Progress in the analysis of the delayed proton and gamma decay of ^{27}P for nuclear astrophysics

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One of the first and most well observed gamma-ray lines in the interstellar medium is that of 1.809 MeV, coming from the β-decay of the ground state of ^{26}Al. The observation of this line provided more proof of the existence of a dynamic universe. However, the creation site of ^{26}Al is still under debate, requiring a fuller understanding of the creation and destruction reactions involving both the isomeric and ground state of ^{26}Al. In order to study the destruction reaction of $^{26m}Al(p,\gamma)^{27}Si^*$, which is dominated by resonant capture, an indirect method was employed, that of the β-delayed proton and gamma decay of ^{27}P. Due to selection rules, the same levels of interest, those above the proton threshold in ^{27}Si, were populated from the β-decay of ^{27}P. Determination of the energy, spin and parity of these resonance states, along with their partial gamma and proton widths, allows for the determination of their resonance strengths and thus, their contribution to the astrophysical reaction rate.

This experiment was done in November 2010 [1] with the K500 superconducting cyclotron at TAMU with a beam of $^{28}Si^{+10}$ at 40 MeV/u impinging on a hydrogen gas target kept at LN_2 temperatures and a pressure of 2 atm in the MARS beam line. The nuclei of interest, ^{27}P, were created in a (p, 2n) fusion evaporation reaction. The productivity measured at the beginning of the experiment determined that there was about 26 pps of ^{27}P and approximately 18% total impurities with the coffin (momentum) slits at ± 1.0 cm. With the coffin slits closed to the ± 0.4 cm needed for implantation, the rate dropped to about 10.5 pps.

The ^{27}P nuclei were then implanted, with the use a rotating aluminum degrader, in the center of a thin BB2 (45 μm thick) double sided strip detector, referred to as the proton detector. Silicon detectors were placed on either side of this proton detector, referred to as β-detectors, in order to reduce the background through coincidence requirements implemented in the electronics acquisition trigger. The beam from the K500 cyclotron was pulsed in order to measure the β-p and β-γ coincidences simultaneously.

In order to obtain an internal energy calibration ^{28}P was implanted in the center of the proton detector. It was chosen due to the fact that it is also a β-delayed proton emitter with known protons in the energy region of interest. Once this was done, the thin 45 μm proton detector was replaced with a detector similar in every regard save that it was 104 μm thick. This thicker proton detector allowed for the momentum slits to be opened further and thus, allowed a higher beam rate to be obtained. At this point ^{24}Al was implanted in the proton detector in order to obtain data on its known gammas, giving an extended energy calibration up to 8 MeV. With the thicker BB2-104 still in place, ^{27}P was again implanted in order to study the resulting gammas with the increased beam rate.

In the previous year, better extended energy calibrations have been obtained by a more careful selection of calibration peaks as well as using multiple sub-ranges, each with their own energy calibration, and making the necessary adjustments for the recoil energy not recorded in the detectors. The extended efficiency calibrations were also improved, taking into account the sum peak issue that arose for the ^{60}Co and ^{152}Eu sources used in the close geometry of this experimental setup. With these new and better calibrations, and a better understanding of the effect of the close geometry involved, several gamma peaks in the ^{27}P spectrum that had been previously un-assigned turned out to be sum peaks, however, there are still new gammas to be fit into the decay scheme. The background, ^{24}Al and ^{28}P gamma spectra have had all their peaks identified, including several peaks in the background spectrum that were found to be from material activation created during this experiment (aluminum activation of the degrader) and some created in previous experiments (lead activation of the shielding placed around HpGe 1). Fig. 1 shows the current known peak assignments in the ^{27}P gamma spectrum.

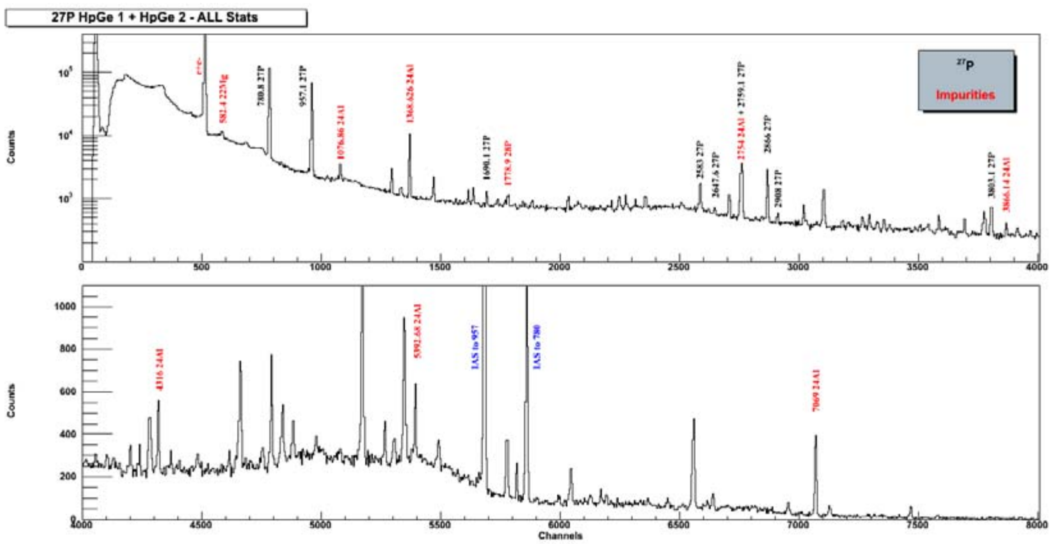

FIG. 1. The ^{27}P Gamma spectrum created from all good statistics.

The proton analysis has had several significant improvements. First, a ROOT macro was created to better fit the alpha source peaks and thus obtain a better gain matching of all strips on both sides of the proton detectors. Careful evaluation of the individual strips required the discarding of a few of them but once done, the results were significantly better than what had been previously obtained. With these improvements, all peaks have been identified in all spectra; those in ^{27}P (both proton detectors), ^{28}P and in ^{24}Al. An internal calibration will be created with the peaks found in the ^{28}P spectrum which will not be affected by the dead layer of the detectors, as the alpha source data had been, allowing for an accurate energy assignment of the proton peaks found in the ^{27}P spectrum. However, in the energy region of interest (around 200 keV) the β-background was still the dominant feature due to the low total proton branching ratio (previously estimated at 0.07 %). Background subtraction attempts are ongoing with ROOT and a new (lower) limit on the total proton branching ratio is expected.

[1] E. Simmons *et al*., in *Progress in Research*, Cyclotron Institute, Texas A&M University (2011 – 2012), p. I-27

[2] A. Saastamoinen *et al*., Phys. Rev. C **83** 045808 (2011).