ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-WEXMH02

HEAVY ION CYCLOTRONS OF FLNR JINR – STATUS AND PLANS

I.V. Kalagin*, G.G. Gulbekian, S.N. Dmitriev, Yu.Ts. Oganessian, B.N. Gikal, S.L. Bogomolov, I.A.Ivanenko, N.Yu.Kazarinov, V.A. Semin, G.N. Ivanov, N.F.Osipov
Joint Institute for Nuclear Research, FLNR, Dubna, Moscow region, Russia

Abstract

Status of JINR FLNR cyclotrons and plans of their modernization together with plans on creation of new facilities are 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 Bi 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 DC130 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 DC280 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 pμA for ion masses over A=50. The main systems of the DC280 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.

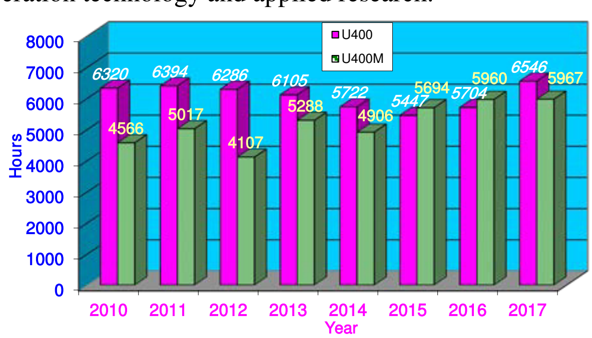

Figure 1: U400 and U400M operation in 2010-2017.

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.3). Total annual operating time of the U400 and U400M cyclotrons is more than 10000 for many years (Fig.1).

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 2: The sketch of the new U400 experimental hall.

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. The axial injection and ion extraction systems will be changed. For the ion extraction both the stripping foil and the deflector methods are considered.

* kalagin@jinr.ru

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-WEXMH02

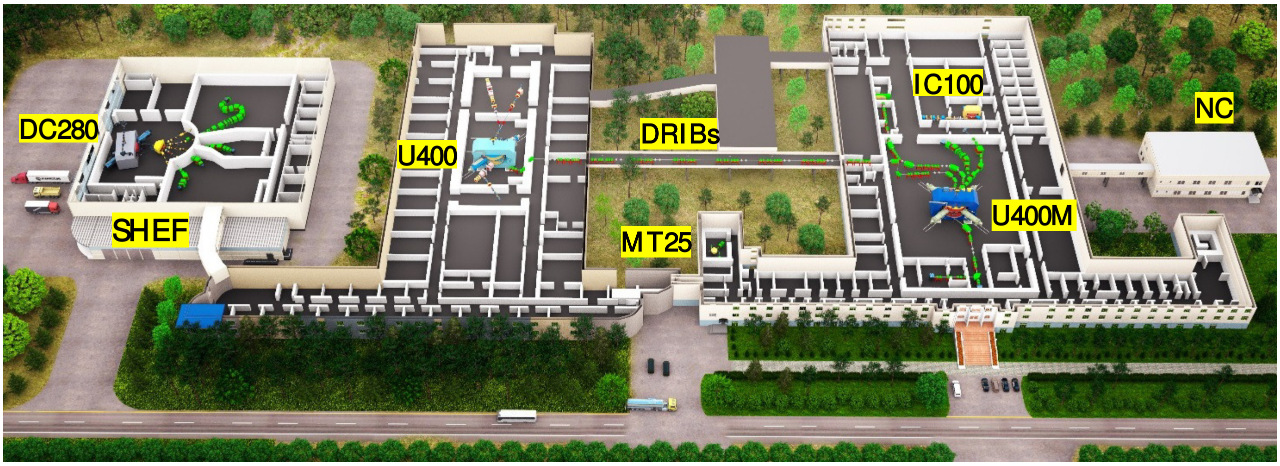

Figure 3: The layout of the Flerov Laboratory buildings, where: U400, U400M, IC100, DC280 are heavy ion cyclotrons, MT25 is the microtron, SHEF is the Super Heavy Element Factory, NC is the Nanotechnology Centre.

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 [4].

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. 2). 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 [5].

In 2019 we plan to begin modernization of the cyclotron by means of 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 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 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=5,5 ÷ 5,95 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.

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-WEXMH02

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.

