Appendix 1

Form № 24

PROJECT

MODERNIZATION OF THE EG-5 ACCELERATOR AND ITS EXPERIMENTAL INFRASTRUCTURE

Theme: « Studies of the interaction of neutrons with nuclei and properties of the neutron»
Theme code: : 03-4-1128-2017/2022

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Appendix 2

Form № 25

PROJECT ENDORSEMENT LIST

MODERNIZATION OF THE EG-5 ACCELERATOR AND ITS EXPERIMENTAL INFRASTRUCTURE

THEME: « Studies of the interaction of neutrons with nuclei and properties of the neutron»

THEME CODE: 03-4-1128-2017/2022

		SIGNATURE	DATE
APPROVED BY THE JINR DIRECTOR			«____»_______2020
ENDORSED BY			
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Brief annotation of the project

The project serves to modernize the high-voltage part of the EG-5 electrostatic charged particle accelerator and the joint service systems, develop experimental methods using high-energy particle fluxes to determine the elemental composition of the near-surface layers of solids.

The project aims to carry out a scientific program to study the processes of interaction of high-energy particles with the matter within the framework of the JINR Roadmap and the JINR Problem Thematic Plan (PTP).

Project objectives. The main technical task of the Project is to restore the technological parameters of the EG-5 accelerator: Energy of accelerated particles: 4.1 MeV / core at ion beam current: 50-100 μA; obtaining a neutron flux sufficient for conducting nuclear physics experiments with fast neutrons and an ion beam energy stability sufficient to create a microbeam spectrometer / nuclear microprobe.

The scape of the project includes the creation of industrial infrastructure to be capable to ensure the accelerator operability for 20 years, including the rise of personnel potential, the intensification of international scientific and technical cooperation, the formation of an Expertise Center in the field of electrostatic accelerator technology based on FLNP JINR with formation of associated methodological base.

The actuality of the project is defined due to the prospects of using the facility for the scientific work of FLNP JINR.

The demand for this facility is validated by the spectrum of the scientific and technical activity of FLNP JINR,

In the list is the task to resume research on nuclear reactions with fast neutrons, also the implementation in our experiments the unique option of the EG-5 accelerator - a microbeam spectrometer (nuclear microprobe), as well as for other nuclear physics experiments. Commissioning the accelerator 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 provide the possibility of implementing the user policy at the EG-5 facility.

Ways to solve problems. The group "Accelerator EG-5" was created to resolve listed tasks and achieve the goal of the project. The establishment is a part of The Sector of investigations of neutron-nuclear interactions of the Division of nuclear physics (DNP), including leading specialists in the field of ion-beam methods for studying solids (Dr. A.P. Kobzev, Dr. M. Kulik), development of accelerator technology (prof. V.A. Romanov), highly qualified engineers and technicians also some young employees – university students. Young staff is trained to obtain the skills to work with the facility.

The partnership with specialists from High Voltage Engineering Europa BV serves to replace the high-voltage accelerating HV-tube, an ion source, and quadrupole lens that have lost their performance. The work to be done for getting the required technical parameters of the equipment.

In the course of the project implementation, the accelerator premises will be redecorated and a certain amount of work will be carried out to create a new laboratory for the preparation of research objects.

Round-the-clock run of the facility performs the most effective way to use it for collaboration with partners in the Russian Federation, near and far abroad, and increases the effectiveness of the scientific activity of FLNP JINR.

The estimated cost of the modernization project is $ 471 000 USD. The duration term of the project is 1 year.

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1. Introduction

Justifications of research

Thematic plan of research of the group "Accelerator EG-5" in FLNP (sector of demand for the accelerator EG-5). At the moment, nuclear physics research using electrostatic accelerators is extremely relevant. Up-to-date information on the processes of nuclear transmutation using neutron-induced reactions is extremely important for astrophysics and nuclear power [1].

Of considerable interest are the data on reactions with the emission of charged particles induced by fast neutrons, which are necessary for the study of the mechanisms of nuclear reactions, the structure of atomic nuclei, radiation materials science, and calculations for the creation of new installations for nuclear power.

Modern nanotechnology research extremely needs in Ion-beam spectrometers based on electrostatic accelerators having astronomical accuracy.

Radiation medicine is an extremely promising and vital area of science that also manifests a huge need in the date of high-energy particles with biological objects interaction.

At the same time, microsize ion-beam instruments allow to penetrate of a biological cell and study radiation effects at the microscopic level. As well as to conduct scanning spectroscopic studies of solid-state objects (including microscopic objects, objects of historical heritage) at a microscopic scale and to carry out ion doping of microscopic areas in semiconductor crystals (nanoelectronics and microsystem technology).

At this moment there is a wide range of applied and fundamental scientific problems that are relevant for several sectors of the national economy. Electrostatic accelerators (ESA) have great potential to work in tasks that are associated with nuclear reactions on fast neutrons and with the interaction of high-energy charged particles with living and inanimate matter.

1.1. Scientific program of the FLNP concerning EG-5 accelerator. The authority of JINR (JINR PTP) has formulated three main directions to develop using an electrostatic accelerator**.**

1. Nuclear physics
   (Study of excited nuclei properties, charged particle emission reactions, fission physics, relevant data for astrophysics; nuclear power, nuclear waste transmutation with using neutron and gamma-induced reactions).
2. Condensed matter physics.
3. Applied and methodological research. (Application of neutron physics methods in other fields of science and technology).

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

- research of fast neutron fission: measurements of the prompt fission neutron (PFN) spectra and total kinetic energies (TKE) in reactions $^{235}U(n,f)$, $^{238}U(n,f)$, $^{237}Np(n,f)$, $^{239}Pu(n,f)$ in the range of neutron energies 1-5 MeV/core;

- study of the multiplicity of PFNs in these fast neutron reactions exponentially with high efficiency of PFN registration;

- measurement of the spectra of the reactions charged particles (n, α), (n, p) depended on the neutron energy in the range of up to 5 MeV and higher;

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

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

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

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

- using the TOF technique in a pulsed accelerator mode (f~ 1 MHz, dt~1-10 ns).

Condensed matter physics. Research subjects with the usage of an electrostatic accelerator:

- deep element profiles of near-surface layers of solids (multilayer semiconductor architectures such as TiO_2 / SiO_2 / Si, SiO_2 / TiO_2 / Si, GaAs, etc.);

- processes of structural relaxation of solid surface layers, accompanied by oxidation or hydrogenation (Metallic (Fe, Cu) and metal-oxide (ZrO_2, CuO, ZnO, SnO_2) solid solutions - ceramics, etc.);

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

Researches of biological objects, monitoring of chromosomal aberrations in human blood lymphocytes, in particularly.

Methodology research is for the development of a methodological and experimental infrastructure for carrying out scientific work using controlled electronic technology in the two above mentioned programs.

1.2. Unique facilities of the accelerator. Electrostatic accelerator EG-5, based on the Van de Graaff generator, permanently operates at the DNP of the FLNP since 1965. The relative simplicity and reliability of the design, unique parameters of the accelerated ion beam characteristic of single-stage electrostatic accelerators (high spatial and energy stability at a relatively high current), allow using the EG-5 accelerator as the most efficient and convenient nuclear physics tool for solving a wide range of urgent scientific problems in 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 the irradiation of a tritium target with deuterons (reaction D (d, n) ^{3}He), a wide spectrum of neutrons for nuclear physics research in the energy range up to 20 MeV. The list of the most urgent problems of modern nuclear physics (Nuclear Data High Priority Request List (Table 1) named this energy range is the most in-demand in modern nuclear physics research.

Table 1.

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

ID	View	Target	Reaction	Quantity	Energy range	Sec.E/Angle	Accuracy	Cov	Field	Date
2H		8-O-16	(n,a),(n,abs)	SIG	2 MeV-20 MeV		See details	Y	Fission	12-SEP-08
3H		94-PU-239	(n,f)	prompt g	Thermal-Fast	Eg=0-10MeV	7.5	Y	Fission	12-MAY-06
4H		92-U-235	(n,f)	prompt g	Thermal-Fast	Eg=0-10MeV	7.5	Y	Fission	12-MAY-06
8H		1-H-2	(n,el)	DA/DE	0.1 MeV-1 MeV	0-180 Deg	5	Y	Fission	16-APR-07
15H		95-AM-241	(n,g),(n,tot)	SIG	Thermal-Fast		See details		Fission	10-SEP-08
18H		92-U-238	(n,inl)	SIG	65 keV-20 MeV	Emis spec.	See details	Y	Fission	11-SEP-08
19H		94-PU-238	(n,f)	SIG	9 keV-6 MeV		See details	Y	Fission	11-SEP-08
21H		95-AM-241	(n,f)	SIG	180 keV-20 MeV		See details	Y	Fission	11-SEP-08
22H		95-AM-242M	(n,f)	SIG	0.5 keV-6 MeV		See details	Y	Fission	11-SEP-08
25H		96-CM-244	(n,f)	SIG	65 keV-6 MeV		See details	Y	Fission	12-SEP-08
27H		96-CM-245	(n,f)	SIG	0.5 keV-6 MeV		See details	Y	Fission	12-SEP-08
29H		11-NA-23	(n,inl)	SIG	0.5 MeV-1.3 MeV	Emis spec.	See details	Y	Fission	12-SEP-08
32H		94-PU-239	(n,g)	SIG	0.1 eV-1.35 MeV		See details	Y	Fission	12-SEP-08
33H		94-PU-241	(n,g)	SIG	0.1 eV-1.35 MeV		See details	Y	Fission	12-SEP-08
34H		26-FE-56	(n,inl)	SIG	0.5 MeV-20 MeV	Emis spec.	See details	Y	Fission	12-SEP-08
35H		94-PU-241	(n,f)	SIG	0.5 eV-1.35 MeV		See details	Y	Fission	12-SEP-08
37H		94-PU-240	(n,f)	SIG	0.5 keV-5 MeV		See details	Y	Fission	15-SEP-08
38H		94-PU-240	(n,f)	nubar	200 keV-2 MeV		See details	Y	Fission	15-SEP-08
39H		94-PU-242	(n,f)	SIG	200 keV-20 MeV		See details	Y	Fission	15-SEP-08
41H		82-PB-206	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y	Fission	15-SEP-08
42H		82-PB-207	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y	Fission	15-SEP-08
45H		19-K-39	(n,p),(n,np)	SIG	10 MeV-20 MeV		10	Y	Fusion	11-JUL-17
97H		24-CR-50	(n,g)	SIG	1 keV-100 keV		8-10	Y	Fission	05-FEB-18
98H		24-CR-53	(n,g)	SIG	1 keV-100 keV		8-10	Y	Fission	05-FEB-18
99H		94-PU-239	(n,f)	nubar	Thermal-5 eV		1	Y	Fission	12-APR-18
102H		64-GD-155	(n,g),(n,tot)	SIG	Thermal-100 eV		4	Y	Fission	09-MAY-18
103H		64-GD-157	(n,g),(n,tot)	SIG	Thermal-100 eV		4	Y	Fission	09-MAY-18
114H		83-BI-209	(n,g)Bi-210g,m	BR	500 eV-300 keV		10	Y	ADS,Fission	09-NOV-18
115H		94-PU-239	(n,tot)	SIG	Thermal-5 eV		1	Y	Fission	08-APR-19

It should be noted that these problems are difficult and expensive to solve with other types of neutron facilities.

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

The most performed property of a single-stage accelerator is the high energy stability (over 0.01%) of the ion beam, which makes it possible to study 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 the EG-5 accelerator with a beam size of fewer than 1 μm. The beams of these characteristics cannot be obtained, for example, at the now popular charge-exchange accelerators - tandetrons.

The microbeam spectrometer (it was manufactured at the Institute of Applied Physics of the National Academy of Sciences of Ukraine (Sumy, Ukraine) which is in operations in the Russian Federation now is located in Sarov and for obvious reasons is difficult to access for most users.

Energy stability, produced by the equipment, appeared by the absence of a charge-exchange target is an important factor for achieving high resolution in studies of thin surface layers. The development of nanotechnology and applications of nuclear power shows that the range of applied research problems for electrostatic accelerator complexes of the EG-5 type is expanding daily. The ion-beam microbeam with a diameter of about 1μm significantly expands the capabilities of the nuclear-physical methods of the FLNP JINR in the field of natural sciences. It's indispensable in solving problems of nanophysics and bionanotechnology.

Thereby, the accelerator EG-5 – a kind of equipment of unique potential to serve for modern scientific researches of JINR, to run nuclear physics experiments, nuclear astrophysics (stellar nucleosynthesis) [3] and bionanotechnology as it was designated in the JINR PTP).

1.3. Problems of the project realization have an organizational and technical character and is associated with physical deterioration of the main units and systems of the installation, obsolescence of the scientific and experimental base, the loss of cooperation ties, and a general decrease in the efficiency of the work of the group providing scientific support for accelerator topics at FLNP JINR.

At the moment the technical problem is the physical deterioration of the main units and systems of the installation and the obsolescence of the scientific and experimental base. The decrease of performance in power of the accelerator (the beam current decreased from 50 μA to 100 nA) caused impossibility to use it for works that are currently unique at JINR and in the Russian Federation such as generating neutrons, studying nuclear reactions, and developing a microbeam spectrometer based on it

It should be noted that the problem of obsolescence and shutdown of accelerators over the past 30 years in the Russian Federation had a systemic character. In the period from 1990 to 2014, the number of accelerators decreased from 27 to 12-15 units. The development and production of accelerators in the Russian Federation practically ceased (except for Sarov), while the leading positions in the production of accelerators have been assigned to the United States.

The implementation of the Modernization Project EG-5 accelerator called up to solve this technical problem, providing concentration of resources for updating the accelerator and reactor base of the Institute [4], following the Concept of the Seven-Year Development Plan of JINR for 2017–2023

1.4. Project objectives and the way to solve them.

Task 1. The main technical objective of the project is to achieve technological parameters with the EG-5 accelerator: the terminal voltage is 4.1 MV at a beam current of up to 100 μA (Task 1).

