STATUS REPORT OF THE U400 CYCLOTRON AT THE FLNR JINR

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Abstract

The isochronous U400 cyclotron has been constructed and put into operation since 1978. The cyclotron produces ion beams of atomic masses from 4 to 209 at maximum energy up to 26 MeV/nucleon. Since 1996, the U400 axial injection system with the ECR4M ion source has been constructed and put into operation. To increase output intensity, the double buncher system (Sine and Line types) was installed in the injection channel in 1997-1998. Since 1998, the annual operation of the U400 has been more than 4800 hours. The main time was spent to accelerate $_{48}Ca^{5+}$ ions for the purpose of synthesis the new super heavy elements. The modernization of the axial injection system was done in 2002 with the aim of further increasing the U400 output intensity. To extract the accelerated ions from the U400, the stripping foils method is used. At present time, the average intensity of $_{48}Ca^{18+}$ ions before the physical target is about 1.4 pμA.

Figure 1: The U400 overview

INTRODUCTION

The isochronous U400 cyclotron (Figure 1) has been in operation since 1978. [1]. The main parameters of the U400 are presented in Tab.1 (U400). Until 1996, the PIG-ion source has been used for ion production. Since 1996, the ECR-4M ion source (made in Ganil, France) has been installed at the U400. The axial injection system was created to inject ions from the ECR-4M to the U400 center [2]. To increase the capture into acceleration efficiency, the sine and line bunchers were installed into the axial injection canal [3]. The given modernization allows us to carry out experiments with ions of the rare $_{48}Ca$ isotope. In 2002 the modernization of the horizontal part of injection channel has been carried out.

Table 1	**U400**
Parameters	**Value/Name**
Magnet weight	2100 t
Electrical power of magnet power supply system	850 kW
The magnetic field level in the magnet center	1.93÷2.1 T
The hill angular width at the external radius	42°
The hill gap at the external radius	42 mm
The valley gap	300 mm
The number of trim coils	8, radial 1, azimutal
The number of dees	2
The dee voltage (amplitude)	80 kV
The A/Z range	5÷12
The frequency range	5.42÷12.2 MHz
Harmonic modes	2
The ultimate extraction radius	1.72 m
K- factor	305÷625
Vacuum level	$(1\div5)\cdot10^{-7}$ Torr
Ion extraction method	Stripping foil
Number of directions for ion extraction	2

THE U400 OPERATION IN 1997-2003

The U400 has 12 experimental channels, the main experimental setups are [4]: GFRS- gas filled recoil separator, VASILISSA- the electrostatic separator, CORSET/DEMON- the setup for study of fusion-fission reactions, U600- the setup for production the track membranes, MSP144- the magnetic separator.

The diagram of using the U400 beams in 1997-2003 is shown in Figure 2. In 1998-2003, the U400 was mainly used for experiments with $_{48}Ca^{5+}$ ions for the purpose of synthesis the new super heavy elements.

