**Annex 3.**

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

***Sub-project of LRIP***

 **APPROVED**

 **JINR DIRECTOR**

 **/**

 **" "2023**

**PROJECT PROPOSAL FORM**

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

1. **General information on the research project of the theme/subproject of the large research infrastructure project (hereinafter LRIP subproject)**
	1. **Theme code / LRIP** (for extended projects) - *the theme code includes the opening data, the closing date is not given, as it is determined by the completion dates of the projects in the topic.*

**1.2 Project/LRIP subproject code** (for extended projects)

**1.3 Laboratory** FLNP

**1.4 Scientific field** Nuclear physics

**1.5 Title of the project/LRIP subproject**

"Modernization of the accelerator EG-5 and its experimental infrastructure"

**1.6 Project/LRIP subproject leader(s)**

Doroshkevich A.S.

**1.7 Project/LRIP subproject deputy leader(s) (scientific supervisor(s))**

**2 Scientific case and project organization**

**2.1 Annotation**

The project is aimed at modernizing the main systems of the electrostatic charged particle accelerator EG-5 and related service systems, developing complementary experimental methods for studying the elemental composition and physical properties of near-surface layers of solids.

**The purpose of the project:** to provide technical feasibility for the implementation of the scientific program of the TP JINR 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 substances, solution of problems of neutron radiation materials science, implementation of practical applications of neutron physics; provision of technical feasibility for the implementation of unique options for 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 up 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 to implement the option of a microbeam spectrometer/nuclear microprobe.

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 updating the experimental infrastructure of the accelerator complex, in particular, the development of new methods complementary to the methods of ion-beam analysis, methods for studying the physical properties of the surface of materials that can complement and improve the quality of the obtained scientific products, the intensification of international scientific and technical cooperation, the organization of user policy, formation on the basis of FLNP JINR of an interlaboratory accelerator center for solving a wide range of unique scientific and technological problems.

The main criteria for the successful implementation of the project are: obtaining a neutron flux sufficient for conducting nuclear physics experiments with fast neutrons and energy stability of the ion beam sufficient for creating a microbeam spectrometer/nuclear microprobe.

**The relevance of the project** is dictated by the demand for this facility as a part of the scientific and technical infrastructure of the FLNP JINR, in particular, the need to resume research on nuclear reactions with fast neutrons, the need to implement a unique option at the EG-5 accelerator - a microbeam spectrometer (nuclear microprobe), the need to conduct other nuclear physics experiments with fast neutrons. Putting the accelerator into operation at the rated power will increase the volume of scientific research carried out at FLNP within the framework of the JINR Roadmap and the JINR PTP, and will ensure that possibility of implementing the user policy at the EG-5 facility.

**Ways to solve tasks.** To solve the set tasks and achieve the goal of the Project, a separate group «EG-5 facility" was created as a part of the SINNI DNP (Sector of investigations of Neutron-Nuclear Interactions, Department of Nuclear Physics), including experienced specialists in the development of accelerator technology (Prof. TaskaevS.Yu.), ion-beam methods for studying solids (Phan Luong Tuan), young employees - students and high-class engineering and technical workers. Currently, young employees are being trained to work with the accelerator and elements of its experimental infrastructure.

With the participation of specialists from the Budker Institute of Nuclear Physics of the Siberian Branch of the Russian Academy of Sciences, it is planned to replace the high-voltage accelerating tube, the ion source, which has lost its performance, and setting up the ion optics of the ESA (Electrostatic Accelerator), thereby ensuring the required technical parameters of the accelerator. During the implementation of the project, cosmetic repairs of the premises of the accelerator complex will be carried out, a laboratory for the preparation of research objects will be installed.

It is planned to organize round-the-clock operation of the accelerator and create a stable collaboration with partners in the Russian Federation, near and far abroad, increase the output of scientific products of FLNP JINR.

**The estimated cost** of the modernization project is $615,000.

**The Project implementation period** is 3 years (2024-2026).

**2.2 Scientific case** (aim, relevance and scientific novelty, methods and approaches, techniques, expected results, risks)

**Relevance. Thematic research plan in FLNP related to the EG-5 accelerator (sector of demand for the EG-5 accelerator).** At the moment, nuclear physics research using electrostatic accelerators is very relevant. Up-to-date information on nuclear transmutation processes using neutron-induced reactions is extremely important for astrophysics and nuclear energy [1]. Data on reactions with the emission of charged particles induced by fast neutrons are of considerable interest for studying the mechanisms of nuclear reactions, the structure of atomic nuclei, radiation materials science, and performing calculations when creating new installations for nuclear power. Ion-beam spectrometers built on the basis of electrostatic accelerators have astronomical accuracy and are extremely important and relevant in modern research related to nanotechnology. An extremely promising is radiation medicine. New knowledge about the interaction of high-energy particles with biological objects is required. At the same time, microbeam ion-beam instruments make it possible to penetrate inside a biological cell and study radiation effects at the microscopic level, to conduct scanning spectroscopic studies of solid objects (including microscopic objects, objects of historical heritage) at the microscopic scale, to carry out ion doping of microscopic areas in semiconductor crystals (nanoelectronics and microsystem technology).

