**Annex 1.**

***Form of opening (renewal) for Theme /***

***Large Research Infrastructure Project***

**APPROVED**

**JINR Vice-Director**

**/**

**" " 2023 г.**

**THEME PROPOSAL FORM**

**Opening/renewal of a theme/large research infrastructure project within the Topical plan of JINR**

**1. General information on the theme / large research infrastructure project (hereinafter LRIP)**

**1.1. Theme code / LRIP** (for extended themes) *–* *the theme code includes the opening date, the closing date is not given, as it is determined by the completion dates of the projects in the theme.*

**Nuclear physics with neutrons**

**1.2. Laboratory**

**FLNP**

**1.3. Scientific field**

**Nuclear Physics**

**1.4. The title of the Theme / LRIP**

**Nuclear physics with neutrons**

**1.5. Theme / LRIP Leader(s)**

**Kopatch Yu. N., Sedyshev P. V., Shvetsov V. N.**

**1.6. Theme / LRIP Deputy Leader(s)**

**2. Scientific case and theme organization**

**2.1. Annotation**

Nuclear physics research with neutrons is traditionally one of the priority areas developed at JINR. To date, these studies are being carried out within the framework of the scientific topic "Investigations of Neutron Nuclear Interactions and Properties of the Neutron" (03-4-1128-2017/2023). The integrated usage of the FLNP basic facilities - the IREN pulsed source of resonance neutrons, the IBR-2 pulsed reactor and the EG-5 electrostatic generator, as well as the TANGRA facility - makes it possible to conduct nuclear physics research in a wide range of neutron energies - from cold neutrons to ~20 MeV. Collaboration with other research organizations and application of their neutron sources, such as n\_TOF (CERN), makes it possible to expand the energy range to several hundreds of MeV.

Works and studies within the framework of the topic are aimed at the implementation of the tasks formulated in the proposals for the JINR Seven-Year Development Plan 2024-2030 in the direction of "Nuclear Physics". They could be divided into three areas:

- investigation of fundamental symmetries violations in the interactions of neutrons with nuclei, obtaining of the nuclear data;

- study of the fundamental properties of the neutron, physics of ultracold and very cold neutrons;  
 - applied and methodological research.

The scientific program of the topic "Neutron Nuclear Physics" will be implemented within the framework of three projects: two scientific *("Investigations of Neutron Nuclear Interactions  
and Properties of the Neutron"* and *"TANGRA"*) and one scientific and technical (*"Modernization of the EG-5 accelerator and its experimental infrastructure"*). Work on the *development of the concept of a UCN source at a pulsed reactor* is planned to be singled out as a separate activity.

**2.2. Projects in the Theme / LRIP subprojects**

1. Investigations of neutron nuclear interactions and properties of the neutron.  
2. Development of the tagged neutron method for determining the elemental structure of matter and studying nuclear reactions (TANGRA project).  
3. Modernization of the EG-5 accelerator and its experimental infrastructure.

**2.3. Scientific case** (no more than 20 pages)

(aim, relevance and scientific novelty, methods and approaches, techniques, expected results, risks).

The scientific program of the topic "Neutron Nuclear Physics" will be implemented within the framework of the following projects:  
 "*Investigations of neutron nuclear interactions and properties of the neutron",  
 "TANGRA",  
 "Modernization of the EG-5 accelerator and its experimental infrastructure"*. Work on the *development of the concept of a UCN source at a pulsed reactor* is planned to be singled out as a separate activity.

Within the framework of the project "Investigations of neutron nuclear interactions and properties of the neutron" the following tasks will be solved:  
 • Study of the properties of neutron resonances, search and study of the effects of parity violation and effects indicating the 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 (quadruple and quintuple fission; fission into three fragments of comparable mass).  
 • Study of neutron-induced reactions with emission of charged particles.  
 • Obtaining data for nuclear power engineering and astrophysics: measurement of integral and differential neutron cross sections, angular correlations in the energy range from cold neutrons to hundreds of MeV.

It is proposed to resume measurements of angular correlations and gamma-ray yields for known p-wave resonances in various nuclei. It is also planned to measure the characteristics of p-wave resonances, including for the purpose of subsequent verification of the compliance of the distributions of these characteristics with standard statistical models; study of interference effects of both p- and s-wave resonances, and s-wave resonances with each other, going beyond the simplified approximation of isolated Breit-Wigner resonances; study of the characteristics of "negative" s-wave resonances, which manifest themselves in interference with p-wave resonances close to the thermal point; search for new T-violating effects.  
 Investigations of the angular distributions of gammas will be started with unpolarized neutrons, and, subsequently, will be developed by including neutron polarization, spin orientation of target nuclei and measurements of observables of the interaction of neutrons with nuclei in the elastic channel, including the total interaction cross sections. For resonances on actinide nuclei, the measured quantities can also include those observables in the fission channel.

Experiments to measure the 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 beam of polarized neutrons from the IBR-2 reactor. In 2018, the ROT effect for gamma rays in 235U fission at a low-lying resonance of 0.3 eV was measured for the first time. The obtained results agree with the theory, however, for further study of the quantum mechanical properties of the fission process, it is prospective to continue this research to obtain data for higher-lying resonances, as well as for other nuclei. In particular, the 241Am and 245Cm nuclei were proposed as candidates. Despite the long duration of the IBR-2 reactor pulses, the resolution of the time-of-flight technique makes it possible to resolve low-lying resonances up to several electronvolts at flight bases of the order of 15–30 m. Further work could be continued on external neutron sources such as nTOF (CERN), CSNS (China) or ESS (Sweden).

