MARS status report for 2014-2015

B.T. Roeder, A. Saastamoinen, and A. Spiridon

This year we produced and separated several radioactive beams for the physics program at the Cyclotron Institute at Texas A&M University with the Momentum Achromat Recoil Separator (MARS) [1]. Some of the beams in this report were developed during previous years [2]. A new, low energy $^{16}$N beam was also developed (see below in section IV).

I. Production of radioactive beams for superallowed $\beta$-decay measurements

During 2014-2015, we tuned several radioactive beams with MARS for the group of Prof. J.C. Hardy with the $(p, 2n)$ fusion-evaporation reaction. Nearly pure beams of $^{30}$S, $^{26}$Si, and $^{34}$Ar were produced. These beams were needed as part of Prof. Hardy’s research group’s continuing studies of the lifetime and branching ratios for superallowed $\beta$-decays.

The $^{30}$S beam was produced with the $(^{31}$P, $^{30}$S)2n reaction. A primary beam of $^{31}$P$^{10+}$ at 30 MeV/u from the K500 cyclotron bombarded the MARS gas cell target to produce the $^{30}$S. The target was filled with 2 atm of H$_2$ gas cooled to 77K. After optimizing the tune of MARS, we obtained 90 eV/nC, or about 18,000 particles/sec of $^{30}$S at the end of MARS with the full primary beam intensity. The total impurity rate was about 1.3%, with the main contribution coming from $^{27}$Si at about 0.4%.

The $^{26}$Si beam was produced with the $(^{27}$Al, $^{26}$Si)2n reaction. A primary beam of $^{27}$Al$^{8+}$ at 30 MeV/u from the K500 cyclotron bombarded the MARS gas cell target to produce the $^{26}$Si. The target was filled with 2 atm of H$_2$ gas cooled to 77K. After optimizing the tune of MARS, we obtained 240 eV/nC, or about 22,000 particles/sec of $^{26}$Si at the end of MARS with the full primary beam intensity. The total impurity rate was about 1.6%, with the main contribution coming from $^{23}$Mg at about 0.8%.

The $^{34}$Ar beam was produced with the $(^{35}$Cl, $^{34}$Ar)2n reaction. A primary beam of $^{35}$Cl at 30 MeV/u from the K500 cyclotron bombarded the MARS gas cell target to produce the $^{34}$Ar. The target was filled with 2 atm of H$_2$ gas cooled to 77K. After optimizing the tune of MARS, we obtained 51 eV/nC, or about 20,400 particles/sec of $^{34}$Ar at the end of MARS with the full primary beam intensity. The total impurity rate was about 1.1%, with the main contribution coming from $^{31}$S at about 0.2%.

II. $^{35}$K secondary beam

In March 2014, we produced and separated $^{35}$K with MARS [2]. Following this successful test run, the $^{35}$K $\beta$-delayed proton decay experiment was conducted in June 2014. Details of the measurement are given in a separate report [3]. For this measurement, the $^{35}$K was produced with the fusion-evaporation reaction $(p, 2n)$ in inverse kinematics with $^{36}$Ar primary beam at 36 MeV/u. Hydrogen gas at a pressure of 2 atm and at a temperature of 77K was used in the MARS gas cell target.

In the experiment, the $^{35}$K secondary beam was slowed down and implanted into a thin silicon strip detector that is only ~45 µm thick. Thus, the $^{35}$K secondary beam must have a small momentum spread such that all the nuclei produced are implanted into the detector. For the $^{35}$K production test, we set
the MARS momentum slits (the “coffin slits”) to ± 0.5 cm, which corresponds to a momentum spread of the secondary beam of $\Delta P/P \approx \pm 0.3\%$. With this momentum slit setting, we produced $^{35}\text{K}$ at a rate of about 3.0 events/nC. This gave a rate of about 450 particles/sec for the $^{35}\text{K}$ (using 150 nA of $^{36}\text{Ar}$ primary beam) with about 40% impurities. The largest impurity contribution came from $^{32}\text{Cl}$, but this did not significantly affect the experiment. The $\Delta E$ vs. $Y$-position spectrum on the MARS target detector showing the resulting secondary beam for the $^{35}\text{K}$ is shown in Fig. 1.

