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Measured Slowing Down Distribution at the Indium Resonance from a Line Source of Fission Neutrons in Heavy Water*

Although a number of measurements have been reported (*1–4*) of the slowing down distribution at the indium resonance from a point source of fission neutrons in heavy water, no corresponding measurements seem to have been made for a line source.[1] Such line source distributions are of considerable interest since they are often the starting point for the calculation of flux distributions of resonance neutrons in heterogeneous reactor lattice theory (*5, 6*). The integration of measured point source distributions to obtain line source distributions is unreliable since it assumes knowledge of the point source distribution far beyond the region of measurement. For these reasons, the line source distribution has been measured directly in the Process Development Pile (PDP). This measurement also permitted a new determination of the neutron age to the indium resonance in heavy water.

The Process Development Pile is a heavy-water-moderated, unreflected reactor with an inner tank diameter of 494 cm and a moderator height adjustable up to 466 cm. The pile loading used in this experiment consisted of a driver lattice of natural uranium fuel assemblies surrounding a central heavy water region about 245 cm in diameter. The critical moderator height with this loading was about 200 cm. A rod one inch in diameter composed of 5% enriched uranium (93.2% U^{235}) alloyed with aluminum was placed at the center of the reactor to simulate a line source of fission neutrons with a cosine-shaped strength distribution. The moderator purity was 99.70 mol % D_2O, and the moderator temperature was 22°C.

The detectors were ½-in. diam foils of a lead–indium alloy containing 5.87% indium by weight. Each foil contained 5.6 mg/cm² of indium and was enclosed in cadmium 0.020 in. thick. The foils were placed at approximately 4-cm intervals on a lightweight aluminum tube which was perpendicular to the fission source rod at the center of the pile. At these intervals, mutual shadow shielding between samples was negligible. The plane of the foils was parallel to the fission source. A similar foil irradiation was later made with the source rod replaced by a solid aluminum rod, to obtain the background distribution of pile neutrons at the indium resonance.

TABLE I
Corrected Epicadmium Indium Activations Using a Single Enriched Uranium Rod as a Source

Distance from center of rod, r(cm)	Foil activities, A(arbitrary Units)	
	Totals counts	Background Corrected
6.41	70,340	70,220
10.41	56,960	56,840
14.41	42,530	42,410
18.41	28,940	28,820
22.41	18,530	18,410
26.41	11,670	11,540
30.41	7207	7065
34.41	4292	4140
39.2	2300	2140
43.2	1366	1180
47.2	824	608

* The information contained in this article was developed during the course of work under contract AT(07-2)-1 with the U. S. Atomic Energy Commission.

[1] Referred to in what follows as "Point (line) source distributions."

The foils were counted with NaI scintillation equipment, and corrections were made for counter background, foil decay, and slight differences in foil weights. The distributions obtained with and without the source rod in place were normalized at a distance of 70 cm from the reactor center where the contribution to the activations made by the source rod was negligible compared to the contribution made by the driver region. The normalized background distribution was then subtracted from the distribution obtained when the source rod was in place. For the foil thickness of 5.6 mg/cm² no correction to the distribution was necessary to account for absorptions at energies other than that of the 1.46-ev indium resonance. The resulting count rates, in arbitrary units, are given in Table I as a function of distance from the center of the source rod in the range from 0 to 50 cm. No correction was made for the finite diameter of the source rod.

The simplest function which fits the data points is a weighted sum of two gaussians:

$$A = C\left[\frac{\alpha_1}{4\pi\tau_1}e^{-r^2/4\tau_1} + \frac{\alpha_2}{4\pi\tau_2}e^{-r^2/4\tau_2}\right]$$

An excellent fit was obtained with the following parameters determined by a least squares analysis:

$$\begin{aligned} \alpha_1 &= 0.551 \qquad & \alpha_2 &= 0.449 \\ \tau_1 &= 147.9 \text{ cm}^2 \qquad & \tau_2 &= 61.9 \text{ cm}^2 \end{aligned} \qquad \text{(I)}$$

The above expression represents the distribution from a line source of cosine source strength, as obtained in the PDP. If the above function is assumed correct for all distances r, then the distribution for a line source of uniform strength can be obtained by replacing the above weighting

