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An ECR Charge Breeder for the ^{252}Cf Fission Source Project (CARIBU) at ATLAS*

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Abstract A new radioactive beam facility for ATLAS, the Californium Rare Ion Breeder Upgrade (CARIBU), is under construction. The facility will use fission fragments from a 1 Ci ^{252}Cf source; thermalized and collected into a low-energy beam by a helium gas catcher. In order to reaccelerate these beams, the existing ATLAS ECR-I ion source is being redesigned to function as a charge breeder source. The design and features of this charge breeder configuration is discussed and the project status described.

Key words ECR ion source, charge breeder, fission fragments, radioactive ion beams

1 Introduction

Most existing nuclear physics accelerator facilities provide good access to proton-rich nuclei but can access only the periphery of the much larger neutron-rich region. Facilities that will reach further into the neutron-rich region and provide interesting beams into the far neutron-rich region, such as the previously proposed Rare Isotope Accelerator (RIA)[1], are still years away.

In the interim, an interesting, transitional facility, based on fission fragments of ^{252}Cf can allow a large class of important measurements. Fig. 1 shows the distribution of fission fragments from ^{252}Cf[2], which covers a wide region of the neutron-rich side populating some of the most important nuclei, such as ^{132}Sn and $^{100-106}$Zr, for nuclear physics studies. In addition the mass distribution of ^{252}Cf is quite complimentary to that of proton or neutron-induced uranium fission[2].

At Argonne National Laboratory, a new ATLAS improvement project is now under construction. The Californium Rare Ion Breeder Upgrade (CARIBU) will thermalize fragments from fission of ^{252}Cf to provide nuclei which will be thermalized in a helium gas-catcher, mass separated and injected into an ECR charge breeder to raise their charge state sufficiently for subsequent acceleration in the ATLAS superconducting linear accelerator.

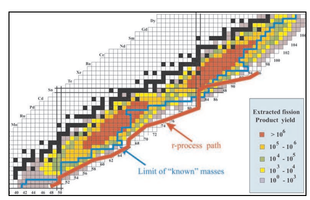

Fig. 1. Distribution of fission products from the spontaneous fission of ^{252}Cf. The color code gives the extracted low-energy ion beam intensity (s-1) for a 1 Curie source.

The maximum energy available after acceleration in ATLAS for these beams will be typically 10.5 to 12.5MeV/u allowing transfer reactions with good angular distribution signatures to be observed. Intensities will range up to a maximum of $4\times10^5 s^{-1}$.

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219 — 222

In this paper, we will provide a description of the design of the ECR charge breeder ion source to be used in this project. This source is based on the redesign of an existing ATLAS stable-beam ECR source[3] and is mounted on a high voltage isolation platform to provide the necessary velocity to match the velocity profile of the first ATLAS linac resonator.

The overall CARIBU facility is shown in Fig. 2. The 1Ci ^{252}Cf source will be mounted in a heavily shielded cask assembly attached in a helium gas catcher/RFQ ion guide which will thermalized the fission fragments and deliver them to an isobar separator after a 50kV acceleration. The isobar separator, with a mass resolution of 1:20,000, will be located on the first high voltage platform along with the source and helium gas catcher. This system is to be located in a new building addition allowing isolation from the rest of the facility.

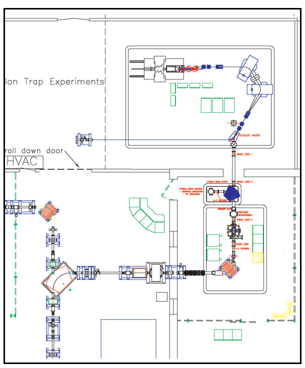

Fig. 2. Schematic overview of the proposed ^{252}Cf fission fragment beam facility.

After analysis by the isobar separator, the mass analysed beam is delivered to the ECR charge breeder through an electrostatic transport beam line system.

2 The ECR source and modifications required for charge breeding

The ATLAS ECR-I ion source will be modified to serve as a charge breeder for the CARIBU project. ECR-I has been serving as one of two stable beam ion sources for ATLAS operating at 10GHz fundamental frequency and often in a two-frequency mode using 14GHz RF as well.

