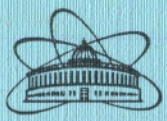

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V. L. Aksenov

SCIENTIFIC PROGRAMME OF THE FRANK LABORATORY OF NEUTRON PHYSICS: Report for 1999 and Prospects for 2000

Report to the 87th Session
of the JINR Scientific Council
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INTRODUCTION

In 1999, the FLNP scientific program was realized under the auspices of five research themes of the JINR Plan of Scientific Research and International Scientific and Technical Cooperation (PSRISTC) and it was aimed at obtaining new results in condensed matter physics (theme 07-4-1031-99/2003 "Neutron Investigations of Structure and Dynamics of Condenced Matter", headed by V.L.Aksenov and A.M.Balagurov) and neutron nuclear physics (theme 06-4-0974-92/99 "Study of the Fundamental Characteristics of Neutrons and Nuclei", headed by W.I.Furman and V.N.Shvetsov). To effect scientific research, work to develop, modernize, and construct the FLNP basic facilities, IBR-2 (theme 07-4-0851-87/2002 "Development and Upgrading of the IBR-2 Complex", headed by V.D.Ananiev) and IREN (theme 06-4-0993-94/99 "IREN Project", headed by W.I.Furman and I.N.Meshkov) as well as the IBR-2 computation and spectrometry complex (theme 07-4-1012-96/2000 "Development of the IBR-2 Spectrometers Complex and Computation Infrastructure", headed by A.V.Belushkin and V.I.Prihodko) continued. Also, FLNP took part in the JINR themes: «ATLAS. General-Purpose pp Experiment at the Large Hadron Collider in CERN» (theme 02-0-1007-94/2005, headed by N.A.Russakovich), «Theoretical and Experimental Investigations of the Electronuclear Method of Energy Production and Radioactive Waste Transmutation» (theme 03-0-1008-95/99, headed by A.N.Sissakian and I.V.Puzynin).

This report contains a brief account of 1999 scientific results and outlines the 2000 year plans of the Laboratory reflected in the JINR Plan of Scientific Research (PSRISTC) submitted for approval to the present session of the JINR Scientific Council. The FLNP annual report for 1999 will give a more detail account of 1999 results.

1. SCIENTIFIC RESULTS IN 1999

1.1. Condensed Matter Physics

Experimental investigations. In 1999 under theme 1031, neutronography investigations in condensed matter physics were conducted at IBR-2 using four basic experimental techniques: diffraction, small-angle scattering, inelastic scattering, and polarized neutron optics. During the reported year there were eight reactor sessions. Beam-time on spectrometers was allocated according to experts recommendations on the basis of the submitted experimental proposals taking into account the existing long-term agreements for cooperation.

In 1999, the list of spectrometers operating in the user regime included 10 instruments: HRFD, DN-2, DN-12, SKAT, YuMO, SPN, REFLEX-P, KDSOG, NERA, and DIN. A close type refrigerator-based cryostat to conduct experiments under simultaneous action of low temperatures, down to 12 K, and high pressures,

up to 7 GPa, was put into operation. Filling of a two-axis position sensitive detector with a working gas mixture, 3 atm ^3He + 2.0 atm propane, was accomplished. The detector was installed in the diffractometer DN-2 and tested in the neutron beam. The modernization project of the DIN-2PI spectrometer was developed to raise the upper limit of initial working energies. Assemblying of the supporting systems of the thermostat TS3000 started and a pavilion for control systems of the thermostat was built to allow measurements of materials at 3000 K with DIN-2PI.

Diffraction. Structural changes in ammonium iodide, ND_4I, at high pressures up to 3 GPa and temperatures to 12 K were investigated. Dependence of lattice parameters and the deuterium position parameter on the pressure and temperature was established.

Structural changes in samarium hexaboride, SmB_6, at pressures up to 7Gpa were investigated. At 4-5 GPa there was observed anysotropic broadening and splitting of diffraction peaks, which points to the existence of the structural phase transition to a lower symmetry phase in SmB_6 at pressures up to 7 Gpa. Neutron diffraction investigations were conducted to study the effect of single axis elastic strain on the magnetic structure of terbium monocrystals. Decreasing of the wave vector of the helicoid magnetic structure under the action of a single axis strain on the order of 1 kbar was observed.

