Initial Results of the ECR Charge Breeder for the $^{252}\text{Cf}$ Fission Source Project at ATLAS

ECRIS08
September 15-18, 2008
Richard Vondrasek, John Carr, Richard Pardo, Robert Scott
Overview

- The CARIBU project overview
- Charge breeder system
  - Stable sources, beamline, ECR source
- Results
  - Initial results with Cesium
    - Faraday cup problems
    - Background effect
  - Recent results with Cesium and Rubidium
- Future plans
The CARIBU project – CALifornium Rare Ion Breeder Upgrade

In its final configuration, a 1.0 Ci $^{252}$Cf fission source will provide radioactive species to be delivered to the ECR ion source for charge breeding.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life (s)</th>
<th>Low-Energy Beam Yield (s$^{-1}$)</th>
<th>Accelerated Beam Yield (s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{104}$Zr</td>
<td>1.2</td>
<td>$6.0 \times 10^{5}$</td>
<td>$2.1 \times 10^{4}$</td>
</tr>
<tr>
<td>$^{142}$Ba</td>
<td>14.3</td>
<td>$1.2 \times 10^{7}$</td>
<td>$4.3 \times 10^{5}$</td>
</tr>
<tr>
<td>$^{145}$Ba</td>
<td>4.0</td>
<td>$5.5 \times 10^{6}$</td>
<td>$2.0 \times 10^{5}$</td>
</tr>
<tr>
<td>$^{130}$Sn</td>
<td>222.</td>
<td>$9.8 \times 10^{5}$</td>
<td>$3.6 \times 10^{4}$</td>
</tr>
<tr>
<td>$^{132}$Sn</td>
<td>40.</td>
<td>$3.7 \times 10^{5}$</td>
<td>$1.4 \times 10^{4}$</td>
</tr>
<tr>
<td>$^{110}$Mo</td>
<td>2.8</td>
<td>$6.2 \times 10^{4}$</td>
<td>$2.3 \times 10^{3}$</td>
</tr>
<tr>
<td>$^{111}$Mo</td>
<td>0.5</td>
<td>$3.3 \times 10^{3}$</td>
<td>$1.2 \times 10^{2}$</td>
</tr>
</tbody>
</table>
The CARIBU project

- Fission products are collected and thermalized in a helium gas catcher
  - ~20% of all activity extracted as ions
  - Mean delay time <10 msec
  - Extraction is element independent
  - Provides cooled bunched beams for post acceleration
    - Energy spread <1 eV
    - Emittance ~3 π·mm·mrad

- High resolution mass analysis (1:20,000) limits the number of isobars in the analyzed beam
  - To achieve the required resolution, beam extraction must occur at ≥50 kV
  - Must maintain a voltage stability of ±1 V
Transfer line and stable beam source

- Transfer line
  - Three einzel lenses with emittance measurement station and weak beam profile and current monitors
  - Image points of transfer line and stable beam source are matched

- Stable beam sources
  - Surface ionization
    - For metals
  - RF discharge source
    - For gases

50kV A=100 Single Gap de-celeration
Lens1 17.5; Lens2 21kV; Lens3 23kV
Increase Source voltage to 50.00kV
Focusing electrode optics, apt dia=24 mm
Stable beam sources

- **HeatWave HWIG-250**
  - 15 keV beam of over 1.0 µA
  - Spot size: <1 mm² at 2.5 cm from aperture
  - Pellet materials: Li, Na, Mg, K, Ca, Rb, Cs, Ba, Sr

- **RF discharge source**
  - Source has been run off line providing 1-2 eµA beams of Ne, Ar, Kr, and Xe
  - Expect a larger emittance but can be controlled with slits
Source modifications for charge breeder operation

- Improved the high voltage isolation for 50 kV operation
- Modified the injection side of the source to accept low charge state beams
  - Removed the central iron plug to allow for transfer tube penetration
  - Moved the RF injection from an axial to a radial position
    - *Open hexapole allows radial RF injection*
    - *Provides more iron so that the magnetic field on injection side is symmetric*
  - Reshaped the remaining iron to improve $B_{\text{inj}}$
Injection side configuration

- Lexan insulator provides structure with an alumina liner exposed to vacuum
  - Base pressure: 2.0x10^{-8} Torr
    - Increases to 1.7x10^{-7} with plasma on
- Movable transfer tube
  - Highly polished stainless steel
  - 3.15 cm of travel
  - Originally placed just outside of the magnetic maximum
    - Resulted in drain current of 4.0 mA at 50 Watts and unstable source operation
  - Retracted position by 4.0 cm
    - Drain current decreased to 0.3 mA and source operation stabilized
**High voltage relationships and stability**

