Monte Carlo Simulation of Linear Accelerator for Dosimetry Analysis

Under the guidance of Dr.Jayaraj P B and Dr.Pournami P N

Darshana Suresh B160373CS
Shalini Nath B160613CS
Saai Lakshmi B160584CS

Department of Computer Science and Engineering
NIT Calicut

05 March 2020

Introduction - Problem Statement

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

- Simulation of radiation beam production in LINAC.
- Simulation of beam transport from LINAC head to phantom.
- Dosimetry analysis of radiation.

Work Done

- Installed GATE (Geant4 Application for Tomographic Emission) and compared the ease of usage with Geant4 for simulation purposes.
- Obtained sample specifications of an Elekta Synergy LINAC from "Grid Monte Carlo Simulation of a Medical Linear Accelerator" paper and updated the simulation of LINAC using GATE v8.2 [1]
- Researched on the various types of interactions of photons with matter and studied its relevance in the radiotherapy treatment process.

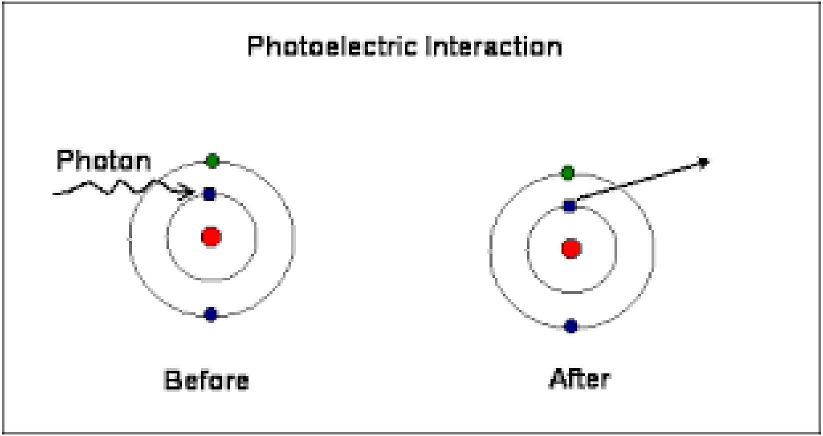
Photon Interactions with Matter

- Radiotherapy treatment uses high energy photons
- If the source of photon is from the nucleus of a radioactive atom, they are called gamma rays
- If it is created electronically, for eg. using LINAC, they form X-rays
- The maximum energy of the X-ray spectrum produced can be controlled, unlike the case of gamma ray
- X-ray, on getting produced from the linac, goes through several interactions with matter.

Photon Interactions with Matter

- The energy of photons is imparted to matter in a two stage process.
- In the first stage, the photon radiation transfers energy to the secondary charged particles (electrons) through various photon interactions
- In the second stage, the charged particle transfers energy to the medium through atomic excitations and ionizations.
- The measure of energy transferred from radiation to matter is called KERMA (Kinetic Energy Released per unit MAss).

Photoelectric Effect

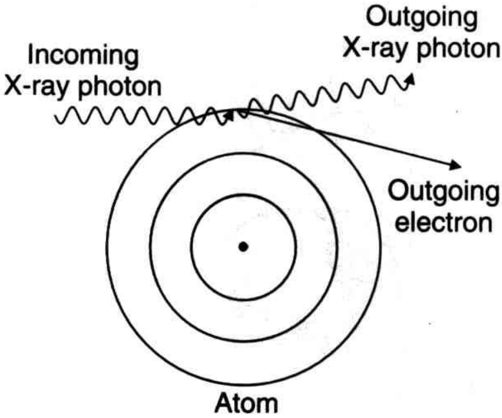


The incoming photon transfers its energy to an atomic electron, ejecting it out from the atom and ionizing its neighbouring molecules

Photoelectric Effect

- Energy conservation is given by $E_e = hv$ - E_b
- This can only take place with an atom as a whole and not with free electrons
- The most probable origin of the photoelectron is the most tightly bound shell (K-shell) of the atom
- The PE interaction is most probable for low energy and high atomic number and high density materials
- This effect is predominant in tissues in the energy range 10-25 keV.[4]

Compton Effect



A high energy photon collides with a free electron and gets deflected with respect to its original direction through an angle θ.

