Status of the SuperHeavy Element Factory

V.Semin and V. Utyonkov

- **Cyclotron DC280**

The new DC280 cyclotron for the Factory of Super Heavy Elements (SHE Factory) was developed and created at the FLNR JINR. The cyclotron has to provide intensities up to 10 pmkA for ions with atomic masses over 50 to solve new problems on synthesis of super heavy elements. The development of the DC280 was started in 2010, most of the equipment was manufactured by 2015, in parallel with construction of the new experimental building - the SHE Factory, where the DC280 was planned to be located. Since 2016 to 2019 installation and adjusting of the cyclotron have been done. The high voltage (HV) axial injection system with the ECR ion source having a permanent magnet structure DECRIS-PM was created and successfully tested for the DC280 cyclotron. The first beam of $^{84}Kr^{+14}$ ions was accelerated on December 26, 2018 and extracted to the beam transport channel on January 17, 2019. Experiments on acceleration of ^{84}Kr, ^{12}C, ^{40}Ar and ^{48}Ca ions have been carried out in 2019. At the commissioning stage from January 2019 to April 2019, beams of accelerated $^{84}Kr^{+14}$ ions with intensity of 1.44 pmkA were extracted from the DC280 to the beam transport channel with energy of 5.9 MeV/nucleon (Table 1). Then, $^{40}Ar^{+6,+7,+8}$ ions were accelerated in the DC280 and extracted to the beam transport channel with energies from 5 to 7 MeV/nucleon. The maximal intensity of the accelerated beams in CW mode of operation for $^{40}Ar^{+7}$ ions with energy of 5.9 MeV/nucleon was 6.3 pμA. With using the electrostatic beam chopper at beam duty cycle of 25% to avoid possible damaging of the deflector we observed extracted current of $^{40}Ar^{+7}$ ions which was equivalent to 9.2 pmkA. For today, the maximal extracted intensity for $^{40}Ar^{+7}$ ions with energy of 4.88 MeV/nucleon at acceleration in CW mode is 10.43 pmkA. In November ions of $^{48}Ca^{+7,+8,+9,+10}$ were accelerated up to energy of 4.8 - 5 MeV/nucleon. For today, the maximal extracted intensity of 5,1 pmkA was received for $^{48}Ca^{+7}$ ions.

Table 1. Ion beam intensities at acceleration in the DC280

		Intensities (pmkA)				
		HV injection		Cyclotron		Transport line
Ion	**Energy (MeV/nucleon)**	**After HV platform**	**Vertical channel**	**At radius of R=0.4 m**	**At radius of R=1.77 m**	**At third Faraday cup**
$^{40}Ar^{+7}$	5.9	14,3	12,9	9	7,7	6,3
$^{40}Ar^{+7}$	4.88	28,67	24,67	17,06	14,24	10,43
$^{48}Ca^{+7}$	5	13,8*	9,8	6,93	6,12	5,1
$^{84}Kr^{+14}$	5.9	3,09	2,8	1,68	1,56	1,44

* together with attended ions: $^{40}Ca^{+6}$, $^{4}N^{+2}$

The DC280 cyclotron shows high values of ion capture into acceleration (60-70%) with using the polyharmonic buncher (3 harmonics) for injected currents of 3,1-28.7 pmkA (Table 2). The total acceleration efficiency is 36.4% - 46.6%. The efficiency allows us to carry out experiments with rare isotopes such as ^{48}Ca, ^{50}Ti at low material consumption.

