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Development of a New Method for Measurement of Neutron Detector Efficiency up to 20 MeV

N.V. Kornilov,[1] S.M. Grimes,[1] T.N. Massey,[1,*] C.E. Brient,[1] D.E. Carter,[1] J.E. O'Donnell,[1] F.B. Bateman,[2] A.D. Carlson,[2] R.C. Haight,[3] and N. Boukharouba[4]

[1] *Department of Physics and Astronomy, Ohio University, Athens, OH 45701, USA*
[2] *National Institute of Standards and Technology, Gaithersburg, MD 20899 USA*
[3] *Los Alamos Neutron Science Center, Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[4] *Department of Physics, University of Guelma, Guelma 24000, Algeria*

A new approach to neutron detector efficiency detemination has been taken. A neutron detector has been calibrated with a ^{252}Cf source at low energy. The calibration can be extended to energies above 8 MeV with accelerator-based neutron sources. This techniques uses the fact that the cross section for a symmetric reaction with nucleus of atomic number A yielding a final nucleus with atomic number $(2A-1)$ and a neutron $A + A \rightarrow (2A-1) + n$. This reaction must be symmetric about 90° in the center-of-mass system. The laboratory energies for the neutrons at the paired energies differ substantially. Thus, an efficiency known at one of the two angles can be used to determine the efficiency to higher energies or, for a negative Q, to lower neutron energies.

I. INTRODUCTION

The efficiency of a neutron detector is a critical characteristic for the successful conduct of experiments in nuclear and neutron physics. This characteristic of the detector depends not only on scintillator properties but is also strongly influenced by environmental conditions and should be thoroughly investigated both experimentally and with model-based calculations. For many of the fundamental standard measurements, such as the 1-2% determination of the (n,p) angular distribution, and for other applied tasks, like the 1-2% measurement of neutron standards used in neutron field characterization up to 20 MeV, there is a very strong demand for a high accuracy which is far from easily satisfied.

In this report we suggest a new method for the measurement of the neutron detector efficiency. It is based on the well known fact of the equality of the neutron yield from a symmetric reaction. When the projectile and the target are identical, the differential reaction cross section is the same for a forward angle, θ, and the supplementary back angle, $180° - \theta$, in the center of mass system. The neutron energies at these corresponding angles in the laboratory system are different. This allows the relative efficiency at two energies to be measured directly. A series of efficiency ratios can be measured by changing the beam-energy and angle. If more than one excited state is populated, each excited state can be used to determine efficiency ratios.

The ^{6}Li(^{6}Li,n) reaction is a very attractive candidate to cover the energy range 1-20 MeV with an input ^{6}Li ion energy of 4-12 MeV. The low energy range of the efficiency may be determined relative to the ^{252}Cf spontaneous fission neutron spectrum standard.

By using reactions with a large positive Q-values, we may move up to 20 MeV neutrons. We discuss in this report the method itself and its applications for the $^{6}\mathrm{Li}(^{6}\mathrm{Li,n})$, $^{12}\mathrm{C}(^{12}\mathrm{C,n})$, $^{13}\mathrm{C}(^{13}\mathrm{C,n})$, and D(d,n) reactions, and demonstrate the results for an NE213 detector.

II. CALIBRATION WITH A ^{252}CF FISSION CHAMBER

The calibration with ^{252}Cf has been carried out using similar methods to previous work [1]. A major difference was in using the swinger facility [2] at the Ohio University Accelerator Laboratory (OUAL) which eliminates the need to move the neutron detector when changing the detection angle. The calibrated detector was a 5.08 cm thick by 12.7 cm diameter bubble free NE213 detector coupled to a RCA-4544 photomultiplier. A bare ^{252}Cf source was obtained from Eckert & Ziegler [3]. A low mass fission chamber was fabricated and used with just above atmospheric pressure with a 95% Ar and 5% CO_2 gas mixture. The discrimination between alphas and fission events was made very similar to previous work [1]. The distance between the fission chamber and the detec-

* Corresponding author: massey@ohio.edu

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tor was kept at $\sim$ 4 m. The detector was located in the time-of-flight tunnel adjoining the beam swinger facility [2]. The neutron collimation consisted 30 cm diameter cylindrical sections of high density nylon. A continuous conical shape was machined in these sections. The conical shape had its minimum diameter of 2-4 cm diameter at the target position and had a 24 cm diameter opening in the tunnel 3.8 m from the target. The result of a ^{252}Cf time-of-flight measurement is shown in Fig. 1.

