RECENT DEVELOPMENT IN ECR ION SOURCES AT FLNR JINR

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Abstract

In the Flerov Laboratory of Nuclear Reactions (JINR) the development of ion sources based on the plasma electrons heating at the frequency of electron cyclotron resonance (ECR) is stimulated by the necessity of the accelerator complex (U-400, U-400M and CI-100 cyclotrons) upgrading as well as by creation of the new high current cyclotrons for basic and applied research.

Several ECR ion sources have been operated in the Flerov Laboratory of Nuclear Reactions (JINR) supplying various ion species for the U400 and U400M cyclotrons correspondingly for experiments on the synthesis of heavy and exotic nuclei, using ion beams of stable and radioactive isotopes, for solid state physics experiments and polymer membrane fabrication. In this paper the new development concerned with modernization of ECR4M ion source, development of the new superconducting source DECRIS-SC2 and creation of the DECRIS-5 ion source for the DC-110 cyclotron complex will be presented.

INTRODUCTION

Main theme of FLNR JINR is super heavy elements research. From 2000 up to 2010 more then 40 isotopes of elements 112, 113, 114, 115, 116, 117, 118 were synthesized in the laboratory.

At present four isochronous cyclotrons: U-400, U-400M, U-200 and IC-100 are under operation at the JINR FLNR. Three of them are equipped with ECR ion sources. In the DRIBs project for production of accelerated exotic nuclides as ^{6}He, ^{8}He etc. the U-400M is used as radioactive beam generator and U-400 is used as a post-accelerator. Layout of FLNR accelerators complex is presented in Fig.1 [1]. Red stars indicate the location of the ECR ion sources.

