SCIENTIFIC AND TECHNICAL JUSTIFICATION FOR PROLONGATION OF THEME IN THE JINR TOPICAL PLAN for 2022-2023

Theme code 03-5-1129-2017/2023 **Flerov laboratory of nuclear reactions**

Field of research: Nuclear Physics

Theme title: Development of the FLNR accelerator complex and experimental setups (DRIBS-III)

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Scientific Leader: Yu.Ts. Oganessian

Theme funding:

(USD, in thousands)

No.	**Budget item**	**2022**	**2023**
1	Wages	2 922.4	2 922.4
2	International cooperation on research and development	60.0	60.0
3	Materials, equipment	12 400.0	10 870.0
4	Electric energy, water		
5	Operational costs	120.6	132.6
6	Basic facility	2 039.8	2 092.3
7	General and administrative costs	897.1	971.8
	TOTAL:	**18 439.8**	**17 049.1**

ABSTRACT

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 exotic nuclei using ion beams of stable and radioactive isotopes, study of the nuclear reaction mechanisms. The development of accelerator technology and the FLNR experimental set-ups is an integral part of the elaboration of the program of the Laboratory physical experiments.

DEVELOPMENT OF THE FLNR ACCELERATOR COMPLEX

To be implemented by (FLNR staff): G.G. Gulbekyan, I.V. Kalagin, V.A.Semin + 77 persons, N.F. Osipov + 16 persons, S.V. Paschenko + 50 persons.

U-400 CYCLOTRON

The FLNR has developed the project of the U400 accelerator reconstruction. It is planned to start the modernization of the cyclotron in 2023. The parameters of the existing U-400 and the reconstructed U-400R cyclotrons are shown in Table 1.

The main goals of the reconstruction:

1. Improvement of the parameters of the accelerated ion beams:

- Ensuring a smooth variation of the accelerated ion energies within the working diagram with an accuracy $\Delta E/E=5\cdot10^{-3}$.
- Decrease of the energy spread in the ion beam on the physical target to $\Delta E/E=10^{-3}$.
- Improvement of the ion beams emittance at the target to 10π mm·mrad.
- Increase in the intensity of accelerated ions of rare stable isotopes.

2. Expansion of the experimental areas, construction of the new experimental hall having three radiation isolated zones.

Table 1. Compared parameters of the U-400 and U-400R cyclotrons.

Name	U-400	U-400R
Magnet weight	2100 t.	2100 t.
The power supply of the main magnet	850 kW	200 kW
The magnetic field level	1.93 - 2.1 Tesla	0.8 - 1.8 Tesla
The angular length of the sector at the final radius	42°	42°
The gap between the sectors at the final radius	45 mm	45 mm
The gap between the poles in the valley	300 mm	300 mm
Number of dees	2	2
Voltage on the dees	80 kV	80 kV
The range of accelerated A/Z	5 - 12	4 - 12
The range of acceleration frequencies	5.42 - 12.2 MHz	5.42 - 12.2 MHz
Accelerating field harmonics	2	2÷6
The final acceleration radius	1.72 m	1.8 m
The energy factor K	305 - 650	100 - 506
The working vacuum	$(1\text{-}5)\cdot10^{-7}$ Torr	$(1\text{-}2)\cdot10^{-7}$ Torr
Beam extraction	Charge exchange	Charge exchange and/or electrostatic deflector
Number of extraction lines	2	2

The magnetic system reconstruction

The U-400 reconstruction project assumes a reduction in the magnetic field level in the cyclotron center from 1.93-2.1 to 0.8-1.8 Tesla. The work will be carried out without changing the design of the main magnet. Only sector hasps and correction coils will be replaced. The ranges of change of magnetic field and frequency harmonics of the U-400R cyclotron shown in Fig. 1. Comparative working diagrams of U400 cyclotron and U400R one (for the ion extraction radius R_{extr} of 1.8 m) are shown in Fig. 2.

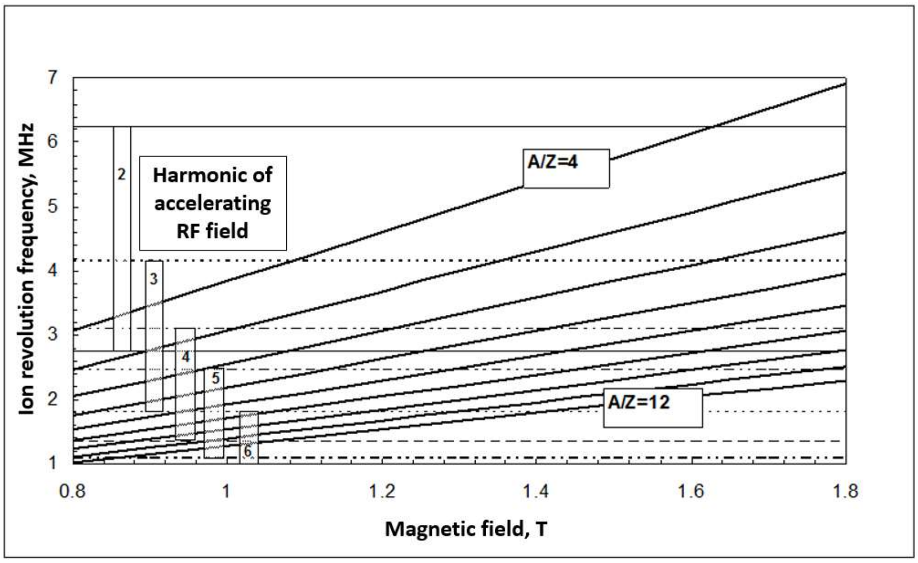

Fig. 1. Ranges of change of magnetic field and frequency harmonics of the U-400R.

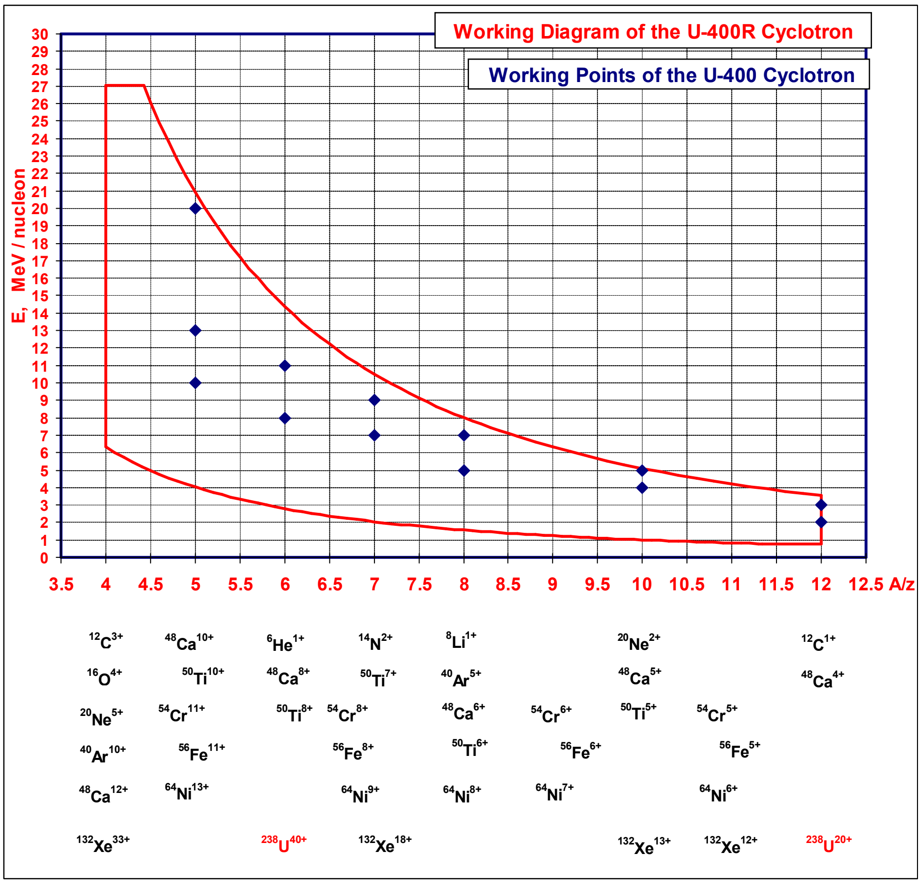

Fig. 2. Comparative working diagrams of U400 and U400R (R_{extr}=1.8 m).

