JOINT INSTITUTE
FOR NUCLEAR RESEARCH
ОБЪЕДИНЁННЫЙ ИНСТИТУТ
ЯДЕРНЫХ ИССЛЕДОВАНИЙ

The DC-140 project: new multipurpose applied science facility at FLNR JINR Accelerator Complex.

S. Mitrofanov
on behalf of
FLNR team

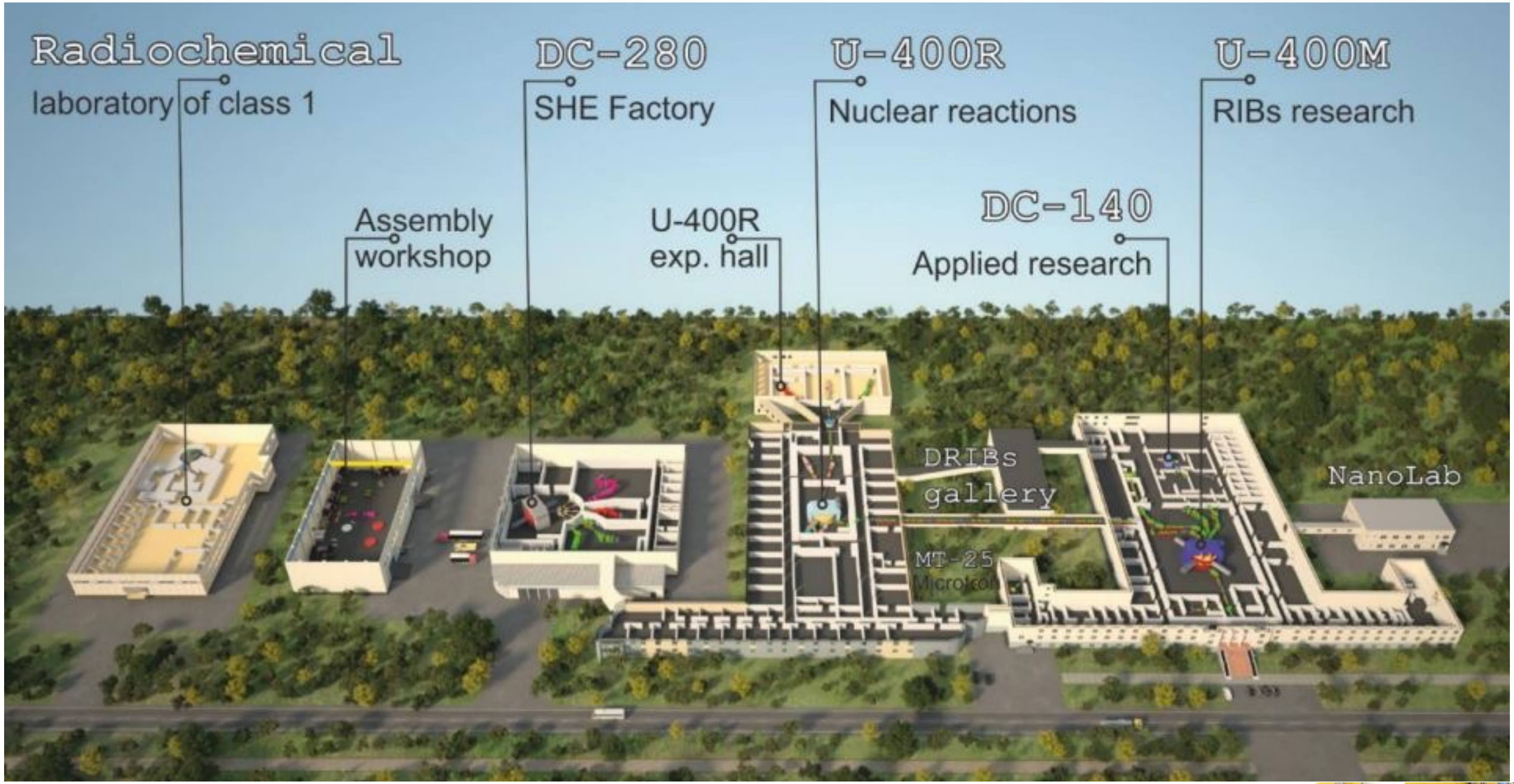
FLEROV LABORATORY
OF NUCLEAR REACTIONS

JOINT INSTITUTE FOR NUCLEAR RESEARCH
ОБЪЕДИНЁННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

JINR FLNR: tools and instrumentation of accelerator physics for scientific research and applied tasks **in 2025.**

4 cyclotrons and Microtron

Beam operation time : ~ 6 000 hours/year/per machine of beams **ON** physical targets



U-400M

U-400

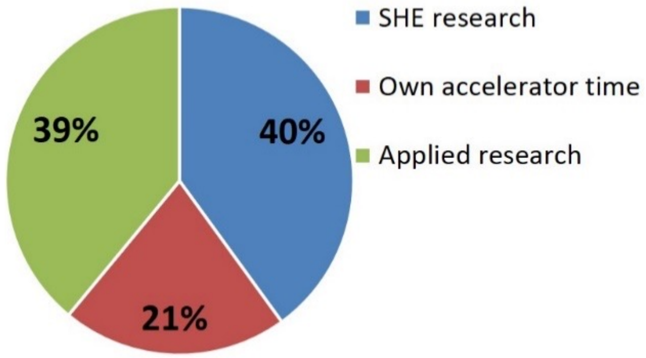
MT-25

DC-280

IC-100

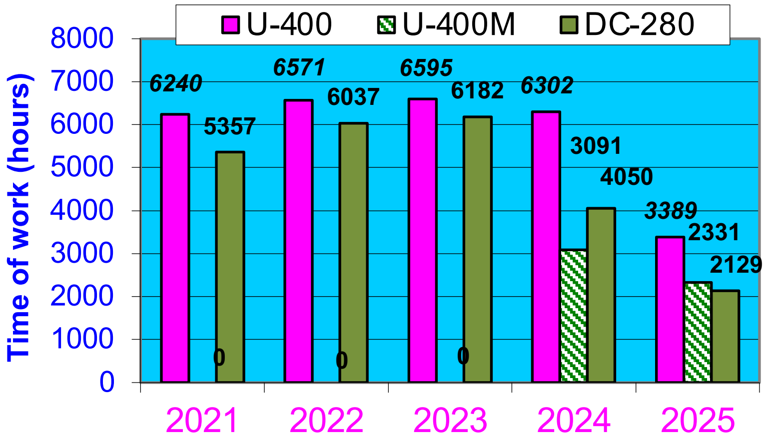
Efficiency of FLNR accelerating complex in 2025.

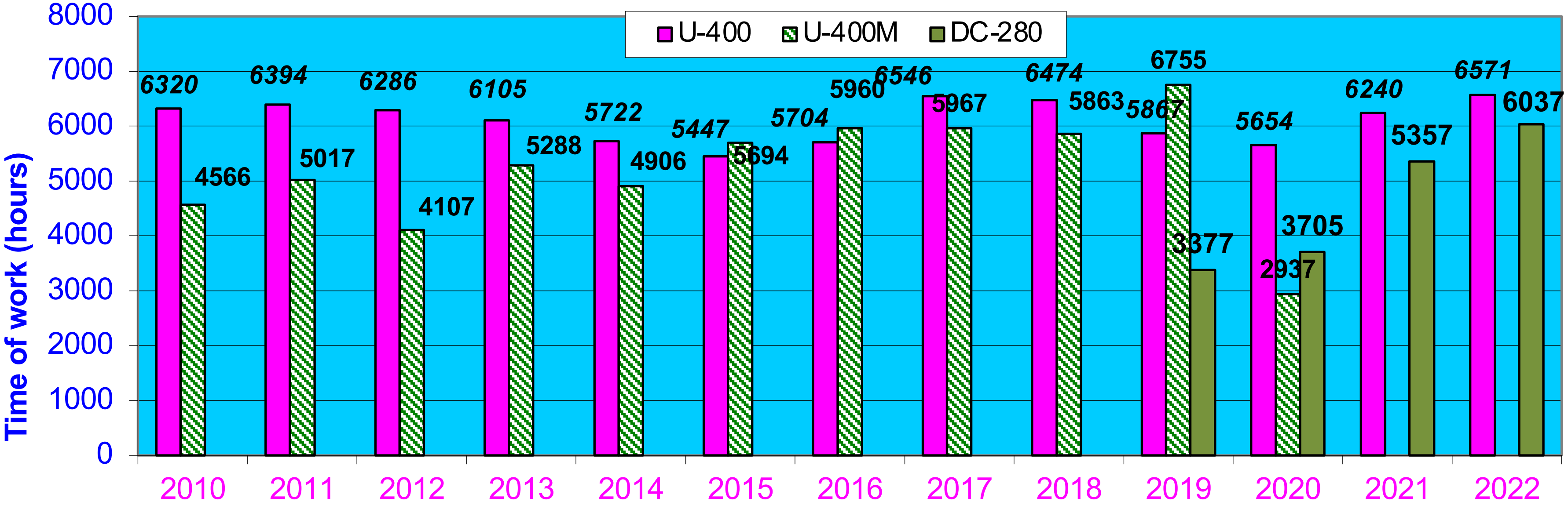
Summary of time of work of accelerator facilities (hours)	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025 (up 1st July)
	14034	15724	16657	16904	20110	15124	15065	16834	16583	14405	8161



Working time of main cyclotrons

(time: beam **ON** physical target)