As a subtask of 1.1, it should be done the repairing of the premises in which systems of the accelerator complex are located (accelerator's hall, the right, and the left experimental halls). Air conditioning and a sufficiently high level of cleanliness in the premises (at least ISO-9 class), will ensure to increase the terminal voltage and the energy of the accelerated particles by about 20%.

Subtask 1.2. includes a comprehensive check, cleaning, and repair of high-voltage structure elements and equipment providing high terminal voltage.

Subtask 1.3. supposed to provide an appropriate level of safety for the employees.

Task 2. An equally important task is the development of the experimental infrastructure of the accelerator complex to maximize it's production potential, scientific effectiveness of research, and expand the field of applicability of the available research methods **(Task 2)**.

Subtask 2.1. is the checking of the operability and bringing to the proper functional state of all units and systems of the accelerator.

Subtask 2.2. is the automation and modernization of functional units and service systems of the accelerator. The accomplishment of this task is dictated by the need to increase the degree of control and retention of the beam parameters. The planned microbeam spectrometer requires a high degree of energy stabilization as well as spatial stabilization of the beam, which requires the automation of the beam positioning system with precision accuracy.

RBS–camera. The equipment currently used for studying the elemental composition of materials was developed and manufactured over 50 years ago. It is morally outdated. Modern ion-beam spectrometric measuring systems have a significantly higher performance. Replacement of outdated spectrometers (RBS, ERD, NRA, and PIXE methods) with a new modern multifunctional analytical module RC43, manufactured by NEC (subtask 2.3.) allows increasing the efficiency of object research and the yield of scientific products.

The purchase deal of the RC43 module from NEC is under consideration at the current moment. This module will increase the number of spectrometers in the chamber, expand the working range and resolution of the RBS spectrometer, fully automate the process of sampling and data processing, and make the transition to modern standards and data formats.

Sample manufacturing laboratory. It is planned to install a new laboratory for the formation of monolithic objects from powder materials (subtask 2.4.). The laboratory is designed to carry out work on the preparation of experimental samples in the form of monolithic objects, thin and thick films of a wide range of solid materials, including powder materials, for research by nuclear-physical methods of RBS, ERD, and PIXE. The new laboratory will be stuffed with facilities (methods) to complementary nuclear-physical research methods (subtask 2.5.), such as 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 equipment of the laboratory will allow on-site correction and preparation of samples, independent research joined with research methods of EG-5.

Task 3 (staff) implies the laying of personnel potential, which will ensure the autonomous operation of the accelerator for the production of scientific products in the future 20 - 30 years. It is planned a staff training of ion-beam methods for studying materials and servicing the accelerator (subtask 3.1.), hiring students of local universities with good academic performance, highly qualified professionals in accelerator technology, organizing conferences and symposia at the international level based on FLNP JINR, establishing a training center for qualifications in the field of accelerator technology and associated experimental techniques (subtask 3.2).

2. Expected results

As a result of the project, the technical parameters of the accelerator will be restored (the energy of accelerated particles is 4.1 MeV at a current of 100 µA, Table 2.), which will allow to study reactions with fast neutrons at JINR and provide technical conditions for installing a microbeam spectrometer. The list of the main capabilities of the accelerator complex after the implementation of 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 the upgrade are shown in Table 2.

Table 2.

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

Before modernization	**After modernization**
Terminal voltage - 2,1 MV Beam current – 100nA Ion Energy – 2,9 MeV	Terminal voltage - 4,1 MV Beam current – 50-100mkA Ion Energy – 4,1 MeV
- Nuclear physics experiments conducting is **not possible**, - NRA (3,1 MeV) - **not possible**	- Nuclear physics experiments conducting is **possible**, - NRA (3,1 MeV) - **possible**
Microbeam option installing – **not possible**	Microbeam option installing – **possible**;
Work with biological objects - **not possible**	Work with biological objects – **possible**

Table 3.

Capabilities of the accelerator complex before and after the modernization project.

Before modernization	**After modernization**
- 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.**	Microbeam option installing – **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).	The performance of EG-5 spectrometers: **- 32** samples / per day, **Methods:** 1-3. RBS, ERD, PIXE 4. Nuclear Reaction Analysis (NRA); 5. Proton Induced Gamma Emission (PIGE); 6. Ion Beam Induced Luminescence (IBIL); 7. High-resolution (HR RBS).

A new modern high-performance ion-beam research module RC43 from NEC with advanced capabilities (High-resolution - HR RBS), (Nuclear Reaction Analysis NRA), methods for analyzing the spectra of ion beam-induced gamma radiation (Proton Induced Gamma Emission - PIGE) and luminescence (Ion Beam Induced Luminescence -IBIL) will be installed.

New specialized laboratory for the preparation of research objects, equipped with complementary methods for studying the optical and electronic properties of the surface, such as ellipsometry, optical and electron microscopy, methods for studying electrical properties on constant and variable current (voltammetry and impedance spectrometry) will be established in the frame of the project as well.

In addition to the modernization and expansion of the instrumentation base of the accelerator complex, the development of employee potential will be provided for the next 20-30 years.

Modernization of EG-5 accelerator at JINR, stuffed highly qualified professionals, provided with detecting equipment of quality and valuable scientific results in the neutron study of atomic nuclei, provide conditions for new, unique experiments on measuring energy spectra and angular distributions of charged particles from the reactions (n, α) and (n, p) / (α, n) and (p, n) and the integral and differential cross-sections of the latter in the neutron energy range up to ~ 20 MeV, fission processes of atomic nuclei by fast neutrons, activation analysis [5, 6], etc.

3. Research state on the announced scientific problem

3.1. Existing scientific groundwork. The EG-5 accelerator was used to measure the neutron yield from solid-state and gas targets obtained in the reaction D(d, n)^{3}He; the calibration of the neutron monitor was performed, which is necessary to measure the absolute neutron flux in experiments; a charged particle spectrometer based on an ionization chamber with a grid and an electronics module for registration, accumulation and primary processing of data based on PIXIE-4 and PIXIE-16 was created. The EG-5 accelerator was used for testing a charged particle spectrometer based on an ionization chamber with a grid and an electronics module (PIXIE-4 and PIXIE-16) for registration, accumulation, and primary processing of nuclear data for measurements at the HV-2500 accelerator in the Institute of Experimental and Applied Physics, Czech Technical University (Prague, Czech).

The EG-5 properties are joint with the development of experimental nuclear physics at JINR (d,d - reactions, neutron - charged particle reactions, the study of the passage of nuclear radiation through various media, calibration of neutron detectors, etc.), radiobiology (monitoring of chromosomal aberrations in human blood lymphocytes, etc.), radiation materials science (interaction of nuclear radiation with matter, comprehensive studies of the radiation resistance of materials and products for various purposes, research of materials for nuclear reactors, radiation doping of semiconductor materials), condensed matter physics (the study of the elemental and isotopic composition, elemental depth profiles of the near-surface layer of materials), etc.

Accelerator repair, work performed. To solve Task 1, the FLNP management carried out several measures (of a consulting nature) aimed to identify the causes of the accelerator's loss of performance and ways to eliminate the identified technical problems. Group of experts commissioned by FLNP from the Institute of Applied Physics of the National Academy of Sciences of Ukraine (Sumy, Ukraine), specializing in the development of accelerator technology under the guidance of prof. A.G. Ponomarev carried out the scientific and technical research "Analysis of the technical condition and measurement of the parameters of the electrostatic accelerator EG-5, FLNP JINR". The main reasons for the decrease in the efficiency of the accelerator was detected. Thereby, the leading expert in the field of ESA prof. V.A. Romanov (at the moment - advisor to the FLNP director) run, independently, a study of the operating modes and technical condition of the main components of the accelerator at the site. 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) performed design and computational work on the microprobe channel (The well-established term Nuclear microprobe) based on the EG-5 accelerator of the FLNP JINR. FLNP holds the complete pack of design documentation.

Group "Accelerator EG-5". To solve the tasks set in the project, a separate group " Accelerator EG-5" was established as part of the Sector of investigations of neutron-nuclear interactions of the DNF in September 2019, which is include a leading scientists - profile specialists (Dr. A.P. Kobzev, Dr. M. Kulik), high-class engineers and technicians (A.N. Likhachev, Tkachenko S.V., Kudryavtsev V.P., Zaitsev I.A.) and young employees - students and postgraduates of the Dubna State University (9 persons). Employees are being trained in the peculiarities of the operation of the accelerator complex instruments, they attend weekly lectures - seminars (M. Kulik) and individual practical lessons on the RBS method (M. Kulik, A.P. Kobzev) till now as well as investigate technical principles of the accelerator and its service systems (A.N. Likhachev). Students actively participate in scientific conferences at various levels, take leading positions at university Olympiads and conferences. The leading specialist in the development of accelerator technology prof. A.V. Romanov runs work to increase the level of the group's competence in technical matters. The technical part of the group is strengthened by the arrival of two young employees to the positions of a leading engineer and a laboratory assistant with a corresponding distribution of vacant labor functions.

International scientific and technical cooperation. As of 2020, within the framework of theme No. 03-4-1128-2017 / 2022, a 9 research projects have been won within the framework of joint works of JINR - participating country:

1. Project "Synthesis, Structure and Magnetic Properties of Tin Dioxide Films Containing Clusters of Magnetic Metals", BSU, 2020, (JINR - 2020; BSU) Order №246 / 2020 p.23.
2. Project «The study by DLS and RBS methods of structures and elemental composition of surface layer of nanoparticles ZrO_2 under hydration conditions», Project, JINR – Romania - 2020, Order №268 / 20.05.2020, p.57, "UNIVERSITY "LUCIAN BLAGA" of SIBIU.
3. Project «Development and characterization of magnetic nanostructured systems for targeted cancer therapy by means of Nuclear Physical Methods», National Centre for Nano and Micromaterials. Project JINR– Romania - 2020, Order № 268 / 20.05.2020, p.63, University POLITEHNICA of Bucharest.

4. Project «Investigation of the properties of deposited on different plastic substrates organic thin films after high-energy ion and neutron irradiation», Project, JINR -Romania - 2020, Order № 268 / 20.05.2020, p.59, "National Institute for Materials Physics (NIMP), Bucharest-Magurele.
5. Project "Formation of transition layers in ceramics SiC by ion implantation and study of the distribution of implanted ions in depth. Study of the effect of ion implantation on the elemental composition and optical properties of multilayer dielectric structures on semiconductor substrates" Project, JINR - Republic of Poland - 2020, Order №75 from 03.02.2020, p.31, Institute of Physics" of UMKS, Lublin.
6. Project «The relationship among features of crystal and magnetic structures and physical properties of nanosized ferrites», Project, JINR-Romania - 2020, Order № 268 / 20.05/2020, p.58, "National Institute of Research and Development for Technical Physics (NIRDTP)" - IFT, Iasi.
7. Protocol No. 4890 4-20/22 JINR-CTU, Prague "Research and development to study the reactions induced by fast and thermal neutrons with the yield of charged particles".
8. Protocol 15.03.2005 JINR-PU, Beijing, China "Studies on the mechanism of interaction of neutrons with nuclei and on the properties of high excited nuclear states".
9. Agreement 11.11.2019 No. 313/1670-D "Experimental studies of the cross section of the reaction (n, α) on several isotopes for the national library of nuclear physical data "BROND".

3.2. Description of the current state of the scientific-technological problem. Unfortunately, at the moment in the Russian Federation and the JINR member countries, there are only one microbeam spectrometer in Sarov [7] and no more than five operating accelerators suitable for the production of fast neutrons [8], which is significantly limits research opportunities in the field of modern radiation biology, medicine, condensed matter physics and physics of the atomic nucleus.

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 $^{22}Ne(\alpha,n)$ ^{25}Mg were obtained by a group led by Professor Yu.M. Gledenov at a similar accelerator at Peking University [9]. Over the past three years, our group on fast neutrons measured sections (n, α) reactions for elements ^{144}Sm, ^{66}Zn, ^{10}B, ^{25}Mg, ^{54,56} Fe, $^{58, 60, 61}Ni$ 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 (^{6}Li, ^{14}N, ^{35}Cl, ^{91}Zr, and ^{56}Fe).

Ion-ray 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 / core. Studies of multilayer high-temperature superconducting systems are underway [10]. Besides, work is actively underway to study the processes of ion implantation of the surface of solids

(GaAs, layered structures TiO_2 / SiO_2 / Si, SiO_2 / TiO_2 / Si) ions N^{2+}, Ar^+, Xe^+, Bi^+, N^{2+}, Al^+, In^+ and induced by irradiation and subsequent thermal annealing (at temperatures: 500 ° C, 700 ° C and 900 ° C) structural relaxation processes [11, 12], accompanied by oxidation [13, 14] or hydrogenation [15] 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 an accelerator EG-5 at a distance of 1 cm from the output, carried in May 2018 showed unsatisfactory flounce for working with biological objects. At a beam current of 0.1 μA / h, 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 / h, the neutron energy of $E_{neutrons}$ is ~ 5MeV / nucleus).

On the verge of disruption of work on RBS, ERD, PIXE spectrometers due to the loss of beam stability: the accelerator operates in limiting (minimal) modes, far from nominal modes, which increases the processes of spatial instability of the ion beam.

3.3. Variety of decisions to be implemented for achieving the goals of the project. The objective of the project can be achieved by acquiring a new accelerator.

Comparative analysis of technical parameters of EG-5 and new accelerators of the same class. There is difficulty to compare from the physical point of view, the tasks of obtaining a high energy of the beam for the generation of fast neutrons and its good focusing (up to 0.1 mm), which is necessary for the operation of a microbeam spectrometer, difficult to match when designing with the use of a single accelerator device. It is required to obtain both a large beam current and a small energy spread, which are usually mutually exclusive parameters.