DC280 CYCLOTRON

The new DC280 cyclotron (Fig. 4) will significantly increase the potential of the existing accelerator complex of the FLNR. 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). The DC280 will be the basic facility of the Super Heavy Element Factory (SHEF) that is being created at the FLNR. 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 [4].

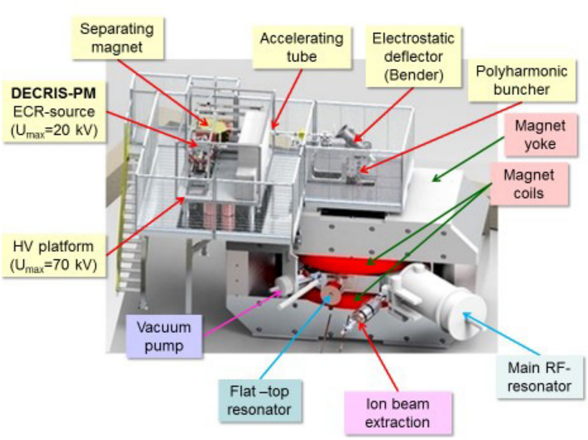

Figure 5: Configuration of the DC280 cyclotron.

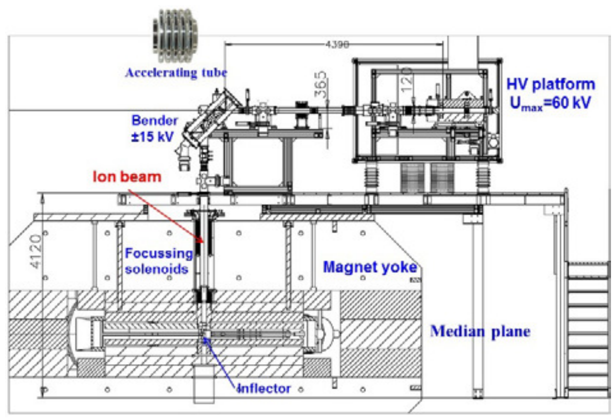

Figure 6: Scheme of the DC280 axial injection.

Configuration of the DC280 cyclotron is shown in the Fig.5. The four sectors isochronous cyclotron was equipped with high voltage injection system that provides injection energy of ions up to 80 keV/Z (where Z- is an ion charge). The scheme of injection system (Fig. 6, Fig. 7) consists of a high voltage (HV) platform with maximal potential of 70 kV (Fig. 8), accelerating tube and 90° electrostatic deflector (bender) which is used to bend the ion beam to the DC-280 centre. The spiral inflector is installed into the center of the accelerator to bend the ion beam to median plane. To increase the accelerating efficiency the polyharmonic buncher is used.

The DC280 RF system has two main 40° dees with resonators (Fig.9, Fig.10) and two 20° flat- top dees (Fig.11).

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-WEXMH02

Figure 7: The high voltage platform of the DC280 cyclotron, where: 1 - DECRIS-PM, 2, 4 - Solenoids, 3 - Analysing magnet, 5-Bender, 6- Power supplies and UHF- generator.

Figure 8: DECRIS-PM ECR ion source at HV platform, where: 1- DECRIS-PM, 2- Focussing solenoid.

Designed frequency range of the DC-280 RF system is 7.32÷10.38 MHz. Acceleration is on the third harmonic of particle revolution, the flat- top system is operated on the ninth harmonic [6].

The electrostatic deflector (Fig.12) with passive magnetic channel are used for ion beams extraction.

To transport ion beams to physical setups 5 channels with ±50° bending magnet are used (Fig.13, Fig.14) [7]. The channels equipped with focusing quadrupole lenses, steering magnets, diagnostic boxes. The water cooled current aperture diaphragms are installed into all beam lines to prevent the tube damage. The beam diagnostics consists of the Faraday caps, slit collimators, sector aperture diaphragms and ionization beam profile monitors.

The HV platform equipped with the new DECRIS-PM ECR ion source with permanent magnet structure (Fig. 8). The source extraction voltage is up to 20 kV. Also the focusing solenoid, 90° analysing magnet, diagnostic boxes, vacuum system and power supplies installed on the HV platform.

