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Measurement of conversion coefficients between free in air kerma and personal dose equivalent for diagnostic X-ray beams

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Abstract

Conversion coefficients between free in air kerma and personal dose equivalent were experimentally determined for the diagnostic X-ray qualities recommended by the International Electrotechnical Commission (IEC) for primary beams (RQR) and three RQA. Harshaw LiF-100H thermoluminescent dosemeters (TLD) were used for measurements after being calibrated against an ionization chamber traceable to the National Metrology Laboratory. A 300 mm × 300 mm × 150 mm polymethilmethacrylate (PMMA) slab phantom was used for deep-dose measurements. The dosemeters were placed in the central axis of the X-ray beam at five different depths in the phantom (5, 10, 15, 25 and 35 mm) upstream the beam direction. The typical combined standard uncertainty of conversion coefficient value was 12%.

Keywords: Conversion coefficients; Diagnostic X-ray; TL dosimetry

1. Introduction

The International Commission on Radiological Protection (ICRP, 1991) and the International Commission on Radiations and Units (ICRU, 1985,1992, 1993, 1998) recommended the personal dose equivalent at a determined depth d, $H_{\mathrm{p}}(d)$, as the operational quantity for individual monitoring. Although the $H_{\mathrm{p}}(d)$ is defined in a human body, it is determined by measuring the air kerma in the absence of a body phantom; conversion coefficients are required to convert air kerma values to $H_{\mathrm{p}}(d)$ at the exposure conditions.

Conversion coefficients are also necessary for evaluating dose on patients that are submitted to radiographic exposure for establishing or verify the diagnostic reference levels for patient protection purpose. Standardization in the X-ray diagnostic area was made possible by the international standard 61267 (ISO/IEC, 2005) of the International Electrotechnical Commission (IEC). The IEC standard defined free scattered radiation qualities called RQR, RQA, RQC, RQT, RQR-M e RQAM and qualities that include the scattered radiation due to the patient presence, called RQN, RQB, RQN-M e RQB-M.

Using the formulation by Will (1991) conversion coefficients is given by

$$H_{\mathrm{p}}(d)/K_{\mathrm{air}} = BSF \times T^{\mathrm{s}}(d)\left(\frac{\mu_{\mathrm{en}}}{\rho}\right)_{\mathrm{air}}^{\mathrm{PMMA}}, \tag{1}$$

where $\mathrm{BSF} = K_{\mathrm{air}}^{\mathrm{s}}(0)/K_{\mathrm{air}}$ is the backscatter factor; $\mathrm{T}^{\mathrm{s}}(d) = K_{\mathrm{air}}^{\mathrm{s}}(d)/K_{\mathrm{air}}^{\mathrm{s}}(0)$ is the dose factor at depth d, and $(\frac{\mu_{\mathrm{en}}}{\rho})_{\mathrm{air},d}^{\mathrm{PMMA}}$ is the ratio of mass energy absorption coefficient of the polymethilmethacrylate (PMMA) tissue to that for the air, averaged over the photon spectrum at the phantom depth, d. The combined standard uncertainties are calculated by error propagation considering the combined standard uncertainties of backscatter factor, dose factor and the ratio of mass energy absorption coefficient of the PMMA tissue to that for the air.

Experimental determination of conversion coefficients was described in the literature (Will, 1991; Nogueira et al., 1999). Other authors have calculated the conversion coefficients by Monte Carlo simulation. In this work, experimental measurements of conversion coefficients for the all IEC RQR and three RQA qualities were carried out and their associated uncertainties were estimated.

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2. Materials and methods

A constant potential Isovolt HS320 Pantak Seifert industrial X-ray machine was used to produce the X-ray beams at the Dosemeter Calibration Laboratory of the Development Center of Nuclear Technology (CDTN/CNEN). Aluminum filters with 99.5% purity were used although the IEC standard recommends the 99.9% purity. IEC RQR qualities were implemented in such X-ray machine as already described.

