A9－2

Determination of overall perturbation factors for parallel-plate ionization chambers in electron beams

Fujio Araki[1)], Yuichi Shirakawa[2)], Ryuji Ikeda[2)], Toshiaki Shimonobou[2)], Nobuyuki Moribe[2)], Takao Takada[2)], Mutsumasa Takahashi[2)], Hiroki Oura[3)], Masaru Matoba[4)]

1) Kumamoto University College of Medical Science, 2) Department of Radiology, Kumamoto University Hospital, 3) Department of Radiology, Kumamoto National Hospital, 4) Department of Nuclear Engineering, Kyushu University

INTRODUCTION

To determine the absorbed dose in electron beams, especially for energies below 10 MeV, the modern dosimetry protocols recommend the use of parallel-plate ionization chambers.[1-5)] This is because these chambers have a good depth resolution and a small fluence perturbation effect. A major source of uncertainty in the electron dosimetry with ionization chambers is the perturbation effect introduced by the chamber itself. This effect consists mainly of two origins. The first is the perturbation of the electron fluence due to existence of the low density air cavity in the phantom. This cavity "in-scatter" effect called the replacement correction factor P_{repl} may be an important correction factor if the chambers with narrow guard rings are used. The second is the lack of equivalence of the chamber walls to the phantom material. This effect is wall collection factor P_{wall}, which has been assumed implicitly to be unity in electron dosimetry protocols to date.[1-5)] The product of the two perturbation factors P_{repl} P_{wall} is expressed as the overall perturbation factor P_Q. For several parallel-plate chambers it is equal to unity in mean energy above 15 MeV.[3-5)]

The purpose of this work is experimentally to determine values of P_Q for the commonly applied NACP, PTW/Roos and PTW/Markus parallel-plate chambers in electron beams, especially for energies below 10 MeV.

INSTRUMENTS AND METHODS

1. Measuring conditions

P_Q for a NACP chamber was determined by comparison with a cylindrical Farmer-type chamber, while for the PTW/Roos and PTW/Markus chambers it was determined by compared with the NACP chamber. For these parallel-plate chambers, P_Q was measured as function of mean electron energies from 1.5 MeV to 11.5 MeV. In this work, we used a solid water phantom (Model 457, RMI-Gammex Inc., Middleton, WI 53562) with water equivalence compared to an acrylic phantom. The effective point of measurement for the Farmer-type chamber was taken at 2/3 of an inner radius proximal to the chamber axis, while for the parallel-plate chambers it was the inner surface of the entrance window.

The therapy instruments used were a Mitsubishi EXL-15 DP with 4-15 MeV electron energies and a Varian Clinac 2100C with 4-16 MeV electron energies. For all charge measurements, a RAMTEC 1000 Dose-Dose Rate Meter (Toyo Medic Co., Ltd, Osaka, Japan) and a Victoreen

500 electrometer were used. The charge measurements were taken with positive and negative polarity, and the average value was used to determine P_{repl}. The results of the polarity effect are also described below. The ion recombination correction factor P_{ion} for the parallel-plate and Farmer-type chambers was determined by the two-voltage method. A series of measurements were repeated at least three times in different days to make sure that the ratio does not fluctuate by more than 1.0% in day-to-day operation. Also, the charge measurements were continued until the last three readings were within $\pm 0.2\%$ to minimize systematic errors.

2. Determination of the replacement correction factor

For the NACP chamber P_Q was obtained from dose comparison with the Farmer-type chamber at the depth of d_{max} in a solid water phantom. If P_Q for the NACP chamber is taken to be unity for 16 MeV with the highest electron-beam energy available in this work, it can be obtained from the following relation:

$$P_{Q,E}^{NACP} = \frac{[MP_{ion}P_{repl}]^{cyl,E} / [MP_{ion}]^{NACP,E}}{[MP_{ion}P_{repl}]^{cyl,16\,E} / [MP_{ion}]^{NACP,16\,E}}. \quad (1)$$

