Joint Institute for Nuclear Research, FLNR, Dubna, Russia

The Institute of Nuclear Physics

Production of metal ion beams from ECR ion source

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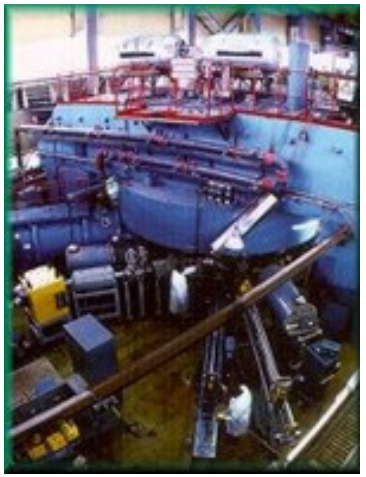
The report describes the production of metal ion beams from ECR ion sources by MIVOC (Metal Ions from Volatile Compounds) method. The method is based on the use of volatile metal compounds having high vapor pressure at room temperature: for example, $Cr(C_5H_5)_2$, $(CH_3)_5C_5Ti(CH_3)_3$ and several others. Using this method, intense beams of chromium, titanium, iron, and other ions were produced at the U-400 FLNR JINR and DC-60 cyclotrons (Astana branch of the INP, Alma-Ata, Kazakhstan Republic).

The cyclotron U-400 of Flerov laboratory nuclear reaction (JINR, Russia)

The main parameters of the beams

Atomic mass range (A)	**4 - 209**
Accelerated ion energy	3 – 29 MeV/nucleon



MAIN OBJECTIVES :

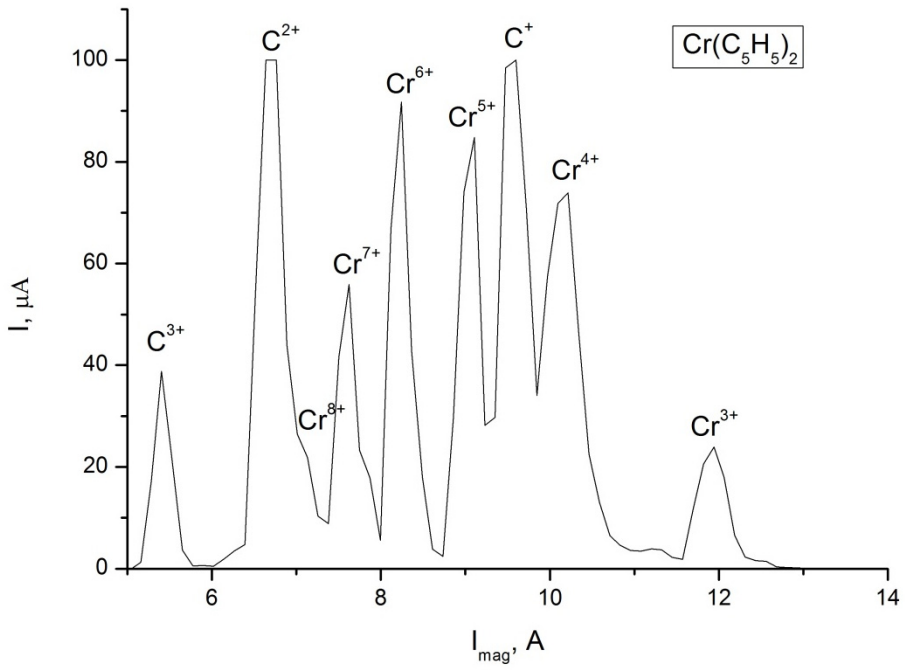
- synthesis of superheavy elements
- study of the chemical properties of superheavy elements
- study of the structure of light nuclei at the nucleon stability boundary
- study of the resonant structure of nuclear systems beyond neutron stability
- study of fusion-fission mechanisms of nuclei

