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Absorbed Dose Conversion Factors of Several Ionization Chambers to Determine Absorbed Dose by the Use of Acrylic Plastic Phantom for High Energy X-rays

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Introduction

When intercomparisons of ionization chambers are carried out between hospitals in Saitama prefectural region, opportunities of the calibration with acrylic plastic phantom are increasing recently. Listing the merit to use acrylic plastic as phantom, although its density is larger than that of water, the uniformity of density, the transparency and the strength of material are picked up in comparison with MixDP, and the position for calibration depth of ionization chamber can be set up easily and its precision will be increased in comparison with that of water phantom. When the absorbed dose is measured and determined by using phantom, a protocol of the standard dosimetry (1986) presented by the Japanese Association of Radiological Physicists (JARP) is used. We calculated absorbed dose conversion factors of 8 types of commercially available cylindrical ionization chambers by the use of acrylic plastic phantom for high energy X-rays of 4, 6, 10 and 15 MV and ^{60}Co γ rays. In order to compare the absorbed dose given according to absorbed dose conversion factors calculated, twin ionization chambers were installed in the acrylic plastic intercomparison phantom for each exposure and five types of chambers were used to measure for 4 and 10 MV X-rays.

Methods and Materials

8 types of ionization chambers used for calculation of absorbed dose conversion factors are PTW (Physikalish-Technische Werkstatten) 30001, PTW 23333, NE (Nuclear Enterprises) 2571, NE 2581, NE 2505/3A, NE 2505/3B, JARP C-110 and CA (Capintec) PR-06C. The characteristics of these ionization chambers and build-up caps for ^{60}Co γ rays are shown in Table 1.

1) Equations to Calculate Absorbed Dose Conversion Factor

The absorbed dose conversion factor ($(C_\lambda)_{acryl}$) in acrylic plastic phantom for high energy X-ray of the energy λ is shown as eq. (1).

$$(C_\lambda)_{acryl} = \frac{W_{air}}{e} \; A_c \; A_w \; \frac{1}{(f_{acryl})_\lambda} \; P_\lambda \qquad (1)$$

where

$$A_c = (\beta_{\Delta m}) \cdot (A_{\Delta m}) / P_c \qquad (2)$$

$$A_w = [\alpha (\overline{L}/\rho)_{air,cap} \cdot (\overline{\mu}_{en}/\rho)_{cap,air} + \gamma (\overline{L}/\rho)_{air,wall} \cdot \beta_{wall,cap} \cdot (\overline{\mu}_{en}/\rho)_{wall,air}]_C \qquad (3)$$

$$P_\lambda = [P_d \cdot P_f]_\lambda \qquad (4)$$

$$(f_{acryl})_\lambda = [\alpha(\overline{L}/\rho)_{air,acryl} + \gamma(\overline{L}/\rho)_{air,wall} \cdot \beta_{wall,acryl} \cdot (\mu_{en}/\rho)_{wall,acryl}]_\lambda \quad (5)$$

$$\alpha = [1 + \frac{\delta}{(1-\delta)} \frac{(\overline{L}/\rho)_{air,cap}}{(\overline{L}/\rho)_{air,wall}} (\overline{\mu_{en}/\rho})_{cap,wall}]_\lambda^{-1} \quad (6)$$

Ac and Aw that are the correction factors of the wall thickness and the wall material of ionization chamber for ^{60}Co γ rays, are shown as eqs. (2) and (3), respectively. P_λ, the perturbation correction factor is shown by eq. (4) and P_c is the value for ^{60}Co γ rays. P_d and P_f are the displacement and the electronic fluence factors, respectively. W_{air} is the average energy expanded to create an ion pair in air, and e is the electronic charge.

$(\beta_{\Delta m})$ and $(A_{\Delta m})$ shown in eq. (2) are the correction factors and are expressed the ratio of the absorbed dose to the collision kerma and the ratio of the absorption to the scattering for the thickness of chamber wall and build-up cap at the calibration by ^{60}Co γ rays, respectively.