In particular, in modern accelerators, the recharging principle proposed by W. X. Bennett (USA) in 1935 is used to increase the energy of accelerated particles reducing mass and size characteristics and cheaper the design of accelerators [16]. The use of recharging allows at the same generator voltage to double the proton energy and the energy of heavier particles by several times. So-called tandem systems are able to "accelerate" to high energies a wide range of chemical elements, including Au, Cu, Ni, etc., but such systems, in principle, cannot form the narrow-directional beam (less than 20 µm) required to creating a microbeam spectrometer. For such a task is the better-suited powerful single-stage electrostatic accelerator, for example, EG-5 accelerator or Singletron (HVE) with a relatively high (above 4MV) terminal voltage. Such accelerators are capable of forming narrow-directional beams at a maximum beam current of up to 100 µA. Thus, a compromise is achieved between the subtasks of the installation of a microbeam spectrometer and neutron generation. The new accelerators are fully automated and more functional, in particular, they allow pulse mode, quickly switch to various modes in voltages and power. Table 4 shows the electrical limits and functionality of the EG-5 class instruments recommended for acquisition by NEC and HV Europe BV. From Table 4, it follows that the most suitable devices for solving task 1 (in terms of technical parameters) are the Singletron EG-5 and accelerator Singletron manufactured by HV Europe BV with maximum terminal voltage 3,5MV or 5MV. It can be seen that along with the accelerator EG-5, singletrons with a maximum voltage of up to 5-6MV are suitable for their technical capabilities. Increasing the energy above the limit for EG-5 (4.1MeV) will expand the available range of fast neutron energies.

Price policy of accelerator manufacturers. The price of accelerating technology ranges from $ 1bn (1GeV, European Spallation Source (ESS) [17]) to $ 1mln (Pelletron 6SDH, NEC). In its niche of compact, cheap in construction and in operation systems that allow generating beams of charged and secondary neutral particles, as well as causing nuclear reactions, electrostatic accelerators of type EG-5 have the lowest cost. The price of accelerators with the energy of accelerated particles 3-5MeV (linear electrostatic accelerators of the Van de Graaf type, Tandetrons, etc.) is on average within 1- $10mn. For a rough estimate of the cost of the new accelerator C, the formula is applicable:

$$C = \$1000xV, \qquad (1)$$

where V is the maximum energy of the accelerated particles.
Accordingly (1), the estimated cost of the new EG-5 class accelerator will be about $4-5mn.

Table 4.

The limits of technical parameters and functionality of the upgraded EG - 5 accelerator and the closest analogues offered by NEC and HVE.

EG-5 after modernization	**Singletron (HVE)**	**Tandetron** 4130) (**HVE**)	**Pelletron** 6SDH (**NEC**)
Terminal voltage - **4,1 MV** Beam current – **50-100mkA** Ion beam energies: **$1H^+$ - 4.1 MeV** Terminal voltage stability **±400V**; Pulsed mode: **missing**; The ability of accelerating heavy ions: **missing;** The ability of accelerating negative ions: **missing.**	Terminal voltage - **5.0 MV** Beam ion current – **100mkA** (Short bottle RF ion source): **$1H^+$– - 5.0 MeV** Terminal voltage stability **±500V**; Pulsed mode: **present;** The ability of accelerating heavy ions: **present;** The ability of accelerating negative ions: **missing.**	Terminal voltage - **3,3 MV** Beam ion current - **50mкA** Ion beam energies: **$1H^+$ –** 6**.6 MeV** Terminal voltage stability **±300V**; Pulsed mode: **present;** The ability of accelerating heavy ions: **present;** The ability of accelerating negative ions: **present.**	Terminal voltage - **2 MV** Beam ion current– **50mkA** Ion beam energies: **$1H^+$ – - 4.0 MeV** Terminal voltage stability: **± *200;V*** Pulsed mode: **present;** The ability of accelerating heavy ions: **present;** The ability of accelerating negative ions: **present.**;
Nuclear physics experiments - **possible;** Microbeam – **1mkm;** NRA (3,1 MeV) **- possible.**	Nuclear physics experiments - **possible;** Microbeam – **1mkm;** NRA **- possible.**	Nuclear physics experiments - **possible;** Microbeam – **20mkm;** NRA **- possible.**	Nuclear physics experiments - **possible;** Microbeam – **20mkm;** NRA **- possible.**.
Work with biological objects – **possible.**	Work with biological objects – **possible.**	Work with biological objects – **possible.**	Work with biological objects – **possible.**
Cost: $ **0,6 mln**	Cost: $ **4- 5mln***	Cost: **4,3 mln**	Cost: **1 mln**

* The estimated cost is calculated according to formula 1. The firm did not provide a commercial offer.

3.4. Short SWOT - Case Analysis with purchase of new accelerator

Strengths of the option with the purchase of a new accelerator. The new accelerator has a number of new possibilities; in particular, it has the option of automatically stabilizing the geometric position of the beam. This option is especially necessary for a microbeam spectrometer.

The accelerator may be equipped optionally with an ion source capable of injecting heavy ions.

The new device has significantly smaller size than the EG - 5, requires smaller number of personnel.

When buying a new accelerator, the risks of incompatibility of the new HV-tube with service systems of EG-5, etc. is absent.

The new device consists of new parts and units that have an unused life and, therefore, a lower probability of failures than in the EG-5.

The manufacturer company is supposed to remotely advise the accelerator maintenance personnel in troubleshooting and monitor the accelerator condition throughout the life of the accelerator.

An increase of beam energy (up to 6 MeV) compared to available in EG-5, will allow expanding the range of nuclear-physical research

A new accelerator will be installed in specially constructed room. The main properties of the room will be provided for the suppression of reflected neutron fluxes, which will increase the accuracy and safety of experiments with fast neutrons.

Weaknesses of the option with the purchase of a new accelerator. The new device consists of sophisticated high-tech elements that cannot be repaired by EG-5 technical personnel. It makes FLNP dependent on the manufacturer and its service centers. As an option, NEC offers branded service of the device at least 10-20 thousand dollars per year. It can be assumed that approximately the same amount will be required annually on average for the maintenance of the accelerator with the involvement of specialists from the service centers of manufacturers.

In the Russian Federation, there are no base of components and consumables necessary for the repair of removable defects. Parts will have to be ordered from the manufacturer. The supply can be affected by the political situation in the world. The manufacturer produce the parts for old models no more than 20 years, after which parts cannot be found or it’s manufacturing is ordered for a lot of money.

The new accelerator has a horizontal design, which will lead to major redesigns of the premises of EG-5 (if it is installed in place of EG-5) and a significant increase the cost of repairing and construction work.

Unlike EG-5, the new device is critical to temperature, humidity, and cleanliness of the air, which will require the purchase of a powerful air conditioner and organization of a "clean" room, and consequently, additional costs.

3.5. Justification of the project, description of problems that remain unsolved in the framework of ongoing research. The ion accelerator has been in operation since 1965 and needs to be modernized. In addition, in terms of the development of analytical methods, it is necessary to the creation of a microbeam spectrometry technique, which will make it possible to study not only deep profiles of elements in the surface layer of solid objects but also scanning of a surfaces with high resolution (commensurate with the size of the ion beam). A new analytical technique should be based on an already modernized accelerator. There is no a current methodology in Russian Federation yet.

In addition, after the modernization of the EG-5 accelerator, the high-energy charged particle beam will satisfy the conditions for carrying out experimental work in the field of nuclear physics including:

- study of PFN and TKE in the reactions ^{235}U (n, f), ^{238}U (n, f), ^{237}Np (n, f) in the neutron energy range1-5 MeV / nucleus (EG-5) in geometry with low efficiency of PNF registration;
- investigation of the multiplicity of PFN in the reactions ^{235}U (n, f), ^{238}U (n, f), ^{237}Np (n, f) on fast neutrons in geometry with a high detection efficiency of PFN.

It should be noted that the study of nuclear reactions with ^{237}Np (n, f) is extremely important for the development of a new nuclear reactor that will replace the IBR-2.

- Investigation of the counting characteristics of the fission chamber in the current and noise (Kampbell) modes in applications to the measurement of the neutron lifetime on the IBR2, IREN, EG-5 beams;

The Method of activation analysis, as one of the possible promising new methods, can be developed after upgrading the accelerator.

Investigation of the biological effectiveness of radiation with different physical characteristics is the main task of the Laboratory of radiobiology (LRB) JINR. Chromosomal aberrations as a result of unrepaired or improperly repaired DNA damage - are the best indicator of the absorbed dose of radiation. Monitoring of chromosome aberrations in blood lymphocytes of human is practically the only reliable method of human biodosimetry and accelerator EG - 5 with an energy range up to 20 MeV/core is the best source of accelerated charged particles.

The use of the microbeam spectrometer planned for installation on the EG-5 accelerator will allow to make a significant progress in the development of new functional materials, devices, and technologies for a number of areas of the national economy, including high-tech healthcare technologies, functional food production technologies included in the list of priority tasks of scientific and technological development of the

Russian Federation [18].

Several new possibilities for studying the effect of irradiation by fluxes of accelerated particles biological objects, solids, and functional structures based on them are opened after modernization of the accelerator.

Prospects for interaction with new scientific groups from the Russian Federation, countries of near and far foreign countries will be opened after the upgrade of the Accelerator. Thereby, Polish colleagues from the University of Szczecin are interested in neutron fluxes with energies of 0.1-15 MeV / nucleus, providing a maximum dose rise time of 0.1-2 Gy, no more than 2 hours. There is interest in working with EG - 5 colleagues from the University of Lisbon (i3N / CENIMAT, Department of Materials Science, Faculty of Science and Technology, New University of Lisbon and CEMOP / UNINOVA, Portugal), Romania (National Institute for Research and Development of Isotopic and Molecular Technologies, Cluj-Napoca, Romania) and other. A colleagues from Vietnam, Azerbaijan, Ukraine are currently working in the group "Accelerator EG-5", (respectively from the Donetsk Institute for Physics and Engineering named after A.A. Galkin of the National Academy of Sciences of Ukraine, Kyiv, Ukraine; National Nuclear Research Center CJSC, Baku, Azerbaijan; etc.).

At the EG-5 accelerator, it is planned to work with the Dubna State University to study the elemental composition of thin-film kesterite photoelectronic converters, with the Belarusian State University - collaborate on the study of new semiconductor structures, able to work in conditions of strong radiation, Bulgarian colleagues (Institute Nuclear Research and Nuclear Power Engineering INRNE BAS, Institute of Solid State Physics BAS) on the research of radiation-resistant materials, Donetsk Republican University, Laboratory of Radiation Biology, colleagues from FLNP, etc. Thus, the Use capabilities of the existing accelerator EG-5 in the infrastructure of FLNP JINR will significantly effectiveness and increase the number of international cooperative scientific contacts which are strengthen a JINR's position in the international scientific community.

4. Description of the proposed study / Description of work progress

Based on the expert assessment of the state of the accelerator, prof. V.A. Romanov, and data from the report of prof. A.G. Ponomarev (Sumy, Ukraine) on scientific and technical work "Analysis of the technical condition and measurement of the parameters of the electrostatic accelerator EG-5, FLNP JINR" the following activities in the process of implementing the Modernization project will performing.

4.1. Stages of work (in chronological order)

1. Taking measures to improve the safety of work with the accelerator.
    - 1.1 Painting the ion guide in bright paint.
    - 1.2 Installation of protection and signaling of potentially dangerous places in the Accelerator hall.
    - 1.3 Installation of fences around open technological windows on a removable repair accelerator site.

2. Taking measures to increase the electrical strength of the accelerator gas media, including indoor air.
    - 2.1. Repair and bringing the accelerator service premises into compliance with sanitary norms ensuring of the "Clean zone" (ISO-9) mode.
    - 2.2. Installation of inlet filters from oil to the dielectric gas preparation system.
    - 2.3. Adding SF6 gas to the nitrogen gas mixture.
    - 2.4. Installation of a gas supply system with atomic drying. Reaching the dehumidification limit 60%.
    - 2.5. Eliminate leaks in the cylinders / isolating gas system.
    - 2.6. Manufacturing and installation of a nitrogen trap sample in front of the chamber for capturing oil vapor from the system.
    - 2.7. Transition to turbomolecular sediments.
    - 2.8. Compressor repair / replacement of gas compressor equipment for obtaining and dehumidification of nitrogen, renewal of cylinders.
    - 2.9. Installation of an SF6 gas processing and storage system.

3. Checking the performance of all accelerator systems, eliminating factors that worsen the quality of the installation (reducing the limiting voltage and beam current, increasing energy spread), carrying out preparatory measures to replace the high-voltage accelerating HV-tube.
    - 3.1. Repair of floors, elimination of tilt of the analyzer magnet. Deviation compensation beam

from the horizontal with permanent magnets.

3.2. Checking the alignment of the stone of the magnetic analyzer with the ion guide.

3.3. Checking the shape of the beam at the entrance and exit of the accelerating HV-tube.

3.4. Manufacturing and installation of a focusing quadrupole lens to increase the efficiency of beam transmission after the measuring magnet.

3.5. Cleaning the surface of the high voltage terminal (corona triode area), high-voltage column insulators (gradient rings) with solvent and hydrofluoric acid (to obtain the lowest recombination coefficient H^+).

3.6. Cleaning the charging tape.

3.7. Smoothing the transition from a small diameter of the column screen to a large one for leveling the field gradient and eliminating breakdowns.

3.8. Strengthening the insulation of the springs holding the HV-tube in the column (by Teflon pipes).

3.9. Adjustment (strictly in one plane) and partial replacement of needles in the corona triode.

3.10. Adjustment of the gap on the discharge brushes.

3.11. Changing the configuration of the recharge brushes: separating the monolithic plates into three sections to reduce tape pressure and tape wear.

