Extended abstract of the report

Project «Modernization of the EG-5 accelerator and development of its experimental infrastructure»: current state of affairs and development strategy»

A promising scientific research program of the investigation in the FLNP with using the electrostatic accelerator will be consider in the report. The results of the planned modernization of the existing accelerator EG-5 by means of HV Europe BV are compared with the options of installing a new accelerator in terms of technical parameters and cost. The purpose of the report was to obtain the PAC recommendations regarding the development strategy for the launch of an electrostatic accelerator for nuclear physics research at JINR.

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1. Introduction.

At present, nuclear physical research using electrostatic accelerators is extremely relevant. Current information on the processes of nuclear transmutation by neutron-induced reactions is essential for astrophysics and nuclear energetic [1]. Data on reactions with the outflow of charged particles induced by fast neutrons are of considerable interest for studying the mechanisms of nuclear reactions, the structure of atomic nuclei, radiation materials science and calculations in the development of new nuclear power plants. Ion-beam spectrometers based on electrostatic accelerators have astronomical accuracy and are extremely important and relevant in modern research involving nanotechnologies. Radiation medicine is an extremely promising and vital area of science. New knowledges about the interaction of high-energy particles with biological objects are needed. At the same time, micro-ion-beam tools allow to penetrate inside the biological cell and study radiation effects at the microscopic level, to carry out scanning spectroscopic studies of solid-state objects (including objects of historical heritage) at the microscopic scale level, to carry out of ion doping of microscopic regions in semiconductor crystals (nanoelectronics and microsystem technique) etc.

Thus, at present there is a wide range of applied and fundamental scientific tasks which is relevant for a number of branches of the national economy, which are related with nuclear reactions on fast neutrons and interaction of high-energy charged particles with living and non-living matter requiring the use of electrostatic accelerators for solving.

1.1. Scientific program of EG-5 group. The JINR Program and Thematic Plan (PTP) outlines two main directions that we plan to develop using an electrostatic accelerator:

1. Study of the properties of excited nuclei, reactions with the escaping of charged particles, fission physics, obtaining relevant data for astrophysics, nuclear energy and the problem of transmutation of nuclear waste by neutron and gamma induced reactions.

2. Application of neutron physics techniques in other fields of science and technology.

Nuclear Physics. The scientific program of the acceleration complex is saturated. The whole spectrum of nuclear reactions with fast quasi-monoenergetic neutrons (directions 1 - 2) supposed to be investigated, including:

- Research of prompt fission neutron spectra (PFN) and Total Kinetic Energies (TKE) in reactions of ^{235}U(n,f), ^{238}U(n,f), ^{237}Np(n,f) in the area of neutron energies of 1-5 MeV/core (EG-5) in geometry with low efficiency of PFN registration;

- Research of (PFN) multiplicity in ^{235}U reactions ^{235}U(n,f), ^{238}U(n,f), ^{237}Np(n,f) on fast neutrons in geometry with high efficiency of PFN registration;

- Investigation of the process *(n,γf)* in the reaction ^{239}Pu (n_{res}, f).

- **Condensed matter Physics.** The following studies are planned using an electrostatic accelerator:

- - A deep element profiles of near-surface layers of solid bodies (multilayer semiconductor type architectures: TiO_2 / SiO_2 / Si, SiO_2 / TiO_2 / Si, GaAs et al.);

- - The composition of elements and isotopes of near-surface layers of solid bodies (Metal (Fe, Cu) and metal-oxide (ZrO_2, CuO, ZnO, SnO_2) solid solutions - ceramics et al.);

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

The work with biological objects, in particular, monitoring of chromosomal aberrations in human blood lymphocytes is planned to.

In addition, the developing a new methodology of working with nanopowder objects, creation of stable collaborations with partners from the Russian Federation, near and far abroad, opening of a new User program on EG-5 spectrometers are planned also.