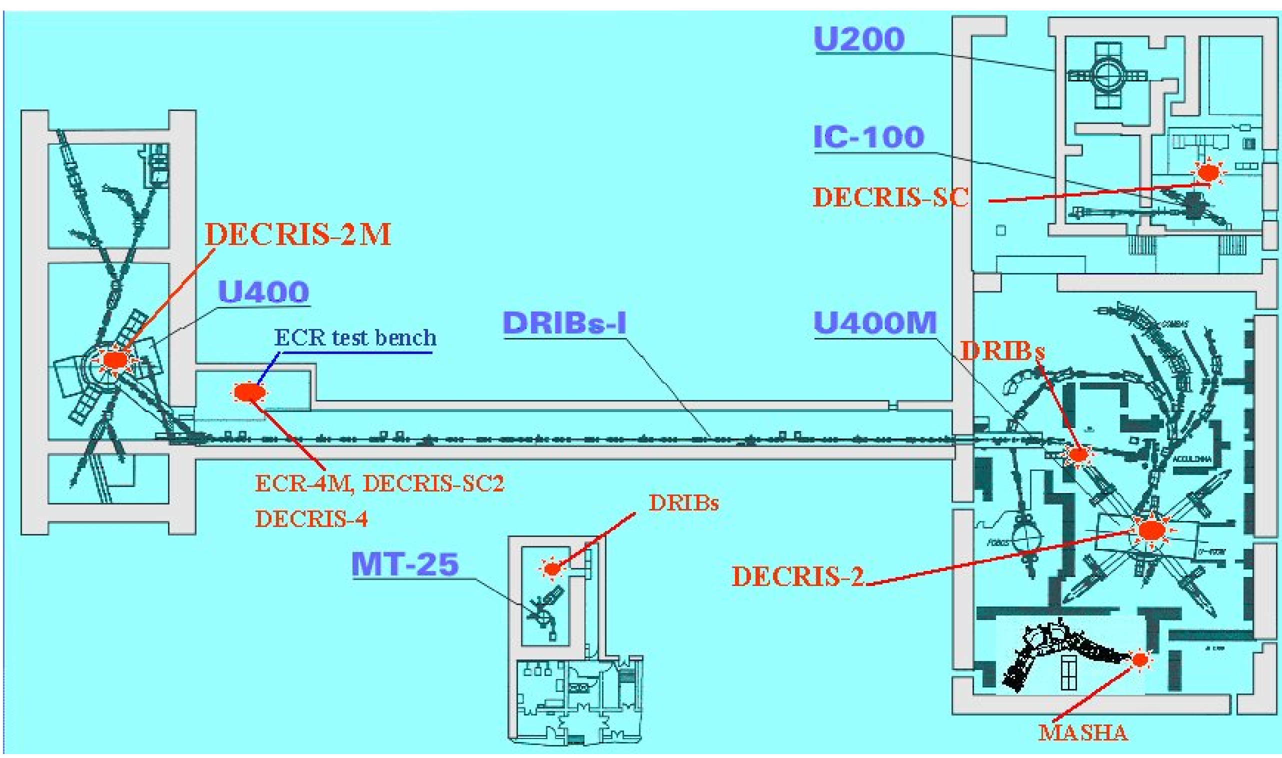

Figure 1: Layout of FLNR JINR accelerator complex. Red stars indicate the location of the ECR ion sources.

ECR4M ION SOURCE

The ECR4M source and the axial injection system were assembled and commissioned in 1996. First accelerated Ar beam was produced in November 1996 [2]. The main goal was to provide the intense beam of the ^{48}Ca ion beam for the experiments on synthesis of super heavy elements at a minimal consumption of this enriched and expensive isotope. First experiment on the synthesis of superheavy elements with the beam of ^{48}Ca was performed in November 1997. Since that about 66% of total operation time was used for acceleration $^{48}Ca^{5+,6+}$ ions for research

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on synthesis and investigation of properties of new elements.

The modernization of the U400 axial injection, which included sharp shortening of the injection channel horizontal part, was performed. These changes allow us to increase the $^{48}Ca^{18+}$ ion intensity at the U400 output from 0.9 to 1.4 pμA

According to the plans of the reconstruction of the U400 cyclotron (U400R project [3]) the project of the modernization of the ECR4M source was developed and realised. This modernization include production of the higher magnetic field in the injection region by insertion an iron plug in the injection side; the increase of the plasma chamber diameter from 64 to 74 mm; waveguide UHF injection into plasma chamber. The modified magnetic structure of the ECR4M and the axial magnetic field distribution are shown at Fig.2 and Fig3 correspondingly.

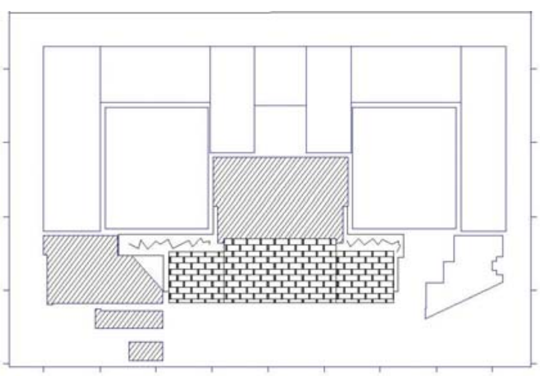

Figure 2: The modified magnetic structure of ECR4M source.

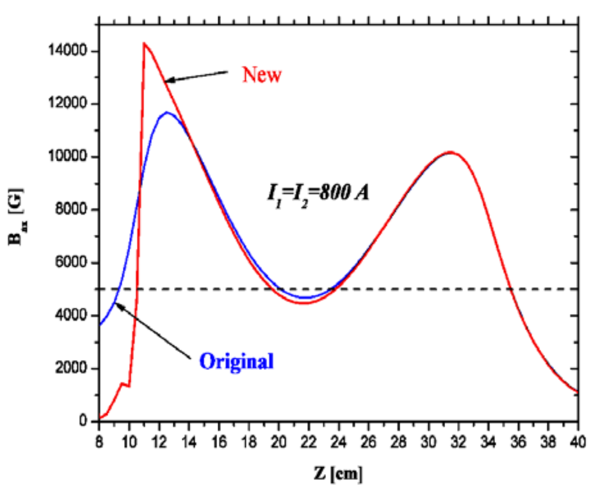

Figure 3: Axial magnetic field distribution of ECR4M source.

The modified ECR4M source was installed at the test bench, and after the tuning with Ar beam the experiments on production of Ca beam were performed. The same technique with the use of microoven and thin cylindrical Ta sheet placed inside the discharge chamber to prevent the condensation of metal at the chamber wall [4] was employed. The Ca spectrum optimized for production of Ca^{11+} is shown in Fig.4.

