MARS Status Report for 2019-2020: Tuning of new rare isotope beams ^{12}B, ^{11}Be, ^{10}Be, ^{13}B, ^{23}Ne, and ^{7}Be

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This year, we continued the program of providing rare isotope beams (RIBs) for the physics program at the Cyclotron Institute at Texas A&M University with the Momentum Achromat Recoil Separator (MARS) [1]. The MARS beam line was utilized in 20 separate experimental runs for RIB development and various experiments. The beams that had 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 once again to Dr. Hardy's research group for their continuing studies of super-allowed β-decay. ^{14}O was prepared for experiments with Dr. Rogachev's research group in collaboration with L. Sobotka's group from Washington University in St. Louis for experiments with the TexAT active target. Also, a degraded ^{8}B beam was prepared for the CENTAUR collaboration for Prof. Scott Marley from Louisiana State University. Finally, a ^{27}P beam was made with the p(^{28}Si,^{27}P)2n reaction with ^{28}Si beam at 40 MeV/u for a measurement of ^{27}P β-p decay with Astrobox2.

Six new RIBs were developed this year: ^{12}B, ^{11}Be, ^{10}Be, ^{13}B, ^{23}Ne and a low energy ^{7}Be beam. These new MARS tunes are described in the following paragraphs.

The ^{12}B, ^{11}Be and ^{10}Be RIBs were requested by Dr. Christian's group to measure (d,^{3}He) transfer reactions with TexAT. The (d,^{3}He) reactions in question have relatively high Q-values and thus secondary beam energies greater than 20 MeV/u were required. All three of these RIBs were produced with a $^{13}C^{4+}$ beam at 30 MeV/u from the K500 cyclotron bombarding a 1mm thick ^{9}Be target. Primary beam intensities up to 400 enA (electrical) were available. For the case of ^{12}B, with the MARS momentum slits at ± 1.0cm, a production rate of 5240 eV/nC was obtained. About 2.6% of the total secondary beam was from ^{10}Be and ^{7}Li contamination, both of which could be reduced by closing the focal plane slits. The ^{12}B beam energy was 20.9 MeV/u. With the full intensity of the primary beam, a rate of about 2×10^{6} p/s of ^{12}B was measured. A spectrum showing the final tune for ^{12}B is shown in figure 1. For the case of ^{11}Be, with the MARS momentum slits at ± 1.0cm, a production rate of 191.7 eV/nC was obtained. About 10% of the total secondary beam was from ^{8}Li contamination. The ^{11}Be beam energy was 22.9 MeV/u. With the full intensity of the primary beam, a rate of about 7.7×10^{4} p/s of ^{11}Be was measured. For the case of ^{10}Be, with the MARS momentum slits at ± 1.0cm, a production rate of 600 eV/nC was obtained. About 4% of the total secondary beam was from ^{11}Be contamination, which could be reduced by closing the focal plane slits. The ^{10}Be beam energy was 21.6 MeV/u. With the full intensity of the primary beam, a rate of about 2.4×10^{5} p/s of ^{10}Be was measured. The ^{12}B experiment with TexAT has already been completed and the measurements with ^{11}Be and ^{10}Be are planned for next year.

The ^{13}B beam was also requested by Dr. Christian's group for a future (d,^{3}He) transfer reaction experiment with TexAT. It was prepared in a similar way as the previous three RIBs. ^{13}B was produced with $^{15}N^{5+}$ beam at 30 MeV/u from the K500 cyclotron bombarding a 1mm thick ^{9}Be target. Primary beam intensities up to 420 enA (electrical) were available for the production test run. With the MARS momentum slits at ± 1.5 cm, a production rate of 100 eV/nC was obtained. About 20% of the total secondary beam was from contaminants, mostly from ^{8}Li and lower mass particles. The ^{13}B beam energy was 19.7 MeV/u. With the full intensity of the primary beam, a rate of about 4.2×10^4 p/s of ^{13}B was measured. The ^{13}B experiment is also planned for the coming year.

The ^{23}Ne beam was requested by Dr. Melconian's group for a β-decay measurement with the TAMU tape drive. This experiment will be conducted in collaboration with Prof. G. Ron from the Hebrew University of Jerusalem. ^{23}Ne was produced with $^{22}Ne^{6+}$ beam at 24.8 MeV/u from the K500 cyclotron bombarding the MARS gas production target, filled with deuterium gas at a pressure of 1.5 atm and cooled with liquid nitrogen. Primary beam intensities up to 100 enA (electrical) were available for the production test run. With the MARS momentum slits at ± 0.5 cm, a fantastic production rate of 6500 eV/nC was obtained. About 5.8% of the total secondary beam was from contaminants, mostly from ^{21}F. The ^{23}Ne beam energy was 20.9 MeV/u. With the full intensity of the primary beam, a rate of about 7.8×10^5 p/s of ^{23}Ne was measured. A spectrum showing the final tune for ^{23}Ne is shown in Fig. 1. The ^{23}Ne experiment is planned for the coming year, depending on the availability of the collaborators.

