Comparison of Primary Doses Obtained in Three 6 MV Photon Beams Using a Small Attenuator

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Abstract:

It is a common technique in radiotherapy treatment planning systems to simplify the calculations by splitting the radiation beam into two components: namely the primary and scattered dose components. The contributions of the two components are evaluated separately and then summed to give the dose at the point of interest.

Usually the primary dose is obtained experimentally by extrapolating the ionization measured within the medium to zero field size (Godden, 1983). This approach offers the opportunity to obtain the primary component of dose without the need for an uncertain non-linear extrapolation. It is based on a paper by Nizin & Kase from 1988.

The primary dose can be obtained from two measurements of ionization in a large beam in a water phantom, as well as four measurements of ionization in a narrow beam geometry. The measurements were done over a range of different depths and thus the primary linear attenuation coefficient was also obtained.

The values for the primary dose components at d_{max} in a 10 cm x10 cm field obtained in three different 6 MV beams using this method range from D_p (d_{max}, 10 cm x 10 cm) = 0.925 – 0.943 Gy / 100 MU.

The obtained values of the primary dose components compare well with measurements in the same beams extrapolated to zero-field size and also to literature (Rice and Chin, 1990). One can thus conclude that this method has the potential to provide an independent measurable verification of calculations of primary dose.

Key Words:

Primary dose, attenuation, attenuation coefficient

1) Introduction

The primary dose component of a megavoltage beam cannot be measured directly. Usually the phantom scatter correction factor is extrapolated to zero-field size to obtain the primary dose component. However, extrapolation methods suffer from a number of problems that result in the primary dose being uncertain from 3 – 10 % (Bjärngard and Petti, 1988; Kijewski *et al*., 1986; Day, 1983). Nizin and Kase (1988) introduced an approach for deriving the primary component of a megavoltage X-ray beam and applied their method successfully in a ^{60}Co beam (Nizin and Kase, 1990). The method is based on the difference in spatial origin of primary and scattered photons. A small attenuator of thickness h is positioned between the source and the detector (Figure 1). The idea behind this is that the primary photon fluence will be modified, while the perturbation of the scatter component remains small. The attenuator must alter the primary radiation significantly, but at the same time the phantom generated scatter must be negligible. The second requirement is that the radius of the attenuator is greater than the effective lateral electron mean free path in the phantom material.

The separation of primary and scattered dose components is not a new concept (Cunningham, 1972; Holt *et al*., 1970; Khan *et al*., 1980). There are a number of better and more accurate dose calculation methods, as described in a review on dose calculations for external photon beams by Ahnesjö and Aspradakis (1999).

2) Theory

The total dose (D_T) on the central axis of a broad beam of photons at depth $d \geq d_{max}$ can be described as the sum of the primary (D_P)and scattered (D_S) dose components.

$$D_T = D_P + D_S \quad (1)$$

A small diameter central axis absorber (denoted by superscript i) is placed between the source of radiation and the point of interest, resulting in additional attenuation of primary photons without appreciably changing the scattered component of the beam.

$$D_T^i = D_P^i + D_S \quad (2)$$

For a specified depth d in a phantom, the ratio of primary components is independent of field size:

$$D_P / D_P^i = \text{constant} = C_D(d) \quad (3)$$

These three equations can be combined to give:

$$D_P(d) = [1 - 1/C_D(d)]^{-1} \cdot [D_T(d,S) - D_T^i(d,S)] \quad (4)$$

$C_D(d)$ compensates for a possible hardening of the beam in the attenuator and can be measured by a series of ionization measurements with and without the attenuator in a narrow beam. It is given by:

$$C_D(d) = \frac{\ln\left[\frac{I(d+\Delta)}{I(d)}\right]}{\ln\left[\frac{I(h+d+\Delta)}{I(h+d)}\right]} \cdot \frac{I(d)}{I(h+d)} \qquad (5)$$