Table 2. Efficiencies of ion acceleration in the DC280

		Efficiencies				
Ion	**Energy (MeV/nucleon)**	**Transmission through HV injection**	**Ion capture in DC-280 center**	**Transmission at acceleration in DC280**	**Extraction from DC280**	**Total (from ECR to transport line)**
$^{40}Ar^{+7}$	5.9	90,2%	69,8%	85,6%	81,8%	44,0%
$^{40}Ar^{+7}$	4.88	86,0%	69,1%	83,5%	73,2%	36,4%
$^{48}Ca^{+7}$	5	~90%	70,9%	88,2%	83,4%	46,9%
$^{84}Kr^{+14}$	5.9	90,6%	60,0%	92,9%	92,3%	46,6%

The first beam of $^{40}Ar^{+6}$ ions was transported to the new gas-filled separator GFS-II beam stopper on 09.09.2019. Beam transmission efficiency was more than 90%. The first beam of $^{48}Ca^{+10}$ ions was transported to the GFS-II beam stopper on 21.11.2019. Beam intensities for the first tests of the GFS-II are less than 1 pmkA.

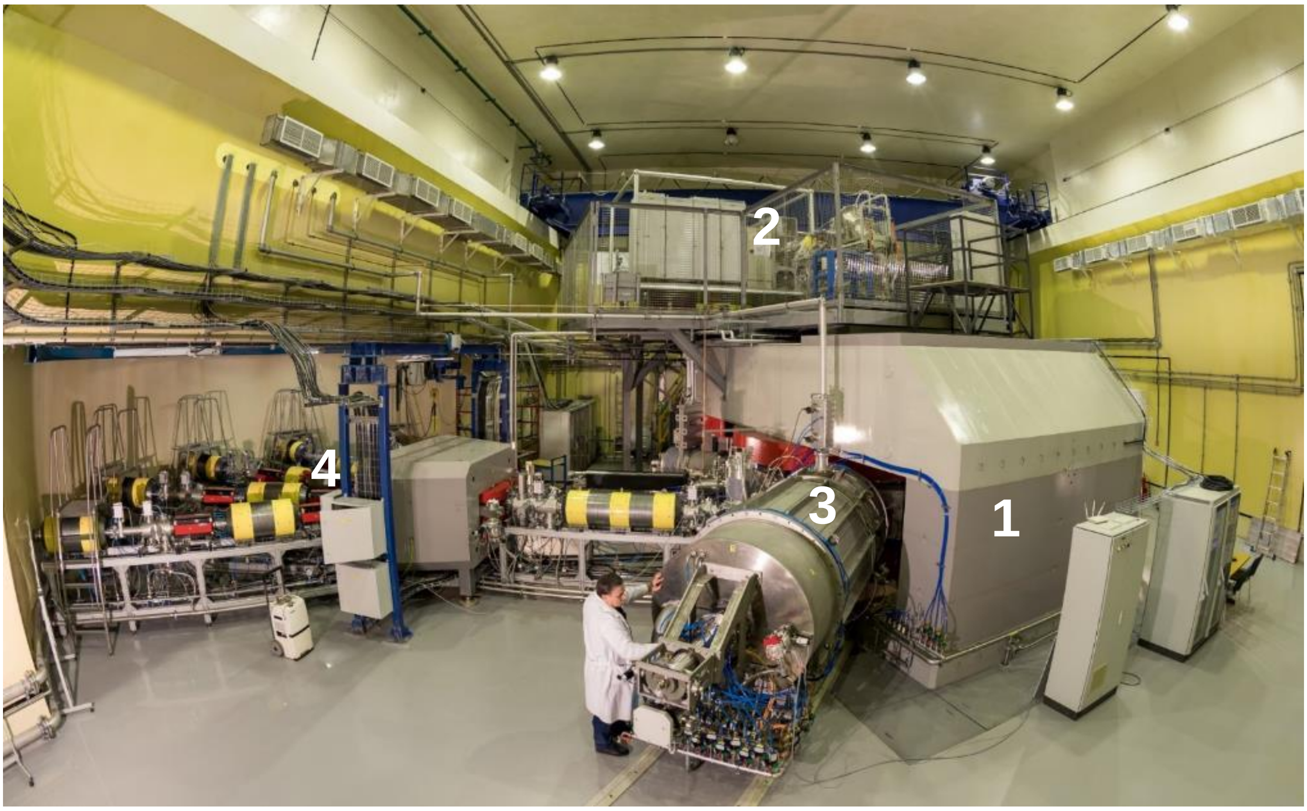

Fig. 1. DC280 cyclotron, where: 1- main magnet, 2-HV injection system, 3-RF resonator, 4- five beam lines.

