Angular Dependences of Responses of Cylindrical Cavity Ionization Chambers

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1. Introduction

Cylindrical graphite cavity ionization chambers are used for measuring air kerma rates of gamma rays at primary standard laboratories. At NMIJ, cylindrical ionization chambers are set at 45 $^{\circ}$ to the gamma ray beam because of the angular dependence of the responses of the chambers [1]. We incorporated wall correction factors obtained by the Monte Carlo simulation from two years earlier and found that there was not a large difference in values between the correction factors obtained through the simulation and the factors obtained through measurements using linear extrapolation methods. However, the cylindrical ionization chambers used at most other laboratories are usually fixed at 90° when determining the absolute measurement of air kerma. We measured angular dependences of signal currents from ionization chambers and compared the correction factors obtained by the Monte Carlo simulation with those obtained by measurements.

2. Experiments

The Ionization chamber setup is shown in Figure 1. The primary air kerma standards at NMIJ for ^{60}Co and ^{137}Cs gamma rays were obtained using two different-size graphite cylindrical ionization chambers. The smaller chamber has an ionization volume of 40 mm in diameter and 50 mm long. The larger chamber has an ionization volume 20 mm in diameter and 19.3 mm long. The density of the graphite is 1.85 g/cm^3. The chambers were placed so that the center of the ionization volume becomes at the reference point of the gamma ray fields and were rotated around the center and fixed at
0 $^{\circ}$, 22.5 $^{\circ}$, 45 $^{\circ}$, 67.5 $^{\circ}$ and 90 $^{\circ}$ from the gamma ray beam direction. Signal currents from the ionization chambers were measured at these angles for cavity wall thicknesses of 3, 4, 5 and 6 mm for ^{60}Co gamma rays and 2, 3, 4, 5 and 6 mm for ^{137}Cs gamma rays. The different wall thicknesses were achieved by using build up caps of different thicknesses.

3. Simulation

The Monte Carlo calculation was made using a EGS4 code and the PRESTA for electron transport algorithms. The value of the wall correction factor, 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 on the air in the cavity by electrons generated by primary photon interactions, r^1 the energy deposited by electrons generated by second and higher-order scattered photons, μ the linear attenuation coefficient of graphite for the primary photons, and d the pass length of the photon to the first interaction point in the chamber wall [2].

4. Results and Comparisons

Figure 2 shows the attenuation curve of the signal currents from the larger cavity chamber in ^{60}Co and ^{137}Cs gamma ray fields for several irradiation angles. All data were normalized by the value for 3 mm wall thickness in the ^{60}Co gamma ray field and 2 mm wall thickness in the ^{137}Cs gamma ray field at an incident angle of 45 °. The extrapolated values to zero wall thickness for each angle show currents corrected for attenuation of the gamma rays in the chamber wall and for the effects of the scattered gamma rays on the signal currents but not for the depth of the center of electron production. The change in the signal currents with the wall thickness is small at 0 ° and at 90 ° compared with other angles.

In Figure 3, (○) show the signal currents measured for 3 mm wall thickness (^{60}Co) and for 2 mm (^{137}Cs) at several angle settings. (□) show currents corrected for values obtained by experiments for attenuation and scattering of gamma rays. (◊) show currents corrected by the wall correction factors obtained by using the Monte Carlo calculation. These data are normalized using the currents measured at 45 °. The values obtained by experiments for correction correspond to the attenuation of gamma rays and the effects of scattered gamma rays but not for the depth of the center of electron production. However, the wall correction factor obtained by the Monte Carlo calculation corresponds to these three factors. It was noted that the currents corrected using the wall correction factor obtained by calculations become nearly the same for all angles. On the other hand, the values obtained using the experimental correction factors were smaller for 0 ° and 90 °. This difference is because the attenuation length in the end walls does not become zero when the chamber wall thickness is extrapolated to zero when the chamber is fixed at 90 °. The end walls are nearly parallel to the gamma ray beams and the path length in the walls does not become smaller than the diameter of the wall.

