ICANS-XVII
17th Meeting of the International Collaboration on Advanced Neutron Sources
April 25-29, 2005
Santa Fe, New Mexico

SPALLATION NEUTRONS AT INR RAS – A FACILITY STATUS REPORT

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Abstract

We give information about current status of the neutron complex of the Institute for Nuclear Research, the Russian Academy of Sciences (INR RAS). The operation of the INR RAS Neutron Complex, which is located in Troitsk near Moscow, is provided by the high-current proton Linac, and three spallation neutron sources: an impulse neutron source (INS-0.6), a 100-ton spectrometer for neutron slowing down in lead (LNS-100) and a time-of-flight neutron spectrometer based on a beam-stop irradiation facility RADEX. A research program and trends for further progress are discussed.

1. Introduction

Slow neutrons (cold, thermal and resonant) with energies in the range of several micro- to hundreds of electronvolts are effective tools for studies of fundamental features of matter: atomic structures (condensed matters) and atomic nuclei. Existing neutron methods help to solve problems of new material manufacturing, development of biotechnology, safe nuclear energy.

Progress of neutron studies is determined, in a great extend, by availability of intense neutron sources, which may provide with high luminosity and low background conditions at experiments. Over last decades, the main trend of such a progress is related with creation of pulsed neutron sources based on intense beams of proton accelerators.

The Neutron Complex of INR RAS operates on the base of the high current accelerator of hydrogen ions [1,2]. The Complex includes a set of experimental facilities for multipurpose neutron studies around three spallation neutron sources: the pulsed neutron source INS-06, the 100-tons neutron spectrometer on slowing down in lead (LNS-100), and the RADEX facility (the beam stop), which was modified as a neutron TOF spectrometer. Some additional possibilities for investigations appear at a set of modern X-ray crystallography installations.

The current situation in Russian Federation in the field of neutron studies and their applications is rather complicated: there is a decrease of available nuclear reactors, while from the other hand the necessity of neutron studies for new materials and technology in the world is increasing. At the same time some restructuring of scientific researches at the government level is on the way to optimize budget expenses and simultaneously to promote innovative projects for high-tech progress of national industry. At this background, the pulsed reactor IBR-2 at the JINR (Dubna) will be stopped in 2007 for an upgrade work. Its new start is expected to take place in 2010. As far as the stationary high flux reactor PIK in Gatchina (Petersburg Nuclear Physics Institute, RAS) is concerned, it is still under construction.

Such circumstances may attract attention to possibilities of the INR RAS. After some current work improving parameters of the proton Linac beam (increase of energy, current, quality of the beam transport and its stability) the INS-0.6 may suggest promising features for neutron studies. For example, for energy of protons ~ 400 MeV, average current ~ 5 mcA, pulse repetition rate ~ 25 Hz and pulse duration of protons ~ 50 mcs (i.e. ~ 60 mcs for neutrons) the flux density of thermal neutrons at the sample after a flight base 10 m would be ~ 10^6 n/cm^2/s. This value is comparable with fluxes at IBR-2 experimental studies, where the neutron pulse is longer (320 mcs) and the rather high background of delayed neutrons exists.

The pulsed neutron source INS-0.6 based on hydrogen ion Linac with realistic parameters (see Table 1) – energy up to 0.5 GeV and beam power about 150 kW – may provide with effective investigation program of structure and dynamics of condensed matter including metals, segnetoelectrics, dielectrics and semiconductors, superconductors, albuminous moleculas, chemical structures, liquids, etc.

Table 1. Projected and available parameters of the Linac (INR RAS)

<table>
<tr><th>Parameters</th><th>projected</th><th>available</th><th>Comments</th></tr>
<tr><td>Energy, MeV</td><td>600</td><td>209 (502)*</td><td rowspan="5">*Energy 209 MeV is limited by available quantity of klystrons.
Energy 502 MeV was reached at a small intensity.

**Such current is typical for experiments at 160 MeV, average current 50 mcA was reached at energy 209 MeV at the RADEX facility and is limited only by temporal requirements of the State Sanitary Inspection. Permission for 100-150 mcA is not problematic</td></tr>
<tr><td>Average current, mcA</td><td>500</td><td>150**</td></tr>
<tr><td>Impulse current, mA</td><td>50</td><td>16</td></tr>
<tr><td>Pulse duration, mcs</td><td>100</td><td>200</td></tr>
<tr><td>Pulse repetition rate, Hz</td><td>100</td><td>50</td></tr>
</table>

