Monte Carlo Simulation of Linear Accelerator for Dosimetry Analysis

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Abstract. Radiation therapy is a means to treat cancer that makes use of beams of intense energy to kill cells that are cancerous in nature. The equipment most often used for the procedure is the Linear Accelerator(LINAC). This machine produces beams of X-rays and transports them to the patient's cancerous region. The dose of radiation to be deposited on the patient body needs to be evaluated before application.

This project aims at simulating the radiotherapy process using a LINAC in order to carry out the dosimetric analysis. The simulation makes use of the Monte Carlo method, which has been proven to provide realistic results in terms of accuracy. The project is in collaboration with MVR Cancer centre at Calicut and is expected to help in the dosimetric analysis of their specific LINACs in future.

The proposed simulation was carried out using GATE (Geant4 Application for Tomographic Emission) software based on a 6MV Elekta Synergy Platform LINAC. Depth dose and dose profile curves were plotted for dosimetric analysis and uncertainty error values were compared with a similar work on the same field. It was observed that the values are in the same range, proving the credibility for the proposed simulation.

Keywords: Radiation therapy, linear Accelerator, Monte Carlo, dosimetric analysis, uncertainty

1 Introduction

When the cells in the human body get exposed to a carcinogenic substance, they begin to multiply uncontrollably. In essence, they fail to die and eventually cause fatal damage to the body. Cancer refers to the umbrella of over 100 diseases caused in this manner, making it the second leading cause of death worldwide. As of 2018, cancer was alone responsible for about 1 in 6 deaths globally [15].

Radiotherapy is among the major techniques used for cancer treatment. It uses waves of energy such as light or heat to treat tumours and other conditions.

The most commonly used machine in radiotherapy is the Linear Accelerator (Linac). A LINAC produces X-rays in the range of 5-30 MeV through an electron acceleration structure (Figure 1) [10].

The electron gun attached to the waveguide acts as the electron source. The electrons are accelerated down the structure by pulses of microwave from a magnetron or klystron. The electron beams, on leaving the accelerator tube, are bent by magnetic fields in varying angles depending on the machine vendor. Once the electron beams hit the target, X-ray beams are produced.

The beams are then transported through the LINAC head (Figure 2) in the required configuration to reach the patient body. The required dose of the radiation is determined from the Computed Tomography (CT) images taken during patient diagnosis. This project simulates the LINAC head, beam production, and its transportation to a phantom, which acts as the patient body.

Physical phantoms are widely used to calculate the precision of dose in radiotherapy. A simulated version of the process can carry out the dose evaluation in the same manner. If the accuracy of the simulated version can be proven, the physical dose analysis with a phantom can be avoided.

The proposed simulation is based on Monte Carlo methods which are commonly used for applications in radiotherapy. These methods depend on repeated random sampling to generate outputs and can help us to acquire accurate results. The accuracy depends on the number of events, and consequently, the simulation time.

The Geant4 Application for Tomographic Emission (GATE) is a Monte Carlo simulation toolkit for medical physics applications. It is an open-source software

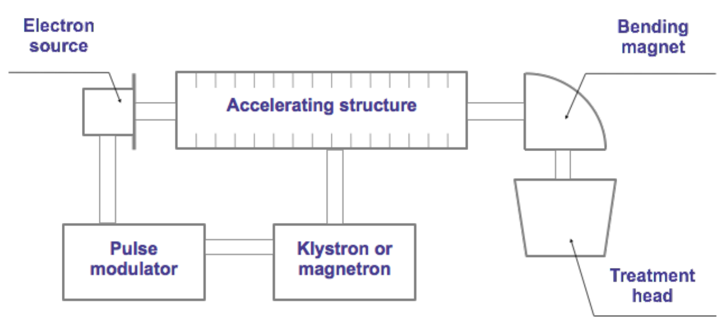

Fig. 1. Block Diagram of LINAC electron acceleration structure.

used for simulations of preclinical and clinical scans in emission tomography, transmission tomography and radiation therapy [16]. This project makes use of GATE version 8.2 for LINAC and radiotherapy simulation.

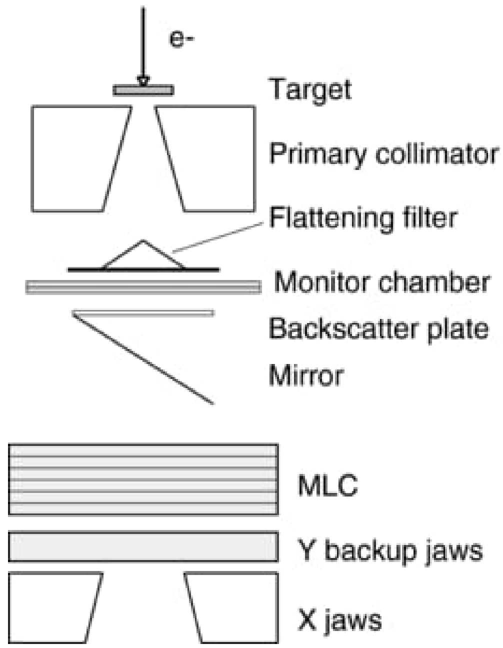

Fig. 2. Components of LINAC Head

In the following sections, the report discusses the literature survey carried out for the project, including the theory for implementation as well as the related works of research (section 2), the motivation behind the project along with the problem statement (section 3), the methodology (section 4) describing its design and implementation, followed by the results and conclusions in sections 5 and 6.

