3. DETERMINATION OF BORON CONCENTRATION IN BORATED POLYETHYLENE

Objective: Measuring the density distribution of thermal neutrons in borated polyethylene and determining the concentration of boron impurity.

1. BASIC THEORETICAL INFORMATION

The study of spatial distribution of slow neutrons in a moderator is closely connected with the most important issues of determining the critical dimensions of reactors, operating on thermal neutrons, as fast neutrons, resulting from the fission, must be moderated to thermal energy before they leave the working volume of a reactor. Furthermore, according to the distribution of thermal neutrons in a moderator, one can estimate the initial energy of source neutrons and absorption cross section of thermal neutrons by moderator nuclei.

Fast neutrons emitted by the source, surrounded by a moderator, are moderated to thermal energies E_T. Co-flow of generation, moderation, diffusion and disappearance of neurons leads to the establishment of some distribution of the density of thermal, intermediate and fast neutrons in a moderating medium.

If a neutron source is placed in the center of a moderator of a large volume, then due to the spherical symmetry the thermal neutron density must depend only on the distance r to the source. The process of neutron distribution in a moderator is characterized by the fact that, along with the distribution in space, the continuous change in their energy occurs. At that, the cross section of neutron interaction with nuclei changes, as it depends on energy $\sigma_s=f(E)$. Also, free path length changes up to distance λ_s, as $\lambda_s = \dfrac{1}{N \cdot \sigma_s(E)}$, where N – number of nuclei per unit volume of moderator. Dependence of $\lambda_s$on E is complicated, therefore using λ_s to calculate total displacement of a neutron in the process of moderation from initial energy E_0 to energy E is more complicated. Typically, the mean square of distance $\bar{r}^2(E)$ by which the neutron is displaced, is determined experimentally. Distribution of neutrons with energy E ($E < E_0$) over spherical layers is depicted by a curve with maximum at some value r_m , at that, r_m depends on E_0 and on final energy of a neutron. The lower the final energy of neutron and the more E_0, the farther away the maximum of distribution is shifted to large values of r. When $r > r_m$, the number of neutrons with a given energy E in a spherical layer decreases to zero. After measuring the distribution of neutrons over spherical layers by a detector, which is sensitive to specific energy, we can determine $\bar{r}^2(E)$. These measurements can be carried out by a resonant detector behind screened cadmium - a neutron detector is activated by strictly determined energy.

Distribution curves of thermal neutron density along the radius $n_T(r)$ can be used to estimate the energy of fast neutrons from neutron sources, which have not been studied yet. For this purpose, for a number of sources (usually photo neutron ones) emitting neutrons of known energy, the calibration curves of $F(r, E_0)=n_T(r)/n_T(0)$ type are plotted, where $n_T(0)$ - thermal neutron density near the source. According to the position of curve $F(r, E)$, obtained with the studied source with respect to the grid of calibration curves, one can estimate the unknown energy of neutrons of the source under study.

The distribution curve of thermal neutrons over spherical layers $f(r) = n_T \cdot r^2$ is interesting in this regard that the area S, under it, is proportional to the total number of neutrons Q in a moderator. We use it to determine the effective thermal neutron absorption cross section by hydrogen atoms.

The essence of this method is as follows. If we neglect thermal neutrons leakage outside the moderator, the number of fast neutrons q, generated by the source per unit of time (generation rate) will be equal to the number of thermal neutrons absorbed in a moderator per second; hence it follows that $q=Q/\tau$, where τ – mean lifetime of a neutron in a moderator. To connect the parameters of neutron with the characteristics of medium, we use the well-known relations: $\tau = \lambda_a / \bar{v}$; $\lambda_a=1/\Sigma_a$; $\Sigma_a = N \cdot \sigma_a$, where λ_a – mean free path of thermal neutron up to absorption; $\bar{v}$ – mean velocity of a thermal neutron; σ_a, Σ_a – microscopic and macroscopic absorption cross sections, respectively.

In hydrogen-containing absorbents (water, polyethylene etc.) we can neglect the absorption of neutrons by nuclei of oxygen and carbon, because their thermal neutron absorption cross sections are small, compared with the cross section of the hydrogen nuclei ($\sigma_a^C = 0{,}0034$, barns; $\sigma_a^O = 0{,}0002$, barns). Taking this into account, we can write the following balance condition of thermal neutrons in a hydrogen-containing moderator: $q = Q \cdot \bar{v} \cdot N_H \cdot \sigma_H$, (1)

where N_H and σ_H – concentration and absorption cross section of hydrogen nuclei.

