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PECULIARITIES OF PRODUCING ^{48}CA, ^{48}TI, ^{52}CR BEAMS AT THE DC-280 CYCLOTRON

K.B. Gikal†, S. L. Bogomolov, I. A. Ivanenko, N. Yu. Kazarinov, V. I. Lisov, A. A. Protasov, D.K. Pugachev, V.A. Semin, Joint Institute for Nuclear Research, Dubna, Russia

Abstract

The main task of the new accelerator is implementation of the long-term program of researches on the SHE Factory aimed on synthesis of new elements (Z≥119) and detailed studying of nuclear- physical and chemical properties of earlier opened 112-118 ones. The first beam of $^{84}Kr^{14+}$ ions was accelerated in the DC-280 on December 26, 2018 and extracted to the ion transport channel on January 17, 2019. In March 2019, beams of accelerated $^{84}Kr^{+14}$ ions with intensity of 1.36 pμA and $^{12}C^{+2}$ ions with and intensity of 10 pμA were extracted from the DC-280 to the beam transport channel with energy about 5.8 MeV/nucleon. In 2020-2021 years, beams of $^{48}Ca^{7+,10+}$ ions with intensity up to 10,6 pμA were accelerated and 7,1 pμA were extracted from the DC-280 to the beam transport channel with energy in range 4,51 - 5,29 MeV/nucleon. In 2021 year, beams of accelerated $^{52}Cr^{10+}$ ions with intensity up to 2,6 pμA were extracted from the DC-280 to the beam transport channel with energy 5,05 MeV/nucleon and beams of $^{48}Ti^{7+,10+}$ with intensity up to 1 pμA with energy 4,94 MeV/nucleon.

DC-280 DESCRIPTION

DC-280 is the accelerated ions source for experiments on synthesis of super heavy elements [1]. It is part of Super Heavy Element (SHE) Factory which was created in FLNR in JINR. It is isochronous cyclotron designed for acceleration of ion with mass to charge ratio from 4.5 to 8 to energy from 4 to 8 MeV/n. Main parameters design and achieved present in Table 1.

Table 1: Main Parametrs of DC-280 Cyclotron

parameters	design	achieved
Injecting beam energy	Up to 80 keV/Z	38,04 – 72,89 keV/Z
A/Z	4÷7.5	4,4($^{40}Ar^{+7}$) ÷6,9($^{48}Ca^{+7}$)
Energy	4÷8 MeV/n	4,01 – 7 MeV/n
Ion (for DECRIS-PM)	4-136	12 ($^{12}C^{+2}$) – 84 ($^{84}Kr^{+14}$)
Intensity (A~50)	>10 pμA	10,4 pμA ($^{40}Ar^{+7}$);
Magnetic field level	0.6÷1.3 T	0.8÷1.23 T
K factor		280
Dee voltage	2x130 kV	130 kV
Power of RF generator	2x30 kW	
Accelerator efficiency	>50%	51,9 % ($^{48}Ca^{+10}$ 5 pμA)

Electron Cyclotron Resonance (ECR) source DECRIS-PM is used for production of ions [2, 3]. It has magnetic structure from permanent magnets. It placed on high voltage platform with work voltage up 70 kV for increasing efficiency of initial beam transport and capture to acceleration [4].

In the DC-280 cyclotron, a spiral inflector is used to rotate the beam from the vertical direction of axial injection into the median plane. Both the cyclotron magnetic field and own electrostatic field of inflector rote the ion beam by spiral. To ensure optimal injection conditions for all range of accelerated ions, two versions of the inflector type A and type B with two magnetic radii of 7.5 and 9.2 cm are used.

Inflectors with magnetic radii of 7.5 cm and 9.2 cm for the range of accelerated ions with A / Z from 4 to 7 is shown in Fig. 1.