The isochronous magnetic field of the U-400R has to be formed up to the radius of 1.8 m. As the first step the magnetic field was simulated with the 3-dimensional code. After the new magnetic elements being installed, magnetic field optimization will be performed using shimming and correction coils.

Reconstruction of the axial injection system

The horizontal section of the beam axial injection system from the ECR source to the bending magnet is proposed to be made shorter to reduce the space charge effects. To reduce losses in the horizontal section and in the bending magnet, we propose increasing the aperture of the first SL lens from 80 to 100 mm and the gap of the AM90 bending magnet to 110 mm.

Calculations show that for focusing ions into the inflector input at reduced magnetic field the additional solenoid S4 at a distance of 750 mm from the median plane is required. The maximal field of the solenoid is 1.3 kG at the effective length of 500 mm.

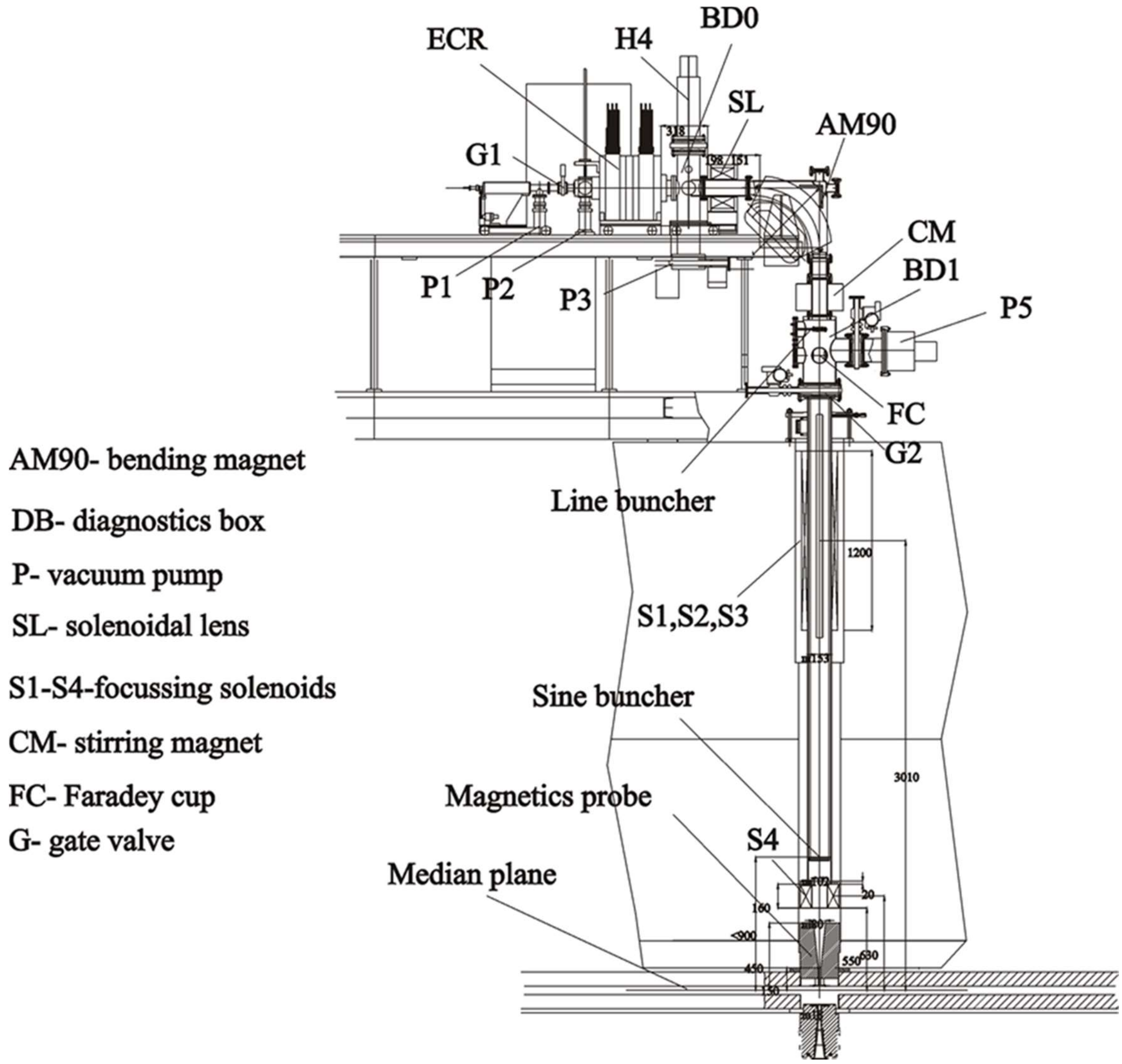

Fig. 3. The U-400R axial injection system.

Reconstruction of the extraction system

Both charge exchange and electrostatic deflector methods for ion beam extraction from the U-400R are being considered.

The charge exchange method is suitable for extraction of beams of light ions. An electrostatic deflector should be used for very heavy ion beams and maximal energy beams. To assess the potential of the extraction system and choose the position of the starting part of the ion guide, numerical simulation of the ion beam dynamics in the range of A/Z = 4-12 was carried out.

The average radius of the final beam orbit R = 180 cm. The beam deflection from the acceleration zone is ensured by the use of an electrostatic deflector with an angular length of 40, located in the valley. The electric field strength in the ESD does not exceed 100 kV/cm.

To provide the extraction efficiency of 80%, magnetic field stability $\Delta B/B=5\cdot10^{-6}$ and high voltage amplitude stability on the dees $\Delta U/U=2\cdot10^{-4}$ are required.

The vacuum system reconstruction

The reconstruction of the cyclotron vacuum pumping system includes the replacement of five VA-8-7 high vacuum diffusion units with the nitrogen pumping speed of 4250 l/s with two turbomolecular pumps with a pumping speed of 1900 l /s (booster pumps) and five cryogenic pumps with a nitrogen pumping speed of 10 000 l/s each.

Table 2. Time schedule of U400- U-400R reconstruction

No.	Works	2022	2023	2024	2025
1.	Equipment picking				
2.	U400 dismantling				
3.	Equipment assembling and tuning				
4.	Construction of the new Experimental Hall				
5.	Beam tuning, U400R commissioning				

The new U-400R Experimental Hall

Currently, the beam extraction at the U-400 cyclotron is performed in directions of two independent experimental halls. Each experimental hall accommodates several set-ups. This makes impossible simultaneous works with different setups. The U-400 cyclotron modernization project includes construction of a new experimental hall. The developed scheme of channels for beam transportation from the U-400R cyclotron to physical set-ups is shown in Fig. 4. The construction of the new experimental hall U-400R provides for an increase in experimental areas by 1000 m2 and the creation of 3 experimental zones with biological protection, where new physical facilities will be located. In 2021 a positive conclusion of the Glavgosexpertiza (Main Department of State Expertise) of Russia on the project was received. At present, the working project for the new Experimental Hall is underway. The planned timespan for the construction is 2.5 years (2022-2024).

