NUCLEAR INSTRUMENTS AND METHODS 116 (1974) 41–43; © NORTH-HOLLAND PUBLISHING CO.

NEUTRON-DETECTOR EFFICIENCY MEASUREMENTS FROM 7 TO 14 MeV*

P. LELEUX†, P. C. MACQ, J. P. MEULDERS and C. PIRART

Institut de Physique Corpusculaire, B-1348 Louvain-la-Neuve, Belgium

Received 17 September 1973

The neutron efficiency of an NE 102 plastic scintillator is measured for neutron energies from 7 to 14 MeV, using the $D(d,n)^3He$ reaction. The experimental results are compared with the predictions of two program codes. Different values of the $^{12}C(n,\alpha)^9Be$ reaction cross sections are introduced in the calculations; they strongly affect the calculated efficiency.

1. Introduction

In nuclear spectroscopy studies where neutrons have to be detected, the knowledge of the neutron-detector efficiency is very useful: absolute spectroscopic factors are indeed deduced from absolute neutron cross sections. In the recent past, some program codes[1–3]) have been written. From a satisfactory agreement between the measured and calculated efficiency over a limited energy range, it should be possible to confidently extend the calculation to other energies or other neutron detector types.

In this paper, we report on measurements of an NE 102 plastic scintillator neutron detection efficiency, for neutron energies ranging from 7 to 14 MeV, using the $D(d,n)^3He$ reaction. The experimental results are compared with Kurz's and Stanton's programs.

2. The detector

The neutron detector was a 2 cm thick, 20 cm diameter NE 102 plastic scintillator, coupled via a lucite light pipe to a Philips 58 AVP photomultiplier (PM). Netic and Co-netic μ-metals shielded the detector against magnetic fields. Preliminary to the efficiency measurements, we first of all measured and minimized the transit time differences for events across the photocathode; for this we used a method derived from Kalyna[4]): a light emitting diode (LED) driver triggered a photodiode placed on the lucite light pipe. The PM anode pulses were fed to a constant fraction discriminator (CFD) whose output started a time-to-amplitude converter (TAC). The stop input of the TAC was triggered by the direct LED driver output, through another CFD. The TAC spectrum was analyzed in a standard 400-channel analyzer, resulting in a well-defined peak, whose width (0.8 ns) was a direct measurement of the time resolution of the system.

When varying the photodiode position across the light pipe surface, the peak shift and the anode pulse amplitude were recorded. The PM dynode voltages have been adjusted in order to minimize the transit time differences while trying to keep constant the anode pulse amplitude. Fig. 1 displays the final results, obtained for a total voltage $V_{\mathrm{tot}} = 2600$ V. In fig. 1, the pulse heights are absolute values (in V), while the transit time differences (in ns) are relative to position 0 (LED at the center); the LED displacement was either along or perpendicular to the dynode axis.

3. Experimental method

A 35 MeV deuteron beam from the new Louvain University isochronous cyclotron (CYCLONE) bombarded a deuterium gas target placed in the center of a scattering chamber. The outgoing charged particles were detected in a telescope consisting of two silicon surface barrier detectors, 100 μm and 1000 μm thick. A coincidence between the two detectors was requested

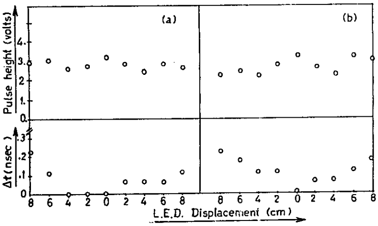

Fig. 1. Transit time difference (in ns) and pulse height (in V) for point illumination of the light pipe. The LED displacement was either along (a) or perpendicular to (b) the dynode axis. The total PM voltage V_{tot} was equal to 2600 V.

---

* Work sponsored by I.I.S.N., Belgium.

