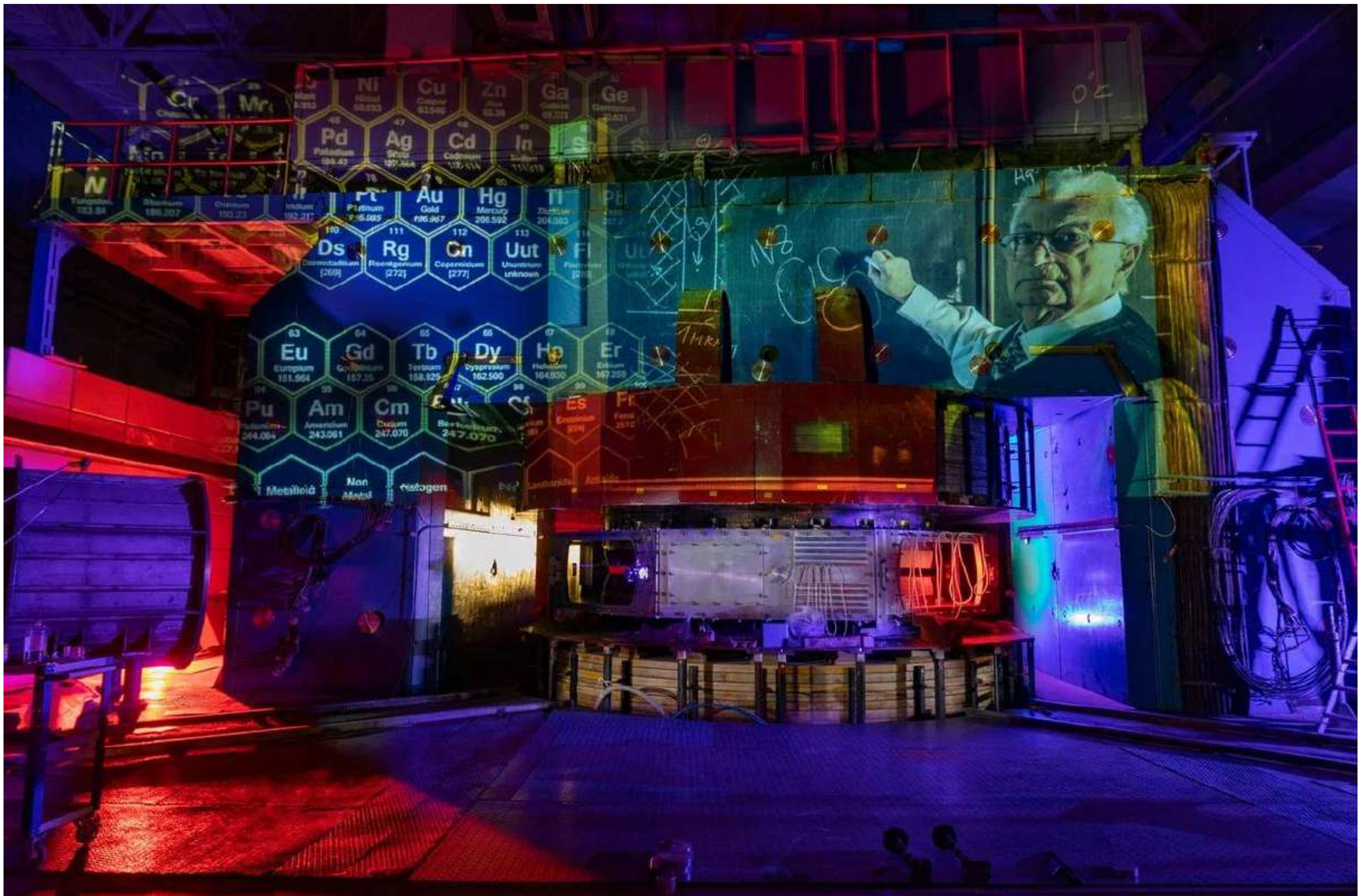
FLEROV LABORATORY OF NUCLEAR REACTIONS

С. В. Митрофанов

Ускорительный комплексе ЛЯР ОИЯИ в 2024 году.
Некоторые аспекты прикладных исследований.



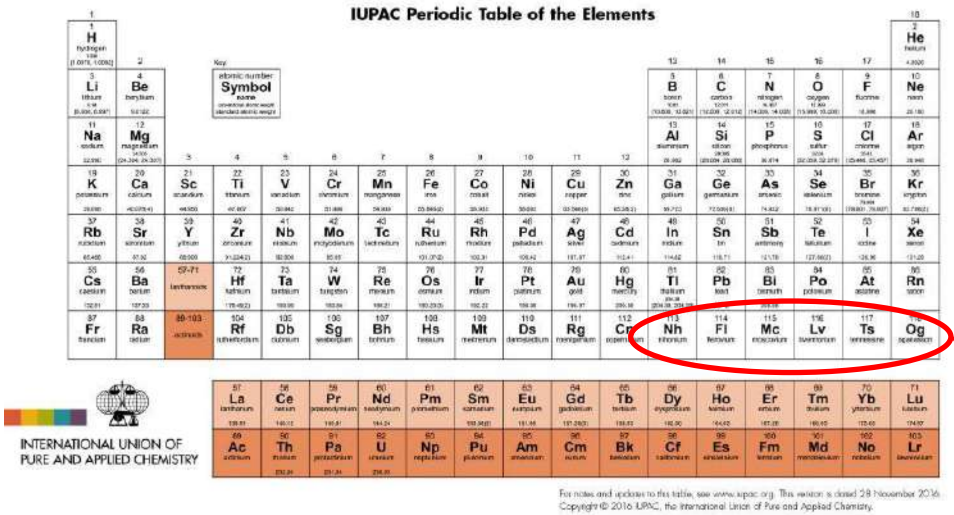
JOINT INSTITUTE FOR NUCLEAR RESEARCH

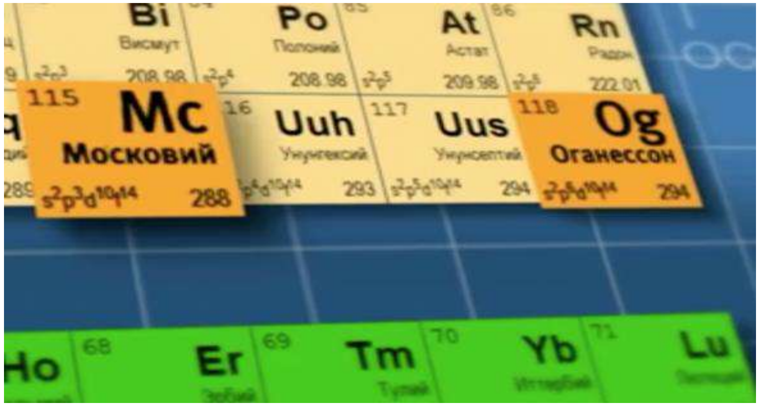
FLNR main activities

*Flerov Laboratory of Nuclear Reactions was founded in the Joint Institute for Nuclear Research in 1957.

FLNR carries out research in the field of heavy ion physics in three main directions:

- Synthesis and properties of nuclei at the stability limits
- Accelerator complex of ion beams of stable and radioactive nuclides (DRIBs-III)
- Radiation effects and physical bases of nanotechnology, radioanalytical and radioisotope investigations at the FLNR accelerators



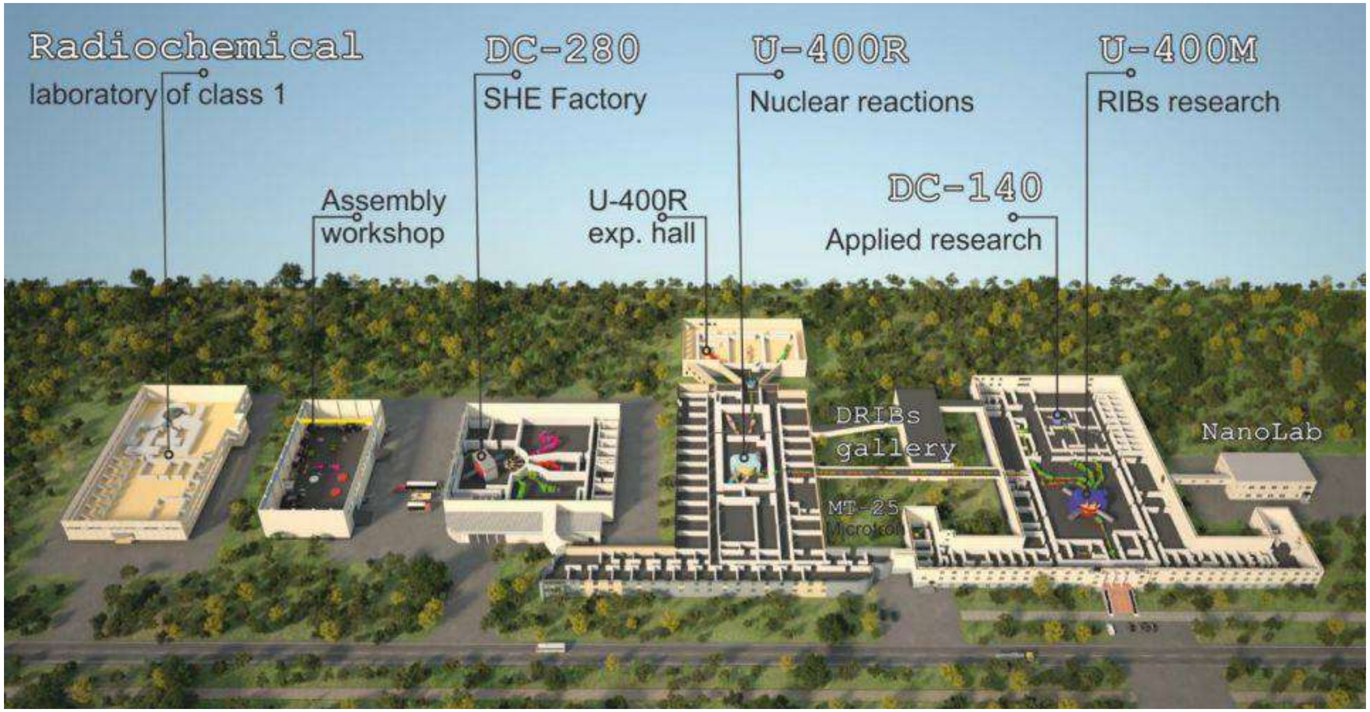


2016

FLNR accelerating complex in 2024.

4 cyclotrons and Microtron

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



U-400M

U-400

MT-25

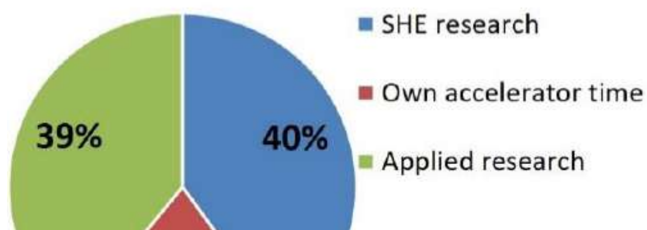
DC-280

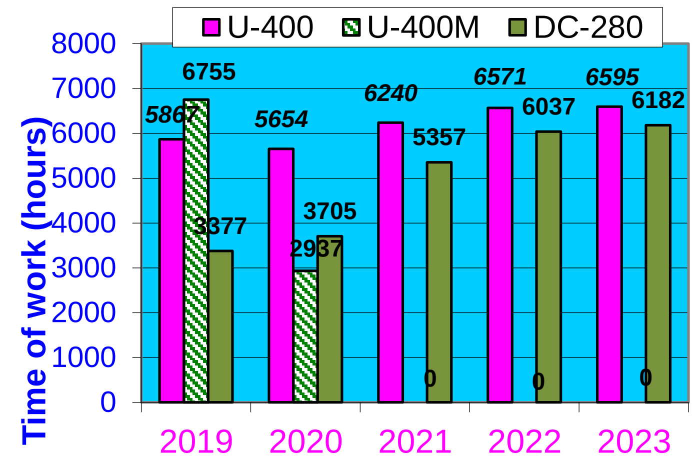
IC-100

FLNR accelerating complex in 2023.