- **Gas-filled recoil separator (DGFRS-2)**

During 2019, the work on commissioning of all the units of the separator DGFRS-2 (Fig. 2) was completed. Optical elements of the separator are configured as $Q_{1,v}$ $D_{1,h}$ $Q_{2,h}$ $Q_{3,v}$ D_2. Quadrupole lens $Q_{1,v}$ focuses the recoil nuclei that are knocked out of the target vertically to increase their transmission through the gap of dipole magnet $D_{1,h}$, where the products of the complete-fusion reactions (ERs) are separated from the main part of the beam particles and background reaction products. The ERs are further focused by the two quadrupole lenses $Q_{2,h}$ and $Q_{3,v}$. The dipole magnet D_2 is used for additional separation of ERs from the background particles.

All the beam line elements are mounted ahead of the separator. Components have been developed and installed for control of the vacuum systems of the beam line and separator, for measuring the parameters of the ion beam, for supplying gas in the separator, for control of the magnetic elements, for control and blocking of the elements of vacuum systems.

The first test experiments were carried out in order to determine the optimum parameters of the DGFRS-2 using alpha particles and products of the reaction ^{nat}Yb(^{40}Ar,*xn*)$^{207\text{-}212}$Ra. Experiments are launched with the ^{48}Ca beam and targets of ^{nat}Yb, ^{174}Yb, ^{170}Er, and ^{206}Pb. The results of these experiments and conclusions made will be reported.

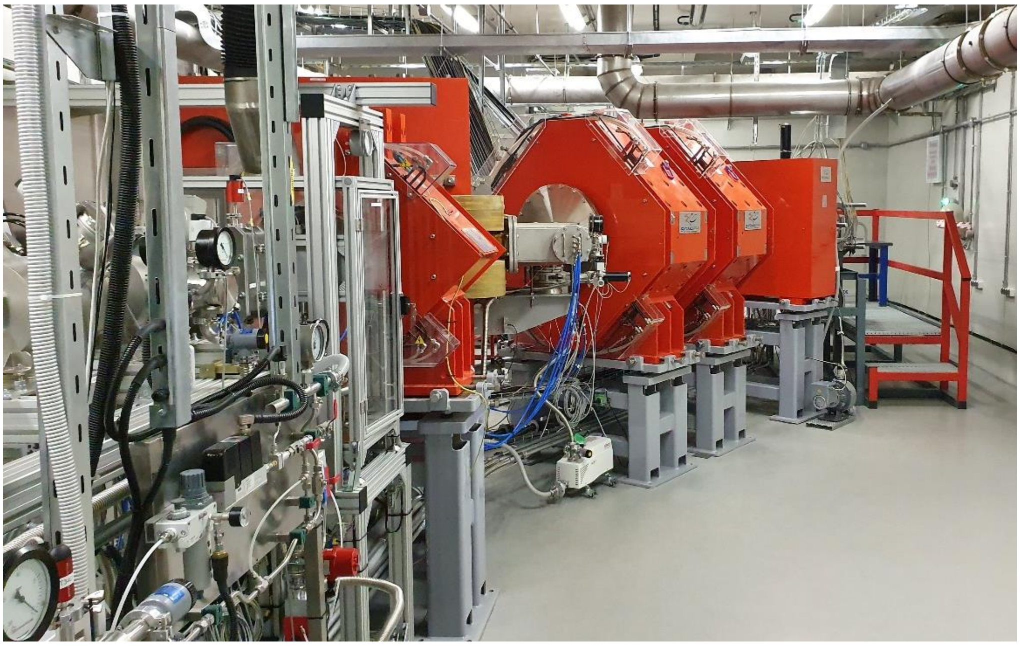

Fig. 2. Photo of the gas-filled separator DGFRS-2.