Harshaw LiF:Mg,Cu,P thermoluminescent (TL) detectors were chosen to be used due to their good repeatability of about 2% in the range of interest. They also have a proper sensitivity and equivalence to the human tissue. TL detectors were read out in a Harshaw 4500 Reader under a nitrogen gas flux with a standard annealing cycle. The stability of the reader was followed through measurements with the LED reference light that shows to fit within 5%.

The conventional true values of air kerma free in air were obtained against a Radcal Corporation 180 cm^3 sensitive volume ionization chamber that is connected to a Radcal Corporation 9015 electrometer. The chamber response has a variation of 5% in the energy range of measurements. In all IEC RQR and three RQA qualities, air kerma rates were measured and the mean value of four readings was considered. The main sources of uncertainty in this procedure were the variation of the air kerma values under the same condition (standard deviation), the chamber energy dependence and the change in the environmental temperature and pressure.

For each IEC RQR and three RQA qualities, the TL detector individual calibration was done by giving 5 mGy air kerma to all 30 detectors used. A complete calibration curve was obtained for each quality by exposing five sets of six detectors each to 1, 3, 5, 7 and 10 mGy air kerma. This procedure was done for each quality for decreasing the energy dependence of LiF:Mg,Cu,P TL detectors. Calibration curves were plotted in terms of air kerma versus TL charge reading with a least-square fitting to get a linear equation. In this procedure the main sources of uncertainty were the repeatability, reproducibility and energy dependence of the TL detectors, the reader stability and the variation of the linear equation parameters.

A 30 cm × 30 cm × 15 cm PMMA phantom was used to simulate a human trunk where air kerma was measured at different depths. TL detectors were positioned in small cavities along a PMMA 10 mm × 70 mm × 25 mm that was introduced at the central axis of the PMMA phantom. Air kerma values at 5, 10, 15, 25 and 35 mm depths were determined for each IEC RQR quality with six TL detectors. The air kerma on the phantom (0 and 10 mm depth) was obtained by extrapolation procedure of the adopted curve fitting. Variations of the curve equation parameters were considered as an additional source of uncertainty.

3. Results

Fig. 1 a shows the calibration curve for the IEC RQR5 quality. Fig. 1b shows the variation of the air kerma values at different depths of the PMMA phantom for the same quality.

