Chapter 1

INTRODUCTION

Radiotherapy is one of the major medical specialty which uses ionization radiation to treat malignant diseases (Cancer). Radiation oncology department uses highly sophisticated and complex medical equipments for management of cancer. Tumours could be classified into sub-categories (i) benign and (ii) malignant tumour. A benign tumor is a cluster of cells that lacks the ability to invade neighbouring tissue, it has slower growth rate and it is relatively less harmful. In contrast malignant tumours are more harmful as they could invade / destroy the nearby surrounding tissues and could spread in other parts of the body. To treat malignant cancer principally three modalities are used, the Radiation therapy, also known as radiotherapy, radiation oncology or therapeutic radiology, and the other two being surgery and chemotherapy. In early days surgery was the only modality by which malignant diseases could be treated. However, the surgery of large tumour was very complicated and in some cases it wasn't feasible to perform resect. The treatment of tumour with the use of ionizing radiation is known as radiation therapy. The tumours cells are more sensitive to the ionizing radiation than normal cells, therefore, killing is more in malignant cells than normal healthy cells and this principle is used to treat cancer with radiotherapy. Unlike the other medical specialties that rely mainly on the clinical knowledge and experience of medical specialists, radiotherapy, relies heavily on use of modern technology for treatment of cancer. The commonly used ionizing radiations are X-Rays and Gamma rays. Usually X-Rays used for radiation treatment are produced by Linear accelerators (linac) and Gamma rays by the telecobalt unit. There has been a revolution in medical field after the discovery of X-rays in **1895 by Wilhelm Conrad Roentgen** due to its vast application in treatment and diagnosis. Within the first year of the discovery, X-rays were used for treatment of malignant tumours diseases. The first application of X-rays for therapeutic purpose was made in **1896 in Chicago by Grubbe** for the treatment of breast carcinoma **(Reddy *et al.* 2008).** This new innovative type of treatment eventually became external beam radiotherapy **(EBT)** and established itself as an effective cancer management tool. **Harold E. John's** group conducted physics research on a cobalt-60 teletherapy machine in **1950's** which utilizes radioactive cobalt-60 source to produce monoenergetic gamma radiation. In **1951** the first patient in the world was treated with cobalt-60 teletherapy in **London (United Kingdom), Ontario (Canada)**. With the advance in technology, teletherapy machines were replaced by particle accelerators, which were capable of producing megavoltage X-ray for treatment. These particle accelerators would later develop into more sophisticated medical linear accelerators (Linac). Today in the field of Radiation Oncology, linacs are in routine use due to their ability to produce variable energy X-ray beams (Photon/Electron) and these machines are free from radioactive sources. As the use of medical linear accelerators for the treatment of cancer has become common, there is an essential requirement of accurate estimation of radiation dose deliver by these machines.

1.1 Motivation

To achieve the objective of using radiotherapy to treat cancer, it is essential to have a good understanding of the dose distribution delivered by the radiation beam theoretically and verify it by experimental measurements. Currently, the commercially available treatment planning systems are using dose calculation algorithms which are applying several approximations for computing the dose delivered by the radiation beam. These algorithms apply analytical approximations for the calculation of the delivered dose. Such estimates lead to errors in the computed values of beam parameters. Monte Carlo methods have the established reputation to accurately calculate the dose delivered by the radiation beam as these methods do not inherently use any approximations for computation of dose distribution. These methods provide a very capable and efficient way of determining the dosimetric and spectral characteristics of radiation beam. In addition to the accuracy required in the computation of radiation dose, it is important to gather the information of the spectral characteristics of the radiation beam as it has several applications like, in the designing of treatment head components and using linear accelerator for imaging employing megavoltage photon beams. The knowledge of these spectral characteristics allows improving the efficiency of dose delivery. Thus, in our study we have first developed an accurate Monte Carlo simulation model of 6 MV photon beam produced by Varian Clinic 600 linear accelerator (unique performance model) available at our institute. To validate the accuracy of our simulation model, we have compared the various dosimetric parameters calculated using our simulation model with experimentally measured data. After the satisfactory validation, this simulation model was used to obtain various types of spectra of different particles contributing in radiation beam to understand the influence of various components of treatment head on radiation beam characteristics. In recent year the introduction of flattening filter free beams to routine clinical application has produced significant interest in radiotherapy because of the possible advantages of unflattened beams as compared to traditionally used flattened beams. The requirement to have a flattened beam profile for treatment delivery is no longer necessary for many relatively new types of treatments such as intensity modulated radiation therapy, intensity modulated arc therapy. In these treatments the patient dose distribution can be shaped by the multileaf collimator (MLC) to deliver the desired dose. In addition the removal of the filter from the beam path has other advantages such as it increase dose rate and reduces the head scatter present in radiation beam. A decrease in head scatter may improve the dosimetry of unflattened beams, which can result in reduced output variation with the radiation field size and reduced variations in all field-size-dependent parameters. Flattening filter free (FFF) beams in radiotherapy thus have the benefit of shorter treatment delivery time and lower out of field dose compared to the conventional flattened beams. Therefore, we have made an attempt with Monte Carlo simulations to study the characteristics of an unflattened photon beam on an existing machine Varian Clinic 600 Unique Performance which is a new model and at present operates only in flattened mode.

