OPTIMIZATION OF DUAL SCATTERING FOIL FOR 6 TO 20 MeV ELECTRON BEAM RADIOTHERAPY

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Abstract

From last 50 years, electron beam therapy has an important radiation therapy modality. The electron beam from the LINAC is of size $\sim$ 2 mm, whereas the size required for actual treatment is usually larger than 2×2 cm^2 up to 25×25 cm^2 at the isocenter. In the present work, it is proposed to use dual scattering foil system for production of clinical electron beam. The foils for 6 to 20 MeV electrons were optimized using the Monte Carlo based FLUKA code. The material composition, thickness of primary foil, Gaussian width and height of secondary foil were optimized such that it should meet the design parameters such as dose at isocenter, beam uniformity, admixture of bremsstrahlung, etc. In conclusion, the primary scattering foil has been optimized with high Z element (Ta) having uniform thickness, whereas the secondary foil has been optimized with low Z element (Al) having Gaussian shape.

INTRODUCTION

For the last several years electron accelerators are extensively used in the medical field with special applications of electron and photon beam to cancer therapy and various skin diseases. In radiation therapy, broad and uniform beams are generally required, particularly when treating large tumor masses. This is mainly due to the very steep dose-response relation observed for both normal and malignant tissues. The initial particle beam delivered by most electron accelerators is generally quite narrow and non-uniform. One of the most fundamental tasks in the design of high quality therapeutic electron beam is generation of broad uniform beams of varying sizes.

Naturally, the most flexible and general way to achieve broad beams is by scanning or wobbling a narrow pencil beam over the cross-section of the target volume to obtain a flat radiation field. A brief review of early electron beam flattening techniques for use in radiation therapy was presented by Brahme [1] and Ma [2]. During the early seventies a technique was developed for electron beam flattening using shaped scattering foils. It was first used for betatrons, which have a broad fan like electron beam at extraction. Unfortunately, this technique does not work for accelerators with a narrow initial electron beam. However, by using dual scattering foils the technique was later developed and optimized for accelerators with a narrow initial beam width. It was first used on microtrons and later also on linear accelerators by using two scattering foils of accurately chosen thicknesses and profiles [1]. Today this technique is the dominating one on clinical electron accelerators as it improves the beam quality significantly over the single scattering-foil systems. Dual scattering foil not only can make the beam flat, but also reduced the required total foil thickness. Consequently, the loss in beam energy is considerably reduced and the beam quality improved due to the lower energy spread.

The objective of this paper is to optimize the scattering foils for 6-20 MeV electron beam. The thickness and shape of the foils were calculated using Monte Carlo based FLUKA tool. The intention was to meet the following specifications while maintaining a reasonable dose rate and a treatment distance within the constraints of the treatment room.

- The field size of the composite electron beam at the patient treatment plane must be approximately 25×25 cm^2.
- The most probable energy (E_P) of the electron energy spectrum at Source to Surface Distance (SSD) of 100 cm should be 6, 12 and 18 MeV.
- The maximum percentage variation of the electron beam intensity at SSD of 100 cm should not exceed 5% (within the 80% of the longitudinal and transverse axes relative to the central axis) for field size of 25×25 cm^2 for all electron beam energies.
- The X-ray contamination should be less than 5% of the maximum electron dose for all beam energies.

MATERIALS AND METHODS

The majority of practical problems connected with the passage of electrons through materials were easily solved by Monte-Carlo methods. Therefore, a computer code called FLUKA, allowing a suitable simulation of the entire process and is based on Monte Carlo technique is useful tool for calculations of scattering of electrons. The major advantage of this method is the opportunity of calculating generation of the secondary radiation and most complex geometrical borders of a target. Therefore, we investigate a designated problem with the help of a FLUKA tool which can simulate passage of 60 different particles through layered targets. Also, it can handle the accurate Multiple Coulomb Scattering of charged particles, electron-nucleus and electron-electron bremsstrahlung over the whole energy range [3].

The Linear accelerator and beam bending magnet system provides electron beam in vertical direction which further

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passes through scattering foils and other accelerator head assembly to generate clinically application electron beam. The schematic of the components in accelerator head assembly for electron beam therapy is shown in Fig. 1.