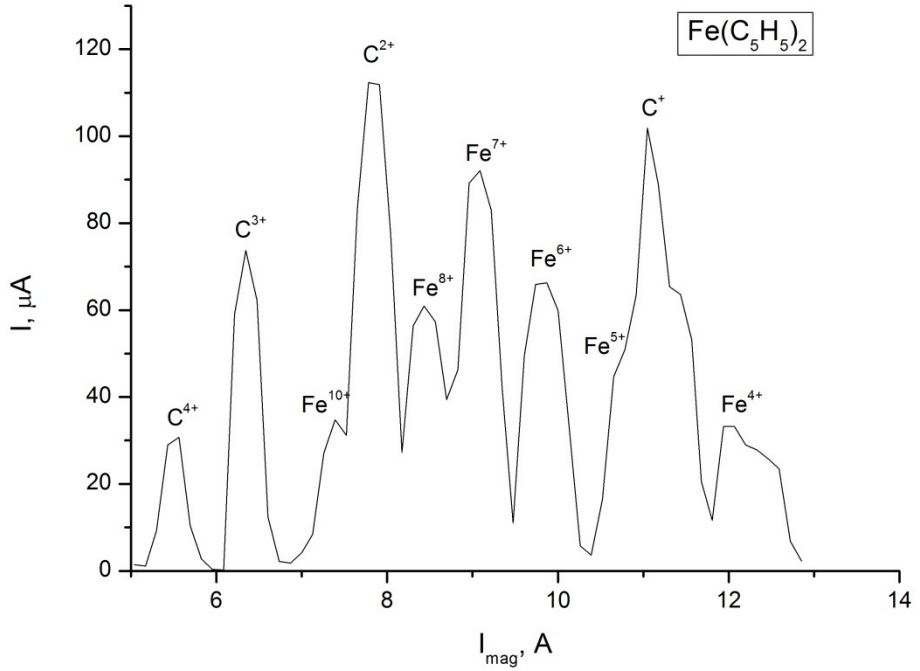
ECR4M ion source

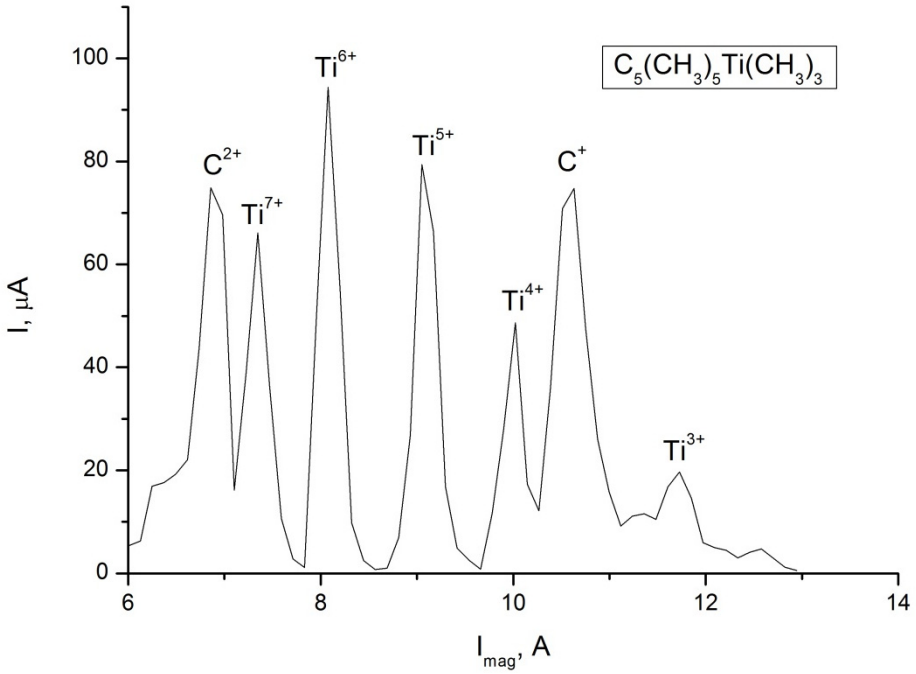
Beams of metal ions from ECR-4M ion source at the cyclotron U-400

At the U-400 cyclotron, stable beams of metal ions were obtained by the MIVOC method for various research areas:

- ^{52}Cr, ^{56}Fe – study of fusion-fission processes, quasi-fission and multi-nucleon transfer reactions
- ^{54}Cr, ^{50}Ti – alpha, beta and gamma spectroscopy of isotopes of heavy and superheavy elements
- ^{56}Fe – study of reactions with beams of stable and radioactive nuclides leading to the formation of exotic nuclei







The spectrum of ^{50}Ti , the source settings are optimized for $^{50}Ti^{5+}$ – 78 μA. UHF power – 51 W.