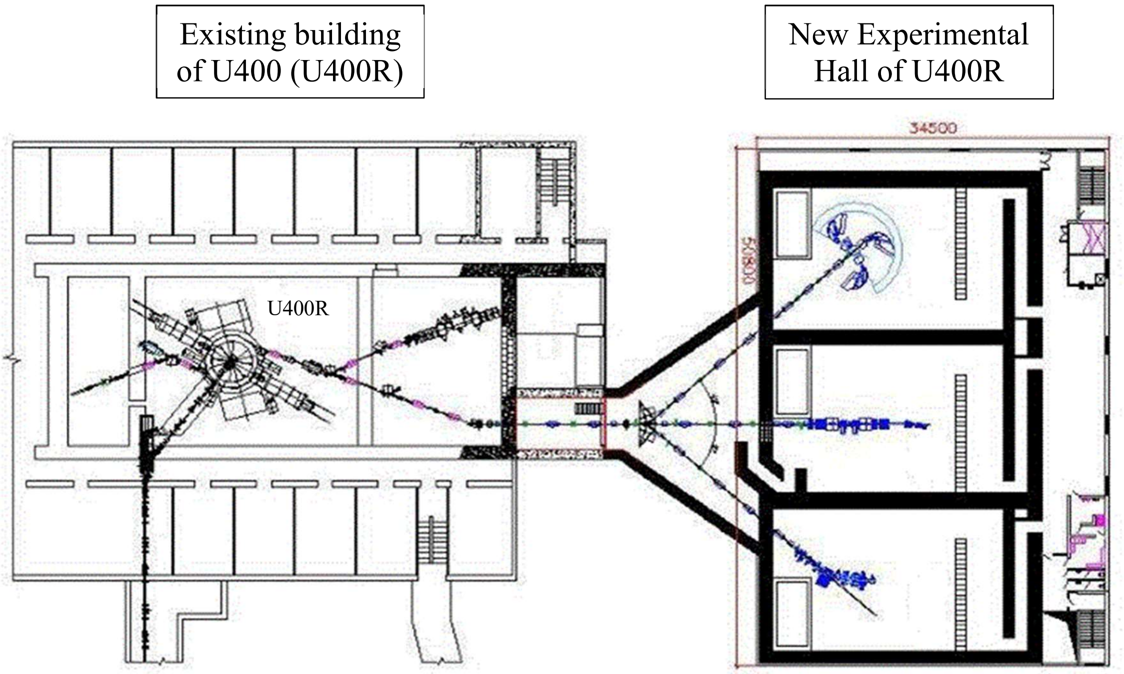

Fig. 4. The new experimental building of U400R (on the right).

Parameters of the U-400R beams

The ions accelerated on the U-400R cyclotron will range from helium to uranium. One of the main advantages of the new accelerator is the possibility of a smooth variation of ion energies in a wide range, which will make possible carrying out spectrometric experiments. Parameters of the U-400R cyclotron accelerated ion beams are shown in Table 2

Table 2. Planned parameters of U-400R beams of stable nuclei

Ion	Ion Energy, (MeV/nucleon)	Intensity of the extracted beam
$^{4}He^{1+}$	6.4 - 27	23 pμA *
$^{16}O^{2+}$	1.6 - 8	19.5 pμA *
$^{16}O^{4+}$	6.4 - 27	5.8 pμA *
$^{40}Ar^{4+}$	1 - 5.1	10 pμA
$^{48}Ca^{6+}$	1.6 - 8	2.5 pμA
$^{48}Ca^{7+}$	2.1 - 11	2.1 pμA
$^{50}Ti^{10+}$	4.1 - 21	1 pμA
$^{58}Fe^{7+}$	1.2 - 7.5	1 pμA
$^{84}Kr^{7+}$	0.8 - 3.5	1.4 pμA
$^{132}Xe^{11+}$	0.8 - 3.5	0.9 pμA
$^{238}U^{27+}$	1.5 - 8	0.1 pμA

* The intensity of the beam is limited by the beam power - 2.5 kW.

U-400M CYCLOTRON

The main task for the U-400M cyclotron complex is production of secondary beams of radioactive nuclei. This calls for the energy of primary beams accelerated at the cyclotron of some tens MeV/n. Expected beam parameters of the modernized U-400M cyclotron are shown in Table 3. Nowadays the cyclotron is under modernization started in the middle of 2020. The main goals of the modernization are the increase of energies and intensities of extracted beams.

The replacement of the faulty main winding will improve the reliability of the accelerator and will optimize the magnetic structure in order to increase the accelerated ion intensity. Today, the process of dismantling the faulty winding (Fig.5) and preparing for the installation of the new one is underway. The work is being carried out under the contract with the GKMP, Bryansk. After the repair, magnetic field of the U400M will be measured. Based on results, additional shimming of magnetic structure should be carried out in order to compensate for the 1-st harmonic of magnetic field and increase the final acceleration radius.

Fig. 5. Dismantling of the U400M main winding

Table 3. **Intensities and energies of typical ions before and after U400M upgrade**

Ion	2019		2022	
	E (MeV/u)	I(pμA)	E (MeV/u) planned	I(pμA) planned
^{7}Li	35	5	39	10
^{11}B	30	3	33	6
^{15}N	47	0.5	51	2
^{18}O	36	0.5	40	1.5
^{22}Ne	45	0.3	50	1
^{36}S	40	0.2	44	0.2
^{48}Ca	34	-	38	0.1

Modernization of RF accelerating system and upgrade of the analog RF control system to digital LLRF (Low-Level RF) one will allow to improve stability and quality of accelerated beams.

The upgrade of the cyclotron vacuum system from oil diffusion pumps to cryogenic and turbo-molecular ones will improve vacuum and allow to reduce vacuum losses of ions. Also stability of RF accelerating system operation will be improved.

The upgrade existing Radiation Monitoring system of the U-400M to the new automated radiation monitoring system (ARMS) will be based on modern developments using new types of microprocessor-controlled sensors and new software. The main goal of the upgrade is reliable operation of ARMS, operational processing of data and ensuring of personnel safety.

The launch of the U-400M cyclotron after modernization is planned in 2022.

Table 6. Schedule of U400M modernization.

N	Work content	2020												2021												2022											
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1	PREPARATORY WORKS (since 2019)	■	■	■	■	■	■																														
2	WORKS ON EQUIPMENT DISMANTLIN							■	■	■	■	■	■	■	■	■	■																				
3	NEW EQUIPMENT ASSEMBLY WORKS																	■	■	■	■					■	■	■	■								
4	UPGRADE OF POWER SUPPLY AND CONTROL SYSTEM (since 2019)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
5	MEASUREMENTS AND CORRECTION OF MAGNETIC FIELD																					■	■	■	■												
6	COMISSIONING OF THE CYCLOTRON AFTER MODERNIZATION																													■	■						

DC-280 CYCLOTRON

In 2019, the FLNR JINR launched the Superheavy Element Factory (SHE Factory) based on the new heavy ion cyclotron DC-280, which should provide the intensity of ion beams of intermediate mass up to 10 pμA.

