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 ^{6}He, ^{8}He, etc. The layout of FLNR accelerators complex is presented on Fig.1 [1].

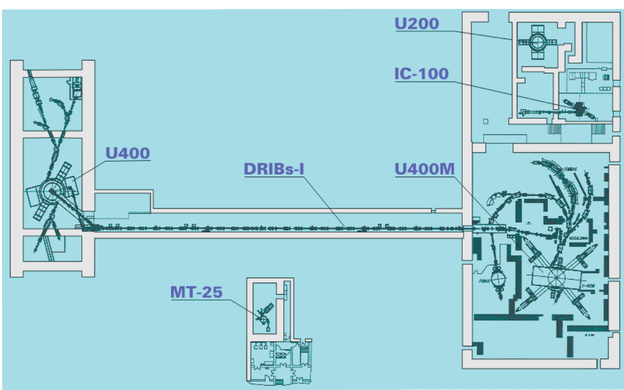

Figure 1: Layout FLNR JINR accelerator complex.

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 ^{48}Ca$^{5+,6+}$ 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 ^{48}Ca beam intensity on the target is $8\cdot10^{12}$ pps (1.2 pμA) at ^{48}Ca substance consumption of 0.4 mg/hour. Extraction efficiency of ^{48}Ca beam by stripping is on the level of 40% only. The U400→U400R modernization is planned to start in 2010 and finished in 2011. The aim of the modernization:

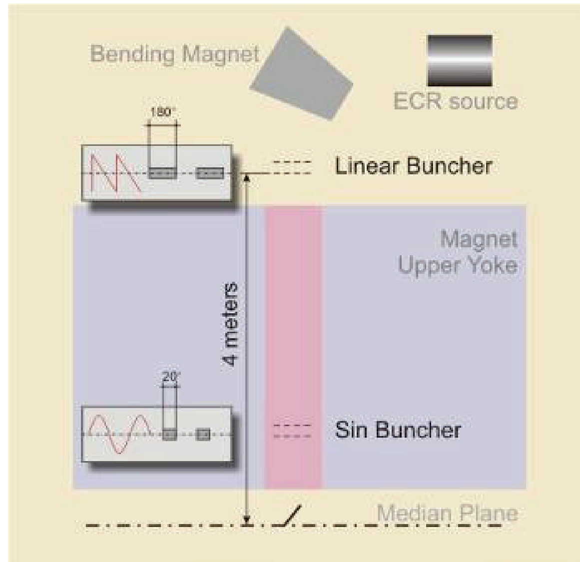

Figure 2: Scheme of the beam bunching system.

– increasing ^{48}Ca, ^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}N, 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 10 π mm·mrad.

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

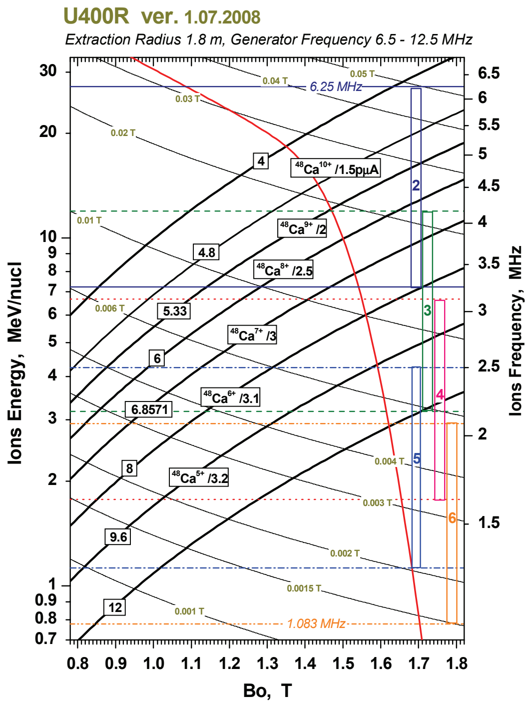

Figure 3: Operating chart of the U400R cyclotron.

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

The working diagram of the U400R cyclotron with ^{48}Ca beams intensities is presented in Fig. 3.

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

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 in Fig. 4.

