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Study of the volume reduction impact on secondary photons emergent from flattening filter for high radiotherapy quality

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Abstract

This study aims to investigate and evaluate the secondary photons characterizations under flattening filter (FF) for high radiotherapy quality in terms of fluence, energy fluence, energy fluence distribution, spectral distribution and angular spread distribution of secondary photons, which are mainly coming from primary collimator originated in the whole Linac head. However, the flattening filter illuminates the photons of low energy. After this component, the secondary photons of low energy are coming from flattening filter and secondary collimators that contaminate the dosimetry for deep tumor treatment.

Fluence profile, energy profile and angular spread of secondary photons decreased with FF volume reduction percent but energy distribution and spectral distribution kept almost constant with FF volume reduction. The FF volume reduction allows reducing the secondary photons emergent from FF in number and in energy and it permits to increase the radiotherapy efficiency by decreasing the photons contamination when the cancer is treating.

Key words: flattening filter; Monte Carlo simulation; secondary photons; BEAMnrc code; BEAMDP code.

Introduction

Previously, the materials used in the flattening filter construction were studied to optimize the delivered dosimetry [1,2]. Then, we have studied the dosimetry quality for removing flattening filter from the Linac head [3,4], in parallel to study of the flattening filter geometry improvements [5,6] and the gain of dose while the flattening filter is removed from Linac head [7]. In this study, we are focused on secondary photons originated in the flattening filter (FF) which are investigated with the FF volume reduction percent in terms of fluence, energy fluence distribution, spectral distribution, mean energy and angular distribution at phantom surface. This study was carried out in the framework of the photon beam quality as recommended by many international instances [8,9].

Secondary photons under flattening filter contribute in the delivered dose at shallower depths due to their low energy. The purpose of this work is to evaluate the secondary photons with FF volume reduction for optimizing the dosimetry. The knowledge of secondary photons characterizations with FF reduction is a basic floor to find an optimal FF volume for the photon dosimetry improvement and the FF geometry enhancement for Linac development. This Monte Carlo study is performed using BEAMnrc code and BEAMDP.

Monte Carlo simulation is a technique that provides both accurate and detailed energetic and dosimetric calculation of a medical linear accelerator head. It has been used extensively in the medical physics for modeling this device and radiation transport [10,11]. In this work, the Monte Carlo geometry is built for 6 MV photon beam produced by Varian Clinac 2100 using BEAMnrc code [12]. The irradiation field size is 10×10 cm^2 and the source-to-surface distance (SSD) is 100 cm. Physics of radiation transport simulation is based on EGSnrc [13]. The BEAMDP is used to evaluate the secondary photons characterizations at the phantom surface [14].

Materials and methods

Monte Carlo simulation

Linac head is formed by different components for shaping and modifying the photon beam for clinical usage. **Figure 1** shows a section of Monte Carlo geometry of Linac head, including different components and their positions and the scoring plane to stock particles for further studies.

After Monte Carlo simulation validation of Varian Clinac 2100, the FF volume was reduced by 10%, 20% and 30% according to manufacturer data (Varian Medical Systems).

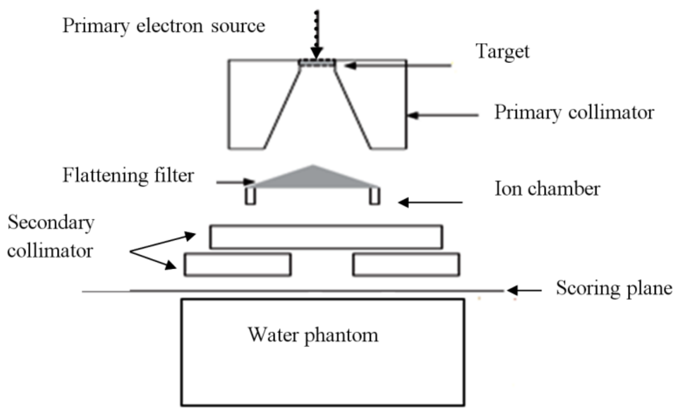

Figure 1. Section view of Monte Carlo geometry of Linac head and the position of scoring plane for phase space file recording.