3.12. Annealing and polishing of the diaphragm that forms and aligns the ion beam.

3.13. Revision of divider resistors nominal values changed during operation. Replacement of resistors in the compensating section (5 sections after the section with straight fields).

3.14. Training the source with high voltage to get a good current.

3.15. Installation of an external slit size control system, a dynator ring for suppressing secondary electrons, and forced cooling in the beam energy stabilization system.

3.16. Optimization of the geometry of the ion source induction coil.

3.17. Matching the ion optics of the ion source to match the beam parameters at the HV-tube outlet.

4. Replacement of the accelerating HV-tube in cooperation with the specialists of “High Voltage Engineering Europa B.V.”.

    4.1. Testing, insertion the accelerator into normal operation.

5. Repairs in the experimental halls.

    5.1. Cosmetic repairs in the left experimental halls.

    5.2. Installing a passive vibration damping system (slabs - bases for microbeam spectrometer on a sand cushion, mechanically decoupled from the floor in the spectrometer hall).

    5.3. Sealing with plasterboard the technological passage between the halls, filled with concrete blocks (biological protection).

6. Installation of a reinforced concrete frame of the laboratory for the preparation of objects for research ion-beam methods.

7. Development, manufacture, and installation of a new high-performance chamber for ion-beam materials research (RBS, ERD, PIXE).

8. Modernization of service equipment. Automation of accelerator units, which are extremely important for the implementation of the functions of a microbeam spectrometer and a generator of quasi-monoenergetic neutron generator.

    8.1. Automation of the system of spatial stabilization of the beam position.

    8.2. Replacement of obsolete devices on the Control Panel.

9. Training of personnel for work on the installation from among young employees, intensification international cooperation, organization of user program.

10. Staffing the experimental infrastructure with complementary research methods surface layers of materials (electrical, electronic, and optical properties).

Other activities

11. Restoration of technical documentation for the accelerating HV-tube.

12. Preparation and signing of documents for the inclusion of the accelerator in the list of SES.

Additional activities (implementation if it will be possible)

13. Making an additional vacuum inlet in the upper part of the vessel with an accelerating HV-tube (differential pumping of the column).
14. Installation of a laboratory for preparing objects for research by ion-beam methods (finishing works, installation of communications and equipment).
15. Purchase and installation of an ion-beam module RC43 manufactured by NEC.
16. Installation of a breeding and homogenization system for a 200mm diameter beam (purchase from "High Voltage Engineering Europa B.V.".
17. Installation of the beam coordinate control system with documentary fixation.
18. Purchase of a set of spare belts (in Yaroslavl, RF).
19. Organization of an experimental site for the manufacture and testing of high-voltage tubes. Retrofitting of the section for gluing the HV-tube, preparation of the box for gluing the HV-tube for the corresponding work.
20. Manufacturing of an ultra-stable ion source with an energy spread of less than 10 eV using available domestic developments. Consideration of the possibility of application Penning source for operation in the neutron generator mode, which allows to obtain a beam ions He^{2+}, which will increase the energy of the beam by 2 times.
21. Replacement of PVA in the glue joints of the HV-tube with less evaporating glue.
22. Replacement of obsolete HV-tube vacuum gauges with semiconductor analogs.
23. Installation of remotely controlled monitors for monitoring the beam shape and current (cylinder Faraday), quartz screen with beam position fixation, video camera with the ability to visual observation of the image and the position of the beam on the control panel.
24. Transition to remotely controlled vacuum valves in order to ensure emergency cutting off the accelerating HV-tube (in automatic mode) in the event of a leak in ion ducts.
25. Checking the pressure vessel and all ESU systems.
26. Replacement of power supply cables and the accelerator control system due to the end of operation resource.
27. It is recommended to replace the flow system in the power supply of the analyzing magnet cooling stationary closed cycle system.
28. Development of an action plan (sequence of actions) according to the nuclear microprobe based on the EG-5 accelerator, FLNP JINR, 2015, performed by the staff of the Institute of Applied Physics of the National Academy of Sciences of Ukraine.
29. Ordering the main units of the installation in the FLNP workshops according to the design documentation for channel fabrication at FLNP.
30. Organization of the pit in the right experimental hall which is necessary for conducting experiments with fast neutrons.

4.2. Ways to solving the problems.

All project activities will be carried out in stages. Activity p.1 to improve the safety of work with the accelerator (Painting the ion guide in bright paint, installation of protection and signaling of potentially dangerous places in the Accelerator hall, installation fences around open technological windows on the removable repair site of the accelerator) will be carried out as a matter of priority.

4.2.1 Task 1. To solve task 1, it is planned to carry out a set of measures including:

- replacement of the high-voltage accelerating tube;

- repairing of office premises;

- revision of the high-voltage structure, modernization of the service systems of the accelerator (vacuum farms (transition to oil-free pumping); gas compressor equipment, electronic systems (replacement of obsolete devices), etc.

Activities p.2. to increase the dielectric strength of the accelerator gas media, to ensure the conditions for long-term operation of the new accelerating tube at the nominal terminal voltage and ion beam current. In particular, the cleanliness of the air in the accelerator room and the purity of the insulating gas gives an increase in voltage efficiency up to 20%). Therefore, measures pp. 2.1 - 2.8 must be carried out before the delivery of the high-voltage tube by the company "High Voltage Engineering Europa B.V. ". Otherwise, the surfaces of the new high voltage tube will be contaminated from the external airborne dust particles and oil vapors from the vacuum line with the inner side at the first start. This will not allow the accelerator to reach the required technical parameters and will significantly accelerate the aging and destruction of structural elements new HV-tube. With a high probability, if the requirements for the purity of gas environments are not met, which the HV tube will operate, suppliers will shorten the period of its warranty service.

According to clause p. 2.1. it is planned to carry out repairs of the accelerator premises until they correspond to the ISO-9 class purity. Measures will be taken to remove oil vapors from the gas compressor and vacuum equipment by installing oil filters, dryer's of gases and nitrogen traps in the first case, and turbomolecular pumps instead of steam-oil pumps (p.2.7.), respectively - in the second. In addition, the dielectric constant of the gas medium with the outer side of the HV tube will be increased to the required value (set by the manufacturer of the HV tube) by adding expensive dielectric SF6 gas.

Dealing with expensive SF_6 gas will require an additional work to organize storage sites, eliminate leaks in the lines through which it is transported. Phosphorus Pentoxide P_2O_5 is planned to use it for dehumidification of dielectric gas (pp. 2.2 - 2.6). Fill out the floor surfaces in the accelerator rooms with special polymer enamel based on epoxy resins, painting walls with oil paint, installing a local system of thermal stabilization of an air in premises of the accelerator, a checking of the ventilation system will be carried out (clause 2.1).

A checking and cleaning high voltage terminal surfaces (corona triode area), high voltage column insulators (gradient rings) will be carried out with solvent and hydrofluoric acid before installing a new High Voltage tube (after dismantling the old one) to obtain the smallest recombination coefficient H^+ (p. 3.5.).

Smoothing the transition from a small diameter of the column screen to a large one for leveling field gradient and elimination of breakdowns (p.3.7) will be carried out before cleaning the insulators. Strengthening the insulation of the springs holding the HV-tube in a column using Teflon pipes (Activities p.3.8) will be carried out after the installation of a new HV-tube.

After assembling the column with the installed HV-tube, the high voltage source training was conducted with a high voltage to get a good current (Activity 3.14). The possibility of using the Penning ion source, which allows to obtain a beam of He^{2+} ions, which is will allow double the beam energy if necessary (Activity 3.18) will be discussed separately during the investigating of new ion source supplied by "HV Europe B.V".

Compressor. Repairing / replacement of gas compressor equipment for receiving and drying nitrogen, installation for an SF6 gas processing and storage system (measures of pp. 2.8 and 2.9.) will be carried out as part of the ongoing maintenance of the technical infrastructure of accelerator.

Replacing the high-voltage tube. To guarantee receipt of the result, by the end of the project (1 year) the option of purchasing a high voltage tube in a specialized firm ("High Voltage Engineering Europa B. V.") with the installation and commissioning of the works by the manufacturer and, as a condition of warranty service up within the warranty period was offered. In order to implement this aspect of the plan after all the prepare work, the accelerator HV-tube will be replaced in the presence of specialists of the manufacturer (p. 4), test and electrical training HV-tube at high voltage (p.4.1) will be held. After that, documentation indicating that the Accelerator has been tested and subsequent permits for the SES will be produced (pp, 11-12). This will be followed by testing and putting the accelerator into normal operation regime (activity 4.1).

Repair of premises (p. 5.) will be cosmetic type and will include the following operations.

1. Dismantling of equipment.
2. Removing old paint from the walls and ceiling.
3. Preparation of the surface for putty (primer).
4. The putty.
5. The sanding.
6. Painting the walls and ceiling.
7. Floor preparation for pouring the polyurethane coating.
8. Removal of split tiles, sealing with cement obvious problem areas.
9. Framing of cable channels.
10. Filling the floor with a polymer composition.
11. Production and installation of decorative hatches for cable channels.
12. Dismantling of old lamps.
13. Installation of new lamps (10 units).
14. Plasterboard Sealing of the technological passage between the halls filled with concrete blocks (biological protection) (p.5.3).

In the left experimental hall, in addition to cosmetic repairs (p. 5.1.), a massive slab – base for a microbeam spectrometer, mechanically untied from the floor, will be installed on a sand cushion (p. 5.2.).

4.2.2. Task 2. The condition of the HV-column and service systems of the accelerator is an extremely important factor in solving the problem of restoring / increasing (in comparison with the parameters as of 1965) of its technical parameters. Installation of a new high-voltage tube must be preceded by checking all accelerator systems and Troubleshooting all possible problems (see step 3). Carrying out preparatory measures for replacing the high-voltage accelerating tube is a sub-task 2.1. (action item 3). It is expected to eliminate a number of serious violations identified by experts in the design of the accelerator and the building in which it is located.

First of all, will be carried out repair floors – base, on which are the analyzing magnet and deflecting magnets in the right and left experimental halls (p. 3.1.). In particular, it will resolved the drawdown in the floor of the right experimental hall, which, according to experts, can lead to loss of alignment of the ion beam and ion conductor and, as a consequence, the observed sharp decrease in the beam current and increasing the radiation background in the accelerator operation in the mode of the neutron generator. The floor will be reinforced by reinforcement (steel welded structure) followed by pouring concrete (see p. 3.1.). To determine the exact cause of the current decrease in the neutron generator mode, as well as after the repair work, the alignment of the magnetic analyzer chamber with the ion conductor will be checked (p. 3.2.). the gap between the ion beam and the ion conductor should be about 20 mm. The beam shape at the inlet and outlet of the accelerator HV-tube will be checked (p.3.3). The shape of the beam can reveal misalignment (if it's available).

The organization of the pit required for conducting experiments with fast neutrons (p. 30.) requires the development of a separate project and significant financial costs, so it refers to additional activities that can be performed within the framework of this project if additional resources become available.

The next significant disadvantage of the existing accelerator design is the absence of a quadrupole magnet at the output of the analyzing magnet. At the moment, only 30% of the beam is used, because, after the magnet, the beam is compressed horizontally into a vertical rectangle, from which a segment of the order of 5 mm is cut out by the diaphragm. Therefore, the next point of the work plan is to manufacture and install a focusing quadrupole lens to increase the efficiency of the beam passing after the measuring magnet (item 3.4.).

Development of experimental infrastructure of the accelerator complex. Measures to prepare for the installation of the nuclear microbeam channel (subtask 2.3.). Sketch of the designed channel of the nuclear microprobe is shown in Fig.1. The following technical measures (p. 3.6, pp. 3.9-3.13, 3.15-3.17) will be performed to increase the current stability, which is necessary for installing a microbeam spectrometer channel / nuclear microprobe. The installation of an external slit size control system, a dynator ring for suppressing secondary electrons and forced cooling in the beam energy stabilization system are necessary to clear the ion beam spectrum from the electronic component. Optimization of the ion source induction coil geometry, coordination of the ion source optics are necessary to reduce the energy spread of the ion beam and coordinate the ion beam parameters at the HV-tube outlet. Adjustment strictly in one plane and partial replacement of needles in the corona triode to needles which are made from a material resistant to corona discharge (needles from German sewing machines) is necessary to reduce the current fluctuations on the corona triode. The criterion for successful adjustment is the current within 20-30mkA, the absence of current runout (fluctuations).

Adjustment of the gap on the discharge brushes (p. 3.10). Installing a gap of 6 mm instead of the existing gap of 10 mm on the discharge brushes will increase the stability of the ion beam current and the reliability of the accelerator as a whole by slightly reducing the recharge voltage (analogous to increasing negative feedback). Changing the configuration of the recharge brushes and dividing the monolithic plates into three sections (p.3.11) will reduce the pressure on the tape, reduce its wear, and reduce low-frequency fluctuations in the ion beam current. Cleaning the charging tape with a solvent will be carried out to reduce the energy spread of the accelerator (clause 3.6.), which is extremely important for the subsequent development of a microbeam spectrometer. Annealing and polishing of the diaphragm that forms and aligns the ion beam (p.3.12), replacement of the divider resistors with the nominal values changed during operation in the compensating section (5 sections after the section with straight fields (p. 3.13), after revision of the resistors will also increase the energy stability of the beam.

The preparation of the nuclear microprobe channel in the project includes a passive vibration suppression system (p. 5.2.) means a base plate which is a mechanically untied from the floor in the spectrometer hall. A 0.7 m high recess will be made on the floor, followed by filling it with fine-grained sand to a depth of 0.2 m and pouring concrete on a slab isolated from the floor. Such foundation is not needed for the entire channel, but only for its final part, where the lenses and the target camera are located (Fig. 1.). Floor reinforcement (reduces the cost of an active vibration suppression system).

