COMMISSIONING OF CARIBU EBIS CHARGE BREEDER SUB-SYSTEMS*

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Abstract

A high-efficiency charge breeder based on an Electron Beam Ion Source (EBIS) to increase the intensity and improve the purity of accelerated neutron-rich radioactive ion beams is being developed by the ANL Physics Division. The design of the CARIBU EBIS charge breeder is complete and manufacturing of the components and sub-systems is in progress. Two key elements of the breeder - a 6-Tesla superconducting solenoid and a high-perveance electron gun were recently delivered and successfully commissioned. The current status of the ANL EBIS development and commissioning results of different EBIS sub-systems will be presented.

INTRODUCTION

The Californium Rare Isotope Breeder Upgrade (CARIBU) for the Argonne National Laboratory Argonne Tandem Linac Accelerator System (ATLAS) has been recently commissioned. In its full capacity, the CARIBU facility will use fission fragments from a 1 Curie (Ci) ^{252}Cf source [1]. The ions are thermalized and collected into a low-energy ion beam by a helium gas catcher, mass selected by an isobar separator, and charge bred to higher charge states for acceleration in ATLAS. To reach energies E/A ~ 10 MeV/u, one should inject ions with a charge-to-mass ratio (q/A) $\geq$ 1/7 into the ATLAS. In the first stage, the existing Electron Cyclotron Resonance (ECR) ion source is used as a charge breeder [2]. The maximum intensity of radioactive ion beams at the output of the gas catcher for a 1 Curie ^{252}Cf source will not exceed 10^7 ions per second. A charge breeder (CB) based on an Electron Beam Ion Source (EBIS) has significant advantages over the ECR option for ion beam intensities up to about 10^9 ions per second, providing higher efficiency, shorter breeding times and significantly better purity of highly charged radioactive ion beams for further acceleration. The EBIS CB project for CARIBU is heavily utilizing state-of-the-art EBIS technology recently developed at Brookhaven National Laboratory [3]. However, the parameters of the electron gun, potential distribution in the ion trap region, electron collector and injection/extraction lines are substantially modified to obtain the highest acceptance and breeding efficiency of low intensity rare isotope beams which is expected to be higher than 20%. Special attention was paid to the vacuum system because the vacuum inside the EBIS trap will define the purity of charge-bred radioactive ion beams.

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DESIGN OF CARIBU EBIS CHARGE BREEDER

In this section the main features of the CARIBU EBIS design will be highlighted. The main parameters of the CARIBU EBIS CB are presented in Table 1.

Table 1: Main parameters of CARIBU EBIS CB

Parameter	Low current e-gun	High current e-gun
Superconducting solenoid: length/field	1 m/6 T	1 m/6 T
Diameter of IrCe thermionic cathode	1.6 mm	4 mm
Electron beam current	0.2 A	2 A
Electron beam energy	~ 2 keV	~ 5 keV
Electron beam diameter in the trap	~ 230 μm	~ 580 μm
Electron beam current density in the trap	~ 480 A/cm^2	~ 750 A/cm^2
Ion trap length	0.5 m	0.5 m
Trap capacity (in elementary charges)	~ $4\cdot10^{10}$	~ $2\cdot10^{11}$

Two e-guns were developed and built for the breeder: a high-current (2 A) and a low-current (0.2 A) e-gun. The low-current e-gun will be used to study the possibility of higher breeding efficiency for shell closures with lower electron beam energies.

Prior to installation into the CARIBU-ATLAS beam line, the breeder will be commissioned off-line and breeding efficiency will be optimized by injecting a pulsed ion beam generated by a surface ionization Cs^+ ion source. Setup for off-line commissioning of the breeder is presented in Fig. 1.

Scintillator-based pepper-pot emittance meters [7] developed at ANL and Faraday cups will be installed at several locations along the injection and extraction lines to measure emittance and current of injected and extracted ion beams.

Eleven drift tubes are used to transport the electron beam from the EBIS e-gun to the collector entrance. All drift tubes have longitudinal slots to facilitate pumping of the ion trap volume (Figures 2 and 3).