Monte Carlo simulation validation

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 [15]. The Monte Carlo simulation validation is done in our previous work using gamma index criteria of 3%/3mm and the acceptance rate was approximately 99% for percentage depth dose (PDD), and approximately 98% for beam dose profiles [11]. Thus, Varian Clinac 2100 Monte Carlo geometry was validated according to tolerance limit recommended by IAEA in TRS430 [16] and in IAEA-TECDOC-1583 [17].

According to the Monte Carlo simulation of Linac, the incident electron energy and radial spread were both adjusted to produce the best match between Monte Carlo calculation and measured dose. So, the electron source was in Gaussian spread and its characterizations were X and Y coordinates equal to 1.4 mm, mean angle spread was 1°, electron source energy was 6.52 MeV and nominal photon beam energy was 6 MV.

Results and discussion

Secondary photons originated in the flattening filter (FF) are affecting the dosimetry at the shallower depth because of their low energy at phantom surface. For each FF volume reduction percent, the secondary photons characterizations are determined and compared to these of FF with initial volume. At phantom surface, we have introduced the reduction rate of secondary photons and it was evaluated as a quotient of characterization of secondary photons originated in reduced FF to characterization of secondary photons originated in FF with its initial volume (manufacturer data) as percentage according to the following formula:

$$\text{Reduction rate (\%)} = 100 \times \frac{X\,(n\,\%)}{X\,(0\%)} \qquad \text{Eq. 1}$$

Where X is fluence profile, energy fluence profile, energy fluence distribution, spectral distribution, mean energy distribution and angular distribution of secondary photons originated in Linac head. n% is 10%, 20% and 30%.

Fluence profile

Fluence profile describes the distribution of secondary photons originated in FF with off-axis distance. **Figure 2** shows planar fluence profiles of secondary photons emergent from FF and reduction rate as a function of off-axis distance for each FF volume reduction percent.

We notice from **Figure 2** that the fluence of secondary photons originated in FF decreases with FF volume reduction percent inside the irradiation filed and the fluence is high near the central beam axis.

The reduction rate of secondary photons number increases with FF volume reduction and with off-axis distance inside the irradiation field (**Figure 2**). Thereafter, the FF volume reduction can decrease substantially the secondary photons fluence and subsequently the radiotherapy efficiency will increase.