^{50}Ti runs:

Since October 2013 beam time of ^{50}Ti constitutes 46 weeks

One ampule with compound (850 mg in average) – ≥ two weeks of non-stop operation

Ti-50 current at the target

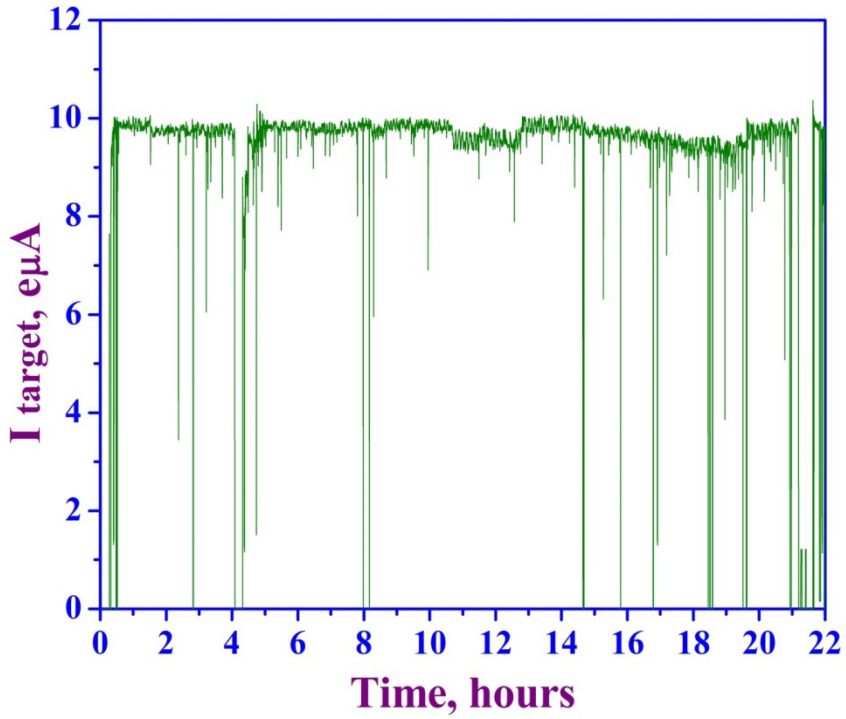


Table 2. The intensity (μA) of metal ion beams produced from the ECR ion sources of the FLNR JINR using the MIVOC method

Z	5+	6+	7+	8+	9+	10+	11+	12+	14+	16+	17+	18+	19+
^{56}Fe*		43	93*	125	172	145	114	73					
^{46}Ti*	62*	51	40										
^{48}Ti*	79*						68						
^{50}Ti*	82*				90	72	60	23					
Ni		45	43	48	53		30	10					
Co		57	80	86	98		82	25					
Cr*	50	74*	68	42	17	8							
Ge			43	54		47							
V	75	54	41	54	55	43	34	19					
Hf									45	50	45	36	27

* – accelerated metal ion beams at the U-400 cyclotron, FLNR

The accelerator complex DC-60 of Astana branch of the INP (Alma-Ata, Kazakhstan Republic)