α shown by eq. (6) is expressed the transmission rate of second electron for the thickness of chamber wall. γ is the rate of increase for second electron by chamber wall. δ shows the rate of ionization by second electron occurred from chamber wall. $(\overline{L}/\rho)_{a,b}$ is the mean restricted collision mass stopping power ratio of material a to material b. $(\mu_{en}/\rho)_{a,b}$ is the mean mass energy absorption coefficient ratio of material a to material b.

2) Estimation of Various Parameters Used for Calculation of the Absorbed Dose Conversion Factor

Before the calculation of absorbed dose conversion factor in acrylic plastic phantom of high energy X-rays, the value of (W_{air}/e) was used 33.73 J/C, and various parameters expressed in eqs. (2) to (6) including Ac and Aw for ^{60}Co γ rays were looked for by using data in the protocol of the standard dosimetry by the JARP.

3) Measurement of Absorbed Dose by the Use of Acrylic Plastic Phantom

To compare the absorbed dose measured by various ionization chambers in acrylic plastic phantom, five types cylindrical ionization chambers of JARP C-110, PTW 30001, PTW 23333, NE 2571 and NE 2581 and acrylic plastic intercomparison phantom (Perspex Intercomparison Phantom supplied by Nuclear Enterprises Co.) shown in Fig.1 were used. Twin ionization chambers are installed and irradiated at calibration depth in its intercomparison phantom with SCD (source chamber distance) 100 cm and a field size of 10 x 10 cm^2 for 4 and 10 MV X rays from a linac by Nippon Electric Co. (NELAC-1018DP). The absorded dose (D_{water}) in water was found by using eq. (7) for the reading value (M) of each chamber.

$$D_{water} = (C_\lambda)_{acryl}\ M\ N_c\ k_1\ P_{ion} \cdot (\overline{\mu_{en}/\rho})_{water,acryl} \cdot (SF)\ (ESC) \quad (7)$$

Here, Nc is the exposure calibration factor for ^{60}Co γ rays, k_1 is the temperature and pressure correction factor, P_{ion} is the ion-recombination correction factor, SF is the scaling factor, and ESC is the excess scatter correction factor.

Results and Considerations

1) Comparison of the Values of Absorbed Dose Conversion Factors Calculated

Calculated absorbed dose conversion factors of acrylic plastic phantom for 8 types of ionization chambers with high energy X-rays and ^{60}Co γ rays are shown in Table 2. When the photon energy is increased, the values of absorbed dose conversion factors become decreased gradually. The values for 15 MV X-rays of NE 2581 and NE 2505/3B chambers are the first and second smallest of 34.52 and 34.66, respectively. The values for 4 MV group. The values for ^{60}Co γ rays are larger than those of 4 MV X-rays.

The values shown in parenthesis of Table 2 are the ratios of absorbed dose conversion factors between various chambers and JARP C-110. The difference in absorbed dose conversion factors of 7 types of chambers for JARP C-110 chamber is from -1.1 % to +0.4 %.

The first and second largest differences are the values for NE 2581 and NE 2505/3B chambers and their differences are from -1.1 % to -0.5 % and from -0.7 % to +0.1 %, respectively.

The values of absorbed dose conversion factors $(C_\lambda)_{water}$ in water phantom reported by Tomaru (1988) are shown in Table 3 and compared with ours. The values in parenthesis of Table 3 are the ratios of acrylic plastic phantom to water phantom. The values for acrylic plastic phantom are larger than about 3 % (from 2.6 % to 3.3 %) for water phantom.

2) Comparison of Absorbed Dose Measured by Various Ionization Chambers at Calibration Depth in Acrylic Plastic Phantom

Five types of PTW 30001, JARP C-110, PTW 23333, NE 2571 and NE 2581 chambers are used to measure the absorbed dose for 4 and 10 MV X-rays by inserting into acrylic plastic intercomparison phantom. The mean values of absorbed dose per 100 MU (monitor unit) for 5 exposures measured by installing twin ionization chambers at calibration depth in acrylic plastic phantom for each exposure are shown in Table 4. The values of PTW 30001 chamber for PTW 23333 chamber were estimated from the values of NE 2571 chamber.

The ratios of the mean absorbed dose between five chambers (including the value of PTW 30001 chamber) and PTW 30001 chamber are 1.0008 and 1.0006 for 4 and 10 MV X-rays respectively and the value of PTW chamber is equivalent to the mean value of five chambers.

