained field distributions were further used by the VITESS software package for simulating changes in the polarization vector.

A study of waveguide layer structure CuNi(15 nm)/$TbCo_5$(150 nm)/CuNi(50 nm)//Si(substrate) has been conducted. Here Cu(33 at.%)Ni(67 at.%) is a nonmagnetic layer and $TbCo_5$ is a weak-magnetic one (saturation magnetization of 500 G) at room temperature. It has been found that changes in magnetization of the order of 10 G can be detected by measuring the intensity of polarized neutron microbeam leaving the end face of the waveguide layer of this structure. Thus, polarized neutron microbeams may be used as a more sensitive method for studying weak-magnetic layers than conventional neutron reflectometry with a sensitivity threshold of the order of 1000 G.

On the REMUR reflectometer a mode of small-angle scattering in grazing incidence geometry has been tested in the framework of planned measurements with a ferromagnetic-superconducting sample. The replacement of motors in the spectrometer drives has been done. For the most part, new software for a 2D position-sensitive detector, which provides data accumulation in four polarization operating modes, has been put into service. Work to design a polarization analyzer with a cross-section of 16 cm × 18 cm is in progress.

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1.2. NEUTRON NUCLEAR PHYSICS

1.2.1 Experimental and instrument development activities.

1.2.1.1. Development and improvement of multi-detector systems for neutron cross-section easurements at the IREN facility

A mobile reconfigurable gamma-spectrometer system nGamma has been developed and tested. The system is intended for studying nuclear reactions with the emission of gamma-rays induced by neutrons of various energies. In the initial (minimum, test) configuration it consists of 24 NaI(Tl) gamma-ray detectors mounted on two rings (**Fig. 18**). The energy and time characteristics of individual sections of the system have been determined experimentally. Using the system, the energy dependence of neutron flux density has been measured at a distance of 60 m from a neutron-generating target of the IREN pulsed neutron source.

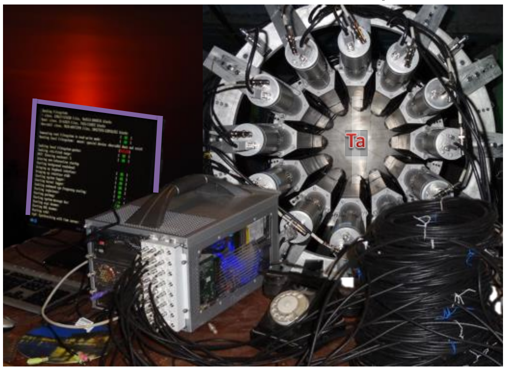

Fig.18. Multi-detector mobile reconfigurable gamma-spectrometer

A 12-detector (2 modules of 6 NaI(Tl) crystals each) gamma-spectrometer system “Romashka” designed to study resonance radiative capture (and fission) of nuclei by neutrons has been assembled and tested on beam 4 of the IREN facility (**Fig. 19**). The energy characteristics of individual sections of the system have been measured using a computerized acquisition and analysis system of the nGamma instrument. A gamma-neutron beam collimator has been assembled and installed.

Fig. 19. 12-detector NaI(Tl) gamma-spectrometer system “Romashka” (INRNE-BAS) on beam 4 of the IREN pulsed neutron source.

1.2.1.2. Activities on the preparation of the (n,e) scattering experiment.

The adjustment of the experimental setup AURA for measuring the energy dependence of angular anisotropy of slow neutrons scattered by noble gases in order to determine the (n,e)-scattering length is in progress. At present, the AURA setup is placed on a 15-m flight path of beam 2 of the IREN facility. The layout of the AURA setup is presented in **Fig. 20**.

Four shielded ^{3}He-counters and a sample holder (a cylindrical aluminum chamber is provided for gaseous targets) are fixed on a rotating platform. The platform is rotated through ±180° by a PC-controlled stepper motor.

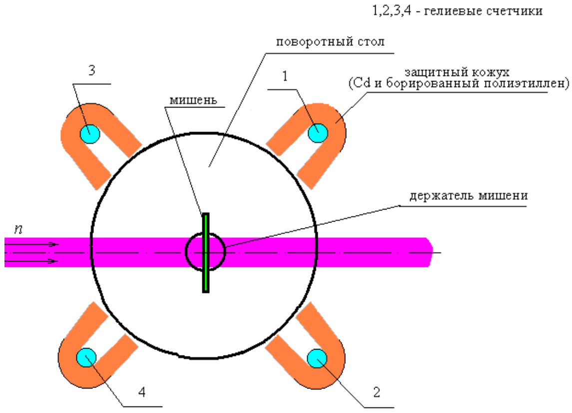

Fig.20. Layout of a detector module of the AURA setup for studying solid samples.

An 8-channel time encoder is connected with a computer via a USB-2 port and receives signals from detectors and two monitor ^{3}He-counters. Changes in the detectors' position at specified parameters, in the exposure in each position and the accumulation of measured data in 8 spectra (for each counter in 2 positions) are handled by the experiment control software.

Test experiments on solid samples have been performed at a neutron beam intensity of IREN of ~$2{\cdot}10^{11}$ n/s. **Fig. 21 a** and **b** illustrate the time-of-flight spectra obtained by neutron scattering from a 0.5-mm-thick cadmium target and a 0.3-mm-thick tungsten target, and **Fig. 22** presents the time-of-flight spectra obtained with a plexiglass target. As is obvious from **Fig. 22** forward-scattering of neutrons is predominant as it should be on a hydrogen-containing target.

a) b)

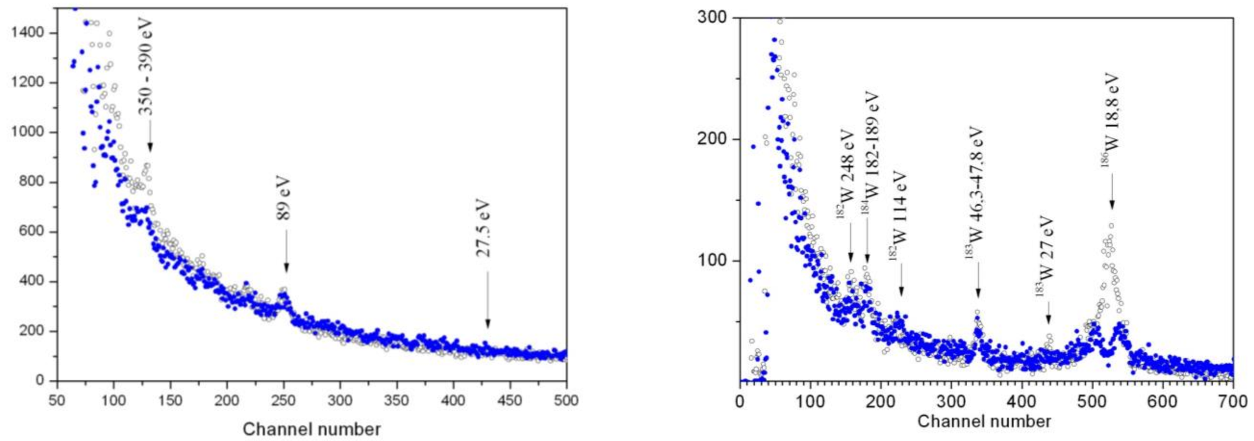

Fig. 21. a)Time-of-flight neutron scattering spectra of cadmium obtained by one of the detectors. Open circles – back-scattering, full circles – forward-scattering. Time channel width is 0.5 μs. b) Time-of-flight neutron scattering spectra of tungsten. Open circles – back-scattering, full circles – forward-scattering. Time channel width is 0.5 μs.

The inlets of the 2nd and 4th detectors were covered by silver plates, which resulted in a dip in the respective neutron forward-scattering spectra at an energy of ~ 10 eV. The dip is related to the fact that neutrons with this energy after scattering by hydrogen at 45° acquire an energy corresponding to a "silver resonance" at 5.15 eV.

The calculations aimed at refining the corrections for the experiment on the determination of the n,e-scattering length from the angular anisotropy of slow neutrons scattered by argon at normal pressure are in progress. To determine b_{ne} with a precision of 2-3%, the accuracy of all corrections should be no worse than 10^{-4}.

A kinematic correction — the ratio between the efficiencies of the detectors registering slow neutrons scattered forward or backward taking into account the thermal motion of gas atoms — is calculated by the Monte Carlo method in the real geometry (using LIT cluster). The accuracy of this correction required for a time-of-flight experiment has been obtained for measurements with argon. The corrections have been calculated for 20 energy points in the neutron energy range from 0.0065 to 0.8 eV. The calculated dependence of neutron scattering anisotropy on the initial neutron energy with regard to the thermal motion of argon atoms at bne = $-1.32{\cdot}10^{-3}$ fm and the anisotropy without considering n,e-scattering are presented in **Fig. 23**.

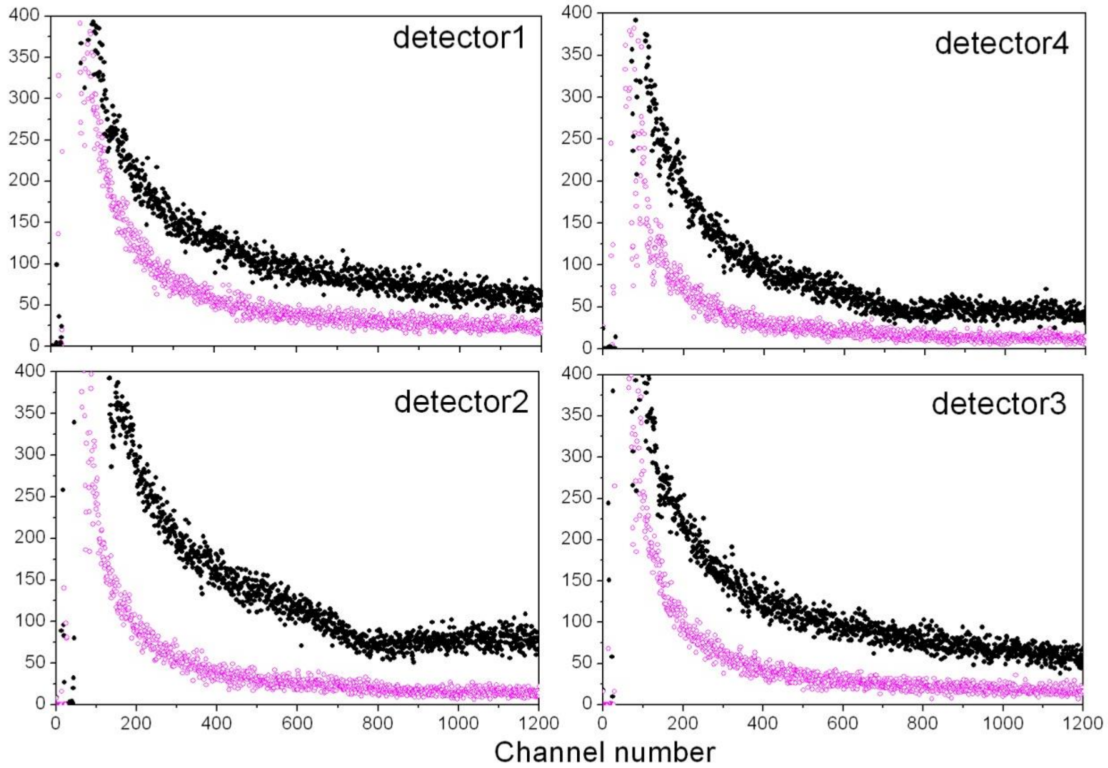

Fig. 22. Time-of-flight neutron scattering spectra of Plexiglas. Open circles – back-scattering, full circles – forward-scattering. Time channel width is 0.5 μs.

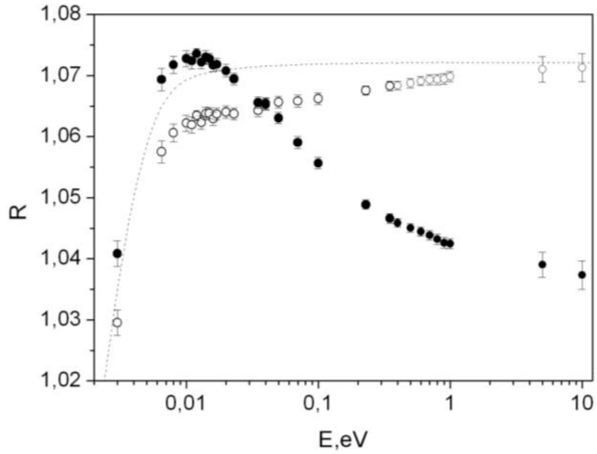

Fig. 23. Dependence of neutron scattering anisotropy on the initial neutron energy with regard to the thermal motion of Ar atoms at $b_{ne} = -1.32 \cdot 10^{-3}$ fm. Open circles – calculations corrected for efficiency, full circles – without corrections. The dotted curve is the anisotropy without considering n,e-scattering.

The correction $C(E)=\varepsilon(135^0)/\varepsilon(45^0)$ obtained from the Monte Carlo calculations for the differences in the intensities of neutrons scattered forward and backward by argon with regard to the thermal motion of its atoms along with the calculation of this correction without considering the thermal motion of gas atoms (dashed curve) are shown in **Fig. 24**. Similar calculations of this correction for krypton as a scatterer are in progress.

The estimates of neutron scattering by cadmium covering the walls of collimators have shown that at a neutron energy of 0.5 eV $0.6{\cdot}10^{-4}$ neutrons incident at various angles pass through 0.2 cm-thick cadmium and 10^{-4} neutrons are reflected. This uncertainty is acceptable in our experiment.

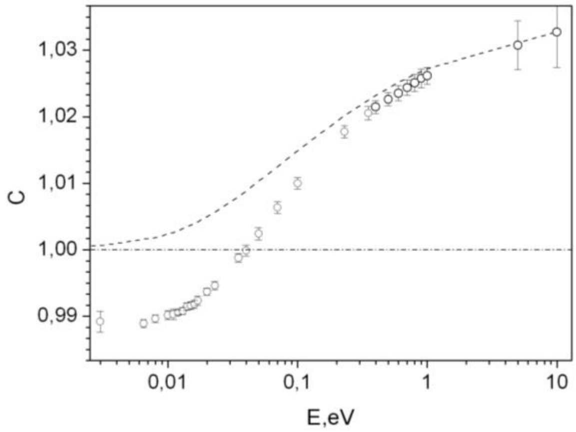

Fig. 24. The correction $C(E)=\varepsilon(135^0)/\varepsilon(45^0)$ obtained from the Monte Carlo calculations for intensities of neutrons scattered forward and backward by argon. The dashed curve is the correction *C(E)* without regard to the thermal motion of gas atoms.

Upon completion of tests on IREN the AURA setup is proposed to be placed on beam 1 of the IBR-2 reactor for carrying out measurements with noble gases. To perform a final check of the AURA setup, it is planned to carry out measurements with a vanadium sample in order to obtain scattering anisotropy in the thermal neutron energy range. In this energy range in the experiment with vanadium performed earlier on IBR-2 the observed anisotropy of neutron forward- and back-scattering differed from a kinematic one. It would be of interest to confirm this result by carrying out measurements with the AURA setup on IREN.

The corrections for multiple neutron scattering from vanadium of different thicknesses have been estimated. The calculations have been made for neutron energies of 0.025 eV and 0.1 eV for three forward-scattering angles 30°±2.5°, 45°±2.5° and 60°±2.5° and for respective back-scattering angles 150°±2.5°, 135°±2.5° and 120°±2.5°. It can be seen from the calculations that the earlier negligence of multiple scattering for such thickness of vanadium was justified.

1.2.1.3. Development of methods for studying physics of fission

The activities carried out in cooperation with the Czech Technical University in Prague on the application of pixel silicon detectors for detecting charged particles emitted in fission are in progress. In earlier studies the possibility of measuring the energy of fission fragments using pixel detectors Medipix2 as well as the directions of fragment emission due to a high position resolution of these detectors has been demonstrated. A Medipix2 detector is a two-layer silicon detector with dimensions of 1.4×1.4 cm^2. The upper sensor layer is a conventional semiconductor detector (as a rule, a 300 μm-thick silicon layer is used). The lower layer (called a read-out layer) consists of 256×256 pixels (size of one pixel is 55×55 microns). Each pixel is an integrated chip, which makes it possible to register a signal in a pixel and to count events at specified differential (upper and lower) thresholds. The detection principle in the detectors of the Medipix family is based on the charge sharing effect, i.e. the charge created by the particle entering the detector sensitive area spreads over a rather wide region during the charge collection process and can be finally collected by several adjacent pixels forming a cluster. The cluster size depends on the type and energy of the particle.

A new generation of pixel detectors – TimePix – also makes it possible to measure the arrival time of a particle to impinge on each pixel. In addition, the detector can operate in the time-over-threshold mode, in which the charge deposited by the incoming particle is determined by measuring the time during which the signal exceeds the detection threshold level. In 2013 the measurements of ternary spontaneous fission of ^{252}Cf using Timepix detectors were carried out in FLNP in collaboration with the Technical University in Prague. The ΔE-E technique, which allows charge identification of light charged particles, was used to identify ternary particles. A thin silicon detector (12 μm) was used as a ΔE-detector and a pixel detector TimePix with a 300 μm-thick sensor layer – as an E-detector.

The scheme of the experimental setup is shown in **Fig. 25**. A spontaneous fission source ^{252}Cf and the assembly of ΔE-E detectors are placed in a vacuum chamber. A 31-μm-thick aluminum foil is put between the source and detectors and provide full absorption of fission fragments and alpha-particles from spontaneous alpha-decay of californium (6.2 MeV). Thus, the detectors register only long-range light charged particles from ternary fission. A signal from a ΔE detector is fed to a charge-sensitive preamplifier, then the amplified signal is divided and passed to the fast and spectroscopic tracts, respectively. The fast tract consists of a shaping amplifier and a discriminator with a fixed threshold; a shaped logic signal (+3.3 V CMOS-TTL) is fed to the external input (determining trigger) of the Timepix detector.

