1.1. CONDENSED MATTER PHYSICS

General situation at the IBR-2. Fourteen neutron beams are extracted to the experimental halls of the IBR-2 reactor. On nine of them, neutron spectrometers for investigations in condensed matter physics are positioned. Three of nine beams are split into two by means of optical systems and as a result, the experimenters have twelve spectrometers (see the Table). After the replacement of the movable reflector in March 1995, the reactor operates stably and as a rule, in accordance with the adopted schedule.

Spectrometers for investigations in condensed matter physics. To conduct condensed matter investigations at IBR-2, four main techniques are applied: diffraction, small-angle scattering, inelastic scattering, and polarized neutron optics.

The group of diffractometers includes **HRFD**, the high resolution Fourier diffractometer for analyzing the structures of polycrystal substances, as well as internal stresses in bulk samples for industrial application products, **DN-2**, the multipurpose diffractometer for investigations of single crystals and long-range structures and for experiments in real-time mode, **DN-12**, the diffractometer for investigations of microsamples primarily at high pressures, and **NSVR**, the multidetector diffractometer for texture investigations.

Also, one small-angle scattering spectrometer, **YuMO**, exists and allows a diverse program of investigations into large-scale inhomogeneities (macromolecules in solutions, micelles, density fluctuations in hardening concretes, etc.) to be carried out.

The group of inelastic scattering spectrometers includes **DIN**, the direct geometry spectrometer with a fast chopper mainly designed for investigations of liquids (quantum and classical), **KDSOG**, the inverted geometry multidetector spectrometer-diffractometer for investigations of the phonon density of states and phase transitions, and **NERA**, the inverted geometry spectrometer with crystal analyzers for investigations of inelastic and quasielastic scattering in hydrogen containing substances, as well as for molecular spectroscopy.

The group of neutron-optical instruments includes **SPN**, the polarized neutron spectrometer operating both in the transmission mode (depolarization) and reflectometer modes, **REFLEX-P**, the polarized neutron reflectometer, and **REFLEX-N**, the nonpolarized neutron spectrometer. The experiments with the reflectometers are conducted with the beams reflected in the horizontal plane.

User program. The 1996 list of the IBR-2 spectrometers operating in the user mode includes 9 instruments: HRFD, DN-2, NSVR, YuMO, SPN, REFLEX-P, KDSOG, NERA, and DIN. The beam time is distributed in accordance with experts recommendations on the submitted proposals and the existing long-term agreements for cooperation. The new spectrometer on the list is the REFLEX-P with its first stage commissioned for test operation in the spring. At present, DN-12 is under radical modernization to be completed by the middle of 1997. The formation of the neutron beam on REFLEX-N was completed, but its operation has been temporarily suspended in connection with the necessity to concentrate efforts on the provision of the experimental program for REFLEX-P. The SNIM spectrometer was closed in 1996 in accordance with the recommendations of the Program Advisory Committee.

The main parameters of the spectrometers and their sample environment systems meet the world level standards. The number of countries from where applications for beam time were received has increased to 23. The application for the 1996-II round is 1.6 times larger than for the 1996-I round. This is connected with that the user program is being continually developed, as well as with the increased activity of the spectrometer leaders. The user program can be extended by increasing the number of experiments on DN-2, REFLEX-P, DN-12, and DIN.

Execution of the scientific program. The formation of the program was determined by the parameters of the existing spectrometers and users' demands. The main directions of research have been almost the same for a few recent years.

Diffraction. At the IBR-2, neutron diffraction is used to investigate the atomic structure of polycrystalline materials, phase transitions in crystals under the action of external fields, crystals with incommensurable structure modulation, structure of novel materials (HTSC, GMR-compounds, superprotonics, etc.), multilayer lipid membranes, orientational magnetic phase transitions, texture of rocks, metals and alloys, and internal stresses in bulk samples, composite and gradient materials.

In 1996, the program for investigations of mercury-based superconductors by neutron diffraction continued. In the HRFD experiments, precision structural data were obtained. These allowed the dependence of the superconducting transition temperature on the excess oxygen content to be determined. This dependence appeared to be a parabolic one with the maximum at about 0.20 free charge carriers per CuO_2 layer, in agreement with the established idea of the formation mechanism of superconducting properties in layered copper oxides (V.L.Aksenov, E.V.Antipov, A.M.Balagurov et al., Phys. Rev. 1997). Experiments to determine the symmetry of a low temperature superconducting phase (Fmmm or Cmca from the data in the literature)

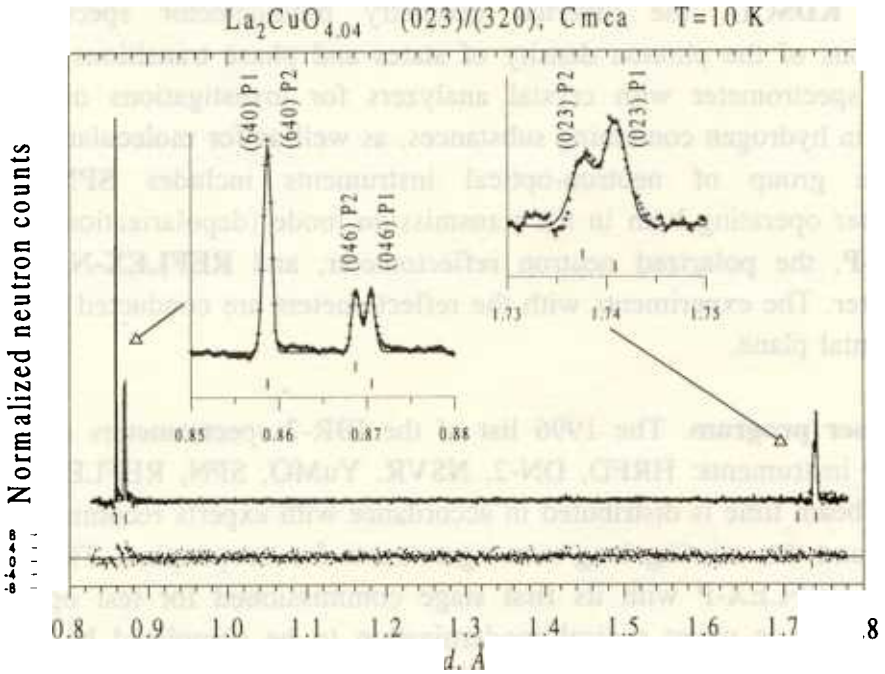

Fig.1. The diffraction spectrum of $La_2CuO_{4.04}$ measured for the [023] reciprocal lattice direction

were conducted with a $La_2CuO_{4.04}$ single crystal containing extra oxygen in the miscibility gap region. Figure 1 illustrates the HRFD diffraction spectrum for the [023] direction of the reciprocal lattice of the crystal. At T=10 K, one can easily see that peak (023) splits into two components corresponding to the oxygen-poor (P1) and oxygen-rich (P2) phases. The existence of the (023) peak is the evidence of the Cmca symmetry of the P2 phase because for the Fmmm space group this peak is forbidden (A.M.Balagurov, V.Yu.Pomjakushin, V.G.Simkin et al. Physica C, 1997).

In cooperation with Institute of Crystallography RAS (Moscow) and LLB (Saclay), investigations of the magnetic structure of the system $U(Pd_{1-x}Fe_x)_2Ge_2$ with a complicated magnetic behavior at T<140 K were initiated. The experiments were conducted with the HRFD diffractometer in Dubna and with the G4.1 diffractometer in Saclay. A radical change in the character of ordering of the magnetic moments of uranium atoms in dependence on the temperature has been detected already at lowest levels of iron doping. So, at temperatures lower than 65 K in compounds with x=0.02, instead of the initial sinusoidally modulated structure a simple antiferromagnetic structure appears and at temperatures above ~65 K, the z-component of the propagation vector decreases with a jump from k_z=1 to k_z≈0.76 and continues to decrease as the temperature increases (Figure 2).