The physical start of the spallation source INS-0.6 and the installation RADEX took place at the end of 1998. The proton beam parameters were as it follows: proton energy 209 MeV, average current ~0.1 mcA, proton pulse duration 60 mcs and frequency 1 Hz. The LNS-100 facility had successful start in December of 2000. In 2003 first physical measurements began at this installation. In December 2004 the physical start of the multipurpose neutron spectrometer DIAS took place. The DIAS spectrometer is first one in a set of research facilities around the IN-0.6. During the same Linac run, the TOF neutron spectrometer based on a modified facility RADEX started its operation. In 2004-2005 three new X-ray installations were arranged and now are ready for studies of condensed matter structure. So the neutron complex of INR RAS looks as a perspective experimental base for manifold investigations in the Moscow Region by groups of the Lebedev Physical Institute (PI RAS), the Institute for High Pressure Physics, (HPI RAS), the Institute for Solid State Physics, (SSPI RAS), the Institute of Crystallography, (CI RAS), the Joint Institute for Nuclear Research (JINR, Dubna), the Russian Federation State Scientific Center "Institute for Theoretical and Experimental Physics" (SSC ITEP), the Russian Federation State Scientific Center "Institute for Physics and Power Engineering" (SSC IPPE, Obninsk), the Russian Research Center "Kurchatov Institute" (RRC KI), and others.

2. The pulsed spallation source of slow neutrons INS-0.6

At the present stage the tungsten neutron targets with water-cooling are in operation. The first box of INS-0.6 contains a neutron target for structural and spectrometric researches of condensed matter. A possibility to perform multiplying targets with liquid metal cooling was considered. In this case the neutron intensity may be 15-20 times higher at the same configuration of experimental area and radiation shielding.

Several aspects related to probable experiments for the technology of accelerator-driven systems and the nuclear transmutation of spent nuclear fuel at the second box of INS-0.6 are under investigation [3].

Short pulses of slow neutrons are interesting for development of researches in nuclear physics (nuclear reactions at isolated resonances), and precise measurements of effective neutron cross sections for nuclear materials. Parameters of neutron beams may be advanced after completing of the storage ring construction, as it was considered in the project of the experimental complex.

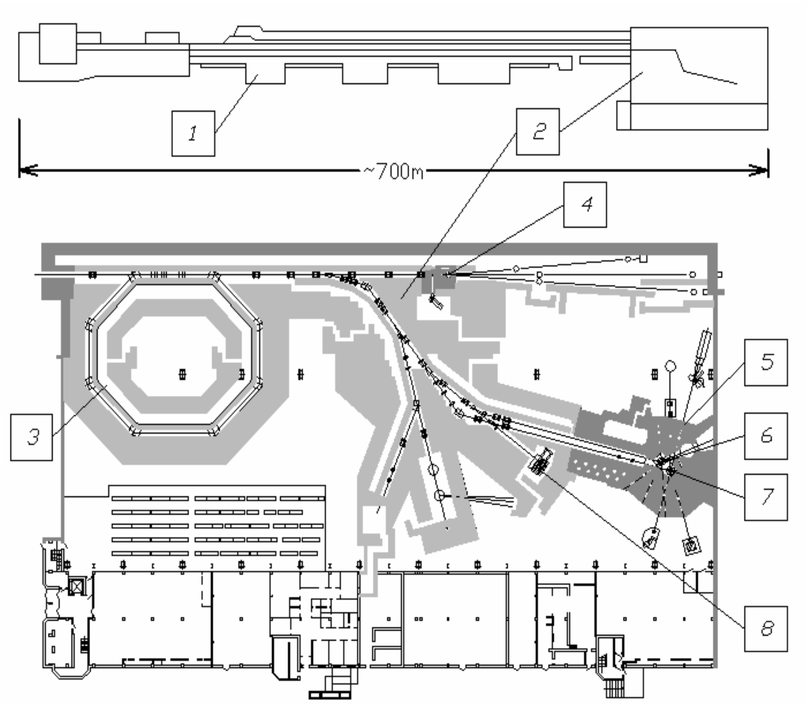

Figure 1: The Linac and the Experimental Complex of INR RAS: 1- the main building of the Linac; 2- the Experimental Complex; 3- the storage ring (not completed); 4- the RADEX facility (modified beam stop) with neutron guides for TOF spectrometry; 5- the spallation neutron source INS-0.6 with neutron guides for solid-state spectrometers; 6- the target box of INS-0.6 for ADS studies; 7- the tungsten target of INS-0.6; 8- the 100-tons spectrometer on slowing down in lead.

3. Superluminous neutron spectrometer on slowing down in lead LNS-100

The neutron slowing down in lead spectrometry gives a possibility to measure effective cross sections of neutron-nuclei interactions in the energy range 1 eV – 50 keV with high luminosity [1,2]. Expected upgrade of the proton beam parameters will provide with unique luminosity in experiments and registration of processes with small cross sections and/or investigate micro quantities of samples. For example, at the average proton current 100 mcA precise measurements of heavy nuclei fission cross sections in samples with mass above 10^{-12} g would be available.

