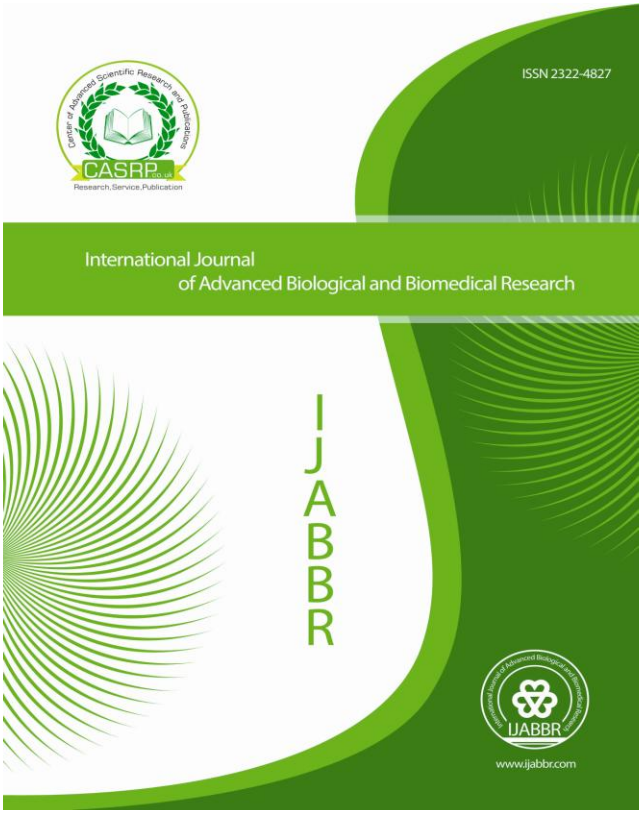
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Original Article **Open Access**

A Monte Carlo study on Photoneutron Spectrum around Elekta SL75/25 18 MV linear accelerator

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Abstract

Medical linear accelerators are one of the most widespread methods for cancer treatment. Despite their advantages, unwanted photoneutrons are produced by high energy linacs. This photoneutrons are as undesired doses to patients and a significant problem for radiation protection of the staffs and patients. Photoneutrons radiological risk must be evaluated because of their high LET and range.in order to achieving this aim, photoneutron spectrum are calculated**.** The head of linac and a common treatment room was simulated by the MC code of MCNPX. Photoneutron spectrum was calculated in different field sizes, distances from isocenter and different cases (with and without structures and materials such as flattening filter, compensator, air and treatment room walls). The inclusion of the flattening filter and compensator had not any effects on shaping the photoneutron spectrum but neutron fluence and the average neutron energy are reduced obviously. Also effect of air on photoneutron spectrum was negligible. The calculation of photoneutron spectrum with concrete walls show that the component of fast neutrons is decreased and thermal neutrons are increased due to the room-return. In this case, with increasing distance from isocenter, fast neutrons are decreased and thermal neutrons are increased. As the field size is increased from 5×5 to 15×15 cm^2, the neutron flux is increased clearly in isocenter. The neutrons flux are decreased near the door due to maze effect. The photoneutron spectrum investigation and

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risk estimation due to inclusion of neutron contamination in treatment room prevent from secondary cancer mortality.

Keywords: Photoneutrons, Medical linear accelerators, Monte Carlo.

