**APPROVED**

**JINR Vice-Director**

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**" " 2023**

**SCIENTIFIC AND TECHNICAL REASONING FOR THE**

**RENEWAL OF LARGE RESEARCH INFRASTRUCTURE PROJECT**

**IN RESEARCH AREA WITHIN THE TOPICAL PLAN FOR JINR RESEARCH**

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

**1.1. LRIP**: 03-0-1129-2017

**1.2. Laboratory**: Flerov Laboratory of Nuclear Reactions

**1.3. Scientific field:** Heavy-ion physics

**1.4.** **The title the LRIP:** Development of the FLNR Accelerator Complex and Experimental Setups (DRIBS-III)

**1.5. LRIP Leaders:** I.V. Kalagin, S.I. Sidorchuk

**LRIP Scientific leader:** Yu.Ts. Oganessian

**1.6. LRIP Deputy Leaders:** V.A.Semin, A.V.Yeremin

**2. Scientific case and theme organization**

**2.1. Annotation**

The scientific program of the Flerov Laboratory of Nuclear Reactions in heavy-ion physics includes experiments on the synthesis and study of properties of heavy, superheavy and light exotic nuclei using ion beams of stable and radioactive isotopes, study of the nuclear reactions mechanism. The development of accelerator technology and the FLNR experimental setups is a continuous task of the Laboratory.

The fleet of accelerators in the Flerov Lab includes three cyclotrons DC-280, U-400, U-400M and a cyclic implanter IC-100, designed to produce intense ion beams from C to W with the energy of 1.0 - 1.2 MeV/nucleon for irradiation of polymer films and performing of a wide range of scientific and applied research. The microtron MT-25 accelerating electrons to an energy of 25 MeV is successfully used in joint applied studies with scientists from the Russia, Kazakhstan, Mongolia, Vietnam, Cuba, and other countries.

The LRIP includes two subprojects:

* The project “The U-400R Accelerator Complex” that in turn falls into three subprojects:
  + - modernization of the cyclotron U-400 ( U-400R after upgrade);
    - construction of a new experimental hall;
    - construction of new physical separators and ion beam lines for transporting beams from the U-400R.
* The project “Development of the experimental setups for the study of chemical and physical properties of superheavy elements” combines two subprojects:
  + separator for study of chemical properties of short-lived SH nuclides based on a superconducting solenoid (GASSOL);
  + Multi-Reflection Time-Of-Flight (MR-TOF) spectrometer for precise measurement of masses of heavy and superheavy nuclides.

Furthermore, the Laboratory continues construction and launching the DC-140 cyclotron complex for applied research. These works are carrying on in the framework of the "Project for the creation of the JINR Innovation Research Center," in the part "Research Complex in the FLNR for Materials Science".

Another significant part of the LRIP is the support for physical experiments and development of existing accelerators and experimental setups.

**2.2. LRIP subprojects**

1. The U-400R Accelerator Complex;
2. Development of the experimental setups for the study of chemical and physical properties of superheavy elements;

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

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

The Superheavy Element (SHE) Factory based on a specialized DC-280 cyclotron and equipped with new-generation experimental facilities, is the most important component of the DRIBs-III (Dubna Radioactive Ion Beams) project. The full-scale implementation of this project is a priority task for the Flerov Laboratory of Nuclear Reactions for the period 2024–2030, the phased solution of which will significantly expand the possibilities for conducting fundamental and applied nuclear physics research at JINR at the highest level in broad cooperation with scientific centers of the Member States of the Institute and other countries. In the period 2024–2030, the following is planned:

1. Development of methods for obtaining intense beams of 48Ca, 50Ti, 54Cr, etc.

2. Development of a fleet of experimental facilities. This item is seen as the subproject of the LRIP entitled as "Development of the experimental setups for the study of chemical and physical properties of superheavy elements". It falls into two subsubprojects: **Superconducting gas filled separator GASSOL and Multi-reflection TOF mass spectrometer.**

**Subsubproject I*.* Superconducting gas filled separator GASSOL*.***

Magnetic gas-filled separator (GASSOL) is intended for the study of atomic properties and chemical behavior of superheavy elements including those with rather short half-lives: T1/2< 0.5 s. The design of the setup is based on the use of a superconducting solenoidal magnet. The main task of the separator, apart from effective separation of reaction products, is focusing nuclei of interest into the spot of the diameter less than1 cm2.

