Electron contamination fluence evaluation of flattening filter free (FFF) configuration of Linac head

Mohamed BENCHEIKH *, Abdelmajid MAGHNOUJ, Jaouad TAJMOUATI, Abdessamad DIDI and Abdesslam LAMRABET

LISTA Laboratory, Physics Department, Faculty of Sciences Dhar El-Mahraz, University of Sidi Mohamed Ben Abdellah, Fez, Morocco
*Corresponding e-mail address: bc.mohamed@gmail.com

Abstract

The Monte Carlo calculation method is considered the most accurate method for photon beam modelling and dose calculation in radiotherapy, in this study, the Varian Clinac 2100 medical linear accelerator was modelled with and without flattening filter (FFF). The purpose of this study is to determine the removing flattening filter impacts on the fluence properties of photons, electrons and positrons at the phantom surface.
The removing flattening filter from Linac head gives way to photons, electrons and positrons. At the phantom surface, the photon fluence of Linac head without flattening filter increased up to 80% of that of Linac head with flattening filter; however, the electron fluence increased more than 250% of that of Linac head with flattening filter. At the phantom surface for the FFF configuration of Linac head, the photon beam is more contaminated by electrons and photons of low energy even the delivered dose is higher.

Keywords: Monte Carlo simulation, Electron contamination, BEAMnrc code, Positron contamination, FFF Linac head.

Introduction

Recent advances in radiation therapy techniques have increased the irradiation time and workload for linear accelerators. Therefore, reducing the treatment time and workload is a challenging issue in radiotherapy physics. In the medical linear accelerator, the photon beam is produced by energetic electrons striking a target generally constructed of tungsten due to its high atomic number to facilitate the production of photons by bremsstrahlung. The photon beam travelled inside the Linac head and reached water phantom

Several studies have evaluated the effects of removing flattening filter from Linac head (FFF Linac configuration) on energy characteristics of photon beams at phantom surface [1] The Monte Carlo (MC) method is a powerful tool for analyzing the particle characterizations and to study Linac technology [2,3]. The Monte Carlo methods used are considered the most accurate method for predicting dose distributions for treatment-planning purposes [4, 5]. In this work it is was performed with BEAMnrc code for modelling Varian Clinac 2100 [6], for investigation the removing flattening filter impacts on photon beam quality and it was in terms of fluence profile.

Materials and methods

After building the Monte Carlo geometry of 6 MV photon beam Varian Clinac 2100 with flattening filter by BEAMnrc and representing the Linac head model as realistically as possible, the flattening filter was removed from Monte Carl model for investigating the flattening filter effects on the electron and photon numbers at phantom surface. The field size was 10×10 cm^2 and the distance source surface (SSD) was 100 cm. The physical process simulation was based on the EGSnrc code [7], the transport of radiation was simulated the as realistically as possible.

1. Monte Carlo simulation

Varian Clinac 2100 Monte Carlo simulation validation was performed using gamma index method as a technique for quantitative evaluation of comparison of calculated dose distributions to measured dose distributions. Gamma index acceptance rate was almost 99% for percentage depth dose (PDD) and almost 98% for beam dose profiles [8]. The Varian Clinac 2100 Monte Carlo geometry was validated according to tolerance limit recommended by IAEA in TRS430 [9] and in IAEA-TECDOC-1583 [10].

The Linac Monte Carlo simulation generates the phase space file (PSF) that contained particles' information, it was used to calculate dose distributions by DOSXYZnrc code and determinate particles' properties and characterization by BEAMDP [11].

