STATUS OF THE FLNR JINR CYCLOTRONS

Boris Gikal, Igor Kalagin#, Georgy Gulbekyan, Sergei Dmitriev,
Joint Institute for Nuclear Research, FLNR, Dubna, Moscow Region, Russia

Abstract

The current status of the JINR FLNR cyclotrons and plans of their modernization are reported. At present time, four isochronous cyclotrons: U400, U400M, U200 and IC100 are under operation at the JINR FLNR. The U400 and the U400M are the basic cyclotrons that are under operation about 6000 and 3000 hours per year correspondingly. Both the accelerators are used in DRIBS experiments to produce and accelerate exotic very neutron-rich isotopes of light elements such as 6He and 8He. The U400 (pole diameter of D=4 m) is designed to accelerate ion beams of atomic masses from 4 to 209 to maximum energy of 26 MeV/u for synthesis of the new super heavy elements and other physical experiments. The U400M cyclotron (D=4 m) is used to accelerate ions of elements from Li to Ar up to 50 MeV/u and heavier ions such as 48Ca,Kr,Xe, up to 6 MeV/u after recent modernization. The U200 cyclotron (D=2 m) is used to produce isotopes by using He ions with energies about 9 MeV/u, modernization of the cyclotron injection is planned. Modernized IC100 accelerator (D=1m) is used to produce track membranes and carrying out experiments in solid-state physics by using Ar, Kr and Xe ions at energies of 1.2 MeV/u.

INTRODUCTION

The Flerov Laboratory of Nuclear Reactions scientific program on heavy ion physics 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, Flerov Laboratory of Nuclear Reactions of Joint Institute for Nuclear Research has four cyclotrons of heavy ions: U400, U400M, U200, IC100 (DC40), that provide performance of the basic and applied researches. Total operating time of cyclotrons is about 8000 hours per year, mainly for the U400 and U400M (Fig.1).

U400 CYCLOTRON

The isochronous U400 cyclotron has been in operation since 1978. [1] The cyclotron produces ion beams of atomic masses 4÷209 at energies of 3÷29 MeV/nucleon. The main parameters of the U400 are presented in Table 1 (U400). In 1996, the ECR-4M ion source (made in Ganil, France) was installed at the U400, instead the PIG- ion source. The axial injection system with two bunchers (sine and line types) was created to inject ions from the ECR-4M to the U400 center. The system allows us to carry out experiments with ions of the rare $_{48}$Ca isotope. In 2002, the horizontal part of the injection channel was shorted to increase injection efficiency [2].

#kalagin@nrmail.jinr.ru

Table 1: Comparative Parameters of U400 and U400R

	U400	U400R
Parameters	**Value/Name**	
Magnet weight	2100 t.	2100 t.
Electrical power of magnet power supply system	850 kW	200 kW
Electrical power of RF system	100 kW	100 kW
The magnetic field level in the magnet center	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 ultimate 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 directions for ion extraction	2	2

The U400 modernization is planned. 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 Tab.1 (U400R). The axial injection and ion extraction systems will be changed. For ion extraction both the stripping foil and the deflector methods are considered. Moreover, the project intends changing the U400 vacuum, RF and power supply. The expected U400R ion beam parameters in comparison with U400 ones are shown in Table 2.

U400R will offer better possibilities for DRIBs project due to the lower level of fringing magnetic field in injection line and more effective ion extraction by special stripping foil probe.

