MARS status report for 2016-2017: tuning of rare isotope beams of ^{14}O, ^{10}C, ^{42}Ti, and ^{31}Cl

B.T. Roeder and A. Saastamoinen

This year, we continued the program of providing rare isotope beams for the physics program at the Cyclotron Institute at Texas A&M University with the Momentum Achromat Recoil Separator (MARS) [1]. ^{14}O, ^{23}Si and ^{22}Si beams were provided to outside collaborations. The description of the production of ^{23}Si and ^{22}Si was provided in last year's progress report [2]. The ^{10}C and ^{42}Ti beams were provided to Dr. Hardy's research group for their continuing studies of super-allowed β-decay. A low energy ^{10}C beam at 3.3 MeV/u was also prepared for a planned future experiment with Dr. Rogachev's research group. Finally, a ^{31}Cl beam was made for Dr. Tribble's group for their continuing studies of β-delayed proton decay with the Astrobox2 detector.

^{14}O beam production for the WASHU group

The ^{14}O rare isotope beam has been produced many times with MARS with either the p(^{14}N,^{14}O)n or p(^{15}N,^{14}O)2n reactions. In the latest experiment, a group from Washington University in St. Louis (WASHU) was interested in studying the elastic scattering of ^{14}O with protons in inverse kinematics at two beam energies. For the higher energy case, ^{14}N at 30 MeV/u bombarded the MARS gas target filled with 2 atm of H_2 gas at 77K. This produced the ^{14}O beam secondary beam via a direct transfer reaction with a magnetic rigidity of 1.35 T·m and an energy of 28.3 MeV/u. In this reaction, ^{14}O was produced at a rate of 198 eV/nC with the MARS momentum slits at ± 0.4 cm, which corresponds to a momentum spread of the secondary beam of $\Delta P/P \approx 0.5\%$. This setup gave about $2.7 \cdot 10^4$ particles/sec ^{14}O for the experiment. About 11% of the rate secondary beam came from ^{7}Be, which has the same charge-to-mass ratio as the ^{14}O and thus could not be separated.

For the lower energy case, ^{14}N at 18 MeV/u bombarded the MARS gas target filled with 2 atm of H_2 gas at 77K. This produced a ^{14}O beam secondary beam via a direct transfer reaction with a magnetic rigidity of 0.999 T·m and an energy of 15.6 MeV/u. In this reaction, ^{14}O was produced at a rate of 100 eV/nC with the MARS momentum slits at ± 0.4 cm, which corresponds to a momentum spread of the secondary beam of $\Delta P/P \approx 0.5\%$. This setup gave about $1 \cdot 10^4$ particles/sec ^{14}O for the experiment. About 25% of the secondary-beam rate came from ^{7}Be, which has the same charge-to-mass ratio as the ^{14}O and thus could not be separated.

It has been observed during the analysis of the above data that it was possible to obtain a good focus in "X" and "Y" at the target position. The beam spot size was about 4mm in diameter. However, the beam needed to be re-focused strongly to obtain this beam spot size, resulting in a X-divergence of about 40 mrad. Calculations with the MARS LISE++ model [3] are being carried out to attempt to make the beam more parallel in future experiments.

Production of ^{10}C and ^{42}Ti for super-allowed β-decay studies

The ^{10}C rare isotope beam has been produced many times with MARS with either the p(^{10}B,^{10}C)n or p(^{11}B,^{10}C)2n reactions. In the latest experiment, Dr. Hardy's research group planned to obtain a high precision measurement of the branching ratio for the super-allowed β-decay of ^{10}C. Thus, they needed to have ^{10}C provided at the highest production rate possible, but also at sufficiently high enough energy to implant the ^{10}C into their tape transport system. With the p(^{10}B,^{10}C)n reaction at 17.2 MeV/u, we obtained 1500 eV/nC of ^{10}C with the MARS momentum slits at ± 1.5 cm, which corresponds to a momentum spread of the secondary beam of $\Delta P/P \approx 1.8\%$. The beam was easily separated from other reaction products and was thus 100% pure. Considering the production rate and the amount of primary beam available, about $2 \cdot 10^5$ p/s of ^{10}C was available for the experiment at this energy.

^{42}Ti was also produced [4] again this year in order to obtain a high precision measurement of its half-life. With the ^{4}He(^{40}Ca,^{42}Ti)2n reaction at 32 MeV/u, we obtained 5 eV/nC of ^{42}Ti with the MARS momentum slits at ± 0.5 cm, which corresponds to a momentum spread of the secondary beam of $\Delta P/P \approx 0.6\%$. The final energy of the ^{42}Ti was 26.6 MeV/u. In the latest experiment, it was found to be extremely important to remove, as much as possible, the ^{41}Sc and ^{39}Ca components of the beam. This was accomplished by adjusting the bottom slit #4 of MARS and the D3 dipole such that the majority of the ^{42}Ti was still passing into the tape, but the ^{39}Ca and ^{41}Sc had been reduced to less than 1% of the total intensity of the ^{42}Ti. The optimized ^{42}Ti tune for the latest experiment is shown in Fig. 1.