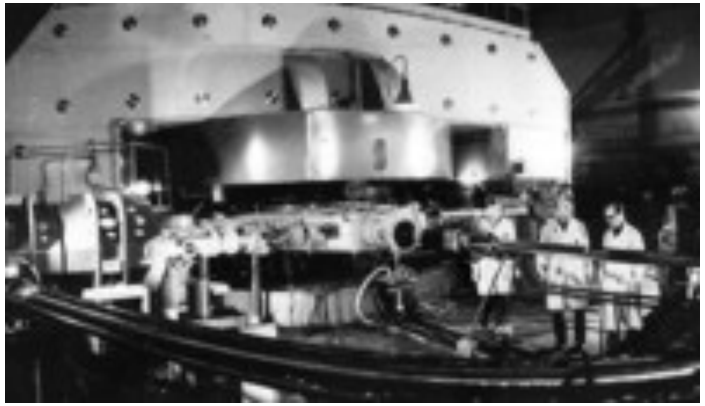




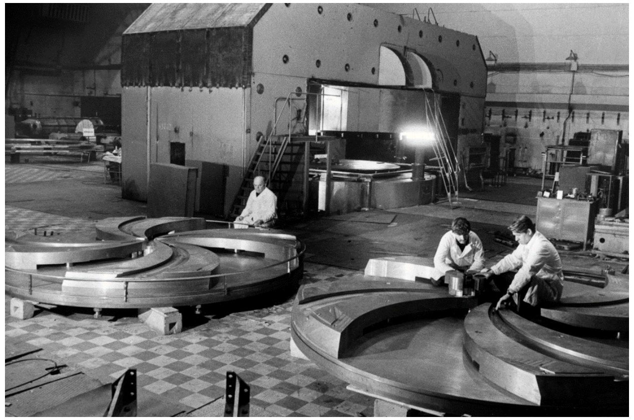
FLNR JINR Accelerator Complex **for multipurpose applied research**

Interactions of accelerated heavy ion beams with matter : projectile + target

Since middle of 1970's track membrane technology based on HIB were realized at U300 in FLNR.



... In 2025



How can heavy ions help the economy and humanity?

Approx 2500 + 2300 + 1500 hours per year

- CREATION AND DEVELOPMENT OF TRACK MEMBRANES (NUCLEAR FILTERS) AND THE HEAVY ION INDUCED MODIFICATION OF MATERIALS.

- ACTIVATION ANALYSIS, APPLIED RADIOCHEMISTRY AND PRODUCTION OF HIGH PURITY ISOTOPES (**METHODOLOGY !!!**).

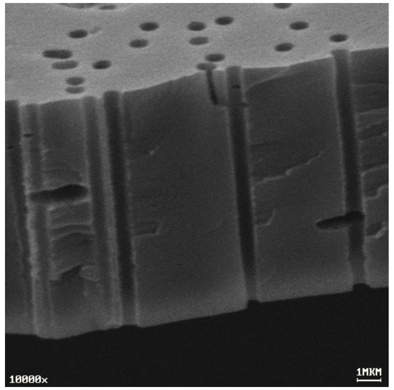
- ION-IMPLANTATION NANOTECHNOLOGY AND RADIATION MATERIALS SCIENCE.

- TESTING OF ELECTRONIC COMPONENTS (AVIONICS AND SPACE ELECTRONICS) FOR RADIATION HARDNESS.

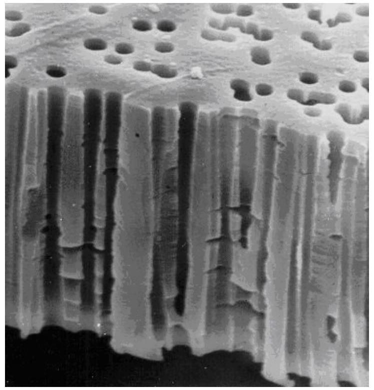
… for multipurpose applied research: Ion track etching technology

Creation and development of track membranes (nuclear filters) and the heavy ion induced modification of materials.

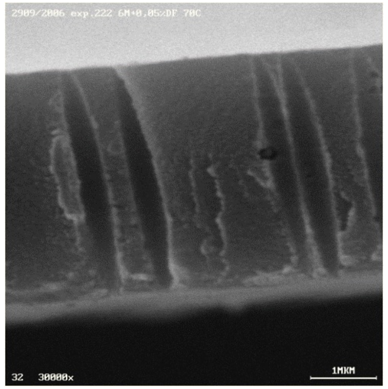
Variety of pore shapes in track-etched membranes



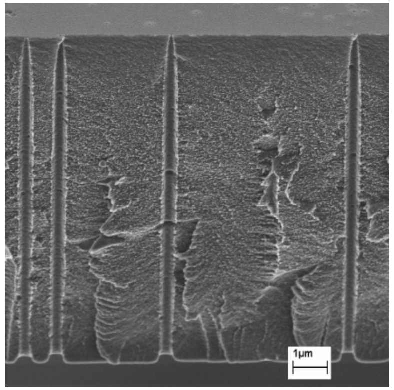
Cylindrical



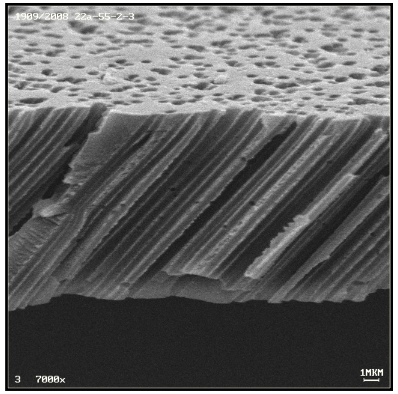
Doubly conical



Cigar-like

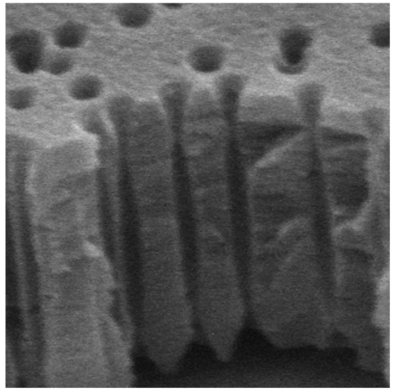


Highly asymmetric with bullet-like tip

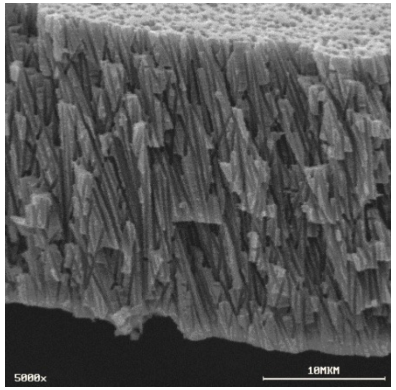


Cylindrical, parallel,

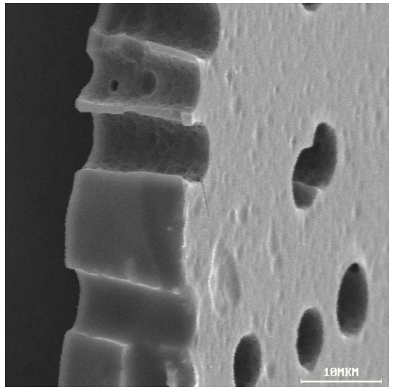
all tilted at an angle of 45°



Bow tie like



Cylindrical, non-parallel (typical commercial TM with small pores)



Typical commercial TM with large pores

… for multipurpose applied research:

Radiation materials science with swift heavy ion beams

Main direction of research activities

Microstructural phenomena in swift heavy ion (SHI) tracks: experiment and simulation

- **Ion track parameters as function of electronic stopping power, irradiation temperature, structural state of materials etc.**

- **Relationship of nanoscale defects induced by SHI on the surface and in the bulk**

  Radiation tolerance of nanooxides in oxide dispersion strengthened (ODS) alloys against SHI impact

- **Helium behavior in ODS steels irradiated with SHI beams**

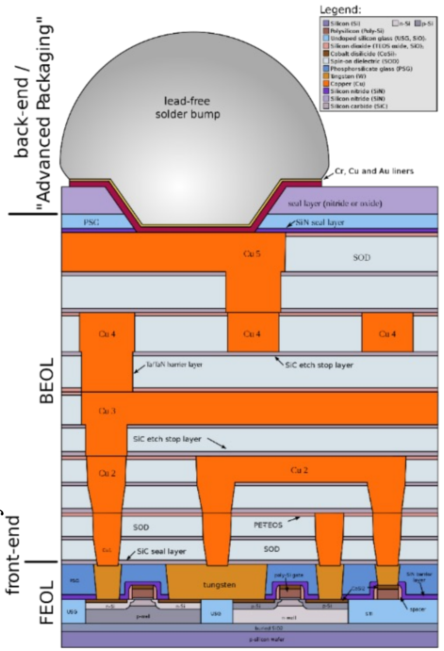
- **Helium + dense ionization effects on diffusion and migration of fission products in SiC**

Study of nanostructured materials using Swift Heavy Ion beams

… for multipurpose applied research:

Testing of electronic components (avionics and space electronics) for radiation hardness.

Question to be answered – what will be if…you have TOO much species in your "sandwich"…. or ONE is already enough ???