1. Introduction

Radiotherapy with medical linear accelerator, LINAC, is a common method for treatment cancer (Hsu et al., 2010). High energy beams (E>10 MV) are used for treatment deep tumors. Those have several advantages such as lower skin dose, low damage to soft tissue, etc. But high energy beams produce unwanted neutrons and deliver undesirable dose to the patient (Wu and McGinley, 2003). Studies showed that dose to patient due to photoneutrons is less than 2.5 % of prescribed dose (Difilippo et al., 2003). Also, photoneutrons escape and leak out the treatment room, induce radioactivity in the materials. Therefore prompt γ-rays are produced (Polaczek-Grelik et al., 2010; Vega-Carrillo et al., 2010). Prompt γ-rays will be a radiological risk for staffs. Basically, photoneutrons are produced in the treatment room due to mega voltage beam interactions with high –z materials such as target, primary and secondary collimator, that they are located in the beam track (Barquero et al., 2002; Zabihzadeh et al., 2009). Two main reactions for producing photoneutrons are (e, e'n) and (γ, n). Studies that were carried out by researchers showed that the cross section of the (e, e'n) reaction is considerably small to compare with the cross section for (γ, n) reaction (approximately 137 times) (Vega-Carrillo et al., 2010). Therefore contribution of electroneutrons in undesired dose to patient is negligible. Photoneutrons are classified according to their energy into three groups. Including thermal neutrons (energy less than 0.5 eV), epithermal neutrons (energy range from 0.5 eV to 10 Kev) and fast neutrons (energy higher than 10 Kev) (Rohrig, 2003). We must evaluate photoneutrons radiological risk, because the photoneutrons have high Linear Energy Transfer (LET) and range. In order to achieve this goal, photoneutron spectrum must be determined (Schneider et al., 2008). Photoneutron fluence and spectrum are measured directly by passive detectors that this measurements is very complex (Esposito et al., 2008). The MC code is an alternative method for determining photoneutron spectrum. Nuclear data tables of MC code are used for neutron and photon interactions and neutron dosimetry (Forster and Godfrey, 1985). Photoneutron spectrum and average neutron energy were calculated by MC or measurement in many studies. When field size is increased, the average neutron energy is increased too (Kry et al., 2007). The larger is the distance from isocenter (IC), the lower is the average neutron energy (Lin et al., 2001). The flattening filter (FF) provide a uniform dose distribution and a homogeneous profile dose. Photoneutron spectrum comparison between flattened and unflattened beams shows the higher fluence for unflattened beams (Mesbahi, 2009a). The compensator is used in Intensity-Modulated Radiotherapy (IMRT) in order to modulate beam (Custidiano et al., 2011). No study has been investigated influence of compensator on photoneutron spectrum yet. The photoneutron spectra is modified by the photoneutrons interactions with materials that there are in treatment room (Pena et al., 2005). The aim of our study is to investigate effects of flattening filter, compensator, walls and the air inside the room on photoneutron spectrum at different distances from IC and field sizes.

2. Materials and methods

Our study carried out MCNPX version 2.6.0 (Forster and Godfrey, 1985). The head of Elekta SL75/25 with photon beam of 18 MV was modeled using manufacture's informations. The main structures of modeled linac are target, primary collimator, flattening filter, ion chamber, jaws and shielding. A brass compensator with dimensions of 21×21×1 cm^3 was simulated in 67.2 cm from the target. Details of this simulation are shown in figure 1. Linac head simulation was benchmarked by comparing percentage depth dose (pdd) and profile dose curves, resulting from Monte Carlo (MC) method and measurement. To calculate pdd and dose profiles curves, for photons and electrons are selected an energy cutoff 10 KeV and 700 Kev, respectively. For photoneutron spectrum calculations, these energy cutoff values for both electron and photon altered to 7 MeV. A water phantom with dimensions of 50×50×50 cm^3 was located at source–surface distance (SSD) of 100cm. In order to calculate depth dose in water phantom, a cylinder with 1 cm radius and 25 cm height was simulated in open field size. This cylinder was divided into scoring cell with 0.75 cm height along the beam central axis. For beam profile calculation, all simulation setups were same as depth dose calculation, except the main cylinder was defined at the depth of 10cm in phantom and it is perpendicular to the beam central axis. A void sphere cell with 10 cm diameter was used as a detector. The *F8 and f4 tally was used for dose and photoneutron spectrum calculations, respectively. A common radiation therapy room was simulated according to NCRP No. 144. The ceiling, floor and walls were made of concrete with the density of 2.26gr/cm^3. The concrete compositions were 0.92% H, 49.83% O, 1.71% Na, 4.56% Al, 31.58% Si, 1.92% K, 8.26% Ca and 1.22% Fe (Simmons, 1978). The hall is shown in figure 2. In order to reduce the running and calculating times, the thicknesses of the ceiling, floor and walls were selected 30 cm (Agosteo et al., 1995). It is due to the negligible contribution of neutrons covering forward and backward distances larger than 30 cm. The maze thickness was defined 100 cm. All detectors were located at the same plane as the IC. One detector was located at IC and the other detectors were at 40,100,250 and 390 cm from IC. For investigation the effect of maze on photoneutron spectrum, a detector was located at near the door. Photoneutron spectrum around the linac was calculated for four cases, including the head with and without flattening filter (A,B, respectively), the head with compensator and flattening filter(C), the head with compensator and flattening filter without air(D) and all the mentioned structures with walls(E). All results were obtained with an uncertainty less than 2%.

