Radiotherapy Treatment Planning of 16 MV X-Ray Linear Accelerator Using OMEGA BEAMnrc Monte Carlo Code System

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Abstract:

The Monte Carlo (MC) simulation of radiation transport is considered to be one of the most accurate methods of dose calculation in radiotherapy as one of the most important application of Medical Physics,. MC-based treatment planning for radiation therapy is becoming practical, particularly with the rapid development of computer technology. The treatment planning using MC method requires detailed knowledge of radiation beams of medical linear accelerators (linacs).

In the present work 16 MV x-ray linear accelerator was simulated using OMEGA BEAMnrc MC code system. The detailed spectra of the phase-space files for the photon beam of 10 cm x 10 cm field of view were modeled using the BEAMnrc MC system. The central axis depth-dose curves and dose profiles of the photon beams in water phantom were also scored and analyzed using DOSXYZnrc and STATDOSE code. This study demonstrates that the MC can create the phase-space data files which can be used to generate accurate MC dose distributions for photon beams from high energy linear accelerator in water phantom or in patient .

Keywords: Medical Physics, Radiation Dosimetry, Linear accelerators, Monte Carlo OMEGA BEAMnrc, Phase Space File

Introduction:

In the high energy medical linear accelerators (Linacs), important components are to be controlled in order to shape the output beam in either electron or photon mode [1-4]. These beams passes through a conical hole through a collimator of heavy metal. Below this collimator there is a slide containing a flattening filter of tungsten and a one section for an electron beam. Ion chamber is positioned near the slide to monitor the dose and a quadrant is connected to mechanism to control the beam optics. A light localizer is placed below the ion chamber which is retraced from the beam after patient position under the beam. A pair of collimator at right angles can be rotated about the axis to give square or rectangle field and all these are mounted in the head to about 50 cm, in general from the source. The types of external beam radiation therapy include conventional external radiotherapy. For example, many tumors can be treated with a single field from the front and a single field from the back or with two fields from the opposite sides. The combination of fields helps to uniformly deliver dose across the tumor. Sometimes 3 or 4 fields will be used. Occasionally, the gantry of the linear accelerator will rotate during treatment using what is called arc therapy. In the 3-D Conformal Radiation Therapy, there is an advancement of imaging technology for enhanced images of the body which allow for programming of treatment beams to conform better to the shape of a tumor. By treating with large numbers of beams each shaped with a Multi Leaf Collimator (MLC), radiation dose is delivered uniformly and conformally to the tumor. In recent years, the Intensity Modulated Radiation Therapy (IMRT) is considered as one of the latest advancements in radiation therapy. This new approach to treatment allows for dose sculpting and even distribution of delivery to avoid critical structures while delivering precise uniform treatment. In this technique, the MLC moves and modulates the radiation as the linac treats the patient [8-12].

The main objective of this project is to, first, simulate the whole 16 MV photons linear accelerator to produce the phase space file at 100 cm Source to Surface Distance (SSD)above the patient or the phantom using OMEGA BEAMnrc code. A phase space file is defined as a collection of representative pseudo-particles emerging from a radiation therapy treatment source along with their properties that include energy, particle type, position, direction, progeny and statistical weight. Analysis of the phase space is done using BEAMDP code. Second, calculations of the transmitted dose in the water phantom are investigated. The Monte Carlo code system BEAMnrc and DOSXYZnrc were used in the current work to model the high energy X-ray linac head and to calculate the transmitted dose in the water phantom [1].

Materials and Methods:

The linear accelerator is a primary tool in external beam radiotherapy [5-7]. Every pseudo-particle in the phase space file should be scored in such a way that it is recorded only once during the course of passage through the scoring surface (i.e., no further recording of the same particle or descendents). A phase space file can take the form of a computer file containing the detailed description of the phase space file particles, i.e., phase space file variables as generated via a Monte-Carlo simulation of the treatment source, or the form of a computer code (event generator) which simulates the treatment source using either a full Monte-Carlo simulation or beam model of the radiation therapy source.

