STATUS REPORT AND FUTURE DEVELOPMENT FLNR JINR HEAVY IONS ACCELERATOR COMPLEX

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Abstract

Four heavy ions cyclotrons are in operation at FLNR now. Heavy ion beams used for super heavy elements synthesis, RIB production and application. Plan for seven years accelerator development and operation are presented.

INTRODUCTION

At present time four isochronous cyclotrons: U400, U400M, U200 and IC100 are under operation at the JINR FLNR. Total operation time is about 10 000 hours per year. The U400M is a primary beam generator and U400 is as postaccelerator in RIB(DRIBs) experiments to produce and acceleration exotic nuclides as 6He, 8He etc.. Layout of FLNR accelerators complex presented on Fig.1 [1].

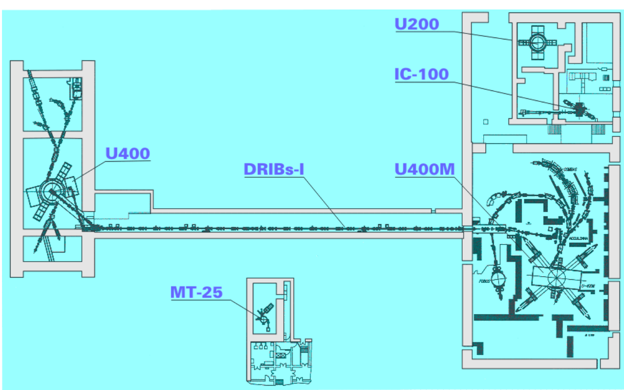

Figure 1: Layout FLNR JINR accelerator complex.

U400→U400R CYCLOTRON

The cyclotron U400 (pole diameter 4 m)has been in operation since 1978 [2], [3]. In 1996, the ECR-4M ion source (GANIL) was installed at the U400. The axial injection system with two bunchers (sin and linear) and spiral inflector was created to inject ions in cyclotron Fig.2. From 1997 to present time U400 had worked in total 64 000 hours. About 66% of the total time was used for acceleration $48Ca^{5+,6+}$ ions for synthesis of new super-heavy elements. Within the mentioned period elements with Z=113, 114, 115,116,118 were synthesized. Chemical properties of Z=112 were studied. The 48Ca beam intensity on the target is $8 \cdot 10^{12}$ pps (1.2 pμA) at of 48Ca substance consumption of 0.4 mg/hour. Extraction efficienthy of 48Ca beam by stripping on the level 40% only. The U400→U400R modernization is planned to start in 2010 and finished in 2011. The aim of the modernization:

– increasing 48Ca, 50Ti, 54Cr, 58Fe, 64N, beam intensity on the target up to 2.5÷3 pμA;
– providing the fluent ion beam energy variation at factor 5 by magnetic field variation from 0.8 up to 1.8 T instead 1.93÷2.1 T now;
– improvement of the energy spread in the ion beam at the target up to 10^{-3};
– improvement of the ion beam emittance at the target up to 10π mm·mrad.

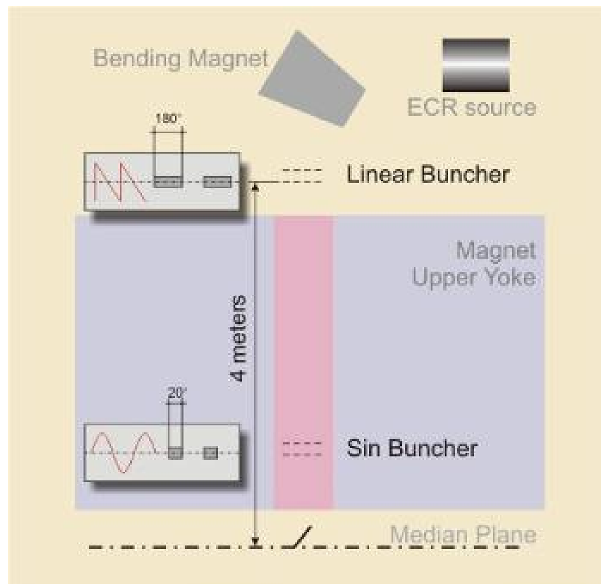

Figure 2: Scheme of the beam bunching system.

