Correction factors for free–air ionization chambers for X–rays transmitted through a diaphragm edge and scattered from the surface of the diaphragm aperture

Tadahiro Kurosawa, Nobuhisa Takata
Ionizing Radiation Section, NMIJ/AIST, Tsukuba, 305-8568, Japan

Abstract: Correction factors for the contribution of X-rays transmitted through the diaphragm of a free-air ionization chamber and those scattered from the surface of the diagram aperture are obtained by Monte Carlo simulation for two free-air ionization chambers for various diaphragm aperture sizes, X-ray energies, and source to chamber distances. The dependences of these contributions on conditions are specified.

1. Introduction

Free-air ionization chambers are widely used by standards laboratories as primary standards for the absolute measurement of air kerma in X-ray fields. The area of the diaphragm aperture hole of free-air ionization chambers is an important factor for absolute measurements because it defines the size of the X-ray beam incident into the free-air chamber. Some X-rays, however, enter the free-air chamber passing through the edge of the aperture and those scattered from the surface of the aperture also enter the free-air chamber. Consequently it is necessary to correct for X-rays transmitted through the diaphragm edge (correction factor K_{tr}) and for those scattered from the surface of the aperture (correction factor K_{sd}). Figure 1 shows a schematic view of transmitted X-rays, scattered X-rays, and normal X-rays that enter into the free-air chamber through the diaphragm aperture without interactions.

K_{tr} can be evaluated by Monte Carlo calculations [1] or estimated by using theoretical equations [2]. In the present work, we evaluate these correction factors for various conditions of National Metrology Institute of Japan (NMIJ) free-air ionization chambers for low- and medium-energy X-rays by Monte Carlo calculation.

2. Calculations

K_{tr} and K_{sd} are calculated for mono-energetic photons by using the program MCNP4B [3]. At NMIJ, diaphragms with two different sized apertures are used for medium-energy X-rays and one is used for low-energy X-rays. The diaphragms for medium-energy X-rays have apertures of diameter 10 mm and 25 mm and are 20 mm thick. The diaphragm for low-energy X-rays has an aperture of diameter 6 mm and is 12 mm thick. All the diaphragm edges extend 3 mm from the inside surface of the ionization chamber because the apertures are angled at 45°, as shown in Figure 1. The diaphragm material is tungsten alloy with 5% Ni and 2% Cu and its density is 14.5 g/cm^3.

K_{tr} and K_{sd} are given by

$$K_{\mathrm{tr}} = \frac{\sum D_{\mathrm{p}}}{\sum D_{\mathrm{p}} + D_{\mathrm{tr}}} \tag{1}$$

$$K_{\mathrm{sd}} = \frac{\sum D_{\mathrm{p}} + D_{\mathrm{tr}}}{\sum D_{\mathrm{p}} + D_{\mathrm{tr}} + D_{\mathrm{sd}}} \tag{2}$$

where D_{p} is the energy transferred to the air in the charge collecting volume of the free-air chamber by primary photons that enter through the diaphragm aperture, D_{tr} is the energy transferred by primary photons transmitted through the diaphragm edge, and D_{sd} is the energy transferred by secondary photons scattered from the surface of the diaphragm aperture. We assumed that the X-rays are emitted from a point source. Calculations were made for distances between the X-ray source and the chamber of 1.2, 1.5, 2, 3, and 5 m for medium-energy X-rays and of 1 m for low-energy X-rays. Calculations were made for X-ray energies in the range from 10 keV to 250 keV with 20-keV steps for medium-energy X-rays and in the range from 2 keV to 50 keV with 2-keV steps for low-energy X-rays.

3. Results

Figure 2 shows K_{tr} for medium-energy X-rays for diaphragm apertures with two different diameters. The correction for the effect of transmitted X-rays is slightly larger for the smaller aperture. This is due to the fact that the ratio of the length of the peripheral to the area of the aperture hole is larger for the smaller diameter. The correction increases with an increase of the incident X-ray energy. It also increases with a decrease in the source to chamber distance. This is due to the path length of X-rays in the diaphragm near the edge being shorter when the source chamber distance is smaller. K_{tr} for low-energy X-rays was larger than 0.9999 and the result of the calculations is not shown in the present paper.