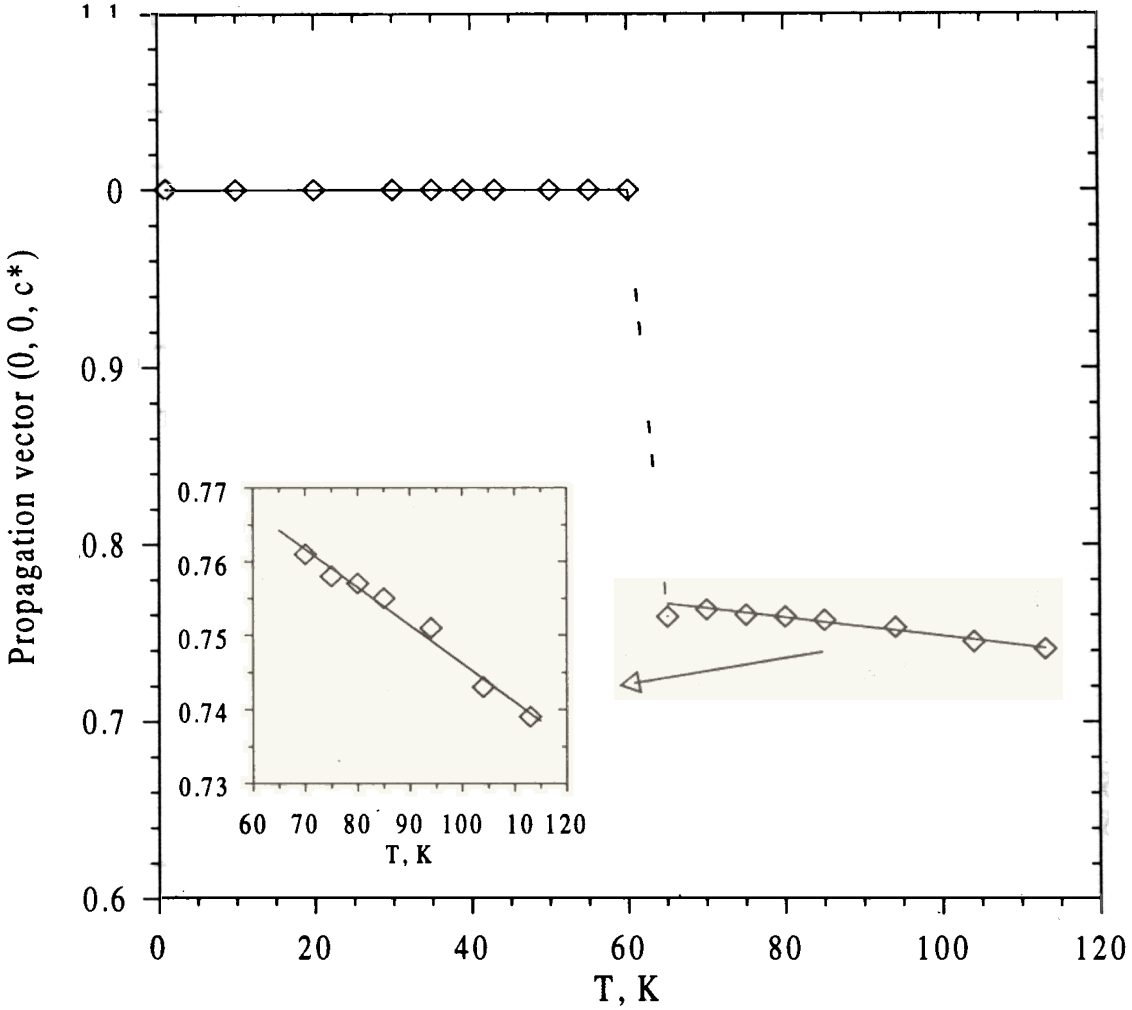

Fig.2. The temperature dependence of the z-component of the propagation vector of the $U(Pd_{0.98}Fe_{0.02})_2Ge_2$ structure

In the first half of the year (just before the start of modernization) in cooperation with the RNC "KI", on the DN-12 diffractometer for investigations of microsamples at high pressures, a series of experiments with ammonium gallogenids ND_4Cl and ND_4Br was completed (earlier, the results for NH_4Cl were obtained and published (A.M.Balagurov et al, High Press. Res. 14 (1995) 55)). The measurements were performed up to the pressure 35 kbar for ND_4Cl and 45 kbar for ND_4Br (Fig. 3). The equations of state, as well as the dependence of the position parameter of the structure and interatomic distances on the pressure, were obtained.

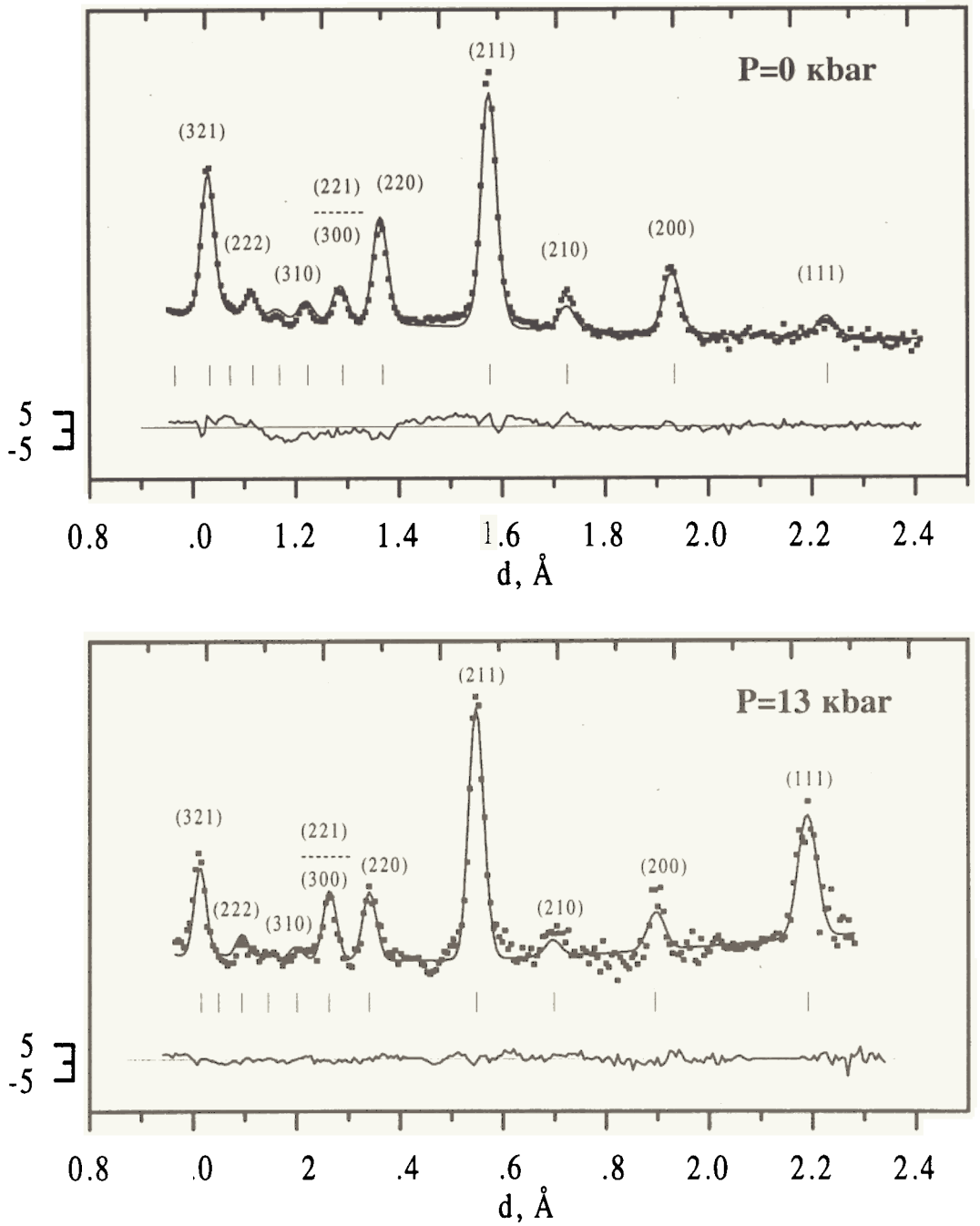

Fig.3. Diffraction patterns of ND_4Cl, measured at 0 and 13 kbar and processed by the Rietveld method. The scattering angle $2\theta=90°$. The experimental points, calculated profile, and the difference curve are shown

The conclusion can be made that the behavior of all the investigated systems is similar in many respects. The configuration of ammonium atoms does not practically change (the length of the *N-D/H* bond remains constant), the distance between halide atoms and ammonium decreases about linearly with pressure and at a certain pressure, the structural phase transition connected with ordering of the ammonium orientation in the lattice ($P_c \approx 25$ kbar for ND_4Br) takes place. The important observation was that the molecularity of these compounds decreases as the pressure increases and at some pressure, the hypothetical phase transition to a pure ion structure might take place.

On HRFD, a program for residual stress investigations was realized in the frame of the agreement for cooperation between FLNP and Fraunhofer Institute for Nondestructive Testing, Saarbruken, Germany. Though this is a quite new direction for HRFD, a lot of studies were performed in a short time. For details see the experimental report by V.L.Aksenov et al. in this book.