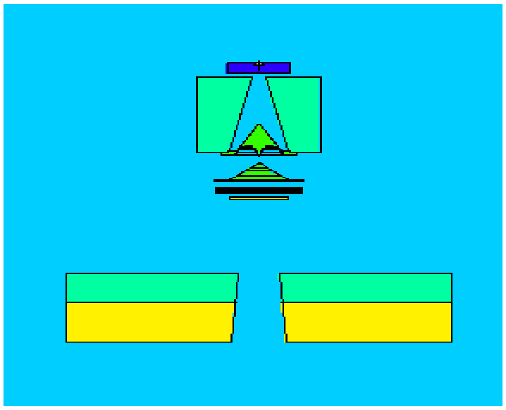

Fig. 1. The geometry of Elekta SL 75/25 head in z-x direction.

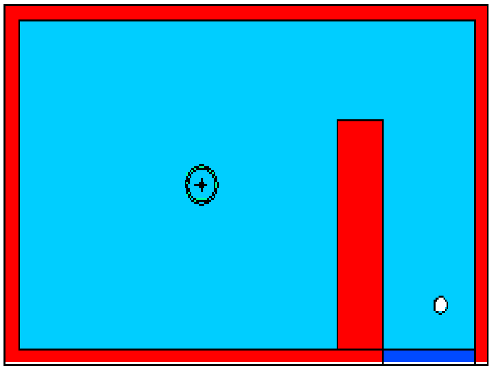

Fig. 2. The geometry of radiotherapy hall with the detector near the door in x-y direction.

3. Results

The comparison between percentage depth dose and profile dose curves, resulting from MC method and measurement are shown in figure 3, 4. The difference between two pdd curves is less than %1 for those points that located after build up region. For profile dose curves, this value is lower than 2% in flat region of the curves (Mesbahi et al., 2007b). The photoneutron spectrum for flattened and unflattened beams in IC and 100 cm from IC are shown in figure 5.Both curves have a peak around 0.6 MV. The average energies for flattened and unflattened beams are 0.907 Mev and 0.957 Mev in IC .these values are 0.889 Mev and 0.876 in 100 cm from IC, respectively. The moderation spectrum by the compensator is shown in figure 6. It's peak do not change in comparison to the previous case. The spectrum calculations without air are shown in figure 7. The effect of air on photoneutron spectrum was negligible and unimportant. The inclusion of the walls are shown in figure 8. The changes in spectrum with increasing distance from IC are shown in figure 9. When the distance from IC is increased, the neutron flux is reduced. As the field size is increased, the neutron flux is increased obviously in the IC but it's increase is not clear in far from the IC. This variations are shown in figure 10. The average neutron energy is determined for all simulated cases and this results are shown in table 1.

