**APPROVED**

**JINR DIRECTOR**

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

**SCIENTIFIC AND TECHNICAL REASONING FOR THE OPENING**

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

**1. General information on the project**

* 1. **Theme code** 03-5-1130-2017

**1.2 Project**

**1.3 Flerov Laboratory of Nuclear Reactions**

**1.4 Scientific field:** Heavy-ion physics

**1.5 The name of the Project** Investigation of heavy and superheavy elements

**1.6 Project Leaders:** M.G. Itkis, A.V. Karpov

**1.7 Project Deputy Leader(s):** none

**2 Scientific rationale and organisational structure**

**2.1 Annotation**

In 2020 a next-generation accelerator complex, Superheavy Element Factory (SHE Factory), was commissioned in JINR. The novel facility opened up unique opportunities for experiments aimed to study nuclear, atomic, and chemical properties of the heaviest elements of the Mendeleev's periodic table.

First experiments at the SHE Factory of JINR were conducted during 2020-2023. A series of experiments were performed on the synthesis of the isotopes of elements 115 (moscovium) and 114 (flerovium) in the 243Am+48Ca and 242Pu+48Ca reactions, respectively. The Factory has proved to outpace manyfold all existing current-generation instruments, thereby offering a wide range of possibilities for further experiments on superheavy nuclei.

The Project aims to study the heaviest nuclei and atoms in a comprehensive way: conducting experiments on the synthesis of elements with Z=119 and Z=120; synthesizing new isotopes of superheavy elements; studying the nuclear (spectroscopy) and chemical properties of superheavy elements; investigating nuclear reaction dynamics, including multinucleon transfer reactions, leading to the formation of neutron-rich heavy nuclei.

**2.2.**Feasibility study (a goal, relevance and novelty of research, methods and approaches, methodology, expected results, risks)

Experiments that have been performed at the DGFRS separator of the Flerov Laboratory of Nuclear Reactions (FLNR JINR) over the last 20 years resulted in the discovery of the region of superheavy elements. Six superheavy elements with atomic numbers 113 through 118 were synthesized for the first time. The radioactive properties of about 55 new, the heaviest isotopes of elements from Lr to Og were studied. Their production cross sections were measured in reactions of 48Са ions with various actinide target isotopes.

The largest cross sections of about 10–15 pb were observed for the isotopes of Fl and Mc. Decreasing significantly with increasing atomic numbers, the cross sections for the isotopes of heavier elements Lv, Ts, and Og amounted to 4, 2.5, and 0.5 pb, respectively. Further investigations of superheavy nuclei and the synthesis of new, heavier elements 119 and 120 required higher experimental sensitivity because their production cross sections could be an order of magnitude lower than that for Og.

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| Fig. 1. DC-280 cyclotron of SHE Factory |

To further explore superheavy nuclei in FLNR JINR, a novel experimental complex, Superheavy Element Factory (SHE Factory), was constructed. The basic facility of the Factory, DC-280 cyclotron (Fig.1), is capable of producing beams with intensities tenfold higher than those provided by the existing U-400 cyclotron. The first experimental set-up for the synthesis and study of superheavy nuclei was the novel DGFRS-2 separator (Dubna gas-filled recoil separator). In comparison to DGFRS, the transmission efficiency of DGFRS-2 was doubled and higher suppression of background reaction products was provided. Nevertheless, higher experimental sensitivity is required for a more detailed study of superheavy elements as well as synthesis of new elements because the production cross sections for elements 119 and 120 may reach tens and even a units of femtobarns.

Further investigation of the heaviest nuclei and atoms will focus on three main areas: synthesis of new elements with Z>118; extension of the region of the known isotopes of superheavy elements; and studies of the nuclear and atomic (chemical) properties of SHE.

**Synthesis of superheavy nuclei and study of their decay properties**

The studies of neutron-deficient superheavy nuclei allow the evaluation of the influence of the neutron shells *N*=162 and *N*=184 on the nuclei stability, acquisition of new data on their properties and the probability of their formation in reactions. One of the possible ways of approaching stability limits in moving away from the island of stability may be the synthesis of new SHE isotopes via the emission of an increased number of neutrons. This is possible at higher 48Ca beam energies. Such experiments are also of interest with respect to the examination of the excitation function in a wide excitation energy range, allowing, in particular, a more reliable estimation of fission barriers. Ion beams with a fewer number of neutrons could be another way to probe the contours of the island of stability.

Experiments involving neutron-deficient target nuclei are also on the agenda. Thus, the following reactions will be used for synthesizing and studying nuclei with an odd number of protons:

1. 241Am(48Ca,2-5n)284-287Mc. This is a cross reaction for the synthesis of element 119 in the 243Am(54Cr,3-4n)293,294119 285,286Mc reaction, which is necessary for reliable identification of the isotopes 293,294119.

2. 231Pa(48Ca,3-5n)274-276Rg. In the reaction under consideration, new isotopes 275,276Rg and their daughter nuclei 281,282Mt, 268Bh, and 264Db can be produced; a decay chain from the region of superheavy nuclei to the region of the known nucleus (through 267Bh) can be observed for the first time; and the known isotope 274Rg, produced earlier in a cold fusion reaction, can be synthesized.

