DC130: Next Step of the FLNR Accelerator Complex for Applied Science Activity

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The main activities of Flerov Laboratory of Nuclear Reactions, following its name - are related to fundamental science, but, in parallel, plenty of efforts are paid for practical applications. Certain amount of beam time every year is spent for applied science experiments on FLNR accelerator complex. For the moment, the main directions are: the production of the heterogeneous micro - and nano-structured materials; testing of electronic components (avionics and space electronics) for radiation hardness; ion-implantation nanotechnology and radiation materials science. Basing on FLNR long term experience in these fields and aiming to improve the instrumentation, the accelerator department start the Design Study for new cyclotron DC130 which will be dedicated machine for applied researches in FLNR. Following the users requirements DC130 should accelerate the heavy ions with mass-to-charge ratio A/Z of the range from 5 to 8 up to fixed energies 2 and 4.5 MeV per unit mass. The first outlook of DC130 parameters, its features, layout of its casemate and general overview of the new FLNR facility for applied science are presented.

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

Science for life - **applied physics** researches
- 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.
- Ion-implantation nanotechnology and radiation materials science.
- Testing of electronic components (avionics and space electronics) for radiation hardness.

Applied physics needs:

Ion track needs:
- -energy 2 and 4,5 MeV per nucleon
- -Ions from Ne up to Bi
- -Intensity with Xe (as example) $1x10^{12}$ c^{-1}
- -Irradiation zone 650*250 mm (2 AMeV) and 325*190mm (4,5 AMeV)
- -Beam uniformity 5 %
- -Casemate - "green area" - people around irradiation chamber
- -Oversize irradiation chamber => dedicated beam line

Radiation materials science:
- -energy up to 2 and **4,5** MeV per nucleon
- -Ions from Ne up to Bi or U
- -Intensity with Xe (as example) $1x10^{12}$ c^{-1}
- -Irradiation zone Ø30 mm (2 AMeV) and Ø20 mm (4,5 AMeV)
- -Dedicated beam line due to specific T° requirements and sample preparation procedure.
- -Casemate - "green area" - people around irradiation chamber

Testing of electronic component (SEE testing):
- -Energy, which could provide the ion range in Si around 50 mkm - 4,5 MeV per nucleon
- -Ions from Ne up to Bi
- -LET up to 100 MeV/(mg×cm²)
- -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.
- -Casemate - "green area" - people around irradiation chamber
- **-Cocktail – quick switching between ion types.**

The question is that, usually, for these activities people use powerful machines which were created and developed to solve the wide range of fundamental research. The usage of 'usual' accelerators for applied science is connected which high cost of beam time and difficulty to meet quick changes of user's requirements. That's why Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research begins the works under the conceptual design of the dedicated applied science facility based on the new DC130 cyclotron.

- 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 from the FLNR stock

U-200 Cyclotron

In 1968 the U-200 was put into operation in the FLNR. In 2013 it was decommissioned, because of being outdated physically and technologically.

Parameters of U-200:
- Diameter of the magnet pole – 2 m
- Internal ion source of PIG type
- Accelerated ions – He – Ar
- The ion energy 3 -18 MeV/nucleon

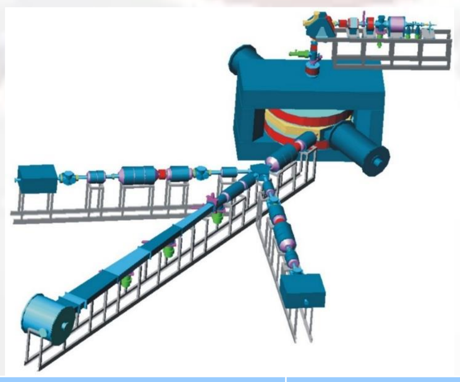
The idea is to modernize and totally upgrade the old U200 machine

The project of DC-130 cyclotron

Technical characteristics of DC-130:
- range of ions from O to Bi,
- external beam injection from ECR ion source,
- ion energies:

2 MeV/nucleon (A/Z=7.818 – 8.25)

4.5 MeV/nucleon (A/Z=5.212 - 5.5).



DC130 cyclotron magnet main parameters

Size of the magnet, mm	5000×2100×3600
Diameter of the pole, mm	2000
Distance between the poles, mm	160
Number of the sectors pairs	4
Sector angular extent (spirality)	43° (0°)
Sector height, mm	45
Distance between the sectors (magnet aperture), mm	30
Distance between the sector and pole (for correcting coils), mm	20
Number of radial coils	6
Maximal power, kW	≈ 300

	Bi		Au		Xe		Kr		Ar		Ne	
MeV/u	range	LET	range	LET	range	LET	range	LET	range	LET	range	LET
4.5	54,47	99,64	54,88	94,06	47,39	68,77	46,96	39,11	48,32	14,32	58,5	5,77

The Design Study should be finished before the end of 2018.

