DETERMINATION OF DOSE EQUIVALENT QUANTITIES IN A PHANTOM FOR CALIBRATION PURPOSES

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For the introduction of the new measurement quantity in radiation protection by external exposure which has been under discussion for some years [1], no primary standard exists at present. Conversion factors have therefore been determined, allowing the new quantities to be linked to the primary standards for air kerma or absorbed dose in water. Conversion factors presented in the literature are based on Monte Carlo calculations and only a few experimental results.

Measurements of the distribution of dose equivalent in the ICRU sphere were therefore performed, using a 0.8 cm^3 spherical ionisation chamber which was developed at the PTB. A PMMA hollow sphere, 30 cm in diameter and filled with water, served as a phantom.

For determining the energy dependence of the conversion factors in the X-ray range, heavily-filtered radiation was used. The small volume of the ionisation chamber and the filtering caused very small signals, while the leakage current was of the same order of magnitude. In order to separate the signal from the leakage current the X-ray beam was chopped and the pulsed ionisation current was measured using the lock-in technique.

With this arrangement depth dose curves in the phantom were obtained in the range from 30 kV up to 300 kV tube voltage and with ^{137}Cs and ^{60}Co γ-radiations. The ionisation chamber was calibrated to indicate the air kerma free in air. For calculating the dose equivalent, the different spectra in air and at the various depths in the phantom had to be considered.

The spectra in the phantom were obtained by segment-by-segment multiplication of the real X-ray spectra [2] with the interpolated spectra known from Monte Carlo calculations for mono-energetic radiation [3]. Two examples of heavily-filtered radiation for 30 kV and 300 kV tube voltage are shown in figures 1 and 2. In each case the points represent the spectrum of the incident X-ray beam, while the lines describe the spectra in the phantom with the depth as a parameter. For low energies the spectra in the phantom are similar in shape to that of the primary beam, but as a consequence of the photon scattering the mean energy at the surface is displaced to smaller values. The spectra decrease and flatten with increasing depth. At higher energies (fig. 2) the Compton effect becomes important, indicated by the second peak which appears at nearly half-energy of the first peak.

Using these spectra it is possible to calculate the dose equivalent from the response of the ionisation chamber in the phantom and the calibration free in air.

The following relation between the measured value M_i and the value m(E) which would have been caused by a monoenergetic spectral fluence giving rise to the same air kerma as the fluence φ^i can be considered:

$$M_i = \int_0^{E_{max,i}} \varphi_E^i(E)\ m(E)\ dE$$

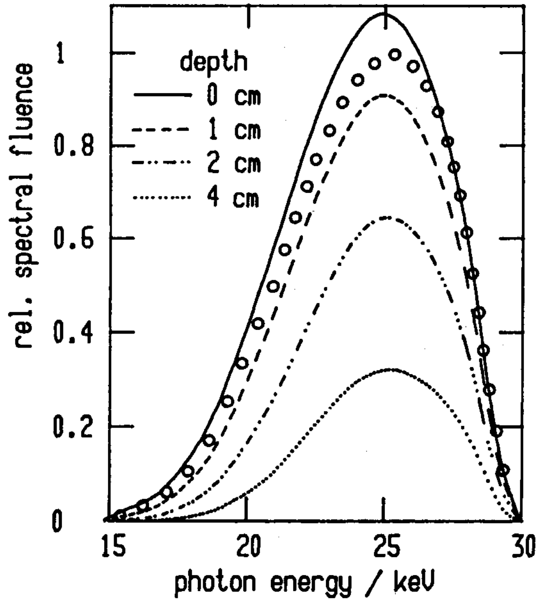

Fig. 1 X-ray spectra at various depths in the ICRU-sphere for a heavily-filtered X-ray beam with 30 kV tube voltage. Points indicate primary spectrum.