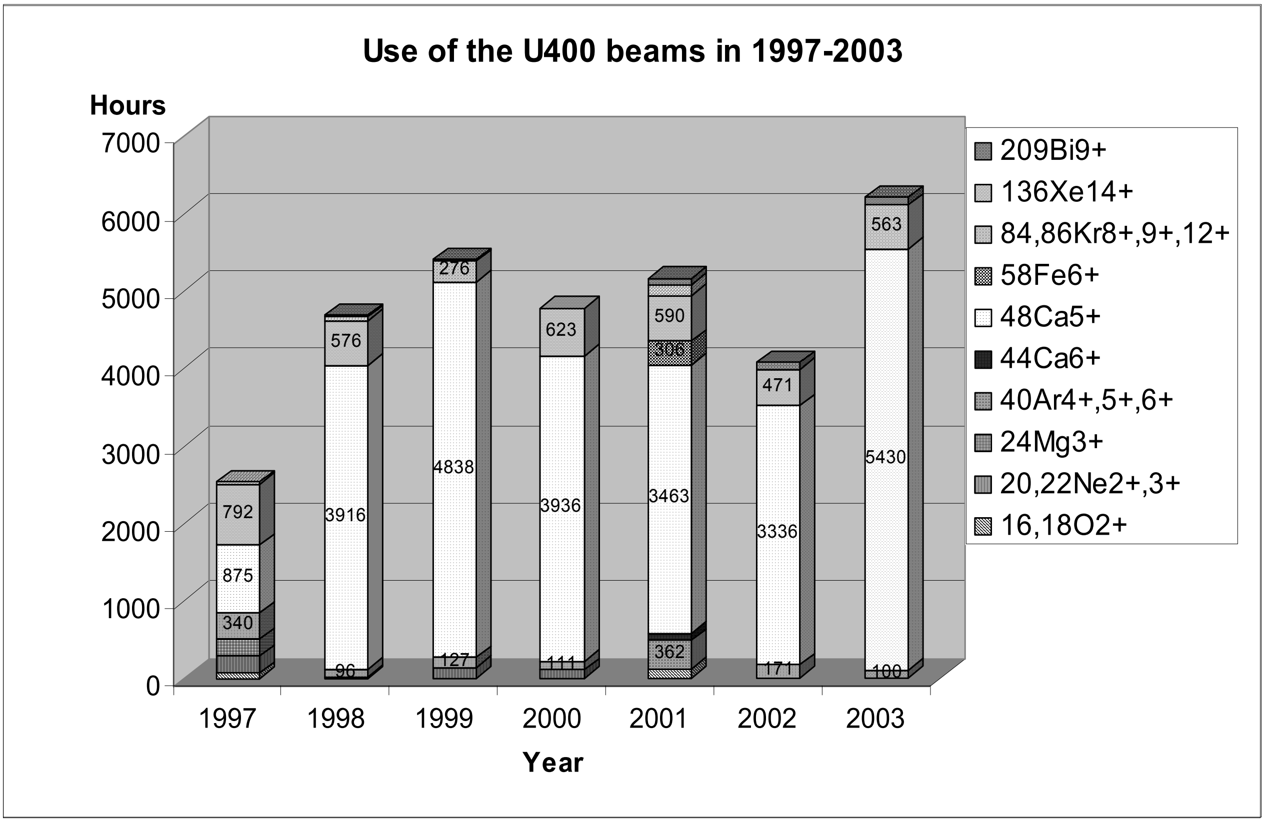

Figure 2: Use of the U400 beams in 1997-2003

The average intensity of $_{48}Ca^{+5}$ ions at the U400 extraction radius is about 4.3 pμA (21.5 μA). The typical $_{48}Ca^{+5}$ ion energy is 250÷270 MeV. In 2003, the TOF method [5] with two capacitive pickup electrodes was realized to measure the extracted ion energy and to adjust the ion acceleration regime.

The energy of extracted ions received by means of changing the charge of accelerated particle (rough method) and by means of changing the stripping foil position, or changing the RF frequency and the magnetic field level (fluent method). To realize the $_{48}Ca^{+5}$ ion extraction with energies more than 260 MeV with keeping the beam intensity, the special magnetic channel has been constructed and situated at the hill outer edge. The aim of the channel is addition focusing of the extracted ion beam at the second turn after the stripping foil, when the foil is moved to the big radius.

In experiments on synthesis the new super heavy elements, the average intensity of the $_{48}Ca^{+18}$ before the experimental target is about 1.4 pμA (25μA). The main $_{48}Ca^{+18}$ line of the ion spectrum after the stripping foil is mainly used for the physical experiments. The results of $_{48}Ca$ acceleration in 2003 presented in Figure 3. In the regimes, the average consumption of solid $_{48}Ca$ is about 0.8 mg/hour.

In 2000÷2002 the first stage of the DRIBs project [6] has been realized at the U400-U400M accelerator complex. The experiments with radioactive $_{6}He$ ions have been started since the end of 2001. In the experiments the U400 intended to accelerate the secondary $_{6}He^{+}$ ions from the energy of 3.5 keV/amu to 5÷20 MeV/amu.

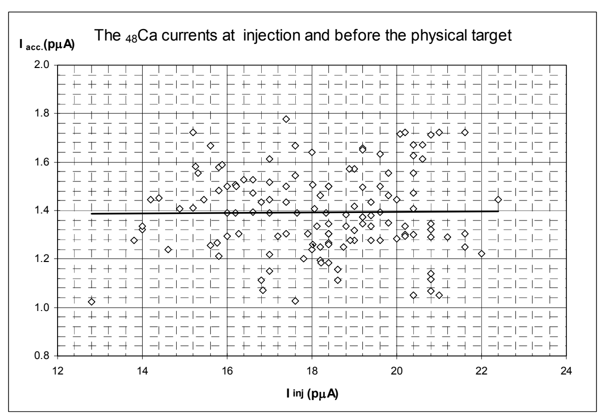

Figure 3: The dependence of $_{48}Ca$ ions current before the physical target (I_{acc}) on injected one (I_{inj}) in 2003.