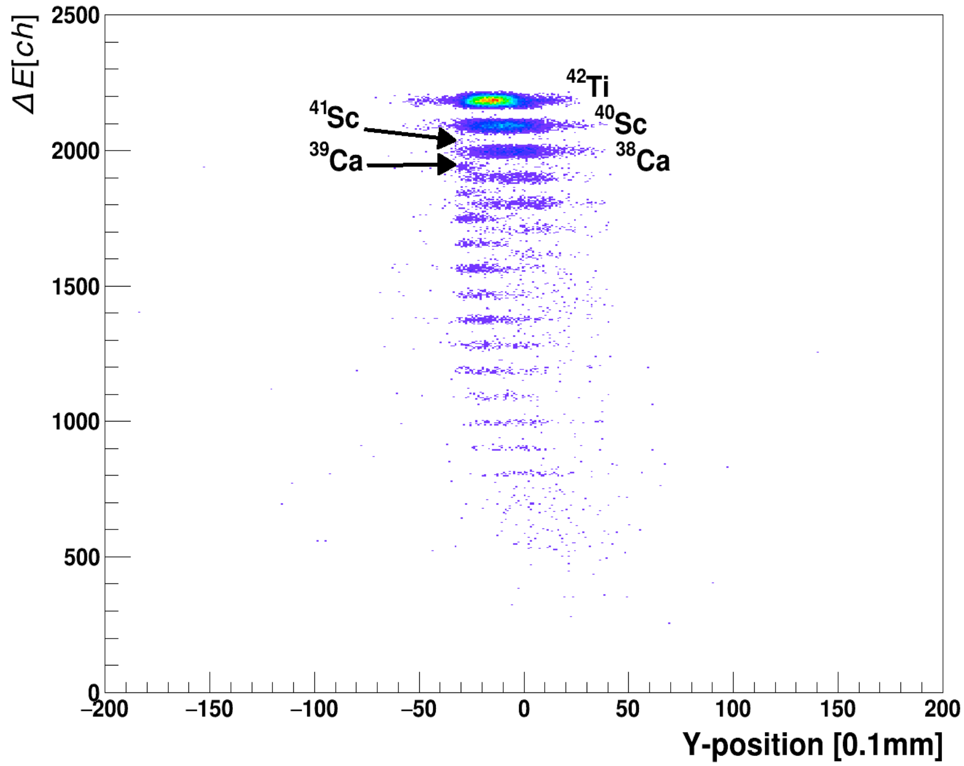

FIG. 1. Result of the ^{42}Ti beam tune. The contributions of the ^{41}Sc and ^{39}Ca contaminants are less than 1% of the total beam.

Production of low energy ^{10}C beam

^{10}C beam at low energy has also been developed for future experiments that are planned with Dr. Rogachev's research group. In this case, the p(^{10}B,^{10}C)n with ^{10}B beam at 7.0 MeV/u from the K150 cyclotron was used. The ^{10}B beam bombarded the MARS gas target filled with 1 atm of H_2 gas at 77K. During the test run, ^{10}C was produced at a rate of 61.5 eV/nC at an energy of 3.3 MeV/u. With this result, a low energy ^{10}C beam with an intensity of 10^4 p/s should be feasible.

Production of ^{31}Cl for the Astrobox2 experiment

The ^{31}Cl rare isotope beam has been produced many times with MARS via the p(^{32}S,^{31}Cl)2n reaction. In the latest experiment, ^{32}S at 40 MeV/u from the K500 cyclotron was used. The ^{32}S beam bombarded the MARS gas target filled with about 2 atm of H_2 gas at 77K. During the experiment, ^{31}Cl was produced at a rate of 3.2 eV/nC with the MARS coffin slits at $\pm$ 0.5 cm and at an energy of 35.4 MeV/u. The main contaminant of the beam was ^{28}P, which composed about 17% of the intensity of the secondary beam mixture. Once the beam was implanted into Astrobox2, a nearly pure sample of ^{31}Cl was obtained. A more detailed explanation of the ^{31}Cl experiment can be found in a separate report [5].

[1] R.E. Tribble, R.H. Burch, and C.A. Gagliardi, Nucl. Instrum. and Meth. A **285** (1989) 441.

[2] B.T. Roeder *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2015-2016), p. IV-21; http://cyclotron.tamu.edu/progress-reports/2015-2016/SECTION IV.html.

[3] B.T. Roeder *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2013-2014), p. IV-40; http://cyclotron.tamu.edu/progress-reports/2013-2014/SECTION IV.html.

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

[5] A. Saastamoinen *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2016-2017), p.I-45;http://cyclotron.tamu.edu/progress-reports/2016-2017/SECTION I.html.