Small-angle neutron scattering. The method is applied for investigations of polyelectrolyte solutions, polymers, micellar formations, metallic glasses, concretes, and fractals. The goal of the investigations is to determine the parameters of large scale inhomogeneities and their behavior in dependence on the external conditions in these substances.

In collaboration with the Institute of Macromolecular Chemistry (Prague), the program of investigations of amphiphile polymers with the YuMO small-angle scattering spectrometer continued. As is known, in water, block copolymers consisting of hydrophile and hydrophobic molecules form micelles with a surprisingly homogeneous size distribution and, in addition, can solubilize different organic molecules. In the conducted experiments, the dynamics of the solubilization process was studied. This appeared possible thanks to an exclusively high efficiency of the YuMO spectrometer. Separate small-angle scattering spectra were measured in 10 min (and sometimes, in 2 min). It appeared that in the process of chloroform solubilization, the change of the radius of a PMMA-PAAc micelle in the course of time strongly depends on the extent of the initial neutralization of the solution (Fig. 4) (J.Kritz et al, Macromolecules, 1996).

In the experiment with DMPC lipid membrane multilayers, the reason for an increase in their repetition period in the vicinity of the phase transition temperature which is close to the critical temperature for lipid membranes, has been clarified. It has been shown that the effect is mainly connected with an increase in the intermembrane space, i. e., with an increase in the entropic repulsion in the critical region.

Detailed precision data on the temperature dependence of the length of cylindrical self-organizing TDMAO (tetradecyldimethylaminoxide) micelles in water solution were obtained. As it was to be expected, first the micelle lengths increased as the temperature increased, then reached some plateau and, what was totally unexpected, started to decrease at the temperature above 50°C. The obtained results, as well as the block copolymer results, have yet to be interpreted (N.Gorski et al, J.Appl.Cryst., 1997).

A large volume of work to study structural changes in tylacoid membranes during the formation process has been carried out. Dark tylacoid membranes are directly connected with the fundamental biochemical process of photosynthesis and therefore, to study their structure and, specifically, the influence of external factors on the structural parameters is an urgent problem. In the conducted experiments, the technique for obtaining standard samples of tylacoid membranes has been finished off. With these samples, we managed to prove the existence of

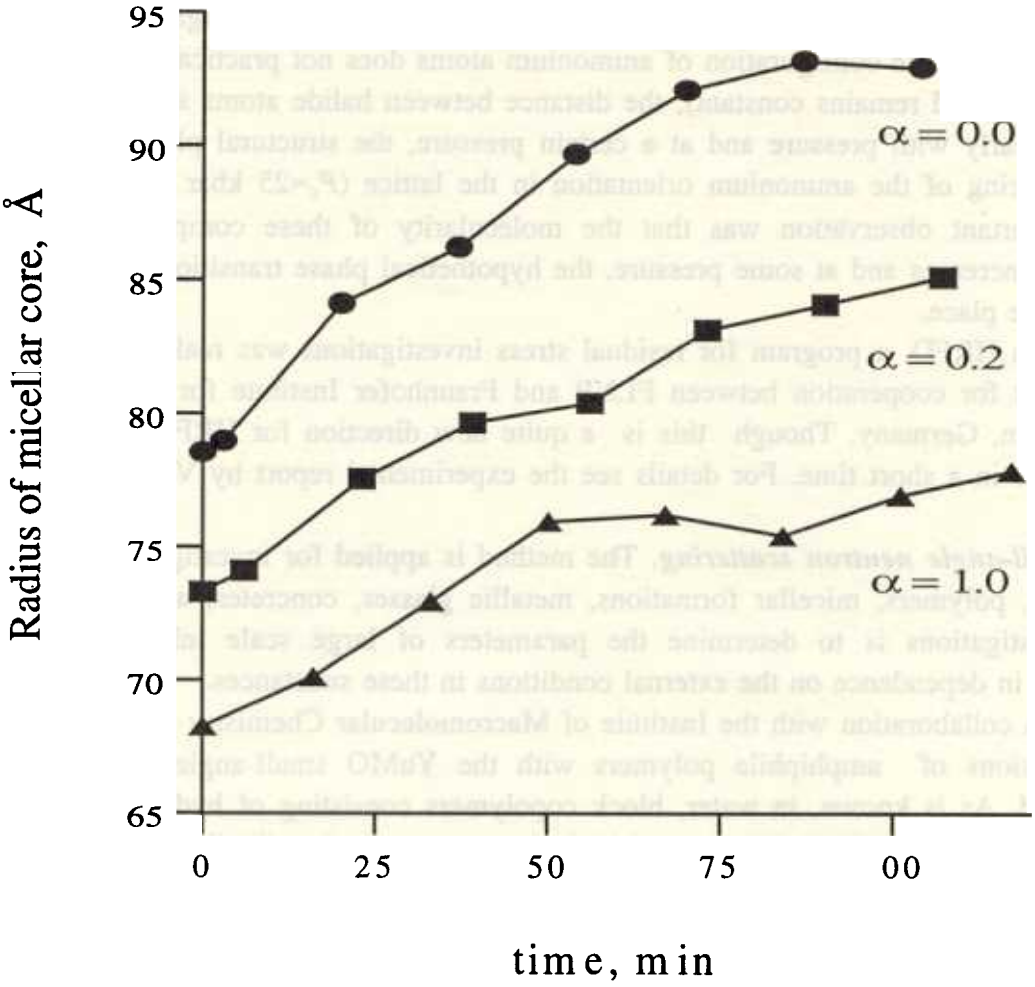

Fig.4. Variation of the micellar radius during the solubilization of chloroform into PMMA/PAAc micelles for the chosen degree of neutralization α. The mean radius was determined by fitting the SANS experimental data to the theoretical scattering curve of homogeneous spheres with a Schulz-Zimm distribution of radii.

structural changes caused by a long exposition to light. The measured effects were analyzed in the framework of the model of topological structural rearrangement. This allowed us to make the conclusion that the rearrangement involves the formation of quasicylindrical domains in the membrane and in the process of formation, the scattering density near the surface of the tylacoid membrane increases (A.D.Tugan-Baranovskaya et al, Biochem. and Mol. Biol., 38 (1996) 485).

Neutron optics with polarized neutrons. The purpose of the experiments is the investigation of the micromagnetic properties of matter, determination of the characteristics of the magnetic field interaction with matter, investigation of thin mono- and multilayer films, and investigations of open surfaces and hidden interfaces.

Earlier experiments to investigate small-angle scattering and polarized neutron depolarization in a $Fe_{70}Ni_{30}$ alloy revealed the existence of two magnetic correlation lengths different by a few tens of times in the vicinity of the Curie point (T_c=287 K) for this alloy. On the SPN spectrometer, the first experiments to discover the effects connected with the possible dependence of the phenomenon on the neutron wavelength were conducted. The measurements were carried out over a wide temperature range in the vicinity of the transition point at several

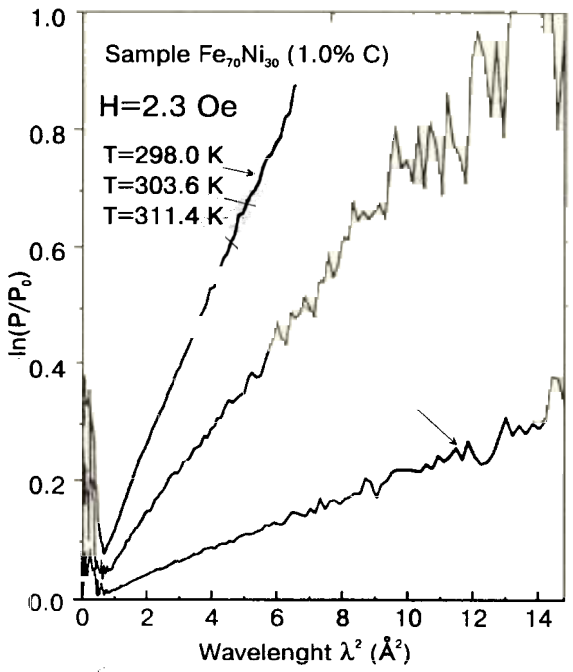

Fig.5. The dependence of the logarithm of the function $P(\lambda)/P_0(\lambda)$ on λ^2 shows its linear character without noticeable oscillation effects

external magnetic fields. Clear evidence for the temperature hysteresis of a magnetically disordered state above T_c and its dependence on the magnetic field has been found. Figure 5 shows the neutron depolarization as a function of λ measured for three temperatures near T_c. The data are well described by the function $P(\lambda)=P_0(\lambda)exp(-\alpha\lambda^2)$ without any oscillations. This is the evidence for a complete disorder of the magnetic induction vector inside the sample.