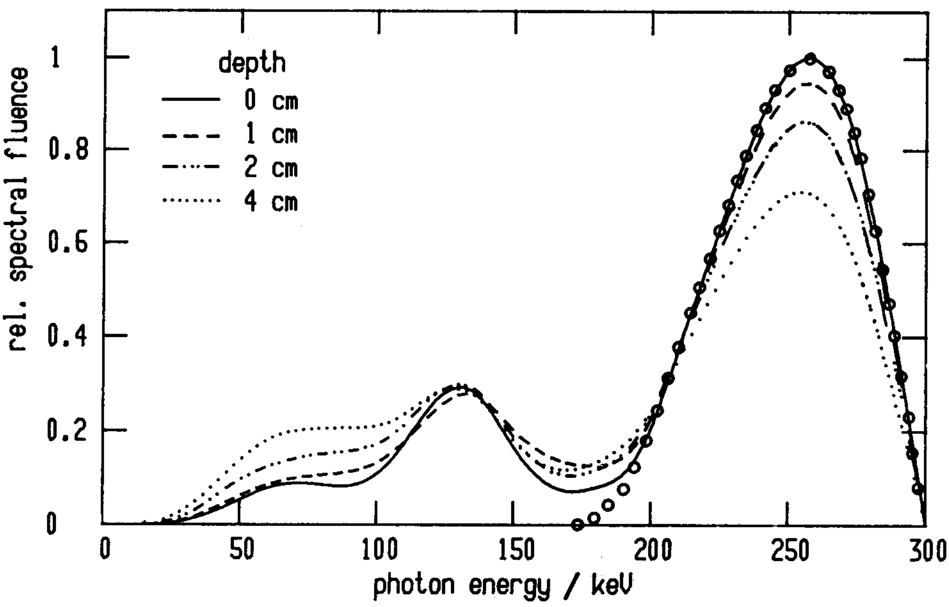

Fig. 2 X-ray spectra at various depths in the ICRU sphere for a heavily-filtered X-ray beam with 300 kV tube voltage. Points indicate primary spectrum.

where $\varphi_E^i(E)$ is the spectrum of the X-ray beam (i) with the maximum energy $E_{max,i}$. This integral equation can be solved for m(E) by iteration. Applying this method also to the values determined from calibration free in air, one obtains a calibration function k(E) corrected by the primary spectra.

The dose equivalent is now given by

$$H(E_o) = Q\int_0^{E_o} m(E) \cdot k(E) \cdot \mu_{a\to t}(E) \cdot k_D(E) \cdot \tilde{\varphi}_E(E)\, dE$$

The quality factor Q is unity for photon radiation, $\mu_{a\to t}$ is defined as

$$\mu_{a\to t} = \frac{(\mu_{en}/\rho)_{tissue}}{(\mu_{en}/\rho)_{air}}$$

and $k_D(E)$ is a correction factor for the displacement effect. $\tilde{\varphi}_E(E)$ represents the spectrum in the phantom caused by monoenergetic primary radiation with the energy E_o.

The correction $k_D(E)$ which depends on photon energy, depth in the phantom and the radius of the ionisation chamber was determined theoretically by Monte Carlo calculations and a passage to the limit $R\to 0$ for the chamber radius R.

The values of the displacement correction vary between 0.87 at 30 keV and 0.97 at 1250 keV for 1 cm depth and a chamber radius of R = 6 mm.

