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Nuclear Instruments and Methods in Physics Research A 547 (2005) 592–600

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Design of a single moderator-type neutron spectrometer with enhanced energy resolution in the energy range from a few to 100 keV

Y. Tanimura*, J. Saegusa, M. Yoshizawa, M. Yoshida

Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki 319-1195, Japan

Received 8 July 2004; received in revised form 4 February 2005; accepted 4 March 2005
Available online 23 May 2005

Abstract

The moderator structure for a neutron spectrometer was optimized with the Monte Carlo code MCNP-4B. The spectrometer consists of a cylindrical moderator and a position-sensitive thermal neutron detector and obtains energy spectra from thermal neutron distribution along its cylindrical axis. The structure of the moderator was improved by using a low hydrogen density material on one end and a high hydrogen density on the other, and inserting a neutron absorber that eliminates thermal neutron diffusion. This design improves the energy resolution of the spectrometer, especially for low-energy neutrons from a few to 100 keV. The designed spectrometer can be applied to the measurement of energy spectra over a neutron energy range from a few keV to 20 MeV.

PACS: 29.30.Hs; 29.40.Yam

Keywords: Neutron spectrometer; Moderator; Position-sensitive thermal neutron detector; Neutron spectrum; Reference field; MCNP-4B

1. Introduction

In the measurement of neutron dose equivalents, it is ideal for the fluence response of a neutron dosemeter to comply fully with the fluence-to-dose equivalent conversion coefficients, h_{Φ}, at any energy. Virtually no neutron dosemeter possesses this ideal fluence response, and it is thus difficult to estimate accurate neutron dose equivalents in various neutron fields such as in nuclear power plants, fuel reprocessing facilities and high-energy particle accelerators. The implication is that dosemeters should be calibrated at neutron fields with energy spectra quite similar to those found at practical workplaces, that are called

*Corresponding author. Tel.: +81 29 284 3567; fax: +81 29 282 5609.
E-mail address: tanimura@popsvr.tokai.jaeri.go.jp (Y. Tanimura).

0168-9002/$ - see front matter
doi:10.1016/j.nima.2005.03.162

simulated workplace neutron calibration fields [1–6]. These fields are produced using radionuclide sources, accelerators and reactors.

Such calibration fields need to be traceable to the national standard. However, there are some issues in establishing traceability. A critical one is that there are few spectrometers that can be applied to a wide energy range of neutrons. For example, proton-recoil proportional counters are limited to the neutrons with the energy range from a few tens of keV to a few MeV [7]. Proton-recoil telescopes or liquid scintillation counters can be only applied to neutrons of more than a few MeV [2,8]. In contrast, spherical multimoderator spectrometer systems (generally known as Bonner multispheres) are applicable to a wide energy range of neutrons. These systems consist of several spherical moderators with different diameters and a thermal neutron detector at the center of the moderators. However, they require sequential measurements with combinations of the different moderators and the detector, and these measurements take a long time to perform [9,10]. This makes it difficult to confirm that the measurements are performed under the same condition, in particular for fields produced with accelerators or reactors whose intensity is likely to vary from moment to moment. In conclusion, there is a great demand for a spectrometer that can measure neutron spectra in a wide energy range without changing detectors or moderators.

The Long Counter, which is a combination of a thermal neutron counter tube and a cylindrical moderator, has a flat energy response to neutron fluence [11,12]. This detector is extensively used over the wide energy range, but is not suited to establish traceability in the calibration fields for radiation protection with continuous spectra, because no energy information can be obtained from the detector. As the coefficients h_Φ vary with neutron energy, not only the neutron fluence but also the energy spectrum data are needed to derive a reference dose equivalent rate of the field. Some researchers have developed spectrometers using position-sensitive-type detectors for the thermal neutron counter tube [13,14], which can estimate the energy of the incident neutron by determining the position along the cylindrical axis where the thermal neutrons are detected. However, the energy resolution of incident neutrons using their spectrometer is insufficient for our purpose. In this work, the spectrometer's moderator was improved in order to measure neutrons in the simulated workplace neutron fields from a few keV to 20 MeV by optimizing the size, structure and material of the moderator using a Monte Carlo radiation transport code. In the low-energy region from a few to 100 keV, the coefficient h_Φ rises drastically and the measurement of the neutron spectrum is important for the evaluation of dosimetric quantities [8,15]. The improvement in the present work was intended to enhance the energy resolution in this energy region.

2. Principle of the spectrometer

The spectrometer was designed to be used in standardizing simulated workplace neutron fields for calibrating neutron dosemeters. Because such neutron fields have spectra spread over a wide energy range [1,16,17], neutron spectrum the spectrometer can measure should be as wide as possible. We designed a spectrometer that can measure neutrons ranging from a few keV to 20 MeV.

The spectrometer consists of a cylindrical moderator and a position-sensitive thermal neutron detector. A schematic drawing of the designed spectrometer is shown in Fig. 1. This spectrometer can obtain energy information about the unidirectional neutrons entering through the front face parallel to the cylindrical axis. Therefore, it can be applied to fields with point-like sources, e.g., D_2O-moderated fields and some accelerator-based neutron fields [4,6,18]. The material and structure of the moderator were improved by using two kinds of material with different hydrogen densities and by inserting a thermal neutron absorber. The shape of the absorber was optimized to suppress the diffusion of thermal neutrons that otherwise worsens the energy resolution. When neutrons enter from the left face of this spectrometer parallel to its cylindrical axis, they lose their energy in the moderator and become thermal neutrons. The thermalized neutrons diffuse in the