Compton Effect

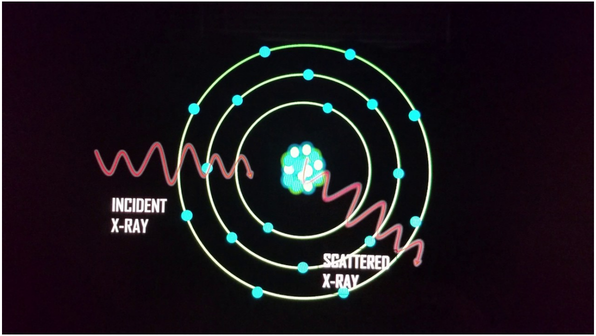
- The transfer of energy is given by the formula

$$h\nu_0 = \frac{h\nu}{(1 + (h\nu/m_0c^2)(1 - cos\theta))}$$

- The probability of this effect is independent of the matter's atomic number but is inversely proportional to the energy of the incoming photon
- The energy range for the effect is 25keV - 25MeV [4]
- It is the most dominant interaction mechanism in tissue.

Coherent Scattering

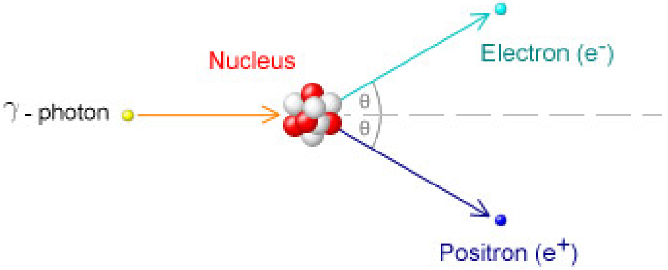
There are two types of elastic scattering : Rayleigh scattering and Thomson scattering. [3]



- Energy of the X-ray or gamma photon is low (10 keV).
- The only significant change is a change of direction of the photon.
- It varies with the atomic number of the absorber (Z) and incident photon energy (E) by Z/E^2.

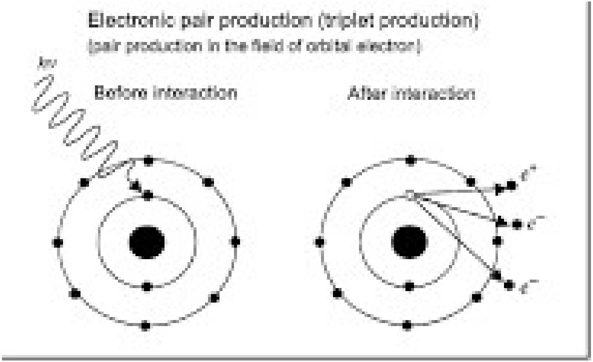
Pair Production

- It which occurs when a photon is in close proximity to the nucleus of an atom with an energy of at least 1.022 MeV.[4]



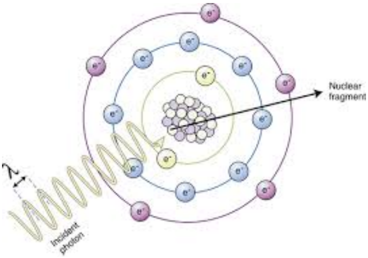
- Results in formation of a pair of particles, an electron and a positively charged positron.
- Related to the atomic number of a material through Z^2.

Triplet Production



- Triplet Production is a special case of pair production which occurs in the vicinity of an orbital electron instead of a nucleus.
- Here, a positron (anti-electron) and an electron are produced spontaneously as a photon interacts with a strong electric field with an electron.[3]

Photodisintegration



- Photodisintegration occurs when a photon is absorbed by the nucleus of an atom.
- The nucleus becomes excited and becomes radioactive. To become stable, the nucleus emits any one among negatrons, protons, neutrons, alpha particles, clusters of fragments or gamma rays.
- The threshold for this effect is over 10 MeV for most nuclei.[3]

GATE- Geant4 Application for Tomographic Emission

- GATE is an open-source software developed by the international OpenGATE collaboration for numerical simulations in medical imaging and radiotherapy. [2]
- Several of the previous simulations of LINAC have been carried out using GATE.
- This software makes use of macros entirely to define geometry, beam transportation, and further simulations, therefore increasing the readability of the code.
- We have installed GATE and compared the ease of usage with Geant4 for simulation purposes.

