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S. Sathiyan, M. Ravikumar

Exit Dose Measurement in Therapeutic High Energy Photon Beams and Cobalt-60 Gamma Rays

Department of Radiation Physics, Kidwai Memorial Institute of Oncology,
Dr. M. H. Mari Gowda Road, Bangalore – 560 029, India
e-mail: ssathiyan@rediffmail.com

To estimate the skin dose to the patient from the treatment planning, the knowledge about exit dose is essential, which is calculated from the percentage depth dose. In this study 6 MV and 18 MV beams from linear accelerator and cobalt-60 beams were used. The ionometric measurements were carried out with parallel plate chamber of sensitive volume 0.16 cc. Parallel plate chamber was fitted in to 30×30 cm^2 polystyrene phantom at a fixed FSD with the measuring entrance window facing farther from the source. The field size for this measuring condition was maintained at 10×10 cm^2. The ionization measurements were also carried out by changing the thickness of the polystyrene phantom at the entrance side of the point of measurement. In order to find out the variation of relative exit dose (RED) with field size the measurements were carried out without and with the full back-scattering material (27.2 gm/cm^2) placed beyond the entrance window of the chamber. The measurements were also done for the entrance polystyrene phantom thicknesses of 10, 20 and 30 cm for the field size ranging from 5×5 cm^2 to 30×30 cm^2. The dose at the exit surface with no backscatter material is about 4.4%, 3.7% and 5.8% less than the dose with the full backscatter material present beyond the point of measurement for 6 MV, 18 MV X-rays and cobalt-60 gamma rays. The reduction in exit dose does not depend much of the phantom thickness through which the beam traverses before exiting at the chamber side. Dose enhancements of about 1.03 times were observed for a field size of 5×5 cm^2 for 6 MV, 18 MV X-rays and cobalt-60 gamma rays. The dose enhancement factor (DEF) values were noticed to vary with field size beyond 15×15 cm^2 for all the energies studied. Also it can be observed that the dose enhancement factor (DEF) values do not depend on the thickness of the phantom material through which the beam has traversed. The DEF values were found to vary marginally for different phantom material thickness for the particular field size. The study indicates that a reduction of 4.4% and 3.7% in relative exit dose when there is no backscatter material present for 6 and 18 MV X-rays for most of the clinically used radiotherapy portals. The measured exit dose was found to be mostly independent of field size and the thickness of the phantom material through which the beam gets transmitted at the entrance side. An addition of backscatter material of thickness equal to two-thirds of the d_{max} depth of the radiation beam concerned results in full dose at the exit side.

Key words: relative exit dose, dose enhancement factor, polystyrene, parallel plate, backscatter.

Introduction

Knowledge of exit dose is essential in determining the dose to the skin in parallel opposed or multiple external beam treatments. According to ICRU Report 24 [7] exit dose is defined as the absorbed dose delivered by the single fixed beam of radiation to the surface of the patient through which the beam emerges. The report also suggests that the exit dose be measured with the detector surrounded by the full backscattering material. The exit dose depends on the photon energy, the tumor dose, the treatment technique and the presence or absence of the scattering material beyond the patient. It is usually calculated from the percentage depth dose data measured using semi-infinite water or water equivalent solid phantoms. But in clinical practice there is no sufficient backscattering medium present beyond the exit surface of the patient. This lack of full scattering condition will result in the dose less than the estimated dose using the percentage depth dose data. Though there are many energy, field size, beam scattering material and Source-skin distance (SSD) dependant detailed studies exists for the entrance dose measurements [1, 3, 5-6, 9, 14, 16-17], not many studies are reported for exit dose measurements in literature.

