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Range of Ra $-\alpha-$ Be Neutrons in Water*

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Radial distributions of Ra $-\alpha-$ Be neutrons about an approximate point source in water were determined by means of indium foil activations. Values for migration area (M^2) derived from the data are: For all activating neutrons, 54.7 cm²; for indium resonance neutrons, 45.4 cm².

STANDARDIZATION of a set of indium foils involved mapping the distribution of both total and indium-resonance activations about an approximate point source of neutrons in water. The same data can be used to evaluate the mean-square distance $\langle r^2\rangle$ and the migration area ($M^2=\langle r^2\rangle/6$) in water.

The saturated activity (A_s) of a foil irradiated at radius (r) from a point source of neutrons is a function $f(r)$ of the radius and can be determined experimentally. The total neutron flux at energies which activate the foil is proportional to the space integral $\langle A_s\rangle$ of the saturated activity:

$$\langle A_s\rangle = 4\pi\int_0^\infty A_s r^2 dr.$$

The mean square $\langle r^2\rangle$ of the migration distance of a neutron, i.e., the distance from the source to the point at which the neutron is captured, is then:

$$\langle r^2\rangle = 6M^2 = \frac{\int_0^\infty A_s r^4 dr}{\int_0^\infty A_s r^2 dr}.$$

EXPERIMENTAL DETAILS

Supports for source and foil holder were set up on a 4 ft.×4 ft. cylindrical galvanized steel tank (Fig. 1). The aluminum source cup was suspended from three supports on the angle iron rim of the tank by 0.016 inch steel piano wire; each wire was fixed in a bead which rested in a conical socket clamped to the tank rim. One of the wires was attached to a cord fastened to the tank rim, so that the time of beginning or ending an irradiation could be controlled within one second by slipping the support wire in or out through a slot in the socket, causing the source to swing into or away from the central position. A lead counterweight of about 1 lb, suspended 30 cm below the source on a $\frac{1}{8}$-inch aluminum rod, held the system taut.

Each foil holder was carried on the end of a $\frac{3}{16}$-inch aluminum tube held radial to the source

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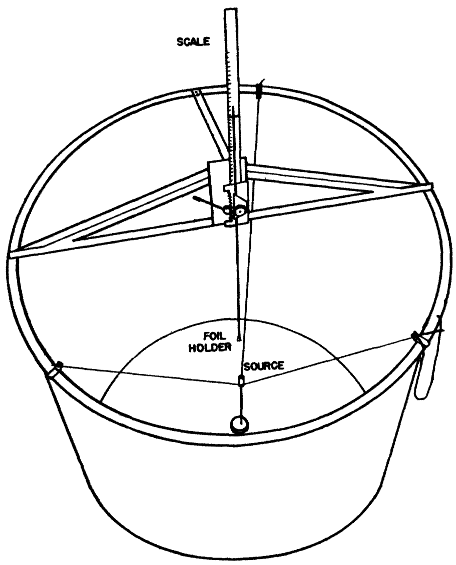

FIG. 1. Apparatus used in determining range of Ra$-\alpha-$Be neutrons in water.

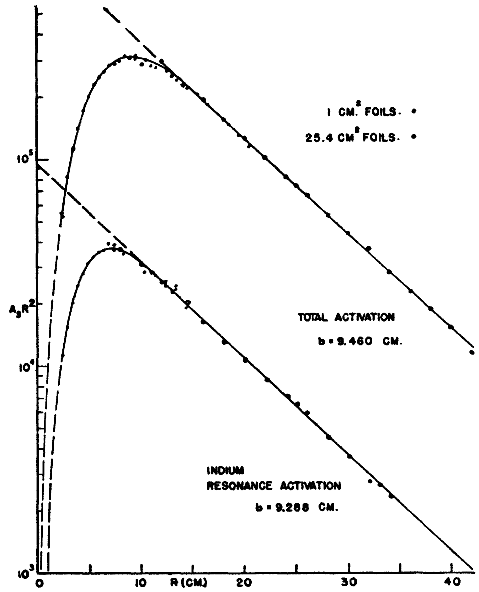

FIG. 2. Spherical space distribution ($A_s r^2$) of neutron flux from 0.5 g Ra$-\alpha-$Be source in water, using indium detectors.

in a movable clamp mounted on a rigid truss of 1-inch angle iron bolted to the rim of the tank; by this means the support for both foil and source was made a rigid structural unit. The aluminum tube could be quickly clamped at the approximate position desired, as indicated by a flag moving on a meter stick fixed to the support; and the clamp itself was mounted on a ratchet having about 2-cm vertical travel. By means of this mechanism, settings of (r) were easily reproducible to about 0.02 cm.

The various foil holders will be described in turn. The source was 0.5 g of radium with 3 g of beryllium in the form of a $\frac{9}{16}$-inch$\times\frac{9}{16}$-inch cylinder inside a brass cylinder $\frac{7}{8}$-inch long$\times\frac{11}{16}$-inch o.d. (Clinton Labs. source No. 3). Earlier calibration of this source had indicated a strength of 5.17×10^6 neutrons/sec.

Measurements were made with a set of about 500 indium foils, approximately 1 cm$\times$1 cm$\times$ 0.005 inch. No individual calibrations were used, as few foils deviated from the mean by more than 2 percent. A different, randomly selected foil was used for each irradiation, and the resulting data smoothed graphically.

