DEVELOPMENT OF FLNR JINR HEAVY ION ACCELERATOR COMPLEX IN THE NEXT 7 YEARS. NEW DC-280 CYCLOTRON PROJECT.

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Abstract

At present, four isochronous cyclotrons: U-400, U-400M, U-200 and IC-100 are in operation at the JINR FLNR. Total operation time is more then 10,000 hours per year. The U400M is a primary beam generator and U400 is used as a postaccelerator in RIB (DRIBs) experiments to produce and accelerate exotic nuclides such as ^{6}He, ^{8}He etc [1],[2],[3],[5],[6].

One of the basic scientific programs which are carried out in the FLNR is synthesis of new elements which requires intensive beams of heavy ions. Now U-400 is capable of providing long term experiments on Ca^{48} beams with an intensity of 1 pμA [1].

To enhance the efficiency of experiments for the next 7 years it is necessary to obtain accelerated ion beams with the following parameters:

Ion energy	4÷8 MeV/n
Ion masses	10÷238
Beam intensity (up to A=50)	10 pμA
Beam emittance	less 30 π mm·mrad

These parameters have formed the base for the new cyclotron DC-280.

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. An axial injection system with two bunchers (sinusoidal and linear) and a spiral inflector was created to inject ions in the cyclotron. Since 1997 the total operation time of the U400 amounts to 80,000 hours. About 66% of the total time was used for acceleration of $^{48}Ca^{5+,6+}$ ions for synthesis of new super-heavy elements. Within the mentioned period elements with numbers 113, 114, 115, 116, 117, 118 were synthesized. Chemical properties of the 112th element were studied. The ^{48}Ca beam intensity on the target was $8\cdot10^{12}$ pps (1.2 pμA) at 0.4 mg/hour ^{48}Ca substance consumption. The efficiency of the ^{48}Ca beam extraction by the stripping foil was on the level of 40% due to charge spread. The purpose of cyclotron modernization:

- increasing ^{48}Ca, ^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}N, beam intensity on the target up to 2.5÷3 pμA;
- providing smooth energy variation of ions by a factor of 5 through magnetic field variation in the range of (0.8 - 1.8) T instead of the currently provided 1.93÷2.1 T;
- 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.

The project of cyclotron modernization aims at changing the axial injection system, magnetic structure, vacuum system, RF system, power supply system, beam diagnostic system and in addition to that an electrostatic deflector will be instilled. The main parameters of U-400 and U-400R are compared in Table 1.

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

The scheme of ion beam extraction from U-400R by stripping foils in two opposite directions A and B and by deflector in direction A is presented in Fig.1.

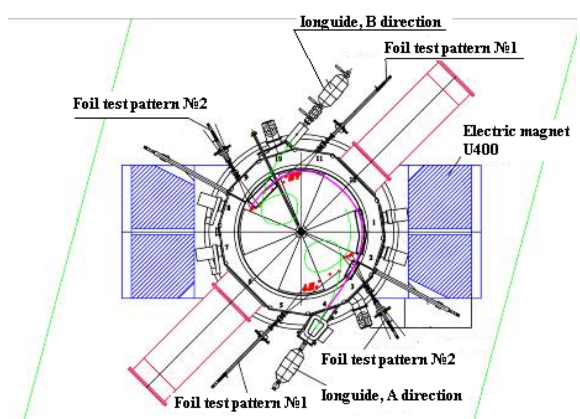

Figure 1: The scheme of beam extraction from U400R.

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 the cyclotron by a stripping foil with a stripping ratio Z_2/Z_1= 1.4÷1.8. This determines the extracted beam energy range of 30 to 50 MeV/n. The light ion beams from U-400M are used for radioactive beams production. The intensity of light ion beams such as ^{7}Li or ^{11}B on the targets is $(3÷5)10^{13}$ pps. Tritium ions are accelerated as a $(DT)^{1+}$ molecule with an intensity of $6·10^{10}$ pps and an energy of 18 MeV/n. For generation of $(DT)^{1+}$ ions a special RF ion source is used. In 2008 the U-400M possibilities were widened to include acceleration of ion beams with a mass/charge ratio of 5÷10 with energies of 4.5÷20 MeV/n. This low energy ion beams (such as ^{48}Ca) will be used for synthesis and study of new elements.

A scheme of low and high energy beam extraction from U-400M in two opposite direction are presented in Fig.2.

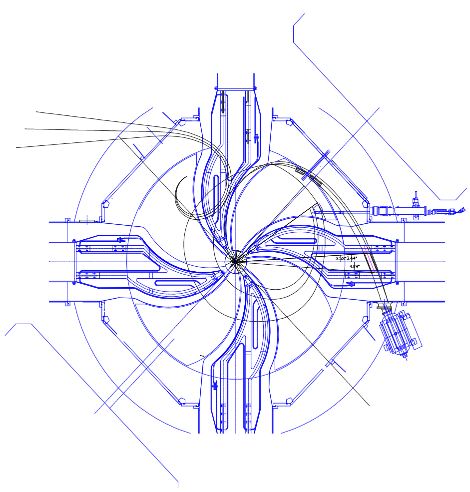

Figure 2:A scheme of beam extraction from U400M.

DRIBS PROJECT

The DRIBs (Dubna RIB) project has been running at the Laboratory since 2002 [3]. The primary ion beams (^{7}Li or ^{11}B) from U-400M used for production of nuclides such as ^{6}He, ^{8}He in the target (Be or C). The produced radionuclides come by diffusion from a hot catcher into the ECR (2.45 GHz) ion source, where they are ionized. After separation, radioactive ion beams extracted from the ECR are transported through 120 m transport line into the U-400 for acceleration. At present, $^6He^{2+}$ ions with an energy of 11 MeV/n are available for physical experiments. DRIBs possibilities will be widened after carrying out the U-400 modernization.