2 Literature Survey

The radiotherapy treatment technique can be divided into three sections - radiation beam generation, beam transportation, and dosimetric analysis. They are described below.

2.1 Beam Generation

The LINAC accelerates electrons in the waveguide using microwave technology. The accelerated electrons are suddenly slowed when it collides with the tungsten target, from which x-ray beams are generated. This is called the Bremsstrahlung process.

Primary collimators, which are situated right below the target, direct the beam in the direction of the treatment and reduce leakage (Figure 2). At the lower end of the primary collimator is the flattening filter, which reduces the beam intensity in the centre to provide uniform radiation intensity distribution.

The beam then enters the ionization chamber, from which measurements of the amount of radiation are taken and uniformity of the beam is controlled. The backscatter plate avoids backscattered radiation from secondary collimators. The mirror placed below it shows the position of the radiation beam and enables patient set-up.

The next focus is to ensure that the radiation dose to cancer cells target the affected region precisely. This is to reduce side effects and to eliminate the damaging of cells that are normal. Contouring of the shape and location of a tumour is done using imaging tests and boundaries are defined accordingly.

The multileaf collimators (MLC) usually customizes the shape of the beam. These collimators are also fixed into the head of the machine. The treatment coach on which the patient lies is moveable and the position of the patient is determined with the help of lasers. The couch can move in directions up, down, right, left, in and out.

The main part of the accelerator is the gantry from which the beam emerges. It too can be rotated around the patient, enabling radiation to be transferred from many angles.

2.2 Beam Transportation

When it comes to radiotherapy, radiation is transferred in high doses to kill cancer cells by damaging their DNA, thus diminishing the cell's ability to replicate.

A typical radiation therapy treatment makes use of high-energy photons. The source of photons can either be from the nucleus of a radioactive atom, in which case they are called gamma rays, or it could be created electronically to form x-rays.

While X-rays have a spectrum of energies, gamma rays have discrete energies. For this reason, the maximum energy of the x-ray spectrum produced can be controlled, unlike the case of gamma rays. Here, the linear accelerator electronically produces X-rays by controlling its energy according to the requirements.

During the beam transportation in the radiotherapy process, when the photons interact with matter, several processes are bound to take place. They are listed below.

Photoelectric Effect Photoelectric effect occurs when an incident photon transfers its energy to an atomic electron. The electron gets emitted from the atom and ionizes its neighbouring molecules. The resulting photoelectron's kinetic energy (E_e) is equal to the difference between energy of the incident gamma photon and the binding energy (E_b) of the electron and is given by $E_e = hv$ - E_b.

This effect is mostly observed in tissues within 10-25 keV energy range. The lower the energy of the photon and the higher the atomic number of the target matter, the more likely it is for the effect to occur. The electron needs to overcome its binding energy to absorb the photon energy. This occurs only with a whole atom and not with free electrons.

Compton Effect During the Compton interaction, only partial energy of the photon gets transferred. In this collision, a high-energy photon interacts with a free electron, from which the electron gets deflected with an angle θ with respect to its original direction. Since a portion of the photon's energy is transferred to the electron, the outgoing deflected photon will have lesser energy.

The transfer of energy is given by the formula

$$hv_0 = \frac{hv}{(1 + (hv/m_0c^2)(1 - cos\theta))}$$

where hv and hv_0 are the energies of the incident and deflected photons, h is the Planck's constant, m_0 is the rest mass energy of the electron, c is the velocity of light and θ is the angle of scatter of photon relative to its original direction of travel.

The scattered photons may continue to have further interactions with energy that is lower, and the electrons begin to ionize with the energy obtained from the photon. The energy range for the effect is 25keV - 25MeV.

Coherent Scattering Coherent scattering (elastic scattering) occurs when the atom's ionizing energy is greater than the X-ray or gamma-photon energy. There are two types of coherent scattering:

- Rayleigh scattering is the elastic scattering of a photon off an entire atom.
- Thomson scattering is the elastic scattering of a photon off a single unbound electron.

When the photon interacts with the atom, it does not have sufficient energy to ionise the electron from its orbits. Thus there is neither energy transfer nor wavelength transition. A change in direction of the photon is the only significant occurrence. This effect is observed when the photon energy is around 10keV. In most diagnostic procedures this is usually not observed.

Coherent scattering is given by the formula Z/E^2 where Z is the atomic number of the absorber and E is the incident photon energy.

Pair Production Pair production is an interaction between photon and matter that takes place when a photon is in near proximity to an atom's nucleus. It can interact only with photons possessing high energy of at least 1.022 MeV. In this process, energy gets converted into matter on photon interaction with the nucleus. As a result, a pair of particles, an electron, and a positively charged positron are formed.

These two particles possess the same mass, each equivalent to a rest mass energy of 0.51 MeV. The remaining energy of the photon gets converted to kinetic energy which helps these particles move away. Pair production varies with the atomic number of a material by Z^2.

Triplet Production Triplet production happens in the vicinity of an orbital electron. This effect is a special case of Pair production. In Triplet production, a positron (anti-electron) and an electron are produced spontaneously as a photon interacts with a strong electric field with an electron.