Table 2. Parameters of U400 and U400R Typical Ion Beams

U400			U400R (expected)		
Ion	Ion energy [MeV/u]	Output intensity	Ion	Ion energy [MeV/u]	Output intensity
$^{4}He^{1+}$	-	-	$^{4}He^{1+}$	6.4 ÷ 27	23 pμA **
$^{6}He^{1+}$	11	$3{\cdot}10^{7}$ pps	$^{6}He^{1+}$	2.8 ÷ 14.4	10^{8} pps
$^{8}He^{1+}$	7.9	-	$^{8}He^{1+}$	1.6 ÷ 8	10^{5} pps
$^{16}O^{2+}$	5.7; 7.9	5 pμA	$^{16}O^{2+}$	1.6 ÷ 8	19.5 pμA **
$^{18}O^{3+}$	7.8; 10.5; 15.8	4.4 pμA	$^{16}O^{4+}$	6.4 ÷ 27	5.8 pμA **
$^{40}Ar^{4+}$	3.8; 5.1 *	1.7 pμA	$^{40}Ar^{4+}$	1 ÷ 5.1	10 pμA
$^{48}Ca^{5+}$	3.7; 5.3 *	1.2 pμA	$^{48}Ca^{6+}$	1.6 ÷ 8	2.5 pμA
$^{48}Ca^{9+}$	8.9; 11; 17.7 *	1 pμA	$^{48}Ca^{7+}$	2.1 ÷ 11	2.1 pμA
$^{50}Ti^{5+}$	3.6; 5.1 *	0.4 pμA	$^{50}Ti^{10+}$	4.1 ÷ 21	1 pμA
$^{58}Fe^{6+}$	3.8; 5.4 *	0.7 pμA	$^{58}Fe^{7+}$	1.2 ÷ 7.5	1 pμA
$^{84}Kr^{8+}$	3.1; 4.4 *	0.3 pμA	$^{84}Kr^{7+}$	0.8 ÷ 3.5	1.4 pμA
$^{136}Xe^{14+}$	3.3; 4.6; 6.9 *	0.08 pμA	$^{132}Xe^{11+}$	0.8 ÷ 3.5	0.9 pμA

* Possible energy variation is ±5%

** Current is limited by maximal beam power of 2.5 kW

U400M CYCLOTRON

The isochronous U400M cyclotron has been in operation since 1991. The cyclotron was originally intended for acceleration ion beams with A/Z=3÷3.6 (A-atomic weight of the accelerated ion; Z - ion charge when accelerated) at energies of 34÷50 MeV/nucleon. The beam extraction method is stripping foil. In 2008 the U400M possibilities have been extended by addition of the ion beams with A/Z=8÷10 at energies of 4.5÷9 MeV/nucleon. The additional ion beams intended to carry out physical experiments on synthesis the new super heavy elements and applied researches. The experiments will be continued at U400M in the period of U400→U400R modernization. To carry out the experiments a new ion beam transport system was created in opposite direction to the main transport system.

The new axial injection system of the U400M was put into operation in 2006. The design of the axial injection system of the U400M cyclotron is similar to that of the U400R cyclotron.

The DECRIS-2 (Dubna ECR Ion Source) is used at the cyclotron. In the nearest future the axial injection will be equipped by the new superconducting ECR ion source made in FLNR [3], named DECRIS-SC2.

The beam is focused by the solenoidal lens situated between the ECR and the 90°magnet, and by six solenoids placed in the vertical part of the injection channel. The axial injection was equipped by the sine buncher and the electrostatic chopper. To enter the ion beam into the cyclotron center the electrostatic mirror is used. We plan to design the helix inflector for the injection channel.

The channel is pumped out by two turbomolecular and two cryogenic pumps, which provide vacuum of $2.5{\cdot}10^{-7}$ Torr.

Due to good vacuum in the cyclotron chamber (better than $1{\cdot}10^{-7}$ Torr) and high acceleration rate, the beam losses during the process of acceleration up to the final radius is less than 10%.

DRIBS PROJECT

The DRIBs (Dubna Radioactive Ion Beams) project has been running at the FLNR since 2002 [4]. Project suggests the use of two accelerator setups (U400M and U400). The primary ion beams (^{7}Li or ^{11}B) from U400M accelerator produce reactions at a production target (Be). The produced radioactive nuclei transported into the ECR (2.45 GHz) ion source where are ionized. Then, the radioactive ions are extracted out of the ECR, separated and transported trough 120 m transport line into the U400 where are accelerated.

At present time, only $^{6}He^{+2}$ ions at energy of 11 MeV/nucleon are available for physical experiments. DRIBs possibilities will be extended after carrying out U400→U400R modernization (see Table 2).

