THE LIGHT ION GUIDE CB-ECRIS PROJECT AT THE TEXAS A&M UNIVERSITY CYCLOTRON INSTITUTE

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Abstract

Texas A&M University is currently configuring a scheme for the production of radioactive-ion beams that incorporates a light-ion guide (LIG) coupled with an ECRIS constructed for charge-boosting (CB-ECRIS). This scheme is part of an upgrade to the Cyclotron Institute and is intended to produce radioactive beams suitable for injection into the K500 superconducting cyclotron. The principle of operation is the following: the primary beam interacts with a production target placed in the gas cell. A continuous flow of helium gas maintains a constant pressure of 500 mbar maximum in the cell. Recoils are thermalized in the helium buffer gas and ejected from the cell within the gas flow through a small exit hole. The positively charged recoil ions (1^+) are guided into a 2.43 m long rf-only hexapole and will be transported in this manner on-axis into the CB-ECRIS (Charge Breeding – ECRIS). The CB-ECRIS will operate at 14.5 GHz and has been specially constructed by Scientific Solutions of San Diego, California for charge-boosting [1]. An overall image of the entire project will be presented with details on different construction phases. Specific measurements and results will be presented as well as future developments.

PROJECT OVERVIEW

In 2005 the Cyclotron Institute at Texas A&M University initiated a facility upgrade project [2]. This project will extend the research capabilities as a stable beam facility with moderate rare beam capabilities. This will be achieved by re-activating the 88” Cyclotron to deliver high intensity light-particle and heavy-ion beams, to be used for production of rare isotopes for acceleration in the existing K500 Cyclotron. The plan is to produce radioactive species for re-acceleration by the existing K500 Cyclotron. The main items of the scientific program that drive this project are summarized as: nuclear astrophysics (the extension of the Asymptotic Normalization Coefficients method and study of the (^{3}He,d) reactions), nuclear structure (study of the Giant Monopole Resonances and the cluster structure of the nuclei using the radioactive beams), fundamental interactions and nuclear thermodynamics (multifragmentation). We are expecting also to gain valuable experience in the development of radioactive ion sources and different methods of diagnosis for weak beams.

The project is divided in three tasks: a) recommission of the existing 88” Cyclotron and install new beam lines; b) construct light-ion and heavy-ion guides and produce and transport 1^+ radioactive ions; c) charge boost radioactive ions, transport and accelerate in the K500 Cyclotron. Table 1 presents the new beams intended to be developed using the Light Ion Guide (LIG).

Table 1: Projected beam intensities from the LIG after K500 re-acceleration.

(p,n) reaction Product $T_{1/2}$	**Max Energy** [MeV/A]	**Intensity** [particles/sec]
^{27}Si (4.16s)	57	4×10^4
^{50}Mn (0.28s)	45	1×10^5
^{54}Co (0.19s)	45	4×10^4
^{64}Ga (2.63m)	45	2×10^5
^{92}Tc (4.25m)	35	2×10^5
^{106}In (6.20m)	28	4×10^5
^{108}In (58.0m)	28	2×10^5
^{110}In (4.9h)	26	4×10^5

PRODUCTION OF RADIOACTIVE IONS

The Light-Ion Guide (LIG) will produce radioactive species mainly from (p,n) reactions. The beam (a proton beam around 30 MeV) interacts with a production target (e.g. ^{27}Al) placed in a gas cell. In the gas cell helium gas is flowing continuously at constant pressure of 500 mbar maximum. The recoil ions (e.g. ^{27}Si from ^{27}Al(p,n)^{27}Si)) are trapped in the buffer gas and ejected at a 90° direction (with respect to the beam direction) through a small exit hole [3]. All ions created in the gas cell are collected and transported by a rf-only hexapole: a resonant structure similar to the RFQ in a residual gas analyzer. The large flow of helium gas is evacuated by a differential pumping system. The ions are then injected into a Charge Breeding ECRIS (CB-ECRIS) source which will ionize them to higher charge states. The radioactive species are injected into the K500 Cyclotron and re-accelerated. The primary beam (proton beam) will exit the gas cell and will be stopped in the beam dump. Figure 1 shows an engineering drawing of the LIG coupled with the CB-ECRIS. The main new feature of the device is the rf-only hexapole with a length of 2.43 m. Extensive calculations performed with SIMION [4] software confirm early theoretical approaches [5] where it was shown that all the particles entering the central region of the hexapole should have almost 100 % transport efficiency. The rf-only hexapole is non-selective device, meaning that all ions, singly and possibly doubly charged, as well