The DC-280 is being working for physical experiments. Further plans (2022, 2023 years) are related with achievement of design parameters for beam intensities, production and acceleration of new ion beams for physical experiments to cover working diagram of the DC-280 (Fig. 6), improvement of the beam extraction system, adjusting the Flat-top system to increase the efficiency of ion beam acceleration and extraction and also development of a methodic for producing intensive Ti and Cr ion beams in injection line from the ECR source to improve experimental beam parameters (Table 7).

Table 7. Experimental ion beam parameters of DC-280

Ion	E_{ion} [Mev/nucl.]	I_{INJ} [pμA]	I_{EXTR} [pμA]
$^{12}C^{+2}$	5.9	29,8	10
$^{40}Ar^{+7}$	4.9	28.7	10.4
$^{48}Ca^{+10}$	4.8	24	7.1
$^{48}Ti^{+10}$	4.8	2.2	1
$^{52}Cr^{+10}$	5.2	7	2.4
$^{84}Kr^{+14}$	5.9	2.9	1.4

$\mathbf{I_{INJ}}$- ion current in the injection channel, $\mathbf{I_{EXTR}}$- ion current extracted from the DC-280.

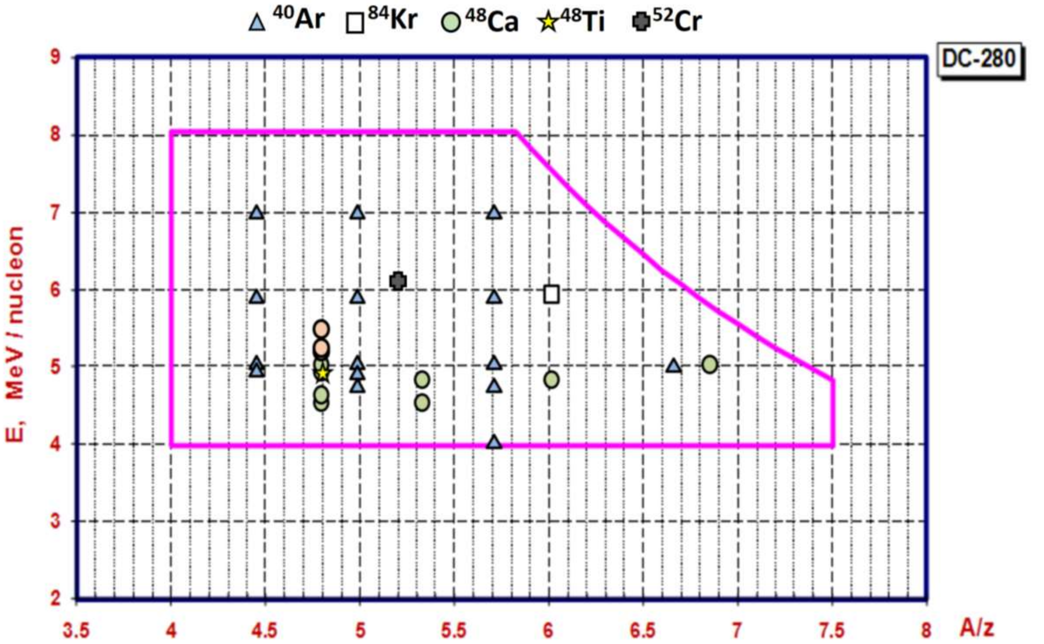

Fig. 6. Working diagram of the DC-280 cyclotron. Points indicate accelerated ions.

DC-140 CYCLOTRON COMPLEX

Development of the acceleration complex DC-140 intended for applied studies is underway in the Flerov Laboratory since 2020. The main goals of the project include studies within solid state physics, surface modifications of materials, production of track membranes and testing of electronic components for single radiation effects (SEE). The complex is based on the operation of the dedicated compact DC-140 cyclotron. We are planning that upon the launch, the cyclotron DC-140 will replace the cyclotron IC-100 in applied studies carried out in the FLNR. Construction of the DC-140 cyclotron complex is planned to be completed by the end 2023 (Tab. 8). Conceptual design of the cyclotron complex and the study of its feasibility have been performed in 2020. Design work continues in 2021.

Cyclotron DC-140 is intended for the acceleration of ion beams from O to Bi with energies 4.8 and 2.1 MeV/n (Fig. 7). Beams of lower energy are assumed to be used to produce track membranes based on polymer films up to 30 µm thick. Ion beams with the energy 4.8 MeV/n will provide a depth of ion penetration in Si up to 55 µm and LET in Si up to 100 MeV*cm2/mg for effective SEE testing. The working diagram of cyclotron DC-140 is shown in Fig. 7.

Three dedicated beam-channels are planned to be installed at DC-140 cyclotron, including upgraded operating channel for irradiation of polymeric materials (Fig. 8).

Construction of the DC-140 cyclotron complex of the FLNR is planned to be completed by the end of 2023 (Tab. 8).

The IC-100 cyclotron operation is planned till the launch of the DC-140.