**Subsubproject II*.* Multi-reflection TOF mass spectrometer*.***

A dedicated high resolution mass spectrometer is intended for the measurement of the masses of superheavy elements with Z=104-118 and A=266-294 and their radioactive decay products with the accuracy <100 keV. Operating principle of the spectrometer is based on the use of multi-reflection time of flight (MR TOF) technique.

**Reconstruction of the U-400 accelerator complex.** These works are included into the subproject “The U-400R Accelerator Complex”. The goal is the creation of the U-400R accelerator complex for detailed study of mechanisms of nuclear reactions with stable heavy-ion beams (fusion-fission, quasifission, multinucleon transfer, etc.), production of new nuclides with the use of those reactions as well as decay spectroscopy of nuclei of interest.

The subproject includes the construction of a new Experimental Hall, the upgrade of the U-400 cyclotron and the construction of new separators and ion guides for beam transportation.

The complex will be used for the detailed study of isotopes of heavy and superheavy elements, as well as to search for new methods of the synthesis of heavy nuclides. These studies do not imply the use of radioactive target materials in amounts exceeding 105 Bq.

Extension of experimental areas through the construction of a new building is one of the main purposes of the Subproject. The area of the existing experimental hall of the U-400 cyclotron makes about 200 m2. The physical facilities located on two levels of the hall occupy almost the entire available area. New facilities require additional space. The design of the radiation shielding of the existing hall does not allow preparation for one experiment while another is underway. To provide conditions for further development a project of a new experimental hall was proposed and the work on the preparation of this project was highly appreciated by the 54th PAC meeting in 2021. Experimental caves of a total area of about 1100 m2 are intended for placing the equipment of experimental facilities.

The reconstruction of the cyclotron being the second main task of the subproject will be carried out, with a focus on:

* increase in the intensity of accelerated beams of 48Са ions up to 2-2.5 рμА;
* upgrade of a beam extraction system. The upgraded system will provide beam extraction both with a re-charging foil and an electrostatic deflector, which will improve beam quality;
* smooth variation of the beam energy in a wide range of ion mass-to-charge ratios A/Z, which is important for experiments on the dynamics of fusion-fission reactions, multinucleon transfer MNT reactions, and experiments on nuclear spectroscopy;
* decrease of the energy spread of the beam to 3·10-3;
* decrease of the maximum level of the magnetic field in the center of the cyclotron from 2.1 T to 1.8 T, which will significantly reduce the power consumption of the cyclotron and reduce the level of the scattered magnetic field.

Along with the construction and reconstruction of the cyclotron, new experimental facilities will be created. At the current stage it was proposed to include in the project construction of a kinematic separator consisting of the combination of an electric deflector, a magnetic sector, and a detector station for studying the characteristics of MNT reactions and properties of radioactive decay of neutron-rich isotopes of heavy elements formed in MNT reactions. The separator is intended for operation with high beam intensity to provide reliable separation of heavy and superheavy nuclei at high background suppression. The separator has to provide high efficiency of the transmission of fusion and transfer reaction products.

Development of new setups of the U-400R accelerator complex will be one of the main tasks for FLNR for the seven year period 2024-2030. One more setup, provisionally called SCIF-D, is intended for the study of mechanisms of fusion-fission reactions. Besides, the facility allows detecting three coincident particles, two of them are fission products, thus providing an important piece of information on the MNT mechanism. The SCIF-D spectrometer will make it possible to measure the cross sections of various processes, mass-energy, charge, and angular distributions of reaction fragments and evaporation residues. It is planned to conduct experiments using high-intensity beams varying from Ne to U and actinide targets*.* In addition, the simultaneous measurement of all kinematic characteristics of nuclear reaction fragments will make it possible to determine their excitation energy, which is extremely important for estimating their survival during de-excitation process, and can also provide information on the reaction time.

The complete scheme of the SKIF-D spectrometer is now under discussion. The base component of the future facility will be CORSET time-of-flight spectrometer, complementary parts could be electrostatic beam deflector for measuring evaporation residues, magnetic mass analyzer, Bragg chambers. During 3 years (from 2024 to 2026) in the frame of this **activity** we plan to perform complete technical project of the SCIF-D facility.

**Construction and launching the DC-140 cyclotron for applied research**

The construction and launching of the DC-140 cyclotron is aimed at creation of the accelerator complex for basic research and application of heavy ion beams in the fields of solid state physics, surface modifications of materials, production of track membranes, testing of electronic component base components (ECB) on single radiation effects (SEE). This includes creation of the specialized compact heavy ion accelerator with multi-charge ion injector based on an ion source of the ECR type and having three specialized channels.