Small angle scattering. Purple membranes from the bacterium *Halobium Salinaris* were studied with the YuMo spectrometer. The observed conformational fast alterations occur within the first 10 min and are irreversible for hours suggesting strong interaction of guanidine hydrochloride with illumination-induced PM in the samples.

Polarized neutron optics investigations. The magnetic field distribution inside thin $YBa_2Cu_3O_7$ films in the mixed state was studied by polarized neutron reflection. The experiments showed a peculiar behavior of flux-lines in the films under the action of an external magnetic field applied parallel to the film surface if the thickness of the film d is of the same order of magnitude or smaller than the magnetic penetration depth. Flux-line row transitions were observed. They extend the penetration of the magnetic flux occurring in the form of flux-lines to an appreciable range of external fields. The restricted geometry of the film does not only affect the flux-line arrangement inside the film but also the distribution of the magnetic field around the single flux-line core. This happens because on the film interface the normal component of screening currents around the core should vanish. In our polarized neutron reflectometry experiment we were able to verify the effect. The atomic and magnetic structures of Fe/Cr superlattices were studied by means of polarized neutron reflectometry and complementary methods, such as X-ray diffraction, electron microscopy and Moessbauer spectroscopy.

Inelastic neutron scattering. Investigations with DIN-2PI of water solutions were aimed at revealing the influence of dissolved particles on the microdynamics of water molecules in the hydrate spheres of the particles. Hydrophobic hydration effects and their influence on diffuse mobility and rotation-vibrational dynamics of hydrate water molecules were investigated. A comparative analysis of two types of

hydration was carried out and it was discovered that there existed a principal difference between them consisting in that, differently from ions (Li^+ or Cs^+), big polar particles did not destroy the hydrogen bonds lattice in the surrounding water. Low frequency vibrational modes of atoms in the normal and superionic phases of lead fluoride (PbF_2) were investigated at T=293 and 823K. The obtained data evidence in favour of a liquid-like state of anionic lattice in the superionic phase of PbF_2 the nature of collective excitations in which is different from classical liquids.

1.2. Neutron Nuclear Physics

The 1999 experimental research program in FLNP includes traditional research directions: experimental investigations of the fundamental properties of the neutron, studies of the processes of spatial parity violation in different nuclear reactions induced by neutrons, investigations of highly excited states of nuclei in reactions with resonance and fast neutrons, astrophysical aspects of neutron physics, experiments with ultracold neutrons. An extensive program of studies in resonance neutron induced fission completed in the main.

Also, experimental approaches are investigated in such a complicate field as time-noninvariance effects in the interaction of resonance neutrons with nuclei.

Applied research in the field of neutron activation analysis (NAA) by neutron detectors of different types and make were also conducted.

The main part of these investigations was carried out on seven neutron beams of the IBR-30 booster, beam 1 and 11 of the IBR-2 reactor and the experimental facility «Regata» for neutron activation analysis at IBR-2. At the same time, a number of investigations were conducted in collaboration with nuclear centers in Russia and other countries.

The most important reason why the scientific program at IBR-30 continued in 1999 and will be executed in near future is to preserve a solid research team capable to carry out investigations with the IREN source, develop new techniques and prepare instruments for such investigations.

Experimental Researches

Combined investigations of parity- nonconserving (PNC) and parity-conserving (PC) interference effects that may extend essentially the possibilities of theoretical analysis of the experimental data on nuclear fission continued using ^{239}Pu. A new multilayer fission chamber containing 0.5 g of ^{239}Pu is made, the pulse height spectra of fission fragments are obtained using an isotope neutron source.