Thus, at the moment there is a wide range of relevant for a number of industries, applied and fundamental scientific problems that are associated with nuclear reactions on fast neutrons and with the interaction of high-energy charged particles with vital and non vital matter. These problems require the use of electrostatic accelerators (ESA) for their solution.

**2.2.1. Scientific program of group EG-5.** The JINR PTP formulated three main areas that we plan to develop using the electrostatic accelerator.

**1.** Nuclear physics. (Study of the properties of excited nuclei, reactions with the emission of charged particles, fission physics, obtaining relevant data for astrophysics, nuclear energy and the problem of nuclear waste transmutation using neutron- and gamma-induced reactions).

**2.** Condensed matter physics (nanotechnology, radiation materials science, biological research using ionizing radiation of various natures, induced by ESA).

**3.** Applied and methodological research (Application of neutron physics methods in technology (microelectronics), other fields of science and technology).

**Nuclear physics.** The scientific program of the accelerator complex is very rich. It is planned to study the whole spectrum of nuclear reactions with fast quasi-monoenergetic neutrons, including:

- study of fission by fast neutrons: measurements of the spectra of prompt fission neutrons (PFN) and total kinetic energies (TKE) in the reactions 235U(n,f), 238U(n,f), 237Np(n,f) in the neutron energy range 1-5MeV / nucleus;

- study of the multiplicity of PFNs in these reactions on fast neutrons in a geometry with a high efficiency of registration of PFNs;

- measurement of the spectra of charged particles from the reactions (n,α) and (n,p) depending on the neutron energy in the region up to 5 MeV and above;

- measurement of the integral and differential cross sections of these reactions depending on the neutron energy;

- study of the spectrum and angular distributions of charged particles at a neutron energy of ~20 MeV in order to study non-statistical effects;

- study of reactions (α, n) and (p, n) in combination, respectively, with reactions (n, α) and (n,p);

- study of elastic and inelastic scattering of fast neutrons by atomic nuclei;

- use of the TOF technique in the pulse mode of the accelerator (f~ 1 MHz, dt~1-10 ns).

**Condensed matter physics.** The following studies are planned using the electrostatic accelerator:

- deep elemental profiles of near-surface layers of solids (multilayer semiconductor architectures such as TiO2 / SiO2 / Si, SiO2 / TiO2 / Si, GaAs, etc.);

- processes of structural relaxation of surface layers of solids, accompanied by oxidation or hydrogenation (metal (Fe, Cu) and metal-oxide (ZrO2, CuO, ZnO, SnO2) solid solutions - ceramics, etc.)

- studies of the oxygen subsystem of the surface layers of materials by the method of nuclear reactions (E > 3.1 MeV, NRA).

Works with biological objects are also planned, in particular, the study of the impact of atmospheric neutrons on the variability of planetary biological forms using the example of rice crops, triticale, etc., monitoring of chromosomal aberrations in human blood lymphocytes.

Methodological should include the development of a new method of elemental analysis of materials, in particular, using inelastic neutron scattering, as well as a combination of nuclear physics and other local and integral methods for studying the surface of materials.

Scientific and methodological researches involve the development of the methodological and experimental infrastructure necessary for carrying out scientific work using the ESA technique in the framework of the first two areas.

**2.2.2. Unique features of the accelerator.** The electrostatic accelerator EG-5, created on the basis of the Van de Graaff generator, has been stationary at the FLNP since 1965. Due to the relative simplicity and reliability of the design, as well as the unique parameters of the accelerated ion beam characteristic of single-stage electrostatic accelerators (high spatial and energy stability at a relatively high current), the EG-5 accelerator currently remains the most efficient and convenient nuclear physics instrument for solving a wide range of topical scientific problems of nuclear physics, condensed matter physics, biology, electronics, medicine. The relatively high current of the ion beam (up to 100 µA) makes it possible to obtain, as a result of irradiation of a deuterium target with deuterons (reaction D(d,n)3He), a wide spectrum of neutrons for nuclear physics research in the energy range up to 5.5 MeV. As can be seen from the list of the most urgent problems of modern nuclear physics (Nuclear Data High Priority Request List, Table 1), this energy range is the most demanded in modern research in nuclear physics. It should be noted that these problems are difficult and expensive to solve on other types of neutron facilities.

Studies of neutron-induced reactions with the emission of charged particles provide valuable information about the mechanisms of nuclear reactions and the structure of the atomic nucleus, processes of stellar nucleosynthesis, etc.