Work will continue on measuring the cross sections for the reactions (n,p), (n,α) on various isotopes. The experiments are important both for fundamental nuclear physics and for nuclear astrophysics (refining the parameters of the global α-particle potential used in calculations of various astrophysical scenarios). In astrophysics, the reaction cross sections (n,α) are very important for understanding the nucleosynthesis of elements. It is assumed that most elements heavier than iron are produced by neutron capture and beta decays (s- and r-processes), while rare proton-rich isotopes are mainly produced by reactions with charged particles (p-process). Measurements of the reaction (n,α) are necessary for a better understanding of the s-process in the case of light nuclei. Obtained data are also important for adjustment of the α-particle potential for heavy nuclei to improve modeling of the reactions occurring in the p-process. Experiments can be conducted at IREN (En=th-100 keV); electrostatic accelerators EG-5 FLNP, EG-4.5 PKU, Beijing (En=3-6 MeV); HI-13 tandem accelerator CIAE, Beijing (En=8-11 MeV) and CSNS.

The study of the properties of prompt fission neutrons (PFN) is important for understanding of the fission process and, in particular, the distribution of excitation energy between fission fragments (FFs). PFN studies in fission reactions at low energies have been carried out at JINR for more than 20 years. The main object of these studies was PFN in the reactions 252Cf(sf) and 235U(nres,f) in the region of resolved resonances. In the 235U(nres,f) reaction, fluctuations were observed in the FF mass and energy distributions depending on the energy of resonance neutrons.

Within the framework of the topic, it is planned to study the correlations between variations in the PFN multiplicity and mass energy distributions (MEDs) in fission induced by resonance neutrons. The experiments are planned to be carried out on channel No. 2 of IREN facility using the ENGRIN setup, created in 2021-23 and consisting of 32 modules of BC501 liquid scintillator neutron detectors and an ionization chamber (IC) with built-in fissionable target. The faces of the detectors are located on the surface of a sphere with a diameter of 1000 mm and with a center coinciding with the center of the IC. The value of the geometric efficiency of PFN registration is 0.18. A position-sensitive IC can be used as a fission fragment spectrometer, which makes it possible to measure the kinetic energies, masses of fission fragments, and orientation of the fission axis (the angles of the fission axis with respect to the axes of the Cartesian coordinate system with the origin at the center of the IC). In this case, the neutron beam axis passes through the geometric center of the IC, and the neutron detectors are arranged compactly around the neutron beam axis. The PFN and MED studies impose opposite requirements on the fissile target: in the first case, it is better to use a relatively thick target to increase the neutron yield. In the second case, a thin target is needed to ensure the passing of fission fragments from it and the possibility of their separate registration. Thus, it is convenient to divide the studies of correlations of total kinetic energy variations with PFN s into two experiments: in the first one, PFN variations with a “thick” target are measured, while the correlations of mass-energy distributions and PFN multiplicity are measured in the second one with a thin target and a position-sensitive ionization chamber.

Within the framework of the study of the physics of ultracold and very cold neutrons (UCN and VCN), three main areas of research can be distinguished: the 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 the study of non-stationary diffraction by surface acoustic waves (SAWs). The modern technology of reflectometric experiments makes it possible to measure with high accuracy the angular distribution and absolute amplitudes of diffracted waves of both the first and higher orders in the reflection geometry. The measurements will be carried out for a wide range of samples in which both traveling and standing surface waves are excited. In this case, it is assumed that the wave frequencies can reach values of the order of Gigahertz, and the energy transferred to neutrons will reach a value of the order of 4 μeV. The transfer of such a large energy to neutrons as a result of non-stationary action has not been observed before.  
 Carrying out experiments of this kind will also provide answers to two more important questions: about the reflection time of neutron and X-ray waves when the glancing angle exceeds the critical angle of total internal reflection, and also about the validity of the basic laws of neutron optics in the case of high accelerations (of the order of 108 g).

In addition to the study of non-stationary diffraction by SAW, within the framework of the proposed topic, it is planned to undertake work aimed at the development of neutron spin interferometry (NSI) with ultracold neutrons (UCN). The physical basis of the phenomenon is closely related to the quantum picture of spin precession in the presence of both a constant magnetic field and a perturbing potential with which the neutron interacts. Technically, we are talking about the creation of a miniature UCN spin-echo spectrometer, which is a rather difficult task.  
 It is planned to use the developed NSI methodology both for fundamental research and for the creation of new methods of applied research. In particular, it is planned to use the Larmor clock method to measure the interaction time of a neutron with quantum objects. This approach was proposed as a theoretical method for calculating the neutron scattering time, and much later the possibility of its practical application was demonstrated in experiments with cold neutrons. Since the sensitivity of the method is proportional to the cube of the wavelength, the usage of UCN in such experiments will open up completely new experimental possibilities.

To extract neutrons from neutron sources, such as the core of a reactor, neutron reflectors are often used, which significantly (in some cases many times) increases the intensity of neutron beams available for scientific research. However, at present there are no effective reflectors of cold neutrons. One of the innovative solutions proposed by FLNP JINR scientists in collaboration with colleagues from ILL is the development of neutron reflectors based on detonation nanodiamond (DND) powders. The use of such reflectors is most efficient for neutrons in the energy range from ~0.3 μeV to ~5.0 meV.  
 As a result of comprehensive studies conducted with the participation of FLNP staff, technologies and methods were developed that made it possible to significantly improve the quality of DND powders: to reduce the concentrations of pollutants that decrease the neutron albedo and impurities that are activated in intense neutron fields. To reduce the content of chemically bound hydrogen by a factor of 30 (the source of the main losses of VCN and CN), a method was proposed and implemented to replace hydrogen atoms with fluorine atoms from the surface of nanodiamonds, which does not change the structure of the powder and individual nanoparticles. The procedures of DND structural changes were also carried out: splitting large DND clusters into individual nanoparticles (deagglomeration) and DND separation by size. All of the listed modifications of DND powders should potentially improve the albedo of the VCN and CN nanodiamond reflectors.