The main parameters of the beams

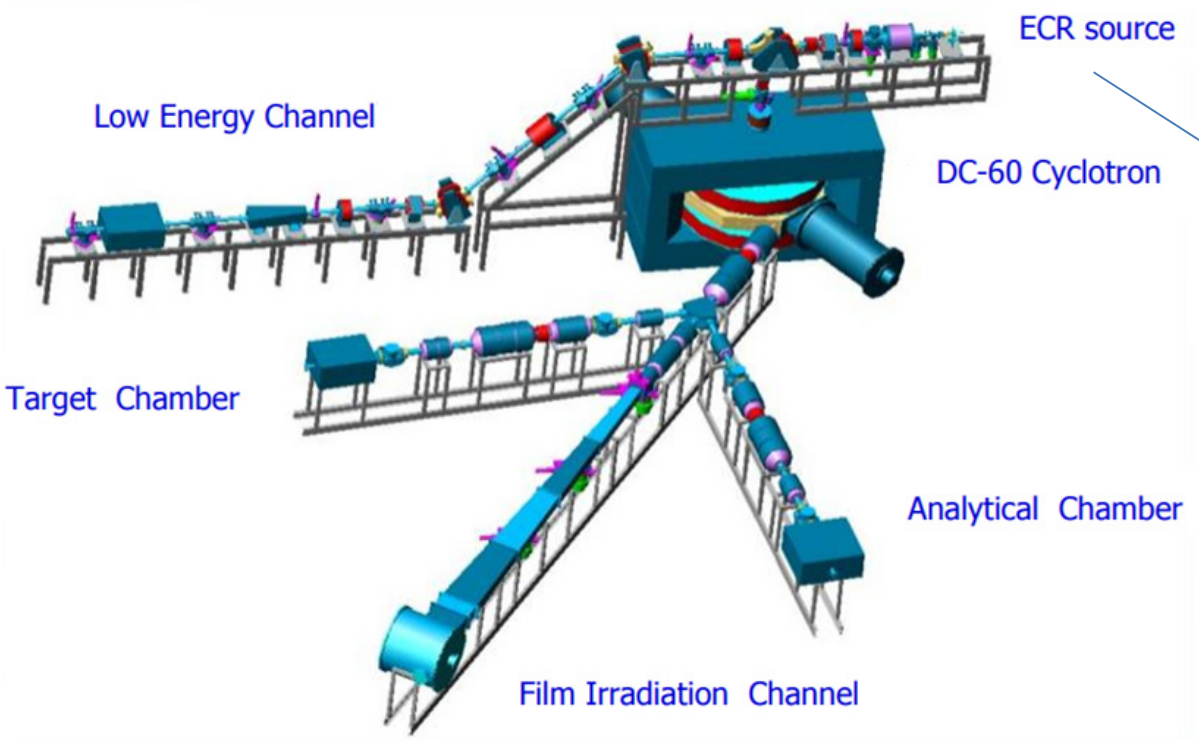
Type of ions	Li - Xe
Mass to charge ratio (A/Z)	6 - 12
Accelerated ion energy	0,35 – 1,7 MeV/nucleon

MAIN OBJECTIVES :

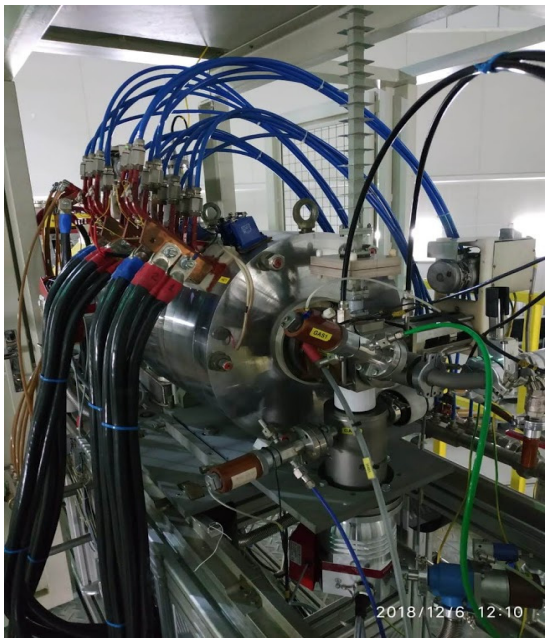
- Scientific research
- Education
- Production of track membranes with special properties
- Creation of micro and nano structures
- Surface modification of standard materials, creation of new materials with required properties

The cyclotron is equipped with the Electron Cyclotron Resonance (ECR) ion source DECRIS-3

CYCLOTRON DC-60



DECRIS-3 ion source

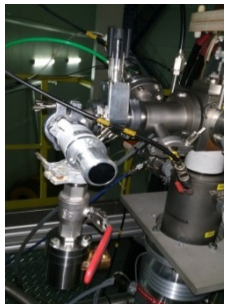


The experience and knowledge on the production of metal ion beams from ECR ion sources in FLNR by the MIVOC method has been successfully transferred to the DC-60 cyclotron.

The preparation of the titanium compound.

Titanium ions beams were produced from the compound $(CH_3)_5C_5Ti(CH_3)_3$.