The working diagram of DC130 cyclotron is presented.

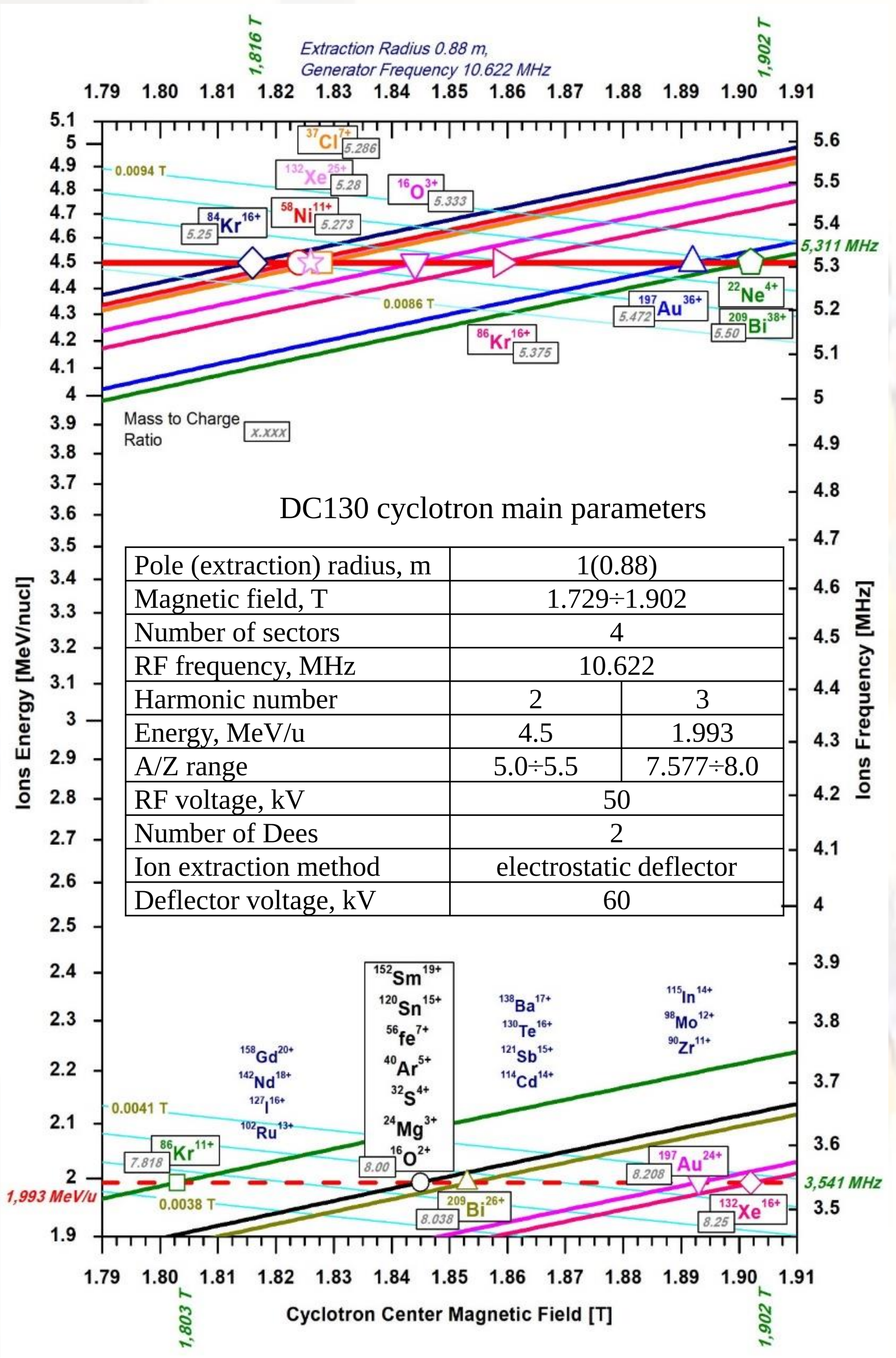
There is a set of required ions with a fixed energy (^{16}O, ^{37}Cl, ^{58}Ni, ^{84}Kr, ^{86}Kr, ^{132}Xe, ^{197}Au, ^{209}Bi, ^{22}Ne - Ok from the point of view of LET) => no changes in RF.

