^{26}Al Beam Production and its Application to Nuclear Astrophysics

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Introduction

One could say that Nuclear Astrophysics merges the study of infinitesimal with the infinite, combining the study of the reactions of the building blocks of matter with the study of the structures of the cosmos [1]. Thanks to satellite telescopes, impressive scientific progress has been made in the field of astrophysics. For example, the INTEGRAL project has shed light on many celestial phenomena thanks to its gamma ray investigations. These have revealed much about the unexplored areas of our Galaxy and have led to the discovery of impressive phenomena, such as on-going nucleosynthesis and gamma ray bursts.
The aforementioned advances in space sciences have given the possibility to measure the 1.8 MeV gamma-ray line from Al-26 in the Galaxy [2].

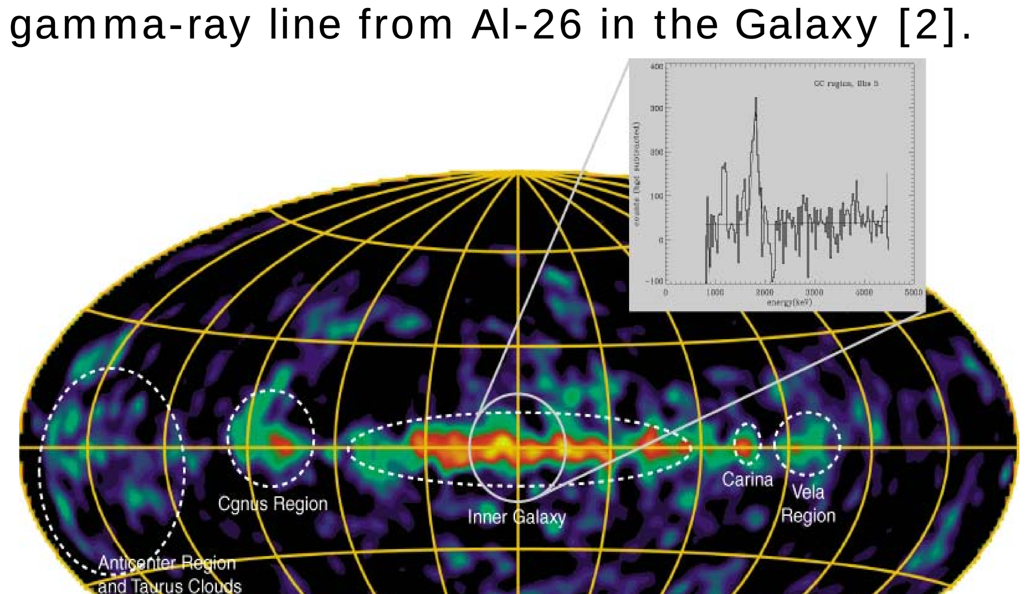


Figure 1. COMPTEL map of Milky Way Galaxy, 1.8 MeV gamma ray emissions.

^{26}Al is, presumably, produced during the supernova stage of stellar evolution. When it decays to ^{26}Mg, it emits the unique 1.8 MeV gamma ray detectable from space (Figure 1). Such gamma rays give insight into the location of supernovae and similar sources.

In fact, accurate measurements of ^{26}Al gamma ray emission can improve the understanding of nucleosynthesis currently occurring in the galaxy and the pre-SN phases of stellar evolution, which according to several authors [3] are the main sources of the Galactic ^{26}Al. In order to do this, the nuclear reaction paths involved in the production and destruction of ^{26}Al need to be investigated with improved accuracy.

Trojan Horse Method

One of the difficulties in studying such reactions is the Coulomb barrier. As the energy of the penetrating particle decreases so does the barrier penetration. It is balanced with the rapidly decreasing probability of having highly energetic particles (Maxwell-Boltzman distribution) to produce the Gamow peak. Direct measurements are difficult due to the high Coulomb barrier and therefore rare occurrence of measurable events. The Trojan Horse Method is a means of indirectly observing and measuring the ^{26}Al induced reactions [4].