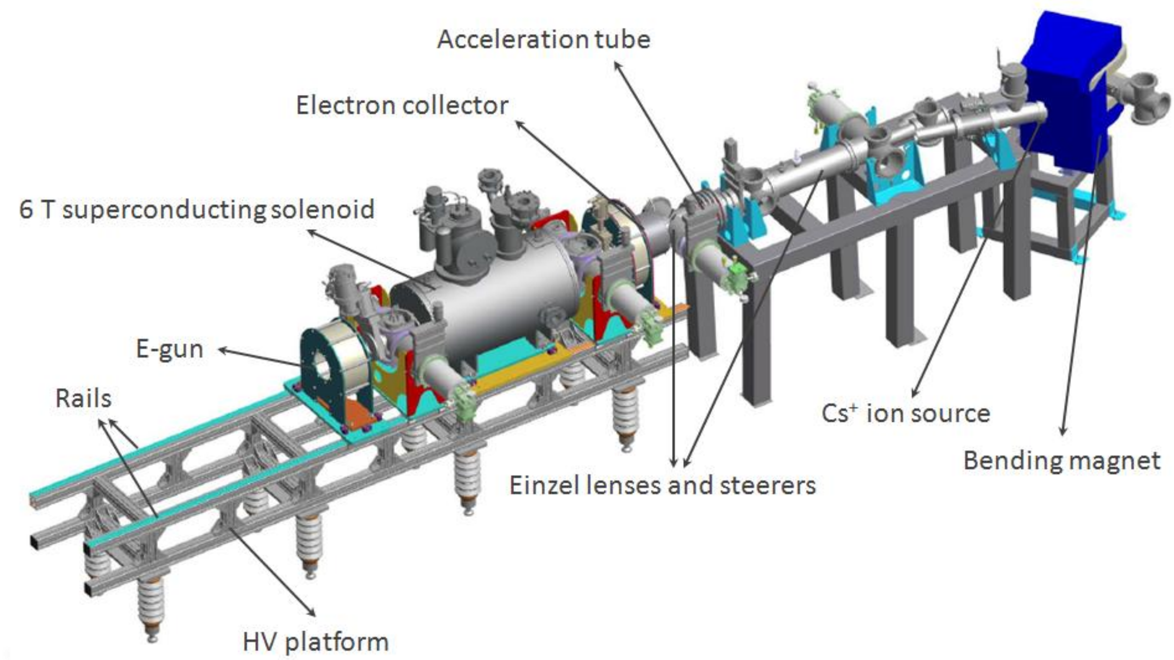

Figure 1: Setup for off-line commissioning of CARIBU EBIS charge breeder.

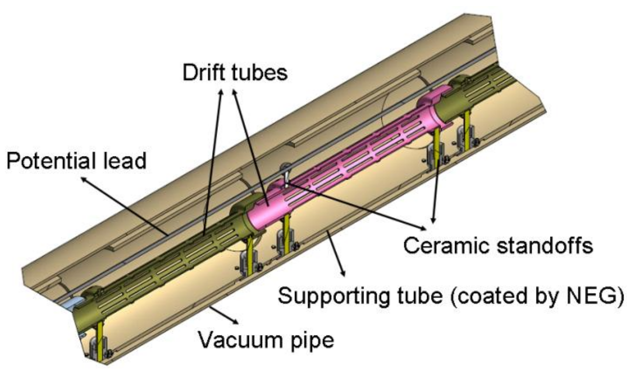

Figure 2: 3D model of drift tube structure.

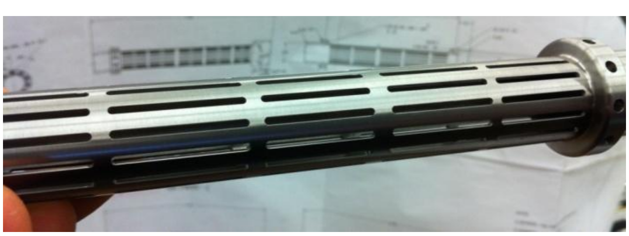

Figure 3: Photograph of drift tube.

The internal surface of the surrounding (supporting) tube will be coated with non-evaporable getter (NEG) to provide high pumping speed in the trap region.

More details on parameters and design of the CARIBU EBIS CB can be found elsewhere [4, 5, and 6].