To reduce the costs and following operating simplicity, the acceleration of ion beam will be performed at constant frequency f = 10.622 MHz of the RF-accelerating system and for two different harmonic numbers h only.

The harmonic number h = 2 will correspond to the ion beam energy W = 4.5 MeV/u and value h = 3 corresponds to W = 1.993 Mev/u.

The same approach for magnetic field – just to provide the necessary ions.

The design should based on **existing** systems of IC100 and U200 cyclotrons and use only proven technical solutions of DC110.



DC130 cyclotron main parameters

Pole (extraction) radius, m	1(0.88)	
Magnetic field, T	1.729÷1.902	
Number of sectors	4	
RF frequency, MHz	10.622	
Harmonic number	2	3
Energy, MeV/u	4.5	1.993
A/Z range	5.0÷5.5	7.577÷8.0
RF voltage, kV	50	
Number of Dees	2	
Ion extraction method	electrostatic deflector	
Deflector voltage, kV	60	

Ion source for DC130 project

The 18 GHz DECRIS-5 ion source was developed on the basis of sources of the DECRIS-4 (14 GHz) series with copper windings created at FLNR (JINR, Dubna) by intensifying the magnetic structure and changing to a new type of microwave oscillator.

The DECRIS-5 ion source created for industrial application is characterized by increased reliability. It was already successfully commissioned in the framework of DC110 project (mass production of the track membrane).

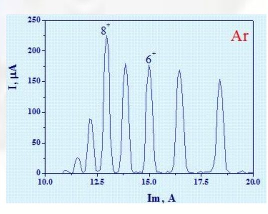
To ensure the design parameters of the DC-110 project , the ion source should generate intensities of $^{40}Ar^{6+}$, $^{86}Kr^{13+}$ and $^{132}Xe^{20+}$ ion beams of not less than 85μA, 150 μA and 150 μA, respectively.

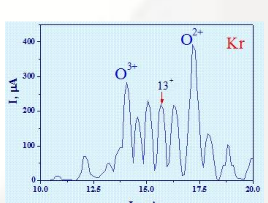
After assembling the ECR source and axial injection system, thorough adjustment of all systems of the source and axial injection channel was carried out.

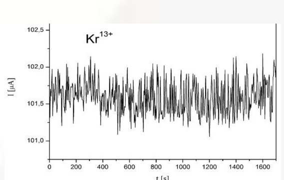
Beams of Ar, Kr, and Xe ions were produced from the source.

Assembled DECRIS-5 and axial injection system at the DC-110 cyclotron

Beams of Ar, Kr, and Xe ions were produced from the source.



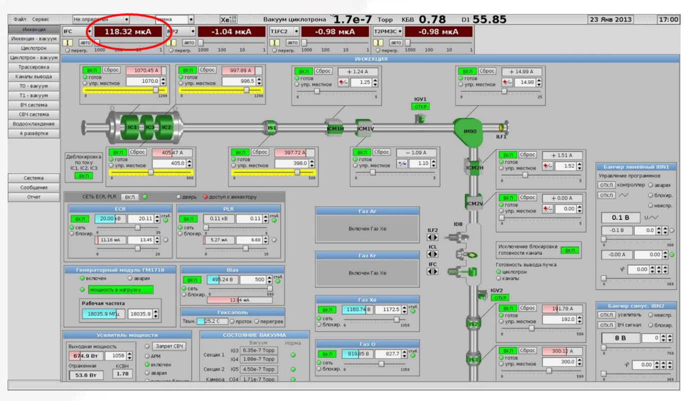




Results of the test

Ion	Current, (eμA)
Ar^{8+}	1200
Ar^{9+}	750
Ar^{11+}	300
Kr^{15+}	325
Kr^{17+}	230
Kr^{18+}	182
Kr^{19+}	120
Kr^{20+}	70
Xe^{20+}	220