For a 2020 within the framework of topic № 03-4-1128-2017/2022, and JINR - participating countries cooperation program the next project application forms were submitted:

1. Project "Synthesis, Structure and Magnetic Properties of Tin Dioxide Films Containing Clusters of Magnetic Metals" BSU, 2020, (Scientific Projects within the Framework of the Cooperation Program Belarus - JINR);

2. Project "The study by DLS and RBS methods of structures and elemental composition of surface layer of nanoparticles ZrO_2 under hydration conditions,"UNIVERSITY "LUCIAN BLAGA" of SIBIU, 2020, (Scientific Projects within the Framework of the Cooperation of JINR –Romania);

3. Project "Development and characterisation of magnetic nanostructured systems for targeted cancer therapy by means of Nuclear Physical Methods," National Centre for Nano and Micromaterials - University POLITEHNICA of Bucharest (CNMN-PUB);

4. Project "Investigation of the properties of deposited on different plastic substrates organic thin films after high-energy ion and neutron irrigation," National Institute for Materials Physics (NIMP)" Scientific Projects within the Framework of the Cooperation of JINR -Romania, 2020;

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, "Institute of Physics" of UMKS, Lüblin, 2020, (In the framework of the cooperation program Poland - JINR);

6. Project "The relationship among features of crystal and magnetic structures and physical properties of nanosized ferrites", 2020, (Romania - JINR Research Project Competition);

The interaction with the next scientific groups from Russian Federation, countries of near and far abroad is planned in the future:

- National Institute for Research and Development of Isotopic and Molecular Technologies, Cluj-Napoca, România;
- National Nuclear Research Center CJSC, Baku, Azerbaijan;
- Lisbon University i3N/CENIMAT, Department of Materials Science, Faculty of Science and Technology, New University of Lisbon and CEMOP/UNINOVA, Portugal,
- The University of Dubna, Dubna, Russia.

1.2. Field of application of Van de Graaf-type accelerators. Created on the basis of the Van de Graaf generator, the electrostatic accelerator EG-5 is stationary work in the Department of Nuclear Physics FLNP JINR (Dubna) since 1965. Due to the relative simplicity and reliability of the design, as well as the unique parameters of the ion beam (continuity, high intensity and energy stability (0.01%)) which is peculiar for direct-action accelerators, the ЭГ-5 accelerator is without alternative the most effective and convenient nuclear-physical tool for solving a wide range of topical scientific problems of nuclear physics, condensed meter physics, biology, electronics, medicine, etc.

The development in JINR of experimental nuclear physics (d, d - reactions, neutron-charged particle reactions, study of the passage of nuclear radiation through various media, calibration of neutron detectors, etc.), radiobiology (monitoring of chromosome 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 (study the elemental and isotopic composition, the elemental depth profiles of the surface layer material) etc. were largely due to the possibility of obtaining of the fast neutron fluxes and the accelerated ion beams by using EG-5.

1.3. The uniqueness of Van de Graaf-type accelerators with an energy of over 3MeV. At present, there is a tendency in the world to use electrostatic accelerators mainly for solving applied problems of material science, condensed state physics and medicine. Typically, cheap 2-cascade (tandem) recharges accelerators are produced with accelerated particle energy up to 3MeV are usually produces. Thus elemental composition and ion irradiation can be carried out for example in the Russian Federation no less than 12 nuclear centers, including JINR. Nevertheless, instruments (direct-acting electrostatic accelerators) with energy of more than 3MeV are extremely important for solving a number of unique problems, which are laid down in the Program-Thematic Plan of the JINR.

A significant advantage of the linear direct-acting accelerators to which EG-5 refers is the high spatial and energy stability of the ion beam which makes it possible to create a unique micro-beam spectrometers based on them. The single in the Russian Federation micro-beam spectrometer produced at the Institute of Applied Physics of NASU (Sumy, Ukraine) is located in Sarov and is difficult to access for most users.

Energy stability due to the absence of a charge exchange target is an important factor for achieving high resolution in studies of thin surface layers.

Thus, at present, in JINR is only one accelerator produced in 1965, which potentially has a technical capabilities for solving modern scientific problems of experimental nuclear physics, nuclear astrophysics (star nucleosynthesis) [2] and bionanotechnology.