![Figure 1: Results of the $^{35}\text{K}$ MARS tuning for the June 2014 experiment.](image)

III. $^{9}\text{C}$ secondary beam

Also in March 2014, we produced and separated $^{9}\text{C}$ with MARS [2]. $^{9}\text{C}$ was needed by the group of Prof. G. Rogachev for their experiment with resonant elastic proton scattering using the Thick Target Inverse Kinematics (TTIK) method. The $^{9}\text{C}$ secondary beam was employed to study the unbound $^{10}\text{N}$ nucleus. The experiment was conducted in October 2014.

For the $^{9}\text{C}$ experiment, a $^{10}\text{B}$ primary beam at 31 MeV/u bombarded the MARS gas cell target. The gas cell target was filled with 3 atm of hydrogen gas at a temperature of 77K. The $^{9}\text{C}$ was produced with the fusion-evaporation reaction ($\text{p},2\text{n}$) in inverse kinematics. The Q-value for the $\text{p}^{(10}\text{B},^{9}\text{C})2\text{n}$ reaction is -25.7 MeV. Thus, 31 MeV/u was chosen for the primary beam energy as a compromise.
between the production rate for $^9$C, which is better at higher primary beam energies, and the desire to have the $^9$C at the lowest possible energy. For the experiment, the $^9$C energy was reduced to ~11 MeV/u with degraders and a thick scintillator foil at the entrance of their scattering chamber.

The optimized production rate for the $^9$C secondary beam was about 7.0 events/nC with the 3 atm of gas in the target, which gave ~about 1.4 x 10^3 particles/sec with 200 nA of $^{10}$B beam on target. The $^9$C secondary beam was relatively pure, although there was some contamination in the beam from $\alpha$-particles and $^3$He. Some of this contamination from the $\alpha$-particles was removed in the experiment by closing the slits of MARS. The resulting $^9$C secondary beam as measured by the MARS target detector is shown in Fig. 2.

![MARS Target Det. $\Delta E$ vs. Y - $^{10}$B+$^1$H $\rightarrow ^9$C](image)

**FIG. 2.** Result of the $^9$C production with MARS. The main contaminant of the secondary beam is from $^3$He.

**IV. Production of $^{16}$N secondary beam**

$^{16}$N secondary beam was produced with MARS at low energy in preparation for upcoming experiments to study the pionic fusion reaction mechanism with Prof. Yennello’s group.
In the test, a $^{15}$N$^{2+}$ primary beam at 7 MeV/u from the K500 cyclotron bombarded the MARS gas cell target. The gas cell was filled with $^2$H$_2$ (deuterium) gas at a pressure of 948 torr and a temperature of 77K. The reaction $^{15}$N($^{15}$N,$^1$H)p was used to produce the $^{16}$N. However, $^{16}$O was also produced with high cross section at this energy from the $^{15}$N($^{15}$N,$^1$H)n reaction. It is possible for the $^{16}$O ions to be produced in other charge states besides $^{16}$O$^{8+}$. Thus if $^{16}$O$^{7+}$ is produced, it is indistinguishable from $^{16}$N$^{7+}$ in MARS unless a thin silicon detector or degrader foil is employed to separate the two secondary beams by their different energy losses in the materials. Since a thin silicon detector was not available for the experiment, a thin Al degrader foil with areal density 4.4 mg/cm$^2$ was inserted in front of the MARS target detector. To optimize the production of $^{16}$N$^{7+}$ vs. $^{16}$O$^{7+}$, the MARS magnet settings were kept constant (D1-2 = 255.2 A, or $B\rho = 0.60$ T*m) while the gas cell pressure was varied from 1220 torr to 777 torr in steps of about 50 torr. We found the optimized $^{16}$N$^{7+}$ production with 948 torr, $^{16}$O$^{7+}$ at 832 torr, and some mixture of the two elements at the settings in-between.

Depending on the MARS quadrupole settings used, the production rate for $^{16}$N$^{7+}$ varied between 900 events/nC and 2200 events/nC. With ~100 nA of primary beam on target, this implies that production rates of greater than $10^5$ particles/sec are available for this beam at this energy. This relatively intense $^{16}$N beam may be employed in future nuclear astrophysics experiments.