Unknown cross section σ_H is determined by the method of comparison with a well-known cross section of thermal neutron capture by natural boron (σ_B = 755 barns), caused by nuclear reactions:

$$B_5^{10}(n,\alpha)Li_3^7;\ B_5^{11}(n,\alpha)Li_3^8;\ B_5^{10}(n,p)Be_4^{10}.$$

In practice, the comparison is performed as follows. The distribution of thermal neutrons in a hydrogen-containing coolant is meathured. Then we use a moderator with little (without substantial changes in the concentration N_H of hydrogen atoms) additives of boron atoms N_B, such as borated polyethylene or weak solution of boric acid in water. When introducing boron, the mean path of thermal neutron up to absorption will be equal to:

$$\lambda'_a = \frac{1}{N_H\sigma_H + N_B\sigma_B}.$$

Equation (1) for this case can be written as:

$$q = Q'\bar{v}(N_H\sigma_H + N_B\sigma_B), \qquad (2)$$

where Q' – total number of thermal neutrons in a moderator with an admixture of boron.

From equations (1) and (2) we obtain:

$$\sigma_H = \sigma_B \cdot \frac{N_B}{N_H} \cdot \frac{1}{(Q/Q'-1)}. \qquad (3)$$

Then, using the proportionality of area under the curve of distribution of thermal neutrons over spherical layers $f(r) = n_T \cdot r^2$ total number of thermal neutrons in a moderator, equation (3) can be rewritten as:

$$\sigma_H = \sigma_B \cdot \frac{N_B}{N_H} \cdot \frac{1}{(S/S'-1)} \text{ or } N_B = N_H \cdot \frac{\sigma_H}{\sigma_B} \cdot (S/S'-1), \quad (4)$$

Where S and S' – areas, restricted by curves $f(r) = n_T \cdot r^2$, for a pure moderator and a moderator with an admixture of boron, respectively.

2. DESCRIPTION OF EXPERIMENTAL INSTALLATION

Experimental installation consists of two prisms of equal dimensions. One of them is assembled from blocks of pure polyethylene, the other one - from blocks of borated polyethylene. In the central experimental channel of each prism, it is possible to place neutron source alternately.

Neutron density at different points is determined by the end counter of neutrons and scaling unit. It is conceptually possible to use activation detectors. The distance from the source is changed by means of spacer inserts.

3. MEASUREMENT PROCEDURE

To study the safety instructions when working in a laboratory and performing the requirements contained therein, to start measurements with the permission of the instructor.

1. To measure the background of counting device 3-4 times.

2. To set a neutron source in the center of polyethylene prism.

3. To remove the dependence of thermal neutron concentration on the distance to the source of fast neutrons: $n_T = f(r)$.

4. To repeat measurements from pp 1-3 on a prism with borated polyethylene, tending to the highest possible identification of measurements.

5. To remove the source of neutrons from the prism and to repeat the measurements of the background of counting device.

6. To represent the measurement results obtained for pure and borated polyethylene in Table № 1.

Table № 1

r, cm	n_T, cm^{-1}	$n_T \cdot r^2$, s$^{-1} \cdot$cm^2
0		

2		
and so on		

4. PROCESSING OF MEASUREMENT RESULTS

1. To calculate a mean background of counting device and its error.

2. To calculate for calculated distances n_T.

3. To calculate value $f(r)=n_T \cdot r^2$.

4. To plot the distribution of thermal and resonance neutrons in spherical layers depending on r.

5. Using computer, to integrate numerically (when graphically is impossible) the dependence $n_T \cdot r^2$ for the prism of pure and borated polyethylene (S and S').

6. Using formula (4), to calculate boron concentration in borated polyethylene.

7. To calculate the mean square error in determining the concentration of boron.

8. To draw up a report on the performed work.

Note: polyethylene density ρ = 0,97·10^3 kg/m^3; cross section of radiative capture of neutrons by nuclei of natural boron σ_B = 759·10^{-28} m^2; cross section of radiative capture of neutrons by nuclei of hydrogen σ_H = 0,332·10^{-28} m^2.

5. REVIEW QUESTIONS

1. How can we write the law of distribution of neutron flux density around the point source in a homogeneous isotropic medium?

2. Write down the reaction between boron isotopes and thermal neutrons.

3. Write down a chemical formula of polyethylene and calculate nuclear hydrogen concentration in it.

4. Basic processes of the interaction of thermal neutrons with nuclei.

6. Explain the need to moderate neutrons to thermal energy in nuclear thermal neutron reactors.

7. Physical meaning of λ_s and λ_a.