Use of Aluminum as a Threshold Neutron Detector

The use of threshold neutron detectors for measuring the fast neutron energy in a reactor (*1*, *2*, *3*) is well established. The preceding references describe the use of Pu^{239}, Np^{237}, U^{238}, and S^{32} for determining, respectively, total fast neutron flux, neutron flux above 0.75 Mev, 1.5 Mev, and 2.5 Mev. This note will discuss the usefulness of aluminum for determining the neutron flux above 2.1 Mev.

When aluminum is exposed to reactor neutrons, the activations of interest which occur are (a) thermal, Al^{27} (n, γ) Al^{28}, and (b) fast, Al^{27} (n, p) Mg^{27}. The amount of thermal and fast activation induced is determined by counting the 1.8-Mev gammas from Si^{28} and the 0.84-Mev gammas from Al^{27}, i.e., gammas from the β-decay products of Al^{28} and Mg^{27}. In our experiments, the counting system consisted of a NaI well crystal, a nonoverload linear amplifier, and a twenty channel analyzer in which the photopeak spectra were recorded.

The fast flux is obtained by taking the ratio of the fast and thermal induced saturation activities. Thus

$$\phi_f = \phi_{\text{th}} \left(\frac{C}{\epsilon F \bar{\sigma}_a} \right)_f \left(\frac{\epsilon F \bar{\sigma}_a}{C} \right)_{\text{th}} . \tag{1}$$

The factors in Eq. (1) are obtained as follows:

(a) ϕ_{th}—the absolute thermal flux at the point of interest is measured using standard indium foil activation techniques.

(b) λ—the decay constant for the fast activation, Mg^{27}, is 0.105 min^{-1}. The decay constant for the thermal activation, Al^{28}, is 0.43 min^{-1}.

(c) C—the saturated activity of the sample is obtained using the conventional formula

$$C = \frac{N\lambda}{(1 - e^{-\lambda t_c}) e^{-\lambda t_d} (1 - e^{-\lambda t_e})}$$

where N is the experimental number of counts from the photopeak of interest less Compton background of neighboring lines, λ the appropriate decay constant in min^{-1}, t_c the counting time in minutes, t_e the exposure time in minutes, and t_d is the delay time between the exposure and the counting in minutes.

(d) F—the number of gamma rays of given energy emitted per disintegration. F_f and F_{th} are both unity in this case.

(e) $\bar{\sigma}_a{}^{\text{th}}$—the thermal absorption cross section, 0.205 barn (*4*),

(f) $\bar{\sigma}_a{}^f$—the absorption cross section for the (n, p) reaction in aluminum (*4*) averaged over the fission spectrum. Assuming a Watt (*5*) spectrum this yields a value of 0.0035 barn.

(g) $\epsilon_{\text{th}}/\epsilon_f$—the ratio of the absolute detector efficiency for counting the 1.8-Mev gamma and the 0.84-Mev gamma. This is equivalent to the relative ratio of the photopeak efficiencies if there is no difference in self-absorption in the sample for the two lines. Mn^{56} is used to obtain this ratio since it has decay gammas that have the same energy as those from the aluminum. The 1.8-Mev gamma from Mn^{56} occurs in only 25% of the disintegrations. The relative detector efficiency is then the net area under the 1.8-Mev peak, normalized to 100%, divided by the net area under the 0.845-Mev peak. The relative photopeak efficiency ratio of our system was 0.49.

To determine the fast flux at a point in a reactor using the above technique, four exposures are required. The first two, bare indium and cadmium-covered indium, determine the absolute thermal flux. The third and fourth exposures, bare and cadmium-covered aluminum, allow measurement of the slow and fast gamma lines without much Compton

electron background. The data obtained are then inserted into Eq. (1) to determine the fast flux.

Figure 1 shows the spectra obtained for a bare and a cadmium-covered aluminum sample $\frac{1}{2}$-in. o.d. and $\frac{1}{2}$-in. long exposed in a flux of about 10^7 n/sec cm^2. The number of pulses due to Compton electrons from adjacent lines is seen to be small because of the time delay before counting the sample.