1.4. Existing scientific background. The measurements of neutron yields from the solid state and gas targets in D (d, n)^{3}He reaction were held using the EG-5 accelerator. The neutron monitor calibration was held to measure the absolute neutron flux in the nuclear physics measurements. The spectrometer of charged particles based on an ionization chamber with a grid and an electronics module for recording, storing and primary processing of data based on PIXIE-4 and PIXIE-16 was made. Testing of a charged particle spectrometer based on a mesh ionization chamber and an electronics module for recording storing and primary processing of data based on PIXIE-4 was made for measurement conducting on an accelerator HV-2500 in the Institute of Experimental and Applied Physics of the Czech Technical University, Prague, Czech Republic.

1.5. Current state of the accelerator. Currently, the experiments with fast neutrons are impossible due to a significant decrease in the accelerator power as a result of the exhaustion of the life of the high-voltage accelerating tube. However, existing parameters of EG-5 are enough for the RBS, ERD, and PIXE ion beam spectrometers operation. Unique non-destructive experimental studies of elemental depth profiles with a depth resolution of about 10 nanometers are currently being carried out on helium ion beams. (RBS method) [3]. There is a unique opportunity to explore layered structures. The limit of sensitivity of a method makes 10^{15} ат. · cm^2 [4] that allows to determine, for example, impurity content in number of 0.001 ат. % [5] or to distinguish substance in the form of a layer up to 1 nanometer in thick. In complex use, the methods of: Elastic Recoil Detection (ERD), Nuclear Reaction Analysis (NRA), Particle Induced X-Ray (PIXE), which are based on proton and helium ion beams with energies ranging from 1 to 3.1 MeV/core are allow to determine with high accuracy the quantitative composition and spatial distribution in the volume of the near-surface layer of all elements of the Mendeleev table and their isotopes (including light hydrogen).

The current technical problem is the physical deterioration of the main units of accelerator and the moral ageing of the scientific and experimental base. The accelerator power loosing (beam current was decreased from 50mkA to 100nA) has led to the impossibility of using it for initiation of the nuclear reactions and to develop a micro-beam spectrometer, which are currently unique options in the JINR and in the Russian Federation.

It should be noted that the problem of aging and stopping accelerators was systemic in the Russian Federation over the last 30 years. Only in the period from 1990 to 2014 the number of accelerators decreased from 27 to 12 - 15 units. The Russian Federation practically stopped development and production of its own accelerators (except for Sarov), while the leading position on production and number of accelerators was assigned to the USA. In order to solve this technical problem in the FLNP according to the Concept of the Seven-Year Development Plan of the JINR for 2017-2023, which provides for the concentration of resources for the renewal of the acceleration and reactor base of the Institute [6] a project for the modernization of the EG-5 accelerator and its experimental infrastructure is appear.

The aim of the proposed project is to provide technical conditions for the implementation of the scientific program of study the processes of interaction of high-energy particles with the substance within the framework of the FLNP Roadmap and the Problem-Thematic Plan JINR, in particular, reactions with fast quasi-monoenergic neutrons, interaction of radiation with biological objects, condensed media, provision of technical capabilities for implementation of the micro-beam project, development of a complex of ion-beam spectrometers RBS, ERD, NRA, PIXE, etc.

2. The following tasks of the project and activities currently being carried out to solve them

The main technical objective of the project **(Task 1)** is **to achieve technological parameters of the EG-5 accelerator**: voltage on the conductor 3.2 - 4.1 MV and a beam current of up to 100 μA (the state of the issue will be discussed below).

An equally important task **(Task 2)** is **the development of instrument infrastructure**, which will maximize the using of the accelerator complex potential, which will increase the yield of scientific products and expand the scope of applicability of existing research methods. Currently, a project of laboratory for the formation of monolithic objects from powder materials is under development. The laboratory is designing by LLC 'SPETSATOMSERVIS OOO'. It is planned to equip the laboratory with complementary nuclear physics methods, in particular, methods for studying the electrical, optical and electronic properties of the surface layers of objects (methods of spectroscopy of electrochemical impedance; voltammetry, ellipsometry). The laboratory will allow for the correction and preparation of samples on the site, to conduct independent studies associated with the research methods of EG-5.

The task of modernizing the scientific and experimental part of the accelerator complex (Task 3). The accelerator equipment which is currently use to studding of the elemental composition of materials was produced more than 50 years ago. It is very outdated in moral terms. Modern ion-beam spectrometric measuring systems have significantly higher productivity.