The aim of the work on the study of the interaction of cold neutrons with intercalated graphite is to create a promising reflector of cold neutrons. They are based on the fact that Bragg scattering on a crystal is possible only if the radiation wavelength does not exceed twice the distance between the crystal planes. Usually, in natural crystals, the interplanar spacing does not exceed ~2 Å; therefore, neutrons with wavelengths longer than ~4 Å are no longer scattered by them. Due to this property such neutrons are allocated into a separate group called cold neutrons. However, it is possible to create artificial crystals with multiple interplanar spacing. Usually, in their production, a single crystal of graphite is used as a basis, and atoms of another substance are introduced between its crystal planes and pushing them apart. Intercalated graphite is produced with this technology. Such crystals can effectively scatter cold neutrons, however, they are not radiation resistant enough to be used near the reactor core.  
 Recently, a technology has appeared for introducing a whole plane (or two planes) of fluorine atoms between graphite planes. Such a material seems to be promising as a cold neutron reflector, which can be used in strong fields of ionizing radiation. The study of such material is one of the potential areas of activity.

As part of applied research, it is planned to continue monitoring the air quality and the state of water bodies in the JINR Member States using a number of analytical methods, in particular, neutron activation analysis at the REGATA facility of the IBR-2 reactor. Another branch of studies, nanotoxicology, will also be performed, where microorganisms, plants and animals will be used as objects of research. Particular attention will be paid to the development of methods for cleaning water and soil, as well as assessing the quality of food.  
 The use of nuclear and complementary methods will continue to study monumental painting, building materials of the past, archaeological artifacts, environmental, geological and other samples. To conduct mass multielement neutron activation analysis, the capabilities of the IREN facility and the IBR-2 reactor will be used. The elemental composition by short-lived isotopes will be determined using the REGATA-2 pneumatic transport system at the IREN facility. Irradiation of samples for elemental analysis for medium- and long-lived isotopes will be carried out using the facility on the 3rd channel of the IBR-2 reactor, as well as directly on the surface of the moderator of the IREN facility. In addition, channel 11b of the IBR-2 reactor will be used for fully non-destructive activation analysis based on prompt gamma quanta.

In addition, X-ray fluorescence analysis will be used to determine the elemental composition. It is planned to use complementary methods of infrared and Raman spectroscopy, optical and polarization microscopy, chemical microanalysis, and other methods and approaches.  
 As part of the topic, methodological work is planned to determine the potential for conducting gamma-activation analysis using the REGATA-2 pneumatic transport system and activation analysis on prompt gammas on the 6th channel of the IREN facility, as well as the creation of appropriate methods.

*The TANGRA project* is dedicated to solving fundamental and applied problems using the tagged neutron method (TNM). The essence of this approach (the term API-method (Associated Particles Imaging) is also used in the English literature) is to register the products of a neutron-nuclear reaction in coincidences with an α-particle formed in the reaction:  
 d +3Н → 4He (3.5МэВ)  + n (14.1МэВ).                                     (1)

Due to the conservation of momentum, the products of this reaction scatter in almost opposite directions, and therefore, information about the direction of the momentum of the α-particle provides the possibility to determine with good accuracy the direction of neutron emission. "Tagging" of neutrons is carried out using a position-sensitive α-detector built into a portable neutron generator. By registering signals from secondary radiation detectors in coincidence with α-detector responses, it is possible to separate useful and background events, as well as to estimate the coordinates of the point at which the neutron-nuclear reaction occurred. In this case, depending on the configuration of the detector systems and data processing algorithms used, background suppression can reach 200 times compared to the experiment without neutron labeling.  
 The area of interest of the project is nuclear reactions that take place with action of neutrons with an energy of about 14 MeV. The relevance of the study of these processes is due to the advent of compact neutron generators, which make it possible to create setups for the rapid elemental analysis of various substances that will be in demand in various fields of industry (metallurgy, production of mineral fertilizers), security (analysis of potentially hazardous objects), geological exploration (analysis of samples) and agriculture (analysis of the chemical composition of soils). To date, one of the main obstacles to the widespread use of these devices is the lack of a relevant database on the γ-radiation cross emitted by nuclei of various elements under neutron irradiation. The currently available data are replete with inaccuracies and incomplete.  
 In addition to information on the γ-spectra, data on their angular distributions is also in demand, which is necessary, on the one hand, for accurate modeling of nuclear physics experiments and optimization of the geometry of setups for elemental analysis in order to increase their efficiency. On the other hand, angular correlations (n,γ) and (n,n',γ) are useful for understanding the properties and mechanisms of nuclear reactions. It should be noted that the currently used neutron generators are capable of producing a sufficiently intense neutron flux, which makes it possible to use these devices to obtain nuclear data on the reactions (*n,n’*), (*n,p*), (*n,a*) and (*n,2n*) at relatively low financial costs.

Successful studying of these reactions can significantly improve both the understanding of the mechanisms and processes that occur during the interaction of fast neutrons with nuclei and increase the accuracy of modeling nuclear physics facilities.

Within the framework of the topic, it is planned to implement the project “Modernization of the EG-5 accelerator and its experimental infrastructure”. As a result of its implementation, the accelerator parameters will be significantly improved, the infrastructure of the accelerator complex will be updated, and the development of setups for non-destructive elemental and structural analysis of various objects will begin.  
 **The purpose of the project**: to provide technical conditions for the implementation of the scientific program of the JINR Topical plan on the study of reactions with fast quasi-monoenergetic neutrons, the processes of interaction of accelerated charged particles with matter, the development of nuclear-physical methods for studying the elemental composition using the methods of ion-beam analysis, inelastic interaction of neutrons with matter, solving problems of neutron radiation materials science, implementation of practical applications of neutron physics; providing the technical capability to implement the unique options of a microbeam spectrometer and a tunable high-power quasi-monoenergetic neutron generator for two energy ranges (12 - 800 keV, 3.3-5.1 MeV).  
 **Project tasks**. The main technical task of the Project is to restore the energy range of accelerated particles: 900 keV - 4.1 MeV and increase the ion beam current to 100-250 μA while maintaining the energy stability of the ion beam at a level no worse than 15 eV, ensuring the spatial stability of the ion beam, sufficient for the implementation microbeam spectrometer / nuclear microprobe options. The main organizational task is to lay down and develop human resources to ensure the full implementation of the project's goal in the perspective of at least 3 seven-year periods.

