COMPARISON OF ABSORBED DOSE MEASUREMENTS WITH AN EXTRAPOLATION CHAMBER AND A FARMER CHAMBER IN HIGH ENERGY ELECTRON BEAM

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ABSTRACT

In this paper, the comparison of absorbed dose measurement performed with an extrapolation chamber and a Farmer chamber in high energy electron beam is described. The experiments performed in the course of this work show that the Xinjiang extrapolation chamber is suitable for calibration of high energy electron beams produced from medical linear accelerators.

Keywords: Electron beam Calibration Extrapolation chamber Farmer chamber

I. INTRODUCTION

The extrapolation chamber (EC) which was developed at the Xinjiang Institute of Physics (XIP) was used for the determination of relative absorbed dose distribution in various materials in the work described by Jin Tao[1]. Following this, experiments have been undertaken in a high energy electron beam, the purpose of which was to check the suitability of the EC for the determination of absolute absorbed dose by comparison with a calibrated Farmer type ionization chamber. These experiments were performed with a radiotherapy linear accelerator at the Xinjiang People's Hospital. The first chamber of a variable–spacing parallel–plate geometry was disigned by Failla[2] and given the name "EC" by him. Loevinger[3] applied such a chamber for beta and Böhm and Schneider[4] for low energy X–ray. Manson et al.[5] measured surface doses in megavoltage photon radiation with an EC.

II. EXPERIMENTAL EQUIPMENT AND METHODS

The EC designed and constructed at the XIP is fitted with a thin entrance window and has a collecting electrode made of graphite 30 mm in diameter. The electrode spacing can be varied by means of a computer controlled stepping motor drive achieving high precision electrode setting. The dosimeter used in these experiments as a reference for measuring the absorbed dose was a Farmer dosimeter type 2570 (Nuclear Enterprises, U.K.) fitted with a thimble chamber of 0.6 cm^3 sensitive volume and a graphite cap (type NE 2571). The chamber had a calibration factor determined at the XIP in ^{60}Co radiation in comparison against an NPL Secondary Standard

Therapy level X- ray exposure meter type 2560 with a chamber type NE 2561 calibrated at the National Physical Laboratory in England against a primary exposure standard. The source of the electron beam was a linear accelerator type FL- ZJ11- 10 produced in Shanghai with maximum energy of 10 MeV. Measurements of electron beam energy were performed by a thin window chamber type 23342 (PTW, W.Germany).

Ⅲ. MEASUREMENTS AND RESULTS

1) Beam energy parameters The Parameters required for determination of the absorbed dose depend on the electron energy and this was therefore the first one to be measured. In order to determine the beam energy parameters, a depth ionization curve was measured at 100 cm SAD in suitable perspex sheets, the thickness of which was converted into an equivalent depth in water using a 1.14 factor allowed for the differences both in physical density and stopping power between the materials. The accelerator was set up in a vertical gantry orientation for all of the experiment performed. The extrapolation electron range R_p and the half- value depth in water (*HVD*) were then determined[6] from the depth- ionization curve and found to be equal to 4.25 cm and 3.1 cm respectively. The peak of the depth- ionization curve was found to occur at 1.3 cm and this point was selected as the depth of experiment of measurement of the absorbed dose for both chamber.

The above data are required for calculating the electron energy parameters in accord with the requirements of the Code of Practice for Electron Beam Dosimetry in radiotherapty published by the HPA[7]. Subsequently, the mean incident energy E_o was found to be

$$E_0 = 2.5 \times HVD = 7.75 \text{ MeV} \quad (1)$$

and the mean electron energy E_d at the calibration depth z is

$$E_d = E_0 (1 - z/R_p) = 5.38 \text{ MeV} \quad (2)$$

where $HVD = 3.1$, $E_0 = 7.75$ MeV $z = 1.3$ cm and $R_p = 4.25$ cm. The mean electron energy at the measurement depth was used to find from the data in the Code of practice[7], the value of the air kerme- to absorbed dose conversion factor, C_e, for the Farmer chamber used in water, as required by the absorbed dose formula(3).