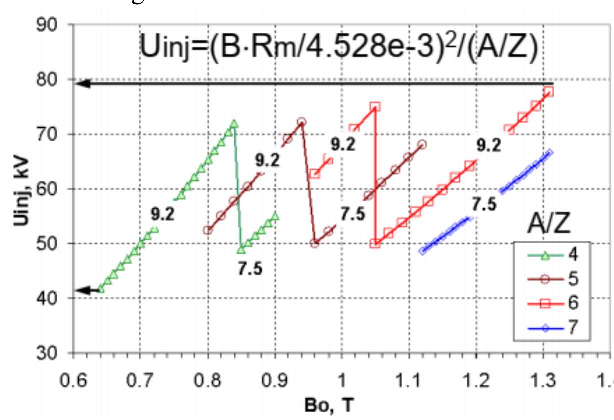

Figure 1: Dependence of the magnetic field on the injection voltage for the inflector A and B.

During experiments both of them were successful tested. There is electrostatic quadrupole lens in central part of cyclotron. Polyharmonic buncher is used for increasing of ions capture to acceleration [4].

Accelerated beam is extracted from cyclotron by electrostatic deflector. It works in conjunction with magnetic channel. Deflector length is 1.3 meters. The work electric field strength in gap between electrodes is up 90 kV/cm [1].

Extracted beam is delivered by transport channel to experimental setups [5]. There are 5 channels connected with 3 isolated halls.

On 26 December 2018, the first accelerated beam was got inside of DC-280 cyclotron [1, 6]. On January 2019, accelerated beam was extracted from cyclotron to transport channel. On September, the new experimental facility Dubna Gas Filled Separator 2 was mounted, and test with accelerator beam was started [7]. On December of 2019, work with beam of ^{48}Ca was initiated. On November 2020, the first experiment on production of ^{115}Mc was started.

† kbgikal@jinr.ru

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The cyclotron has worked 9350 hours during three years. Different mode of work with different ions and energy were explored. The work diagram of DC-280 cyclotron with marks of tested regimes is presented on Fig. 2. The cyclotron has shown reliable and highly effective work. The control and extraction systems were optimized for improving of efficiency and reliable of accelerator.

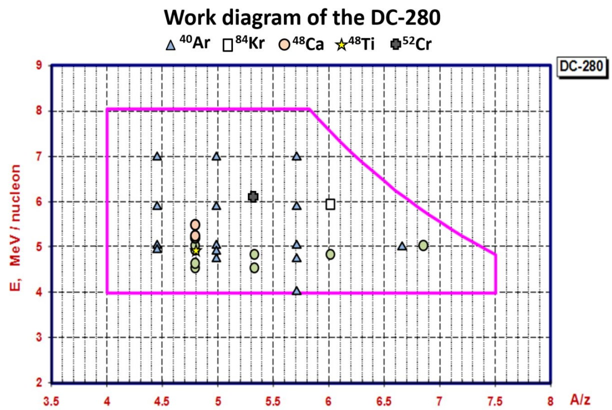

Figure 2: DC-280 work diagram with mark of test modes.

RESULTS

Producing of ^{48}Ca

The six heaviest chemical elements with atomic numbers 113 to 118 that fill the 7th row of Mendeleev's Periodic Table were synthesized in reactions of ^{48}Ca ions with actinide targets in the experimental studies carried out over the recent years. Over 50 new isotopes of elements 104 to 118 with maximum neutron excess were for the first time produced and their decay properties were determined in these investigations. The new isotopes considerably filled up the Chart of the Nuclides and expanded it up to Z = 118 and N = 177 superheavy elements. Fundamental conclusions of the modern theory concerning the limits of existence of nuclear matter have for the first time received experimental confirmation.

The first test experiments on DC-280, were on ^{48}Ca beams with actinide targets.

From the spectrum obtained from the ECR source, ions with charge +7, +10 don't have other ions with the same A / Z. The accelerated beam of $^{48}Ca^{+10}$ with intensity is about 7.1 pμA and $^{48}Ca^{+7}$ with intensity is about 5 pμA were obtained. Due to the lower consumption, $^{48}Ca^{+10}$ was chosen for experiments on the synthesis of superheavy elements.