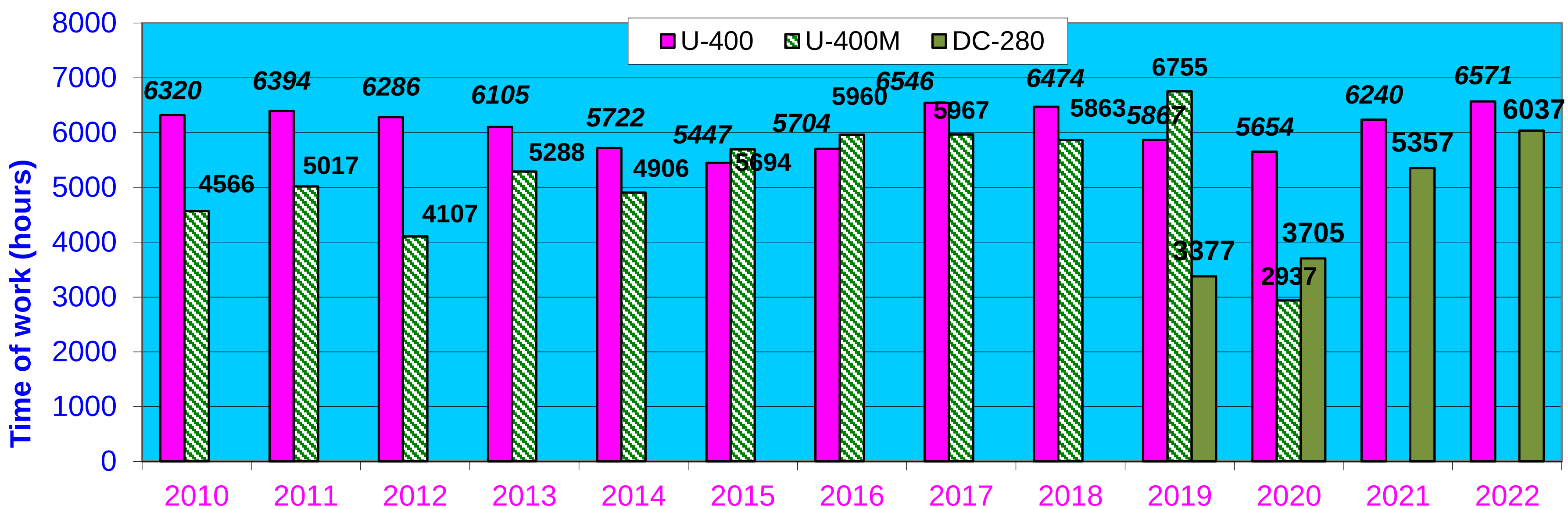
Sum time of work of accelerator facilities (hours)	2015	2016	2017	2018	2019	2020	2021	2022
	14034	15724	16657	16904	20110	15124	15065	16834

Using of accelerator times in 2020





Working time of main cyclotrons
(time: beam ON physical target)



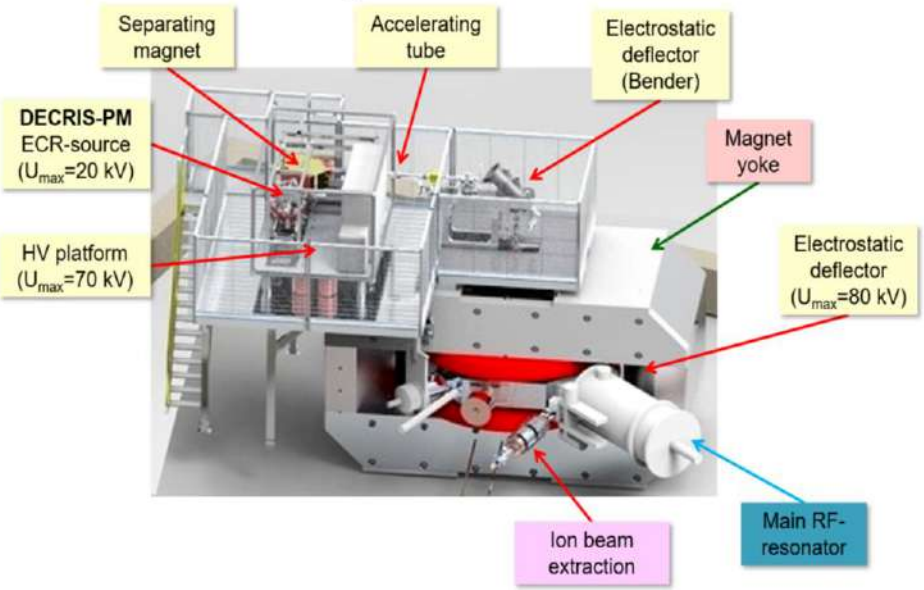
DC280

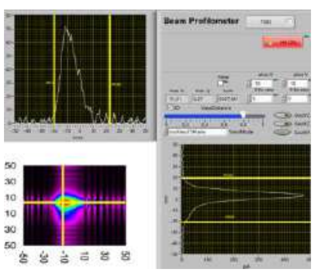
Year	Total work time	Ions
2018	First Beam	^{84}Kr
2019	3377	^{12}C, ^{40}Ar, ^{48}Ca, ^{84}Kr
2020	3705	^{40}Ar, ^{48}Ca, ^{48}Ti
2021	5357	^{48}Ca, ^{48}Ti, ^{52}Cr
2022	6037	^{40}Ar, ^{48}Ca, ^{48}Ti, $^{52,54}Cr$

Main parameters of the DC-280

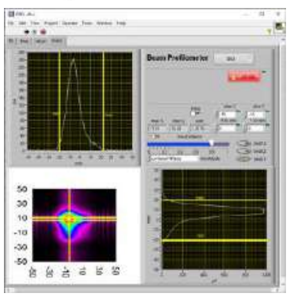
parameters	design	realized
Ion source	DECRIS-PM - 14 GHz on the HV platform (U_{max}=60kV)	
Injecting beam potential	Up to 80 keV/Z	38,04 – 72,89 keV/Z
A/Z	4÷7.5	4,44 ($^{40}Ar^{+7}$) – 6,86 ($^{48}Ca^{+7}$)
Energy	4÷8 MeV/n	4,01 – 7 MeV/n
Ion (for DECRIS-PM)	4-136	12 ($^{12}C^{+2}$) – 84 ($^{84}Kr^{+14}$)
Intensity (A~50)	>10 pμA	10,43 pμA ($^{40}Ar^{+7}$), 7,7 pμA ($^{48}Ca^{+10}$)
Magnetic field level	0.6÷1.3 T	0.8÷1.23 T
K factor	280	
Dee voltage	2x130 kV	130 kV
Power of RF generator	2x30 kW	
Flat-top dee voltage	2x13 kV	13 kV
Power of Flat-top generator	2x2 kW	
Emittance	less than 30 π mm·mrad	
Accelerator effectivity	>50%	51,9 % ($^{48}Ca^{+10}$ 5 MeV/n 5 pmkA)

Configuration of the DC-280

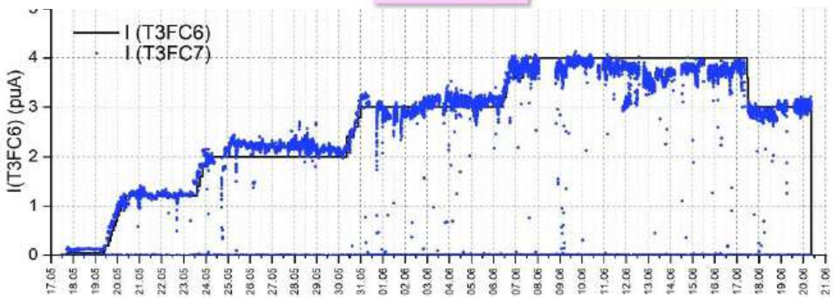




Profile of $^{54}Cr^{10+}$ beam in transport channel



Profile of $^{48}Ti^{9+}$ beam in transport channel



Stability of the Ca-48 beam during 1 month of work

DC-280. The basic facility of the Superheavy Element Factory — DC-280 cyclotron — provided 5357 h of beam-time for research in 2021. During this period, the novel gas-filled separator GFS-2 was employed for conducting experiments on the synthesis of element 114 (flerovium) in the $^{242}Pu + ^{48}Ca$ reaction, element 115 (Moscovium) in the $^{243}Am + ^{48}Ca$ reaction, and element 112 (copernicium) in the $^{238}U + ^{48}Ca$ reaction. The experiment on the synthesis of Mc lasted for 1820 h; Fl, for 410 h; and Cn, for 810 h. The energy of ions extracted from the cyclotron could be smoothly varied, which was of particular importance for experiments conducted at the SHE Factory. Thus, the intensity of the beams of ^{48}Ca ions in experiments varied from 0.05 up to 7.7 pμA. Work on adjusting the acceleration modes for the $^{52,54}Cr^{10+}$ and $^{48}Ti^{9+}$ ions continued. The intensity of the accelerated ^{52}Cr beam reached 2.4 pμA, and the intensities of the beams of ^{54}Cr and ^{48}Ti ions were 2.2 and 1 pμA, respectively. In addition, preparations were complete for experiments at a new physics set-up GFS-3.

U400M

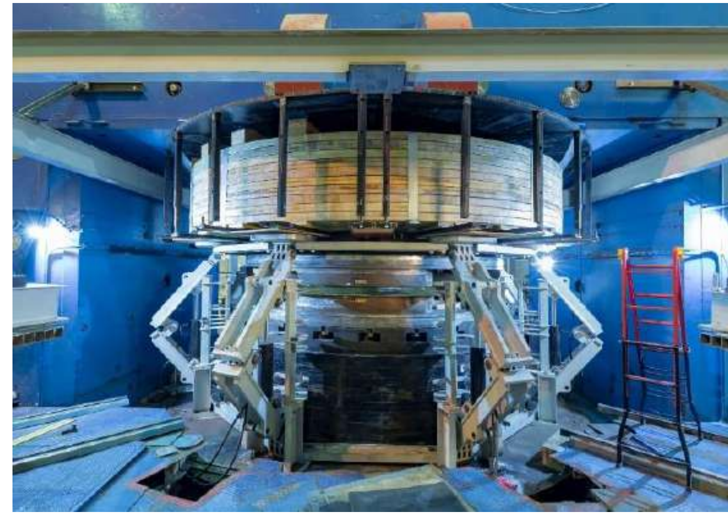
Системы	Список планируемых работ
Аксиальная инжекция	Замена «теплого» ECR источника **DECRIS-2 → DECRIS-2M**
Магнитная система циклотрона	Замена катушек основного магнита
	Магнитные измерения
	Коррекция магнитного поля (компенсация первой гармоники)
	Установка долинных шиммов
	Восстановление корректирующих катушек
Ускоряющая система	Замена системы перемещения и контактных групп закорачивающих пластин резонаторов
	Новая система автоподстройки частоты (емкостная)
	Новая фидерная линия с системой согласования
Оборудование циклотрона	Новые токовые пробники
	Доработка системы вывода пучка
	Система проверки положения центра орбиты пучка
Вакуумная система	Замена оборудования на современное.
Каналы пучков	Замена вакуумного оборудования
	Новые элементы диагностики
Система управления	Новая система управления

График модернизации У-400М → МЦ-400

№	Работы	2023	2024	2025	2026	2027	2028	2029
	Модернизация У-400М→ МЦ-400	Модернизация			Работа МЦ-400			

U400M

The cyclotron electro-magnet with 4-meter pole diameter since 2020 is under reconstruction now that includes a replacement of magnet main coil, corrections of the magnetic field at the central region and at the extraction radius. For measurements and shimming of cyclotron magnetic field the automatic mapping system, based on 14 Hall probes, was created.



Ion	2019		Project	
	E (MeV/u)	I(pmA)	E (MeV/u)	I(pmA)
^{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	0.12	44	0.2
^{48}Ca	34	-	38	0.1
^{56}Fe^{15+}	36	0.01	40	0.1

U-400M. As part of the U-400M cyclotron upgrade project, the main magnet coils were replaced with a new set-in collaboration with the OOO NPO GKMP, Bryansk. The novel components were connected to the power supply and cooling system; a magnetic field measuring system was installed.

Another major enhancement involved an upgrade of operational elements and manufacturing of novel components for the vacuum system and for the cooling and control systems of the U-400M cyclotron.

The start-up of U-400M is planned for the beginning of 2024.

