A NEW TYPE ACTIVE PERSONAL DOSEMETER WITH A SOLID STATE DETECTOR

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INTRODUCTION

At present there is no active personal neutron dosemeter which is commercially available and covers a wide energy range from thermal to MeV. There have been a few works on pocket neutron dosemeters that indicate the dose equivalent and a review on these dosemeters has been reported(1). Among of these works, two works by Tyree and Falk(2), and Eisen et al.(3,4) have described the use of a silicon surface barrier detector and proposed a small size and real time dosemeter for personnel monitoring. Tyree and Falk have used a polyethylene radiator which is sensitive in the MeV energy range, and Eisen et al. have extended the sensitivity to the energy from 1 eV to 15 MeV by using both B-10 and polyethylene radiators.

We have developed a new type personal dosemeter by using a B-10 doped silicon p-n junction detector with a polyethylene radiator and a polyethylene moderator. The purpose of this study was to develop a real time neutron dosemeter with a nearly flat response in the energy range from thermal to 15 MeV and low angular dependence to the incident neutron direction. The neutron response of the dosemeter was obtained with the Monte Carlo calculation and the monoenergetic neutron experiment in a free air field and also under a condition attached on a phantom.

DETECTOR DESIGN

A planar-type silicon p-n junction detector fabricated by Fuji Electric Co. Ltd. was applied for a neutron dosemeter. A boron film enriched in 90% B-10 is deposited in about 0.6 μm thickness on an n-type silicon crystal. A polyethylene radiator of 0.8 mm thickness is positioned in front of the boron film. The silicon detector encapsulated in a stainless steel case is covered with a hemispherical polyethylene moderator of 1 cm thickness.

This dosemeter has a sensitivity to neutrons of wide energy range. Low energy neutrons can be detected by alpha ions from the B-10(n,α)Li-7 reaction and fast neutrons by the recoil protons from the elastic scattering of hydrogen in the polyethylene radiator, and the polyethylene moderator has a role to increase its sensitivity to the intermediate energy neutrons and also to depress its angular dependence.

EXPERIMENT

The neutron response of this dosemeter was measured in the monoenergetic neutron field at the Fast Neutron Laboratory of Department of Nuclear Engineering, Tohoku University and the moderated Cf-252 neutron field at the Cyclotron and Radioisotope Center, Tohoku University. The five monoenergetic neutrons of energies of 150 keV, 500 keV, 1 MeV, 5 MeV and 15 MeV were produced by the p-T, p-Li, d-D and d-T reactions by using the Dynamitron accelerator.

Figure 1 shows the experimental arrangement. The absolute neutron fluxes were measured by the fission chamber placed in front of the dosemeter. The contribution of the room scattering was evaluated by the shadow shield method, consisting of 20-cm long iron and 30-cm long boron polyethylene shield. The hydrogen proportional counter was also used subsidiarily as a neutron flux monitor. The dosemeter was placed in a free air field or in front of a ellipsoidal water phantom or a tissue-equivalent phantom developed by the Central Research Institute of Electric Power Industry (5). The dosemeter response to neutrons were measured under these three conditions. The dosemeter was operated at very low voltage (+5V) in order to suppress the gamma-ray sensitivity and the output pulses were fed into the multi-channel pulse height analyzer. The thickness of the depletion layer was estimated to be about 50 μm.

RESULTS AND DISCUSSIONS

Figures 2 and 3 show examples of the pulse height spectra for 151.3 keV and 5.0 MeV monoenergetic neutrons normally incident to the front surface of the dosemeter attached on the water phantom. The pulse height spectrum for 151.3 keV neutrons shows a Li-7 peak and two alpha peaks corresponding to 1.47 MeV and 1.77 MeV energies from the B-10(n,α) reaction, while for 5.0 MeV neutrons a plateau peak of recoil protons from the H(n,n) reaction is added to Li-7 and alpha peaks. The recoil proton peak could be noticed for neutrons of energy above 1 MeV and made an increase of the sensitivity of the dosemeter to fast neutrons. Only the pulses beyond the discrimination level indicated in Fig. 3 were integrated to obtain the real neutron counts, since the lower pulses included the electrical noises and gamma-ray pulses. The neutron response of the dosemeter was obtained experimentally by dividing this real neutron counts by the incident neutron flux measured with the fission chamber. The results obtained in a free air field and on the water phantom are shown in Fig. 4.

The experimental results are limited to neutron energy above 150 keV in the present stage, then the dosemeter response to neutrons below that energy was calculated by the group Monte Carlo code MORSE(6). The MORSE calculation gave the neutron flux $\phi(E)$ at the position of the silicon detector through the polyethylene moderator for thermal to 15 MeV neutron incidence. The dosemeter response was estimated as follows,

$$R = N \int \phi(E)\ \sigma(E)\ dE$$

where N is the total number of B-10 atoms and $\sigma(E)$ the B-10(n,α) reaction cross section. The calculated results are also shown in Fig. 4 in a free air field and on a water phantom for comparison. The calculated results show very good agreement in absolute values with the experimental results below 1 MeV, where the contribution of recoil protons can be negligible. The neutron response of the dosemeter on the water phantom becomes much higher in the higher neutron energy range than that in a free air field, because of the increase of slow neutrons backscattered from the phantom.

From the figure, it was clearly found out that the dosemeter has rather flat response to neutrons in a wide energy range from thermal to 15 MeV under a condition attached on a phantom. This neutron response is much better than that of personal dosemeters now in use, such as film badge, albedo dosemeter and solid state track dosemeter. We are now performing to increase its sensitivity to neutrons and to fit the response further closer to the flux-to-dose conversion factor defined by the ICRP-21(7).