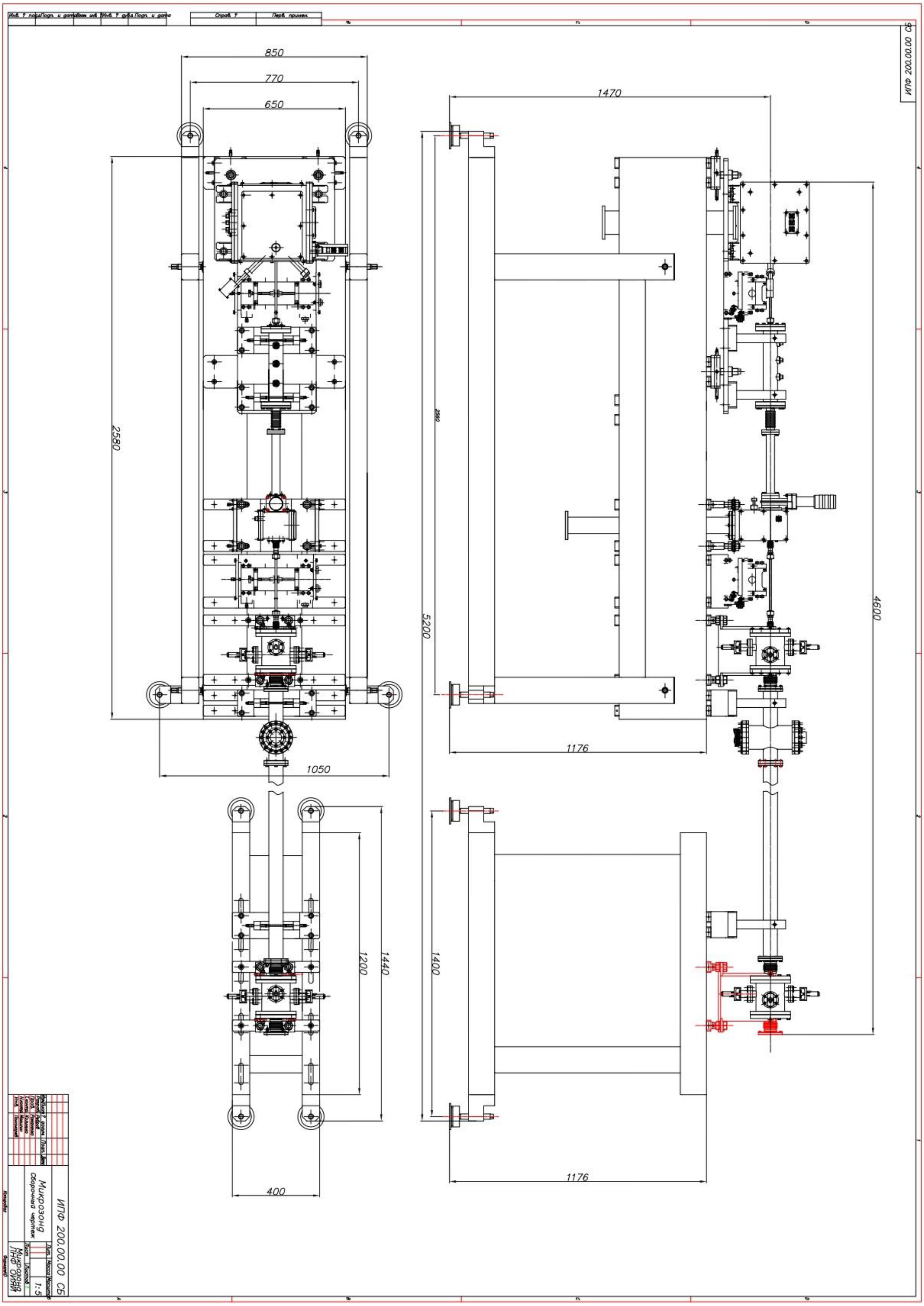


Fig. 1. Sketch of nuclear microbeam channel.

Activities (p. 28 and p. 29) for the assembly of a microbeam spectrometer (Development of an action plan - a sequence of actions according to the Project of the nuclear microbeam for the EG-5 accelerator FLNP JINR of 2015, developed by employees of the Institute of Applied Physics of the National Academy of Sciences of Ukraine (Responsible Dmitry Magilin) and order in the FLNP workshops of the main units according to the design documentation as well as, actions p.11 and p.12 (Restoration of technical documentation for accelerator HV-tube and preparation / signing of documents for inclusion of EG-5 to SES list) will be carried out in parallel with the main activities by individual staff temporarily not engaged in technical work. According to preliminary estimates, the resource of the Design Bureau of the FLNP will need about 240 norm-hours and FLNP workshops - at least 1000 norm-hours. The purchase of an appropriate quadrupole lens with power supplies and a focused beam scan control system from Oxford microbeams (http://www.microbeams.co.uk/Products.html) will be carried out after the end of the project or as an additional activity when appropriate resources are available.

Laboratory for the production of samples (subtask 2.4). According to the functional purpose at the laboratory site (Fig. 2), a room for remote control of the TANGRA plant (P1), a room for the chemical laboratory (P2), a room for the measuring laboratory (P3), and a section for high-temperature sintering and mechanical processing of consolidated materials (P4) are planned.

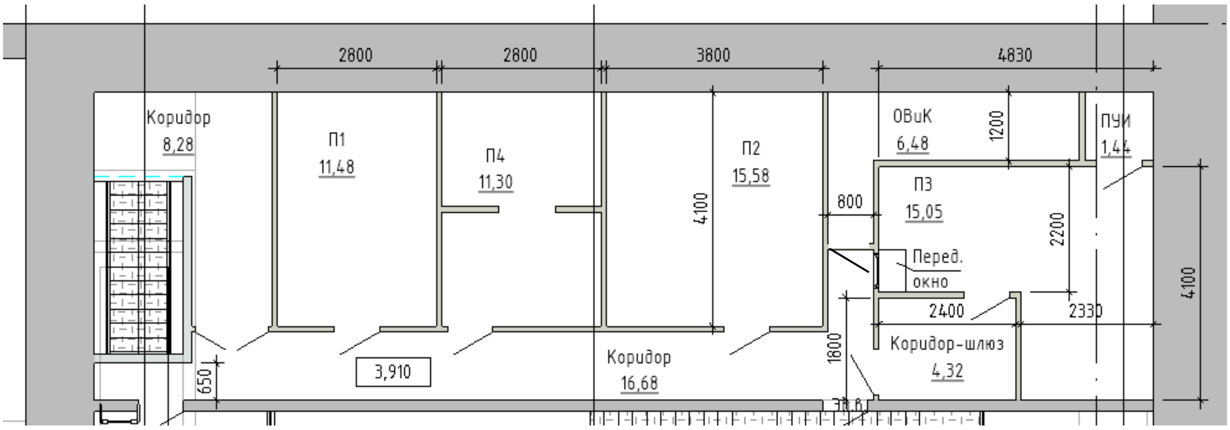


Fig .2. The layout of laboratory premises on the second floor of Bench Hall №3, where:

P1 – TANGRA group room.
P2 – Chemical laboratory.
P3 – Measuring laboratory.
P4 – High-temperature sintering and machining area (dirty area).

The laboratory will be placed on the second floor in the bench hall №3 (Fig. 3, Fig. 4) and will be an isolated room with a separate entrance and emergency exit

Installation of laboratory for preparation of objects for studies by ion-beam methods (measures pp. 6 and 14) will be performed by the contractor organization after installation of the HV tube. As part of the project, steel constructions and a partition separating the laboratory from the room where the TANGRA neutron generator is located will be installed (Fig. 3). The corresponding technical project is currently under development by «SREZATOMSERVICE» and will be ready by the time when the HV tube was installed. The remaining work will be carried out as additional activities. The laboratory will be located in newly formed rooms on the second floor above the boxes in Bench Hall No. 3.

Pre-integration of experimental infrastructure with complementary research methods (subtask 2.5.) of the surface layers of materials (electrical, electronic, and optical properties, activity 10) will be carried out during the project implementation.

Ion Beam Spectrometer Chamber. The development, manufacture, and installation of a new high-performance chamber for ion beam research of materials (RBS, ERD, PIXE, p. 7) will be carried out by the group “Accelerator EG-5” and production infrastructure of FLNP. The procurement and installation of the NEC RC43 ion beam module (p.15) and the HVE bundle system (p. 16) are additional activities and will be implemented outside the project timeframe when an appropriate funding becomes available.

Upgrade of service equipment (p. 8). Automation of accelerator units, which are extremely important for realization of functions of microbeam spectrometer and generator of quasimonoenergy neutrons, in particular, automation of system of spatial stabilization of beam position (p. 8.1), will be carried out after installation of HV tube. Replacement of obsolete devices at the Console (p. 8.2) and in the infrastructure of the acceleration complex, in particular, the replacement of steam-oil pumps with turbomolecular pumps will be carried out throughout the project in the service mode by the team of the «Accelerator EG-5 » group.

Staff training (p.3). Training of young employees to work at the EG-5, intensification of international cooperation, organization of the user program (p 9) will be carried out during the project implementation by members of the "Accelerator EG-5" group with the support of FLNP directorate.

Task 3.1. To solve task 3.1. it is planned to recruit the most motivated and capable students to work in the group, study, selection, and subsequent full-time employment after graduation. It is planned to complete the formation of the group and the training of young personnel by the end of 2023. It is planned to adapt the composition of the group for shift work (transfer of part of the scientific subgroup to harmful working conditions, segmentation into subgroups by performed labor functions).

Task 3.2. To solve task 3.2. under the guidance of prof. Romanov plans to hold annual international conferences and seminars on electrostatic acceleration technology with the involvement of leading specialists in the field of ESA technology and associated research methods, which will make it possible to form a circle of potential customers (from among production and scientific entities, presumably representatives of the electronic industry, groups specializing in the field of radiation biology, nanomaterial science, etc.) as well as strengthening the position of the FLNP JINR and taking into account the significance and scope of potentially feasible scientific tasks, will allow the JINR to be considered as a center of competence in the field of ESA technology and related experimental research methods.

It is planned to increase the number of cooperative bonds, intensify interaction with new scientific groups from the Russian Federation, countries near and far abroad. In particular, in 2021 it is planned to begin interaction with teams from the University of Lisbon (i3N/CENIMAT, Department of Materials Science, Faculty of Science and Technology, New University of Lisbon and CEMOP/UNINOVA, Portugal); National Institute for Research and Development of Isotopic and Molecular Technologies, Cluj-Napoca, România; National Nuclear Research Center CJSC, Baku, Azerbaijan).

The following (additional) activities in paragraphs 13 to 27 below will be carried out subject to the availability of the required resources.

1. Manufacture of an additional vacuum inlet in the upper part of the vessel with an acceleration HV-tube (differential pumping of the column) to increase the homogeneity of the vacuum (the difference is 2 of the order of 10^{-6} and 10^{-4} Torr) and prevent contamination of the upper sections of the HV-tube (p. 13).
2. Installation of beam coordinates control system with documentary fixation (p. 17).
3. Purchase of a set of spare tapes (in Yaroslavl, Russia) (p. 18).
4. Organization of experimental area for manufacture and testing of high-voltage tubes. Completion of the HV-tube gluing area with the missing equipment, preparation of the HV-tube gluing room for the corresponding work (item 19).
5. Manufacture of a superstably ionic source with an energy spread of less than 10 eV using existing domestic developments. Consideration of the possibility of using a Penning source for operation in the neutron generator mode, which allows obtaining a beam of Ne^{2+} ions, which, if necessary, will increase the beam energy by two times (p. 20).
6. Replacement of PVA in adhesive joints of the HV-tube with less evaporating glue (p. 21).
7. Replacement of obsolete lamp vacuometers with semiconductor analogues (p.22).
8. Installation of remotely controlled monitors of beam shape and current control (Faraday cylinder), quartz screen with beam position fixation, video camera with possibility of visual observation of image and beam position on the panel (p. 23).
9. Transition to remotely controlled vacuum gates to provide emergency isolation of the acceleration HV-tube (in automatic mode) in case of leakage in ion beam lines (p. 24).
10. Checking the pressure vessel and all ESU systems (p. 25).
11. Replacement of power supply cables and accelerator control system due to the end of service life (p. 26).
12. Replacement of stationary closed-loop flow cooling system in analysis magnet power supply (p.27).

