Measurement of the d(^{26m}Al,p)^{27}Al reaction with TECSA

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Following the success of the commissioning experiment for the Texas A&M-Edinburgh-Catania Silicon detector Array (TECSA) to measure the d(^{14}C,p)^{15}C reaction featured in last year's annual report [1] and in a published article [2], new experiments were planned during 2011 to measure reactions with rare isotope beams. It was found during the previous experiments that it would be difficult to observe reactions with beam rates less than 10^5 pps because of the background arising from the interacting of the primary beam on the primary target of MARS, and background from reactions associated with the secondary beam stopping in the end of the TECSA scattering chamber.

To prepare for these new measurements, some improvements were made to the TECSA scattering chamber and associated electronics. These improvements were carried out in order to shield the TECSA array from background reactions and β-decay of the rare isotope beams occurring inside the chamber and associated with stopping the beam. First, the TECSA detectors were shielded upstream of the target with a ¼ inch steel plate attached to the back of the mounting ring. The detectors were also shielded downstream of the target with a thick Al plate with a hole in the middle to allow the beam to pass through. To further reduce the background, the back flange of the TECSA scattering chamber was modified such that a section of 4" diameter beam pipe, approximately 1 m long, could be attached to the back of the chamber. With this addition to the setup, the beam was stopped 1m further away from the TECSA array than before, which further reduced the background from the decay of the beam. Finally, to improve the function of the scintillator-PMT detector with respect to the heavy-ion – proton coincidence in TECSA, the scintillator-PMT detector was moved from the front (upstream of the target) to the back of chamber. Fig. 1 shows the TECSA detector setup used in the rare isotope beam experiments after the improvements.

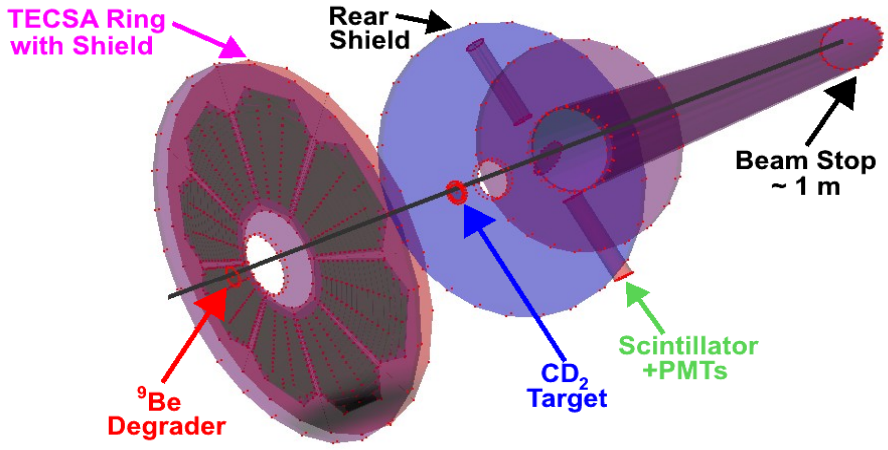

FIG. 1. Drawing of the TECSA setup for the rare isotope beam experiments

The first experiment with rare isotope beam carried out with the improved TECSA setup was a measurement of the d(^{26}Al,p)^{27}Al reaction in inverse kinematics. The ^{26}Al beam was produced in two forms which are relevant for this study: the ground state, ^{26g}Al with $J^{\pi} = 5^{+}$, and the isomeric state, ^{26m}Al with $J^{\pi} = 0^{+}$. Due to the short half-life of the ^{26m}Al (6.3 s), the d(^{26m}Al,p)^{27}Al reaction has not been studied previously. Both the d(^{26g}Al,p)^{27}Al and d(^{26m}Al,p)^{27}Al reactions could potentially populate ^{27}Al states that isobaric analogs of states in ^{27}Si that could be of importance in studying the ^{26g}Al(p,γ) and ^{26m}Al(p,γ) reactions that are important in stellar nucleosynthesis [3].