In order to increase the efficiency of object research and the yield of scientific products, it is proposed to replace obsolete spectrometers (RBS, ERD, NRA and PIXE methods) with a new modern multifunctional analytical module RC43, manufactured by NEC. This module will increase the number of spectrometers in the chamber, expand the operating range and resolutions of the RBS spectrometer, fully automatized the process of sample investigations and data processing, make it transition to modern standards and data formats. The analyzer chamber with the location of the main elements is shown in Fig. 1. Cassette - sample holder allows the simultaneous loading of up to 16 samples. The system is capable of automatically processing signals from seven spectrometers in parallel using the functionality of the appropriate methods:

1. RBS - analysis method (RBS analysis);
2. The method of recoil protons (Elastic Recoil Detection ERD);
3. The method of nuclear reactions (Nuclear Reaction Analysis NRA);
4. Particle Induced X-Ray Emission, PIXE;
5. γ-radiation induced by protons (Proton Induced Gamma Emission, PIGE);
6. Induced by ion flux of luminescence (Ion Beam Induced Luminescence, IBIL);
7. RBS - high resolution analysis (Magnet / MCP high-resolution RBS measuring system).

A commercial proposal for the purchase of an RC43 module by NEC B is currently under consideration.

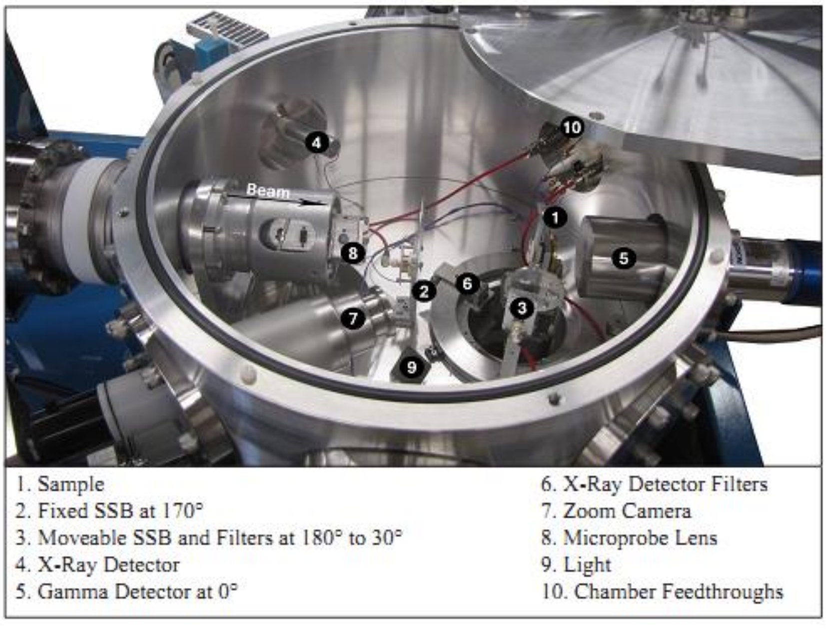

Fig. 1. The working chamber of the ion-beam analyzer RC43 manufactured by NEC. Numbers show the main elements.

The list of the main capabilities of the accelerator complex after the modernization project is given in table. 1.

Table 1.

The capabilities of the accelerator complex before and after the implementation of the modernization project.

Before modernization	After modernization
- Nuclear physics experiments - 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).

In addition to modernizing and expanding the instrument base of the accelerator complex, the project objectives include **bookmark professional staff** for the next 20-30 years (**Task 4**). To solve it, a separate group “EG-5 Installation” has been created as part of the Neutron-nuclear interaction research sector of the Department of nuclear physics of the FLNP. The group includes leading scientists (Dr. A.P. Kobzev, Dr. M. Kulik), highly skilled engineering and technical workers (A.N. Likhachev) and young employees - students of the University of Dubna (9 employees). During the project implementation period a training of future specialists of accelerator complex devices is performs. At the moment a weekly lectures are organized for young people - seminars (M Kulik) and individual practical classes of RBS (M. Kulik, A.P. Kobzev). Mastering of the technical principles of the accelerator and its service systems are carried out (A.N. Likhachev). Young employees are actively participate in scientific conferences, occupies a leading positions at university olympiads and symposia.