The effective distance of the "point source" from the zero on the meter stick was determined by taping 10 foils at 3-cm intervals to a $\frac{3}{16}$-inch aluminum tube which was offset so as to pass vertically about 5 cm to one side of the source, and irradiating such a set at each of three successive positions 1 cm apart vertically. The axis of symmetry of the resulting activity curve, 80 cm below the top of the tank, was taken as the level of the source ($r=0$).

The holder used for small foils consisted of a stirrup-shaped strip of 0.005-inch aluminum weighing 0.19 g fixed to the end of a $\frac{3}{16}$-inch aluminum tube with Plicene cement; a projection from the base of the stirrup was folded back on itself to form a 1-cm² envelope to receive the foil, holding it normal to the radius from the source and about 3 cm beyond the end of the tube. Overlapping covers of cadmium were made to slip over the loaded holder, encasing the foil in a 0.04-inch shield without disturbing its position.

Activations of the small foils beyond 15- to 20-cm radius were too low for reliable counting. Rather than increase the source strength, it was decided to extend the range of the measurements with larger foils (4$\times$6.35 cm) of the same thickness as the small ones, and to normalize the two portions of the curve empirically by taking overlapping data. One holder consisted of two plates of $\frac{1}{16}$-inch Lucite between which the foil was placed, the other of two plates of 0.015-inch cadmium, the upper plate in each case being cemented to the end of the supporting aluminum tube. The error caused by the variable value of (r) over a large flat foil was compensated by calculating a corrected radius (r') to the center of the foil such that half the area of the foil should be located at a lesser radius than the desired value (r). A setting corresponding to (r') was then made on the apparatus, and the value (r) recorded for that irradiation. A set of 8 calibrated large foils was used.

Two corrections to the small-foil data were made. By attaching to the holder first one and then two strips of aluminum duplicating the holder in both shape and weight, together with duplicate sections of tubing adjacent to the holder, it was found that an augmentation of about 1 percent in activity resulted from each addition. Data taken with the aluminum holder should, therefore, be corrected by a factor of 0.99 to give the "free foil" value. Addition of one and then two duplicate coverings of cadmium to the large cadmium holder (the small holder not being used here because of mechanical difficulties) indicated a decrease of about 4 percent for each 0.015-inch layer. The corresponding decrement for the small-foil holder of 0.04-inch cadmium is thus 0.11; and the resulting correction to the observed cadmium ratio is ($0.99 \times 0.89 = 0.88$). The graph (Fig. 2) is based on corrected values.

RESULTS

Figure 2 is a plot of ($A_s r^2$) in arbitrary units against (r). The cadmium ratio C.R. (A_s total/A_s in Cd) rises sharply until, around 14-cm radius, it becomes a slowly-increasing exponential. Representative values are:

r_{cm}:	2	5	8	12	16	24	34
C.R.;	4.7	6.4	8.1	10.8	11.4	11.6	11.9

Relaxation lengths (b) derived from the curves, Fig. 2, (defined by: $A_b = A_0/e$) are:

Curve I (uncovered foils): $b = 9.46$ cm.
Curve II (Cd-covered foils): $b = 9.29$ cm.

The space integrals of ($A_s r^2 dr$) and ($A_s r^4 dr$) were evaluated by formal integration over the exponential region of ($A_s r^2$), assuming exponential decrease without limit, and by Simpson's rule over the remainder. Results are:

$$\langle r_T^2 \rangle = \frac{4\pi \int_0^\infty A_T r^4 dr}{4\pi \int_0^\infty A_T r^2 dr} = \frac{2.107 \times 10^{10}}{6.42 \times 10^7} = 328 \text{ cm}^2$$

$$\langle r_{\mathrm{In}}^2 \rangle = 1.853 \times 10^9 / 6.811 \times 10^6 = 272 \text{ cm}^2,$$

where $\langle r_T^2 \rangle$ and $\langle r_{\mathrm{In}} \rangle$ are the "second moments" indicated by total and by indium resonance activation, respectively. The corresponding migration areas are:

$$M_T^2 = r_T^2/6 = 54.7 \text{ cm}^2$$
$$M_{\mathrm{In}}^2 = \tau_{\mathrm{In}} = 45.4 \text{ cm}^2,$$

where (τ_{In}) is the "age" of indium resonance neutrons in water.

If the previously reported value for diffusion length (L) in water of 2.88 cm[1] and the above value for (M_T^2) are inserted in the equation $M^2 = L^2 + \tau_{\mathrm{thermal}}$ the result is $\tau_{\mathrm{th}} = 46.4$ cm^2 and $\tau_{\mathrm{th}} - \tau_{\mathrm{In}} = 1.0$ cm^2.

This result is comparable to the value 0.6 cm^2 previously reported.[2]

Comparable determinations of $\langle r^2 \rangle$ reported by Auger, Munn, and Pontecorvo[3] are:

$\langle r_{\mathrm{In}}^2 \rangle = 278$ cm^2
$\langle r_T^2 \rangle$ (Dy detectors) $= 330$ cm^2.

A memorandum from Anderson[4] gives $\langle r_{\mathrm{In}}^2 \rangle = 288$ cm^2.

I should like to acknowledge particularly the assistance of A. Weinberg and H. Jones, in connection with the theoretical background and some details of the experiment.

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[1] S. Allison *et al.*, Project Report C-82.
[2] Project Handbook IV E 8.
[3] P. Auger, A. M. Munn, and B. Pontecorvo, Can. J. Research **A25**, 143–56 (1947).
[4] H. L. Anderson, Report N-1708.