U400M

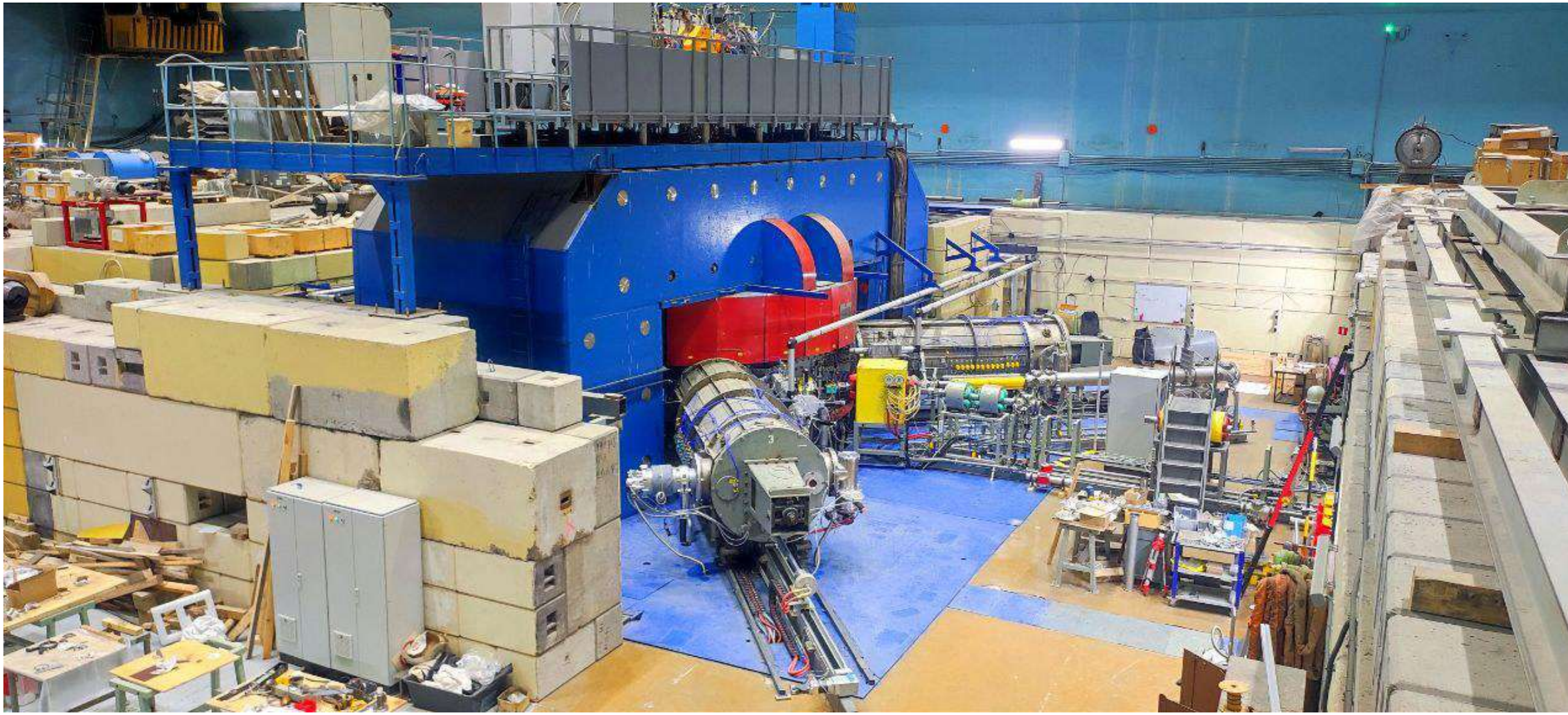
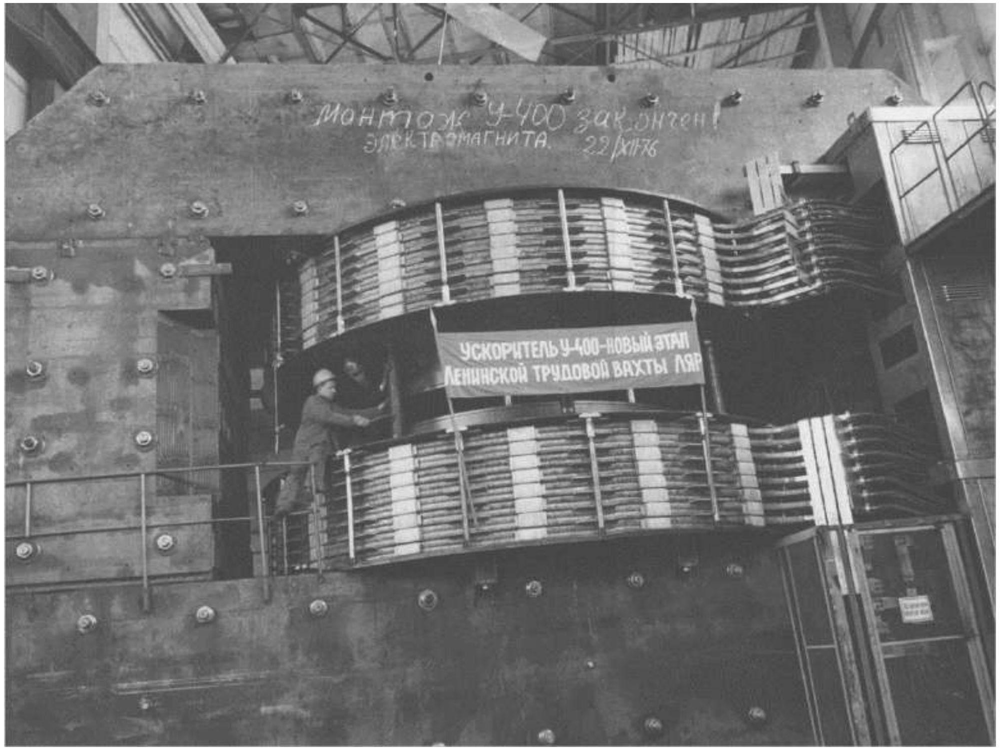


График модернизации У-400М → МЦ-400

№	Работы	2023	2024	2025	2026	2027	2028	2029
	Модернизация У-400М→ МЦ-400	Модернизация			Работа МЦ-400			

U400 ===> U400R + Новый Экспериментальный Зал

Main cyclotron parameters		
Parametersc	**U400**	**U400R**
A/z range	5÷12	4÷12
Magnetic field	1.93÷2.1 T	0.8÷1.8 T
K factor	530÷625	100÷500
RF modes	2	2, 3, 4, 5, 6
Injection potential	10÷20 kV	10÷50 kV
Ion energy range	3÷20 MeV/n	0.8÷27 MeV/n
Number of sectors	4	4
Number of dees	2	2
Beam extraction	stripping	Stripping, deflector
Power consuption	~1 MW	~0.4 MW

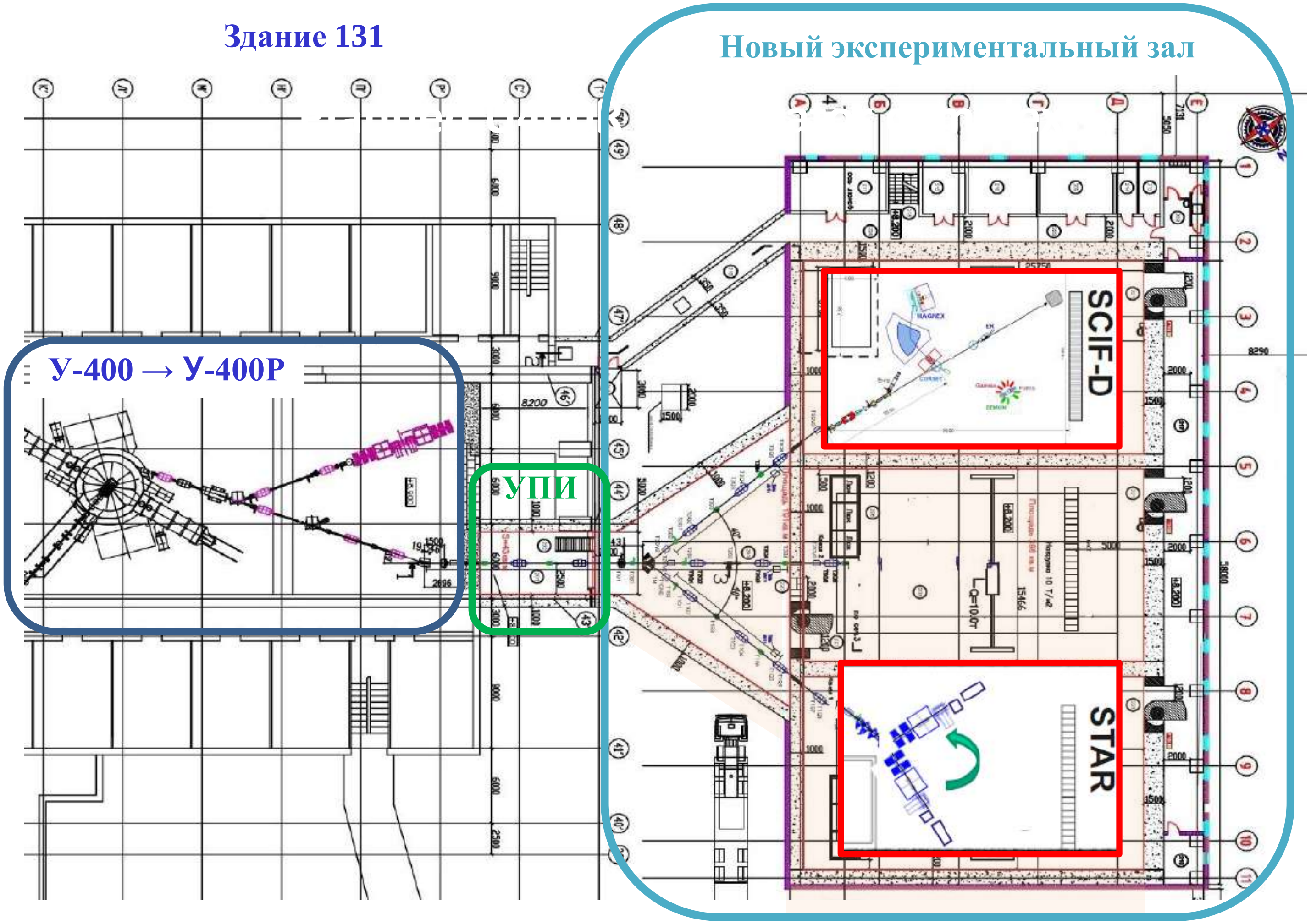


1. Increasing the intensity of ion beams with mass A ≈ 50 and energy ≈ 6 MeV/nucleon to 2.5 ρμA.
2. Ensuring ion energy variation by 5 times, with an accuracy of $\Delta E/E=5*10^{-3}$.
3. Reducing the induction of the average magnetic field from 1.9 ÷ 2.1 T to 0.8 ÷ 1.8 T.
4. Vacuum system upgrade. Vacuum improvement.
5. Ensuring the energy spread of the beam on the target - 10^{-3}.

U-400. A wide variety of scientific and applied investigations in heavy-ion physics were conducted using the U-400 cyclotron. In 2023, the cyclotron provided 6595 h of beamtime. Most of the operation time was devoted to the implementation of the program focused on studying the beams of ^{22}N ions (SHELS set-up), ^{46}Ti ions (chemical set-up, SHELS), ^{48}Ca ions (CORSET, SHELS, MAVR), and ^{56}Fe ions (MAVR). In addition, experiments on accelerating ^{238}U ions were carried out.

Applied studies (SEE tests and material science) were also conducted employing the U-400 cyclotron.