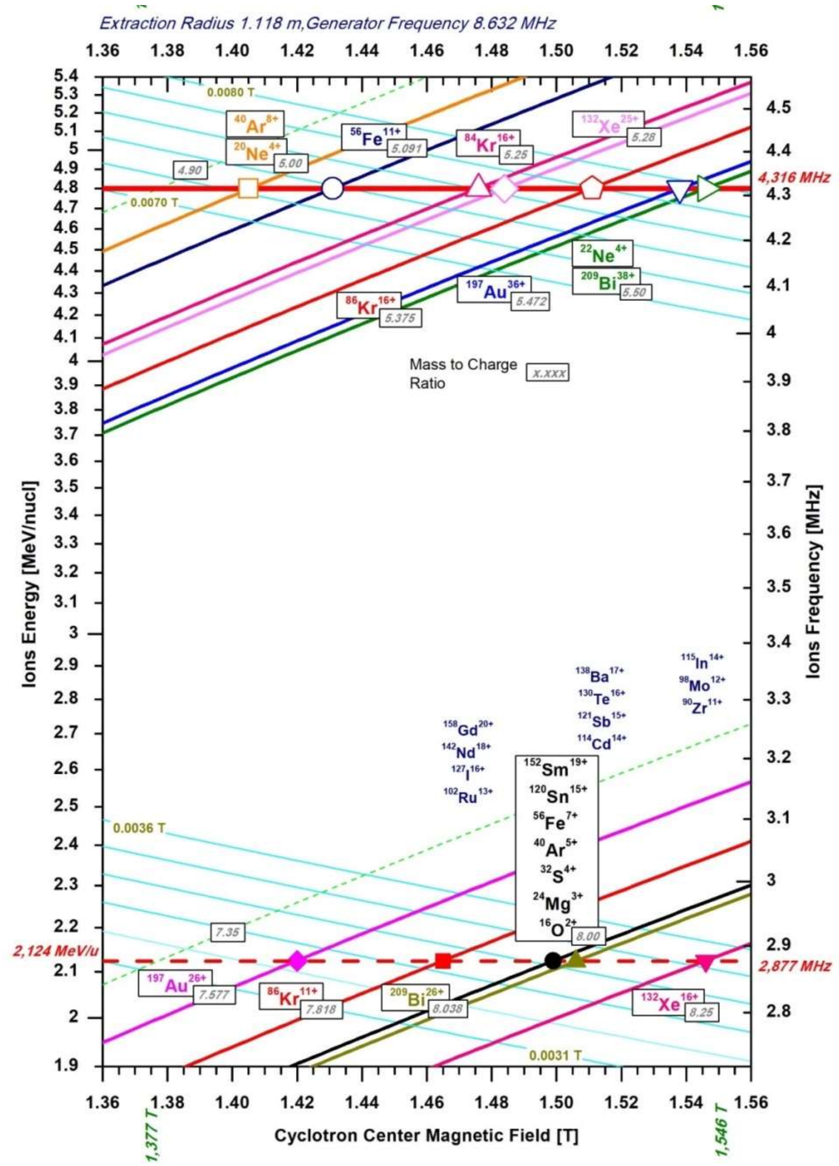

Fig. 7. Working diagram of the DC-140 cyclotron

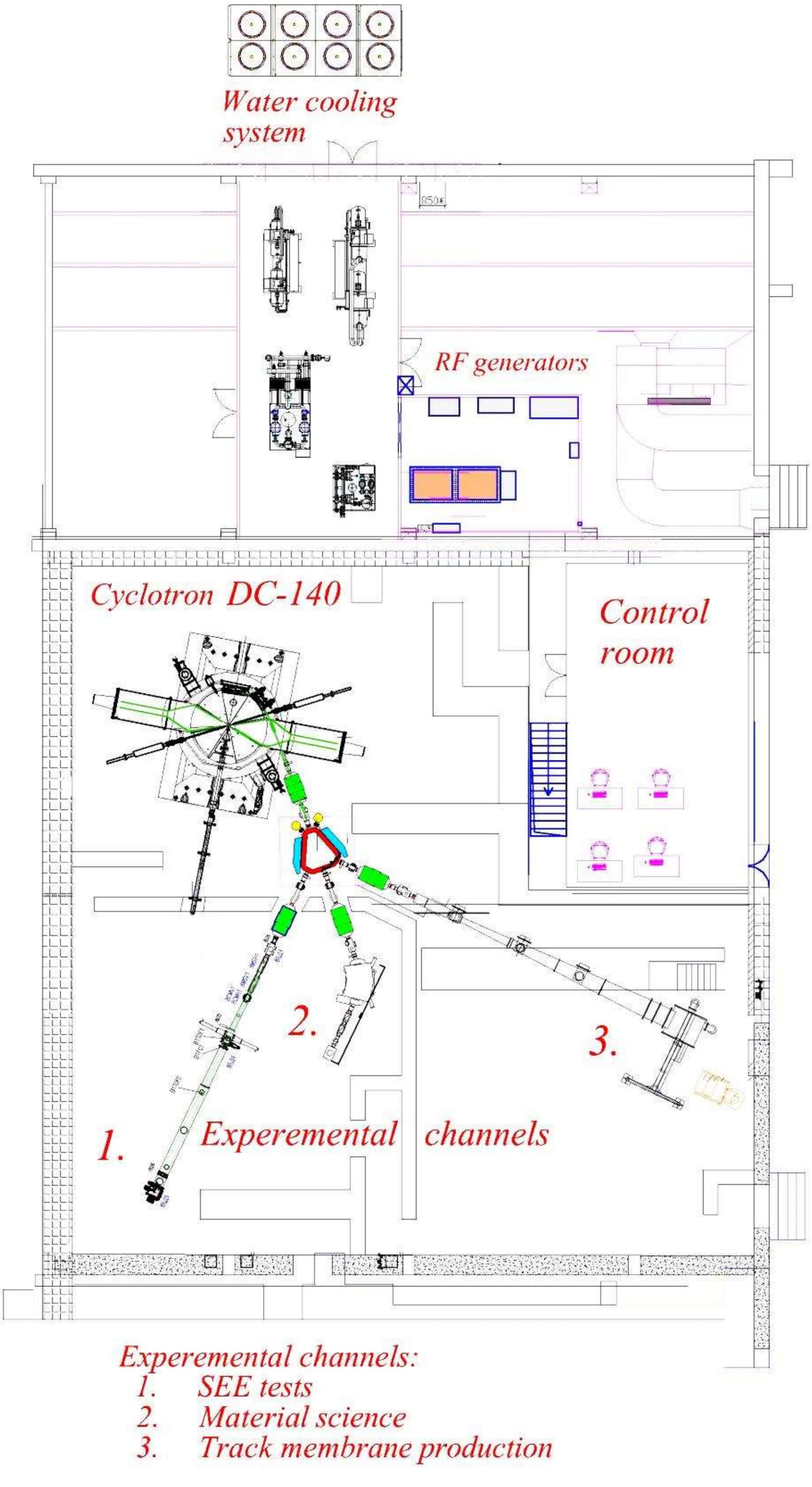

Fig. 8. Layout of the DC-140 cyclotron complex

Table 8. Time schedule of DC140 creation

No.	Works	2020	2021	2022	2023
1.	U200 dismantling				
2.	Layout and preparation of DC140 premises				
3.	DC-140 design, picking				
4.	Equipment assembling and tuning				
5.	Beam tuning				

The time-table of the FLNR cyclotron complex operation for the period 2017 – 2023.

Accelerator	2017	2018	2019	2020	2021	2022	2023
DC-280	assembling	commissioning	3377	3705	5000	5000	5000
U400M	5967	5863	6755	2937	upgrade	commissioning	5000
U400-U400R	6546	6474	5867	5654	5000	5000	start of reconstruction
The new Experimental Hall of U400R						Building construction	
U200-DC140				U200 dismantling	hall reconstruction	assembling	commissioning
Time of target irradiation	12 513	12 337	15 999	12 296	10 000	10 000	10 000
Power consumption MW	19 869,758	19 152,081	22 745,327	17 500	18 000	18 000	18 000

N hours - **actual time of target irradiation** N hours **- forecast**

EXPERIMENTAL SETUPS

Development of the fragment separator ACCULINNA-2.

Due to the modernization of the U400M cyclotron experiments at the ACCULINNA-2 fragment separator are expected to start in the end 2022. In 2022 we intend to continue works on the development of detection systems and main facilities of the separator. To perform full scale experiments with radioactive beams at the ACCULINNA-2 fragment separator (Fig. 9) the following setups are foreseen to be put into operation (the positions of these setups are shown in

Fig. 9): i) the cryogenic target complex to operate with helium and hydrogen isotopes, including tritium, with a thicknesses of up to 15 mg/cm^2, ii) the radio frequency filter (RF-kicker), to enhance significantly (factor 10÷20) the purity of radioactive beams and iii) the zero-angle spectrometer to provide high accuracy momentum determination of the reaction products emitted in the forward direction.