As it was planned for 1996, the first stage of the REFLEX-P polarized neutron reflectometer was put into operation and the first test and physical experiments were conducted. The neutron beam is polarized by means of an optical system of two high-quality mirrors positioned in parallel. The mirrors are made by sputtering *Fe-Co* alloy on a *Ti-Gd* substrate. The achieved beam polarization over a wide wavelength range is one of the best in the world for instruments of its type (Fig. 6). One of the first REFLEX-P experiments was conducted to investigate neutron reflection from self-organizing polymeric films, polysteinsulfonate and polyallilamine with deuterization of each alternate layer. The stability of these systems, as well as the possibility to exert an influence on their structural parameters by introducing small molecules into the interlayer space, was estimated. It was shown that, in spite of the essential rigidity of the system, this influence exists, i.e., steeping in salt solution will noticeably change the repetition period of the structure.

Inelastic neutron scattering. On the IBR-2 spectrometers, the method of inelastic neutron scattering is used to study the dynamics of atomic motion in molecular crystals, the dynamics of hydrogen in metals, the dynamics of atoms and molecules adsorbed on the surface of substances, magnetic excitations in rare-earth intermetallic compounds, the density of phonon states in novel materials and adsorbed layers, generalized frequency spectra, and stochastic dynamics in metals and alloys. Investigations of the spectra of elementary excitations in superfluid ^4He are of fundamental interest in connection with recent theoretical predictions of their properties not studied experimentally before.

In 1996, the main direction of research with NERA was the investigation of the dynamics of methyl and ammonium groups in compounds $(NH_4)_2SO_4$, $(ND_4)_2SCN$, $C(NH_3)_6I_2$, and $(CH_3)_2C_6H_4$ and solid solutions $(NH_4)_{1-x}K_xSO_4$ and $(NH_4)_{1-x}Rb_xSCN$ in cooperation of the Institute of Nuclear Physics, Krakow. For solid p-xylenes, incoherent inelastic scattering spectra were measures for different substitutions of hydrogen by deuterium: $D0=(CH_3)_2C_6H_4$, $D4=(CH_3)_2C_6D_4$, $D6=(CD_3)_2C_6H_4$, and $D10=(CD_3)_2C_6D_4$. This allowed modeling of the rotational potential of methyl groups and the quantum mechanical calculation of the structure of molecules and their vibrational spectra to be performed. In the first approximation, it appeared possible to describe satisfactorily the results for all four molecules using one set of atom-atom interaction potentials (Fig.7) (I.Natkaniec, J.Kalus et al, ECNS-96, Interlaken).

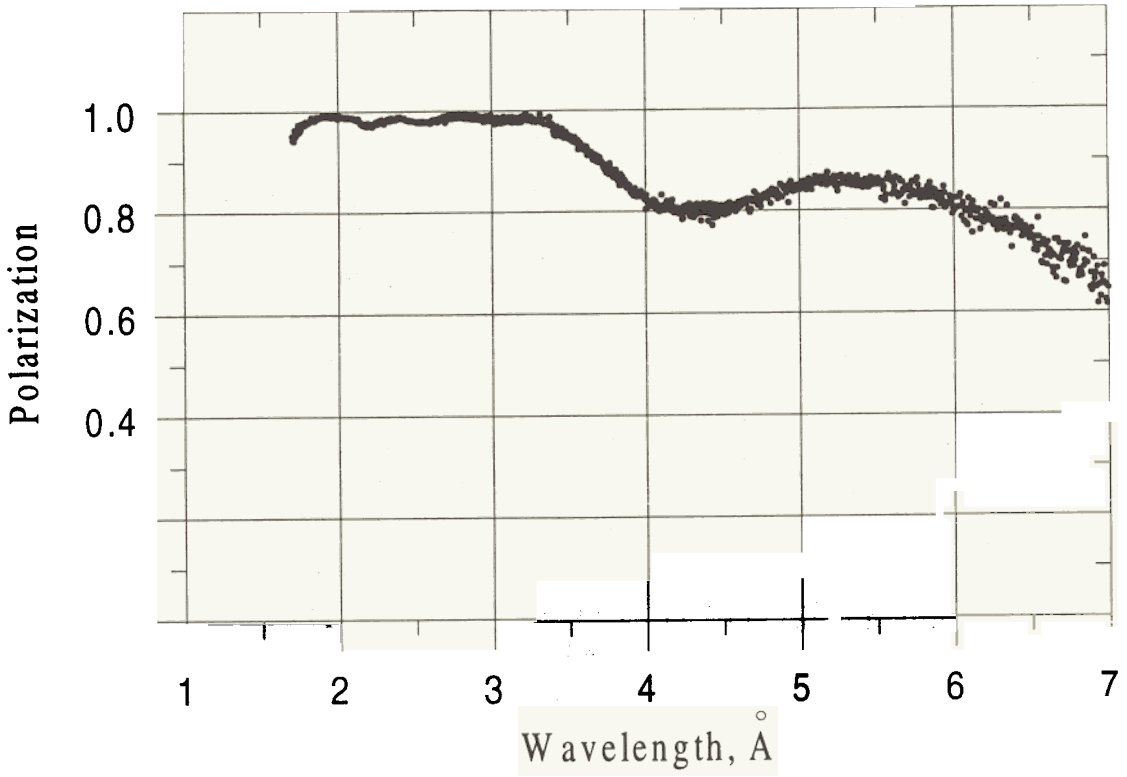

Fig.6. The wavelength dependence of the neutron polarization at REFLEX-P

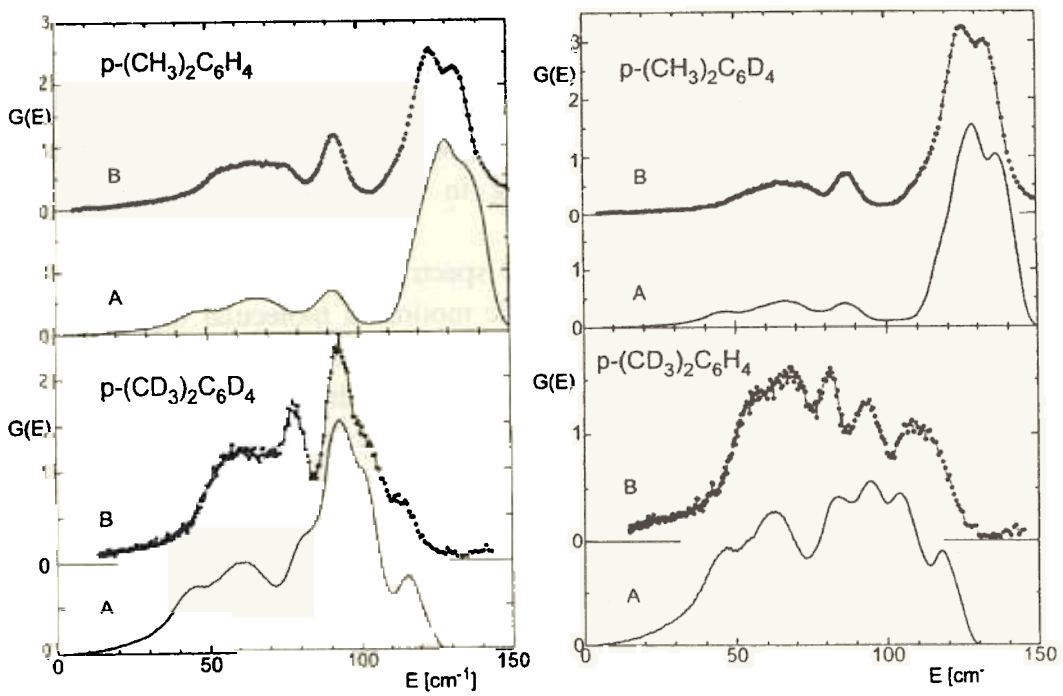

Fig.7. The calculated (A) and measured (B) phonon spectra of solid p-xylenes at 10 K for various deuterium contents

With the KDSOG spectrometer, inelastic neutron scattering spectra (INS) of hydrogeneted fullerite C_{60} samples were measured in cooperation with the Institute of Solid State Physics RAS. The samples were synthesized in hydrogen atmosphere at 620 K under the

pressure 0.6 GPa with subsequent quenching to the temperature 85 K. After taking the INS spectra, the sample was annealed at 300 K to have the composition $C_{60}H_{24}$ and its INS spectra were measured again. In the process of annealing *~1.4*H_2 per C_{60} molecule were removed. It appeared possible to obtain the information about intra- and intermolecular vibrations in the $C_{60}H_{24}$ molecule, while the difference spectrum provided the information about the transition energies between the rotational states of the hydrogen molecule, in particular, splitting of the level *(0→1)* at 14.7 meV due to interaction of H_2 with the neighbor molecules $C_{60}H_{24}$ was observed (A.I.Kolesnikov et al, ECNS-96, Interlaken).