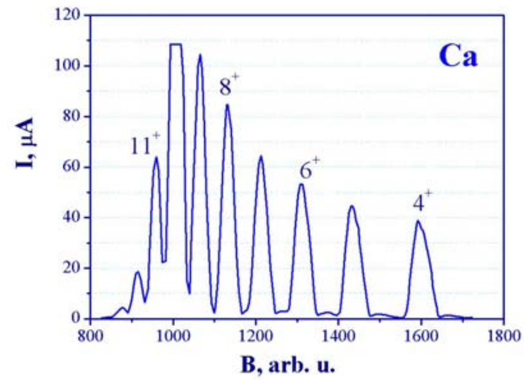

Figure 4: Calcium spectrum . The source tuning is optimized for production of Ca^{11}+ ions.

After the tests with calcium beam the source was used for development of titanium beam using MIVOC method with $(CH_3)_5C_5Ti(CH_3)_3$ compound, first used by Jyvaskyla group [5]. The aim of these experiments is the production of intense ^{50}Ti ion beam for research on synthesis of superheavy elements.

During the experiments up to 80 μA of Ti^{5+} and up to 70 μA of Ti^{11+} ion beams were produced at different source tuning. Fig. 5 shows the titanium spectrum with the source tuning optimized for production of Ti^{11+} ions. The spectrum is obtained at the UHF power level about of 300 W.

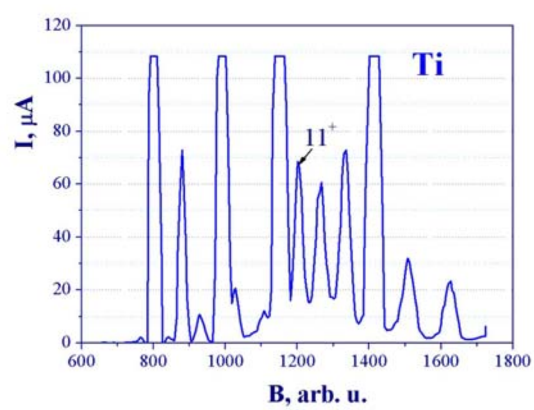

Figure 5: Titanium spectrum. The source tuning is optimized for production of Ti^{11+} ions.

DECRIS-SC2 ION SOURCE

Using the experience obtained during construction and operation of the DECRIS-SC [6] source the new source DECRIS-SC2 was developed [7]. The source is planned to be used at the U-400M cyclotron aiming the production of more intense ion beams in the mass range heavier than Ar. For ECR plasma heating the existing microwave system (14 GHz) will be used. Taking this into account the magnet system of the source was designed with the minimum magnetic field about of 0.4 T, maximum

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magnetic field about of 1.4T and 1.9T in the injection and the extraction side correspondingly.

The design of the superconducting magnet system of the new source differs essentially from the previous source. To decrease the weight and dimensions of the system it was decided to produce the vacuum vessel from chromium plated soft steel, so it will simultaneously serves also as a magnetic yoke. The main parameters of the source are listed in the Table 1. The axial magnetic field distribution at different coils currents setting is shown at Fig. 6. The current of the middle coil was adjusted to keep the minimum constant. The radial magnetic field distribution is shown at Fig. 7.

Table 1: Main parameters of the DECRIS-SC2 ion source

UHF frequency	14 GHz
Injection side magnetic field	1.9 T
Extraction side magnetic field	1.4 T
Radial magnetic field	1.05 T
Hexapole structure (NdFeB)	24 sectors
Plasma chamber diameter	74 mm
Plasma chamber length	300 mm
Max. extraction voltage	30 kV

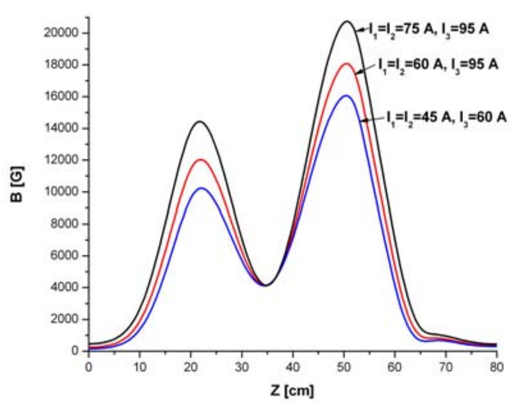

Figure 6: Axial magnetic field distribution of the DECRIS-SC2 source.