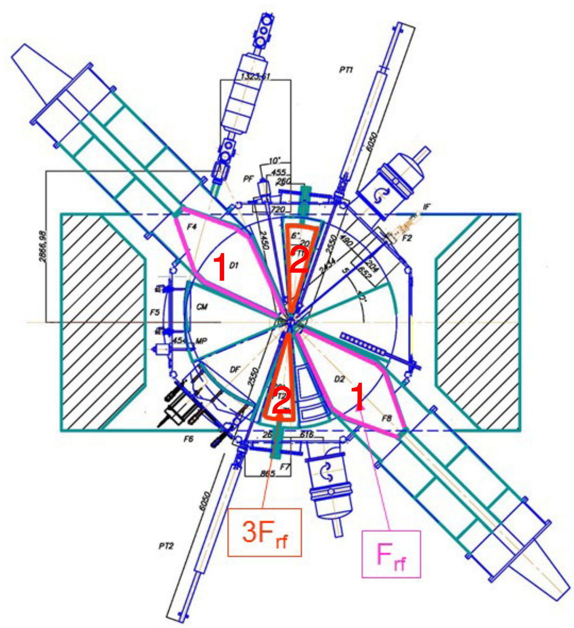

Figure 9: Scheme of the DC-280 RF-system, where: 1- Main dees, 2- Flat- top dees.

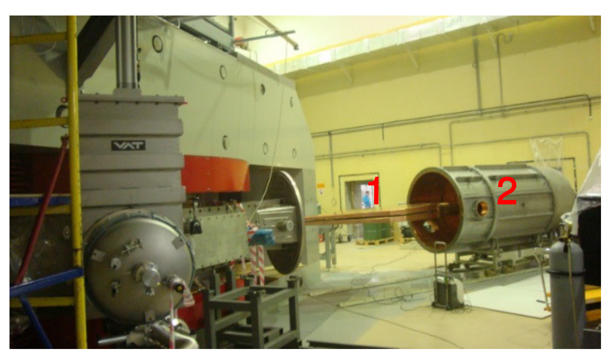

Figure 10: Main resonator with dee, where: 1 - dee, 2- resonator.

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-WEXMH02

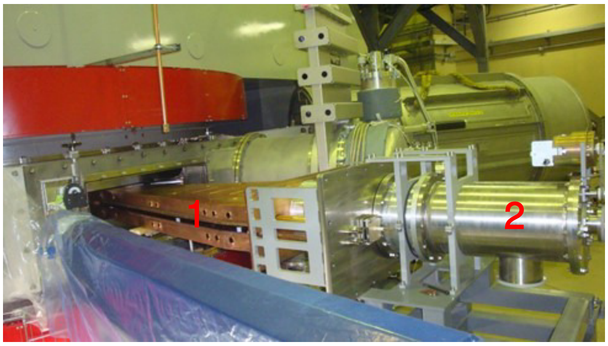

Figure 11: Flat - top resonator, where: 1 - dee with plating, 2- resonator.

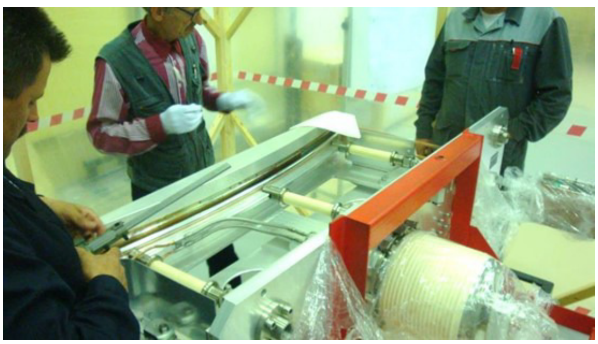
Figure 12: Electrostatic deflector.

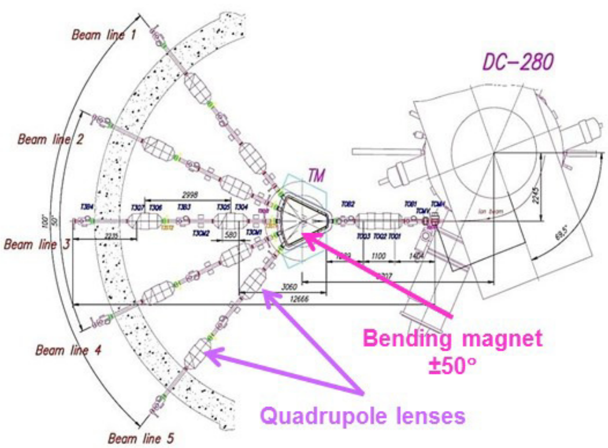

Figure 13: Scheme of beam transport.