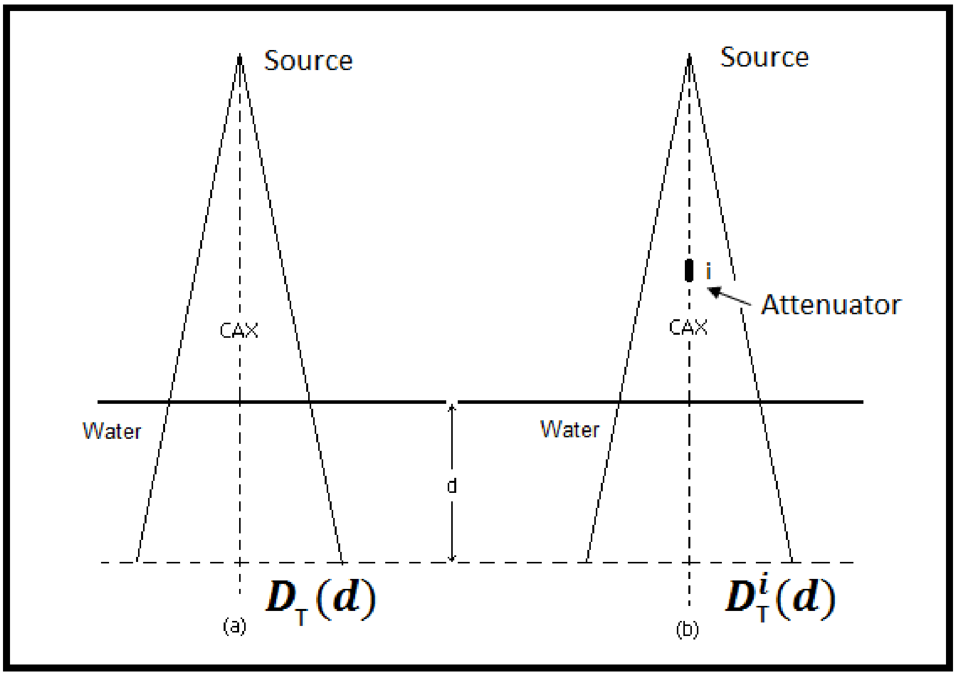
where I(d) is the measured ionization after the beam has passed through depth d of water, I(d+Δ) is the measured ionization after the beam has passed through depth d plus a small increment Δ of water and h is the thickness of the attenuator. Thus, $C_D(d)$ values can be measured at various depths together with $D_T(d,S)$ and $D_T^i(d,S)$ and then be used to calculate $D_P(d)$.

3) Measurements

The central axis attenuator method was applied to three different 6 MV beams, on a Philips SL75-5 linear accelerator, on a Siemens Mevatron KD2 linear accelerator and on a Varian 2300 Clinac. Measurements of the dose with and without the central axis attenuator in the beam were done at different depths in a 10 cm x 10 cm field. A mini-ionization chamber (Schreuder *et* al., 1997) with an active volume of 0.0067 cm^3 was used in the Philips beam, while a PTW 0.016 cm^3 PinPoint chamber was used in the Siemens and Varian beams. Two sets of measurements with two different central axis attenuators were made; the first set with a cylindrical lead attenuator of 1 cm radius and 1 cm height, the second set with a cylindrical lead attenuator of 1 cm radius and 2 cm height.

All measurements of D_T^i were made with the attenuator at least 20 cm above the water surface. Fig. 1 shows the measurement setup.