On the DIN spectrometer, experiments to study the effects of ion and hydrophobic hydration, in particular, diffusive and vibrational-rotational motion of water molecules hydtrating the Li^+ ions in comparison to the motion of molecules of pure water, continued. The comparison has shown that the intensity of the first translational mode ($\varepsilon \approx 6$ meV) decreases, the intensity of the second mode ($\varepsilon \approx 20$ meV) increases, and the region of librations remains practically without changes (A.G.Novikov et al, ECNS-96, Interlaken).

Further investigations of localized states of hydrogen and oxygen in dilute solid solutions VH_x, VO_y, and VH_xO_y aimed at the determination of the interinfluence of *p*- and *s*-doping elements on the local structure of the defect space showed that at low doping concentrations, in a triple system *V-O-H,* hydrogen is localized in the tetrahedral or "displaced" tetrahedral positions. For the triple system, a considerable increase of quasielastic scattering possibly connected with its delocalized hydrogen state was observed.

On DIN-2PI, trial experiments to measure dispersion curves for single crystals of simple compounds were performed in the cooperation with the Physical Energetic Institute (Obninsk). For a nitrogen-free sample of steel (18% *Cr*, 15% *Ni*, 10% *Mn*), the positions of phonons in the [110] direction were measured. The results were approximated by the model of central forces taking into account the second coordination sphere. It is seen that the model describes well the experimental data for the branch *Tl* over the entire range of momentum transfers and for the *L* branch up to $q/q_m \approx 0.3$ at least. The experiments have shown that conditions for dispersion relation measurements in the low-frequency region of excitation spectra exist.

Development activities. In addition to work on the completion of the first stage of the REFLEX-P spectrometer, intense effort was concentrated on the reconstruction of the DN-12 diffractometer (project SUPERMAN). By the end of 1996, we managed to complete the preparation for positioning of the mirror neutron guide manufactured by the Hungarian firm "Mirrotron". In the first quarter of 1997, the neutron guide will be put into operation and this will allow the background conditions of the diffractometer to be essentially improved, as well as the neutron flux in the region of long waves to be increased.

At HRFD, work to modernize the instrument and extend its possibilities continued. In the system for control of Fourier chopper rotation, a magnetic type encoder capable of holding higher radiation load than optical encoders was installed. This will make it possible to increase the neutron beam aperture, as well as increase the neutron flux on the sample by ~2 times. A large +90° detector with 20 photomultipliers was installed, tuned, and put into operation. This detector in combination with the -90° detector put into operation at the end of 1995 will allow the radial and tangential components of the tensor of internal stresses to be measured simultaneously without changing the orientation of the sample. At the beginning of 1997, the second detector at a large scattering angle (2θ=152°) will be put into operation and this will allow the data collection rate from polycrystal samples to be doubled. With support of the

Institute of Nondestructive Testing (Saarbruecken, Germany), the necessary equipment for increasing the efficiency of internal stress experiments was purchased and include a loading machine, a tensor scanner, and a nitride boron slit system. At present, experiments with the loading machine are being carried out. The scanner and the slit system will be put into operation at the beginning of 1997.

The two-dimensional detector with a position resolution ~3 mm for both axes started operations at DN-2. This detector allows the realization of the three-dimensional neutron diffractometry of single crystals, i.e. the collection of information in the volume of the reciprocal space of the crystal without rotating the sample or the detector.

The new position sensitive detector for the SPN spectrometer was tested in real conditions and will be put into operation in near future. The parameters of the detector (the resolution ~1.5 mm and the registration area 40x120 mm) will ensure effective investigations of the diffusion scattering of neutrons following reflection and small-angle scattering for small momentum transfers (10^{-4}-10^{-2}Å^{-1}).

For DIN, an essential decrease in the background over the low energy region has been obtained with the help of a rotating double collimator operating in phase with the IBR-2 power pulses.

Scientific program of the Condensed Matter Physics Division in 1996 was performed in cooperation with the following institutes and organizations:

Bulgaria	University; Institute for Nuclear Research and Nuclear Energy (Sofia)
Czech Republic	Polytechnical Institute (Prague)
Egypt	Atomic Energy Authority of Egypt (Cairo)
Finland	Technical Center (Espoo)
France	Laboratoire Leon Brillouin (Saclay); Institut Laue-Langevin (Grenoble)
Georgia	University (Tbilisi)
Germany	Hahn-Meitner Institute (Berlin); Research Center (Rossendorf); University (Bayreuth); Technical University (Kemnitz); Research Center (Darmstadt); GKSS (Geesthacht)
Hungary	Research Institute for Solid State Physics (Budapest)
D.P. Republic of Korea	University (Pyongyang)
Poland	Institute of Nuclear Physics (Cracow); University (Poznan);
Romania	Atomic Physics Institute (Bucharest)
Russia	Kurchatov Institute; Institute of Solid State Physics; Institute of Theoretical and Experimental Physics; Petersburg Nuclear Physics Institute; Institute of Physics of Metals; Moscow State University; Institute of Crystallography
Slovakia	University (Bratislava)
Sweden	University (Goteborg)
Switzerland	Paul Scherrer Institute (Villigen)
U.K.	Rutherford Appleton Laboratory (Abingdon)
Uzbekistan	Institute of Nuclear Physics (Tashkent)
Vietnam	Institute of Physics (Hanoi)

In greater detail, this cooperation is described in the "Topical plan for JINR research and international cooperation" (Dubna, 11-7160 or http://www.jinr.ru/jinr/plan/).

1.2. NEUTRON NUCLEAR PHYSICS

In 1996, nuclear physics investigations with slow neutrons were carried out on seven beams of the IBR-30 + LUE-40 neutron source, on the eleventh beam of the IBR-2 reactor and on the neutron beams of other sources in Russia, Germany, France, the USA, and China. It is necessary to note that the new, valuable opportunities which opened after Russia jointed ILL, Grenoble, have been used effectively: some measurements with cold and ultracold neutrons were successfully performed. The research program for IBR-30 was formed, taking into account the time schedule of creating the new neutron source for nuclear physics investigations — the IREN project. In accordance with this schedule, the IBR-30 + LUE-40 complex has to be shutdown by the middle of 1997, so it was necessary to concentrate all available resources on the most important experiments. An extensive program for investigations of resonance neutron induced fission was realized, as well as traditional investigations of the properties of highly excited states of heavy nuclei, parity violation effects, and reactions with the emission of charged particles.

1.2.1. EXPERIMENTAL

Parity Violation and Time-Noninvariance Effects in the Interaction of Resonance Neutrons with Nuclei

The first measurements of some neutron resonances (E_n< 20 eV) of the pseudo-scalar correlation $(\sigma_n k_f)$ between the neutron spin σ_n direction and the fission fragment momentum k_n were performed on the POLYANA setup with the polarized neutron beam of the IBR-30. The specially designed ionization chamber and high intensity of the neutron source allowed us to measure the energy dependence of the effect for the ^{235}U target shown in Fig.1. For the first time, the *P*-odd effect in the cross-section demonstrated interference in the energy dependence. The quantitative analysis of the obtained results was closely related to the multi-level, many-channel treatment of other interference effects investigated in FLNP for the resonance neutron induced fission of the same target nucleus (see section **Nuclear Fission** for more details).

In the framework of the TRIPLE collaboration, the investigation of the mass dependence of the mean-square matrix element M_W of the weak neutron-nucleus interaction continued on the polarized neutron beam of LANSCE, Los Alamos. The measurements of the $(\sigma_n k_n)$ correlation were done by the method of capture gamma-ray registration for the ^{117}Sn and ^{103}Rh isotope targets. For neutron energies E_n < 1000 eV, there are 15 and 17 known *p*-wave neutron resonances for ^{117}Sn and ^{103}Rh nuclei, respectively. Only in three of them for *Sn* and in two for *Rh*, the meaningful *P*-odd effects (on the level of three standard deviations or higher) were observed. The results are being analyzed now. The recently completed analysis of the experimental results obtained in 1995 for the ^{107}Ag target nucleus yielded the respective M_W value 2.4+1.7-1.1 meV. This indicates that the mean-square matrix element M_W has equal values for nuclei with close level densities.