A photon has the highest momentum per unit energy, so when it forms an electron-positron pair, another mass has to be present in the system to conserve momentum and that mass is an electron. Excess photon momentum is transferred to an electron, and the associated kinetic energy transferred is considerable.

Photodisintegration Photodisintegration (also called photo transmutation) is an unusual occurrence that takes place when a photon is absorbed by the nucleus of an atom. The nucleus gets energized and becomes radioactive. To become stable the nucleus emits negatrons, protons, neutrons, alpha particles, clusters of fragments or gamma rays.

The threshold for this effect is over 10 MeV for most nuclei and these photons are found in radiotherapy. Indeed, photodisintegration is an rare phenomenon even at high energies, and does not limit a large portion of a photon beam. For radiation protection concerns it is progressively important - if neutrons are discharged they are extremely penetrating and can change atoms into unstable isotopes.

In general, releasing a nucleon from the atom also results in a radioactive daughter product. Production of neutrons in high-energy linear accelerators means that bunkers have to be consistently ventilated to prevent radioactive gasses from developing.

2.3 Dosimetric Analysis

An x-ray beam's intensity is determined by the Inverse Square Law. This law states that the radiation intensity from a point source is inversely proportional to the square of the distance away from the radiation source. That is, the dose is less when the source is farther away.

$$intensity \propto \frac{1}{distance^2}$$

The dose distribution on the phantom or patient body is generally measured using two parameters - percentage depth dose and dose profile.

The percentage depth dose refers to the values of the absorbed dose as it varies with the depth of the phantom. It is measured along the axis of the radiation beam. The dose profile refers to the transverse dose measurements on the phantom in the cross-plane or in plane. These are in directions perpendicular to the radiation beam.

Another means of measurement is KERMA, which stands for Kinetic Energy Released per unit MAss. Its unit of energy is the same as that of absorbed dose - grays (Gy), which stands for energy absorbed per unit mass [19]. However, KERMA is not the same as absorbed dose, as will be explained ahead.

The transfer of photon energy to matter happens in two steps. First, it is passed to secondary charged particles through several photon interactions as described in section 2.2. Next, the charged particles pass the energy to matter through atomic excitations and ionizations. KERMA stands for this transfer of energy from radiation to the charged particles per unit mass, while absorbed dose stands for the energy absorbed per unit mass by the matter [20].

The difference in energies of transfer and deposition is only significant in higher energies. For instance, when a high energy photon interacts with a tissue at a particular location, it could transfer enough energy to eject an electron that can deposit energy in a different location. The dose absorbed here is the remaining energy from the photon. In the case of lower energy photons, no secondary particles are generated.

2.4 Related Works

Several works have been done in the field for the simulation of Linear Accelerators, some of which are briefed below.

Alex C. H. Oliveira et al.[10] worked on the evaluation of dose distributions in radiotherapy planning. They aimed at creating a computational model of the head of a 6 MeV Linac using a Monte Carlo code in Geant4 for the generation of phase spaces. For assessing the quality of the beam and analyzing the physical processes which take place in the beam production, information was taken from the phase space. The MC simulations had two parts.

- In the first, the radiation beam production was simulated and then the phase space was generated.
- In the second, certain configurations of the irradiation field of the sampled phase space were simulated as part of the transportation and the assessment of dose distribution was carried out in the phantom.

This work was to analyze the methodology of phase space generation, understanding beam characteristics, and accuracy of dosimetry. It was concluded that it is important to implement error analysis methods for reliability.

In a work done by Kagri Yazgan and Yigit Cecen[2], Monte Carlo N-particle (MCNP) code was used to simulate a medical electron linear accelerator gantry. Flux, dose, and spectrum analyses were performed for filtered and FFF systems separately. Percent depth dose and dose profile measurements were calculated with Monte Carlo simulations and compared with experimental and theoretical values for quality assurance of the model.

The following were the results of the experiment:

- The average photon energy was 3.54 times higher in the filtered system than in the FFF system
- The average photon dose was 3.18 times higher for the FFF system than for filtered system
- The errors in the comparison of simulation-experimental values were only 0.22

The study successfully carried out a detailed analysis of filtered and FFF systems with respect to their working principles.

Mohammad Taghi Bahreyni Toossi et al. [4] on the other hand used the MCNP-4C to simulate electron beams from Neptun 10 PC medical linear accelerator. They measured and calculated results for 6, 8 and 10 MeV electrons. The three energy values were implemented with eleven different conventional fields.

Wellhofler-Scanditronix dose scanning system was used to carry out the measurements. The results obtained from the MCNP-4C simulation were found to be in good agreement with those acquired from experimental measurements.

In another work of theirs[1], a 6 MV photon beam of Elekta LINAC was simulated using GATE for the optimization of dosimetric parameters. The spatial distribution of electron beams, the energy spectrum, and the simulation of LINAC were verified before the dose distribution was calculated in water phantom. Further on, the curves for dosimetric parameters for the radiation fields (standard and wedge with size = 10×10 and 30×30 cm) were plotted.