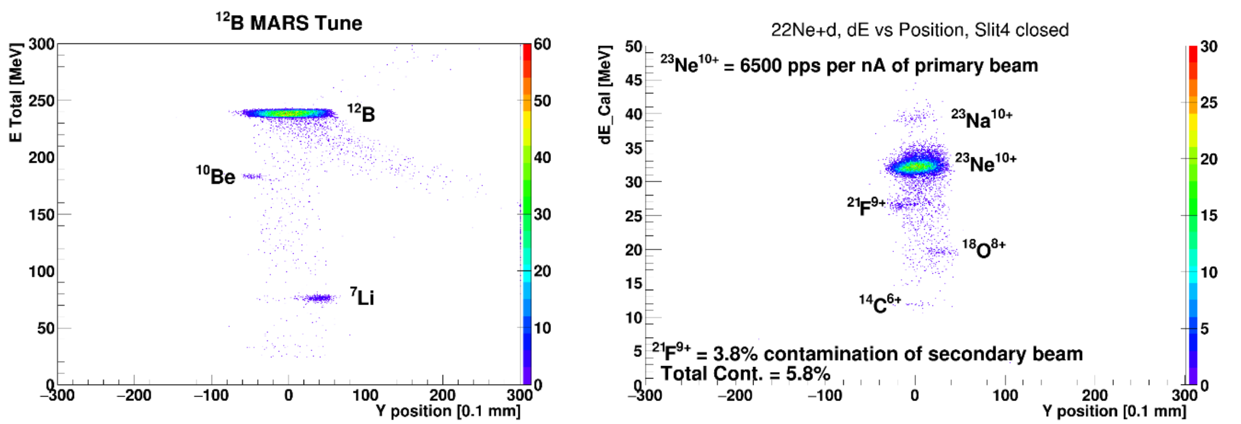

Fig. 1. Spectra showing the final MARS tunes for the new RIBs 12B (left panel) and 23Ne (right panel). See text for further explanation.

Finally, a low energy ^{7}Be beam was requested by Dr. Rogachev's group to measure reactions related to nuclear astrophysics with the new TexCAM detector. To reach the beam energies relevant to astrophysics, the ^{7}Be beam energy needed to have 10 MeV total energy or less. This low energy secondary beam was produced with $^{7}Li^{1+}$ beam at 3.0 MeV/u from the K150 cyclotron bombarding the MARS gas production target, which was filled with H_2 gas at a pressure of 100 torr and cooled with liquid nitrogen. With the MARS momentum slits at ± 1.0 cm, a production rate of 3661 eV/nC was obtained with no contamination. Due to the low beam energy, the focus was extremely poor and could not be improved except by closing the focal plane slits. With the focal plane slits (slit #4) closed to ± 1.0 cm, the production rate was reduced to 2350 eV/nC. The final ^{7}Be beam energy was 8 MeV total energy. The full intensity of the ^{7}Li primary beam at 3.0 MeV/u has yet to be determined and may be limited by the relatively low energy. However, an intensity of 100 enA on target should be achievable, providing about 2.4×10^5 p/s of ^{7}Be for the measurement. The ^{7}Be experiment with TexCAM is also planned for the coming year.

As part of a continuing study to produce nuclei near the proton dripline for β-decay measurements, a beam of ^{54}Fe at 36 MeV/u and ^{40}Ca at 40 MeV/u were fragmented on Be, Al and Ni targets and measured with a silicon ΔE vs. E telescope. These measurements were conducted as part of the Research Experience for Undergraduates (REU) and undergraduate students participated. The results of these experiments are summarized in a separate report [2].

A summary of the new rare isotope beams produced this year with MARS is given in Table I.

Table I. Summary of New MARS RIBs for 2019-2020.

RIB beam	**Reaction**	**Primary Beam**	**Purity**	**Intensity on Target**
^{12}B*	^{9}Be(^{13}C,^{12}B)X	^{13}C at 30 MeV/u	~97.4%	2×10^{6} p/s
^{11}Be*	^{9}Be(^{13}C,^{11}Be)X	^{13}C at 30 MeV/u	~90%	7.7×10^{4} p/s
^{10}Be	^{9}Be(^{13}C,^{10}Be)X	^{13}C at 30 MeV/u	~96%	2.4×10^{5} p/s
^{7}Be*, (1.1 MeV/u)	p(^{7}Li,^{7}Be)n	^{7}Li at 3.0 MeV/u	~100%	2.4×10^{5} p/s
^{13}B	^{9}Be(^{15}N,^{13}B)X	^{15}N at 30 MeV/u	~80%	4.2×10^{4} p/s
^{23}Ne	d(^{22}Ne,^{23}Ne)p	^{22}Ne at 24.8 MeV/u	~94%	7.8×10^{5} p/s

[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 (2019-2020), p. IV-36, http://cyclotron.tamu.edu/progress-reports/2019-2020/SECTION IV.html.