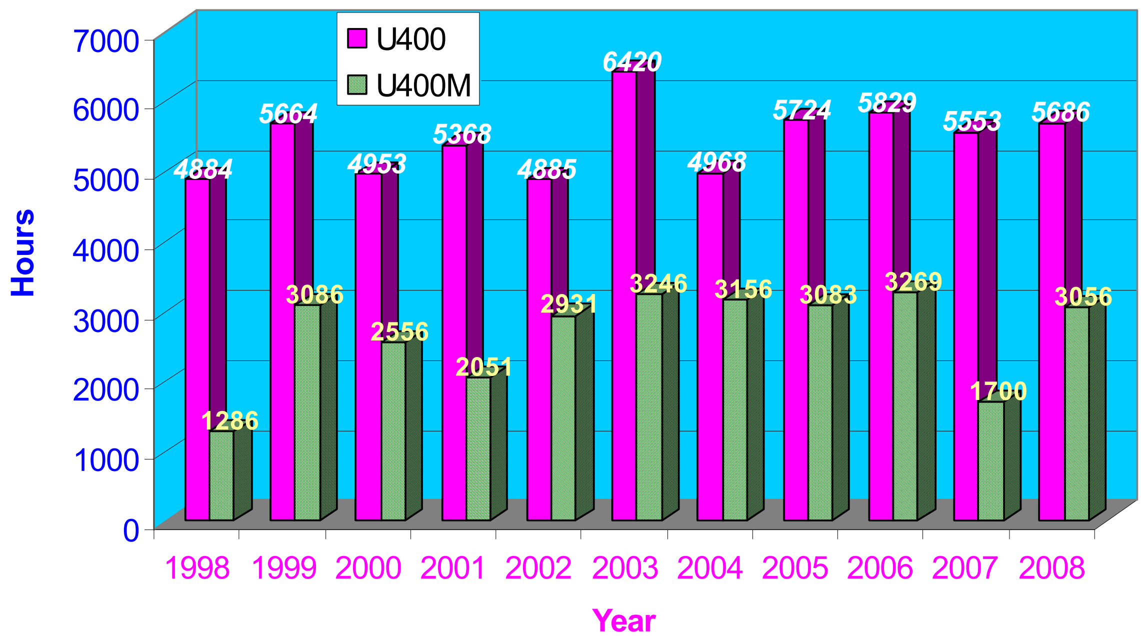

Figure 1: U400 and U400M operation in 1998-2008.

U200 CYCLOTRON

The U200 isochronous cyclotron has been in operation since 1991.The cyclotron was designed for production of nuclear beams with A/Z=2.8÷5 (from D to Ne) at energies up to 9 MeV/nucleon [5]. The internal PIG ion source is used at the accelerator.

The cyclotron is used for production of different radioisotope markers for study of properties of synthesised transplutonium elements, radiobiological investigation of direct and mutative effect of various ionization density particles on cells with different genome organization, production of ultraclean radioisotopes for medical investigations (^{237}Pu, ^{26}Al, ^{211}At), experiments on science of materials, as well as detector calibration for other accelerators.

In the future, the U200 will be equipped by the ECR ion source and the axial injection system.

IC100 CYCLOTRON

The isochronous IC100 (DC40) cyclic implanter with the PIG ion source was created in 1985.

Years 2003-2005 update [6] resulted in IC100 equipment with external axial beam injection system and the superconducting ECR ion source (DECRIS-SC [3]) 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. Helix inflector is installed into the center of the accelerator. The accelerated beams are extracted by electrostatic deflector with two magnetic channels. In routine operation IC100 provides intensities of the ion beams of $^{86}Kr^{+15}$ and $^{132}Xe^{+23}$ 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.

REFERENCES

[1] Gulbekian G. and CYCLOTRONS Group, “Status of the FLNR JINR Heavy Ion Cyclotrons” in Proc. of 14th Int. Conf. On Cyclotrons and Their Applications, Cape Town, South Africa, pp. 95-98,1995

[2] Yu. Ts. Oganessian, G.G. Gulbekyan, B.N. Gikal, I.V. Kalagin et al.,”Status report of the U400 cyclotron at the FLNR JINR “, in Proc. of APAC2004, Gyeongju, Korea, pp.52-54, 2004

[3] Efremov A.A., Bekhterev V.V., Bogomolov S.L. et al., “Status of the ion source DECRIS-SC”, Review of Scientific Instruments, V. 77, P.235–239, No.03A320,2006

[4] B.N. Gikal, S.L. Bogomolov, S.N. Dmitriev et al., “Dubna cyclotrons- status and plans”, in Proc. of Cyclotron04 Int. Conf., Tokyo, Japan, 2004. accelconf.web.cern.ch/accelconf/c04/data/CYC2004_papers/20A1.pdf

[5] B.N.Gikal et al., "U200 cyclotron operating experience and upgrade". JINR preprint, 9-83-311, Dubna, 1983

[6] B.N.Gikal, S.N.Dmitriev et al., " IC-100 Accelerator Complex for Scientific and Applied Research ". ISSN 1547-4771, Physics of Particles and Nuclei Letters, Vol. 5, No. 1, pp. 33–48. © Pleiades Publishing, Ltd., 2007