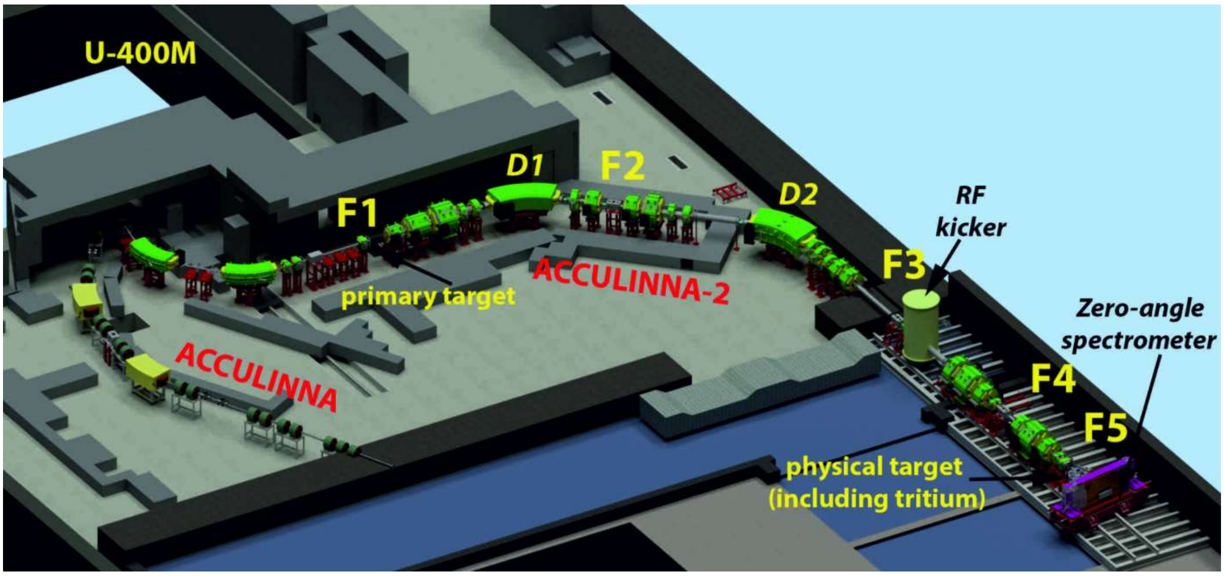

Fig. 9. The layout of the ACCULINNA-2 fragment-separator at U-400M cyclotron with the additional equipment at F3-F5 focal planes: RF-kicker, zero-angle spectrometer, and tritium complex.

The tritium-target complex (Fig. 10) will include a comprehensive gas-vacuum and tritium safety system for the supply, cooling-heating, control, radiation safety, and utilization of unwanted gases. The tritium-target complex will provide operation at gaseous and liquid targets at cryogenic temperatures. As a result, the targets of all long-living isotopes of hydrogen (including tritium) and helium with the thickness being in a wide range (10^{20}÷$5*10^{21}$ atoms/cm^2) will be available for use in experiments since the end of 2023.

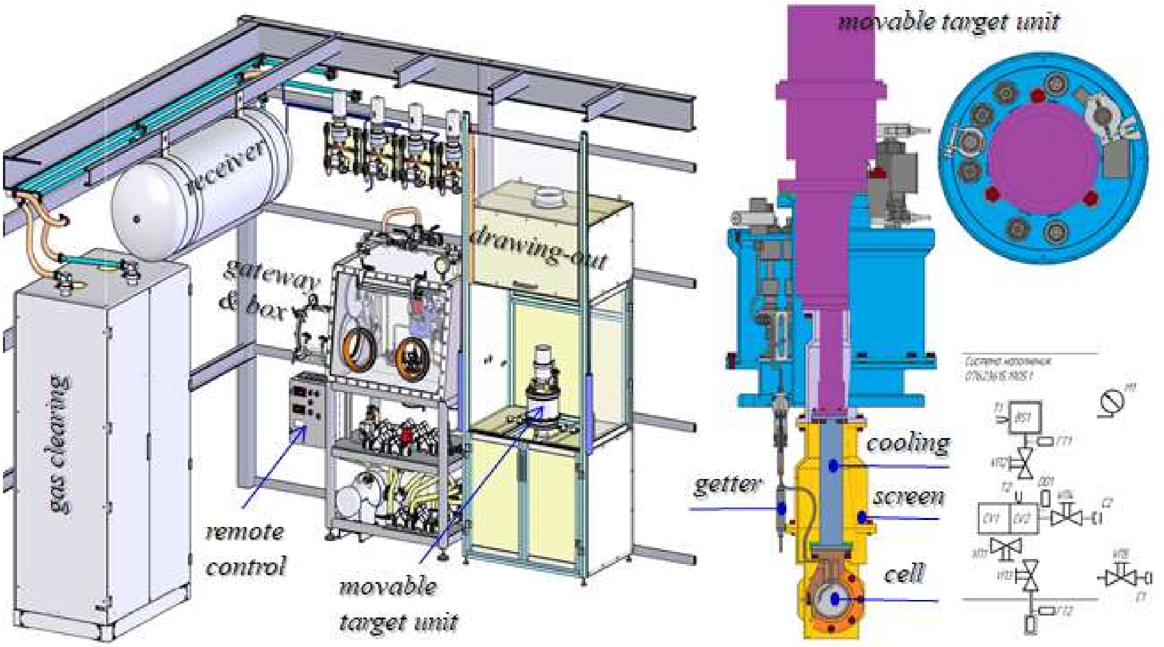

Fig. 10. Scheme of the gas-vacuum system (left) and the tritium target cell with related subsystems (right).

The RF kicker (Fig. 11) will be put into operation in 2023. The full-scale tests of this separator will be carried out with the ^{24}Si beam. This beam will be used then in the experiments aimed at the production of ^{26}S nuclei in the 2p transfer reaction $^{24}Si(^{3}He,n)^{26}S$. As a result, the experimental purification factor at neutron deficient beams will be determined. According to the project assumptions, the RF-kicker should enhance RIBs purification by a factor of 10÷20.

The zero-angle spectrometer (Fig. 12) will be tested in the experiment on the study of the energy spectrum of ^{10}Li populated in the 1n transfer reaction $^{9}Li(^{2}H,p)^{10}Li$ at ~25 AMeV.

Frequency range (MHz)	14.5 – 20
Peak voltage (KV)	120
Gap (mm)	170
Width of electrode (mm)	120 min
Length of electrodes (mm)	700
Cylinder diameter (mm)	1200 max
Stem diameter (mm)	120 max
Length of coaxial line (mm)	1830
Distance from A-2 primary target (m)	25

Fig. 11. The principal parameters and a side view of the RF kicker installed at the ACCULINNA-2 beam line after the achromatic focal plane F3.

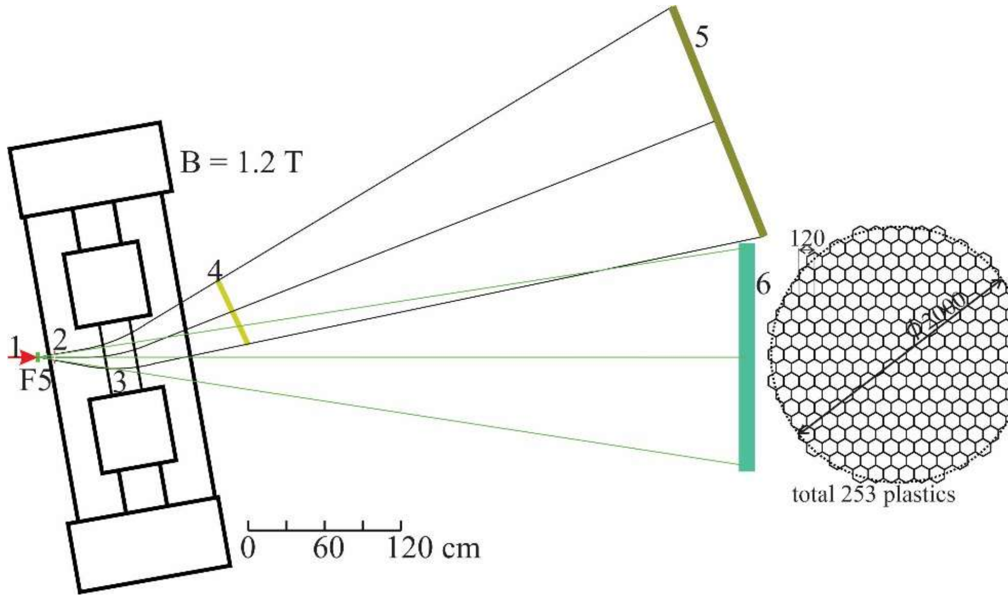

Fig. 12. The dipole magnet of the zero-angle spectrometer installed after the physical target (focal plane F5). 1 – radioactive beam, 2 – annular Si detector giving triggering signals, 3 – the lower magnetic pole, 4 – the array of position sensitive ΔE-TOF detectors, 5 – position sensitive TOF detector structure, 6 – The neutron-detector wall.