In the experiment to study angular correlations of fission fragments in the resonance neutron induced fission of an aligned ^{235}U nucleus in beam 5 of IBR-30, data taking completed. A combined data analysis of the A_2 energy dependence and known data on total and spin- separated cross sections is performed. As a result, a set of s- wave resonance parameters is obtained, including data on partial fission widths Γ_{fk}. Measurements of temperature-sensitive anisotropy of α- particles and

fission fragments started in 1999. The aim is to increase the accuracy of the absolute value A_2.

Studies of fission modes and correlations with quantum states of compound nuclei continued on beam 2 of IBR-30. A method of precise measurements of the kinetic energy of fission fragments is developed and realized for actinide isotopes. The method employs a double ionization chamber with Frish grids. Using the method it was possible to measure TKE for low lying ^{235}U resonances with a statistical accuracy an order of magnitude better than in earlier experiments. This makes it possible to measure TKE in narrow energy bins of 0.2 eV over a wide energy region and creates grounds for model calculations of fission parameters.

A technique for extracting detail information on the level density and strength functions of levels excited by dipole primary transitions is developed. It is the first time that the corresponding data have been extracted from the experimental spectra of two-quantum γ- cascades for 30 nuclei in the mass region $113 < A < 201$. A higher adequacy interpretation requires more precise consideration of the quasi-particles - phonon interaction in the excitation energy region 1-2 MeV to 3-5 MeV in comparison with the existing models. Data taking for Br isotopes from an uninvestigated mass region started on beam 1a of IBR-30 and will continue in the year 2000.

Using the γ- ray spectrometers PARUS and ROMASHKA the pulse height and multiplicity spectra of ^{117}Sn, ^{235}U, ^{239}Pu are measured in a wide energy region. Relative yields of high energy γ- quanta are obtained for ^{117}Sn and also, α- values ($\alpha = \sigma_\gamma / \sigma_f$) are derived from multiplicity spectra for all measured isotopes. An increase of multiplicity and decreae of α with increasing U and Pu sample thickness are first observed.

In the reported period an additional mechanism of UCN escape from traps was observed in experiments at ILL (Grenoble, France). It is associated with an approximately two-fold increase of UCN energy with the probability about 10^{-6} per collision for the stainless steel surface and lower for other studied materials (Cu, Be). The observed effect is not reduced to known UCN upscattering leading to an increase in neutron energy to about thermal.

Theoretical Researches

A new theory of nuclear fission induced by resonance neutrons is developed. It provides a new and sufficiently natural interpretation of A.Bohr's fission channels. A similar-based description of P-even and P-odd angular correlations of fission fragments is obtained. Part of the predicted new effects found confirmation in experiments performed in FLNP.

Possible experimental versions of CP-violation in neutron resonance reactions are analyzed. The dependence of the effects and their relative errors on the neutron energy and target thickness is studied. The necessity to compensate strong pseudo - magnetic precession by applying an external magnetic field is demonstrated. Analysis of some other quantities shows that although their values

do not show resonance enhancement, their relative errors decrease sharp in the vicinity of the p-wave resonance.

Methodical Researches

Construction work in the experimental pavilion completed with installing the UGRA spectrometer. A vacuum chamber, sample movement mechanism and two detector shielding blocks are assembled on the 250 m flight path in beam 6 of IBR-30. Assemblying of electric motors and signaling systems completed. A computer-aided control block is manufactured and the software is developed. The first experimental researches were done in 1999 using this unique facility to study neutron scattering in the resonance energy region.

To carry out investigations in paramagnetic neutron resonance and nuclear pseudomagnetism at the IBR-2 pulsed reactor, an experimental complex "Kolkhida" is being built to consist of a polarized neutron spectrometer and a polarized nuclear target. A spectrometer for investigations with polarized neutrons is built and its parameters are measured. The conducted tests show that the spectrometer can be conveniently used to carry out investigations with polarized neutrons over the thermal to several eV neutron energy range.

