



# Calculation of electron contamination doses produced using blocking trays for 6 MV X-rays

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## Abstract

Calculation of electron contamination doses whilst using blocking trays in radiotherapy is achieved by comparison of measured absorbed dose within the first few centimeters of a water phantom. Electron contamination of up to 28% of maximum dose is produced at the central axis of the beam whilst using a 6 mm Perspex blocking tray for a 30 cm × 30 cm field. The electron contamination is spread over the entire field reducing slightly towards the edge of the beam. Electron contamination from block trays is also present outside the primary collimated X-ray beam with more than 20% of the maximum dose deposited at the surface, 5 cm outside the primary collimated beam at a field size of 40 cm × 40 cm. The electron contamination spectrum has been calculated from measured results. © 2002 Published by Elsevier Science Ltd.

## 1. Introduction

High energy medical linear accelerators are used for the treatment of cancer in radiotherapy. X-ray beams are used to deposit absorbed dose at depth within a patient at the site of the tumor. High energy X-rays produce a skin sparing effect whereby more dose is deposited at depth than in the skin tissue region (Biggs and Russell, 1983; Butson et al., 1996; Nilsson, 1985; Sixel and Podgorsak, 1994). This effect is due to longitudinal disequilibria of electrons excited by the high energy X-rays. When areas such as vital organs not associated with the cancer are within the rectangular collimated field, attenuation blocks, normally made from lead are used to reduce dose delivered to this region. To position these blocks a block tray is required. These trays are normally made from Perspex due to its strength and the fact that it does not significantly attenuate X-ray radiation and is clear. These blocking trays however do interact slightly

with the X-ray field producing electrons which are then incident upon the patients skin depositing a higher dose level to this region than required. This can cause early radiation effects such as erythema or late effects such as telangiectasia (Turesson and Thames, 1989). Using experimental data and Monte Carlo simulations, electron contamination produced with the use of Perspex blocking trays at 6 MV X-ray energy can be calculated and their spectral components evaluated.

## 2. Materials and methods

Measurements were performed with a Varian 2100C linear accelerators which produces a photon spectrum with a maximum energy of 6 MeV. The detectors used for measurement of absorbed dose deposited by the linear accelerator were an Attix parallel plate ionization chamber and radiochromic film.

The Attix parallel plate ionization chamber is constructed primarily from solid water to closely approximate the interaction properties of water itself. The chamber window consists of a 0.025 mm thick, 4.8 mg/cm Kapton conductive film. The conducting surfaces are minimal thickness

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colloidal graphite. The air gap is 1 mm giving an ionization collecting volume of approximately  $0.127 \text{ cm}^3$  which is vented to atmosphere. Its over response due to side wall scatter is less than 1% (Rawlinson, 1992).

The radiochromic film used was Gafchromic MD-55-2 with batch number 970116. Film measurements were made using the AAPM TG-55 recommendations for appropriate precautions in handling, calibration and scanning of the radiochromic film (Niroomand-Rad et al., 1998). The film results were analyzed using a double exposure technique (Meigooni et al., 1996). This is performed by giving each film an initial dose of 5 Gy to ascertain if any corrections are needed due to non-uniformity in dose response (Zhu et al., 1997). A variation of  $\pm 3\%$  (2SD of the mean) was recorded in optical density for the films used in the experiment. The film was analyzed with a 660 nm, 3000 mcd, GaAlAs ultra-bright LED which had been integrated into a Scanditronix RFA300 densitometer (Carolan et al., 1997). A set of standard films were irradiated at each energy used in dose increments of 0.5 Gy to produce an optical density versus dose calibration curve from 0 to 20 Gy. A third-order polynomial function was then applied to the data to produce the calibration curve. The film was left for a period of 24 h before optical density measurements were performed to reduce the effects of post-irradiation coloration (Muench et al., 1991). The effective depth of measurement in MD55-2 is  $0.17 \pm 0.03 \text{ mm}$  water equivalent (Butson et al., 1998). The Gafchromic film was placed perpendicular to the beams path for phantom experiments. The Gafchromic film was handled using soft gloves to avoid fingerprints and other contaminants which affect readout. By attaching a paper or plastic tab on the side of the film with sticky tape, it was easier to handle without touching the film. Gafchromic film is prone to scratching which can also affect the optical density readout. Care was taken not to slide the film on surfaces with any force. Assessment of measured dose using this technique for an applied dose of 10 Gy was found to have a variance of  $\pm 5\%$ .

