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STATUS OF JINR FLNR CYCLOTRONS

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Abstract

Status of JINR FLNR cyclotrons and plans of their modernization together with plans on creation of new facilities will be reported. At present, three cyclotrons: U400, U400M and IC100 and MT-25 microtron are under operation at the JINR FLNR. U400 and U400M are the basic FLNR facilities that both are under operation is about 12000 hours per year. The U400 (pole diameter of D=4 m) was designed to accelerate ions from B to Bi up to 19 MeV/u. U400 reconstruction is planned. The U400M cyclotron (D=4 m) is used to accelerate ions from Li to Xe up to 60 MeV/u. U400M modernization is planned. The IC100 accelerator (D=1m) is used for applied researches with Ar, Kr and Xe ions at energy of 1.2 MeV/u. Creation of the dedicated DC-130 cyclotron (D=2m) with ion energies of 4.5 and 2 MeV/u is planned on the base of U200 cyclotron. The Super Heavy Element Factory (SHE factory) is the new FLNR JINR project. The DC-280 cyclotron (D=4 m) is the basic facility of the SHE factory, which will accelerate ions with energies 4 - 8 MeV/u cyclotron at intensities up to 10 pmkA for ion masses over A=50. The main systems of the DC-280 were assembled and tested, the cyclotron is preparing for commissioning.

INTRODUCTION

The scientific program of the Flerov Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research (FLNR JINR) consists of experiments on synthesis of heavy and exotic nuclei using ion beams of stable and radioactive isotopes and studies of nuclear reactions, acceleration technology and applied research.

Presently, the FLNR JINR has four cyclotrons of heavy ions: U400, U400M, IC100 (IC-100), that provide performance of the basic and applied researches (Fig. 1). Total annual operating time of the U400 and U400M cyclotrons is more than 10000 for many years (Fig. 2).

The old U200 cyclotron will be reconstructed to the DC130 cyclotron for applied research.

At present time, the project of Super Heavy Element Factory is being performed at the FLNR JINR [1]. The project implies design and creation of the new experimental building with new DC280 cyclotron which has to provide intensities of ion beams with middle atomic masses (A~50) up to 10 pμA.

U400 CYCLOTRON

The isochronous U400 cyclotron has been in operation since 1978. [2] The cyclotron produces ion beams of atomic masses 4÷209 with energies of 3÷29 MeV/nucleon. Before 2017 about 66% of the total time has been used for acceleration of $^{48}Ca^{5+}$ ions with intensities up to 1.2 pμA for synthesis of super heavy elements. New prospects for the synthesis of super heavy elements may appear to be connected with the usage of the intense beam of neutron-rich ^{50}Ti. The beam of $^{50}Ti^{5+}$ ions has been accelerated into the U400 cyclotron with extracted beam intensity is about 0.5 pμA [3]. In 2017, about 40% of the total time was used for $^{50}Ti^{5+}$ acceleration.

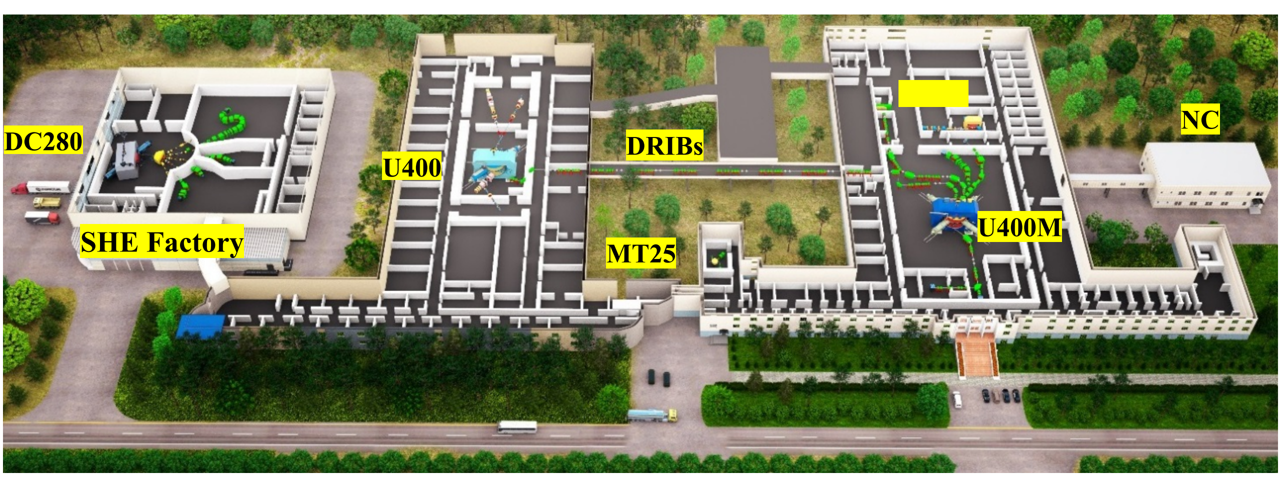

Figure 1: The layout of the Flerov Laboratory buildings, where: U400, U400M, IC100, DC280 are heavy ion cyclotrons, MT25 is microtron, SHE Factory is Super Heavy Element Factory, NC is Nanotechnology Centre.

