# PROGRESS TOWARD THE FACILITY UPGRADE FOR ACCELERATED RADIOACTIVE BEAMS AT TEXAS A&M*

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*Abstract*

The upgrade project at the Cyclotron Institute of Texas A&M University continues to make substantial progress toward the goal of providing radioactive beams accelerated to intermediate energies by the K500 Cyclotron. The K150, which will function as a driver, is now used extensively to deliver both light and heavy ion beams for experiments. The ion-guide cave for the production and charge-breeding of low-energy radioactive beams has been constructed, and the light-ion guide (LIG) has been commissioned with an internal radioactive source. The charge breeding electron-cyclotron-resonance ion source (CB-ECRIS) has been commissioned with a source of stable 1+ ions, while the injection line leading to the K500 has been commissioned with the injection and acceleration of charge-bred beams. Despite the lack of good field maps, both light and heavy ions beams have been developed for the K150. Progress and plans, including those for the heavy-ion guide (HIG), are presented.

## INTRODUCTION

The Texas A&M Cyclotron Institute has been in the process of upgrading the facility since 2005 [1, 2]. The scheme is the following (Fig. 1):

1. The K150 provides either an intense beam of light ions (p, d, α) to a target in the LIG chamber or an intense beam of heavy ions (e. g. argon) to a target in the BIGSOL superconducting-solenoid spectrometer.
2. Products from the target directly enter a helium gas flow in the case of LIG, or in the case of HIG the products are focused through an entry foil in the HIG chamber.
3. Products in either chamber are stopped by the helium and extracted by the helium flow. Since in helium the products remain ionized, after they exit the stopping chamber they are guided by a multipolar rf structure and formed into a beam. The neutral helium is pumped away.
4. This low-charge-state beam of products is focused inside of CB-ECRIS where the products are stopped in the plasma and further ionized by the energetic electrons.
5. Extracted beam from CB-ECRIS is analyzed and a beam of one charge-state is injected into the K500.

Recent progress has focused on: a) improving the intensity and variety of beams from the K150 Cyclotron, which will be used as a driver for the production of short-lived isotopes, b) outfitting the ion-guide cave where these isotopes will be produced and charge-boosted by CB-ECRIS and c) finishing the low-energy injection line connecting CB-ECRIS with the K500 Cyclotron. In conjunction with these tasks a variety of beams have been developed along with a better comprehension of the K150 magnetic fields, charge-breeding has been successfully demonstrated with the CB-ECRIS and the injection-line has been commissioned with beams traveling from source to cyclotron.

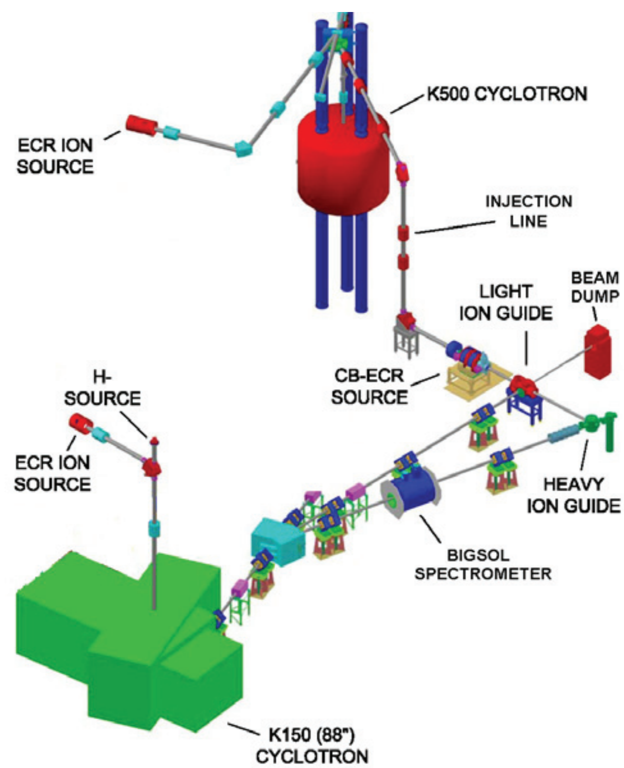


Figure 1: Simplified layout of the Texas A&M Radioactive Beam Facility.

## K150 CYCLOTRON

For acceleration by the K150 Cyclotron a multi-cusp ion source produces negative ions of hydrogen and deuterium which are extracted from the cyclotron by stripping to obtain proton and deuteron beams. A two-frequency (14GHz plus 11GHz) ECRIS produces positive-ion beams. The mass and energy range of K150 beams is illustrated by Fig. 2 and includes both first-harmonic and second-harmonic beams (≤ 5 AMeV).