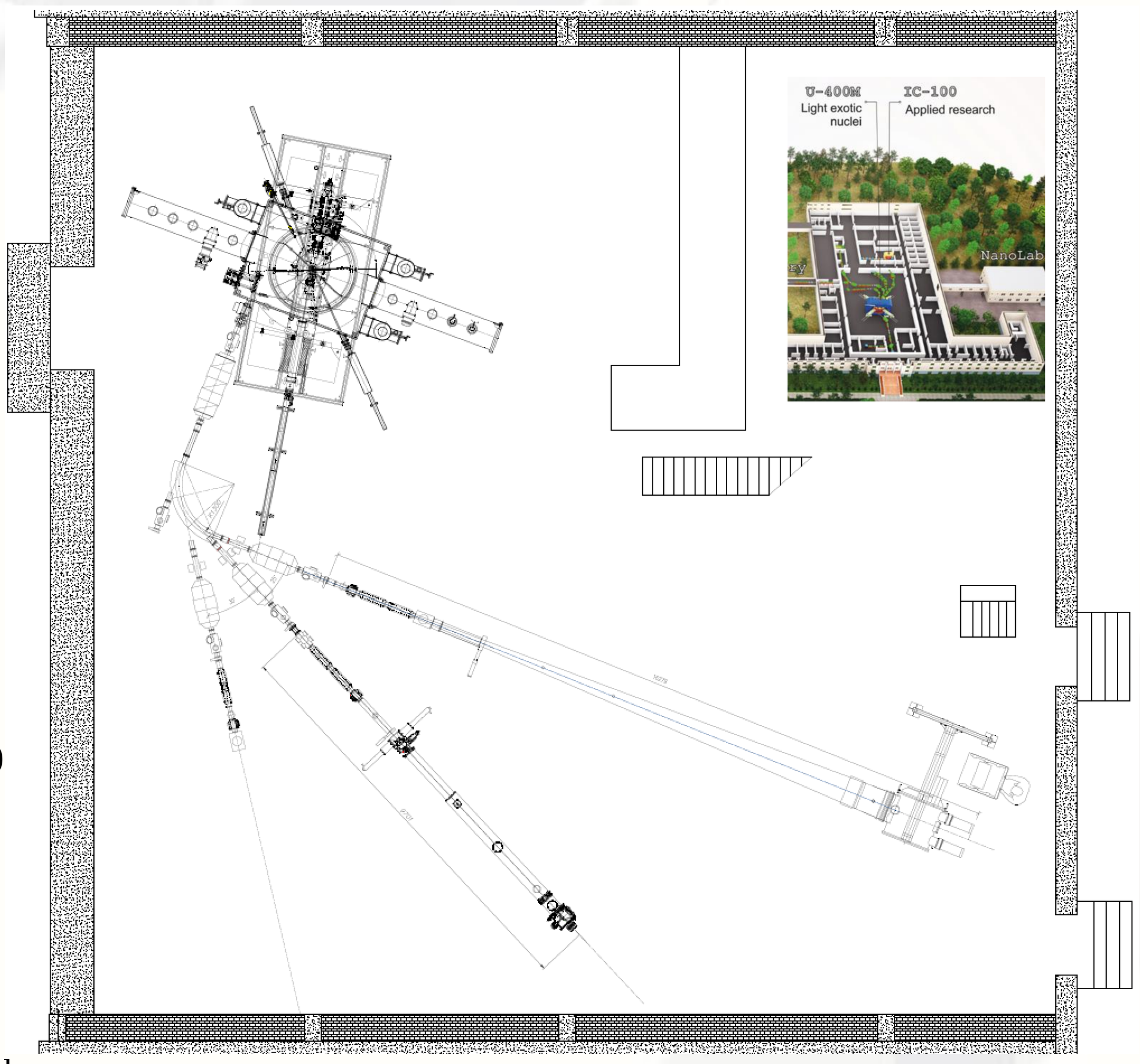
DC-110 control panel: Xe is online



DC130 prelaminar roadmap

What to do:
- Vacuum system + main chamber(new)
- Colling system (new)
- Control system (new)
- Beam extraction (new)
- Cyclotron magnetic structure (upgrade)
- RF system (upgrade)
- Magnet main coils (new)
- Beamlines (upgrade)
- Safety features (new)
- ………

2018 – Old stuff removing
2018 – Design Study
2018 – Building renovation
2019 – Equipment accumulation (purchasing)
2020 – Assembling
2020- 2021 the future …..



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