The ^{26m}Al and ^{26g}Al beams were produced in-flight with the p(^{26}Mg,^{26}Al)n reaction using ^{26}Mg beam at 16 MeV/u from the K500 cyclotron at the Texas A&M University Cyclotron Institute (TAMU-CI). The ^{26}Al beam could be separated from other contaminate beams with the MARS spectrometer, but the ^{26m}Al and ^{26g}Al beams are only separated by 228 keV in mass and therefore are indistinguishable using normal mass separation and energy-loss techniques. However, it was expected that when the p(^{26}Mg,^{26}Al)n reaction occurred with the "Transfer" reaction mechanism, it would produce mainly ^{26m}Al (0^{+} to 0^{+} spin-transfer) and when the reaction occurred with the "Fusion-Evaporation" reaction mechanism, it would produce mainly ^{26g}Al. As the reaction products of these two reaction mechanisms are transported through MARS at different magnetic rigidities, the ^{26m}Al and ^{26g}Al can be selected depending on which beam was needed. In order to test the above assumptions, the ^{26}Al beam was tested using the TAMU Tape Transport system [4] by measuring the number of β-decays to the number of ions. Since the ^{26g}Al is long-lived ($T_{1/2} \sim 7 \times 10^{5}$ years), measuring this ratio gives a direct measurement of the ^{26m}Al content of the beam. For the magnetic rigidity where the "Transfer" reaction mechanism dominated (MARS D1-2 = 420 A), it was found that the ^{26}Al beam intensity was 2×10^{5} pps and had 66% ^{26m}Al and 33% ^{26g}Al. For the magnetic rigidity where the Fusion-Evaporation reaction mechanism dominated (MARS D1-2 = 402 A), it was found that the ^{26}Al beam intensity was 2×10^{6} pps and had 36% ^{26m}Al and 64% ^{26g}Al. Spectra showing the ^{26}Al beam for both solutions measured with the MARS target detector are shown in Fig. 2.

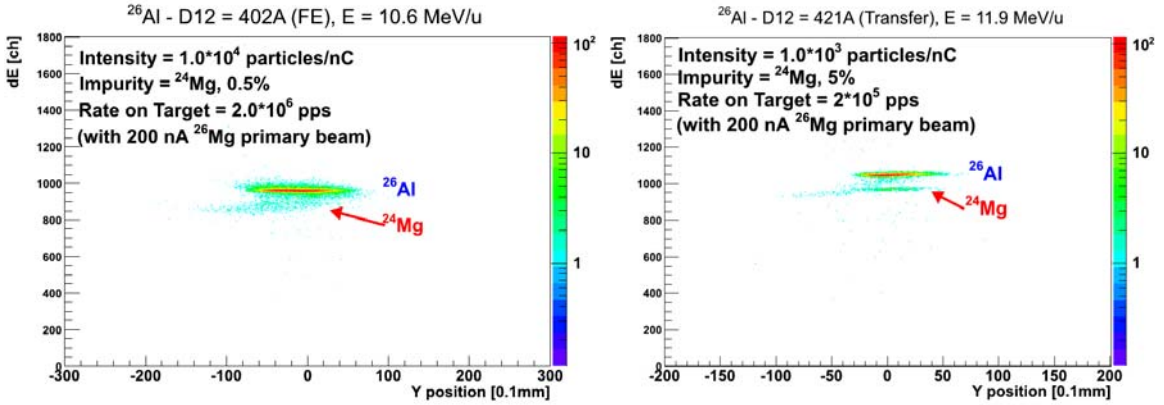

FIG. 2. MARS target detector spectra showing the separated ^{26}Al beam at the "Fusion-Evaporation" (left) and the "Transfer" (right) magnetic rigidity settings.

Following the beam tuning, the ^{26m}Al and ^{26g}Al beams were degraded in energy to ~5 MeV/u and ~3 MeV/u respectively by passing the beams through a 152 μm ^{9}Be foil, located upstream of the TECSA array (see Figure 1). The beams were energy degraded to increase the cross sections for the (d,p) reactions and also to reduce the background from contaminate reactions. After passing through the degrader, the beams impinged on a target of deuterated-polyethylene (CD_2) with areal density of 451 ± 5 μg/cm^2 and D:H ratio enriched to 98%. For this reaction, the protons from the forward center-of-mass angles would be detected at the backward lab angles. Thus, TECSA was mounted upstream of the CD_2 target in the flat configuration. The detector thickness of ≈ 300 μm was sufficient to stop the protons from the reaction at all angles measured. Also, the detector ring had a hole in middle to allow the ^{26}Al beam to pass through it on its way to the target. The d(^{26m}Al,p)^{27}Al and d(^{26g}Al,p)^{27}Al reactions were measured with the CD_2 target distances of 21cm and 12cm to obtain angular distributions for the ^{27}Al states.