The investigation of nuclei with an even number of protons will be pursued in the reactions of 48Ca with the light isotopes of uranium: 233U(48Ca,3-4n)277,278Cn and 235U(48Ca,3-4n)279,280Cn, leading to the new isotopes 278-280Cn and 274Ds. In addition, the known isotope 277Cn that was produced earlier in cold fusion can be synthesized. Furthermore, the properties of 273,275,276Ds and the products of their α-decay can be more thoroughly studied.

The series of experiments will allow a substantial extension of systematics for the cross sections for the reactions of actinide targets and 48Ca, α-decay energies, spontaneous fission half-lives, and for the α-decay of nuclei.

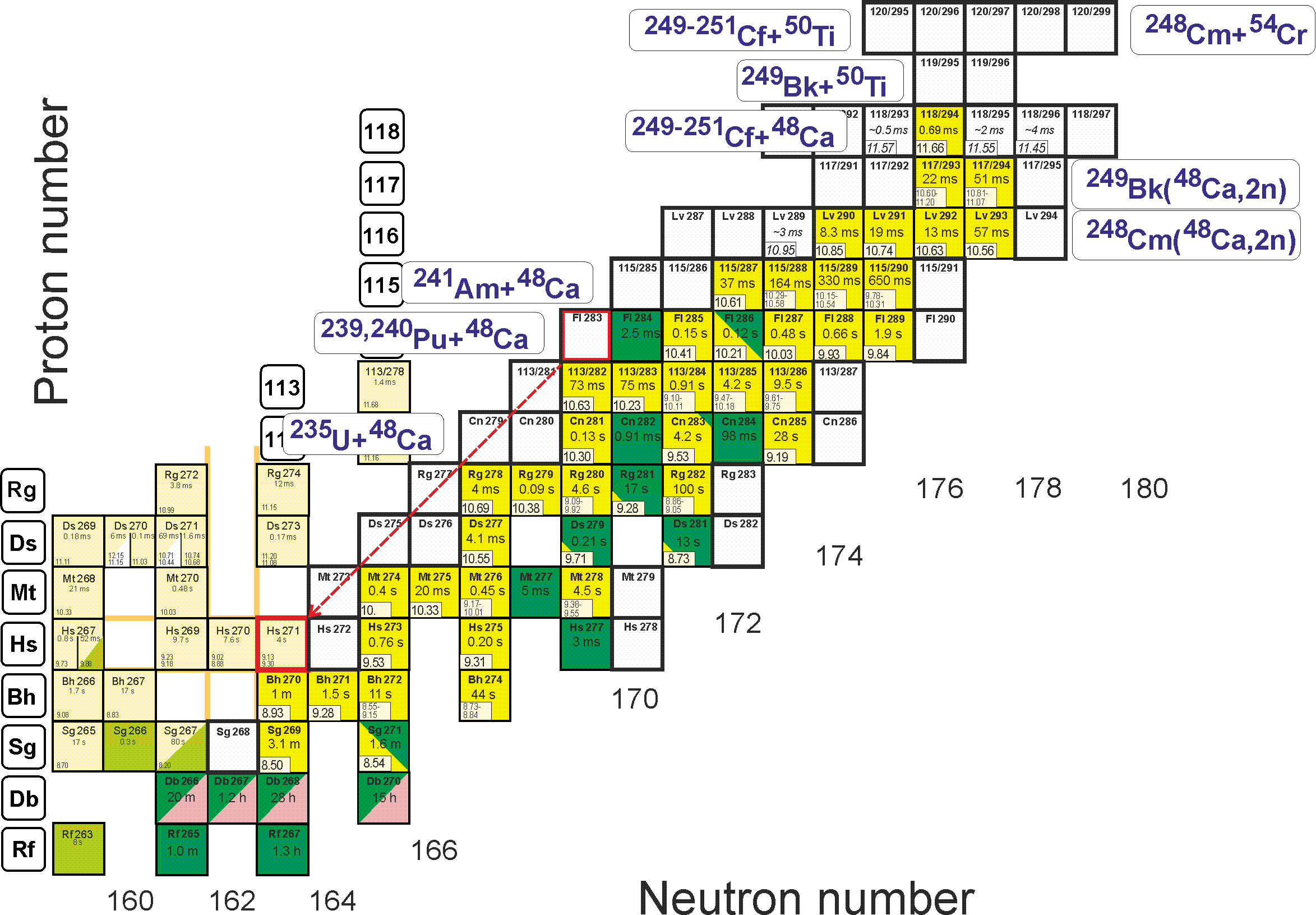
Another task of current importance is advancing toward the domain of even heavier isotopes of SHE. Several paths are possible to making isotopes in reactions with 48Ca:

1. using more neutron-rich targets (for example, 250,251Cf isotopes);

2. searching for evaporation-residue production events in 1-2n channels;

3. searching for reaction channels with the emission of a proton and neutrons. Reactions with the 248Cm and 244Pu targets are particularly promising in terms of an increased neutron number in the residual nucleus;

4. registering SHE isotope formation events following electron capture, predicted by theory but have not yet been observed experimentally in the region near the island of stability.