The presentwork focuses on the general design of the Linac head that produces high energyx-ray beam generally range between 4 and 23 MV. The 15 MV simulated accelerator components are shown in Figure 1, including the exit window, target, primary collimator, flattening filter, monitor chamber, Y jaws and MLC. PEGS4 (EGS preprocessor) cross-section data for the specific materials in the accelerator were from 700 ICRU PEGS4 data file.

The simulation was done using Linux 64 bit work station where 10^7 history were used for creating both the phase space file and scoring the transmitted dose.

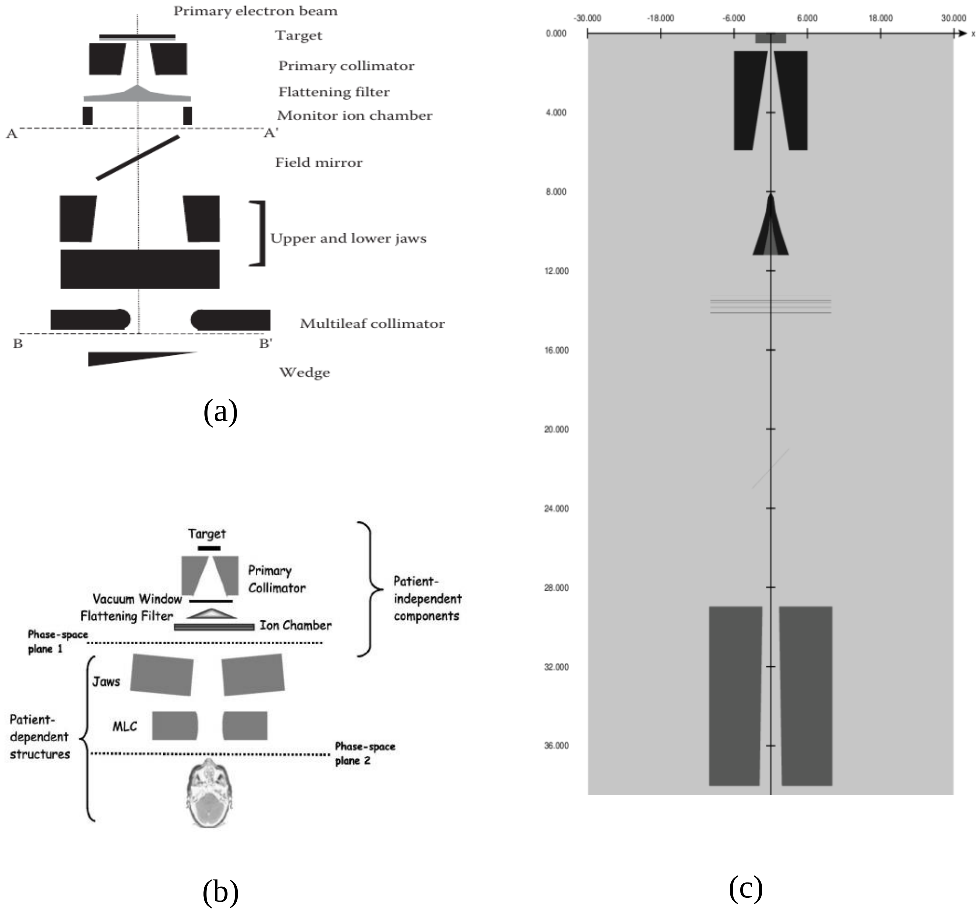
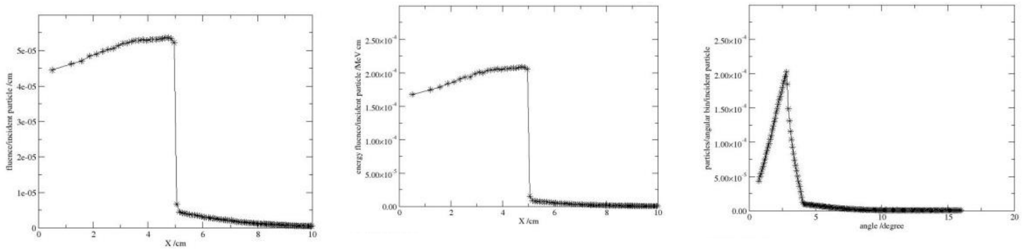


Figure 1: Schematic representation of linac components in a Monte Carlo model of a photon linac [13]. Figure (a) is the generic form, figure (b) represent the setup of the whole treatment planning of typical Varian linac [14] and figure (c) is the model using BEAMnrc code in the present work.

