A method for determination of parameters of the initial electron beam hitting the target in linac

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Abstract. Detailed characteristics of the electron beam incident on the target of the Linac are almost impossible to be measured. With Monte Carlo technique it is possible to simulate the transport of radiation through the accelerator head and find out the initial beam parameters. These parameters, such as energy spectrum and spatial distribution can be ascertained by matching the simulated dose distributions with the measured dose distributions using trial and error. In this work, a Monte Carlo modeling of the HPD Siemens Primus linear accelerator in 6 MV photon beams at Dong Nai general hospital was performed. The simulated Percent depth doses (PDD) and beam profiles (OCR) were then compared with the measured ones. Excellent agreements were obtained between simulations and measurements with an average difference of 0.7% for PDD less than 2% for OCR. The percentage gamma passing rate is 100% with 1% dose difference and 1 mm distance to agreement as acceptance criteria. The best suited energy and radius of the electron beam incident on the target were found at 6.04 MeV and at FWHM = 1.2 mm respectively.

1. Introduction
The EGSnrc (Electron–Gamma–Shower) is a well-known Monte Carlo simulation package widely used in medical physics application. BEAMnrc, built on the EGSnrc, is a user code for modeling radiotherapy sources from linear accelerators [1]. Detailed information (i.e. the position, direction, charge, and energy) of all the particles leaving the accelerator was stored in a phase-space data file. DOSXYZnrc [2] is an EGSnrc user code for calculating radiation dose in Cartesian voxels. In our study, the phase space files obtained with BEAMnrc are used as source inputs to the DOSXYZnrc to simulate dose distributions in a water phantom. Due to difference in structures of linac, beam parameters have to be determined for each linac. This paper introduces a method for determination of the parameters of the electron beam as it leaves the accelerator vacuum and hits the target for Siemens Primus M5497 linac. The simulated and measured percentage depth dose (PDD) and beam profiles (OCR) for a 10x10 cm² field’s size were compared. The energy and radius of the electron were adjusted until the best fit was found.

2. Materials and methods
2.1. Monte Carlo simulation of the HPD Linac with BEAMnrc

The BEAMnrc user code was used to simulate a 6 MV photon beam from a Siemens Primus linear (Siemens Medical Solutions USA, Inc.) at Dong Nai general hospital, Vietnam, with a 10x10 cm$^2$ field at SSD=100 cm. This linear accelerator was installed at the department of radiation oncology in 2009. All the physical dimensions and material of the relevant components of the accelerator head were incorporated according to the manufacture’s detailed specifications. In BEAMnrc these components were modeled by a number of predefined component modules (CM). The primus accelerator components are shown in figure 1, which consists of 9 component modules: Vacuum envelope (SLABS), the target (SLABS), the flattening filter (FLATFILT), chambers for monitoring the linac output (CHAMBER), mirror made of SiO$_2$ (MIRROR), the jaws X and jaws Y made of tungsten (JAWS), reticle tray of mica (SLABS), and slab air (SLABS).

![Figure 1. Component modules of the accelerator (6 MV)](image)

The global cutoff energy (ECUT) and production cutoff energy (AE, AP) used in simulation were 0.7 MeV for electron and 0.1 MeV for photon. A total of $2 \times 10^8$ electron histories were simulated. The simulations run on Intel(R) Core i5 2400 processors. The history of particles is ended when its energy is below a predefined energy threshold (ESAVE). In our study, ESAVE was set to 2 MeV in all component modules and directional bremsstrahlung splitting (DBS) was applied [3]. The output of the BEAMnrc simulation is a phase space file, which contains information about all the particles leaving the accelerator such as energy, position, direction, etc. This phase space was scored in a plane perpendicular to the beam axis at 100 cm distance from the target. From this phase space, the BEAMDP was be used to analyze parameters of beam production and plot energy spectrum of photon beam.

2.2. Dose calculation with DOSXYZnrc

The EGSnrc user code DOSXYZnrc was used to calculate dose distribution in a water phantom (50x50x30 cm$^3$ water tank). The voxel size was presented in figure 2. The phantom is divided into 3x5x2 voxels in the x, y, and z directions. In z-axis there were 10 slices of 0.2 cm thickness and 56 slices 0.5 cm of thickness; in the x-axis 2 slices of 24 cm thickness and 1 slice of 2 cm thickness; in the y-axis 2 slices of 17 cm thickness 28 slices of 0.5 cm thickness and 1 slices of 1.5 cm thickness. There were in total 6138 voxels.
Figure 2. Voxels set in DOSXYZnrc simulation

The water phantom was located at source to surface distance (SSD) of 100 cm. The electron and photon cut-off energy (ECUT, PCUT) was set to 0.7 MeV and 0.01 MeV, respectively. 10^9 histories were simulated. The output file from DOSXYZnrc program was analyzed by an in-house MATLAB code.