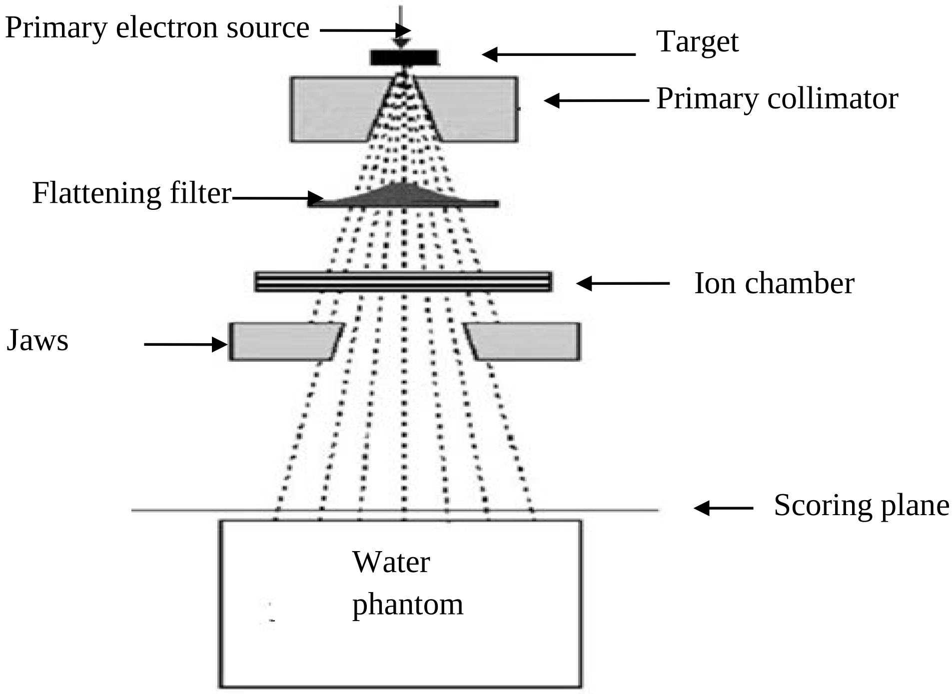

Figure 1: Monte Carlo geometry scheme including the Linac head and the position of the scoring plane for the phase space file and water phantom.

A representation of the Linac head and its components are shown in Figure 1. The head's components, including the target, primary collimator, flattening filter (FF), ion chamber, and secondary collimator (jaws), were simulated based on manufacturer-provided information by the BEAMnrc code, the number of histories used for BEAMnrc of 3×10^9. This number is sufficient to reach à statistical uncertainty of Monte Carlo simulation of 1% as found by M. Aljamal et al. [12]

2. Particle characterization study

After validation of Monte Carlo geometry of Varian Clinac 2100 in our previous work [13] and based on phase space file (PSF) generated by BEAMnrc code, the fluence of photons, electrons and positrons were determined at phantom surface using BEMADP code.

For good interpretation of obtained results, the local difference between with FF Linac configuration and without FF Linac configuration, which called FFF Linac configuration, was determined as a function of off-axis distance according to the following formula:

$$Local\ difference\ (r)\ (\%) = 100\ \times \frac{(\emptyset_{FFF}(r) - \emptyset\ (r))}{\emptyset\ (r)} \quad (1)$$

Where,

$\emptyset_{FFF}(r)$: fluence at off-axis distance r for FFF Linac configuration.

$\emptyset(r)$: fluence at off-axis distance r

Results and discussion

1. Beam fluence study

For all parameters, the evaluation was done at the water phantom surface for field size of 10×10 cm^2, source-to-surface distance (SSD) of 100 cm and nominal beam energy of 6 MV. Based on phase space files (PSF), the beam fluence (photons + electrons + positrons) was determined at water phantom surface (SSD =100 cm).

The figure 2 shows the beam fluence for both Linac configurations with FF and without FF.

Beam fluence profile of FFF Linac configuration (without FF) is higher than beam fluence of Linac configuration with FF with off-axis distance. The question may be put in this case, what is the origin of this increasing of the beam fluence of FFF Linac configuration?

For answering to the above question, we have studied the photons, electrons and positrons fluence with off-axis distance for both Linac head configurations.

2. Photon fluence profile

Figure 3 shows the photons fluence profiles for both Monte Carlo simulations with and without FF.