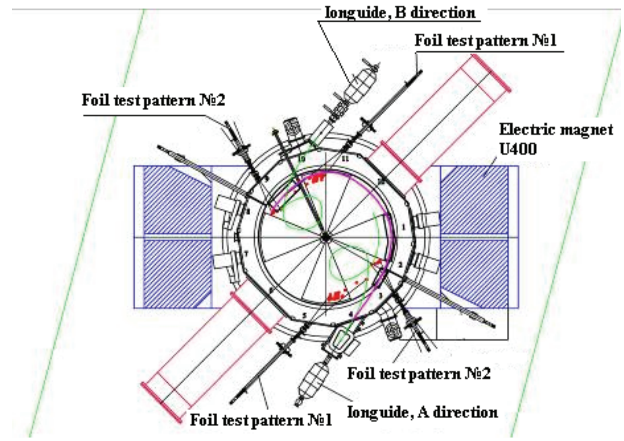

Figure 4. Scheme of the beam extraction in two selected directions.

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 ^{7}Li or ^{11}B on the targets $3÷5 \cdot 10^{13}$ 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 ^{48}Ca will be used too for synthesis and study of new elements.

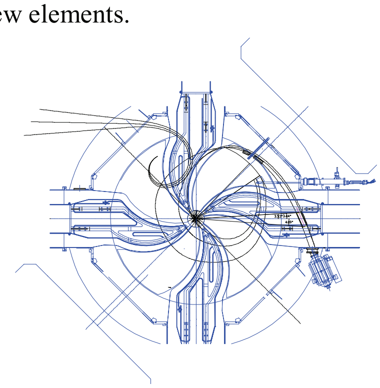

Figure 5: Scheme of beam extraction from U400M.

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

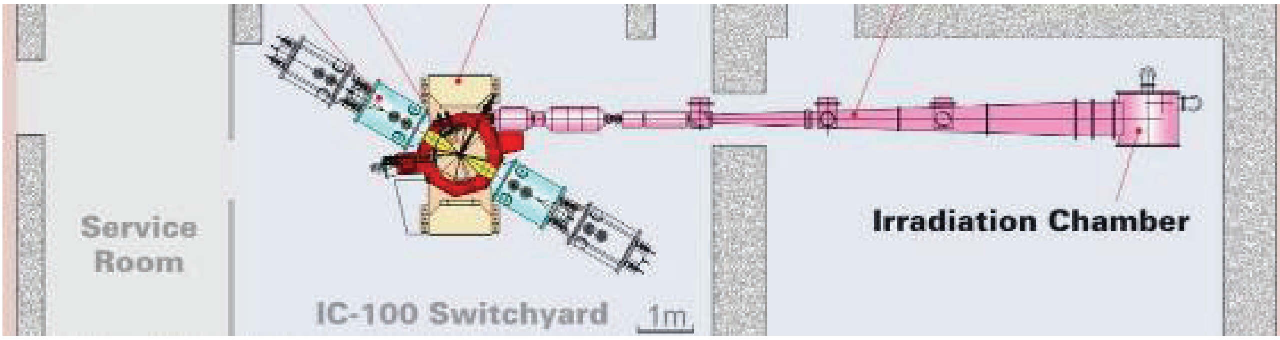

Figure 6: Plan of a specialized complex for applied research based on the IC100 cyclic implanter.

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 ^{4}He 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 ions with a fixed energy 1.2 MeV/n. The range of accelerated ions goes from C up W. The IC-100 is used for polymer film irradiation (200x600 mm) and solid matter investigation. The $^{132}Xe^{23+}$ beam intensity, for example, is 0.2 pμA at the target. Layout of IC-100 is presented in Fig. 6.

The DRIBs (Dubna RIB) project has been running at the Lab since 2002 (Fig. 1) [3]. The primary ion beams (^{7}Li or ^{11}B) from U400M are used for production nuclides as ^{6}He, ^{8}He at the target (Be or C). The produced radionuclides are transported from the hot catcher into an ECR (2.45 GHz) ion source where they are ionized. Then, the radioactive ions are extracted, separated and transported through a 120 m transport line into the U400, where they are accelerated. At present, $^6He^{2+}$ ions at energy of 11 MeV/n are available for physical experiments. DRIBs possibilities will be extended after carrying 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 the 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 the ECR source by the 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 $^{40}Ar^{4+}$ are presented in Fig. 8. The reasons of the decreasing efficiency in the regime with bunchers can be the 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.

