HIGH INTENSITY CYCLOTRONS FOR SUPER HEAVY ELEMENTS RESEARCH OF FLNR JINR

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Abstract

Main theme of FLNR JINR is super heavy elements research. From 2000 up to 2010 more then 40 isotopes of elements 112, 113, 114, 115, 116, 117, 118 were synthesized in the laboratory. As a target we used 243Am, 242Pu, 248Cm, 249Bk, 249Cf et al. Total flux 48Ca ion beam was on the level $5{\cdot}10^{20}$ ion. 48Ca matter consumption in ion source averaged 0.4 mg/hour at the beam intensity of 1 pμA .

According plan after U-400 cyclotron modernization (2012) 48Ca beam intensity will be increased up to 3pμA on the target and 48Ca. New cyclotron DC-200 planed to be put in to operation in 2014 will allow to reach 10 pμA of 48 Ca beam intensity.

INTRODUCTION

At present four isochronous cyclotrons: U-400, U-400M, U-200 and IC-100 are under operation at the JINR FLNR. Total operation time is about 71 000 hours per year. In the DRIBs project for production of accelerated exotic nuclides as 6He, 8He etc. the U-400M is used as radioactive beam generator and U-400 is as postaccelerator. Layout of FLNR accelerators complex presented at fig.1 [1].

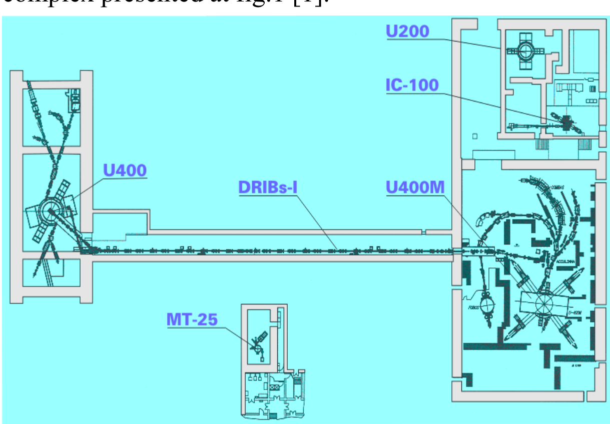

Figure 1: Layout of FLNR JINR accelerator complex

U400→U400R CYCLOTRON MODERNIZATION

The cyclotron U-400 (pole diameter 4 m) has been in operation since 1978 [2], [3]. In 1996, the ECR-4M ion source (GANIL) was installed at the U-400. The axial injection system with two bunchers (sin and linear) and spiral inflector was created to inject ions in cyclotron Fig.2. Since 1997 total operation time of the U400 amounts 71 000 hours. About 66% of the total time was used for acceleration 48Ca5+,6+ ions for synthesis of new super-heavy elements. Within the mentioned period elements with number of 113, 114, 115, 116, 117, 118 were synthesized. Chemical properties of 112 element were studied. The 48Ca beam intensity on the target was 8·1012 pps (1.2 pμA) at 0.4 mg/hour 48Ca substance consumption. Extraction efficiently of 48Ca beam by stripping foil was on the level 40% due to charge spread. The U-400 modernization in to U-400R is planned to start in 2011 and finishing in 2012. The aim of the modernization:

- increasing 48Ca, 50Ti, 54Cr, 58Fe, 64N, beam intensity on the target up to 2.5÷3 pμA;
- providing the smooth ion energy variation by factor 5 by magnetic field variation in the range of (0.8 - 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.

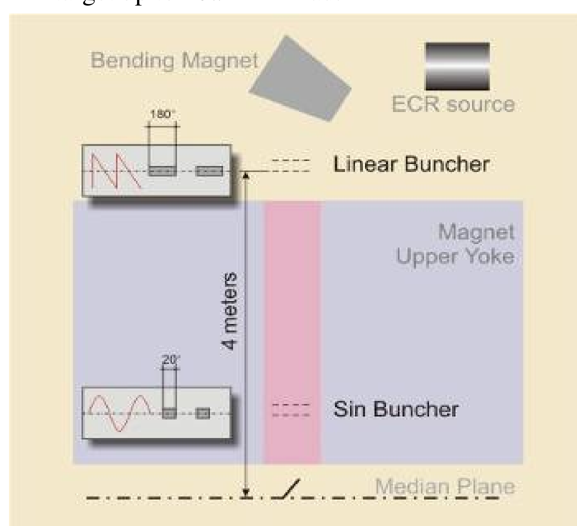

Figure 2: Scheme of the beam bunching system

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 instillation. The main comparative parameters of U-400 and U-400R are presented in Table 1.

