Monte Carlo Simulation for High Energy Photons in Radiotherapy Dosimetry

Dennis Shklyar

Introduction

Radiotherapy (RT) is a method for treating cancer that consists of bombarding tumorous cells with particles – photons, electrons, etc. Those particles physically collide with tissues, depositing energy (dose) and thus causing cell damage. Your average x-ray consists of 70 keV photons, while photons used in RT have energies in the order of 1000 keV. Consequently, dosimetry is essential to assure patient safety.

Dosimetry for patient RT has two major foci: verification of patient positioning, and verification of delivered dose [2]. Computer simulations using Monte Carlo (MC) method have become common practice in order to aid treatment planning. MC simulations differ from traditional simulations in that the model parameters are treated as stochastic, rather than fixed values [1]; in dosimetry, a probabilistic model can be used to predict the deposited dose by approximating numerical solutions via MC method.

To explore this technique, we implemented a MC simulation for a flat, high-energy, polarized photon beam and compared its results with real measurements produced by a medical linear particle accelerator (LINAC).

Event Characterization

Let us consider a flat, high-energy, polarized photon beam, such that all photons have the same energy when entering in contact with the discretized target of interest. The simulation generates an ionization track for our photon by computing a travel length

$$\ell = -\frac{1}{\mu}\ln(1-r) \qquad (1)$$

before an attenuation event occurs. In (1), r is a random uniform variable (i.e., $r \in [0,1]$) and the attenuation coefficient

$$\mu = \frac{\rho}{A\, m_u}\,\sigma_{tot} \qquad (2)$$

With the total atomic cross section,

$$\sigma_{tot} = \sigma_{incoh} + \sigma_{ph.elec.} \qquad (3)$$

, atomic mass constant, m_u, and A the relative atomic mass of the target. Since for high-energy photons (i.e., 0.1-15 MeV), incoherent scattering is the dominating mode of photon interaction [3], and for photons with energy in the order of 0.01 to 100 keV the dominating mode of interaction becomes the photoelectric effect [4], we assume that all attenuation interactions will either be photoelectric or incoherent – as in (3). We used the stochastic length, (1), to compute the cumulative probability of each event type occurring,

$$P(l) = \int_0^l \mu\, e^{\mu\,\lambda}\, d\lambda \qquad (4)$$

with μ given by (2), but only considering the cross section for the event in matter. And we then choose the event based on this probability.

Energy Deposition

In case of incoherent scattering, we have that the energy deposited by a photon

$$E = E_o - E_f = E_o\left(1 - \frac{1}{1+\left(\frac{E_o}{m_e\,c^2}\right)(1-\cos\theta)}\right) \qquad (5)$$

E_0 is the incident energy of a photon and θ the scattering angle of a photon (i.e., $\theta \in [0,\pi]$), chosen from a uniform distribution – θ is also taken into account when updating the depth traveled, $d = \ell\cos\theta$.

In the case of a photoelectric interaction, all the energy of the photon (i.e., $E = E_o$) is deposited in the interaction. Any energy below 100 keV will be considered negligible.

Analysis Method

Considering our source to be a 10 cm by 10 cm field size LINAC treatment head (i.e., source of photons) and our target to be a water tank 100 cm source to skin distance (SSD) with 70 cm of air in between.