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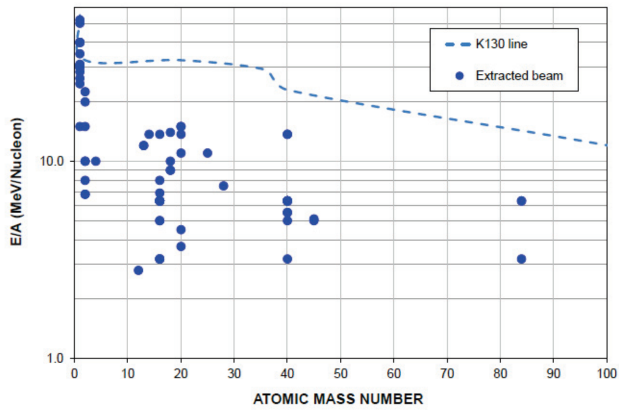


Figure 2: K150 developed beams.

### *Beam Tuning*

Trim-coil currents for the K150 are predicted, as at the LBNL 88" cyclotron, using the code CYDE [3]. Also as at LBNL, the predicted currents have often not been completely accurate, as evidenced by the failure to reach the extraction radius of 39 in., and have only served as a starting point for tuning. Both Texas A&M and LBNL use magnetic field maps made in the 1960's at LBNL with an upper limit of K130 [4].

Under the assumption that there is some degree of inaccuracy in these maps, the field has been modelled in 3D using the TOSCA code. Figure 3 shows a comparison of plots of the average field versus radius taken from the CYDE maps and from TOSCA calculations, justified for both at R=36 in. The difference between the two plots of about 40 gauss in magnitude can be accommodated with an additional 200 A contribution from one of the outer trim-coils, either coil 13 or coil 14. Coil 17 is the outermost. In practice for beams in this field region, the best tune is achieved with an approximate extra 200 A on trim-coil 14 and an approximate 50 A on trim-coil 7.

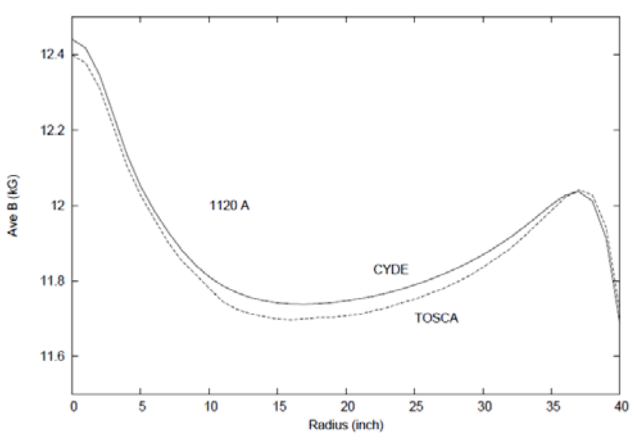


Figure 3: Average radial field measured and calculated.

### *Cryopanel*

A cryopanel for extra pumping close to the median plane was recently installed in the K150. The panel occupies an area of 0.55 $m^2$ from R= 10 in. to R= 70 in. below the median plane (Fig. 4). Since coolant plumbing had not been fabricated the panel was tested with $LN_2$ from a dewar. The intensity of a 6.3 AMeV beam of $^{84}Kr^{23+}$ increased by an approximate factor of 30 with this extra pumping

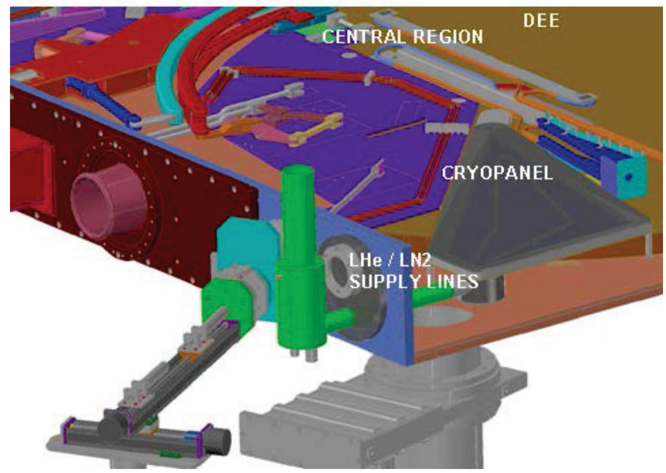


Figure 4: Location of K150 cryopanel.

## CHARGE-BREEDING

The heavy-ion guide has been described elsewhere [5], and the operation of the Texas A&M light-ion guide has been demonstrated with radioactive-decay products from a thorium source [6]. Charge-breeding, which is necessary to obtain the charge-states for the short-lived isotopes, has now been demonstrated with CB-ECRIS [7]. For capture in the ECR plasma to occur both the low-charge-state beam energy and optics must be carefully matched to CB-ECRIS. Specifically, the low-charge-state beam energy must within plus/minus a few volts of the CB-ECRIS extraction voltage plus a small (tens of volts) positive plasma voltage. The optics must be such that the ions are focused at the entry point but are not reflected by the strong magnetic gradient after the defocusing of deceleration. High-charge-state ions escaping from the plasma through the extraction aperture can now be formed into a beam. Magnetic analysis selects one charge-state for injection into the K500.