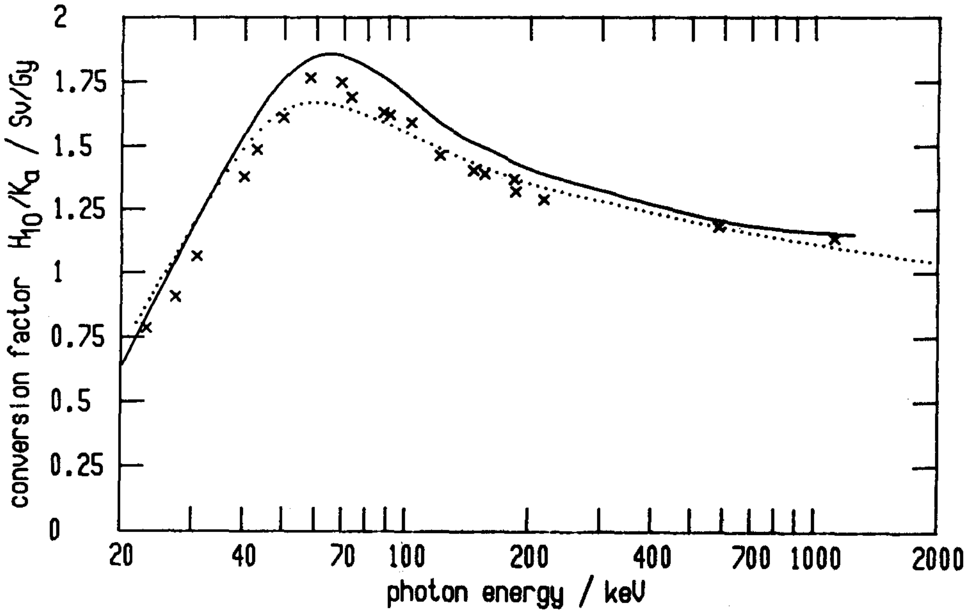

Fig. 3 Energy dependence of the conversion factor for the dose equivalent H_{10} at a 10 mm depth in the ICRU sphere.
solid line: Monte Carlo calculation [3]
dotted line: IEC Recommendation [5]
points: own measurements

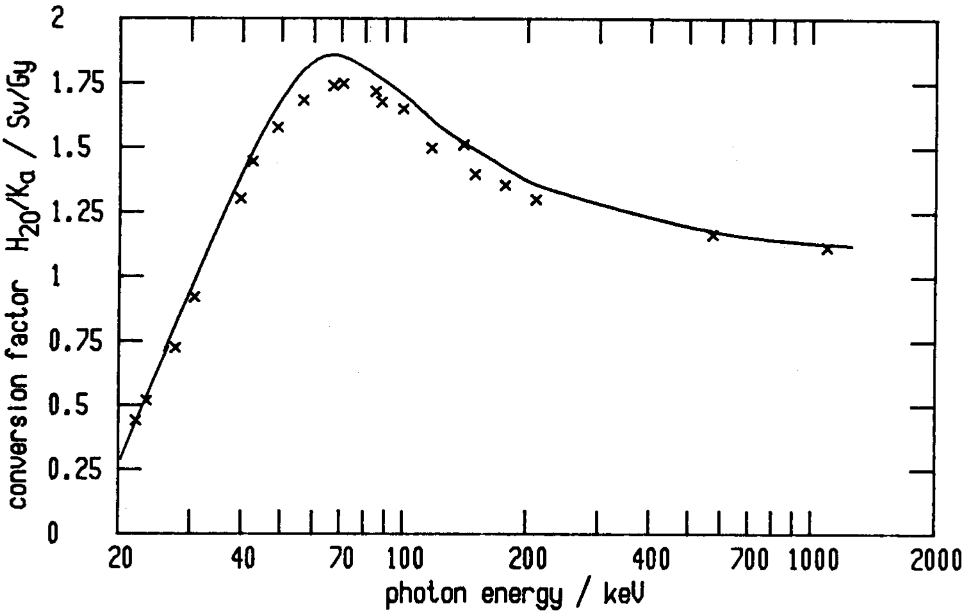

Fig. 4 Energy dependence of the conversion factor for the dose equivalent H_{20} at a 20 mm depth in the ICRU sphere
solid line: Monte Carlo calculations
points: own measurements

Dividing the measured and corrected dose equivalent at a 10 mm depth by the air kerma at the point of measurement yields the conversion factor H_{10}/K_a in the units Sv/Gy.

The results of these investigations are shown in fig. 3. The experimental values are in good agreement with theoretical Monte Carlo calculations [4], but on the average they are by about 6 % smaller. The curve specified by the IEC [5] shows a smaller maximum (about 5 %) and is flatter in shape. The conversion factor for the dose equivalent at a 20 mm depth shown in fig. 4 also confirms the Monte Carlo calculations with even smaller deviations. Altogether, the agreement between the experimental results and the theoretical data is very satisfactory.

1 ICRU Report 25, Conceptual Basis for the Determination of Dose Equivalent ICRU Washington, D.C. (1976)

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