The simulation was done using DEBIAN GNU Linux 64 bit work station running a complete Electron Gamma Shower (EGS) Monte Carlo system. The GNU compiler suite c, c++ and Fortran along with the tools TK, TCL, and MAKE were used to compile the codes. DOSXYZ_SHOW was compiled using the Motif development software. For all simulations, 10^8 history were used for creating both the phase space file and scoring the transmitted dose.

Results and Discussions:

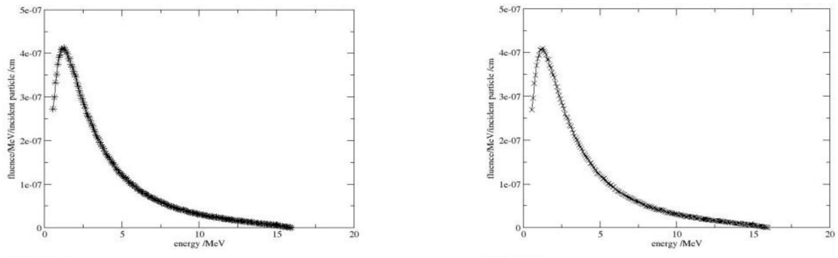
Phase Space File: The phase space file at 100 cm SSD where produced using BEAMnrc and analyzed using STATDOSE code. Figure 2 shows the total fluence and energy fluence. Also the results shows the angular distribution of the beam components where about 4^o is the maximum angle in the distribution. The figures show a value drop at about 5 cm radius of the field of view of the photon beam.



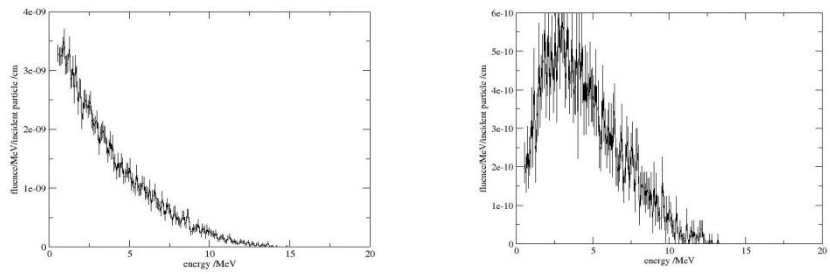
(a) (b) (c)

Figure 2: Fluence (a), Energy Fluence (b) and angular distribution against the radial distance from central axis of the photon beam.

Spectral Distribution: The phase space file were used to obtain the spectral distribution of
10 cm x 10 cm field of view beam as shown in Figure 2. The figure shows that the photons are the main component of the beam and the least are the electrons and positrons. The less is the number of electrons and positrons in the produced beam, the higher is the scattering of points of the spectral curve. This is due to the poor statistics of the very small number of electrons and even more for positrons. This is expected for a photon beam of any linear accelerator.



(a) (b)

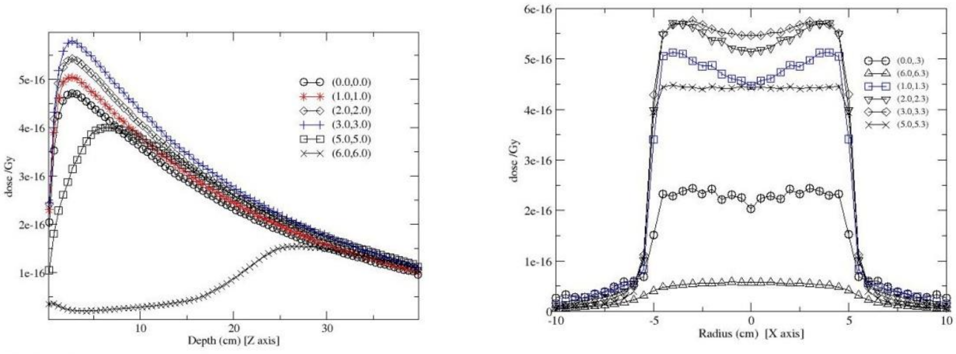


(c) (d)

Figure 3: Total (a), photon (b), electron (c) and positron (d) spectral distribution are represented as functions of energy bins.