U400 ===> U400R (Новый Экспериментальный Зал)



Создание новых экспериментальных установок

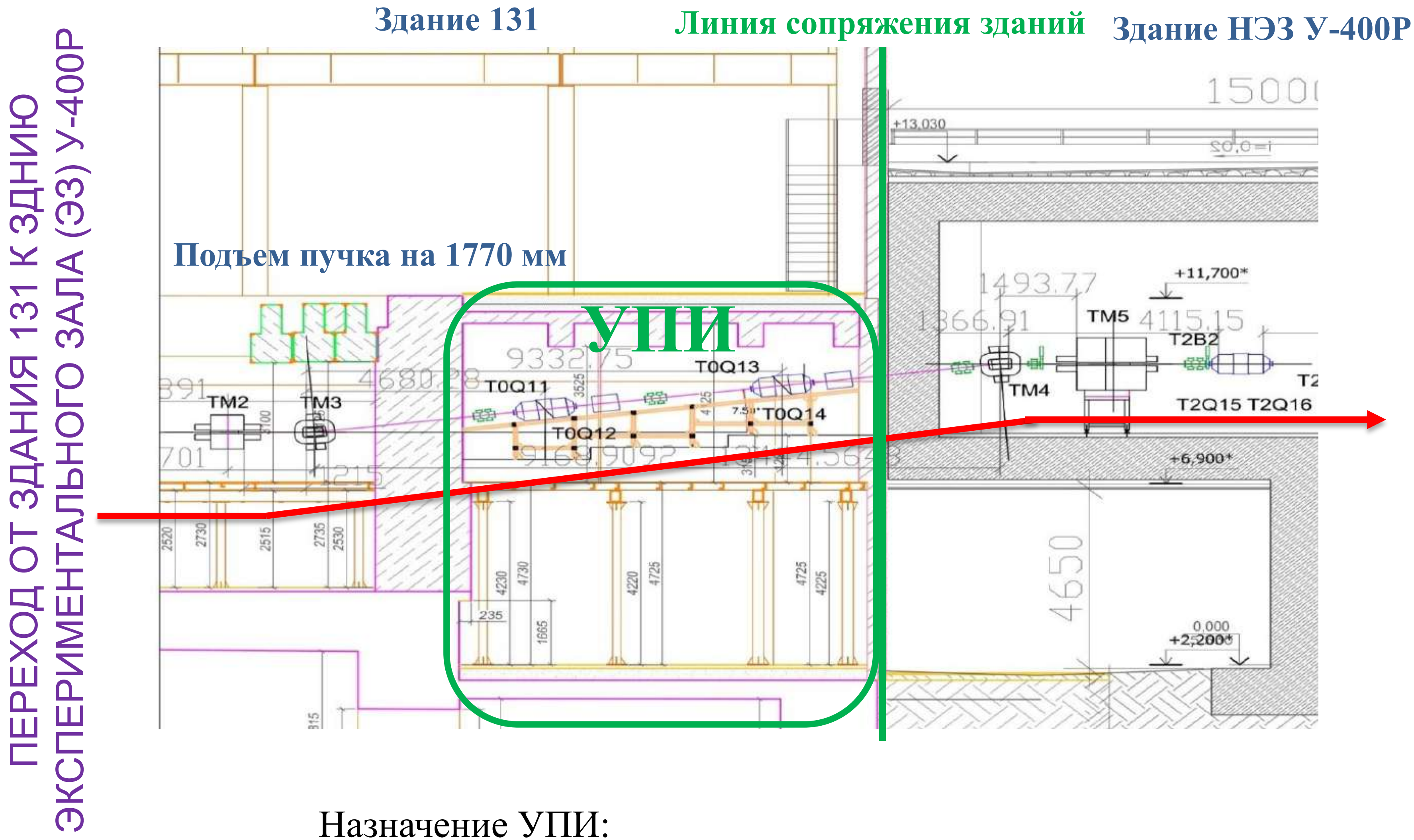
Работы в по модернизации У-400 → У-400Р

№	Работы	2023	2024	2025	2026	2027	2028	2029
	Физ.Установки	Проектирование		Комплектация		Монтаж, наладка		

JOINT INSTITUTE FOR NUCLEAR RESEARCH

U400 ===> U400R (Новый Экспериментальный Зал)

Участок Проводки Ионопровода (УПИ)



Назначение УПИ:

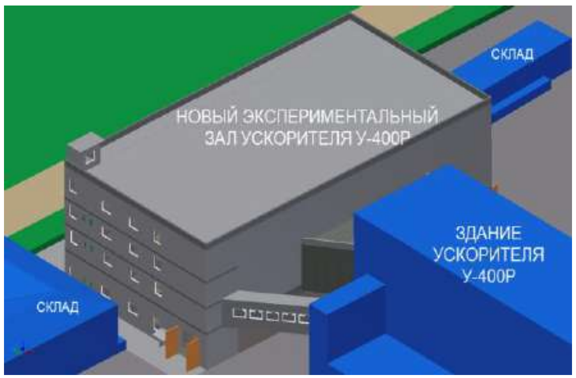
- Транспортировка ускоренного пучка
- **Транзит коммуникаций из зд. 131 в НЭЗ**

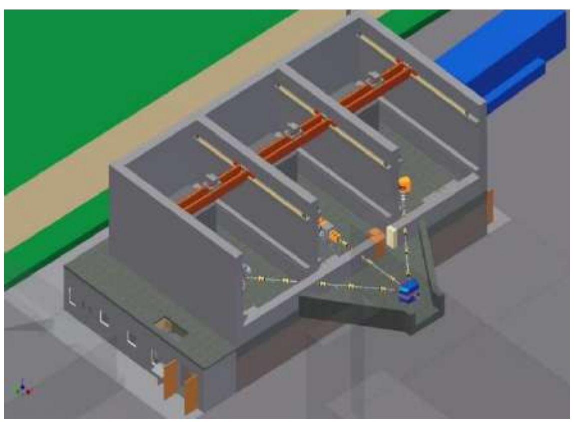
U400 ===> U400R (Новый Экспериментальный Зал)

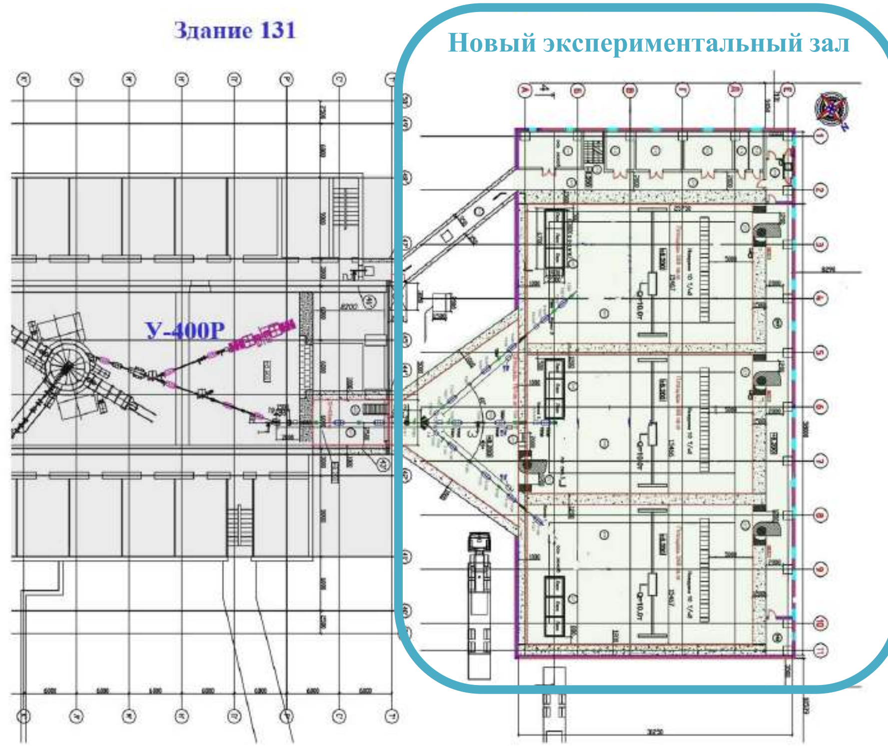
ЭЦМ ЭЛЕКТРОЦЕНТРОМОНТАЖ

Начало **Май 2023 г.**

Окончание Июль 2026 г.







Площадь застройки здания: 2073 м^2 ; Общая площадь здания: 4565,7 м^2 ;

Здание будет иметь 4 этажа:
1-й этаж:
технологические системы;
2-й этаж:
саншлюз и выходы к физкабинам;
3-й этаж:
измерительные комнаты и серверные;
4-й этаж:
источники питания физустановок.

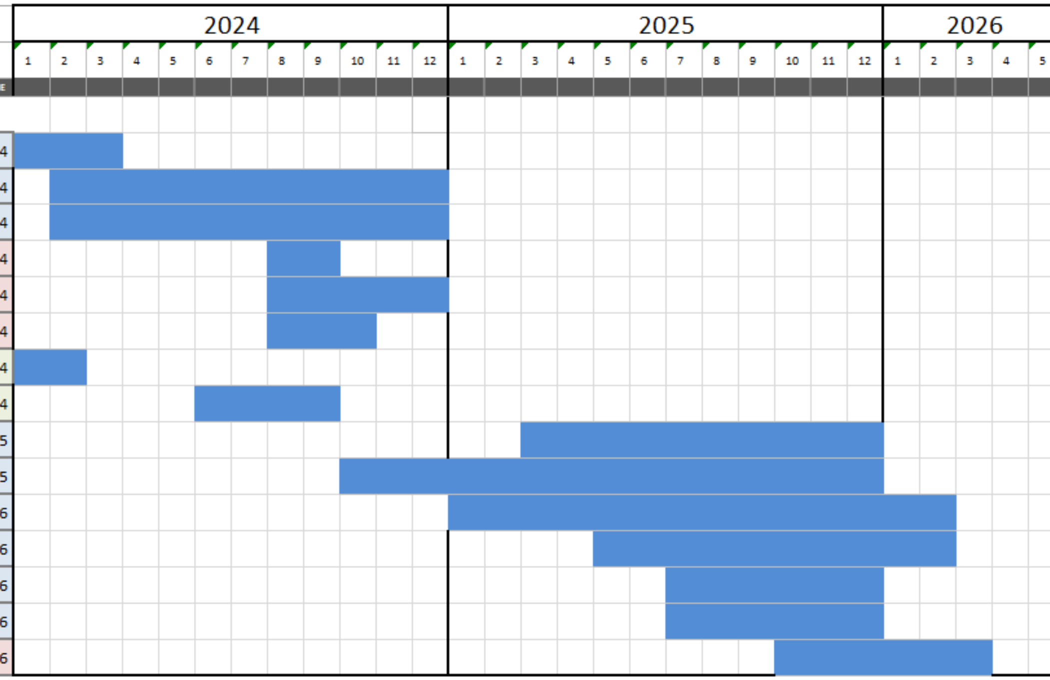
U400 ===> U400R (Новый Экспериментальный Зал)

Новый экспериментальный зал

ЭлектроЦентроМонтаж

Пн, 01.01.2024

ЗАДАЧА	НАЧАЛО	ЗАВЕРШЕНИЕ
Ростверк (1-4 захватки)	01.01.24	04.03.24
Устройство монолитных стен и перекрытий на отметке -0.100 - +24.000	01.02.24	30.12.24
Лестничные марши, наружная лестница. Стремянки	09.01.24	30.12.24
Утепление фундамента	01.08.24	15.09.24
Фахверковые колонны	01.08.24	30.12.24
Устройство перегородок	01.08.24	31.10.24
Проектные работы по прокладке инженерных сетей	01.01.24	01.03.24
Прокладка инженерных сетей	01.06.24	01.10.24
Отделочные работы внутри помещений	01.03.25	30.12.25
Отделочные работы снаружи здания	16.09.24	30.12.25
Монтаж инженерных систем здания	01.01.25	28.02.26
Монтаж АСРК и СБиС	01.05.25	28.02.26
Организация проездов	01.07.25	01.01.26
Благоустройство территории	01.07.25	01.01.26
ПНР работы	01.10.25	01.04.26



U400 ===> U400R (Новый Экспериментальный Зал)

