**Work program of the theme “Neutron Nuclear Physics” and projects under the theme for 2024**

Nuclear physics research with neutrons is traditionally one of the priority scientific fields developed at JINR. The combined use of the FLNP basic facilities (IREN pulsed source of resonance neutrons, IBR-2 pulsed reactor and EG-5 electrostatic generator, as well as the TANGRA facility) allows experiments to be carried out in a wide range of neutron energies – from cold to ~14 MeV at present, and the use of external neutron sources, such as n\_TOF (CERN), makes it possible to expand the energy range to several hundred MeV. Work is underway to establish cooperation with CSNS (China) and iThemba (South Africa).

The activities within the framework of the theme are aimed at implementing the tasks formulated in the proposals for the JINR Seven-Year Development Plan for 2024-2030 in the field of “Nuclear Physics”. Physics research can be divided into three areas:

* study of violations of fundamental symmetries in the interactions of neutrons with nuclei, obtaining nuclear data;
* study of fundamental properties of the neutron, physics of ultracold and very cold neutrons;
* applied and methodological research.

The scientific program on the theme “Neutron Nuclear Physics” will be implemented within the framework of three projects: two scientific projects (“*Investigations of neutron nuclear interactions and properties of the neutron*" and "*TANGRA*") and one scientific and technical project ("*Modernization of the EG-5 accelerator and its experimental infrastructure*"). Activities on the *development of the concept of a UCN source on a pulsed reactor* are grouped into a separate activity.

1. **"TANGRA" project**

The project is dedicated to solving fundamental and applied problems using the tagged neutron method (TNM). The area of interest of the project is nuclear reactions induced by neutrons with an energy of about 14 MeV. The main areas of research in 2024 are:

1. Continuation of the program for measuring γ-ray emission cross sections. This information is necessary for elemental analysis, Monte Carlo simulations of nuclear instruments, and verification of theoretical calculations. The available data are inaccurate and incomplete. For these measurements, a special setup was developed and constructed, and successful test experiments were carried out with C, O, Si. In 2024, it is planned to measure the reaction cross sections (n,Xγ) for 22 elements.
2. Measurements of angular correlations of scattered neutrons and gamma-rays in inelastic neutron scattering from carbon. Experiments to study correlations (n'γ) are important for understanding the mechanism of (n,n') reactions. These correlations are unknown for a large number of nuclei, while similar data exist for reactions involving protons on a large number of targets, so it is interesting to compare proton and neutron data.
3. The development of methods for elemental analysis of soils will be continued in collaboration with Diamant LLC. In 2023, a series of test measurements were carried out with various soil samples to assess the sensitivity of the technique and optimize the configuration of the compact setup for field analysis. It is planned to assemble and test a prototype of the field setup in 2024.
4. **Project “Modernization of the EG-5 accelerator and its experimental infrastructure.”**

As a result of the implementation of the project in 2024, in cooperation with the [G.I.Budker Institute of Nuclear Physics SB RAS](https://www.inp.nsk.su/), the parameters of the high-voltage system of the EG-5 accelerator will be significantly improved: the ion source will be replaced with a modern UHF analogue with fiber-optic control; the accelerating tube will be changed to an analogue with condenser-type ion optics; the setup for ion-beam elemental analysis of planar objects will be modernized (replacement of the high-vacuum steam-oil pump with a modern a turbomolecular analogue, installation of the setup chamber on a vibration-proof foundation, replacement of the signal processing module with a modern analogue developed at JINR, improvement of overall performance of the setup by optimizing the arrangement of the vacuum system elements).

The modernization of the high-voltage accelerator system will bring us closer to solving the main technical tasks of the project – restoring the energy range of accelerated particles: 900 keV - 4.1 MeV and increasing the ion beam current to 100-250 μA while maintaining energy stability at a level of no worse than 15 eV and its spatial stability sufficient to implement the microbeam spectrometer/nuclear microprobe option. Activities within the framework of the project in 2024 will enable us to get closer to solving the problem of creating a neutron source (energy ranges of 20 keV - 1 MeV and 3 - 5.1 MeV, fluxes of up to 107 particles/s cm2), which makes it possible to study neutron-nuclear reactions, radiation resistance of solids and conduct studies of various objects using nuclear physics methods. Also, in 2024, it is planned to develop complementary experimental techniques for studying the structure, microstructure, optical, electrical and electronic properties of near-surface layers of solids.

1. **Project «*Study of the interaction of neutrons with nuclei and the properties of the neutron."***

Within the framework of this project it is planned:

* Study of the properties of neutron resonances, search and study of the effects of parity violation and effects indicating violation of T-invariance.
* Comprehensive study of the process of nuclear fission: study of TRI and ROT effects in fission; measurement of mass-energy and angular distributions of fragments, prompt neutrons and gamma-rays; measurements of delayed neutrons and gamma-rays; search for rare and exotic fission modes (ternary, quaternary and quinary fission; fission into three fragments of comparable mass).
* Study of neutron-induced reactions with the emission of charged particles.
* Obtaining data for nuclear energy and astrophysics: measuring integral and differential neutron cross sections, angular correlations in the energy range from cold neutrons to hundreds of MeV.

It is planned to resume measurements of angular correlations and gamma-ray yields for already known p-wave resonances in various nuclei, as well as to search for new p-resonances and new effects indicating violation of parity and T-invariance. The main work is expected to be carried out at the IREN resonance neutron source.