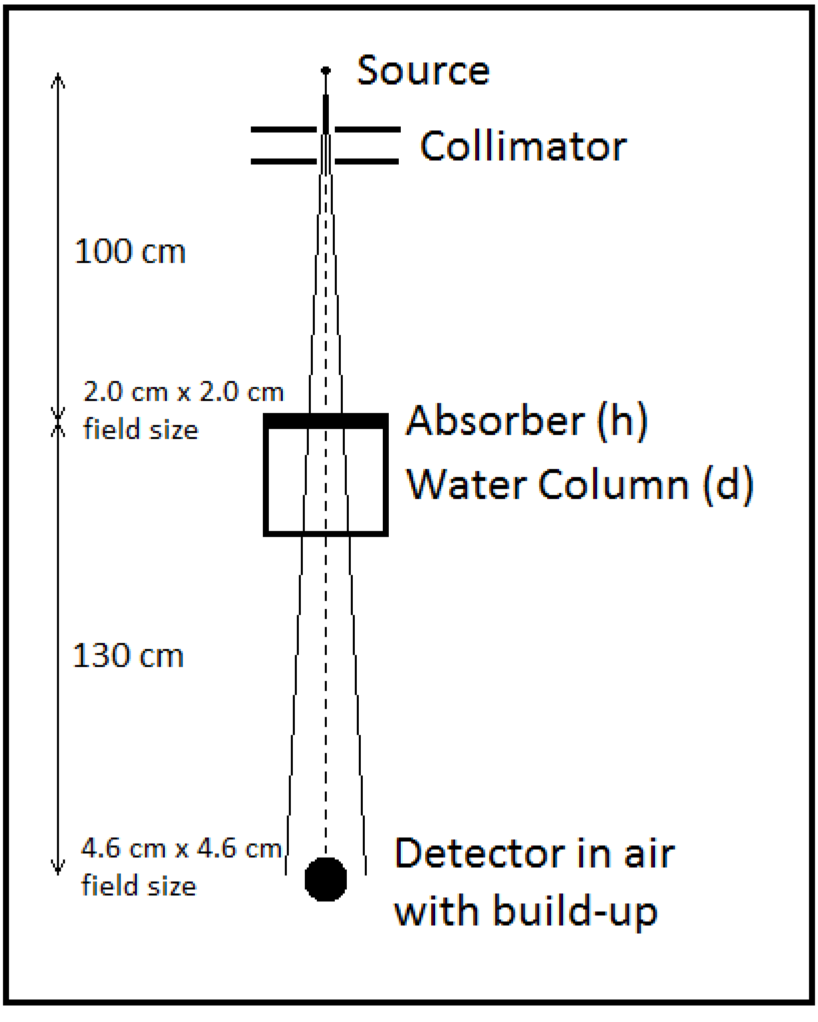
Figure 1: Measurement Setup



The experimental setup used to measure $C_D(d)$ is shown in Fig. 2.
Narrow beam measurements were done in a 2 cm x 2 cm field. However, the detector was situated at an extended SDD of 200 cm for the Philips beam and 230 cm for the Siemens and Varian beams, resulting in field sizes of 4 cm x 4 cm and 4.6 cm x 4.6 cm respectively at the point of measurement. The field size at the extended SDD was large enough to cover the 0.6 cm^3 Farmer type ionization chamber with build-up.

The absorber thickness h must be identical to the thickness of the central axis attenuator used when measuring $D_t^i(d)$.

Figure 2: Measurement Setup



Ionization measurements with ($I(d+h)$ and $I(d+h+\Delta)$) and without ($I(d)$ and $I(d+\Delta)$) the additional attenuator in the beam were done at 2 cm intervals from 1.5 cm to 20 cm depth (Philips) and from 1.5 cm to 15 cm depth (Siemens and Varian) with $\Delta = 0.5$ cm. Measurements at $d = d_{max}$ were done to determine the primary dose component at d_{max}.

Large uncertainties were introduced in the value of $C_D(d)$ and ultimately the primary dose component when using the measured ionization values directly for calculation. An exponential function was thus fitted to each I(d+h), I(d+h+Δ), I(d) and I(d+Δ) and the fitted data was then used in calculating $C_D(d)$.

Values for the primary dose component were calculated for d = d_{max} and for depths up 20 cm (Philips) and 15 cm (Siemens and Varian) respectively.

4) Results

The total doses with and without the central axis attenuators in the beam were measured with a calibrated ionization chamber in a water phantom at d_{max} for the two different attenuators in a 10 cm x 10 cm field and are shown in table 1. The values determined for the various dose components were normalized to 1.00 Gy for the total dose at the depth of maximum dose (1.5 cm) in a 10 cm x 10 cm field. Fig. 3 shows the results for the 1 cm thick lead attenuator for the Varian 6 MV beam.

