Monte Carlo Calculation of Physical Constants of Spherical Ionization Chambers for Pulse Height Distribution of ^{60}Co Gamma-Rays

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Introduction

In the field of radiation dosimetry, various types of ionization chamber have been used as a primary standard of air kerma for ionizing photons. For photon energies between 10 and 300 keV, the primary standard instrument for the measurement of air kerma is traditionally a Free Air Chamber (FAC). For photon energies above 300 keV the FAC is not a practical instrument because the range of the recoiled electrons generated in air becomes large. For ^{60}Co we would require a Free Air Chamber the size of the irradiation room. Instead, thick-walled ionization chambers are used, based on the assumptions of Bragg-Gray cavity theory[1]. The definition of a thick-walled chamber is that for a particular incident photon energy all the secondary electrons that contribute to the ionization in the cavity are produced in the wall (i.e. there is charged particle equilibrium).

The purpose of the present paper is to investigate physical constants of the air kerma response for ^{60}Co gamma-rays using the MCNPX Monte Carlo system[2]. The spherical ionization chambers used in the study were 1 cm^3 and 10 cm^3 graphite wall chambers.

Two physical constants, mass energy-absorption coefficient ratios and stopping power ratios required for the determination of the absolute air kerma rate for ^{60}Co gamma-rays were estimated using spherical cavity chambers.

Calculation method

The fundamental equation for air kerma rate $\dot{K}_{air}$ for a graphite-walled chamber is given by

$$\dot{K}_{air} = \frac{I}{v\rho} \cdot \frac{\left(\frac{W}{e}\right)_{air}}{1-g} \cdot \left(\frac{\overline{\mu}_{en}}{\rho}\right)^{air}_{G} \cdot \left(\frac{\overline{S}}{\rho}\right)^{G}_{air} \cdot \prod_i K_i \qquad (1)$$

where the ratio of mass energy absorption coefficients for air to graphite (wall material).

$\left(\frac{\overline{\mu}_{en}}{\rho}\right)^{air}_{G}$ is defined as,

$$\left(\frac{\overline{\mu}_{en}}{\rho}\right)^{air}_{G} = \frac{\left(\frac{\overline{\mu}_{en}}{\rho}\right)_{air}}{\left(\frac{\overline{\mu}_{en}}{\rho}\right)_{G}} = \frac{\int_{E=0}^{E=max} \Psi_{ph}(E) \cdot \left(\frac{\overline{\mu}_{en}}{\rho}\right)_{air} dE}{\int_{E=0}^{E=max} \Psi_{ph}(E) \cdot \left(\frac{\overline{\mu}_{en}}{\rho}\right)_{G} dE} \qquad (2)$$

$\Psi_{ph}(E)$ is the energy fluence spectrum of incident photons that arrived at the outer surface of the sphere with kinetic energy E, and E_{max} is the maximum kinetic energy of the incident particle. $\Psi_{ph}(E)$ was calculated by the *F2 tally card (energy fluence averaged over a surface). Mass energy absorption coefficients of both air and graphite were taken from the data published by

Seltzer[3] for the incident photons.

The stopping power ratio of graphite to air was given by the following equation

$$\left(\frac{\bar{S}}{\rho}\right)_{\mathrm{air}}^{\mathrm{G}}=\frac{\left(\frac{\bar{S}}{\rho}\right)_{\mathrm{G}}}{\left(\frac{\bar{S}}{\rho}\right)_{\mathrm{air}}}=\frac{\int_{E=\triangle}^{E_{\max}}\Phi_{el}(E)\cdot\left(\frac{\bar{L}}{\rho}\right)_{\mathrm{G}}dE+\Phi_{el}(\triangle)\cdot\left(\frac{\overline{S^{\mathrm{un}}}}{\rho}\right)_{\mathrm{G}}\cdot\triangle}{\int_{E=\triangle}^{E_{\max}}\Phi_{el}(E)\cdot\left(\frac{\bar{L}}{\rho}\right)_{\mathrm{air}}dE+\Phi_{el}(\triangle)\cdot\left(\frac{\overline{S^{\mathrm{un}}}}{\rho}\right)_{\mathrm{air}}\cdot\triangle} \quad (3)$$

where $\left(\frac{\bar{L}}{\rho}\right)$ and $\left(\frac{\overline{S^{\mathrm{un}}}}{\rho}\right)$ are the restricted and unrestricted stopping powers for the medium, respectively. $\Phi_{el}(E)$ is the pulse height distribution of electrons that cross the inner surface of the sphere with kinetic energy E. Electron pulse height distribution was calculated by F2 tally card (fluence averaged over a surface). The cutoff energy $\triangle$ was chosen 22.5 keV and 34.4 keV for 1 cm^3 and 10 cm^3 chamber[5]. Because $\triangle$ usually depends on the size and geometry of the chamber cavity. Stopping power values for graphite and air were taken from the data for electrons in graphite and air in ICRU report37[4].

Table 1. Dimension of the KRISS and NIST spherical graphite ionization chambers.

Chamber	Volume (cm^3)	Outer Dia. (cm)	Inside Dia. (cm)	Wall thickness (cm)	Density (g/cm^3)	Mean chord length (cm)	Cut off energy (keV)
KRISS	1	2.071	1.271	0.4	1.8	0.848	22.5
	10	3.398	2.598	0.4	1.779	1.729	34.4
NIST	1	2.065	1.270	0.398	1.73	0.847	22.5
	10	3.428	2.677	0.376	1.72	1.785	34.4

Results

The physical constants were calculated using the MCNPX Monte Carlo simulation for two spherical type graphite-walled chambers from the energy pulse height distributions of ^{60}Co which was obtained by the KRISS[6]. The uncertainty of MCNPX calculation were 0.01 %. Table 2 shows a comparison between the calculated physical constants obtained in this study and those of other primary standard institutions NIST[5] and NRCC[7].

Table 2. Mass energy-absorption coefficient ratios air to graphite and stopping power ratios to air for 1 cm^3 and 10 cm^3 chambers in the ^{60}Co using MCNPX Monte Carlo calculation and values from NIST and NRCC.

Chamber air cavity volume cm^3	KRISS $\left(\frac{\mu_{en}}{\rho}\right)_{G}^{air}$	KRISS $\left(\frac{S}{\rho}\right)_{air}^{G}$	NIST $\left(\frac{\mu_{en}}{\rho}\right)_{G}^{air}$	NIST $\left(\frac{S}{\rho}\right)_{air}^{G}$	NRCC $\left(\frac{\mu_{en}}{\rho}\right)_{G}^{air}$	NRCC $\left(\frac{S}{\rho}\right)_{air}^{G}$
1	0.99920	1.00022	0.9990	1.0004	-	-
10	0.99921	0.99978	0.9990	0.9999	0.9987	1.0010

Conclusion

The mass energy-absorption coefficient ratios were 0.99920 for the 1 cm^3 chamber and 0.99921 for 10 cm^3 and the value differed by 0.02~0.05 % for ^{60}Co from those of NIST and NRCC. The stopping power ratios were 1.00022 for the 1 cm^3 chamber and 0.99978 for 10 cm^3 and the comparison with NIST[5] values showed differences of 0.018 %.

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