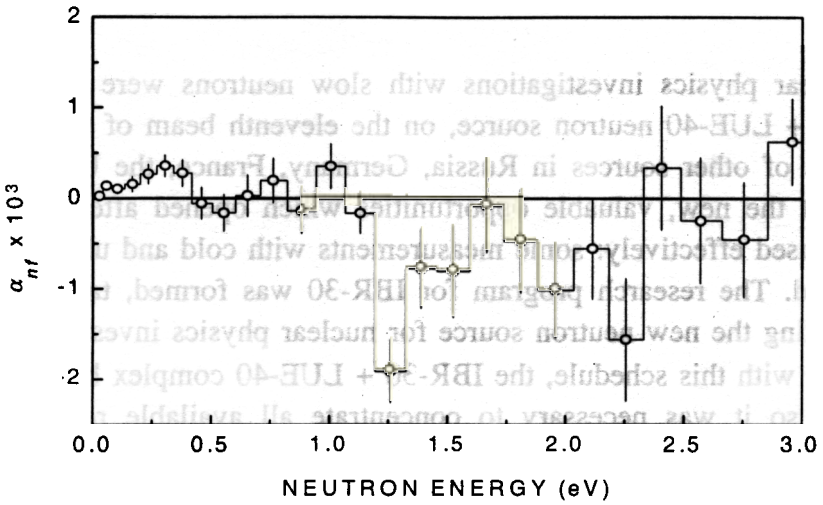

Fig.1. The parity violating interference effect of fission fragment emission in the neutron induced fission of ^{235}U

A very actual problem for some leading neutron centres is the study of time–non invariant (*T*-odd) effects in resonance neutron induced reactions. The key difficulty is large polarized nuclear targets. Up to the end of 1995, when the high *P*-odd effect was discovered near E_n = 3.2 eV for a natural *Xe* gas target, the only real candidate for a polarized target was a ^{139}La nucleus. However, the possibility of utilizing a polarized *Xe* target is feasible only if the *Xe* isotope responsible for the observed *P*-odd effect is odd. In this case, it is conceivable, in principle, to polarize a *Xe* gas target by a circular polarized laser beam. The first isotope of the *p*-wave neutron resonance at E_n = 3.2 eV was identified in the measurement of the (*n*, gamma)-reaction for a natural *Xe* target on the IBR-30 pulsed neutron source. It is ^{131}Xe with the spin 3/2. This result opens new possibilities for the experiments.

A new method of studying the time–noninvariant effect in the transmission of polarized neutrons through a polarized target was proposed at FLNP. It consists of rotating the neutron polarizer round the target by 180°. The estimated accuracy of the ratio of *T*-odd to *P*-odd matrix elements is on the level of 10^{-4} if the above-mentioned rotation is realized with a rather reasonable precision of 10^{-5} rad. The method requires one neutron polarizing device and is free at many false effects inherent in other known experimental schemes. The only feasible neutron polarizer for the proposed method is a ^3He polarized filter. In collaboration with the Lebedev Institute, a prototype of such a polarizer is being created. It consists of two aligned aluminosilicate glass cells filled with ^3He at the pressure 10 atm. The active volume of one cell is 40 cm^3 with the cross-section 5.3 cm^2. The first experiments with this device on the neutron beam of the IBR-30 source are planned for the end of 1997.

Nuclear Fission

Angular correlations of fission fragments in resonance neutron induced fission of the ^{235}U nucleus

Essential progress has been achieved in the realization of "full" experiments for investigating resonance neutron induced fission of the ^{235}U target nucleus. Due to improvement of the experimental technique at low sample temperature (T~0.1 K), the statistics for measuring the angular anisotropy of fission fragments $A_2(E_n)$ with respect to the target spin orientation was increased more than twice. Thus, the experimental data for $A_2(E_n)$ are now available in energy bins of 0.05 eV with an accuracy of 3–10 %, up to E_n < 30 eV. With the aid of the original code for multi-level, many-channel R-matrix analysis, as well as with the specially modified standard code SAMMY, $A_2(E_n)$ data fitting together with spin separated and total fission cross-sections, and the neutron capture and total cross-sections was carried out. Some of the results are shown in Fig.2.

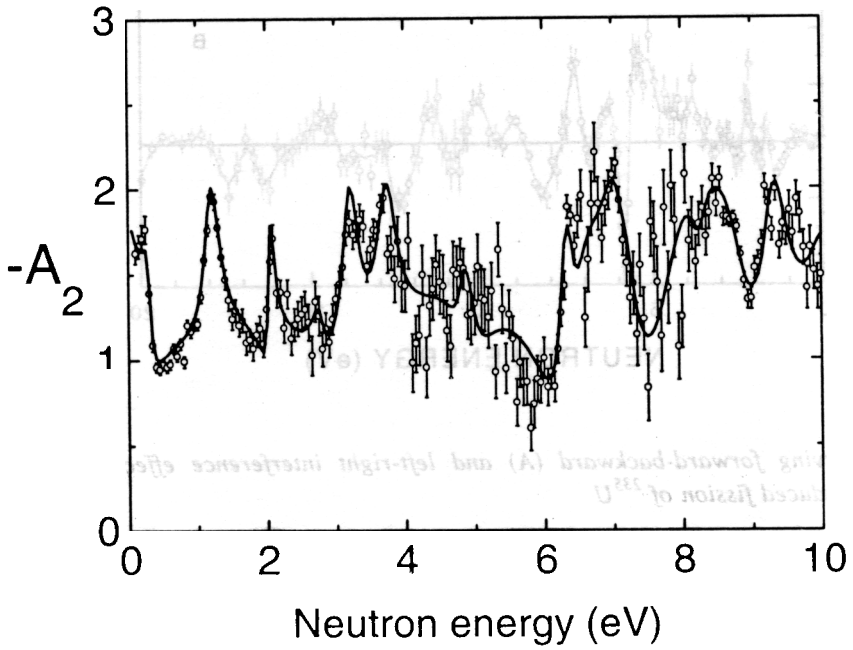

Fig.2

For the first time, three fission channels were taken into account: $J^{\pi}K$ = 3^-0, 3^-1 and 3^-2 for compound-states 3^- as well as the interference of the ^{236}U excited states with different spins. The presence of the $A_2(E_n)$ data influences the results of the analysis, namely, the signs and values of fission partial amplitudes. It is clear that the experimental accuracy over the inter-resonance regions has to be improved in order to have an unambiguous analysis.

Even at this stage of the investigation, the obtained partial fission amplitudes form a reliable basis for the quantitative analysis of other angular correlations of fission fragments measured recently by a FLNP-PINP collaboration and related with the interference of s- and p-wave neutron induced fission. As mentioned above, P-odd correlations were first measured in 1996. Also in 1996, the measurements of the left-right (with respect to the plane formed by the directions of the neutron spin and moment) correlations (see Fig.3) were completed. For

comparison, in the same Fig.3, the previously obtained data for the energy dependence of the forward-backward correlation (between k_n and k_f) are shown.

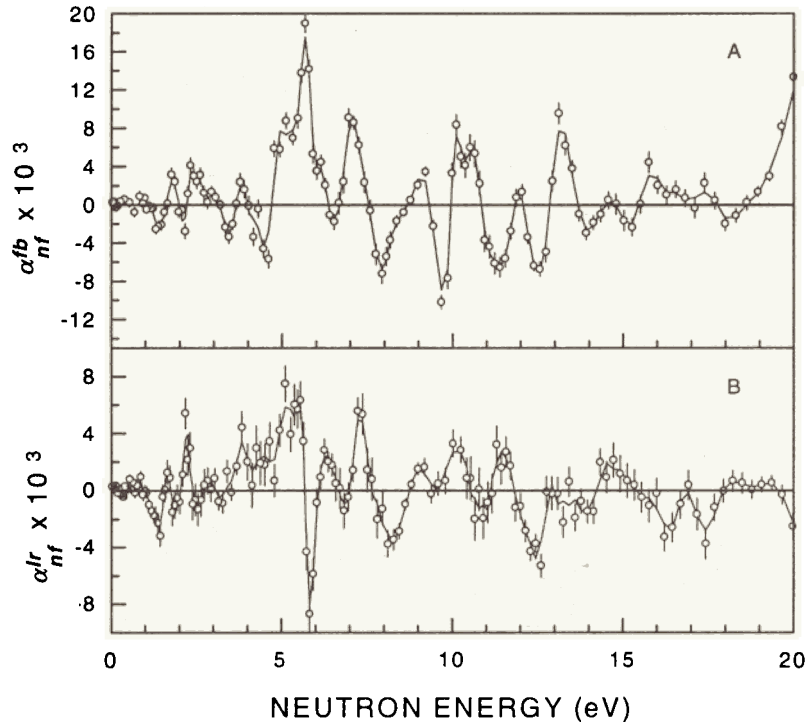

Fig.3. The parity conserving forward-backward (A) and left-right interference effects (B) of fission fragment emission in the neutron induced fission of ^{235}U

Irregularities in both dependences take place near unknown *p*-wave neutron resonances of ^{235}U. Fitting of these data is necessary to determine the full set of unknown *R*-matrix parameters for all *p*-wave resonances involved. This could be achieved, in principle, if all necessary parameters of the *s*-wave resonances are extracted from other experimental data. A comparison of the partial fission amplitudes of *s*-wave and *p*-wave neutron resonances allows one to study the parity structure of fission barriers.

