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MONTE CARLO SIMULATION FOR CORRECTION OF IONIZATION CHAMBER WALL

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Abstract - In precise measurement of air kerma with cavity ionization chambers, the effect of wall attenuation and scatter are corrected by Kwall and that of nonuniformity by Knu. Using the EGS4 code, we calculated these two correction factors. Correction factors calculated for two different-sized cylindrical ionization chamber differ by up to 0.7% from those obtained by measurements.

INTRODUCTION

Wall attenuation and scatter correction factors for ion chambers are used by standards laboratories to establish primary standards for exposure or air kerma in ^{60}Co and ^{137}Cs gamma ray fields. These correction factors are for the photon beam attenuation in the ionization chamber wall and for scattered photons contribution to the ionization chamber response. Two main approaches are used to determine these correction factors. In the first approach, correction factors are determined by measuring the variation in ionization chamber response as a function of wall thickness in the full build-up region, extrapolating to infer the response at zero wall thickness and then applying a theoretical correction factor to account for the effects of electron transport. For cylindrical ionization chambers, the procedure for calculating the corrections for the center of electron production is even less clear. The second approach uses Monte Carlo calculations to simulate an ionization chamber's response and to extract correction factors. Although the ion chamber response to photons is extremely sensitive to details of the Monte Carlo simulation, calculated correction factors are much less sensitive. There is agreement at the 0.2% level between three published reports covering a wide variety of commercial chambers [1-3]. In addition to problems related to wall corrections, debate has arisen over correction for nonuniformity or the point of measurement correction. Most standards laboratories use K_{nu}=1.000 but a few major institutes use corrections that differ significantly from unity. In a major theoretical paper, Bielajew extended the work of Kondo and Randolph [4] to include anisotropic electron effects within an analytic theory [5,6]. By using Monte Carlo techniques, Bielajew and Rogers [7] confirmed predictions of this theory for the NRC and BIPM chambers by quite literally running the calculation for weeks. We applied the EGS4 code [8] to calculate these two correction factors. To estimate the accuracy of calculated values, we compared them with experimental data on chamber response versus wall thickness.

EXPERIMENT

The primary air kerma standard at AIST for ^{60}Co and ^{137}Cs gamma rays is based on two different size cylindrical graphite ionization chamber. One has an outer electrode 50mm long and 40mm in diameter, and the other has an outer electrode with 19.3mm long and 20mm in diameter. The graphite used had a density of 1.85g/cm^3. A chamber was placed so that the center of it becomes at the reference point of the gamma ray field and at 45 degrees from the direction of the gamma ray beam.

Calculation accuracy was estimated by comparing calculated and experimental results for the change of response with wall thickness. Ionization current was measured for 3, 4, 5 and 6mm thick-wall for ^{60}Co gamma rays and 2, 3, 4, 5 and 6mm for ^{137}Cs gamma rays. (Figure 1) From these data, we estimated calculation accuracy to be within 0.1%.

Measurement was made in ^{60}Co and ^{137}Cs standard fields at BIPM. The ionization volume center of a chamber was placed at the reference point of the field, 1m away from the gamma ray source.

CALCULATION OF CORRECTION FACTOR

The Monte Carlo calculations was made using the EGS4 code and PRESTA for electron transport algorithm. The value of K_{wall} is determined by scoring

$$K_{wall} = \frac{\sum_i r_i^0 e^{+\mu d_i}}{\sum_i \left(r_i^0 + r_i^1\right)} \qquad (1)$$

where r^0 is the energy deposited in cavity air by electrons generated by primary photon interaction, r^1 the energy deposited by electrons generated by second and higher-order scattered photons, μ the attenuation coefficient for primary photons, and d the pass length of the photons in the chamber.

The value of K_{nu} was obtained from the equation:

$$K_{nu} = \frac{D_{parallel}}{D_{point}} \qquad (2)$$

where D is the energy deposited by both of primary and scattered photons per unit fluence of incident photons at the center of the chamber for a parallel or point source beam.