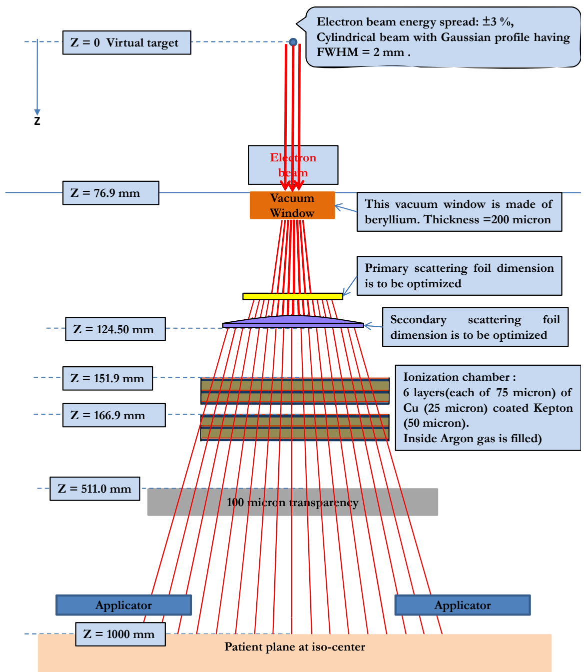

Figure 1: Schematic of the components in accelerator head assembly for electron beam therapy facility.

DUAL SCATTERING FOIL SYSTEM

Electrons while passing through the scattering foil, undergo multiple coulomb scattering and therefore the pencil beam is converted in to a beam of Gaussian profile. The area of the beam increases with the distance between the scattering foil and the surface on which electron falls.

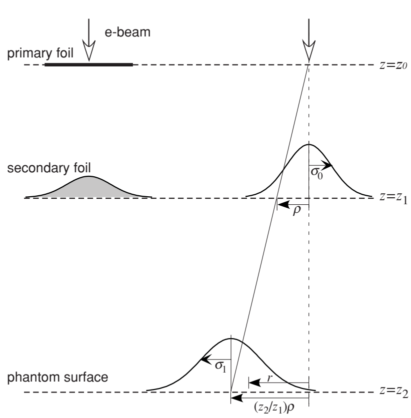

Figure 2: A diagram to define the parameters in the geometry of the dual scattering foil system (left) and the profile of the scattered beam (right).

However, uniform intensity of electrons is required for the therapy applications and therefore instead of single scattering foil, a dual scattering foil system is employed. Uniform thickness of primary scattering foil broadens the electron beam into Gaussian profile. The secondary foil is of Gaussian shape with varying thickness; maximum at the center and minimum at the edges. Fig. 2 illustrates the effect of the secondary scattering foil on the Gaussian beam profile generated by the uniform primary scattering foil. Electrons falling at and around the centroid of secondary foil will experience maximum scattering events, whereas those falling at the tail will experience minimum scattering events. As a result the profile of the electron beam is reasonably flat over the designated field area of 25×25 cm^2, with sharp fall off at the edges of the field.

RESULTS

The foil parameters were adjusted using a method based loosely on the technique recommended by Kozlov and Shishov [5] , so as to achieve the desired foil shape in a reasonably efficient manner. At first the primary scattering foil has been optimized by FLUKA simulation in absence of secondary foil. The materials such as gold, tantalum, and lead were studied for primary scattering foil. The 2 mm diameter electron beam is allowed to fall on the material. The simulation was carried out for calculating the relative electron fluence at the edges of treatment field size. The edge of the treatment field size is at radius $12.5\sqrt{2}$=17.7 cm at (SSD=100 cm). The thickness of the primary scattering foil at which relative electron fluence at edges of the proposed treatment field size becomes approximately 60 % has been optimized. The scattering foils were designed to obtain the treatment field size of 25×25 cm^2. Based on the results of bremsstrahlung production and electron energy loss in the scattering foil, the gold and tantalum were found to be the best materials for primary scattering foil. For further simulation, the tantalum has been optimized as primary scattering foil. The thickness of 40, 130, and 260 micron of tantalum scatterer has been optimized for the electron beam of 6, 12 and 18 MeV respectively.

Using the optimized primary scattering foil for each electron energy, the respective simulation for the optimization of secondary foil was carried out. The radius (R) and height (H) of the Gaussian shape scattering foil was optimized such that the relative height of the electron fluence profile at the edges of the treatment field is 95 % of the central-axis value. The shape of the smooth-Gaussian secondary foil was approximated as three equally thick beveled disks stacked top each other. This was done to facilitate modeling of the secondary foil geometry in the FLUKA Monte Carlo user code. For each layer of the foil, the inner (proximal) and outer (distal) radii were determined. A listing of the electron beam energies alongwith the optimum dimensions for a tantalum as primary and aluminium as a smooth-Gaussian secondary foil that scatter the beam into a circular field of radius 17.7 cm at the

Table 1: A listing of the electron beam energies along with the optimum dimensions for primary and secondary foil.