The intensity of the injected charged particle beam affects its passage through the injection channel and its further capture into acceleration. At the same time, this effect is not observed for the passage along the horizontal part of the axial injection, and on the vertical, with an increase in the intensity from the ion source to 240 μA, we observed a deterioration of the beam transmission through the spherical deflector (Bender) from 94.22% at 150 μA to 79% at 240 μA, and the capture in acceleration decreased from 72.41% to 64.63%, respectively. This may be due to an increase in the space charge of the beam or the tuning of the accelerator as a whole. The efficiency of capture into acceleration at different intensities from an ECR source is shown in Fig. 3.

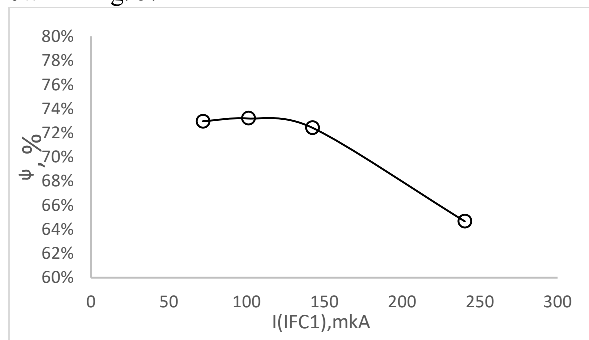

Figure 3: The efficiency of capture into acceleration.

The efficiency of transmission of the $^{48}Ca^{10+}$ beam at different initial currents from the DECRIS-PM ion source is shown in Fig. 4.

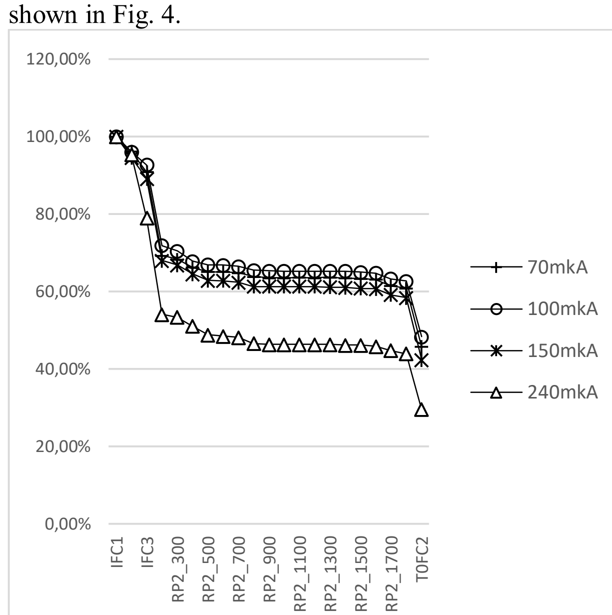

Figure 4: The efficiency of transmission of the $^{48}Ca^{10+}$.

The total efficiency of transporting the ion beam of $^{48}Ca^{10+}$ from the vertical part of the injection to the transport channel is about 50%.

At the moment, the beam is given to the DGFRS-2 experimental setup for a series of test experiments. The efficiency of passing through the transport channel is about 90%.

Producing of ^{48}Ti

For further experiments for super heavy elements will be needed beams of accelerated ions of ^{50}Ti and ^{54}Cr. For development of technology, we have accelerated their naturally occurring isotopes ^{48}Ti and ^{52}Cr.

From the spectrum obtained from the ECR source, the ions of ^{48}Ti with a charge of +7, +10 do not have other ions with the same A / Z and we can use them in experiments on the synthesis of SHE.

The beam of $^{48}Ti^{+10}$ from ECR source with intensity is about 2.5 pμA and $^{48}Ti^{+7}$ with intensity is about 3.14 pμA were obtained and accelerated with intensity 1,0 pμA and 0,93 pμA respectively.