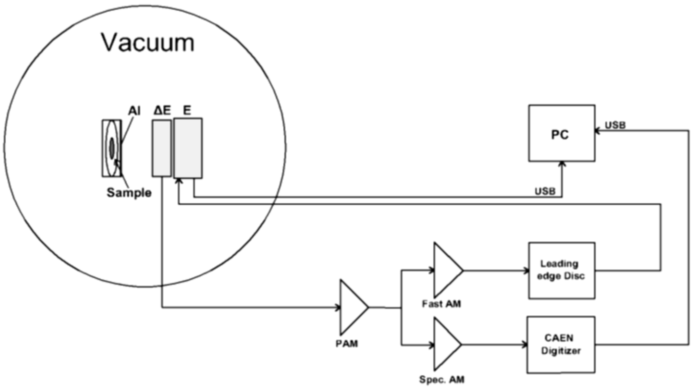

Fig. 25. Scheme of the experimental setup.

The second part of the signal is fed to a spectrometric amplifier, which forms a signal for processing it in a digitizer CAEN DT5720. The digitized signals are saved in the computer memory through a standard USB port. Signals from a Timepix detector operating in a TOT mode are read through a USB FitPIX interface and also saved in the computer memory using a Pixelman program. The synchronization of two independent data flows (from ΔE and E detectors) is performed in the off-line mode by comparing the time stamps from the digitizer and FitPIX interface.

A 2D ΔE-E spectrum is presented in **Fig. 26**, where one can clearly see the separation of light charged particles by charge. Hydrogen isotopes cannot be observed because of a high threshold of the ΔE detector. Heavier particles have a significantly lower yield and are not observed when a weak source is used. The final objective of the experiment is to search for and study a quaternary fission with the simultaneous emission of two light charged particles.

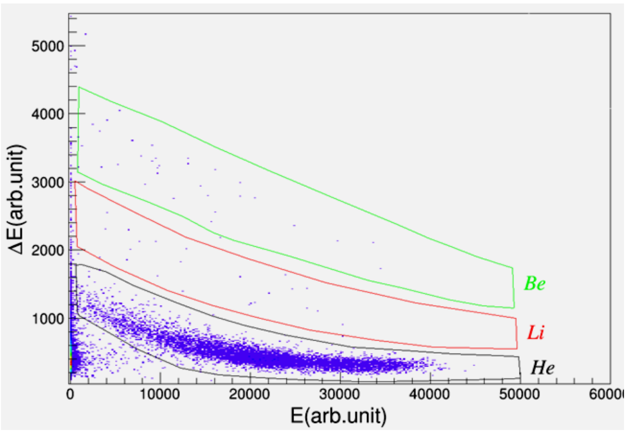

Fig. 26. ΔE-E distribution of light charged particles from spontaneous fission source ^{252}Cf.

In 2013, a setup for precision measurements of prompt fission neutron multiplicity depending on the mass distributions of fission fragments and their total kinetic energy was designed and constructed. The detector is based on a position-sensitive double fission ionization chamber with the anode consisting of 48 strips (**Fig. 27**). According to calculations the spatial resolution in the anode plane does not exceed several hundredths of a millimeter. This setup makes it possible to perform not only high-quality measurements of prompt fission neutron distributions but also mass-energy characteristics. In addition, it has been suggested that the detector be used in neutron radiography experiments as a competitive alternative to the available present-day solutions. For this purpose a fully digital variant of electronics based on 128 parallel channels for discretization of signals of the double ionization chamber has been considered.

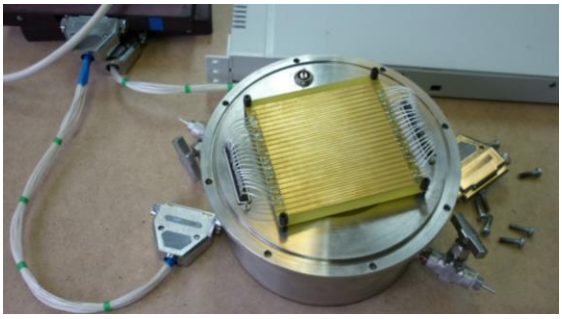

Fig.27. General view of the position-sensitive chamber.

1.2.1.4 Investigations of space parity violation effects in nuclear reactions

Previously, the measurements of the P-odd asymmetry in the radiative cross-section on natural lead have been performed on the PF1B instrument of the ILL reactor (Grenoble, France). The experiment was conducted to obtain additional information to explain an anomalously high value of the neutron spin rotation in the measurements of transmission of transversely polarized neutrons through a sample. A constraint on the effect in the radiative capture $\alpha_\gamma \leq 8.1\cdot10^{-7}$ was obtained. A theoretical analysis was performed and calculations of P-odd effects in the interactions of polarized neutrons with natural lead were made. The calculations were done for two sets of resonance parameters. For further investigation of parity violation effects in lead two experiments may be suggested to be carried out: the measurement of the asymmetry in total cross section and in radiative capture cross section. Though these effects are much weaker than in the spin rotation experiments, but their realization is much easier methodologically.

The experimental coefficients of the left-right and P-odd asymmetry in the integral spectrum of γ-quanta in the interaction of nuclei with polarized thermal neutrons have been analyzed. From the results it follows that in all cases when a significant effect is observed in the measurements of the P-odd asymmetry, the coefficient of the left-right asymmetry is much less than the coefficient of the P-odd asymmetry, while according to the theoretical calculations one expects that they should be approximately the same for the integral spectrum of the thermal energy of neutrons from one and the same nucleus. No left-right asymmetry has been reliably observed in the nuclei under study except for bromide. Since the measured coefficients of the left-right asymmetry are significantly less for ^{nat}La, ^{nat}Cl, ^{nat}Br, than it follows from the calculations, these investigations should be continued at high-flux neutron sources to obtain, if possible, the reliable results on the coefficients of the left-right asymmetry and to clarify the reasons for the deviations between calculations and experiment.

1.2.1.5. Investigations of a possibility to search for space parity violation effects in neutron diffraction

Neutron diffraction investigations with a potassium bromide single crystal in the vicinity of p-wave resonance of ^{81}Br have been carried out on beam 1 of the IBR-2 reactor. Neutron diffraction spectra for three neutron angles of incidence on a single crystal are presented in **Fig. 28**. It can be seen that the rotation of the crystal through 100" results in the splitting of the 1st order diffraction peak and in a shift of the 2nd order diffraction peak. The observed effect is most likely connected with three-wave neutron diffraction (multiple scatterin).

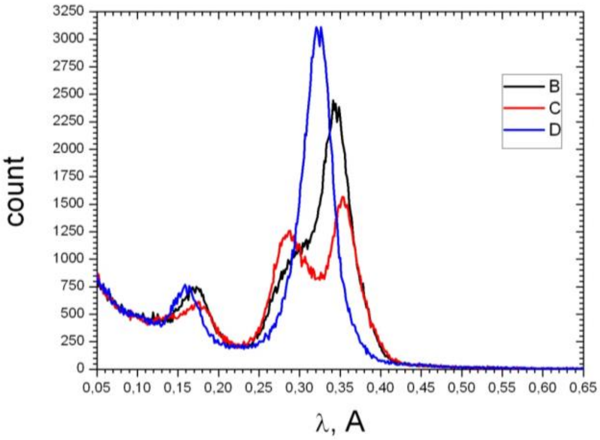

Fig. 28. Neutron diffraction spectra. The blue line is exact satisfaction of Bragg conditions, the black line – the crystal is rotated through 60'', the red line – the crystal is rotated through 100''.

In order to verify the multiple scattering effect in neutron diffraction, it has been decided to perform investigations with neutrons in the lower energy range. The results of the measurements are presented in **Fig. 29**. One can see that the 2nd order diffraction peak is larger than the 1st order diffraction peak and it can be explained only by three-wave neutron diffraction (multiple Bragg scattering).

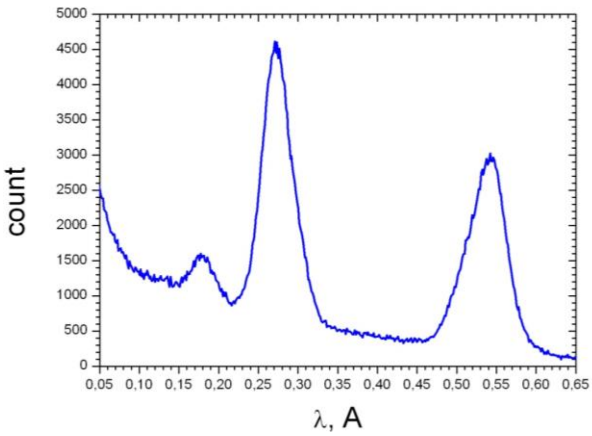

Fig. 29. Neutron diffraction spectra of single crystal KBr, 1st order diffraction peak corresponds to the neutron wavelength of ~ 0.55 Å.

12.1.6. Investigations of (n,p), (n,α) reactions

The experimental and theoretical investigations of the (n,p), (n,α) reactions induced by fast neutrons continued. The experiments are carried out at the Van de Graaf accelerators EG-5 in FLNP JINR (Dubna, Russia) and EG-4.5 of the Institute of Heavy Ion Physics of Peking University (Beijing, China). Data on the neutron reactions with the emission of charged particles induced by fast neutrons are of much interest for studying the mechanisms of nuclear reactions and atomic nuclear structure. In addition, these data are of importance in choosing engineering materials and in performing calculations in the development of new facilities for nuclear power engineering.

At the end of 2013 the measurements of the ^{66}Zn(n,α)^{63}Ni and ^{144}Sm(n,α)^{141}Nd reactions at E_n=4 MeV were conducted, thus completing a series of measurements that started a year ago. The measurements of the ^{54}Fe(n,α)^{51}Cr reaction were also carried out at E_n=5.5 and 6.5 MeV. The energy spectra of charged particles were obtained and the data treatment is in progress.

The data treatment for the measurements of the ^{57}Fe(n,α)^{54}Cr and ^{63}Cu(n,α)^{60}Co reactions at E_n~4.0-6.5 MeV has been completed. A comparison with the available library estimates and with the data obtained by other authors has been performed (**Fig. 30, 31**).

The analysis reveals a significant discrepancy between the estimates given by different nuclear data libraries, while no experimental data are available for ^{57}Fe isotope. The available data for ^{63}Cu from two rather old measurements in the range of several MeV show a considerable discrepancy.

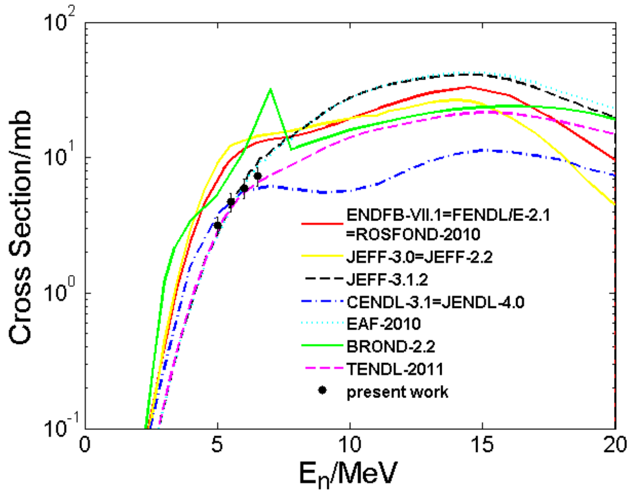

Fig. 30. The obtained cross sections of $^{57}Fe(n,\alpha)^{54}Cr$ in comparison with the available library estimates and with the data obtained by other authors (left).

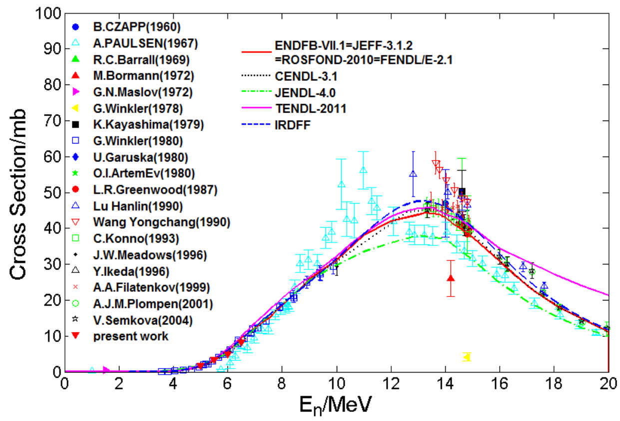

Fig. 31. The obtained cross sections of $^{63}Cu(n,\alpha)^{60}Co$ in comparison with the available data and estimates(right).

A theoretical analysis of the cross-sections (averaged over the fission spectrum) of the (n,p), (n,α) reactions has been done in the framework of the statistical model. The cross-sections of the (n,p), (n,α) reactions induced by fast neutrons are of importance, on the one hand, for evaluating the production of hydrogen and helium, the nuclear heating and transmutations in constructional materials for nuclear power engineering; on the other hand, the systematic analysis of neutron cross-sections is required in studies of the mechanisms of nuclear reactions. Additionally, it is often necessary to estimate the neutron cross-sections for the nuclei, for which the experimental data are unavailable or may be difficult or impossible to be obtained. The statistical model based on the Weisskopf-Ewing theory was used for systematic analysis of the known experimental cross-sections of the (n,p), (n,α) reactions averaged over the fission neutron spectrum of ^{235}U. Since the main objective of the research was to obtain the averaged systematic behavior of the cross-sections of the (n,p), (n,α) reactions for intermediate and heavy nuclei in the energy range of the neutron fission spectrum, the detailed Hauser-Feshbach theory, which employs the optical potential depending on the specific properties of nuclei, was not considered. For the intermediate and heavy nuclei (Z >> 1) the following formulas were obtained:

$$\sigma(n,p) = C_p \pi (R + \lambda/2\pi)^2 e^{-K_p \frac{N-Z+1}{A}},$$

where $C_p = \exp\left(Z A^{1/6} \frac{2\gamma - 1}{\sqrt{13.5(E_n + Q_{np})}} \right)$, $K_p = 4\xi \sqrt{\frac{A}{13.5(E_n+Q_{np})}}$

$$\sigma(n,\alpha) = C_\alpha \pi (R + \lambda/2\pi)^2 e^{-K_\alpha \frac{N-Z+0.5}{A}},$$

$$C_\alpha = 2exp\sqrt{\frac{A}{13.5(E_n + Q_{n\alpha})}}\left(-3\alpha + \gamma\left(\frac{4Z}{A}\right) + \varepsilon_\alpha - 2.058\frac{Z}{A^{1/3}}\right), K_\alpha = 2\xi\sqrt{\frac{A}{13.5(E_n + Q_{n\alpha})}}.$$

Here Z, N, A are the neutron, proton and mass numbers of the target nuclei, respectively; α, γ, ξ are the Weizsäcker constants; ε_α is the binding energy of the α-particle. The parameters K_i and C_i (I = p or α) for each neutron energy can be obtained from the corresponding dependences in the available experimental data. In **Figs. 32 a** and **b** the values of the cross-sections for the mean neutron energy of 5 MeV (calculated in accordance with the above formulas with the parameters $K_p = 80$, $C_p = 2.8$, $K_\alpha = 65$, $C_\alpha = 0.04$) are compared with the experimental data.

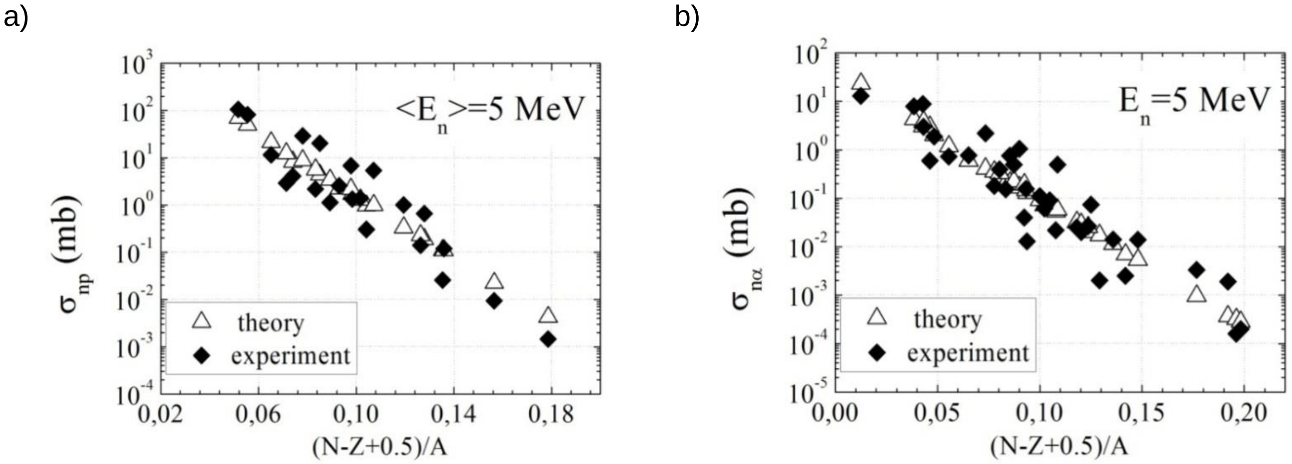

Fig. 32. a) Theoretical and experimental cross-sections of the (n,p) reactions. b) Theoretical and experimental cross-sections of the (n,α) reactions.

1.2.1.7. Investigations of nuclear structure

The first variant of a promising practical model of the cascade gamma-decay of the neutron resonance has been developed on the basis of the Strutinsky model for the density of n-quaziparticle levels and the Kadmensky-Markushev-Furman model for radiation widths of E1-transitions between highly excited levels using some phenomenological representations. The model is based on the results of the analysis performed in FLNP JINR of the experimental data obtained to date on the intensities $I_{\gamma\gamma}$ of two-quantum cascades between the neutron resonance and the group of its low-lying levels. The model suggests that the co-existence and interaction of fermion and boson components of nuclear matter can determine the properties of the latter in an excitation energy interval equal to or slightly larger than the binding energy of the neutron in the nucleus.