For orthovoltage beams a semi-empirical thickness dependent correction factor has been suggested to the exit dose estimated from percentage depth dose data. [2, 12]. The ICRU report [7] has tabulated correction factors for orthovoltage beams in the HVL range 1.5 to 2.5 mm copper. Legare [11] has suggested a correction factor ranging from 0.91 to 0.95 depending on the field size and phantom thickness for Co-60 gamma rays. Though Johns and Cunningham [8] have reported that no correction is necessary for Co-60 gamma beams a correction factor of about 5% has been recommended by Massey and Meredith [13] and ICRU report [7]. A variation of 2-3% in delivered tumor dose and significant reduction in skin dose has been reported when there is lack of full backscatter material present at the exit surface [4, 5, 11]. A reduction of 3-7% in exit dose for thickness of 1 to 20 cm was reported when the beam traverse 1 to 20 cm of water for a Co-60 beam [4]. Ravikumar and Ravichandran [16] have reported a field size dependant exit dose enhancement with different backscattering materials for 6 and 18 MV X-ray beams. A loss in dose at the exit surface of the order of 15% and 11% were reported for 6 and 18 MV beams [10]. Lambert et al [12] have measured the exit dose for Cobalt 60 gamma rays and different x-ray energies and noticed a reduction in exit dose of 17% for Cobalt-60 gamma rays. They have reported that full electron back-scattering could be restored with 1.0 to 2.7 mm of unit density material placed beyond the chamber depending on the photon energy. For a Varian Clinac 6/100 linear accelerator 6 MV X-ray beam a 15% field size and depth independent reduction in exit dose was reported and it was observed that field size dependent 5-10 mm backscatter material could restore the dose to within 3% of full backscatter condition [15].

In the present study we have estimated the reduction in exit dose for various field sizes and thicknesses of the phantom material for the photon beams generated from our dual energy accelerator and Cobalt-60 gamma rays. Also the optimum thickness of the phantom material along the beam axis required for attaining most of the scatter was estimated for these photon energies.

Materials and Methods

The Varian Cinac DHX-3172 linear accelerator photon beams of nominal energies of 6 MV and 18 MV and cobalt-60 gamma ray beams from Theratronics Theratron-780C were used in this study. The ionometric measurements were made with NACP-02 parallel-plate ionization chamber along with Scanditronix Wellhofer Dose1 electrometer. The chamber had a sensitive volume of 0.16 cc with a diameter of sensitive volume 10 mm and plate separation 2 mm. The front window of the chamber was made up of 0.5 mm of graphite covered with 0.1 mm mylar foil for water proofing. The ion chamber polarizing voltage was maintained at 200 V and both positive and negative collecting potentials were used for the measurements. The exit surface ionization measurements were made with the gantry rotated to 180° (under couch) and the polystyrene phantom positioned above the treatment couch. The parallel plate chamber was snuggly fitted into a 30×30 cm^2 polystyrene phantom at a fixed FSD of 100 cm for X-ray beam and 80 cm for gamma ray beam with the measuring entrance window facing farther from the source. The geometry of the experimental setup is shown in Figure 1. The validity of positioning the parallel plate chamber in the reverse geometry was