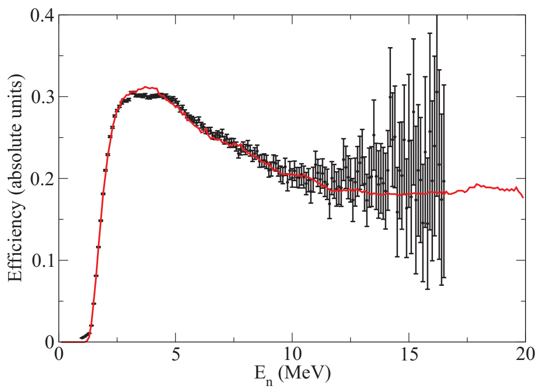

FIG. 1. The efficiency determined from a ^{252}Cf fission measurement. The continuous line is a calculation of the efficiency based on codes by Dietze [4].

III. SYMMETRIC REACTIONS

We have looked at a number of options for use in symmetric reactions. The symmetric reactions are shown in Table I. These reactions require both a beam and a stable target of the same isotope. High-current beryllium beams are not presently available.

TABLE I. Symmetric Input Reactions.

Reaction	Q-Value (MeV)
d + d → ^{3}He + n	3.269
^{6}Li + ^{6}Li → ^{11}C + n	9.452
^{7}Li + ^{7}Li → ^{13}C + n	18.619
^{9}Be + ^{9}Be → ^{17}O + n	15.434
^{10}B + ^{10}B → ^{19}Ne + n	14.270
^{11}B + ^{11}B → ^{21}Ne + n	14.996
^{12}C + ^{12}C → ^{23}Mg + n	-2.598
^{13}C + ^{13}C → ^{25}Mg + n	11.371

The low cross sections of some of the symmetric reactions can make the observed spectra sensitive to background reactions.

The well known d + d reaction is thoroughly studied in the existing literature and its cross section is easy to measure at all angles. Our typical method of producing neutrons with this reaction would be with a deuterium gas cell with a 5 micrometer tungsten foil. The angular spread due to straggling was estimated at 2 degrees for tungsten and 1 degree for a molybdenum foil. A titanium deuteride target is estimated to produce an angular spread of 0.2 degrees while the lowest angular spread was found to occur with a deuterated polyethylene target which produces a spread of 0.1 degrees. Angular spread matters when comparing cross sections from two different angles and it is significant in the case of a rapidly varying angular distribution such as the D(d,n) angular distribution.

We have performed preliminary measurements with a deuterated polyethylene target fabricated in the manner of Matsuki [5]. The results using this target are shown in Fig. 2. One of the important features is the large cross section for ^{12}C(d,n) reaction.

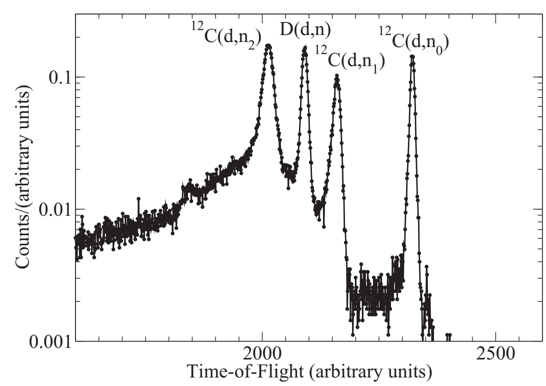

FIG. 2. Time-of-flight measurement of neutrons for a CD_2 target at 120 degrees and an incident energy of 8.123 MeV. The peaks from ^{12}C(d,n) and D(d,n) are marked in the figure. The peak from D(d,n) crosses the ^{12}C(d,n) peaks as the angle increases.