**Fig. 2.** Upper part of the nuclear chart. Open boxes show some of new isotopes of SHE that can be synthesized at the SHE Factory.

**Synthesis of new superheavy elements**

One of the most important tasks for 2024–2030 is the synthesis of the isotopes of new elements 119 and 120, which will necessitate the use of projectiles that are heavier than 48Ca (such as 50Ti and 54Cr). A number of experiments and calculations have shown that the production cross sections for the isotopes of new elements may be 1–2 orders of magnitude lower than that for the heaviest known isotope 294Og. To date no experimental data are available on the cross sections for the reactions of 50Ti and 54Cr with actinide target nuclei. A series of experiments on the synthesis of lighter nuclei are required so as to evaluate a decrease in the cross sections. Such reactions include:

1. 244Pu(50Ti,3-4n)290,291Lv and/or 238U(50Ti,3-4n)284,285Fl. Measuring the cross sections for the reactions will allow a more precise evaluation of the probability of synthesizing the isotopes of new elements 119 and 120 in reactions with the 50Ti beam fired at the targets of 249Bk and 249−251Cf.

2. 238U(54Cr,3-4n)288,289Lv. Studies of the reaction are necessary for understanding the possibility of synthesizing elements 119 and 120 in 54Cr-induced reactions with the 243Am and 248Cm targets. The reaction can lead to the new isotopes 288,289Lv whose decay results in the production of the known 284,285Fl nuclei.

Three reactions are considered for the synthesis of element 119 (see Fig. 2):

1. 249Bk(50Ti,3-4n)295,296119. The α-decay of the synthesized nuclides leads to the unknown nuclei 291,292Ts, but since the decay properties of the daughter nuclei 287,288Мс are well known, the identification of the isotopes 295,296119 will be reliable.

2. 243Am(54Cr,3-4n)293,294119. The lighter isotopes 293,294119 can be synthesized in the reaction, the products of their α-decay being the unknown nuclei 289,290Ts. However, the properties of nuclei in the decay chain of the daughter nucleus 286Мс have been recently measured, and the properties of 285Мс can be determined upon studying the 241Am+48Ca reaction.

In summary, the isotopes of element 119 can be unequivocally identified using all the reactions mentioned above.

The following reactions can be used for synthesizing element 120: 249–251Cf+50Ti or 245,246,248Cm+54Cr. The final decision on the reaction choice will be based on the results of preliminary experiments as well as the availability of target material and attained beam intensities. The 295,296120, 296,297120, and 298,299120 nuclei are produced in reactions with the above target isotopes via the 3n- and 4n evaporation channels, respectively. The α-decays of nuclei under consideration lead to the known 270–273Hs or known isotopes of heavier elements Ds, Cn, Fl, Lv, and Og. A number of as-yet-unknown isotopes can be synthesized and identified in experiments with light uranium isotopes in the 233U(48Ca,3-4n)277,278Cn and 235U(48Ca,3-4n)279,280Cn reactions.

The identification of all the isotopes of element 120 mentioned above will thereby be unambiguous, resulting from the cross reactions and the properties of daughter nuclei described earlier.

**Spectroscopy of the radioactive decay of heavy and superheavy nuclei**

The development of experimental heavy-ion physics techniques over the last years has allowed spectroscopy of the region of nuclei heavier than fermium (Z ≥ 100). The properties of the radioactive decay of heavy and superheavy nuclei can be studied in FLNR JINR using the SHELS velocity filter (U-400 accelerator complex) and the gas-filled GRAND separator of the SHE Factory commissioned in 2022 (Fig.2).



**Fig. 3**. GRAND (GFS-3) separator

The FLNR research programme is significantly extending our understanding of the properties of nuclear matter in the region of heavy, mainly neutron-deficient, nuclei. The measurements of partial half-lives and the decay energy, as well as studies of isomerism of heavy nuclei, expand the frontiers of knowledge that will drive the development of nuclear models and the assessment of the limits for the existence of nuclear systems. Carried out earlier at the SHELS, the studies of the properties of spontaneous fission and the structure of nuclei heavier than fermium (up to 257Db) provided new data on nuclei with neutron numbers from 149 to 155 located in the vicinity of the deformed neutron subshell N=152. Experiments at the GRAND separator allow close examination of the structure of nuclei near the subshell at N=162, thus extrapolating the received data more reliably to the region of the isotopes of superheavy elements.

First, these studies aim to explore the properties of radioactive decay, determine the positions of low-lying energy levels, and estimate the isomeric states of nuclei. The SHELS and GRAND separators constructed in FLNR, in combination with the GABRIELA detector system comprising five "clover" high-purity germanium detectors, allow the registration of alpha- and gamma-decays with record efficiency, providing data about the structure of the heaviest nuclei.

Second, spontaneous fission of heavy nuclei is examined. Of fundamental importance are studies of prompt fission neutron yields, the determination of complete fusion cross sections leading to the formation of spontaneously fissioning nuclei, stability of nuclei against spontaneous fission (partial half-lives) and other types of decay (alpha-, beta-decay). For performing research, the combined detector system SFiNX is used, with the focal multi-strip semiconductor detector surrounded by 114 neutron counters.