The results were compared with a Gamma index of 3%/3 mm criteria. It was compared between the experimental computation and the GATE simulation to give up to 1.9% and 1.6% for 10×10 cm and 30×30 cm, respectively for the profile dose curves. Based on this accuracy level, it was concluded that GATE can be a convenient toolkit for evaluating quality control in radiotherapy.

In a work done by B. Serrano et al.[7], an MC code MCNPX was used to model a 25 MV photon beam from a PRIMUS(KD2-Siemens) medical linac. The whole geometry of the linac, with the accelerator head and water phantom simulation was carried out. Using this, the dose profile and the relative depth-dose distribution were calculated.

The ionization chamber in water was used for measurements in different square field sizes. Siemens had provided the mean electron beam energy as 19 MeV, but it was observed to be 15 MeV from the results. These results can contribute to the validation of IMRT (Intensity-modulated radiation therapy) treatment's dose deposition. It will particularly help for the regions of head and neck.

Yahya Tayalatia et. al [3]developed a computational model for 6MV Elekta Synergy Platform LINAC using GATE Monte Carlo software. The simulation was carried out using v6.2 of GATE, built on top of GEANT4 simulation toolkit. There were only a few primary event interactions in the penumbra tail of radiation field, because of which points lower than 10% of the maximum dose area were not considered.

The simulated depth dose profiles were found to be in good agreement with the measured ones, with uncertainty less than 1.6%. The simulation of lateral dose profiles also fit accurately with the measurements with less than 1.8% of error uncertainties.

In a work accomplished by L Grevillot et. at [6], extension of usage of GEANT4-based GATE Monte Carlo platform was investigated. The simulations were divided into two parts: the patient-independent part(target to phase space) and patient-dependent part(phase space to phantom). This work simulated a 6MV

Elekta Precise Linac photon beam.

It made use of the Selective Bremsstrahlung Splitting (SBS) variance reduction technique, which was observed to have helped in increasing the output rate of the photon by a factor of 9.7. At the same time, the increase by a factor of 6.2 was observed for the simulation of electron beam's efficiency to a water phantom.

Simulations using the multiple source model (MSM) were in an agreement within 1% of the entire simulations. The study concluded that GATE can be used for radiotherapy applications but also mentioned that absolute dosimetry comparisons will be required so as to completely measure the platform's accuracy.

3 Problem Definition

Monte Carlo simulation of a linear accelerator for treatment planning of cancer:

1. Simulation of radiation beam production in LINAC.
2. Simulation of beam transport from LINAC head to phantom.
3. Dosimetry analysis of radiation on phantom.

3.1 Motivation

With cancer threatening the lives of a significant population across the world, any step that contributes towards its treatment is of immense help. Radiotherapy, being one of the primary treatment techniques for cancer, requires a proper analysis of the dose of radiation to be transferred to the patient.

For this dosimetric analysis, the LINAC shoots radiation beams on a physical phantom serving as the patient body. This process is quite expensive especially due to the high costs of physical phantoms. With the help of a software simulation of the process, the analysis can be carried out without the use of the physical equipment.

Our project aims to do the same, which in turn can help in cutting down the costs of dosimetric analysis. The existing code simulations of the process are proprietary, and hence, add to the expenses if used. By keeping our work open-source, we hope to widen its availability and thus pave the way for reduced treatment expenses for patients.

3.2 Input and Output

Input - Number of primary particles for the simulation (here, number of electrons)

Outputs -

1. 3D image of dose distribution on phantom
2. Percentage depth dose and its statistical uncertainty
3. Dose profile and its statistical uncertainty

4 Methodology

4.1 Design

The simulation of the LINAC and radiotherapy process is divided into two parts.

Part 1 - Beam Generation The aim of this part is to generate a phase space. The phase space contains information about millions of particles. They typically include its energy, position, direction, etc. Figure 3 shows the steps involved in generating the same.

1. Creation of geometry: The geometry of LINAC components such as the target, primary collimator, flattening filter, ionizing chamber, backscatter plate, and mirror are simulated. The following are the details of the compositions of each component:

– Target: 90% Tungsten, 10% Rhenium and the target support is made of copper.
– Primary Collimator: 95% Tungsten, 3.75% Nickel and 1.25% Iron.
– Flattening Filter: 75% Iron ,17% Chromium and 8% Nickel
– Ionizing Chamber: Carbon, Mylar(62.5% Carbon, 33.3% Oxygen and 4.2%Hydrogen)
– Backscatter Plate: Aluminium
– Mirror: Aluminium, Mylar

2. Describe general particle source: Details of the particle source are described here including its type (here, electron), position distribution (type, shape, coordinates, rotation matrix, standard deviation), energy distribution (type, energy value, standard deviation), angular distribution (type, rotation matrix, standard deviation), and direction of the generated particle.

3. Describe particle interactions: Particle interactions required for the simulation include photons with matter (section 2.2), as well as the Bremsstrahlung process where electrons are decelerated to generate photons. These physics processes are defined for the simulation.

4. Set number of primary particles: The number of electrons to carry out the process simulation is set. This is generally in the range of millions.

5. Apply Monte Carlo simulation: Monte Carlo method is applied to the Bremsstrahlung physics process by using the Russian Roulette and Splitting variance reduction technique [13, 14].