Первая свая 27.07.2023

Завершение свайного поля
08.12.2023

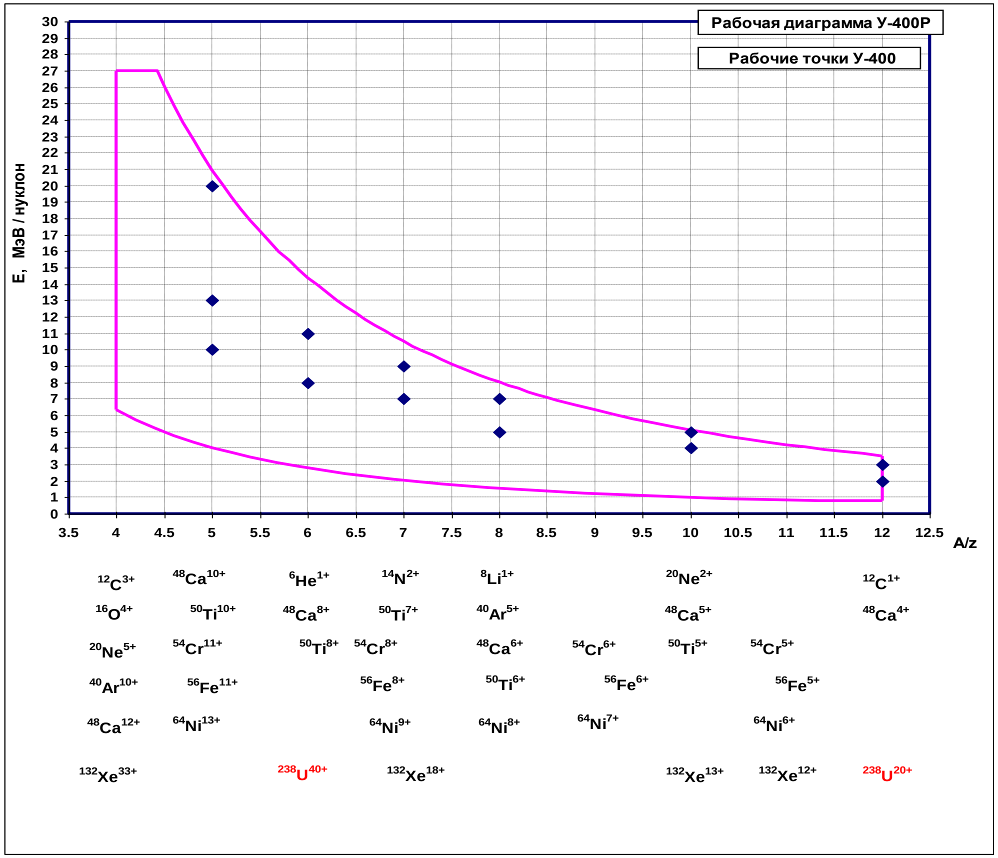
Начало заливки ростверка 21.12.2023

Состояние на 08.04.2024

U400 ===> U400R

Рабочие диаграммы У-400 и У-400Р

1. **Система аксиальной инжекции**
   - новые внутренние соленоиды
   - новый инфлектор
2. **Магнитная система**
   - новые корректирующие катушки
   - новая центральная область
3. **Новая вакуумная система**
   - новые высоковакуумные насосы (ТМН, Крио)
   - модернизация линий форвакуумной откачки
   - новые элементы системы диагностики
4. **Новая ускоряющая система**
   - новые резонансные баки
   - новые приводы закручивающей пластины
   - новые системы подстройки частоты (триммер АПЧ)
5. **Новая ВЧ система**
   - новые генераторы
   - новая фидерная линия
6. **Новая система вывода**
   - электростатический дефлектор
   - магнитные каналы (3 шт.)
7. **Система транспортировки пучка**
   - новый канал в новый экспериментальный корпус
   - модернизация существующих каналов
8. **Модернизация системы питания и управления**
9. **Модернизация системы охлаждения**
10. **Новая система СБИС и АСРК**



1. Увеличение интенсивности пучков ионов средних масс с энергией 6 МэВ/Нуклон до 2.5 ρμA
2. Плавная вариация энергии 2-20 МэВ/Нуклон с точностью $\Delta E/E=5\cdot10^{-3}$.
3. Уменьшение уровня магнитного поля 0.8-1.8 Т
4. Ремонт и замена вышедших из строя систем

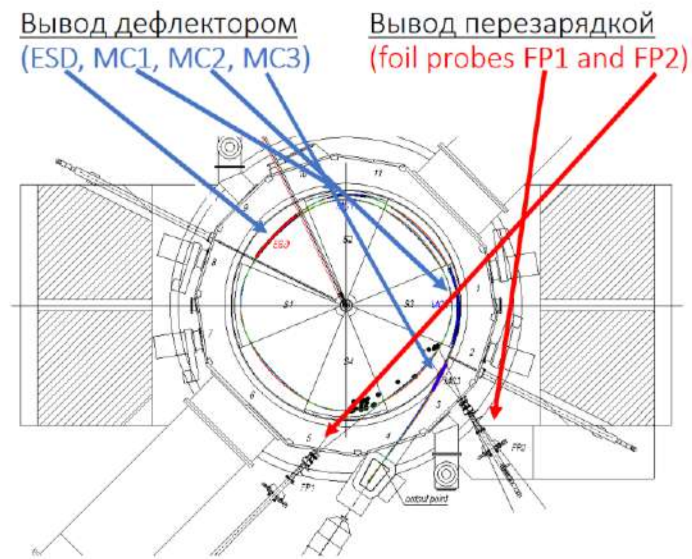
U400 ===> U400R

Typical ion beam parameters of U400 and U400R

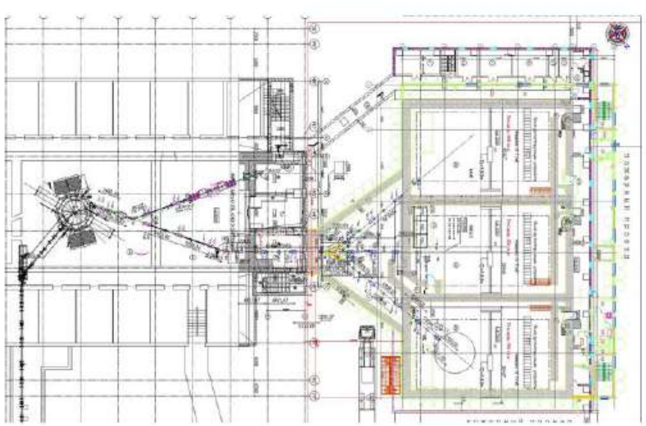
U400		
Ion	Ion energy [MeV/u]	Output intensity
$^{4}He^{1+}$	-	-
$^{6}He^{1+}$	11	$3\cdot10^{7}$ pps
$^{8}He^{1+}$	7.9	-
$^{16}O^{2+}$	5.7; 7.9	5 pμA
$^{18}O^{3+}$	7.8; 10.5; 15.8	4.4 pμA
$^{40}Ar^{4+}$	3.8; 5.1 *	1.7 pμA
$^{48}Ca^{5+}$	3.7; 5.3 *	1.2 pμA
$^{48}Ca^{9+}$	8.9; 11; 17.7 *	1 pμA
$^{50}Ti^{5+}$	3.6; 5.1 *	0.4 pμA
$^{58}Fe^{6+}$	3.8; 5.4 *	0.7 pμA
$^{84}Kr^{8+}$	3.1; 4.4 *	0.3 pμA
$^{136}Xe^{14+}$	3.3; 4.6; 6.9 *	0.08 pμA

U400R (expected)		
Ion	Ion energy [MeV/u]	Output intensity
$^{4}He^{1+}$	6.4 ÷ 27	23 pμA **
$^{6}He^{1+}$	2.8 ÷ 14.4	$(1\text{-}5)10^{9}$ pps
$^{8}He^{1\text{-}2+}$	1.6 ÷ 27	$10^{5\text{-}6}$ pps
$^{16}O^{2+}$	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
$^{132}Xe^{11\text{-}22}$	0.8 ÷ 15	1-0.3 pμA
$^{238}U^{27\text{-}44+}$	1.5 ÷ 15	1- 0.1 pμA

Система вывода ускоренного пучка:



Система транспортировки ускоренного пучка:



TM2 (19º, R=2.2м)

TM3/TM4 (8º, R=3.1 м)

MT 25

parameters	
Energy range	5 to 25 MeV
Average beam current	20 mkA
γ-ray flux	10^{14} pps
Thermal neutron flux	10^{9} pps cm^{-2}
Fast neutron flux	10^{12} pps

1. Neutron and Gamma activation analysis.
2. Production and accumulation of nuclides and tracers for radiochemical and environmental studies.
3. Conducting diffraction studies using x-ray bremsstrahlung.
4. Study of nuclear reaction induced by g-quanta
5. Biological and genetics research
6. Hardness tests…

IC-100 Pure applied research

Commissioned: 1985
Reconstructed: 2002

Setups:

- polymer film irradiation unit with uniform implantation over a 600x200 mm target
- box for material science research

Parameters	
Accelerated ions	$^{22}Ne^{+4}$ $^{40}Ar^{+7}$ $^{56}Fe^{+10}$ $^{86}Kr^{+15}$ $^{127}I^{+22}$ $^{132}Xe^{+23}$ $^{132}Xe^{+24}$ $^{182}W^{+32}$ $^{184}W^{+31}$ $^{184}W^{+32}$
A/Z ratio	5.5 – 5.95
Ion energy	0.9-1.2 MeV/A
Pole diameter	1 m
Vacuum	$5 \cdot 10^{-8}$ Torr
$^{86}Kr^{15+}$ beam intensity	$1.4 \cdot 10^{12}$ pps
$^{132}Xe^{23+}$ beam intensity	~ 10^{12} pps

Science for life - applied physics researches

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 2024

- 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.

NANOLAB

Nanotechnology Centre

Scanning electron microscopy

FESEM Hitachi SU8020
Resolution of 1 nm at 15 kV
X-ray element microanalysis (EDS)
Deceleration mode (500 eV)

SEM Hitachi S3400N
Resolution of 1 nm at 15 kV
EDS, WDS
Electron backscattering diffraction

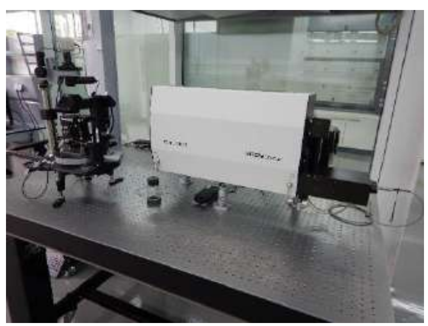
Multi-functional chemical laboratory

(studies of heavy ion irradiation effects, modification of materials, polymers, membranes)

X-ray photoelectron spectroscopy K-Alpha

Chemical analysis of thin layers and surfaces

NTEGRA Spectra – Atomic force microscopy (AFM)/ Confocal Raman & Fluorescence



Studies of nanostructures induced by single ion impact on the surface of solids; depth-resolved Raman and photoluminescence spectra

Capillary porometer
Porolux

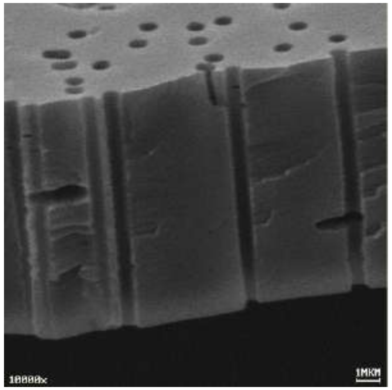
Precise characterization of ultra- and microfiltration membranes

KRUESS DSA100
system

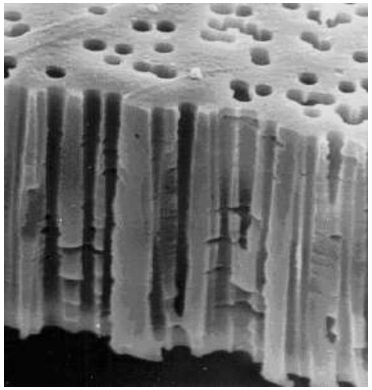
nvestigations of static and dynamic wetting phenomena

Ion track etching technology

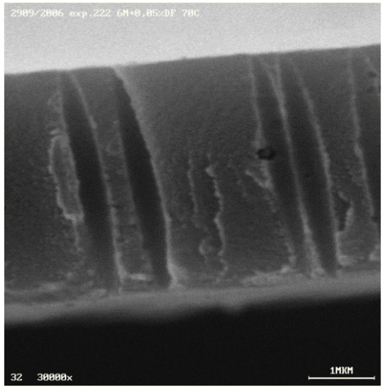
Variety of pore shapes in track-etched membranes