New detector systems for the ACCULINNA-2 separator are also under development:

- The neutron-detector wall of 253 plastic scintillators.
- Active Gaseous Target – Time Projection Chamber (AGT-TPC).

The neutron-detector of 253 of tightly composed 20-cm thick plastic scintillators (BC400), each plastic having the transverse shape of a hexagon fit into a circle with radius 69 mm. The detector is intended for the investigation of nuclei beyond the neutron dripline nuclei emitting two, three and even four neutrons. This setup is especially important for the study of ^{7}H. Its granular structure provides high accuracy angular measurements and decreases the cross-talk effects.

The AGT-TPC is a joint project of FLNR, JINR, and Faculty of Physics, UW, Warsaw, aimed at the study of structure and decays of the most exotic nuclei. The AGT-TPC is a novel gas-filled detection system in which a gas volume acts as a tracking medium and a target simultaneously. The AGT-TPC will consist of a vacuum vessel with a low-pressure gas system, an active volume of $200 \times 330 \times 200$ mm^3 with a uniform electric field and charge amplification structures based on GEM (Gas Electron Multipliers) foils, and a readout system based on GET (General Electronics for TPCs) electronics. It offers considerable advantages over traditional nuclear physics detectors and techniques, especially for the detection of low energy particles.

Development of a new gas-filled separator DGFRS-2.

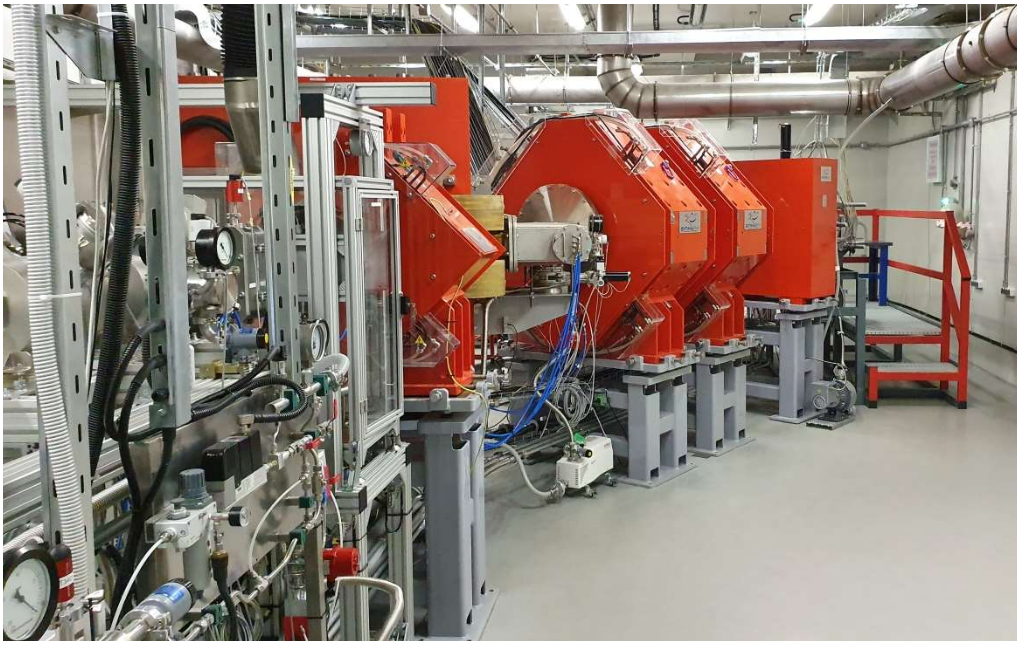

Fig. 13. Photo of the gas-filled separator DGFRS-2.

Further upgrade of gas and vacuum system of the gas-filled fragment separator DGFRS-2 (Fig. 13) as well as detectors system will be performed in the years 2022 – 2023.

Construction and commissioning of the pre-separator for radiochemical studies of SHE.

A new gas-filed separator, DGFS-3, (Fig. 14) is being developed for spectroscopic as well as for chemical studies of SHE. This separator is manufactured, equipped and installed for testing at the beam of the DC280 cyclotron. High-beam intensities from the DC280 cyclotron and the increased detection efficiency of the modernized GABRIELA set-up for gamma and conversion electrons will allow us to plan spectroscopy experiments in 2022 aimed at study the nuclear structure of superheavy nuclei. In the complete fusion reaction $^{48}Ca+^{243}Am \rightarrow ^{291}Mc^*$ with the beam intensity of 1.5-2 pμA we plan to detect about 100 decay chains of isotopes of element 115 consisting of 5 subsequent alpha decays from Z=115 to 105. Coincidences with prompt and delayed gammas and conversion electrons will allow us to obtain the information on the level structure of the populated isotopes.

Fig. 14. Separator DGFS-3 (during assembly) at the experimental hall of the SHE Factory.

We plan to finish assembling of DGFS-3 in 2022 and start test experiments for tuning of ion optical elements of the separator. In 2022 first experiments with the use of DGFS-3 as a pre-separator for radiochemical studies of SHE are expected to be performed.

Besides, we perform a feasibility study of a new setup (pre-separator) for the research of chemical properties of SHE. For this purpose we consider a gas-filled superconducting magnet. Coupled with a reaction product collection chamber or a gas catcher, this set-up will serve as a pre-separator for further chemical separation and precise mass measurements, respectively. The negotiations with potential manufacturers are currently underway.

Gas catcher and multi-reflection time-of-flight mass spectrometer.

The cryogenic gas catcher for studying the chemical properties of superheavy elements with lifetimes longer than 100 ms is under development at FLNR. We plan to finish assembling of this setup in 2023. A general view of the catcher is shown in Fig. 15. The gas cell itself 3 is cooled to 40K and placed in a vacuum volume 2. The gas cell contains: a cylindrical eight-electrode transport system 4 and a radio-frequency multi-electrode cone 5. At the exit of the cell, a Laval nozzle 7 is installed, which forms a supersonic jet from a mixture of gas and ions and directs it into the volume where the neutral gas is evacuated by the pumping system, and the beam ions by the radio-frequency quadrupole transport system 8 is transferred to the next volume, where the next quadrupole system forms bunches from a continuous ion beam.