In the implemented variant the model has made it possible to describe the intensities of such cascades with a precision of the experiment for the available set of 40 compound nuclei in the mass region from ^{40}K to ^{200}Hg. The existing so far model descriptions of the nucleus as a purely fermion system repeat these data with an error from several tens to hundred percent (or even higher).

The investigations have demonstrated that neutron resonance gamma-decay spectra and probably neutron-nucleus interaction cross sections can be calculated with the precision of the present-day experiments when the breakup of maximum four Cooper pairs of neutrons (and/or protons) are taken into account. Thus, our model makes it possible to gain fundamental information (which cannot be obtained using other experimental techniques) about the properties of nuclear matter in an object of finite size containing charged and neutral fermions and others.

As an example, the results of the model approximation to the cascade intensities in three even-odd isotopes of tungsten are given below (**Fig. 33**). The experimental data were obtained in one and the same experiment. Correspondingly, small experimental errors are strongly correlated and cannot explain the difference between the experimental data and calculations, which use the model representation of the nucleus as a purely fermion system.

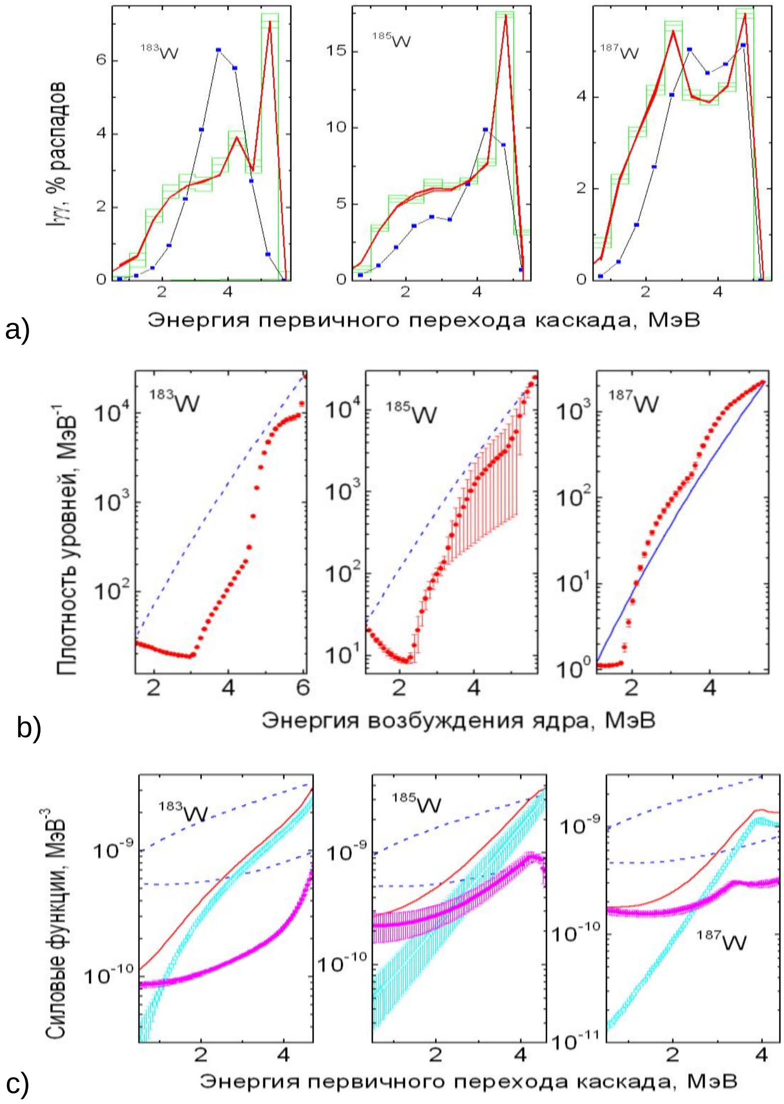

Fig. 33. **a**. Histograms comparing experimental cascade intensities (along with experimental errors) and calculations using the statistical representation of the nucleus and generally accepted models of the level density and radiation strength functions (blue points). The red lines denote a group of seven best approximations, which differ in the initial data of the proposed model and stochastic ways of the χ^2 minimization processes. A very narrow spread of these data shows that for the realized model there is only one minimum of the likelihood function. **b**. The red points with errors denote the mean value of the best approximated level density and their spread for the above seven variants of approximation. The blue line denotes the density of intermediate cascade levels for the Fermi-gas model. The break points are the most probable pair-breaking thresholds of the next Cooper pair of nucleons in the nucleus. **c**. The upper blue lines show the extrapolation of the tail of a giant dipole electric resonance; the lower lines show the KMF models summated with the constant strength functions of M1-transitions. The blue and magenta points with errors show the strength functions of E1- and M1-transitions and their spreads, respectively. The red lines denote the mean value of the sum of the strength functions of E1- and M1-transitions providing best approximation of $I_{\gamma\gamma}$ (without coefficients accounting for the ratio between the model and approximated level densities (**Fig. 33 b**)).

This is a direct consequence of the fact that the coefficients of the error recalculations from the errors of the level density and strength functions to the $I_{\gamma\gamma}$ errors increase sharply when the energy of the primary transition of the cascade decreases and can exceed the value of 10^2-10^3.

A step-like structure of the most probable level density can be explained only in the frame of the model which suggests that the number of unpaired neutrons and protons (quasiparticles in terms of the theoretical models of the nucleus) increases by two at threshold energies of Cooper pair breakup. The necessity to use in the experimental analysis the fully phenomenological representations of the boson excitation density and width of gamma-transitions at their decay/excitation causes inevitable systematic errors in the obtained data for both level density and strength functions. At the moment, there are no proper models for experimental analysis, which would account for the successive breaking of Cooper pairs and describe the corresponding parameters of the boson component of the nucleus.

A significant but finite spread of the data for the fixed multipolarities of gamma-transitions and its practical absence for their sum is indicative of a strong anticorrelation of the density of the levels with the given parity and the multipolarity of primary transitions exciting them. However, this correlation is significantly lower as compared to the data of other experiments performed so far.

1.2.1.8. Search for the singlet state of the deuteron

An experiment to search for the singlet deuteron in the reaction $n + p \rightarrow d + 2\gamma$ has been conducted on beam 11b of the IBR-2 reactor. Gamma-quantum spectra from a polyethylene target have been obtained using an HPGe detector. The peak corresponding to a direct transition with an energy of 2223 keV contains $2{\cdot}10^8$ counts. The upper boundary for the cross section of emitted gamma quanta with an energy in the range of 2100-2200 keV was found to be of the order of 15 μb (at the level of 3σ) which is half the value obtained by R.Hackenburg (BNL). It is planned to continue this experiment with an improved technique and new software. There is also a probability to carry out this experiment in Grenoble.

1.2.1.9. Modernization of the "Kolkhida" setup

The "Kolkhida" setup intended for studies of neutron optics phenomena in interactions of polarized neutrons with polarized nuclei has been constructed at the IBR-2 pulsed reactor. The "Kolkhida" instrument consists of the following components: polarized neutron spectrometer, polarized nuclear target, control system. The polarized neutron spectrometer is located on the tangential beam 1 of the IBR-2 pulsed reactor. The layout of the spectrometer is shown in **Fig. 34**.

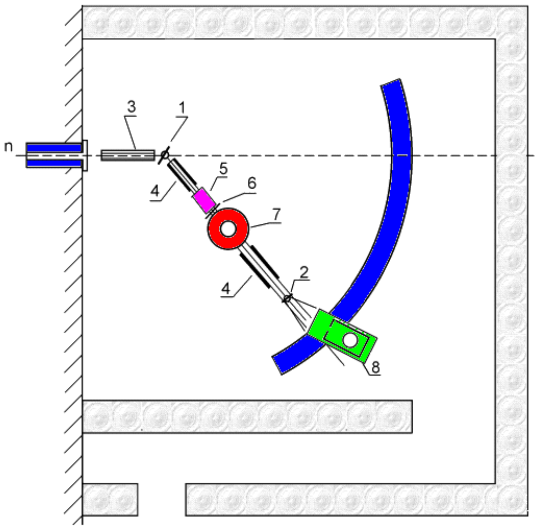

Fig. 34. The layout of the spectrometer: 1 – primary collimator; 2 – Soller collimator; 3 – polarizer crystal; 4 – guiding field electromagnets; 5 – Mezei flipper; 6 – shim; 7 – cryostat; 8 – analyzer crystal; 9 – detector.

Within the framework of the preparation of the “Kolkhida” setup for regular operation the modernization of control electronics of actuating mechanisms has been carried out. In particular, for the polarized neutron spectrometer the stepper motors FL57STH76-1006B for changing the angular position of the detector arm, platform, polarizer and analyzer have been installed. To determine the rotation angles, angle sensors OCD-SL00B-0016-C100 CRW have been set up. The rotation of various components of the setup is controlled by a computer program. The program uses the algorithm that accounts for the motor play. Thus, the angles can be specified with an accuracy of $< 0.1°$. Another computer program controls a power supply, which allows us to set the current in the superconducting solenoid to 110 A with an accuracy of 5 mA.

A polarized nuclear target has been modernized as well. The infrastructure of a ^{3}He-in-^{4}He dilution cryostat has been upgraded by replacing outdated vacuum devices with modern ones; a new dilution bath and a new component of the cryostat for neutron scattering studies of samples in a strong magnetic field and at room temperature have been developed (**Fig. 35**).

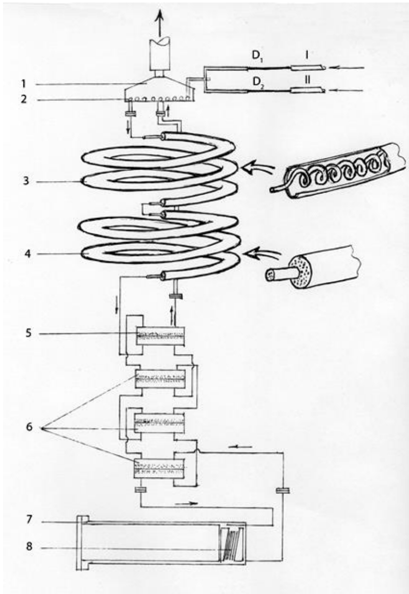

Fig. 35. General view and diagram of ^{3}He-^{4}He dilution stages: 1 – evaporation bath; 2 – evaporation bath heat exchanger; 3 – continuous heat exchanger; 4 – continuous sintered heat exchanger; 5 – discrete copper heat exchanger; 6 – discrete heat exchangers of sintered silver powder; 7 – dilution bath; 8 – ferromagnetic neutron resonator with polarized nuclear target.

1.2.1.10. Experimental study of the possibilities of cold neutron accumulation at the end of a thermal neutron beam line

Earlier we proposed a project of a new high-intensity UCN source capable of producing ~10^8 UCN/s with the UCN density in the storage volume reaching 10^5 n/cm^3, which is 3 orders of magnitude higher than that of the available sources. The idea consists in producing the flux of cold (wavelength of 9 Å) neutrons by using a helium UCN source in the cavity of the moderator/reflector placed at the end of a neutron guide with thermal neutrons. In this case the cavity itself is a source of cold neutrons. Solid methane was proposed to be used as a moderator/reflector. Thus, the source is a spherical vessel filled with liquid helium at a temperature of 0.6 K and surrounded by a solid methane moderator. This layout of the source makes it possible to position it on extracted thermal neutron beams, which reduces many fold the heat load on the source and, accordingly, its cost as compared to the sources located near the reactor core. This allows the range of applications of UCN to be extended many times and to use them not only for scientific research but for applied and educational purposes as well.

Test measurements have been carried out to test the idea of using a cavity of solid methane for producing a cold neutron flux at the end of a neutron guide with thermal neutrons. For these measurements a special cryostat was designed and constructed in 2012-2013. The test measurements were done in 2013 on the DIN-2PI instrument on beam 2 of the IBR-2 reactor. The instrument is intended to measure the inelastic neutron energy transfer by the time-of-flight method. The preliminary results on the measurements of the neutron spectrum formed in the methane cavity under irradiation of neutrons with an energy of 25.0 eV (wavelength 1.8 Å) are presented in **Fig. 36**.

The Maxwellian neutron spectra corresponding to various temperatures are shown for comparison with the measured spectrum. One of them is the spectrum at which the maximum number of neutrons with the wavelength of 9 Å (T = 6 K) is achieved. The second one is the neutron spectrum in one of the neutron guides at the cold moderator of the ILL reactor (France) (T = 15 K). The integrals of all spectra are the same. On the basis of the results of the measurements, it has been estimated that methane albedo for the spectrum that is presented in **Fig. 36**, is ~ 65%, which is very close to the preliminary calculated estimates that follow from the energy dependence of the cross-sections.

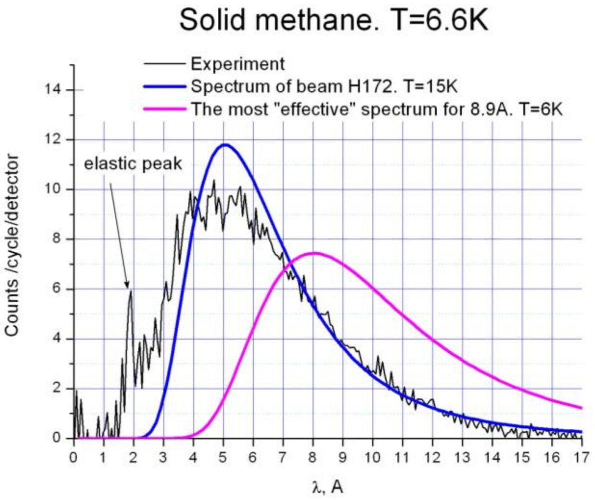

Fig. 36. Spectrum of neutrons moderated in the methane cavity.

The results of the test measurements show that one can obtain the neutron spectrum close to that from the cold reactor source by using the thermal neutron beam inside the methane cavity. The albedo of solid methane for cold neutrons is close to the calculated value. Thus, the idea of a helium UCN source inside a cold cavity at the end of a neutron guide with thermal neutrons appears feasible. The next step in the development of the given idea is to construct a prototype of the source to test the solutions for a number of technical problems. Further optimization of the temperature of the moderator is possible at the prototype UCN source using the yield of cold neutrons, since the contribution of multi-phonon processes in the UCN production can be significant.

1.2.1.11. Investigations of UCN physics

In the framework of the UCN collaboration (LANSCE, Los Alamos) inelastic scattering (UCN upscattering) cross sections for vanadium, V, and polyethylene, $[C_2H_4]_n$. have been measured and published. Such measurements are of contemporary importance since these materials are widely used in UCN experiments, but the available data are conflicting and often do not agree with the theory. The measurements have been performed using a solid-deuterium ultracold neutron source driven by an 800-MeV proton beam. The performed measurements are based on the comparison between V and $[C_2H_4]_n$ ratios of count rates from a γ-detector and neutron scattering detector using the known values of radiative capture cross sections. The measurements with the γ-detector (high purity germanium detector HPGe) and neutron detector (^{3}He gas counter) were carried out simultaneously. For the UCN velocity spectrum with an average velocity of 4 m/s the upscattering cross section values of 1970 ± 130 b and 25 ± 9 b have been obtained for polyethylene and vanadium, respectively. The result for vanadium has been obtained for the first time, and it is in agreement with the theoretical value. A comparison with the data from other experiments has shown that the result for polyethylene agrees only with the value obtained by Yu.Pokotilovski in Grenoble, but it is much lower than the model value of 3500 b obtained from extrapolation to 4 m/s using MCNP calculations with the available thermal neutron data library.

Within the framework of the same collaboration a measurement of the average energy of the flux of upscattered neutrons after the interaction of UCN with hydrogen bound in polycrystalline polymer PMP, $[C_6H_{12}]_n$, has been performed. This study is of interest for comparison with the UCN upscattering in polyethylene, $[C_2H_4]_n$, and in the context of the as-yet-unresolved problem of UCN losses during storage. The measurement has been conducted at the Los Alamos National Laboratory solid-deuterium ultracold neutron source. The ratio of count rates of scattered neutrons for two detectors of different efficiencies has been measured and this ratio depends on the shape of the spectrum of the flux and its average energy. Gas ^{3}He detectors with a partial pressure of 180 kPa in one detector and 20 kPa in the other detector were used. To obtain the result, the measured ratio was compared to the calculations for different average energy values using the MCNP program in which the modeling of scattering is mainly based on one-phonon approximation and also takes some account of multiphonon processes of inelastic neutron scattering. This modeling has demonstrated that the energy spectrum of the neutron flux is clearly not Maxwellian. We obtained an average energy value of 26 ± 3 meV for polymer PMP (polymethylpentene), which is twice as much as the value of 10-13 meV for polyethylene that was obtained earlier in the analysis in the frame of Maxwellian approximation. Finally we adduce some arguments, which allow us to expect close average energy values for $[C_6H_{12}]_n$ and $[C_2H_4]_n$.

1.2.1.12. Cooperation in the framework of the GRANIT project in ILL (France)

FLNP JINR in cooperation with the P.N.Lebedev Physical Institute of RAS and Virginia State University (USA) are the members of the GRANIT collaboration. The GRANIT project aimed at designing and building a second-generation gravitational neutron spectrometer with ultra-high energy resolution GRANIT (**GRA**vitational **N**eutron **I**nduced **T**ransitions). This spectrometer will make it possible to observe resonance transitions between neutron quantum states in the Earth's gravitational field. It is planned for the first time to directly measure the energy of quantum states. The storage time of UCN in quantum states for this spectrometer is expected to reach values of the order of a second.

By the end of 2013 all the main units of the spectrometer have been put into operation and tested. The UCN source designed for the spectrometer operates reliably and neutrons from the source have been extracted into the spectrometer. The spectrum of the neutrons extracted into the spectrometer has been obtained and turned out to be a very soft one. In connection with the shutdown of the reactor in ILL (from August, 2013 to July, 2014) where the GRANIT spectrometer is located, the collaboration is conducting research activities on the improvement of parameters of the UCN source and neutron detection system.