The project of modernization intends changing axial injection system, magnetic structure, vacuum system, RF system, power supply system, beam diagnostic system and additionally electrostatic deflector positioning. The main comparative parameters of U400 and U400R are presented in Table 1.

Table 1: Comparative Parameters of U400 and U400R

Parameters	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
Flat – top system	-	+
Beam extraction	stripping	Stripping, deflector
Power consuption	~1 MW	~0.4 MW

The working diagram of the U400R cyclotron with intensities 48Ca beams presented on Fig. 3.

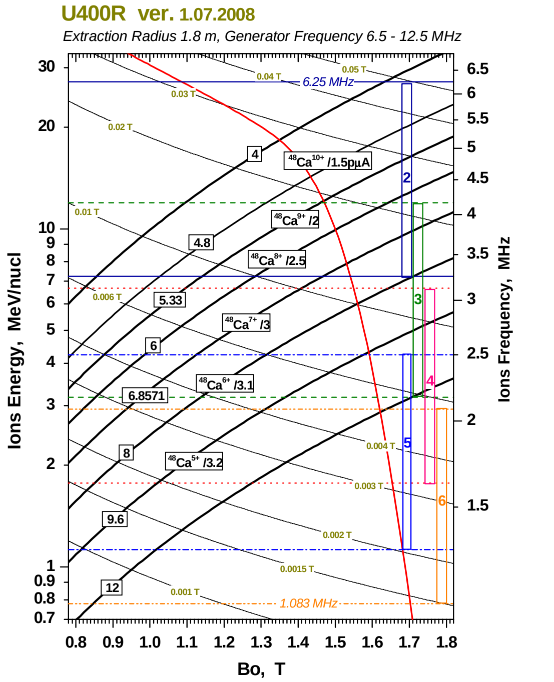

Figure 3: Operating chart of the U400R cyclotron

Parameters of U400 and U400R typical ion beams presented in Table 2.

Table 2.Parameters of U400 and U400R Typical Ion beams

U400		
Ion	Ion energy [MeV/u]	Output intensity
$^{4}He^{1+}$	-	-
$^{6}He^{1+}$	11	$3{\cdot}10^{7}$ 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	10^{8} pps
$^{8}He^{1+}$	1.6 ÷ 8	10^{5} 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
$^{132}Xe^{11+}$	0.8 ÷ 3.5	0.9 pμA

Scheme of the ion beam extraction from U400R by stripping foils in two opposite directions A and B and by deflector in direction A are presented on Fig. 4.

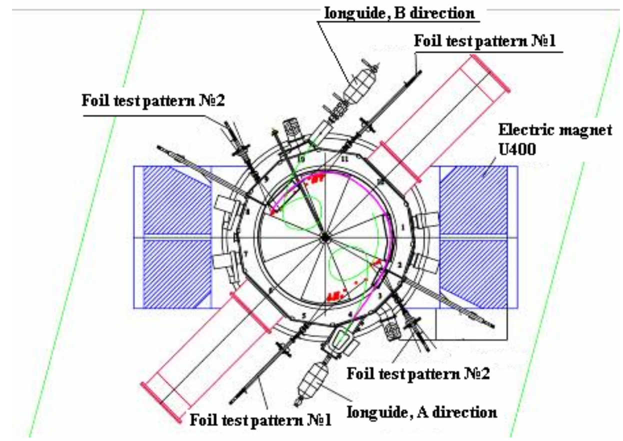

Figure 4. Scheme of the beam extraction in two selected directions.