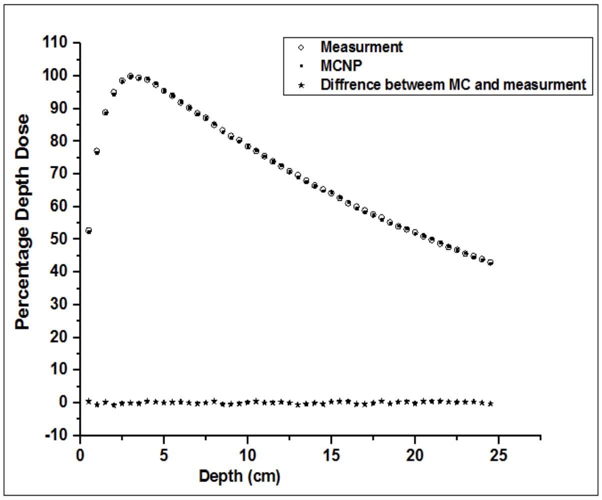

Fig. 3. Comparision of the MC and measurment percentage depth dose curves for 10×10 cm^2 field size.

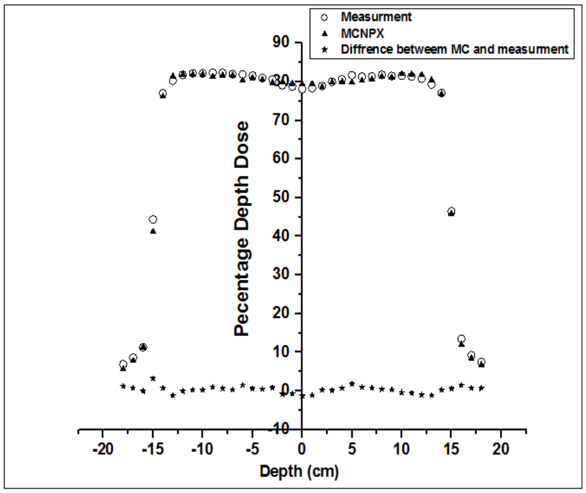

Fig. 4. Comparision of the MC and measurment profiles dose curves for 30×30 cm^2 field size.

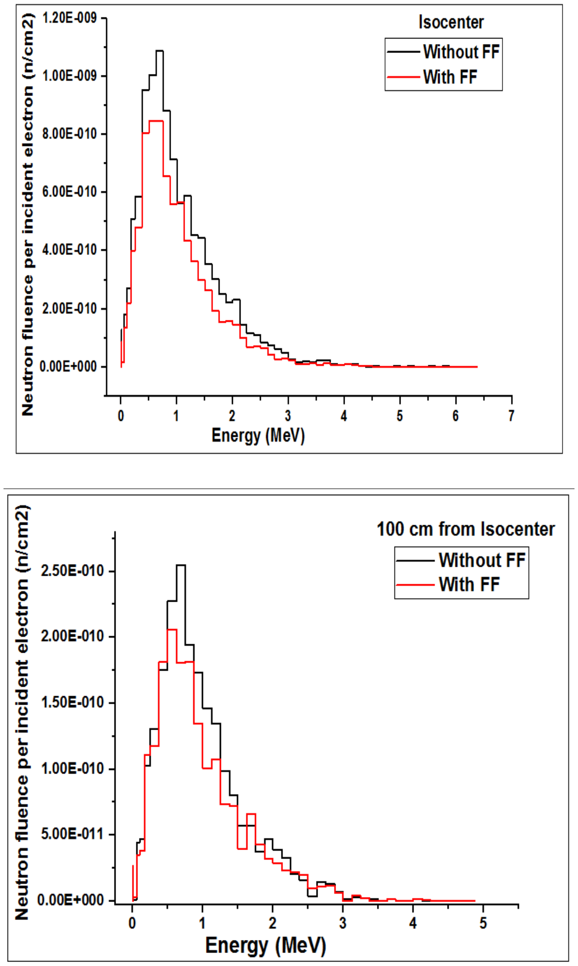

Fig. 5. Photoneutron spectra for the flattened and unflattened photon beams in 15×15 cm^2 field size.