COMMISSIONING OF 6 T SUPERCONDUCTING SOLENOID

An unshielded 6-Tesla superconducting solenoid with a warm bore diameter of 155 mm and a length of 1 m, from Cryomagnetics, Inc., was delivered in October 2011. The photograph of the solenoid installed in the final position on the high voltage (HV) platform for on-site commissioning is presented in Figure 4.

Figure 4: Photograph of 6 T solenoid installed at HV platform.

The warm bore of the solenoid is equipped with x and y translators. In the first step the mechanical axis of warm bore was aligned with magnetic axis of the solenoid using these translators in real magnetic environment.

The main specified and measured parameters of the solenoid are presented in Table 2.

Table 2: Parameters of the solenoid

Parameter	Specification	Measurements
Central Field	6.0 T	6.05 T @ 82.66 A
Maximum Field	6.6 T	6.6 T @ 90.17 A
Charge Time to 6 T	70 min	70 min
Field Homogeneity	± 0.4% over ± 30 cm on axis	± 0.2% over ± 30 cm on axis
Coil Inductance	195 H	193 H
Field Decay Rate	< 1 ppm/hour	< 0.01 ppm/hour

The simulated and measured axial magnetic field profiles along the solenoid axis are shown in Figure 5 (a, b). A zoomed profile (Figure 5 (b)) shows the flatness of the central field.

As one can see from Table 2 and Figure 5 (a, b) all specified parameters were met. The measured magnetic field homogeneity and field decay rate exceeded the design requirements.

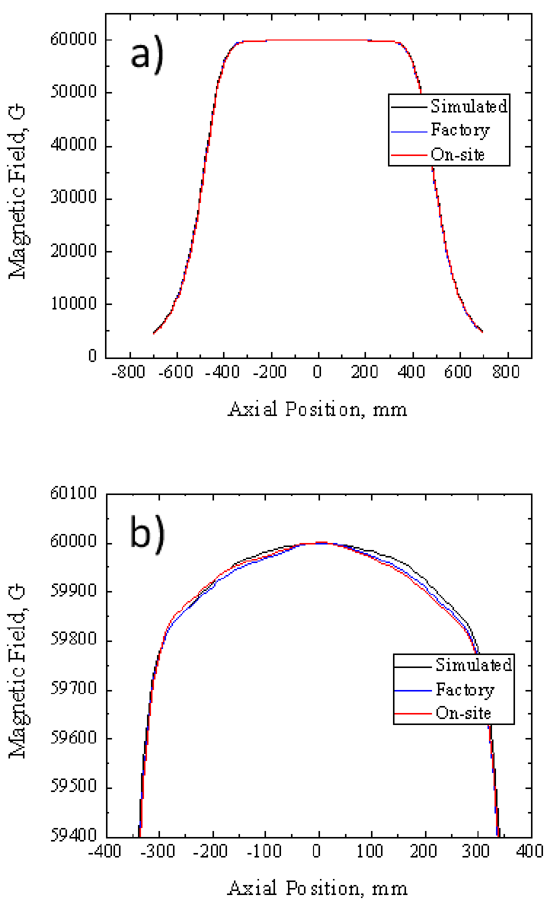

Figure 5 (a, b): Axial magnetic field profiles (Figure 5 (b) is zoomed from Figure (a)).

COMMISSIONING OF E-GUN

High-current (2 A) and low-current (0.2 A) e-guns have been ordered from BINP (Novosibirsk, Russia) and were delivered in April 2012. The main specified parameters of both e-guns are summarized in Table 3.

Table 3: Main specified parameters of 2 A and 0.2 A e-guns.

Parameter	CARIBU (high current)	CARIBU (low current)
Current	Up to 2 A	Up to 0.2 A
Current density at the cathode	10–15 A/cm²	10–15 A/cm²
Magnetic field at the cathode surface	~ 0.15 T	~ 0.15 T
Cathode material	IrCe	IrCe
Cathode diameter	4 mm	1.6 mm
Radius of cathode convex surface	6.6 mm	1.8 mm
Expected cathode lifetime	~ 20000 hours	~ 20000 hours

As mentioned above, a 2 A e-gun is the main option for the new CARIBU EBIS charge breeder and the 0.2 A e-gun will be used to study the possibility of higher breeding efficiency for shell closures with lower electron beam energies.

The engineering model of the e-gun is presented in Fig. 6.