The use of aluminum to determine the fast flux in a reactor has several advantages over the use of U^{238}, Np^{237}, or S^{32}. These are:

(1) Pure aluminum (2s) is readily available in a form convenient to mechanical handling in most reactors. It needs no coating to protect it from water as do S^{32} or U^{238}.

(2) No assumptions concerning fission product activity are necessary as in the case of Pu and U.

(3) The half-lives of the aluminum activities are convenient.

(4) By using the manganese sample, it is not necessary to determine absolute detector sensitivity.

(5) Use of a scintillation spectrometer allows precise identification and separation of the concurrent slow and fast activities.

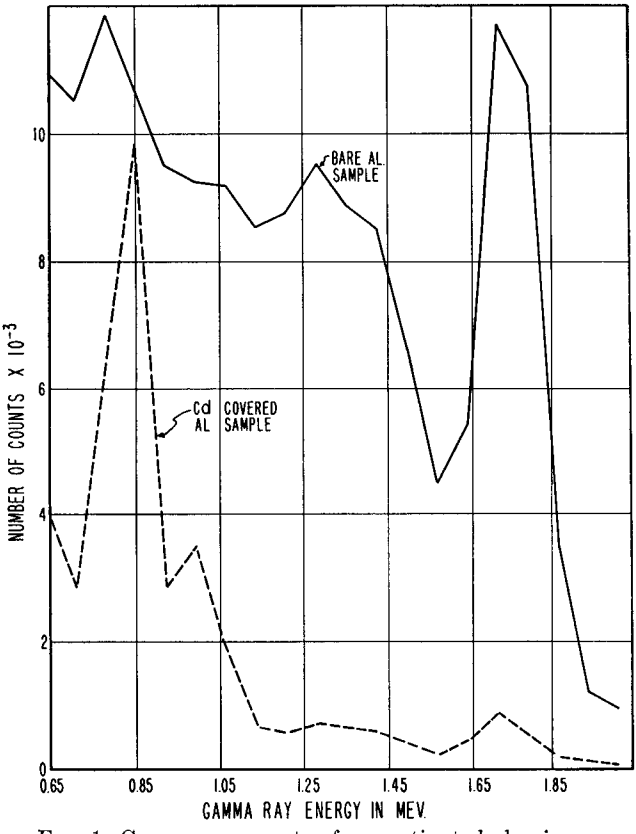

FIG. 1. Gamma-ray spectra from activated aluminum.

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Equivalence Factors for D_2O[1]

In reference (*1*), R. W. Deutsch presented a table of equivalence factors for a variety of materials with respect to H_2O. These factors have the property that if material x has the equivalence factors α, β, then the age in a mixture of H_2O and x is:

$$\tau_{\text{mix}} = \frac{\tau_{H_2O}}{v^2_{H_2O}} \frac{1}{[1 + (\alpha v(x)/v_{H_2O})]} \frac{1}{[1 + (\beta v(x)/v_{H_2O})]}.$$

Also

$$D_{\text{mix}} = \frac{D_{H_2O}}{v_{H_2O}} \frac{1}{[1 + (\beta v(x)/v_{H_2O})]}$$

where $v(x)$, $v(H_2O)$ are the volume fractions of the elements of the mixture and D is the diffusion coefficient.

TABLE I

D_2O CONSTANTS

Group	τ(cm²)	D(cm)
I	48	1.27
II	79	1.24

We have calculated equivalence factors with respect to D_2O for Mg, Al, Zr, and stainless steel (SS). These equivalence factors are given for two groups. Group I covers neutron energies from 10 Mev to 180 kev, Group II from 180 kev to 1.4 ev. The D_2O constants for these groups are given in Table I, the equivalence factors in Table II.

To collapse the two groups to one, the age is the sum of the two ages. Denoting the con-

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