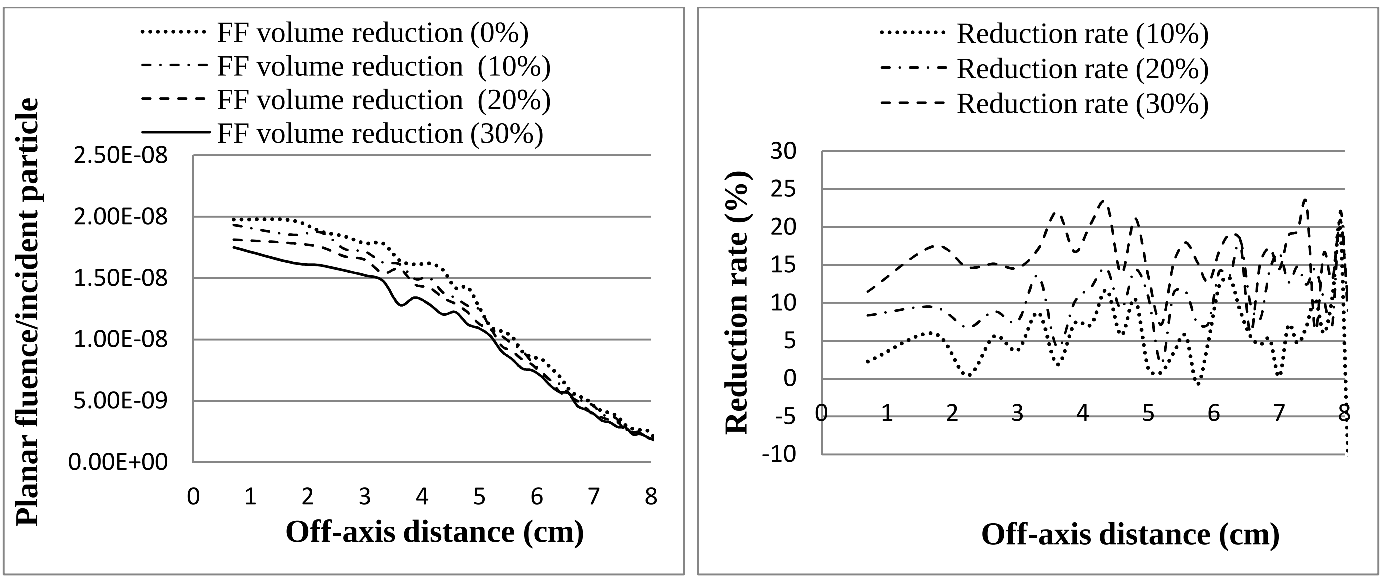

Figure 2. Fluence profile of secondary photons and reduction rate as a function of off-axis distance.

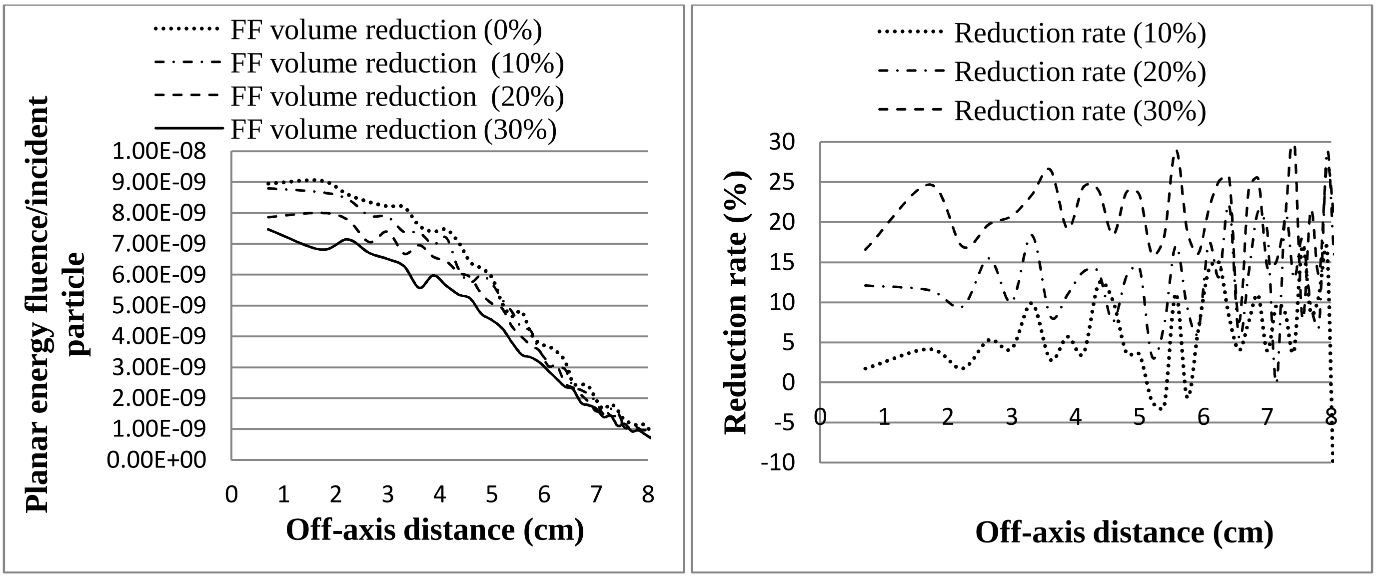

Figure 3. Energy fluence profile of secondary photons and reduction rate as a function of off-axis distance.

