A POSSIBLE $^{12}C(n,2n)^{11}C$ TOTAL CROSS SECTION MEASUREMENT

Abstract

Tertiary neutron production can be used as an indicator of the burn fraction of a deuterium-tritium pellet in inertial confinement fusion reactions. One way to monitor tertiary neutrons is by carbon activation using the $^{12}C(n,2n)^{11}C$ reaction, which has a threshold of 20.3 MeV and so is insensitive to primary neutrons produced in the DT reaction. However, the cross section for this reaction is not well known. Several different experimental techniques for measuring $^{12}C(n,2n)$ have been examined, with an activation experiment being the most feasible.

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Introduction

The $^{12}C(n,2n)$ reaction has been proposed as a possible way to measure the flux of tertiary neutrons above about 20 MeV produced by the DT reactions occurring in the inertial confinement fusion (ICF) reaction chamber at the National Ignition Facility (NIF). One of the biggest remaining obstacles to the implementation of this diagnostic technique is that its accuracy depends on the $^{12}C(n,2n)$ cross section, which has not been well-measured. Figure 1 is a plot of all the measurements to date for this reaction. The previous measurements, which were all made using activation techniques, disagree by as much as a factor of two.

Four different methods have been examined for measuring the $^{12}C(n,2n)$ cross section by detecting different outgoing radiation: neutrons, recoiling ^{11}C, de-excitation gamma rays from the $^{12}C(n,2n)^{11}C$ reaction, and gamma rays from activation. Count rates for each technique were determined.

The feasibility of these measurements has been studied for two laboratories that could provide beams with very different characteristics. At WNR, which is part of the Los Alamos Neutron Science Center (LANSCE), well collimated pulsed beams with an energy spectrum from a fraction of an MeV up to 800 MeV are available, while the John E. Edwards Accelerator Laboratory at Ohio University can produce intense monoenergetic neutron fields up to 24 MeV, and possibly non-monoenergetic neutron fields at higher energies.

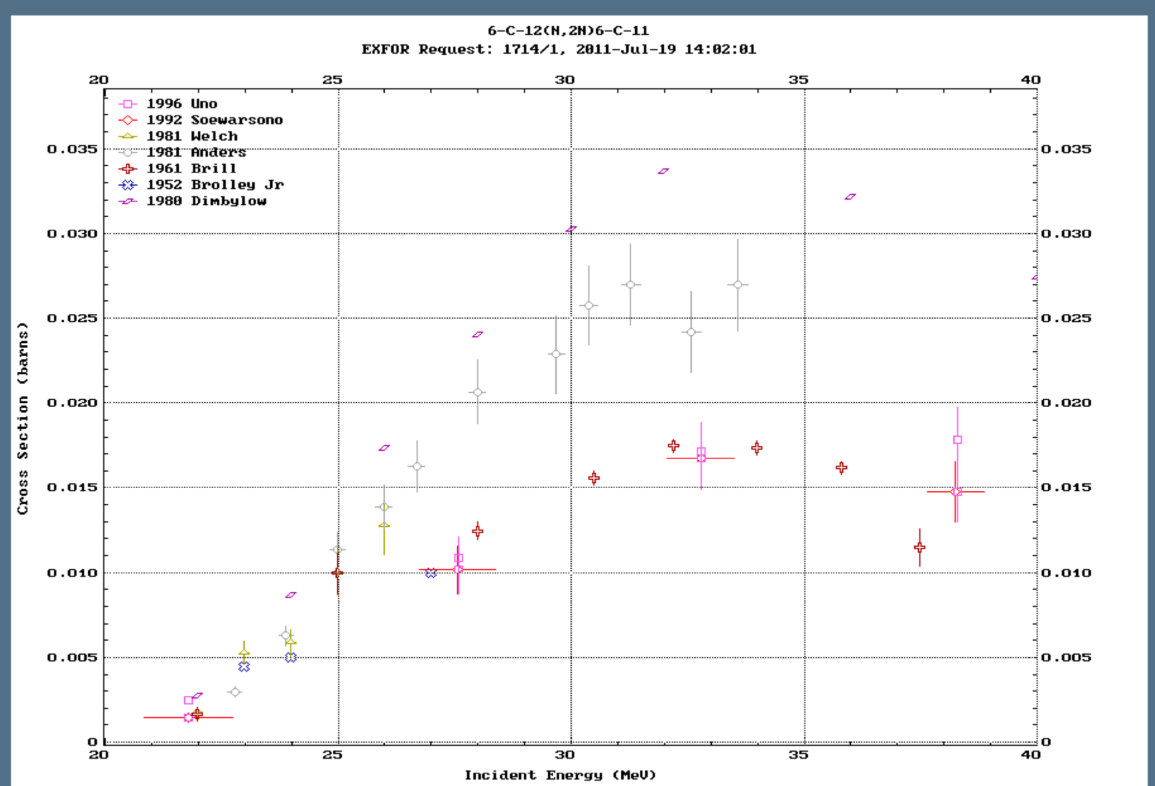

Figure 1 – Measurements to date for the $^{12}C(n,2n)^{11}C$ reaction in the energy region of interest.