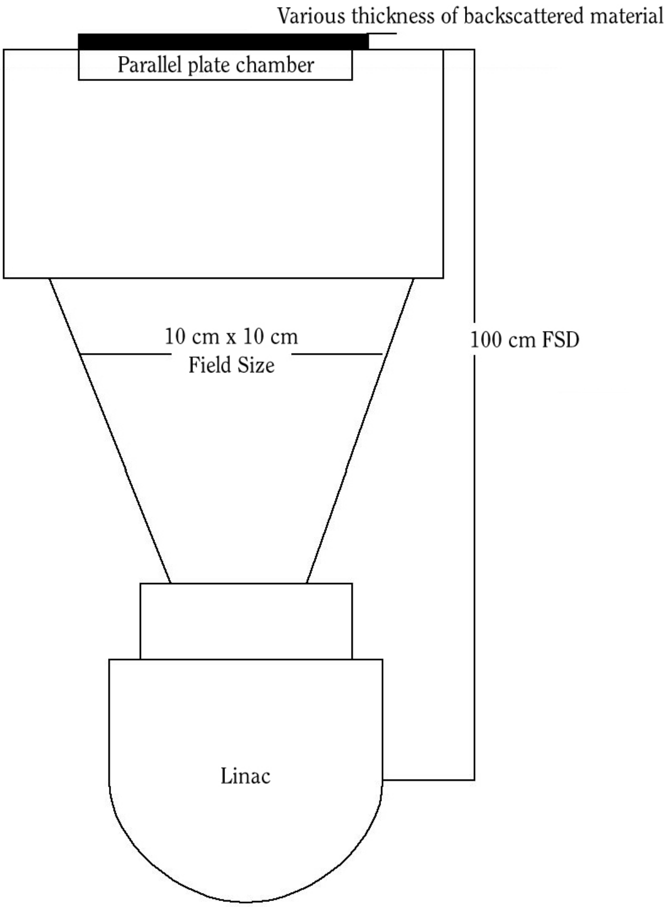


Figure 1. Geometry of the experimental arrangement.

confirmed by measuring the percentage depth dose for a 10×10 cm^2 field with the chamber positioned on both sides. The two estimated percentage depth dose values agreed within 2%.

The charge measurements were carried out by placing varying thickness of thin sheets of polystyrene in close contact with the window of the chamber. The water equivalent thickness of graphite-mylar window (0.104 g/cm^2) was included in the added thickness of the water equivalent polystyrene sheets. The field size for this measuring condition was maintained at 10×10 cm^2. The ionization measurements were also carried out by changing the thickness of the polystyrene phantom at the entrance side of the point of measurement.

In order to find out the variation of relative exit dose with field size the measurements were carried out without and with the full back-scattering material placed beyond the entrance window of the chamber. The measurements were also done for the entrance polystyrene phantom thicknesses of 10, 20 and 30 cm for the field sizes ranging from 5×5 cm^2 to 30×30 cm^2. The validity of measurements for field sizes 30×30 cm^2 was checked against the measurement by adding an additional polystyrene block around the smaller size phantom. No significant difference was observed as a result of added phantom material, which is similar to that reported in earlier studies [16, 18].

Results

The relative exit dose (RED) for 10×10 cm^2 field with varying thickness of the phantom material (10, 20 and 30cm) placed at the exit surface is shown in Figure 2a, 2b and 2c for 6 MV,18 MV and Co-60 gamma rays. The relative exit dose (RED) is defined as the ratio of ionization charge measured with and without the backscattering material placed in contact with the parallel plate chamber. The results show that for a 10×10 cm^2 field the