2) Absorbed dose determination with the calibrated Farmer chamber For determing the absorbed dose, the chamber was placed with its effective point of measurement at the peak of the depth ionization curve (1.3cm). When the Farmer Thimble Chamber is used for electron the position of the effective point of measurement must be taken as being situated about two thirds of the internal radius ($r = 3.15$ mm) of the cavity in front (i.e.nearer the electron source) of the axis of the chamber. A water phantom used in the experiment was positioned so that its water surface was at the linear accelerator isocentre that is at 100cm SAD. The chamber was

protected by a thin perspex sheet. The chamber readings taken with a $10\times 10cm^2$ radiation field were corrected to standard ambient conditions but no correction for ion recombination was attempted. The absorbed dose in water D_w was derived from the equation used in the Code of practice[7] given by

$$D_w = R\,N_f\,C_e \qquad (3)$$

where R is the chamber mean reading correcting for temperature and pressure, N_f is the air kerma calibration factor for the Farmer chamber (FC) and C_e is the conversion factor of an ionization chamber calibrated in terms of air kerma in ^{60}Co γ - radiation when used for absorbed dose measurement in water in high energy electron beam. The dimension of Ce defined by the ratio of absorbed dose in water to air kerma and, since they are both expressed in grays, Ce has no units. The Ce factors are listed in the HPA Code of Practice as a function of the mean electron energy at depth E_d. For $z=1.3$cm, $E_d=5.38$MeV,Ce was found by interpolation, to be 1.0042 for the FC used in water.

The calibration factor for the Farmer in Urumqi was given in exposure in Roetgens (0.991 R/div) hence its conversion into air kerma was necessary using a factor of 8.78 $\times 10^{-3}$ GyR^{-1}. This yielded a calibration factor $N_f = 8.70\times 10^{-3}$Gy div^{-1}.

The FC exposure in the electron beam under conditions of the experiment yielded a mean reading corrected to standard ambient conditions $R=$ 104.86 for 200 monitor units set on the accelerator.

Using the data described above, thus $D_w = 104.86/200\times 8.7\times 10^{-3}\times 1.0042 = 0.458$ cGy per monitor unit was determined with Farmer dosimeter.

3) Determination of the absorbed dose by means of the extrapolation chamber An EC is a variable- spacing, parallel- plate ionization chamber having an uncalibrated sensitive volume. In this respect the dosimetry with this chamber differs from the dosimetry performed with any other conventional type ionization chamber which has a sensitive volume defined by calibration against a chamber of known constructional features by subjecting both chambers to a known exposure of megavoltage radiation. Such a calibrating requires high precision instrumentation and is performed in selected dosimetric centres. The EC on the other hand does not require calibration enabling the dose to be derived from the first principles. Provided the chamber is used under conditions of , at least approximately, the Bragg- Gray cavity theory the energy (dose) absorbed per unit mass of solid phantom can be given by

$$E_m = S_{s.a}\,W/e\times J_a \qquad (4)$$

where J_a is the ionization per unit mass in the vanishingly small air cavity, W is the average energy required to produce an ion pair in air, e is the electron charge and $S_{s,a}$ is the ratio of the stopping power in solid to that in air.

The crucial point in the EC dosimetry is to obtain the ionization, hence the charge, produced in the mass of air which is unknown since the exact chamber volume is not

known. This difficulty is overcomed by measuring the ionization per unit volume as a function of the spacing between the chamber parallel- plane electrodes. Then

$$J_a = \lim_{d \to 0} J_a(d) \tag{5}$$

In priactice the charge is measured with various electrode spacing and an extrapolation curve is plotted which should be a straight line for small electrode spacings and should extrapolate to zero for electrode gap. The limit slope of the extrapolation curve may be determined in terms of charge per mm spacing. This approach renders the determination of the exact chamber volume unnecessary. It is reasonable to assume that, at the limit of a vanishingly small cavity, the presence of the air cavity does not disturb the electron fluence and thus the condition of the cavity theory are reasonably well approximated. While the theory of cavity chamber has been worked out for X- , γ - and β - rays primarily, there is no difficulty in principle in applying it to the measurement of high energy electrons. The only difficulty has to do with is the correct computation of the appropriate value of the ratio of the average mass collision stopping powers for water and air which should be averaged over the spectral electron particle density.