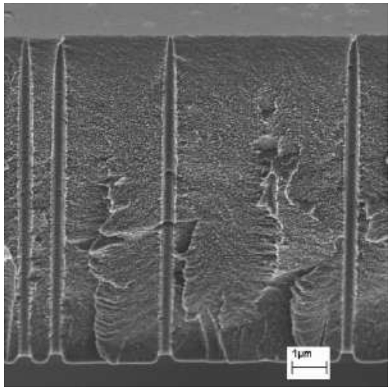
Cylindrical



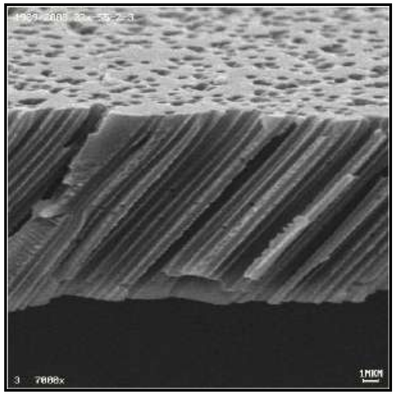
Doubly conical



Cigar-like

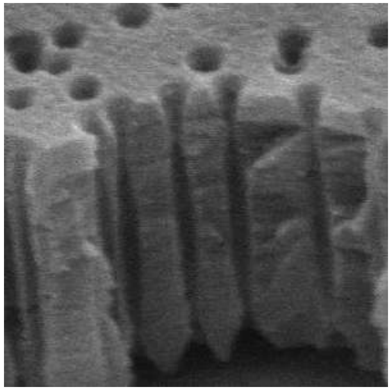


Highly asymmetric with bullet-like tip

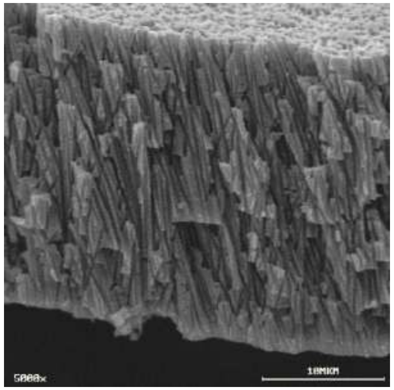


Cylindrical, parallel,

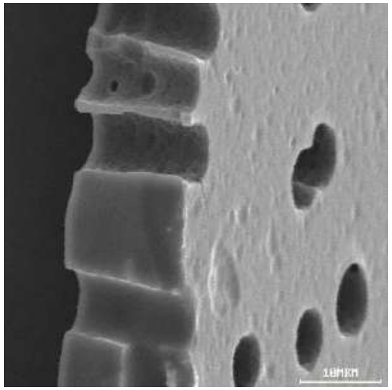
all tilted at an angle of 45°



Bow tie like



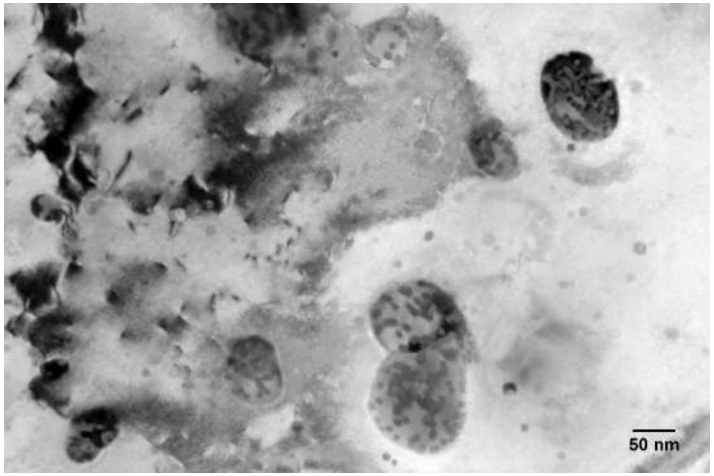
Cylindrical, non-parallel (typical commercial TM with small pores)



Typical commercial TM with large pores

Ion-implantation nanotechnology and radiation materials science.

Radiation stability of oxide nanoparticles in ODS alloys against swift heavy ion irradiation simulating fission fragments impact



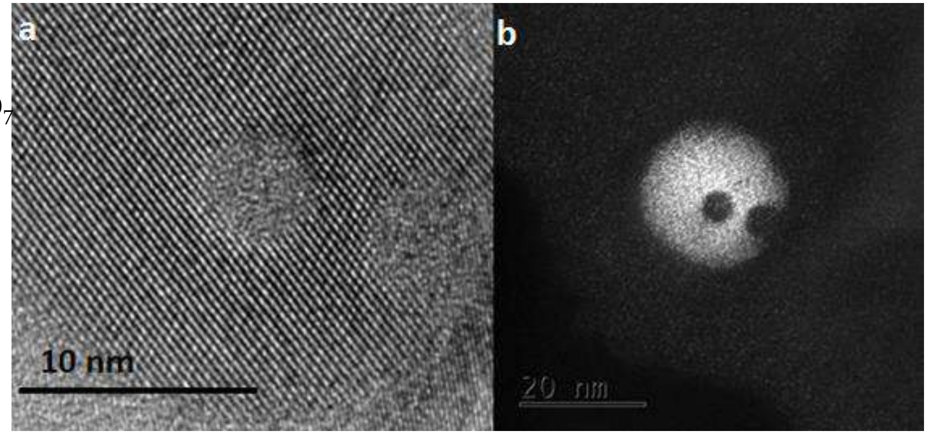
ODS = Oxide Dispersion Strengthened alloys:
Ferritic matrix + 5÷50 nm size thermally stable oxides dispersed within it

Strengthening principle in ODS alloys:
Nanoparticles are obstacles to dislocation glide

ODS steels are promising candidates for fuel cladding

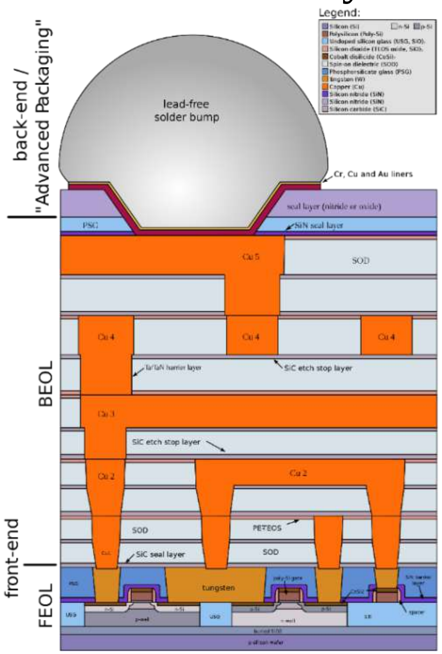
Microstructure of 167 MeV Xe ion irradiated EP450 ODS specimen.
Ion fluence is 10^{12} cm^{-2}.
Dark spots are amorphous latent tracks in $Y_2Ti_2O_7$ nanoparticles.

HRTEM micrograph micrographs of latent tracks in $Y_2Ti_2O_7$ in EP450 ODS steel showing the amorphous nature of ion tracks



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 <u>well-known</u> 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 dedicated beamlines with E=3÷64 MeV/n.

Since 2008, more then 5000 devices has been tested.

Heavy ion beam parameters do these all-sort practical applications need in 202? ?

Ion track technology needs:

- energy > 1 MeV per nucleon
- Ions from Ne up to Bi
- Intensity with Xe (as example) $1x10^{12}$ 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

Radiation materials science:

- energy up more than 1 MeV per nucleon
- Ions from Ne up to Bi or U
- Intensity with Xe (as example) $1x10^{12}$ 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.

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 LowEnergyMode)*
- Ions from Ne up to Bi (Ne, Ar, Kr, Xe, Au, Bi)
- LET up to 100 MeV/(mg×cm^2)
- Intensity $1x10^5$ c^{-1}×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.*

What we need from cyclotron to fit applied science requirements?

- 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

Administrative issues:

The new accelerator complex should solve the following tasks:

• reduce the application program of the main cyclotrons U400(R) and U400M in order 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 for the production of 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;.

New dedicated applied science facility at FLNR Accelerator Complex.

International innovative research center of JINR

ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

ПРИКАЗ

26.05.2021 № 417

г. Дубна

Об организации работ по созданию проекта инновационного исследовательского центра ОИЯИ

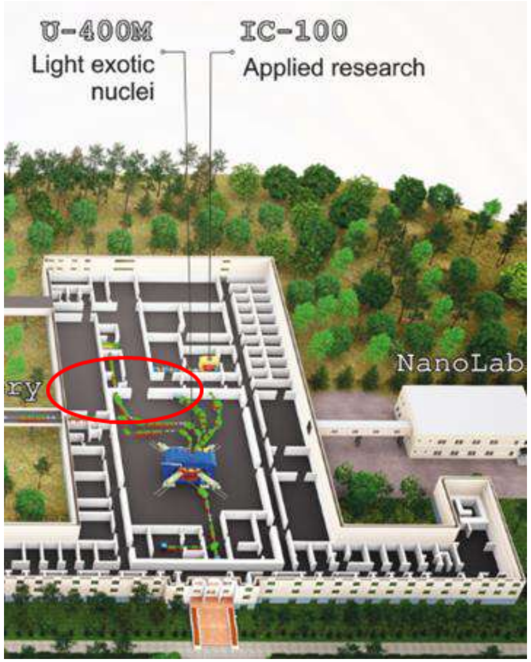
В связи с одобрением КПП ОИЯИ деятельности дирекции по формированию концепции Инновационного исследовательского центра ОИЯИ в области ядерных технологий (далее — Центра) и необходимостью организации работ по созданию проекта Центра в рамках утвержденного Стратегического плана долгосрочного развития ОИЯИ до 2030 года и далее

- научно-исследовательского комплекса в ЛЯР для материаловедения и НИОКР в области технологий для ядерной медицины на базе создаваемых циклических ускорителей и проектируемой РХЛ 1-го класса.

DC-140 Project Plots

DC140 prelaminar "what to do list"

- Dismantling of the U200 cyclotron and old stuff removing
- Geo surveys (determine bearing capacity of soil and quality of old basement constructions)
- Building renovation
- Vacuum system + main chamber (new)
- Colling system (new)
- Control system (new)
- Axial injection (partly new)
- Beam extraction (new)
- Cyclotron magnetic structure (upgrade)
- RF system (upgrade)
- Magnet main coils (new)
- Beamlines (upgrade)
- Safety features (new)
- ………



Technical issues of DC-140:

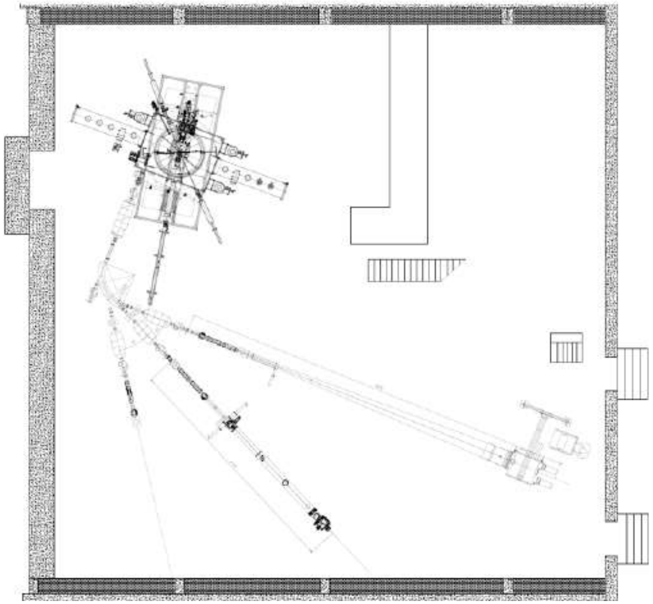
- range of ions from O to Bi,
  - external beam injection from ECR ion source,
  - ion energies:

2.124 MeV/nucleon (A/Z=7.35 – 8.25).

4.8 MeV/nucleon (A/Z=4.9 - 5.5).

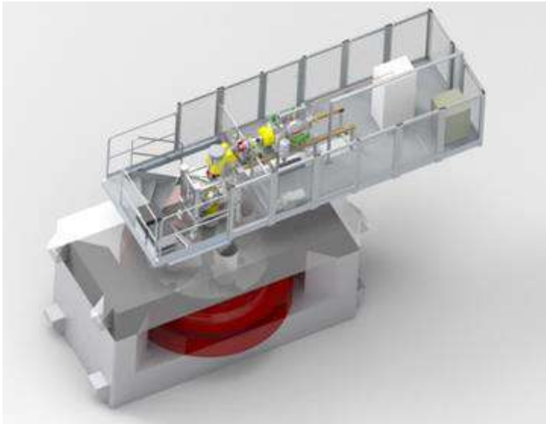
Physical installations:

- installation for scientific and applied research,
- facility for irradiation of polymer films,
- installation for testing of electronic components.