A review of the literature for the ^{6}Li + ^{6}Li reaction showed only neutrons measured in coincidence with gamma-rays had been reported [6–9]. The cross section was only reported for proton emission. The estimated cross section was $\sim$ 500 microbarns/sr for neutron decay to a given state. We made measurements using a ^{6}LiF target. A continuum spectrum was found with no indication of individual states. To remove the neutron backgrounds associated with fluorine, we are currently working on a lithium target which is sandwiched between a backing of nickel and a covering of nickel. The kinematics of the ^{6}Li(^{6}Li,n) reaction are shown in Fig. 3.

We plan to look at this system to reach the highest energies for the efficiency measurements. The literature on the ^{7}Li + ^{7}Li reaction had no measurement of the outgoing neutron [10–20]. The separation of individual states will be a challenge for these energies.

The most recent study found of the ^{12}C + ^{12}C reaction was [21]. We have observed individual levels with neutron energy less than 11 MeV from this reaction at an incident

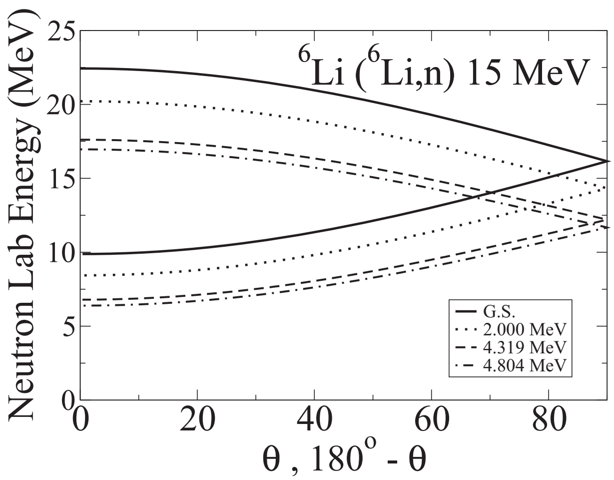

FIG. 3. The laboratory neutron energy of the first four levels from the ^{6}Li(^{6}Li,n) reaction is plotted relative to the forward and backward angles in the center of mass. Each final state is represented by a continuous curve. The center of mass angle is plotted as θ for $\theta < 90^{\circ}$ and $180^{\circ} - \theta$ for $\theta > 90^{\circ}$.

energy of 20 MeV. This was possible after a special tune of the time-of-flight pulsing and bunching system that resulted in an improved timing width of 2.0 ns as measured by the gamma-ray peak in the neutron detector. The beam width was measured independently using elastic scattering from a gold foil and a fast photomultiplier to have a width of 0.5 ns.

Current literature on the ^{13}C + ^{13}C reaction contains no reports of measurements of the neutron channel including the most recent study [22]. We have made initial measurements at 12 MeV incident energy and found no separation of the individual levels. The level spacing is very small in this energy region and the cross sections to each level are no more than ~ 1 mb/sr.

IV. STOPPING TARGET REACTIONS

A target which stops the incident beam completely is called a stopping target. A stopping target produces a neutron spectrum which is smooth with neutron energy. A precise target thickness is not needed and the reaction yield is high. The detector counting rate during a calibration with ^{252}Cf is low, making an efficiency determination to $\sim 1 - 2\%$ is difficult at high energy. If the efficiency is determined with ^{252}Cf and symmetric reactions and the neutron fluence is determined from a stopping target for Be(d,n), B(d,n), Al(d,n) and V(d,n). The absolute neutron yield from these targets can be used for subsequent detector calibrations

High purity and stability of the stopping targets is then needed for candidates for secondary standards. Stopping target spectra have been calibrated to an accuracy of about 5% relative to the ^{235}U(n,f) cross section standard using a fission chamber. The spectra have been successfully used for calibration of neutron detectors [23, 24]. It is hoped that the combination of these reactions together with a neutron detector calibrated by these new methods would increase the accuracy of these “secondary” standards.

V. CONCLUSIONS

This method is a path to reducing the error in the efficiency and extending it reliably to higher energies. The use of symmetric reactions has the promise of greatly increasing the accuracy of neutron detector efficiency. Our work so far indicates that only the d + d reactions can produce sufficient neutrons to allow calibration using the symmetric reactions method.

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