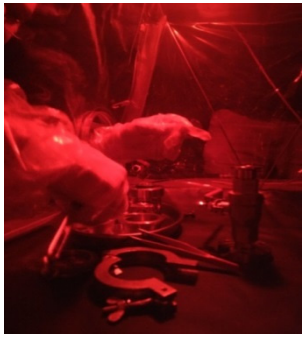
Preparation of the titanium compound $(CH_3)_5C_5Ti(CH_3)_3$ for operation. Left - an ampoule with a substance is placed in a container; in the center - the container with the substance is pumped to the forevacuum; on the right - the container with the working substance is connected to the ECR ion source through a mechanical regulating valve.

The preparation compounds ferrocene, cobalt, chrome, nickel, germanium and hafnium.

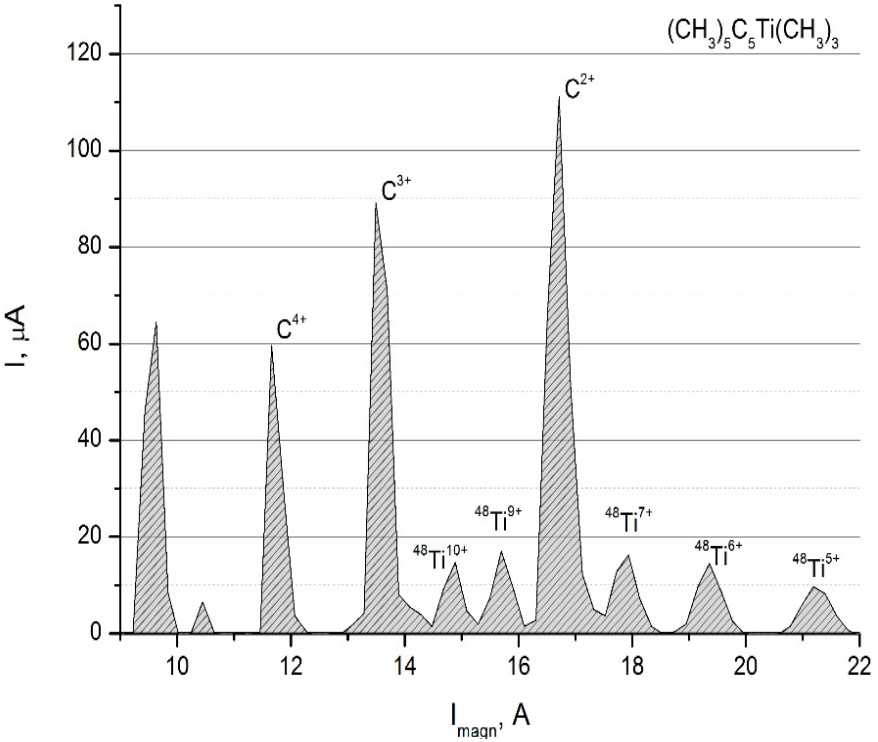
The organometallic compound $Fe(C_5H_5)_2$ hasn't a chemical activity with oxygen and isn't sensitive to visible light. Therefore, the preparation of the MIVOC chamber with the compound $Fe(C_5H_5)_2$ was carried without an argon box.