The bulk of the studies implemented under the Project (2024–2028) will be carried out at the GRAND separator of the SHE Factory owning to the U-400 shutdown for upgrade. The planned upgrades to the components and systems of SHELS include the development of a new target unit with a larger exit aperture, modernization of beam diagnostic systems, and tests of detector systems using a digital data acquisition system. When completed, the refurbishment is expected to contribute to a significant increase (up to 50%) in the transmission efficiency for evaporation residues in asymmetric hot fusion reactions (Ne,Mg + Th,U,Pu), allowing for the study of transfermium nuclei in the deformed subshell region *N*=162.

Furthermore, the SHE Factory will enable experiments on the spectrometry of nuclei with Z> 110. Studies on the synthesis of flerovium isotopes (Z = 114) carried out at DGFRS-2 showed a yield of superheavy nuclei up to several events per day. In 2024–2028 we are planning on conducting a number of pioneering experiments on the spectroscopy of superheavy nuclei. First experiments will focus on studying the 286,287Fl and 288Mc nuclei synthesized by firing high-intensity beams of 48Ca ions into the targets of 242Pu and 243Am at cross sections of several picobarns. The SHE Factory is capable of synthesizing the isotopes of interest in amounts sufficient for obtaining spectrometric data. One of the most profound issues is the measurement of a spectrum of low-lying collective states containing direct information about the deformation of nuclei, one of the key properties of the nucleus.

**Measurement of the masses of superheavy nuclei**

The energy measurements of alpha particles emitted during the radioactive decay of SHE give the mass differences between the mother and daughter nuclei along the α-decay chains with an accuracy of about 30 keV (some uncertainty in values may be due to the fine structure of the alpha decay in odd-A and odd–odd nuclei). A direct experimental measurement of the mass of at least one nucleus in the decay chain, provided that the accuracy is close to 30 keV, will allow us to determine the masses of all nuclei in that decay chain. It should be emphasized that masses predicted by theory generally have an uncertainty of at least one order of magnitude higher. Therefore, experimentally measured masses with an accuracy in the order of 10-7 (30 keV) will lay the foundation for theoretical mass models to be further refined.

In 2020–2022 a preliminary design of the multireflection time-of-flight mass spectrometer, meeting the requirements with respect to the mass measurement precision, was elaborated in collaboration with the Institute for Analytical Instrumentation RAS in Saint-Petersburg. The construction of the instrument is planned in the upcoming seven-year period at FLNR JINR. The spectrometer will be installed at the SHE Factory, following the GRAND separator and the cryogenic gas catcher. First experiments using the novel mass spectrometer are planned under the Project in 2027–2028.

**Study of the chemical properties of SHE**

A key role of nuclear chemistry in studying SHE is the separation of SHE radioisotopes from complex mixtures of nuclear reaction products, chemical identification, and the study of their properties using radiochemical methods. The investigation of the chemical properties of SHE, from Z = 112 to Z=118, are fundamental to understanding the structure of the Mendeleev's periodic table and to adhering to the periodic law. The predictions of the behaviour of new elements and their chemical identification, based on the analogies and regularities of the periodic table, are rather complicated due to stronger relativistic effects in the region of superheavy atoms taking over to govern the electronic structure of superheavy atoms and, in turn, their chemical properties.

One of the important avenues of research in the chemistry of transactinides is the experimental studies of the volatility and inertness of Cn, Nh, and Fl (Z = 112–114), the heaviest elements within reach of current experimental facilities. The results of quantum chemical calculations and pioneering thermochromatographic studies performed in FLNR show drastic differences in the chemical behavior of Fl and its closest homologue, lead. This may point to an anomalously strong influence of relativistic effects on the electronic structure of Fl atoms, resulting in the stability of elemental Fl, and, perhaps, its oxide under standard conditions, too. Research will be pursued at the currently upgraded Cryogenic Detector set-up, following studies at the GRAND physics separator (2024–2026).

The chemical studies of elements heavier than Fl, i.e. those with atomic numbers 115 through 118, are of particular interest. Given low production cross sections and short half-lives of their isotopes (less than 0.1 s), novel approaches and set-ups are required, beyond the constraints of conventional radiochemical methods.

Further research in FLNR will be centered around the superconducting GASSOL separator based on a gas-filled solenoid, a cryogenic gas ion catcher, and a novel chemical set-up. The GASSOL set-up aims at studies of the chemical properties of nuclides with the lifetimes markedly below the one-second level. First experiments aimed at studying Mc ions, and perhaps Lv, are planned for 2027–2028.

Theoretical quantum chemical calculations, needed in studying the chemical properties of superheavy elements, not only help plan experiments and interpret results, but also draw conclusions about SHE properties whose direct measurement is currently out of reach of experimental techniques. Such properties include the ability of atoms to form chemical compounds, for instance, oxides and hydroxides. The calculation results show that the adsorption energy of the FlO and CnO oxides on gold was higher than that of copernicium and flerovium in the atomic states by a factor of 2–3. Similarly, the adsorption energy of NhOH on a quartz surface is higher than that of nihonium in the atomic state. Changes in experimental conditions and the comparison of experimental adsorption data with the results of theoretical calculations will also allow us to either confirm or disprove the formation possibility of these compounds in the recoil chamber.

