A device for measurements of neutron radiation spectra

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Abstract. The method of neutron spectrum measurement with the use of a device with measuring unit based on dysprosium activation detectors has been developed. This article contains the diagram and the exterior of the measurement device. Moreover, it includes the calculated response function of the detectors from neutron energy in the range of 0.05 to 14.5 MeV along the axis of the measuring unit, the algorithm for reconstruction of neutron spectrum and the results of method implementation at the distance of 12 m from the reactor PRIZ-M.

The measurement device for the energy-angular distributions of neutron radiation [1] has been developed. It can be used during the experimental research of protective technical features of special equipment.

This device is based on the design of “all-wave” counter from Hanson and Mac-Kiben [2]. Its component parts include a collimator of neutron radiation; a boron filter that absorbs thermal neutrons from the neutron radiation incident on the lateral surface of the counter; a cylindrical measuring unit made of hydrogen containing materials (for example, paraffin or Plexiglas), inside which activation detectors are placed in a special insert. This design allows registering neutron fluxes in certain bodily angles. The external view of the device is shown in figure 1(a), and its diagram is represented in figure 1(b).

Neutron detectors in the form of plates $^{164}$Dy in cadmium covers and without them are placed in pairs along the axis of the measurement device at distances no more than thermal neutron diffusion length. The response due to interaction with thermal neutrons is determined by the difference of the detector readings. All the results are given by the time of the first detector measurement as far as the period of half decay of $^{165}$Dy in the reaction $^{164}$Dy + n $\rightarrow$ $^{165}$Dy + $\beta^-$ is short (2.234 h) [3].

Energy of each neutron corresponds to the particular depth of the measuring unit, at which the efficiency of the neutron detector is maximal. The detectors that are placed at a distance $L$ from the end surface have their own response function $S(E, L)$. It depends on the energy ($E$) of incident neutrons and is determined by calculation in accordance with the programme MCNP-4C and with account for the design of the developed device.

The dependencies $S(E, L)$ are obtained for the range of neutron energies from 0.05 to 14.5 MeV with a step of 0.05 MeV and given for some neutron energies in figure 2. The obtained dependences allow to determine energy spectrum of neutrons $\Phi(E)$ by solving the
following integral equation

\[ F(L) = \int_{E_{\text{min}}}^{E_{\text{max}}} \Phi(E)S(E, L)dE, \]  \hspace{1cm} (1)

where \( F(L) \) is the distribution of the detector responses along the axis of the measuring unit on account of interaction with thermal neutrons. Equation (1) belongs to the category of so-called “ill-posed” problems, and special mathematical methods are required to solve them, e.g., a regularization method [4].
Equation (1) can be represented as the system of linear algebraic equations

$$F(L_i) = \sum_{j=1}^{m} S(E_j, L_i)\Phi(E_j)\Delta_j,$$

where $i = 1, \ldots, n$; $\Delta_j$ is the width of the $j$-th energy interval taken to solve integral equation (1). Equation (2) can be written in the matrix form

$$F = S\Phi.$$  

The system of equations (3) can be represented with the help of the method of least squares as following

$$S^+S\Phi = S^+F,$$

where $S^+$ is a matrix conjugated to the $S$ matrix.

Solving the equation (4) by conventional methods often leads to unacceptable errors in the final results, which are caused by errors in defining the elements of matrixes $S$ and $F$. Therefore it is necessary to use special methods to solve the equations. One of them is a regularization method. In the simplest case, the regularization method reduces to solving the following equation:

$$S^+S\Phi = S^+F + \alpha F,$$

where $\alpha$ is a numerical parameter.
Figure 3. (a) The dependence $F(L)$ along the axis of the measuring unit. (b) The spectrum of neutrons $\Phi(E)$ at a distance of 12 m from the reactor PRIZ-M.

In a number of papers it is shown that if an appropriate choice of the parameter $\alpha$ is made during the solution of the system of equations (5), the error of determining the function $\Phi$ will be sharply reduced and become acceptable for the practical use.
The measurement results are shown in figure 3(a). These are the measurement results of the response of dysprosium detectors $F(L)$ along the axis of the measuring unit in accordance with interaction with thermal neutrons at a distance of 12 m from the reactor PRIZ-M, which operates at the power of 2 kW. The results of neutron spectrum recovery are given in figure 3(b).

Except from direction of action, the main features of the device include the performance at high levels of neutron fluxes and under high-dose concomitant gamma radiation. The neutron radiation spectrum measurement device has been implemented in the test center of the Russian Defense Ministry and is accompanied by spectrometric testing of special equipment.

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