The objectives of the project also include the improvement of the main systems of the electrostatic charged particle accelerator EG-5, the creation of a neutron source on its basis, which makes it possible to study neutron-nuclear reactions and carry out the study of various objects using nuclear physics methods. Also, within its framework, it is planned to develop complementary experimental methods for studying the elemental composition and physical properties of near-surface layers of solids. The unique property of a single-stage accelerator is the high energy stability (over 0.01%) of the ion beam, which makes it possible to carry out studies of the elemental composition of the surface layers of materials with very high accuracy and makes it possible to create a unique microbeam spectrometer based on EG-5 with a beam diameter of less than 1 μm. Such beams cannot be obtained, for example, at the currently popular charge-exchange accelerators—tandetrons. Within the framework of the proposed project, it is planned to carry out, with the support of the Budker Institute of Nuclear Physics (BINP, Novosibirsk), work to replace the obsolete and out-of-service high-voltage system (HF ion source and accelerating tube), upgrade and automate the service systems of the accelerator, launch the neutron generator, modernize a complex of ion-beam spectrometers and develop a complementary methodological base.

**The plan for the modernization of the complex of setups based on EG-5 provides for the following work:**

1. Replacement of the accelerating tube, resistive divider and ion source, performance of related service work.  
 2. Automation and optimization of accelerator control systems, vacuum and ventilation systems, replacement of the power source of the analyzing magnet.  
 3. Creation of a neutron source based on EG-5.  
 4. Installation of equipment for the preparation and study of samples by ion-beam methods, creation a laboratory with complementary research methods

As a result of the implementation of the EG-5 accelerator modernization project, JINR will obtain a reliable, compact, economical multifunction device for unique scientific research (deep elemental profiling / mapping, studying radiation resistance of materials to neutron and proton fluxes, helium porosity, semiconductor junction degradation processes, etc.) and technological operations (ion implantation / cutting, chemical modification and crystal chemical design, production of isotopes, mutagenesis, etc.). The option of a powerful operatively tunable source of monochromatic neutrons in the range from thermal (12 keV) to fast (3.3 - 5.5 MeV) neutrons will be implemented.

After the completion of this project, the program of modernization of the accelerator complex will be continued, for which it is planned to open two additional projects within the topic under consideration in the future. As part of the project "Deep modernization of the EG-5 accelerator" (2027-2028), the charging tape will be replaced with a cascade multiplier. Then, during the implementation of the project "Nuclear microprobe at FLNP JINR" (2029-2030), with the support of BINP, the option of a microbeam spectrometer will be implemented (2027-2030).  
  
 The upgraded accelerator will be equipped with a powerful modern microwave ion source with a fiber-optic control system, an accelerating tube with improved ion-optical characteristics, a computer control system, and in terms of performance (the energy of accelerated particles is 4.1 MeV at a beam current of up to 200 μA) will correspond to modern devices of this class.

Deep modernization of the EG-5 electrostatic accelerator and its experimental infrastructure will ensure that JINR conducts studies of reactions with fast quasi-monoenergetic neutrons, the ability to work with biological objects. The performance and resolution of existing ion-beam spectrometers (RBS, ERDA, NRA, PIXE) will be significantly increased. The experimental base will be supplemented by complementary methods for studying the electrical, optical and electronic properties of the surface (ellipsometry, impedance spectroscopy).

**Activity:** "Development of the concept of a UCN source at a pulsed reactor"

The purpose of this activity is to create a conceptual design for an ultracold neutron (UCN) source on a pulsed reactor. This can be both the JINR IBR-2M reactor available at FLNP and the projected NEPTUNE reactor.  
 Since the discovery of UCN, a number of intense UCN sources have appeared in the world, and several more of them are under construction. There is no UCN source in Dubna, which is largely due to the features of the IBR-2M reactor. Its average power of 2 MW is relatively low for creating a continuous UCN source, and the repetition rate of 5 Hz is too high to accumulate neutrons produced in each individual pulse. However, the pulsed flux of thermal neutrons from this reactor is very high, since the interval between pulses is hundreds of times longer than their duration.  
 A specific feature of the future UCN source at JINR is the pulsed filling of the trap, in which neutrons enter it only during the pulse, while the rest of the time the trap remains isolated. The practical implementation of this idea is hindered by the fact that, due to the presence of biological shielding, the trap is remote from the moderator in which UCNs are generated and must be connected to it by a neutron guide. In this case, the spread of transport transit times can significantly exceed the intervals between pulses, depriving the very idea of accumulation of meaning. To solve this problem, it was proposed to use a special device — a temporal lens, which dosed changes the energy of neutrons as they arrive at this lens. Such a device restores the impulse structure of the neutron beam immediately before entering the trap.  
 Recently, the idea of pulsed filling of a UCN trap has been the subject of intense discussion in the literature. As a result, a significant set of ideas and proposals has emerged that can form the basis of a project for a new UCN source.  
 The aim of this activity is to formulate the concept of a UCN source in a pulsed reactor based on an analysis of both already formulated and some new ideas regarding the transport of UCN, the evolution of the duration of neutron bunches, and the formation of the optimal temporal structure of bunches at the entrance to the trap. It is assumed that the final UCN spectrum at the entrance to the trap will be formed by slowing down the VCN.