1.2 Aim and objective

The intention and objective of the present research work are as follows:

1. To 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) and with the use of this simulation model: **(a)** To evaluate the contribution of dose by the different type of particles present in radiation beam in the total dose deliver by the beam. **(b)** To examine the spectral characteristics of radiation beam by computing photon fluence spectra, photon average energy distributions, photon energy fluence spectra and contaminant electron fluence spectra.

2. To investigate the following change in the characteristics of 6 MV photon beam transported through the multileaf collimators (MLC). The characteristics evaluated are, the effect of MLC on percentage depth dose, photon spectra and photon average energy distributions and the variation of MLC leakage as a function of field size.

3. To investigate the following basic dosimetric properties of Varian Clinic 600 linear accelerator (unique performance) as this machine is used without flattening filter in beam line using Monte Carlo Simulations: **(a)** Central-axis absorbed dose, **(b)** Lateral beam profiles **(c)** Photon and Electron fluences spectra. Theses parameters would be evaluated for the flattened as well as unflattened beam and radiation field size would be defined by the X & Y jaws only.

4. To compute the dosimetric properties of unflattened 6 MV photon beam shaped by multileaf collimator instead of jaws and to compare these parameters with the results obtained for the flattened beams using the Monte Carlo (MC) simulations. To compare the dosimetric and spectral characteristics (Lateral profiles, Central axis depth dose, MLC leakage, total scatter factor, photon and electron fluence spectra) for both flattened and unflattened beams.

1.3 Methodology

Throughout our research work we have used the BEAMnrc, BEAMDP and DOSXYZnrc user code provided with EGSnrc code system to carry out the simulation studies. This code system has well established reputation as Monte Carlo (MC) simulation tool for accurate results. The simulation model of Varian Clinic 600 linear accelerator (unique performance model) was designed in BEAMnrc code system with the use of inbuilt component modules in it. Geometry and materials details used to build the MC simulation model of the linear accelerator were obtained by the manufacturer Varian Medical Systems after signing the copyright agreement with them. The BEAMnrc user code were used to create the phase space files and theses files were used first by BEAMDP user code to drive various type of spectrum of different type of particle present in the radiation beam. Thereafter these phase space files were imported in the DOSXYZnrc user code to compute the dose delivered by the radiation beam. The computed dose distributions by the Monte Carlo simulations were compared with experimentally measured data to evaluate the accuracy of our simulation model. After the satisfactory match between the MC computed and measured data we have used this simulation model to achieve our research objectives.

1.4 Outcome of Thesis

The outcome of the present research work can be presented as the following:

We have successfully configured the 6 MV photon beam produced by Varian Clinic 600 linear accelerator (unique performance) in BEAMnrc user code for Monte Carlo simulations. The contribution by different types of particles present in radiation beam was evaluated to know the total dose. Investigation of the spectral characteristics of radiation beam showed that both photon and electron fluence spectra strongly depend upon the variation in field size. Most of the scatter energy fluence of photon comes from the flattening filter and primary collimator.

Our study of the effect of multileaf collimator (MLC) on radiation beam characteristics showed that photon spectra and photon average energy distributions were substantially modified by MLC as it removes lower-energy photons resulting in increase of percentage depth dose (PDDs) for MLC blocked fields in comparison to the jaw define open fields. A significant increase in MLC leakage with increase in field size was observed.

The results obtained in our study showed that removing flattening filter from the radiation beam transport path significantly increases the photon fluence delivered by the beam and thus is responsible for increased dose rate associated with the unflattened beam. Therefore, shorter beam delivery time for treatments can be achieved with the unflattened beam, which reduces the total exposure time and integrated dose deliver to the patient.