Conclusion

Clearly, the only method that is presently feasible is the activation technique. We are currently planning an experiment to be performed this summer. Detectors and electronics will be set up prior to performing the experiment, which we anticipate will take several weeks of beam time. The end of the summer will be used for data analysis.

1. Prompt Gamma

The $^{12}C(n,2n)^{11}C$ reaction often leaves the ^{11}C in an excited state. Characteristic prompt gamma rays from the de-excitation of the ^{11}C nuclei could be used to identify the production of ^{11}C. The time-of-flight of the outgoing gamma rays could be used to determine the energy of the incident neutron beam. Unfortunately, at the energy range of interest, most of the ^{11}C nuclei are left in the ground state, requiring a very large correction based on a theoretical model.

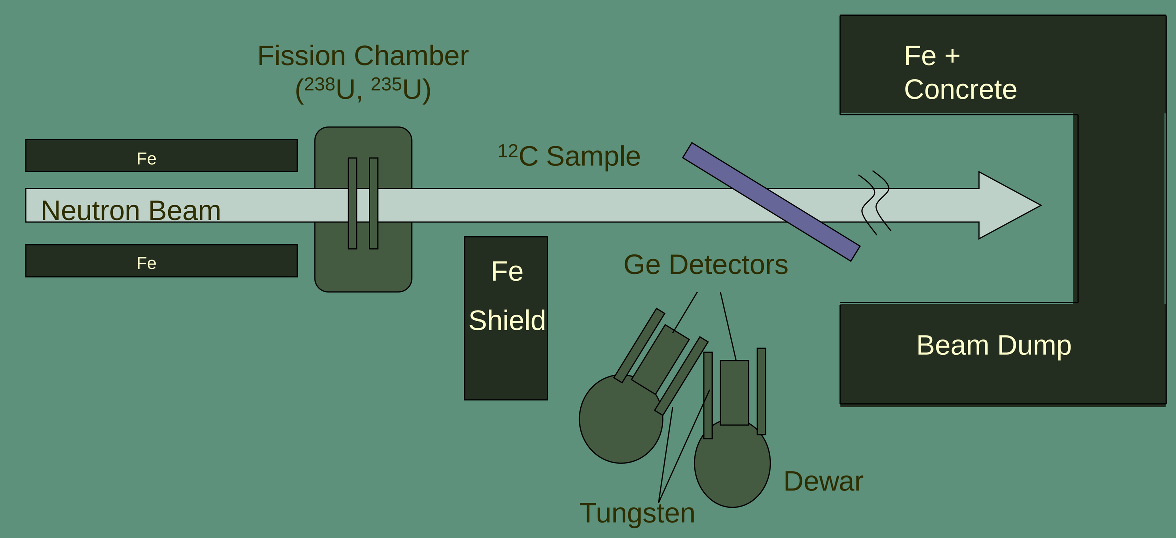

Figure 2 – Experiment to measure prompt gamma rays at LANSCE. ^{11}C nuclei that are left in excited states by the $^{12}C(n,2n)^{11}C$ reaction decay, yielding partial cross sections.

Table 1 – "Prompt Gamma" Experimental Parameters and Count Rate Estimate.

Flux (4FP15R) (20-30 MeV)	45000 neutrons/sec/MeV
Cross section (25 MeV)	0.007 b
Detector Absolute Efficiency at 2 MeV (50% Rel Eff HPGE, ~200 cc)	1.3×10^{-3}
Detector Absolute Efficiency at 4 MeV (50% Rel Eff HPGE, ~200 cc)	8×10^{-4}
Distance to detector	14 cm
Target (graphite)	5 mm thick
Count rate @ 2 MeV (assume 1/3 of total decays)	80 counts/hour/MeV
Count rate @ 4 MeV (assume 1/3 of total decays)	50 counts/hour/MeV

3. Recoiling ion

In this technique, the neutron beam is incident on a thin graphite target allowing the ^{11}C ions to escape the target. One advantage of this technique is that it would allow ions from other reactions to be simultaneously measured. In order identify the outgoing ions and to increase the low count rate due to the thin target, a focusing magnetic spectrometer would provide excellent mass resolution and a large solid angle by focusing ions onto a focal plane. The well collimated beam at LANSCE would be needed to reduce the number of ions from neutron interactions in the vacuum chamber walls. Unfortunately, because the focused ions have different path lengths, the ions' flight times would not be well measured, making the uncertainty in the incident neutron energy too large.

Table 3 – "Recoil Ion" Experimental Parameters and Count Rate Estimate.

Flux (4FP15R) (20-30 MeV)	45000 neutrons/sec/MeV
Detector	25 msr
Cross section (0.007/4π b/sr @ 25 MeV)	0.56 mb
Target	0.15 μm graphite foil
Count rate	0.1 counts/day/MeV

2. Two-Neutron

The collimated, pulsed neutron beam at LANSCE strikes a set of 10 thin active targets. The neutrons produced in the $^{12}C(n,2n)^{11}C$ reaction in the active targets then scatter into large plastic scintillators that surround the target. The active target scintillators define the time-of-flight of the incident neutrons as well as flight time of the outgoing neutrons to the large detectors. Both the angle distributions and the energies of the incident and outgoing neutrons can be determined. Unfortunately, this method is very expensive in terms of both time and resources.