U400M CYCLOTRON

The 4 sector and 4 dees cyclotron U400M has been in operation since 1991 [3]. The cyclotron was originally intended for ion beam acceleration with A/z =2÷5 at energies of 20÷100 MeV/n. The ion beams is extracted from cyclotron by stripping with stripping ratio Z_2/Z_1= 1.4÷1.8 and why energy range of extracted beams from 30 up to 50 MeV/n. The light ion beams from U400M are used for radioactive beams production. The intensity of light ion beams as 7Li or 11B on the targets $(3÷5)10^{13}$ pps. Tritium ions are accelerated as molecular $(DT)^{1+}$ with intensity $6{\cdot}10^{10}$ pps and energy 18 MeV/n. The generation of $(DT)^{1+}$ ion is in special RF ion source. In 2008 the U400M possibilities have beam intended by addition ion beams with A/z =5÷10 at energies of 4.5÷20 MeV/n. This low energy ion as 48Ca will be used too for synthesis and study of new elements.

Scheme of low and high energy beam extraction from U400M in two opposite direction are presented on Fig. 5.

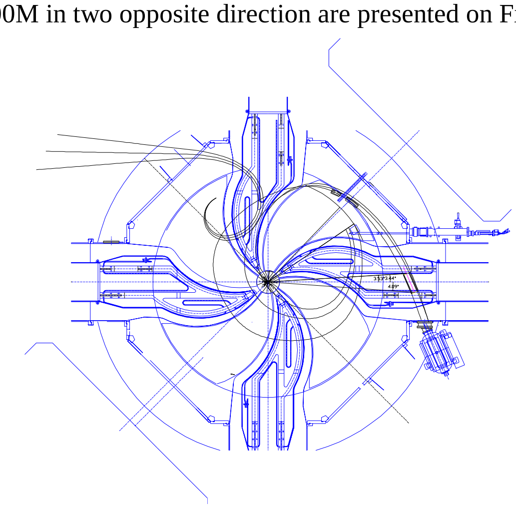

Figure 5: Scheme of beam extraction from U400M.

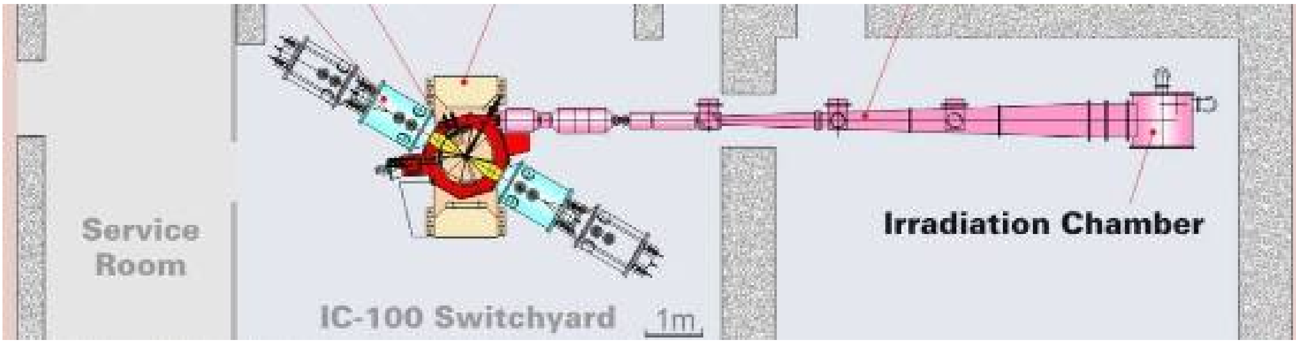

Figure 6: Plan of a specialized complex for applied research based on the IC100 cyclic implanter.

U200 CYCLOTRON

The 2 m, 4 sectors and 2 dees U200 cyclotron has been in operation more than 40 years. At present accelerator is used for isotope production with 36 MeV 4He beam.

In the next year we are going to install ECR ion source at U200.

IC-100

The 1 m pole diameter, 4 sector, 2 dees cyclotron equipment with SC ECR ion source. The cyclotron was designed to accelerate ion with a fixed energy 1.2 MeV/n. The range of accelerated ion from C up W. The IC-100 used for polimer film irradiation (200x600 mm) and solid matter investigation. The $132Xe^{23+}$ beam intensity, for example, 0.2 pμA at the target. Lay-out IC-100 presented on Fig. 6.DRIBS PROJECT

The DRIBs (Dubna RIB) project has been running at Lab since 2002 [3] Fig.1.. The primary ion beams (7Li or 11B) from U400M used for production nuclides as 6He, 8He at the target (Be or C). The produced radionuclides transported from hot catcher by dissision into ECR (2.45 GHz) ion source where are ionized. Then, the radioactive ions are extracted, separated and transported trough 120 m transport line into the U400, where are accelerated. At present time 6He2+ ions at energy of 11 MeV/n are available for physical experiments. DRIBs possibilities will be extended after carring out U400→U400R modernization (see Table 2).