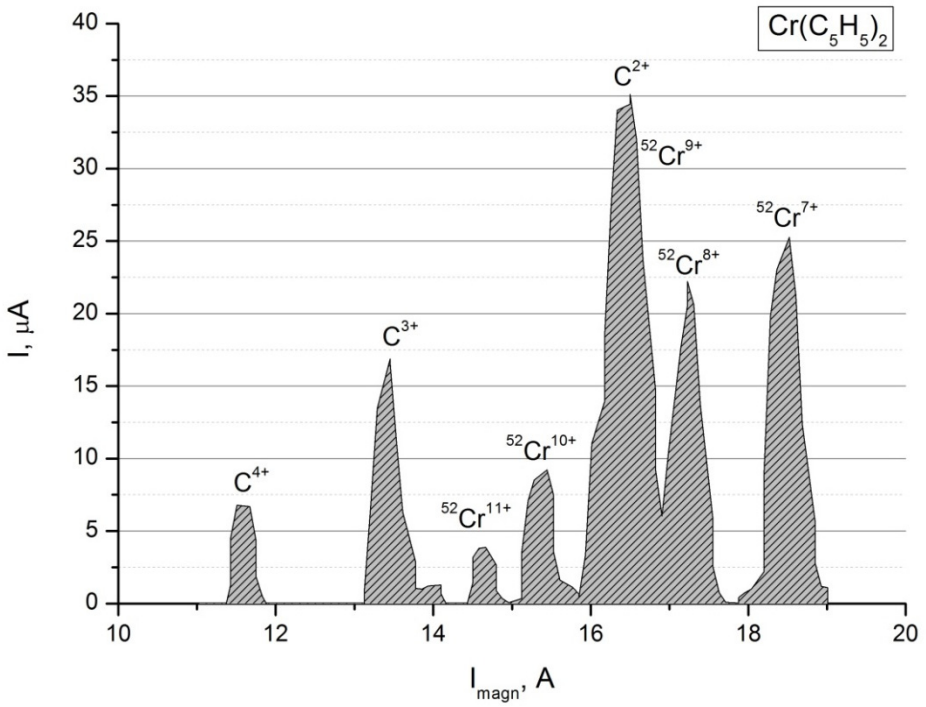
The compounds $Cr(C_5H_5)_2$, $Co(C_5H_5)_2$, $Ge(CH_3)_4$ and $(C_5H_5)_2Hf(CH_3)_2$ has a chemical activity with oxygen. So, the preparation of the MIVOC chamber was carried out an argon box.

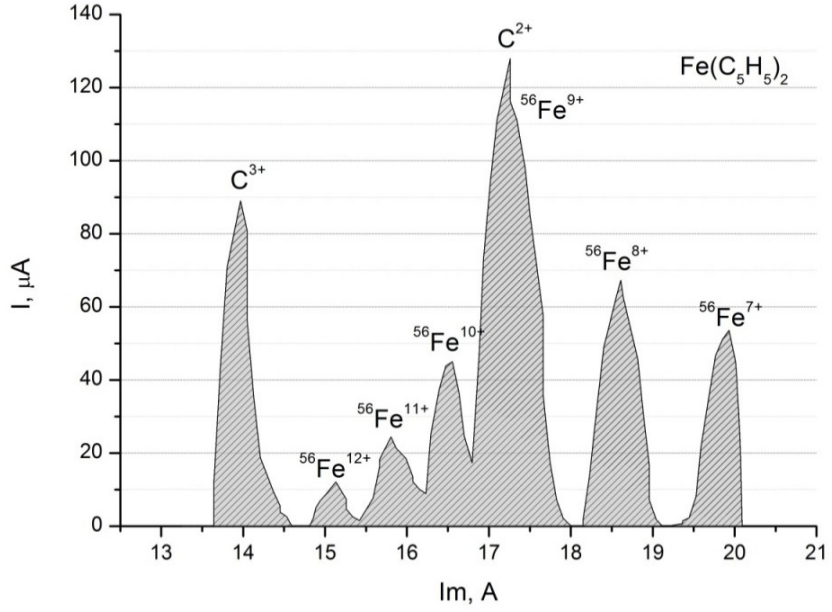
The compound $Ni(C_5H_5)_2$ has a high chemical activity with oxygen and is highly sensitive to visible light. Therefore, the preparation of the MIVOC chamber with the compound $Ni(C_5H_5)_2$ was carried out in an argon box under red light.