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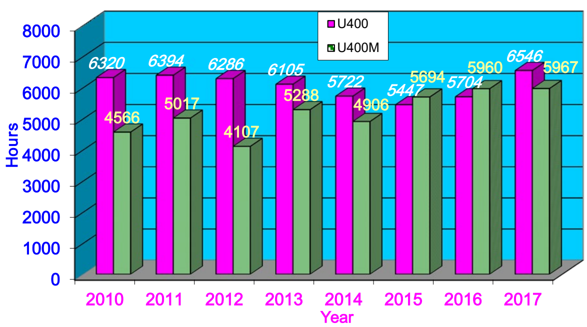

Figure 2: U400 and U400M operation in 2010-2017.

The U-400 modernization is planned to begin in 2021. The aims of the modernization are increasing the total acceleration efficiency and possibility to vary ion energy fluently at factor 5 for every mass to charge ratio (A/Z). The width of ion energy region will be 0.8÷27 MeV/nucleon. The project of U400 modernization intends decreasing the magnetic field level at the cyclotron center from 1.93÷2.1T to 0.8÷1.8T, see Table 1 (U400R).

Figure 3: The sketch of the new U400 experimental hall.

The axial injection and ion extraction systems will be changed. For the ion extraction both the stripping foil and the deflector methods are considered. Moreover, the project intends changing the U400 vacuum, RF and power supply systems. The expected ion beam intensities will be at least 2.5 times more than U400 ones [1].The U400 experimental hall will be essentially modernized in the period from 2020 to 2023. The total experimental building will be extended to about 2000 m^2. New halls will be attached to the old building from sides (Fig. 3). The new experimental area will consists of six separated halls located on two floors. Every hall will be radiation shielded.

U400M CYCLOTRON

The isochronous U400M cyclotron has been in operation since 1991. The cyclotron was intended for acceleration ion beams Li to Bi with A/Z=3÷3.6 (A- atomic weight of the accelerated ion; Z - ion charge when accelerated) at energies of 34÷60 MeV/nucleon and ion beams with A/Z=8÷10 at energies of 4.5÷9 MeV/nucleon.

The beam extraction method is performed by ion stripping method. At present, the U400M has two opposite directions of ion extraction with corresponding ion beam transport lines. The cyclotron ion beams intended to carry out physical experiments on study properties and structure of light exotic nuclei, synthesis the new super heavy elements and applied researches. Two types of spiral inflectors are used in the U400M axial injection system for low and high energy regimes. To produce required ions the 14 GHz ECR ion source DECRIS-2 and the superconducting 18 GHz ECR ion source DECRIS-SC2 are being used [4].

Table 1: Comparative Parameters of U400 and U400R

	U400	U400R
Parameter	**Value/Name**	
Magnet weight	2100 t.	2100 t.
Magnet power	850 kW	200 kW
RF system power	100 kW	100 kW
Magnetic field level	1.93÷2.1 T	0.8÷1.8 T
The A/Z range	5÷12	4÷12
The frequency range	5.42÷12.2 MHz	6.5÷12.5 MHz
Harmonic modes	2	2÷6
The max extraction radius	1.72 m	1.8 m
Vacuum level	(1÷5)·10^{-7} Torr	(1÷2)·10^{-7} Torr
Ion extraction method	Stripping foil	Stripping foil Deflector
Number of ion extraction directions	2	2

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We plan to begin modernization of the cyclotron in 2019. The modernization will include replacement of the main coils of the cyclotron magnet, correction of the first harmonic of magnetic field at magnetic measurements, replacement of the vacuum pumping system with diffusion pumps to the system with cryopumps, modernization of RF- resonators and changing the analog RF control system to digital one. In the result, we expect to increase

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Figure 4: The new DC-280 cyclotron, where: 1- Main magnet, 2- HV injection system, 3- RF resonator, 4- Flat-top resonator, 5-Vacuum pumps.

intensities and maximal energies of ion beams. We also consider the possibility to increase energies of light ions to 60÷80 MeV/nucleon by using an electrostatic deflector for ion extraction from ultimate cyclotron radiuses.

U200 - DC130 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. In 2019 we plan to begin creation of the new DC130 cyclotron which will be based of the U200 yoke. The cyclotron will be intended to provide ions from O to Bi with energies 2 and 4.5 MeV/nucleon for SEE testing of electronic components and 2 MeV/ nucleon for production of track membranes and research in the field of solid state physics.

IC100 CYCLOTRON

The isochronous IC100 cyclotron was put into operation the in 1985 with PIG internal ion source. Due to the upgrade in 2003 IC100 was equipped with external axial beam injection system and the superconducting ECR ion source (DECRIS-SC) which allowed to produce intensive beams of highly charged ions of Xenon, Iodine, Krypton, Argon and other heavy elements of the Periodic Table with A/Z=5,545,95 at energies of 0,9÷1,1 MeV/nucleon.