DEVELOPMENT OF THE U400 AXIAL INJECTION SYSTEM

The essential modernization of the U400 axial injection in 2002 included sharp shortening the horizontal part of the injection canal, as it was proposed in [7]. The view of the modernized injection is shown in Figure 4. The first horizontal bending magnet was removed together with 8.5 m of the line. As the result, the distance from the ECR to the AM90 banding magnet became equal to 730 mm.

The axis of the ECR- AM90 was situated in parallel to the main U400 magnet axis with the aim to symmetry the fringing magnetic field around the ECR- AM90 axis. The fringing field level in the area of ECR extraction became higher- about 300 Gauss, instead 80 Gauss before modernization. To lover the field level a special magnetic screen around the area was created. The box-shape screen was made from the electrotechnical steel plates of 0.8 mm (inner screen) and the carbon steel plates of 16 mm (outer screen). The screen allows us to decrease in the area the fringing magnetic field level to ~100 Gs.

The sine buncher was lowered to 360 mm toward to he median plane to decrease the influence of the beam space charge, as it was demonstrated by numerical calculations. The modernization gave us possibility to increase the ${}_{48}Ca^{+5}$ current into the injection line from 40÷60 to 80÷100 μA at the similar capture in acceleration efficiency (Figure 5). Correspondingly, the average output ${}_{48}Ca^{+18}$ ion current was increased from 15 to 25 μA.

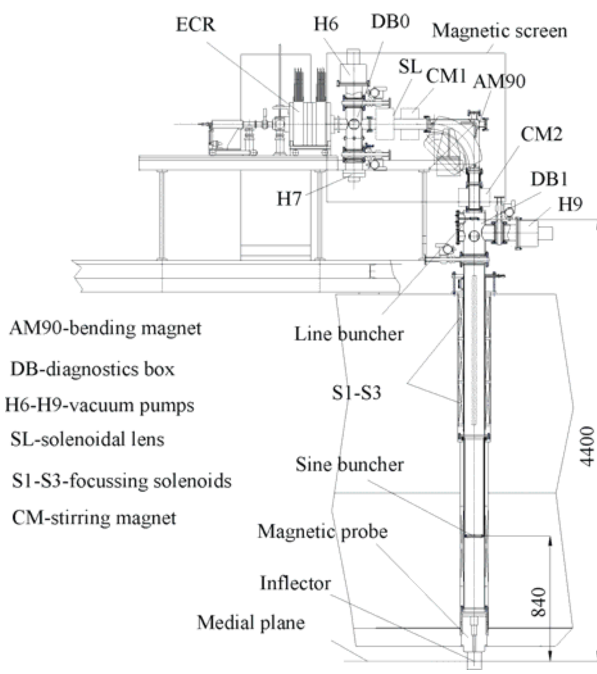

Figure 4: The sketch of the U400 modernized injection

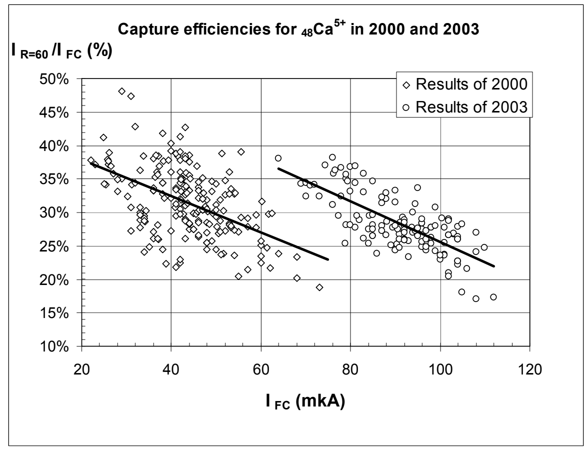

Figure 5: The ${}_{48}Ca^{+5}$ ion capture in acceleration efficiencies before (2000) and after (2003) the injection modernization

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