Subthreshold fission and delayed neutron yields

On the basis of the experimental technique described in the previous annual review the measurements and analysis of the data on the cross-sections and relative yields of prompt gamma-quanta from the $^{234}U(n,f)$ reaction were completed. The energy dependence of the cross-section up to 1 keV was obtained and the neutron resonance parameters up to 300 eV were found. It was established that no correlations of gamma-quanta yields with reciprocal fission widths exists and an approximately constant ratio $R = N_{coin}/N_{fis}$ for all observed resonances

(within a limit of two standard deviations). This means that the (*n*,gamma *f*) process makes a negligibly small contribution to the subthreshold neutron induced fission of ^{234}U.

In the course of 1996, the study of delayed neutrons (DN) continued with the aid of a modernized ISOMER setup. The results for the DN yield from the thermal neutron induced fission of ^{239}Pu were essentially improved due to the use of new metallic plutonium samples (30 and 56 mg). The background connected with the (α,*n*)-reaction decreased by an order of magnitude. The measurements of the ratio β of delayed to prompt neutron fission yields for ^{237}Np at thermal energies were performed. Due to a very low cross-section (< 20 mb) even for a large (40 g) and highly purified (to 10^{-6} of $^{233, 235}U$ and ^{239}Pu) sample, these measurements were difficult to carry out. However, a high neutron flux of the IBR-2 reactor allowed the β value at a thermal point to be first obtained with an acceptable accuracy: β=(0.41± 0.06)%.

Also, the first direct measurements of the time dependence of the DN count rate have been made for ^{235}U and ^{239}Pu in time intervals of 350 ms. The results are shown in Fig.4.

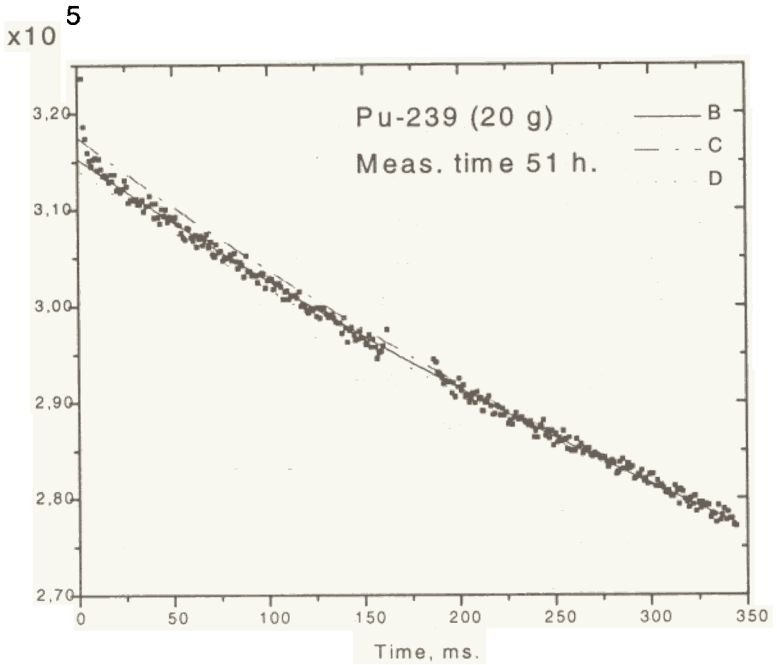

Fig.4. The experimental delayed neutron decay curve for ^{239}Pu and the calculated ones using different six-group sets of constants: B- R.J. Tuttle, C- A.C. Wahl, D- R.W. Waldo et al.

These data could be used to evaluate the contributions of shortest-life DN groups with the precursor lifetime less than 0.1 s.

Highly excited states of nuclei

Cascade gamma decay of compound states after thermal neutron capture

The coincidence gamma spectra of the $(n,2\gamma)$ for ^{128}I, ^{166}Ho, $^{176,177}Lu$ and ^{182}Ta target nuclei with excitation of intermediate levels below the neutron binding energy, were studied. The probabilities of primary gamma-transitions and transitions from intermediate to low-lying levels obtained from the experimental data for these isotopes, as well as for a broad set of previously investigated heavy nuclei, demonstrate the following general peculiarities of gamma decay: a) the dominant role of the vibration excitation modes in the excitation energy interval

1-3 MeV; and b) the failure of common nuclear models to reproduce the shape (and energy dependence) of the observed gamma spectra. These results could be interpreted as a strong evidence of the existence of the phase transition from mainly vibrational excitations to quasi-particle ones in heavy excited nuclei.

Radiative resonance neutron capture

On the basis of the modified ROMASHKA setup, spectra of gamma quanta multiplicities after the radiative capture of neutrons with energies from 20 eV to 2 keV on the ^{115}In, ^{117}Sn, ^{127}J, ^{175}Lu, and ^{239}Pu targets were measured on the sixth beam of IBR-30. The spins of the neutron resonances of the ^{118}Sn and ^{176}Lu compound nuclei were obtained. From the measurements of the multiplicities of gamma-quanta emitted after fission and radiative capture in the ^{235}U target, the ratios $\alpha = \sigma_\gamma / \sigma_f$ were extracted for 72 resolved resonances and energy groups below 1 keV. These data allows one to resolve the contradictions between the α values obtained for the resonance region and those from experiments with critical assemblies.

Neutron capture by ^{48}Ca at thermal and thermonuclear energies

The thermal cross-section of the $^{48}Ca(n,\gamma)^{49}Ca$ reaction was measured at the BR1 reactor in Mol, Belgium. It was obtained by the registration of γ-quanta from the reaction, as well as from the decay of ^{49}Ca using a set of Compton suppression HP Ge detectors. The result is 0.982+-0.046 b. This value is about 10% lower than the previously measured one. Our experimental error is also three times less.

The cross-sections of the same reaction were measured at the Van-de-Graaf accelerator, Karlsruhe, Germany, by the method of fast cyclic activation at the neutron energies 25, 151, 176, and 218 keV. The enrichment of the ^{48}Ca sample was 77.87%. The respective results were 751±68, 331±40, 306±31 and 304±31 μbarn.

The astrophysical reaction rate extracted from our data does not depend on temperature and is equal to $N\langle\sigma v\rangle = 1.2 \times 10^5$ cm^3 mol^{-1} s^{-1}.

Neutron induced reactions with charged particle emission

For the first time, the cross-section of the $^{35}Cl(n,p)^{35}S$ reaction was measured at thermal energies by the time-of-flight method using the neutron beam of the IBR-30 source. Different from previous measurements, which were done by the activation technique, the original ionization chamber was used to register the emitted protons. The obtained result 575±13 mb considerably exceeds the previously published ones.

Investigations with ultracold neutrons

The first stage of the test experiments has been completed with the high-density ultracold neutron (UCN) source at the BIGR pulsed reactor, VNIIEF, Sarov. The results show the opportunity for an essential increase in the obtained UCN density, which is now on the order of 50 n/cm^3. This value, even at the preliminary stage, appeared to be close to the UCN density achieved at the most powerful UCN source in ILL, Grenoble, France.

The first experiments studying UCN up-scattering in the velocity range of 10-200 m/s were carried out on the MANAGR experimental setup created in 1995 at the ILL reactor, Grenoble, in collaboration with PINP, Gatchina. The results stimulated the modernization of the

installation, which will be completed by the beginning of the next experimental run in the second quarter of 1997.

In the frame of the FLNP–Kurchatov Institute, Moscow–ILL–Melbourne University collaboration, the first experiments were carried out on a precision test of the neutron wave dispersion law using an original method based on the Fabri-Perrot interferometry. These measurements confirm the feasibility of the technique and allow the actual sensitivity of the method to be estimated. These experiments will be continued in 1997 at ILL.