On the other hand, P_Q for the PTW/Roos and PTW/Markus chambers was obtained from dose comparison with the NACP chamber at d_{max}, and it is given by

$$P_{Q,E}^{pp} = \frac{[MP_{ion}P_Q]^{NACP,E} / [MP_{ion}]^{pp,E}}{[MP_{ion}]^{NACP,16\,E} / [MP_{ion}P_Q]^{pp,16\,E}}. \quad (2)$$

where M is the measured charge corrected for temperature, pressure, and polarity effect. The symbols cyl and pp indicate the cylindrical and parallel-plate chambers, respectively. The mean electron energy $\bar{E}z$ at d_{max} (depth of 1.5 cm) for 16 MeV electrons is 11.5 MeV, thus $P_{Q,16\,E}$ for PTW/Markus chamber was taken to the value of 0.999 from the IAEA TRS-381 protocol[5]. For the PTW/Roos chamber $P_{Q,16\,E}$ was taken to be unity.

All of the measurements were made in phantom with a source-surface distance of 100 cm and the effective measuring point for each chamber placed at d_{max}. A 15×15 cm^2 field defined at the phantom surface was used at nominal electron energies from 4 to 16 MeV. Following the TG-21[1] and JARP[2] protocols, the mean incident energy $\bar{E}o$ was determined by multiplying the depth of the 50% dose in water by 2.33 MeV/cm and the mean energy at depth $\bar{E}z$ was obtained from Table A18.2 of the JARP protocol. Also, $P_{repl,cyl}$ for $\bar{E}z$ was obtained from Eq. (A18-1) of the JARP protocol. The difference between $\bar{E}z$ obtained from the JARP protocol and the relation $\bar{E}z = \bar{E}o(1 - Z/R_p)$ in the TG-21 protocol does not affect on the estimation of $P_{repl,cyl}$ (within 0.1%).

All the data were read in about 1.00 Gy at a dose rate of 4.00 Gy/min, for both positive and negative polarity. The average value of P_{ion} ranged from 1.009 to 1.005 for the Farmer-type chamber and from 1.005 to 1.003 for the parallel-plate chambers, respectively.

RESULTS AND DISCUSSION

1. Polarity effect

The polarity effect for the parallel-plate chambers is shown in Fig. 1. The polarity effect is defined here as half the difference in the absolute values of the readings with positive and negative polarity divided by the mean value as follows:[5)]

$$\frac{\Delta M}{M}=\frac{|M_+|-|M_-|}{|M_+|+|M_-|}, \qquad (3)$$

where $M+$ and $M-$ are the measured charges in positive and negative polarity, respectively. The effect for the NACP chamber increase at large electron energies, but it is within 0.2%. The PTW/Roos chamber shows the polarity effect of less than ±0.1%. The effect for the Markus chamber is negligible for mean energies above 8 MeV, but it is large for low electron energies. It shows about 0.5-1.0% deviations for mean energies of 2-4 MeV, thus for Markus chamber the polarity effect should be considered in the case of low electron energies. The polarity effect for the Farmer-type chamber is within 0.1% in all the electron energy range used in this work.

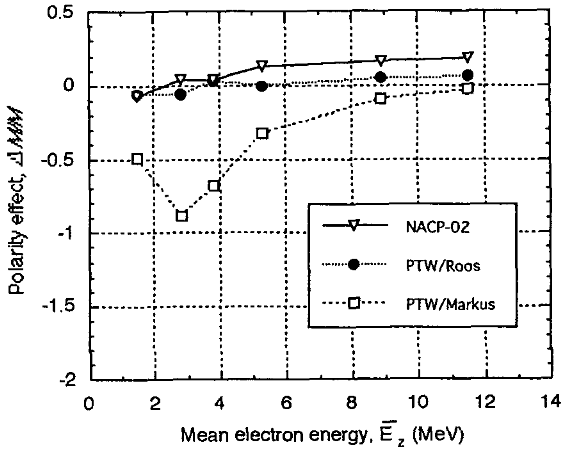

Fig. 1. Polarity effect (difined as $(M_+-M_-)/(M_++M_-)$) as a function of electron energy for different chambers.