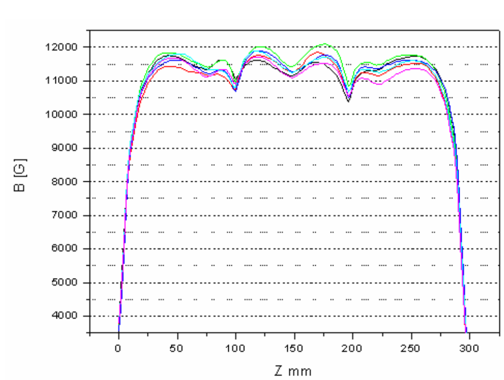

Figure 7: Radial magnetic field distribution of the DECRIS-SC2 source.

The source was tested at the test bench for production of gaseous ions from oxygen to xenon. For commissioning the traveling wave tube amplifier (TWTA) with the maximum output power of about 600 W was used to feed UHF power directly into the plasma chamber through the standard rectangular waveguide. With the one gap extraction system and a stainless steel puller the source can work without discharge at 25 kV. The transmission efficiency right until the Faraday cup installed after the analyzing magnet was estimated with an oxygen beam in the range of 40%–60% for the extraction voltage varied from 15 to 25 kV.

Generally, the operation of the DECRIS-SC2 ion source was very stable and reproducible. Biased disc and mixing gas effect were actively adopted to maximize the ion beam production. Fig. 8 shows the argon spectrum with the source tuning optimized for production of Ar^{11+} ions. The results obtained with the DECRIS-SC2 source during the tests are summarized in Table 2.

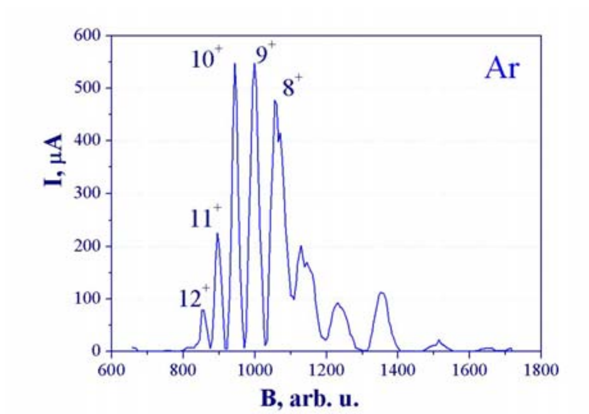

Figure 8: Argon spectrum. The source tuning is optimized for production of Ar^{11+} ions.

Table 2: Ion yields from the DECRIS-SC2 ion source

Ion	O	S	Ar	Kr	Xe
5+	920				
6+	820				
8+			880		
9+		265	680		
11+		90	250		
12+			120		
15+				250	
17+				150	
30+					~ 1

DECRIS-5 ION SOURCE FOR DC-110 CYCLOTRON COMPLEX

The project of the DC-110 [8] cyclotron facility to provide applied research in the nanotechnologies (track pore membranes, surface modifcation of materials, etc.) has been designed by the Flerov Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research (Dubna). The facility includes the isochronous cyclotron

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DC-110 for accelerating the intensive Ar, Kr, Xe ion beams with 2.5 MeV/nucleon fixed energy. The cyclotron has 2m pole diameter, and to provide the energy of 2.5 Mev/nucleon the accelerated ions should have the mass to charge ratio about of A/Z = 6.6, that is $^{40}Ar^{6+}$, $^{86}Kr^{13+}$ and $^{132}Xe^{20+}$. The parameters of the source are determined mainly by required intensity of $^{132}Xe^{20+}$ ion beam (≥150 μA), and are listed in the Table 3.

