# Chapter 7

## CONCLUSION
## AND
## FUTURE DIRECTIONS

### 7.1 Summary and general conclusion

The objective of the work undertaken for the thesis was to first develop an accurate Monte Carlo (MC) simulation model for the 6 MV photon beam produced by the Varian Clinic 600 linear accelerator (unique performance model). Thereafter to use this simulation model to evaluate the spectral and dosimetric properties of the radiation beam and also to evaluate the effect of multileaf collimators on it . The major objective of the work undertaken was to study the characteristics of flattening filter free beam using our Monte Carlo Simulations.

**Summary and brief conclusions of the work are as follows:**

**The Monte Carlo** simulation model of 6 MV photon beam produced by the Varian Clinic 600 linear accelerator (unique performance model) was developed by using BEAMnrc code. The percentage depth-dose and lateral profile data calculated using our simulation model when compared with experimentally measured data showed very close agreement which gave us enough confidence about the accuracy of our simulation model. Thereafter, we used this simulation model to calculate the contribution of contaminant electron to the percentage depth dose (PDDs) at various depths for different field sizes. It was observed in our study of contribution of electron to the central-axis depth-dose for various field sizes that its contribution to total dose at surface increases with increase in field size. However, with increase in depth for a given field size the contribution of electron dose to total dose decreases. These results were verified with the study of on axis electron spectra at phantom surface which showed strong dependency on field size and was found to increases with increase in field size. Our study of photon spectra of four different field size showed that the number of photon reaching the scoring plain increases with increase in field size which also increased the amount of total dose. In our investigation of photon energy fluence spectra we separated spectra into direct and scatter components from the primary collimator, flattening filter and the adjustable collimators. We observed that most of the energy fluence reaching the phantom surface was due to direct photons and rest part was due to scatter photons in which major portion of scatter radiation was of primary collimator and flattening filter.

Thereafter, we investigated the properties of radiation beam as it is being transported through the secondary collimators system consisting of multileaf collimators (MLC) which are used to deliver inhomogeneous fluence required for many morden radiotherapy treatments. To carry out this task, we performed Monte Carlo simulations to investigate how the various characteristics of photon beam including changes in spectrum are influenced by the MLC. The complex geometry of 120-leaf Varian Millennium$^{TM}$ Multileaf Collimators was precisely modelled in our simulation study. We used our simulation model to calculate MLC leakage as a function of field size. It was observed that the calculated MLC leakage value increases with increase in field size. The computed percentage depth dose (PDDs) for MLC blocked field showed slightly higher values in comparison to the jaw define open beam for all field sizes. To study that how MLC effect the spectrum of photon beam we evaluated average energy distribution of photon as a function of off axis distance and central axis photon fluence spectra as a function of energy for both MLC blocked and jaw define open fields. Considerable increment in average energy on central axis was observed for MLC blocked field in comparison to jaw define open field. This increment in average energy is due to the removal of low energy photons by MLC which also affects the on axis photon spectra as for MLC blocked field it contains more high energy photons in comparison to the jaw define open field. MLC substantially modified the photon energy spectrum of radiation beam by removing the lower-energy photons which results in rise of PDDs for MLC blocked fields in comparison to the jaw define open fields.

