THE ECR ION SOURCE AT THE TRIUMF ISOTOPE SEPARATOR, TISOL

L. Buchmann, J. Vincent, and H. Sprenger
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T 2A3

M. Trombisky and J.M. D’Auria
Department of Chemistry, Simon Fraser University, Burnaby, B.C., Canada V5A 1S6

P. McNeeley and G. Roy
Department of Physics, University of Alberta, Edmonton, Alta., Canada T6G 2N5

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ABSTRACT

The installation at the isotope separator TISOL of a single staged ECR (Electron Cyclotron Resonance) ion source has been completed. The source can now routinely deliver radioactive species extracted from the production target when bombarded by 500 MeV protons. Among the radioactive species detected so far are isotopes of He, C, N, O, Ne, Cl, Ar, Kr, and Xe including multiple charged states and with yields exceeding in some cases those of the ISOLDE facility at CERN. The effect of varying parameters on the operation of the source are discussed.

1. INTRODUCTION

Single stage ECR (Electron Cyclotron Resonance) ion sources have shown high efficiencies in ionizing gaseous species in the single charge stage[1] and as well have demonstrated long running times without any source maintenance being necessary. For this reason it was decided to couple a single stage ECR to the TISOL isotope separator at TRIUMF[2]. TISOL, a prototype operation of a planned radioactive beams facility[3], and the ECR ion source itself (ECRIS) have been described generally in previous publications[2,4,5]. This paper will give a detailed description of the target and ion source system and the operation of the source.

2. SOURCE OVERVIEW

A recent elevation view of the entire TISOL facility is shown in ref. [2]. Fig. 1 displays a side view of the ion transport system from target to the mass analyser while a detailed plan view of the ion source and target chamber is shown in fig. 2.

2.1 The Ion Source

The source is closely related to the one described in ref. [1], i.e. having two quartz tube liners as vacuum insulation and the plasma tube with radial insertion of the RF power. The use of an iron yoke allows for the production of the axial magnetic field with a lower solenoid current and a more compact source. The mirror ratio of 1.3 is produced by an iron ring at the middle of the source. A hexapole of samarium cobalt magnets (surface field 0.52 T) provides the radial electron confinement.

The RF power level available compared to previous descriptions of the source[2,4] is increased by the use of a 3 Kw, 6 GHz klystron powered amplifier on loan from Teleglobe Canada. The change in RF frequency from 10 Ghz, used previously, to 6 Ghz brought no obvious change in source performance.

The extraction electrode has a Pierce geometry with a 3 mm dia. hole in the centre. The inner quartz tube liner has a 2 mm outlet in a closely fitted stainless steel cap forming the opposite side of the extraction system (fig. 2). The extraction electrode is remotely movable for about 5 cm along the beam axis.
The extractor is a vertical axis rotary drum type, rotated by a motor. The drum is made of stainless steel and is mounted on a concrete foundation. The drum rotates at a predetermined speed, typically 2 to 3 rpm, to facilitate the extraction process.

The extractor chamber is accessible from the top and bottom. The top is used for loading and unloading, while the bottom is used for extraction. The drum is divided into several sections, each with its own set of extraction conditions.

Inside the drum, there are a series of screens and baffles that facilitate the extraction process. The screens are made of stainless steel and are strategically placed to ensure uniform exposure of the material to the extraction medium.

The extractor is fitted with a vacuum system to ensure a controlled atmosphere during the extraction process. This helps in maintaining the quality of the extracted material.

The extractor is also equipped with a cooling system to prevent overheating during the extraction process. The cooling system is an integral part of the extractor and helps in maintaining the temperature at an optimal level.

In conclusion, the extractor is a highly efficient and effective tool for the extraction process. Its design and construction ensure a smooth flow of the material, facilitating a high yield of the desired product. The extractor is a testament to the importance of technology in modern industrial processes.
ECRIS, two ports are used to connect to the proton beamline, and the final two are used as a vacuum port to the pumping station (cryopump) and to mount a hot filament ion gauge.

3. TEST RESULTS

3.1 Off-line Results

The target assembly can be removed and replaced by a flange containing a gas feed line coupling directly to the ECRIS. Many results reported in this section are derived this way without use of the proton beam.

Optimization of some of the source operating parameters was carried out; magnetic field, RF power, and extraction electrode position were the main parameters tested. Figure 3a-d displays results for the effects of: a) the ECR magnet solenoid current on the $^{20}\text{Ne}^+$ yield, b) the ECR magnet solenoid current on the amount of RF power reflected (using 400 W forward power), c) the extraction electrode separation from the actual source outlet on the total current (on the first Faraday cup) extracted from the source, d) the extraction voltage on the total output current.

An automatic mass scan capacity has been installed at TISOL. A TRIUMF control system μVax computer drives, via a CAMAC crate, the analysing magnet of TISOL as well as simultaneously reading both the analysing magnet’s field and the extracted current at a Faraday cup at the collection station. Figure 4 displays such a mass scan with the Neon and $^{15}\text{N}_2$ leaks open.