Figure 3: Results for the 1 cm lead attenuator in the 6 MV beam of the Varian 2300 Clinac

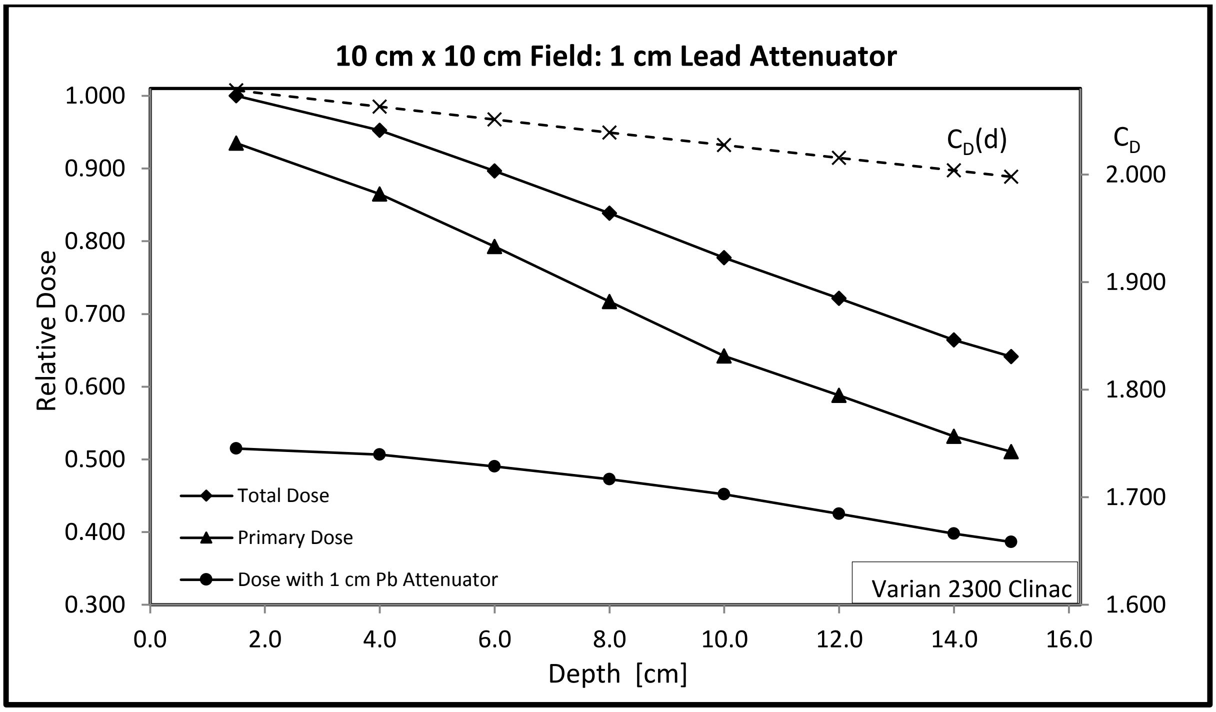


Table 1: Total doses with and without the central axis attenuators

	Philips SL 75-5	Siemens Mevatron KD2	Varian 2300 Clinac
Total Dose [Gy/100 MU]	1.00	1.00	1.00
1 cm Pb attenuator [Gy/100 MU]	0.528	0.528	0.515
2 cm Pb attenuator [Gy/100 MU]	0.309	0.302	0.309

The ionization measurements done in a narrow beam resulted in the following C_D values at d_{max} (Table 2).

Table 2: Calculated C_D values

	Philips SL 75-5	Siemens Mevatron KD2	Varian 2300 Clinac
C_D (1 cm Pb), using 1.5 cm and 2 cm depths	2.042	2.014	2.078
C_D (2 cm Pb), using 1.5 cm and 2 cm depths	3.765	3.864	3.951

The uncertainty in $C_D(d)$ was obtained as follows (Taylor, 1982): Suppose x,…,z are measured with uncertainties δx,…,δz and the measured values are used to compute the function q(x,…,z). If the uncertainties in x,..,z are independent and random, then the uncertainty in q is:

$$\delta q = \sqrt{\left(\frac{\partial q}{\partial x}\delta x\right)^2 + \ldots + \left(\frac{\partial q}{\partial z}\delta z\right)^2} \qquad (6)$$

The four partial derivatives of $C_D(d)$ with respect to I(d), I(d+Δ), I(h+d) and I(h+d+Δ) were worked out and equation 6 was applied with the fractional uncertainty of each beam / ionization chamber combination (= standard deviation expressed as a percentage of the mean of 15 consecutive measurements).