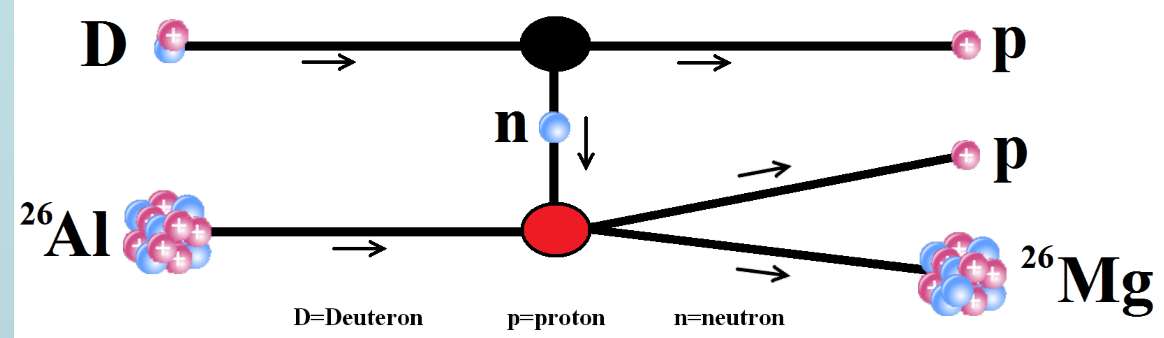


Figure 2. THM: the proton from the Deuteron continues on with no change in its momentum as if unaffected by the reaction. An astronomically significant cross section of the $^{26}Al + n \rightarrow {}^{26}Mg + p$ reaction is determined.

The reaction proposed, ^{26}Al(n, p)^{26}Mg, is not affected by the Coulomb barrier, but nonetheless this method is useful in the study of neutron induced reactions. For this case, the THM can provide a virtual neutron beam via deuteron break-up (Figure 2).

MARS

The beam of ^{26}Al was produced using inverse kinematics: a heavy ion beam on a light target. The reaction of the beam with the target produces many different unstable nuclei. However, MARS (Momentum Achromat Recoil Separator – figure 3) [5] is able to separate and remove most of these unwanted products. The products are selected by their magnetic rigidity in the momentum achromat and by q/m through the recoil separator. Once different particles are produced and separated, they are detected in the scattering chamber by a target detector, a MSPSD position sensitive detector (an example in Figure 4).

Momentum Achromat Recoil Separator layout

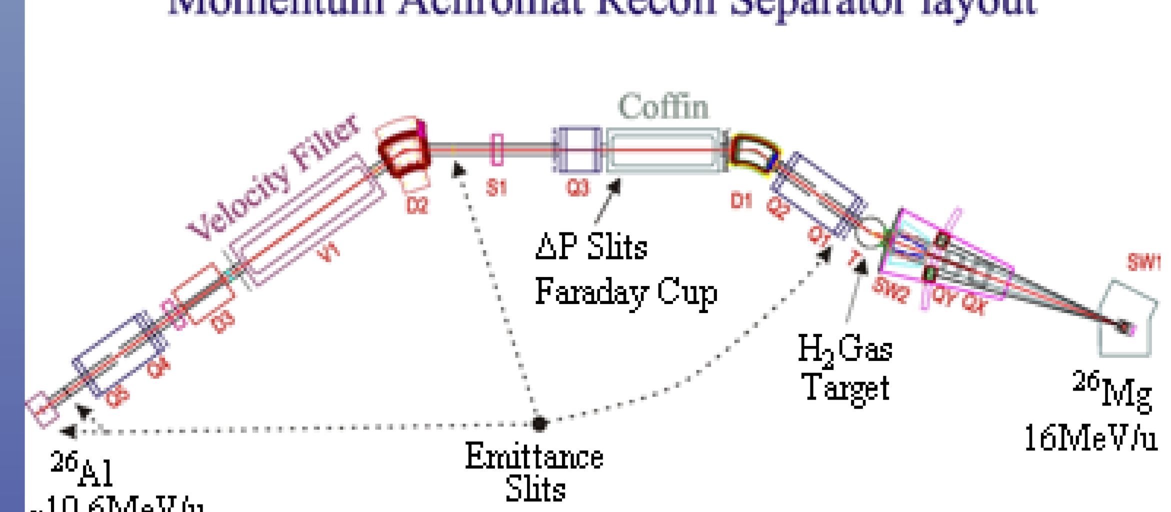


Figure 3. MARS setup with beam entry and targets on right and detectors on left.