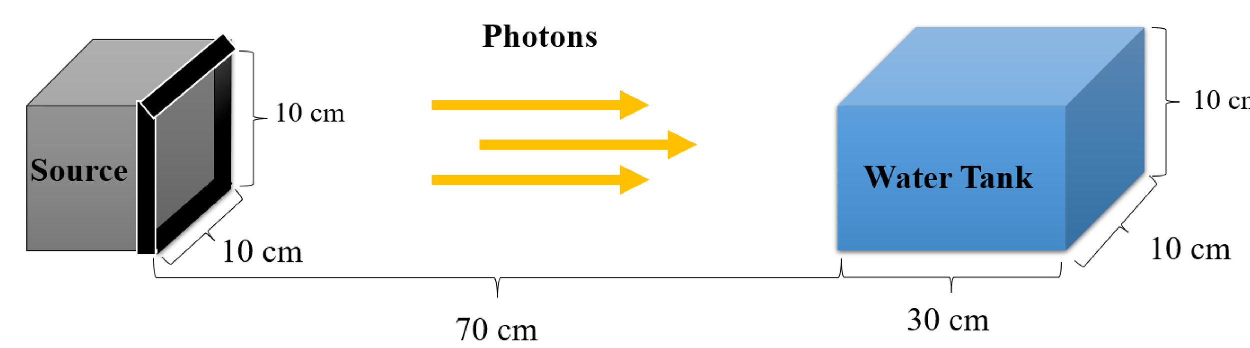

Figure 1: Photons travelling from source to target.

We ran a 10 000 photons simulation under these conditions twice, once with a 6 MeV beam configuration and a second time with a 10 MeV beam configuration. We then discretized the target medium in 1 cm thick slabs and computed the dose deposited in each slab by all the photons.

$$D_{slab} = \frac{1}{m_{slab}}\sum_{E\,\in\,slab} E \qquad (6)$$

defined as the sum of all energies deposited in the slab, divided by the mass of the slab, m_{slab}.