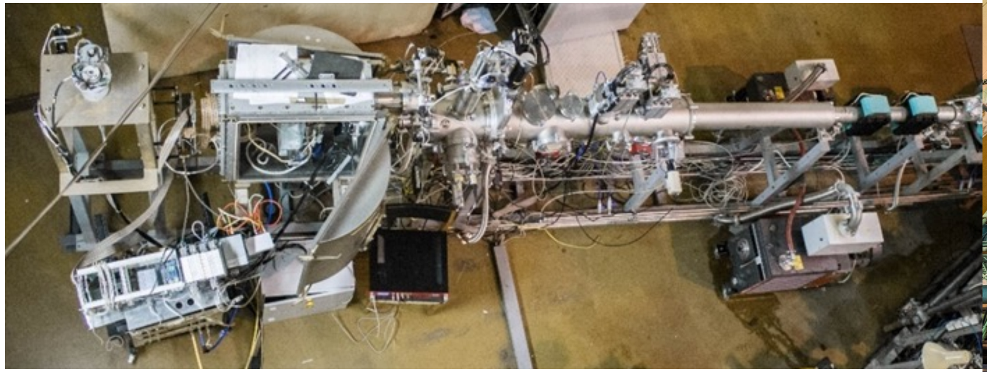
*Courtesy to Wiki

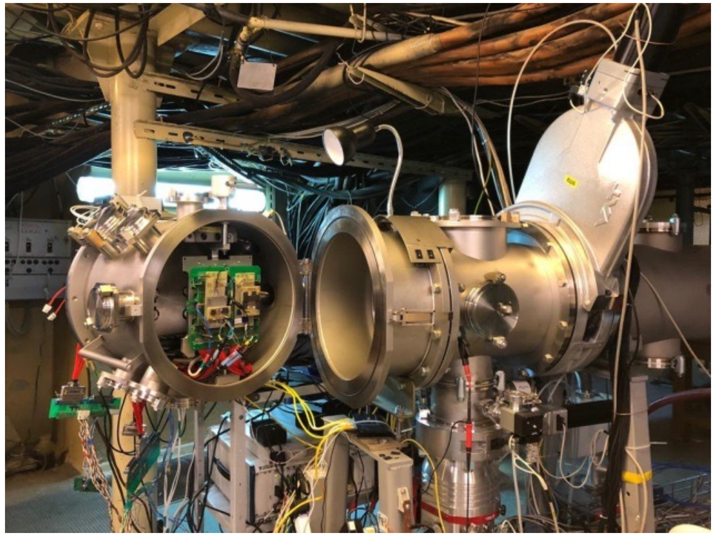
- What does it mean for FLNR ??
Using the accelerator complex to irradiate the DUT (Device Under Test) with the heavy ion beams (with well-known characteristics).

- What does it mean for Users ??
To observe response and operate the DUT under exposure online.

Goal:
Obtaining experimental data within Earth limits to predict SEE rate in space.

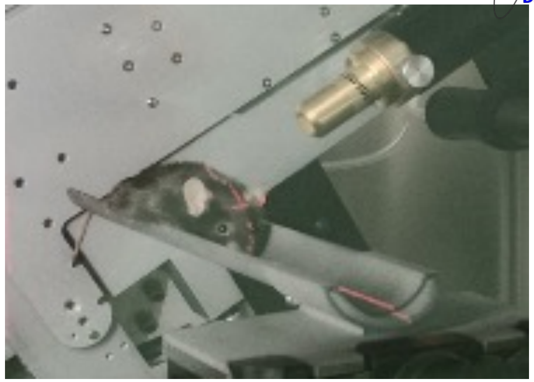
3 (and 2 more in 2026) dedicated beamlines with E=3÷64 MeV/n.
Since 2008, more then 8000 devices has been tested.

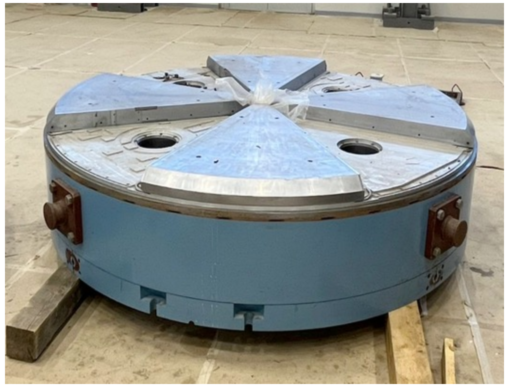




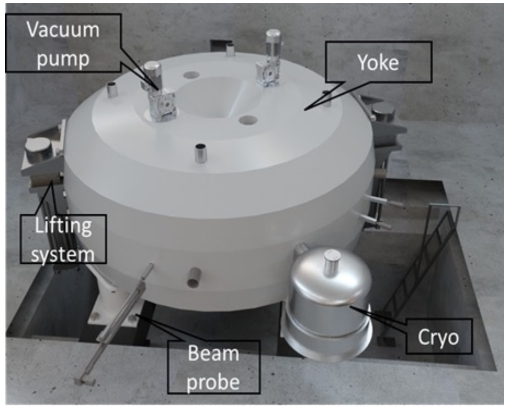
JINR innovations: international center for nuclear research

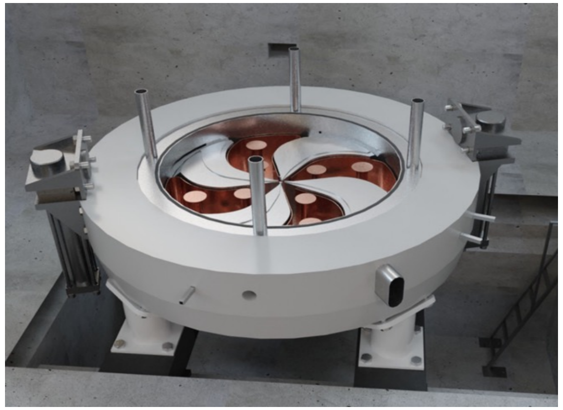
- **Radiation Biology @ LRB**, OMICS, neuro-RB studies, radiation neuroscience. Approaches to increase radiosensitivity: pharmaceuticals, transgene systems, targeted delivery and radionuclide;
- **ARIADNA.** Applied beams@NICA: radiobiological studies (400-800 MeV/n); irradiation of electronics and material science (3; 150-350 MeV/n); nuclear physics (1-4.5 GeV/n);
- **DC140 cyclotron:** ***Space electronics testing, radiation material science, new generation of track membranes; FLNR***
- **MSC230 cyclotron:** research and beam therapy: treatment planning; radiomodificators for γ– and p- therapy, flash-therapy, pencil beam (10 μA, >5 Gr/l @ 50 ms pulse).
- **Radiochemical Laboratory Class-I** ***for production of radioisotopes (Ac^{225}, ^{99m}Tc), nuclear medicine R&D in photonuclear reactions @ 40MeV e-accelerator. P and Alfa are in discussion. FLNR***





DC-140 (construction phase)





MSC-230 (general view)

DC-140: new cyclotron for all-sort practical applications in FLNR ongoing in 2026.

Ion track technology needs:
- energy > 1 MeV per nucleon
- Ions from Ne up to Bi
- Intensity with Xe (as example) 1×10^{12} c^{-1}
- Irradiation zone 650*250 mm (1-2 MeV/n) and 325*190mm (4,8 AMeV/n)
- Beam uniformity 5 %
- Casemate - "green area" - people around irradiation chamber
- Oversize irradiation chamber => dedicated beam line

Testing of electronic component (SEE testing):
- *Energy, which could provide the ion range in Si around 50 mkm - 4,8 MeV per nucleon (70% timing is Low Energy Mode)*
- Ions from Ne up to Bi (Ne, Ar, Kr, Xe, Au, Bi)
- LET up to 100 MeV/(mg×cm^2)
- Intensity 1×10^5 $c^{-1} \times cm^{-2}$
- Irradiation zone 200*200 mm at least
- Dedicated beam line due to specific requirements and sample preparation procedure.
- *Cocktail beam – quick switching between ion types.*

Administrative issues:

The new accelerator complex should solve the following tasks:

• reduce the application program at the main cyclotrons U400(R) and U400M, to be more focused on the scientific tasks of the Laboratory (SHE, radioactive ions and exotic nucleus are required more accelerator time);

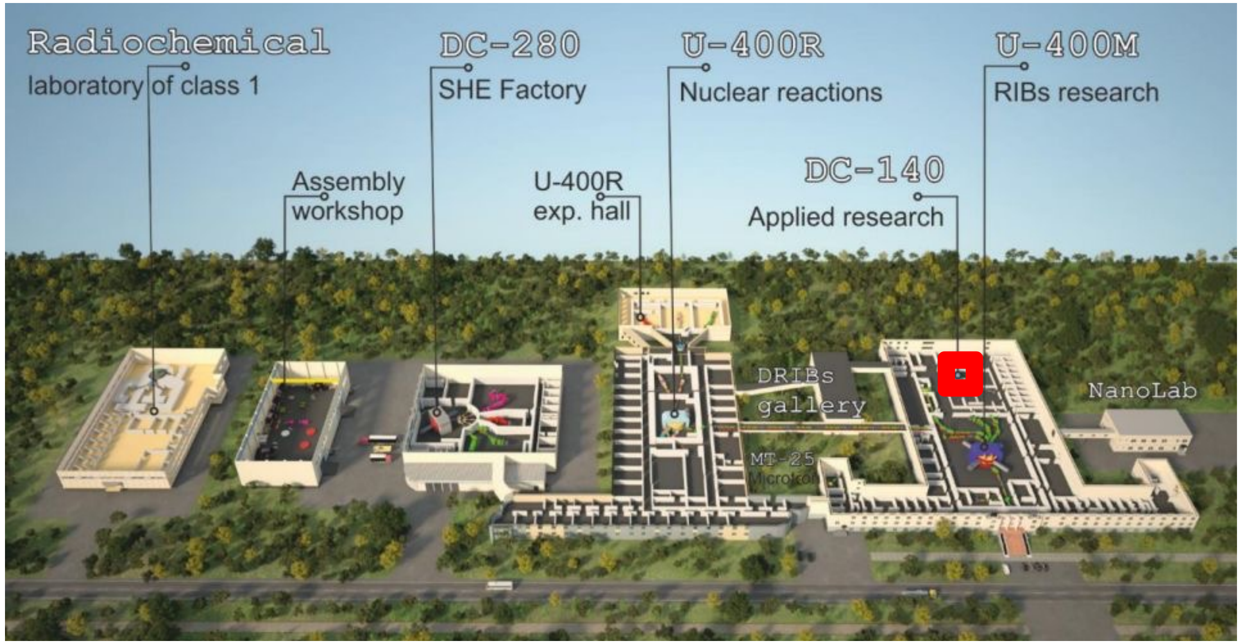
• increase the energy of heavy ion beams to produce nuclear filters to at least 2 MeV/n, which will allow irradiating polymer films up to 30 microns thick and fits new standards in this field;