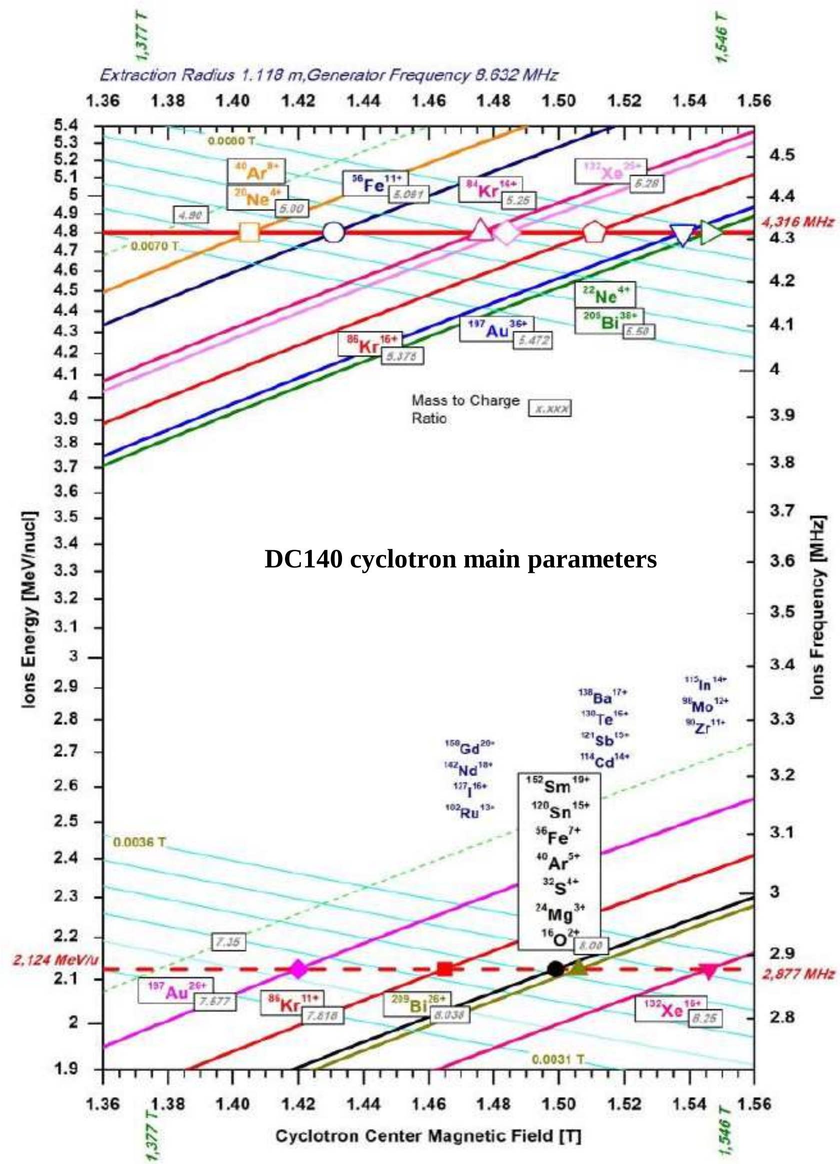


Sketch of 10'2018

DC-140 Design Study



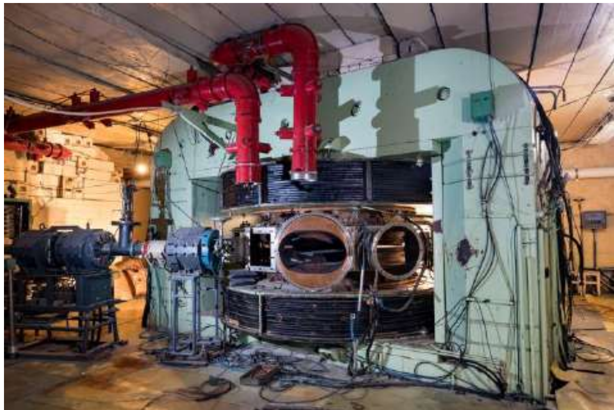
The acceleration of ion beam in the cyclotron will be performed at constant frequency f = 8.632 MHz of the RF-accelerating system for two different harmonic numbers h. The harmonic number h = 2 (f=4.316 MHz) corresponds to the ion beam energy E = 4.8 MeV/u and value h = 3 (f=2.877MHz) corresponds to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



DC140 cyclotron main parameters

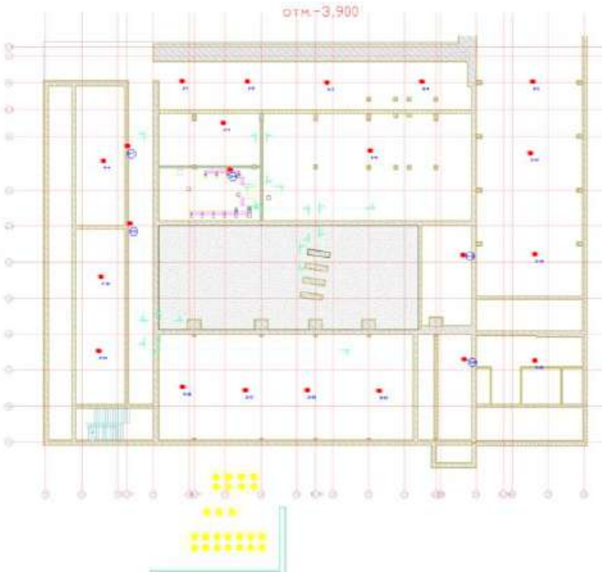
Pole (extraction) radius, m	1.3(1.18)	
Magnetic field, T	1.415÷1.546	
Number of sectors	4	
RF frequency, MHz	8.632	
Harmonic number	2	3
Energy, MeV/u	4.8	2.124
A/Z range	5.0÷5.5	7.577÷8.25
RF voltage, kV	60	
Number of Dees	2	
Ion extraction method	electrostatic deflector	
Deflector voltage, kV	73.5	

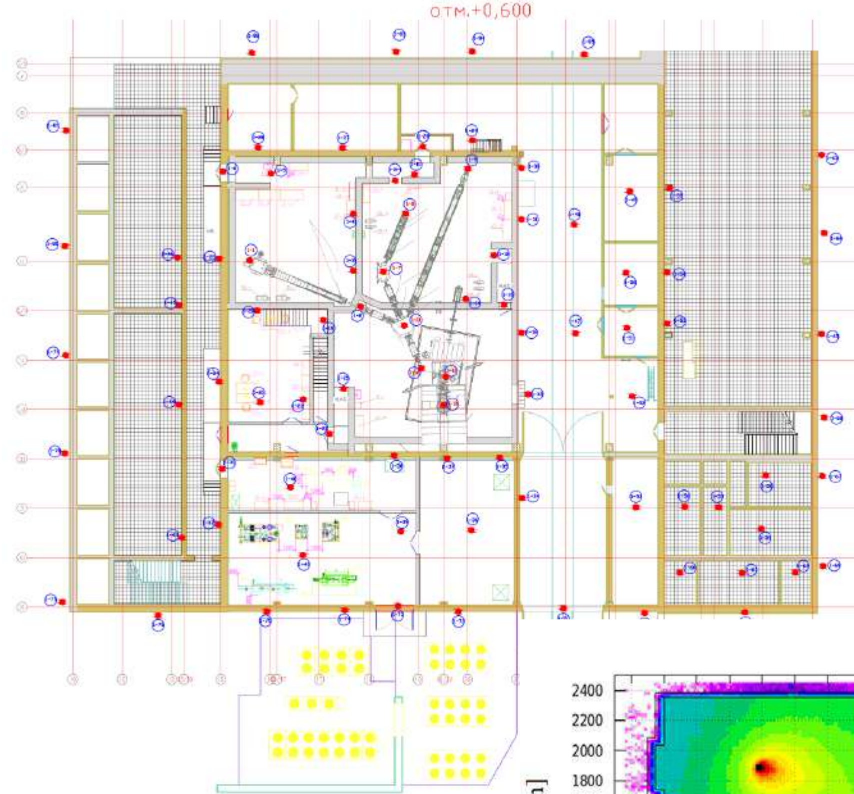
Dismantling of the U200 cyclotron and old stuff removing