Typical spectra from TECSA for the d(^{26m}Al,p)^{27}Al and d(^{26g}Al,p)^{27}Al reactions for the TECSA ring positioned at 21cm from the target are shown in Figure 3. The spectra are shown in center-of-mass frame, which allows the addition of all the detectors and rings of TECSA in order to increase statistics. The background in these spectra was reduced by requiring a coincidence with a timing signal from a heavy-ion in the beam (^{26}Al) or from a reaction (^{27}Al) in the scintillator-PMT detector. Gating on this coincidence in the data analysis software, and the other improvements to the scattering chamber mentioned previously, reduced the background significantly. The remaining background under the peaks was due to reactions of the beam with the carbon in the CD_2 target that could not be removed, and some remaining background from the β-decay of the ^{26}Al beam stopped in the chamber. In Fig. 3, ^{27}Al states were observed from both the ^{26m}Al and ^{26g}Al beams. While similar states were populated in the two cases, it is expected that the angular distributions of these states will show which states were populated by the ^{26m}Al and which were populated by ^{26g}Al. Analyses of these angular distributions are currently underway.

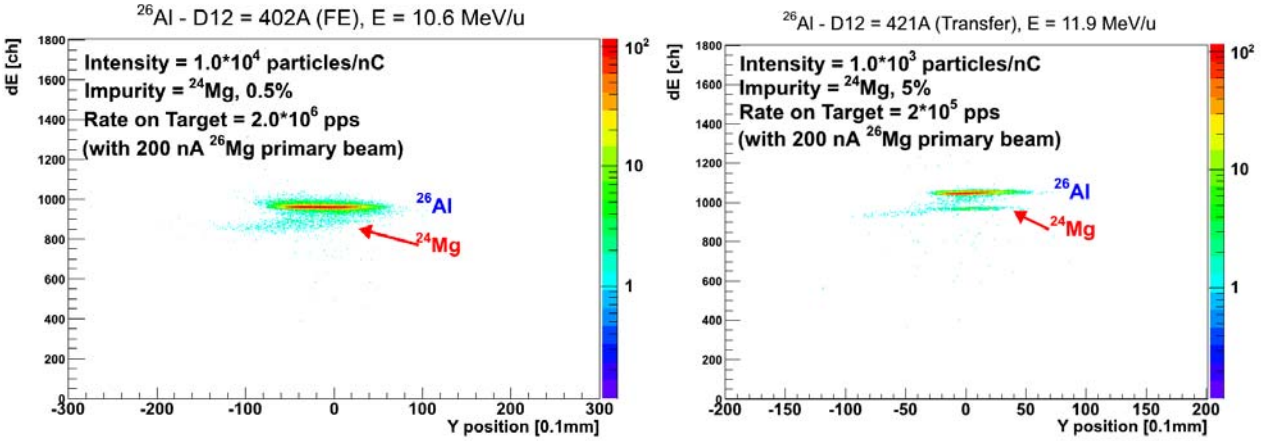

FIG. 3. Summed Center-of-Mass spectra for d(^{26m}Al,p)^{27}Al (left) and d(^{26g}Al,p)^{27}Al (right) obtained with TECSA at 21cm distance from the target.

In conclusion, the TECSA array was used to measure d(^{26m}Al,p)^{27}Al reaction at ~5 MeV/u and d(^{26g}Al,p)^{27}Al at ~3 MeV/u. Several states in ^{27}Al were selectively populated. In particular, the ^{27}Al level at 8.6 MeV excitation energy may be an isobaric analog state of a level in ^{27}Si, but further analysis of these data is needed.

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