Model experiments with ultramicro quantities of the nearest light homologues of SHE (elements of the 6th period) are of great importance in studying the specific features of the chromatographic method and the currently developed techniques in moving toward *single-atom chemistry*. Thus is developed an irradiation system for producing the radioisotopes of Hg, Tl, Pb, Bi, At, Rn, etc. at the U-400M accelerator. These elements will be used in model experiments with a view to developing methodological approaches at the single-atom level and selecting promising chemical reactions for the synthesis of oxides, hydroxides, hydrides, etc. in terms of optimal yields and system equilibrium.

In this connection, studies focusing on the development of *wet* methods for radiochemical separation of radioisotopes synthesized in multinucleon transfer reactions or in studies of low-yield reactions are also on the agenda. Of the greatest interest are experiments on the chemical identification of the new isotope 264Lr with a half-life of about 5 h, a product of the α-decay of 268Db. The chemical properties of dubnium and its radionuclide, 268Db, should also come under scrutiny. The longest half-life (about 16 h) of all SHE isotopes and the highest cross section for the 243Am(48Ca,3*n*)288Mc reaction, along with the availability of target material, suggest that experiments with 268Db may be unique.

Development of methods will be continued for manufacturing actinide targets from Th to Cf stable under long, intense heavy-ion irradiation. These targets will be used for SHE synthesis.

**Dynamics of heavy-ion nuclear reactions**

Reactions with heavy ions are characterized by a strong overlap of several competing reaction channels, which are: quasi-elastic scattering, deep-inelastic collisions, quasi-fission, fusion-fission, and fusion-survival. Experiments planned to be performed at the modernized U400R cyclotron will be aimed at the study of reaction mechanisms as well as at the use of different reaction channels as a method for production and study of new nuclei. In reaction studies we will mainly concentrate on studying competition of fusion-fission and quasifission processes as well as on studying multinucleon transfer (MNT) reactions, which are being considered as an alternative and promising way of the production of new (especially neutron-rich) nuclei. At the latter case, the key characteristics of reactions are cross-sections (see Fig. 4) angular (see Fig. 5 for predicted strong sensitivity of the angular distributions to the reaction energy as well as to the exit channel of interest) and energy distributions, etc. Another important requirement to be fulfilled is a possibility to measure binary and triple (sequential fission of one of the fragments) exit channels. It will give an access to larger transfer channels, which mainly undergo fission (difference between dashed curve and thick solid curve in Fig. 4) As a next step, decay properties (decay spectroscopy) of new nuclei produced in MNT reactions can be studied. The region of neutron-rich isotopes of transuranium, and even transfermium, elements is of particular interest.

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| **Fig. 4.** Calculated cross sections for different nuclei produced in 238U+238U collisions at 7 MeV/u beam energy down to 1 b. The dashed curve show the 1b cross section level for primary (excited) products, while the solid ones correspond to final (survived) reaction products. |

The study of the competition between the processes of complete fusion and quasi-fission is an important task of nuclear physics allowing in particular to estimate the fusion cross section for synthesis of superheavy elements. Since quasi-fission can probably be observed already for fairly light systems with Z1Z2 ≈ 700, it is extremely important to measure all possible channels, both for the reactions leading to the formation of heavy and superheavy systems and for the reactions with light and medium nuclei. There are great difficulties in distinguishing these processes. For estimation of the cross section of the fusion-fission process and more accurate distinguishing of fission fragments of the compound nucleus, it is necessary to measure the cross section of evaporation residues. Measurements of the cross sections of the evaporation residue, fusion-fission, and quasi-fission will make it possible to determine this dependence and conduct a deeper theoretical analysis of the dynamics of a reaction under study. It is extremely important to carry out these measurements in a single experiment at the same values of the interaction energy.

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| *E*c.m.=420 MeV MeV  450 MeV MeV  643 MeV MeVMeV |
| **Fig. 5.** Predicted angular distributions of iridium isotopes produced in the 136Xe+198Pt reaction at three collision energies: *E*c.m.=420, 450, and 643 MeV. The thick histograms correspond to 203Ir126, while the thin ones show calculations for all produced iridium isotopes. |

The following is planned under the project:

1. Studies of shell effects in multinucleon transfer reactions with a view to analyzing a possibility of synthesizing neutron-rich isotopes of superheavy elements in collisions of actinide nuclei (238U+238U, 238U+248Cm reactions).
2. Studies of the properties of nuclei along the N=126 shell are also of great importance for understanding the astrophysical r-process governing the nucleosynthesis of the heaviest nuclei (136Xe+176Yb, 198Pt, 238U+198Pt reactions).

The construction and development of experimental set-ups will be a focus during the U-400 accelerator upgrade into U-400R, with a view to providing exhaustive data on reactions under investigation, involving simultaneous measurements of masses, atomic numbers, energies and emission angles of reaction products, as well as the properties of accompanying processes – emission of light particles (γ-quanta, neutrons, α particles). Such an approach will provide valuable insights for the deeper understanding of the specific features of heavy-ion reactions, help clarify the parameters of existing theoretical models describing the dynamics of heavy-ion interactions and expand their use in terms of both the interaction energy and the region of nuclei under consideration.