The DC-140 cyclotron will produce accelerated ion beams from O to Bi with energies of 4.8 and 2.1 MeV/nucleon for solid state physics research and surface modification of materials, track membrane production and ECB SEE testing. Beams with an energy of 4.8 MeV/nucleus will provide ion penetration depth in Si up to 55 μm and LET in Si up to 100 MeV \* cm2/mg for effective SEE testing. Beams with an energy of 2.1 MeV/nucleus will allow the production of track membranes based on polymer films up to 30 microns thick.

The project of the DC-140 accelerator complex is on its final stage of implementation. It is expected that the complex will be commissioned in 2024.

**Support of physical experiments and development of experimental setups**

Continuous works are foreseen aimed at the support of physical experiments and development of experimental setups. This includes:

* improving the operation stability of accelerators as well as increasing the intensity and quality of ion beams of stable and radioactive nuclides in the energy range from 1 to 100 MeV/nucleon;
* support of experiments at the SHE Factory with the existing DGFRS-2 and GRAND setups:
* development of the infrastructure of the ACCULINNA-2 fragment separator (RF kicker, tritium target complex) at the modernized U-400M cyclotron;
* development of ion sources for cyclotrons;
* implementation of applied research program at the IC100 cyclotron and the MT-25 microtron;
* development of methods for beam diagnostics of stable and radioactive nuclides;
* development of the velocity filter SHELS (Separator for Heavy ELement Spectroscopy) with GABRIELA α, β, γ- detectors array located in the existing U400 experimental hall;
* development of the detector system in the focal plane of the MAVR analyzer and the MULTI spectrometer comprising a 4π-neutron detector and a gamma-detector;

**Risks**

The main risks are linked to restrictions on the purchase of a number of equipment manufactured in the EU and the USA (vacuum equipment, high-voltage power supplies, detectors and electronic equipment), which may cause delays in the implementation of the project. In addition, the risk of construction delay due to the fault of the contractor is not excluded.

**2.4. Participating JINR laboratories**

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

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Organization** | **Country** | **City** | **Participants** | **Type**  **of agreement** |
| ITEP | Russia | Moscow | Kulevoy T.V. + 4 pers. | Collaboration |
| NNRU "MEPhI" |  | Moscow | Polosov S.M. + 3 pers. | Collaboration |
| NRC KI |  | Moscow | Guchkin A.S. Ushakov A.M. | Collaboration |
| INR RAS |  | Moscow, Troitsk | Feschenko A.V. | Collaboration |
| IAP RAS |  | Nizhny Novgorod | Golubev S.V. + 5 pers. Litvak A.G. | Collaboration |
| BINP SB RAS |  | Novosibirsk | Logachev P.V. + 5 pers. | Collaboration |
| VNIIEF |  | Sarov | Yukhimchuk A.A. + 3 pers. | Collaboration |
| NFNC-VNIITF |  | Snezhinsk | Mamaev I.V. + 3 pers. | Collaboration |
| IAI RAS |  | St. Petersburg | Yavor M.I. + 2 pers. | Collaboration |
| NIIEFA |  | St. Petersburg | Sychevsky S.E.  Strokach A.P. + 12 pers. | Collaboration |
| CU | Egypt | Giza | Samman H.El. | Collaboration |
| MU |  | Shibin El Kom | Ozman H.A. | Collaboration |
| INP | Kazakhstan | Almaty | Batyrbekov E.G. + 3 pers. | Collaboration |
| BA INP |  | Astana | Zdorovets M.V. + 3 pers.  Koloberdin M.V. | Collaboration |
| ENU |  | Astana | Kuterbekov K.A. | Collaboration |
| NRC NUM | Mongolia | Ulaanbaatar | Zuzaan Р. | Collaboration |
| INS "VINCA" | Serbia | Belgrade | Belicev P.  Vujovic V.  Petrovic S. | Collaboration |
| IMP CAS | China | Lanzhou | Gan Z. + 6 pers. | Contract |
| iThemba LABS | South Africa | Somerset West | Bark R.  Makhathini L.  Mira J.  Mlungisi Nkosi+ 3 pers.  Rudolph Nchodu  Le Roux Strydom +3 pers. | Collaboration |
| NMU |  | Gqeberha | Smith Farouk | Collaboration |
| SU |  | Stellenbosch | Barnard A. + 2 pers. | Collaboration |
| VUT |  | Vanderbijlpark | Abou el Hossein Khaled | Collaboration |