1.2.1.13. Continuation of the experiment to test the equivalence principle for the neutron

The experiment to verify the equivalence principle for the neutron with the UCN spectrometer Epigraph designed and constructed in 2010-11 has continued. The operation of the instrument is based on the combined use of Fabry-Perot neutron interferometers and neutron flux modulator-chopper (see **Fig. 37**). A change in the energy of the neutron falling in the gravitational field is compared with the energy transferred to the neutron diffracted into the –1 order by a moving diffraction grating.

Fig. 37. Chopper-modulator.

A specific feature of the instrument is the possibility of using an original time-of-flight technique based on the measurement of the detector count rate oscillation phase. The detection of UCN is performed by a scintillation detector synchronized with a modulator. A high degree of beam monochromatization (Δv/v < 2%) makes it possible to work with the times of flight, which many times exceed the modulation period, thus ensuring a unique energy resolution of the instrument.

A full-scale test experiment with new Fabry-Perot interferometers and new diffraction grating has been conducted on the UCN beam of the Institute Laue Langevin (Grenoble, France). A number of improvements have been made in the design of the instrument. As a result, the experimental conditions have been significantly improved (see **Fig. 38** and **39**).

The count rate and the effect/background ratio have increased considerably. An increase in the count rate oscillation amplitude has made it possible to increase the modulation frequency and hence to enhance the sensitivity of the experiment.

As a result, the statistics collection rate in the experiment increased three times (from 1.5×10^{-2} events per day in 2011 to 5×10^{-3} events per day) which reduces the statistics collection time by almost an order of magnitude.

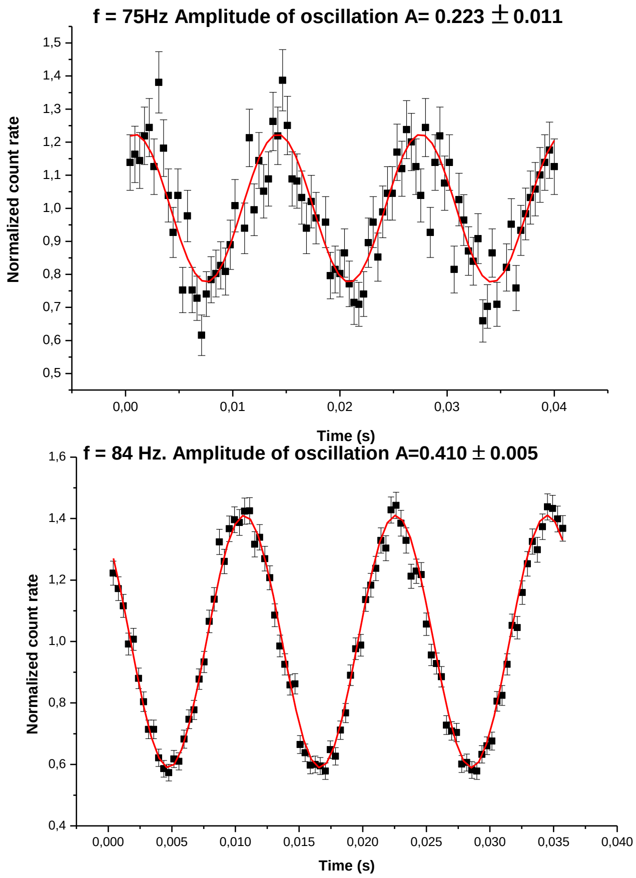

Fig. 38. Count rate oscillation in the experiment in 2011 (top) and in the new experiment

At the same time, the experimental results are indicative of some systematic effects, which should be studied and eliminated in the next stage of the experiment.

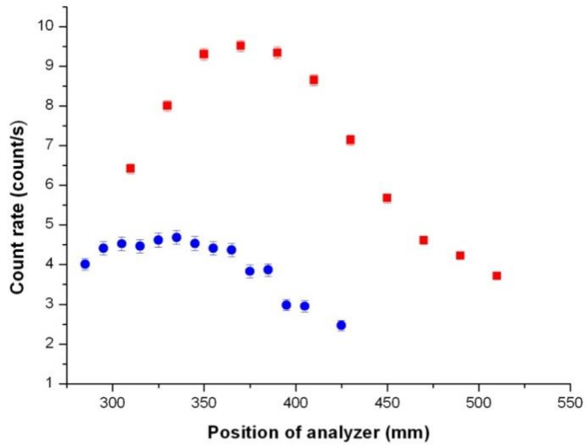

Fig. 39. Neutron scanning (spectrum) curve in the –1 order of diffraction from a moving grating in the experiment in 2011 (blue circles) and in the new experiment (red squares).

1.2.1.14. Search for new type interactions

The interferential method to search for new hypothetical interactions has been considered. At present, the chameleon scalar fields are considered to be a possible reason for the acceleration of the expansion of the Universe. The presence of a chameleon field results in a change in the particle's potential energy in the vicinity of a massive body. A neutron Lloyd's mirror interferometer has been proposed for a highly-sensitive search for effects of the chameleon field, where the interaction of neutrons with the reflecting mirror results in a phase shift of neutron waves.

Possible neutron interferometer experiments to search for new interactions, both spin-dependent (axion interaction) and spin-independent (short-range non-Newtonian gravity), have been analyzed.

1.2.2. Methodical and applied research

1.2.2.1. Activities in cooperation with the Space Research Institute of RAS

The activities to design equipment for studying the planets in the Solar system are in progress. In 2013, the calibration of the neutron detectors and gamma-spectrometer of the scientific instrument "Mercury Gamma-ray and Neutron Spectrometer" (MGNS) was done. MGNS will be placed on board *BepiColombo* European Space Agency interplanetary mission to be launched in 2015. The instrument is intended to search for water ice and to determine the elemental composition of the Mercury shallow subsurface.

The monitoring of the neutron yield of the pulsed neutron generator ING-10K is conducted. An identical generator is a part of the scientific instrument "Dynamic Albedo of Neutrons" (DAN) onboard NASA's Mars rover "Curiosity".

1.2.2.2. Analytical and methodical investigations at the IREN facility

The investigations aimed at detecting cosmic dust in the soil samples from a high-mountain glacier Aktru in Altai continued on a neutron beam of the IREN facility using neutron spectroscopy techniques. The treatment of the data from the neutron transmission measurements with the novel multifunctional materials prepared in the Belarussian State University (Minsk) continued. The research objective was to determine the boron content in the samples. The comparative investigations of ore samples provided by the Central Geological Laboratory of the Mongolian Ministry of Natural Resources and Energy were carried out to further develop the nondestructive testing method for determining the elemental/isotopic composition of samples using neutron spectroscopy techniques. In one case the measurements were performed using the neutron resonance capture analysis, and in the other, employing the activation technique. The results of both methods are in good agreement, but at a given intensity of the IREN facility the activation technique is more sensitive.

In 2013 the radiation tests of scintillators and megatile samples of the CMS setup (CERN) were performed. It was necessary for the optimization of the conditions for future experiments. The neutron spectrum at IREN is close to that at the CMS hadron calorimeter. The samples were irradiated by the total fluence of 10^{12} n/cm^2. Then during three weeks the induced activity was measured at two distances from the sample. The emitted gamma-radiation was measured by a Canberra HpGe-detector.

Several methods for direct measurements of the fast neutron spectrum of the IREN facility have been probed. The use of a fission chamber with ^{235}U target and current preamplifier for reading signals proved to be rather promising. The application of such equipment along with the high time resolution of the facility (100 ns) makes it possible to detect neutrons with an energy of up to 20 MeV (see **Fig. 40**) at a flight path of 60 m. However, in the energy range above 3 MeV there is some deviation between the measured and calculated (by the Monte-Carlo method) flux density. The investigations will continue.

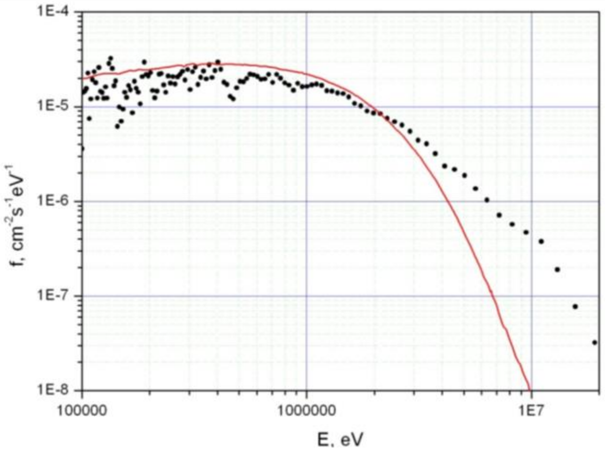

Fig. 40. Neutron flux density of the IREN facility at a 60 m flight path: points are the experimental values; the line is the calculation by the Monte-Carlo method.

1.2.2.3. Analytical investigations on the charged particle beams of the EG-5 accelerator

Over the past year the EG-5 accelerator was in operation for various experiments for about 600 hours. The investigations of depth profiles of elements using nuclear analytical techniques: RBS (*Rutherford Backscattering Spectrometry*) and ERD (*Elastic Recoil Detection*) have been carried out in cooperation with the representatives from various research institutes of the JINR Member States. The specialists from FLNR, DLNP, Voronezh State University, Tomsk Polytechnic University, Marie Curie-Sklodowska University (Lublin, Poland) and Institute of Electrical Engineering of the Slovak Academy of Sciences (Bratislava, Slovak Republic) took part in the experiments. The samples of different elemental composition and prepared using various technologies have been analyzed. In particular, the depth profiles of elements in the samples of nanocrystalline silicon carbide films prepared using PECVD (plasma-enhanced chemical vapor deposition) technology have been investigated. A study of electrical and optical characteristics of films depending on their elemental composition has been carried out.

The depth profiles of hydrogen and deuterium in the samples prepared for studying the nuclear reaction $d(d,\gamma)^3He$ at low energies have been investigated also using nuclear analytical RBS and ERD techniques.

1.2.2.4. Analytical investigations at the IBR-2 reactor

Development of the NAA Sector experimental base

In the reported period the software package has been developed for complex automation of the neutron activation analysis on the IBR-2 reactor, which includes:

- database of samples under study and of all operations for performing NAA;
- software for automation of induced activity spectrum measurement using the Genie-2000 software for collection and analysis of spectra and the S561 Genie-2000 batch programming support package;
- software for automation of calculations of element concentrations on the basis of the results from the treatment of gamma-spectra by Genie-2000 software;
- set of service programs for automation and facilitation of database creation;
- set of assistance programs for ensuring convenience in performing some QC/QA procedures.

In the process of training the personnel to work with the program package, the software underwent development and upgrade. A partial modernization of the mechanical part of the pneumatic transport facility has been carried out. Work to develop and construct automatic sample-changing devices on three detectors is in progress (devices for two-axial linear movement of samples have been purchased; other component devices have been designed and are being manufactured).

The devices that provide linear movement of samples have been tested at a test stand. The design of a control program for automatic sample-changing devices combined with the program for spectrum measurement automation is in progress.

The activities on automation of NAA at the IBR-2 reactor are conducted in the framework of the IAEA Coordinated Research Project «Development of an Integrated Approach to Routine Automation of Neutron Activation Analysis" (F1.20.25/CRP1888, Contract No. 17363).

Method development

New packing materials for sample irradiation and for production of transport containers have been tested to select a material with high radiation resistance and low induced radiation background after irradiation. The measurements of thermal and resonance neutron flux densities have been carried out on some neutron beams in new experimental conditions after the completion of the IBR-2 modernization.

Biomonitoring

In 2013, in the framework of the international program "Heavy metal atmospheric deposition in Europe – estimations based on moss analysis" the multielement analysis of 330 moss-samples from Romania (NAA in Dubna and atomic absorption spectroscopy (AAS) in Valahia University of Targoviste) was completed. The samples were collected by the participants of the JINR-Romania project from four Romanian universities in Targoviste, Galaţi, Baia Mare and Iaşi. A statistical analysis of the obtained data for 34 elements has been performed and the preparation for the publication of the Atlas of Atmospheric Deposition of Trace Elements in Romania has been conducted. The results of this work will be reported at the forthcoming 27th Task Force Meeting of UNECE ICP Vegetation (January 28-30, 2014, Paris). The contribution of the NAA Sector to the European Atlas of Heavy Metal Atmospheric Deposition is reflected in the publications of the Sector for Slovakia, Macedonia, Albania, Croatia. A student's degree thesis has been performed on the assessment of atmospheric deposition of trace elements near a thermal power plant in the territory of Ochakovo-Matveevskoe district of Moscow. The work on the active moss-transplant biomonitoring of airborne trace elements allowed us to study the air pollution in the center of Belgrad, Serbia, as well as in one of the most ecologically unsafe regions of Greece – Greater Thriasion Plain, Attica. The efficiency of using moss-biomonitor technique to study atmospheric depositions of radionuclides has been demonstrated in the joint projects carried out in collaboration with Slovakia, Belarus, South Africa, Serbia and Thailand.

Ecosystem condition assessment

In 2013, the multielement analysis of soils and bottom sediments from various regions of the Nile delta and its near-shore area continued in the framework of the joint JINR-Egypt project «Assessment of the environmental situation in the delta of the Nile River using nuclear and related analytical techniques». It has been shown that the element composition of these samples is determined mainly by geochemical features of the region under study and is not affected by the anthropogenic load.

Within the framework of the Cooperation Agreement with the Institute of Biology of the Southern Seas (Sevastopol, Ukraine) the analysis of macroalgae-biomonitor samples in the coastal zone of the Black Sea has been performed to assess the state of the coastal ecosystem of the Crimea. A technique of sampling and preparation of plankton for NAA on the IBR-2 reactor has been developed and the element composition of 30 samples has been determined. The obtained results have shown that plankton can be successfully used as a biomonitor of water ecosystems.

The results of complex investigations of air pollution using mosses and lichens as well as of water ecosystem using mollusks and oysters near a growing port in Cape Town (Saldanha Bay, the

Atlantic Ocean near the West coast of the Republic of South Africa) have aroused considerable interest among environmental specialists of the Republic of South Africa and *willingness to cooperate in this research area*. In collaboration with the University in Stellenbosch the international project proposal "Mollusks as Biomonitors of Water Ecosystems in the Republic of South Africa" has been submitted for the NFS-RFBR competition for 2014 (reg. number 14-05-93963).

Two joint papers of the NAA Sector and the Analytical Center of the Geological Institute of RAS concerning the application of nuclear physics analytical methods for studying the quality of food, in particular, of basidiomycetes (mushrooms) of the European part of Russia have been completed and accepted for publication in the leading American journal *Advances in Microbiology*, and the paper on the determination of Cl, Br, I and Se in human body – in *Environmental Geochemistry and Health*. The studies of agricultural plants subjected to bioenergy activation have been carried out in collaboration with I.Javakhishvili Tbilisi State University, Georgia (submitted to *Agricultural Chemistry*, 2013).

Geology

In the framework of the joint JINR-Romania project the analysis of bottom sediments and rocks of two semiclosed ecosystems of the glacial lake Balea (Fagaras mountains) and the crater lake St. Ana (Harghita mountains) have been performed to assess the level of anthropogenic pollution and to find the source of origin of bottom sediments. It has been shown that according to the Romanian standards the content of potentially toxic elements (Cr, Co, As, Sb, Se) is comparable to that of the natural environment. Further data treatment (R-mode, principle component analysis) separately for each lake has revealed that Sr, Cr, Co, on the one hand, and As, Sb, Br, Se, on the other, create two different clusters with different geochemical properties for these lakes.

In cooperation with the Western Cape University (South Africa) the NAA study of coal fly ash from the Matla coal power station in the Mpumalanga province in South Africa has been conducted. The analytical advantages of NAA using epithermal neutrons in determining the elemental composition of ash have been demonstrated over such methods as inductively coupled plasma atomic emission spectroscopy (ICP-AES), laser ablation inductively coupled plasma mass spectrometry (LA ICP-MS) and X-ray fluorescence (XRF).

Within the framework of the joint project of the NAA sector and the University in Bucharest the elemental analysis of therapeutic muds collected at different sites in Romania has been completed. Further investigations of the structure of the mineral matrix of the muds under study are essential for a better understanding of the significance of increased concentrations of some heavy metals as well as of the role of the organic compounds present in the muds.

Analysis of materials of extraterrestrial origin

In 2013, the intermediate stage of the search for cosmic dust in peat columns collected in Siberia and in the meltwater from the high-mountain glacier Aktru in Altai was completed. The age determination of peat column layers was carried out at the Adam Mickiewicz University in Poland. The particles detected by means of electron microscopy along with the results of the neutron activation analysis of peat column samples (judging from the iron/nickel concentration ratio) allow us to assume that these particles could be of extraterrestrial origin. The identification of the material collected using magnetic traps in the meltwater from the glacier in Altai is more controversial. The results of these studies were reported and discussed at a seminar in the Sternberg Astronomical Institute of the Moscow State University in October, 2013.

Anthropological research

In the framework of the RFBR project (№12-06-00096/13 due to be completed in 2013) in cooperation with the Moscow State University (*D.N.Anuchin Research Institute* and *Museum of Anthropology*) the NAA of hair samples of a representative group of children from the Ongudaysk District of the Altai Republic as well as soil and plant samples from the places of their residence has been conducted to find possible correlations between their elemental composition and to reveal the endemic features of the effect of the geochemical environment on the human body.

Biotechnologies

In 2013, in collaboration with the E.Andronikashvili Institute of Physics, I.Javakhishvili Tbilisi State University and I.Chavchavadze State *University* (*Tbilisi*, *Georgia*) the studies continued on the development of methods for synthesis of silver and gold nanoparticles by certain new kinds of bacteria – extremophilic bacteria and blue-green algae *Spirulina platensis*. In combination with a number of optic and analytical methods the neutron activation analysis was used to develop the technology for the synthesis of nanoparticles by the bacteria under study. On the IBR-2 reactor using the NAA method the elemental composition of the microbiological samples containing gold and silver nanoparticles was investigated to assess the possibility of application of the obtained nanomaterials for medical and pharmaceutical purposes. The effect of the synthesis of nanoparticles on the distribution of matrix and trace elements in cells was studied as well.