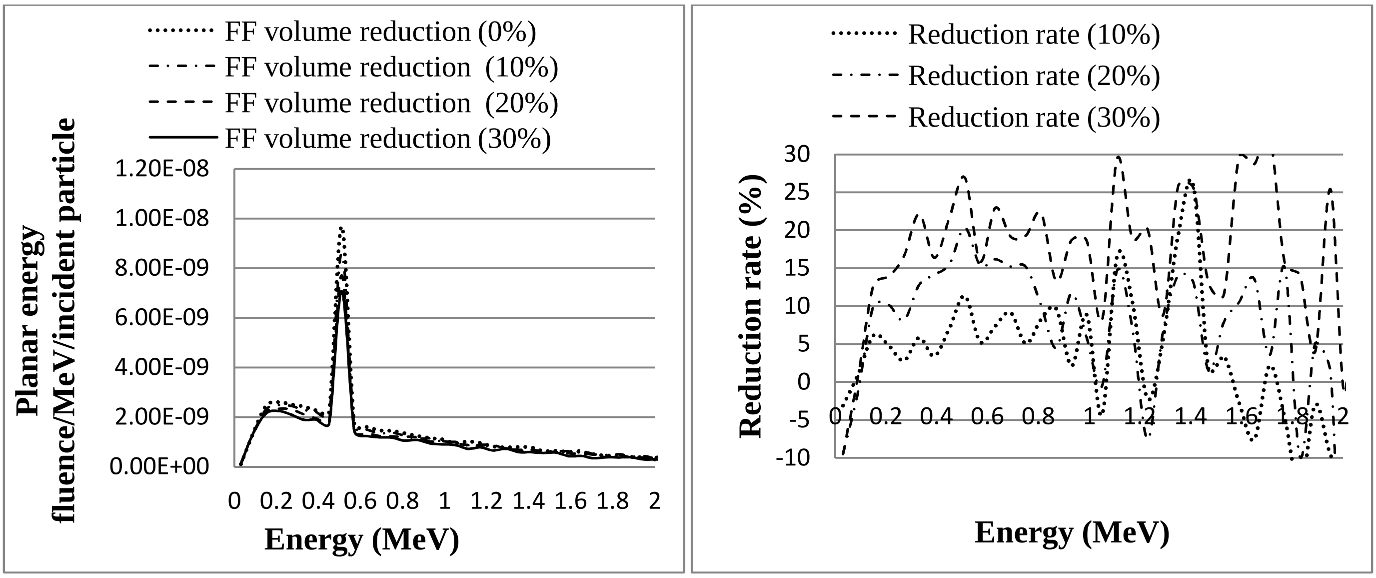

Figure 4. Energy fluence distribution of secondary photons and reduction rate as a function of energy.

Energy fluence profile

Energy fluence profile describes the variation of the energy of secondary photons with off-axis distance. **Figure 3** shows energy fluence profile of the secondary photons originated in FF as a function of off-axis distance for each volume reduction percent.

Energy fluence profiles are as fluence profiles variation according to the FF volume reduction and also with off-axis distance. The reduction rate of secondary photons energy fluence increases with FF volume reduction percent and with off-axis distance inside the irradiation filed. FF volume reduction decreases substantially the secondary photons in fluence and in energy but the FF volume reduction affects more the energy fluence profile than the fluence profile of secondary photons (**Figures 2** and **3**).

Energy fluence distribution

Energy fluence distribution and reduction rate of secondary photons originated in FF are presented in **Figure 4** for each volume reduction percent.