The working diagram of the U-400R cyclotron with 48Ca beams intensities presented on Fig.3.

Scheme of the ion beam extraction from U-400R by stripping foils in two opposite directions A and B and by deflector in direction A are presented on Fig.4.

Table 1: Comparative parameters of U-400 and U400R

Parameters	U-400	U-400R
Mass to charge ratio of accelerated ions	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	Strip. deflector
Power consumption	~1 MW	~0.4 MW

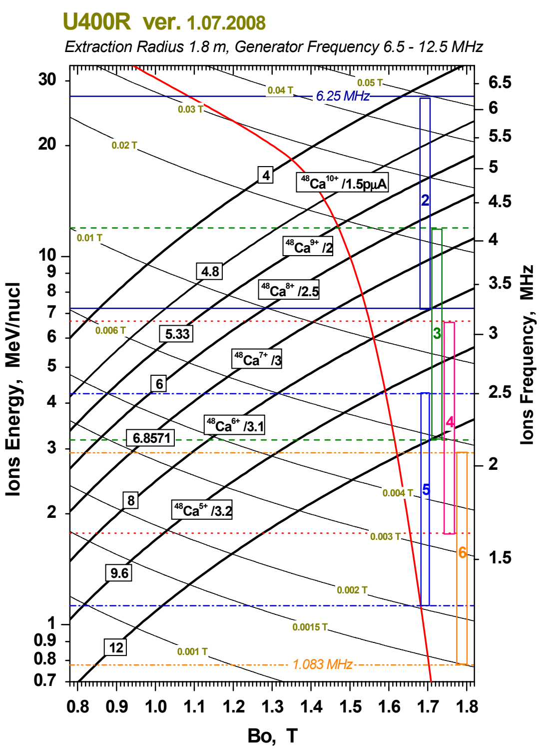

Figure 3: Working diagram of the U400R cyclotron

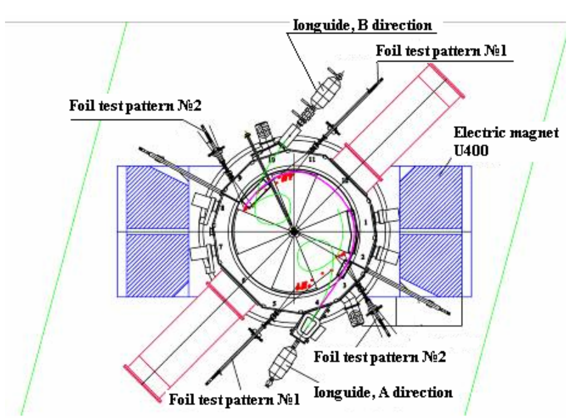

Figure 4: Scheme of the beam extraction from U400M in two selected directions.

U-400M CYCLOTRON

The 4 sectors and 4 dees cyclotron U-400M 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. Now the ion beams are extracted from cyclotron by stripping with stripping ratio Z_2/Z_1= 1.4÷1.8. It defines energy range of extracted beams from 30 up to 50 MeV/n. The light ion beams from U-400M 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. For generation of $(DT)^{1+}$ ions special RF ion source is used. In 2008 the U-400M possibilities were widened by acceleration of ion beams with mass to charge ratio of 5÷10 with energies of 4.5÷20 MeV/n. This low energy ion beams (as 48Ca) will be used for synthesis and study of new elements.

Scheme of low and high energy beam extraction from U-400M in two opposite direction are presented on Fig.5.