1.2.2. THEORETICAL

The contradiction between the results of two experimental groups reporting different values of the n-e scattering amplitude extracted from transmission and diffraction measurements was analysed. It was shown that in the transmission experiments, important corrections due to the difference between the coherent scattering length and the scattering amplitude were not taken into account. In the diffraction experiment, it was pointed out that scattering by a crystallite is not necessarily proportional to the coherent cross section. For a sufficiently large crystallite, it is proportional to the coherent scattering amplitude. Thus, it is necessary to measure the distribution of the crystallites in the given sample, which had not been done. Therefore, for now, neither experimental value for the *n-e* scattering amplitude can be taken as reliable.

An analytic derivation of the extended (generalized) Hartry-Fock potential (EHFP) and the real part of the nucleon optical potential for finite spherical nuclei have been obtained, taking into account the structure of the free nucleon-nucleon interaction. It is shown that in finite nuclei, the real part of the nucleon optical potential constructed on the basis of the EHFP has more complicated radial, isotopic and energy dependences, and the form of the spin-orbit term in comparison with phenomenological optical potentials. In calculations based on the proposed approach the realistic scale of the spin-orbit potential was first obtained without the use of relativistic nuclear models. The essential role of the gradient terms of the EHFP in forming the optical potential was revealed.

1.2.3. METHODOLOGY

New method of neutron spectra generation at star temperatures

The method of Maxwellian neutron spectra generation (creation) is proposed with a variable temperature in the range of 10-50 keV. To obtain the necessary spectra, the reactions $^{7}Li(p,n)$ and $T(p,n)$ as neutron sources and a graphite or lead moderator of special configuration can be used. The calculation of the setup parameters and Monte-Carlo simulation of the neutron spectra have been carried out. The first experiments with the new neutron source are planned for the middle of 1997.

Test experiment on the UGRA setup

The first stage of testing of the UGRA setup has been completed and the test measurements at planned vacuum were performed. It was confirmed that the accuracy necessary to measure the electric polarizability of the neutron can be achieved. The problem of more stable and effective detectors has to be solved to start data taking.

1.3. APPLIED RESEARCH

In the reported year, analysis of methodological possibilities for analytical and radiation investigations on the IBR-2 channels continued. In particular, the directions of scientific research and the present state of the instruments and their equipment on channel 11 (BPC) were discussed. Earlier plans were to use the channel mainly for biophysical experiments and dynamic neutron radiography. Recently, the mirror neutron guide forming the thermal neutron spectrum on channel 11 (one of the first channels at IBR-2) has been successfully used for investigations in the physics of delayed neutrons by the group of Yu.S.Zamyatnin together with the NAA sector staff. This work has got financial support and is developing successfully. At the same time, experiments to investigate residual stresses in materials (A.M.Balagurov and J.Schreiber) have a claim (also financed) on channel 11 with a mirror neutron guide. These two directions form the scientific activity on channel 11. In this situation, a compromise has been made by proposing the creation of a split neutron guide system instead of the old system of collimators and one neutron guide.

In the reported year, experimental investigations were carried out in several directions.

On the IBR-2 radiation channels of the pneutransport facility REGATA, NAA investigations of the distributions of heavy metals and other elements in environmental objects and novel materials were conducted.

The NAA sector, in cooperation with Romanian scientists, completed the biomonitoring stage of heavy metals and other elements in industrial and adjacent areas in Romania under the auspices of the European project "Heavy Metal Atmospheric Deposition in Northern Europe". The data on the *Cu, Cd, Pb, V, Cr, Fe, Ni, Zn,* and *As* contents (the *Pb* and *Cd* contents were determined by the method of atomic adsorption (AAS) in Norway) were accepted by the Organizing Committee for publication in European Atlas for 1996. It is the first time the obtained experimental information on 37 elements, including rare-earth and toxic elements, in addition to the above enumerated elements, has allowed a complete picture of the technogenic effect on the environment of the heavy industry centers and gas- and oil-refining plants of Romania to be obtained.

Under the auspices of the bilateral agreement with the Polish Republic "Determination of Elemental Composition of Aerosols by INAA as a Tool for Evaluation of Environmental Pollution", an analysis of air filters taken from Warsaw and Krakow was conducted to determine the main pollutants and finishing off the method of analysis by different types of filters. The analysis has shown that Krakow experiences a strong influence of the most developed industrial region in Poland, the Katowice region.

Investigations of the moss, peat, and soil samples collected above the Pole circle in Norway and Finland were completed. The analysis of peat drills to the depth of 50 cm allows changes in the element composition of distant air transfers over a long historical period to be detected. Analysis of halogen contents over the Arctic Ocean - European continent transacts has allowed the role of marine components in atmospheric aerosols in Scandinavia to be determined.

The important directions of research connected with monitoring of different ecosystems in Russia, in particular, the Murmansk region and central Russia (ecosystems of the Volga and Oka rivers), and the atmosphere in West and East Siberia were conducted in cooperation with ecologists from the Kola Scientific Research Center of the Institute of Industrial Ecology of the North of RAS (the town of Apatity), The Institute of the Lithosphere of Earth (Moscow), and the Institute of Chemical Kinetics and Burning of the Siberian Branch of RAS (Novosibirsk).

On the basis of the analysis of 160 samples of soil and pine needle taken in the vicinity of the plant for production of phosphorus fertilizers in the town of Apatity and the adjacent areas in the Murmansk region, the source of environmental pollution with a number of elements, including rare-earth elements (REE), *La, Ce, Nd, Sm, Eu, Tb,* and *Yb,* was identified. The REE concentration is very high in Apatity. These results are extremely important because for the present, the role of REE and their influence on ecosystems and animal life is yet little studied.

For monitoring of ecosystems of central Russia (the basin of the Volga and Oka rivers) samples of soil, plants and sediments were analyzed. The data on the concentrations of 30 to 45 elements in 150 samples were submitted to the Institute of the Lithosphere of Earth of RAS (Moscow).

The element analysis of atmospheric aerosols (AA) with different dispersion compositions from West and East Siberia was conducted with the aim of a complex investigation of their properties and characteristics. The NAA analysis of 500 AA samples yielded the data on AA compositions in different areas of the Novosibirsk and Baikal regions (Novosibirsk, Kliuchi, Karasuk, Lake Chany, Lake Baikal, etc.) important for clarifying the similarities and peculiarities of AA compositions on the regional and local levels and studies of year's and seasonal changes in the dynamics of the AA element composition. The obtained data were submitted to the Institute of Chemical Kinetics and Burning and will be used for the formation of the data bank on AA in Siberia, determination of the sources of antropogenic pollution to estimate the AA effect on the environment, vegetation and animal world, as well as on the health of local population.

To investigate radiation-resistant materials for new detectors, the nature of radiation dying centers, and the structure of defects, the following work has been carried out.

Single crystals of *TlSe, $TlInSe_2$* and *InSe* superconducting compounds with a strongly anisotropic lattice structure were synthesized and grown by the method of orientational crystallization.

With the REGATA facility at IBR-2, crystals of *TlSe* ($\rho_{\parallel} \approx \rho_{\perp} \approx 1 \cdot 10^{1}$ ohm cm) and *$TlInSe_2$* ($\rho_{\parallel} \approx \rho_{\perp} \approx 2 \cdot 10^{4}$ ohm cm and $\rho_{\parallel} \approx \rho_{\perp} \approx 5 \cdot 10^{7}$ ohm cm) were irradiated with a fast neutron fluence $1.5 \cdot 10^{16}$ n cm^{-2} and $1.5 \cdot 10^{17}$ n cm^{-2} to investigate the influence of radiation defects on the anisotropy in electric conductivity and the parameter "a" of the tetragonal crystal lattice.

The heterotransitions *TlSe - $TlInSe_2$* (110) were obtained by the method of liquid epitaxy. Some of their physical properties were investigated. It is shown that the volume charge region is displaced relative to the metallic boundary of the transition towards the *$TlInSe_2$* substrate. It has also been shown that heterotransitions are sensitive to γ-n-radiation.

The new method for intercalation of anisotropic crystals has been developed. We applied for the RF patent and it was granted.

Distributions of different admixtures in a number of minerals (topaz, beryl, olivine) were studied and their correlation with dying centers before and after neutron irradiation at IBR-2 was found.

A cycle of neutron diffraction experiments was conducted at the reactors in BENSC (Berlin, Germany), FNIFKhI (Obninsk, Russia), and FLNP JINR. *X*-ray experiments were carried out in the University of Kiel and Munich (Germany) and the data on Bragg diffraction and diffusion scattering on single crystals of the *ZrO_2 - Y_2O_3* system (3, 12, 30 mol%) were obtained. On the basis of calculations, models of defect structures accounting for short-range and long-range orders have been suggested.