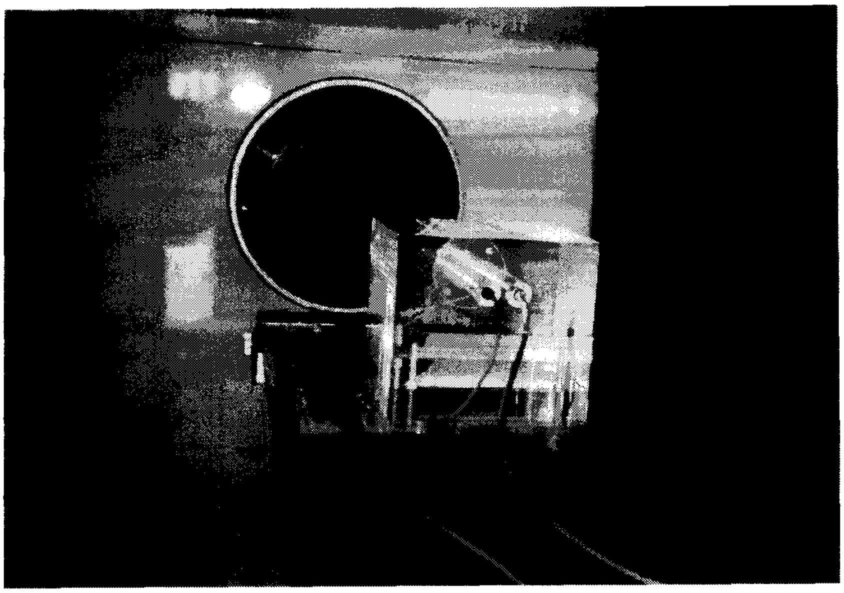
The difference of four chambers for PTW 30001 chamber is from -0.44 % to 0.71 % . The first and second largest differences are those of JARP C-110 and NE 2571 chambers, respectively. The value of the farmer chamber for 4 MV X-rays is larger than 0.5 %.

The mean values of absorbed dose for five chambers are 0.7640 ± 2.26 x 10^{-3} Gy and 0.8289 ± 2.90 x 10^{-3} Gy for 4 and 10 MV X-rays, respectively. Those differences are ±0.30 % and ±0.35 %, and absorbed dose measured by five chambers shows agreement within ±0.5 %.

Mentioned above, a good result was obtained that our calculated absorbed dose conversion factors of various types of chambers could be used to measure for high energy X rays.

Table 1 Characteristics of ionization chambers and build-up caps for ^{60}Co γ rays

Type of chamber	PTW 30001	PTW 23333	JARP C-110	CAPINTEC PR-06C
Cavity dimension	6.1mm φ × 23.0mm	6.0mm φ × 23.0mm	6.0mm φ × 22.0mm	6.4mm φ × 23.0mm
Wall material	Acrylic (PMMA)	Acrylic (PMMA)	Acrylic (PMMA)	C-552
Wall thickness	0.45mm(53mg/cm^2)	0.5mm(59mg/cm^2)	0.5mm(59mg/cm^2)	50mg/cm^2
Material of build-up cap	Acrylic (PMMA)	Acrylic (PMMA)	Acrylic (PMMA)	Polystyrene
Thickness of build-up cap	4.55mm(537mg/cm^2)	3.92mm(462mg/cm^2)	4.0mm(472mg/cm^2)	539mg/cm^2
Type of chamber	NE2571	NE2581	NE2505/3A	NE2505/3B
Cavity dimension	6.3mm φ × 24.1mm	6.3mm φ × 24.1mm	6.3mm φ × 22.5mm	6.3mm φ × 22.5mm
Wall material	Graphite	A-150	Graphite	Nylon
Wall thickness	0.36mm(65mg/cm^2)	40mg/cm^2	65mg/cm^2	49mg/cm^2
Material of build-up cap	Delrin	Lucentine	Acrylic (PMMA)	Acrylic (PMMA)
Thickness of build-up cap	550mg/cm^2	584mg/cm^2	551mg/cm^2	551mg/cm^2