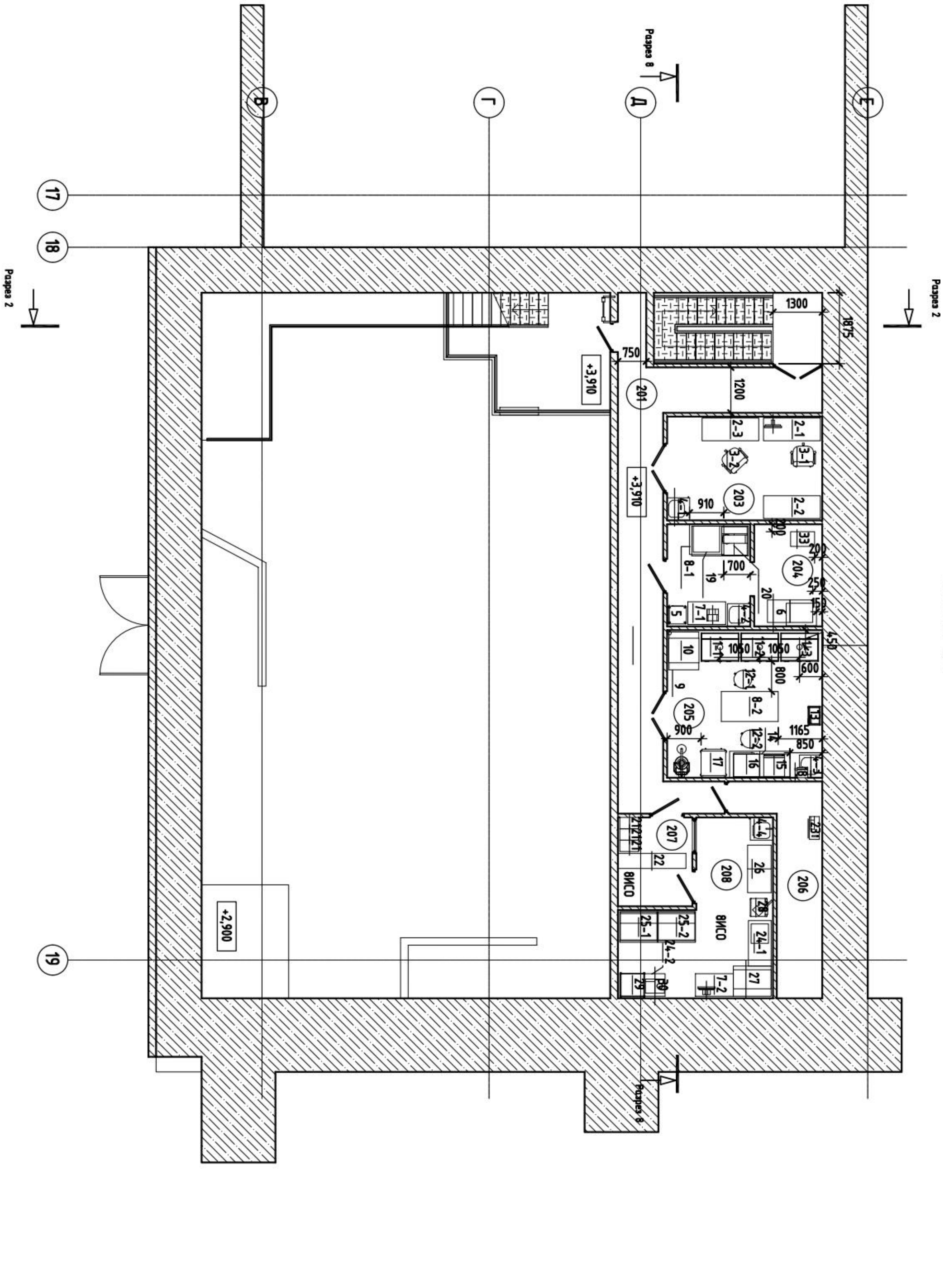


Fig. 3. Sketch of bench hall №3 – second-floor level.

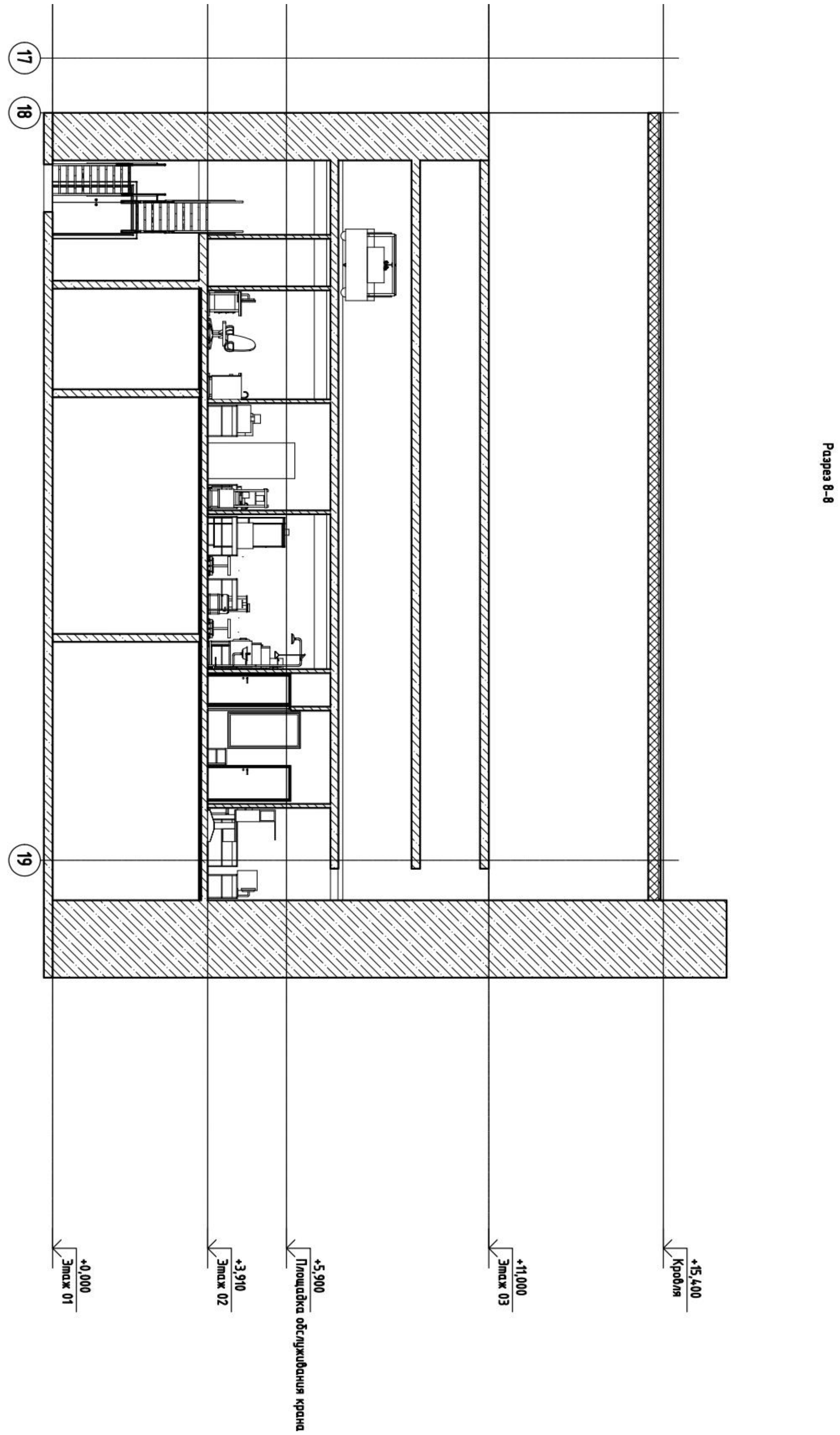
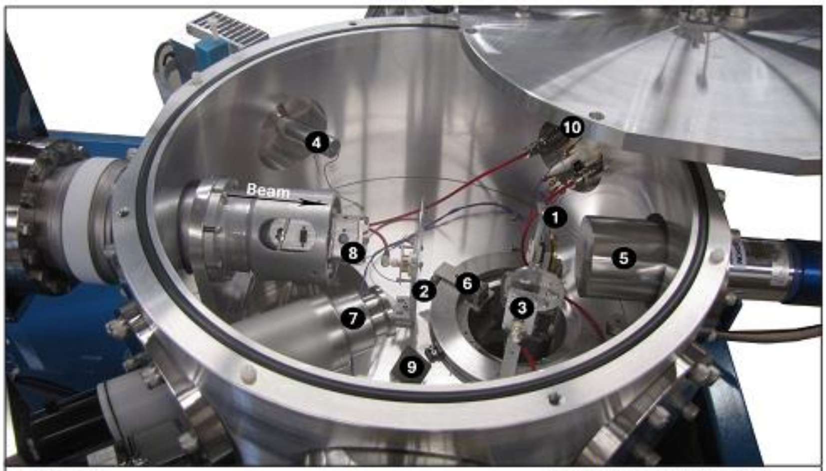


Fig. 4. Sketch of bench hall №3 – cross section.



1. Sample
2. Fixed SSB at 170°
3. Moveable SSB and Filters at 180° to 30°
4. X-Ray Detector
5. Gamma Detector at 0°
6. X-Ray Detector Filters
7. Zoom Camera
8. Microprobe Lens
9. Light
10. Chamber Feedthroughs

Fig. 5. The working chamber of ion beam analyzer RC43 manufactured by NEC planned for purchase. The main elements are shown and specified by numbers on figures.

5. Evaluation of scientific facility personnel

The project team includes world-class specialists in the field of ESA engineering (prof. Romanov V.A.) in the field of nuclear physics, chemistry, and technology, seven engineering and technical workers with many years of experience in servicing and repairing all units of the EG-5 accelerator. The group consists of more than 50% of young employees who are able to quickly solve current technical problems.

Each team member will devote the following amount of time to work within the project in relation to their full employment.

1. Lichachov Alexey Nikolaevich – lead engineer – 100%
2. Kobzev Alexander Pavlovich – lead researcher – 50%
3. Kudryavtsev Vladimir Petrovich – senior engineer – 100%
4. Tkachenko Stanislav Nicolaevich – senior engineer – 100%
5. Bobrakov Vladimir Fyodorovich – engineer – 100%
6. Zaytsev Igor Alexeevich – engineer – 100%
7. Kulik Mirosław – senior researcher – 50%
8. Madadzada Afag Isa – senior researcher – 50%
9. Zakharova Anna Sergeevna – technician – 25%
10. Loginov Alexey Andreevich – technician – 25%
11. Yurenkov Danil Igorevich – technician – 25%
12. Alexandrov Vasiliy Alexeevich – technician – 25%
13. Studnev Constantin Evgenyevich – technician – 100%
14. Tatarinova Alisa Alexandrovna – technician – 25%
15. Gridina Elizaveta Alexeevna – technician – 25%
16. Zelenyak Tatyana Yuryevna – engineer – 100%
17. Doroshkevich Aleksandr Sergeevich – group leader – 100%
18. Tran Van Phuc – junior researcher – 100%
19. Tikhonova Natalia Sergeevna – technician – 50%
20. Phan Luong Tuan – researcher – 100%
21. Romanov Valentin Alexandrovich – advisor to the director of the FLNP – 20%.
22. Chepurchenko Ilya Andreevich – engineer – 100%

Thus, the team has the necessary resource capacity to carry out the modernization and subsequent operation of the accelerator. The scientific potential of the group is made up of famous scientists: prof. A.P.Kobzev, prof. V.A. Romanov, prof. M. Kulik.

6. Valuation of the project budget

The most costly act is the purchase of a high-voltage tube. The estimated cost of purchase, delivery, installation with specialists, and extended warranty life is given below (for full text see Appendix 5).

Total Equipment Price, EXW Seller's site, Amersfoort, NL	€ 337.000, -
1. Transportation, including insurance coverage, see for details	€ 10.100, -
	____________
Total Equipment Price, DAP Buyer's site, Dubna, Moscow region, Russian Federation	€347.100, -
2. On-site Installation: Not included, Instead On-site assistance by Seller, by 1 engineer during 5 days, arrival Sunday, departure Saturday, incl. costs for travel, hotel and meals	€19.600, -
3. Warranty: Instead of Warranty, Seller's standard terms and Seller's standard period, Warranty, Seller's standard terms and Seller's standard period extended by 24 months, see elsewhere for details	€33.800, -
	____________
Grand Total Price	**€400.500, -**
	============

The total amount of the project is 400 500 EUR = 471 000 USD. All modernization works will be carried out by the team of the "Accelerator EG-5" group as part of the performance of labor functions using the available resource base.

7. Short SWOT-analysis of the project

7.1. Strengths of the project.

1. Suitable design of the EG-5 accelerator for solving the specified tasks (creation of a nuclear microbeam and a neutron generator). The design will fully implement the unique capabilities of the EG-5 accelerator, in particular, the possibility of obtaining a large amount of ion beam current (up to 250mkA) and its small energy spread (100 eV), which cannot be implemented on tandem-type installations.

2. Low operating cost of the accelerator EG-5. The excellent reparability of the EG-5 accelerator design and the availability of a resource base makes it possible to carry out modernization with minimal costs and ensure the independent operation of the accelerator complex for a long time. The 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 very long period of time after replacing the HV-tube. Accelerator EG-5 does not require the use of expensive materials and equipment, does not contain units 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 service work.

3. Advanced training of own engineering personnel in the process of modernization, the formation of personnel potential for the long life of the accelerator. During the implementation of the project, personnel resources will be formed from graduates of universities, their training in working with elements of the accelerator infrastructure and familiarization with the specifics of scientific work in the group.

4. Development of a full-fledged experimental infrastructure of the acceleration complex. Saving resources by having in-house infrastructure will significantly expand the pilot infrastructure. Installation of a new complex of ion-beam spectrometers, installation of a laboratory for the formation of research objects will significantly expand the range of studied objects, thereby significantly increasing the output of scientific productions.

5. This option of solving the main problem is less costly financially compare to the purchase of a new accelerator and the creation of an experimental infrastructure based on it.

7.2. Weaknesses of the project.

1. **Moral and technical obsolescence** of service systems and the experimental base of the

accelerator. Significant time resources will be required to checking and upgrade all accelerator systems.

2. **Limited Feature Set**. Compared to modern industrial models of accelerators, the updated EG-5 accelerator has a limited set of functions, the predominant part of the adjustments is carried out in manual mode.

3. The spatial stabilization of the beam position required for the installation of the nuclear microbeam is carried out in manual mode and requires separate rework.

4. No pulse mode which is required for neutron scattering studies using time-of-flight (TOF) spectrometry.

5. It is not possible to accelerate a wide range of ions.

7.3. The main risks that may result in the failure to fulfill the set tasks in time or the failure to achieve the required technical parameters by the accelerator may be related to:

- errors in HV-tube design at the manufacturing plant;
- errors during installation of the new HV-tube;
- non-conformance of technical conditions provided by EG-5 service systems the specifications which necessary for the operation of new acceleration HV-tube (requirements for vacuum, dielectric gas parameters, etc.);
- the presence of additional faults in the accelerator in addition to the loss of parameters of the acceleration HV-tube.