The main tasks to be completed as part of the proposed activity:  
 1) It is important to make a comparative analysis of fundamentally different deceleration methods.  
 2) It is necessary to analyze several possible approaches to creating a pulsed gate at the entrance to the trap, which has the necessary speed and reliability and minimally affects the density of neutrons stored in the trap. There is no experience in creating such gates.  
 3) An analysis will be made of possible options for a UCN moderator that provides the highest UCN flux density at the required pulse duration.  
 The result of scientific activity within the framework of the proposed activity will be the formulation of the concept of an intense UCN source at JINR pulsed reactors. The main goal of the work is to create at JINR a UCN source with parameters corresponding to the modern world level.

**Expected scientific results:**

• Refinement of characteristics of known resonances, detection of previously unknown ones. Measurement of reaction cross sections and product correlations in the resonant region with an accuracy sufficient to study P- and T-odd effects.  
 • Performing experiments to study TRI and ROT effects in fission, to measure the mass-energy and angular distributions of fragments, prompt neutrons and gamma rays; search for rare and exotic fission modes, both using IBR-2 and third-party sources.  
 • Carrying out experimental and theoretical studies of neutron-nuclear reactions in a wide range of energies of incident particles.  
 • Investigation of the pattern of non-stationary neutron diffraction on surface acoustic waves. Verification of the validity of generally accepted laws of neutron optics in the case of large accelerations.  
 • Development of models for calculating the transport of VCN and CN in the material of nanodiamond reflectors and expansion of their range of applicability to the range of thermal neutrons.  
 • Study of the structure of graphites after their intercalation and measurement of cross sections for cold neutron scattering by intercalated graphites.  
 • Obtaining data for nuclear power engineering and astrophysics: measurement of integral and differential neutron cross sections, angular correlations in the energy range from cold neutrons to hundreds of MeV.  
 • Study of the radiation resistance of various materials, including those prospective for use as neutron reflectors and moderators. Testing of the radiation resistance of electronic components, including those operating on new physical principles.  
 • Obtaining new data and monitoring the environmental situation in certain regions of the JINR Member States with the help of NAA.  
 • Study of the influence of neutron irradiation on the properties of living objects  
 • Investigation of layered structures, including high-temperature superconductors using RBS, ERD and PIXE techniques.  
 • Performing elemental analysis of various objects of cultural heritage.  
 • Performing experiments to study the angular distributions of scattered fast neutrons  
 • Experimental study of (n,γ) and (n',γ)-correlations.  
 • Theoretical description of the studied nuclear reactions.  
 • Conducting experiments to study the reaction (n,2n)

**Expected methodological results:**  
 • Development of the method of neutron spin interferometry with UCN.  
 • Determination of optimal technologies for the synthesis and modification of substances for use as UCN and CN reflectors.  
 • Creation of the concept of an intense UCN source at pulsed reactors.  
 • Development of methods for water and soil purification, assessment of food quality.  
 • Study of the processes of accumulation of nanoparticles in the organs of animals and plants, assessment of their impact on the health of the studied living objects.  
 • Development of a technique for non-destructive elemental analysis based on prompt gamma quanta. Improvement of existing methods of activation analysis on thermal and resonant neutrons.  
 • Creation of an intense source of fast neutrons based on EG-5.  
 • Creation of concepts of electronics and sensors of ionizing radiation based on new physical principles.  
 • Conclusion on the applicability of the TNM for elemental analysis of soils. In case of a positive result, the creation of prototypes of stationary and mobile setups, as well as methodological recommendations for their usage for agricultural and environmental monitoring purposes.

The fundamental results obtained during the implementation of research within the framework of the proposed topic will be important for understanding the mechanisms of neutron-nuclear reactions and the development of theoretical ideas about these processes. The study of P- and T-odd effects will provide information on the contribution of the weak interaction to nuclear forces and can serve as an alternative method for determining the mixing coefficient Vud of the SKM matrix. Obtaining new information about ROT and TRI effects, as well as exotic fission modes, will clarify the features of one of the stages of this process - the break-up of a fissile nucleus into fragments. The data obtained during the implementation of the neutron-optical part of the project will be needed to create new neutron moderators and reflectors. In addition, they will lead to significant progress in the development of neutron microscopy methods and studies of the magnetic structure of various objects.  
 The implementation of the applied program of the project will contribute to the progress of environmental, materials science, archaeological and nanotechnological research. Techniques of elemental and structural analysis created and modernized will be in demand in many branches of human activity.

**Risks  
SWOT analysis**  
The work on the topic is supposed to be carried out by the staff of the FLNP Department of Nuclear Physics, which has large experience in studying neutron-nuclear reactions and conducting applied research. It consists of both a large number of young and more experienced employees. Many have PhD and Doctoral degrees. The team has a significant number of detectors of various types, which are able to register practically any products of neutron-nuclear interactions. Some equipment (detector assemblies, ionization chambers, targets for accelerators, digitizers, automation devices) can be created by the team. This is undoubtedly the strength of the project.  
 During the research program, it is planned to use a large number of scientific infrastructure facilities, both FLNP JINR (IBR-2, IREN, EG-5, TANGRA), and third-party organizations: n\_TOF (CERN), EG-4.5 (Beijing University, China), HI accelerators -13 (CIAE, China), which may lead to risks of reducing the scientific program due to changes in the international situation, which can be attributed to the moderately weak side of the project. At the same time, a significant part of the experiments can be carried out on the facilities available at JINR.

The facilities available at FLNP are in need of ongoing repairs, modernization and certification, which may be a factor hindering the implementation of the project. However, to date, there are no significant problems in acquiring critical components for repairs and certification of scientific infrastructure, so in case of complications, one can only expect research to slow down.  
 The design of the EG-5 accelerator is well suited for solving the proposed tasks (creation of a nuclear microprobe and a neutron generator). The project will fully implement the unique capabilities of the EG-5 accelerator, in particular, the possibility of obtaining a large ion beam current (up to 250 μA) and its small energetic spread (<10eV), which cannot be implemented on tandem-type facilities. The design of the accelerator is maintainable and relatively simple. JINR has all the necessary production infrastructure and material base (spare parts, liquid nitrogen, service systems, etc.) necessary to maintain the facility's operability on its own. The team performing work on the project includes both young and active employees, as well as more experienced, age-related personnel. This is undoubtedly the strength of the project. The moderately weak sides of the project include the outdated design of a large number of systems and the possibility of the presence of faults that have not been identified so far, which will slightly increase the amount of work required during the modernization.