- High voltage platforms will be energized by a single power supply (300 kV, 2.5 mA)
  - Beam pipe links the two platforms together ensuring common potential
- Source heads will be energized by separate high voltage power supplies (65 kV, 5 mA)
  - Flexibility to operate in “Stand Alone” mode → low energy traps, source development
  - Decouples any influence of ECR plasma fluctuations on the californium bias voltage
    - Ensures $\pm1.0$ V voltage stability for isobar separator
- Additional $\pm175$ V power supply (‘tweaker’) is in series with the ECRCB
- Feed back controller ensures voltage match between the Cf and ECRCB source heads
  - Adjusts the ‘tweaker’ supply to match the source potentials (nominally 50 kV)
  - Then an additional voltage is summed in to optimize the 1+ ion capture
High stability power supply

- Power supply specifications for charge breeder
  - 65 kVDC, 5 mA
  - Stability: $\leq 0.001\%/K + 20$ mV ($\leq 0.67$ V $\rightarrow$ 1.34 V window)
    - Supply passed factory acceptance test
    - In house testing shows $\leq 0.500$ V deviations at 50 kV
  - Ripple: $< 0.005\% + 20$ mV p-p ($\leq 3.45$ V p-p)
    - Supply passed factory acceptance test
    - In house testing shows $< 0.500$ V p-p ripple at 65 kV
      - Gas catcher power supply will have $< 0.001\% + 20$ mV p-p ripple specification ($\leq 0.67$ V p-p)
**In house stability test**

- Took ~1 hour for supply to warm up and voltage to settle within 1.0 V window
- Voltage stayed within 1.0 V window for 24 hours
**Cesium charge breeding spectrum**

- We achieved our first charge bred beam in May 2008
- Mass spectrum of the ECRCB output with and without Cs\(^+\) injection
  - Background beam, without Cs\(^+\) injection, is shown in brown
  - Other traces represent varying levels of charge bred cesium as a function of the Cs\(^+\) input intensity
Charge bred cesium beam – “initial results”

<table>
<thead>
<tr>
<th>Charge state</th>
<th>Efficiency</th>
<th>Efficiency after tuning 1+ line</th>
</tr>
</thead>
<tbody>
<tr>
<td>12+</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>13+</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>16+</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>18+</td>
<td>3.8</td>
<td>7.1</td>
</tr>
<tr>
<td>20+</td>
<td>6.8</td>
<td>9.0</td>
</tr>
<tr>
<td>24+</td>
<td>2.2</td>
<td></td>
</tr>
</tbody>
</table>

- Previous results at TRIUMF using a Phoenix ECR charge breeder had 2.7% efficiency into $^{133}\text{Cs}^{18+}$
- So what can be wrong?
  - Beam currents are not being measured correctly – 1+ or n+
  - Background measurement is not accurate
**Beam current measurement**

- Using a brand new Thermionics faraday cup
- Picoammeters were calibrated and in good working order
- Built a second small faraday cup and installed it at the front of the transfer tube to check the accuracy of the Thermionics faraday cup measurement
**Beam current measurement**

- Turned the surface ionization source back on to the same settings as the “9.0% efficiency” run
  - Thermionics cup: 34 nA
  - Small faraday cup: 125 nA

- Problem one: faraday cup was not reading properly
  - Traced to an insulating layer on the tantalum charge collector generated during welding
    - Replaced tantalum piece with a stainless steel charge collector
      - Cup readings in agreement

<table>
<thead>
<tr>
<th>Charge state</th>
<th>Efficiency</th>
<th>‘Normalized’ Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>18+</td>
<td>7.1</td>
<td>1.9</td>
</tr>
<tr>
<td>20+</td>
<td>9.0</td>
<td>2.4</td>
</tr>
</tbody>
</table>
**Background measurement**

- Orange trace is with Cs\(^+\) injection
- Brown trace is with Cs\(^+\) stopped using an electrostatic steerer just after the 1\(^+\) source but before the analyzing magnet
  - Confirmed that saturating the steerer generates the same background spectrum as shutting off the 1\(^+\) source
- Red trace is with the Cs\(^+\) stopped using the faraday cup after analysis
  - Clearly see a difference in the background levels of 20\(^+\) and 23\(^+\)
**Background measurement**

- The difference in the background level is due to outgassing in the 1+ analyzing magnet and low energy line which is generated by the beam coming out of the injection side of the ECRCB
  - $^{133}\text{Cs}^{20+}$ very similar m/q as $^{40}\text{Ar}^6+$
  - $^{133}\text{Cs}^{23+}$ very similar m/q as $^{40}\text{Ar}^7+$

