MARS status report: Tuning of rare isotope beams of ^{10}C, ^{14}O, ^{42}Ti, ^{29}P, ^{8}B, ^{12}N, ^{9}Li and ^{76}Ge fragmentation

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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]. The beams that have been developed in previous years that were employed in physics experiments this year are as follows: A ^{42}Ti beam, made with the ^{40}Ca+^{4}He reaction at 32 MeV/u, was provided to Dr. Hardy's research group for their continuing studies of super-allowed β-decay; ^{10}C, ^{14}O, and ^{9}Li beams were prepared for experiments with Dr. Rogachev's research group for experiments with the TexAT active target; and also, a low energy ^{8}B beam was prepared for Dr. Rogachev's group for use in an experiment in collaboration with the University of São Paulo in Brazil.

Two new rare isotope beams were developed this year: ^{12}N and ^{29}P. Also, ^{76}Ge fragmentation at 28 AMeV on Be, Al and Ni targets was investigated to test what could be produced with that primary beam. These new MARS tunes are described below.

The low energy ^{12}N beam was requested by Dr. Rogachev's group for an experiment in collaboration Washington University in St. Louis. The goal was to implant ^{12}N into the gas of the TexAT active target and observe the β-delayed 3α decay. ^{12}N was prepared with a ^{10}B primary beam at 11 AMeV from the K500 cyclotron bombarding the MARS gas target filled with ^{3}He gas at a pressure of 800 torr and a temperature 77K. With the MARS momentum slits at ± 1.0cm, a production rate of 5.6 event/nC was measured for the ^{12}N. About 3% of the total secondary beam was from a tail of ^{7}Be contamination. This production rate was sufficient for the requested ^{12}N rate of about 100 p/s for the experiment. The secondary beam energy was 81 MeV. This beam energy was further degraded with a rotatable aluminum degrader such that the ^{12}N could be stopped in the gas volume of TexAT.

The ^{29}P beam was requested by Dr. Melconian's group for an experiment to measure its half-life with the TAMU Tape Drive system. Several methods of production were proposed. The p(^{30}Si,^{29}P)2n reaction was chosen as the (*p*,2*n*) reaction has been known to provide nearly pure rare isotope beams in the past and was predicted to have high production cross section. During the beam development, a ^{30}Si beam at 24 MeV/u bombarded the MARS gas target filled with H_2 gas at a pressure of 2 atm and a temperature of 77K. The result was a nearly pure secondary beam of ^{29}P with a production rate of 1427 event/nC with the MARS momentum slits at ± 0.5 cm. A tail of ^{27}Si contributed 0.13% to the total rate of the secondary beam, and the total secondary beam contamination was less than 0.5%. Despite the relatively low intensity available for the ^{30}Si primary beam, ^{29}P rates of about $2*10^4$ p/s were typical. The ^{29}P half-life experiment was completed in November 2018 and the analysis is ongoing.

Finally, ^{76}Ge fragmentation at 28 MeV/u on solid targets of Be, Al and Ni was tested for Dr. Christian's group. The goal was to develop neutron-rich rare isotope beams in the region of ^{73}Cu. However, development of heavy mass beams with A > 60 with MARS is problematic because the reaction products are not fully stripped of their electrons. This makes identification of the reaction products difficult. Also, 28 AMeV beam energy was too low to efficiently remove more than 3 nucleons from the ^{76}Ge beam, especially in the case of the Ni target which has a higher Coulomb barrier. Thus, no rare isotopes were observed in the case of the Ni target. For the Al and Be targets, 1 and 2 nucleon removal were favored. Nuclei in charge states with 1 or 2 electrons were populated. There were some events of particles with the correct energy loss in the silicon detectors that could be identified as ^{73}Cu at low rate. ^{72}Ni was not observed. Also, the high rate of undesired reaction products with similar charge-to-mass ratio as the ^{73}Cu would make an experiment with the low rate of ^{73}Cu difficult. Future attempts at the production of ^{73}Cu or ^{72}Ni would greatly benefit from higher energy and higher intensity of the ^{76}Ge primary beam. Perhaps energies 40 MeV/u or greater and intensities above 1 particle-nA would be needed to produce ^{72}Ni.

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