Table 3: Main parameters of the DECRIS-5 ion source

UHF frequency	18 GHz
Injection side magnetic field	2.2 T
Extraction side magnetic field	1.35 T
Radial magnetic field	1.15 T
Hexapole structure (NdFeB)	36 sectors
Plasma chamber diameter	80 mm
Plasma chamber length	300 mm
Max. extraction voltage	30 kV
Maximal power consumption	160 kW

The magnetic system for creation of the axial magnetic field can be realized with copper coils, or with superconducting coils. In case of copper coils the power consumption of the magnetic system will be about of 150 kW, with superconducting coils – about of 10 kW. Taking into account the operating conditions (industrial operation) the use of copper coils was chosen.

Description of the source

The magnetic structure of the source is composed by three independent copper coils. The injection and extraction coils are enclosed in soft iron yokes. Soft iron plug is placed inside the discharge chamber. The scheme of the magnetic structure, and calculated axial magnetic field distribution are shown in the Fig. 9 and Fig. 10 correspondingly.

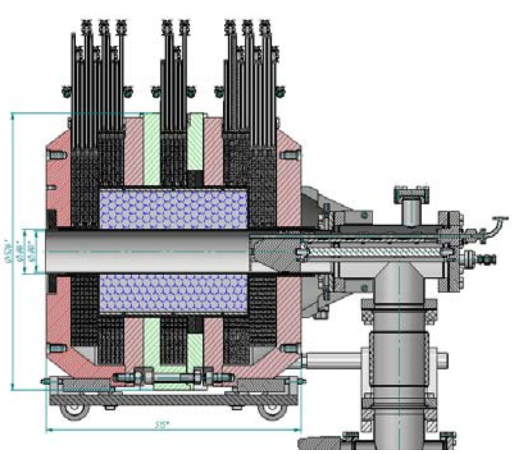

Figure 9: The scheme of magnetic structure of the DECRIS-5 ion source.

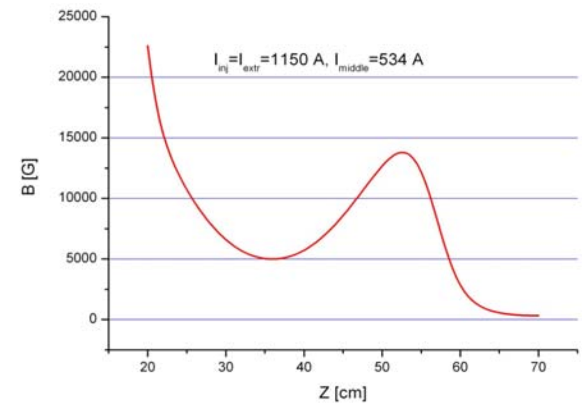

Figure 10: Axial magnetic field distribution of the DECRIS-5 ion source.

The maximal current of the power supplies for the injection and extraction coils is 1200 A, for the middle coil – 800 A. The power consumption of the coils is about 150 kW.

The radial magnetic field distribution is shown in the Fig. 11.

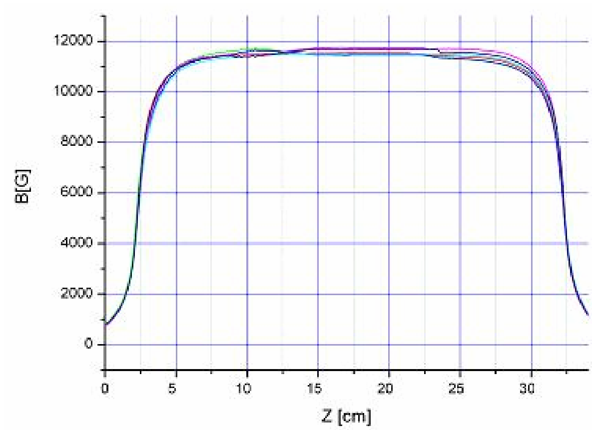

Figure 11: Radial magnetic field distribution of the DECRIS-5 ion source.

The stainless-steel plasma chamber of the source is made as a water-cooled double wall tube. The internal diameter of the plasma chamber is 80 mm. On the injection flange there are mounted soft iron plug, water cooled standard waveguide, gas feeding tubes. Biased electrode is mounted on the soft iron plug and is not cooled, as well as soft iron plug. The working gases (Ar, Kr, Xe) and support gas (O_2) are fed into the source chamber by two double channel piezoelectric valves.