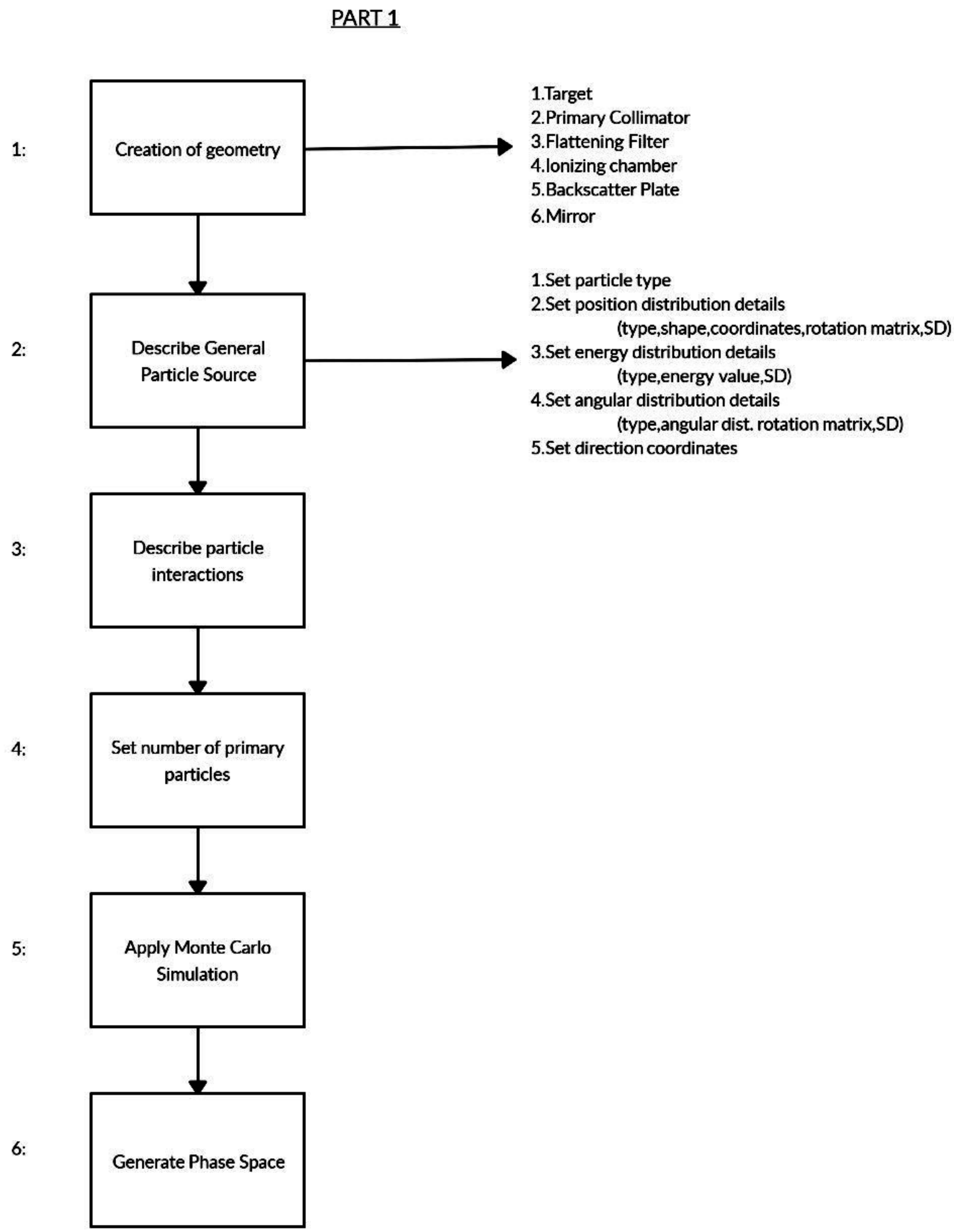

Fig. 3. Simulation Design - part 1

When the electrons from the particle source collide with the target to produce photons through the Bremsstrahlung physics process, generating a significant number of photons is computationally expensive. The Russian Roulette and Splitting technique helps to reduce the processing time.

The large numbers of photons which are produced by the Bremsstrahlung process move either away or towards the source. If photons are found to pass through a surface in a direction away from the source, then the Monte Carlo method uses the Splitting technique to split these favourable photons into 'n' identical photons. Each such photon is then assigned a statistical weight of 1/nth of its former value and is treated as 'n' distinct photons.

If a photon is found to pass through a surface back towards the source, Monte Carlo uses the Russian Roulette technique to determine if the photon's history should be continued or terminated. The probability to continue such a photon's history is set at 1/n. If a photon's history is to be continued its weight is increased by a factor of 'n'.

This combined method helps to drastically reduce the time of simulation as the favourable generations are multiplied in the same event instead of waiting for more photons to be generated. [11, 12]

6. Generate phase space: At this point, the simulation is run and the phase space is generated. This phase space will contain the details of all the photons generated through the bremsstrahlung process. This stored information can be used any number of times in the future as a particle source.

Part 2 - Beam Transportation & Dosimetric Analysis This part as illustrated in Figure 4 makes use of the generated phase space from part 1 as the particle source. The simulation time for beam generation is saved as it is already done in the phase space.