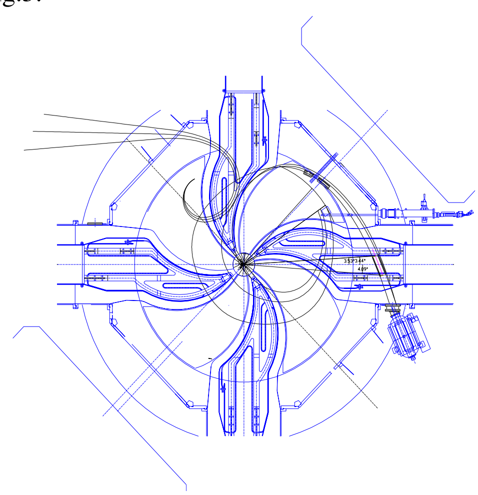

Figure 5: Scheme of beam extraction from U400M

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 U-400M used for production nuclides as 6He, 8He in the target (Be or C). The produced radionuclides come from hot catcher into ECR (2.45 GHz) ion source by diffusion, where they are ionized. After separation, extracted from ECR radioactive ion beam are transported through 120 m transport line into the U-400 for acceleration. At present 6He2+ ions with energy of 11 MeV/n are available for physical experiments. DRIBs possibilities will be widened after carrying out U-400 modernization (see Table 2).

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

For the last 15 years 6 units room temperature 14 GHz ECR sources have been developed in Lab. Two superconducting ECR (DECRIS-SC) have been designed for IC-100 and U400M cyclotrons. Three permanent magnet 2.45 GHz ECR have been created in Lab especially for generation single-charge stable and radioactive ions. Effective axial injection systems have been developed to inject the beam into cyclotron for acceleration. As example, the scheme of U-400R axial injection channel is shown at Fig.6. The results of the capture efficiency for 40Ar4+ are presented in Fig.7. Decreasing efficiency of bunchers effect with increasing intensity can be explained by influence of space-charge effect. In the future, we are planning to increase the injection voltage from 13÷20 up to 50÷100 kV, it means shift of the space charge limits by factor 6÷20.

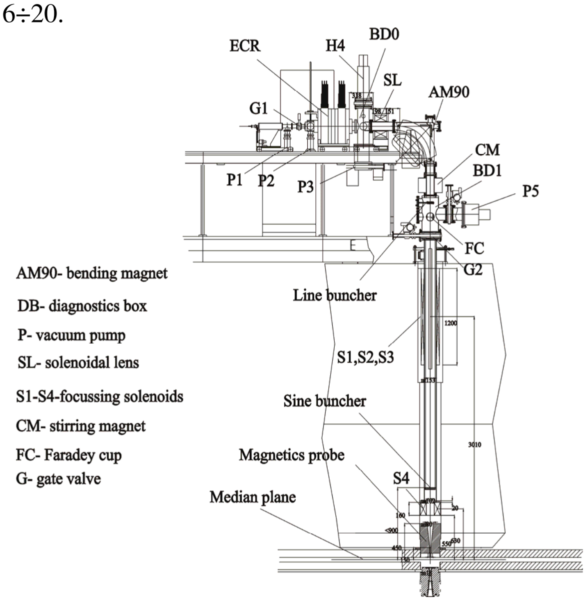

Figure 6: Scheme of U-400R axial injection system.

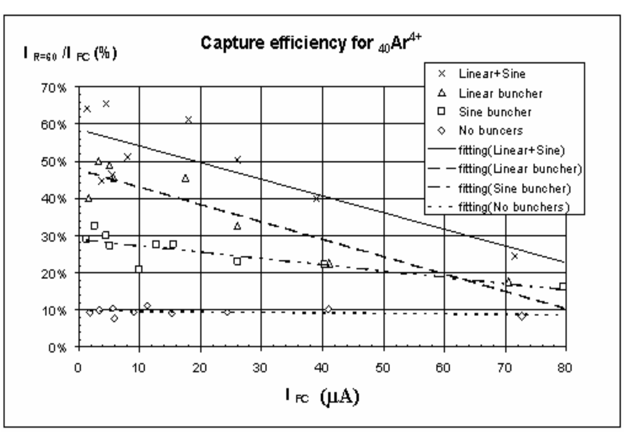

Figure 7: The afficiency of beam capture to acceleration versus injecting beam current and bunchers.

NEW FLNR ACCELERATOR – CYCLOTRON DC-200

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

Energy	4÷8 MeV/n
Masses	10÷238
Intensity (for 48Ca)	10 pμA
Beam emittance	less 30 π mm·mrad
Efficiency of beam transfer	>50%

Main parameters and goals DC-200 cyclotron are in the Table 3.