Experiments were performed in a solid water stack phantom. Measurements were performed with a 6 mm thick Perspex blocking tray in the field. The blocking tray is positioned 65 cm from the X-ray source and is perpendicular to the beam direction. It fully covers all the X-ray beam up to  $40 \text{ cm} \times 40 \text{ cm}$  fields at isocenter without any other material entering the X-ray beam. Dose readings were taken in 1 mm intervals from the surface to 15 mm depth in the phantom for field sizes ranging from  $5 \text{ cm} \times 5 \text{ cm}$  up to  $40 \text{ cm} \times 40 \text{ cm}$  which covers most clinical treatment field sizes. All experiments were performed at 100 cm source to phantom surface distance. To remove electron contamination from the beam a magnetic deflector device was used on the head of the linear accelerator. This device produced a field strength up to 0.6 T perpendicular to the beams direction, thus forcing the electron contamination to be swept away from the X-ray beam (Butson et al., 2000). By comparison of the depth dose curves produced with the magnetic

field on and off, the contribution to skin and build up dose from electrons produced by the blocking trays can be determined. The spectral components of the electron contamination produced by blocking trays can then be ascertained by comparing depth dose results to Monte Carlo simulated mono-energetic electron beams. A Marquardt (1963) algorithm, which uses an iterative subtraction process, is used to produce the spectrum of best fit. That is, it assigns a weighting to each depth dose produced by each energy component and matches the results to experimental data. Monte Carlo simulations were performed using Electron Gamma Shower 4 (EGS4) code. For each mono-energetic electron beam, 20 million histories were scored in voxels of dimensions  $2 \text{ cm} \times 2 \text{ cm} \times 0.05 \text{ cm}$  thickness. The electron cut off energy was set to 20 keV for all simulations.

### 3. Results and discussion

Fig. 1 shows four representative percentage dose build up curves for a  $10 \text{ cm} \times 10 \text{ cm}$  and a  $30 \text{ cm} \times 30 \text{ cm}$  field with the magnetic field on and off with the 6 mm blocking tray at 6 MV energy. All experimental results are normalized to 1.5 cm depth. Experimental results with the magnetic field applied compared to no magnetic field have shown that the contribution to dose at 1.5 cm depth from electron contamination is negligible for all field sizes used. Errors shown are 2SD of the mean for 5 experimental data set measurements taken on five separate occasions. Results are measured at the central axis of the beam using the Attix parallel plate ionization chamber. As can be seen, only a relatively minor change in percentage dose in the build up region is seen for smaller field sizes (6% of maximum dose for  $10 \text{ cm} \times 10 \text{ cm}$ ). This decreases to 4% for a  $5 \text{ cm} \times 5 \text{ cm}$  field size. However, as the field size increases, the changes in build up dose increase with the  $30 \text{ cm} \times 30 \text{ cm}$  field producing up to 28% of maximum change in percentage dose. This increases to

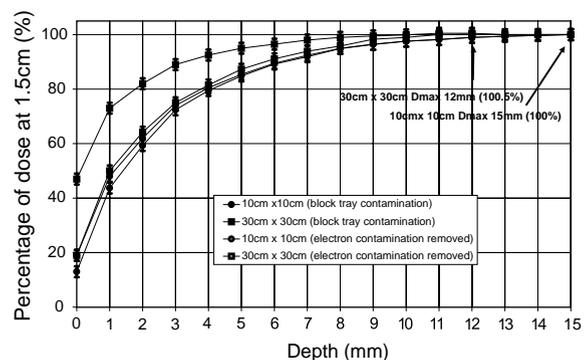


Fig. 1. Build up dose curves produced by a medical linear accelerator for a  $10 \text{ cm} \times 10 \text{ cm}$  and  $30 \text{ cm} \times 30 \text{ cm}$  field with a 6 mm Perspex blocking tray. Build up curves were measured with and without an applied magnetic field.

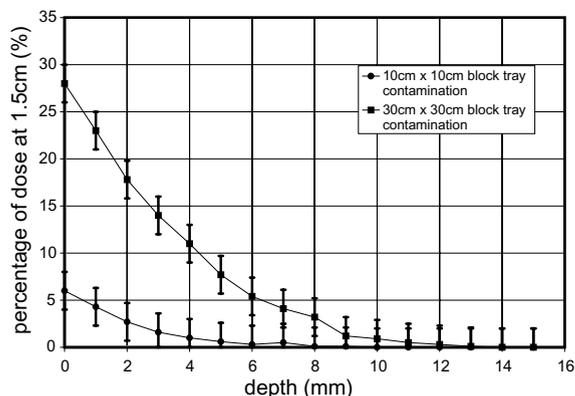


Fig. 2. Percentage contribution in the build up region of electron contamination compared to total dose at 1.5 cm from the blocking tray at 6 MV energy.