DUBNA ECR (DECRIS) ION SOURCE AND INJECTION SYSTEMS [4]

For the last 15 years 6 units room temperature 14 GHz ECR sources have been developed in Lab. Two SC ECR (DECRIS-SC) have been developed too for IC-100 and U400M cyclotrons. Three permanent magnet 2.45 GHz ECR have been developed in Lab for generation single-charge stable and radioactive ions. For increasing beam capture efficiency from ECR source by accelerator axial injection systems have been developed too. For example, the scheme of U400R axial injection channel is shown in Fig.7. The results of the capture efficiency for 40Ar4+ are presented in Fig.8. The reasons of the efficiency decreasing in the regime with bunchers can be influence of space-charge effects. In the future, we are planning to increase the injection voltage from 13÷20 up to 50÷100 kV what means shift of the space charge limits for factor 6÷20.

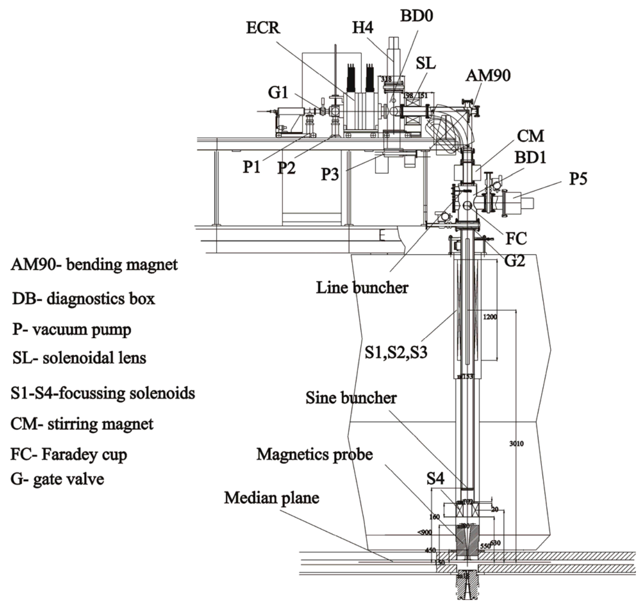

Figure 7: Scheme of U400R axial injection system.

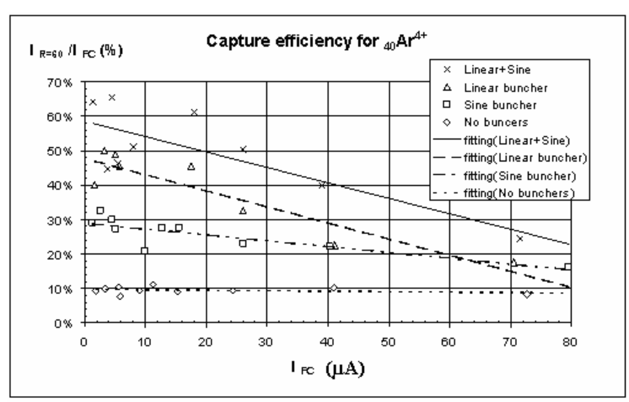

Figure 8: The efficiency of capture versus injecting beam current and bunchers.

NEW FLNR ACCELERATOR

In order to improve efficiency of the experiments for the next 7 years it is necessary to obtain the accelerated ion beams with following parameters.

Energy	4÷8 MeV/n
Masses	10÷100
Intensity (up to 48Ca)	10 pμA
Beam emittance less 30 π mm·mrad	
Efficiency of beam transfer >50%	
ECR frequency	18÷28 GHz

Under consideration here is two variants now: SC linac or specialized cyclotron.