5. Conclusion

Attenuation correction factors for various angles were obtained by experiments for cylindrical cavity ionization chambers and wall correction factors for each angle were obtained using Monte Carlo simulations. Currents which were corrected for attenuation using extrapolation methods varied depending upon the angles of the chamber in the gamma ray fields. Currents corrected using the Monte Carlo simulation show almost a constant value for all angles. Thus the validity of the Monte Carlo simulation for the estimation of wall correction factors was supported. On the other hand, it is preferable to use cylindrical ionization chambers setting at an angle in the rage from 40 ° to 70 °, not only because the wall correction value is small but also because the response dependences of the chambers are small in the range of the angle.

References

[1] Akira Katoh and Iwao Yamachi, "Dependence on Gamma-Ray Incident Angle of Exposure Rate Absolutely Determined by the Use of Cylindrical Cavity Chambers", Bulletin of the Electrotechnical Laboratory Vol.47, 862-69 (1983).

[2] Tadahiro Kurosawa, Yasushi Koyama and Nobuhisa Takata, "Ionization Chamber Wall Correction Factors for Air Kerma Standards of Gamma Rays", Medical Stand. Dose. 6(2) 1-4 (2001).

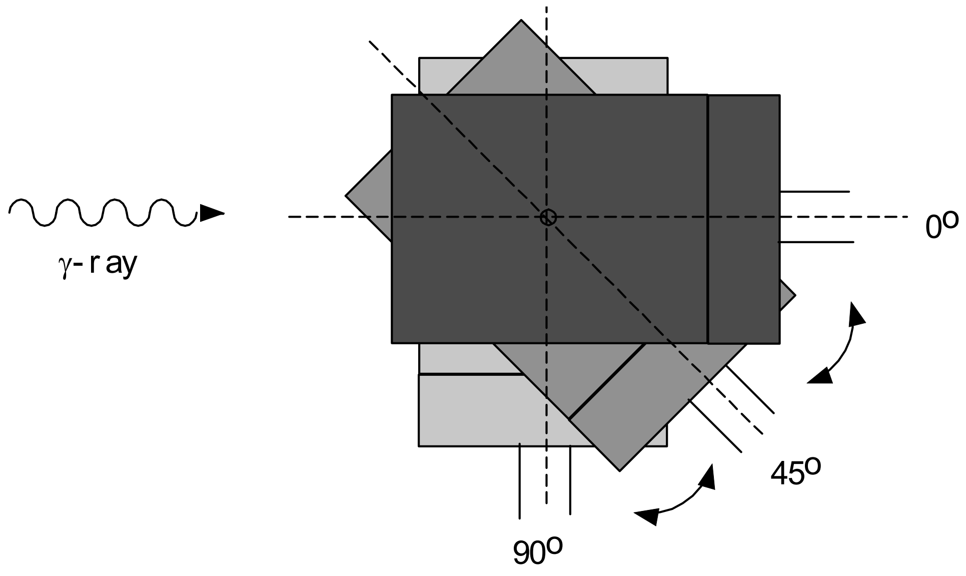

Figure 1. Setup of the cavity chamber in gamma ray fields. Incident angles of the gamma rays on the chamber are shown. The chamber is turned on a horizontal plane around the vertical axis around the center of the ionization volume of the chamber.

