Radiation Measurements 51-52 (2013) 48–54

Contents lists available at SciVerse ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

# Monte Carlo investigation of the effect of small cutouts on beam profile parameters of 12 and 14 MeV electron beams

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## HIGHLIGHTS

► Mesh Tally 1 and *pedep* keyword were used to calculate the PDD and profile values.
► In measurement the coverage for larger fields and fewer doses are better.
► By increasing the depth, the flatness and symmetry values were increased.
► The worst flatness and symmetry (between 3 compared shapes) belonged to triangle.
► The given Penumbra and Coverage Ratio can be helpful for PTV margin and coverage.

## ARTICLE INFO

*Article history:*
Received 28 May 2012
Received in revised form
10 January 2013
Accepted 21 January 2013

*Keywords:*
Electron beam
Flatness
Symmetry
Profile
Monte Carlo
MCNP

## ABSTRACT

Cutouts, which are used as field-shaping shield, affect several electron beam parameters. These effects are more observable for small field sizes and high energy electron beams. Owing to the fact that small fields prevent the lateral scatter equilibrium, at higher energies larger field radius is required for the establishment of lateral equilibrium.

The profile curves are derived from circular, triangular, and square cutout shapes and size placed in a 10 × 10 $cm^2$ electron applicator. These profile curves are obtained using parallel plane type ion chamber at the $R_{100}$, $R_{90}$, $R_{80}$ and $R_{50}$ depths. Correspondingly, the source surface distance is 100 cm.

In this study MCNP Monte Carlo (MC) simulation was used to compare Percentage Depth Dose (PDD) and Profile of electron beams.

Monte Carlo and measured results showed a good compliance for PDD and beam profile. The measurements and calculations showed that as the field width decreases, the Flatness and Penumbra Ratio also decreases. In other words, flatter plateau was available for larger fields. Also the Coverage Ratio for each of the profiles is presented. The flatness and symmetry values for triangle shapes were greater than the two other shapes.

Knowledge of these changes are significant in radiation therapy. Accordingly, a comparison between the Monte Carlo data and the measured results can be beneficial for treatment simulation and development of treatment planning systems.



## 1. Introduction

In Radiation Therapy for the treatment of both shallow lesions (superficial tumors) and lesions close to organs at risk, Cerrobend cutouts may be used. The size and shape of cutout depends on the shape and position of the tumor. Cerrobend is a fusible alloy usually containing Tin, Lead, Bismuth, and Cadmium. Minimum thickness of lead required to stop all of the electrons is obtained from the following empirical formula (Khan et al., 1991):

$$t_{lead}(mm) = \frac{E(MeV)}{2} \quad (1)$$

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http://dx.doi.org/10.1016/j.radmeas.2013.01.019

In this equation, $E$, in MeV, is the most probable energy of the impinging electron beams at the phantom surface in the absence of a shield. Since the density of lead is 11.35 g/cm$^3$ and the density of Low-203 type cerrobend is 9.85 g/cm$^3$, the minimum cerrobend thickness required to stop electrons is obtained from the following formula:

$$t_{\text{cerro.}}(\text{mm}) = \frac{E(\text{MeV})}{2} \times \frac{11.35}{9.85} = 0.58E \quad (2)$$

Only X-rays produced in the shield may contribute to the dose delivered to the patient.

We employed the MCNPX (Hendricks et al., 2008; Pelowitz, 2008) Monte Carlo (MC) code for simulating the percentage depth dose (PDD) and transmitted electron beam profile through the small cutouts at $R_{100}$ and $R_{50}$ depths.

Penumbra, dose coverage, flatness (indicator for the flatness of a profile), and symmetry (indicator for the symmetry of a profile) are expected to change by using the small cutouts. These changes arise from lack of lateral scatter equilibrium (Chow and Grigorov, 2007; Rashid et al., 1990; Sharma et al., 2005; Xu et al., 2009). The minimum radius ($R_{eq}$) for the establishment of the lateral scatter equilibrium is obtained from the following equation (Khan, 2012):

$$R_{eq} \approx 0.88 \times \sqrt{E_{p0}} \quad (3)$$

Where, $E_{p0}$ is the most probable energy at the phantom surface.