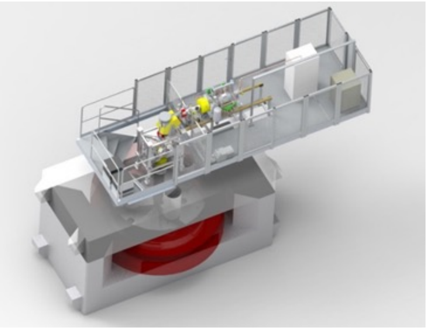
• provide energy of 4.8 MeV/n of heavy ion beams for testing chips for radiation resistance and fits new standards in this field;

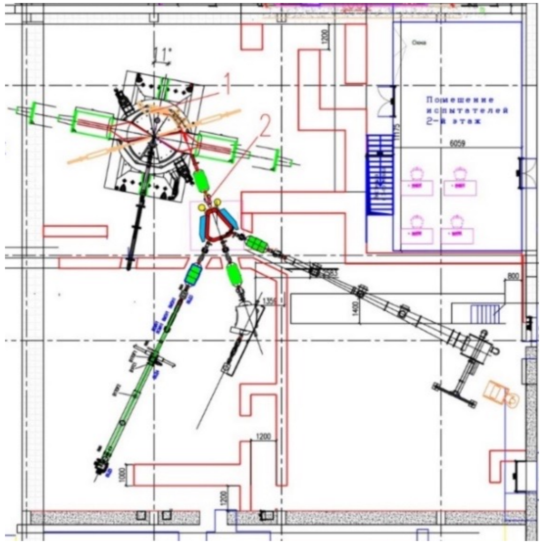
- 24*7*365 ~ 7000 of beam time
- Simplicity of operation
- Time stability
- **Beam cocktail**
- Relatively cheap in use – beam time costs
- Factory approach/routinely use - "turning lathe“
- Economy factor: to use the existing stuff

Radiation materials science:
- energy up more than 1 MeV per nucleon
- Ions from Ne up to Bi or U
- Intensity with Xe (as example) 1×10^{12} c^{-1}
- Irradiation zone Ø30 mm (1-2 AMeV) and Ø20 mm (4,8 AMeV)
- Dedicated beam line due to specific T° requirements and sample preparation procedure.

DC-140: new cyclotron complex for life science.

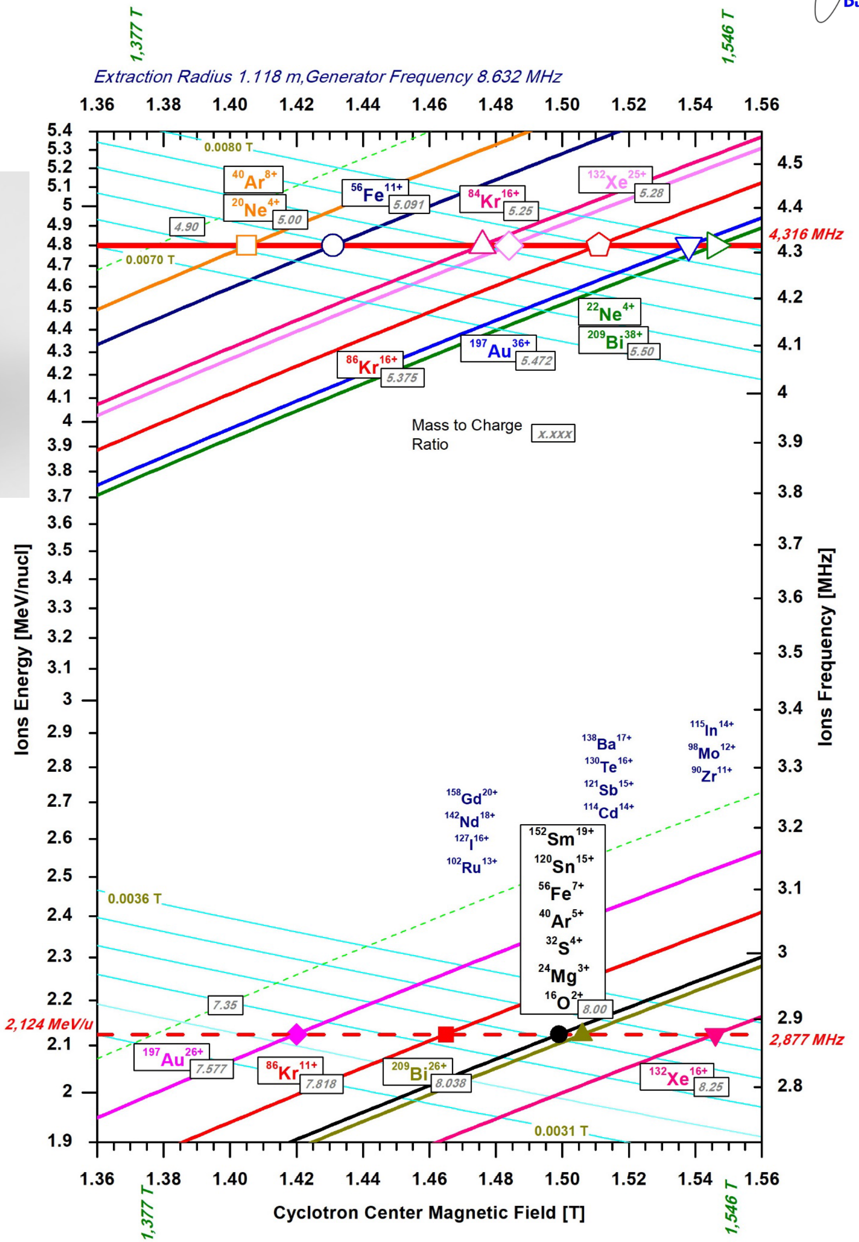




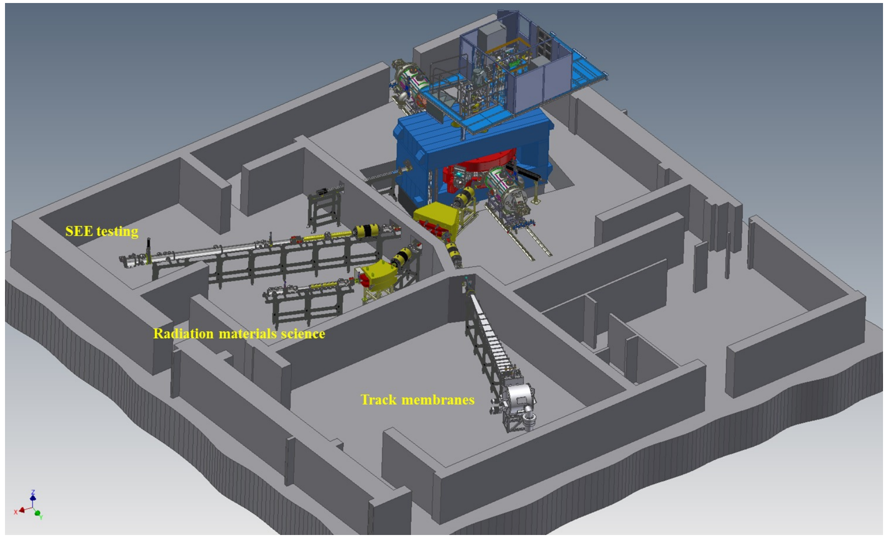


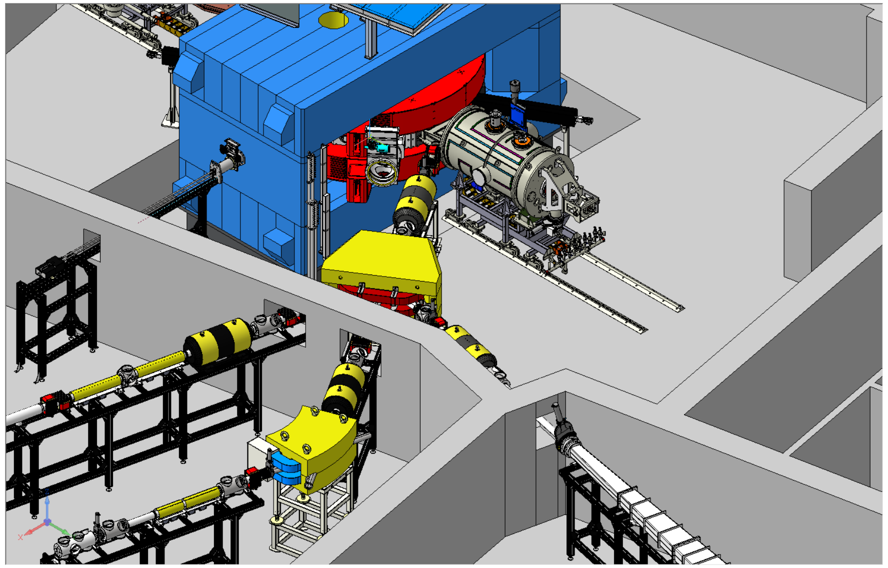
The acceleration of ion beam in the cyclotron will be performed at constant frequency f = 8.632 MHz of the RF-accelerating system for two different harmonic numbers h. The harmonic number h = 2 (f=4.316 MHz) corresponds to the ion beam energy E = 4.8 MeV/u and value h = 3 (f=2.877MHz) corresponds to E = 2.124 Mev/nucleon.