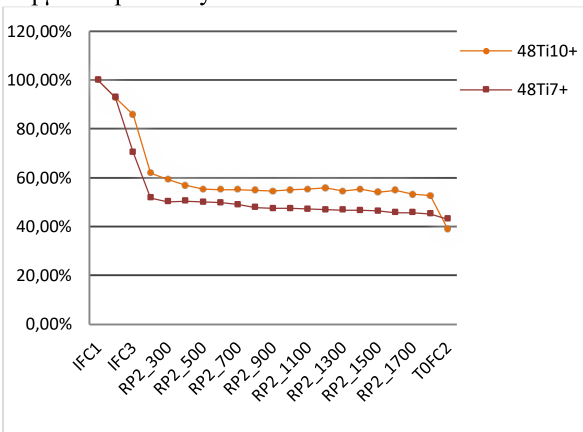

Figure 5: The efficiency of transmission of the $^{48}Ti^{10+,7+}$.

As we can see from Fig. 5, the total efficiency of transporting the ion beam of $^{48}Ti^{10+,7+}$ from the vertical part of the injection to the transport channel is about 40-45%.

Producing of ^{52}Cr

From the spectrum obtained from the ECR source, the ions of ^{52}Cr with a charge of +7, +8, +10 do not contain other ions with the same A / Z, but we cannot accelerate ions with a charge of +7 and +8 to the energy required for the experiment.

The beam of $^{52}Cr^{+10}$ from ECR source with intensity is about 6,3 pμA and accelerated with intensity 2,6 pμA.

We compared the passage of the beam through the cyclotron for different operating modes of the ECR source.

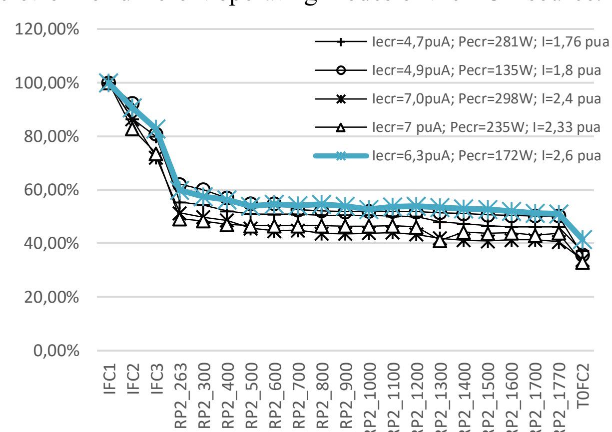

Figure 6: Comparison of normalized ^{52}Cr beam intensity in different points of cyclotron for different beam intensities.

The comparison of normalized intensity distribution for ^{52}Cr ion beam in acceleration process is presented on Fig. 6. There are data for different intensities of beam and different ECR source regimes.

We can see, that efficiency of acceleration worsen then we increase power input to ECR source [8].

The total efficiency of transporting the ion beam of $^{52}Cr^{10+}$ from the vertical part of the injection to the transport channel is about 50%.

CONCLUSION

The beams of $^{48}Ca^{7+,10+}$,$^{48}Ti^{+7,+10}$ and $^{52}Cr^{10+}$ were accelerated and extracted from the DC-280 to the beam transport channel. Maximum intensity of accelerated ^{48}Ca ion beam is 10,6 pμA and 7,1 pμA were extracted. The efficiency of acceleration for ^{48}Ca is about 50 %. The beam is given to the DGFRS-2 experimental setup for a series of test experiments.

The beams of accelerated $^{52}Cr^{10+}$ and $^{48}Ti^{7+,10+}$ ions with intensity 2,6 pμA and 1 pμA respectively were extracted from the DC-280 to the beam transport channel. The efficiency of acceleration for $^{52}Cr^{10+}$ and $^{48}Ti^{7+,10+}$ in range 40-50 %. Carried out only the first experiments dedicated to the production of $^{52}Cr^{10+}$ and $^{48}Ti^{7+,10+}$. At the first experiments, for the ion beam of ^{48}Ti and ^{52}Cr the intensity is limited by ion current from ECR source. We work to improve of the method of ion production and optimize the ECR source work mode.

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