Risks: target material supplies and corresponding licensing; provision of necessary equipment and materials, development of technologies for obtaining beams of 50Ti, 54Cr, and 238U with high intensity and stability.

**2.3 Estimated completion date 2028**

**2.4 Participating JINR laboratories: FLNR**

**2.4.1** **MICC resource requirements**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Computing resources** | **Distribution by year** | | | | |
| 1st year | 2nd year | 3rd year | 4th year | 5th year |
| Data storage (TB)  - EOS  - Ribbons | - | - | - | - | - |
| Tier 1 (core-hour) | - | - | - | - | - |
| Tier 2 (core-hour) | - | - | - | - | - |
| SC Talker (core-hour)  - CPU  - GPU | - | - | - | - | - |
| Clouds (CPU cores) | - | - | - | - | - |

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

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| --- | --- | --- |
| **Organisation** | **Country** | **City** |
| IMP CAS | China | Lanzhou |
| GSI | Germany | Darmstadt |
| MPIK | Germany | Heidelberg |
| VECC | India | Kolkata |
| IIT Roorkee | India | Roorkee |
| IIT Ropar | India | Rupnagar |
| MU | India | Manipal |
| IUAC | India | New Delhi |
| Unina | Italy | Naples |
| INP | Kazakhstan | Almaty |
| CGL | Mongolia | Ulaanbaatar |
| IFIN-HH | Romania | Bucharest |
| SSC RIAR | Russia | Dimitrovgrad |
| IPTP | Russia | Dubna |
| INEOS RAS | Russia | Moscow |
| MSU | Russia | Moscow |
| NRC KI | Russia | Moscow |
| SINP MSU | Russia | Moscow |
| VNIIEF | Russia | Sarov |
| IAI RAS | Russia | St. Petersburg |
| Ioffe Institute | Russia | St. Petersburg |
| KRI | Russia | St. Petersburg |
| SPbSU | Russia | St. Petersburg |
| INR RAS | Russia | Moscow, Troitsk |
| CU | Slovakia | Bratislava |
| iThemba LABS | South Africa | Somerset West |
| PSI | Switzerland | Villigen |

**2.6. Co-executing organisations** *(those collaborating organisations/partners without whose financial, infrastructural participation the implementation of the research programme is impossible. An example is JINR's participation in the LHC experiments at CERN).*

**3. Staffing**

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

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| --- | --- | --- | --- |
| **№№**  **n/a** | **Category**  **employee** | **Core staff,**  **Amount of FTE** | **Associated**  **Personnel**  **Amount of FTE** |
| 1. | scientific staff | 41 | - |
| 2. | engineers | 21.2 | - |
| 3. | professionals | ~~-~~ | ~~-~~ |
| 4. | employees | ~~-~~ | ~~-~~ |
| 5. | workers | ~~-~~ | ~~-~~ |
|  | **Total:** | **62.2** | **-** |