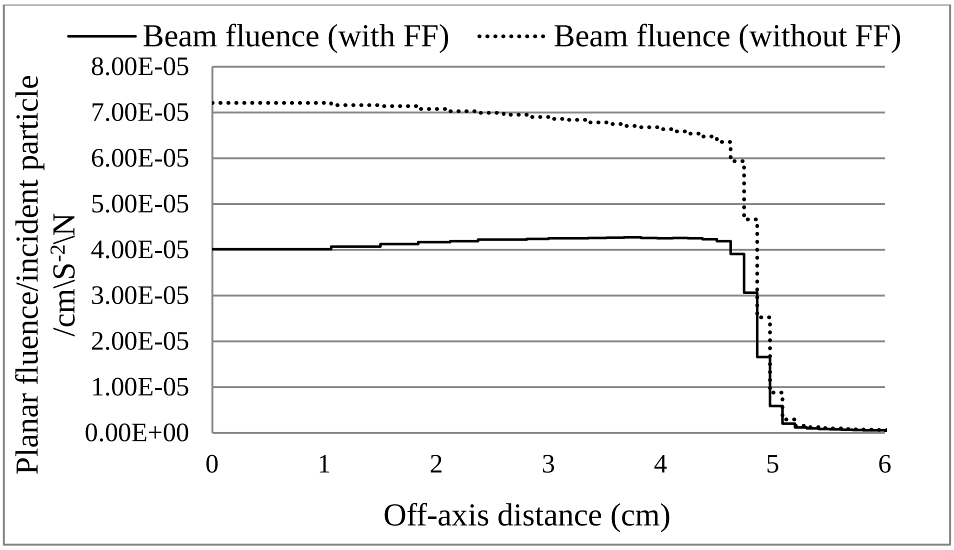

Figure 2: The planar beam fluence profiles as a function of off-axis distance.

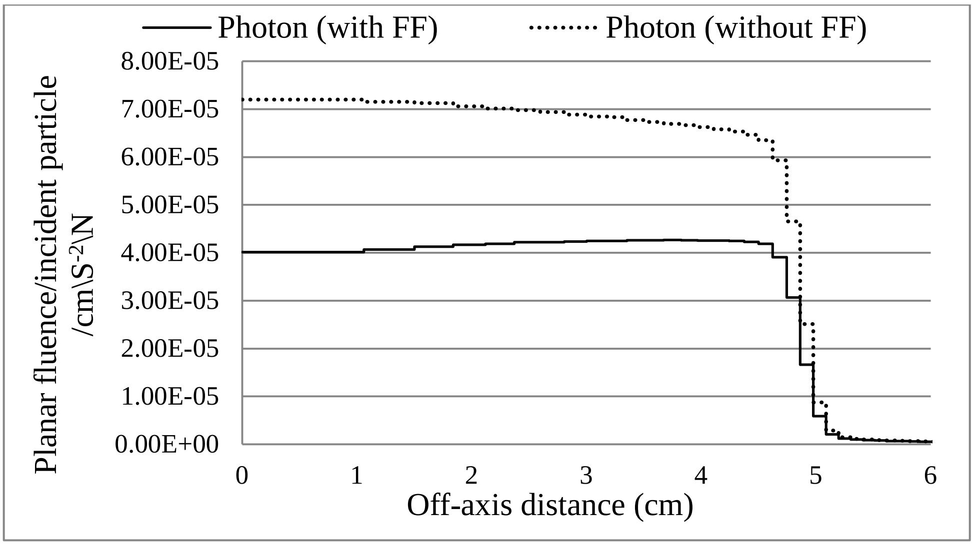

Figure 3: The planar photon fluence profiles as a function of off-axis distance.

It is natural that photons number (fluence) increases for FFF Linac configuration because the main particles in the beam are photons for megavoltage (MV) beam. These results are in coherent with IAEA protocols [9, 10, 13], and for the radiotherapy quality [14].