The focusing system of injection line consists of a solenoidal lens and a quadrupole lens situated between the ECR and the 90°magnet, also three solenoids placed in the vertical part of the injection channel. Spiral inflector is installed into the center of the accelerator. The accelerated beam extraction system consist of electrostatic deflector and two focusing magnetic channels. In routine operation IC100 provides intensities of the $^{86}Kr^{+15}$ and $^{132}Xe^{+23}$ ion beams up to 3 μA.

Special-purpose beam transportation line with polymer film irradiation unit and beam scanning system has been created as well as a box for heavy ion beam research.

DC280 CYCLOTRON

The Super Heavy Element Factory (SHE factory, Fig.3) is the new FLNR JINR project. The main task of the Factory is the synthesis of new chemical elements with atomic numbers 119 and higher, as well as a detailed study of the nuclear and chemical properties of previously discovered superheavy elements. The Factory will be equipped with target materials, new separators and detectors for the study of the nuclear, atomic and chemical properties of the new elements. The new DC280 (Fig. 4) will be the basic facility of the SHE factory.

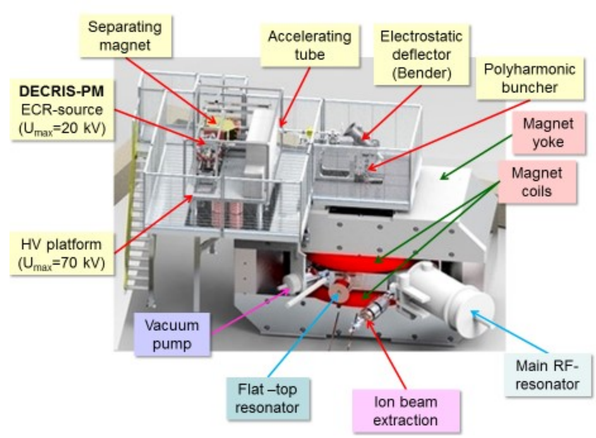

Figure 5: Configuration of the DC280 cyclotron.

The DC280 cyclotron will significantly increase the potential of the existing accelerator complex of the FLNR.

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The accelerator designed at the Flerov Laboratory of Nuclear Reaction of the Joint Institute for Nuclear Research in Dubna (FLNR, JINR, Dubna) is intended for carrying out fundamental and applied investigations with ions from He to U (masses from A = 2 up to 238).

Table 2: Design Parameters of the DC-280 Cyclotron

Parameter	Value/Name
Ion source	DECRIS-4
	14 GHz
Injecting beam potential	Up to 80 kV
A/Z range	4÷7.5
Energy	4÷8 MeV/n
Magnetic field level	0.6÷1.3 T
K factor	280
Gap between plugs	400 mm
Valley/hill gap	500/208 mm/mm
Magnet weight	1000 t
Magnet power	300 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x14 kV

The parameters of the DC-280 cyclotron are shown in Table 2. The energy of the ions extracted from the cyclotron may vary from 4 up to 8 MeV/ nucleon. The expected intensity of extracted beam at DC280 is 10 pμA for ions with masses up to 50 [1]. The cyclotron was equipped with high voltage injection system (80 kV) with new permanent magnet ECR ion source, the RF- system with 2 main resonators and 2 flat- top ones, the electrostatic deflector for ion beams extraction (Fig. 5) and the beam transport system with 5 channels (Figs. 6 and 7) [5]. At present, launching and tuning works of the main systems of the DC-280 cyclotron are carried out as they are completed. In according to FLNR plans the cyclotron commissioning is planned in the end of 2018.

CONCLUSION

The Flerov Laboratory plans implies essential development of the cyclotron complex to 2023.

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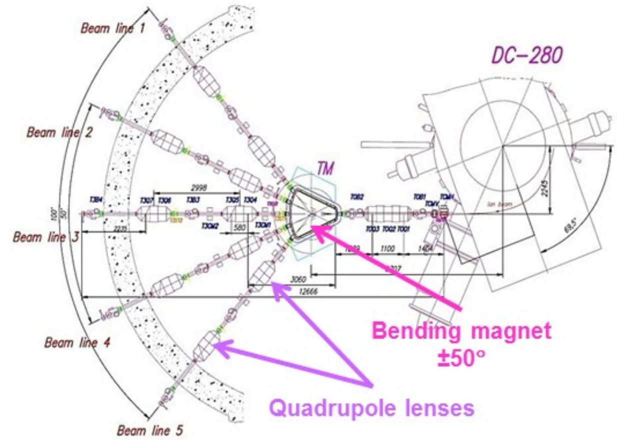

Figure 6: Scheme of beam transport.


Figure 7: Beam transport channels, where: 1- ±50° bending magnet, 2- quadrupole lenses.

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