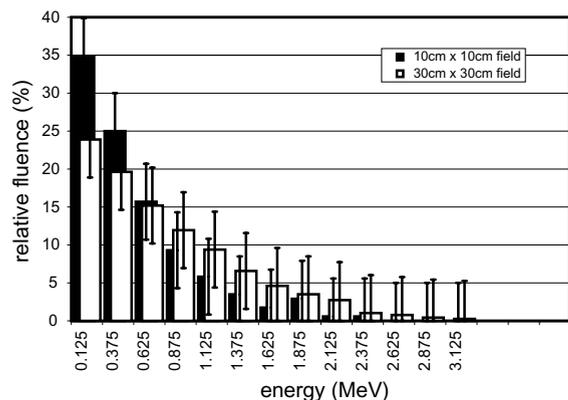


Fig. 3. Derived energy spectrum of electron contamination produced by the blocking trays at 6 MV energy.

32% of maximum for the largest field (40 cm × 40 cm). Fig. 2 shows the percentage dose produced by electron contamination whilst using the blocking tray in the build up region. This is the subtraction of absorbed dose with the magnetic field from no magnetic field. Again this figure highlights the larger effect produced by larger fields. The Perspex tray produces a spectrum of electron contaminations which deposit their dose at various depths. It also absorbs low energy electron contamination produced above and incident towards it. Not only does the blocking tray produce ‘primary’ electron contamination interactions but it would also produce secondary electron contamination from interactions of the low energy scattered photons with the air column and by production of knock-on electrons in the air column from both these sources of contamination.

Fig. 3 shows the derived electron contamination energy spectrum produced by the blocking tray for the 10 cm × 10 cm and 30 cm × 30 cm field size. This is obtained from

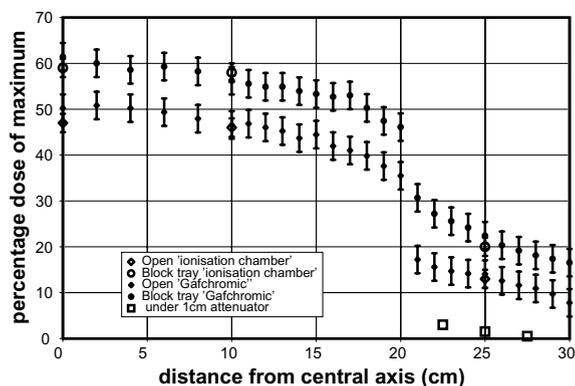


Fig. 4. Off axis and peripheral dose produced by a medical linear accelerator at the skin level for a 40 cm × 40 cm beam at 6 MV X-ray energy.

comparison of Monte Carlo (EGS4) simulations of mono energetic electrons and measured data. The relative fluence of each electron component can be approximated by correlation of the percentage attenuation of the beam in the build up region to the electron ranges of the mono-energetic beams. The percentage attenuation of electrons from depth  $d_i$  to  $d_{i+1}$  corresponds to the relative abundance of electrons with energy range  $E_i$  to  $E_{i+1}$ . Therefore, by comparing these two quantities an approximation of the energy spectrum can be ascertained. Due to the uncertainties in measurement, a high degree of error is seen in the calculation of the energy spectra. However, a general trend follows which shows a higher fluence of low energy electrons for both field sizes shown.

Fig. 4 shows the distribution of skin dose using blocking tray field both within the field and in peripheral regions for a 40 cm × 40 cm field. The effective depth of measurement for the Gafchromic film is approximately 0.15 mm. The electron contamination produced extends beyond the geometric field size of the beam, depositing dose in peripheral regions. Measurements were performed with Gafchromic film and the Attix chamber to produce a dose profile in the regions of interest. As this electron contamination is normally unwanted dose for radiotherapy and due to the low energy nature of these electrons, peripheral doses could easily be removed by placement of a flexible material of approximately 1 cm thickness over the peripheral regions of the patient. Fig. 4 also shows the dose under this material in peripheral regions with a maximum of 3% deposited using this technique for dose reduction. This material acts as an absorber to reduce dose from electron contamination to the patients skin from this sight.

#### 4. Conclusions

Blocking trays used in radiotherapy produce electron contamination. Their energy spectrum for various fields has

been defined. To minimize dose deposited by electron contamination in peripheral regions, an attenuation material could be easily placed over the patients skin thus absorbing most of this dose.

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