**3.2. Human resources available**

**3.2.1. JINR core staff**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **No.** | **Category of personnel** | **Full name** | **Division** | **Position** | **Amount**  **of FTE** |
| 4. | research scientists | Dmitriev S.N. | JINR Directorate | Vice-director of JINR |  |
| 5. | research scientists | Eremin A.V. | FLNR | Deputy director of FLNR |  |
| 6. | research scientists | Popeko A.G. | FLNR | Deputy director of FLNR |  |
| 7. | research scientists | Utyonkov V.K. | FLNR | Head of sector |  |
| 8. | research scientists | Svirikhin A.I. | FLNR | Head of sector |  |
| 9. | research scientists | Aksenov N.V. | FLNR | Head of sector |  |
| 10. | research scientists | Kozulin E.M. | FLNR | Head of sector |  |
| 11. | research scientists | Voinov A.A. | FLNR | Head of group |  |
| 12. | research scientists | Malyshev O.N. | FLNR | Head of group |  |
| 13. | research scientists | Popov Yu. A. | FLNR | Head of group |  |
| 14. | research scientists | Madumarov A.Sh. | FLNR | Head of group |  |
| 15. | research scientists | Sabelnikov A.V. | FLNR | Head of group |  |
| 16. | research scientists | Bodrov A.Yu. | FLNR | Head of group |  |
| 17. | research scientists | Rodin A.M. | FLNR | Head of group |  |
| 18. | research scientists | Subbotin V.G. | FLNR | Leading research scientist |  |
| 19. | research scientists | Izosimov I.N. | FLNR | Leading research scientist |  |
| 20. | research scientists | Chepigin V.I. | FLNR | Senior research scientist |  |
| 21. | research scientists | Sokol E.A. | FLNR | Senior research scientist |  |
| 22. | research scientists | Bozhikov G.A. | FLNR | Senior research scientist |  |
| 23. | research scientists | Knyazheva G.N. | FLNR | Senior research scientist |  |
| 24. | research scientists | Krupa L. | FLNR | Senior research scientist |  |
| 25. | research scientists | Abdullin F.Sh. | FLNR | Research scientist |  |
| 26. | research scientists | Polyakov A.N. | FLNR | Research scientist |  |
| 27. | research scientists | Tsyganov Yu.S. | FLNR | Research scientist |  |
| 28. | research scientists | Sagaydak R.N. | FLNR | Research scientist |  |
| 29. | research scientists | Haleshappa M. D. | FLNR | Research scientist |  |
| 30. | research scientists | Itkis Yu.M. | FLNR | Research scientist |  |
| 31. | research scientists | Rachkov V.A. | FLNR | Research scientist |  |
| 32. | research scientists | Satyan S. | FLNR | Research scientist |  |
| 33. | research scientists | Saiko V. | FLNR | Research scientist |  |
| 34. | research scientists | Salamatin V.S. | FLNR | Research scientist |  |
| 35. | research scientists | Chernysheva E.V. | FLNR | Research scientist |  |
| 36. | research scientists | Kogout P. | FLNR | Research scientist |  |
| 37. | research scientists | Shumeyko M.V. | FLNR | Junior research scientist |  |
| 38. | research scientists | Kovrizhnykh N.D. | FLNR | Junior research scientist |  |
| 39. | research scientists | Solovev D.I. | FLNR | Junior research scientist |  |
| 40. | research scientists | Ibadullayev D. | FLNR | Junior research scientist |  |
| 41. | research scientists | Isaev A.V. | FLNR | Junior research scientist |  |
| 42. | research scientists | Kuznetsova A.A. | FLNR | Junior research scientist |  |
| 43. | research scientists | Tazekbayeva M. | FLNR | Junior research scientist |  |
| 44. | research scientists | Astakhov A.A. | FLNR | Junior research scientist |  |
| 45. | research scientists | Pishalnikova E.V. | FLNR | Junior research scientist |  |
| 46. | research scientists | Albin Yu.V. | FLNR | Junior research scientist |  |
| 47. | research scientists | Abdusamadzoda D. | FLNR | Junior research scientist |  |
| 48. | research scientists | Novikov K.V. | FLNR | Junior research scientist |  |
| 49. | research scientists | Bogachev A.A. | FLNR | Junior research scientist |  |
| 50. | research scientists | Vedeneev V.Yu. | FLNR | Junior research scientist |  |
| 51. | research scientists | Novoselov A.S. | FLNR | Junior research scientist |  |
| 52. | research scientists | Kogoutova A. | FLNR | Junior research scientist |  |
| 53. | research scientists | Opihal A. | FLNR | Junior research scientist |  |
| 54. | engineers | Kuznetsov D.A. | FLNR | Engineer |  |
| 55. | engineers | Salaubekov B. | FLNR | Engineer |  |
| 56. | engineers | Mukhin R.S. | FLNR | Engineer |  |
| 57. | engineers | Chuprakov I. | FLNR | Engineer |  |
| 58. | engineers | Bublikova N.S. | FLNR | Engineer |  |
| 59. | engineers | Goltsman A.I. | FLNR | Engineer |  |
| 60. | engineers | Saveleva E.O. | FLNR | Engineer |  |
| 61. | engineers | Kurkova N.Yu. | FLNR | Engineer |  |
| 62. | engineers | Abakumov A. M. | FLNR | Engineer |  |
| 63. | engineers | Petrushkin O.V. | FLNR | Leading engineer |  |
| 64. | engineers | Chelnokov M.L. | FLNR | Leading engineer |  |
| 65. | engineers | Starodub G.Y. | FLNR | Leading engineer |  |
| 66. | engineers | Rykhlyuk A.V. | FLNR | Leading engineer |  |
| 67. | engineers | Kozulina N.I. | FLNR | Leading engineer |  |
| 68. | engineers | Podshibyakin A.V. | FLNR | Leading engineer |  |
| 69. | engineers | Vostokin G.K. | FLNR | Senior engineer |  |
| 70. | engineers | Voronyuk M.G. | FLNR | Senior engineer |  |
| 71. | engineers | Pchelintsev I.V. | FLNR | Senior engineer |  |
| 72. | engineers | Vorobev I.V. | FLNR | Senior engineer |  |
| 73. | engineers | Gulyaev A.V. | FLNR | Senior engineer |  |
| 74. | engineers | Yukhimchuk S.A. | FLNR | Senior engineer |  |
| 75. | engineers | Komarov A.B. | FLNR | Senior engineer |  |
| 76. | engineers | Tikhomirov R.S. | FLNR | Senior engineer |  |
| 77. | engineers | Zubareva A.M. | FLNR | Engineer |  |
| 78. | engineers | Vakatov V.I. | FLNR | Engineer |  |
| 79. | engineers | Katrasev D.E. | FLNR | Engineer |  |
| 80. | engineers | Muravev I.V. | FLNR | Engineer |  |
| 81. | engineers | Porobanyuk L.S. | FLNR | Engineer |  |
| 82. | engineers | Krasnoyarova E.V. | FLNR | Engineer |  |
| 83. | engineers | Gulyaeva A.V. | FLNR | Engineer |  |
|  | **Total:** |  |  |  | **62.2** |

**3.2.2. JINR associated personnel**

|  |  |  |  |
| --- | --- | --- | --- |
| **№№ п/a** | **Category of employees** | **Partner organisation** | **Amount of FTE** |
| 1. | Scientific employees | - | - |
| 2. | engineers | - | - |
| 3. | professionals | - | - |
| 4. | workers | - | - |
|  | **Total:** | **-** | **-** |

**4. Financial support**

**4.1 Total estimated cost of the project**

Forecast of the total estimated cost (specify cumulatively for the whole period, excluding FPC).