† Aspirant du Fonds National de la Recherche Scientifique, Belgium.

to reduce the gamma background from the entrance and exit target windows, made in HAVAR and MYLAR, respectively. Coincident pulses from the two detectors were first summed; the sum pulses were then analyzed in a 1024-channel NORTHERN analog-to-digital converter (ADC), and stored in the memory of a PDP-8 computer working on-line. A threshold on the second silicon detector spectrum allowed us to select the ^{3}He-particles, which then gated the ADC. The telescope tantalum collimators defined an associated neutrons cone which was intercepted by the 2 cm thick, 20 cm diameter NE 102 plastic scintillator, set at 1 m from the target at an angle derived from the reaction kinematics. Pulses from the PM anode were fed, through a constant fraction discriminator (CFD), to the STOP input of a time-to-amplitude converter (TAC) which was started by the pulses originating from the second silicon detector. The TAC spectrum was analyzed in a standard 400-channel analyzer, which was gated the same way as the charged particles ADC. This gating requirement mainly contributed to the background reduction, as can be verified in the typical TAC spectrum displayed in fig. 2. The energy threshold of the neutron detector was set at 120 keV electron equivalent, as measured from the gamma spectrum of a ^{22}Na source.

4. Results

The rough efficiency ε' is equal to the ratio N_1/N_2, where N_1 is the number of the neutrons in the TAC spectrum and N_2 is the number of ^{3}He recorded in the charged-particles spectrum. We took into account the neutron loss due to absorption in the 1 cm thick aluminium wall of the scattering chamber[5]), before deriving the actual efficiency ε.

The above-described measurement was repeated at some pairs of kinematically related ^{3}He–neutron angles, for neutron energies ranging from 7 to 14 MeV. These energy limits correspond to the lower and upper energy reached in the ^{28}Si(d, n)^{29}P reaction, at 13.5 MeV incident deuteron energy[6]). The efficiency measurement results are shown in fig. 3. The large

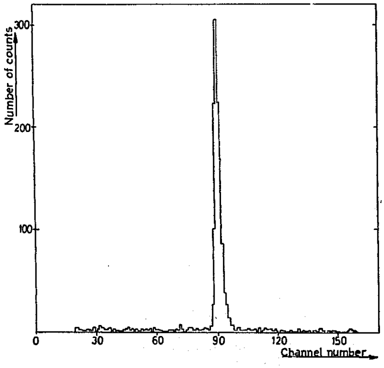

Fig. 2. Neutron TOF spectrum taken at a neutron energy $E_n = 9$ MeV; the horizontal time scale is 0.5 ns/channel.

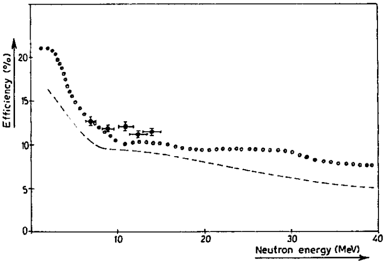

Fig. 3. The measured efficiency compared with calculations using Kurz's[1]) program (dashed curve) or Monte-Carlo[2]) program (dotted curve).

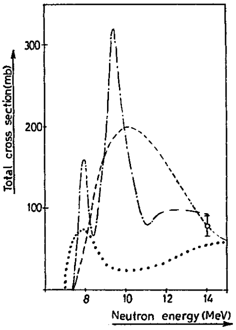

Fig. 4. The ^{12}C(n, α)^{9}Be reaction cross section, from threshold up to 15 MeV, as contained in Kurz's[1]) program (dashed curve), in the Monte-Carlo[2]) program (dotted curve) or as resulting from Obst's[9]) calculations using the reciprocity theorem (dot-dashed curve). The experimental value at 14.1 MeV is from ref. 8.

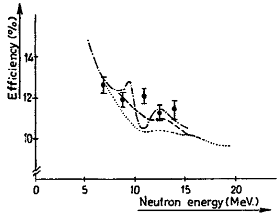

Fig. 5. Monte-Carlo calculations of the efficiency from 7 to 14 MeV for some $^{12}C(n,\alpha)^9Be$ reaction cross-section values; the curves refer to the respective cross sections of fig. 4.

acceptance angle of the neutron detector introduce a wide energy uncertainty. This resulted from a compromise with the neutron couting rate.