Strategy for solving problem 1. Task 1 involves solving 2 sub-tasks:

- achievement by the accelerator of a power which is sufficient for neutrons generations and
- focusing the beam which is sufficient to install a microbeam spectrometer.

Based on the recommendations of the PAC two options for solving Problem 1 was considered:

- Option to repair the old accelerator EG-5 and
- Option with the purchase of a new accelerator of the same class.

3.1. Option with repairing of the existing accelerator EG-5. To solve the problem, it is planned to carry out a number of activities that will be as a separate technical projects. In particular, it is supposed: to implement at least 4 technical projects:

- to replacing a high-voltage accelerating tube;
- for repairing of office premises;
- for replacement of gas compressor equipment;
- for modernization of accelerator service systems (vacuum facilities (switching to oil-free pumping); electronic systems (replacing obsolete appliances); cable facilities (by reason of the exhaustion of the resource); automation of actuators (switching to remotely controlled vacuum shutters in order to ensure emergency shut-off of the accelerator tubes in automatic mode), development of centralized control of the accelerator by means of a computer, project for installing the micro-beam option.

Expected technical parameters of the EG-5 accelerator after modernization. The technical parameters of the accelerator before and after modernization are given in table. 2.

After modernization of the EG-5 accelerator, the accelerator complex will receive the following improvements

- it will be possible to conduct nuclear physics experiments on beams of quasimonochromatic ions.

- it will be possible to install a unique option micro-beam

Table 2.

Technical parameters of the EG-5 accelerator before and after 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**

Estimated cost of modernization of EG-5. The estimate of the main costs for solving problem 1 by repairing the EG-5 accelerator is given in **table. 3**.

Table 3.

Estimated cost estimate for solving task 1 by repairing the EG-5 accelerator

Stage		***Period***	***Cost, (thousand US dollars)***
1	Accelerator technical condition assessment and preparatory work	2020	$2
2	Cosmetic repair of the accelerator tower premise and the control room	2020-2021	$ 90
3	Floor repair under the analyzing magnet in the right experimental room	2020-2021	$ 25
4	Repair of experimental halls and technological premises	2021-2022	$ 25
<u>5</u>	<u>Replacement of a high-voltage tube with divider and ion source</u>	2021	$ 318
<u>6</u>	<u>Automation of technological systems of EG-5</u>	2021-2022	$105
7	Modernization of research infrastructure EG-5. Spectroscopic ellipsometer SER 800 SEN research 4.0; Installation of a complex of spectrometers RBS “Endstation RC43”.	 2021 2021-2022	 $168 $ 628
<u>8</u>	<u>Replacing a compressor in the gas compressor section</u>	2021-2022	$ 64
9	Installation of a laboratory for the research samples preparation	2021-2022	$ 50
Total		2021-2022	$ 1500

As can be seen from table 1. most of the funding is allocated to activities related to the repair of premises and the expansion of instrument infrastructure ($1013). They must be implemented regardless of whether the old accelerator will be repaired or a new one will be purchased. Only the third part ($ 487) is allocated for the purchase of the modules required to restore the accelerator performance (underlined in the table).

Thus, the estimated cost of the modernization project is $ 500 thousand / year. The term of the project is three years.

3.1.1. Brief SWOT-analysis of the repair option EG-5,

Strengths of the updated EG-5. Against the background of updating and expanding the instrument infrastructure (installing a new complex of ion-beam spectrometers, installing a laboratory for the formation of research objects) and laying the human potential, the strength of the updated accelerator option is:

- high quality ion beam (current and focusing) sufficient to achieve the project goal;
- maintainability and full autonomy of the accelerator complex for a long time;
- low operational cost of the installation EG-5;
- advanced training of own engineering personnel in the process of modernization;
- (may be required) the development of its own technological base to provide the necessary conditions for modernization, as well as further maintenance of the accelerator.

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- maintainability and full autonomy of the accelerator complex for a long time;
- low operational cost of the EG-5;
- advanced training of own engineering personnel in the process of modernization;
- development of own technological base to provide the necessary conditions for modernization (may be required), as well as further maintenance of the accelerator.