Applied Researches

Application of instrumental neutron activation analysis (INAA) at the IBR-2 pulsed fast reactor are based on the use of the experimental setup «Regata». In the reported period the activation analysis experience was mostly in pollution studies over some industrial areas of Russia (the South Ural, Tula, Moscow region) and JINR member states (Poland, Romania). The application of neutron activation analysis with epithermal neutrons (ENAA) makes it possible to improve the selectivity and detection power of the method. The dominating part of air pollution studies is based on the use of the moss biomonitoring technique. It was applied to study air pollution by heavy metals and other trace elements in combination with atomic absorption spectrometry in the case of Pb, Cd, Cu and Ni. The results are presented in the form of tables, diagrams, graphs and, using the geographical information system (GIS) technology, in the form of colored contour maps for each element.

In collaboration with the Russian Space Research Institute tests with a High Energy Neutron Detector (HEND) prototype to measure the energy dependence of the detector efficiency were completed in November. HEND will be launched on board the Mars Surveyor Orbiter 2001 in March, 2001. In the year 2000, the test program of HEND will be carried out together with extensive MC calculations.

1.3. Other JINR Programs

Theoretical and Experimental Investigations of the Electronuclear Method of Energy Production and Radioactive Waste Transmutation. In 1999, work to investigate fast neutron yield fluctuations in a subcritical system, reactor + electron

beam of LUE-40, and study the dependence of the neutron yield on the reactor subcritical level was carried out.

2. NEUTRON SOURCES

2.1. The IBR-2 Pulsed Reactor

In 1999, the IBR-2 reactor operated for physical experiments 8 cycles, including three cycles with a cryogenic moderator.

Cryogenic moderator (CM) The main achievement of the year is that CM is constructed and put into operation. On November 18, 1999 the reactor started operation at W=1.05 MW with a cold moderator at T_{CH_4} ~60 K and on November 21, 1999, the CM regime at W=1.5 MW and T_{CH_4}=30 K was achieved. Special program-based CM tests started. In cycle 6, regimes of methane freezing and forming of a slit gap for faster outflow of H_2 were worked off together with investigations of radiolytic hydrogen accumulation and removal for different levels of reactor power and T_{CH_4}=30-70 K. At the same time, the neutron characteristics of CM were measured in three channels.

Modernization project. Work on engineering design of MR-3 resumed and is planned to be completed by the end of the year.

The working plan of the production of TVELs for IBR-2 by the enterprise «Majak» is updated. Work on TVEL engineering project and specifications completed. Work to finish off the production technology of TVEL parts began.

Work on the IBR-2 modernization engineering project started.

2.2. The IREN Project

The project status. Following the recommendations of the JINR Plenipotentiary Committee (March 1993) the JINR Directorate adopted the decision, approved at the 76th Session of the JINR Scientific Council June 1994), to construct the new modern source of resonance neutrons for investigations in fundamental and applied nuclear physics. The completion date (physical startup date) was the end of 1997. The IBR-30 analogous scheme, i.e., combination of a powerful linear electron accelerator and a subcritical multiplying target, was chosen for the new neutron source. The new IREN facility will permit the neutron energy resolution to be increased an order of magnitude at a double increase in luminosity.

Due to lack of financing from the JINR budget, only 1044 K$ was invested in the IREN project by the end of 1998. In spite of insufficient and irregular financing of the project some progress was achieved.

For the linac, the first modulator M-350 created on the basis of an OLIVIN station with a SLAC klystron 5045 was successfully tested; designing and production of a RF feeder and accelerating tubes were partly realized as well as the

designing of the focusing system and the vacuum system; practically all equipment for the latter system was shipped to JINR; an essential part of the full scale stand for testing of accelerating tubes was created in FLNP.

For the multiplying target, the technical project of the subcritical core and respective fuel elements was elaborated; all spare parts of fuel elements, including metallic plutonium rods were manufactured; the technological design of fuel element production is practically completed; the contract for working out of a civil engineering project of the IREN installation and dismounting of the old IBR-30+LUE-40 booster is signed and its first stage is realized.

Above mentioned results were mainly obtained from June 1994 to March 1996 when the financing of the project was on the level ~40% of the scheduled amount. But in the next three years the rate of project implementation dropped, the key contracts were frozen or cancelled and so, the future of the project became questionable.