Parameter	6 MeV	12 MeV	18 MeV
Energy	6	12	18
Primary foil (Ta) thickness (micron)	40	130	260
Secondary foil (Al) width R (cm)	0.50	0.50	0.55
Secondary foil (Al) height H (micron)	3000	3600	4500
Electron Energy loss (keV)	841	1410	2061
Electron Dose (Rad/min) for 0.1 μA	204	261	251
Bremsstrahlung Dose (Rad/min) for 0.1 μA	0.7	3.9	9.8

phantom surface is shown in Table 1. The bremsstrahlung dose generated due the optimized scattering foils along with electron dose was also calculated and shown in Table 1. It is found to be less than 5 % of maximum dose delivered by electron. The separation between the primary and secondary foil was kept 4.0 cm because both the scattering foils are to be fitted in rotating carousel.

The scattered electron fluence profile using respective optimized foils for 6, 12 and 18 MeV electron beam is shown in Fig. 3. The profile is calculated at 100 cm SSD

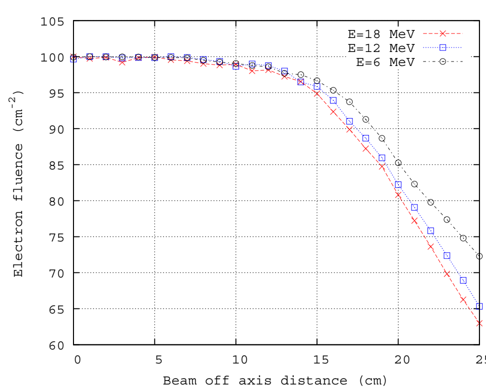

Figure 3: Electron fluence profile along the radius at 100 cm SSD for the optimized primary scattering foil and primary + secondary scattering foil for 6, 12 and 18 MeV.

in FLUKA simulation. Variation in relative electron fluence is less than 5 % for each case of electron energy. The depth dose curve has also been calculated in water phantom kept at 100 cm of SSD. The depth dose curve for 6, 12 and 18 MeV electron beam is shown in Fig. 4. It is observed from figure that the distance in water phantom at which maximum dose deposited is varying between 1 to 4 cm with incident electron energy. For higher electron energy the distance is found to be higher. The electron energy spectra calculated at 100 SSD is shown in Fig. 5.

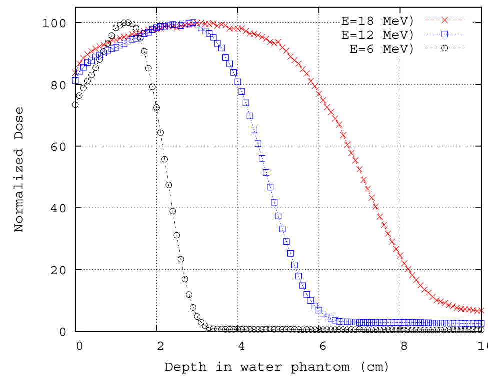

Figure 4: Depth dose curve for 6, 12 and 18 MeV electron beam.

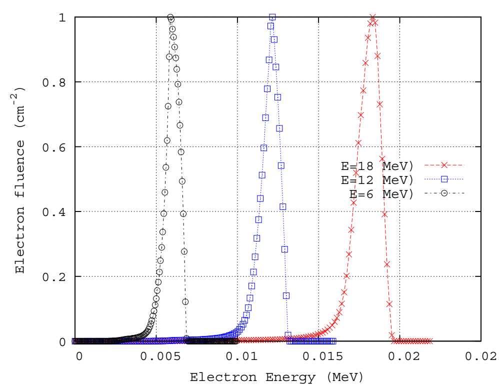

Figure 5: Electron energy spectra at 100 cm SSD.

CONCLUSION

Detailed study on the optimization of primary and secondary scattering foil was carried out. The respective scattering foils were optimized such that it can scatter the electron beam to 25 × 25 cm^2 field size with uniformity more than 95%. In addition, the bremsstrahlung dose generated in this foil is obtained less than 5% of electron dose. The energy of the electron profile is maintained around 6, 12, and 18 MeV.

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