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ABSOLUTE CALIBRATION OF NEUTRON DETECTORS IN THE 10-30 MEV RANGE

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A central problem in fast neutron research is that of finding the absolute efficiency of neutron detectors. Using the associated particle method for this purpose, we have designed a chamber to count He particles from the $D(d,n)^3He$ or the $T(d,n)^4He$ reaction in coincidence with neutron events. The reactions take place in deuterium or tritium gas and a ΔE solid state counter at 80°, 65°, or 43° to the 2-10 MeV deuteron beam direction detects the He particles with 100% efficiency. To reduce background we allow the deuterons to pass out of the gas chamber through a Ni window and stop the beam ∿ 150 cm from the counters. With the $D(d,n)^3He$ reaction we have obtained ∿2% efficiency calibration of the central portion of a liquid scintillator in the 9-10 MeV energy range. With the T(d,n) reaction this calibration can be extended to ∿ 27 MeV and the efficiency can be mapped out as a function of position in the scintillator.

(Absolute Efficiency of Fast Neutron Detectors)

Determining the absolute efficiency of neutron detectors for energies > 10 MeV is a major problem in fast neutron research. Below ∿8 MeV neutron energy (n,p) scattering is sufficiently isotropic in the C.M. system[1] so that a proton recoil telescope allows an absolute neutron flux measurement provided the flux is large enough to compensate for the low efficiency of a telescope. But above 8 MeV the uncertainty in the differential cross section of (n,p) scattering makes precise absolute measurements with a telescope somewhat questionable. Between ∿8.0 MeV and 50 MeV only one more or less complete set of differential measurements of forward scattering of neutrons by protons appears in the literature[2] and these do not agree with theoretical expectations based on extrapolations from higher energies. Recently, measurements at 24 MeV with high statistical accuracy for two forward scattering angles have been published,[3] but these are inconsistent with the earlier results. Thus from an experimental point of view there is a lack of definite knowledge of differential scattering of neutrons from protons. This leads to an uncertainty in proton recoil telescope results ranging from ∿1% at 14 MeV to ∿3% at 30 MeV. Because of this as well as because of the basic significance of (n,p) scattering, we have set up an experiment at A.E.R.E. Harwell to measure forward scattering of neutrons from protons at energies below ∿30 MeV. In order to determine the absolute efficiency of our neutron detector we use the associated particle method[4] in which we detect neutrons from the $D(d,n)^3He$ or the $T(d,n)^4He$ reactions in coincidence with the He reaction products.

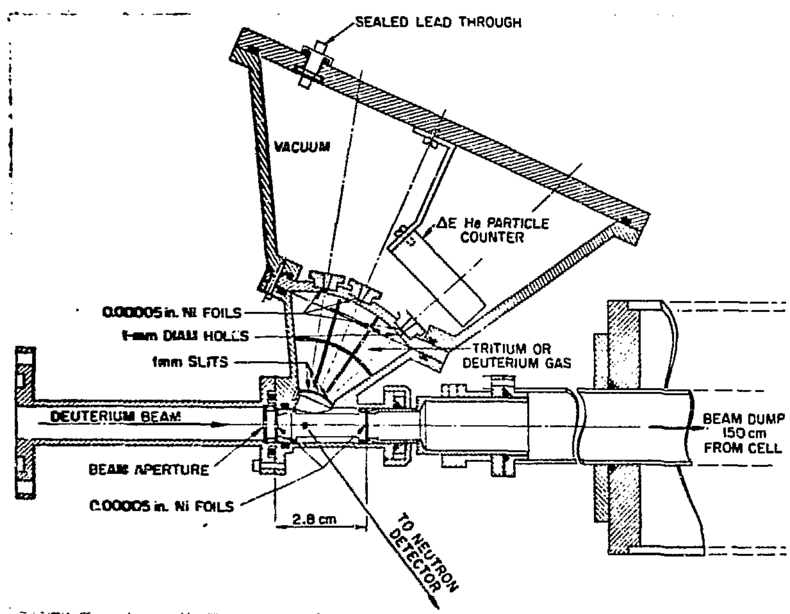

FIG. 1. Reaction chamber for absolute calibration of neutron detectors.

Figure 1 shows the reaction chamber for absolute calibration of neutron detectors. An aperture about 20 cm from the entrance foil limits the beam to ~3 mm in dia. so that no direct beam is incident upon the aperture just in front of the entrance foil. After passing through the deuterium or tritium gas the beam leaves the reaction chamber through an exit foil and is stopped in a beam dump 150 cm from the cell. This reduces the neutron and γ-ray background in the vicinity of the He and neutron detectors. One mm slits and one mm dia. apertures define a column of reaction He particles which are counted by the ΔE solid state particle detector at 43^0, 65^0, or 80^0 to the incident deuteron beam direction.

The lower graph in Figure 2 shows the ^{3}He spectrum from the D(d,n)^{3}He reaction at 43^0 to a 9.9 MeV deuteron beam. The small background, which is found to be uniform under the peaks by substituting hydrogen for deuterium in the gas cell, is due to neutrons and or γ rays. In the upper part of the figure is the coincidence neutron time-of-flight spectrum as found with a 10.2 cm dia. 2.54 cm thick NE-213 scintillator centered on the ^{3}He associated neutron cone 25 cm from the reaction chamber. For this data the bias on the NE-123 scintillator was set to count neutrons above 4 MeV. The neutron detection efficiency in the center of the scintillator is the ratio of the neutron counts to the ^{3}He counts.