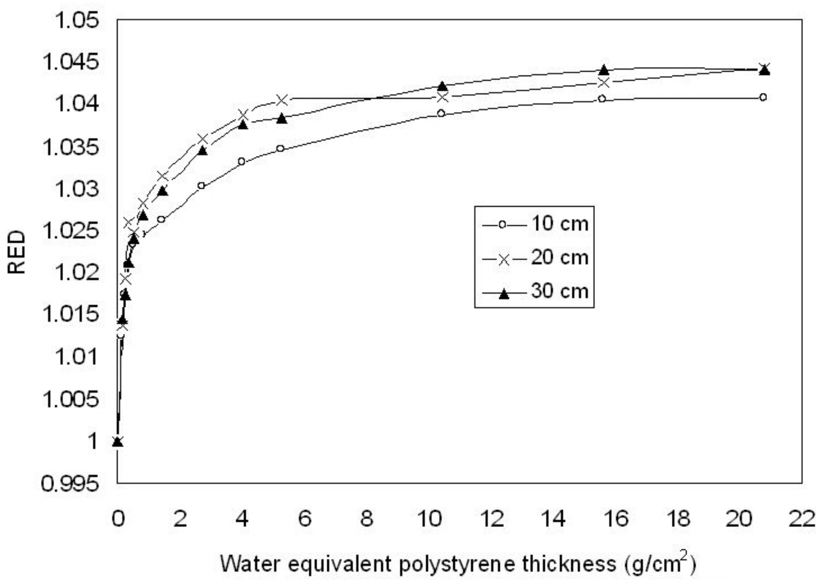
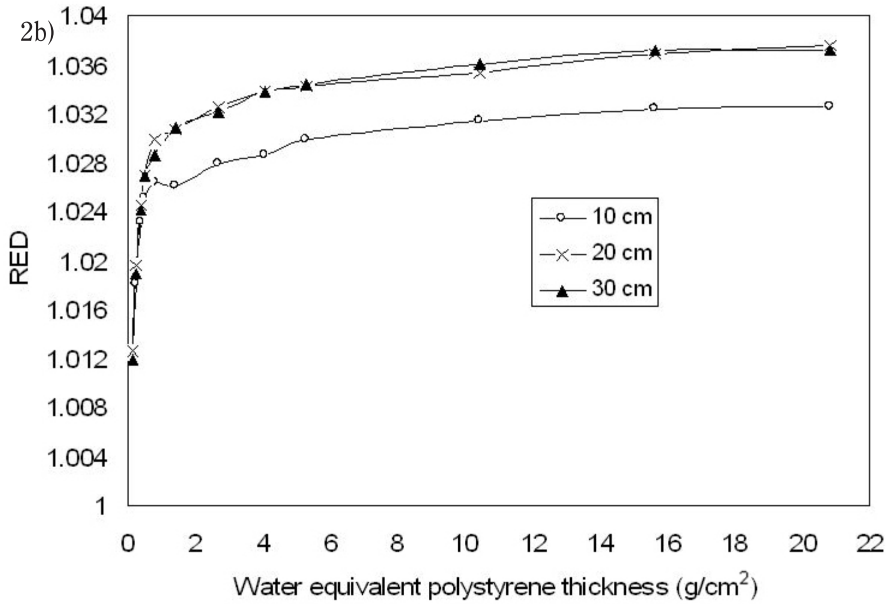


Figure 2a. Backscatter thickness versus relative exit dose for 6MV photons.

2b)



2c)

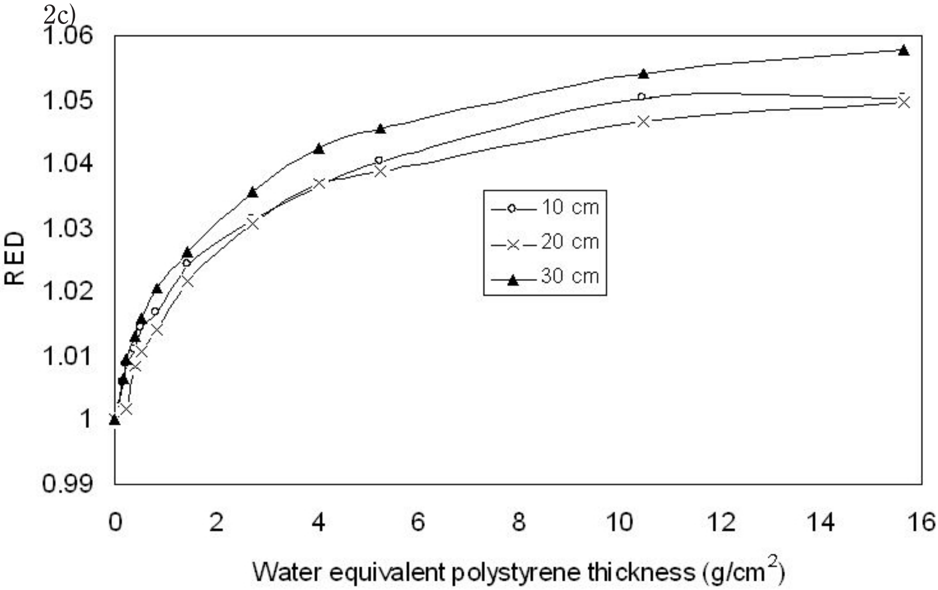


Figure 2. Backscatter thickness versus relative exit dose for (b) 18MV and (c) Co-60 photons.

