Development of Real Time Personal Neutron Dosimeter with Two Silicon Detectors

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Introduction

The development of personal neutron dosimeters that indicate the dose equivalent in real time becomes important with the increased number of people working in high intensity, high energy accelerator facilities and nuclear fuel reprocessing plants. To produce an instrument that is small and light, and has enough sensitivity to neutrons is a difficult task.

Recently, two types of direct-reading personal neutron dosimeters have newly been developed. One is a bubble-damage polymer detector which uses tiny, superheated droplets of a detector liquid uniformly dispersed in a firm elastic polymer developed separately by Ing et al.[1] and Apfel et al.[2] The other is a silicon dosimeter developed by Nakamura et al.[3] which uses two types of silicon p-n junction detectors fabricated by Fuji Electric Co. Ltd. This dosimeter had low neutron sensitivity and we further realized the dosimeter of higher sensitivity by using larger silicon detector of 1 cm × 1 cm.

Dosimeter Design

The dosimeter installs two neutron sensors and one gamma-ray sensor, which enables us to give neutron and gamma-ray doses at the same time. One type, slow neutron sensor, is an n-type silicon crystal on which a p^+ layer of elementary boron enriched 94 % ^{10}B is deposited in about 1 mm thickness and the other type, fast neutron sensor, is a p-type silicon crystal without boron coating. Both crystals are contacted with 0.08 mm thick polyethylene radiators and in some cases only the slow neutron sensor is covered with thermal neutron filter of 0.5 mm thick cadmium to improve its energy response. Figure 1 shows schematic cross sectional view of two neutron sensors. The gamma-ray sensor is the p-type silicon detector of 3 mm × 3 mm without any radiator.

These three sensors are encapsulated in a metal package together with the charge sensitive preamplifier and the linear amplifier circuits. The output pulses from the sensors are counted through the pulse height discriminator and fed to the CPU for computing and displaying the dose equivalent values. The external size of the dosimeter is 100 mm × 60 mm × 20 mm and its weight is about 170 g, as shown in Fig. 2.

Neutron Sensitivity Measurement

The neutron detection efficiencies of these two sensors were measured in the monoenergetic fast neutron field at the Fast Neutron Laboratory of Tohoku University. Monoenergetic neutrons of six discrete energies of 200 and 550 keV by the Li (p,n) reaction, 1 and 2 MeV by the T (p,n) reaction, 5 MeV by the D (d,n) reaction and 15 MeV by the T (d,n) reaction were produced using the Dynamitron accelerator. The dosimeter was placed in the forward direction to the beam axis. The efficiency measurement of the slow neutron sensor to thermal neutrons was done in the experimental hole of the TRIGA-II type reactor of Rikkyo University and in the thermal neutron field leaked from a graphite pile of Institute of Radiation Measurements.

The dosimeter was placed in front of a commercially available ellipsoidal water phantom, 45 cm high and 30 cm wide. The output pulses due to alpha particles produced by the ^{10}B (n,α) reaction and protons recoiled from the elastic collision in the polyethylene radiator were measured with a multichannel analyser in this sensitivity measurement.

Figure 3 shows the neutron detection efficiency of the dosimeter as a function of neutron energy. The measured results are the sum of the integrated counts given by the slow neutron sensor and the integrated counts of the fast neutron sensor multiplied by a factor of 20, in order to get the detection efficiency as close as possible to the fluence-to-dose-equivalent conversion factor given by ICRP-51 which is drawn in a solid line. In Fig. 3, the results calculated with the Monte Carlo method are also shown to compare with the measured results. Very Good agreement between experiment and calculation can be seen in the energy below 5 MeV. Above 5 MeV, the calculation underestimates the measured results due to the neglection of the contribution of charged particles which are produced in the silicon crystal itself and the surrounding material by various neutron reactions.