LNS-100 will be used for measuring of fission cross sections of transuranium elements [4], which are collecting in a nuclear reactor fuel. Such data are of great importance for optimization of minor actinides (MAs) burning out process. MAs are, as it is known, the most ecologically dangerous components of nuclear power engineering waste. The installation LNS-100 gives possibilities for detailed investigation development in physics of heavy nuclei fission (isomers, sub barrier fission).

First experiments at LNS-100 were carried out to investigate the neutron slowing-down dynamics and the energy resolution of the installation at different points of the lead moderator and in a wide range of energy. The value of resonance neutron flux ~10^9 n/cm^2/s at the irradiation position was achieved, and possibilities of energy discrimination by neutron slowing-down time were applied to super pure samples. At these measurements the target was driven by proton beam with energy 209 MeV, pulse duration 1-2 mcs, pulsing frequency 50 Hz. These parameters provide with neutron source intensity 10^{13}-10^{14} n/s, which corresponds to flux 10^9-10^{10} n/cm^2/s for epithermal energies. The measured value of energy resolution in energy region 1 eV-1 keV is 28.5-31% that is close to the theoretical limit (~26%).

Cross-sections of (n-γ)-reactions in samples of Cu, Cl, Bi, Sb, Fe, Va, Co, Mn were measured [5] in test experiments. Experimental investigations of subthreshold fission reactions for a chain of transuranium nuclei in the energy region 1-40 keV are under preparation. Data acquisition on minor actinides is planned in view of its special meaning for accelerator-driven technology [3].

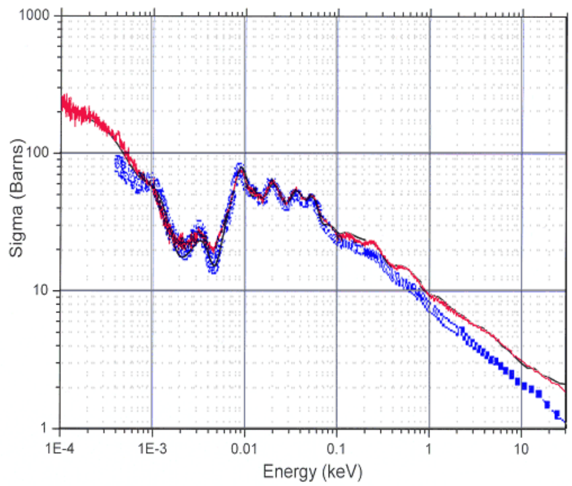

Figure 2: First measurements with Lead Slowing Down Spectrometers. Upper points belong to data at WNR [6]; points below correspond to preliminary results of INR RAS at LNS-100.

4. The TOF neutron spectrometer on the base of the RADEX facility

The RADEX (RADiation Experiment) facility was created for development of studies for manufacturing of new materials for nuclear power engineering, which must be resistant in intense neutron fields [7]. The irradiation channel of the RADEX may supply, at the project parameters of the proton beam, with mean effective flux of fast neutrons ~ 2×10^{14} n/cm^2/s that is perspective for studies of physical and mechanical features of nuclear materials. For protons with energy ~ 300 MeV, some modernization of the installation was undertaken, which resulted in creation and start for operation of the new time-of-flight neutron spectrometer with a flight base up to 50 m and intermediate areas for measurements.

For neutron TOF experiments, the structure of the neutron beam must be tailored to suit the needs of experiment. The pulses must be narrow enough to provide suitable energy resolution and separated enough in time to avoid interference with lower energy neutrons produced in the previous burst (recycle neutrons). These requirements are usually quite different for low and resonance high-energy neutrons. Low-energy neutron experiments generally prefer burst widths from 10 to 100 mcs and pulse separations of several milliseconds, while resonance high-energy experiments need both widths and spacing one – two orders of magnitude smaller. The standard proton bunch time duration is 60 mcs and the proton width may be changed step-by-step up to 0.25 mcs with lower total intensity by a chopper of proton current. The average proton current is now up to 50 mcA, the repetition rate is 1-50 Hz and the maximal integrated neutron intensity at W-target is up to $1.2\text{x}10^{15}$ n/s*4π.

Calculations show, that on a moderator surface the density of neutron flux is ~$2\text{x}10^{11}$ n/cm^2 s in neutron energy region from thermal to 100-300 keV. These calculations have been confirmed experimentally in measurements of neutron flux density on a W-target surface. The activation method was used for analysis of irradiated standard samples, which were located in the vertical channel of RADEX. The measured density of neutron flux is equal to $(2.5\pm1.7)*10^9$ n/cm^{2}s, that corresponds to integrated intensity of evaporating neutrons in the W-target $(7.5\pm5.5)*10^{12}$n/s for an average proton current 0.5 mcA. The error is defined by the accuracy of the data constant for irradiated samples. The basic studying of the total parameters of TOF-spectrometer was carried out at the central horizontal channel on the time-of-flight paths 20 and 50m.

