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NEUTRON DOSE EQUIVALENT DETERMINATION
IN THE ENERGY RANGE
FROM THERMAL
TO HIGH-ENERGY NEUTRONS

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Способ определения эквивалентной дозы
нейтронов в диапазоне от тепловых до высоких
энергий

Международной комиссией по радиационным единицам и измерениям (ICRU) была рекомендована новая система операционных величин эквивалентной дозы для радиационного мониторинга. Предложен способ определения операционных величин эквивалентной дозы нейтронов, основанный на линейной суперпозиции показаний двух типов детекторов и позволяющий оценивать эквивалентную дозу нейтронов в диапазоне энергий от тепловых до нескольких сотен МэВ.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Aleinikov V.E., Krylov A.R., Timoshenko G.N. E16-89-668
Neutron Dose Equivalent Determination
in the Energy Range from Thermal
to High-Energy Neutrons

The International Commission on Radiation Units and Measurements (ICRU) has recommended a new system of operational dose equivalent quantities for radiation monitoring. The technique for the determination of neutron operational dose equivalent quantities is proposed. Linear superposition of two types of detector reading allows the estimation of the neutron dose equivalent with energies from thermal to hundreds of MeV.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

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Introduction

Neutrons usually dominate the dose equivalent in radiation fields outside the shield of high-energy accelerators. There are significant differences in the neutron spectra outside the accelerator shielding and no single detector can be expected to give a response that is proportional to dose equivalent under all circumstances in the entire energy range.

The ICRU has recommended⁽¹⁾ a new operational dose equivalent quantity, the ambient dose equivalent $H^*(10)$ that is appropriate for strongly penetrating radiation for purposes of environmental and area radiation monitoring.

This article has been prepared as a contribution to the still ongoing international discussion on implementation of a new system of ICRU operational quantities. The purpose of the paper is to propose a technique used to determine $H^*(10)$ and the peak summed dose equivalent H_p for neutrons in the energy range from thermal to hundreds of MeV in radiation areas outside the shield of accelerators.

Method and technique

Let us consider the function

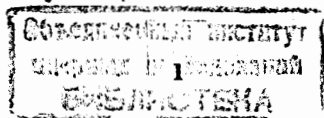
$$f(E) = \sum_i a_i R_i, \quad (1)$$

where a_i 's are independent on energy coefficients,

R_i 's are the detector responses.

If a_i 's were selected so, that $f(E)$ is proportional to the neutron fluence-to-dose conversion factor $h(E)$ of monoenergetic neutrons for the additive operational dose equivalent quantity H , that is

$$f(E) \approx h(E), \quad (2)$$



then in a radiation field of neutrons with the spectrum $\Phi(E)$ the operational dose equivalent quantity H is given by:

$$H = \int_{E_{min}}^{E_{max}} \Phi(E) h(E) dE \approx \sum_i a_i \int_{E_{min}}^{E_{max}} \Phi(E) R_i(E) dE. \quad (3)$$

Taking into account that

$$N_i = \int_{E_{min}}^{E_{max}} \Phi(E) R_i(E) dE, \quad (4)$$

where N_i 's are the detector readings, we obtain

$$H \approx \sum_i a_i N_i. \quad (5)$$

Thus, in order to estimate the quantity H we should find such detector responses $R_i(E)$, for which the linear superposition (1) meets condition (2), then measure readings and calculate the sum (5).

Two types of detectors were chosen to cover the neutron energy range from thermal to hundreds of MeV. These are a multisphere detector⁽²⁾ and a neutron counter with plastic scintillator⁽³⁻⁵⁾. The multisphere detector is well known. The counter with a plastic scintillator is a neutron detector (a plastic polystyrene scintillator 120 mm in diameter and in height) surrounded by a protective scintillator in the form of a cup viewed by another photomultiplier of a veto counter operated in anticoincidence with the neutron detector to suppress the recording of the charged component of the radiation field. In the case of measurement outside the shield of high-energy accelerators no special rejection of gamma-rays is necessary as the high threshold of the neutron signal registration is used. The pulse - height spectrum is measured in a multichannel analyzer, the scale of which is calibrated in the units of electron energy. The quantity of the form

$$N_i(T_j) = n_j \quad (6)$$

is used as the readings of the detector, where is the threshold expressed in the units of equivalent electron energy (MeV eee), which corresponds to the channel number j ; n_j is the summary count in channels with numbers over j .

The detector response functions for different thresholds of signal registration were calculated by the Monte Carlo code (6).

Multisphere detector response functions (7) as well as the response function of the counter with the plastic scintillator are shown in Fig. 1.