In this critical situation in March 1999, the JINR directorate approved the revised working schedule of the IREN project with a new startup date in the year 2002 and found the possibility to allocate a special grant to save the project. The promised 250K$ to be paid by the end of 1999 will make it possible for the management of the IREN project to start negotiations with partners on the preparation of new contracts and prolongation of some old ones.

3. DEVELOPMENT OF THE IBR-2 SPECTROMETER COMPLEX AND COMPUTATION INFRASTRUCTURE

In 1999, work was carried out to continue developing of the information and computation infrastructure of the IBR-2 complex:

- a high-rate network switch was purchased and installed in the second experimental hall of the IBR-2 reactor
- the number of high-rate lines in the central network switch CISCO 5000 was increased
- transition to twisted pairs in the experimental halls of IBR-2 to connect the spectrometers equipment to the network completed
- the working place infrastructures of engineers and programmers were considerably improved

The architecture and electronic modules of unified VME-based data acquisition and control systems for the IBR-2 spectrometers were developed. These systems are based on a limited but functionally complete set of identical (from hardware viewpoint) modules in which distinctions in parameters, functional capabilities, encoding as well as correction and preliminary data processing procedures are realized by means of microprograms, electronic tables, switches, etc. The main elements of technical solutions and software were tested in the structure of VME data acquisition systems operating at NSVR, SCAT, HERA-PR, EPSYLON, and HRFD spectrometers. In 1999, the first stage of VME equipment and software for data acquisition was put into operation on the YUMO

spectrometer, and in December it is planned to complete work on PSD. Over the same period, unified VME-systems on the DN-2 (including PSD) and DN-12 spectrometers will be put into operation.

4. SCIENTIFIC RESEARCH PLAN FOR 2000

The 2000 FLNP Scientific Research Plan contains 5 first priority themes.

Theme	Leader	Priority	Code
Neutron investigations of the structure and dynamics of condensed matter	V.L.Aksenov A.M.Balagurov	1	07-4-1031-99/2003
Study of the fundamental properties of neutrons and nuclei	W.I.Furman V.N.Shvetsov	1	06-4-0974-92/99
Upgrading of the IBR-2 complex	V.D.Ananiev, E.P.Shabalin	1	07-4-0851-87/2002
Realization of the IREN project	I.N.Meshkov W.I.Furman	1	06-4-0993-94/99
Development of the spectrometer complex and computation infrastructure of IBR-2	A.V.Belushkin V.I.Prikhodko	1	07-4-1012-96/2000

In the year 2000, in the framework of theme 1031 investigations in condensed matter will be carried out in the following directions:

- *Provision of the IBR-2 spectrometers user program in full volume*
- *Completion of assembling of supporting systems for the thermostat TS3000 and equipment of a pavilion to install the thermostat control systems*
- *Investigation of a new class of copolymers – lamellar nanocomposite materials, consisting of copolymers with incorporated magnetic nanoparticles with a size of several nanometers.*
- *Installing of a new head part of SPN, manufacturing of the reflectometer measurement shoulder.*
- *Modernization of the existing YuMO small angle neutron scattering instrument to adapt it to the new conditions provided by a cold moderator. This will extend the Q-range of the instrument to 2.5 10^{-3} $Å^{-1}$ and the dynamic range to 100.*
- *Completion of the development of a bio-chemical laboratory for users of the IBR-2 facilities to provide modern tools for sample preparation for neutron scattering experiments.*

- *Completion of the creation of an X-ray laboratory for testing and preliminary investigations of samples for neutron scattering experiments.*
- *Building of a multidetector system with 8 rings (only two rings exist at present) on the DN-12 spectrometer to reduce the measuring time and the time of work with high pressure cells with diamond anvils.*
- *Studies of atomic and magnetic structure changes in intermetallic compounds of the type $R_2Fe_{17-x}M_x$ (R is an element in the rear earth group, M is an element in the iron group) at high pressures and low temperatures.*