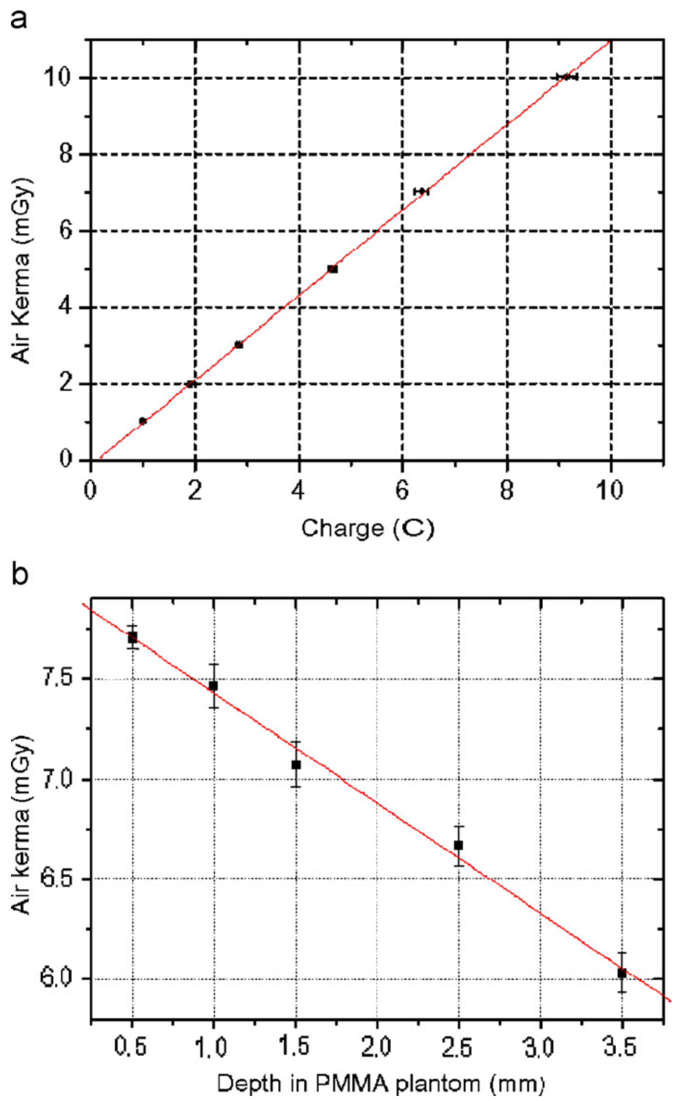

Fig. 1. (a) Calibration curve for the IEC RQR5 quality (b) Air kerma at different depths in the PMMA phantom for the IECRQR5 quality.

For all IEC analyzed qualities, the correlation between air kerma and TL charge readings showed to be linear as it was shown at Fig. 1a. As it was expected, the air kerma values are reduced as depths increase. Two effects are to be considered: the attenuation caused by the phantom material thickness and the inverse square law.

The main sources of uncertainties in backscatter factor for the IEC RQR5 are shown at Table 1 .

Table 1 shows that the relevant sources of uncertainties that contribute the most for the combined standard uncertainty of the backscattering factor were the energy dependence of the ionization chamber and of the TL detectors, the use of the air kerma versus TL charge reading and air kerma versus depth curves and the variation of the TL detector readings.

The combined standard uncertainties for basckscattering factor were approximately 6%, in deepness were approximately 5% and the ratio of mass energy absorption coefficient of the PMMA tissue to that for the air about 7%. From Eq. (1) and using error propagation the combined standard uncertainties on the conversion coefficients were approximately 12%.

Table 1
The main sources of uncertainties in backscatter factor for the IEC RQR5

Uncertainty source	Source value (%)	Probability distribution	Divisor	Uncertainty type	Relative uncertainty (%)
Energy dependence (IC)	5.0	Rectangular	Square 3	B	2.9
Temperature variation (IC)	1.0	Rectangular	Square 3	B	0.6
Pressure variation (IC)	1.5	Rectangular	Square 3	B	0.9
Reading variation (IC)	0.3	Normal	Square 3	A	0.2
Energy dependence (TLD)	2.0	Rectangular	Square 3	B	1.2
Reproducibility (TLD)	1.2	Rectangular	Square 10	A	0.4
Reader stability (TLD)	5.5	Rectangular	Square 256	A	0.3
Fading (TLD)	0.0	Rectangular	Square 3	B	0.0
Reader variation (TLD)($K \times C$)	0.97	Rectangular	Square 6	A	0.4
Calibration curve	3.3	Rectangular	Square 3	B	1.9
Air kerma versus depth curve	1.6	Rectangular	Square 3	B	0.9
Air kerma variation (TLD)($K \times D$)	2.1	Rectangular	Square 6	A	0.9
Combined standart uncertainty-u_c		Normal	U_c(%)=	4.1	

Table 2
Coefficients factors for each IEC RQR and three RQA qualities

Quality	Mean energy (keV)	BSF	$T^s(10)$	$H\text{p}(10)/K_{\text{air}}$ (Sv/Gy)
RQR2	27.03 ± 0.04	1.20 ± 0.08	0.86 ± 0.06	0.64 ± 0.07
RQR3	30.78 ± 0.06	1.36 ± 0.08	0.89 ± 0.05	0.75 ± 0.07
RQR4	34.44 ± 0.03	1.41 ± 0.09	0.91 ± 0.06	0.79 ± 0.07
RQR5	38.2 ± 0.4	1.53 ± 0.09	0.92 ± 0.05	0.88 ± 0.09
RQR6	41.64 ± 0.08	1.53 ± 0.09	0.94 ± 0.05	0.91 ± 0.08
RQR7	44.6 ± 0.1	1.54 ± 0.09	0.95 ± 0.05	0.95 ± 0.09
RQR8	48.64 ± 0.08	1.6 ± 0.1	0.96 ± 0.06	1.06 ± 0.09
RQR9	56.2 ± 0.1	1.7 ± 0.1	0.97 ± 0.06	1.24 ± 0.1
RQR10	66.56 ± 0.08	1.7 ± 0.1	1.00 ± 0.07	1.55 ± 0.2
RQA3	40.2 ± 0.3	1.58 ± 0.09	0.95 ± 0.05	0.95 ± 0.09
RQA5	52.5 ± 0.4	1.9 ± 0.1	0.99 ± 0.07	1.4 ± 0.2
RQA7	63.4 ± 0.4	2.1 ± 0.2	1.0 ± 0.1	1.9 ± 0.3