It is clear, that in the slow neutron energy region the TOF-spectrometer of INR RAS does not concede with its parameters to next generation modern neutron pulse TOF-spectrometers. However in the resonance energy region, where the high-energy resolution is necessary, it concedes to the best neutron pulse spectrometers of such type. Increasing of proton beam energy and current will essentially improve the quality of TOF neutron spectrometer

Figure 3: The TOF neutron spectrometer on the base of modified beam-stop

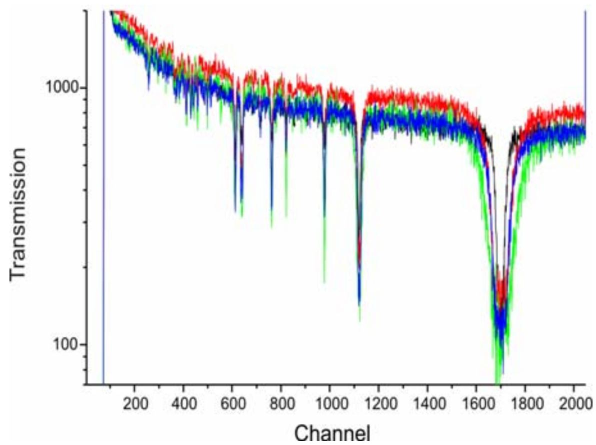

Figure 4: Transmissions for several Ta-targets at the neutron energy region 0.001 – 5.0 keV (RADEX-TOF spectrometer) [8].

5. A set of research facilities around INS-0.6 for condensed matter studies

The first stage of the Neutron complex includes arrangement of a number of installations at channels of the INS-0.6. These facilities were created in different research centers, previously cited, by research groups involved in the collaboration.

The set includes the DIAS facility, which was created in RRC KI and includes a powder diffractometer, a high-resolution diffractometer of reverse geometry with temporal focusing, and an inelastic scattering diffractometer of reverse geometry. This facility was arranged for studies of both structures and dynamics in samples of different nature and at various conditions.

As a second facility the powder diffractometer of the Institute for Physical Problems, RAS (the PDIPP), for structural studies at normal, cryogenic temperatures, strong impulse magnetic fields and high pressures, may be regarded.

A first turn of a Multifunction Neutron Spectrometer (MNS) is creating specially for the INS-0.6 and preparing to physical start together with the PI RAS. The full scale MNS will consist of four diffractometers for structural studies at different space ranges from the tenth lobes to several hundred nanometers, and three spectrometers for dynamic parameter determination in a wide range of transferred energies and resolutions. In order to wider the range of investigated neutron energies and to reduce their losses in air, the mirror neutron guide is planned for use. The ready for operation part of the MNS includes a neutron guide, an adjusting desktop for the installation of samples, and a high-resolution diffractometer of reverse geometry with temporal focusing.

In addition to described above facilities, an upgrade of diffractometer DN-500 in cooperation with the HPI RAS is under preparation for condensed matter studies at extreme conditions (super high pressure and/or super low temperatures)

Special attention is paid to data flow registration, acquisition and analysis. In particular, there is a modern 2D position sensitive detector of neutrons indispensable for more effective obtaining for the structural information of investigated object.

Further development of neutron studies in the INR RAS supposes upgrade of the INS-0.6 neutron channels by mirror guides with their duplication for increase of quantity of the research installations. This work will be realized in cooperation with the Petersburg Nuclear Physics Institute. This second stage of development will include also completeness of the MNS performance. A project of a unique direct geometry neutron spectrometer combined with a small angle diffractometer is ready. Some other proposals are under consideration.

Figure 5: Mounting of installations for condensed matter studies around the INS-0.6

6. X-Ray Crystallographic Installations

For research of single-crystal structures a four-roundabout X-ray diffractometer of the corporation HUBER and a single-crystal X-ray diffractometric system IPDSII with IMAGING PLATE of the corporation STOE are prepared for operation.

For research of powders there is an X-ray powder diffractometer of a system STADI MP with a horizontal plane of diffraction.

7. Conclusions

The current activity at the Neutron Complex of the INR RAS enters a new stage: a phase of debugging of the equipment and creation of the first-order installations around the spallation neutron sources (INS-0.6, LNS-100 and RADEX-TOF spectrometer) will be finished soon. The second task is to ensure capabilities for realization of researches by different collaborators from Moscow Region in a mode of normal exploitation of neutron targets and equipment. Further applications of our experimental possibilities and their development are under considerations [3,9].

Figure 6: Layout of X-Ray Laboratory

Acknowledgements

We are thankful to Profs A.N. Tavkhelidze, V.M. Lobashev and Yu.Ya. Stavissky for their prolonged efforts and fruitful ideas which are now close to realization.

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