DETERMINATION OF THE AVERAGE NUMBER OF NEUTRONS $\nu_{\text{eff}}$ Emitted In A Single Capture Event By The Isotopes U$^{233}$, U$^{235}$ And Pu$^{239}$ In The Suprathermal Region Of Neutron Energes


The variation of $\nu_{\text{eff}}$ for the isotopes U$^{233}$, U$^{235}$ and Pu$^{239}$ is measured in the suprathermal region of neutron energies. For U$^{233}$ $\nu_{\text{eff}}$ remains constant up to an energy of the order of 100 ev. For Pu$^{239}$ $\nu_{\text{eff}}$ drops by 12% on going from the thermal spectrum to the spectrum of energies from 0.15 to 0.5 ev, and then remains constant. For U$^{235}$ $\nu_{\text{eff}}$ remains constant on going from the thermal spectrum to the spectrum of energies from 0.15 to 0.5 ev, and then drops by 18% on going to the spectrum of energies from 0 to 100 ev.

INTRODUCTION

One of the basic parameters of a nuclear chain reaction which is of use in reactor calculations is the average number of secondary neutrons that are emitted by the splitting nucleus in one capture event,

$$\nu_{\text{eff}} = \frac{\nu}{\sigma_f}$$

where $\nu$ is the average number of secondary neutrons emitted per fission event, and $\sigma_f$ and $\sigma_a$ are the effective cross sections for fission and absorption, respectively.

The values of $\nu_{\text{eff}}$ that have been obtained for the isotopes U$^{233}$, U$^{235}$ and Pu$^{239}$ in several experiments [1-3] indicate that a chain reaction is possible in any one of these three isotopes.

For extensive breeding of "nuclear fuel" the value of $\nu_{\text{eff}}$ must be greater than two. In the thermal neutron region this condition is realized for the thorium cycle (for the isotope U$^{233}$, $\nu_{\text{eff}} - 2 = 0.28$). For the plutonium cycle the difference $\nu_{\text{eff}} - 2$ is close to zero.

In order to solve the problem of extensive breeding, it is imperative to know the values of $\nu_{\text{eff}}$ for fissionable isotopes in other neutron energy regions.

In the present article we give a description of the measurement of the variation of $\nu_{\text{eff}}$ for the isotopes U$^{233}$, U$^{235}$ and Pu$^{239}$ for intermediate neutron energies from the thermal region to 100 ev. The various results of these investigations were stated briefly by the authors in references [4] and [5].

Here we give a complete account of the data concerning the measurement of $\nu_{\text{eff}}$ in the superthermal region of neutron energies which was performed on the reactor RFT [6] by P.E. Spivak, B.G. Erozolimsky, G.A. Dorofeev, and V.N. Lavrenchik, and of the additions to this work on the measurement of $\nu_{\text{eff}}$ in the neutron energy region from 0.15 to 0.5 ev which were performed by B.G. Erozolimsky, I.E. Kutikov, and YuP. Dobrynin on the reactor VVR [7] (water-water reactor).
The measurement method

A diagram of the measuring apparatus is presented in Fig. 1. The neutron beam from the reactor passes through a filter of gadolinium, cadmium, or boron, which establishes the neutron spectrum, then through an inlet collimator, and enters the cavity of a graphite prism. Outside the cavity and evenly spaced throughout the volume of the prism, are located boron neutron counters, which comprise the indicating system.

In the center of the prism is a sample of the fissionable isotope. In this set-up the number of neutrons recorded varies both because of absorption of neutrons by the sample and because of neutrons resulting from fission. This variation in the indicating system can be expressed in the following ways:

\[ \Delta N_1 = -F \Sigma_{av} k_1 + F \Sigma_{av} k_2 \nu_{eff}, \]

(1)

where \( F \) is the total neutron flux passing through the sample, \( \Sigma_{av} \) is the macroscopic cross section for neutron absorption per square centimeter of the sample, averaged over the whole spectrum of the neutron beam, \( k_1 \) is the indicator efficiency for the primary spectrum of the neutron beam, and \( k_2 \) is the indicator efficiency for the fission neutron spectrum.

In order to eliminate the determination of the absolute values of the neutron flux \( F \) and the total cross section \( \Sigma_{av} \) from the measurements, a second measurement was performed with the same sample surrounded with a spherical boron-paraffin filter. The dimensions of the filter are chosen so that the primary neutron spectrum is completely absorbed. In this case variation in the counting rate of the indicating system \( \Delta N_2 \) will be caused only by the neutrons resulting from fission.

\[ \Delta N_2 = F \Sigma_{av} k_3 \nu_{eff}, \]

(2)

where \( F \) and \( \Sigma_{av} \) have the same meaning as in Equation (1), and \( k_3 \) is the indicator efficiency for the fission neutron spectrum in the presence of the boron-paraffin filter.

Comparing expressions (1) and (2), we obtain

\[ \nu_{eff} = \frac{k_1}{k_2} \frac{1}{1 - \frac{k_3}{k_2} X}, \]

(3)

where \( X \) is the ratio of \( \Delta N_1 \) to \( \Delta N_2 \).

As will be shown below, the ratio of the coefficients \( k_1 \) and \( k_2 \) is easy to determine with sufficient accuracy with the aid of simple measurements. It is not difficult to see that the direct determination of the ratio of the coefficients \( k_1 \) and \( k_2 \) would necessitate measuring the magnitudes of the neutron flux for the primary spectrum and the fission spectrum.

We may limit ourselves to the relative variation of the coefficient \( k_1 \) and thus obtain the relative variation of \( \nu_{eff} \). In order to obtain the absolute value of \( \nu_{eff} \), we can normalize the variation to a known value of \( \nu_{eff} \) measured for thermal neutrons. The ratio of \( \nu_{eff} \) for the observed spectrum to \( \nu_{eff} \) for thermal neutrons will be of the form

\[ \frac{\nu_{eff}}{\nu_{eff}} = \frac{k_1}{k_2} \frac{X_0}{1 - \frac{k_3}{k_2} X}, \]

(4)

where quantities with the index 0 are the values obtained from measurements on thermal neutrons.

It should be noted that in the derivation of expression (4) it is assumed that there are no effects from the.