CALCULATION OF FLUENCE-TO-DOSE EQUIVALENT CONVERSION COEFFICIENTS FOR NEUTRONS TO BE USED FOR CALIBRATION OF PERSONAL DOSIMETERS

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ABSTRACT

Conversion coefficients from neutron fluence to the ICRU slab dose equivalent for personal dosimeter calibration were calculated using the MCNP-4 code and the cross section library based on JENDL-3.1. Influences given by the changes of neutron quality factor and phantom size were also investigated.

INTRODUCTION

The international Commission on Radiation Units and Measurements(ICRU) has recommended in its report No.47(1) that the dose equivalent at the depth of d in a 30x30x15cm ICRU tissue slab phantom, ICRU slab dose equivalent, $H_{sl}(d,\alpha)$ (α: incident angle), should be used as the quantity for calibration of personal dosimeters. Though the scope of that report focuses on photons and electrons, the consistent calibration procedure requires the same quantity for neutrons as well. Conversion coefficients from neutron fluence, Φ, to $H_{sl}(d,\alpha)$ for a broad parallel beam of neutrons incident in angle α are needed to apply the quantity $H_{sl}(d,\alpha)$ to calibration of personal dosimeters. There are only a few published reports(2-4) on $H_{sl}(d,\alpha)/\Phi$. To improve the reliability of the conversion coefficients, the calculation should be made with different techniques and nuclear data. In addition, neutron quality factors, Q_n, that mean the average quality factors for the neutron-induced heavy charged particles, have been recalculated based on the new data on stopping powers and ranges for protons and alpha particles(4), thus the influence of this alteration on $H_{sl}(d,\alpha)/\Phi$ needs to be investigated. To clarify the contribution of neutrons and secondary photons to the dose in the phantom, it is important to compare the values of the conversion coefficients calculated for the phantoms with different size. This paper presents the calculated values of $H_{sl}(d,\alpha)/\Phi$ at depths of 0.07, 3, and 10mm in the range from thermal to 20MeV in energy and from 0°(normal incidence on the surface of the phantom) to 75° in incident angle, and the influences of the alteration of Q_n and of the difference of the phantom size on the conversion coefficients are also described.

METHOD

The Monte Carlo code MCNP-4 was used in the calculation. The surface crossing estimators were employed to calculate spectral fluences of neutron and neutron-induced photon at depths of 0.07, 3, and 10mm on the mid-axis within the ICRU tissue slab phantom, irradiated by a broad parallel beam of neutrons incident in angle α. This type of estimator would be more effective than volume-type ones to evaluate the fluences that vary significantly with depth in the phantom. The estimator was a disk with a radius of 2cm, which was chosen by test calculations. The number of particle histories was selected dependently on energy and incident angle so that one relative standard deviation could be maintained within 1%.

The continuous energy cross section libraries employed in this work are FSXLIB-J3(5), generated from JENDL-3.1 evaluated in Japan(6), for neutrons, and MCPLIB, based on data from ENDF, for photons. Since $S(\alpha,\beta)$ data for treatment of chemical binding effect in thermal neutron scattering are not available for ICRU tissue, the data for hydrogen bound in light water were adopted in the calculation.

The absorbed dose was calculated by the kerma approximation. The kerma factors were taken from the data of Caswell *et al*(7) for neutrons and of Hubbell(8) for photons. The neutron quality factors used in the calculation of dose equivalent are the data of Schuhmacher and Siebert(9). In order to avoid the round error due to the structure of energy bins, we did not use energy bins, but each particle was weighted by the kerma factor and Q_n corresponding to the particle energy on the estimator.

RESULTS AND DISCUSSION

Figure 1 shows the conversion coefficients for normal incidence, $H_{sl}(d,0°)/\Phi$, as a function of incident neutron energy. $H_{sl}(d,0°)/\Phi$ increases significantly with energy in the range between 10keV and 1MeV due to a rapid augmentation of kerma factor in this energy region. No significant energy dependence of $H_{sl}(d,0°)/\Phi$ is observed in the low energy region (below ~10keV). This is because the contribution of slowing down neutrons to the dose is predominant in this energy region. $H_{sl}(d,0°)/\Phi$ increases with depth in the low energy region, and the values at 10mm depth are roughly two times higher than those at 0.07mm depth. The contribution of secondary photons to $H_{sl}(d,0°)/\Phi$ is also plotted in Figure 1. The secondary photons give 20-30% of dose equivalent in the low energy region, whereas they give quite a small contribution in the high energy region.

A variation of the conversion coefficient at 10mm depth with incident angle, α, is illustrated in Figure 2 as the angular dependence factor, defined as the ratio of $H_{sl}(10,\alpha)/\Phi$ to $H_{sl}(10, 0°)/\Phi$. As is apparent from this figure, $H_{sl}(10,\alpha)/\Phi$ depends significantly on the incident angle, and the angular dependence factors in the low energy region vary slightly due to the same reason in the above.