A second major line of investigation carried out in cooperation with the Institute of Microbiology and Biotechnology of ASM is focused on the biosorption of zinc from wastewater by microalgae *Spirulina platensis*. The elemental composition of microbiological samples and the efficiency of accumulation of zinc and other metals by *Spirulina* biomass were determined using the NAA technique on the IBR-2 reactor. This study was awarded with a gold medal at the V European Exhibition of Creativity and Innovation EUROINVENT 2013, Iaşi, Romania in the category "PhD research project". On the basis of the research results in the field of biotechnologies a PhD dissertation was defended in October, 2013.

Materials science

In 2013, in the framework of the BRFBR-JINR joint grant and in cooperation with the Scientific and Practical *Materials Research Center* of the National Academy of Sciences of Belarus and the specialists in x-ray diffraction and scanning electron microscopy from the University of Galaţi, Romania, the investigations of the changes of nitride characteristics in the Li-N system synthesized at different pressures continued. It has been shown that the increase in nitrogen pressure during the formation of nitrides results in the formation of structures with a higher nitrogen content in the bulk and a smaller crystallite size.

Educational activities.

In 2013, on the basis of the NAA&AR Sector the training courses were held for senior-year students of the University of Dubna and for students and school teachers of International Summer Schools (May-June, July and October, 2013) organized by the JINR University Center, as well as for attendees of the III All-Russian Summer Field Session of the Academic community "Ecos" together with the Summer School “Russian Reporter” (http://letnyayashkola.org/ecos) (July 20 - August 10, 2013).

During the reported period two term papers, four Bachelor’s degree and two Master’s degree theses have been completed in the NAA Sector. Five Ph.D. theses are being written.

1.3. NOVEL DEVELOPMENT AND CONSTRUCTION OF EQUIPMENT FOR THE SPECTROMETER COMPLEX of the IBR-2 FACILITY

In 2013, work in the framework of the theme was focused on several activities connected with the construction and modernization of the equipment, electronic data acquisition and accumulation systems as well as the information-computation infrastructure of the IBR-2 spectrometer complex.

Cryogenic moderator.

In January, 2013 during the last and longest operation cycle of the moderator at a reactor power of 2 MW the research activities were carried out in the framework of the CM-202 commissioning program. All in all, during the start-up period there was five CM operation cycles with fresh loadings of beads composed of a frozen mixture of mesitylene and m-xylene with the duration of the cycles ranging from several hours to 178 hours (the reactor operated for up to 350 MW-hr).

As a result of the analysis of the CM-202 operation in the specified cycles the key questions, which are important for ensuring efficient and long-term operation of the moderator were answered:

- Time of loading beads into the moderator chamber – minimum 4 hours (according to the design 8-10 hours are allowable). Loading proceeds without jams and noticeable defragmentation of beads at a gas flow rate of 1.2-1.5 g/s and a temperature of 80-85 K.
- Hydraulic resistance of the contour and parameters of a gas blower ensure a helium flow rate of 6 g/s (design value is 7 g/s).
- A KGU-700/15 cryogenic refrigerator cools beads in the CM-202 chamber at a reactor power of 2 MW down to an average temperature of 32-33 K (design value is 23-25 K).
- Gain factor for cold neutrons with wavelengths of 8-10 Å is 13-14 (**Fig. 41**) design value is up to 20 at 20 K. Degradation in the cold neutron (6-10 Å) flux for 350 MW-hr is no more than 5-7%; the flux of neutrons with shorter wavelengths increases with a radiation dose.
- Discharge of the spent liquid proceeds rather quickly; the initial solution viscosity increases no more than 10 times after operating for 7.3 days (**Fig. 42**).
- Filling of the chamber and subsequent discharge of mesitylene have no effect on the reactivity of the IBR-2 reactor.

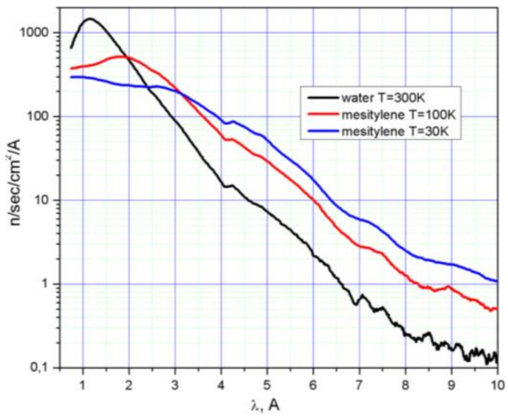

Fig. 41. The differential neutron flux density at the location of a PSD detector for an empty chamber (black line) and for the filled one at temperatures of 100 K and 30 K (left).

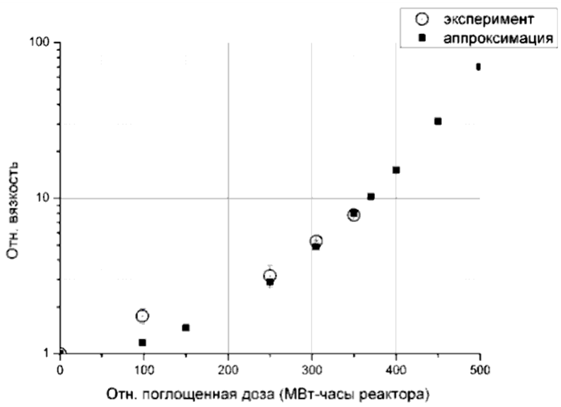

Fig. 42. A change in liquid mixture relative viscosity against a relative radiation absorbed dose (reactor MW-hr), where: circle – experiment, square – approximation (right).

Over the past year the main technological systems of the cryogenic moderator have been fully developed and modernized. In all IBR-2 cycles in a cold moderator mode for physics experiments the

CM-202 has demonstrated stable and trouble-free operation. The moderator control system allows the technicians to control the moderator key parameters (fan shaft rotation speed (gas blower), helium flow rate and temperature, vacuum in pipelines, movement of beads when loading the pipeline) during operation. The characteristics of CM-202 monitoring instruments meet in general the design requirements and make it possible to ensure the operation and maintenance of the moderator in a regular mode. A report on the start-up of CM-202 and its commissioning documentation have been prepared.

We have developed a program and started experiments on irradiation of both the spent liquid and fresh liquid solutions of mesitylene and m-xylene doped with inhibitors of radiolysis of aromatic hydrocarbons on beam 3 of IBR-2. First experiments have showed that the addition of inhibitors may increase the cycle duration up to 9-9.5 days on one loading. These results should be verified for a solid phase of the solution. These investigations are conducted in cooperation with the Chemical Faculty of the Moscow State University.

The design of a cryogenic test stand to study loading, transport and discharging of beads has begun for CM-201—a future cold moderator in the direction of beams 4-6.

Calculation and simulation of spectrometers.

In 2013, special VITESS modules that allow simulation and calculation of neutron time focusing for time-of-flight spectrometers on pulsed neutron sources continued to be improved. Here, the time focusing surface may be approximated by a plane/planes, cylinder/cylinders and sphere/spheres. For the FSD spectrometer the simulation of the ASTRA detector (7 surfaces, **Fig. 43**) with time focusing was performed. The simulation was done for ideal and approximated (modification of a cylindrical surface) time-focusing surfaces. The comparison of the obtained results shows practically no shift in the position of both diffraction peaks. However, a small broadening of the diffraction peak for the approximated surface can be observed. **Figure 44** illustrates an example of simulation of the 4th time-focusing surface of the ASTRA detector (covered angles– 89.0-84.031 degrees; sample dimensions – 0.1 mm × 0.1 mm; d-spacing of Bragg scatterer – 10 Å). All other surfaces of the detector yield similar results. An experimental check showed that the suggested approximation of time-focusing surfaces is feasible for practical realization.

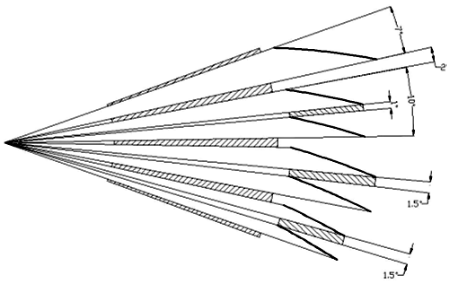

Fig. 43. ASTRA detector in a horizontal plane

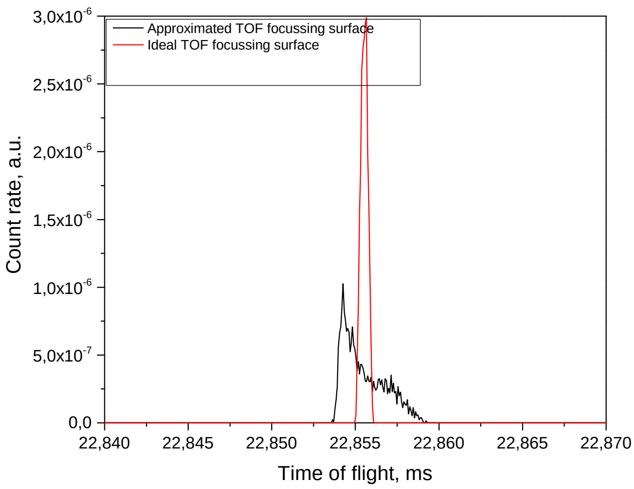

Fig. 44. Example of simulation of the 4th surface.

Using the VITESS software the Monte Carlo calculations have been performed for the project of a new neutron guide for the REFLEX spectrometer with a total length of about 30 m, 1 cm wide and 8 cm high. A special feature of this neutron guide is its small width (1 cm) and considerable height (8 cm). The neutron guide will have a curved part (about 16 m), which will make it possible to reduce the fast-neutron and gamma-ray background at a sample position, and a straight part that will ensure uniform irradiation of samples. The neutron guide is planned to be coated with ^{58}Ni.

In the middle of 2013 we started work on the application of the Reverse Monte Carlo (RMC) method to reconstruct a 3D structure of glasses (or other disordered systems) using neutron diffraction data. An RMC_POT program was used in the calculations. Also, a special program was developed, which allows one to determine coordination of glass atoms using Voronoi networks. This program reads the data obtained by means of the RMC_POT program, and calculates coordination numbers. In particular, for a three-element system FeYB nine coordination numbers are determined. If necessary, two options can be used in the calculations, namely: to build a Voronoi network with regard for ionic radii of particles and to discard the particles for which the Voronoi surface area is less than a specified level. An example of a reconstructed 3D structure from diffraction data for FeYB glass with the help of the RMC_POT program is given in **Fig. 45**.

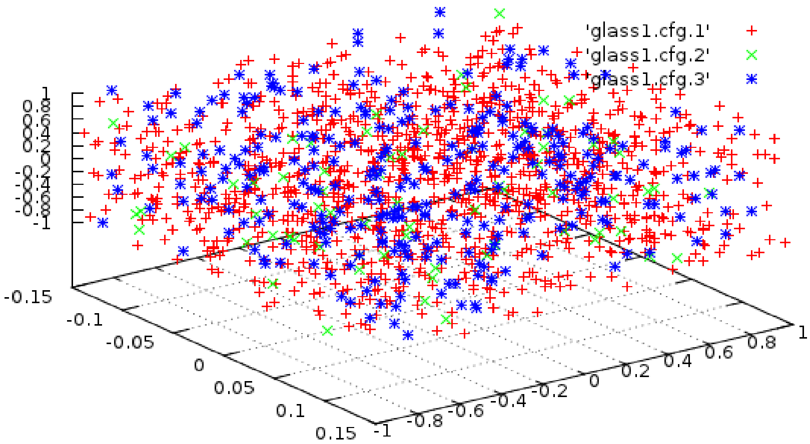

Fig. 45. Example of a reconstructed structure of FeYB glass (Fe atoms – red, Y atoms – green, B atoms – blue).

Development and production of equipment for new and modernized spectrometers.

The work continued on the construction of a new high-resolution Fourier diffractometer on beam 13 of the IBR-2 reactor on the basis of the units of the FSS spectrometer (Fourier Stress Spectrometer), which had been used for a long time in the GKSS Research Centre (Geesthacht, Germany). In accordance with a concluded contract with PNPI the FSS spectrometer equipment packaged in containers has been transported to Dubna. At present, the equipment is being checked and a design study of its layout and installation on IBR-2 beam 13 is in progress. On the same beam the infrastructure for testing spectrometer equipment is under construction.

Fig. 46. Ring-shaped helium backscattering detector on the RTD diffractometer.

A ring-shaped helium backscattering detector along with 8-channel analog electronics and multichannel data accumulation electronics (MPD) has been developed and produced for the **RTD diffractometer** (DN-2) intended for real time studies of transient processes. The detector system has been adjusted and tested at a test stand, and then installed on IBR-2 beam 6a (**Fig. 46**) where the first stage of tests has been carried out. After the background shielding is manufactured and installed, physical characteristics of the detector will be measured and it will be put into service in a regular mode. A 2D position-sensitive detector on RTD operates with a PC-built-in data acquisition and accumulation electronics module De-Li-DAQ1. In the near future it will be replaced with a NIM-standard De-Li-DAQ2 module with a count rate of up to 10^6 events/s.

An adjustable neutron beam diaphragm capable of linear movement along horizontal and vertical axes has been developed and manufactured (**Fig. 47**). It is mounted on an exit flange of the RTD neutron guide. The diaphragm dimensions are 20×105 mm^2; 1.1-mm-thick pyrolytic boron nitride is used as a neutron absorption material. FL57STH51 stepper motors are employed to control the diaphragm; a four-channel control unit of the motors is connected through a CAN/USB converter to a control computer.

The modernization of the detector system, which consists of two detector rings each comprising 16 gas detectors has been completed for the DN-12 diffractometer for investigations of micro-samples at high pressures. New detectors SNM-31 are installed in collimators and are in a common protective housing. Each detector has its independent output, which is connected to a separate preamplifier input. New detector and control electronics provide amplification and selection of signals, as well as control (from a computer) over detection thresholds and high voltage on the counters. Data acquisition and accumulation are performed by a 32-channel MPD electronic unit developed in FLNP. The software of DN-12 is similar to that of the DN-6 diffractometer.

Fig. 47. Adjustable neutron beam diaphragm for the RTD diffractometer.

The analog electronics of two ring-shaped 8-channel detectors of the YuMO small-angle neutron scattering spectrometer have been completely replaced. The detectors have been tested at the test stand and put into operation. A new MPD-32-based data accumulation system has been introduced.

Modernization of sample environment and control systems on IBR-2 spectrometers. Cryogenics.

At present, sample environment and control systems have been modernized on 10 spectrometers out of 13. Key features of the new systems are:

- development of all systems according to a unified scheme;
- spectrometer control systems are realized as an independent module connected to a PC through a USB interface;
- control system can be brought to a sample via an optical USB extender;
- unification of the system basic elements (sensors, motors, movement controllers, temperature controllers, etc.) and their interfaces;
- focus on the use of industrial equipment.

As an example a block diagram of the YuMO spectrometer control system after modernization is given in **Fig. 48**.

In 2013 using the same scheme the automation systems for the ***Fourier diffractometers***: ***HRFD*** (6 control channels) and ***FSD*** (12 channels) were modernized, and a new system was developed and constructed for the ***GRAINS*** spectrometer (26 channels). A 19-inch crate 3U high with stepper motor controllers (their number is equal to the number of control channels) is placed near a sample. A USB-RS485 OWEN AC4 adapter for communication between PC and stepper motor controllers is accommodated in a similar crate near PC. Each controller has its own address in RS485 line. A simultaneous movement of stepper motors can be specified by a control program and this option is limited only by the power source used.

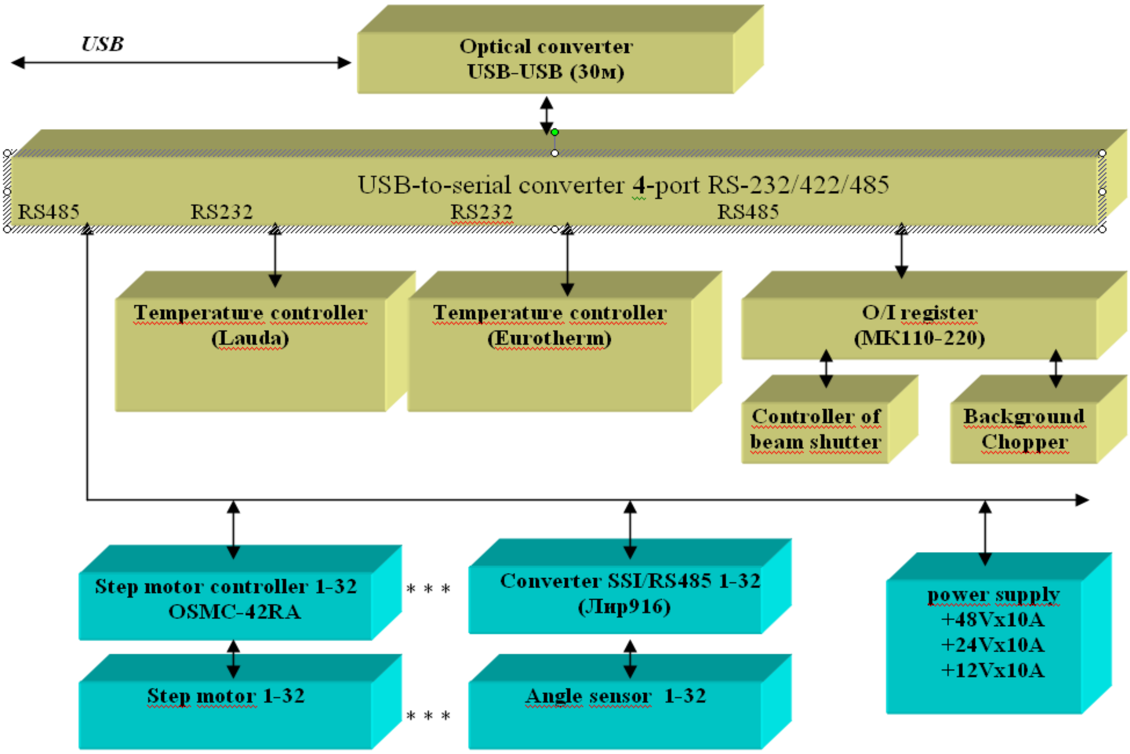

Fig. 48. Block diagram of the YuMO spectrometer control system.