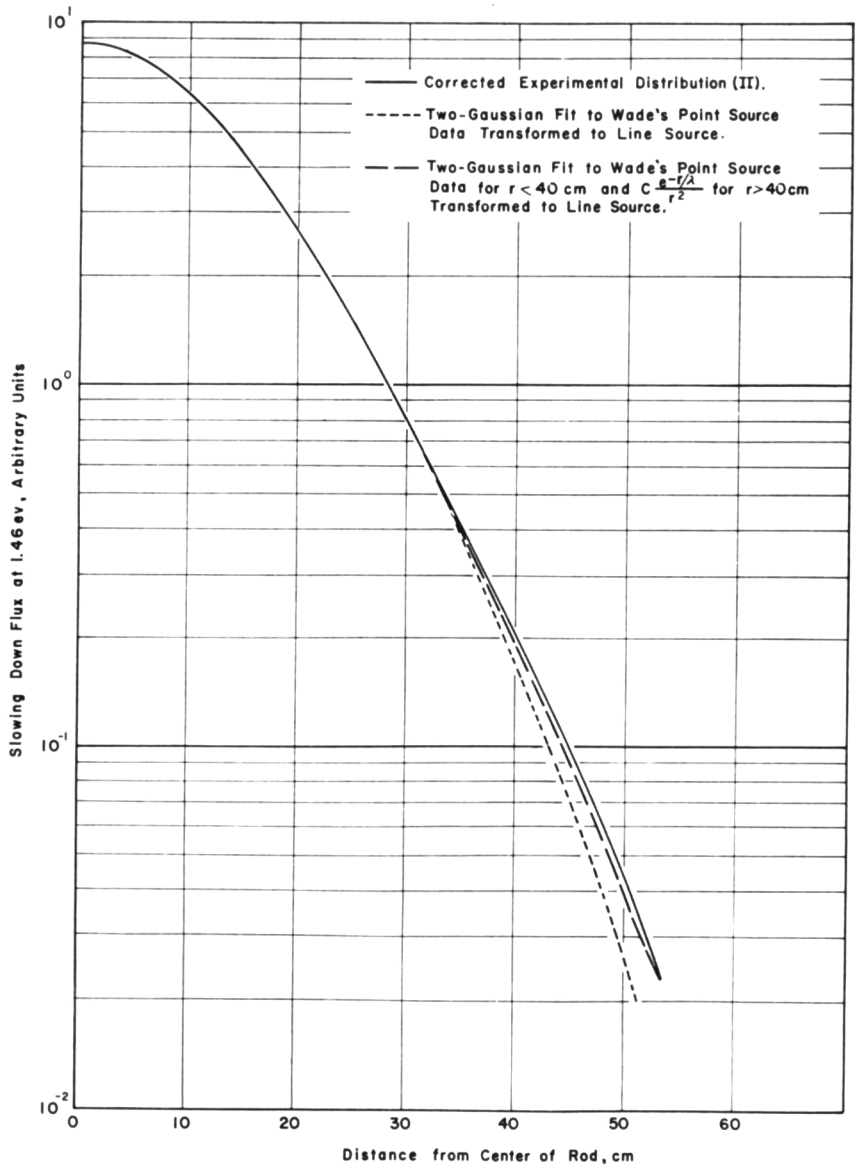

FIG. 1. Comparison of line source distributions

constants by

$$\alpha_1' = \frac{\alpha_1 I_2}{\alpha_1 I_2 + \alpha_2 I_1} \quad \text{and} \quad \alpha_2' = \frac{\alpha_2 I_1}{\alpha_1 I_2 + \alpha_2 I_1}$$

where

$$I_n = \frac{1}{\sqrt{4\pi\tau_n}} \int_0^{\pi/2} \cos\theta \exp\left(-\frac{H^2}{4\pi^2\tau_n}\theta^2\right) d\theta$$

H being the extrapolated pile height and τ_n being given the values obtained in (I). The result is

$$\begin{array}{ll} \alpha_1' = 0.560 & \alpha_2' = 0.440 \\ (\tau_1 = 147.9 \text{ cm}^2) & (\tau_2 = 61.9 \text{ cm}^2) \end{array} \qquad \text{(II)}$$

The most convenient way of comparing this result with previous data obtained with point sources is to integrate the point source distributions to obtain constant strength line sources and compare the result with distribution (II). This can be done under various assumptions as to how the point source distributions should be extrapolated beyond the range of measurement. The results of Wade (*4*) for a point source in 99.8 mol % D_2O were chosen for comparison. These data, in the range from 0 to 50 cm, were fitted to a sum of two gaussians by least squares. The resulting function was then integrated to obtain the corresponding line source distribution under two different assumptions for extrapolating the point source distribution to infinity. These assumptions were:

(a) The two-gaussian fit was assumed to hold over the entire range zero to infinity.

(b) The function $Ce^{-r/\lambda}/r^2$ was matched to the two-gaussian distribution at $r = 40$ cm and was assumed to hold over the range $r = 40$ cm to infinity.

These two distributions are compared to the corrected experimental distribution from a line source (II) in Fig. 1. The sensitivity of the result to knowledge of the point source distribution beyond the range of measurement is apparent.

The corrected experimental line source distribution (II) can be used to obtain a value of the age to the indium resonance in heavy water. This was done by integrating the line source distribution to obtain a plane source distribution $q(z)$, and then using the relation

$$\tau = \frac{1}{2} \frac{\int_0^\infty q(z) z^2 \, dz}{\int_0^\infty q(z) \, dz}$$

where z is the perpendicular distance from the plane. If distribution (II) is assumed to hold over the entire range zero to infinity, one obtains $\tau = 110$ cm^2. If, on the other hand, one extrapolates the distribution beyond the range of measurement by the physically more reasonable function, $Ce^{-r/\lambda}/r$, one obtains $\tau = 111$ cm^2. This is considered to be the best estimate of the age in 99.7 mol % D_2O, with an uncertainty of ± 2 cm^2. It is in agreement with the results of previous work (*3, 4*).

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