The following main problems are to be solved in the year 2000 in the framework of theme 1012:

- *Trials of VME-systems on the spectrometers YUMO, DN-2, and DN-12; development of software (graphic interface, etc.)*
- *Completion of VME work on the spectrometer FSD (RTOF-analyzers for the multidetector)*
- *Creation and putting into operation of the VME-system of data acquisition and SPN spectrometer control*
- *Maintenance of the IBR-2 measuring and control systems*
- *Development of the central server Enterprise 3000 (installation of an additional processor)*
- *Equipment connection via twisted pairs in two LAN segments*
- *Integration of the real time data base Varman (IRI TU Delft) into SONIX software*
- *Adaptation of HDF for OS-9 and introduction of NEXUS format into SONIX.*
- *Integration of SONIX with the visualization programs based on the PV-Wave packet*
- *Development of programs permitting work with files in the NEXUS format in the PV-Wave package*
- *Development of PV-Wave packet-based applications for two-dimensional data*
- *Study of Web-technologies with the aim of their application for spectrometer control and data analysis*
- *Participation in the creation of a prototype of hybrid 2D-MSGC thermal neutron detector:*

- completion of development, manufacturing and tuning of electronics for the data acquisition system; development of instrumental software,

- development of detector elements.

The following main tasks are to be accomplished in the year 2000 in the framework of theme 0851:

- *Execution of an in-beam physical measurements program in the volume of 2000 hr in 8 cycles a year of which cycle No.3 is with a cold moderator.*

- *Start the production of MR-3.*
- *Continue work on new fuel loading.*
- *IBR-2 modernization engineering project, including the reactor CES engineering project.*

In the year 2000, the main task in the direction «Neutron nuclear physics» will be the realization of the IREN project.

The IBR-30+LUE-40 complex will be used as a working stand to adjust, model and test the IREN systems. Due to the fact that the implementation of the IREN project proceeds with at least two-year delay, the installation IBR-30+LUE-40 has to be in operation up to the middle of the year 2001. During this time it will be used not only as a working stand but also as a neutron source for the realization of the nuclear physics research program in accordance with the recommendations of the VII Session of the JINR Program Advisory Committee for Nuclear Physics.

The following research program will be realized with IBR-30 and other neutron sources (theme 0974):

- *Left-right asymmetry and PNC effects in the resonance energy region will be measured in the end of 1999 - first half of the year 2000.*
- *Experiments in UCN physics and neutron optics are planned to continue in ILL in the years 2000 – 2002.*
- *The experiments of fission modes and correlations with quantum states of compound nuclei will continue in the years 2000 – 2001*
- *There are plans to conduct complex investigations of ^{232}Th in collaboration with PAL (Republic of Korea) in the years 200 –2001.*
  Work to study delay neutron (DN) yields with a modernized ISOMER facility is planned for the years 2000 – 2002.
- *In the year 2000 the first methodical measurements of ^{238}U with UGRA will be carried out.*
- *The first measurements of nuclear pseudomagnetism effects with the Kolkhida spectrometer will be conducted in the year 2000.*
- *The REGATA project, including the testing of the quality of food crops in the Republic of Moldavia as contaminated by radionuclides and heavy metals; workplace monitoring and occupational hazard studies at selected phosphate fertilizers plants in Russia, Uzbekistan, Poland, Romania, Netherlands, Denmark; assessment of the environmental situation around the Moscow sea; Neutron Activation Analysis for decommissioning of nuclear power plants (decommissioning of IBR-30).*

5. CONFERENCES AND MEETINGS

In 1999, FLNP organized the following meetings:

1. *VI International Seminar on Interaction of Neutrons with Nuclei ISINN-7, May 12-15.*
2. *II International Seminar on Neutron Scattering at High Pressure NSHP-2, September 29 - October, 2.*

In the year 2000, FLNP will organize the following meetings:

1. *VI International Seminar on Interaction of Neutrons with Nuclei ISINN-8, May 11-14.*
2. *III International Seminar «Ferroelectrics-relaxors», June 23-26.*

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