A set of remote terminal units controls the state of a shutter and beam chopper and using OSM-42RA-3U controllers operates goniometers and Huber scanners (**Fig. 49**), diaphragms, polarizers, collimators and other devices. Up to 8 devices of this kind can be connected using RS 232/422/485 interfaces.

A new 6-position sample-changing device is now available at the HRFD spectrometer.

A **horizontal cryostat** for cooling high-pressure cells with a sample (**Fig. 50**) has been developed, manufactured and installed at the DN-6 diffractometer. A minimum temperature of 4 K was achieved on the sample cell.

Fig. 49. Goniometer and Huber scanner at the FSD diffractometer.

Fig. 50. Horizontal cryostat for the DN-6 diffractometer.

On the NERA spectrometer the modernization of a shaft cryostat is in progress.

Detectors.

A test scintillation detector on the basis of an ND screen with wavelength-shifting fiber readout has been developed and manufactured. Its characteristics have been studied on beam 9 of the IBR-2 reactor and a time-of-flight neutron spectrum has been obtained (**Fig. 51**).

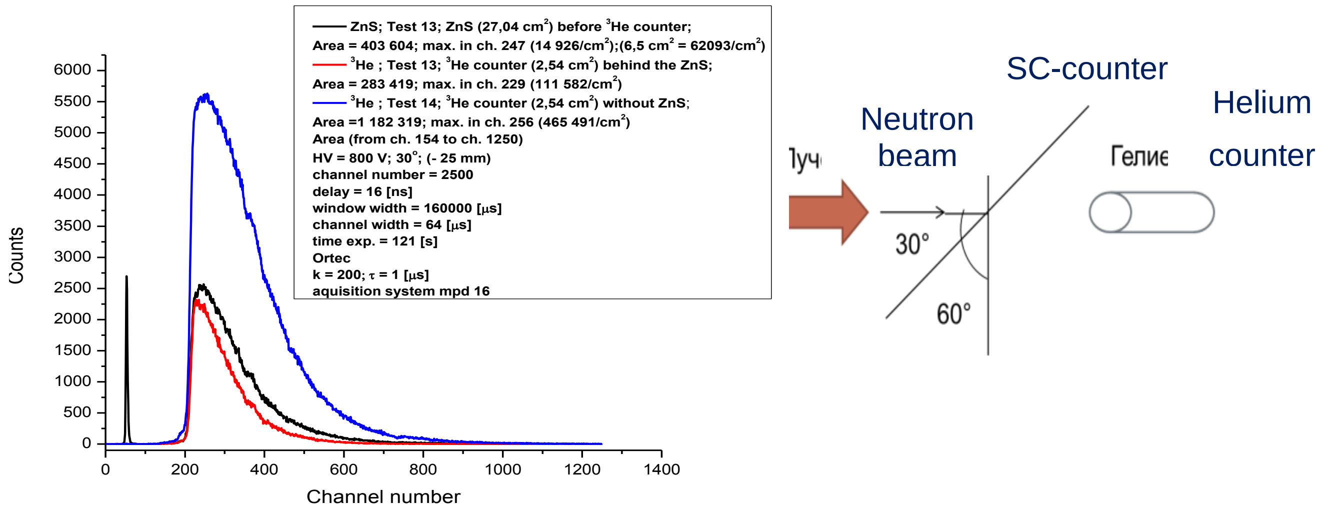

Fig. 51. Time-of-flight neutron spectrum of the test ND-screen-based detector. Spectrum from the test detector is in black, from an SNM-17 counter placed in front of the detector – in blue and from an SNM-17 counter immediately behind the detector – in red. Time channel width is 64 μs. The detector is installed at an angle of 30 degrees to a neutron beam.

In the 2nd quarter of 2013 a prototype of a scintillation counter of the ASTRA detector for the FSD diffractometer was manufactured and tested at a test stand with a source. During the autumn IBR-2 operation cycles we carried out comparison tests of "new" and "old" counters (**Fig. 52**) which produced good results for low-resolution TOF-spectra (**Fig. 53**). The construction of a section consisting of four scintillation counters of the detector ASTRA is in progress.

Fig. 52. A new counter of the ASTRA detector during the comparison tests.

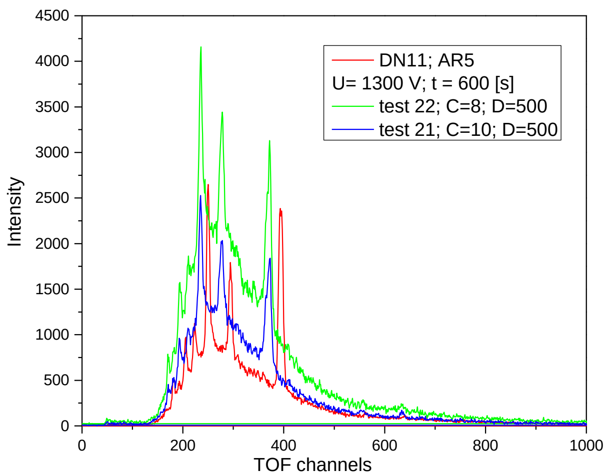

Fig. 53. General view of TOF-spectra (low resolution) of ASTRA detector section R5 (red – only one out of 4 elements was switched on) and of a new ZnS element (blue, green, two spectra were obtained at different thresholds).

Measurements of a profile of neutron beam №10 have been carried out. Measurements of profiles of beams №7a-1, №7a-2, №7-b have been repeated after adjustment of the neutron guide. In cooperation with the employees of the Nuclear Physics Department we have conducted simultaneous measurements of profiles of beams №6a, №6b, №10, №11, №12 using a thermal neutron monitor and evaluated their intensity with the help of a uranium chamber.

A 2D PSD with an active area of 200×200 mm^2 has been manufactured and installed at the REFLEX spectrometer. Design documentation for a 2D PSD has been developed for horizontal channel №3 of the IR-8 reactor in the NRC "Kurchatov Institute". The drawings have been forwarded to the NPO "Atom" for production of the housing and other mechanical units of the detector. Work is now underway toward the construction of a new 2D thermal neutron position-sensitive monitor for measuring IBR-2 beam profiles. The technical specification of the monitor has been agreed with the concerned FLNP Departments of Nuclear Physics (NP) and Neutron Investigations of Condensed Matter (NICM).

Data acquisition electronics.

Seven sets of digital and analog MPD-32 units for data acquisition and accumulation systems for the IBR-2 spectrometers have been manufactured and adjusted. The DAQ systems assembled from these units have been put into operation on the RTD, YuMO, DN-12 spectrometers mentioned earlier, and also the systems for the FSD and HRFD diffractometers have been completed and are in the adjustment stage. Firmware software for digital filtration of input signals from scintillation detectors has been developed for MPD-16 and MPD-32 units. It is with these units that the tests of a "List Mode"-analyzer for accumulation of "raw" data in the list mode and the debugging of data processing programs for plotting high-resolution spectra are in progress. The measurements are carried out in parallel with the old system of RTOF-analyzers using two 90º-modules of the ASTRA detector or back-scattering (BS) detector and with the "List Mode"-analyzer using all modules of the ASTRA and BS detectors. **Fig. 54** illustrates high-resolution spectra obtained using DSP and "List Mode" -analyzers. It can be seen that the spectra are identical, but there are some differences in absolute values of intensity and background. We try to find the reasons for these differences in the investigations now under way.

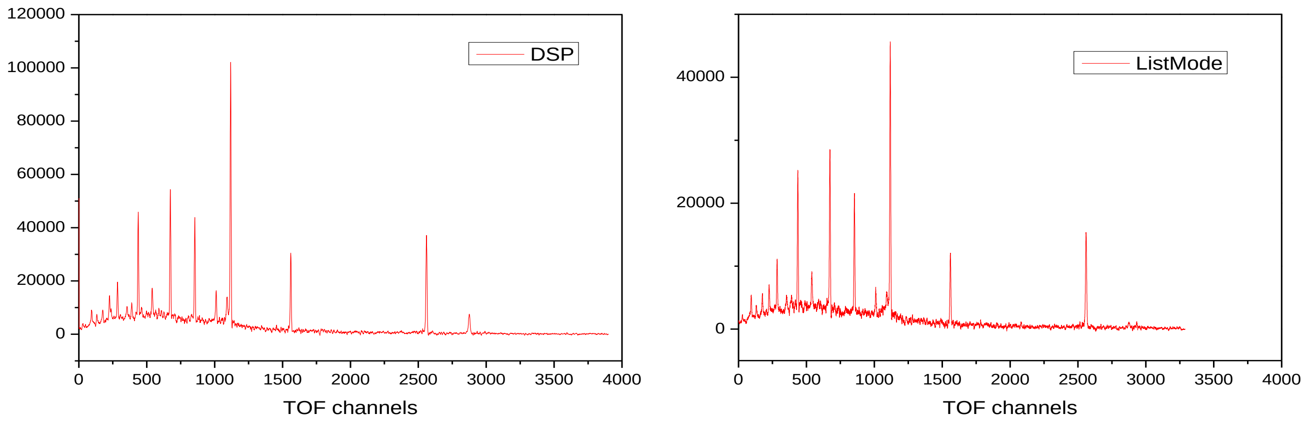

Fig. 54. High-resolution spectra obtained using DSP and "List Mode" -analyzers.

A new data acquisition and accumulation unit De-Li-DAQ2 for 1D and 2D position-sensitive detectors (**Fig. 55**) has been constructed and adjusted and the development of its software is nearing completion. The unit has a 1GB built-in histogram memory and a high-speed interface providing fiber-optic communication with a PC. The unit can operate in two modes: histogram mode (on-line sorting and accumulation of spectra in the internal memory) and list mode (accumulation of raw data immediately on a computer disk). The real count rate (with consideration for data transfer and recording to a PC) is no less than 10^6 events/s.

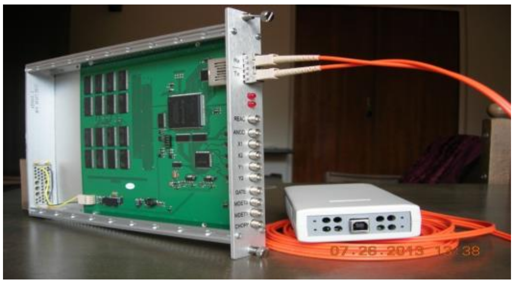

Fig. 55. De-Li-DAQ2 unit for data acquisition and accumulation from PSD.

Reactor-start couplers with optical isolation have been manufactured and installed on six IBR-2 spectrometers. Also, preventive maintenance on the IBR-2 spectrometers, as well as routine modernization and repair of electronic equipment were done.

Software.

In 2013, in accordance with the plan the Sonix+ software package developed in FLNP was installed in full on the DN-6, SKAT, DN-12 spectrometers and only for the available equipment on RTD and GRAINS (the package will be installed further as new devices become available). On the HRFD diffractometer because of the tight schedule of the user program the replacement of VME system and installation of Sonix+ proceed in-between the measurements, which somewhat slows down the pace of work.

The activities on the development of the Sonix+ software package included:

- development of a new universal graphical user interface (GUI) on the basis of PyQt and matplotlib (introduced on the YuMO, NERA-PR, SKAT, REMUR spectrometers), an example is given in **Fig. 56**;
- improvement of an operation library for reflectometers (REMUR, REFLEX, GRAINS);
- improvement of programs for visualization (SpectraViewer) and adjustment (ICE) on demand of the users.

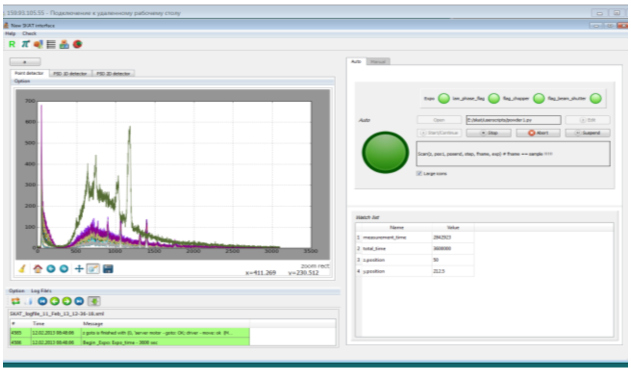

Fig. 56. New GUI using the SKAT spectrometer as an example (top).

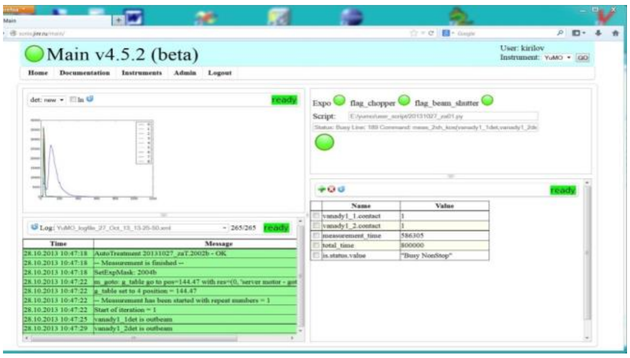

Fig. 57. Main page of WebSonix using the YuMO spectrometer as an example (left).

Over the past year a new significantly improved version of the system for remote monitoring of parameters and control of spectrometers (WebSonix) has been prepared, which is now in trial operation on the SKAT and YuMO spectrometers (**Fig. 57**).

Local area network.

In 2013, the FLNP network service installed and configured a Supermicro DP SSG-6047R-E1R24N file server (**Fig. 58**) with the following technical characteristics:

processor – 2x Intel(R) Xeon(R) CPU E5-2637 0 @ 3.00 GHz;
RAM – 32 GByte;
hard disks – 2x 500 GByte and 24x 3 TByte.

A free distributed **Freebsd 9.1** was chosen as an operating system as it proved to be the most fault-tolerant and high-performance OS among the users. Its important feature is the support of ZFS file system, which allows the implementation of a software RAID array using a host bus adapter. It is a journaling file system, which uses a snapshot technology making it possible to create a point-in-time image of a database, thus increasing the probability of recovering the lost data. The file system can tolerate the loss of up to 2 disks.

Fig. 58. New file server.

The disk array is implemented on 24 Hitachi HUA72303 disks using ZFS file system. Its storage capacity is 58 TByte. It can be accessed via such protocols as **cifs**, **smb**, **nfs**, and **scp**. At present, the server is in trial operation.

The creation of a WiFi network has been completed in the FLNP main buildings: 42, 42a, 117 (tower) and 117 (IBR-2 experimental halls), 119. D-link DW-360AP and Ubiquiti UniFi AP are used as network access points. At present, 21 wireless Internet access points are available in the Laboratory.

2.1. THE IBR-2 PULSED REACTOR

The IBR-2 research nuclear facility is operated under Rostechnadzor license № ГН-03-108-2614 of 27.04.2012.

In 2013, in accordance with the license requirements the specialized organizations in cooperation with the IBR-2 personnel performed the scheduled work on the technical evaluation and assessment of the remaining life of the technological reactor equipment. The activities to prolong the service life of the equipment of the IBR-2 safety-related systems have been completed.

Since January 2013 regular IBR-2 cycles of physical experiments have been carried out at a power of 2 MW with the CM-202 moderator operating either in the water or cryogenic mode depending on the schedule of the physical start up of the cold moderator.

From September 13 to September 19 a fresh fuel assembly was loaded into the IBR-2 reactor core and the reactor was brought to criticality in a steady-state operation mode followed by an assessment of the efficiency of the loaded fuel assembly and of the integrated efficiency of the regulating units of the control and safety system. The reactor was turned on to a power of 250 kW followed by an assessment of the efficiency of the loaded fuel assembly at pulsed criticality.

The **table 1** presents data on the IBR-2 operation for physics experiments in 2013.

Table 1. Data on the IBR-2 operation for physics experiments.

№ cycle	Period	Moderator type	Reactor operation for physics experiments, hr
1	22.01-30.01	cryogenic	176
2	11.02-22.02	water	260
3	18.03-29.03	cryogenic	264
4	09.04-20.04	water	242
5	21.05-02.06	water	281
6	23.09-04.10	water	262
7	14.10-22.10	water	169
8	24.10-01.11	cryogenic	174
9	11.11-18.11	water	170
10	21.11-23.11	cryogenic	44
11	29.11-13.12	water	330
12	17.12-26.12	cryogenic	206
Total:			**2578**

2. NEUTRON SOURCES

In 2013, in accordance with the contract with the JSC “Dose” the dosimetry equipment for the stationary radiation monitoring system (RMS) of IBR-2 was delivered. Its installation and adjustment began.

2.2. IREN FACILITY

In 2013, in FLNP the scientific activity in the field of neutron nuclear physics was carried out in the following traditional directions: investigations of time and space parity violation processes in neutron-nuclear interactions; studies of the fission process; experimental and theoretical investigations of fundamental properties of the neutron; gamma-spectroscopy of neutron-nuclear interactions; atomic nuclear structure, obtaining of new data for reactor applications and for nuclear astrophysics; experiments with ultracold neutrons. The greater part of the fundamental investigations was conducted IREN pulsed resonance neutron source. In 2013 the IREN facility operated for physical experiments for about 1050 hours.

2.3. EG-5 ACCELERATOR

In 2013, the EG-5 accelerator operated for various experiments for 656 hours. Studies of elemental depth profiles using nuclear-physical analytical methods RBS (Rutherford backscattering) and ERD (elastic recoil detection) were conducted in cooperation with representatives of various institutes of the JINR Member States. Employees from FLNR (V.F. Reutov, A.Yu. Didyk), DLNP (V.M. Bystritskii), VSU (V.M. Vakhtel), TPU (V.V. Sokhoreva), UMCS (D. Monchka, M. Kulik), IEE SAS (Y. Guran, D. Makhaydik) participated in the experiments. Samples of different elemental composition and various preparation technologies were analyzed; in particular, elemental depth profiles in the samples of nanocrystalline silicon carbide films prepared using PECVD (plasma-enhanced chemical vapor deposition) technique were investigated. The study of electrical and optical characteristics of the films based on their elemental composition was performed.