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

**3. Manpower**

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

|  |  |  |  |
| --- | --- | --- | --- |
| **№№**  **n/a** | **Category of personnel** | **JINR staff,**  **amount of FTE** | **JINR Associated**  **Personnel,**  **amount of FTE** |
| 1. | research scientists | 15.6 |  |
| 2. | engineers | 15.2 |  |
| 3. | specialists | 1.5 |  |
| 4. | technicians | 3.0 |  |
|  | **Total:** | **35.3** |  |

**3.2. Available manpower**

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

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **n/a** | **Category of employees** | **Division** | **Position** | **Amount FTE** |
| 1. | scientific staff |  |  |  |
|  |  | FLNR | Head of sector | 2 |
|  |  | FLNR | Head of group | 0.4 |
|  |  | FLNR | Senior researcher | 2.4 |
|  |  | FLNR | Researcher | 4 |
|  |  | FLNR | Junior researcher | 6.8 |
| 2. | engineers |  |  |  |
|  |  | FLNR | Deputy chief engineer | 0.3 |
|  |  | FLNR | Head of department | 1.1 |
|  |  | FLNR | Deputy head of department | 0.3 |
|  |  | FLNR | Head of department | 0.3 |
|  |  | FLNR | Head of bureau | 0.4 |
|  |  | FLNR | Head of setup | 0.5 |
|  |  | FLNR | Head of service | 0.3 |
|  |  | FLNR | Leading engineer | 2 |
|  |  | FLNR | Senior engineer | 4.8 |
|  |  | FLNR | Engineer | 4 |
|  |  | FLNR | Senior lab assistant | 0.8 |
|  |  | FLNR | Senior technician | 0.4 |
| 3. | professionals |  |  |  |
|  |  | FLNR | Safety senior engineer | 0.3 |
|  |  | FLNR | Document specialist | 0.6 |
|  |  | FLNR | Leading engineer | 0.6 |
| 4. | workers |  |  |  |
|  |  | FLNR | technician | 0.4 |
|  |  | FLNR | Senior technician | 0.8 |
|  |  | FLNR | mechanic | 1.5 |
|  |  | FLNR | mechanic | 0.3 |
|  | **Total:** |  |  | **35.3** |

**3.2.2. JINR associated personnel**

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

**4. Financing**

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

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Items of expenditure** | **Cost** | **Expenditure per year**  **(thousands of the US dollars)** | | | | | | |
| 1st  year | 2nd  year | 3rd  year | 4th  year | 5th  year | 6th  year | 7th  year |
| 1. | International cooperation | 490 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| 2. | Materials | 13 300 | 1100 | 1300 | 1100 | 1300 | 1400 | 3400 | 3700 |
| 3. | Equipment, Third-party company services | 35 500 | 5110 | 4410 | 4700 | 4140 | 4940 | 6000 | 6200 |
| 4. | Commissioning | 240 | 30 | 30 | 40 | 30 | 30 | 40 | 40 |
| 5. | R&D contracts with other research organisations | 360 | 60 | 60 | 60 | 30 | 30 | 60 | 60 |
| 6. | Software purchasing | 280 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| 7. | Design/construction | 18 000 | 9000 | 8000 | 1000 | - | - | - | - |
| 8. | Service costs (*planned in case of direct project affiliation)* |  |  |  |  |  |  |  |  |
| **TOTAL:** | | **68 170** | **15 410** | **13 910** | **7 010** | **5 610** | **6 510** | **9 610** | **10 110** |

**4.2. Extra funding sources**

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

**AGREED:**

**Chief Scientific Secretary Laboratory Director**

**/\_Nedelko S.N.\_ / /\_Sidorchuk S.I. /**

**" " 2023 " " 2023**

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

**/\_Kalinin N.V.\_ / /\_** **Karpov A.V./**

**" " 2023 " " 2023**

**Head of DSOA Laboratory Economist**

**/\_\_\_\_\_\_\_ / /\_Mamonova T.V. /**

**" " \_\_\_\_\_\_\_ 2023 " " 2023**

**Head of HRRMD LRIP leader**

**/\_Kolganova E.A.\_\_\_/ /\_Kalagin I.V. /**

**" " \_\_\_\_\_\_ 2023 " " 2023**

**/\_ Sidorchuk S.I. /**

**" " 2023**

**LRIP Subproject leader ( )**

**/ Popeko A.G /**

**“ “ 2023**

**LRIP Subproject leader ( )**

**/ Kalagin I.V. /**

**“ “ 2023**

**LRIP Subproject leader ( )**

**/ Yeremin A.V. /**

**“ “ 2023**