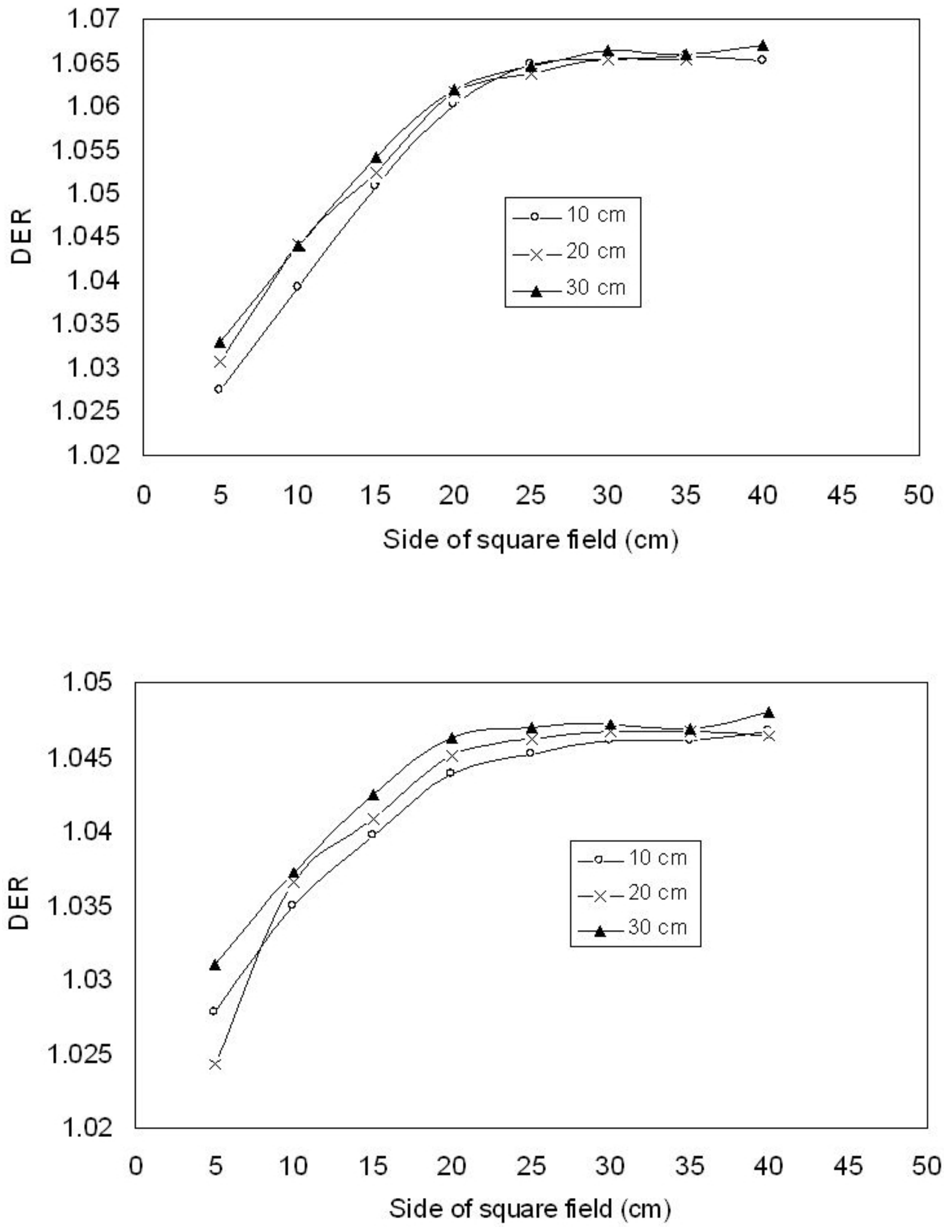


Figure 3. Side of the square field versus dose enhancement factor for (a) 6MV and (b) 18MV photons.