Depth profiles of hydrogen and deuterium were also studied by nuclear-physical analytical methods RBS and ERD in the samples prepared for the study of nuclear reaction d (d, γ)3He at low energies.

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MISCELLANEOUS

I. Zinikovskaia

At the 5th European Exhibition of Creativity and Innovation (9-11 May 2013, Iasi, Romania), a young JINR FLNP scientist from Moldova (Institute of Chemical Research of the Academy of Sciences of Moldova, Kishinev, Moldova), **Inga Zinkovskaia**, won the gold medal.

EURO INVENT
EUROPEAN EXHIBITION OF CREATIVITY AND INNOVATION
EXPOZIŢIA EUROPEANĂ A CREATIVITĂŢII ŞI INOVĂRII

IAŞI - ROMÂNIA

DIPLOMA

BIOLOGICAL TREATMENT OF INDUSTRIAL WASTEWATER CONTAINING ZINC BY SPIRULINA PLATENSIS
I. ZINICOVSCAIA, L. CEPOI, T. CHIRIAC, GH. DUCA, T. MITINA, M.V. FRONTASYEVA, S.S. PAVLOV, S.F.GUNDORINA

GOLD MEDAL

MEMBER OF WIIPA

President of International Jury
Prof. Adrian GRAUR

President of Exhibition
Prof. Ion SANDU

EUROINVENT 2013

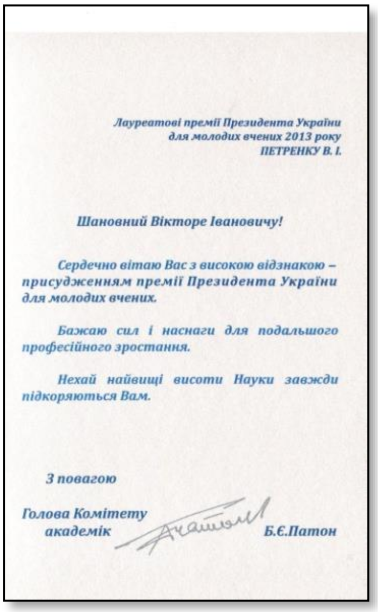
11 May 2013

V.I. Petrenko, O.A. Kizima, T.V.Tropin

The winners of 2013 Award of the President of Ukraine for young scientists were:

- **Victor I. Petrenko,**
- **Olena A. Kizima,**
- **Timur Tropin**,

specialists of the JINR FLNP DCMRD CNICM Surface Physics Group.



Лауреатові премії Президента України
для молодих вчених 2013 року
ПЕТРЕНКУ В. І.

Шановний Вікторе Івановичу!

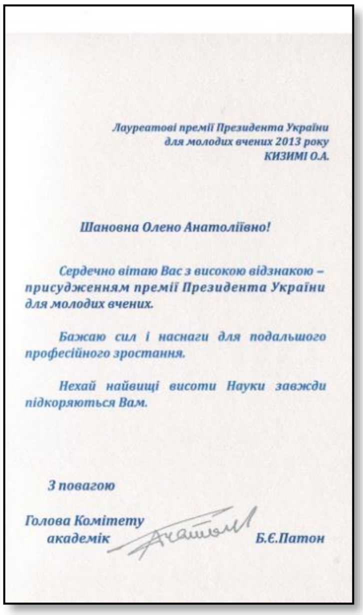
Сердечно вітаю Вас з високою відзнакою – присудженням премії Президента України для молодих вчених.

Бажаю сил і наснаги для подальшого професійного зростання.

Нехай найвищі висоти Науки завжди підкоряються Вам.

З повагою

Голова Комітету
академік Б.Є.Патон



Лауреатові премії Президента України
для молодих вчених 2013 року
КИЗИМІ О.А.

Шановна Олено Анатоліївно!

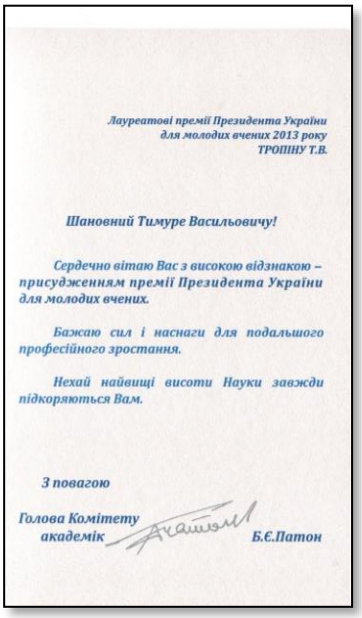
Сердечно вітаю Вас з високою відзнакою – присудженням премії Президента України для молодих вчених.

Бажаю сил і наснаги для подальшого професійного зростання.

Нехай найвищі висоти Науки завжди підкоряються Вам.

З повагою

Голова Комітету
академік Б.Є.Патон



Лауреатові премії Президента України
для молодих вчених 2013 року
ТРОПІНУ Т.В.

Шановний Тимуре Васильовичу!

Сердечно вітаю Вас з високою відзнакою – присудженням премії Президента України для молодих вчених.

Бажаю сил і наснаги для подальшого професійного зростання.

Нехай найвищі висоти Науки завжди підкоряються Вам.

З повагою

Голова Комітету
академік Б.Є.Патон

I.V. Papushkin


Московская областная Комиссия по организации подготовки управленческих кадров для организаций народного хозяйства Российской Федерации

ДИПЛОМ

НАГРАЖДАЕТСЯ

Папушкин Игорь Викторович

инженер Научно-экспериментального отдела нейтронных исследований конденсированных сред Лаборатории нейтронной физики им. И.М. Франка Объединенного института ядерных исследований

Проект: «Нейтронные исследования остаточно-напряженного состояния конструкционных материалов и изделий в целях повышения безопасности их эксплуатации»

за победу в Московском областном конкурсе «На лучший инновационный проект среди выпускников Президентской программы подготовки управленческих кадров в Московской области» в номинации «Научно-исследовательская работа»

Заместитель председателя Московской областной Комиссии по организации подготовки управленческих кадров для организаций народного хозяйства Российской Федерации

Ю.И. Рагозин

2013 год

The project "Neutron investigation of residual stress state in construction materials and products in order to improve their operation safety" by a JINR FLNP DCMRD CNICM engineer **Igor V. Papushkin** was awarded a diploma at the Moscow regional competition "The best innovative project among the graduates from the Presidential Programme of Management Personnel Training in the Moscow region" in the nomination "Research work". **Igor V. Papushkin** also won the competition "Nashe Podmoskovye" (“Our Moscow region”) in the nomination "Neutron investigation of residual stress state in structural materials and products in order to improve the competitiveness of Russian machine-building enterprises".


ПРЕМИЯ ГУБЕРНАТОРА «НАШЕ ПОДМОСКОВЬЕ»

ДИПЛОМ

I степени

НАГРАЖДАЕТСЯ

ПАПУШКИН
Игорь Викторович

победитель конкурса «Наше Подмосковье» в 2013 году

в номинации «Научный прорыв»
проект: «Нейтронные исследования остаточно-напряженного состояния конструкционных материалов и изделий из них в целях повышения конкурентоспособности машиностроительных предприятий России»

Губернатор Московской области [illegible] Андрей Юрьевич Воробьев

The PAC meeting for Condensed Matter Physics held a competition for the best poster presentation among young scientists. The presentation by **N. Zhargalan** "Kinetics of cluster growth in polar solutions of fullerene: study of C_{60}/NMP solution" was chosen as the best poster presentation. The second and the third prize, respectively, went to: **A.V. Churakov** "Measurements of neutron beam profiles at the IBR-2 reactor" and **S. Dzhabarov** "Pressure-induced changes in ferroelectrics with perovskite structure".

JINR AND FLNP FELLOWSHIPS

In 2013, within the framework of the competition of the Association of Young Scientists and Specialists of JINR, the scholarships were awarded to:

1. grant for young PhD researchers
   I.A. Bobrikov
   S.E. Kichanov
   D.V. Solovjov

2. grant for young specialists
   M.V. Bulavin
   J.K. Bulycheva
   A.V. Kutergin
   K.A. Mukhin
   K.V. Udovichenko

3. grant for young researchers
   A.E. Verkhoglyadov
   Z.I. Goryaynova
   I.I. Zinicovscaia
   G.V. Kulin
   K. Łuczyńska

4. grant for young workers
   D.V. Kokunov
   D.A. Korovin

4. PRIZES AND AWARDS

Since 2002, in FLNP a scholarship named after Academician of the USSR Academy of Sciences and first Director of the Laboratory of Neutron Physics **I.M. Frank** has been established in order to stimulate scientific and methodical research of young scientists.

In 2013 I.M. Frank scholarships were awarded to:

- In Neutron Nuclear Physics
  K. N. Vergel
- In Condensed Matter Physics
  E.V. Lukin
- In Methodical Investigations
  V.M. Milkov

Since 2006, a scholarship has been founded to immortalize the memory of outstanding scientist, Corresponding Member of the USSR Academy of Sciences **F.L. Shapiro**. The scholarship is awarded annually to two young FLNP employees in the following research directions: UCN physics; polarized neutrons; neutron spectroscopy.

In 2013 F.L. Shapiro scholarships were awarded to:

- In Condensed Matter Physics
  I. V. Papushkin
- In «Neutron Spectroscopy»
  S.V. Goryunov

JINR PRIZES

JINR Prizes are awarded annually for the best scientific, technical, methodical and applied research studies. In 2013, the following studies performed by the FLNP specialists or in collaboration with the employees from other JINR Laboratories or scientific institutions were awarded with the prizes of various degrees:

Experimental physics research:

Second prize

“Investigation and application of planar waveguides for neutron microbeams”

Authors: Ignatovich Vladimir K., Kozhevnikov Sergey V., Nikitenko Yury V., Keller Thomas, Major Janos, Ott Frédéric, Radu Florin, Rühm Adrian, Thiavill André, Khaydukov Yury N.

Scientific and Methodical Investigations:

Second prize

“Development and construction of the pelletized cold moderator of IBR-2 reactor”

Authors: Anan’ev Vladimir D., Belyakov Aleksander A., Bulavin Maksim V., Verkhoglyadov Aleksander E., Kulagin Evgeny N., Kulikov Sergey A., Kustov Aleksander A., Mukhin Konstantin A., Natkanec Ierenusz, Shabalin Evgeny P.

FLNP SEMINARS

- **I.P.Chernov** (Tomsk Polytechnic University, Russia) Physical processes in metal-hydrogen systems under radiation exposure (07.12.2013).
- **E.P.Shabalin** (FLNP, JINR) Thermal neutron scintillation detectors (28.03.2013).
- **T. Wilpert** (Helmholtz-Zentrum Berlin für Materialien und Energie, Germany) Recent development of detectors at the HZB (13.06.2013).
- **V. Valkovic** (Institute Ruder Boskovic, Croatia) Variations in Carbon/Oxygen Ratio in the Universe and on the Earth (19.06.2013).
- **K. H. Michel** (Department of Physics, University of Antwerp, Belgium) Theory of rigid-plane phonon modes in layered crystals (27.06.2013).
- **V. D. Sizarev** (JSC "NIKIET") Vibration monitoring and diagnostics of movable reflector PO-3 of the research reactor IBR-2.(03.10.2013).

105th anniversary of I.M. Frank; A.I.Frank, Dubna, 2013.

- **A.I.Frank, V.N. Shvetsov** (FLNP, JINR) Seminar dedicated to the 105th anniversary of I.M. Frank (25.10.2013).
- **G.M. Arzumanian** (CKL,JINR) Spectral and structural characteristics of up-conversion oxyfluoride glass materials and nanoglassceramics on their basis (18.11.2013).
- **Yu. E. Penionzhkevich** (FLNR,JINR) Physics of exotic nuclei and its application (19.12.2013).

CONFERENCES AND MEETINGS

On May 13-17, 2013 the 3rd Research Coordinated Meeting (RCM-3) related to the IAEA coordinated research project "Development, Characterization and Testing of Materials of Relevance to Nuclear Energy Sector Using Neutron Beams" was held in Dubna.

ISINN-XXI, Alushta, Ukraine, 2013.

On May 20-25, 2013 the XXI International Seminar on Interaction of Neutrons with Nuclei (ISINN-XXI) was held in Alushta. The seminar was held under the banner of the 50th anniversary of neutron activation analysis at JINR.

On August 18-21, 2013 FLNP in collaboration with the Ministry of Education and Research BMBF organized a meeting “Instrument development on long pulse neutron sources”. The event was aimed at discussing current trends in the development of facilities for neutron scattering on the sources operated in pulse mode.

5. EVENTS

On November 11-14, 2013 Tula hosted the II International Conference "Multiscale modeling of structures, composition of matter, nanostructured materials and nanotechnologies" dedicated to the memory of Professor A.N. Nikitin who used to work at the FLNP. The Frank Laboratory of Neutron Physics was the co-organizer of this event.

EDUCATIONAL PROGRAM

In 2013, two scientific schools for advanced training of young scientists were organized in the Frank Laboratory of Neutron Physics:

- the V **International Neutron School for Young Scientists and Students "Modern Neutron Diffraction Studies: Interdisciplinary Research of Nanosystems and Materials"** (October 28-November1, Dubna) (foto below).

- the **IV International Scientific School for Young Scientists and Students "Instruments and Methods of Experimental Nuclear Physics. Electronics and Automatics of Experimental Facilities"** (November 5-8, Dubna) (foto below).

These Schools were dedicated to the fundamental and applied aspects of research in the fields of neutron physics, condensed-matter physics, and materials science. These Schools were attended by students, postgraduates and young specialists from Russia and 9 JINR member-statesOn November 25-27, 2013 the Joint JINR-Romania International School on Small-angle neutron scattering and complementary methods of research of "smart" materials was held in West University of Timisoara. The School was held in the framework of the TIM 2013 Physics Conference.

Summer student practice, Dubna 2013.

The FLNP successfully collaborates with the JINR University Centre in the organization of summer practical work for students from the JINR Member States (Belarus, Czech Republic, Poland, Romania, Slovakia,) and Associated countries (Egypt, South Africa). Lectures and excursions to the FLNP facilities for teachers of physics from Russia and the JINR Member States were organized as well. FLNP is always a partner of the JINR University Centre in organizing visits to the Laboratory neutron sources for participants of the Scientific School for school teachers from the Russian Federation and other JINR Member States and scientific excursions for pupils from high schools

VISITS AT OUR FACILITIES

- Director of the Institute for Nuclear Research and Nuclear Energy Bulgarian Academy of Sciences, Dimitar Tonyev visited FLNP JINR in July 2013
- Delegation of the Helmholtz Association Research Centres from Germany, visited FLNP JINR in August 2013.
- On September 2013, the Minister of investment and the innovation of the Moscow Region G.V. Bondarenko,visited FLNP JINR.
- On September 24th, 2013, the delegation of Orgenergogaz OAO visited FLNP JINR. The members of the delegation met with the representatives of Department of Neutron Investigations of Condensed Matter and visited the experimental hall of IBR-2 reactor (FSD and SKAT diffractometers).
- On October 9, 2013 a delegation from Republic of South Africa visited the LNF, JINR. Members of the delegation met the Laboratory management representatives and visited the facilities on IBR-2 reactor (fasility REGATA, spectrometers HRFD, SKAT, Epsilon and NERA).
- The members of the Symposium «German – Dubna Astropartical Projects: Status and Perspectives» visited FLNP JINR in November 2013.

Delegation of the Helmholtz Association Research Centres from Germany, Dubna 2013.

5. EVENTS

Delegation from the National Institute for Nuclear Research in Swierk, Poland, Dubna 2013.

- In November 15, 2013 a delegation from the National Institute for Nuclear Research in Swierk, Poland, visited FLNP. The members of the delegation visited IREN and IBR-2.
- On November 23, 2013 the Romanian delegation headed by the Minister of Higher Education, Scientific Research and Technological Development Mr. Mihnea Cosmin Costoiu, and the Czech delegation headed by the Minister of Education, Youth and Sports Mr. Dalibor Štys visited the JINR Laboratory of Neutron Physics. The delegation members met the Directorate of the Laboratory and visited the experimental hall of the IBR-2 reactor.