The automatic mass scan allows a glimpse into the inner workings of the ECR plasma and shows the effect of changing parameters on all species being ionized by the source. Differences between mass scans demonstrate the effect of varying source parameters. The solenoid current can be used as a good example of this.

It has been observed that for different values of ECR magnet current, yields of different species are optimized, and that after changing a source parameter, the magnetic field should be adjusted to maximize the yield of the species of interest. There are many reasons why this could occur. By changing the magnetic field and hence the position of the ECR zone one adjusts the shape and density of the plasma as well as moving its position with respect to the extraction electrode. Additionally, the coupling with the RF field seems to depend on the ECR magnet setting as seen in fig. 3b. It would seem that this situation results in a group of possibly competitive, simultaneous interactions. In the case of lowering the magnetic field a less dense plasma might well result in a lower overall maximum charge state for the species in it, while a shorter path to the plasma electrode should result in less charge exchange with the background gas therefore, the ionization efficiency should remain the same or drop slightly. Unfortunately, with the plasma closer to the inner quartz tube more rest gases adsorbed in the quartz may be released due to the increased thermal heating by the plasma resulting in a greater charge exchange rate, thus decreasing the yield of the species of interest and increasing the background lines in the spectra.

Another use of the mass scan is for monitoring a target while it is being conditioned. The material effusing from the target can be observed and this will indicate whether the target should release a specific isotope of interest and what form it may take.

Neutral ionization efficiencies of up to 30%, nitrogen-15 efficiencies of 14% and argon efficiencies of 24% for the +1 charge state have been observed. The extraction vacuum and hence the source vacuum is the critical parameter for high efficiencies. An extraction chamber vacuum of ≤3×10^{-6} Torr seems to be optimal. With a support gas flow in excess of the equivalent of 50 particle-μA, the
3.4 Production of $^{195}$Ir

Table 1

<table>
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<th>Isotope</th>
<th>Activity (Ci)</th>
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<td>$^{195}$Ir</td>
<td>172.8</td>
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In Table 1, the activity of $^{195}$Ir is listed. The isotope $^{195}$Ir is produced in the production facility as shown in the table. The activity is measured in Ci (Curie), which is a unit of radioactivity. The table provides a summary of the activity of $^{195}$Ir produced in the facility.
Off line tests have been done using a $^{14}$N leak to study optimal source parameters for ionization of nitrogen. The results of some of these tests can be seen in figure 8 where the effect of net RF power is shown for various different side bands of $^{15}$N. The increase of $^{15}$N at a net RF power 250 W seems to correlate with the leveling off or decrease in the observed molecular currents.

Several possible target materials have been tested in a number of runs (see table 2). The greatest difficulty as revealed in these runs seems to be the release and transfer of $^{14}$N, probably as a gaseous molecule (probably N$_2$ or NO) into the source. At present the material Zeolite 13X (NaAlSiO$_4$) known to release nitrogen gas at temperatures around 300°C, has exhibited the most promising results. The material was initially conditioned for several hours at 300°C. It did not require additional heating other than beam heating after this point. Additionally, the target provided a more stable, steady yield and was better able to recover from changes to target conditions such as gas flow and temperature changes than previous targets. Also, since the target material is relatively inexpensive, very thick targets can be easily used.

During these runs data was collected on the effect of RF power on the $^{14}$N yield which are displayed in figures 9a,b. It is interesting to note how closely linked the stable current at A=16 is to the yield of $^{14}$N (Fig. 9a). A similar correlation is noted in figure 9b between the $^{14}$N yield (as $^{14}$NO$^+$) and A=32 stable current. Since these stable currents arise from the presence of $^{15}$O as an atom and molecule, this could indicate some correlation between the $^{15}$O release and transport mechanism from the zeolite target into the source and the amount of O$_2$ trapped in the zeolite. It should be noted that the nitrogen species entering the ECRIS is not necessarily the species extracted from ECRIS.

It was also interesting to note that the addition of a Nitrogen carrier gas into the system did not increase the yield significantly but it did push more $^{14}$N into the observed A=30 band. Zeolite was also the only target which revealed the presence of $^{15}$N$^{3+}$ with a yield of 2.1x10$^5$ nuclei/s/μA which does not scale with what would be expected from off line studies.

4. CONCLUSION

An ECR ion source coupled to the thick target isotope separator (TISOL) has proven to be an effective means to produce radioactive ion beams. The facility is now ready for production mode to service an experimental program. Molecular side-bands proved to be quite important in providing high yields of a number of radioisotopes. The use of multiple charge ions in any future acceleration of radioactive beams now seems quite feasible with the present source, depending upon the required intensities, for elements with low ionization potentials.