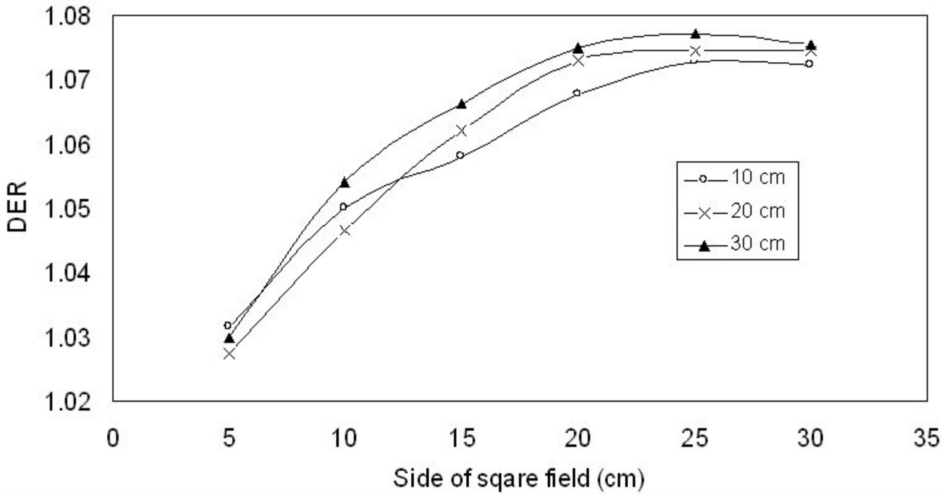


Figure 3c. Side of the square field versus dose enhancement factor for (c) Co-60 photons.

dose at the exit surface with no backscatter material is about 4.4% and 3.7% less than the dose with the full backscatter material (20.818 g/cm^2) present beyond the point of measurement for 6 and 18 MV X-rays, for a ^{60}Co beam the RED is more by 5.8% with enough backscattering material (15.64 g/cm^2) was present and the value RED increases to 7.5% for 20 × 20 cm^2 field. The reduction in exit dose increases marginally with the phantom thickness through which the beam traverses before exiting at the chamber side. When about 10 and 22 mg/cm^2 of backscattering material present the relative dose could reach the full dose for 6 and 18 MV X-rays.

The dose enhancement factor (DEF) for field sizes ranging from 5 × 5 cm^2 to 30 × 30 cm^2 for the phantom thicknesses of 10, 20 and 30 cm is shown in Figure 3a, 3b and 3c for 6 MV,18 MV and Co-60 gamma rays. The dose enhancement factor (DEF) is the ratio of ionization with a full backscattering of polystyrene material (20.818 g/cm^2) present to that of the ionization recorded without any backscattering medium present beyond the entrance window of the chamber at the exit side of the beam. A dose enhancement factor was increased by 2.7% for 6 MV, 2.8% for 18 MV and 3.2% for ^{60}Co beam with the field size of 5 × 5 cm^2. The DEF values were noticed to vary from 2.7% to 6.5% with field size for 6 MV and by 2.8% to 4.7% for 18 MV. For ^{60}Co beam the DEF values varied from 3.2% to 7.2% with the field size. It was observed that the DEF values do not vary significantly on the thickness of the phantom material through which the beam has traversed.

Discussion and conclusion

At the energy levels studied the primary photons mainly undergoes interaction by Compton process. Though the scattered photons and the Compton electrons travel in the forward direction initially, their energy gets degraded as they travel through the medium due to further interactions. As the energy reduces they undergo backscattering and the amount of which is slightly more for Co-60 gamma rays and 6 MV X-rays compared to 18 MV X-rays. Whenever there is no medium present beyond the exit surface the dose due to the backscattered photons and electrons are absent and this results in less exit dose being measured. When the backscattering material is present, the increase in dose is mainly due to the short ranged back scattered electrons which can be confirmed by the sharp raise in dose enhancement ratio with few millimeters of added phantom thickness at the exit surface. When the phantom thickness is increased further, the slow increase in relative dose is due to backscattered photons and the amount of which depends on the volume of scattering material exposed. The increase in dose gets saturated when the phantom thickness exceeds the range of backscattered photons (Figure 2a, 2b, 2c). The measured variation of relative exit dose was essentially independent of the phantom thickness present in the front side of the point of measurement. This result was similar to that noticed by the other investigators for different photon energies [12, 15]. No strong dependence of dose enhancement factor was found on phantom thickness at the entrance side for all the energies studied (Figure 3a, 3b, 3c).