Our study showed that removing flattening filter from the beam line can reduce significantly the amount of head scatter photons present in the radiation beam, since most of the scatter energy fluence is contributed by the flattening filter. Also it was observed that for unflattened beam, lateral profiles have faster rate of decline and lower dose value. We found that the dosimetric field size and penumbra was smaller for unflattened beam and the decrease in radiation field size was less for MLC shaped in comparison to jaw shaped unflattened beam. Therefore, doses to surrounding normal tissues and organs other then targeted in any radiation treatment should be reduced for the unflattened beam in comparison to the corresponding flattened beam.

1.5 Organization of the Thesis

This thesis is presented in a series of seven successive chapters.

Chapter-I provides an overview of the thesis and briefly describes the research problem. This chapter depicts the aim and objectives, methodology to achieve research objectives and outcome of the present thesis work. The thesis organization part presented in this chapter briefly highlights all the chapters presented in the present thesis.

Chapter-II provides a introductory report on the following various aspects of the presented research problem: **(i)** A brief overview of the algorithms currently used for dose calculation in radiotherapy, **(ii)** The role of the Monte Carlo simulations in external beam radiotherapy dose calculation process and an review of the various Monte Carlo methods available for radiotherapy applications.

This chapter outlines the importance of Monte Carlo simulations for improving the accuracy of dose calculations in external beam radiation therapy.

Chapter-III is focused on the Monte Carlo (MC) study of spectral characteristics of 6 MV photon beam. The effect of contaminant charged particles (electrons) on its dosimetric properties has been evaluated and presented in this chapter. We have developed an accurate Monte Carlo simulation model for 6 MV photon beam produced by the Varian Clinic 600 linear accelerator (unique performance). The benchmarking of MC calculated data was done with experimentally measured percentage depth dose and profile data. Thereafter, we have used this simulation model to calculate the contribution of contaminant electron to the central axis depth dose, as with traditional methods of measurements it is difficult to compute dose delivered by different type of particles present in the radiation beam. We have also evaluated the spectral characteristics of radiation beam by computing photon fluence spectra, photon average energy distributions, photon energy fluence spectra and contaminant electron fluence spectra. The photon energy fluence spectra were separated into direct as well as scatter components from the primary collimator, flattening filter and the adjustable collimators to understand the influence of various components of treatment head on the radiation beam characteristics.

Chapter-IV is focused on the Monte Carlo (MC) study of the properties of radiation beam as it is being transported through the multileaf collimators (MLC) which are the part of secondary collimators system(tertiary collimators as attachment) and are the key elements used for the delivery of modern radiotherapy treatment. Accurate simulation model of 6 MV photon beam produced by Varian Clinic 600 unique performance was used to calculate the MLC radiation leakage as a function of field size by precisely modelling the complex geometry of 120-leaf Varian Millennium^{TM} Multileaf Collimators. We have also evaluated and presented the effect of MLC on percentage depth dose characteristics, photon spectra and photon average energy distributions in this chapter.

Chapter-V reports on the basic dosimetric properties of a Flattening-filter-free 6-MV photon beam produced by the unique performance model of the Varian Clinic 600 linac operated with and without a flattening filter in beam line to examine the possible different dosimetric properties of unflattened photon beams compared to the flattened beams. In this investigation the radiation field sizes were defined by the X & Y collimation jaws only. Dosimetric and spectral characteristics, including the central-axis absorbed dose, the beam profiles and the photon and electron fluences spectra were calculated and compared for both the flattened and unflattened beams individually by using Monte Carlo simulations to investigate the possible advantages of the unflattened beam.

Advances in radiotherapy treatment technologies have removed the essentiality of flattened beam profile for treatment and as a replacement for the flattening filter the leaf sequences of multileaf collimator (MLC) could be adjusted accordingly to produce desired fluence distributions similar to those of a flattened beam thus in **Chapter-VI** we have presented the study of dosimetric properties of unflattened 6 MV photon beam shaped by multileaf collimator and compares them with those of flattened beams using the Monte Carlo simulations. Dosimetric and spectral characteristics including lateral profiles, central axis depth dose, MLC leakage, total scatter factor, photon and electron fluence spectra were computed and compared for both flattened and unflattened beams.

Chapter-VII Presents the conclusion of the thesis work and recommendation for future research work.