Pole (extraction) radius, m	1.3(1.18)	
Magnetic field, T	1.415÷1.546	
Number of sectors	4	
RF frequency, MHz	8.632	
Harmonic number	2	3
Energy, MeV/u	4.8	2.124
A/Z range	5.0÷5.5	7.577÷8.25
RF voltage, kV	60	
Number of Dees	2	
Ion extraction method	electrostatic deflector	
Deflector voltage, kV	73.5	

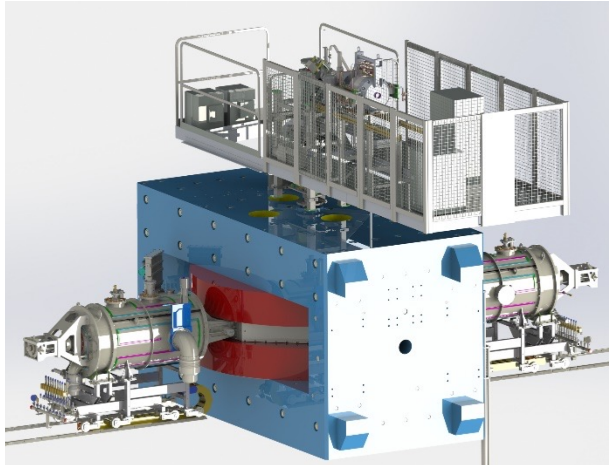


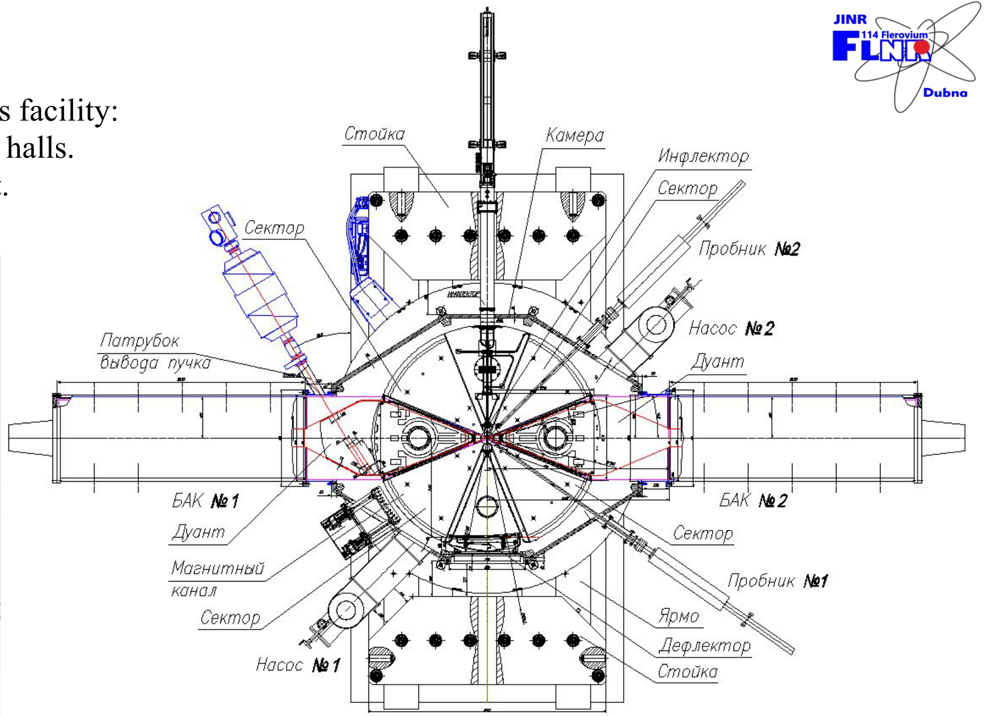
DC-140: new cyclotron complex for life science.



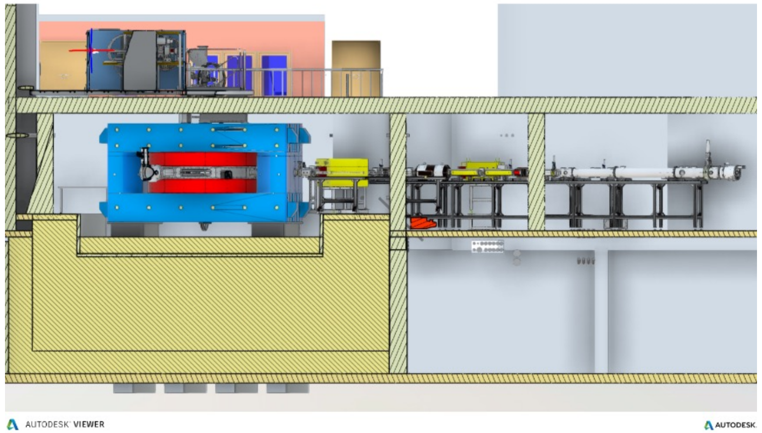


General layout of the DC140 cyclotron and its facility: vault of the cyclotron and experimental setup halls. Detailed equipment and systems arrangement.





DC140-TX_13_04_22.rvt.png

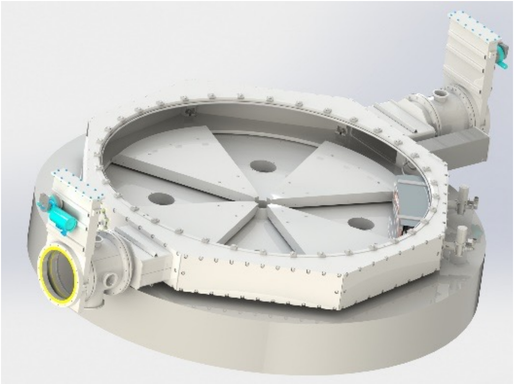


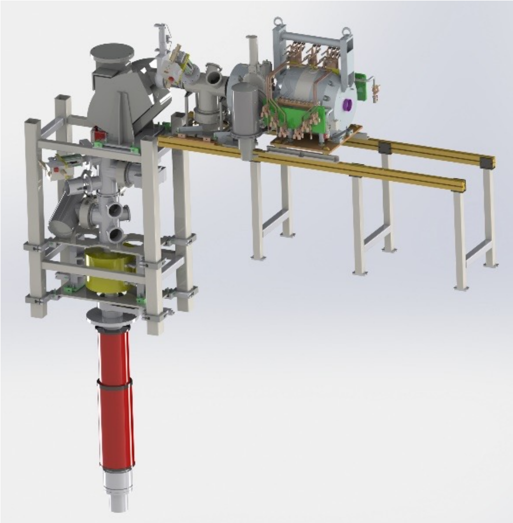
Energy **4,8** MeV/nucleon			Energy **2,214** MeV/nucleon		
Ion	A/Z	I, μA	Ion	A/Z	I, μA
$^{209}Bi^{38+}$	5,5	20,67	$^{209}Bi^{26+}$	8,038	0,416
$^{197}Au^{36+}$	5,472	19,58	$^{197}Au^{24+}$	8,208	3,84
$^{132}Xe^{25+}$	5,28	13,6	$^{158}Gd^{20+}$	7,9	3,2
$^{86}Kr^{16+}$	5,375	8,7	$^{142}Nd^{18+}$	7,889	2,88
$^{56}Fe^{11+}$	5,091	5,98	$^{132}Xe^{16+}$	8,25	2,56
$^{40}Ar^{8+}$	5	4,35	$^{98}Mo^{12+}$	8,167	1,92
$^{16}O^{3+}$	5,333	1,63	$^{90}Zr^{11+}$	8,182	1,76
$^{22}Ne^{4+}$	5,5	2,18	$^{86}Kr^{11+}$	7,818	1,76
$^{20}Ne^{4+}$	5	2,18	$^{16}O^{2+}$	8	0,32

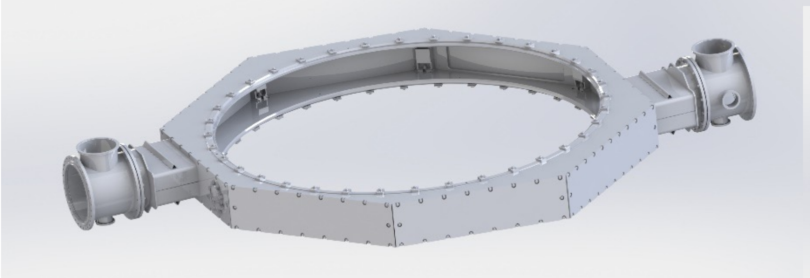
JOINT INSTITUTE FOR NUCLEAR RESEARCH
ОБЪЕДИНЁННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