The study indicates that a reduction of 4.4% and 3.7% in relative exit dose when there is no backscatter material present for 6 and 18 MV X-rays and for ^{60}Co beam the corresponding value found to be 5.8%. The measured exit dose was found to be mostly independent of thickness of the phantom material through which the beam gets transmitted at the entrance side. An addition of backscatter material of thickness equal to two-thirds of the d_{max} depth of the radiation beam concerned will result in full dose at the exit side.

References

[1] Biggs PJ, Ling CC. Electrons as the cause of the observed D_{max} shift with field size in high energy photon beams. Med Phys 1979; 6: 291-295.

[2] Clarkson JR, Herbert RJT. Surface and emergent doses in radiotherapy. Br J Radiol 1948; 21: 494-500.

[3] Gagnon WF, Grant WG. Surface dose from megavoltage therapy machines Radiology 1973; 117: 705-708.

[4] Geode MR, Anderson DW, McCray KL. Corrections to megavoltage depth dose values due to reduced backscatter thickness. Med Phys 1977; 2: 123-126.

[5] Gagnon WF, Hortan JL. Physical factors affecting absorbed dose from cobalt-60 gamma rays and 25 MV X-rays. Med Phys 1979; 6: 285-290.

[6] Gerbi B, Khan F. Measurement of dose in the buildup region using fixed separation plan-parallel ionization chambers. Med Phys 1990; 17: 17-26.

[7] International Commission on Radiation Units and Measurements. Determination of absorbed dose in patients irradiated by beams of X and gamma rays in radiotherapy procedures. 1976 ICRU Report 24 (Washington DC, USA).

[8] Johns HE. Cunningham R. The physics of Radiology (Thomas Springfield, Illinois 1969) 316-317.

[9] Krithivas G, Rao SH. A study of the characteristics of radiation contaminants within a clinically useful photon beam. Med Phys 1985;12: 764-768.

[10] Klein EE, Purdy JA. Entrance and exit dose regions for a Clinac-2100C. Int J Radiat Oncol Biol Phys 1993; 9: 429-435.

[11] Legare JM. Exit-surface-dose correction factors for X-rays of 1.5 to 4.0 mm Cu half value layer. Radiology 1964; 82: 272-276.

[12] Lambert GD, Liversage WE, Hirst AM, Doughty D. Exit dose studies in megavoltage photon therapy. Br J Radiol 1983; 56: 329-334.

[13] Meredith WJ, Massey JB. Fundamental Physics of Radiology (Williams and Wilkins, Baltimore 1972) 413.

[14] Petti PL, Goodman MS, Gabriel TA, Mohan R. Investigation of buildup dose from electron contamination of clinical photon beams. Med Phys 1983; 10: 18-24.

[15] Purdy JA. Buildup/surface dose and exit dose measurements for a 6-MV linear accelerator. Med Phys 1986; 13: 259-262.

[16] Ravikumar M, Ravichandran R. Dose measurements in the build-up region for the photon beams from Clinac-1800 dual energy medical linear accelerator Strahlenther. Onkol 2000; 5: 223-228.

[17] Tannous NBJ, Gagnon WF, Almond PR. Buildup region and skin dose measurements for the Therac 6 linear accelerator for radiation therapy. Med Phys 1981; 8: 378-381.

[18] Velkley DE, Manson DJ, Purdy JA, Oliver GD. Build-up region of megavoltage photon radiation sources. Med Phys 1975; 2: 14-19.