JINR has all necessary production infrastructure and material resources (spare parts, liquid nitrogen, service systems, etc.), which are necessary for the maintenance of the EG-5 operability for a long period of time after replacing the tube.

EG-5 does not require the use of expensive materials and equipment, does not contain nodes with unknown parameters (programmable microprocessor modules for the service equipment management system, etc.) does not require the visits of foreign specialists for repairs and maintenance work.

This option for solving the main problem is less expensive financially.

Weaknesses options of the updated EG-5. Compared with modern industrial accelerators, the updated EG - 5 has a limited set of functions, the majority of adjustments are carried out manually.

The main risks that may entail failure to meet the deadlines or failure to achieve the required technical parameters by the accelerator may be associated with:
- Errors in the design of the tube at the manufacturer;
- errors in the installing of a new tube;
- the mismatching of the technical conditions provided by the EG-5 service systems (requirements for vacuum, dielectric gas parameters, etc.);
- the presence of additional faults in the accelerator in addition to the loss of parameters of the accelerator tube.

3.2. Option to purchase a new accelerator.

The solution to problem 1. The solution to problem 1 by acquiring a new accelerator involves the following activities - technical projects:
- dismantling of the EG-5 accelerator (in case of using the EG-5 premises);
- overhaul with alteration of technological premises / construction of a new premises;
- installation of a new accelerator and related service systems, personnel training in the operation and maintenance of the new accelerator.

Pricing policy for accelerator manufacturers. The price of accelerator technology ranges from $1 billion (1 GeV, European Spallation Source (ESS) [7]) to $1 million (Pelletron 6SDH, NEC). In niche of compact, cheap and operation systems which allow generating a beams of charged and secondary neutral particles, as well as causing nuclear reactions the electrostatic accelerators of the EG-5 type have the lowest cost. The cost of accelerators with accelerated particle energies of 3 - 5 MeV (linear electrostatic accelerators such as Van de Graaf, Tandetron and others) is on average in the range of 1- $ 10mn. For a rough estimate of the cost of new accelerator C, the following formula is applicable:

$$C = \$\ 1{,}000{,}000 \times V, \text{ where} \qquad (1)$$

V is the maximum energy of accelerated particles.

Accordingly, the estimated cost of the new accelerator of EG-5 class will be about $ 4-5mln.

A comparative analysis of the technical parameters of the EG-5 and new accelerators of the same class.

The tasks of obtaining a high beam power for producing fast neutrons and obtaining a good beam focusing (up to 0.1 mm) for the operation of a micro-beam spectrometer are poorly compatible from the standpoint of modern accelerator technology designing.

In modern accelerators, to increase the energy of accelerated particles and reducing the cost and mass & size characteristics use the principle of recharging, proposed by W. H. Bennett (USA) in 1935, [8]. Using recharging allows to double the energy of accelerated protons and at several times - the energy of heavier particles at the same voltage of the generator: The so-called tandem systems can forms powerful beams (1.3 mA, Tandetron 4130 MC+(HC) 3MV, HVE) that can "accelerate" a wide range of chemical elements, including Au, Si, Ni, etc., however, such systems can’t form a narrowly directed beam (less than 2 mm) required to create a micro-beam spectrometer. The powerful single-stage electrostatic accelerator, for example, of EG-5 or Singletron (HVE) with rather high (more then 4MV) voltage on the conductor is better suitable for such task. Such accelerators are capable to form a narrow-directional beams with the maximum beam current of up to 100mkA. Thus, a trade-off is achieved between the sub-tasks of setting up the micro-beam spectrometer and generating neutrons.

The new accelerators are fully automated and more functional, in particular, they allow pulse mode, quickly change to different modes by voltage and power. Maximal technical characteristics and functionality of the EG – 5 accelerator after modernization and the closest analogues which were offered by the companies NEC and HVE are presented in table. 4.

Table 4.

The limiting technical parameters and functional capabilities of the modernized EG - 5 accelerator and the closest analogues proposed by NEC and HVE.