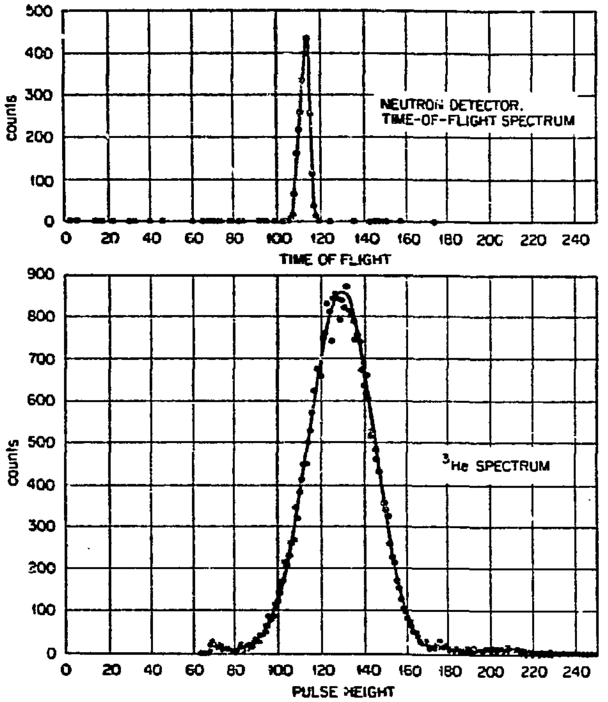

FIG. 2. Spectrum of ^{3}He particles from the D(d,n)^{3}He reaction for 9.9 MeV deuterons. An upper portion of the figure is the coincident neutron time-of-flight spectrum.

Figure 3 compares the measured efficiency for the 4 MeV detector bias with the average efficiency calculated with the computer program, DETEFF, written by R. J. Kurz[5] and altered by S. T. Thornton and J. R. Smith[6] and others. Recent scans across two perpindicular diameters of the scintillator indicates the average efficiency is within about 3% of the central efficiency at 9.3 MeV. Since the computer program is not expected to give efficiencies to better than 10%[5] the disagreement with the calculations is not significant. Nevertheless this 10% uncertainty in efficiency given by the computer program is not permissible in the (n,p) scattering measurements we are making at Harwell. With the bias set at 6 MeV on the NE-213 scintillator a very recent run with T(d,n)^{4}He neutrons shows the central efficiency which is about 4.3% at 9.3 MeV rises to a maximum of 4.9% at 14 MeV and then decreases to 4.2% at 25 MeV.

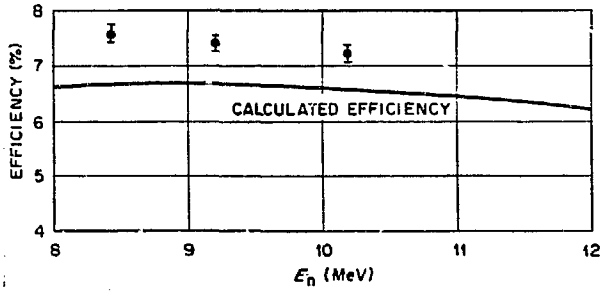

FIG. 3. Central efficiency of a 2.5 cm thick 10 cm dia. NE-213 scintillator compared with average efficiency calculated with the computer program of R. J. Kurz.

By moving the scintillator across the cone of neutrons associated with the He particles one scans the efficiency of the scintillator as a function of position in the detector. An interesting geometrical principle concerning the area of overlapping circles allows the average neutron efficiency of a detector to be readily evaluated from the results of such a scan. If one moves the small circle in Figure 4 across the large circle along a line passing through the two centers, and integrates the common area, A, as indicated below:

$$2\pi \int_0^{R_1 + R_2} \frac{A D dD}{\pi R_2^2} = \pi R_1^2$$

one obtains the area of the large circle for all radii of the small circle from 0 to R_1. Thus if the small circle represents the cross section of the neutron cone at the detector and the large circle represents the detector, then moving the small circle across the large one corresponds to mapping the efficiency of a detector of constant efficiency with an uniform beam of neutrons. Since neutron beams and detectors with cylindrical symmetry can be subdivided into circular discs with constant beam intensity or detector efficiency the integration indicated allows one to evaluate exactly the efficiency of a cylindrical symmetric detector with a beam of cylindrical symmetry.

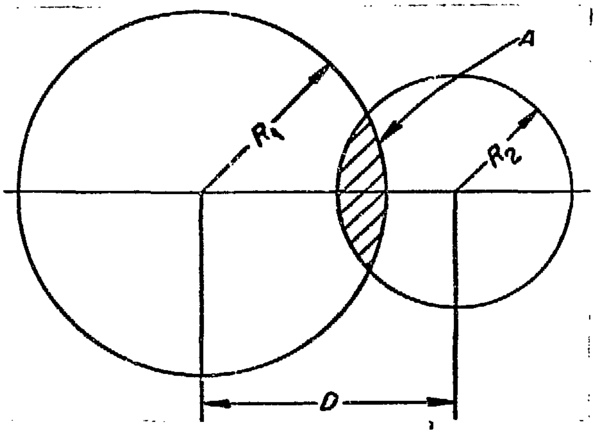

FIG. 4. Geometrical equivalent of mapping a neutron detector with uniform efficiency with a uniform circular cone of neutrons.

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