The calculated values of $H_{sl}(10,\alpha)/\Phi$ were compared with the data of the previous works(2,3). As a whole, the present results agree with the data of other authors within 15%, even though the cross section library and the estimator were different from theirs. In detail, the present values are about 5% less than those of the previous works in the high energy region, and the discrepancies increase up to about 15% with decreasing energy. Major differences in the method between the previous works and ours are cross section library, estimator, and the treatment of kerma factors below 0.025eV. They used the cross section libraries based on ENDF/B-IV, volume-type estimators, and the 1/v-dependent kerma factors below 0.025eV, whereas we used the library based on JENDL 3.1, surface crossing estimators, and the constant factors below 0.025eV though the data source is the same. The influence of each of these differences is now being studied.

The conversion coefficients $H_{sl}(d,\alpha)/\Phi$ using the revised Q_n (4) was calculated for normal incidence. Q_n was reestimated to be smaller than the previous one. Consequently, this reduces the conversion coefficients as seen in Figure 3. A large descent appears at several tens of keV.

Influence given by the change of the phantom size was investigated. A comparison of the values of $H_{sl}(d,0°)/\Phi$ calculated for a 40×40×15cm phantom with those for the 30×30×15cm one shows that the enlargement of the phantom leads to 3-10% growth of the conversion coefficients in the range below 10keV. A further comparison of each component of neutrons and secondary photons demonstrates that secondary photons induced in the phantom, rather than neutrons, have an important contribution to dose for neutrons below about 10keV.

CONCLUSIONS

$H_{sl}(d,\alpha)/\Phi$ for personal dosimeter calibration was calculated using the MCNP-4 code and the cross section library based on JENDL-3.1. The present results of the $H_{sl}(10,\alpha)/\Phi$ agree with data of other authors within 15%, even though the cross section library and the estimator were different from theirs. It is found that the recalculated Q_n reduces $H_{sl}(d,\alpha)/\Phi$ in all energies considered. A study on the influence given by the change of the phantom size makes it clear that secondary photons induced in the phantom, rather than neutrons, have an important contribution to dose for neutrons below about 10keV.

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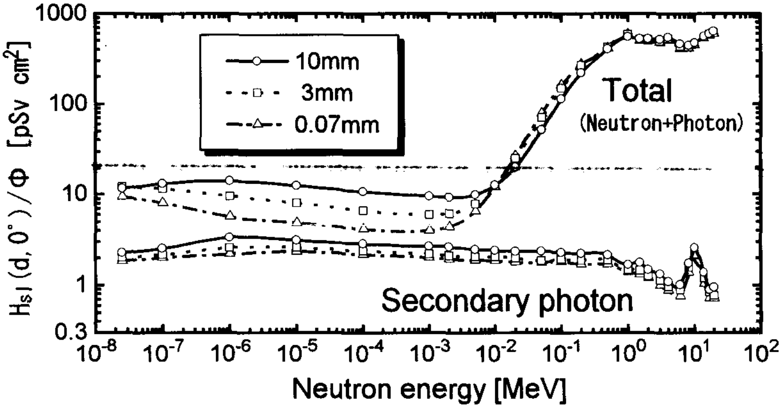

Figure 1. Fluence-to-ICRU slab dose equivalent conversion coefficients, $H_{sl}(d, 0°)/\Phi$, for a broad parallel beam of neutrons incident normal to the phantom, and their component of secondary photons.

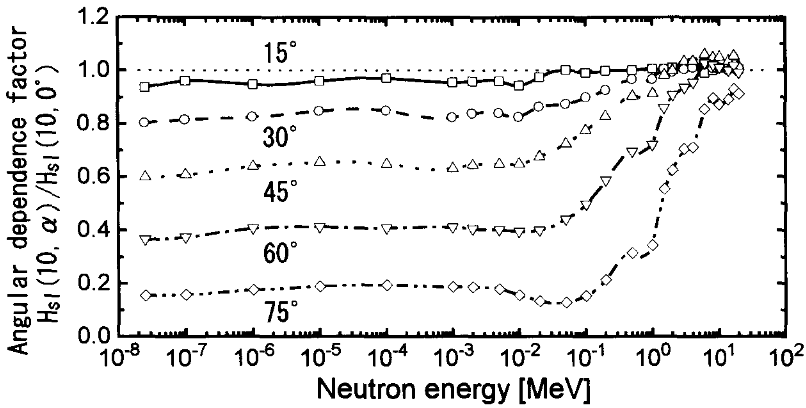

Figure 2. Angular dependence factors of ICRU slab dose equivalent.

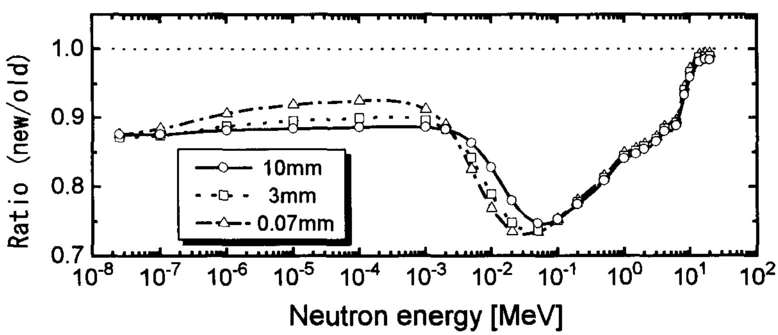

Figure 3. Ratios of $H_{sl}(d,0°)$ calculated with the new(4) and old(9) neutron quality factors.