The most 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 now popular exchange accelerators - tandetrons.

Currently the only microbeam spectrometer in the Russian Federation manufactured at the Institute of Applied Physics of the National Academy of Sciences of Ukraine (Sumy, Ukraine) is located in Sarov and, for known reasons, is difficult to access for most users. The energy stability due to the absence of a charge-exchange target is an important factor for achieving high resolution in studies of thin surface layers.

With the development of nanotechnologies and applications of nuclear energy, the range of applied research problems for electrostatic accelerator complexes of the EG-5 type is expanding daily. The ion-beam "microprobe" with a diameter of about 1 μm significantly expands the possibilities of nuclear physics methods of FLNP JINR in the field of natural sciences, and is indispensable for solving problems of nanophysics and bionanotechnology. Thus, EG-5 is currently the only accelerator at JINR that, by its technical capabilities, is potentially suitable for solving modern scientific problems of experimental nuclear physics, nuclear astrophysics (stellar nucleosynthesis) [3] and bionanotechnologies (indicated in the JINR PTP).

**2.2.3. The problem that the project aims to solve.** Unfortunately, at the moment in the Russian Federation and the JINR member countries there is only one microbeam spectrometer in Sarov [3] and no more than five operating accelerators suitable for the production of fast neutrons [4], which significantly limits research opportunities in the field of modern radiation biology, medicine, condensed matter physics and nuclear physics.

**Reactions with fast neutrons.** Due to the exhaustion of the technical resource of the EG-5 accelerator, at the moment at JINR, studies of reactions with quasi-monoenergetic fast neutrons are practically stopped or taken out of the Russian Federation. Recent significant results indicating the need to refine the existing ideas about the main source of neutrons in astrophysical processes - the reactions 22Ne(α,n) 25Mg were obtained by a group led by Professor Yu.M. Gledenov at a similar accelerator at Beijing University [5]. Over the past three years, our group on fast neutrons measured sections (n, α) reactions for elements 144Sm, 66Zn, 10B, 25Mg, 54,56 Fe, 58, 60, 61Ni and at the moment, together with Obninsk State Research Center of the Russian Federation work is underway on the Russian Library of Nuclear Data BROND for a number of nuclei (6Li, 14N, 35Cl, 91Zr, and 56Fe).

**Table 1.**

The list of the most relevant objectives of modern nuclear physics "Nuclear Data High Priority Request List" [2].

**Ion beam spectrometry.** Using the EG-5 accelerator on helium ion beams, nondestructive experimental studies of the depth profiles of elements with a depth resolution of about 10 nanometers are currently being carried out. There is a unique opportunity to study layered structures. The analysis uses non-destructive techniques RBS, ERD, and PIXE, based on beams of helium ions with energies from 1 to 3 MeV/nucleus. Studies of multilayer high-temperature superconducting systems are underway [6]. Besides, work is actively underway to study the processes of ion implantation of the surface of solids (gas, layered structures TiO2 / SiO2 / Si, SiO2 / TiO2 / Si) ions N2+, Ar+, Xe+, Bi+, N2+, Al+, In+ and induced by irradiation and subsequent thermal annealing (at temperatures: 500 °C, 700 °C and 900 °C) structural relaxation processes [7, 8], accompanied by oxidation [9, 10] or hydrogenation [11] of the surface layers.

**Biological research**. At the moment, there is no possibility of conducting nuclear physics experiments, as well as to work with biological objects due to the loss of particle flow intensity. In particular, trial experiments on irradiation of blood samples of neutrons (d,d – reaction) on the accelerator EG-5 at a distance of 1 cm from the output, carried in May 2018 showed unsatisfactory intensity for working with biological objects. At a beam current of 0.1 μA, the duration of irradiation to accumulate the required dose of 0.4 Gy took more than 4 hours, which turned out to be unacceptable and led to the death of biological samples. For further work with biological objects, the expected beam current must be at least 1 μA, the neutron energy of En is ~ 5MeV).

**2.2.4. Methods and approaches to achieve the project goal.**The problem of the project is of an organizational and technical nature and is related to the physical wear and tear of the main components and systems of the installation, the obsolescence of the scientific and experimental base, the loss of cooperative relations and a general efficiency decrease of the group carrying out scientific support of accelerator topics in the FLNP JINR.

At the moment the technical problem is the physical wear of the main components and systems of the installation and the moral aging of the scientific and experimental base. The loss of power by the accelerator (the beam current decreased from 50 µA to 1 µA) made it impossible to use it to generate neutrons, study nuclear reactions and develop a microbeam spectrometer based on it – options that are currently unique in JINR and in the Russian Federation.

