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GERALD S. LELLOUCHE

Brookhaven National Laboratory,
Upton, N. Y.

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Application of the Pile Oscillator to Large-Neutron-Dose Measurement

Determination of large neutron dose is indispensable to the estimate of the burnup of nuclear fuel and of the yield of radioactive isotopes in the reactor, and to other evaluations in experiments related to irradiation by a large quantity of neutrons.

The mass-spectrometric method (*1*) is one of the standard techniques of measuring a high thermal-neutron absorption cross section. It is also applicable to the large-neutron-dose measurement: a piece of probing material, of which cross sections of the constituent nuclides are known, is irradiated at a place where the neutron dose is to be measured, and the dose is determined from the mass-spectrometric change in the probing material.

The pile oscillator is an instrument convenient for the measurement of thermal-neutron absorption cross sections. As an alternative to the above-mentioned mass-spectrometric method of neutron dosimetry, an application of the pile oscillator to large-neutron-dose measurement will be proposed: the neutron dose will be derived from the measurement of the decrement of the macroscopic absorption cross section of the probe. As far as the relative magnitude is concerned, the pile oscillator can easily measure a neutron absorption cross section with an accuracy better than 1%, providing that the sample to be measured has an adequate value of $\Sigma_a V$, where Σ_a is the neutron absorption cross section per unit volume, and V is the volume of the sample. The following will deal with the applicability of this method.

For the sake of simplicity, it is assumed that the probe consists of a single isotope and the absorption cross section of the product nucleus is negligibly small as compared with that of the original one. The pile-oscillator signals I_0 and I, each of which is proportional to the $\Sigma_a V$ of the probe before and after the irradiation, respectively, are related by

$$I = I_0 e^{-\sigma\Phi}, \quad \text{or} \quad \Phi = \frac{\log_e (I_0/I)}{\sigma},$$

where σ is the absorption cross section effective to the neutron energy spectrum at the place where the probe is irradiated, and Φ is the neutron dose which is defined, in this paper, as the time integral of the neutron flux, and has, therefore, a dimension of inverse square of length. The self-shielding in the probe is assumed to be negligible.

In Table I, some typical values of the neutron dose Φ_{I/I_0}, which is required to reduce the number of original atoms in the probe by a factor of I/I_0, are exemplified. The figure $(4.19 \pm 0.21) \times 10^{16}$ neutrons/cm^2, for example, means that if a piece of Gd^{157} is irradiated in a flux of 10^{12} neutrons/cm^2·sec for a period of 4.2×10^4 sec (about 12 hr), 1% of Gd^{157} in the probe will disappear. In order to facilitate the measurement, it is necessary to select a probing mate-

TABLE II

THE PERCENTAGE ERRORS OF THE NEUTRON-DOSE MEASUREMENTS $\Delta\Phi/\Phi$

$\frac{I}{I_0}$ \ $\frac{\Delta\sigma}{\sigma}$	$\frac{\Delta I_0}{I_0} = \frac{\Delta I}{I}$	3.0%			5.0%		
		0.5%	1.0%	2.0%	0.5%	1.0%	2.0%
	0.99	70%	140%	280%	71%	140%	280%
	0.95	14	28	55	15	28	55
	0.90	7.4	14	27	8.4	14	27
	0.80	4.4	7.0	13	5.9	8.1	14

TABLE I

THE NEUTRON DOSE, Φ_{I/I_0}, WHICH IS REQUIRED TO REDUCE THE NUMBER OF ORIGINAL ATOMS IN THE PROBE BY A FACTOR OF I/I_0[a]

Isotope	σ(2200 meters/sec)[b] (barns)	Φ_{I/I_0}		
		$\Phi_{0.99}$ (neutrons/cm^2)	$\Phi_{0.90}$ (neutrons/cm^2)	$\Phi_{0.50}$ (neutrons/cm^2)
Gd^{157}	240,000 ± 12,000 (5%)	$(4.19 \pm 0.21) \times 10^{16}$	$(4.39 \pm 0.22) \times 10^{17}$	$(2.89 \pm 0.14) \times 10^{18}$
Sm^{149}	40,800 ± 900 (2.2%)	$(2.46 \pm 0.06) \times 10^{17}$	$(2.58 \pm 0.06) \times 10^{18}$	$(1.70 \pm 0.04) \times 10^{19}$
Cd^{113}	20,000 ± 300 (1.5%)	$(5.03 \pm 0.08) \times 10^{17}$	$(5.27 \pm 0.08) \times 10^{18}$	$(3.47 \pm 0.05) \times 10^{19}$
B^{10}	(3813)	(2.64×10^{18})	(2.76×10^{19})	(1.82×10^{20})

[a] The neutrons are assumed to be mono-energetic and have a velocity of 2200 meters/sec.
[b] D. J. Hughes and R. B. Schwartz, BNL-325, 2nd ed. (1958).

rial which does not leave strong residual activity. The product nuclei Gd^{158}, Sm^{150}, Cd^{114}, and Li^{7} produced by the neutron capture of the nuclei listed in Table I are all stable, and their cross sections are sufficiently small to fulfil the assumption made in the derivation of the above formulae.

JRR-1 pile oscillator (*2*) can compare the $\Sigma_a V$ of two samples with an accuracy better than 0.5% for a measurement of 2 hr or so, providing that the sample has a $\Sigma_a V$ greater than 0.1 cm^2. If a probing material of an amount, which is necessary to achieve a required accuracy of the pile-oscillator measurement, can not be prepared in a very thin form, the effect of self-shielding becomes considerable. However, the effect will be estimated by some calculation, or, especially, if the energy spectrum of the neutrons at the irradiation position is the same as that in which the pile-oscillator measurement is done, the effect is determined by using the pile oscillator itself.

The error of the measured neutron dose $\Delta\Phi$ is given by

$$\left(\frac{\Delta\Phi}{\Phi}\right)^2 = \left(\frac{\Delta\sigma}{\sigma}\right)^2 + \frac{1}{[\log_e (I/I_0)]^2}\left[\left(\frac{\Delta I_0}{I_0}\right)^2 + \left(\frac{\Delta I}{I}\right)^2\right],$$

where $\Delta\sigma$ is the error of the cross section of the isotope, and ΔI_0 and ΔI are the errors of I_0 and I, respectively. The magnitudes of $\Delta\Phi/\Phi$ are illustrated in Table II. From Tables I and II, it is apparent that a dose of 5×10^{17} neutrons/cm^2 can be measured by a Gd^{157} probe with an accuracy of about 8%.

The above argument is easily expanded into a case of any probe composed of more than one nuclide. This method also includes a possibility of revealing a rough aspect of the neutron spectrum by using isotopes of which the cross sections have different energy dependences.

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Toyojiro Fuketa

Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken, Japan
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