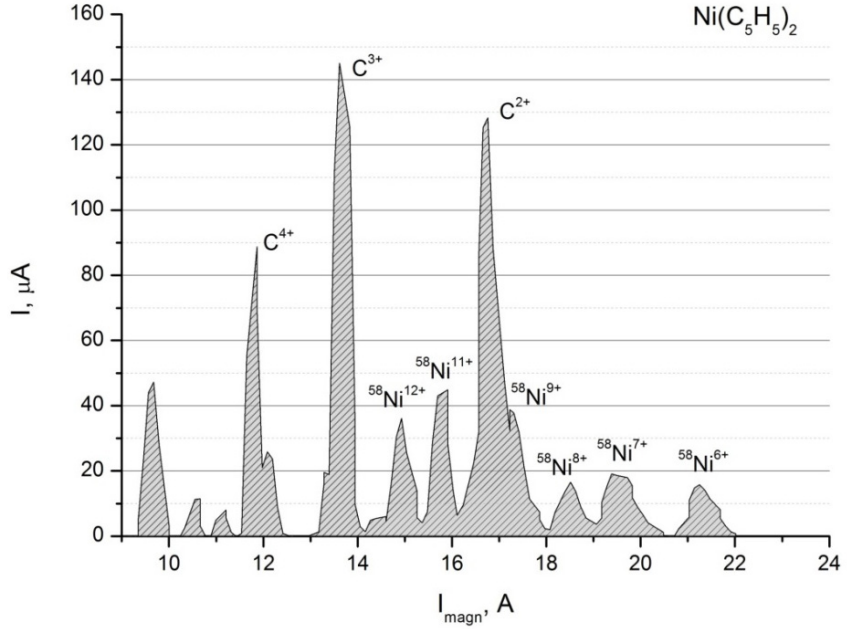


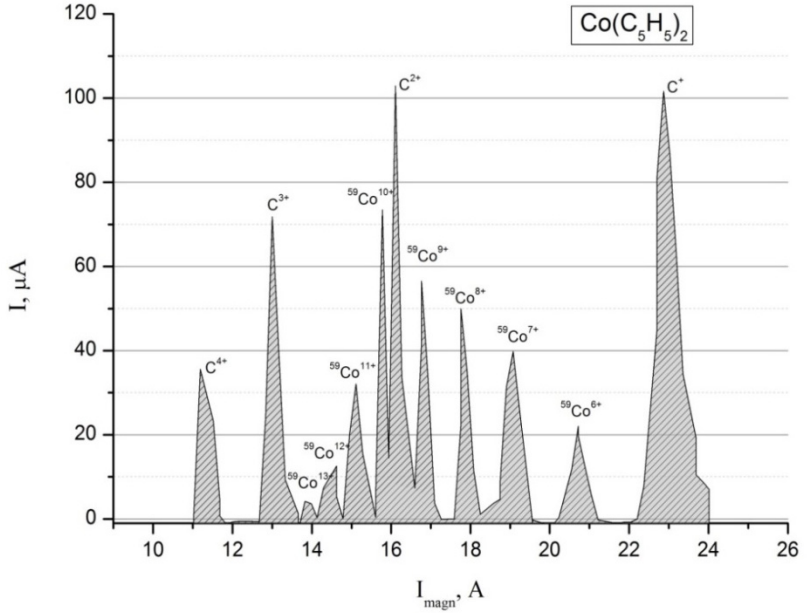
After preparation all containers with compounds are pumped to the forevacuum, and connected to the ECR ion source through a mechanical regulating valve.