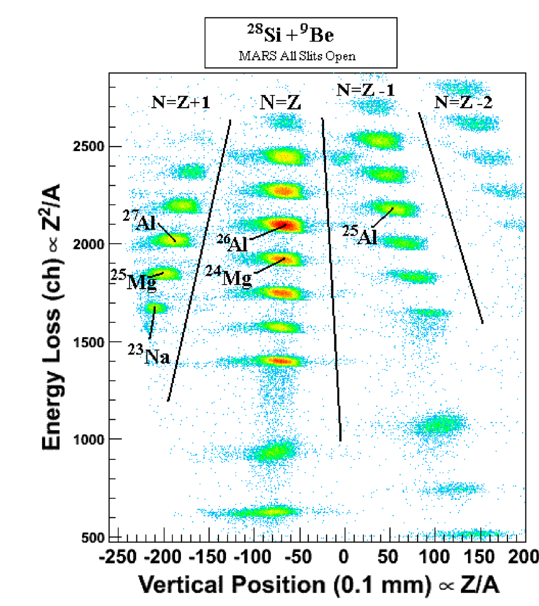
Results

Several techniques were utilized to produce ^{26}Al were tried. One entailed use of a ^{28}Si primary beam through a ^{9}Be target (Figure 4). However, more successful was a primary beam of ^{26}Mg at 16 MeV/u produced and accelerated by the K500 superconducting cyclotron. The beam then traveled through the primary target consisting of LN_2 cooled hydrogen gas pressurized to p=2 atm. This resulted in the production of the many ions. MARS was utilized to isolate the desired ^{26}Al by setting it, first at the parameters given by the Marsinator code, then adjusting for best ^{26}Al production and separation.

The produced ions were filtered closing slits in MARS, thus allowing for fewer ion species in the focal plane (Figure 5). Further selection with the slits produced a final spectrum of ^{26}Al with high purity (Figure 6) and E/A=11 MeV/u.

	Intensity	Energy	Purity	Impurity
^{26}Al	10^6 pps	11 MeV/u	97.2%	^{24}Mg: 2.8%

Figure 4. Example of ion production spectra with MARS slits all open. Many different ions reach the detectors. Many ions present in significant quantities. The lines divide the ions into groups based on their ratio of neutrons (N) and protons (Z).



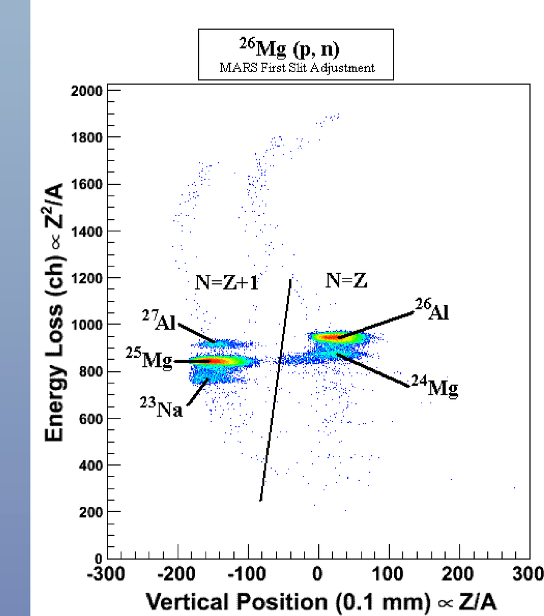
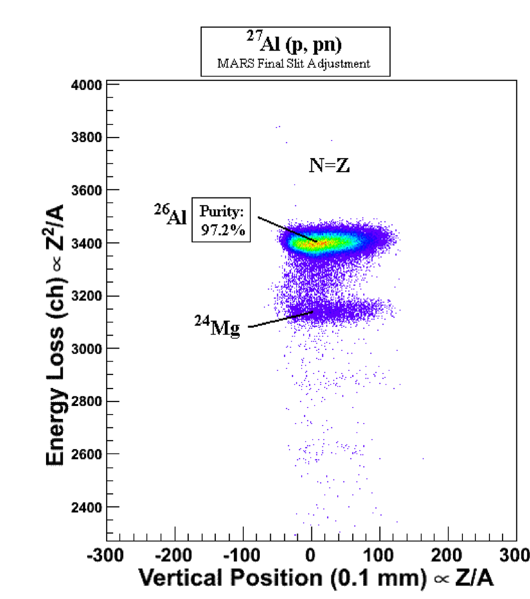


Figure 5. Ion spectra after initial slit adjustment. Many of the unwanted ions have been eliminated. Fewer ions present in significant quantities, particularly ^{25}Mg. Proton rich ions have been eliminated completely and neutron rich ions have been cut down to three.