Table 3.DC-200 cyclotron - main parameters and goals

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

Main technical parameters of the DC-200 cyclotron are presented in Table 4.

Table 4. Main parameters of the DC-200

Injecting beam potential	Up to 100 kV
Pole diameter	4000 mm
A/Z range of accelerated ions	4÷7
Magnetic field	0.65÷1.27 T
K factor	220
Gap between plugs	320 mm
Valley/hill gap	400/300 mm/mm
Magnet weight	915 t
Magnet power	270 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

Working diagram of DC-200 presented at Fig.8. New resources and research opportunities of the Lab are presented in Table 5.

Table 5: New resources and research opportunities.

	U-400M A/Z=3÷3.6,E=34÷50MeV/u A/Z=8÷10,E=4.5÷9 MeV/u		U-400R A/Z=4÷12, E=0.8÷27 MeV/u		DC-200 A/Z=4÷7, E=3.6÷8 MeV/u		
beam	E/A (MeV)	intensity	E/A (MeV)	intensity	E/A (MeV)	intensity	Physics
light RIB 6He 8He 24Ne			 2.8 ÷ 14.4 1.6 ÷ 8 0.8 ÷ 20	 10^8 10^5 ?			structure of light exotic nuclei, reactions, sub-barrier fusion, astrophysics
6<A<40 7Li 18O 40Ar	 35 33 40	 6×10^{13} 10^{13} 10^{12}	 2÷17 2÷19 0.8÷8	 1×10^{14} 1×10^{14} 3×10^{13}	 4÷6 4÷8 4÷8	 1×10^{14} 1×10^{14} 6×10^{13}	production of light RIB, fragmentation, transfer, structure of light exotic nuclei
A ~ 60 48Ca 54Cr 58Fe	 5 5 5	 6×10^{12} 3×10^{12} 3×10^{12}	 4÷7 4÷7 4÷7	 2×10^{13} 6×10^{12} 6×10^{12}	 4÷8 4÷8 4÷8	 6×10^{13} 4×10^{13} 4×10^{13}	superheavy elements, spectroscopy of SHE, fusion-fission, quasi-fission, etc.
A ~ 150 124Sn 136Xe	 5 5	 2×10^{11} 4×10^{11}	 3÷7 3÷7	 2×10^{12} 3×10^{12}	 4÷7 4÷7	 2×10^{12} 2×10^{13}	DIP, multi-nucleon transfer, new neutron rich nuclei, shell effects
A ~ 240 238U	 7	 2×10^{10}	 3÷7	 10^{11}	 4÷7	 10^{11}	neutron-rich SHE, new heavy isotopes, ternary fission, super strong electric fields, $e^+ e^-$ formation
	2011		2012		2014		

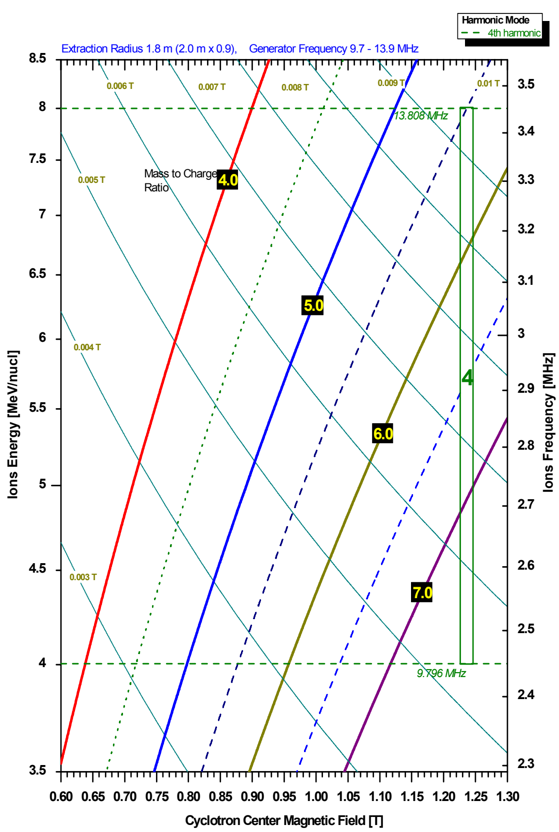

Figure 8: Working diagram of DC-200.

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