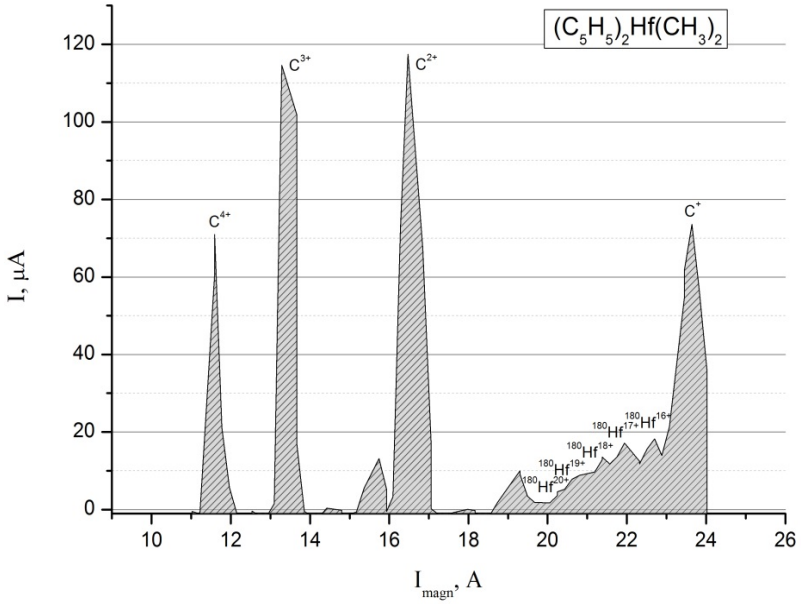

(CH3)5C5Ti(CH3)3
I, μA
Imagn, A
C4+
C3+
C2+
48Ti10+
48Ti9+
48Ti7+
48Ti6+
48Ti5+


Cr(C5H5)2
I, μA
Imagn, A
C4+
C3+
C2+
52Cr11+
52Cr10+
52Cr9+
52Cr8+
52Cr7+


Fe(C5H5)2
I, μA
Im, A
C4+
C3+
C2+
56Fe12+
56Fe11+
56Fe10+
56Fe9+
56Fe8+
56Fe7+


Ni(C5H5)2
I, μA
Imagn, A
C4+
C3+
C2+
58Ni12+
58Ni11+
58Ni9+
58Ni8+
58Ni7+
58Ni6+





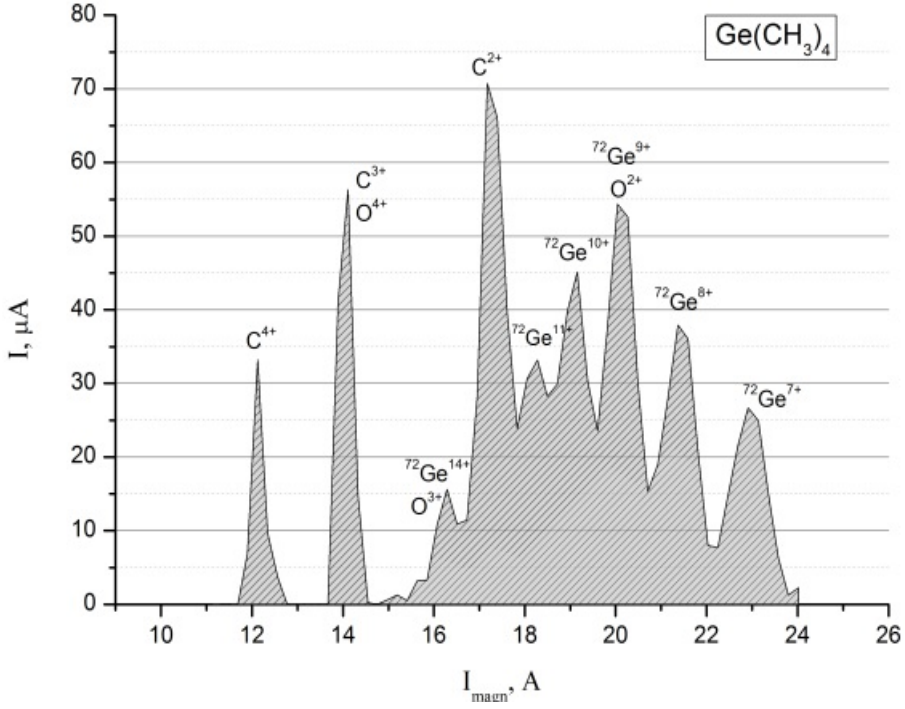


Table 1. The intensity (μA) of metal ion beams produced from the DECRIS-3 ECR ion source of the DC-60 cyclotron using the MIVOC method

Z	8+	9+	10+	11+	12+	17+	18+	20+
^{48}Ti		18*	16					
^{58}Ni		39		43*	37			
^{59}Co		57	73	36	12*			
^{52}Cr	22		9*					
^{56}Fe	68		44*	25	12			
^{72}Ge	38		46*	34				
^{180}Hf						19	15	5

* –metal ion beams accelerated at the DC-60 cyclotron

CONCLUSION

The main goal of this work was to employ the MIVOC method for production of ions of solid and extend the spectrum of accelerated ions at the FLNR cyclotrons and at the DC-60 cyclotron.

With the extention of the spectrum of accelerated elements, it becomes possible to set up new experiments in the field of experimental nuclear physics, radiation solid state physics, and various applied problems, which makes the research objective particularly relevant. As a result of the work done, for the first time at the DC-60 cyclotron, the ion beams of $^{48}Ti^{9+}$, $^{58}Ni^{11+}$, $^{59}Co^{12+}$, $^{52}Cr^{10+}$, $^{72}Ge^{10+}$ and $^{180}Hf^{17+}$ were produced.