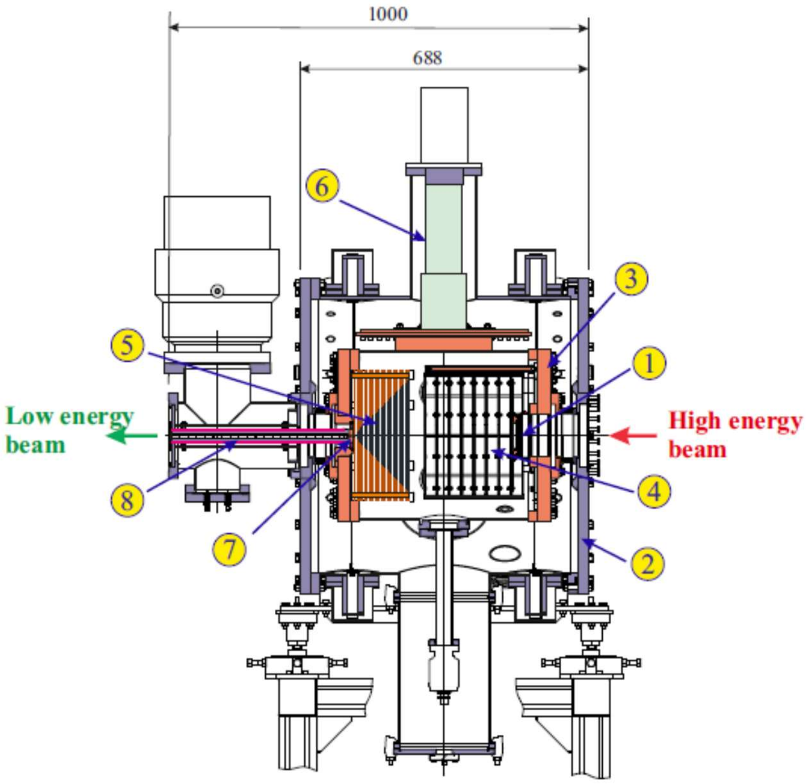

Fig. 15. General view of a cryogenic gas ion trap. Positions in the figure: 1 - entrance window; 2 - outer warm vacuum shell; 3 - inner cold chamber; 4 - cylindrical electrodes of a constant electric field; 5 - radio frequency multi-electrode cone; 6 - the head part of the cryo-refrigerator; 7 - supersonic nozzle; 8 - transport radio frequency quadrupole.

Fig. 16. Assembling of the cryogenic gas ion trap.

The technique of multi-reflection time-of-flight mass spectrometry for precise mass measurement of the masses of exotic nuclei has been intensively developed over the world in the last decade. Currently, in collaboration with the Institute of Analytical Instrumentation of the

Russian Academy of Sciences, we are working out a multi-reflection time-of-flight mass spectrometer of high resolution. The facility is supposed to be used for precise measurement of the masses of isotopes of heavy and superheavy elements. Fig. 17 shows a scheme of the analytical part of the spectrometer. It is planned to complete the design of the facility by the end of 2022. This will allow to start manufacturing the set-up in 2023.

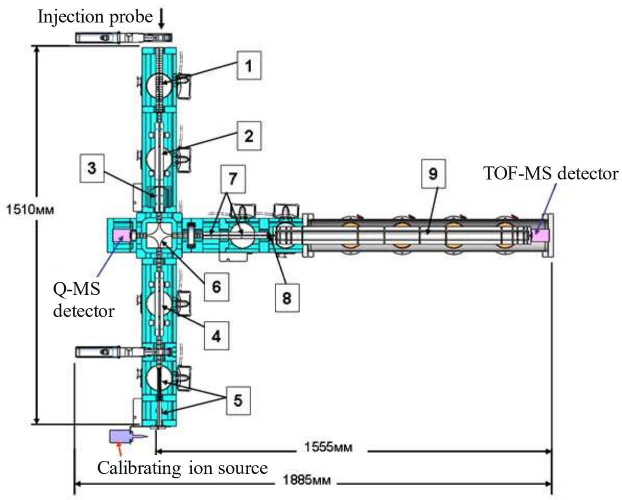

Fig. 17. Analytical part of a multi-reflection time-of-flight mass spectrometer. The main nodes: 1 - collision induced dissociation cell; 2 - quadrupole RF filter of the sample; 3 - radio frequency trap of the sample channel; 4 - quadrupole radio-frequency filter of the calibrant; 5 - transporting system of the calibrant; 6 - quadrupole switchyard; 7 - channel for preparation and pulse extraction of ions; 8 - accelerating-transporting channel; 9 - time-of-flight analyzer.

Development of a separator based ion resonance laser ionization.

Implementation of the GALS project devoted to the production and study of heavy neutron-rich nuclei in multinucleon transfer reactions is in progress. Laser laboratory preparation is close to completion. Laser equipment (TiSa and Dye lasers, beam diagnostic, doubling optics etc.) was delivered and now is being installed in the laser laboratory. Recently, three new Photonics Industries TU-H TiSa lasers were installed and tested (see Fig. 18). Optimization of their working parameters for first off-line experiments is in progress.

The choice of specific laser ionization scheme, the type and number of lasers is determined by the ionization potentials and level schemes of the elements under study. In our case a three-step scheme of ionization looks more favorable. Such a scheme allows choosing more effective optical transitions to increase the yield of resonance-ionized ions, although the use of two-step ionization scheme is not excluded as well. Dye laser systems pumped by second and third harmonics of Nd:YAG can provide tuning in a broad spectral range: from near UV to near IR. The generation of a Ti:Sapphire lasers shifted to the red and infrared edge of the spectrum (680 – 960 nm) can be also used as complementary to that of the dye lasers. Thus, the installation of two laser-ionization schemes – with dye lasers and Ti:Sapphire laser – would be of a great benefit allowing to meet diverse experimental demands.

Fig. 18. Three new Photonics Industries TU-H Titanium-sapphire lasers installed in the GALS laser laboratory.

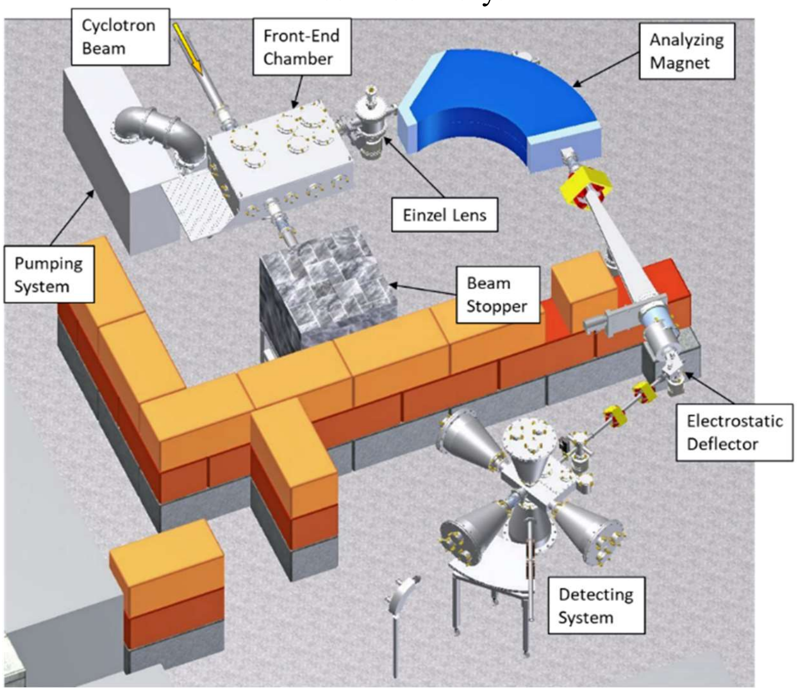

Fig. 19. GALS facility view in experimental room within the FLNR U-400M cyclotron hall.

At the first stage of our experiments, excitation schemes using 3-step ionization with a non-resonant transition to continuum will be tested with the available lasers: two dye lasers Credo (Sirah) and Nd:YAG.

Work on GALS subsystems located in the experimental room within the cyclotron U-400M hall will be continued. Figure 19 presents the view of the GALS facility with its subsystems. It is planned that completion of picking of new separator based on stopping the reaction products in gas and their resonance laser ionization (GALS project) will be done during years 2022-2023.

Radio-chemical laboratory of class 1

Preparation of the project of dedicated radio-chemical laboratory of class 1 has been started at FLNR. The laboratory is intended to handling and processing of high-radioactive materials, in particular:

- Preparing and regeneration of actinide targets for the SHE research
- Development of new technologies for production of radioisotopes and their extraction from irradiated targets for scientific, radioecological, medical and other applications.

Conceptual design is planned to be completed by the beginning of the next 7-year period (2024-2030).