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FAST NEUTRON SPECTRA AND TRANSMISSION MEASUREMENTS

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This article briefly describes a method of evaluating the neutron spectra from measured pulse-height distribution produced by recoil protons in scintillation detector and an algorithm for shielding calculation in subgroup approximation by Monte Carlo method. Results of measurements and calculation of the fast neutron spectra at the external neutron converter at the RB reactor are presented.

Introduction

The measurement and calculation of neutron spectra are widely used in reactor shielding research, radiation damage study of materials and radiation dosimetry. The aim of our work was to establish a measurement technic and to develop an unfolding method and a computing code for shielding calculation for practical application in radiation protection.

Unfolding method

An unfolding program has been developed to determine the neutron spectrum from the measured pulse-height distribution which is produced by recoil protons in a scintillation detector.

Differential treatment is employed for analysis which is much simpler than the integral (matrix) method. Instead of real response functions obtained either experimentally or mathematically (by the Monte Carlo method) upon which matrix methods are based, differential treatment assumes an idealized shape of the detector response function to monoenergetic neutrons, corrected for proton escape and double-scattered neutrons. This provides an unfolding method depending only slightly on the conditions of experiment and reflecting at least approximately the main deformations of the detector's response function [1,2].

The first step of the adopted algorithm is converting the pulse height distribution C(h), measured in the experiment, into a recoil-proton spectrum $N(E_p)$. The scintillation response to protons is nonlinear with respect to their energies. The relation between proton energy E_p and measured amplitude h is utilized from [2], yielding the proton spectrum $N(E_p)$. The neutron spectrum is then obtained from

$$N(E_n) = \psi(E_n)\,\frac{-q}{\Delta E_n} \tag{1}$$

where $q/\Delta E$ is the slope of the proton distribution at the centre of the corresponding neutron energy interval ΔE_n, and $\psi(E_n)$ is the spectrum conversion function given as

$$\psi(E_p) = \frac{E_n}{\varepsilon'(E_n)\beta(E_n)} . \qquad (2)$$

In eq.(2) $\varepsilon'(E_n)$ is the efficiency of the detector, calculated analytically (when possible) or using the Monte Carlo method, and $\beta(E_n)$ is the shape correction factor which involves the effects of the double neutron scattering on hydrogen and the loss of recoil protons through the end of the detector [1]. It may be expressed as

$$\beta(E_n) = 1 - 0.78 \frac{R_m}{L} + 0.09\ \Sigma_s^H(E_n)L + 0.77\ \Sigma_s^H(1.168\ E_n)r \qquad (3)$$

where r is the radius (in cm), L is the length (in cm) of the stilben crystal, $\Sigma_s^H(E_n)$ is the macroscopic cross section for scattering on hydrogen related to E_n and $R_m(E_p)$ is the range (in cm) of a proton which receives the full neutron energy.

The computer program is made according to the above algorithm and owing to the simplicity of the code it can be adapted for use on a personal computer. A separate program was made for calculation of the detector efficiency for inclusion in the unfolding program as the data library.

Measurements were carried out in the mixed fast neutron and gamma radiation field, which was obtained with converter of neutrons containing 80% enriched uranium fuel elements placed outside the RB heavy water reactor [3]. The scintillation detector with a crystal of stilben was used. In the absence of a pulse shape discrimination facility, the elimination of the gamma-ray background was provided by 5 mm thick lead and low voltage discriminator adapted to reject radiation with energy less than 500 keV. This was sufficient to eliminate most of the gamma-ray background, taking into consideration that the gamma spectrum in the experimental area behind the neutron converter has low energy.

Calibration of the measuring facility was carried out with a ^{22}Na gamma source. This calibration gives the constants a and b in the expression which relates the response of the detector (amplitude h) with channel number k

$$h = a + bk \qquad (4)$$

When this relation is provided it is possible, using a table linking proton energy and pulse height [2], to estimate the proton spectrum $N(E_p)$.