Energy fluence distribution decreases with energy and especially around the energy fluence distribution maximum that is at 0.51 MeV. Energy fluence maximum for secondary photons originated is $9.97 \cdot 10^{-9}$ MeV/MeV/incident particle for FF with initial volume; it is $8.58 \cdot 10^{-9}$ MeV/MeV/incident particle for FF reduction of 10%; it is $7.71 \cdot 10^{-9}$ MeV/MeV/incident particle for FF reduction of 20% and it is $7.07 \cdot 10^{-9}$ MeV/MeV/incident particle for FF reduction of 30% (**Figure 4**). The reduction rate of energy fluence distribution of secondary photons increases with FF volume reduction and with off-axis distance for low secondary photons energy.

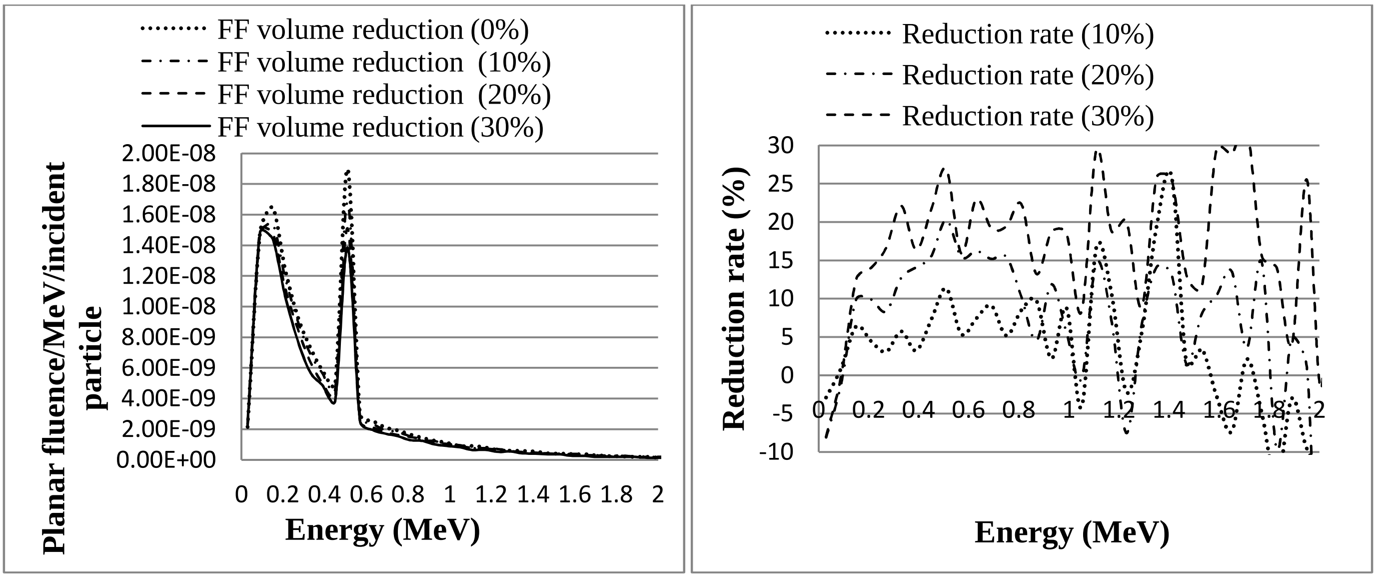

Figure 5. Fluence of secondary photons and reduction rate as a function of energy.

Spectral distribution

Spectral distribution describes the secondary photon fluence variation with energy, the knowledge of spectral distribution of secondary photons is crucial because they contaminate the photon beam dosimetry in deep tumor treatment.

We notice from **Figure 5**, the spectral distribution of secondary photons present tow peaks with energy for each FF volume reduction percent and they decrease with FF volume reduction (**Figure 5**). **Table 1** presents the peaks value of each FF volume reduction percent.

The reduction rate of spectral distribution due to FF volume reduction increases with FF volume reduction and with energy (**Figure 5**).