The calculation results for K_{sd} for medium-energy X-rays are shown in figure 3 and those for low-energy X-rays in figure 4. In figure 3, K_{sd} shows valleys centered around 70 keV. This is due to tungsten K-edge absorption. The contribution of tungsten characteristic X-rays from the diaphragm is not as significant. The shape of the variation in K_{sd} with photon energy is slightly different from the result obtained using theoretical equations [2]. The correction value increases with an increase of the photon energy and is 0.5 % at 250 keV for the medium-energy chamber and 0.1 % at 50 keV for the low-energy chamber. In figure 3, the correction value for scattered X-rays at the surface of the diaphragm aperture increases slightly for smaller source to chamber distances. This is due to the fact that the attenuation length of incident X-rays in the diaphragm decreases with an increase in the X-ray incident angle, i.e. with a decrease of the source to chamber distance.

Tables 1, 2, and 3 show the values of the correction factors K_{tr} and K_{sd} for NMIJ ionization chambers for BIPM reference X-ray quantities. These values were obtained from the values shown in figures 2, 3, and 4, weighted by energy spectra obtained by a Monte Carlo program for these quantities.

4. Conclusions

Correction factors were obtained by Monte Carlo methods for contributions of transmitted X-rays through a free-air ionization chamber diaphragm aperture edge and for X-rays scattered from the surface of the diaphragm aperture for medium- and low-energy X-rays. The correction for scattered X-rays is 0.18 % for a 10-mm diameter aperture for BIPM reference quantities for 250-kV X-rays. These correction factors have been applied at NMIJ for calibrations for air kerma since January 2005.

Reference

[1] T. W. M. Grimbergen, E. van Dijk, and W. de Vries, “Correction factors for the NMi free-air ionization chamber for medium-energy X-rays calculated with the Monte Carlo method”, Phys. Med. Biol., 43 3207-3224 (1998)

[2] A. C. McEwan, “Correction for scattered photons in free-air ionization chambers”, Phys. Med. Biol., 27, 375-386 (1982)

[3] J. F. Briesmeister, “ MCNP – A General Monte Carlo N-Particle Transport Code”, LA-12625-M (1997)

Table 1. K_{tr} for the BIPM reference quantities for medium-energy X-rays.

Diaphragm	K_{tr}			
	100 kV	135 kV	180 kV	250 kV
10 mm	0.9999	0.9998	0.9997	0.9993
25 mm	0.9999	0.9998	0.9997	0.9994

Table 2. K_{sd} for the BIPM reference quantities for medium-energy X-rays.

Diaphragm	K_{sd}			
	100 kV	135 kV	180 kV	250 kV
10 mm	0.9993	0.9989	0.9987	0.9982
25 mm	0.9994	0.9989	0.9987	0.9985

Table 3. K_{sd} for the BIPM reference quantities for low-energy X-rays.

Diaphragm	K_{sd}				
	10 kV	30 kV	25 kV	50 kV (b)	50 kV (a)
6 mm	1	0.9998	0.9999	0.9996	0.9993

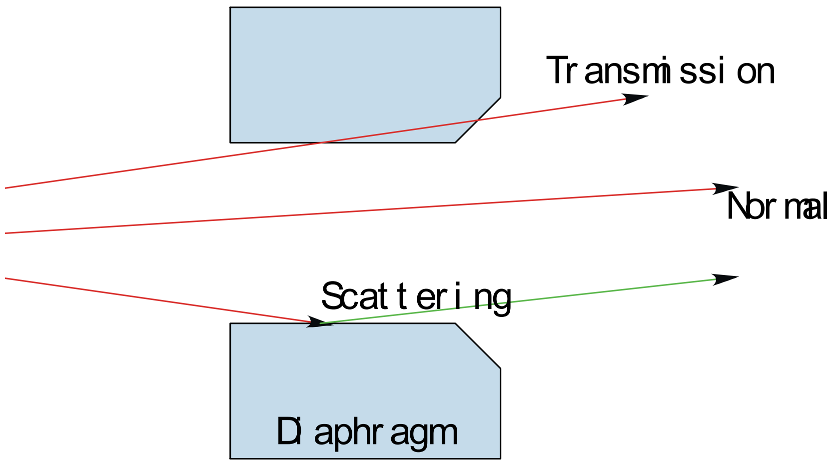


Figure 1. Schematic view of X-rays entering into a free-air ionization chamber through the diaphragm.