2. Determination of the replacement correction factor

The P_Q values as a function of electron energy for the parallel-plate chambers are shown in Figs. 2 and 3. As expected, the P_Q values for the NACP chamber are very close to unity in the measured electron energy range. The deviations are within ±0.4% in comparison with the Farmer-type chamber for mean energies from 1.5 MeV to 11.5 MeV which produced with the Mitsubishi EXL-15 DP and Varian Clinac 2100C. They are within an experimental uncertainty when the uncertainty of P_{repl} for the Farmer-type chamber is taken into consideration. Thus, P_Q for the NACP chamber was taken to be unity for all the electron energies in comparison with the PTW/Roos and PTW/Markus chambers.

The P_Q values for the PTW/Roos chamber are in good agreement with the NACP chamber, and the deviations are within ±0.1%. On the other hand, the P_Q values for the Markus chamber are close to unity at higher energy electrons, but they vary considerably at lower energy electrons

The magnitude of variation increases generally as energy decreases, and it deviates by 3.5% at the mean energy of 1.5 MeV.

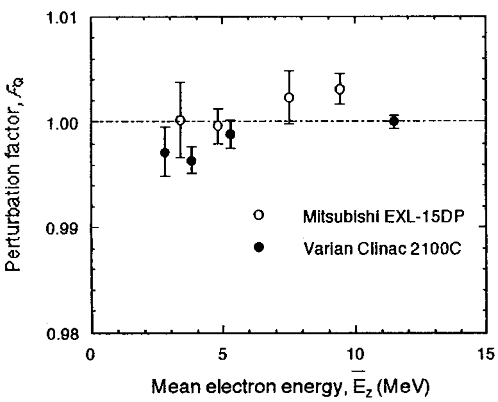

Fig. 2. P_Q values measured for the NACP chamber.

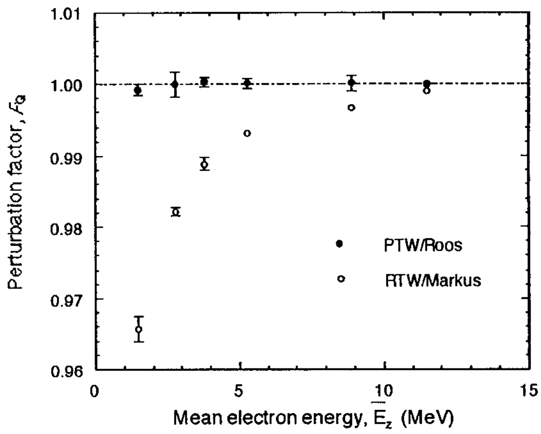

Fig. 3. P_Q values measured for the Roos and Markus chambers. The dashed line is drawn for NACP chamber.

CONCLUSIONS

In this work, we can conclude that the P_Q values for the NACP and PTW/Roos chambers are independent of the electron energy because the guard ring width is sufficiently wide, while the PTW/Markus chamber has an energy dependent P_Q because the guard ring width is narrow. Our results are in good agreement with recommended data of the IAEA TRS-381 protocol. Also, for the PTW/Roos chamber, the polarity effect is not a significant factor, thus this chamber may be most suitable in electron dosimetry with the parallel-plate chambers.

REFERENCES

1) AAPM, Task Group 21: A protocol for the determination of absorbed dose from high-energy photon and electron beams, Med. Phys. 10, 741-771, 1983.
2) JARP: A practical code for the dosimetry of high energy photon and electron beams in radiotherapy (in Japanese), 2nd ed., Tsusho-sangyo-kenkyusya, Tokyo, 1989.
3) AAPM, Task Group 39: The calibration and use of plane-parallel ionization chambers for dosimetry of electron beams: An extension of the 1983 protocol report, Med. Phys. 21, 1251-1260, 1994.
4) IPEMB: The IPEMB code of practice for electron dosimetry for radiotherapy beams of initial energy from 2 to 50 MeV based on an air kerma calibration, Phys. Med. Biol. 41, 2557-2603, 1996.
5) IAEA: The use of plane-parallel ionization chambers in high-energy electron and photon beams; An international code of practice for dosimetry, (IAEA, Vienna, 1997) Tech. Rep. Ser. No. 381.