It should be noted that the problem of ageing and stopping accelerators for the last 30 years in Russia has been systematic. Only in the period from 1990 to 2014, the number of accelerators decreased from 27 to 12-15. In Russia, the development and production of accelerators (except for Sarov and Novosibirsk) have practically stopped, while the leading positions in the production and number of accelerators have been established by the United States. To solve this technical problem, FLNP is supposed to implement this project to modernize the EG–5 accelerator and its experimental infrastructure.

**The tasks of the project and activities to be carried out for their solution.**

**Task 1.** The main technical task of the project is to achieve the technological parameters of the EG-5: the voltage of the conductor of 4. 1 MeV at a beam current up to 250 mkA.
 As a subtask 1.1, it should be noted a replacement of the accelerating tube, an ion source with a control system (with a fiber-optic communication channel), the accelerator hall, the right and left experimental halls maintenance.

Ensuring a sufficiently high level of cleanliness in the rooms (at least ISO-9 class) under the condition of indoor air conditioning will increase the voltage on the accelerator conductor and the energy of the accelerated particles to about 20%.
 Subtask 1.2 includes complex inspection, cleaning and repair of elements of the high-voltage structure and equipment that provides high voltage on the accelerator conductor, replacement of outdated devices with modern analogues, and automation of the accelerator complex.
 It is noteworthy that ensuring an appropriate level of safety of working with the accelerator and elements of its infrastructure, fire and radiation safety is also a subtask (subtask 1.3.) of the first task.

**Task 2.** An equally important task is the development of the experimental infrastructure of the accelerator complex, which will maximize the usage of its production potential, increasing the yield of scientific products and expanding the applicability of existing research methods (Task 2).
 Subtask 2.1 is checking the operability and bringing all systems of the accelerator into proper functional condition. Subtask 2.2 includes the automation and modernization of functional units and service systems of the accelerator. It needs to increase the degree of control and retention of beam parameters. In particular, the micro-beam spectrometer planned to be installed requires a high degree of not only energy but also spatial stabilization of the beam. It is extremely important for the automation of the beam positioning system with precision accuracy. Automation will also reduce the number of personnel in a shift and switch to the recommended round-the-clock operation of the ESA.

**RBS chamber.** The equipment currently used to study the elemental composition of materials was developed and manufactured more than 50 years ago. It is very outdated in moral terms. Modern ion-beam spectrometric measuring systems have significantly higher performance. In order to increase the efficiency of research facilities and the output of scientific products, it is proposed to significantly modernize the ion beam analysis chamber (IBA, RBS, ERD, NRA and PIXE methods) by replacing the sample loading system (robotic manipulator), replacing the vacuum system (oil-free pumping system), installing the IBA module on a vibration-resistant foundation. This module will increase the performance of the camera, and the energy resolution of the RBS, ERD, and NRA spectrometers, and fully automate the process of taking samples and processing data.

**Laboratory for the samples production.** It is planned to install a new laboratory (subtask 2.4.). This laboratory is designed to perform works on the preparation of experimental samples in the form of monolithic objects, thin and thick films and from a wide range of solid-state materials, including powder, for research by nuclear physics methods RBS, ERD and PIXE. We are planning also to equip the new laboratory with methods complementary to nuclear physics research methods (subtask 2.5.). In particular, methods for studying the electrical, optical and electronic properties of the surface and near-surface layers of the objects under study (methods of electrochemical impedance spectroscopy; voltammetry, ellipsometry). The laboratory will allow us to carry out the correction and preparation of samples on-site, to conduct independent studies associated with the research methods of EG-5.

**Task 3 (personnel)** involves the training of employees by the ion-beam methods of materials research and accelerator maintenance (subtask 3.1.), attracting young specialists from among students of local universities with good academic performance to the group and highly qualified specialists in the accelerator technology, organizing conferences and symposiums of an international level on the basis of the JINR FLNP, forming a competence centre in the field of accelerator technology and associated experimental techniques (subtask 3.2). These actions will allow us to achieve the autonomous operation of the accelerator for the development of scientific products in the future 20-30 years.

**2.2.5. Expected results**

The technical parameters of the accelerator will be restored (the energy of the accelerated particles is 4.1 MeV at a maximum current of at least 100 mkA, Table 2.). It enables to conduct the experiments with fast neutrons and provides the technical conditions for the installation of a microbeam spectrometer. A neutron generator based on a solid-state lithium target with a moderator will be added to the existing neutron generator based on a gas target. Also, the sample irradiation chamber with ion flows will be modified. The list of the main capabilities of the accelerator complex and expected technical parameters of the EG-5 after the modernization project is given in Table. 3. **Expected technical parameters of the EG-5 accelerator after modernization.** The technical parameters of the accelerator before and after modernization are given in Table 2.

