NPRE 441 Programming Assignment

Monte Carlo Simulation Assisted Design of a Simplified Radiation Therapy Room

A. Overview

- In this assignment, you will use a particle transport code, **GEANT4**, to simulate radiation transport in a simplified **proton therapy room** setting and to determine critical dosimetry quantities, such as **energy deposition** and **absorbed dose**.
- You will investigate how shielding design (e.g., the choice of shielding materials, their thickness, and different combinations of multiple shielding layers) of the primary and secondary barriers influences the dose delivery to various volumes of interest (VOIs).
- In the simulation studies, you can modify the source strength and shielding configurations by modifying **GEANT4 macro commands**. You don't need to edit the C++ source code in GEANT4 unless you choose to explore optional advanced extensions.

B. Learning Objectives

By completing this project, you should be able to:

- Understand how Monte Carlo methods are used in radiation transport problems.
- Explore how shielding material and thickness affect dose delivery.
- Interpret GEANT4 outputs, such as energy depositions from different particles within given volumes.

C. The Physical Configuration of the Proton Therapy Room

The simplified proton therapy room design used in this simulation study consists of the following components (also shown in the figure below):

- A **monoenergetic beam** traveling along the +Z direction
  - The simulated particle beam strength:
    - Proton beam: fixed at 6.25×10^9 protons/s, and
    - γ-ray beam: fixed at 10^{12} γ-rays /s.
  - Please repeat the MC study with the following three cases:
    - Case 1: Proton beam: each proton has an initial energy of 100, 200, or 300 MeV. Please repeat the MC study for each of these particle energies and report the resultant shielding requirement for each setting.
    - Case 2: γ-ray beam: each γ-ray carries an energy of 662 keV and 1.2 MeV/photon. Please repeat the MC study for each of these particle energies and report the resultant shielding requirement for each setting.
- A fixed **object** made of tissue-equivalent materials, irradiated by the particle beam, and located in the room.
  - The object defined in the GEANT 4 model is 30 cm × 30 cm,× 30 cm in size, filled with tissue equivalent material.
- Two **volumes of interest, VOIs**, outside the room:
  - **On-axis volume**: located along the beam direction and dominated by the primary field.
  - **Off-axis volume**: located away from the beam axis and dominated more by secondary radiation.

- The **dose limit** for the VOIs is 100 μGy/h.
- **Six shielding walls**, each consisting of multiple layers of shielding materials. You can choose to assign the number of layers and the material for each layer. See next section.

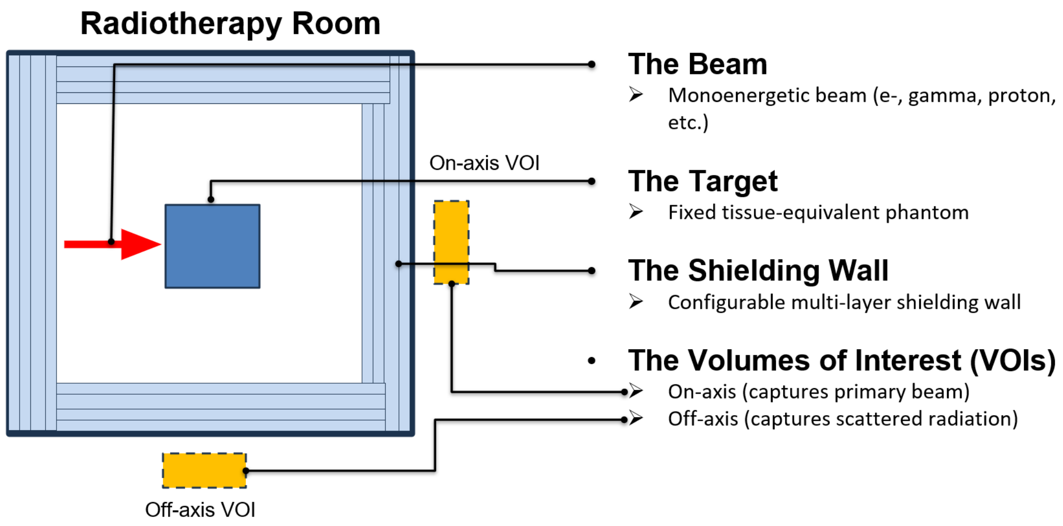

Figure 1: Overview of the simplified radiotherapy room.

D. The Parameter Settings that You Can Change During the Simulation Studies

You may vary the following settings in the simulations by modifying the macro interface:

- Shielding material.
- Shielding thickness.
- Number of shielding layers.
- Number of primary particles that you choose to use in the MC studies. Note that the number of particles used in each MC study will affect the computation speed and the statistical accuracy of your dose estimate. You may want to start with 10,000 particles per simulation and increase the number of particles as computation time permits.

E. Expected Outputs from the Simulation Studies

For each VOI, please extract the following quantities from the output of GEANT 4:

1. **Energy deposition** in the VOI(s) from different types of particles incident on the VOIs:
   a. Beta particles
   b. Photons
   c. Protons
   d. Neutrons
2. **Total energy deposition** in the VOIs from all particles.

F. Final Outcome to be Included in Your Written Report

Item: 1: Visualization

Please provide screenshots of the physical configurations generated through GEANT 4.

Item 2: Numerical Reports

1. Please report the minimum shielding configurations (for both the primary and secondary barriers) that result in dose rates in the VOIs equal to the given limit of 100 μGy/h.

2. Please report the relative dose contributions from different types of particles, including beta particles, X-/gamma-rays, protons, and neutrons, incident on the VOIs.
3. Repeat Item 2 for three different combinations of shielding materials. Please use this data to demonstrate that the composition of shielding (e.g., different combinations of materials and thicknesses) leads to different relative contributions from beta particles, X-/γ-ray, protons, and neutrons that incident on the volumes-of-interest (VOIs).
4. Remember to include the shielding configurations for all five cases: (1) proton beam at 100MeV, (2) proton beam at 200 MeV, (3) proton beam at 300 MeV, (4) γ-ray beam at 662 keV, and (5) γ-ray beam at 1.2 MeV.

Item 3: While reporting these results, please provide **the macro-files** that you used in the simulation studies to obtain the above results.