3. Electron fluence profile

Figure 4 gives the variation of electron fluence with off-axis distance for both Linac configurations with FF and without FF (FFF Linac configuration)

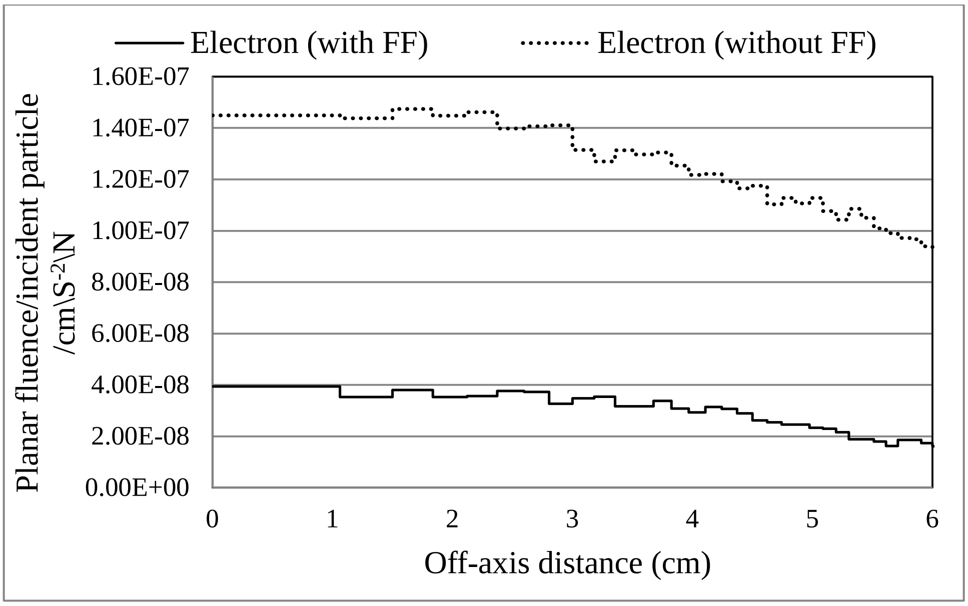

Figure 4: The planar electron fluence profiles as a function of off-axis distance.

The electrons number is higher for FFF Linac configuration than the Linac head configuration with FF. In next paragraph, the positrons fluence will be evaluated with off-axis distance.

4. *Positron fluence profile*

Figure 5 shows the variation of positron fluence as a function of off-axis distance for both Linac configurations with FF and without FF (FFF Linac configuration).

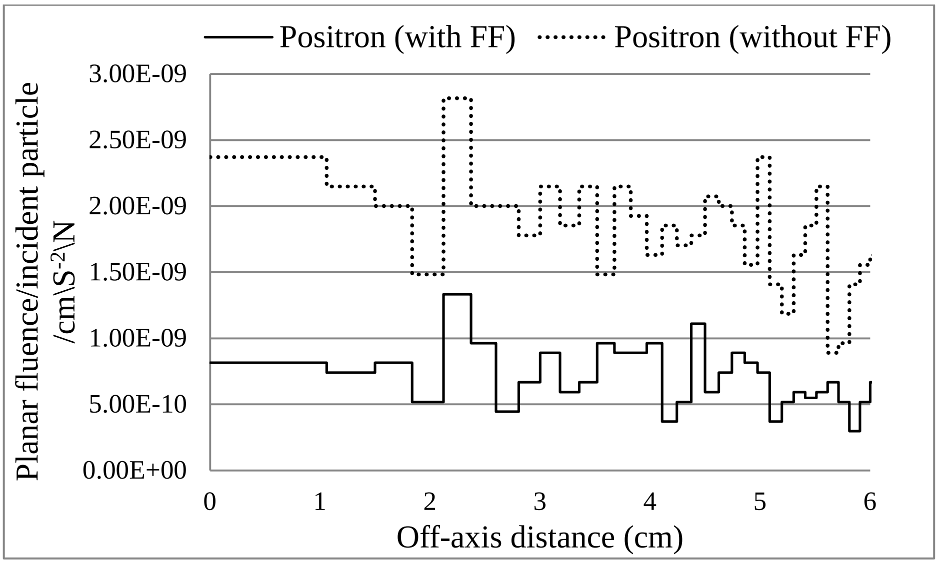

Figure 5: The planar positron fluence profiles as a function of off-axis distance.