Conclusion

Modernization of the electrostatic accelerator EG-5 and its instrument infrastructure will solve a large number of tasks from the Problem-Thematic Plan of the JINR (topic 03-4-1128-2017/2022 "Studies of the interaction of neutrons with nuclei and neutron properties"). In particular, it will provide research in the JINR of reactions with fast quasi-monoenergy neutrons, the possibility of working with biological objects, and the possibility of installing the option of a nuclear microbeam.

Besides, the performance of available methods (RBS, ERDA, NRA, PIXE) will be improved. The experimental base will be supplemented by non-beam complementary methods for studying the electrical, optical, and electronic properties of the surface (ellipsometry, impedance spectroscopy).

The upgraded accelerator will allow obtaining energy up to 4.1 MeV with beam current up to 100 μA/nucleon.

In order to successfully develop the above-mentioned areas of neutron research within the framework of JINR and continue to occupy a leading position, in the future, it is necessary to purchase an additional new modern electrostatic accelerator for operation in the energy range up to 6MeV.

REFERENCES

1. V. Shvetsov. «Transmutation of spent nuclear fuel and radioactive waste is one of the options for the strategic development of the nuclear industry» [Electronic resource] // Nuclear physics on the internet. URL: http://nuclphys.sinp.msu.ru/ecology/trans.htm (date of treatment: 05.11.2020).
2. Nuclear Data High Priority Request List [Electronic resource] // NEA Nuclear Energy Agency URL: https://www.oecd-nea.org/dbdata/hprl/search.pl?vhp=on (date of treatment: 05.11.2020).
3. M. Yu. Khlopov. "Physics of Space" [Electronic resource] // Astronet URL: http://www.astronet.ru/db/msg/1188315 (date of treatment: 05.11.2020).
4. JINR Basic facilities [Electronic resource] // Joint Institute for Nuclear Research URL: http://www.jinr.ru/jinr_facilities/ (date of treatment: 05.11.2020).
5. Komar EG Fundamentals of accelerator technology. M., Atom-Publishing House, 1978, p. 368.6. A.K. Walter. Electrostatic particle accelerators. Edited by Academician of the Academy of Sciences of the Ukrainian SSR A.K. Walter., M., 1963 p. 302.
7. Miscellaneous [Electronic resource] // INCMTA2008 11th International conference on Nuckear Microprobe Technology and Applications URL: http://w3.atomki.hu/atomki/IonBeam/icnmta/microprobefac.html (date of treatment: 05.11.2020).
8. Doyle B. L., Hamm R. W. Reviews of Accelerator Science and Technology Vol. 10 (2019) 93–116 c© World Scientific Publishing Company //Reviews of Accelerator Science and Technology. – 2019. – Т. 10. – С. 93-116.
9. Gledenov, Yu. M.; Sedysheva, M. V.; Khuukhenkhuu, G.; Bai, Huaiyong; Jiang, Haoyu; Lu, Yi; Cui, Zengqi; Chen, Jinxiang; Zhang, Guohui (2018). reaction in the 4–6 MeV region. Physical Review C, 98(3), 034605. doi:10.1103/PhysRevC.98.034605
10. Antonova L. Kh. Et al. Influence of proton irradiation on critical parameters of composite high-temperature superconducting tapes // Perspective materials. - 2014. - No. 5. - S. 34-38.
11. Kulik M. et al. Effect of N 2+ Ion Implantation and Thermal Annealing on Near-Surface Layers of Implanted GaAs // Acta Physica Polonica, A. – 2015. – Т. 128. – №. 5.
12. Kulik M. et al. Chemical composition of native oxides on noble gases implanted GaAs //Thin Solid Films. – 2016. – Т. 616. – С. 55-63.
13. Horodek P. et al. Slow Positron Beam Studies of the Stainless Steel Surface Exposed to Sandblasting //Acta Physica Polonica, A. – 2014. – Т. 125. – №. 3.
14. Horodek P. et al. Positron beam and RBS studies of thermally grown oxide films on stainless steel grade 304 //Applied Surface Science. – 2015. – Т. 333. – С. 96-103.
15. Rzodkiewicz W. et al. Nuclear and Optical Analyses of MOS Devices //Acta Phys. Pol. A. – 2013. – Т. 123. – №. 5. – С. 851-853.
16. Interindustry Internet-based system of search and synthesis of physical principles of energy conversion [Electronic resource] // Site of the Russian State University of Oil and Gas named after THEM. Gubkin URL: http://www.heuristic.su/effects/catalog/tech/byId/description/292/index.html (date of treatment: 05.1.2020).
17. European fission source [Electronic resource] // Habr URL: https://habr.com/ru/post/389279/ (date of treatment: 05.11.2020).
18. Research and development in priority areas of development of the scientific and technical complex of Russia for 2014-2020 [Electronic resource] // Website of the Federal State Budgetary Scientific Institution "Directorate of Scientific and Technical Projects"URL: http://fcpir.ru/business/prioritety-nauchno-tekhnologicheskogo-razvitiya/ (date of treatment: 05.11.2020).

Appendix 3

Form № 26

Proposed schedule and necessary resources for implementation

Project <u>MODERNIZATION OF THE EG-5 ACCELERATOR AND ITS EXPERIMENTAL INFRASTRUCTURE</u>

Names of costs, resources, and sources of funding			Cost (thousands of dollars). resource Requirements	Laboratory proposal for allocation of funding and resources		
				1 year		
Cost		The main components of the equipment, work on its updating, adjustment, etc.	471	471		
		Construction / renovation of premises				
		Materials				
Necessary resources	Normo-hour	Resources – design Bureau of the laboratory, - experimental production of JINR, - experimental production of the laboratory, - accelerator, - reactor, - computer. Operating costs	240 standard hours 1000 standard hours	240 standard hours 1000 standard hours		
Source of financing	Budget funds	Budget expenditures, including foreign currency funds	471	471		
	Extra budgetary funds	The contributions of the collaborators. Funds for the grants. Contributions from sponsors. Funds under the contracts. Other sources of funding, etc.				

PROJECT LEADER [signature] A.S. Doroshkevich

Appendix 4

Form № 29

Cost estimate of the first part of the project MODERNIZATION OF THE EG-5 ACCELERATOR AND ITS EXPERIMENTAL INFRASTRUCTURE

№	Description of cost items	Total cost	2021	2022	2023	
	Direct expenses					
1	Design	k$		-	-	**0**
2	Materials	k$			0	**0**
3	Equipment	k$	0	471	0	**471**
4	Payment for research performed under contracts	k$	0	0	0	**0**
5	Travel expenses	k$	0	0	0	**0**
	Total	k$	**0**	**471**	**0**	**471**

PROJECT LEADER A.S. Doroshkevich

LABORATORY DIRECTOR V.N. Shvetsov

LEADING ENGINEER-ECONOMIST OF THE LABORATORY L.S. Ovsyanikova

HIGH VOLTAGE ENGINEERING EUROPA B.V.
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Joint Inst. for Nuclear Research, Frank Laboratory of Neutron Physics
141980 Dubna, Moscow region, Russian Federation

01768/A31864-02
October 16, 2020

Conditions

Prices

Prices are exclusive of any taxes, duties, fees, etc. without limitation due to enumeration imposed by any governmental body other than The Netherlands.

Prices shall remain firm in the currency of the Contract throughout the duration of the Contract.

Taxes, duties and fees

All taxes, duties and fees arising outside of the Russian Federation in connection with the execution of the Contract shall, except where stated otherwise, be borne by Seller.

All taxes, duties and fees arising inside of the Russian Federation in connection with the execution of the Contract shall, except where stated otherwise, be borne by Buyer.

Country of origin and manufacturer

The Netherlands, High Voltage Engineering Europa B.V.

Approval for export

Delivery is subject to approval for export by the Government of The Netherlands. Application for export approval can be submitted by Seller only after order is in place.

Buyer is to provide Seller with a suitable End-Use Certificate and End-User Statement (template available from Seller), together with the order.

Seller will complete all other documents necessary for Seller's application for export approval and will submit the application no later than one (1) week after receipt by Seller of Buyer's End-Use Certificate and End-User Statement.

Seller will notify Buyer about the outcome of the application for export approval that is generally obtained within twelve (12) to sixteen (16) weeks from application submission date.

In the event a suitable End-use Certificate and End-user Statement is not received by Seller within six (6) weeks after Contract, Seller has the right to extend the time of delivery based on Seller's order backlog at the moment of receipt by Seller of a suitable End-use Certificate and End-user Statement.

5. Documentation package <u>in the English language,</u> including: Included

Within maximal ninety (90) days after notification of order, one set of:
. Overall system layout drawing
. Installation Requirements and Recommendations

With the delivery of the Equipment, one set of:
. Mechanical assembly drawings
. Electrical- and electronic schemes
. Parts list with Seller's part name and part number
. Manuals for the operation and maintenance

Total Equipment Price, EXW Seller's site, Amersfoort, NL	€	337.000, -
6. Transportation, including insurance coverage, see elsewhere for details	€	10.100, -
Total Equipment Price, DAP Buyer's site, Dubna, Moscow region, Russian Federation	€	347.100, -
7. On-site Installation: Not included, Instead On-site assistance by Seller, by 1 engineer during 5 days, arrival Sunday, departure Saturday, incl. costs for travel, hotel and meals	€	19.600, -
8. Warranty: Instead of Warranty, Seller's standard terms and Seller's standard period, Warranty, Seller's standard terms and Seller's standard period extended by 24 months, see elsewhere for details	€	33.800, -
Grand Total Price	€	**400.500, -**

- Flanges, Upper & Bottom:	as per Buyer's drawing
- Overall length:	~1150 mm
- Leak rate:	5 x 10^{-9} mbar ltr / sec

Overall accelerator tube:

- Electrodes:	
. Material	Titanium
. Shape	Dished
. Outer diameter	~235 mm
- Insulators:	
. Material	Borosilicate glass
. Outer diameter	~215 mm
. Thickness:	To suit 25.0 mm pitch (center to center distance of electrodes)
- Discharge point assy's:	3 on each electrode at 120^0 interval with voltage grading resistor mounting clip
- Sealing between sections:	Viton "O-rings" (included by Seller).
- Voltage grading:	by resistors mounted on accelerator tube 160 pcs + 10 pcs as spare See Notes for mounting arrangement
- Overall length:	~4150 mm
- Electron suppression:	by spiraled permanent magnets located inside the vacuum
- Radiation level (1):	< 2 µSv/hr

(1) measured at 100 cm from the tank wall, running a 1 µA He beam at nominal terminal voltage.

3. Pre-conditioning of all three (3) accelerator tube sections: € 17.300, -

Pre-conditioning of all three (3) accelerator tube sections
@ Seller's plant in Seller's KN4000 Van de Graaff accelerator, incl.:
cost for temporarily providing one-off adapter flange

4. Assembly prior to transportation: Included in item 2

- Accelerator tube section shall be assembled complete with discharge point assy's, voltage grading resistor mounting clips and voltage grading resistors prior to transportation.
  Support flanges and double layer temperature insulated packing will be provided to ensure safe transportation.
- RF ion source shall be packed separately and be mounted on-site.

HIGH VOLTAGE ENGINEERING EUROPA B.V.
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Phone: +31-33-4619741. Fax +31-33-4615291. Trade register Amersfoort nr. 31014544
E-mail: info@highvolteng.com – Web: www.highvolteng.com

Joint Inst. for Nuclear Research, Frank Laboratory of Neutron Physics — 01768/A31864-02
141980 Dubna, Moscow region, Russian Federation — October 16, 2020

We have the pleasure in offering you herewith, for use with your existing vertical Van de Graaff accelerator, Model EG-5:

1. RF Ion Source Model SO-173 (short bottle), including: € 20.100, -

- Source body
- Extraction electrode
- Alignment tool
- RF oscillator

- Ion beam current
  . Hydrogen ($^1H^+$): 250 eμA (typical)
  . Deuterium ($^2D^+$): 170 eμA (typical)
  . Helium (4He$^+$): 125 eμA (typical)
- Energy spread: 100 eV (typical)
- Beam emittance: 1.2π mm mrad MeV$^{1/2}$

2. Acceleration tube with magnetic suppression, including: € 299.600, -

Accelerator tube section #1 of 3 (Upper section):
- Electrodes:
  . Number: 73 pcs
  . Beam apertures: 40 mm throughout tube section
- Insulators:
  . Number: 72 pcs
- Flanges, Upper & Bottom: as per Buyer's drawing
- Overall length: ~1850 mm
- Leak rate: 5 x 10^{-9} mbar ltr / sec

Accelerator tube section #2 of 3 (Middle section):
- Electrodes:
  . Number: 45 pcs
  . Beam apertures: 40 mm throughout tube section
- Insulators:
  . Number: 44 pcs
- Flanges, Upper & Bottom: as per Buyer's drawing
- Overall length: ~1150 mm
- Leak rate: 5 x 10^{-9} mbar ltr / sec

Accelerator tube section #3 of 3 (Bottom section):
- Electrodes:
  . Number: 45 pcs
  . Beam apertures: 40 mm throughout tube section
- Insulators:
  . Number: 44 pcs

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October 16, 2020

Phone: 007 496 216 2268/5989
Prof. Dr. Victor Anatolievich Matveev
Joint Inst. for Nuclear Research
Frank Laboratory of Neutron Physics
Joliot-Curie 6
141980 Dubna, Moscow region
Russian Federation

Our ref.: 01768/A31864-02

Dear Doroshkevich,

We have the pleasure in sending you herewith our updated budgetary quotation for **an RF ion source and an Accelerator tube with voltage grading resistors for use with your existing vertical Van de Graaff accelerator, Model EG-5.**

We trust this updated budgetary quotation to be of interest to you and we look forward to hearing from you how to proceed from here.

Sincerely,

HIGH VOLTAGE ENGINEERING EUROPA B.V.