Variant 1 – SC LINAC

The propose superconducting linac structure include RFQ and 26 QuaterWave Resonators (QWR). The total lenth near 46 m, total power consumtion 350 kW, average accelerating gradient (along all QWR) near 1.5 MV/m.

Variant 2 – DC200 high-current Cyclotron [7].

Main parameters and goals DC200 cyclotron in Table 3.

Table 3: Main Parameters and goals DC200 Cyclotron

	Parameter DC200	Goals
1.	High injecting beam energy (up to 100 kV)	Shift of space charge limits for factor 30
2.	High gap in the center	Space for long spiral inflector
3.	Low magnetic field	High starting radius. High turns separation. Low deflector voltage
4.	High acceleration rate	High turns separation.
5.	Flat-top system	High capture. Single turn extraction. Beam quality.

Main parameters of the DC200 cyclotron are presented in Table 4.

Table 4. Main Parameters of the DC200

Injecting beam potential	Up to 100 kV
A/Z range	4÷7
Magnetic field level	0.65÷1.15 T
K factor	200
Gap between plugs	250 mm
Valley/hill gap	350/240 mm/mm
Magnet weight	470 t
Magnet power	170 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x14 kV
Beam turns separation	10 mm
Radial beam bunch size	3 mm
Efficiency of beam transferring	60%
Total accelerating potential	up to ~ 40 MV

The DC200 plan few presented on Fig. 9.

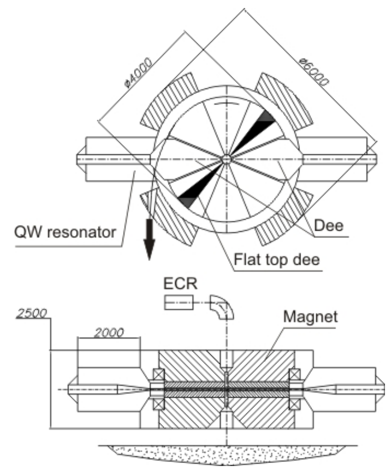

Figure 9: Scheme of the DC200.

Working diagram of DC200 presented on Fig. 10.

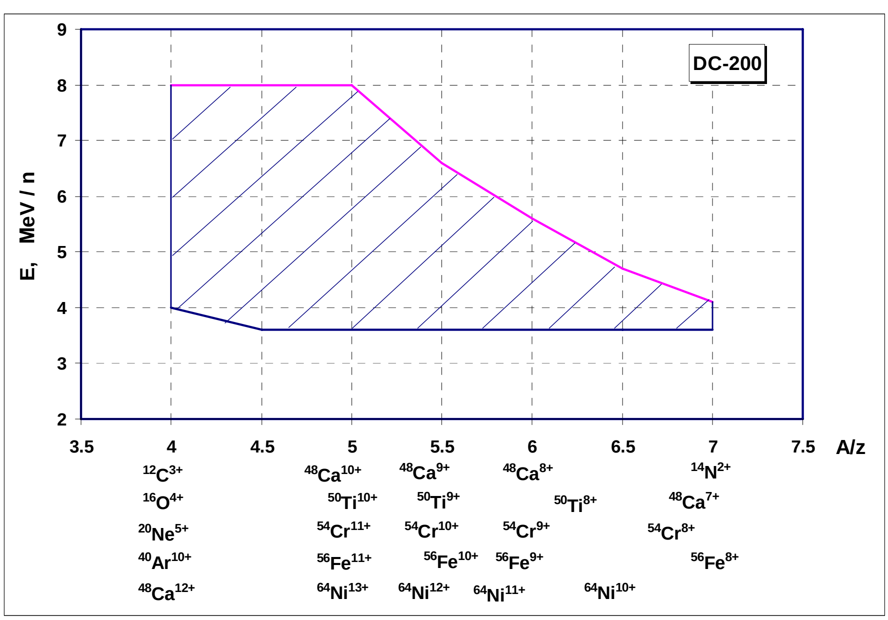

Figure 10: Cyclotron DC200 working diagram.

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