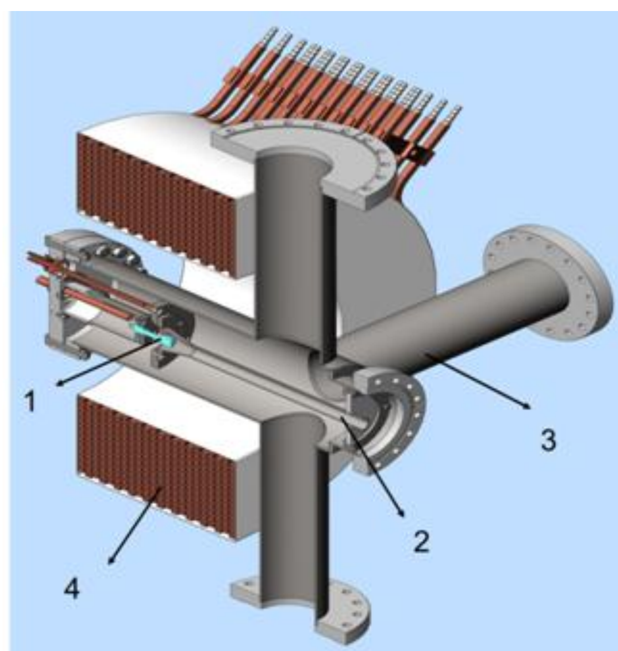

Figure 6: Engineering model of the e-gun (1 – IrCe thermionic cathode, 2 – anode, 3 – vacuum chamber, 4 – magnetic coil).

Both are semi-immersed type e-guns with pure magnetic compression [8]. IrCe thermionic cathodes are used because of their long demonstrated live times [9].

2 A and 0.2 A e-guns are switchable by exchanging the thermionic cathode units only. Pumping of the e-gun vacuum chamber will be provided by turbo and NEG cartridge pumps with total pumping speed for nitrogen of about 1000 l/s.

The photograph of 4 mm IrCe thermionic cathode units mounted for heating tests is presented in Fig. 7.

Figure 7: Photograph of 4 mm IrCe thermionic cathode units mounted for heating tests.

The current-voltage heating curve and the dependence of surface brightness temperature on heating power for 4 mm IrCe thermionic cathode units are reported in Figures 8 and 9.

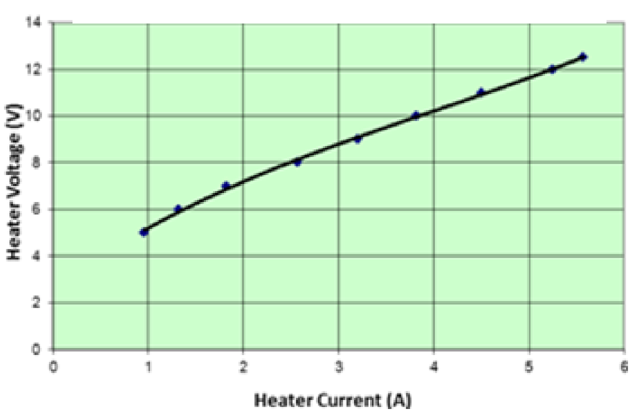

Figure 8: Current-voltage heating curve for 4 mm IrCe thermionic cathode units.

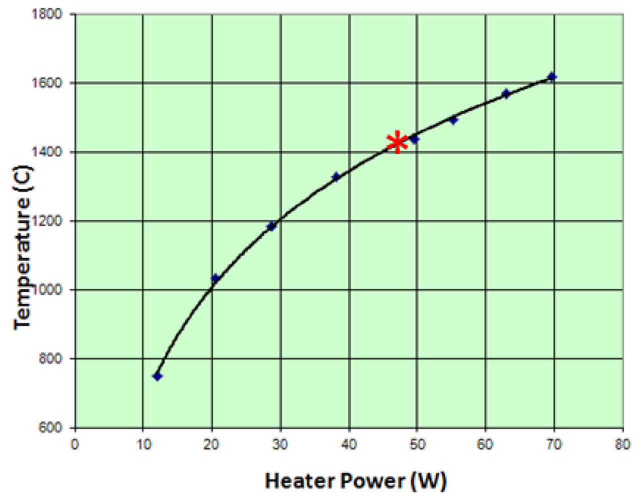

Figure 9: Dependence of surface brightness temperature on heating power for 4 mm IrCe thermionic cathode units.