Henri van Oosterhout
Managing Director

Joint Inst. for Nuclear Research, Frank Laboratory of Neutron Physics — 01768/A31864-02
141980 Dubna, Moscow region, Russian Federation — October 16, 2020

Entire understanding, modification and waiver

This Agreement is the entire understanding and agreement between Parties with respect to the subject matter hereof, including extend of supply and specifications, and supersedes all prior understandings and agreements relating hereto. No modification, alteration or amendment shall be effective unless made in writing and signed by duly authorized representatives of each Party. No waiver of any breach hereof shall be deemed or held to be a waiver of any other or subsequent breach.

Applicable law and dispute resolution

The validity, construction and performance of this Agreement shall in all respects be governed by and interpreted in accordance with the laws of The Netherlands. All disputes which may arise during or from this Agreement shall be submitted for decision to a competent court in The Netherlands, Seller reserves the right however, to bring any claim it may have against Buyer before any other Court.

Validity

This quotation is valid for three (3) months after date.

Sincerely,

HIGH VOLTAGE ENGINEERING EUROPA B.V.

Henri van Oosterhout
Managing Director

such goods, apparatus or machine has been specially designed for Buyer. Buyer shall not be entitled to reverse engineer or build or have built any goods, apparatus or machine supplied by Seller.
Seller shall not be liable to Buyer or to any person for infringement of any patent resulting from use or disposal of any goods, apparatus or machine sold by Seller, except to the extent that Seller may be liable as an infringe to persons claiming patent rights which Seller may have infringed by this sale to Buyer.

Parts returned by Buyer:

Parts returned by Buyer for repair, refurbishing, for credit or for any other reason which are contaminated by radiation producing or poisonous material exceeding The Netherlands standard safety level will not be accepted by Seller and will be returned or, where mandatory under The Netherlands safety standards, be removed and destroyed at Buyer' cost. Buyer will be liable for any injury or damage to persons or property and for all costs of handling.

Seller's liability at Buyer's site:

Seller shall not be liable in any event for any loss or injury to persons or property (including the Equipment being installed) during On-site assistance that results in whole or in part from:

a. negligence or fault of Buyer, its employees, agents and its other independent contractors;
b. Buyer's failure to observe Seller's engineer's instruction;
   or
c. the failure or malfunctioning of tools, equipment, facilities or devices not furnished by Seller, caused by defects therein not observable by Seller's engineer's visual inspection.

Non-assignment

This Agreement and any interest herein or therein, and any payment due or to become due hereunder may not be assigned by Buyer without the prior written authorization and approval by an authorized representative of Seller. Any attempted or purported assignment of delegation without such required consent would be void.

Cancellation

This contract may be cancelled by Buyer only upon the payment of reasonable cancellation charges to be determined by Seller which shall include but not be limited to expenses already incurred for labor and material costs, overhead, commitments made by Seller and a reasonable profit. Buyer will pay these charges within thirty days after invoice date. Cancellation will only be effective after payment of the cancellation charges.

normal wear and tear (e.g. ion source parts). Not covered by the warranty are expenses for removal, re-installation and freight in connection with foregoing replacements.

All obligations of Seller under this warranty shall cease in the event of abuse, accident, alteration, misuse or neglect of the Equipment. In warranty repaired or replaced parts are themselves warranted for a period equal to the original warranty period applicable to the repaired or replaced parts.

Reasonable care must be used to avoid hazards. Seller expressly disclaims responsibility for loss or damage caused by use of its Products other than in accordance with proper operating procedures and written or verbal instruction.

Seller's liability to Buyer whether in contract or in tort arising out of warranties, representations, instructions or defects from any cause, shall be limited exclusively to correcting the Equipment on the terms and under the conditions as aforesaid, and all such liability shall terminate upon expiration of the applicable warranty period as aforesaid.
In no event shall Seller be liable neither for any indirect, special or consequential damages nor for loss, damage or expenses directly or indirectly arising from the use of the Equipment delivered hereunder.

Warranty, Seller’s standard, and Seller’s standard period extended by 24 months:

Same as above except: for a period of thirty-six (36) months after EXW delivery.

<u>Transfer of Risk, Title and Insurance</u>

Title and right of possession of the Equipment sold hereunder or any replacements shall remain in Seller, regardless of mode of attachment to realty of other property, until the full price (including deferred payment and any notes or renewals or extensions) has been paid in cash. Buyer agrees to do all acts necessary to perfect and maintain said title and right in Seller.
Upon delivery DAP (INCOTERMS 2020) Buyer’s site, Dubna, Moscow region, Russian Federation (unless otherwise agreed to in writing) of any of the Equipment, all risk of loss or damage shall pass to Buyer, and Buyer shall procure and maintain for the benefit of Seller and Buyer, as their interests may appear, adequate insurance on the Equipment against damage by fire and other casualty.

<u>Intellectual Property Rights and Patents</u>

As soon as the full price (including deferred payment and any notes or renewals or extensions) has been paid in cash Buyer acquires the right to use any goods, apparatus or machine sold by Seller and Buyer may transfer the right of use to subsequent owners. Seller retains the intellectual property rights to any goods, apparatus or machine sold by Seller even

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Terms of Payment

Payment is to be effected in EURO (€) by an irrevocable Letter of Credit – in the amount of 100% of the contract value, conditions confirmatory to the order conditions and with validity up to 30 days after the scheduled date for Delivery - to be issued no later than 14 days after date of order, in accordance with following scheme:

- 30% as down payment after order, within 8 days against presentation of:
  - Invoice in the amount equal to the amount of the payment
- 70% as final payment after delivery, within 8 days against after presentation of:
  - Invoice in the amount equal to the amount of the payment
  - Document in proof of delivery

Due payments accrue interest at 1.5% per month when not paid on time.

In the event the delivery is delayed by reasons for which Seller cannot be held responsible, Buyer will reimburse Seller for the costs for storage, insurance and other overhead costs attributable to such delay.

Banking charges

Banking charges outside Russian Federation related to (i) opening of LC, (ii) payment out of LC, (iii) extending validity period of LC as a result of delay in Delivery due to reasons for which Seller can be held responsible and (iv) confirmation of LC by Dutch Bank, will be borne by Seller.

Banking charges inside Russian Federation related to (i) opening of LC, (ii) payment out of LC, (iii) extending period of LC as a result of delay in Delivery due to reasons for which Buyer can be held responsible, will be borne by Buyer.

Warranty:

Warranty, Seller's standard terms and Seller's standard period:

The Equipment to be delivered hereunder is, provided that the full price (including deferred payment and any notes or renewals or extensions) has been paid in cash, warranted to be free of defects in design, workmanship and material for a period of twelve (12) months after EXW delivery.

The warranty covers repair or replacement of defective parts with exception of parts that fail due to use outside their specifications or due to negligence and those parts that are subject to

Time of Delivery

6 - 9 Months after receipt by Seller of Buyer's order and Letter of Credit with conditions confirmatory to the conditions of the order, depending on final Equipment configuration and workload at the time of order and subject to confirmation at the time of order and provided that (i) suitable End-Use Certificate and End-User Statement and (ii) approval for export by the Government of The Netherlands have been timely received by Seller and (ii) all payments due at the time of delivery have been timely received by Seller..

In case of delay in Delivery for whatever reason, the L/C shall be extended without imposing Seller liquidated damages and/or cost.

Buyer and Seller will keep each other updated on progress on both sides.

Force Majeure

Seller shall not be liable for delays in delivery or failure to manufacture or deliver, due to causes beyond its reasonable control, such as acts of God, acts of Buyer, acts of civil or military authority, priorities, fires, strikes, floods, epidemics, quarantine restrictions, war, riot, delay in transportation, car shortages, and inability's due to causes beyond Seller's reasonable control to obtain necessary labor, materials or manufacturing facilities. In the event of any such delay, the delivery date shall be extended for a period of time equal to the period of delay and its consequences. Seller's liability for failure or delay in delivery, for any cause whatsoever, whether beyond Seller's control or not, shall not include indirect, special or consequential damages.

Custom clearance

Unless specifically ordered from Seller, custom clearance is not included and is to be arranged and paid for by Buyer, including (pre) payment of any import duties and other local taxes.

Opening of packing, report of damages and claims

Boxes are to be opened by Buyer only in presence of Seller's installation engineer.
Claims for damages and/or missing parts will not be honored when boxes are opened without Seller's installation engineer being present.
Damages to boxes, if any, are (i) to be reported on the documents in proof of delivery at the time of arrival and (ii) to be reported to Seller by e-mail/fax within five (5) days thereafter.
Boxes containing accelerator tubes are not to be opened within forty-eight (48) hours after arrival, see elsewhere.

In the event approval for export by the Government of The Netherlands is not received by Seller within sixteen (16) weeks from Seller's application, Seller has the right to extend the time of delivery based on Seller's order backlog at the moment of receipt by Seller of the approval for export by the Government of The Netherlands.

Contract format and acceptance

In support of expeditious application for and decision about approval for export by the Government of The Netherlands:

- The Contract, including all annexes, if any, referred to therein shall be in English or in dual-language (Russian-English).
- The Contract shall clearly state the full name, street address, zip code, city, province/state, country, web-site, phone number, fax number, if any and the name and job title of the authorized representative of Buyer, intermediate Buyer(s), if any, Seller and End-User as well as their obligations in the execution thereof.

Seller shall have accepted the Contract first when and after the Contract has been signed by authorized representatives all parties referred to therein.

Packing

Packed in wooden boxes suitable for transportation by Air and air-suspended Truck and indoor storage.

Accelerator tubes contain glass-to-metal bonding and are as such sensitive to temperature changes and shocks. Accelerator tubes should be handled with extra care and kept at all times in a temperature controlled ambient: Temperature to remain in between +10 and +35 ^{0}C and not to vary more than 10 ^{0}C per hour. Let acclimatize 48 hours before opening the boxes.

Terms of Delivery

DAP (INCOTERMS 2020) Buyer's site, Dubna, Moscow region, Russian Federation, subject to the terms and conditions stated herein.

Mode of Transportation

Equipment will/is to be transported by Truck.

Freight forwarder

Seller is free to select the forwarder it deems best qualified.

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Applicable law and dispute resolution

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Validity

This quotation is valid for three (3) months after date.

Sincerely,

HIGH VOLTAGE ENGINEERING EUROPA B.V.

Henri van Oosterhout
Managing Director

Appendix 6

Estimated cost and description of the main activities planned for implementation within the framework of the project for modernization of the EG-5 accelerator and its experimental infrastructure under the theme "Investigations of Neutron Nuclear Interactions and Properties of the Neutron " with funding under the budget of the current 7-year development plan of JINR in 2021-2022 and under the extended current or new topic on neutron physics in 2023-2024.

This Appendix shows the estimated cost of additional activities within the framework of the modernization project, subject to its extension for 2023-2024 and the availability of the necessary financial resources (table 5).

Table 5.

Estimated cost of the main activities planned for implementation within the framework of the project of modernization of the EG-5 accelerator and its experimental infrastructure, taking into account its extension.

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Stage / Option		Cost, k$
1	Repairing of the accelerator tower premises	100
2	Replacement of a high-voltage tube with divider and ion source	471
3	Automation of technological systems of EG-5	100
5	Modernization of EG-5 research infrastructure: 5.1. Modernization of ion-beam spectrometers complex. 5.2. Installation of an ellipsometric complex	 29 35
6	Installation of a laboratory for the research samples preparation	165
Total		900

The total cost of the project is 900 thousand dollars, of which 52% is the cost of replacing the accelerator HV-tube. It will be paid in 2 stages. Advance Payment of $120,000 will be paid in 2021, and the rest of the sum will be paid in 2022 as part of the announced project. The 18% of the amount is planned to be spent to the creation of a new laboratory for the preparation and study of complementary methods of the powder objects. It is planned to spend $ 100,000 to the repair of production facilities and $100,000 to modernization / automation of service equipment of the accelerator complex. At the same time, $50,000 of the $100,000 will be spent to the purchase of materials, and the remaining $50,000 will be spent on research and development of electronic circuits and software. It is plane to spent $ 29,000 on the development of a new ion-beam spectrometer using the Laboratory recourses. It is plane to use an amount of many which is equivalent to $ 35,000 for the purchase of an ellipsometric complex of domestic production.

Appendix 7

Form № 26 (3 years)

Proposed schedule and necessary resources for implementation of the project
<u>MODERNIZATION OF THE EG-5 ACCELERATOR AND ITS EXPERIMENTAL INFRASTRUCTURE</u>

Names of costs, resources, and sources of funding			Cost (thousands of dollars). resource Requirements	Laboratory proposal for allocation of funding and resources		
				1 год	2 год	3 год
Cost		The main components of the equipment, work on its updating, adjustment, etc.	556	471	50	35
Cost		Construction / renovation of premises	265		100	165
Cost		Materials	79		50	29
Necessary resources	Normo-hour	Resources – design Bureau of the laboratory, - experimental production of JINR, - experimental production of the laboratory, - accelerator, - reactor, - computer. Operating costs	240 standard hours 1000 standard hours	240 standard hours 1000 standard hours		
Source of financing	Budget funds	Budget expenditures, including foreign currency funds	900	471	200	229
Source of financing	Extra budgetary funds	The contributions of the collaborators. Funds for the grants. Contributions from sponsors. Funds under the contracts. Other sources of funding, etc.				

PROJECT LEADER A.S. Doroshkevich

Appendix 8

Cost estimates (3 years) **of the project** MODERNIZATION OF THE EG-5 ACCELERATOR AND ITS EXPERIMENTAL INFRASTRUCTURE

№	Description of expenditure items	Total	2021	**2022**	2023	2024
Items of expenditure						
1	Design	k$				
2	Construction / renovation	k$			100	165
3	Materials	k$			50	29
4	Equipment	k$	120	**351**		35
5	Payment for research performed under contracts	k$			50	
6	travel expenses	k$				
Total		k$	**120**	**351**	200	229

PROJECT LEADER A.S. Doroshkevich