In this case, the positron fluence is higher for FFF Linac configuration. For more understanding the impacts of removing flattening filter, we have evaluated the increasing rate of each particle in terms of the local difference between both Linac configurations as a function of off-axis distance.

5. Increasing rate evaluation and analysis

For describing the increasing fluence rate for each particle type, the local difference was determined as a fluence deviation of FFF Linac configuration according to formula (1). The local difference was evaluated as done in our previous work [15].

Figure 6 gives the local difference variation as a function of off-axis distance for photons.

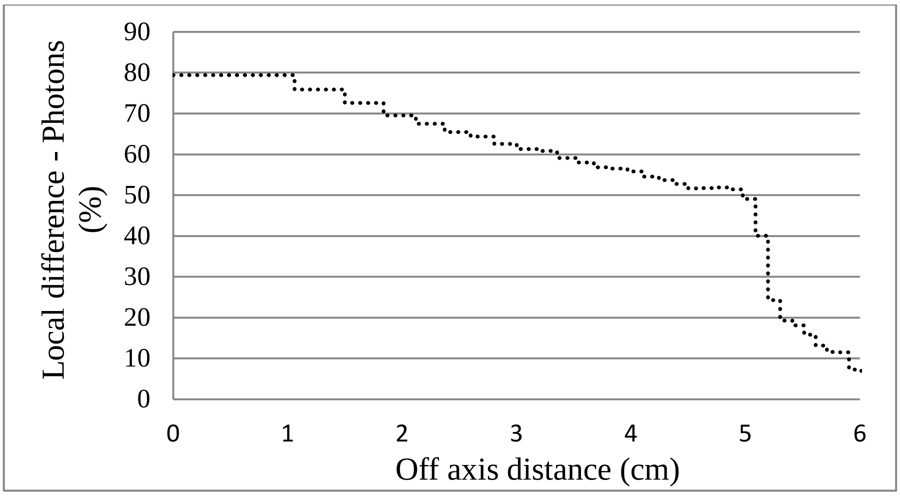

Figure 6: Local difference variation as a function of off-axis distance for photons.

From figure 6, the photons number increases up to 80% in comparison to with FF linac configuration. However, the local difference for photons decreases with off-axis distance and attains 10% in out-of-field region. This region is generaly caracteriased by the leackage photon presence [16].

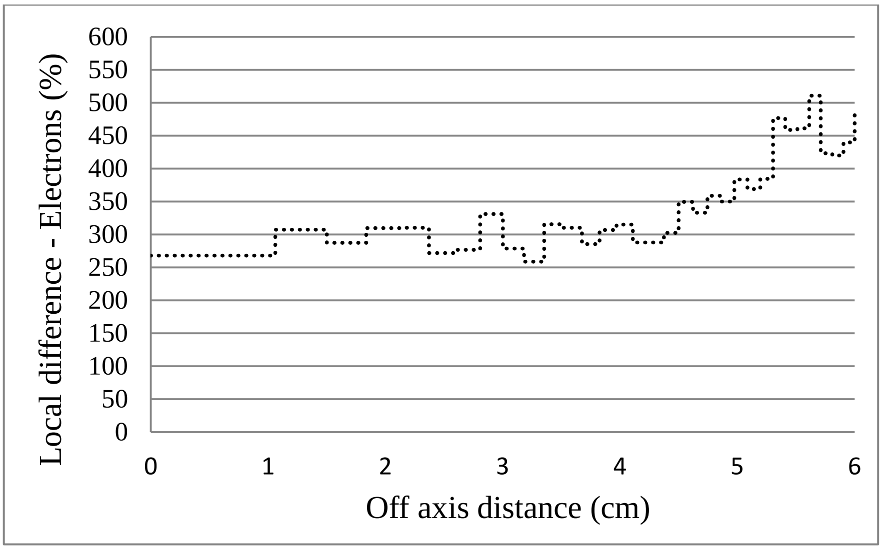

Figure 7: Local difference variation as a function of off-axis distance for electrons.