Calculation

In fast neutron shileding calculation, in the unresolved resonance region and the region in which the average energy loss accompanying the elastic scattering is greater than the practical resonance width, the subgroup method can successfully be applied [4]. In Monte Carlo calculations the subgroup method exhibits the following experimental features:

1. The transmission function T(x) is given by

$$T(x) = \sum_{p=1}^{P} a_p \exp(-\Sigma_p x)$$

$$a_p \geq 0, \quad \sum_{p=1}^{P} a_p = 1, \; \Sigma_p > 0, \tag{5}$$

with clear physical interpretation. It is possible to approximate the real neutron cross section by a step function in the resonance energy interval ΔE, and the neutron flux by a constant function in the same energy interval. The Σ_p has the meaning of the total cross section in the p step (subgroup) with probability a_p that the cross section has a value Σ_p.

2. After collision the neutron "does not remember" in which sugroup p it previously suffered collision. According to this, parameters a_p and Σ_p depend only on incident neutron energy.

In this article the BNAB-78 [5] 26-group constants library with subgroup parameters in the resonance region has been used. In each energy group g of resonance region in the BNAB-78 library the values of partial cross sections Σ_{xp} are given for every subgroup p. The neutron in subgroup p has a total cross section Σ_p and interaction probability Σ_{xp}/Σ_p for channel x. It has been shown [4] that the subgroup method gives good results for calculations of heterogeneity resonance effects.

In the Monte Carlo method that has been used, the tracing of neutron histories was performed using neutron "statistical weights" to account for absorption processes. Neutrons incident on the screen were tracked, collision by collision, until their energy became less than a chosen value or they escaped from the screen [6].

The computer program based on the proposed procedure has been developed and numerous calculations have been performed. The program is used for determination of the fast neutron spectra and transmission through various nonfissible thin screens (a few optical paths length).

Results and discussion

The results presented here illustrate the agreement between measurements and calculation of the fast neutron spectra at the external neutron converter of the RB reactor. Measurements were carried out at 100 energy points from 1 MeV to 10.5 MeV. After correction for neutron scattering in the lead-shield of the scintillation detector, results are condensed in the 4 energy groups in accordance with the BNAB-78 group structure and shown in Table I. Calculation of the fast neutron spectrum at the external converter with a 3 cm Fe-screen has been made with an incident neutron spectrum which was measured previously (Table I, column 3), and used as input in the computing code.

Table I

The fast neutron spectrum at the external neutron converter of reactor RB (arbitrary units)

Energy group	Energy interval [MeV]	External converter	External converter with 3 cm Fe - screen	
			Measurement	Calculation
1	6.5-10.5	1.00±0.056	0.40±0.020	0.409
2	4.0-6.5	5.10±0.180	2.05±0.074	2.108
3	2.5-4.0	7.07±0.127	3.00±0.054	3.117
4	1.4-2.5	11.22±0.078	4.95±0.035	5.665

A good agreement between measurement and calculation results can be observed. The higher differences in low energy groups appear since the pulse shape method for gamma-ray discrimination was not used.

References

1. M.E. Toms, Nucl. Instr. and Meth., 92, 61, 1971.
2. M. Holman, P. Mařik, L. Franc, ZJE Report 190, 1976.
3. P. Strugar, O. Šotić, M. Ninković, M. Pešić, D. Altiparmakov, Kernenergie, 24, 101, 1981.
4. M.N. Nikolaev, A. Ingnatov, N. Isaev, V. Hohlov, Atomnaya Energiya, 29, 11, 1970; 30, 426, 1971.
5. L.P. Abagyan, N.O. Bazazyanc, N.N. Nikolaev, A.M. Cibulya, Gruppovye konstanty dlya raschota reaktorov i zashchiti, Energoizdat, Moskva, 1981.
6. E.O. Cashwell, S.J. Everett, The Monte Carlo Method, Pergamon, New York, 1959.