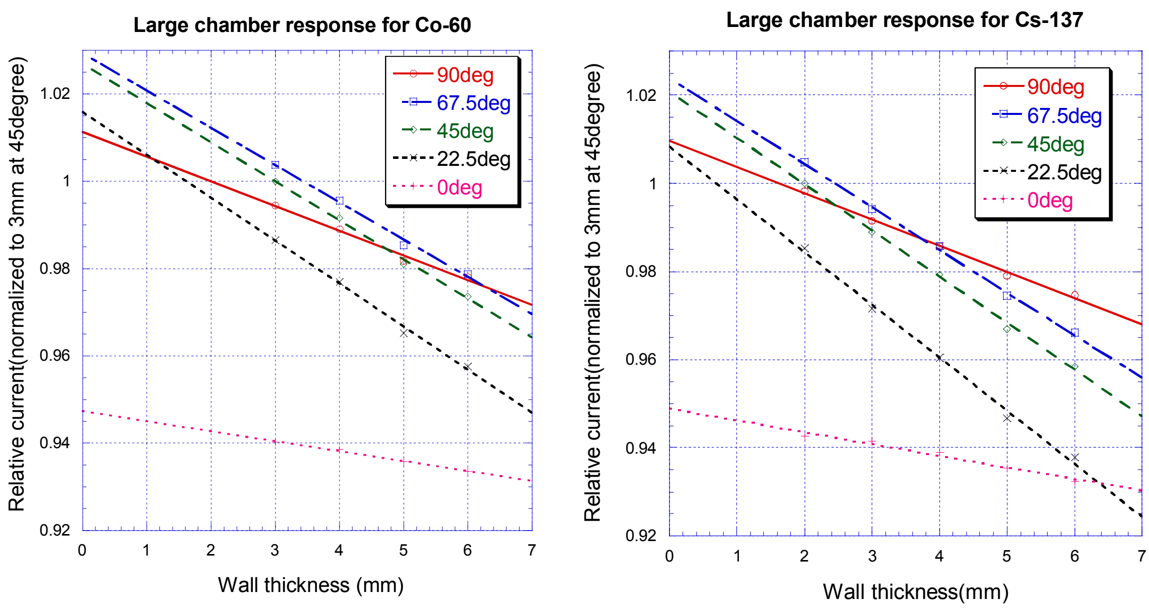

Figure 2. Relative signal currents from the ionization chamber plotted as a function of incident wall thickness for various angles of gamma rays.

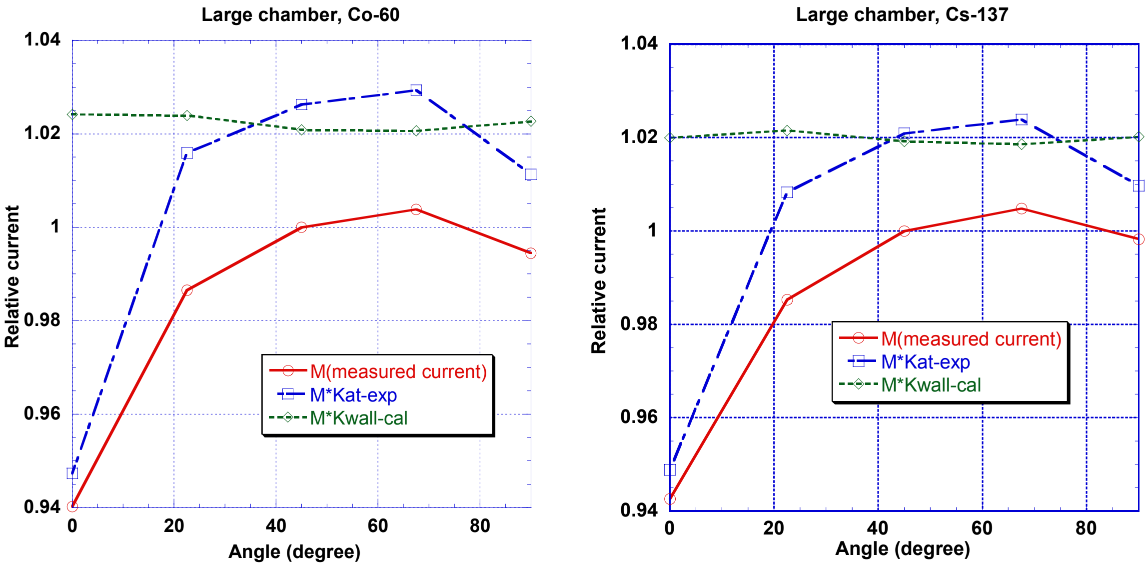

Figure 3. Changes in the measured currents. Those currents corrected for attenuation obtained by experimental methods and those currents corrected for wall effects obtained by calculation. All values are normalized using currents measured at 45 º.