Figure 6. Final ion spectra with MARS slits adjusted to isolate ^{26}Al in the secondary beam with 97.2% purity. Other ions present are in miniscule quantity. A ^{26}Al production rate of 10^6 ions/s on target was achieved before energy degradation.



In order to utilize the Trojan Horse Method the beam must fulfill the quasi-free condition [6]:

$$E_{qf} = E_{Al\text{-}n} - B_{np}$$

Where E_{qf} is the relative energy of the ^{26}Al and the neutron, $E_{Al\text{-}n}$ is the beam energy in the center of mass of the two body reaction (^{26}Al and neutron), and B_{np} is the binding energy of the neutron in the deuteron (2.25 MeV).

Through this equation, it was determined that the energy of the beam must be degraded to ~60MeV. This was accomplished through the use of a 152µm Beryllium foil.

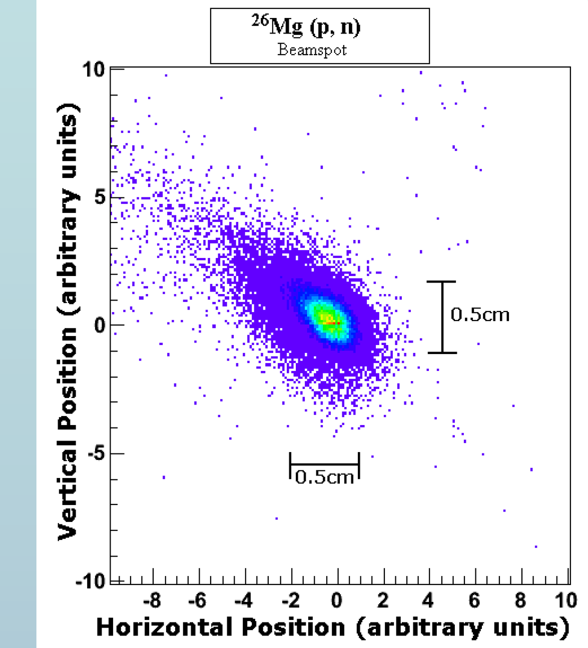
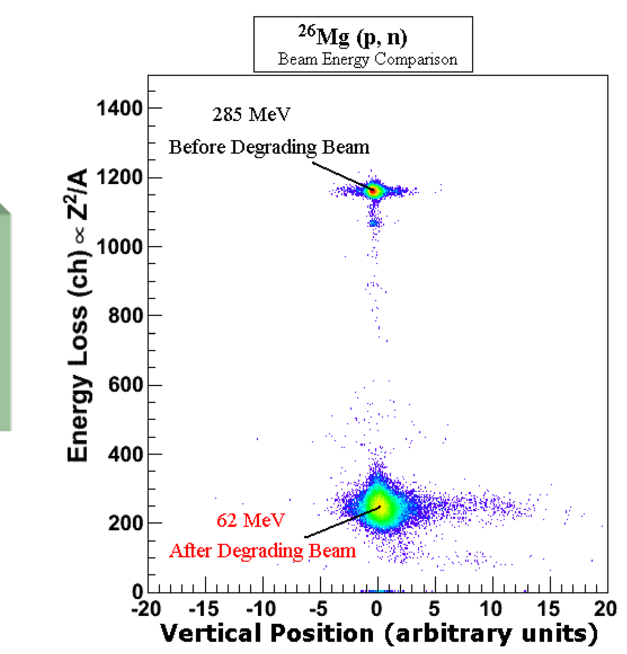


Figure 7. Final ^{26}Al production beamspot (0.5cm x 0.5cm) after degradation.

Figure 8. Spectra showing comparison of ^{26}Al beam energy before and after being degraded by a 152 µm Be foil.



Conclusion

An intense and pure ^{26}Al secondary beam (10^6 pps, 11 MeV/u, >97% pure) was produced with MARS. By use of a Beryllium foil, the beam was successfully degraded to the energy needed for the Trojan Horse Method (60MeV) without intensity loss. The final degraded beam had a beam spot of 0.5cm x 0.5cm, which is suitable for many applications utilizing both direct and indirect methods. With the successful production with a low energy beam, measurement utilizing the Trojan Horse Method can be carried out at the Texas A&M Cyclotron in the near future.

References

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