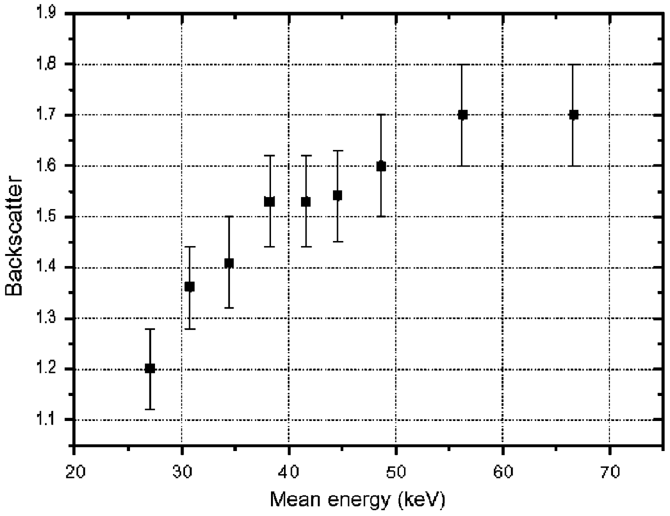

Fig. 2. Variation of the basckscattering factors with the mean energy of each IEC RQR quality.

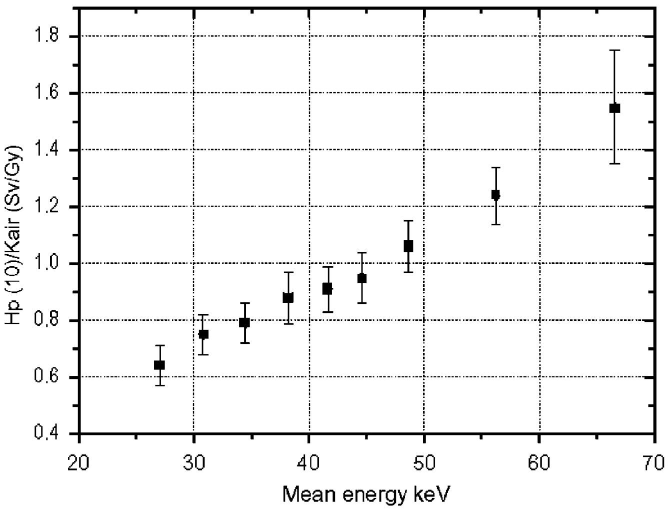

Fig. 3. Variation of the conversion coefficient with the mean energy of each IEC RQR quality.

The conversion coefficients for all IEC RQR and some RQA qualities are shown in Table 2. Each quality is represented by its code; the mean energy was measured during another work (Rosado et al., 2007); $T^s(10) e H_p(10)/K_{\text{air}}$ represents the dose factor and the conversion coefficient between personal dose equivalent and free in air kerma, respectively, both at 10 mm.

In Figs. 2 and 3 are plotted the dependence of basckscattering factor and the conversion coefficient, respectively, as function of the mean energy.

Results showed that the backscattering factors varied from 1.2 to 1.7 and the conversion coefficients varied from 0.64 to 1.55 for IEC RQR qualities that emphasizes the importance of a proper determination of them.

4. Conclusion

The knowledge of the conversion coefficient values is needed for the determination of the personal dose equivalent in occupationally exposed workers. The conversion coefficient and their associated uncertainties were determined for all IEC RQR and three RQA qualities. Results showed that conversion coefficient values varied significantly among the IEC RQR qualities.

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