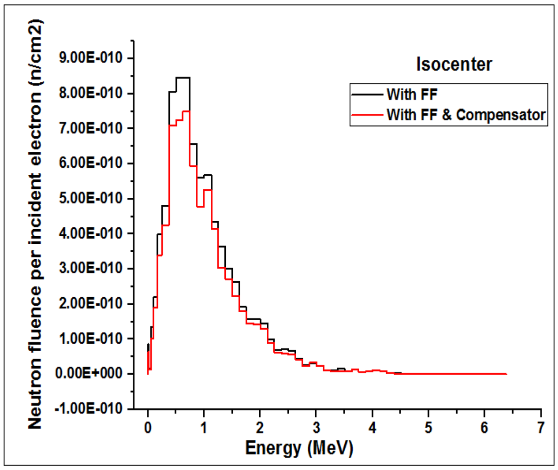

Fig. 6. Photoneutron spectra for the flattened and the inclusion of the compensator beams in 15×15 cm^2 field size.

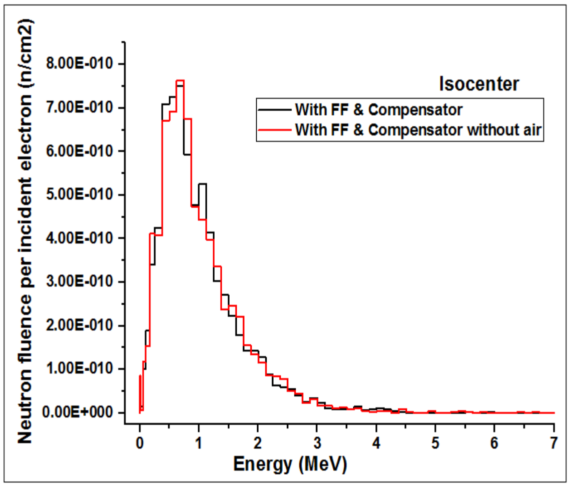

Fig. 7. Comparing photoneutron spectra with and without the air in 15×15 cm^2 field size.

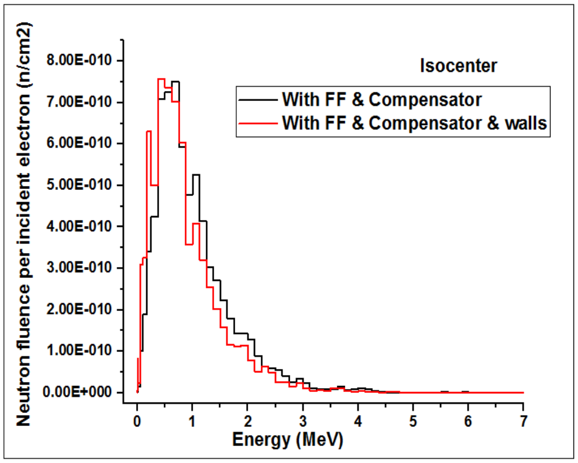

Fig. 8. Comparing photoneutron spectra with and without the walls in 15×15 cm^2 field size.

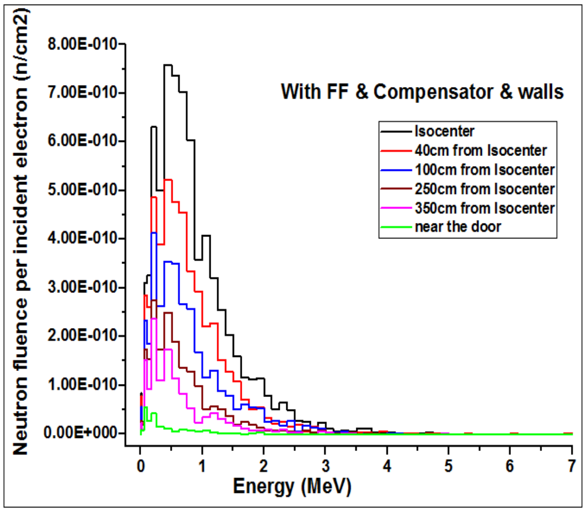

Fig. 9. Comparing photoneutron spectra with the walls in isocenter, 40,100,250,350 cm and near the door for 15×15 cm^2 field size.