It is supposed to use a well-established TNM technology for the TANGRA project implementation. The D-T generators used as neutron sources are relatively inexpensive and safe when used correctly. The project team is highly qualified, although it includes a significant number of young (under 35) specialists. The team has needed equipment that is already sufficient to carry out a minimum research program. The employees participating in the project have extensive experience in studying reactions of the (n,Xγ) type, the feasibility of the program for studying the cross sections for the radiation of γ-quanta in these reactions is beyond doubt if it is possible to purchase all the samples planned for research.  
 The finite operation time of neutron generators can be attributed to insignificant disadvantages of the technique used. The possible existence of hard-to-control factors that affect the results should be considered as a risk in the development of elemental analysis methods based on the TNM.

**2.4. Participating JINR laboratories**

MLIT, LTP, LNP, FLNR, VBLHEP, LRB

**2.5. Participating countries, scientific and educational organisations:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Country or**  **international**  **organization** | **City** | **Institute or**  **laboratory** | **Members** | **Status** |
| Australia | Melbourne | University | Klein A.G. + 3 pers. | Collaborations |
| Austria | Innsbruck | University | Zeilinger + 1 pers. | Collaborations |
| Azerbaijan | Baku | BSU | Gadzhieva S.R. | Collaborations |
| IGG ANAS  IRP ANAS | Huseynov D.A.  Samedov O.A. | Collaborations |
| Collaborations |
| Albania | Tirana | UT | Lazo P. + 3 pers. | Collaborations |
| Armenia | Yerevan | NITSIKN | Simonyan A.E.  Khanzatyan G.A. | Protocol |
| Belarus | Minsk | BSU | Ksenevich V.K. + 2 pers. | Collaborations |
| Research Institute NP BSU | Maksimenko S.A. + 2 pers. | Collaborations |
| SPC NASB for Materials Science | Ignatenko O.V. + 3 pers. | Collaborations |
| Germany | Mainz | JGU | Rhys D. | Collaborations |
| Munich | TUM | Klenke J. Lauer | Collaborations |
| Georgia | Tbilisi | AIP TSU | Japaridze G. + 4 pers. | Collaborations |
| Sapozhnikova N.A. | Protocol |
| TSU | Shetekauri Sh. + 5 pers. | Collaborations |
| Egypt | Alexandria | University | Badavi M.S. + 3 pers. | Collaborations |
| Giza | CU | Sheriff M. | Collaborations |
| Cairo | NRC | Ibrahim M. + 3 pers. | Collaborations |
| Shibin El Kom | MU | El Samman H. + 5 pers. | Collaborations |
| El Mansoura | MU | Sallah M. + 2 pers. | Collaborations |
| India | Varanasi | BHU | Kumar A. + 3 pers. | Collaborations |
| Italy | Rome | ENEA | Map M. + 2 pers. | Collaborations |
| Kazakhstan | Alma-Ata | INP | Glushchenko V.N. | Collaborations |
| Astana | ENU | Lennik S.G. | Protocol |
| Omarova Nu + 5 pers. | Collaborations |
| Kyzylorda | KazRIR | Duysembekov B.A. | Protocol |
| China | Beijing | IHEP CAS | Zifang tea + 3 pers. Zhang Guahui + 5 people | Collaboration Protocol |
|  | Xi'an | NINT | Song Zhaohue + 3 people |  |
| IAEA | Vein | IAEA | Fesenko S. | Collaborations |
| Moldova | Kishinev | IMB ASM | Rud L.B. | Protocol |
| IC | Chokyrlan A.G. | Protocol |
| Mongolia | Ulaanbaatar | CGL | Balzhinnyam N. + 2 pers. | Exchange of visits |
| Collaborations |
| NRC NUM | Huuhenhuu G. + 3 pers. | Collaborations |
| Poland | Wroclaw | UW | Kosior G. + 5 pers. | Collaborations |
| Gdansk | GUT | Bizyuk M. + 4 pers. | Collaborations |
| Krakow | INP PAS | Godzik B. + 4 pers.  Jurkovski J. + 1 pers. | Collaborations |
| Lodz | UL | Andrzejewski J. + 3 pers. | Collaborations |
| Lublin | UMCS | Zhuk E. + 3 pers.  Yasinskaya B. + 7 pers. | Collaborations |
| Opole | UO | Vaclavek M. + 5 pers. | Collaborations |
| Otwock (Sverk) | NCBJ | Miyanovsky C.  Polansky A. + 2 pers. | Collaborations |
| Poznan | AMU | Blashak Z. + 4 pers. Navrotsyk V. + 4 pers. | Collaborations |
| The Republic of Korea | Pohang | PAL | Kim G. + 3 pers. | Collaborations |
| seoul | Dawonsys | Kim Dong-soo | Collaborations |
| Daejeon | KAERI | Chang D. | Collaborations |
| Russia | Arkhangelsk | NArFU | Yeseev M.K. | Protocol |
| Borok | IBIW RAS | Tselmovich V.A. + 2 pers. | Collaborations |
| Vladikavkaz | NOSU | Labrinenko Yu.V.  Tvauri I.V. | Collaborations |
| Voronezh | VSU | Vakhtel V.M.  Kadmensky S.G. + 3 pers. | Collaborations |
| Gatchina | NRC KI PNPI | Vorobyov A.S. + 3 pers.  Voronin V.V. + 10 people | Collaborations |
| Grozny | ChSPU | Okazova Z.P. | Collaborations |
| Dolgoprudny | MIPT | Rogachev A.V. | Protocol |
| Dubna | State. University "Dubna" | Morzhukhina S.V. + 5 pers.  Senner A.E. + 3 pers. | Collaborations |
| Diamond | Syrovatskaya T.N. | Collaborations |
| Ekaterinburg | UrFU | Kruzhalov A.V. + 5 pers. | Collaborations |
| Ivanovo | ISUCT | Grinevich V.I.  Dunaev A.M. | Collaborations |
|  |  |  |  |
| Izhevsk | UdSU | Bukharina I.L.  Zubtsovsky N. | Collaborations |
| Irkutsk | LIN SB RAN | Hodger T.V. | Collaborations |
| Moscow | JSC "MNRHU" | Seregina E.I. | Protocol |