**Table 2.**

**The technical parameters of the accelerator before and after the modernization.**

|  |  |
| --- | --- |
| **Beforemodernization** | **Aftermodernization** |
| Terminalvoltage - 2,1 MVBeam current – 100nAIon Energy – 2,9 MeVNeutron energies – 3.3-5,1MeVNeutron fluxes- 106 | Terminalvoltage - 4,1 MVBeamcurrent – 100 - 250mkAIonEnergy – 4,1 MeVNeutronenergies – 21-800keV, 3.3-5,1MeVNeutron fluxes- 108-109 |
| - Nuclear physics experiments conducting is **not possible**,- NRA (3,1 MeV) - **notpossible** | - Nuclear physics experiments conducting is **possible**,- NRA (3,1 MeV) - **possible** |
| Microbeam option installing – **not possible** | Microbeamoptioninstalling – **possible**; |
| Work with biological objects - **not possible** | Work with biological objects – **possible** |

**Table 3.**

 **Methodological capabilities of the accelerator complex before and after the modernization project.**

|  |  |
| --- | --- |
| **Beforemodernization** | **Aftermodernization** |
| - Nuclear physics experiments - **not possible**- NRA (3,1 MeV) - **not possible** | Nuclear physics experiments - **possible**,- NRA (3,1 MeV) - **possible***.* |
| Microbeam option installIng – **not possible** | Microbeamoptioninstalling –**possible**; |
| Work with biological objects - **not possible** | Work with biological objects - **possible** |
| The performance of EG-5 spectrometers:- **3** samples / per day,**Methods:**1. Rutherford backscattering (RBS);2. Elastic Recoil Detection (ERD);3. Particle Induced X-Ray Emission (PIXE).4. Nuclear Reaction Analysis (NRA); | The performance of EG-5 spectrometers:**- 32** samples / per day,**Methods:**1. Rutherford backscattering (RBS);2. Elastic Recoil Detection (ERD);3. Particle Induced X-Ray Emission (PIXE).4. Nuclear Reaction Analysis (NRA); |
| **Complementary methods** | **Complementary methods**5. Fast neutron analysis (FNAA);6. Neutron activation analysis (NAA);7. Electrochemical impedance spectrometry (EIS);8. Voltammetry (V-I);9. Optical Ellipsometry (OE). |

A new specialized laboratory for the preparation of research objects will be created. It is planned to equip it with complementary methods for studying optical and electronic properties of the surface, like ellipsometry, optical and electron microscopy, and methods for studying electrical properties at direct and alternating current (voltammetry impedance, Table 3).

In addition to the modernization and expansion of the instrument base of the accelerator complex, the staffing for the next 20-30 years will be carried out. Methods of analysis based on inelastic neutron scattering and neutron activation analysis will be added to the existing methods of elemental analysis. The modernization of the EG-5 at JINR with highly qualified specialists, good detection equipment and valuable developments in the study of atomic nuclei by neutrons will make it possible in the short term to conduct many new, unique experiments. We will measure the energy spectra and angular distributions of charged particles from reactions (n, α) and (n, p) / (α, n) and (p, n) and integral and differential cross sections in the range of neutron energies up to ~6 MeV, processes of fission of atomic nuclei by fast neutrons, activation analysis [12, 13], conducting experiments in the field of neutron materials science, etc.

**2.2.6. The state of research on the declared scientific problem (the available reserve)**

**Acceleratorrepair, conductedwork.** To solve the task 1, the FLNP management conducted a number of activities (of advisory nature) before the start of the project, aimed at identifying of the causes of the operability loss by the accelerator and ways to eliminate the identified technical problems. Commissioned by the FLNP by a group of experts from the Institute of Applied Physics of the National Academy of Sciences (Sumy, Ukraine), specializing in the development of accelerator technology under the guidance of prof. Ponomarev was carried out the scientific-technical work «Analysis of the technical condition and measurement of the parameters of the electrostatic accelerator EG-5 FLNP JINR». It allowed to establish the main reasons for the decrease in the efficiency of the accelerator. Independently, the leading expert in the field of ESU Prof. V.A. Romanov made a study of the operating modes and technical condition of the main components of the accelerator. The received recommendations were used as the basis for the accelerator repair work plan (tasks 1, 2).

**Nuclear microprobe.** In 2015, the staff of the Institute of Applied Physics of the National Academy of Sciences of Ukraine (Sumy) carried out design work on the microprobe channel (the well-established term Nuclear microprobe) based on the accelerator EG-5 of FLNP JINR.The design documentation is in full in the FLNP.