Results

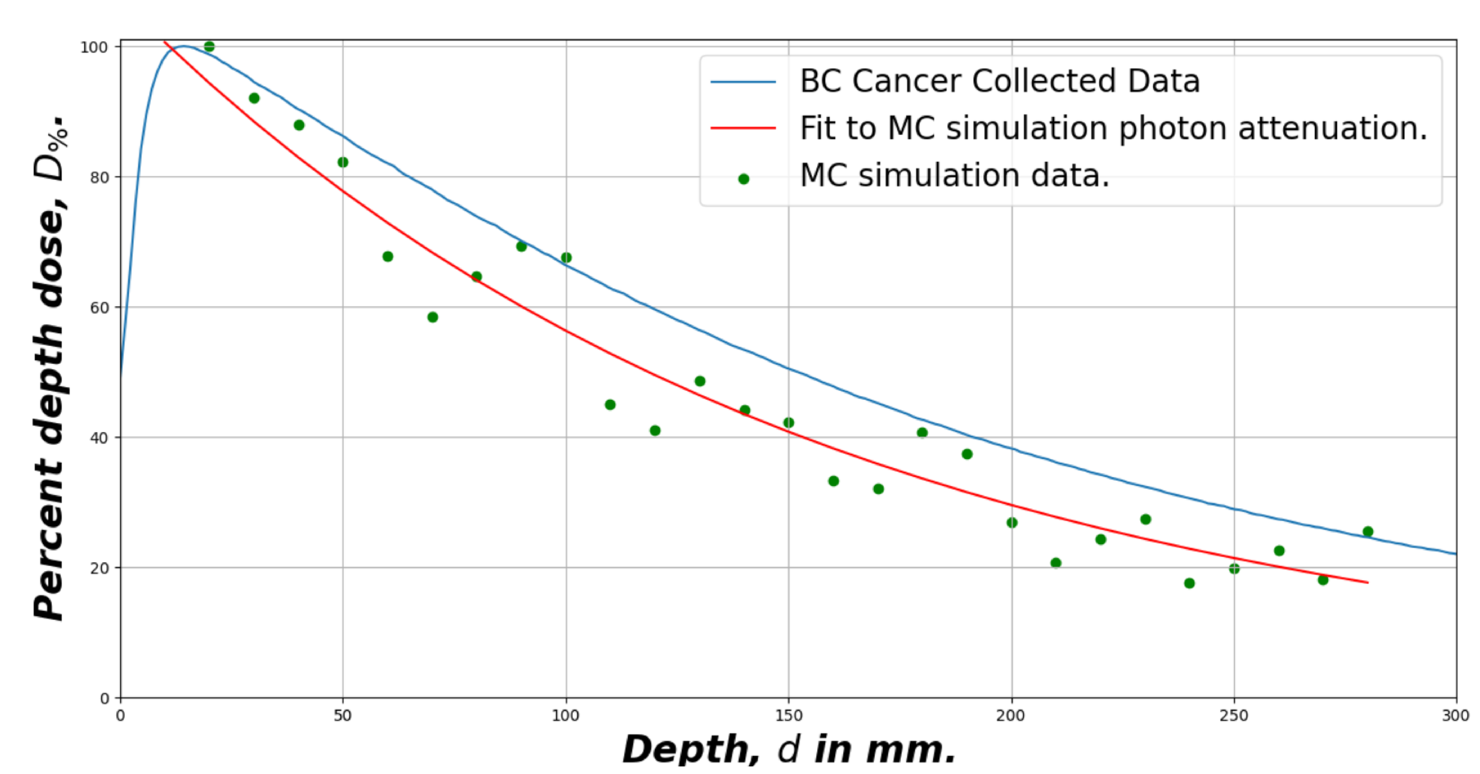

Figure 2: Percent depth dose for a 6 MeV photon beam normalized to the maximum dose with 10 000 simulated photons and data measured at BC Cancer at 100 cm SSD.

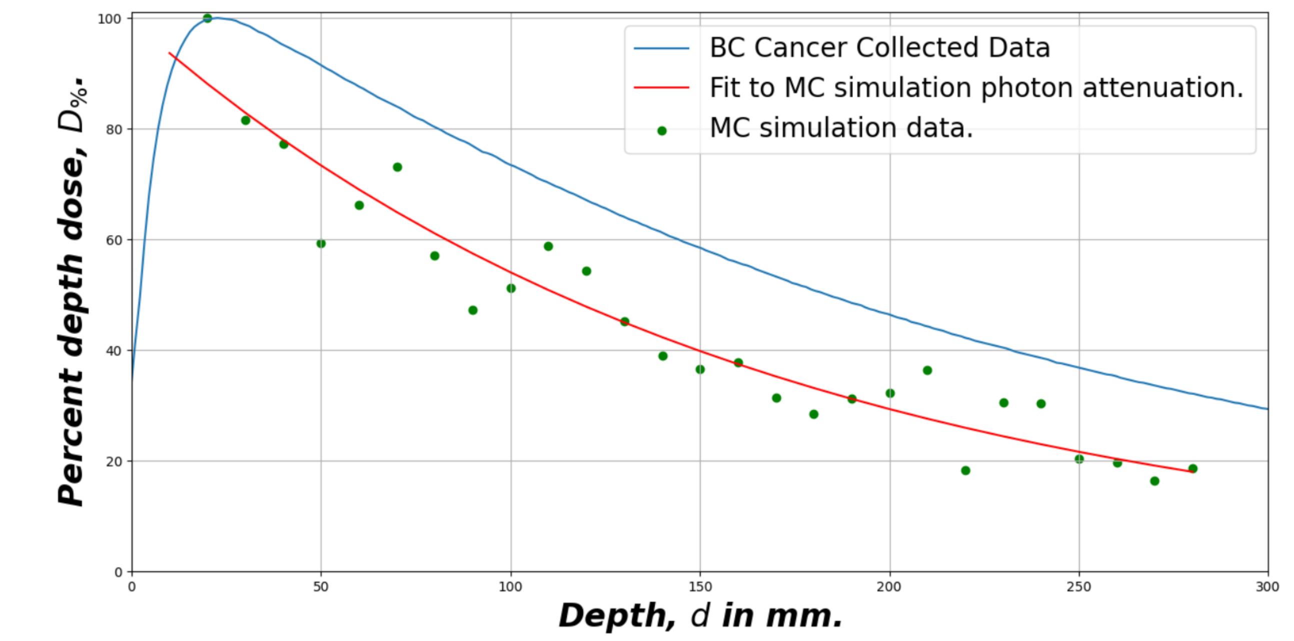

Figure 3: Percent depth dose for a 10 MeV photon beam normalized to the maximum dose with 10 000 simulated photons and data measured at BC Cancer at 100 cm SSD.