1. Creation of geometry: In addition to the components in part 1, secondary collimators, multi-leaf collimators (MLC), and the phantom are simulated. The collimators are composed of 95% tungsten, 3.75% nickel and 1.25% iron. A water phantom is used and 80 number of MLC leaves are described.

2. Set particle source as phase space: The output phase space from part 1 is taken as input here. The particles for the beam transportation to the phantom will be taken in random from this file.

3. Describe particle interactions: Same as in part 1.

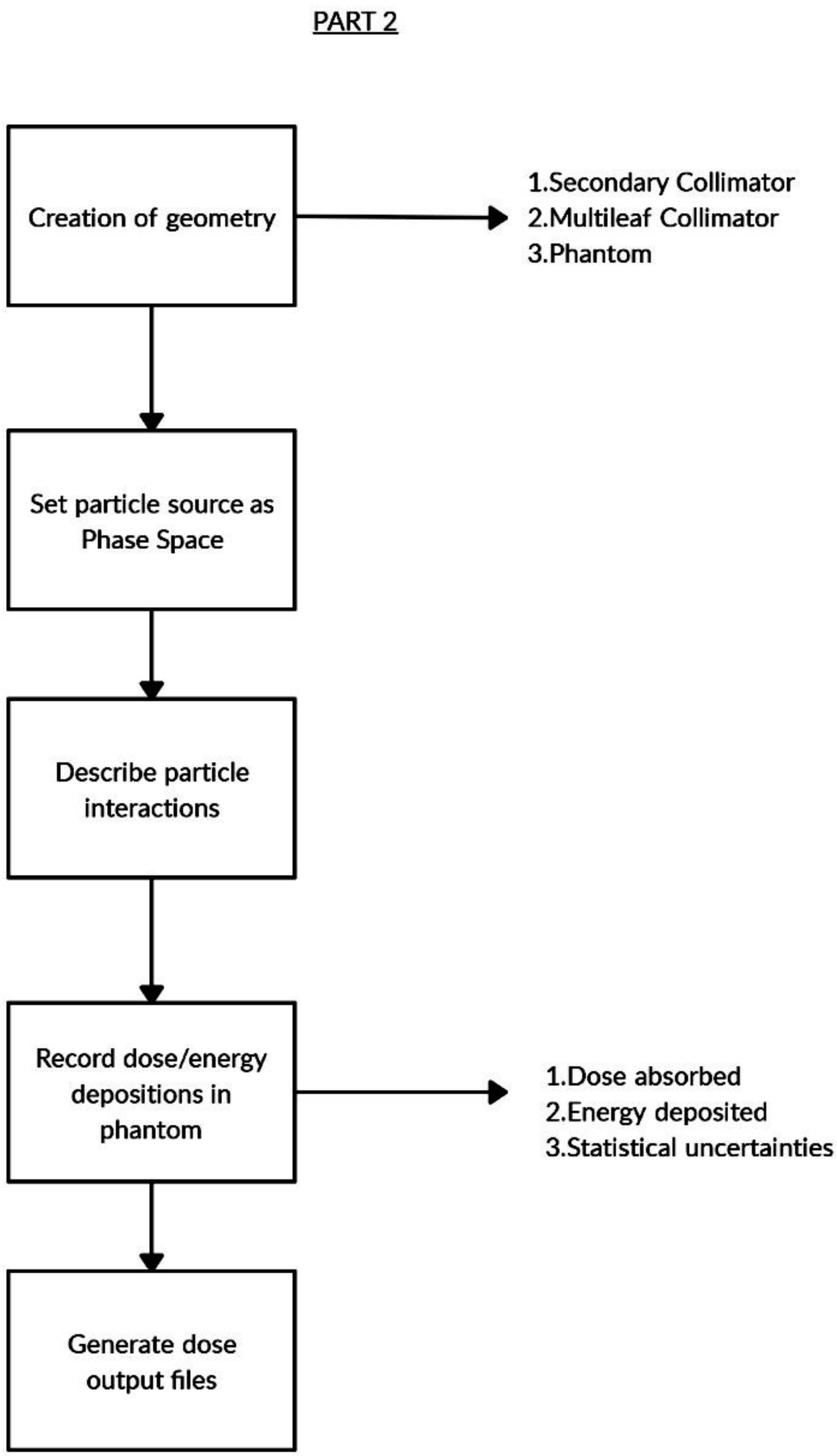

Fig. 4. Simulation Design - part 2

4. Record dose/energy depositions in phantom: The dose absorbed by the phantom and the uncertainties involving the same are recorded when the simulation is run.

There are three fundamental methods of calculating the absorbed dose in physical water phantoms [18]. First, the ionometric method wherein a graphite cavity ionization chamber is inserted in a water phantom at a particular depth. Absorbed dose is determined by the cavity theory, which calculates by using the amount of mean specific energy transmitted to air in the cavity and the stopping power ratio of the graphite wall material to the cavity gas.

Second, the chemical dosimetric method(Fricke dosimeter) measures the chemical change produced in a solution. The absorbance of dose in the solution is calculated by the radiation-induced ferric ion concentration using spectrophotometry. Third, the Calorimetric method computes the temperature rise which is a direct measure of energy absorption in a medium.

The simulation measures the dose by using a detector that detects and records the energy deposition of radiation beams on the phantom. The calculation results stand akin to the physical methods being used, as per previous works in similar fields [3, 6].