The red star in Figure 8 indicates CARIBU EBIS charge breeder operational point.

Photograph of the e-gun assembly during factory commissioning is presented in Figure 10.

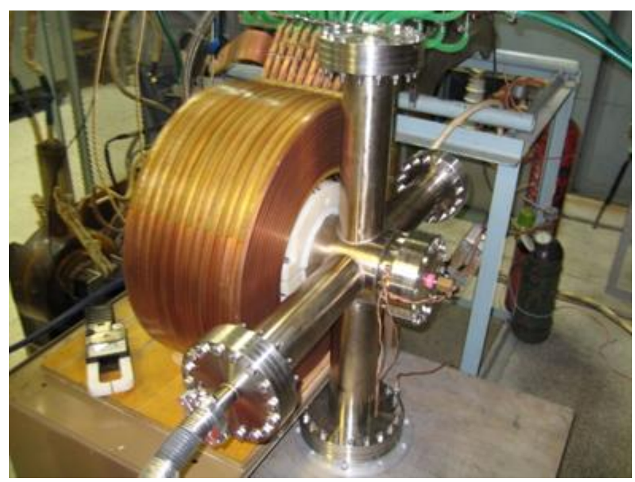

Figure 10: Photograph of e-gun assembly during factory commissioning.

A pulsed negative voltage with a duration of about 10 μs was applied between e-gun cathode and grounded anode. Electron beam current was measured by current transformer. Pulse shapes of the applied voltage and electron beam current are presented in Figure 11.

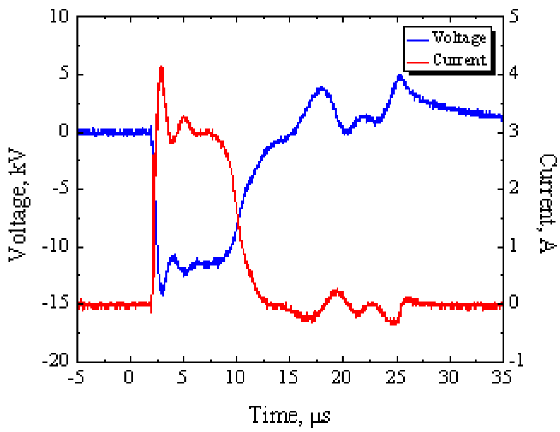

Figure 11: Pulse shapes of applied voltage and electron beam current.

The dependences of electron beam current on applied cathode-anode voltage are reported in Figure 12 for different cathode heating power.

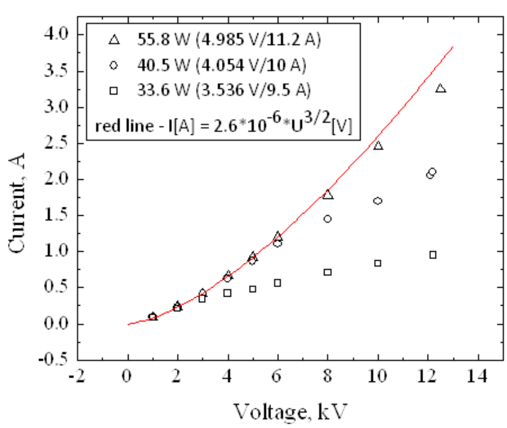

Figure 12: Dependences of electron beam current on applied cathode-anode voltage for different cathode heating power.

As one can see, electron beam current exceeds 3 A for cathode-anode voltage of 12 kV. The perveance of the e-gun was found to be equal to $2.6 \cdot 10^{-6}$ $A/V^{3/2}$. Experimental data was in good agreement with results of e-gun simulations using SAM code [10].

SUMMARY

The EBIS charge breeder is an excellent choice for acceleration of CARIBU radioactive ion beams by ATLAS and should provide high efficiency, short breeding times and superior purity of accelerated beams. Design of the CARIBU EBIS charge breeder has been completed. Manufacturing and procurement of different components and sub-systems are currently in progress. A 6 T superconducting solenoid and a high-perveance e-gun have been recently commissioned and met all specified parameters.

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