| VNIIA | Bogolyubov E.P. + 1 pers. | Collaborations |
| SIAS | Tsarevskaya T.Yu. | Protocol |
| GIN RAS | Lyapunov S.M. + 3 pers. | Collaborations |
| IA RAS | Vdovichenko M.V. | Protocol |
| SRI RAS | Mitrofanov I.G. + 5 pers. | Collaborations |
| GPI RAS | Mikhailova G.N. | Collaborations |
| ITEP | Trouble A.G.  Danilyan G.V. + 3 pers. | Collaborations |
| IPChE RAS | Safonov A.S. + 3 pers. | Collaborations |
| MSMU | Karalkin P.D. | Protocol |
| Moscow State University | Batsevich V.A. + 2 pers. | Collaborations |
| Belokhin V.S. | Protocol |
| Bushuev V.A. | Collaborations |
| Krasnushkin A.B. + 1 pers. | Collaborations |
| SINP MSU | Tretyakova T.Yu. + 2 pers. | Protocol |
| Chuvilsky Yu.M. + 1 pers. | Collaborations |
| NRC KI | Barabanov A.L. + 2 pers. | Collaborations |
| FRC “Soil Institute” | Bolotov A.G. | Protocol |
| Moscow, Troitsk | INR RAS | Dzhilkibaev R.M. | Protocol |
| Kuznetsov V.L. | Collaborations |
| Nizhny Novgorod | IPM RAS | Salashchenko N.N.  Chkhalo N.I. + 1 pers. | Collaborations |
| Obninsk | IPPE | Grudzevich O.T. + 10 people | Collaborations |
| Perm | PSU | Gatina E.L. | Agreement |
| St. Petersburg | KBI RAS | Tkachenko K.G. + 3 pers. | Collaborations |
| FIP St. Petersburg State University | Bunakov V.E. + 1 pers. | Collaborations |
| RI | Smirnov A.N. + 1 pers. | Collaborations |
| SPbFTU | Alekseev A.S. + 10 people | Collaborations |
| SPMU | Vasilenko T.A. | Protocol |
| IPTI | Vul A.Ya. + 5 pers. | Collaborations |
| Sevastopol | IBSS | Milchakova N.A. + 2 pers. | Collaborations |
| Tula | TulSU | Gorelova S.V. | Collaborations |
| Romania | Baia Mare | TUCN-NUCBM | Todoran R. + 3 pers. | Collaborations |
| Bucharest | IFIN-HH | Gita D. | Collaborations |
| Dima O.  Michael O. | Protocol |
| Pantelika A. + 3 pers.  Setnescu R. | Collaborations |
| IGR | Douliou O. | Protocol |
| INCDIE ICPE-CA | Mirela M. + 5 pers. | Collaborations |
| UB | Grue I.  Douliou O.  Lived A.  Lazanu I.  Tudora A. | Collaborations |
| UPB | Fikay A. | Protocol |
| Galati | UG | Ene A. + 3 pers. | Collaborations |
| Cluj-Napoca | INCDTIM | Soran N.L. | Collaborations |
| Constanta | UOC | Belk M. + 2 pers. | Collaborations |
| Magurele | ISS | Potlog P.M. | Collaborations |
|  | NIMP | Badika P. + 6 pers.  Stanculescu A. + 4 pers. | Collaborations |
| Oradea | UO | Oprea A. + 3 pers.  Philip S. | Collaborations |
| Pitesti | ICN | Preda M. | Collaborations |
| Ramnicu Valcea | ICSI | Kuruya M. + 3 pers.  Oprah K.  Stefanescu I. | Collaborations |
| Sibiu | ULBS | Bondrea I. | Protocol |
|  |  | Chisea D. + 8 pers. | Collaborations |
| Timisoara | UVT | Stef M. + 4 pers. | Collaborations |
| Targovishte | VT | Bamwak M.  Bamkuta I.  Radulescu K.  Setnescu T. | Collaborations |
| Poetry S. + 4 pers. | Protocol |
| Iasi | NIRDTP | Chirakh H.+ 2 pers. | Collaborations |
| UAIC | Carmen M. + 5 pers. | Collaborations |
| Northern  Macedonia | Skopje | UKiM | Stafilov T. + 3 pers. | Collaborations |
| Serbia | Belgrade | IPB | Anicic M. + 5 pers. | Collaborations |
|  | University | Popovich D. | Collaborations |
| Novi Sad | UNS | Krmar M. + 3 pers. | Collaborations |
| Slovakia | Bratislava | CU | Kucherka N. + 5 pers. | Collaborations |
|  | Holly K. | Collaborations |
| IEE SAS | Guran E. |  |
| IP SAS | Kliman Ya. + 3 pers. | Collaborations |
| Slovenia | Ljubljana | GeoSS | Shane R. | Collaborations |
| USA | Durham, NC | Duke | Gould K. + 2 pers.  Thornow W. | Treaty |
| Los Alamos | LANL | Systrem S. + 5 pers. | Collaborations |
| Oak Ridge | ORNL | Keler P. | Collaborations |
| Thailand | Hat Yai | PSU | Bongsuwan T. | Collaborations |
| Türkiye | Canakkale | COMU | Koskun M. + 3 pers. | Collaborations |
| Uzbekistan | Tashkent | INP AS RUz | Artemov S.V. | Collaborations |
| Finland | Jyväskylä | UJ | Trzaska V. | Collaborations |
| Oulu | UO | Keronen A. + 3 pers. | Collaborations |
| France | Grenoble | ILL | Geltenbort P.  Yenchel M.  Nesvizhevsky V. | Collaborations |
|  | LPSC | Protasov K.V. + 2 pers. | Collaborations |
| Cadarache | CC CEA | Soul R. + 5 pers. | Collaborations |
| Saclay | LLB | Leroy S. + 2 people | Collaborations |
| Strasbourg | IPHC | Stuttje L. + 2 pers. | Collaborations |
| Croatia | Zagreb | Oikon IAE | Spirich Z. + 5 pers. | Collaborations |
|  | RBI | Valkovich + 2 pers. | Collaborations |
| CERN | Geneva | CERN | Chiaveri E. + 12 pers. | Collaborations |
| Czech Republic | Ostrava | VSB-TUO | Yanchik P. | Collaborations |
| Prague | CEI | Kuchera Ya. + 2 pers. | Collaborations |
| CTU | Shtekl I. + 15 pers. | Collaborations |
| Rzhezh | CVR | Patrick M. | Protocol |
| Switzerland | Willigen | PSI | Lauss B. | Collaborations |
| Schmidt-Welenburg F. | Collaborations |
| South Africa | Bellville | UWC | Petrik L. + 5 pers. |  |
| Pretoria | UNISA | Sofianos S. | Collaborations |
| Stellenbosch | SU | Bezudenot J. + 3 pers. | Collaborations |
| Japan | Kyoto | KSU | Kimura I. + 3 pers. | Collaborations |
| Tsukuba | KEK | Masuda Ya. + 5 pers. | Collaborations |