5. Generate dose output files: The recorded values of dose are generated as output files for further analysis. It includes images for viewing the distribution of dose, along with the measures of dose at each point which can be used to plot curves.

4.2 Implementation

Software Tools Used

- Gate v8.2: This simulation platform is used for medical physics applications. The main code implementation is done using this toolkit.
- Qt 4.8.7: This is a widget toolkit used for creating graphical user interfaces. It is required to display the GUI of GATE simulation.
- Root 6.10.04: It is a modular scientific software toolkit generally used for particle physics data analysis. This is required to view and analyse the phase space.
- VV, the 4D Slicer: A cross-platform image viewer, this is required to view the 3D images of dose distributions on the phantom.
- Python 3.6.9: It is used for plotting depth dose and dose profile curves.

The Simulation Our work is based on an example GATE simulation of a partial LINAC head that was posted on the OpenGate Github repository [21]. As described in the design, our code is divided into two parts. The following parameters were set using the information gathered from various literature for the simulation.

1. Geometric parameters: Composition, positions, and dimensions of LINAC components.
2. General particle source: Type, position distribution, angular distribution, energy distribution, and direction of the particle.
3. Placements of secondary collimators and MLCs.
4. Type of phantom (water).
5. Position and volume in the phantom where dose/energy depositions are to be measured.

Prior to starting work on the simulation, our team met with Dr. Niyas, Chief Medical Physicist at MVR Cancer Centre, to discuss the simulation requirements. We were unable to obtain the exact parameters of a LINAC's components from a vendor. Therefore, the parameters were set primarily based on the work done by Samir Didi et al. [3] among other sources.

The particle interactions were implemented using a pre-defined physics list in Geant4 [17]. This list instantiates physics processes for each particle type and enables them during interactions with matter in the simulation. It is possible to add or remove particular processes if required. For this project, the standard electromagnetic physics list (emstandard_opt3 in Geant4) was used.

With the available resources, we have generated a phase space using 50,000 primary particles of electrons with a mean beam energy of 6.7 MeV. The phase space contains details of generated photon particles with energies ranging from 0 to 6.7 MV.

This phase space was used in part 2 of the code as a particle source to be transported to the phantom. 5 million particles were generated randomly from the phase space for transportation. We used a 50x50 cm water phantom since its composition is known to best resemble the human tissue. The source-to-skin distance (SSD) was kept at 100 cm. The field size was fixed at 5x5 cm^2.

The depth dose, dose profile, and their relative statistical uncertainties were recorded from the simulation. The uncertainty was calculated using the formula given below.

$$D_k = \sum_i^N d_{k,i}$$

$$S_k = \sqrt{\frac{1}{N-1}\left(\frac{\sum_i^n d_{k,i}^2}{N} - \left(\frac{\sum_i^n d_{k,i}}{N}\right)^2\right)}$$

$$\epsilon_k = 100 \times \frac{S_k}{D_k}$$

Where ϵ_k is the uncertainty at pixel k, N is the number of primary events and $d_{k,i}$ is the deposited energy in pixel k at event i.

5 Results

The simulation recorded the depth dose and dose profile values on the water phantom. The dose distribution on the phantom was saved as a 3D image in .mhd format. Figure 5 and 6 shows two slices of the image in the VV image viewer tool.

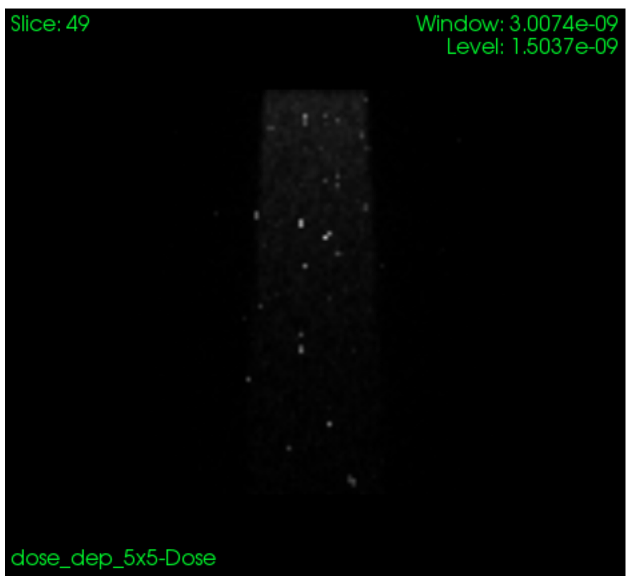

Fig. 5. Lateral view of dose deposited phantom

The image shows the dose distribution on the 50x50 cm phantom from the simulation. The dose deposition is in accordance with the LINAC's field size of 5 x 5 cm^2. Figure 5 shows the lateral view of the phantom, where we can see the intensity of dose decreasing from one end to the other. Figure 6 is the front view of the phantom, showing the 5 x 5 cm^2 region where the dose has been deposited.