In FFF Linac configuration, the electrons number climbs to more than 250% of electrons number of with FF Linac configuration (Figure 7). The electron fluence increases with off-axis distance in opposition to local difference of photons. We notice from figures 6 and 7 that the increasing rate of electron fluence is high in comparison to increasing rate of photon fluence. The beam thereafter was more contaminated and especially nearby the beam edge when FF is removed from the Linac head.

Figure 8 gives the local difference variation between FFF Linac configuration and Linac configuration with FF as a function of off-axis distance for positrons.

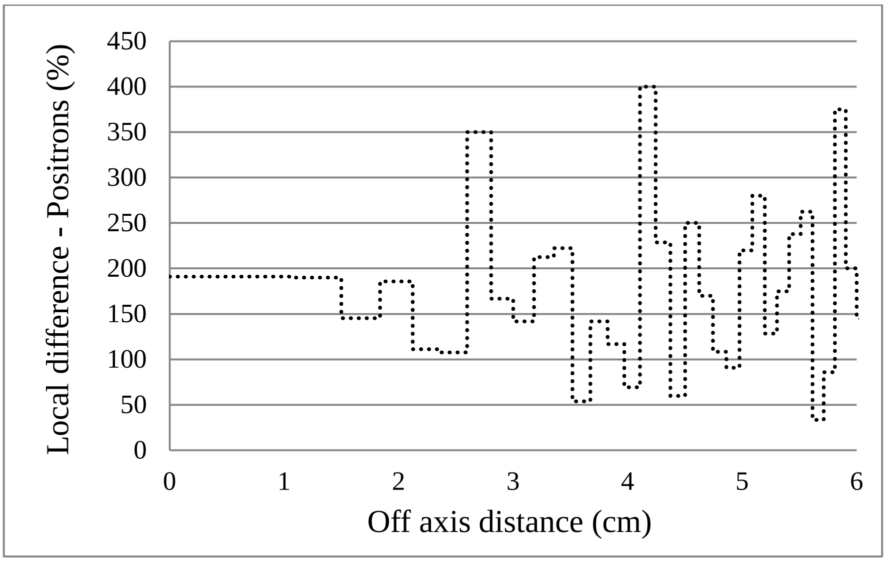

Figure 8: Local difference variation as a function of off-axis distance for positrons.

In nearby central beam axis, the positron fluence of FFF configuration increases by 200% of that of configuration with FF. However, the local difference for positrons is apparently constant with big fluctuations with off-axis distance in contrary to local difference of photons which decreased and to local difference of electrons which increased with off-axis distance (Figures 6, 7 and 8).

Conclusion

In this work, the focus was in the flattening filter effects on the beam quality with off-axis distance. Removing flattening filter from Linac head gives way to photons, electrons and positrons and they reached the patient's skin. All these particles increased in number for flattening filter free configuration of Linac. The increasing rate changed from one particle type to other. It was evaluated in terms of the local difference between FFF Linac configuration and with FF Linac configuration. Therefore, for Linac head configuration without FF, the photon beam was more contaminated by electrons and positrons in comparison to Linac configuration with FF, this is in opposition to IAEA protocols, and the beam quality was deteriorated [17 - 19].

For adopting the FFF Linac configuration for large field size (10×10 cm^2), the particle contamination (especially electrons) should be as low as possible in number and in energy in despite of photon fluence increasing at phantom surface and even the removing flattening filter increased the delivered dose for high radiotherapy efficiency as showed in our previous work [5].

Acknowledgement

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