5. Discussion

We have compared our experimental results with calculations performed with two computer codes: the first one was written by Kurz[1] using an analytical approach, and revised by Thornton[1], the second one was written by Stanton[2], based on Monte-Carlo methods. In the second case, the one-photoelectron level (β) which is known[7] to be an important parameter, was estimated from the half-width of the CFD lower cut-off in the ^{22}Na spectrum. The value $\beta = 100$ keV was kept constant through all calculations. Fig. 3 displays the measured and calculated efficiencies. It immediately appears that the Monte-Carlo program roughly fits the experimental values, while the Kurz's program seriously underestimates the efficiency, which can be expected since the latter calculations neglect the third and upper order rescatterings.

Some ambiguity exists for the non-elastic n-C cross sections which are contained in both programs. In the energy range of interest here, only one direct measurement of the $^{12}C(n,\alpha)^9Be$ reaction cross section was performed by Kitazawa[8] at 14.1 MeV. Obst[9] calculated the same reaction cross section from the threshold up to 14 MeV by applying the reciprocity theorem to the measurement[10] of the $^9Be(\alpha,n_0)^{12}C$ reaction cross section. Kurz, starting from the known n–C total non-elastic cross section, subtracted from it successively the $(n,n'\gamma)$ and $(n,n'3\alpha)$ reactions cross sections; the remainder was then treated as the (n,α) and (n,p) reactions cross sections. On the other hand, the Monte-Carlo program includes cross sections which have been adjusted to reproduce experimental efficiencies. The respective (n,α) cross sections are presented at fig. 4. They were introduced one after an other in the Monte-Carlo program and the calculated efficiency in the energy range 7–14 MeV is displayed in fig. 5. The best adjustment is provided by Kurz's values, which are also the only ones to fit the Kitazawa measurement. At slightly higher neutron energy, the $^{12}C(n,n')3\alpha$ reaction will become important. Its cross section is also underestimated in the original Monte-Carlo program, when compared with both the experimental[11] and Kurz's values.

6. Conclusion

We emphasized the important role of the $^{12}C(n,\alpha)^9Be$ reaction above 7 MeV neutron energy, as Hermsdorf et al.[12] recently did.

As pointed out by Chastel[7], it still seems more careful to measure the efficiency in all cases where it has to be known with an accuracy better than 10%, i.e. for nuclear spectroscopy experiments. From an experimental point of view, the $D(d,n)^3He$ reaction offers a straightforward way for measuring the neutron-detectors efficiency.

We wish to thank the cyclotron staff for efficiently running the machine, Miss D. Schuykens for her computation work and Drs S. T. Thornton and N. R. Stanton for sending us their respective calculation programs.

References

1) R. J. Kurz, Lawrence Radiation Laboratory Report UCRL-11339 (1964); S. T. Thornton and J. R. Smith; Nucl. Instr. and Meth. **96** (1971) 551.

2) N. R. Stanton, University of Colorado, Boulder, COO-1545-92 (1971).

3) R. M. Edelstein, J. S. Russ, R. C. Thatcher, M. Elfield, E. L. Miller, N. W. Reay, N. R. Stanton, M. A. Abolins, M. T. Lin, K. W. Edwards and D. R. Gill, Nucl. Instr. and Meth. **100** (1972) 355.

4) J. Kalyna and I. J. Taylor, Nucl. Instr. and Meth. **88** (1970) 277.

5) D. J. Hugues and R. B. Schwartz, *Neutron cross sections*, B.N.L. (1958).

6) P. Leleux, P. C. Macq, J. P. Meulders and C. Pirart, submitted for publication.

7) A. Chastel, M. B. Davis, C. M. Hoffman, M. N. Kreisler and A. J. Smith, Nucl. Instr. and Meth. **94** (1971) 493.

8) H. Kitazawa and N. Yamamuro, J. Phys. Soc. Jap. **26** (1969) 600.

9) A. W. Obst, T. B. Grandy and J. L. Weil, Phys. Rev. **C5** (1972) 738.

10) L. Van Der Zwan and K. W. Geiger, Nucl. Phys. **A152** (1970) 481.

11) G. A. Grin, B. Vaucher, J. C. Alder and C. Joseph, Helv. Phys. Acta **42** (1969) 990.

12) D. Hermsdorf, K. Pasieka and D. Seeliger, Nucl. Instr. and Meth. **107** (1973) 259.