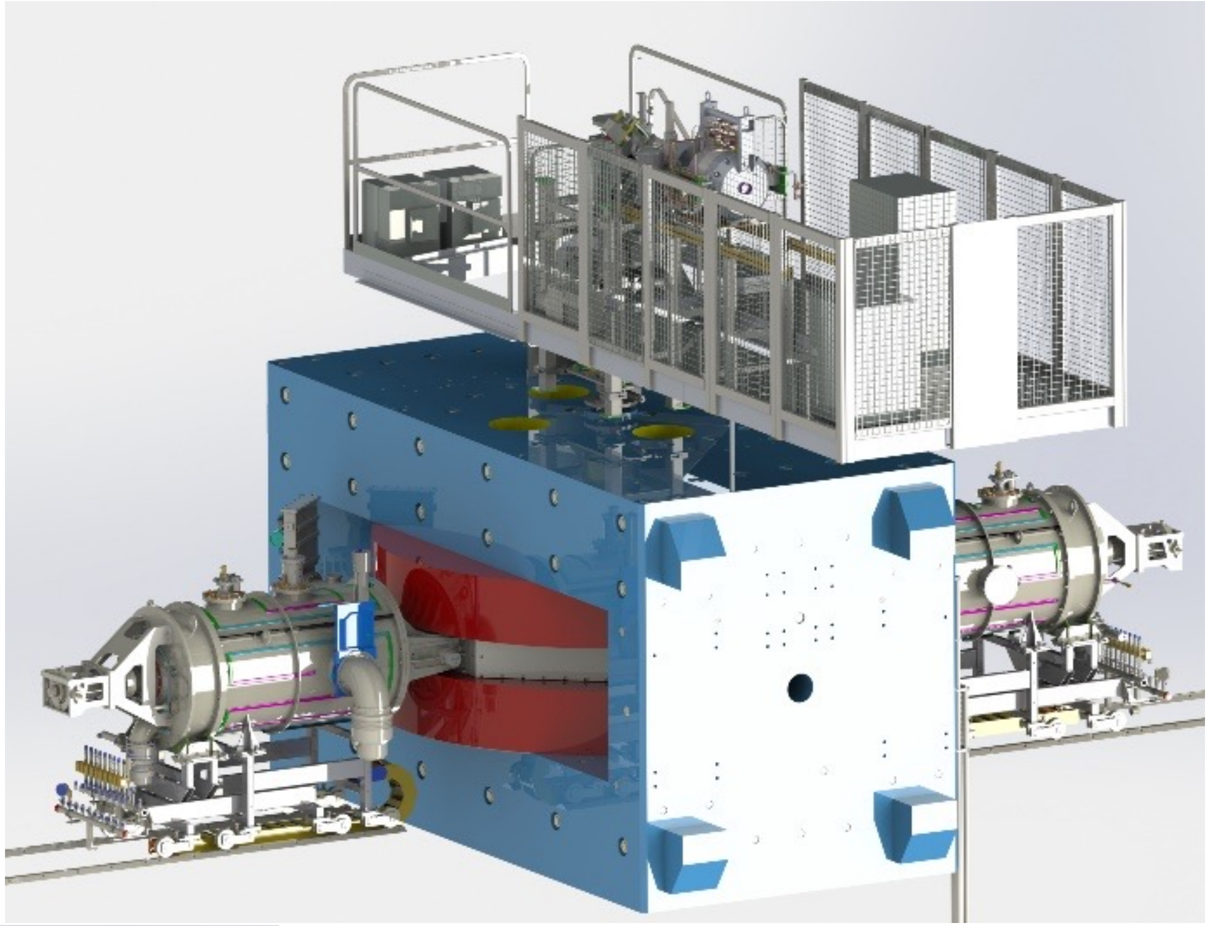
DC-140: new cyclotron complex for life science.