The values from Table 1 and 2 were used to work out the primary dose component at d_{max} in each beam according to equation 4. The results are shown in Table 3.

Table 3: Primary dose components at d_{max}

	Philips SL 75-5	Siemens Mevatron KD2	Varian 2300 Clinac
Primary Dose [Gy/100 Mu] 1 cm Pb Attenuator	0.925 ± 4.5 %	0.938 ± 4.8 %	0.935 ± 3.3 %
Primary Dose [Gy/100 MU] 2 cm Pb Attenuator	0.941 ± 4.8 %	0.942 ± 5.2 %	0.943 ± 3.5 %

The primary dose component is attenuated exponentially (Khan *et al*., 1980), therefore an exponential function was fitted to the primary dose values obtained at all the measurement depths for each beam and attenuator. The fitting procedure gave an estimate of the uncertainty of μ_0. The results are shown in Table 4.

Table 4: Primary linear attenuation coefficients

	Philips SL 75-5	Siemens Mevatron KD2	Varian 2300 Clinac
μ_0 (1 cm Pb) [cm^{-1}]	0.0447 ± 0.0007	0.0436 ± 0.0008	0.0458 ± 0.0012
μ_0 (2 cm Pb) [cm^{-1}]	0.0444 ± 0.0006	0.0436 ± 0.0008	0.0458 ± 0.0008

5) Comparison and Conclusion

The primary dose components at the depth of maximum dose obtained with this method (0.925 & 0.941 Gy / 100 MU for the Philips beam, 0.938 & 0.942 Gy / 100 MU for the Siemens beam and 0.935 & 0.943 Gy / 100 MU for the Varian beam using the 1 cm and 2 cm lead attenuators respectively) compare quite well with the values currently in use on the planning systems. These are 0.935 Gy / 100 MU for both the Philips and Siemens beam and 0.926 Gy / 100 MU for the Varian beam. Rice & Chin (1990) published a value of 0.928 ± 0.013 for the magnitude of the primary dose relative to the total dose at d_{max} in a 10 cm x 10 cm field in a 6 MV beam. All the values are in good agreement.

The primary linear attenuation coefficients of the three beams were also obtained using linear attenuation measurements, fitting a central axis kerma model to measured percentage depth dose (PDD) data (Pistorius, 1991) and extrapolating measured tissue-maximum ratios (TMRs) to zero field size. The results are shown in Table 5.

Table 5: Primary linear attenuation coefficient comparison

	Philips SL 75-5	Siemens Mevatron KD2	Varian 2300 Clinac
μ_0 (1 cm Pb) [cm^{-1}]	0.0447 ± 0.0007	0.0436 ± 0.0008	0.0458 ± 0.0012
μ_0 (2 cm Pb) [cm^{-1}]	0.0444 ± 0.0006	0.0436 ± 0.0008	0.0458 ± 0.0008
Narrow Beam Attenuation Measurements [cm^{-1}]	0.0460 ± 0.0001	0.0477 ± 0.0003	0.0482 ± 0.0002
Pistorius (1991) CAPDD Kerma Model [cm^{-1}]	0.0445 ± 0.0001	0.0445 ± 0.0001	0.0457 ± 0.0001
TMR extrapolation to zero field size [cm^{-1}]	0.0469 ± 0.0006	0.0465 ± 0.0001	0.0477 ± 0.0002

The values of the primary linear attenuation coefficients are also in good agreement.

Therefore one can conclude that the primary dose component and the primary linear attenuation coefficient can be determined using the method proposed by Nizin and Kase (1988). Unfortunately the expression for $C_D(d)$ is extremely sensitive to very small changes in ionization, resulting in large uncertainties in the primary dose component.

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