The details are given in a separate form.

**9 000 000 USD**

**4.2 Extrabudgetary funding sources**

Estimated funding from co-executors/customers - total.

**Project Leader** \_\_\_\_\_\_\_\_\_\_/M.G. Itkis/

**Project Leader** \_\_\_\_\_\_\_\_\_\_/A.V. Karpov/

Date of submission of the project to DSOA: \_\_\_\_\_\_\_\_\_

Date of decision of the laboratory's STC: \_\_\_\_\_\_\_\_\_ document number: \_\_\_\_\_\_\_\_\_

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

(for renewable projects) -- Project start year: \_\_\_\_\_\_\_

**Schedule proposal and resources required for the implementation   
of the Project / Sub-project of the LRIP**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Names of costs, resources,**  **sources of funding** | | | **Cost (thousands**  **of dollars)**  **resource requirements** | **Cost,**  **distribution by year** | | | | |
| 1st year | 2nd year | 3rd year | 4th year | 5th year |
|  | | International cooperation (IC) | 1 250 | 250 | 250 | 250 | 250 | 250 |
| Materials | 3 000 | 600 | 600 | 600 | 600 | 600 |
| Equipment and third-party services (commissioning) | 6 000 | 1 200 | 1 200 | 1 200 | 1 200 | 1 200 |
| Services of research organisations | - | - | - | - | - | - |
| Acquisition of software | 175 | 35 | 35 | 35 | 35 | 35 |
| Design/construction | - | - | - | - | - | - |
| Service costs (*planned in case of direct project affiliation)* | - | - | - | - | - | - |
| **Resources required** | **Normo-hours** | Resources |  |  |  |  |  |  |
| * the amount of FTE, |  | 62.2 | 62.2 | 62.2 | 62.2 | 62.2 |
| * accelerator/installation, | - | - | - | - | - | - |
| * reactor,…. |  |  |  |  |  |  |
| **Sources of funding** | **Budgetary resources** | JINR budget *(budget items)* | It. 4 - 1250  It. 5,6 – 9000  It. 11 – 175 | - | - | - | - | - |
| **Extrabudgetary (supplementary estimates)** | Contributions by  co-contractors  Funds under contracts with customers  Other sources of funding | - | - | - | - | - | - |

Project Leader\_\_\_\_\_\_\_\_\_/M.G. Itkis/

Project Leader\_\_\_\_\_\_\_\_\_/A.V. Karpov/

Laboratory Economist \_\_\_\_\_\_\_\_\_/T.V. Mamonova/

**APPROVAL SHEET FOR PROJECT / SUBPROJECT OF THE LRIP**

NAME OF THE PROJECT: Investigation of heavy and superheavy elements

DESIGNATION OF THE PROJECT

PROJECT CODE

THEME CODE: 03-5-1130-2024

NAME OF THE PROJECT LEADERS: M.G. Itkis, A.V. Karpov

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  | |
| AGREED |  |  |  | |
| JINR VICE-DIRECTOR | \_\_\_\_\_\_\_\_\_\_\_  SIGNATURE | S.N. Dmitriev | \_\_\_\_\_\_\_\_\_  DATE |  |
| CHIEF SCIENTIFIC SECRETARY | \_\_\_\_\_\_\_\_\_\_\_  SIGNATURE | S.N. Nedelko | \_\_\_\_\_\_\_\_\_  DATE |  |
| CHIEF ENGINEER | \_\_\_\_\_\_\_\_\_\_\_  SIGNATURE | B.N. Gikal | \_\_\_\_\_\_\_\_\_  DATE |  |
| LABORATORY DIRECTOR | \_\_\_\_\_\_\_\_\_\_\_  SIGNATURE | S.I. Sidorchuk | \_\_\_\_\_\_\_\_\_  DATE |  |
| CHIEF LABORATORY ENGINEER | \_\_\_\_\_\_\_\_\_\_\_  SIGNATURE | I.V. Kalagin | \_\_\_\_\_\_\_\_\_  DATE |  |
| LABORATORY SCIENTIFIC SECRETARY  THEME LEADER | \_\_\_\_\_\_\_\_\_  SIGNATURE  \_\_\_\_\_\_\_\_\_  SIGNATURE | A.V. Karpov  S.I. Sidorchuk | \_\_\_\_\_\_\_\_\_  DATE  \_\_\_\_\_\_\_\_\_  DATE |  |
| PROJECT LEADER | \_\_\_\_\_\_\_\_\_\_  SIGNATURE | M.G. Itkis | \_\_\_\_\_\_\_\_\_  DATE |  |
| PROJECT LEADER | \_\_\_\_\_\_\_\_\_\_  SIGNATURE | A.V. Karpov | \_\_\_\_\_\_\_\_\_  DATE |  |
| APPROVED BY THE PAC | \_\_\_\_\_\_\_\_\_\_\_  SIGNATURE | \_\_\_\_\_\_\_\_\_  NAME | \_\_\_\_\_\_\_\_\_  DATE | |