EG-5 after modernization	**Singletron (HVE)**	**Tandetron (HVE)** 3MV Tandetron 4130 MC+(HC)	**Pelletron - tandem (NEC)** 6SDH
Terminal voltage - **4,1 MeV** Beam ion current – **50-100mkA** Ion beam energies: $^{1}H^{+}$ - **4.0 MeV** Terminal Voltage stability: **±600V**; With sit stabilisation**: ±50V (manual mode)**; Terminal Voltage ripple: 1000V; Whith tde-rippling kit 350V; Pulse regime: **missing**; The ability to accelerate heavy ions: **missing;** The ability to accelerate negative ions: **missing.** Minimal beam size: 0,1mm;	Terminal voltage – **3.5 MV** or **5.0 MV** Beam ion current – **100 mkA** (Short bottle RF ion soursce) - 200 мкА (Long bottle RF ion soursce) Ion beam energies: $^{1}H^{+-}$ - **4.0 MeV** Terminal Voltage stability: **±500V**; With sit stabilisation: **±30V** Terminal Voltage ripple: **1000V**; Whith tde-rippling kit: **350V**; Pulse regime: **present;** The ability to accelerate heavy ions: **present;** The ability to accelerate negative ions: **missing.** Minimal beam size: 0,1mm;	Terminal voltage - **3,3 MV** Beam ion current - **1300mкA** Ion beam energies: **$^{1}H^{+}$ –** 4**.0 MeV** Terminal Voltage stability**: ±400V**; With sit stabilisation: **±30V**; Terminal Voltage ripple**: 300V**; Whith tde-rippling kit: **50V**; Pulse regime: **present;** The ability to accelerate heavy ions: **present;** The ability to accelerate negative ions: **present.** Minimal beam size 2mm;	Terminal voltage - **2 MV** Beam ion current – **50mkA** Ion beam energies: **$^{1}H^{+}$ –$^{-}$ 4.0 MeV** Terminal Voltage stability: *no data;* With sit stabilisation: *no data;* Terminal Voltage ripple: 200V; Whith tde-rippling kit: *no data;* Pulse regime: **present;** The ability to accelerate heavy ions: **present;** The ability to accelerate negative ions: **present.** Minimal beam size: 2mm;
Nuclear physics experiments conducting - **possible;** Microbeam – **possible;** NRA (3,1 MeV) - **possible.**	Nuclear physics experiments conducting - **possible;** Microbeam - **possible;** NRA (3,1 MeV) - **possible.**	Nuclear physics experiments conducting - **possible;** Microbeam – **possible;** NRA (3,1 MeV) - **possible.**	Nuclear physics experiments conducting - **possible;** Microbeam – **possible;** NRA (3,1 MeV) - **possible..**
Work with biological objects – **possible.**	Work with biological objects – **possible.**	Work with biological objects – **possible.**	Work with biological objects – **possible.**
Cost (thousand dollars) : **400**	Cost: (thousand dollars): 4000- 5000*	Cost: (thousand dollars)::**4300**	Cost (thousand dollars): **1000**

*The estimated cost is calculated according to formula 1. the company did not provide the Commercial offer.

From table 4, it follows that the most suitable devices for solving problem 1 (according to technical parameters) are the **EG-5** and the **Singletron** accelerator manufactured by HV Europe BV with a maximum conductor voltage of 3.5 MV or 5MV. Increasing the energy above the limit for EG-5 (4.1 MeV) will expand the available range of fast neutron energies.

The estimated cost of the project for solving problem 1 by repairing the EG-5 accelerator is shown in table 5.

As can be seen from table. 5. even if there are no provide activities to modernize the instrument and base of the accelerator complex, the most of the amount ($4,300,000 out of $5,200,000) is spent on purchasing the accelerator and repairing/building a room for it.

The estimated cost of the modernization project is about $1,700 thousand / year. The Project completion period is three years.

Table 5.

Estimate of the main costs for solving problem 1 by purchasing a new accelerator.