GATE vs Geant4

- GATE uses only macro files for geometry, scoring, physics and beam, unlike in Geant4 which has separate header files, source files etc. written in C++.
- GATE is flexible and can design different kinds of detectors.
- Geometry designing is easier in GATE.
- GATE contains its own material database. New materials/alloys can be added to the db.

GATE - Implementing Photon Interactions

- Can implement Photoelectric effect, Compton effect, Pair production, Rayleigh scattering.
- Three models are available for electromagnetic processes: Standard, Livermore, and Penelope.
- The Penelope models have been specifically developed for Monte Carlo simulation. They are effective between 250 eV and 1 GeV.

Visuals of the simulation

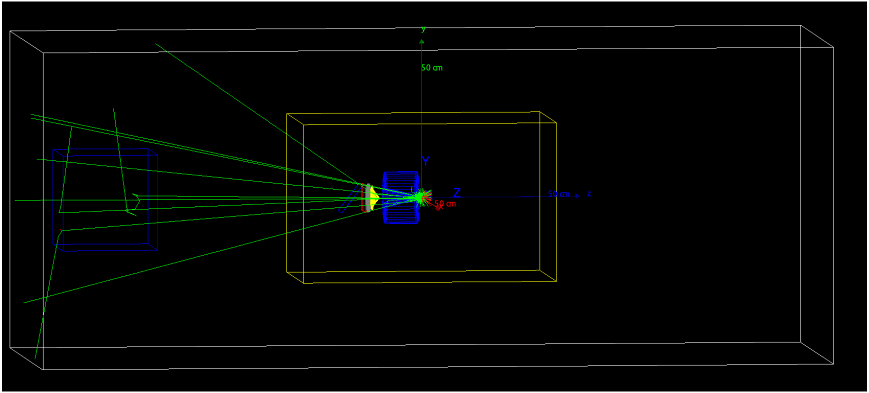


Figure: GATE Linac Simulation

Visuals of the simulation

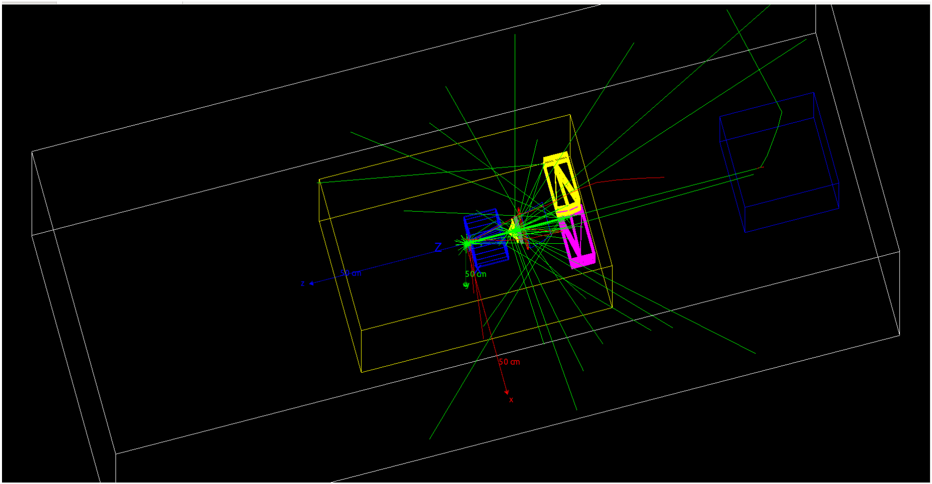


Figure: GATE Linac Simulation with added MLCs

Work Plan

Work to be done

- Study several research papers on Monte Carlo simulation of linacs and work on a review paper.
- Study the role of Monte Carlo methods in the simulations to be done.
- Simulation of radiation beam transportation from the LINAC treatment head to the phantom.

Conclusion

- We have installed GATE and compared the ease of usage with Geant4 for simulation purposes.
- Thorough understanding of photon interactions with matter.

References

[1] Didi et. al. (2018). Grid Monte Carlo Simulation of a Medical Linear Accelerator. 3. 40-43. 10.24018/ejers.2018.3.12.1001.

[2] GATE homepage, http://www.opengatecollaboration.org/. Last accessed 03 March 2020

[3]http://ozradonc.wikidot.com/photon-interactions

[4]https://pdfs.semanticscholar.org/f6c6/e44bd495775ba1433c6c42ff68f71b7f823f.pdf

Thank You