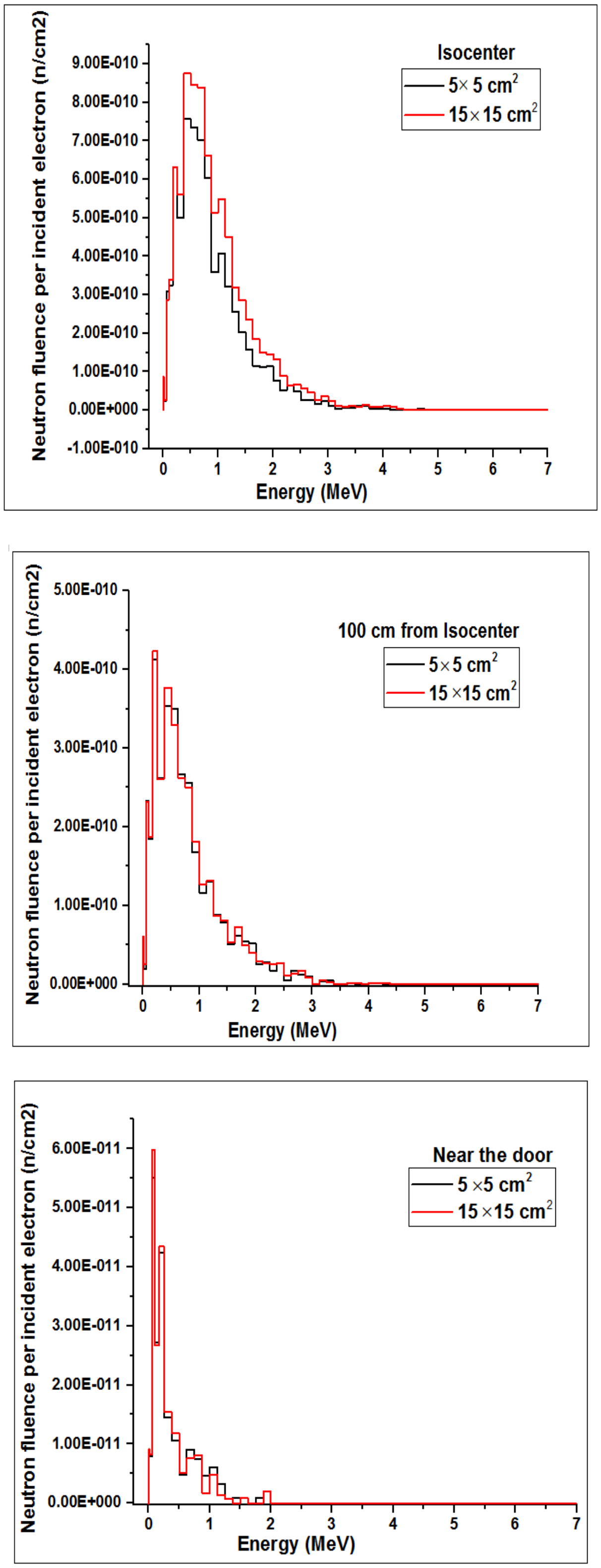

Fig. 10. Photoneutron spectra for 5×5&15×15 cm^2 field sizes in isocenter, 100 cm and near the door.

Table 1
Average neutron energy for all cases.

Average neutron energy (Mev)±SD	Position	Field size(cm^2)	The simulated case
0.907±3.27E-4	IC	15×15	A
0.876±7.57E-5	100cm from IC		
0.957±4.23E-4	IC	15×15	B
0.889±8.74E-5	100cm from IC		
0.918±2.88E-4	IC	15×15	C
0.876±6.63E-5	100cm from IC		
0.931±2.91E-4	IC	15×15	D
0.866±5.01E-5	100cm from IC		
0.751±2.84E-4	IC	5×5	E
0.658±1.34E-4	100cm from IC		
0.274±8.28E-6	Near the door		
0.838±3.45E-4	IC	15×15	
0.664±6.23E-5	100cm from IC		
0.276±8.25E-6	Near the door		