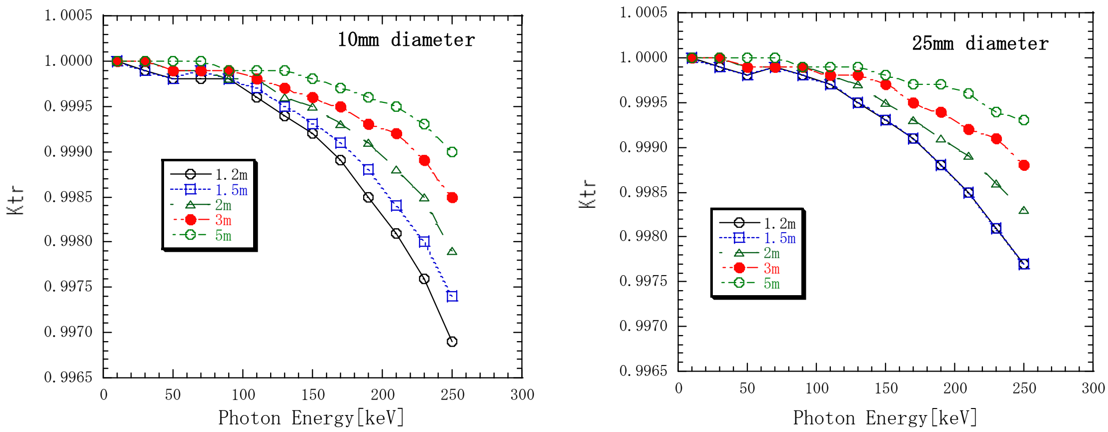
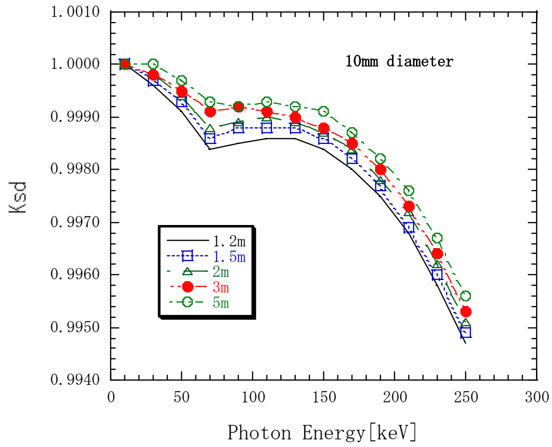


Figure 2. Correction factor K_{tr} for X-rays transmitted through the diaphragm edge for medium-energy free-air chamber. Left: 10-mm diameter aperture, right: 25-mm diameter aperture.



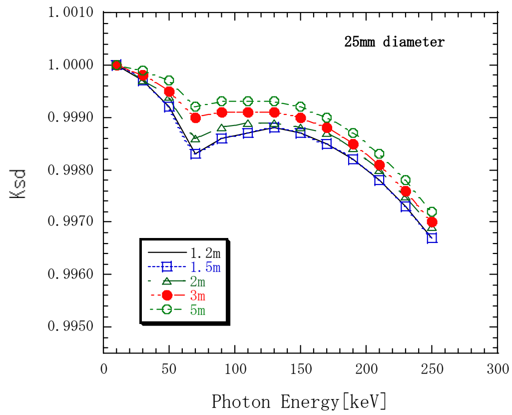


Figure 3. Correction factor K_{sd} for X-rays scattered at the surface of the diaphragm aperture for medium-energy free-air chamber. Left: 10-mm diameter aperture, right: 25-mm diameter aperture.

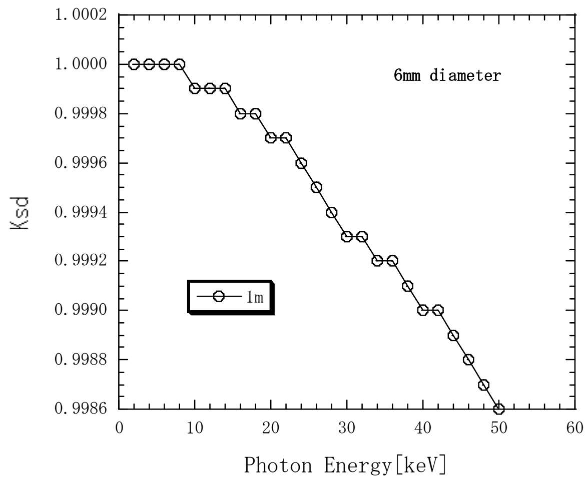


Figure 4. Correction factor K_{sd} for X-rays scattered at the surface of the diaphragm aperture for low-energy free-air chamber.