Table 1: Peaks values of spectral distribution of secondary photons

FF volume reduction percent	Value of the left maximum (photon/MeV/incident particle)	Energy of the maximum (MeV)	Value of the right maximum (photon/MeV/incident particle)	Energy of the maximum (MeV)
0%	$1.65 \cdot 10^{-8}$	0.15	$1.90 \cdot 10^{-8}$	0.51
10%	$1.54 \cdot 10^{-8}$	0.15	$1.68 \cdot 10^{-8}$	0.51
20%	$1.50 \cdot 10^{-8}$	0.09	$1.51 \cdot 10^{-8}$	0.51
30%	$1.49 \cdot 10^{-8}$	0.09	$1.38 \cdot 10^{-8}$	0.51

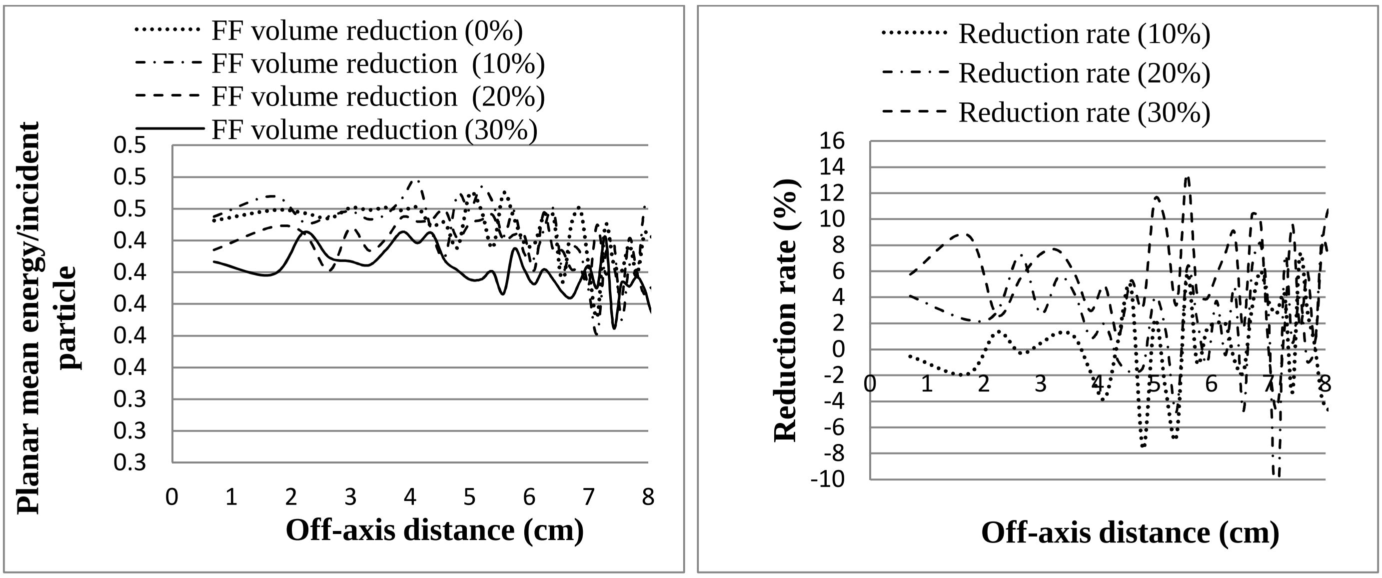

Figure 6: Mean energy of secondary photons and reduction rate as a function of off-axis distance.