In our study of flattening filter free beams we removed the flattening filter from the beam line in our simulation model. First we evaluated and compared the dosimetric and spectral characteristics of unflattened and flattened beam where the field sizes were defined by using the jaws only and thereafter using MLC only. In our investigation of depth dose curves we calculated the absolute absorbed doses per initial electron for the flattened and the unflattened beam for different depths and field sizes. The ratios of the absolute depth doses for unflattened beam to those for the standard flattened beam were found to be more then twofold for all the field sizes indicating the higher dose rate delivered by the unflattened beams. The PDDs calculated for the unflattened beam were found to be slightly lower than those calculated for standard beam for all field sizes. In our investigation of spectral characteristics of unflattened beam, we calculated the photon fluence spectra variation with energy. It was observed that the fluence of photon on central axis increased with removing the flattening filter, explaining the higher central axis dose rate deliver by the unflattened beam. The comparison of photon fluence spectra variation with off axis distance for the two kinds of beam modalities showed the increment in the photon fluence for the unflattened beam; however, the difference in the photon fluence decreases with increase in off-axis distance. Further we computed the average energy distribution as a function of off axis distance for flattened and unflattened beams. It was observed that for flattened beam the average energy of photon show variation with increases in off-axis distance which explains the beam hardening effect produced by the flattening filter. While for the flattening-filter-free beam, the mean energy of the spectrum did not change significantly with increasing off-axis distance. The differences in average energy of the two kinds of beam modalities have much effect on their characteristics. As our investigation of MLC leakage showed that there was a substantial decrease in MLC leakage when the flattening filter was removed from the beam line. The reason for this decrease in MLC leakage is due to difference in the average energy distributions of the two kind of beam. As we discussed above the flattened beam have relatively higher mean energy of photons due to which less amount of attenuation take place, while in the absence of filter more low energy particle contribute in unflattened beam leading to increased attenuation of it by the MLC. The surface dose comparison showed higher dose value for the unflattened beam with respect to flattened beam. The average energy difference on the central axis is the major cause for the superficial dose difference delivered by the two kinds of beams. The lower average energy of the unflattened beam on the central axis produces a higher superficial dose. Also surface dose calculated for different field sizes for the unflattened beam do not show large field size dependence as seen for the flattened beam. The field-size dependence of the superficial dose for the flattened beam is due to the presence of scatter component, which originates mostly from the flattening filter. Our computation of the total scatter factor, $S_{CP}$, for the unflattened and flattened beam showed that the value of $S_{CP}$ for the unflattened beam increase more slowly with increase in field size in comparison to that, it does for the flattened beam. Additionally, our data showed that the amount of variation in $S_{CP}$ was even less for MLC shaped unflattened beam in comparison to jaw-shaped unflattened beam, which suggest that use of MLC to define field size offers advantage over jaw for unflattened beam in terms of more reduced scatter radiation. In our study of unflattened beam characteristics we computed the lateral profiles of them for different field sizes and depths. The forward-peaked profile with significantly reduced off axis fluence make the lateral dose profile of unflattened beam extremely different with respect to the flattened beam. Thus we have normalized unflattened beam profile with different methods and thereafter compared them with the corresponding flattened beam profiles. The comparison of unflattened beam normalized with the method described by **Pönisch *et al.*** with flattened beam showed that for both kind of beams the calculated values of flatness were not significantly different for small field sizes, however, for lager field sizes there is a considerable difference in beam flatness for the two cases. Near the field edge of lateral profiles, relative dose values were found to be inferior for the unflattened beam in comparison to the corresponding flattened beam and in addition out-of-field dose from the flattening filter free beam falls off faster with increase in off-axis distance. However in this comparison the decline in MLC shaped unflattened beam was less than it was for jaw shaped unflattened beam. Also for unflattened beam the relative dose value calculated outside the field edge were found to be smaller for small field sizes when compared to the flattened beam. In his state of art research article **Fogliata *et al*.** described the new concept and definitions to identify the characteristics of unflattened beam profile which are vastly different and difficult to be compared with the corresponding flattened beam. In our comparative study of unflattened and flattened beam profile, where the unflattened beam normalized by the method recommended by **Fogliata *et al.*** showed that for unflattened beam the calculated dosimetric field size appear to be smaller than corresponding flattened beam. However, the amount of decrease in field size was less for MLC shaped than it was with jaw shaped unflattened beam. The penumbras values calculated for the lateral profile of the unflattened beam were found to be smaller in comparison to the corresponding flattened beam. The difference in penumbra values for unflattened beam shaped by MLC and jaw were small but significant for use in modern radiation treatments. Increases in the penumbra values with increase in field size were observed for both the flattened and unflattened beam. The computed value of unflatness for the unflattened beam showed that the beam non flatness is not likely to present any difficulty for treatments delivered for small fields, however for larger field sizes, a significant increase in its value advise difference with the flattened beam. These results are similar to those which were obtained when the unflattened beam lateral profile were normalized with the method described by **Pönisch *et al.*** thus increasing the reliability of our simulation study of lateral profile of unflattened beam. Finally from all above comparative study of unflattened beam lateral profile normalized with different methods we conclude that for small field size there was no significant difference between the unflattened and flattened beam and the treatments could also be benefited with increased dose rate. Unflattened beam offer a considerable decrease in out-of-field dose, thus enhanced sparing of normal tissues and organs close to the targeted region could be achieved.

**7.2 Future scope of the work:**

Till today several studies have been carried out using Monte Carlo simulation methods to accurately evaluate and analyse the dosimetric and spectral characteristics of the clinical beams and how they are influenced by the components of the treatment head. Thus we have used Monte Carlo methods for the study of photon beam characteristics in our research work. Throughout our thesis work we have demonstrated the use of Monte Carlo simulation to calculate the dose distribution and spectral characteristics of radiation beam. The computed scatter energy spectrums of radiation beam have provided the motivation to us to carry out the simulation study of flattening filter free beam. Advanced radio therapy treatment techniques such as IMRT have stimulated the interest in flattening filter free beam, which have potential of delivering higher dose rate. The unflattened beam also offer reduced head scatter, and head radiation leakage. Therefore, we have made an attempt to study the characteristics of unflattened beam on an existing machine. In our investigation using Monte Carlo Simulation model these possible dosimetric and spectral characteristics advantages of unflattened beam were evaluated. The Varian Clinic 600 Unique Performance is a new model of Varian linear accelerator. It has only one mode of operation in which it produces flattened 6 MV photon beam. On the basis of results obtained in our study we recommend that flattening filter free mode should be introduced in this model.