Figure 3. Flowchart of the procedure

Before impinging on the x-ray target the electrons were accelerated in the accelerator tube and then bent by magnet system to a net angle of 270°. The acceleration and bending process result in a beam of electrons which is heteroenergetic and has spatial distribution [4]. In this work, to simplify the problem, we assumed that the incident electron beam is monoenergetic. The determination of the incident electron beam parameters was an iterative process. Figure 3 shows a flowchart of the process. Initially, Monte Carlo simulations were executed for mono-energetic electron beams ranging from 5.7 to 6.2 MeV. The source routine ISOURC = 0 (Figure 4-a) for a parallel circular beam with a uniform radial intensity distribution, was used. The suitable mean energy was found by varying it in steps of 0.1 MeV until the PDD well matched the measurement [5]. Once the best suited energy was found, it was then applied for the source routine ISOURC = 19 (Figure 4-b), which describes a parallel circular beam with a 2-D Gaussian radial intensity distribution. The suitable FWHM of this beam was found by varying it from 1.0 mm to 1.4 mm and looking for a matching between calculating and measured OCR.
2.3. Experimental measurements

In our study, the measurements were performed on Siemens Primus linear accelerator. All the measurements were made using the IBA Dosimetry "blue phantom" scanning system, controlled by Omnipro-Accept 7.4c software. All measurements were done in water using the Scanditronix Wellhofer CC13 cylindrical ionization chamber having an active volume of 0.13 cm\(^3\). A reference chamber was placed in the field to correct for beam output variations during scanning. Ranges of measurement, for depth dose curves; it was from a depth of -0.5 mm to a depth of 350 mm and for beam profiles, the off-axis distance was from -125 mm to +125 mm. All measurements were done in continuous scan mode, output step of 1.2 mm, scan speed of 15 mm/s.

2.4. Method to compare measured and simulated data

The agreement between calculations and measurements was usually evaluated by calculating the mean point to point dose error, with flow formula [6]:

\[
\Delta D = \frac{1}{N} \sum \left( \frac{|D_c - D_m|}{D_m} \right)
\]

(1)

\(\Delta D\) is the mean point-to-point error; \(N\) is the number of points, \(D_c\) is the simulated dose and \(D_m\) is the measured dose.

The evaluation of the result using the point to point errors could give rise to high overall errors in low dose areas and high dose gradient regions. Therefore, calculating the gamma index is an alternative method for this analysis recently [6, 7]. This method has become the gold standard for the comparison between measured and calculated dose distributions. The gamma index is defined for each measurement point \(r_m\) as:

\[
\gamma(r_m) = \min \left\{ \Gamma(r_m, r_c) \right\} \forall (r_c)
\]

(2)

Where

\[
\Gamma(r_m, r_c) = \sqrt{\frac{\Delta d_{M}^2}{\Delta d_{M}^2} + \frac{\delta^2(r_m, r_c)}{\Delta D_{M}^2}}, \quad r_m = |r_m - r_c|, \text{ and } \delta(r_m, r_c) = D_c(r_c) - D_m(r_m)
\]

(3)

\(r_m\) is the position at the measurement point and \(r_c\) is the position at the calculation point.

\(D_c(r_c)\) and \(D_m(r_m)\) are calculation and measurement doses.

\(\Delta d_{M}\) (mm) is the distance-to-agreement (DTA) criterion and \(\Delta D_{M}\) (%) is the dose-difference criterion.

We calculated the number of points passing the 1%/1 mm criterion. In order to analysis gamma index, the PDD data from simulation as well as the corresponding beam profiles at various depth was incorporated in a text file which got from eclipse export option. The PDD file from measurement as well as various depths was converted to another text file. This two text files then were compared by ScanDoseMatch software to plot chart gamma index. On the other hand, the percentage passed gamma criterion is calculated by an in house MATLAB code.
3. Results and discussion
For the 6 MV photon beam from the Siemens Primus M5497 linac at Dong Nai Hospital, the best agreement between simulation and measured data was found for an electron beam of mono-energy 6.04 MeV with Gaussian radial spread of FWHM 1.2 mm

3.1. Percent Depth Dose (PDD)
Depth dose curves in the 6 MV photon beam is normalized at 1.5 cm where the dose is at maximum. Figure 5 shows that the agreement between the measurement and simulation are excellent. The statistical uncertainties in the calculated depth doses were equal to or less than 0.7% of local value for all voxels at depths from 1.5 to 3 cm.

The percentage gamma passing rate (red line in figure 5) is 100% with 1% dose difference and 1 mm distance. In the buildup region and the tail of the PDD curves (at depth from 27 to 30 cm), the PDD are low, the gamma index is much higher than the one in remaining regions. This observation can be explained based on the general law of statistical uncertainty in radiation counting: the lower the number of events the higher the relative uncertainty of measured and calculated counts, which results in the higher values of gamma index.

3.2. Beam profiles (the off-centre ratio-OCR)
The beam profile at the depth of 10 cm for 10x10 cm² field is normalized at central axis.

Figure 5. Comparisons of simulated with measured PDD

Figure 6. The 6MV photon beam profile in water for a 10 x 10 cm² field at 10 cm depth
Figure 6 shows very good matching between the simulations and the measurements. The average dose of beam profile flatness was less than 2%. The percentage gamma passing rate (red line) is 98% with 2% dose difference and 2 mm distance to agreement as acceptance criteria. In the figure 6 there are some points that gamma index is higher than 1, these points at the edge of penumbra region whose doses are very low. Thus it leads to high percentage difference between calculated and measured dose. The same observation was reported in [8].

4. Conclusion
In this work, two parameters of the incident electron beams for the 6 MV photon beam from the Siemens Primus M5497 linac at Dong Nai Hospital have been determined an electron beam with mean energy of 6.04 MeV and an FWHM of radial spread of 1.2 mm was found to give best fit between calculated and measured PDD and OCR.

5. References
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