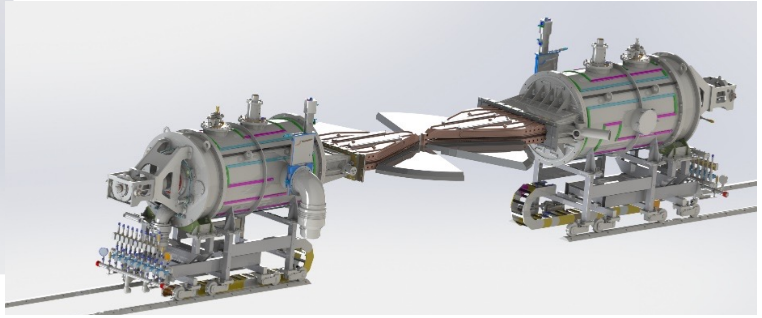
Design and realization

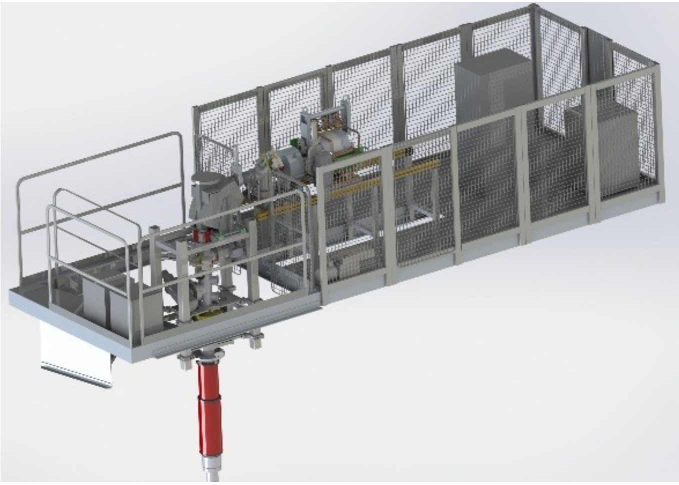


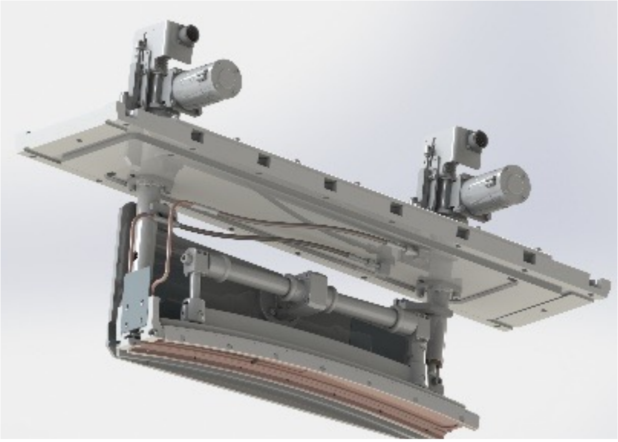






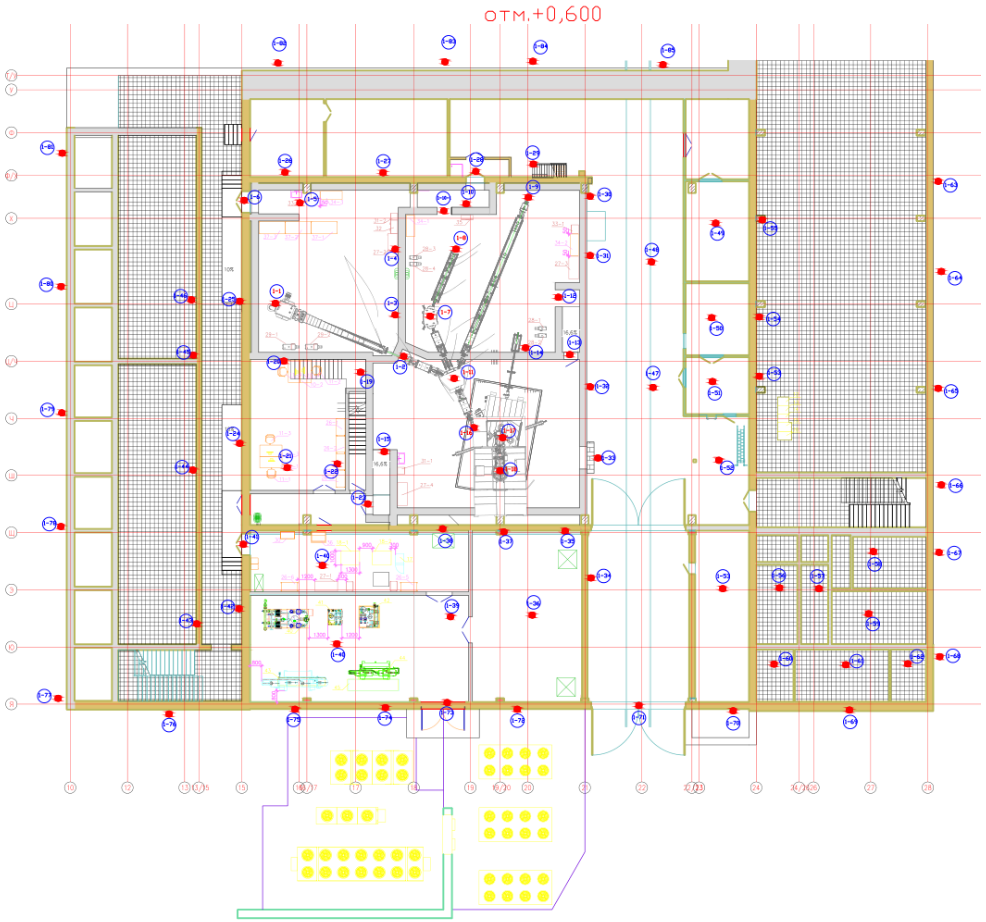


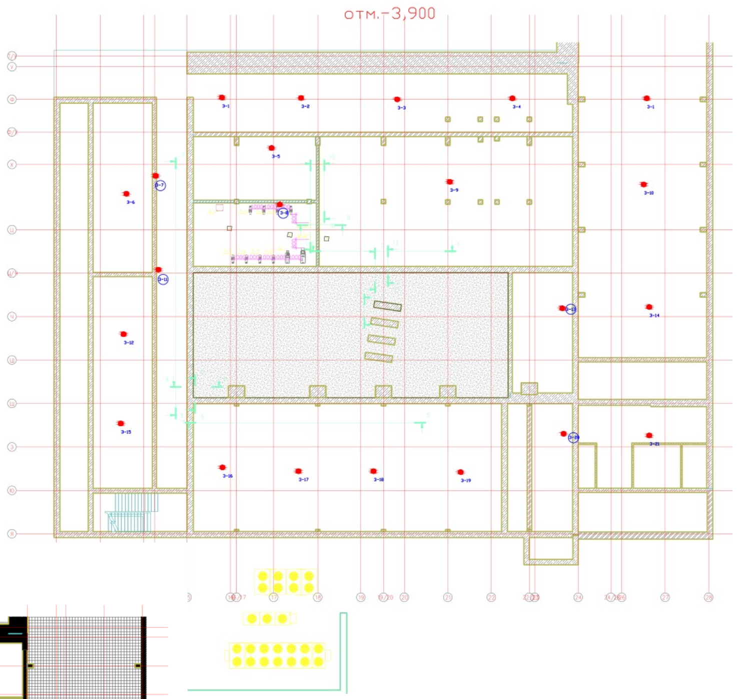


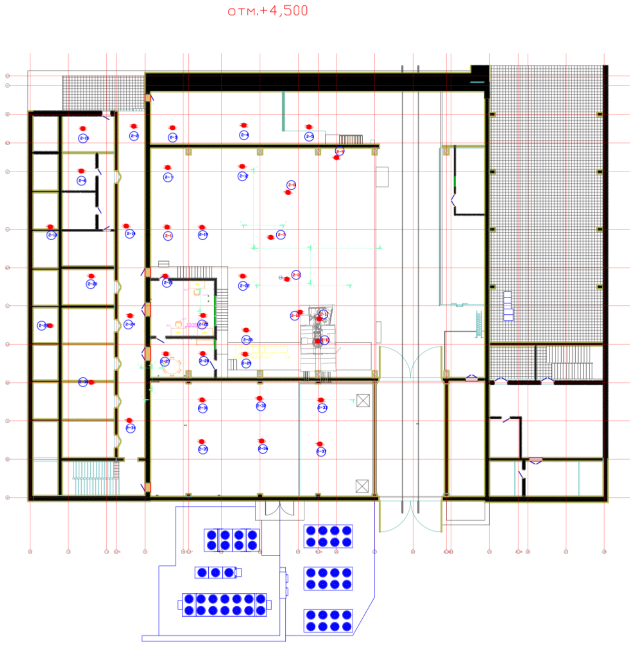


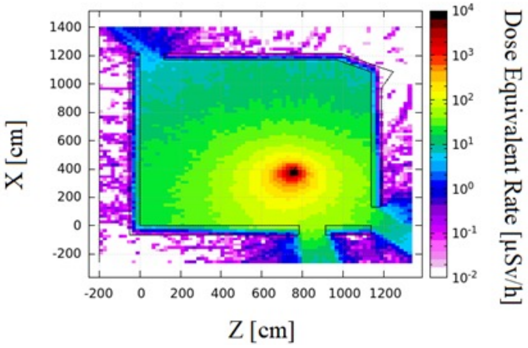
DC-140: new cyclotron complex for life science.

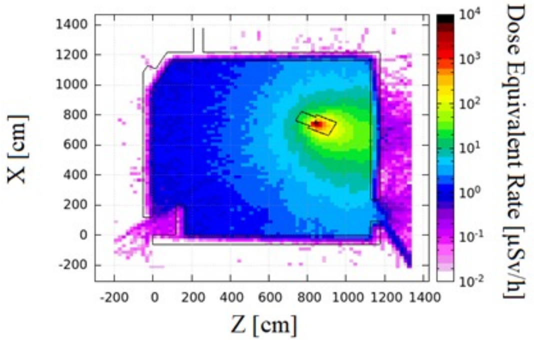
Radiation Safety issues

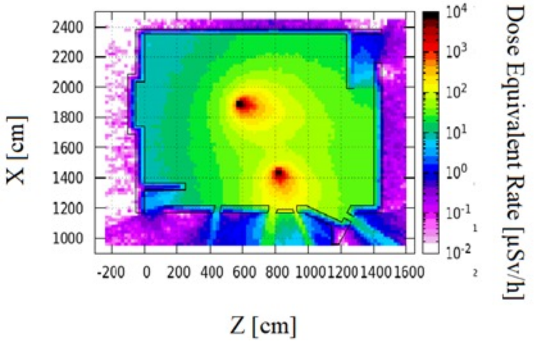










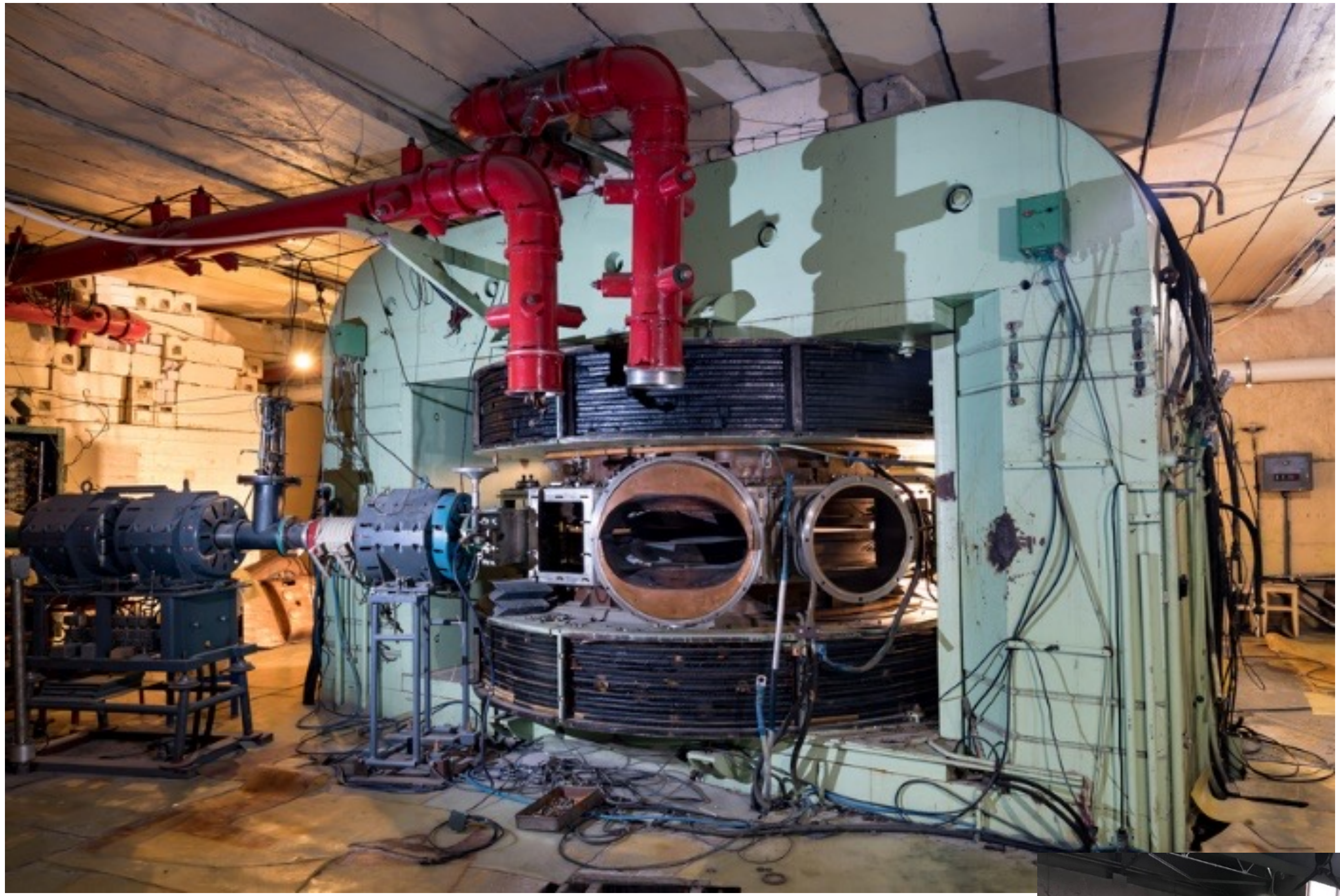


JOINT INSTITUTE FOR NUCLEAR RESEARCH
ОБЪЕДИНЁННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

DC-140: new cyclotron complex for life science.

JINR FLNR 114 Flerovium Dubna

Dismantling of the U200 cyclotron and old stuff removing

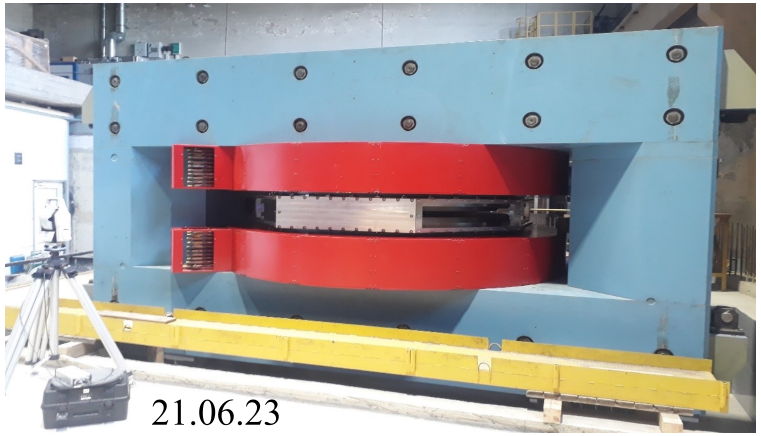


JOINT INSTITUTE FOR NUCLEAR RESEARCH
ОБЪЕДИНЁННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

DC-140: new cyclotron complex for life science.