STRUCTURE OF LABORATORY AND SCIENTIFIC DEPARTMENTS

Directorate:	
Director	*V.N. Shvetsov*
Deputy Director	*O.A. Culicov*
Deputy Director	*E.V. Lychagin*
Deputy Director	*S.V. Kozenkov*
Chief engineer:	*A.V. Vinogradov*
Scientific Secretary	*D.M.Chudoba*
Laboratory Scientific Leader	*V.L. Aksenov*
Advisor to Directorate	*V.D. Ananiev*
Advisor to Directorate	*L.B.Pikelner*

Reactor and Technical Departments	Head
IBR-2 reactor	Chief engineer: *A.V. Dolgikh*
Mechanical maintenance division	*A.A. Belyakov*
Electrical engineering department	*V.A. Trepalin*
Design bureau	*A.A. Kustov*
Experimental workshops	*A.N. Kuznetsov*

Scientific Departments	Head
The Division of Condensed Matter Research and Developments	*A.V. Belushkin*
Nuclear physics department	*V.N. Shvetsov*

Administrative Services
Secretariat
Finances
Personnel

Scientific Secretary Group
Secretariat
Translation
Graphics

6.ORGANIZATION

DIVISION OF CONDENSED MATTER RESEARCH AND DEVELOPMENTS

DEPARTMENT OF NEUTRON INVESTIGATION OF CONDENSED MATTER

Sub-Division	Title	Head
Head of the Department		*D.P.Kozlenko*
Sector 1: Neutron Diffraction. Head: *G D. Bokuchava*		
Group No.1	HRFD	*A.M. Balagurov*
Group No.2	DN-2	*A.I. Beskrovnyi*
Group No.3	DN-12	*B.N. Savenko*
Group No.4	Geomaterials	*D.M.Levin*
Group No.5	SKAT /Epsilon	*Ch. Scheffzük*
Sector 2: Neutron Optics. Head: *M.V. Avdeev*		
Group No.1	Physics of Surfaces	*Yu.V. Nikitenko*
Group No.2	Physics of Nanostructures	*V.I. Bodnarchuk*
Small angle scattering group		*A.I. Kuklin*
Inelastic scattering group		*D. Chudoba*

DEPARTMENT OF IBR-2 SPECTROMETERS COMPLEX

Sub-Division	Title	Head
Head of the Department		*S.A. Kulikov*
Group No.1	Detectors	*A.V. Churakov*
Group No.2	Electronics	*A.A. Bogdzel*
Group No.3	Information technologies	*A.S. Kirilov*
Group No.4	Sample environment and choppers	*A.P. Sirotin*
Group No.5	Cryogenic investigations	*A.N. Chernikov*
Group No.6	Cold moderators	*M.V. Bulavin*

NUCLEAR PHYSICS DIVISION

Sub-Division	Title	Head
Sector 1.	investigations of neutron-nuclear interactions	*Y.N. Kopatch*
Sector 2.	Investigation of neutron fundamental properties.	*Ye.V. Lychagin*
Sector 3.	Neutron Activation Analysis and Applied Research:	*M.V. Frontasyeva*
IREN facility		*V.G. Pytaev*

PERSONNEL

DISTRIBUTION OF THE PERSONNEL PER DEPARTMENT

Theme	Departments	People
-1104-	Nuclear Physics Department	93
-1069-	Department of neutron investigation of condensed matter	88
-1075-	Department of IBR-2 spectrometers complex	41
-1105-	IBR-2 reactor	46
	Mechanical and Technical Department	49
	Electric and Technical Department	30
	Central Experimental Workshops	38
	Nuclear Safety Group	7
	Design Bureau	6
	FLNP infrastructure:	
	Directorate	9
	Services and Management Department	24
	Scientific Secretary Group	3
	Supplies Group	4
Total		**438**

PERSONNEL FROM THE JINR MEMBER STATES (BESIDES THE RF)

Country	People	of which young specialists (≤35 years)
Azerbaijan	7	7
Belarus	1	1
Bulgaria	5	2
Georgia	2	
Germany	1	1
Kazakhstan	8	8
Moldova	2	2
Mongolia	9	7
Poland	11	4
Romania	7	2
Ukraine	14	12
TOTAL	**70**	**48**

6.ORGANIZATION

Our PhD students

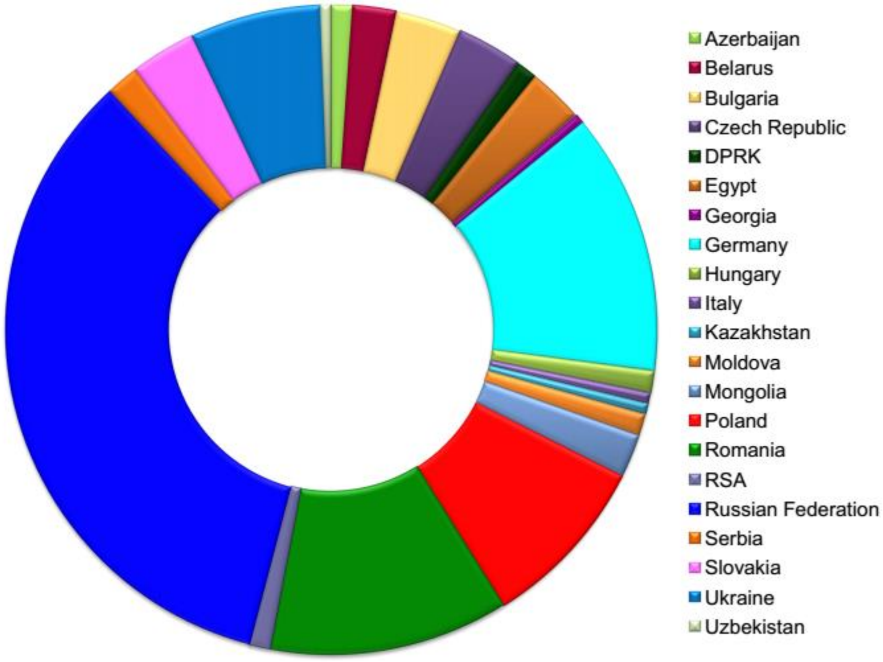
In 2013 23 PhD students from 11 countries conducted their experimental research at the FLNP facilities.

Name	Country	PhD student of
Alekseenok Yu.V.	Belarus	International Sakharov Environmental University
Shushakova V.	Germany	University of Göttingen
Sanislo A.	Hungary	University of Godollo
Bagdaulet M.	Kazakhstan	Al-Farabi Kazakh National University
Nyamsuren B.	Mongolia	National University of Mongolia
Luczynska K.	Poland	Institute of Nuclear Chemistry and Technology
Ordon M.	Poland	Siedlce University of Natural Sciences and Humanities
Anisimov I.I.	Russia	State Scientific Center Of The Russian Federation – Institute For Physics And Power Engineering
Dang N.T.	Russia	Tula National University
Eremin R.A.	Russia	JINR University centre
Rumyantsev I.	Russia	JINR University centre
Rutkauskas A.V.	Russia	JINR University centre
Sudarev V.V.	Russia	State Scientific Center Of The Russian Federation – Institute For Physics And Power Engineering
Shamaev M.S.	Russia	State Scientific Center Of The Russian Federation – Institute For Physics And Power Engineering
Tsaregorodtsev R.O	Russia	Moscow State University
Vergel K.	Russia	Dubna International University for nature, Society and Man / FLNP JINR
Zontikov A.O.	Russia	Dubna International University for nature, Society and Man
Kravtsova A.V.	Ukraine	A.O. Kovalevsky Institute of biology of the Southern Seas
Nekhoroshkov P.	Ukraine	A.O. Kovalevsky Institute of biology of the Southern Seas
Nagornyi A.V.	Ukraine	National University of Kyiv
Samoylenko S.A.	Ukraine	National University of Kyiv
Tomchuk A.V.	Ukraine	National University of Kyiv

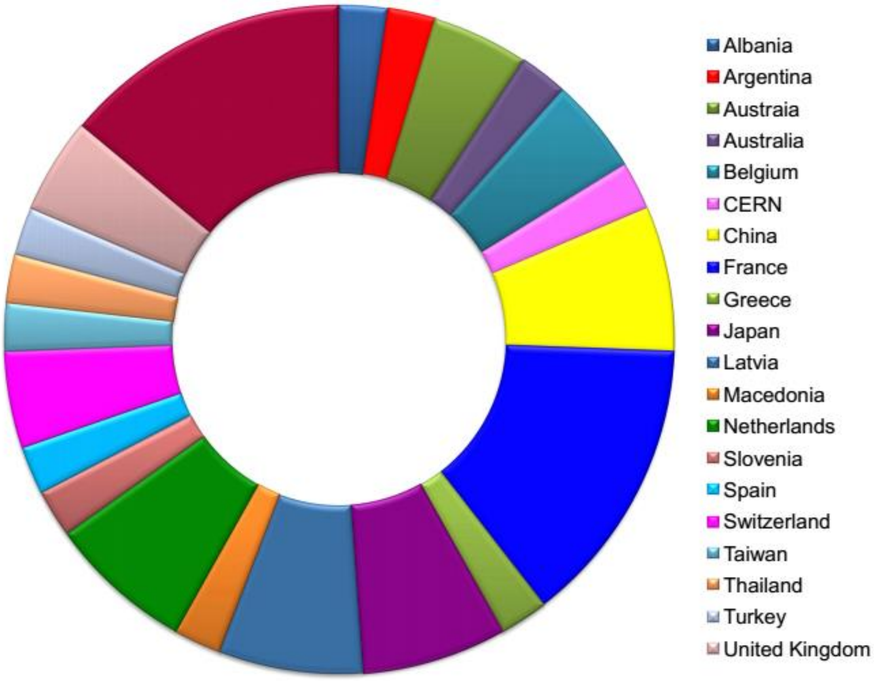
In 2013, 7 BSc theses, 2 Specialist Diplomas and 2 MSc theses were defended using the experimental material obtained in FLNP. One of our employeer was conferred a Doctor of Science degree.

INTERNATIONAL COOPERATION

In 2013 the Frank Laboratory of Neutron Physics collaborated with 185 institutions from 21 JINR Member States or Associated Members of JINR.

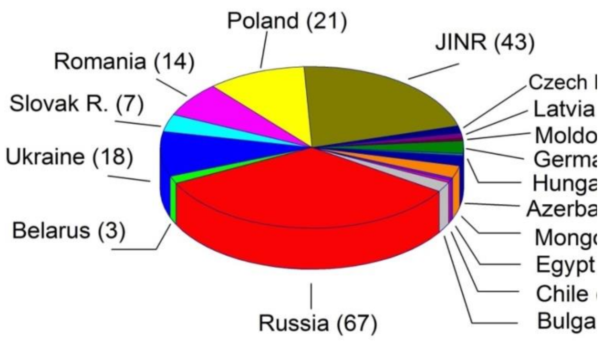


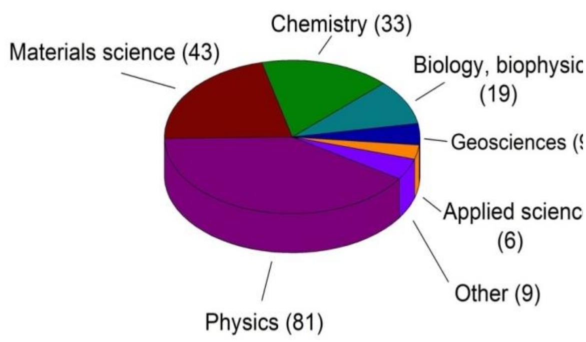
The Frank Laboratory of Neutron Physics collaborated with 43 institutions from 20 Non-Members Statrs of JINR.



USER INTERACTION

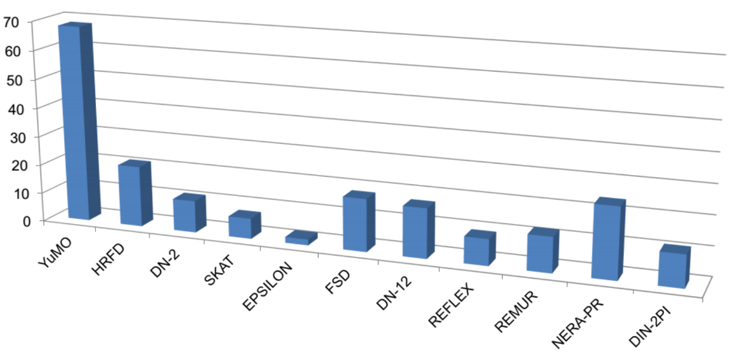
In 2013 were two calls for proposals for experiments at the modernized IBR-2 reactor (15 September – 01 November 2012;Call-II: 15 March – 30 April 2013). A total of 195 proposals for conducting experiments were received from 17 different countries. The received proposals covered the broad spectrum of neutron research in physics (41%), materials science (22%), chemistry, geosciences, biology and applied sciences (constituting the rest 37%). 158 received proposals were admitted for realization.





List of Visitors from the JINR Member States or Associated Members of JINR in 2013

Country	Nr of visitors
Belarus	4
Bulgaria	7
Hungary	3
Germany	11
Egypt	2
Kazakhstan	1
Mongolia	1
Poland	12
Romania	2
Serbia	2
Slovakia	2
Ukraine	7
Czech Republic	2
RSA	1



Proposal distribution by facilities.

List of Visitors from Non-Member States of JINR in 2012

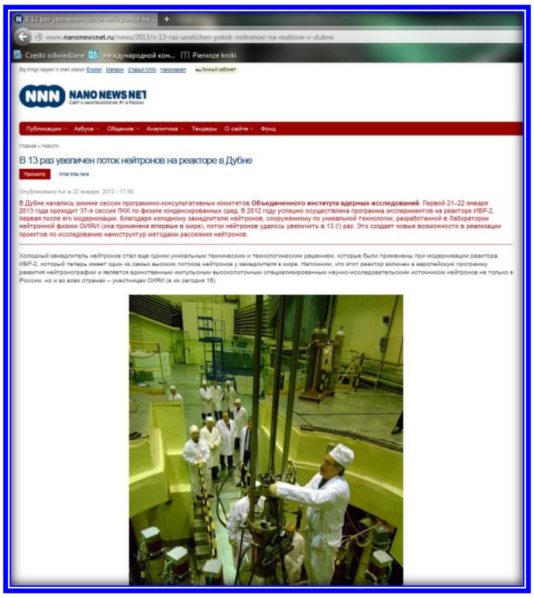
Country	Nr of visitors
China	6
France	1
Latvia	7

In the year 2013 Frank Lab. of Neutron Physics was at center of interest of mass media. There were publications in press as well as programs on TV and radio.

NANO NEWS NET

22.01.2013

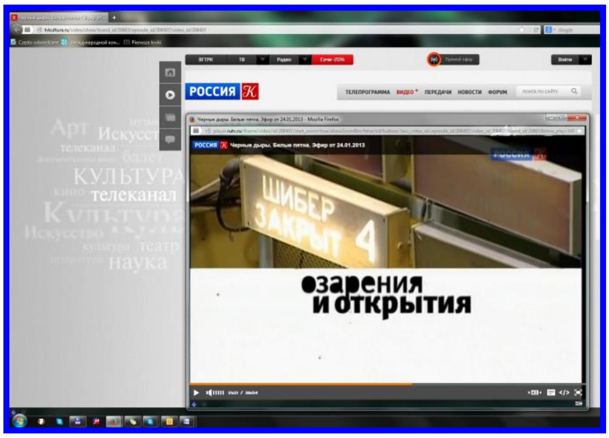
http://www.nanonewsnet.ru/news/2013/v-13-raz-uvelichen-potok-neitronov-na-reaktore-v-dubne



TV RUSSIA CULTURAL

24.01.2013

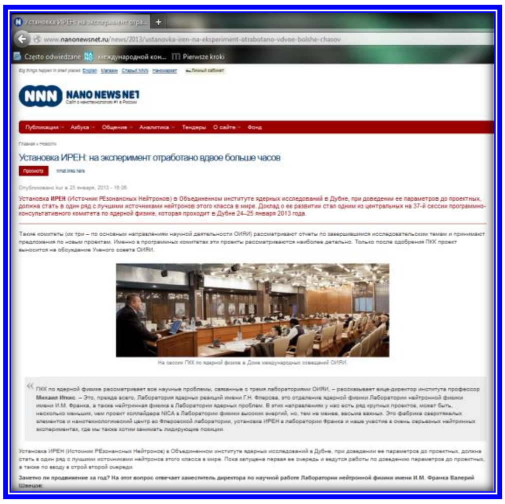
http://tvkultura.ru/video/show/brand_id/20863/episode_id/208407/video_id/208407



NANO NEWS NET

25.01.2013

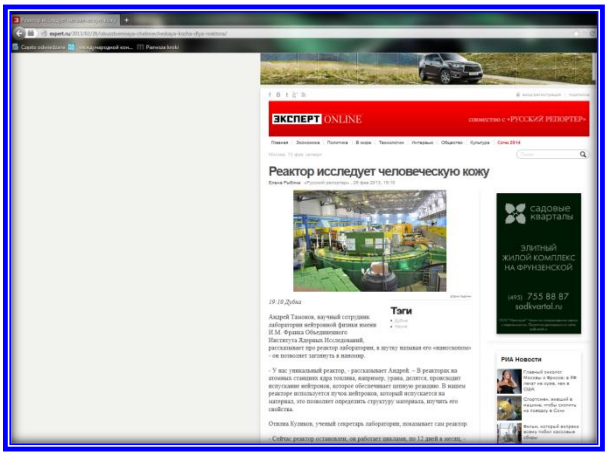
http://www.nanonewsnet.ru/news/2013/ustanovka-iren-na-eksperiment-otrabotano-vdvoe-bolshe-chasov



EXPERT ONLINE

23.02.2013

http://expert.ru/2013/02/26/iskusstvennaya-chelovecheskaya-kozha-dlya-reaktora/



W.I. FURMAN

To the 75th birthday jubilee of, a leading scientist of the Frank Laboratory of Neutron Physics.

The old-timers of the Laboratory can still remember, when in 1960 a graduate from Voronezh State University, an enthusiastic guy, first appeared in the laboratory, immediately proving himself to be a good physicist. It was Walter Furman. Of course, nobody called him by his full name, they were young, all recent graduates, so he was just Slava Furman. One of the first manifestations of his enthusiasm was the organization of a seminar on quantum mechanics, which involved almost all FLNP physicists (and they were about ten at that time). It became clear from the very beginning that Slava was a theoretician, and it was confirmed later.

Furman's interests lay mainly in the field of neutron physics and nuclear reactions. He became a specialist in these areas, and was often visited by his colleagues - experimenters who came to him for a consultation. Significant contribution to the development of the theory was the monograph "Alpha-decay and related nuclear reactions" written by W.I. Furman together with S.G. Kadmenski, his friend from Voronezh State University.

Science was not Furman's only passion. For many years he had been an organizer of the mountain-climbing group in Dubna and had attempted several challenging climbs himself. It is worth noting his volunteering in the rescue work in the mountains and after the devastating earthquake in Spitak (Armenia).

At present, Walter Furman continues to work hard in the field of nuclear fission physics. His works on the creation of quantum-mechanical fission theory written together with A.L. Barabanov, his counterpart from the Kurchatov Institute, are widely known among nuclear fission physicists. He is one of the leaders of the collaboration (E & T Collaboration) conducting the study of the processes occurring deep in the subcritical electronuclear systems and the study of the possibility of using such systems for energy production and radioactive waste transmutation.

W.I. Furman is also involved in the administrative and social activity. He is a member of the JINR Scientific and Technical Council, since 1997 and up to date has been the chairman of the annual international seminar ISINN (International Seminar on Interaction of Neutrons with Nuclei). Having vast experience of administrative work (in the period of 1990-1994 he was the Head of Nuclear Physics Department, from 1994 to 2002 - FLNP Deputy Director for Research, and from 2002 to 2006 headed the project IREN), W.I. Furman gladly passes it on to the next generation.