The modifications required for ECR-I to serve as a charge breeder are in two major areas. First the injection side components must be redesigned to allow delivery of the low charge-state beam from the isobar separator. These modifications include reshaping the iron in the injection region, relocation of the RF waveguides and modification or elimination of the biased disk. Second, the source insulation will be redesigned to allow operation at 50kV. The high bias voltage is required in order to achieve the desired mass resolution with the isobar separator. Since this is a modification of an existing source, the physical space available for upgrading the high voltage isolation materials was limited.

The low charge state ions are to be delivered into the source through a 25.4mm diameter transfer tube. To provide adequate high voltage isolation for this tube, a 38mm diameter section of the on-axis iron has to be removed. The removal of this iron in the central injection region of the source will reduce the peak mirror field by 18% to a value of 1.3T, accompanied by a decrease in the mirror ratio from 4.27 to 3.49. The transfer tube also limits the functionality of the biased disk, and tests will be performed to determine if the disk can be successfully modified or should be removed from operation.

To minimize any further iron loss, as well as to eliminate conflicts in the injection region, the RF waveguide feeds will be moved from an axial to a radial launch configuration. This is accomplished by utilizing the large radial ports (40×17mm^2 slots) which access the plasma between the hexapole bars. The six radial slots allow the simultaneous launching of multiple frequencies as well as the introduction of solid materials into the plasma in the original design.

Significant changes are required in order to sustain a 50kV bias. The penetration of the transfer tube, which is at ground potential, necessitates a 50kV Lexan isolator between the transfer tube mount and the injection region of the source. The 6.3mm gap between the transfer tube and the injection side iron should be sufficient to hold 50kV, but allowances have been made for the insertion of an isolator in this region to improve the voltage hold-off.

The plasma chamber and its associated vacuum vessel are at 50kV potential with the solenoid coils at ground. For test purposes, a replica was made of the source region where the tubular insulator surrounding the plasma chamber meets the sheet insulator which separates the plasma tank vacuum vessel from the solenoid iron. With several joints in this region, and a transition in insulating materials, this was the most difficult section of the source to modify.

The eventual solution consists of a combination of materials. The tubular insulator will be constructed of polyvinyl chloride (PVC) Type-I, Grade-I tube which has a wall thickness of 3.0mm. The insulating ring which transitions the tubular insulation to the planar insulation will be constructed of chlorinated polyvinyl chloride (CPVC) due to its better mechanical properties. The joint between the tubular insulator and the transition ring is made with standard PVC glue. The planar insulator will be a low density polyethylene (LDPE) sheet which is 3.2mm thick. The configuration was tested off-line using the source replica and held 75kV for four days with no sparks.

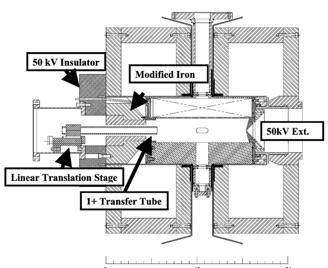

Fig. 3. Cross-section of the modified ECR-I into a charge breeder. Shown are the modified injection iron plug, and ‘deceleration tube’. Changes to the insulation required to achieve 50kV operation are shown in pink.

Other sections of the source will be modified as well. The isolator for the turbo pump will be upgraded using a commercially available alumina insulator. The gas feed isolators will be upgraded as well. The alumina insulator on the extraction side of the source will be modified to eliminate possible surface paths. This is accomplished by having an integral ring on the insulator which shields the plasma chamber from the extraction region iron. The new configuration of the source showing these changes is shown in Fig. 3.

The RF high voltage isolators will be improved as well. The present configuration utilizes a Teflon sheet sandwiched between Lexan rings. This basic design will be improved upon by increasing the diameter of the Lexan rings to increase the surface path and increasing the thickness of the Teflon sheet.