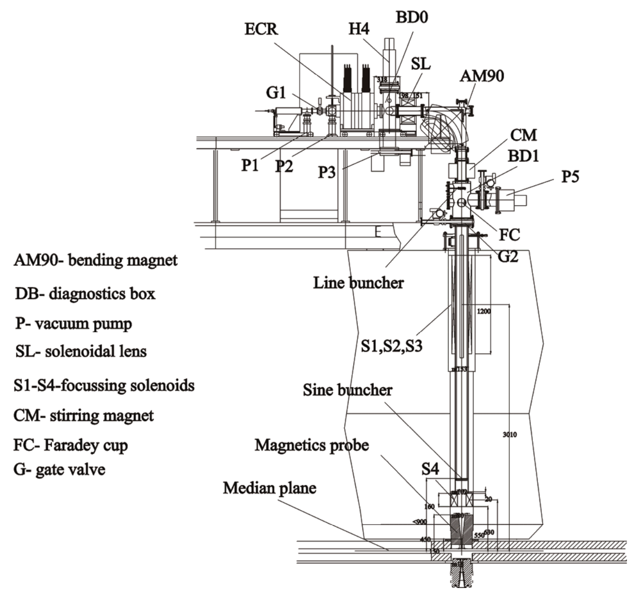

Figure 7: Scheme of U400R axial injection system.

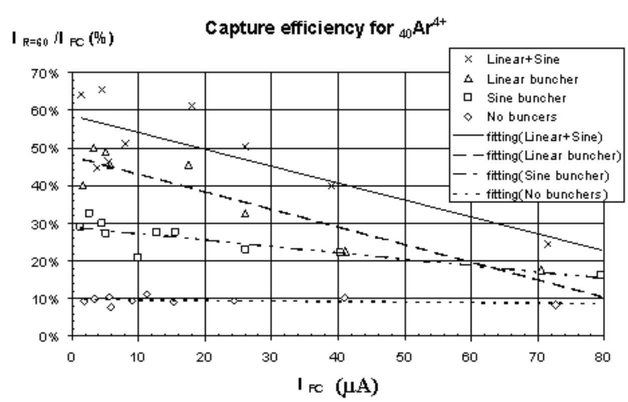

Figure 8: The efficiency of capture versus injecting beam current and bunchers.

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 than 30 π mm·mrad
Efficiency of beam transfer	>50%
ECR frequency	18÷28 GHz

Now two variants are under consideration here: SC linac or specialized cyclotron.

Variant 1 – SC LINAC

The proposed superconducting linac structure includes RFQ and 26 QuaterWave Resonators (QWR). The total length is close to 46 m, total power consumption 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 are presented 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 in Fig. 9.

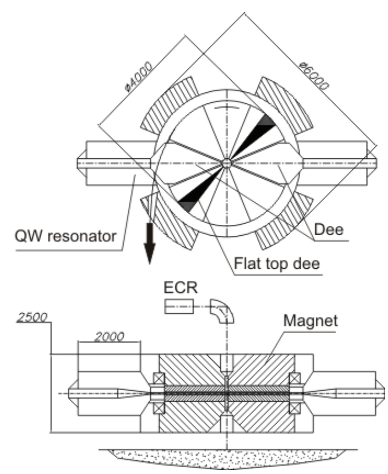

Figure 9: Scheme of the DC200.

The working diagram of DC200 presented in Fig. 10.

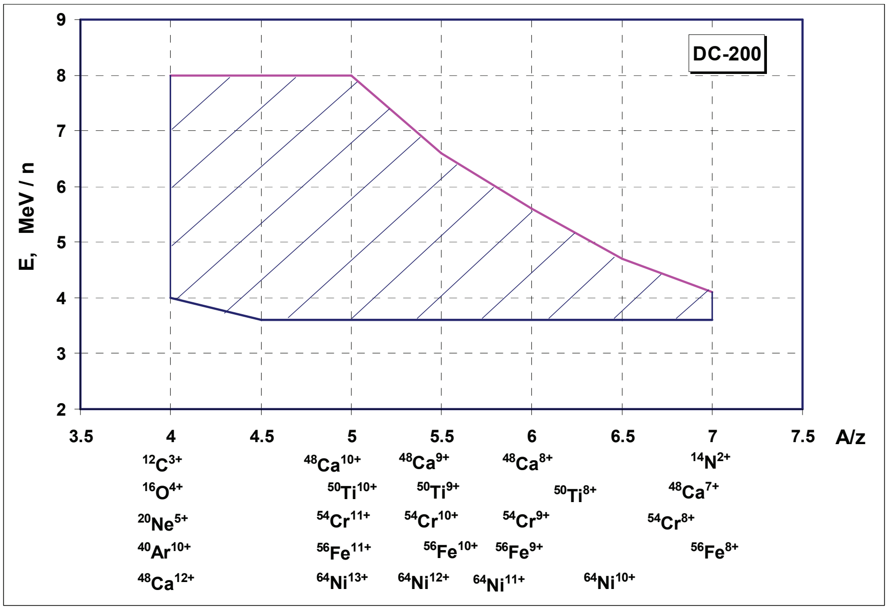

Figure 10: Cyclotron DC200 working diagram.

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