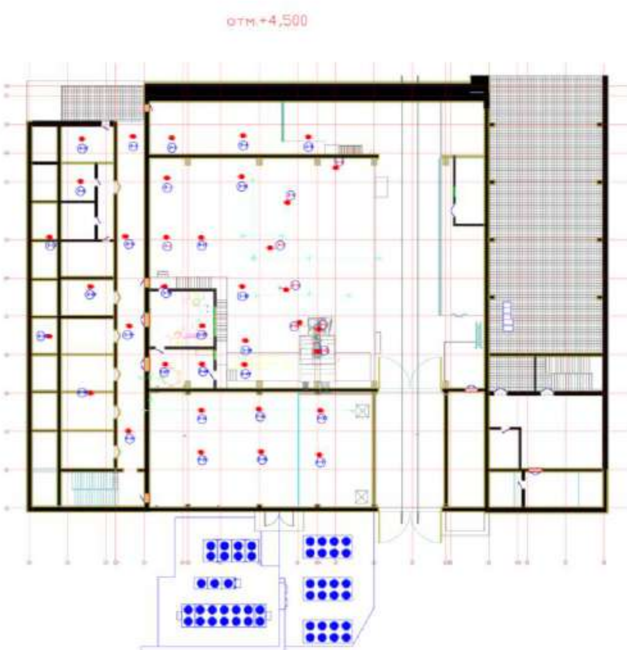


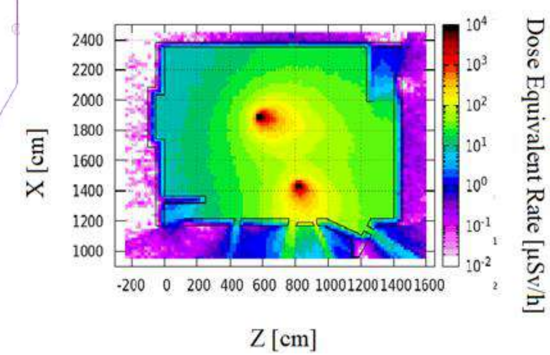
Building renovation

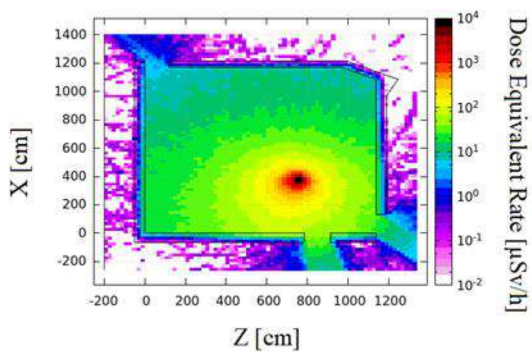
- Safety issues

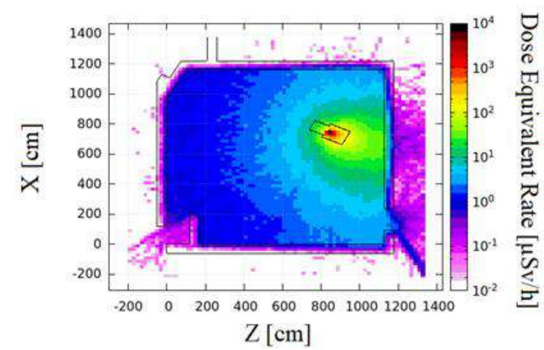




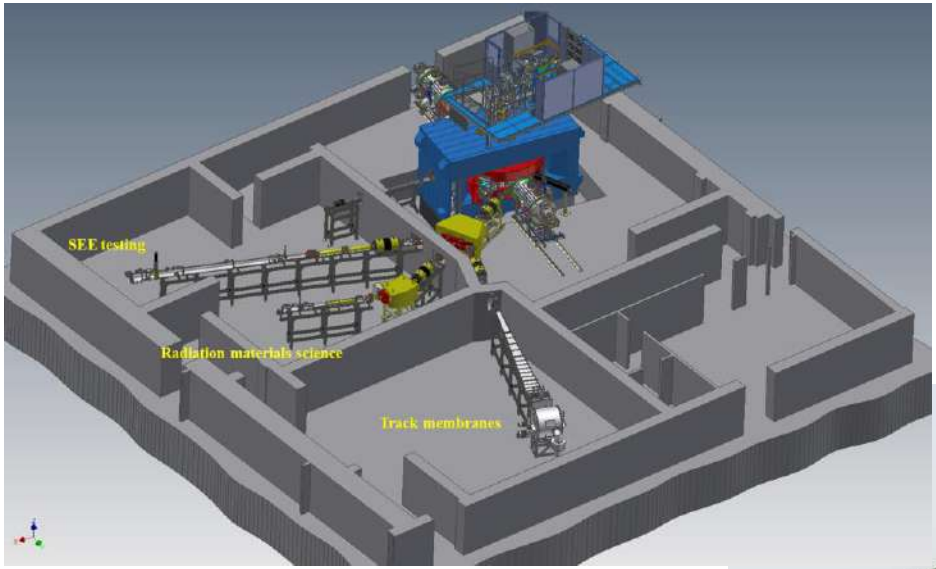


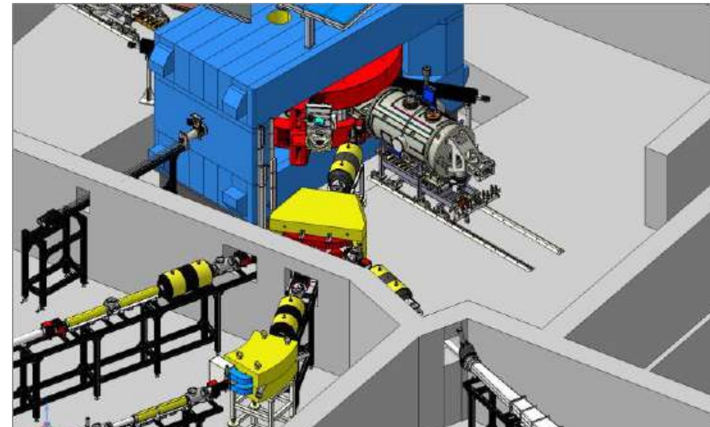


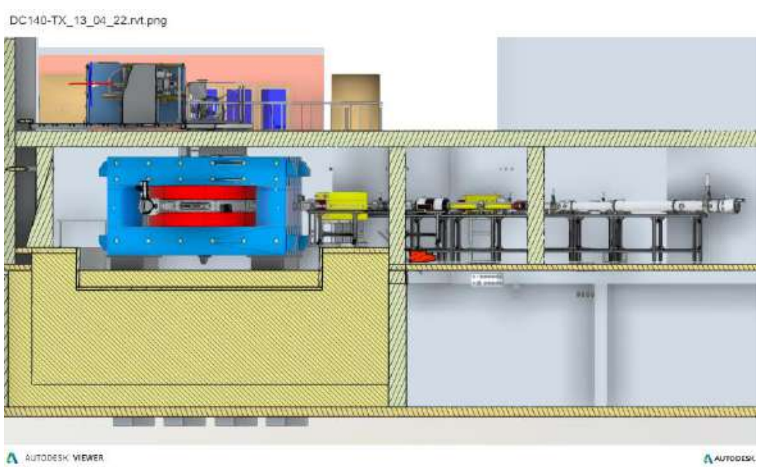


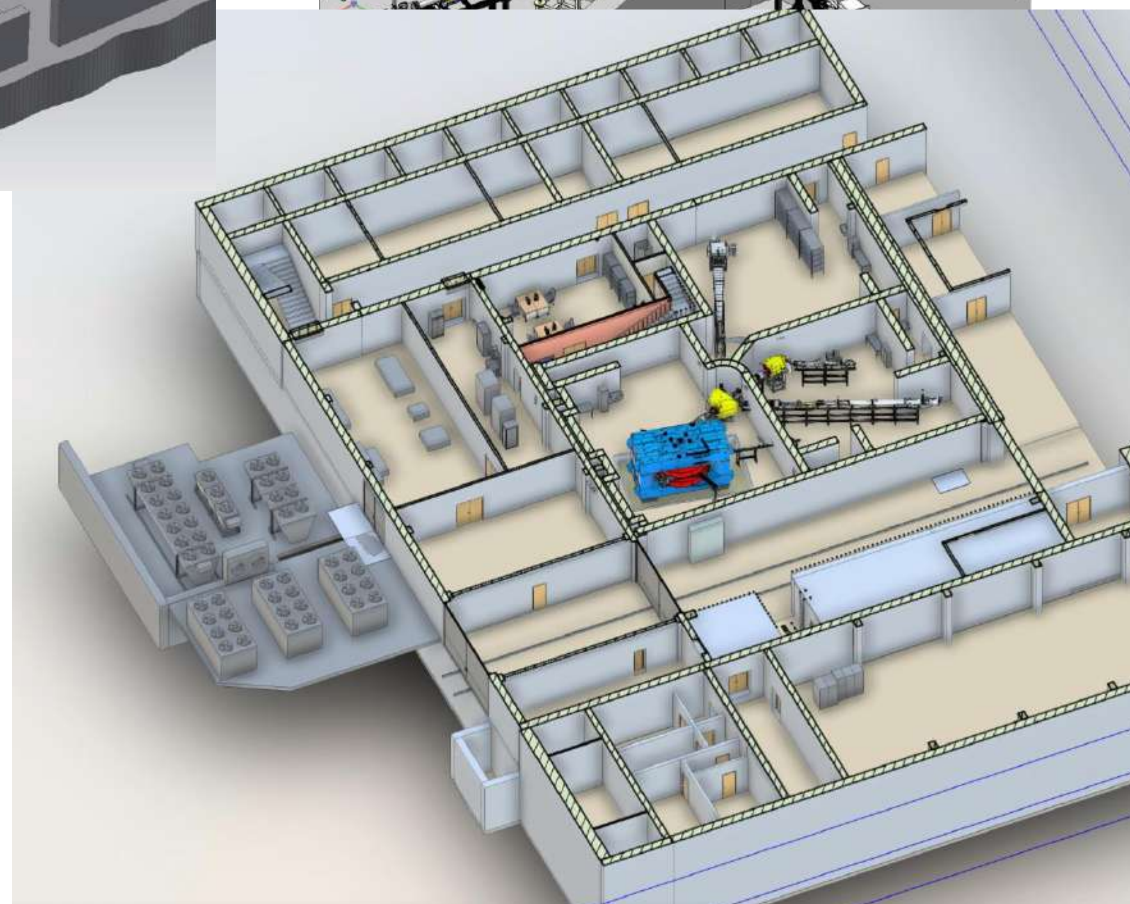


General layout of the DC140 facility: vault of the cyclotron and experimental setup halls.
Detailed equipment and systems arrangement.





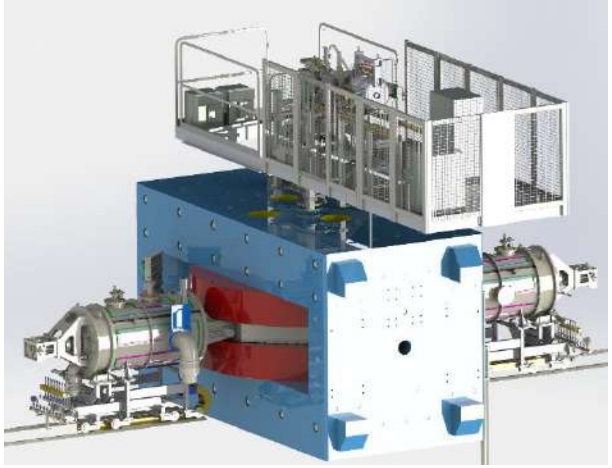


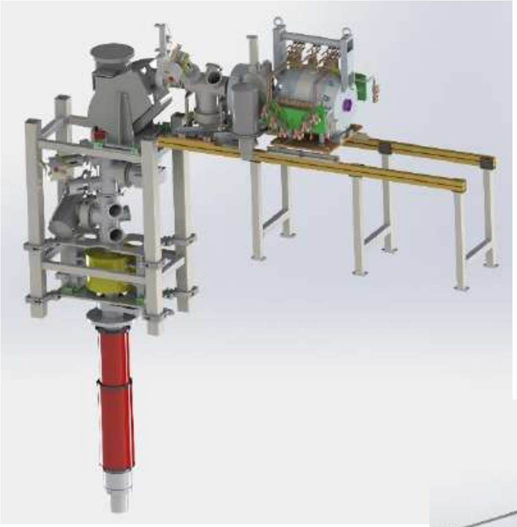


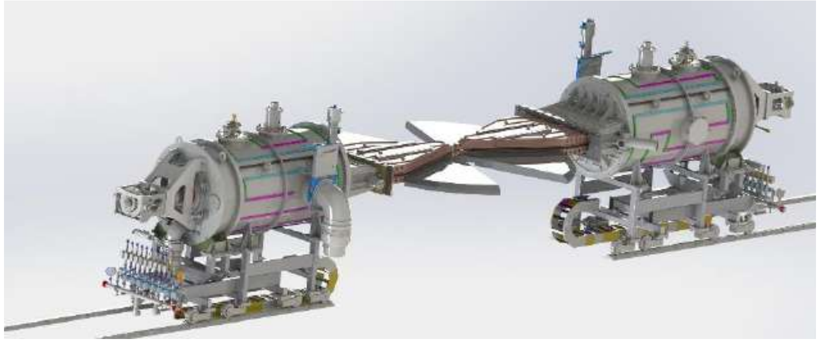
JOINT INSTITUTE FOR NUCLEAR RESEARCH

Release of the DS documentation

Concept → Design → Realization





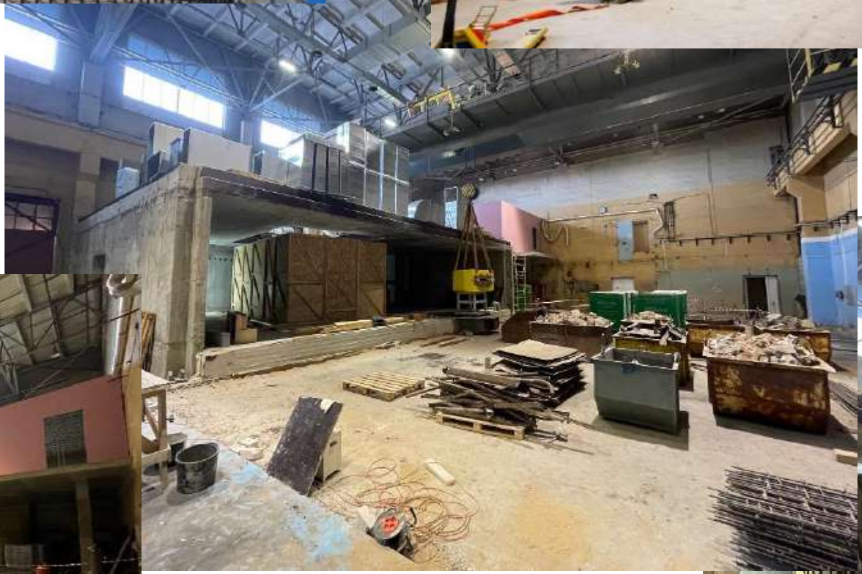


JOINT INSTITUTE FOR NUCLEAR RESEARCH

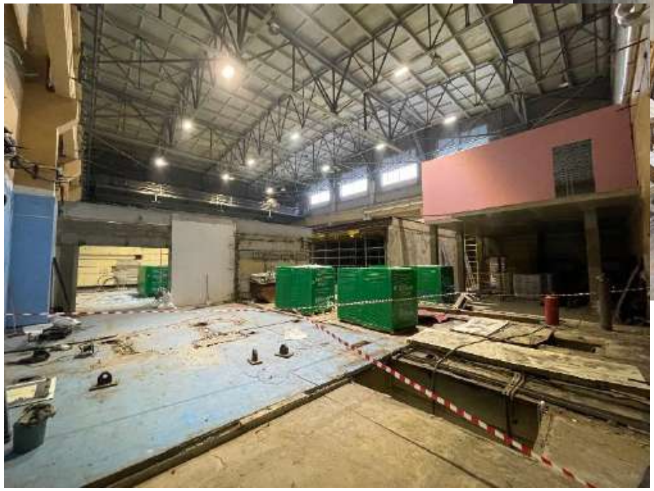
Step by step => 06/07/2023

JINR FLNR 114 Flerovium Dubna

Step by step => 2024



02/12/2023



15/02/2024

Сдача в эксплуатацию – 1 полугодие 2025 года

Step by step => 2024

Control room,
Accelerator hall,
Experimental channels halls

Сдача в эксплуатацию – 1 полугодие 2025 года

Создание УК ДЦ-140

ООО "МастерПром" и ЛЯР

Общестроительные работы (бетонные, металичкские, ЛСТК конструкции)	09.01.24	15.09.24
Установка элементов инженерных систем (газоочистка, вентиляция, канализация, электрика, слаботочные сети)	01.07.24	15.10.24
Изготовление и подготовка элементов циклотрона для монтажа (элементы ВЧ системы, резонаторы, элементы вывода, элемнты каналов, суппорты, ...)	05.02.24	15.10.24
Монтаж элементов инженерных систем циклотрона (система охлаждение, линии ВЧ питания, ВЧ геннераторы, ...)	01.10.24	30.11.24
Сборка циклотрона (ускоряющая система, каналы транспортировки, вакуумная система, ...)	23.11.24	03.03.25
Монтаж систем АСРК и СБИС	15.09.24	03.03.25
ПНР систем УК ДЦ-140	03.03.25	02.04.25
ПНР УК ДЦ-140	02.04.25	09.04.25
Тесты с ускоренным пучком	10.04.25	01.07.25

Cyclotron	2022	2023	2024	2025	2026	2027
U400/U400R	Low and middle energy beam species		U400R project and new experimental hall			Middle energy
U400M	U400M modernization		Low energy beam line B5	Beam line #A1S (High energy)		
DC140	DC140 project			Dedicated beam line #1 at DC140 complex (Low energy)		

70% of testing time is using “low-energy” mode (3-6 MeV/nucl)
20% of testing time is using “middle-energy” mode (9-12 MeV/nucl)
10% of testing time is using “high-energy” mode (13-64 MeV/nucl)

FLEROV LABORATORY
OF NUCLEAR REACTIONS

Ускорительный комплексе ЛЯР ОИЯИ в 2024 году.
Некоторые аспекты прикладных исследований.

С. В. Митрофанов

Благодарю за внимание