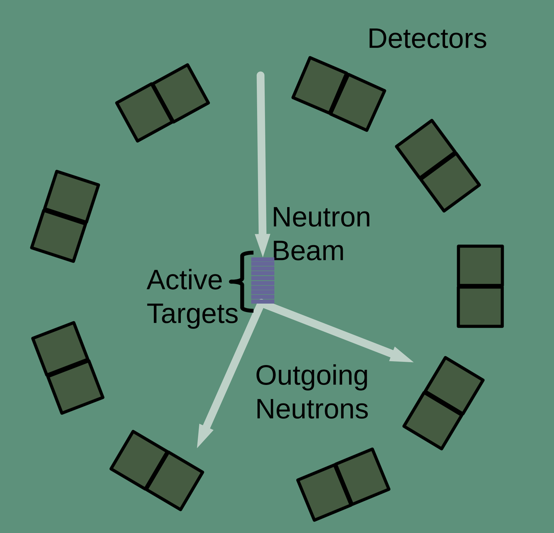

Figure 3 – Experimental arrangement for detecting the two outgoing neutrons in coincidence with the active target and the beam pulse.

Table 2 – "Outgoing Neutron" Experimental Parameters and Count Rate Estimate.

Flux (4FP15R) (20-30 MeV)	45000 neutrons/sec/MeV
Cross section (0.007/4π/4π) b/sr² @ 25 MeV)	44 μb/sr²
Detector (two 2 m × 10 cm × 10 cm plastic)	0.28 Sr
Angles	9
Target (ten BC418 active targets)	10 x 2 mm thick
Count rate	25 counts/pair/day/2 MeV

4. Activation

A thin polyethylene target is exposed to the neutron beam, and is then removed to a counting station. The ^{11}C nuclei from $^{12}C(n,2n)^{11}C$ undergo β+ decay with a half life of 20 minutes. The distinct back-to-back gamma rays characteristic of positron annihilation can be counted in coincidence. To determine the incident neutron flux, elastically scattered protons are monitored during activation using a dE-E silicon surface barrier detector telescope.

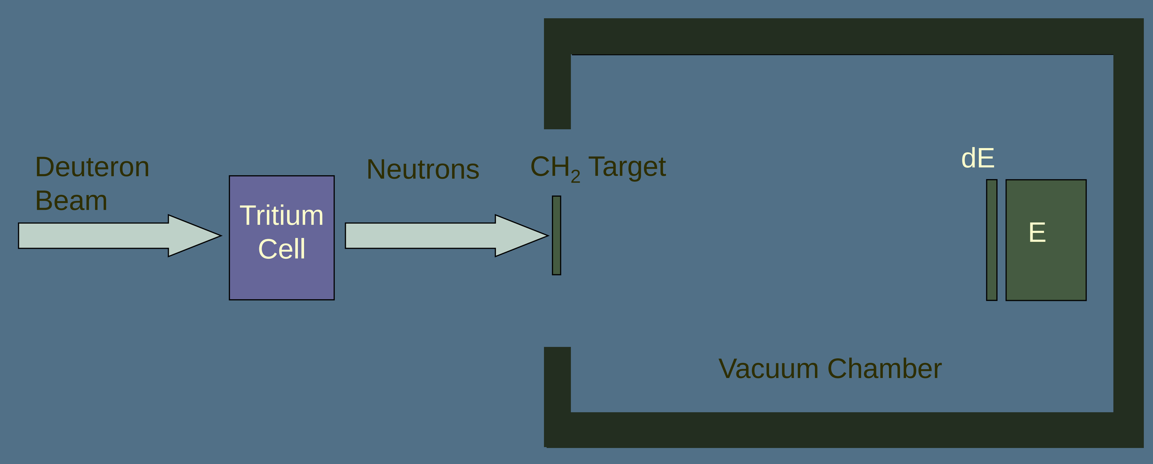

Figure 4 – Experimental setup for activation measurement at Ohio University. The incident neutrons both activate the target by $^{12}C(n,2n)^{11}C$ and elastically scatter from the hydrogen. Elastically scattered protons are identified by the dE-E telescope and used to determine the flux of neutrons.

Table 4 – Activation Experimental Parameters and Count Rate Estimate.

Flux (Ohio Univ. 24 MeV, 2 cm from tritium cell)0	10^7 n/sec
Cross section for $^{12}C(n,2n)$ (24 MeV)	5 mb
Cross section for np scattering at 0° (24 MeV)	33 mb/sr
Silicon Detector (1 cm² at 10 cm from CH2)	10 msr
Target (CH2 0.89 g/cm³)	1 mm thick
^{11}C activity from (n,2n) in CH2 target after 2 h	190 Bq
Recoil proton count rate	13 cnts/sec