In order to obtain a meaningful comparision with the FC measurement, the EC was set up in similar electron beam orientation in a phantom at 100 cm SAD with its entrance window at 1.3 cm below the phantom surface. Thus the effective planes of measurements of the two chambers were at the same depth in the phantom. The XIP chamber is not designed for use in water therefore a solid phantom had to be used. In view of the lack of any other material, a box of Chinese dry rice was used for surrounding the chamber as scattering material whilst the material directly on top of the chamber window was some water similar plastic made at the XIP. The authors noted with interest on Failla's work that he also used rice in his study of backscatter factors in 1937[2]. Setting up the chamber in an identical geometry to the FC, exposures were made with electron beam of the same energy at electrode spacings varying between 6 and 1 mm and the respective values of the charge collected were plotted as a function of spacing obtaining an extrapolation curve. The straight line properly fitted with the method of least squares to the experimental data yield limit value of the extrapolation curve slope $Q/d = 3.23 \times 10^{-6}$C/m. The central axis absorbed dose at the same plane of measurement as that for the FC, was then calculated using the following formula

$$D = S_{w,a}(W/e)(Q/d)(1/A)(1/\rho)f \tag{6}$$

where $S_{w,a}$ is the ratio of the average mass collision stopping power for water and air, W is the average energy required to produce an ion pair, e is the electron charge, $W/e = 33.97$ J/C, A is the surface area of the chamber collecting electrode, ρ is the density of air and $f = [(273.2 + t)/293.2] \times 1031/p$ is the temperature and pressure correction factor, where t is the ambient air temperature in ^{o}C and p is the air

pressure in m bar. The XIP chamber has a diameter of 30.29 mm, hence the surface area $A = 706.4 \times 10^{-6} m^2$. In this experiment, $f = 1.0983$. One important problem is how to determine the stopping power for Eq(6). The data in the HPA protocol can not be used because the stopping power is not listed as a seperate parameter but together with other correction factors combined into the C_e factor. For this reason the stopping power ratio for the EC was taken from the data calculated by Berger for an infinitely wide, plane- parallel monoenergetic electron beam. The data have been adopted by AAPM[8], NACP[9] and IAEA[10]. Actually, the ratios of the average restricted collision mass stopping power calculated by Berger are with a cut- off energy of 10 keV. Because the incident, monoenergetic spectrum is degraded as it penetrates into a phantom, the stopping power increases significantly with depth, so it is important to measure the depth accurately even for measurements made in the region of the depth of maximum dose. Due to the way the Berger data is tabulated, the mean incident energy E_0 (together with the depth of measurement, z) is required to obtain the appropriate stopping power ratio from the tables. Because of the influence of beam spectral spread the mean energy and depth are not fully adequate for the selection of the stopping power[11]. However, there is no better method available at the moment. For the E_0 and z used in this experiment the appropriate stopping power ratio of water to air, $S_{w,a}$ was found to be 1.05. With the data described above employed in Eq(6), $D = 13.886$ cGy for 50 monitor units set on the accelerator, the absorbed dose measured by means of the EC was found to be 0.438 cGy per monitor unit. That in a good agreement with the FC, only 0.95% differ from the latter.

IV. CONCLUSIONS

The experiments performed show that the XIP EC is suitable for calibration of high energy electron beams that, such as are produced from medical linear accelerators. The intercomparison with a Farmer type dosemeter having calibration traceable to The British Exposure Standard (National Physical Laboratory, England) yielded a result within 1% agreement in the measurement of absorbed dose.

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