Charge-breeding was tested using an aluminosilicate ion gun fabricated by HeatWave Labs, Inc. for the production of singly-charged alkali ions. Between the ion gun and CB-ECRIS are an electrostatic x-y steerer, an Einzel lens, a Faraday cup, a grounded, funnel-shaped tube and a separately biased tube positioned immediately before the plasma-chamber entrance aperture (Fig. 5). Not shown is a grounded shield for the metal gas-feed tube.

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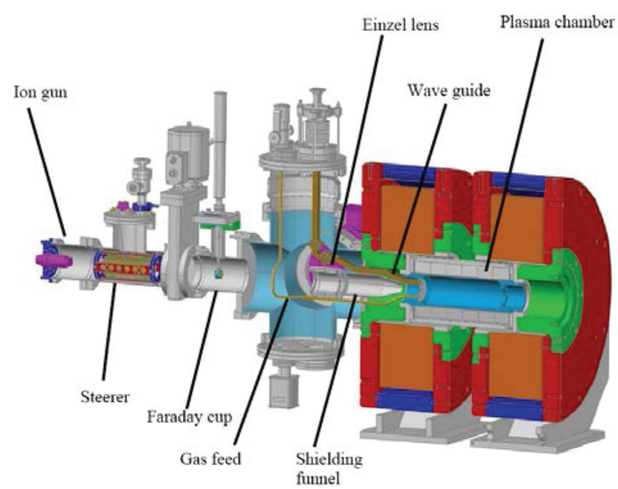


Figure 5: Injection line into the CB-ECRIS.

Beams of sodium, potassium, rubidium and cesium were successfully charge-bred. Figure 6 shows superimposed spectra with the cesium beam injected and not injected. The large peaks are due to the oxygen support gas and to carbon and nitrogen contaminants. The intensity of the 24+ charge-state of cesium is 170 nA.

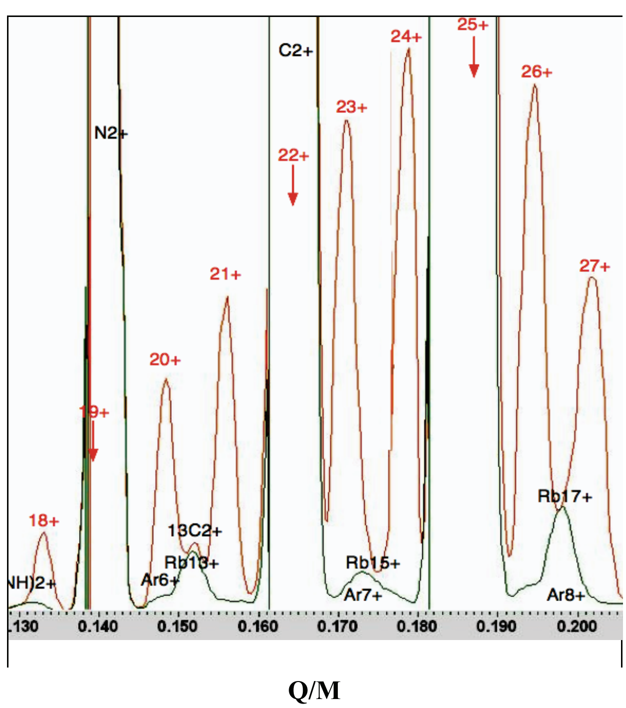


Figure 6: Spectrum of charge-bred cesium.

## CYCLOTRON RIB INJECTION LINE

The injection line from the CB-ECRIS analysis point to the median plane of the K500 is approximately 20 meters in length, and the vacuum is in the low $10^{-8}$ torr vacuum range. Charge-bred beams of $^{85}Rb^{15+}$, $^{85}Rb^{17+}$ and $^{133}Cs^{24+}$ were injected into the K500 through the recently completed RIB injection line and accelerated to 10 AMeV, 15 AMeV and 10 AMeV, respectively, with about 12% efficiency from ECRIS analysis to extracted beam.

## FUTURE PROGRESS

With the refurbishing of a LHe refrigeration system the cryopanel will eventually be supplied with LHe or cold helium gas. Beam intensities of negative ions as well as heavy ions should be substantially enhanced with the increased pumping. The program to study the K150 magnetic field is on-going and should result in improved field maps. This will make beam tuning closer to tuning the K500, which is totally predictable. Since no field maps exist for the new field limit of K = 150 it is imperative to be able to understand the fields at this level.

The HIG stopping-chamber has been constructed and assembled at Argonne National Laboratory and delivered. The HIG line is currently being assembled with the recently upgraded BIGSOL solenoid ready to be moved into position. When this is done and the LHe supply for BIGSOL readied, the cell will be tested with beam. Eventually HIG will require much higher intensities of heavy-ion beams from the K150 which will require improvements in the ECR ion source, the cyclotron tunes and the cyclotron vacuum.

The aluminosilicate ion gun has been removed, the light-ion guide has been electrically isolated so that it can match the extraction potential of CB-ECRIS, and the line between LIG and CB-ECRIS has been assembled. Currently the investigation of matching the beam from LIG to injection into CB-ECRIS is ongoing using stable ions that have been ionized by K150 heavy ion beams in the LIG stopping-chamber. The next step is to use light ions for radioactive ion production for acceleration by the K500.

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