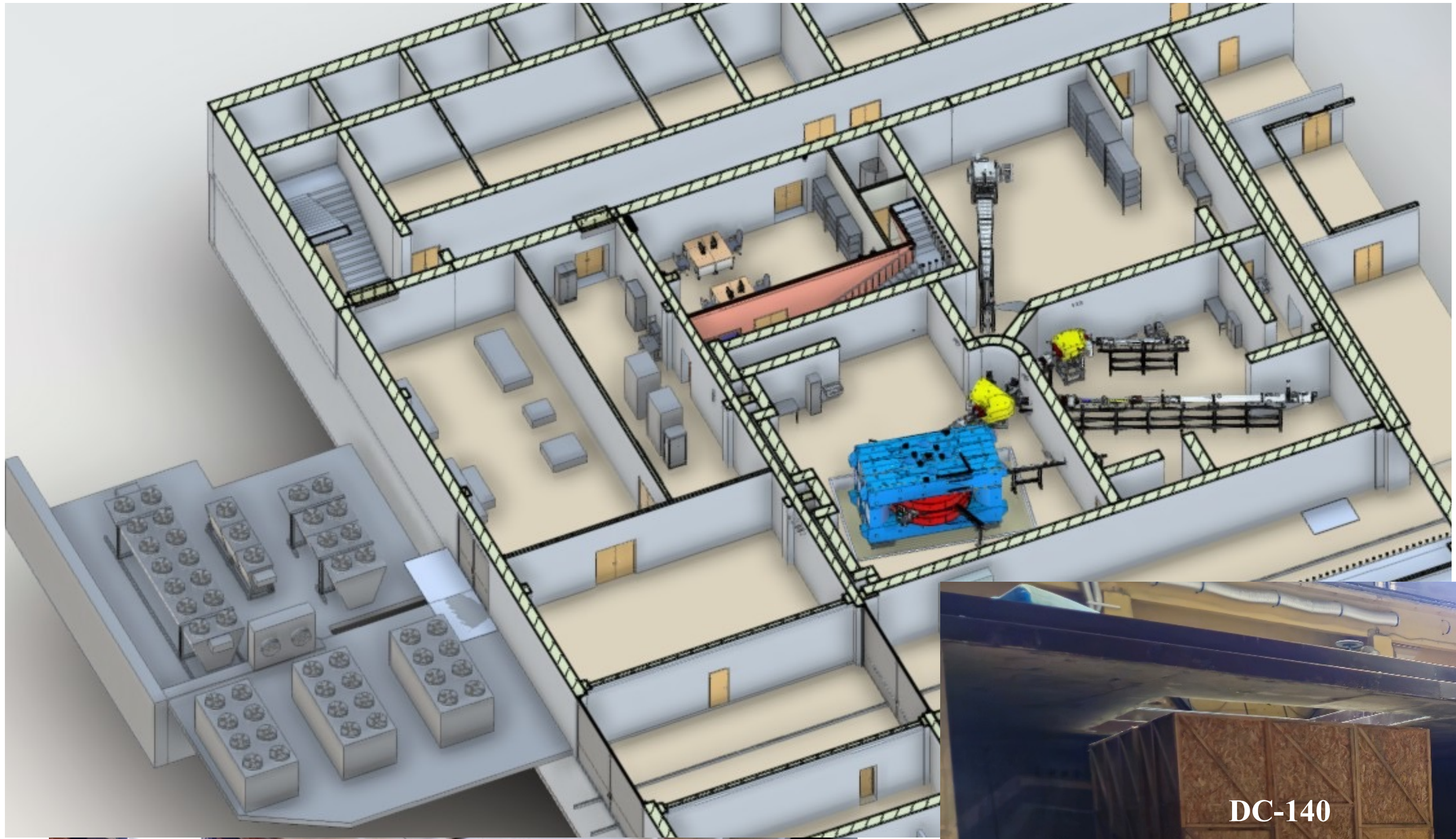
Building renovation and mounting of DC-140 main magnet

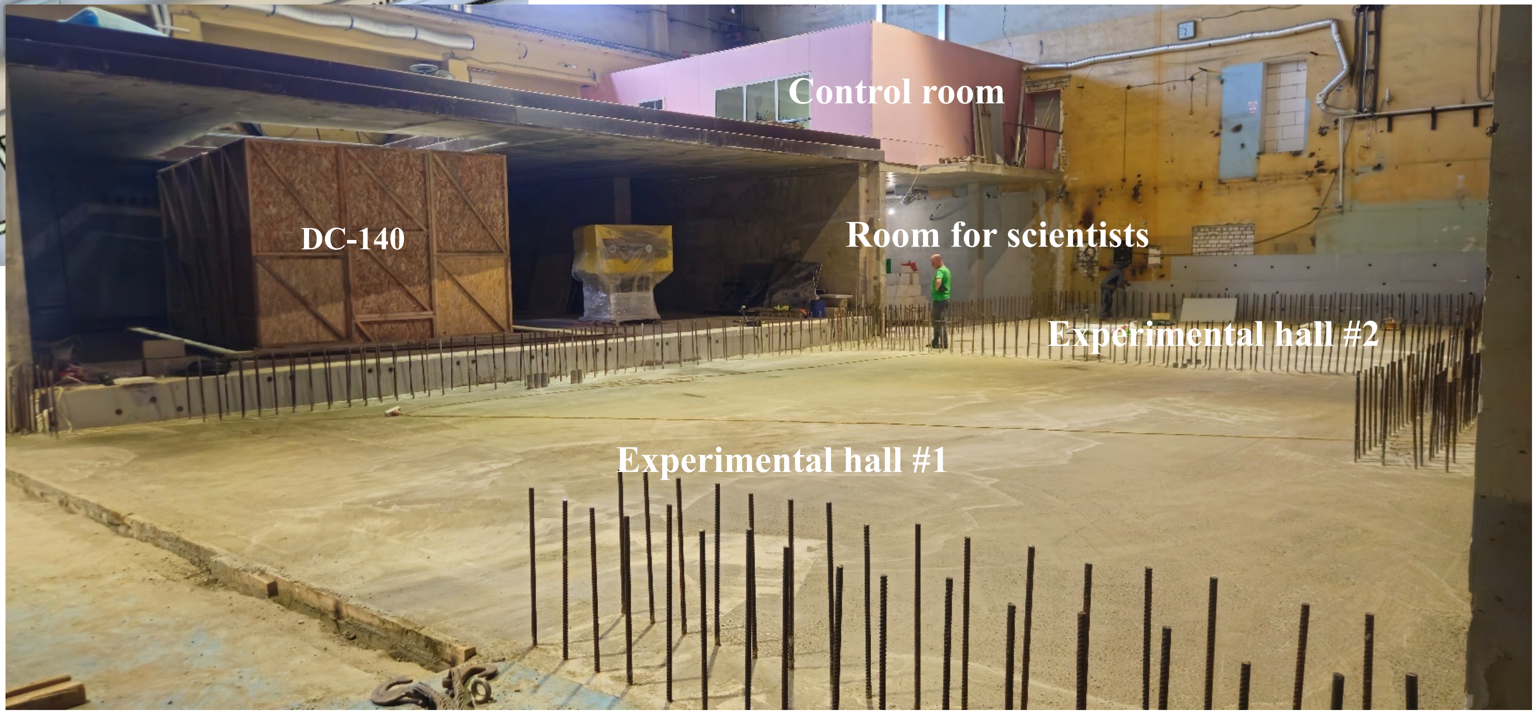
JINR FLNR 114 Flerovium Dubna



DC-140: new cyclotron complex for life science.

Placement of DC-140 in building 101





Engineering systems hall

DC-140: new cyclotron complex for life science.

Technical start – end of 2025

Certifying and licensing

User first run – middle of 2026

Detailed report – CYC '28))

DC-140: new cyclotron complex for life science.

Beam availability in next couple years

Cyclotron	2022	2023	2024	2025	2026	2027	2028	2029
U400/U400R	Low and middle energy beam species (2022–mid 2026)				U400R project and new experimental hall (mid 2026–2028)			Middle energy (2029)
U400M	U400M modernization (2022–mid 2024)		Low energy beam line B5 (mid 2024–2026)			Beam line #A1 (High energy) (2027–2029)		
DC140	DC140 project (2022–2025)				Dedicated beam line #1 at DC140 complex (Low energy) (2026–2029)			
MT-25	…. E-beam …. (2022–2029)							

JOINT INSTITUTE FOR NUCLEAR RESEARCH
ОБЪЕДИНЁННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

Radiochemical Laboratory Class-I *for production of radioisotopes (Ac^{225}, ^{99m}Tc), nuclear medicine R&D in photonuclear reactions @ 40MeV e-accelerator. P and Alfa are in discussion.*

JINR FLNR 114 Flerovium Dubna

Next 7-years planning

- Photonuclear reactions - 40 MeV accelerator
- Proton induced reactions – up to ?? 200 ?? MeV cyclotron
- Alfa – cyclotron with ~ 80 MeV of alfa

Development of new technological processes for obtaining radionuclides for nuclear medicine in photonuclear reactions at an industrial electron accelerator and expansion of the range of research in the field of technologies for nuclear medicine. Manufacture and regeneration of highly radioactive accelerator targets, including those from enriched isotopes of Pu, Am, Cm, Cf and Bk, necessary for the synthesis of new superheavy elements at the STE Factory.

Nuclear physics studies of photodetection of heavy nuclei and production of radioactive beams. Environmental studies and analysis of radionuclides in natural systems using nuclear physics methods.

Goals and objectives of physical research:

1. Obtaining fission fragments for subsequent acceleration;
2. Nuclear spectroscopy of fission fragments;
3. Precision determination of the masses of fission fragments;
4. Laser spectroscopy of fission fragments;
5. Target manufacturing and regeneration;
6. Production of radioactive isotopes for medicine in reactions (γ,x);
7. Study of polymerization and depolymerization reactions;
8. Study of the effects of gamma radiation on biological materials.

99mTc

100Mo(γ,n)99Mo → 99mTc

Accelerator = kind of …….. ?

123I

124Xe (γ,n) 123Xe

225Ac

226Ra(γ,n)226Ra→225Ac

The DC-140 project:

new multipurpose

applied science facility

at FLNR JINR

Accelerator Complex.

Thank you !

* mitrofanov@jinr.ru