The source is equipped with three electrode extraction system. The plasma electrode aperture is 10 mm in diameter, its position can be changed while the source is open. The negatively biased extraction electrode is water cooled, and position of the whole assembly can be adjusted manually without breaking vacuum.

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Results of the test

The test of the source was performed during December 2011 – February 2012. For the test the source was assembled with the part of the axial injection beam line of DC-110 cyclotron (see Fig. 10). The main optical elements of the system are the analyzing magnet IM90, solenoid IS1 and two dipole correcting magnets ICM1 and ICM2. In the diagnostic box after analyzing magnet a Faraday cup, 30 mm diaphragm and luminophor screen are installed. All elements are movable with pneumatic actuators. The vacuum system provides background vacuum about of 2×10^{-8} torr in the extraction and diagnostics boxes.

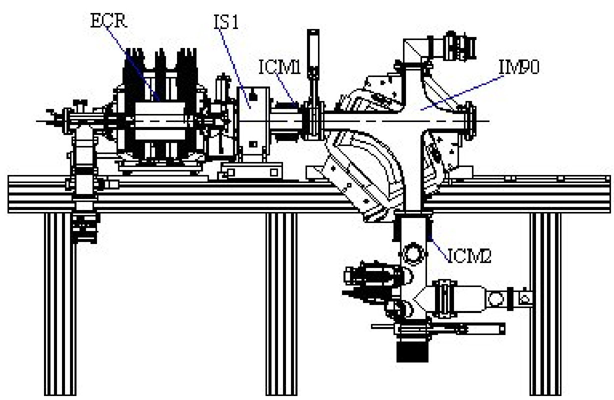

Figure 12: Axial injection system of the DC-110 cyclotron.

The ion source was tested for production of Ar, Kr and Xe ion beams. The production of required intensity of the Ar^{6+} beam (about of 100 μA) should present no problem. Therefore, to study the source performances the parameters of the source were tuned for production of higher charge states. Figure 11 shows the Ar spectr optimized Ar^{11+}. The results were obtained in the UHF power range lower than 700 W at 21÷22 kV extraction voltage.

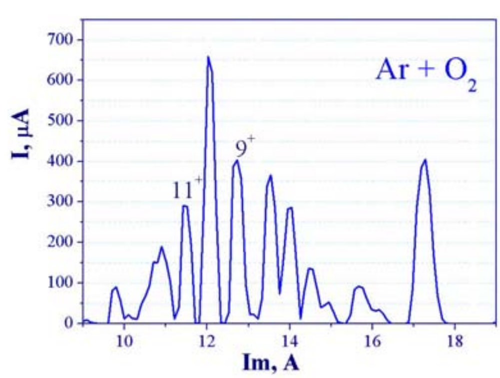

Figure 13: The Ar spectrum. The source tuning is optimized for production of Ar^{11+} ions

During the tests the operation of the DECRIS-5 ion source was very stable and reproducible. The results, obtained during the tests are summarized in Table 4.

Table 4: Ion yields from the DECRIS-5 ion source

Z	8+	9+	11+	15+	18+	19+	20+
Ar	1200	750	300				
Kr				325	182	120	70
Xe							220

SUMMARY

Over past years several types of ECR ion sources of **DECRIS** (**D**ubna **E**lectron **C**yclotron **R**esonance **I**on **S**ource) family were developed in FLNR (JINR). The progress in development of DECRIS sources is illustrated in Fig. 14.

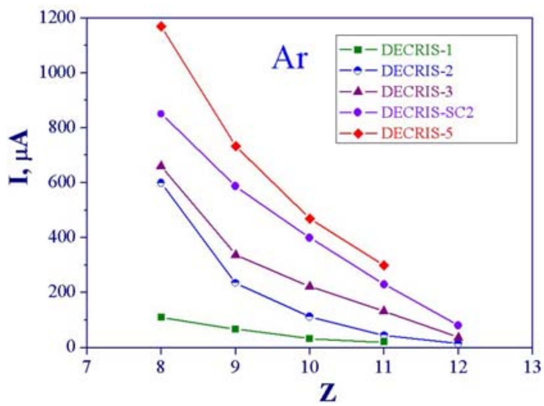

Figure 14: Comparison of Ar currents produced by DECRIS type ion sources.

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