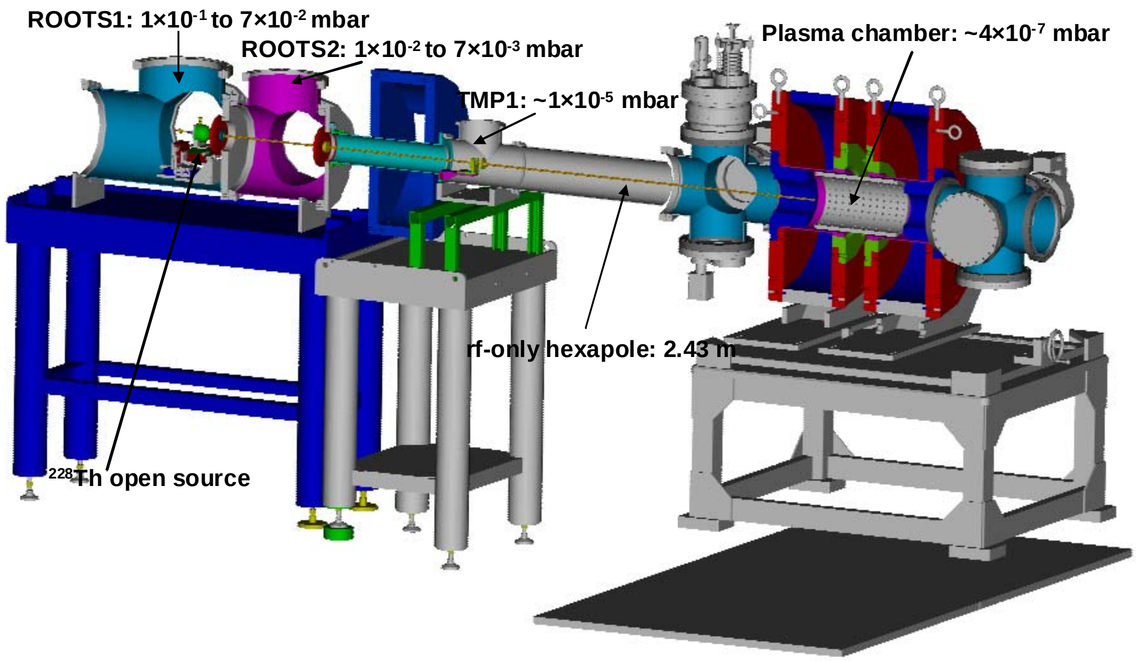

Figure 1: Engineering drawing of the Light Ion Guide coupled with the CB-ECRIS.

molecular ions, are transported with the same efficiency, independent of their mass-to-charge ratio.

DEVELOPMENT OF THE LIGHT ION GUIDE

At the Cyclotron Institute we developed, built and tested a prototype of the Light Ion Guide that will only suffer minor modifications for future operation. The vacuum system consists of two large chambers and a 2 m long beam tube for connection to the CB-ECRIS. The chambers are pumped with ROOTS blowers (2000 m^3/h and 1000 m^3/h pumping speed) and the beam tube is pumped with a turbo molecular pump (520 l/s pumping speed). Two similar turbo pumps are coupled also at the injection and extraction side of CB-ECRIS. Figure 1 indicates the helium pressures in the different sections of the device.

Inside the first vacuum chamber, stands a semispherical gas cell (volume of about 50 cm^3) with an exit orifice: 1 and 2 mm in diameters were used. Between the cell exit and the inlet of the CB-ECRIS plasma chamber is a 2.43 m long rf hexapole divided into three sections: two of 1 m and one of 0.43 m. The hexapole is made from 2 mm brass rods placed on a circle pattern with diameter of 6 mm (equivalent with an interior diameter of the hexapole of 4 mm).

The device was initially developed with ionized gas created by two high-voltage spark electrodes inside the gas cell. We were able to produce a few mA of current, mainly ionized helium and ionized impurities. The transported current (a few nA) was measured at the end of the rf hexapole on a Faraday cup. Figure 2 presents, as an example, a graph of the transported current at the end of the first 1 m long section rf hexapole as a function of the pressure inside the gas cell. The discharge voltage and current were 227 V and about 3.5 mA, respectively. The production of the ions via the spark method has drawbacks: the high voltage needed to ignite the spark accelerates the ions, and at the end of the rf hexapole the ions gain about 180 eV in energy. This energy is too high for the injection into the CB-ECRIS.

In order to eliminate the described feature, and reproduce more closely the future on-line operation, we decided to use an open radioactive source (^{228}Th) as the recoil-ion source. An effort to use a heated alkali source was unsatisfactory due to the fact that the continuous flow of helium in the gas cell prevents attaining the temperature where the alkali source will start releasing the products.