- For $^{133}\text{Cs}^{20+}$, with the same incoming Cs$^+$ intensity, the effect is clear
  - Saturating the steerer
    - 2.6% efficiency
  - Putting the faraday cup in
    - 6.5% efficiency

- Problem two: background measurement was not accurate
  - Due to gas loading that is not present when the faraday cup is in the beamline and intercepts the outgoing ECR beam
    - *Background measurement has to be taken by saturating the steerer*
Real results of charge bred cesium

- We now have no idea how to ‘normalize’ the previous experimental results
  - Repeat all of the measurements
    - Surface ionization source electrical isolation began to degrade
    - Poor beam optics as a result but we still collected some data
- Optimized on $^{133}$Cs$^{20+}$ using oxygen support gas and 250 W at 10.44 GHz
- Cs$^+$ beam current was 62 enA
- Also tried two-frequency heating
  - 175 W at 10.44 GHz
  - 75 W at 12.27 GHz

<table>
<thead>
<tr>
<th>Charge state</th>
<th>Single Frequency Efficiency</th>
<th>Two Frequency Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>16+</td>
<td>0.9</td>
<td>1.4</td>
</tr>
<tr>
<td>18+</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>20+</td>
<td>2.4</td>
<td>2.9</td>
</tr>
<tr>
<td>23+</td>
<td>0.5</td>
<td>1.1</td>
</tr>
</tbody>
</table>
**Charge bred rubidium beam**

- Mass spectrum of ECR ion source output with and without Rb\(^+\) injection
  - Charge bred rubidium is in red
  - Source background, with Rb\(^+\) injection stopped by electrostatic steerer, is shown in brown
  - Source background, with Rb\(^+\) injection stopped by faraday cup, is shown in green
Results of charge bred rubidium

<table>
<thead>
<tr>
<th>Charge state</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>10+</td>
<td>0.7</td>
</tr>
<tr>
<td>11+</td>
<td>0.8</td>
</tr>
<tr>
<td>13+</td>
<td>1.8</td>
</tr>
<tr>
<td>15+</td>
<td>3.6</td>
</tr>
<tr>
<td>17+</td>
<td>0.8</td>
</tr>
</tbody>
</table>

- Optimized on $^{85}\text{Rb}^{15+}$ with oxygen support gas and 270 W at 10.44 GHz
“Pepper Pot” emittance system on 2Q-LEBT

- Mask has 100, 100 µm pinholes, 3 x 3 mm spacing, working area: 27 x 27 mm
- Behind mask is CsI crystal (n80 mm) which is viewed by CCD camera
- Beam energy of 75 keV/q and current density of <1.0 eµA/cm² with Bi beam

See Sergei Kondrashev’s talk on Thursday morning
“Pepper Pot” emittance system for ECR charge breeder

- Mask has 20 µm laser drilled holes, 0.5 x 0.5 mm spacing, 40 mm diameter
- Behind the mask is a CsI crystal (40 mm)
  - Scintillator tested with a 300 nA, 10 kV beam
- Distance between the mask and the scintillator is variable
- Improved sensitivity possible with the addition of a micro channel plate/phosphor
- System is under construction
New fully rear-shielded faraday cup

- Presently using a standard Thermionics faraday cup
- The back of the charge collection cup is not shielded and “sees” the beam coming from the injection side of the ECRCB
  - This means we have to shut off the ECRCB to measure the 1+ beam current
- New cup design is fully shielded and will allow beam measurements without turning off ECRCB
The CARIBU project - status

- High voltage platform and shield cask are complete
- Isoobar separator magnets are in final testing
  - Shipment is expected in October
  - Focusing elements are complete
- Gas catcher construction is nearing completion
- ECRCB commissioning is complete
- CARIBU operation ramps up in 3 steps
  - First $^{252}$Cf source – 3 mCi shipped last week
  - Second source 80 mCi, order placed to ORNL
  - 1.0 Ci source for full operation will not be available until at least September, 2009
    - US production awaits funding from Congress
- The CARIBU project can be commissioned with the 80 mCi source. The goal is to complete commissioning by March 31, 2009.
Future plans for the charge breeder

- Continue with beam development using rubidium source
  - More work with multiple frequency heating
- Install RF discharge source to develop source performance with gases
- Replace stainless steel transfer tube with one made of soft iron and nickel coated
  - Improves magnetic field on injection side of ECRCB
- Improve pumping at injection region
  - Have seen some evidence that a lower pressure will improve the efficiency
  - Recently modified the chamber to accept another turbo pump
- Eliminate sources of outgassing
  - Bake out the 1+ transport line
  - Beamline collimators to inhibit backstreaming into ECRCB
- Pursue cleaning of plasma chamber using high pressure rinsing
  - Background is not yet a critical issue, but will become more important as CARIBU comes on line