This dosimeter which combines two silicon sensors has neutron sensitivity over a wide energy range from thermal to 15 MeV and also has good energy response, excluding a large deviation from the ICRP-51 response curve in the energy range from 50 keV to 1 MeV, as seen in Fig. 3.

Field Test of Dosimeter Response

Because of the deviation of the dosimeter energy response from ICRP-51, it is necessary to determine the conversion factor from counts to dose equivalent values to be fitted in various spectral fields necessary for neutron monitoring. For getting this conversion factor, we have done the field test of the dosimeter calibration in the following typical neutron fields having known neutron energy spectra; 1) moderated ^{252}Cf neutron source calibration field, 2) a beam extraction hole of the fast neutron source reactor of University of Tokyo, 3) labyrinth from the 40 MeV cyclotron room of Tohoku University, 4) MOX (Mixed Oxide) fuel handling room of Power Reactor and Nuclear Fuel Development Corporation, 5) 14 MeV d-T neutron field penetrated through concrete shield, and 6) On the outer surface of the concrete shield surrounding several hundreds MeV electron synchrotron.

In these field tests, the dosimeter was fixed on the water phantom faced to the neutron beam direction. The measured counts were compared with the dose equivalent values obtained from the dose equivalent counters (rem counters) of Studsvik 2202D and Fuji Electric NSN1 which were used as neutron dose monitors. Considering the energy response of the dosimeter shown in Fig. 3, we propose the following two-group dose estimation method which divides neutrons into two energy groups of thermal to 1 MeV and above 1 MeV. The total neutron dose equivalent H is given by adding the neutron dose equivalent of energy higher than 1 MeV, H_1 and that of energy lower than 1 MeV, H_2. H_1 and H_2 are given by

$$H_1 = K_1 C_1 \qquad \text{for } E_n \geq 1 \text{ MeV},$$
$$H_2 = K_2 C_2 \qquad \text{for } E_n \leq 1 \text{ MeV},$$

where C_1, C_2 are the respective counts measured with fast sensor and slow sensor, K_1, K_2 are the respective conversion factor in units of μSv/count. From the results of these field tests, the K_1 and K_2 values were found to be fixed as 2.14 and 0.1.

Figure 4 summarizes the results of these field tests. The ratio of neutron dose equivalent value measured with this personal dosimeter to that with the rem counter is shown as a function of neutron energy in the test field averaged by weighting with the dose equivalent. The ratio must be equal to 1 for the ideal dosimeter, and our personal dosimeter gives neutron dose equivalent within a factor of 2 margin of accuracy, excluding a special field in which thermal neutron fluence occupies more than 50 % of total neutron fluence, such as at some positions in the labyrinth from the cyclotron room. Even in such a field, we can estimate the neutron dose equivalent with good accuracy by adjusting the conversion factor K_2 slightly.

Conclusion

The characteristics of our newly-developed real-time personal neutron dosimeter based on the present study can be summarized as follows;

(1) From these field experiments, this dosimeter will be possible to give the neutron dose equivalent within about a factor of 2 margin of accuracy in the energy range from thermal to 15 MeV.

(2) The dosimeter is insensitive to gamma rays up to about 100 mSv/h.

(3) The size and weight of the dosimeter is about 100 mm × 60 mm × 20 mm and about 150 g, respectively, which is small and light enough for personal dosimeter.

(4) This dosimeter gives both neutron and gamma-ray dose equivalents.