Figue 1 The acrylic plastic international phantom to use measurement of absorbed dose

Table 2 Absorbed dose conversion factors, (C λ)acryl in acrylic plastic phantom

	PTW30001	PTW23333	JARPC-110	CA PR-06C	NE2571	NE2581	NE2505/3A	NE2505/3B
$^{60}Co_{(80cm)}$	35.63(0.999)	35.70(1.001)	35.66(1.00)	35.37(0.992)	35.70(1.001)	35.50(0.995)	35.70(1.001)	35.71(1.001)
$^{60}Co_{(1m)}$	35.70(0.999)	35.77(1.001)	35.74(1.00)	35.44(0.992)	35.77(1.001)	35.57(0.995)	35.77(1.001)	35.78(1.001)
4MV	35.57(0.999)	35.64(1.001)	35.60(1.00)	35.44(0.996)	35.67(1.002)	35.29(0.991)	35.67(1.002)	35.47(0.996)
6MV	35.48(0.999)	35.55(1.001)	35.51(1.00)	35.43(0.998)	35.62(1.003)	35.12(0.989)	35.62(1.003)	35.34(0.995)
10MV	35.21(0.999)	35.28(1.001)	35.24(1.00)	35.16(0.998)	35.35(1.003)	34.86(0.989)	35.35(1.003)	35.00(0.993)
15MV	34.87(0.999)	34.94(1.001)	34.90(1.00)	34.83(0.998)	35.04(1.004)	34.52(0.989)	35.00(1.003)	34.66(0.993)

The number in the parenthesis indicates to the ratio of each chamber to JARP chamber (C-110).

Table 3 Absorbed dose conversion factors for water phantom calculated by Tomaru (1988)

	PTW30001	PTW23333	JARP C-110	CA PR-06C	NE2571	NE2581	NE2505/3A	NE2505/3B
$^{60}Co_{(80cm)}$	36.66(1.029)	36.74(1.029)	36.69(1.029)	36.37(1.028)	36.64(1.026)	36.47(1.027)	36.64(1.026)	36.70(1.028)
$^{60}Co_{(1m)}$	36.74(1.029)	36.81(1.029)	36.77(1.029)	36.43(1.028)	36.72(1.027)	36.54(1.027)	36.72(1.027)	36.77(1.028)
4MV	36.62(1.029)	36.67(1.029)	36.65(1.029)	36.48(1.029)	36.67(1.028)	36.29(1.028)	36.67(1.028)	36.48(1.028)
6MV	36.58(1.031)	36.67(1.032)	36.64(1.032)	36.54(1.031)	36.74(1.031)	36.28(1.033)	36.72(1.031)	36.45(1.031)
10MV	36.28(1.030)	36.39(1.031)	36.35(1.031)	36.26(1.031)	36.42(1.030)	35.91(1.030)	36.42(1.030)	36.08(1.031)
15MV	35.94(1.031)	36.02(1.031)	35.99(1.031)	35.91(1.031)	36.09(1.030)	35.56(1.030)	36.11(1.032)	35.72(1.031)

The number in parenthesis indicates to the ratio of absorbed dose conversion factor for water to acrylic phantom.

Table 4 Comparison of absorbed dose measured with 5 types of ionization chambers at calibration depth in acrylic plastic phantom irradiated by 4 and 10MV X rays

4 MV	C-110 0.7678(Gy) PTW30001 0.7624(Gy) Difference +0.71%	NE2571 0.7610(Gy) PTW30001 0.7630(Gy) Difference −0.26%	NE2581 0.7647(Gy) PTW30001 0.7638(Gy) Difference +0.11%	PTW23333 0.7629(Gy) PTW30001 0.7642(Gy) Difference +0.17%
10MV	C-110 0.8322(Gy) PTW30001 0.8287(Gy) Difference +0.42%	NE2571 0.8238(Gy) PTW30001 0.8275(Gy) Difference −0.44%	NE2581 0.8305(Gy) PTW30001 0.8275(Gy) Difference +0.36%	PTW23333 0.8300(Gy) PTW30001 0.8273(Gy) Difference +0.33%

The values of PTW 30001 for PTW 23333 were estimated from the values of NE 2571.