Comment on “Cross section of the ^{13}C(α,n)^{16}O reaction: A background for the measurement of geo-neutrinos”

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Comment on "Cross section of the $^{13}C(\alpha,n)^{16}O$ reaction: A background for the measurement of geo-neutrinos"

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Abstract

Harissopulos *et al.* report a cross section from a measurement that used a moderated neutron detector not capable of measuring the neutron energy and therefore unable to determine the relative contribution from neutrons that populate the ground state or excited ^{16}O states in $^{13}C(\alpha,n)^{16}O$ reactions above 5 MeV. Since the energies of ejected neutrons populating the excited states are 6 MeV lower than those populating the ground state, the corresponding efficiency of their neutron detector for these neutrons was a factor of two higher than assumed. Therefore, the reported $^{13}C(\alpha,n)^{16}O$ cross sections above 5 MeV may be over-calculated by nearly 50%.

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The measurement of Harissopulos *et al.* [1] used a so-called 4π moderated neutron detector made of ^{3}He-filled proportional counters surrounded by polyethylene moderator material. These types of detectors moderate neutrons until they are captured by the ^{3}He and induce a strong identifiable signal [2]. Such detectors cannot measure the neutron energy spectrum, and therefore cannot determine the partial cross section to any possible reaction channels. At bombarding energies above the reaction Q values for the first excited state (E_1) of the recoil nucleus where both (α,n_0) and (α,n_1) branches are open, a moderated neutron detector cannot distinguish between the two possible ejected neutrons n_0 or n_1.

While they typically have a relatively flat efficiency profile to neutrons up to a few MeV, moderated neutron detectors may have very different efficiencies between the n_0 and n_1 neutrons if the energy between the ground state and an excited state is sufficiently large. Therefore, measurements using moderated neutron detectors at energies above the reaction Q_i value for any excited state E_i incur an uncertainty that scales with the detection efficiency difference between the n_0 and n_i neutrons, unless the relative intensity to these different reaction channels is also measured through some other method. This issue is widely recognized and addressed in detail in Section 2.1.2.1-1 of IAEA Report [3] and these experimental publications (e.g., [4–6]). Additionally, if a detector does not actually cover the entire 4π solid angle, due to beam entrance and exit ports, unknown angular distributions can also add to the uncertainty of the extracted total cross section.

The effect of differing efficiencies to neutrons populating different states is strongest for cases like ^{13}C(α,n)^{16}O because the first excited states in ^{16}O, at 6.05 and 6.13 MeV, are so high that the neutron energies from the $n_{1,2}$ branches are 6 MeV lower than n_0. This occurs at an alpha energies above 5 MeV for ^{13}C(α,n)^{16}O, which is the first excited state Q value. However, it was ignored or forgotten during the analysis for the Harissopulos *et al.* measurement [1].

Using the published efficiency curve for the moderated neutron detector from the original publication [1] (Equation 1), the energy difference for the $n_{0,1}$ neutrons corresponds to detection efficiencies of 21% and 40% for the n_0 and n_1 neutrons, respectively. The calculated cross section data above 5 MeV should have included the uncertainty in their detection efficiency due to the possibility of populating the excited states in ^{16}O. If there is significant branching to the excited states, the actual cross section above 5 MeV could be almost 50% less than reported by Harissopulos *et al.* [1]. Indeed, recent published plots of uncalibrated yield data on ^{13}C(α,n)^{16}O using un-moderated neutron detectors suggest that the (α,$n_{1,2}$) reaction channels are non-negligible at select energies above 5 MeV (Figures 7 & 8 of Ref. [8] and Figure 3-2 of NNSA public report [9]).

In conclusion, the ^{13}C(α,n)^{16}O measurement of [1] used a moderated neutron detector and neglected to account for changes in efficiency due to different neutron energies that are possible above the ^{16}O first excited-state Q value at 5 MeV. This leads to an uncertainty in the cross section of about 50% above 5 MeV. This reaction is important at lower energies for *s*-process nucleosynthesis [7], but, at energies around 5 MeV and above, it is a significant background in underground laboratories as well as reactor neutrino and geo-neutrino experiments. For research that rely on ^{13}C(α,n)^{16}O cross section data above 5 MeV, further experiments are warranted.

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