	Stage	***Period***	***Cost, (thousand US dollars)***
1	Major overhaul / new building of the accelerator tower premise	2020-2021	$ 300
	Accelerator purchase	2021	$ 4000 000
3	Modernization of research infrastructure EG-5. Spectroscopic ellipsometer SER 800 SENresearch 4.0; Installation of a complex of spectrometers RBS "Endstation RC43".	 2021 2021-2022	 $168 $ 628
4	Installation of a laboratory for the research samples preparation	2021-2022	$ 50
	Total		$ 5 146 000

.**3.2.1 Brief SWOT analysis of the option for purchasing a new accelerator.**

Strong point of the option with the purchase of a new accelerator. The new accelerator has a number of new features; in particular, it has an option for automatic stabilization of the geometric position of the beam, which is realized in the EG-5 in manual mode. This option is extremely important for the micro-beam spectrometer.

The accelerator can optionally be equipped with an ion source that allows the injection of heavy ions.

The new device has significantly smaller dimensions than EG – 5 and requires a smaller number of maintenance personnel.

Buying a new accelerator removes the risks of incompatibility of the new tube with EG-5 service systems, etc.

The new device consists of new parts and blocks that have a full resource and, therefore there is a lower probability of failure than in the EG-5.

The manufacturer accelerator company will remotely advise accelerator maintenance personnel in troubleshooting and monitor the state of the accelerator throughout its useful life.

The purchase of a new accelerator will be accompanied by the construction of a specialized room in which special design will be provided for the suppression of reflected neutron flows, 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 complex high-tech elements that cannot be repaired by the EG-5 technical staff. It will be need to invite the manufacturer's specialists for repairs it. Thus, the FLNP becomes dependent on the manufacturer and its service centers. NEC Company as an option offers branded service of the device on site for 10-20 thousand dollars a year. It can be assumed that approximately this amount will be required annually on average for maintenance of the accelerator with the involvement of specialists from the service centers of manufacturers.

In the Russian Federation, there is absent a components base and consumables needed to repair of complex defects. The spare parts will have to be ordered from the manufacturer. Deliveries may be affected by the political situation in the world. The manufacturer produces parts for old models no more than 20 years, and after then terms the parts which can't have modern analogues will need to be made to special order for a lot of money.

The new accelerator has a horizontal design, which will lead to serious alterations of the EG-5 permission (In case of installation in the room EG-5) and a significant increase in the cost of repair and construction works.

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

4. Conclusion

At the current stage of the Scientific and technological development there is a wide range of current scientific problems that can be solved using spectrometers of the accelerator complex based on linear electrostatic accelerators with energy of accelerated particles up to 5MeV.

Modernization of the electrostatic accelerator EG-5 and development of it's experimental infrastructure will solve a number of problems from the Problem-Thematic Plan of the JINR (theme 03-4-1128-2017/2022 «Investigations of Neutron Nuclear Interactions and Properties of the Neutron»). In particular, it will provide research of reactions with fast quasi-monoenergetic neutrons and the possibility to work with biological objects. In addition, a base will be prepared for the implementation of the micro-beam spectrometer project, the productivity of available methods (RBS, ERDA, NRA, PIXE) will be improved and their spectrum will be significantly expanded due to the modern unique techniques HR RBS, Proton Induced Gamma Emission (PIGE), Ion Beam Induced Luminescence. The experimental base will be supplemented by non-beam complementary methods of investigating the electrical, optical and electronic properties of the surface (Ellipsometry, impedance spectroscopy). A laboratory will be installed to produce a wide range of objects under investigation, including powders. Re-equipping the experimental part with modern automated equipment will allow transition to 24-hour operation mode.

The modernized accelerator will allow obtaining energy up to 4.1 MeV with beam current of up to 100mkA/nucleon, and its experimental base will have a standard interface of Beam Analysis (IBA) Endstation System platform.

The implementation of this project on the JINR scale should be considered as a preparatory but mandatory stage in the development of the accelerator complex. As an international nuclear research center JINR should provide an opportunity to solve scientific problems at a high technical level to a wide range of researchers from participating countries. A wide range of current scientific tasks indicates the need to purchase in perspective an additional new modern electrostatic accelerator with an energy of accelerated particles of the order of 5 MeV or higher, which corresponds to the concept of the seven-year development plan for JINR for 2017-2023, which provides the concentration of resources for updating the accelerator and reactor base of the Institute [9].

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