**2.6. Key partners** *(those collaborators whose financial, infrastructural participation is substantial for the implementation of the research program on the theme. Example – JINR participation in the LHC experiments at CERN).*

**3. Manpower**

**3.1. Manpower needs in the first year of implementation**

|  |  |  |  |
| --- | --- | --- | --- |
| **No.** | **Personnel category** | **JINR staff,**  **FTE amount** | **JINR associated personnel,**  **FTE amount** |
| 1. | research scientists | 66 |  |
| 2. | engineers | 42 |  |
| 3. | specialists | 11 |  |
| 4. | office workers | 0 |  |
| 5. | technicians | 2 |  |
|  | **Total:** | **121** |  |

**3.2. Available manpower**

**3.2.1. JINR staff** (total number of participants)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Category of workers** | **Full name** | **Division** | **Position** | **FTE** |
| Scientific workers | Lychagin E.V. | FLNP | Laboratory director |  |
| Kopach Yu.N. | FLNP | Deputy laboratory director for research |  |
| Shvetsov V.N. | FLNP | Head of department |  |
| Sedyshev P.V. | FLNP | Deputy head of department |  |
| Fedorov N.A. + 58 people | FLNP | Head of sector |  |
| Kulin G.V. + 18 people | FLNP | Head of sector |  |
| Zinkovskaya I. + 23 people | FLNP | Head of sector |  |
| Specialists | Pyataev V.G. + 28 people | FLNP | Chief engineer |  |
| Workers |  |  |  |  |
| Total | | | |  |

**3.2.2. JINR associated personnel**

|  |  |  |  |
| --- | --- | --- | --- |
| **No.** | **Personnel category** | **Partner organization** | **Amount of FTE** |
| 1. | research scientists |  |  |
| 2. | engineers |  |  |
|  | **Total:** |  |  |

**4. Financing**

**4.1. Total estimated cost of the theme / LRIP**

**5925 USD**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Items of expenditure** | **Cost** | **Expenditure per year**  **(thousands of the US dollars)** | | | | |
| 1st  year | 2nd  year | 3rd  year... | 4th year | 5th year |
| 1. | International cooperation | 525 | 95 | 95 | 105 | 110 | 120 |
| 2. | Materials | 1255 | 245 | 255 | 295 | 230 | 230 |
| 3. | Equipment, Third-party company services | 3425 | 585 | 715 | 775 | 650 | 700 |
| 4. | Commissioning |  |  |  |  |  |  |
| 5. | R&D contracts with other research organizations | 240 | 140 | 30 | 30 | 20 | 20 |
| 6. | Software purchasing | 480 | 80 | 100 | 90 | 100 | 110 |
| 7. | Design/construction |  |  |  |  |  |  |
| 8. | Service costs (*planned in case of direct affiliation)* |  |  |  |  |  |  |
| **TOTAL:** | | 5925 | 1145 | 1195 | 1295 | 1110 | 1180 |

**4.2. Extra funding sources**

Expected extra funding from partners/customers (total for all projects).

**AGREED:**

**Chief Scientific Secretary Laboratory Director**

**/\_\_\_\_\_\_\_ / /\_\_\_\_ /**

**" " 202\_г. " " 202\_г.**

**Head of BEPD Scientific Secretary of the Laboratory**

**/\_\_\_\_\_\_\_ / /\_\_\_\_ /**

**" " 202\_г. " " 202\_г.**

**Head of DSOA Laboratory Economist**

**/\_\_\_\_\_\_\_ / /\_\_\_\_ /**

**" " 202\_ г. " " 202\_г.**

**Head of HRRMD Theme leader**

**/\_\_\_\_\_\_\_ / /\_\_\_\_ /**

**" " 202\_г. " " 202\_г.**

**Theme leader**

**/\_\_\_\_ /**

**" " 202\_г.**

**Theme leader**

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**" " 202\_г.**

**Project leader (project code) /(LRIP subproject code)**

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**Project leader (project code) /(LRIP subproject code)**

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