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.

ACKNOWLEDGMENT

The authors would like to thank the excellent technical support from the FLNR JINR cyclotrons staff.

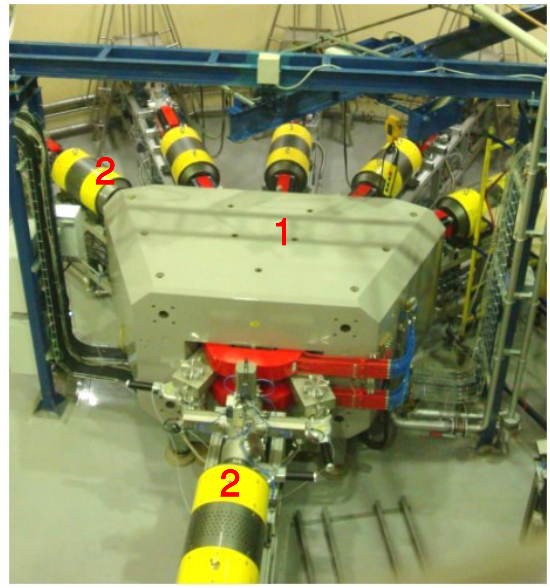

Figure 14: Beam transport channels, where: 1- ±50° bending magnet, 2- quadrupole lenses.

REFERENCES

[1] G. Gulbekyan, B. Gikal, S. N. Dmitriev, S. L. Bogomolov, O. N. Borisov, I. A. Ivanenko, N. Yu.Kazarinov, V. I. Kazacha, I. V. Kalagin, N.F. Osipov, A. V Tikhomirov, J. Franko, "Development of FLNR JINR Heavy Ion Accelerator Complex in the Next 7 Years. Project of New DC-280 Cyclotron", Proc. of PAC-2011, San-Sebastian, Spain, p. 2700÷2702 (2011).

[2] G. Gulbekian and CYCLOTRONS Group, "Status of the FLNR JINR Heavy Ion Cyclotrons" in Proc. of 14 Int. Conf. On Cyclotrons and Their Applications, Cape Town, South Africa, p. 95÷98 (1995).

[3] S. Bogomolov, A. Bondarchenko, A. Efremov, K. Kuzmenkov, A. Lebedev, K. Lebedev,V. Lebedev, V. Loginov, N. Yazvitsky, Z. Asfari, B.JP. Gall, "Production of ion beams from ECR ion sources by MIVOC method", Proc. of RUPAC-2014, Obninsk, Russia, p. 432÷434 (2014).

[4] G. Gulbekyan, B. Gikal, S. N. Dmitriev, S. L. Bogomolov, O. N. Borisov, I. A. Ivanenko, N. Yu.Kazarinov, V. I. Kazacha, I. V. Kalagin, N.F. Osipov, A. V Tikhomirov, J. Franko, "Development of FLNR JINR Heavy Ion Accelerator Complex in the Next 7 Years. Project of New DC-280 Cyclotron", Proc. of PAC-2011, San-Sebastian, Spain, p. 2700÷2702 (2011).

[5] S.Bogomolov el al." Resent Development in ECR Ion Sources at FLNR JINR" Proc. of RUPAC2012, Saint-Petersburg, Russia, pp. 203÷207 (2012).

[6] G.G.Gulbekyan, V.B.Zarubin, G.A.Karmysheva, J.Franko O.V.Karmyshev, "High-Frequency Acceleration System of the DC-280 Cyclotron", Physics of Particles and Nuclei Letters, Vol. 9, N8, p. 637-642 (2012).

[7] G.G. Gulbekian, S.N. Dmitriev, Yu.Ts. Oganessian, B.N. Gikal, I.V. Kalagin, S.L. Bogomolov, I.A.Ivanenko, N.Yu.Kazarinov, G.N. Ivanov, N.F.Osipov, "Status of the DC-280 cyclotron project", in Proc. of Int. Conf. On Cyclotrons and Their Applications, Zurich, Switzerland, p. 363÷365 (2016).