3 Beam optics

3.1 Injection optics and injected beam properties

The beam properties expected from the gas catcher/RFQ system are very good. Transverse emittance has been measured to be approximately 3πmm·mr in similar systems and the beam energy spread is expected to be ≈1eV. The ion charge state emerging from the gas catcher will be either 1+ or 2+ depending on the species.

The beam transport from the exit object of the isobar separator to the ECR source employs only electrostatic elements. After a 30 degree bend by an electrostatic analyzer, the beam is refocused with three Einzel lenses for injection into the source. In addition, a stable-beam source system must also match into the transport optics from the isobar separator.

The optics of the deceleration gap has been studies using the program SIMION[4]. SIMION was augmented with an add-on program that mapped in the solenoid magnetic field from the ECR source. The electric fields of all beam line components were calculated by SIMION and then representative ions were traced through the resulting system. Not included in the calculations were space charge effects and scattering in the plasma.

The optics from the transfer is quite simple and is shown in Fig. 4. Two intermediate foci allow a small beam focus to be created at the point of deceleration. This final focus is quite small, ∼0.2mm radius, but this is dominated by the strong focusing effect of the single deceleration gap.

The optics was explored for a number of conditions. The example shown in Fig. 4 has no well defined deceleration gap, allowing the field lines to terminate on the chamber walls. Also explored was a case with a well-defined deceleration gap similar to having a biased disk (with a central hole) 10mm beyond the end of the transfer tube. This produced a shift in the position of the sharp focus, moving it approximately 1 cm away from the plasma. Otherwise the trajectories were quite similar to those shown in Fig. 4. So long as a good focus is created at the deceleration point, we achieve 100% transfer to the capture point.

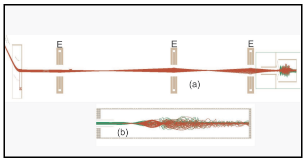

Fig. 4. (a) Beam optics at 50keV for A=100 1+ beam transported from the isobar separator image waist, refocused with einzl lenses, and decelerated into ECR-CB. (b) Enlarged region of the deceleration gap showning the sharp focus from the deceleration gap.

3.2 Extraction optics

The extraction optics has been modeled with the program KOBRA3-INP[5]. An example of the calculated optics is shown in Fig. 5. The optics modeled

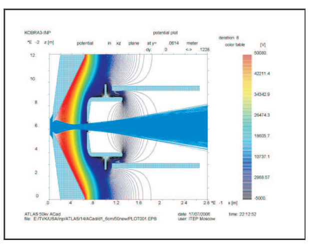

Fig. 5. Extracted beam profile calculated with KOBRA3-INP for A=150 and an extraction voltage of 50kV. The color chart on the right gives the electric field strength in the gap.

is a simple accel-deccel extraction geometry with a variable position biasable puller as in the present source which now operates at ~14kV extraction voltage for most cases. In these calculations, the puller was biased to -5kV. The calculations indicate that this simple geometry provides excellent beam properties at 50kV. In fact the higher voltage situation appears to be an improvement over the present optics.

4 Commissioning and stable beam injection

At least two stable-beam sources are planned for use both during commissioning of the new source and for normal operation to 'tune' the source in preparation of injecting the desired fission-fragment beam from the isobar separator. These will be provided by sources mounted on a stable-beam source platform shown in Fig. 2. The optics is designed to match into the source injection line so as to closely mimic the optics of the fission-fragment beams.

The two stable beam sources planned for at this time are a commercially available surface ionization source[6] and an RF discharge source adapted from an older design in use at ANL on another accelerator. A third possible source is a low-frequency ECR source.

Diagnostics to monitor the injected beam and the high charge-state beam will be an integral part of the system as well. Both 'normal' intensity and weak beam diagnostics will be provided in the injection beam line and in the high charge-state extraction beam line. These diagnostics will include beam current monitors, profile monitors and emittance measuring devices. In addition a tape station is planned at the isobar separator exit waist and the diagnostics station off the platform as shown in Fig. 2.

5 Project status

The CARIBU project was initiated in January, 2006. The ECR charge-breeder plans have undergone outside review and the project is now under construction. First beam from the charge breeder using stable beams from the stable-beam sources is planned for April, 2007.

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