4. Discussion

The spectrum shapes do not change significantly by removing flattening filter. Figure (5) shows that photoneutron fluence per incident electron for unflattened beam is larger than flattened beam. Because the number of neutrons were produced in linac head is dependent on photon fluence per incident electron. Therefore, with increasing photon fluence in unflattened beam, the number of photoneutron interactions were increased and consequently more neutrons are produced. These results are in agreements with study that were done by Mesbahi (Mesbahi, 2009a). Also our findings is in contrast with the results of a study by kery et al (Kry et al., 2007). The major difference between our study and kry's study is the unit of calculated neutrons fluence. We calculated neutron fluence per incident electron but kry calculated neutron fluence per Monitor Unit (MU). In kry's study, Neutron production capability of flattening filter is the main reason for photoneutron fluence reduction in unflattened beam. The composition of the FF is a material with medium atomic number in Varian linac. So FF cannot has a significant effect on photoneutron production (Zanini et al., 2005). The contribution of linac components in photoneutron production were reported by many authors. The contribution of flattening filter in photoneutron production was reported %0.41 for Siemens Primus 15 MV linac in 10×10 cm^2 field size (Pena et al., 2005). With increasing distance from IC, neutron flux and average neutron energy were reduced considerably. Because, farther away from the IC, the number of the photoneutrons that arise directly from linac is fewer. In addition, the photoneutrons are scattered repeatedly and consequently they lost their energies. The decrement of neutron fluence with increasing distance from IC is mentioned in previous studies (Zabihinpoor and Hasheminia, 2011; Zabihzadeh et al., 2009). It seems that due to the compensator's medium atomic number, its role in photoneutrons production is negligibly but neutron fluence is reduced due to scattering and attenuation photoneutrons by compensator. The moderator effect of the compensator and FF reduces the average neutron energy. The simulation results with walls show that the spectrum peak is shifted to lower energies (~0.4Mev) and the component of fast neutrons is decreased and thermal neutrons are increased due to the room-return effect(Mesbahi et al., 2010c). In this case, when the distance from IC is increased, the thermal neutrons peak is larger than the fast neutrons peak and the importance of fast neutrons is decreased obviously. The inducing activation are produced by fast neutrons in walls that its maximum value is at 10 cm deep in the walls (Weinreich et al., 2004). The neutron flux is decreased strongly near the door due to maze effect. Thermal neutrons are increased considerably and the major part of spectrum locate at thermal neutrons region near the door. The previous studies on photoneutron production in linacs show controversial results about effect of field size on photoneutron fluence. Our results showed that, as the field size is increased, the neutron flux is increased obviously in the IC but it's increase is not clear in far from the IC. Our results are in contrast with the results of Mesbahi et al (Mesbahi, 2009a). Their reason for reduction of neutron fluence with increasing field size was the different contribution of jaws in photoneutron production with variations of field size. Mesbahi reported that with retracting the jaws in larger fields, the interaction between photon beams and the jaws reduced and consequently photoneutron fluence is decreased. Our findings are in agreement with the results of Chibani and Ma study (Chibani and Ma, 2003).The majority of photoneutrons are generated by the top structures of the linac head such as target, flattening filter, and primary collimator. According to previous studies jaws have low capability in photoneutron production (Pena et al., 2005; Mao et al., 1997). Thus in smaller fields, the attenuation role of jaws is greater than the neutron production role. Therefore neutron fluence decrease. The average neutron energy is decreased with increasing field size. Because in smaller field, more photoneutrons produced from the upper structures of the linac have to penetrate the jaws and they lost their energies.

5. Conclusion

The contaminated photoneutrons deliver undesirable doses to patients and can lead to Secondary malignancies. Near the IC, the photoneutron spectrum contain more neutron fluence in the entire energy range. As the distance from IC is increased, the fast neutrons peak disappear and there is a thermal peak in all the investigated positions in treatment room. The maze in the room has two significant effects on photoneutron spectrum, reducing the neutron fluence and increasing the photoneutron absorption. Calculations showed that the contribution of fast neutrons negligible in the maze. The concerns due to thermal and epithermal neutrons in the maze are resolved by shielding the door.

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