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

Six room temperature ECR sources of 14 GHz have been developed at the Lab [4] for the last 15 years. Two superconducting ECRs (DECRIS-SC) have been designed for IC-100 and U400M cyclotrons. Three 2.45 GHz ECRs with permanent magnets have been created at the Lab specifically for generation of single-charge stable and radioactive ions. Effective axial injection systems have been developed to inject the beam for acceleration into the cyclotron. The U-400R axial injection channel is presented in Fig.3 as an example of the axial injection system for FLNR cyclotrons. The results of the capture efficiency for $^{40}Ar^{4+}$ are presented in Fig.4. Decreasing bunching effect with increasing intensity can be explained by the space-charge effect. We are planning to increase the injection voltage from 13÷20 up to 50÷100 kV, it means shifting the space charge limits by factor 6÷20.

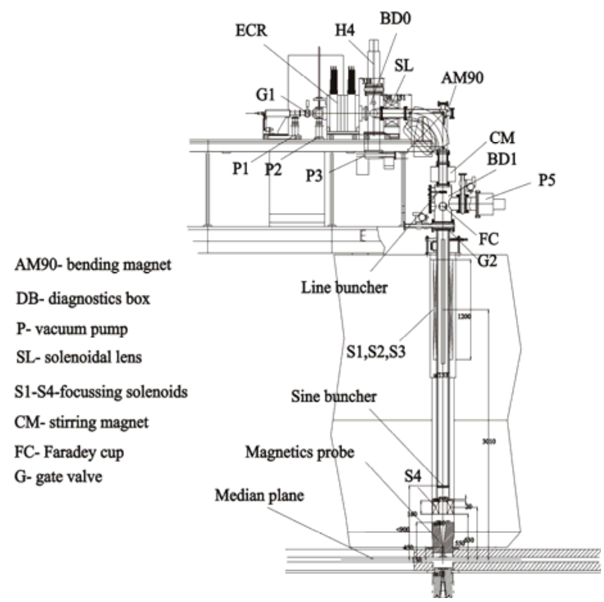

Figure 3: Scheme of the U-400R axial injection system.

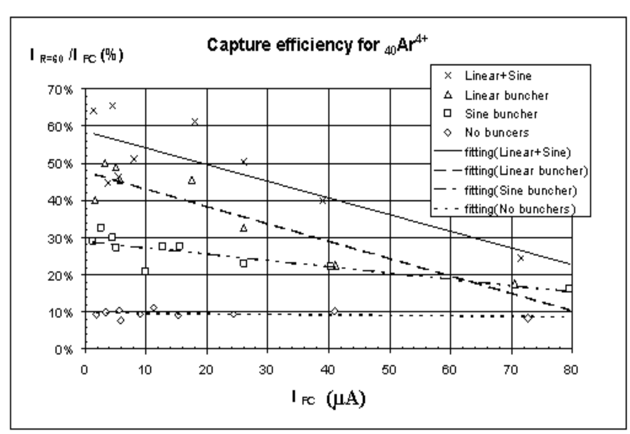

Figure 4:The efficiency of beam capture into acceleration as a function of injecting beam current and bunching effect.

NEW FLNR ACCELERATOR – CYCLOTRON DC-280

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

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

The basic technical solutions which have formed the base of the DC-280 cyclotron project are shown in Table 2.

Table 2: DC-280 Cyclotron - Basic Technical Solutions

	Parameter DC280	Goals
1.	High injecting beam energy (up to 100 kV)	Shift of space charge limits by a factor of 30
2.	High gap in the centre	Space for a long spiral inflector
3.	Low magnetic field	Large starting radius. Good orbit separation. Low deflector voltage
4.	High acceleration rate	Good orbit separation.
5.	Flat-top system	High capture. Single orbit extraction. Beam quality.

The new cyclotron complex provides an opportunity of carrying out physical and chemical research using radioactive targets, such as U, Pu, Am, Cm, Bk. The layout of the cyclotron and physical installations in a new building is shown in Fig. 5.

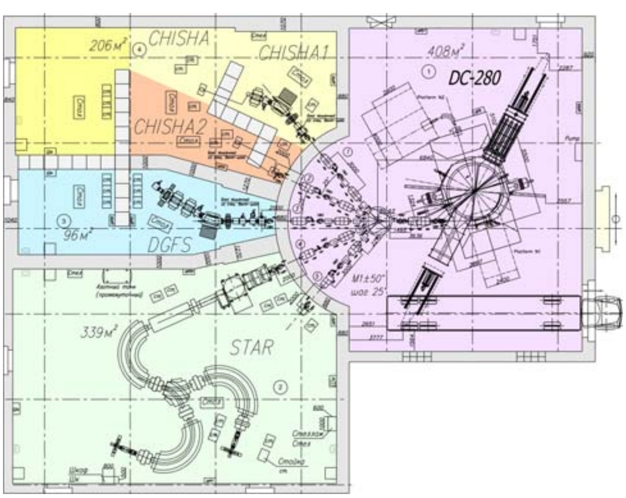

Figure 5: The layout of the DC-280 cyclotron complex.

Main technical parameters of the DC-280 cyclotron are presented in Table 3.

Table 3: Main Parameters of The DC-280

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 orbit separation	10 mm
Radial beam bunch size	3 mm
Efficiency of beam transfer	60%
Total accelerating potential	up to ~ 40 MV

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