Depth Dose Distributions and Dose Profiles:

The phase space file was used to score the depth dose distribution curves in the water phantom at 100 cm SSD using the DOSXYZnrc code system. Figure 4 (a) shows the dose curves at six different xy plane areas in the direction off the central axis where the depth is set in the z-direction. The maximum dose D_{max} moves toward higher depths as the xy area increases. Figure (b) shows the dose profile of the beam around the central axis. It shows the dose fall off at 5 cm on either side which is the radius of the field of view.

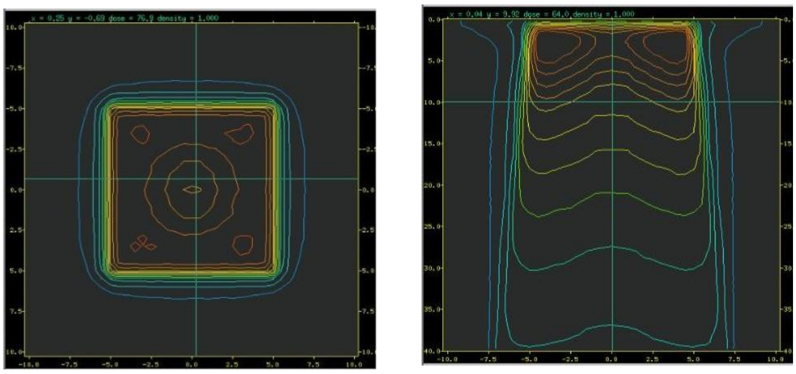


(a) (b)

Figure 4: Depth dose distribution of 10 cm x 10 cm photon beam in eater phantom (a) and dose profile of the central beam (b)

Isodose curves:

The data of the central axis depth dose data combined with the dose profiles give complete 2-D and 3-D information about a radiation beam. This information is difficult to visualize. Planar and volumetric variations in depth doses are usually displayed by means of isodose curves or isodose surfaces, which connect points of equal dose in a volume of interest. The isodose curves and surfaces are usually drawn at regular intervals of absorbed dose and are expressed as a percentage of the dose at a specific reference point. An isodose chart for a given single beam consists of a family of isodose curves usually drawn at regular increments of Percentage Depth Dose (PDD).



(a) (b)

Figure 5: Isodose charts for a 16 MV linear accelerator x-ray beam in water phantom. It shows an SSD set-up (A = 10 × 10 cm^2 SSD = 100 cm).

The dose then could be normalized in either Source to Surface Distance set-up (SSD) or in Source to Axis Distance (SAD) set-up. The DOSXYZ_SHOW software was used to display the dose data with the created water phantom file during the simulation. Figure 5 shows the isodose charts for a 15MV linear accelerator x-ray beam in water phantom. It shows an SSD set-up (A = 10 × 10 cm^2; SSD = 100 cm). Figure 5 (a) shows xy planner view while figure 5 (b) is the xz planner view. The coordinate cross markers in both figures can move everywhere at any position on the image to display the dose information at the top of the images. The isodose curves show that near the beam edges in the penumbra region, the dose decreases rapidly with lateral distance from the beam central axis. This dose fall-off is apparently caused by both the geometric penumbra effect and the reduced side scatter.

Conclusion:

The Monte Carlo MC code OMEGA BEAM was used to simulate the 16 MV photon beam linear accelerator. The accelerator beam spectra at 100 cm source to surface distance SSD were produced and analyzed. The depth dose curves and dose profiles for 10 cm x 10 cm field of view beam were scored in water phantom. OMEGA BEAM code proved to be capable and accurate for radiotherapy treatment planning.

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