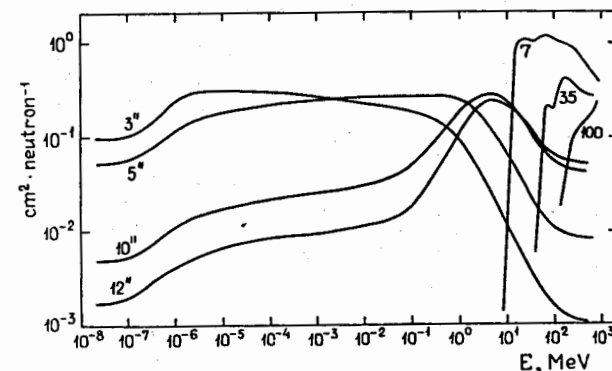


Fig. 1. Response functions of Bonner spectrometer for various moderator diameters in inches and of the neutron counter (reduced by a factor of 10) at various thresholds of signal registration in MeV eee.

Results

The shape of the response functions of detectors can be changed either using different moderators in the case of the multisphere detector or different thresholds T for the counter with a plastic scintillator. Moderator diameters and thresholds T were used as parameters i (see eq.(1)) to approximate the neutron fluence-to-dose equivalent conversion factors $h(E)$ of monoenergetic neutrons for $h^*(10)$ and h_p .

The approximations of $h^*(10)$ and h_p by the expressions

$$h^*(10) = 1.53 \cdot 10^{-10} R_B(3'') - 5.26 \cdot 10^{-10} R_B(5'') + 4.07 \cdot 10^{-9} R_B(10'') - 2.36 \cdot 10^{-9} R_B(12'') + 3.38 \cdot 10^{-11} R_S(7) - 3.17 \cdot 10^{-11} R_S(35) + 4.18 \cdot 10^{-11} R_S(100) \quad (7)$$

and

$$h_p = -5.88 \cdot 10^{-11} R_B(5'') + 2.81 \cdot 10^{-9} R_B(12'') + 1.22 \cdot 10^{-11} R_S(7) + 2.97 \cdot 10^{-11} R_S(30) + 1.02 \cdot 10^{-10} R_S(90) \quad (8)$$

are shown in Fig.2 and Fig.3. In expressions (7) and (8) $R_B(l)$'s are the responses of Bonner spheres with different moderator diameters (in inches). $R_S(l)$'s are the responses of the counter with plastic scintillator for different thresholds (MeV see).

Dose equivalent per unit fluence at depth of 10 mm on the principal axis for neutrons incident in a plane parallel beam on the ICRU sphere (8) was used as $h^*(10)$ in the energy range from

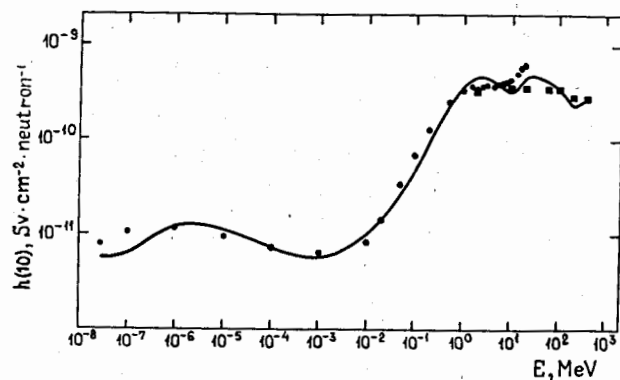


Fig. 2. Approximation of $h^*(10)$ by expression (7).

2.5 10^{-8} to 20 MeV. For higher energies there is no data for $h^*(10)$ that spans the entire energy range. Dose equivalent per unit fluence at a depth of 10 mm for neutrons incident in a plane parallel beam on a 30 cm thick semi-infinite slab phantom (8) was therefore used as h_p for neutron energy more than 20 MeV.

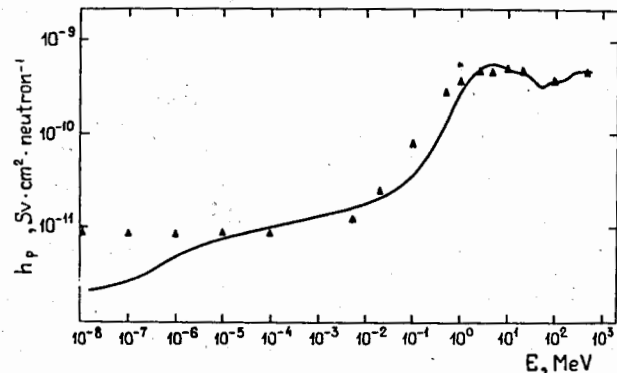


Fig. 3. Approximation of h_p by expression (8).

The conversion coefficients $h_p(E)$ were taken from the USSR radiation protection regulations (9).

Conclusions

Linear superposition of the detector responses as a function of neutron energy follows closely the functions required with the exception of thermal neutrons which are of little importance for neutron dose equivalent in radiation fields outside the shield of high-energy accelerators. The bias errors of the method are estimated to be less than a few per cent for typical neutron spectra at proton accelerators.

It would also be relatively simple to modify this method to accommodate possible changes in the definition of neutron conversion coefficients for operational dose equivalent quantities.

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