**The EG-5 group**. To solve the tasks set in the project, a separate group "EG-5" was created in September 2019 as part of the SINNI, including leading scientists – relevant specialists (Dr A.P. Kobzev, Dr M. Kulik), highly qualified engineering and technical workers (A.N. Likhachev, S.V. Tkachenko, V. P. Kudryavtsev and I.A. Zaitsev) and young employees – students and postgraduates of the Dubna University (9 people). At the moment, future specialists are being trained in the features of the operation of the accelerator complex devices. Weekly lectures - seminars and individual practical classes on the RBS method are organized. Familiarization with the technical principles of the accelerator and its service systems is carried out (A.N. Likhachev). The students actively participate in scientific conferences of various levels and take leading positions in university competitions and conferences. In order to increase the level of competence of the group in technical matters, a leading specialist in the field of accelerator technology development, Prof V.A. Romanov, was engaged as an Adviser to the FLNP Director. Then he was replaced by Professor S. Yu. Taskaev from the Novosibirsk INP. The technical part of the group has been strengthened by the arrival of two young employees to the positions of lead engineer and laboratory assistant with the appropriate distribution of vacant labour functions.

**2.2.7. Description of the proposed study / Description of the work progress**

The expert assessment of the state of the accelerator by Prof V.A., Romanov, Prof S.Yu. Taskaev and data from the report of Prof A.G. Ponomarev (Sumy, Ukraine) on the scientific and technical work "Analysis of the technical condition and measurement of parameters of the electrostatic accelerator EG-5 FLNP JINR", were allowed to form a list of necessary activities:

**Stages of work with deadlines**

**2023-2024**

1. **Carrying out activities to improve the safety work with the accelerator.**

1.1. Installation of a centralized radiation monitoring system in the halls of the ESA and the rooms of the controlled zone (together with IREN specialists).
1.2. Drawing up an up-to-date technological scheme of the ESA (Promexpertiza company).
1.3. Replacement of the gas compressor gearbox with an automatic analogue (Promexpertiza company).
1.4. Obtaining the SEC and commissioning of the accelerator (together with IREN specialists).
1.5. Painting the ion guide in bright colour.
1.6. Protection and alarm installation in potentially dangerous places in the Accelerator Hall.
1.7. Installation of fences around open process windows on the removable repair site of the accelerator.

1. **Carrying out activities to increase the electrical strength of accelerator gas media, including indoor air.**

2.1. Repair of the accelerator's working space according to sanitary standards.
2.2. Installation of oil filters in the dielectric gas preparation system.
2.3. Cleaning of accessible areas of the vacuum system from carbon deposits and oil vapours.
2.4. Transition to turbomolecular pumps.

1. **Elimination of factors that worsen the quality of the installation (reducing the limiting voltage and beam current, increasing the energy spread), carrying out preparatory activities to replace the high-voltage accelerating tube.**

3.1. Repair of floors, and removal of the tilt of the analyzer magnet. Compensation of beam deflection from the horizontal direction by permanent magnets (2023-2024).
3.2. Cleaning the surface of the high-voltage terminal (corona triode area), and high-voltage column insulators (gradient rings) with solvent and hydrofluoric acid (to obtain the lowest recombination coefficient of Н+ ions) (2024).
3.3. Cleaning of the charging tape (2023-2024).
3.4. Smoothing the transition from a small diameter of the column screen to a large one to level the field gradient and eliminate breakdowns (2024).
3.5. Strengthening the insulation of the springs holding the accelerating tube in the column (using Teflon tubes) (2024).
3.6. Adjustment (strictly coplanar) and partial replacement of needles in the corona triode (2025).
3.7. Adjustment of the gap on discharge brushes (2025).
3.8. Changing the configuration of recharging brushes: separation of monolithic plates into three sections, which will reduce the pressure on the tape and its wear (2026).
3.9. Revision of divider resistors with nominal values changed during operation. Replacement of resistors in the compensating section (5 sections after the section with direct fields) (2024).
3.10. Replacement of the accelerating tube, resistive divider and ion source with the help of specialists from the Budker Institute of Nuclear Physics SB RAS (2024).
3.11. Training of the source of the high-voltage system with high voltage (2024).
3.12. Checking the shape of a beam at the input and output of the accelerator tube (2024).
3.13. Coordination of the ion ESA optics with the help of specialists from the Budker Institute of Nuclear Physics SB RAS (2024-2025).
3.14. Cosmetic repairs in the right experimental hall (2025).
3.15. Installation of a passive vibration suppression system (base plates for a microbeam spectrometer on a sand cushion mechanically untied from the floor in the spectrometer hall).

* 1. **Installation of a laboratory for the preparation of objects for research by ion-beam methods (2025-2026).**
	2. **Installation of equipment for ion implantation of silicon wafers together with JSC "Micron" (2024).**
	3. **Installation of a new high-performance camera for ion-beam materials research (RBS, ERD, PIXE) (2024-2025).**
	4. **Modernization of service equipment. Automation of accelerator nodes is extremely important for the implementation of a microbeam spectrometer (as an option) and a quasi-monoenergetic neutron generator**

7.1. Automation of the beam positioning and spatial stabilization system (2024-2025)
7.2. Installation of a beam coordinate control system with documentary fixation (2024-2025).