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REFERENCES

1) J. A. B. Gibson, Rad. Prot. Dos., 10, 197 (1985).
2) W. H. Tyree and R. B. Falk, 9th DOE Workshop on Personnel Neutron Dosimetry, Las Vegas, Nevada, PNL-SA-10714, pp 154-161 (1982).
3) Y. Eisen, G. Engler, E. Ovadia and Y. Shamai, Nucl. Instrum. Methods, 211, 171 (1983).
4) Y. Eisen, G. Engler, E. Ovadia, Y. Shamai, Z. Baum and Y. Levi, Rad. Prot. Dos., 15, 15 (1986).
5) K. Ishida, Private communication (1987).
6) E. A. Straker, P. N. Stevens, D. C. Irving and V. R. Cain, ORNL-4585, Oak Ridge National Laboratory (1970).
7) "Data for Protection Against Ionizing Radiation from External Sources", ICRP Publication 21, International Commission on Radiological Protection (1971).

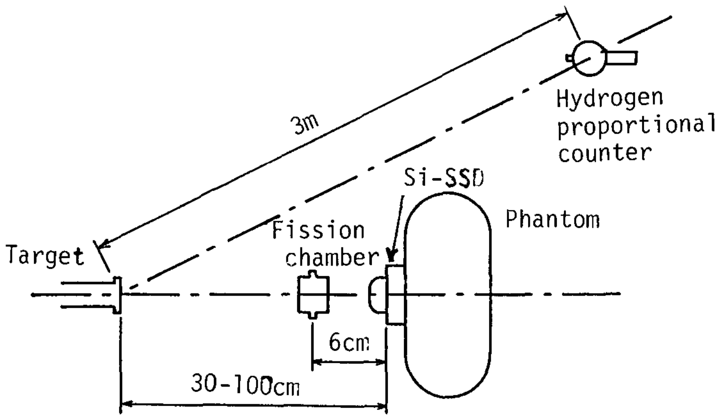

Fig. 1 Experimental arrangement

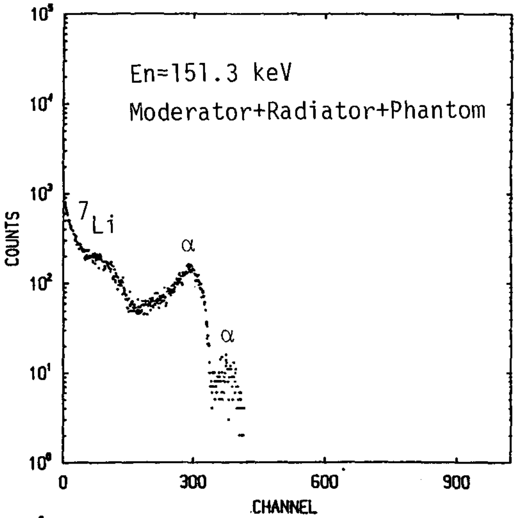

Fig. 2 Pulse height spectrum for 151.3 keV mono-energetic neutrons

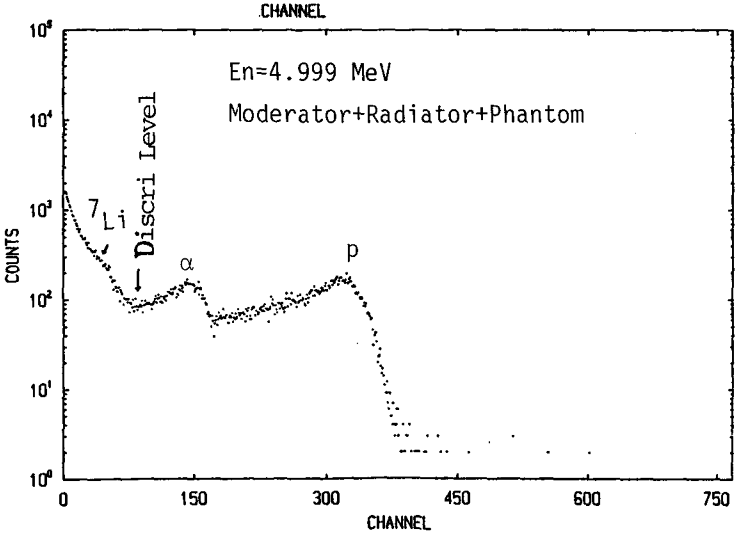

Fig. 3 Pulse height spectrum for 5.0 MeV monoenergetic neutrons

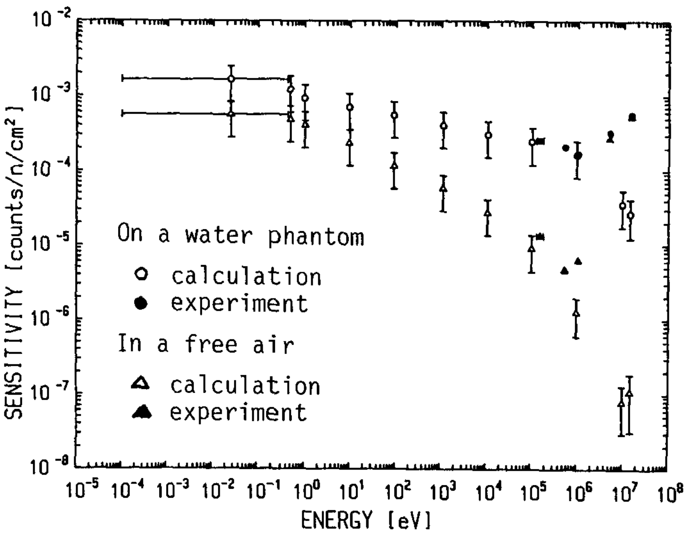

Fig. 4 Neutron response of the dosemeter in a free air and on a phantom obtained by experiment and calculation