MARS status report for 2014-2015

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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 β-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 β-decays.

The ^{30}S beam was produced with the p(^{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 p(^{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 p(^{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 β-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}K at a rate of about 3.0 events/nC. This gave a rate of about 450 particles/sec for the ^{35}K (using 150 nA of ^{36}Ar primary beam) with about 40% impurities. The largest impurity contribution came from ^{32}Cl, but this did not significantly affect the experiment. The ΔE vs. Y-position spectrum on the MARS target detector showing the resulting secondary beam for the ^{35}K is shown in Fig. 1.

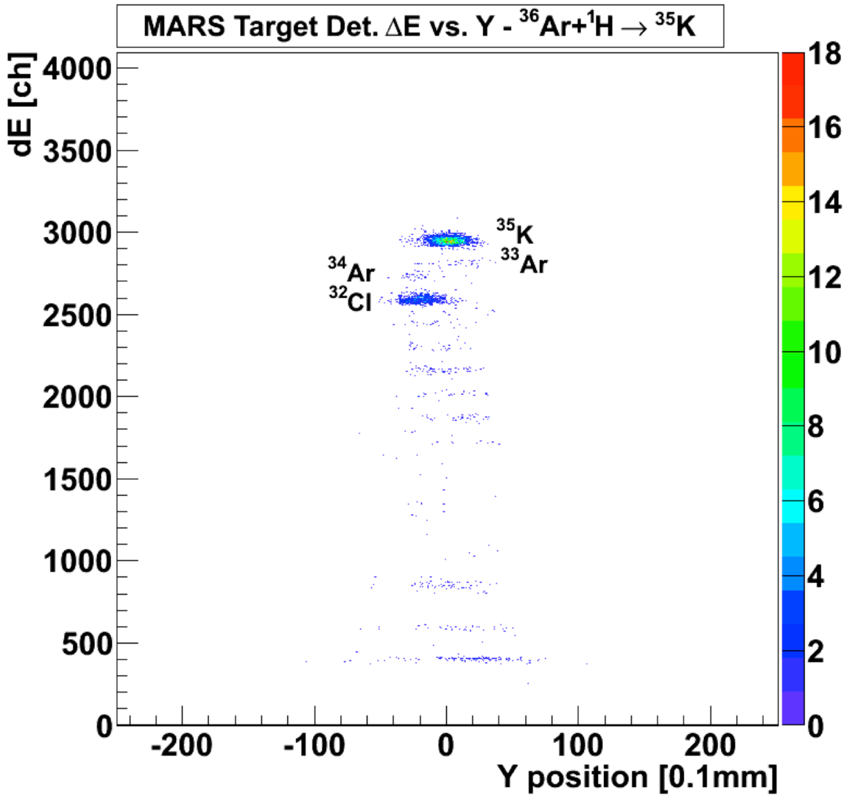

FIG. 1. Results of the ^{35}K MARS tuning for the June 2014 experiment.

III. ^{9}C secondary beam

Also in March 2014, we produced and separated ^{9}C with MARS [2]. ^{9}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}C secondary beam was employed to study the unbound ^{10}N nucleus. The experiment was conducted in October 2014.

For the ^{9}C experiment, a ^{10}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}C was produced with the fusion-evaporation reaction (p,2n) in inverse kinematics. The Q-value for the p(^{10}B,^{9}C)2n 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 α-particles and ^{3}He. Some of this contamination from the α-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.

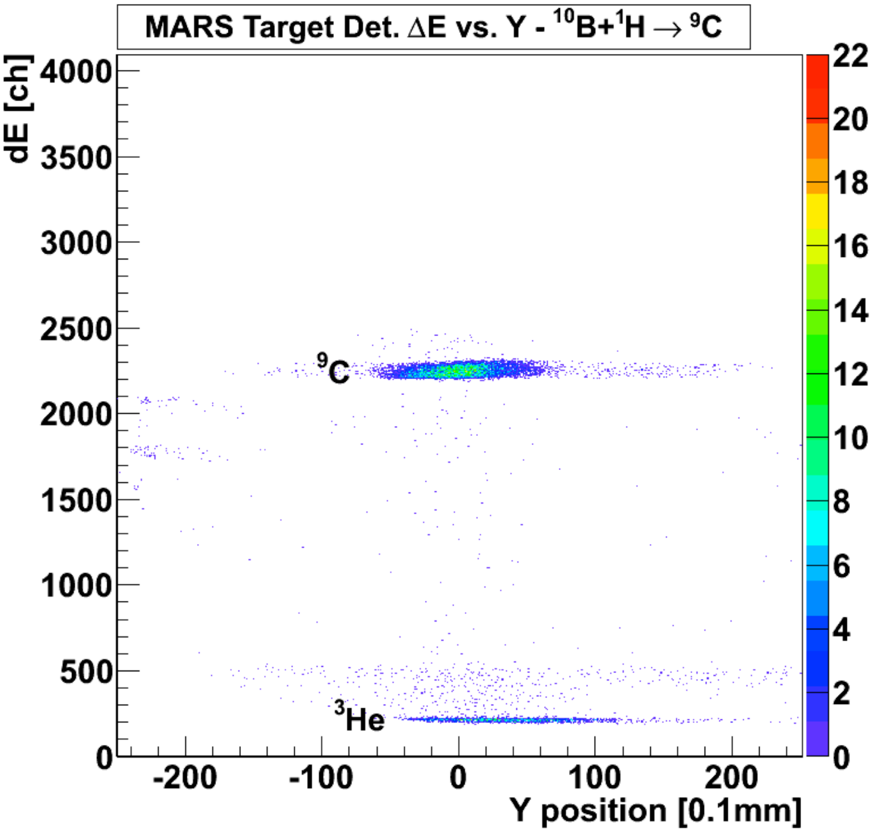

FIG. 2. Result of the ^{9}C production with MARS. The main contaminant of the secondary beam is from ^{3}He.

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 d(^{15}N,^{16}N)p was used to produce the ^{16}N. However, ^{16}O was also produced with high cross section at this energy from the d(^{15}N,^{16}O)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.

[1] R.E. Tribble, R.H. Burch, and C.A. Gagliardi, Nucl. Instrum. Methods Phys. Res. **A285**, 441 (1989).

[2] B.T. Roeder *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2013-2014), p. I-48; http://cyclotron.tamu.edu/2014 Progress Report/index.html.

[3] A. Saastamoinen *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2014-2015), http://cyclotron.tamu.edu/2015 Progress Report/index.html.