* 1. **Replacement of obsolete devices on the Remote Control (2025).**
	2. **Training of personnel to work at the installation from among young employees, intensification of international cooperation, and organization of a user program (2023-2026).**
	3. **Equipping the experimental infrastructure with complementary methods of studying the surface layers of materials (electron microscope, 2026).**
	4. **Switching to remote–controlled vacuum valves to ensure emergency cutting off of the accelerator tube(2023-2024).**

**2.2.8. A brief SWOT analysis of the project**

**Project Strengths**

 1. Suitable design of the EG-5 accelerator for the solving tasks (creation of a nuclear microprobe and a neutron generator). The project will fully realize the unique capabilities of the EG-5 accelerator, in particular, the possibility of obtaining a large ion beam current (up to 250 mkA) and its small spread (<10eV), which cannot be implemented on tandem-type installations.

 2. Low operating cost of the EG-5 facility. The excellent maintainability of the EG – 5 accelerator design and the availability of a resource base make it possible to modernize with minimal costs and ensure the autonomous operation of the accelerator complex for a long time. JINR has all the necessary production infrastructure and material base (spare parts, liquid nitrogen, service systems, etc.) necessary to maintain the plant's operability on its own for a long period of time after replacing the tube. EG-5 does not require the use of expensive materials and equipment, does not contain nodes with unknown parameters (programmable microprocessor modules of the service equipment control system, etc.), and does not require the invitation of foreign specialists for repairs and maintenance work.

 3. Professional development of own engineering personnel in the process of modernization, and the formation of human resources for the long-term operation of the accelerator. During the implementation of the project, the formation of human resources from university graduates, their training in working with the elements of the accelerator infrastructure and familiarization with the specifics of scientific work in the group will be carried out.

 4. Development of a full-fledged experimental infrastructure of the accelerator complex. Resource savings due to the availability of its infrastructure will significantly expand the experimental infrastructure. The installation of a new complex of ion-beam spectrometers, and the installation of a laboratory for the formation of research objects will significantly expand the range of objects under study, thereby significantly increasing the yield of scientific products.

 5. This solution of the main problem is less costly in financial terms compared to the purchase of a new accelerator and the creation of an experimental infrastructure based on it.

**Project Weaknesses**

1. Moral and technical obsolescence of the accelerator's service systems and experimental base. Significant time resources will be required for the revision and modernization of all accelerator systems.
2. Limited set of functions, resources will be required to develop software that will allow coordinating the operation of the accelerator systems after automation.
3. Relative pulse duration in the pulsed mode will have a fixed value.
4. There is no possibility of acceleration of ions heavier than 4He.

**The main threats** that may lead to failure to complete tasks on time or failure to achieve the required technical parameters by the accelerator may be associated with:
 - errors in the design of the tube ;
 - errors when installing a new tube;
 - staff errors when cleaning the vacuum system from oil, which can lead to contamination of new equipment and loss of vacuum quality;
 - critical misalignment of the ion optics of the ESA after the replacement of elements;
 - problems with the purchase of insulators in China;
 - the presence of additional unaccounted failures in the accelerator in addition to the loss of parameters by the accelerator tube;

**2.3. Expected execution period: 2024-2026.**

**2.4. Participating JINR Laboratories: FLNP**

2.4.1 MICC resource requirements

|  |  |
| --- | --- |
| **Computingresources** | **Distributionbyyear** |
| 1styear | 2nd year | 3rdyear | 4th year | 5th year |
| Data storage (ТB)- EOS- Tapes | 0 | 0 | 0 |  |  |
| Tier 1 (CPU corehours) | 0 | 0 | 0 |  |  |
| Tier 2 (CPU corehours) | 0 | 0 | 0 |  |  |
| SC Govorun (CPU core hours)- CPU- GPU | 0 | 0 | 0 |  |  |
| Clouds (CPUcores) | 0 | 0 | 0 |  |  |

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

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Organisation** | **Country** | **City** | **Participants** | **Type****of agreement** |
| **JINR** | **Russia** | **Dubna** |  |  |
|  |  |  |  |  |

***2.6. Key partners*** *(those collaborators whose financial, infrastructural participation is substantial for the implementation of the research program. An example is JINR's participation in the LHC experiments at CERN). – No*

**3. Manpower**

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

|  |  |  |  |
| --- | --- | --- | --- |
| **№№****n/a** | **Categoryofpersonnel** | **JINR staff,****amount of FTE** | **JINR Associated****Personnel,****amount of FTE** |
| 1. | researchscientists | 1,9 |  |
| 2. | engineers | 5,5 |  |
| 3. | specialists | 3 |  |
| 4. | officeworkers | - |  |
| 5. | technicians | - |  |
|  | **Total:** | 10,4 |  |
|  | Leaders | 1,1 |  |

**3.2. Available manpower**

The project team includes world-class experts in the development of ESA-technology (Prof. S.Yu. Taskaev) and electronics (Semenov V. N.), 6 engineering and technical workers with many years of experience in servicing and repairing all units of the EG-5 facility, and others specialists. The group includes more than 50% of young employees who are able to solve quickly current technical problems.

