PULSE METHOD OF MEASURING NEUTRON AGE IN GRAPHITE*

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Translated from Atomnaya Energiya, Vol. 9, No. 3, pp. 182-188, Sept., 1960
Original article submitted December 12, 1959

Using a pulse source located within a prism, the age of thermal neutrons from the reactions D-D and D-T in graphite was measured. From the time dependence of the thermal neutron density the author calculated the effective age of D-D neutrons $\tau_{\text{eff}} = 355 \pm 9 \text{ cm}^2$, recalculated for a graphite density equal to 1.6 g/cm$^3$.

The slowing down of D-T neutrons in graphite can be approximately expressed with the aid of two neutron groups: neutrons suffering but one inelastic collision when slowed down ($\tau_{\text{eff}} = 600 \text{ cm}^2$), and neutrons suffering several inelastic collisions ($\tau_{\text{eff}} = 240 \text{ cm}^2$). In determining the age $\tau$ the relative contributions of both groups were assumed equal to 0.65 and 0.25, respectively. A third group is composed of neutrons slowed down only by means of elastic collisions. These neutrons may be neglected in the first approximation, since their contribution is small (about 0.1), while the increase is large.

**Introduction**

The mean-square distance of neutrons from the source in the slowing-down process plays an important role in the analysis and construction of nuclear reactors. Since the spatial distribution of retarded neutrons is determined by their symbolic age, measurements of the age and diffusion coefficient $D$ would be of significant value.

In the design of reactors for measuring neutron age it is necessary in most instances to make use of a constant source, which is emitting fission neutrons, while the spatial distribution of the retarded neutrons must be determined by means of resonance detectors (e.g., an indium detector having resonance at an energy of 1.44 ev). In the analysis of a reactor with thermal neutrons it appears possible to obtain better results by making use of the value of the age up to thermal energy. The age before thermal energy is clearly determined by measuring the area of migration and calculating from this the square of the diffusion length. It can be measured if we make an appreciable reduction in the effect of diffusion by "poisoning" the medium with an absorbing substance. Such a complex method introduces a certain indeterminateness into the measurement.

It should be borne in mind that the mean lifetime of neutrons in a uranium-graphite reactor (about 1000 $\mu$sec) is not very great in comparison with the time required to slow them down and to establish an equilibrium thermal velocity spectrum. A direct determination of the dependence of symbolic age on time is possible by the method of a pulse source. The advantage of this method lies in the fact that it permits us to obtain detailed information concerning the behavior of the neutrons during the interval starting with slowing down and up to the point of steady-state thermal diffusion. Consequently, it becomes possible to observe the gradual transition of thermal neutrons from retardation diffusion during a time interval of significant duration. The intent of the present paper is thus to measure the values of the age and diffusion coefficient in a retarder by means of a pulse neutron source placed in a prism [1]. The experiment was set up so provide for maximum approach to the ideal case of a point source of manenegetic neutrons in a medium extending infinitely in one direction.

*This work was carried out at the P. N. Lebedev Physics Institute of the Academy of Sciences of the USSR.
**Theory**

In measuring the age of neutrons obtained from a pulse source, two methods can be used. One method is described in [2], where the age of neutrons in water is determined from the dependence of the initial thermal neutron density on a geometric factor characteristic of the retarder. The dimensions of the retarder were chosen such that after sufficiently large times only the first harmonic of the neutron density distribution function would be significant. The advantage of this method lies in the fact that it requires the application of comparatively small amounts of retarding substance. It cannot, however, give precise information on the diffusion of neutrons in the initial instants of time, since the presence of higher harmonics cloud the diffusion picture. Therefore, as in the constant source method, this method makes it difficult to obtain information on the transition of slowing down to the thermal diffusion process. Another method, which was used in [1], stipulates the application of an infinitely long prism for the purpose of measurement. In the center of the prism is brought about a burst of fast monoenergetic neutrons, which then are slowed down and diffuse inside the prism. This method was applied in our measurements.

The prism was a rectangular parallelpiped with cross section $b_0c_0$. In order to ensure an infinite system (along the $x$ axis), it was necessary to make use of a prism whose length $a_0$ was at least four to six times greater than the diffusion length $L$.

Applying the Fermi age theory, it is not too difficult to obtain the following expression for the density of slow neutrons $n(x, y, z, t)$ created by the pulsed point source of fast monoenergetic neutrons:

$$n(x, y, z, t) = \text{const} \frac{1}{V} \frac{x^2}{4\tau(y, z, t)} \Phi(y, z, t) e^{-\frac{t}{T_C}},$$

where $T_C$ is the mean lifetime of the neutrons in the retarder as determined by absorption; $\tau(t)$ is the so-called general neutron age.

The factor $\Phi(y, z, t)$ does not depend on the coordinate $x$. After measuring the neutron density at the points $(x_1, y, z)$ and $(x_2, y, z)$ for a specified time $t$, we obtain the expression in [1] from Eq. (1) for the generalized age:

$$\tau(t) = \frac{x_2^2 - x_1^2}{4\ln \frac{n(x_1, y, z, t)}{n(x_2, y, z, t)}}.$$

In the derivation of Eq. (2) no restrictions had to be imposed on the time. This expression remains valid for any time, the only condition being applicability of the age equation.

The generalized age can be written in the form

$$\tau(t) = \int_0^t D(t) \, dt.$$  \hspace{1cm} (3)

If the neutrons enter into thermal equilibrium with the medium, the diffusion coefficient $D(t)$ must arrive at a constant value $D_T$, and for large times the age may be written in the form

$$\tau(t) = \tau_{\text{eff}} + D_T t.$$  \hspace{1cm} (4)

Consequently, the dependence of generalized age on time for large times becomes linear. Extrapolation of this line to $t = 0$ gives the effective value of the age. Application of the effective age makes it possible to utilize an ordinary approximation scheme, in which the slowing-down process is assumed instantaneous, and the diffusion coefficient is equal to $D_T$ and does not depend on time.