RESULTS

Table 1 shows the values of K_{wall} for ^{60}Co and ^{137}Cs gamma rays obtained by the Monte Carlo calculation and by experiment. The ionization chamber wall thickness for regular measurement is set to 3 mm for ^{60}Co gamma rays and 2 mm for ^{137}Cs. Correction factors listed in the table correspond to the chamber thicknesses. The results of calculations are up to 0.7% higher than those of the experiment. Experimental K_{wall} values were obtained from attenuation curves that include both primary and scattered gamma rays and it is assumed that this curve underestimation of the actual attenuation of gamma ray is erroneous to obtain the correction value for the center of electron production.

Table 1. Value of Kwall for 60Co and 137Cs gamma rays obtained by Monte Carlo method and by experiment.

Source	Chamber diameter (mm)	K_{wall}-MC	$K_{wall\text{-}exp}$	Ratio (MC/exp)
^{60}Co	20	1.0188	1.0119	1.0068
	40	1.0198	1.0131	1.0066
^{137}Cs	20	1.0179	1.0142	1.0036
	40	1.0193	1.0147	1.0045

Table 2 shows the K_{nu} value obtained by Monte Carlo calculation. Correction factors have different tendencies depending on the chamber size. It is assumed that this difference is due to the ratio of the radius to the length of each chamber.

Table 2. Correction factors for nonuniformity obtained from equation (2)

Source	Chamber diameter (mm)	$K_{an\text{-}MC}$	$K_{an\text{-}exp}$
^{60}Co	20	0.9986	0.9990
	40	1.0007	1.0000
^{137}Cs	20	0.9998	0.9989
	40	1.0002	0.9984

Table 3 shows air kerma rates obtained using calculated and measured values for correction

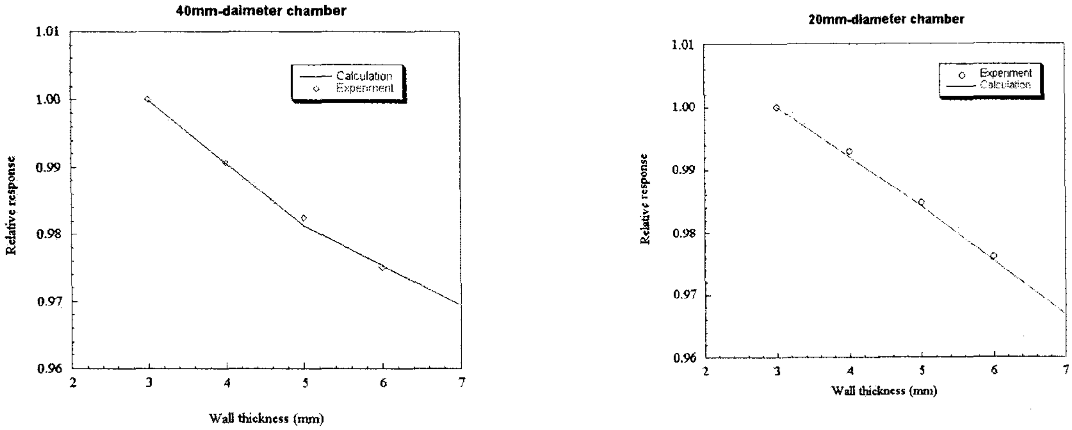

Fig. 1. Comparison of calculated and measured responses of two different-sized chambers for ^{60}Co gamma rays.

factors. The air kerma rates obtained by calculation for 20mm and 40mm diameter chambers agree well within uncertainty and are about 0.7% larger than those obtained using measured correction factors.

Table 3. Air kerma rates obtained from calculated and measured correction factors

Source	Correction factor	Air-kerma rate (Gy/s) 20 mm-diam. chamber	Air-kerma rate (Gy/s) 40 mm-diam. chamber	Ratio (20mm/40mm)
^{60}Co	MC	2.7244E-3	2.7279E-3	0.9987
	Exp	2.7071E-3	2.7084E-3	0.9995
^{137}Cs	MC	1.9355E-5	1.9290E-4	1.0034
	Exp	1.9267E-5	1.9168E-5	1.0052

CONCLUSIONS

We calculated K_{wall} and K_{nu} for our ionization chambers using the EGS4 Monte Carlo calculation code. If calculated correction factors are applied, the air kerma rate increases about 0.7% compared to that for experimentally obtained correction factors. We plan to use calculated correction factors for primary standards in air kerma for ^{60}Co and ^{137}Cs gamma rays in the near future.

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