Experiments to measure formally T-odd TRI and ROT effects in fission, carried out at the high-flux reactors ILL (Grenoble) and FRM-II (Garching), will be continued at JINR using the polarized neutron beam of the IBR-2 reactor. Despite the long pulse duration of the IBR-2 reactor, the resolution of the time-of-flight technique makes it possible to resolve low-lying resonances up to several electron volts at flight path lengths of the order of 15-30 m. Further work can be continued on external neutron sources, such as nTOF (CERN) CSNS (China) or ESS (Sweden).

In 2024, it is planned to carry out a study of resonance neutron capture in 176Lu and 177Lu in the neutron energy range of 1-300 eV. The purpose of the experiment is to study the influence of Coriolis interaction on the structure of nuclear excited states. The measurements are planned to be carried out at the IREN resonance neutron source and at the CSNS spallation neutron source (China).

Research into rare fission modes (ternary, quaternary and quinary) of nuclei will be continued for neutron induced fission of uranium isotopes 233U and 235U. The measurements are planned to be carried out at the VVR-K nuclear research reactor (Kazakhstan).

Work is planned to measure cross sections for reactions (n,p), (n,α) on various isotopes. In 2024, it is planned to measure reaction cross sections (n,α) on gas samples Ar, F, O, Ne at EG-5, FLNP JINR (En=3-5 MeV) and at the tandem accelerator HI-13 CIAE (En=8-11 MeV). Cross sections will also be measured for 148Sm(n,α) at EG-5, FLNP JINR. It is also planned to conduct test measurements of reactions (n,p), (n,α) on 6Li and Cl at the IREN facility, and develop a scientific program for experiments at CSNS in China.

Within the framework of activities to study the physics of ultracold and very cold neutrons (UCN and VCN), there are three main research areas: study of quantum phenomena in neutron optics; study of the interaction of slow neutrons with diamond nanoparticles and study of the interaction of cold neutrons with intercalated graphite.

It is planned to continue work on studying non-stationary neutron diffraction both from surface acoustic waves (SAW) and from diffraction gratings. Work is planned to prepare an experiment with ultracold neutrons (UCN) to directly measure the speed of a neutron in a medium, which will provide an answer about the validity of the potential dispersion law for very slow neutrons, and, accordingly, about the equality of the effective mass of a neutron in a medium to its inertial mass.

It is planned to study the properties of detonation nanodiamond (DND) powders, which can be used as effective reflectors of very cold neutrons (VCNs). The use of such reflectors is most effective for neutrons in the energy range from ~0.3 μeV to ~5.0 meV. In particular, the most important task is to study the radiation resistance of nanodiamond powders when irradiated with high doses of gamma-rays and fast neutrons. This is planned to be studied at the VVR-K research nuclear reactor at the Institute of Nuclear Physics of the Republic of Kazakhstan in 2024.

Not so long ago, the technology of embedding a solid plane (or two planes) of fluorine atoms between graphite planes appeared, resulting in the so-called intercalated graphite, which can effectively scatter cold neutrons. Such a material seems promising as a reflector of cold neutrons, which can be used in strong fields of ionizing radiation. Within the framework of the theme, it is planned to study the radiation resistance of intercalated graphite and measure the differential cross sections for elastic neutron scattering.

Within the framework of applied research, in 2024, investigations will continue on monitoring the air quality and the state of water bodies of the JINR Member States, using a number of analytical methods, in particular, neutron activation analysis at the REGATA facility of the IBR-2 reactor. The field of nanotoxicology will also be developed, where microorganisms, plants and animals will be used as research objects. Particular attention will be paid to the development of methods for water and soil purification, as well as assessing the quality of food products. Using nuclear and complementary methods, the study of monumental painting, building materials of the past, archaeological artifacts, environmental, geological and other samples will continue.

After modernization, the EG-5 electrostatic accelerator at FLNP JINR, will be used to produce intense fluxes of fast particles (H+, He+, D+) and neutrons; for elemental analysis of surface layers of various objects using beams of α-particles, using non-destructive techniques RBS, ERD and PIXE; for implantation of ions into the surface layers of various materials; to study the radiation resistance of materials. Unique opportunities will appear after the implementation of the option of a microbeam spectrometer at the EG-5 accelerator.

**Activity: “Development of the concept of a UCN source on a pulsed reactor”**

The goal of this activity is to create a conceptual design for an ultracold neutron (UCN) source at a pulsed reactor. This could be either the IBR-2M reactor available at FLNP JINR or the projected NEPTUN reactor.

A special feature of the future UCN source at JINR is the pulsed mode of filling the trap, in which neutrons enter it only during the pulse, and the rest of the time the trap remains isolated. The practical implementation of this idea is complicated by the fact that due to the presence of biological shielding, the trap turns out to be remote from the moderator-converter, while the spread of transport flight times can significantly exceed the intervals between pulses, making the very idea of ​​accumulation meaningless. To solve this problem, it is proposed to use a special device – an adiabatic spin flipper, designed for large magnetic fields, allowing for a significant change in the neutron energy. At a sufficiently large value of the energy taken from the neutron, the flux of very cold neutrons (VCN), which, after slowing down, are converted into UCN, has a pulsed structure. In this case, the duration of neutron bunches can be significantly less than the period of their repetition. Using a spin flipper together with a time lens will make it possible to obtain a neutron flux density in a bunch, which is significantly higher than the average value.

In 2024, within the framework of the activity, it is planned to formulate the concept of a UCN source at JINR pulsed reactors. A version of the VCN converter of the first stage will be developed. A superconducting magnetic system for cooling neutrons will be designed. Work will begin on the creation of pulsed magnetic time lenses.