When the radius of the radiation field is smaller than $R_{eq}$, we expect specific changes in the beam profile parameters (Chow and Grigorov, 2007; Rashid et al., 1990; Sharma et al., 2005).

It seems that there have been no comprehensive studies performed regarding flatness, symmetry, penumbra ratio (PR), and coverage ratio (CR), for LINAC electron beams. Penumbra ratio is defined as the residuum of D20% and D80% for each of the given profiles relative to cutout width, and coverage ratio is the ratio of a given isodose line width to the cutout width. Only a few studies have been carried focusing directly on this matter. Xu et al. (2009) investigated the effects of cutouts on the 6 MeV electron beam factors such as PDD, output, and profile beam and concluded that the cutouts increase $PR_{80-20}$. Also, for the diameters smaller than 3 cm the therapeutic field is less than 50% of field size, and finally the rest is outside of the 90% penumbra. In addition, a study by Sharma et al. has shown that the flatness, symmetry, and penumbra ratio is increased by reducing the size of cutout for a 6 MeV electron beam (Sharma et al., 2005).

Lee et al. investigated a method for simulating very small fields (around a few millimeters) which can be beneficial for small animals like mice (Lee et al., 2011). Their work was performed both for 6 and 18 MeV electron beams delivered by a Varian 2100 C/D LINAC and by employing the BEAMnrc MC code and dosimetry phantom.

A comparison between some physical concepts of radiation therapy as well as changes in beam profiles for 5 × 5, 10 × 10 and 20 × 20 cm$^2$ fields was done by Chen et al. (2007).

Chow et al. studied on profile and PDD changes due to shifting of cutouts from central axis (CAX) through the in-line axis and cross-line axis. The electron beam energy used was 16 MeV and a 6 × 6 cm$^2$ applicator with 4 cm diameter cutout. In the end, the beam profile change was observed in cross-line and in-line axis directions (Chow and Grigorov, 2007).

## 2. Materials and methods

In this study, circular, square, and triangular cutouts were used (see Fig.1). The 12 and 14 MeV electron energies of Siemens Primus LINAC was applied, and the applicator size was 10 × 10 cm$^2$.

The cutouts were made of cadmium-free cerrobend alloy with the melting point of about 95 °C.

### 2.1. Monte Carlo Simulations

Several Monte Carlo simulation softwares such as GEANT (Agostinelli et al., 2003; Giani et al., 1998), FLUKA (Ferrari et al., 2011), BEAMnrc (Rogers et al., 2005), and MCNPX (Hendricks et al., 2008; Pelowitz, 2008) were used for radiation and particle transport calculations. The MCNPX code, version 2.6 was used for simulating particle transport and interaction of radiation with matters.

The first simulation was aimed at calculating the mean energy and spectral distribution of the beam.

After the bending magnet (before electrons strike to the primary scattering foil) the energy distribution of output electrons from the linear accelerator is a Gaussian spectrum (Becker, 2007; Sheikh-Bagheri and Rogers, 2002). Since the Gaussian distribution is a symmetric distribution, the position of the peak energy is equal to the mean energy of the spectrum. The spectral shape of electron would change after colliding with Primary Scattering Foil and then with Secondary Scattering Foil (h and g in Fig. 2). Owing to this fact the value of mean energy and full width at half maximum (FWHM) of the electron beam should be calculated before scattering by primary scattering foil. In order to validate model employed for the numerical simulations the agreement between the simulated and measured PDD and simulated and measured beam profile should be provided.

We started the simulation by using the mean energy values introduced in Faddegon et al. study (2009), and repeated the computation by changing the mean energy and FWHM several times to match the depth of 50% dose ($R_{50}$) and practical range ($R_p$) for both simulation and measurement PDD curves (Faddegon et al., 2009; Lee et al., 2011). By using this method the results were as follows: FWHM values were %6 of peak energy (peak energy = 12.35 MeV) and %5.1 of peak energy (peak energy = 14.65 MeV) for 12 MeV and 14 MeV beam, respectively.

The electron scattering and the photon contamination leads to adding up the lower energy spectra to the main Gaussian spectrum. So that the most probable energy (peak energy) at phantom surface ($E_{p0}$) for 12 and 14 MeV electron beams are 11.53 and 12.66 MeV, respectively, which were calculated from their PDD curves.

**Fig. 1.** Circular, square and triangular cutouts.