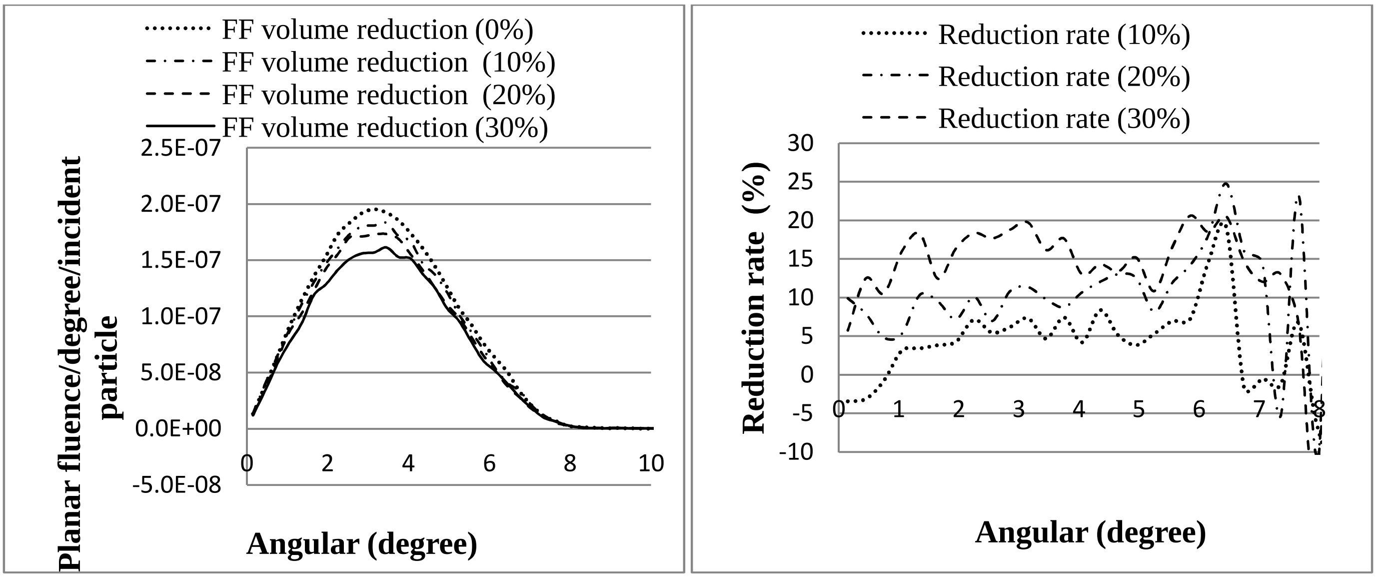

Figure 7. Angular spread distribution of secondary photons and reduction rate as a function of angular degree.

Mean energy

Mean energy is determined for the secondary photons originated in the FF as a function of off-axis distance for each volume reduction percent.

We notice from **Figure 6**, mean energy of secondary photons decreases with FF volume reduction and remains constant with off-axis distance (**Figure 6**). The reduction rate of mean energy increases with FF volume reduction and decreases with off-axis distance that means the FF volume reduction decrease the mean energy and this result is in favor to radiotherapy quality.

Angular spread distribution

Angular spread distribution describes the secondary photons fluence variation with angular spread. **Figure 7** shows the angular spread distribution of secondary photons for each FF volume reduction percentage.

It can be seen from **Figure 7** that angular spread distributions have a maximum which is $1.95 \cdot 10^{-7}$ photon/degree/incident particle at 3.15° for FF with its initial volume; $1.83 \cdot 10^{-7}$ photon/degree/incident particle at 3.45° for FF reduction of 10%; $1.73 \cdot 10^{-7}$ photon/degree/incident particle at 3.45° for FF reduction of 20% and $1.61 \cdot 10^{-7}$ photon/degree/incident particle at 3.45° for FF reduction of 30%.

The reduction rate due to FF volume reduction increases with FF volume reduction and with angular degree (**Figure 7**).

Conclusion

This study has checked out the secondary photons originated in FF for eventual increasing radiotherapy efficiency by reducing the low photons energy contaminations coming from this component. The secondary photons were investigated in terms of fluence profile, energy profile and energy distribution, spectral distribution, mean energy and angular spread of secondary with FF volume reduction. The FF reduction volume allows reducing sustainably the low photons energy contamination at the phantom surface. For this reasons we propose to reduce the FF volume for high radiotherapy efficiency and high patient life quality by increasing the clinical doses for high quality of the cancer treatment.

This work can be a basic investigation that will be used in improvement for future Linac configuration and especially to enhance the flattening filter geometry for improving the dose at the entrance of deep treatment tumor.

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