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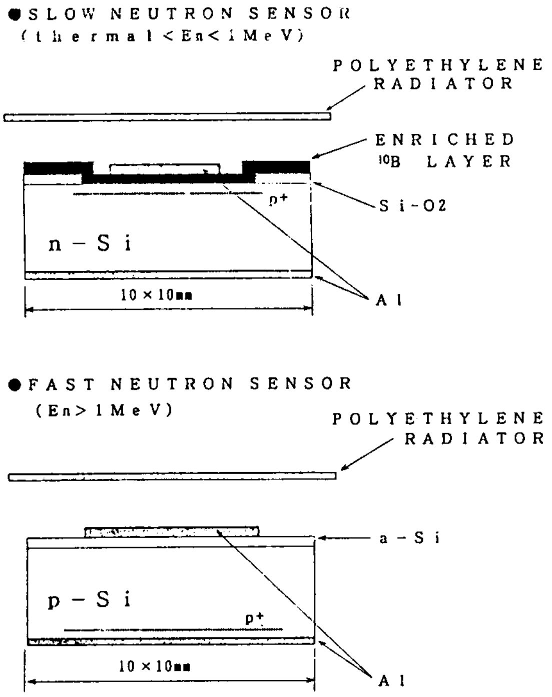

Fig. 1. Schematic cross sectional view of two silicon sensors.

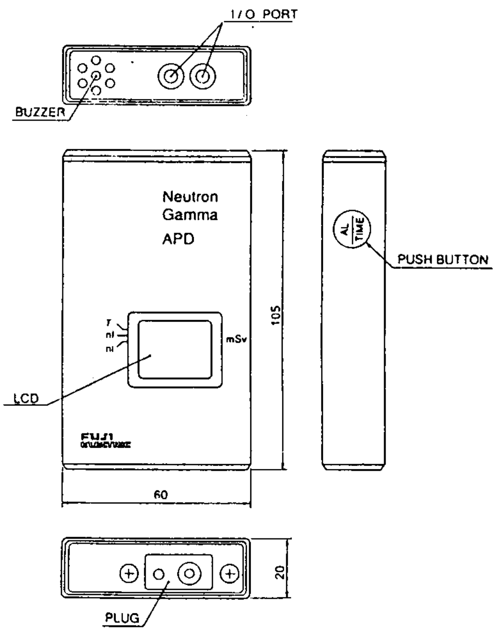

Fig. 2. External appearance of the personal dosimeter.

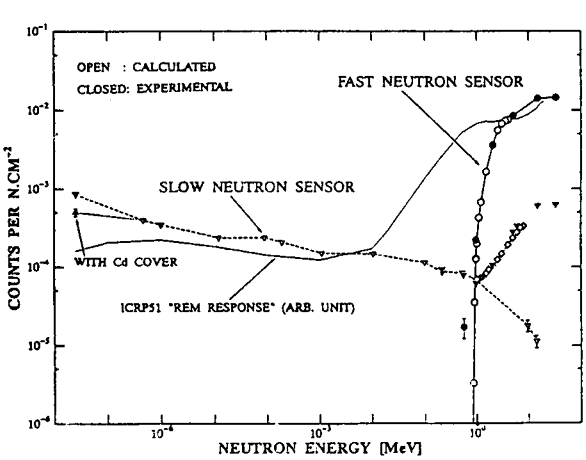

Fig. 3. Comparison of measured and calculated neutron detection efficiencies of the dosimeter, together with the ICRP-51 fluence-to-dose-equivalent conversion factor

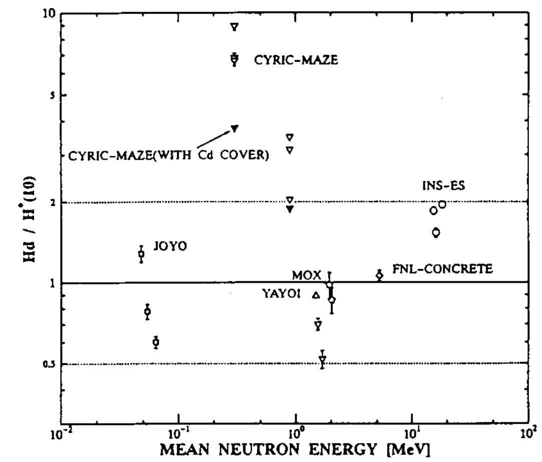

Fig. 4. Comparison of dose equivalent given by this dosimeter to that by the rem counter for various neutron fields having different mean neutron energies