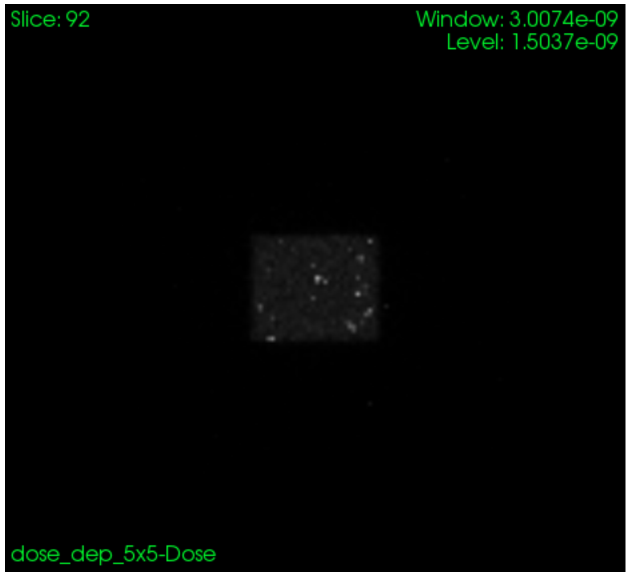

Fig. 6. Front view of dose deposited phantom

For the purpose of analysis, the results can be compared with those from the research paper previously mentioned ([3]), since the parameters set were the same. The plots for the percentage depth dose and dose profile values from our simulation is given in Figure 7.

The Percentage Depth Dose curve (top - green) shows how the dose level has a peak at a depth close to the phantom's surface and then decreases with increase in depth. The Dose Profile curve (bottom - green) shows how the dose is concentrated on the mid-section of the phantom, which is a result of the field size set by the LINAC. The uncertainty values (shown in red in the curves) for both the dose metrics are averaged and compared in Table 1.

It is observed that the values of relative statistical uncertainties are in the same range as that of the simulation carried out in the paper. This tells us that our simulation is working as expected, and can be used for further work regarding dosimetric analysis of specific linear accelerators as required.

6 Conclusion and Future work

This project presents a GATE simulation of a linear accelerator based on a 6 MV Elekta Synergy Platform LINAC. The simulation of photon beam production and transportation was implemented and resources for dosimetric analysis of the dose depositions were generated. 3D image of the dose distribution on

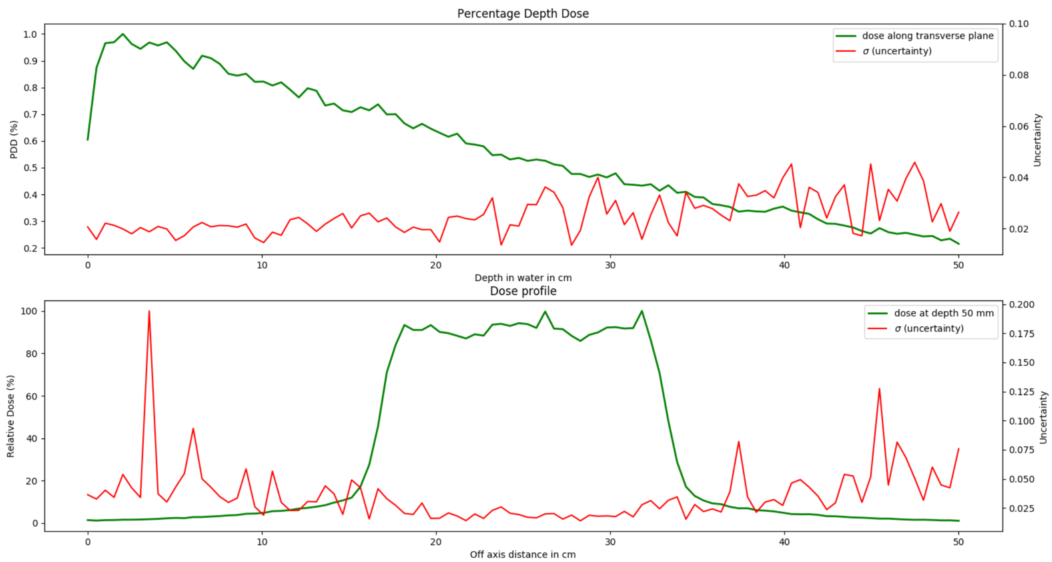

Fig. 7. Curves for Percentage Depth Dose (top) and Dose Profile (bottom) with their uncertainties

Table 1. Dose uncertainty comparisons

Dose (Z: value at a certain depth in the phantom)	Uncertainty from the work done by Samir Didi et al. (5x5 cm field size)	Uncertainty from our proposed simulation (5x5 cm field size)
Percentage Depth Dose ($Z \leq Z$ max)	0.0127	0.0199
Percentage Depth Dose ($Z > Z$ max)	0.0147	0.0255
Dose Profile at depth 5 cm	0.0593	0.0360
Dose Profile at depth 10 cm	0.0418	0.0354
Dose Profile at depth 20 cm	0.0288	0.0329

the phantom was produced. Additionally, graphs for percentage depth dose and dose profile were plotted for further analysis.

The present simulation provides an overall idea on Monte Carlo simulations of linear accelerators for radiotherapy and dosimetric analysis. While it is not in a stage for deployment currently, it can certainly be used and tested for any particular LINAC machine and improved accordingly.

With the influence and power of open source technology, developing this project further can significantly contribute to the treatment of cancer patients. On collaborating with MVR Cancer centre, we hope the project can be carried further to simulate a working linac in their laboratory.

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