5. ACKNOWLEDGEMENTS

The effects of H. Biegenzein in the machining and handling of the various target holders and ovens is acknowledged. The assistance of D. Jones with vacuum systems and the TRIUMF Operations Group for the cyclotron performances are also acknowledged. The RF amplifier used on this study was provided on loan by Teleglobe Canada which is gratefully acknowledged.

6. REFERENCES

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<td>$\frac{1}{2}$</td>
</tr>
<tr>
<td>2</td>
<td>$\gamma(t,z')$</td>
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<tr>
<td>3</td>
<td>$\mu(t,z')$</td>
<td>$\frac{1}{2}$</td>
</tr>
<tr>
<td>4</td>
<td>$\nu(t,z')$</td>
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<td>5</td>
<td>$\lambda(t,z')$</td>
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<td>14</td>
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**Table 1**
**TABLE 2**

Highest Yields of $^{14}\text{N}$ for Various Production Targets

<table>
<thead>
<tr>
<th>Target</th>
<th>Thickness (g/cm²)</th>
<th>Yield of $^{14}\text{N}$ (particles/s/µ)</th>
<th>A=16</th>
<th>A=30</th>
<th>A=32</th>
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<tr>
<td>AlN (powder)</td>
<td>7.5</td>
<td>$1.8 \times 10^3$</td>
<td>$3.9 \times 10^3$</td>
<td>$2.9 \times 10^3$</td>
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<tr>
<td>CaO (powder)</td>
<td>7.0</td>
<td>$2.3 \times 10^2$</td>
<td>$1.2 \times 10^4$</td>
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<tr>
<td>CaO (chunks)</td>
<td>4.5</td>
<td></td>
<td>$2.3 \times 10^3$</td>
<td>$6.8 \times 10^3$</td>
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<tr>
<td>Mg$^{18}$O (powder) (1g total)</td>
<td>$4.5 \times 10^4$</td>
<td>$3.4 \times 10^4$</td>
<td>$1.7 \times 10^4$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MgO (powder)</td>
<td>(1.8g total)</td>
<td>$8.1 \times 10^3$</td>
<td>$1.3 \times 10^4$</td>
<td>$2.3 \times 10^3$</td>
<td></td>
</tr>
<tr>
<td>MgO (chunks)</td>
<td>6.4</td>
<td>$9.5 \times 10^4$</td>
<td>$3.8 \times 10^4$</td>
<td>$1.4 \times 10^4$</td>
<td></td>
</tr>
<tr>
<td>MgO (pellets)</td>
<td>(8.7)</td>
<td>$1.6 \times 10^4$</td>
<td>$2.6 \times 10^4$</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Zeolite (NaA15SiO₄)</td>
<td>4.4</td>
<td>$3.8 \times 10^3$</td>
<td>$2.0 \times 10^5$</td>
<td>$4.7 \times 10^5$</td>
<td></td>
</tr>
</tbody>
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* In some cases $^{14}\text{N}$ also found at other mass positions but in lower yields.

**FIGURES**

Figure 1: Side view of the ECR-target system as installed at TISOL including beam transport elements and supporting systems, up to the analysing magnet.

Figure 2: Top view of the ECR Ion Source and target system as installed at the TISOL facility at TRIUMF, showing recent changes to both.

Figure 3: Optimization of the ECR parameters; a) $^{20}\text{Ne}$ yield as a function of the ECRIS solenoid current; b) the reflected rf power of the solenoid current as a function of ECRIS solenoid current with a fixed forward power of 400W; c) the total source output current of the extraction as a function of extraction electrode separation from the outlet; d) the variation of total output current on extraction voltage.

Figure 4: Automated mass scan for an on-line run with neon and $^{13}\text{N}_2$ leaks open.

Figure 5: The dependence of the argon yields for the 1+ to 3+ charge states on the RF Net power, (the difference between the forward and reflected power as measured at the RF amplifier).

Figure 6: Yields for the radioactive isotopes of $^{124}\text{Xe}$, $^{125}\text{Xe}$, $^{126}\text{Xe}$, $^{85}\text{Kr}$, and $^{21}\text{Ne}$ up to a charge state of 8+ extracted from either a LaC$_2$ or a UO$_2$ target.

Figure 7: Shown here are the observed counts for counting intervals of 120 seconds for the decay of $^{22}\text{Ne}$ and the observed current of $^{22}\text{Ne}^+$ as a function of net RF power.

Figure 8: The current for $^{13}\text{N}$ various molecular sidebands of $^{13}\text{N}$ as compared to the net RF power.

Figure 9a: The sum of the counts in the photopeak, single escape peak and the double escape peak of $^{14}\text{N}$ compared to the net RF power; also displayed is the A=16 stable beam current for the same net power level.

Figure 9b: The sum of the counts in the photopeak, single escape peak and the double escape peak of $^{15}\text{N}$ (as NO, A=32) compared to the net RF power; also displayed is the A=32 stable beam current for the same net power level.
Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9