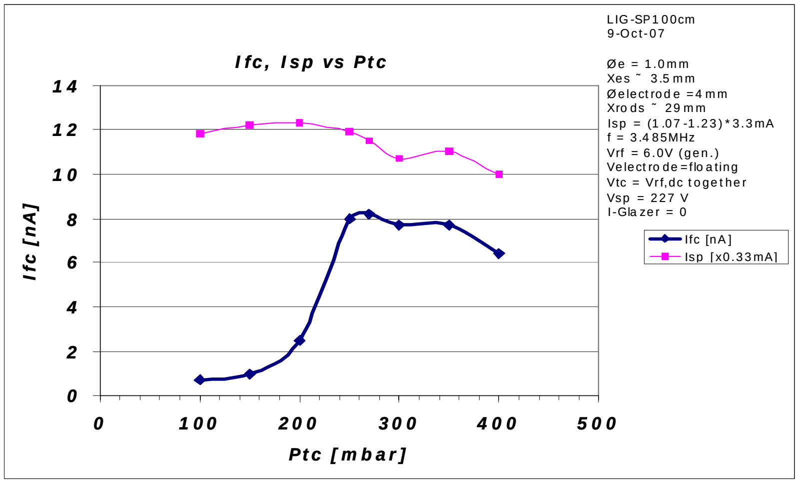

Figure 2: Faraday Cup current (Ifc) vs. the pressure in the gas cell (Ptc).

Inside the gas cell the daughters from ^{228}Th are released continuously and they are thermalized by the helium gas. In order to have maximum stopping efficiency of the radioactive products, a pressure of 30 mbar of helium was used. The daughters are injected into the rf-only hexapole within helium flow by applying a small (approx. 10 - 50 V) acceleration (guiding) voltage between the cell exit and the hexapole inlet. The same voltage will control the injection energy of the recoil ions into CB-ECRIS plasma chamber. In this preliminary experiment the recoil ions were transported to a collector plate (aluminized mylar), placed at the inlet of the CB-ECRIS plasma chamber. The collector plate is backed by a silicon detector. The alpha particles coming from the products pass through the collector plate and are detected with the Silicon detector. The decay series of ^{228}Th include ^{216}Po with a half life of 145 ms. This is an excellent candidate to test our device: the half-life is short enough to provide a reasonable counting rate and is long enough to be charged boosted in the CB-ECRIS. The first tests, without CB-ECRIS plasma, were successful: we were able to measure about 100 alphas/sec coming from the ^{216}Po. We measured also the energy of the ^{216}Po ions, and found that the energy spread is only around 1 eV (see Figure 3). This extra energy will have to be taken into account for stopping the products in the plasma of the CB-ECRIS. The extraction of radioactive highly charged ions will be attempted in future experiments when the CB-ECRIS will be operational.

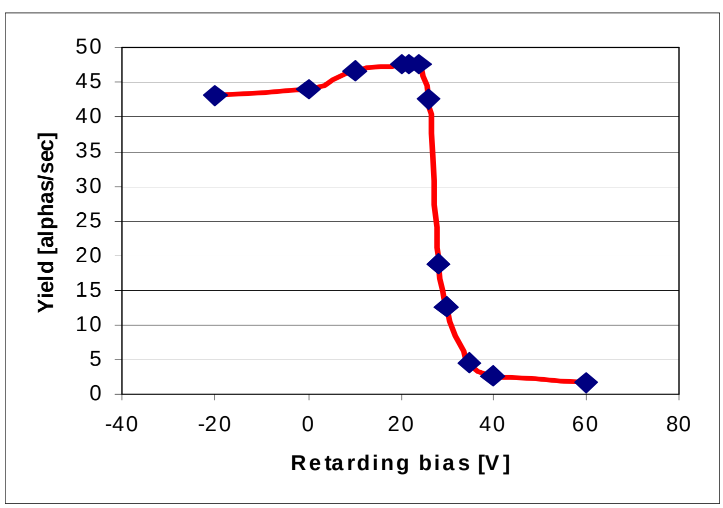

Figure 3: The retarding bias is a measure of the energy of the ions. The radioactive products exhibit an energy of 20-25 eV approximately. The acceleration voltage was 24 V.

FUTURE PLANS

Much further development of this system is necessary before it can produce a usable beam of highly charged radioactive ions with high efficiency for further re-acceleration in the K500 cyclotron. Two major directions should be followed to achieve the proposed efficiencies. The first is to find optimum parameters in the operation of the gas cell in conjunction with the rf-only hexapole. We need to determine the factors that will lead to high efficiency extraction of the radioactive products from the gas cell and high efficiency transport of the products to the CB-ECRIS. The second direction is to determine the ideal conditions for injection and extraction of the highly charged products from the CB-ECRIS with maximum efficiency. In pursuing these two directions the efficiencies of different sections of this system need to be measured along with finally the efficiency of the entire system.

Acknowledgments

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