**3.2.1. JINR staff**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **№** | **Category** | **Full name** | **Subdivision** | **Position** | **Amount****of FTE** |
| 1. | researchscientists | Doroshkevich A. S. + 18 people | FLNP | Group leader |  |
|  | Total |  |

**3.2.2. JINR associated personnel**

|  |  |  |  |
| --- | --- | --- | --- |
| **No.** | **Categoryofpersonnel** | **Partnerorganization** | **Amountof FTE** |
| 1. | Researchers / scientists |  |  |
| 2. | Engineers |  |  |
| 3. | Specialists |  |  |
| 4. | Technicians |  |  |
|  | **Total:** |  |  |

**4. Financing**

**4.1. Total estimated cost of the project/LRIP subproject**

The total cost estimate of the project (for the whole period, excluding salary).

The details are given in a separate table below.

615 000 $.

**4.2 Extra funding sources**

Expected funding from partners/customers – a total estimate.

**Project (****LRIP subproject) Leader**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_/DoroshkevichA. S.

Date of submission of the project (LRIP subproject) to the Chief Scientific Secretary: \_\_\_\_\_\_\_\_\_

Date of decision of the laboratory's STC: 10.04.2023, document number: 18

Year of the project (LRIP subproject) start: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

(for extended projects) – Project start year: \_\_\_\_\_\_\_

**Proposed schedule and resource request for the Project / LRIP subproject**

|  |  |  |
| --- | --- | --- |
| **Expenditures, resources,****funding sources** | **Cost (thousands****of US dollars) /****Resource requirements** | **Cost/Resources,****distribution by years** |
| 1st year | 2nd year | 3rd year | 4th year | 5th year |
|  | Internationalcooperation | 30 | 10 | 10 | 10 |  |  |
| Materials | 105 | 15 | 25 | 65 |  |  |
| Equipment, Third-party company services | 320 | 60 | 140 | 120 |  |  |
| Commissioning |  |  |  |  |  |  |
| R&D contracts with other research organizations | 140 | 120 | 10 | 10 |  |  |
| Softwarepurchasing | 20 |  | 20 |  |  |  |
| Design/construction |  |  |  |  |  |  |
| Service costs (*planned in case of direct project affiliation)* |  |  |  |  |  |  |
| **Resourcesrequired** | **Standardhours** | Resources |  |  |  |  |  |  |
| * theamountofFTE,
 | 61308 | 20436 | 20436 | 20436 |  |  |
| * accelerator/installation,
 |  |  |  |  |  |  |
| * reactor
 |  |  |  |  |  |  |
| **Sourcesoffunding** | **JINR Budget** | JINR budget*(budgetitems)**4, 5, 6, 9, 11* | 615 | 205 | 205 | 205 |  |  |
| **Extrafudning (supplementaryestimates)** | Contributions bypartnersFunds under contracts with customersOthersourcesoffunding |  |  |  |  |  |  |

Project (LRIP subproject) Leader \_\_\_\_\_\_\_\_\_/\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_/

Laboratory Economist \_\_\_\_\_\_\_\_\_/\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_/

**APPROVAL SHEET FOR PROJECT / LRIP SUBPROJECT**

TITLE OF THE PROJECT/LRIP SUBPROJECT

**Modernization of the EG-5 accelerator and its experimental infrastructure**

SHORT DESIGNATION OF THE PROJECT / SUBPROJECT OF THE LRIP

**EG-5**

PROJECT/LRIP SUBPROJECT CODE

THEME / LRIP CODE

**«Neutron nuclear physics»**

NAME OF THE PROJECT/ LRIP SUBPROJECT LEADER

**Doroshkevich A.S.**

|  |  |  |  |
| --- | --- | --- | --- |
| AGREED |  |  |  |
| JINR VICE-DIRECTOR | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| CHIEF SCIENTIFIC SECRETARY | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| CHIEF ENGINEER | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| LABORATORY DIRECTOR | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| CHIEF LABORATORY ENGINEER | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| LABORATORY SCIENTIFIC SECRETARYTHEME / LRIP LEADER | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_DATE |  |
| PROJECT / LRIP SUBPROJECT LEADER | \_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| PROJECT / LRIP SUBPROJECT LEADER | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_DATE |  |
| PROJECT / LRIP SUBPROJECT LEADER | \_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| PROJECT LEADER | \_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| APPROVED BY THE PAC | SIGNATURE | NAME | DATE |

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