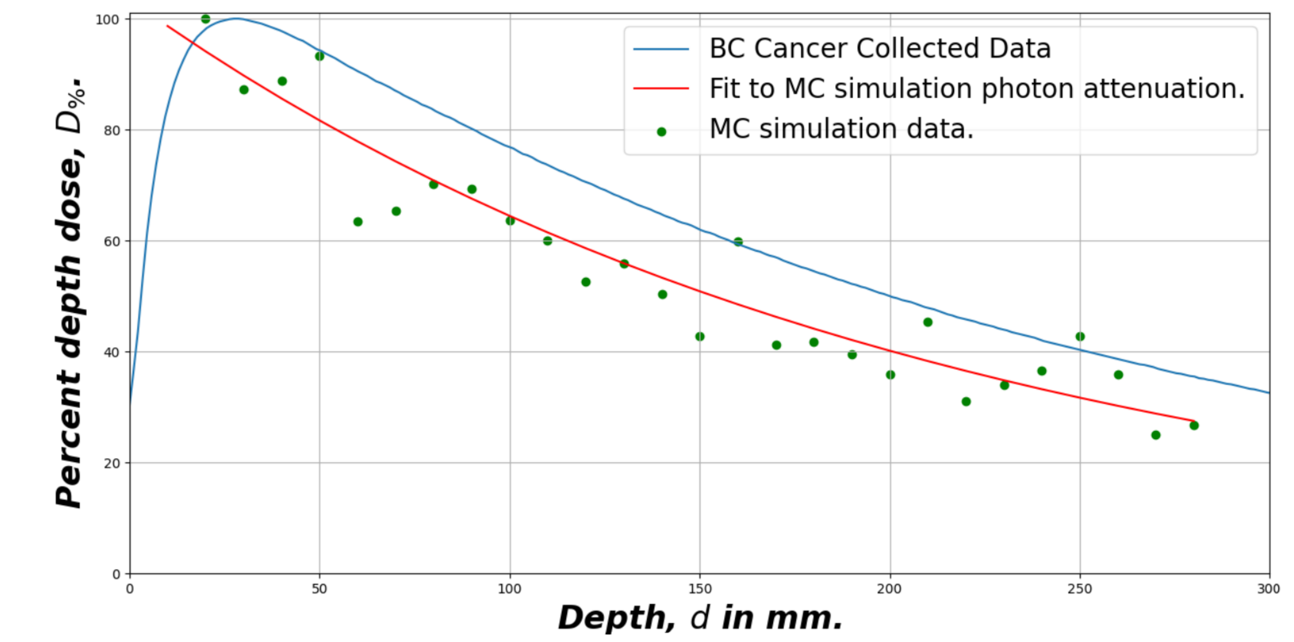

Figure 3: Percent depth dose for a 15 MeV photon beam normalized to the maximum dose with 10 000 simulated photons and data measured at BC Cancer at 100 cm SSD.

Discussion & Conclusion

Considering the dominant behavior within our energy range of interest – incoherent scattering and photoelectric effect – and scattering angles within the medium, we have found that the simulated data agrees within 75-80% to the data from the hospital and follows the real data's trend.

It is of interest to now consider higher-order correction due to sub-leading attenuation events. For all beam energies, it was found that the dose deposited was underestimated; this could be due to our model assuming no secondary track events (STE) (i.e., scattered electrons, x-ray emissions, etc.), which inherently have lower energies and higher attenuation, and thus would increase the dose deposited to the target.

For the next iterations of this simulation, we plan on considering STE to test if it would indeed yield more accurate results. We also plan on extending this model to be well behaved for the imaging energy range (i.e., 15-120 keV) by implementing low energy dominating attenuation events.

Given the assumptions of our model, the proposed MC simulation agrees within reason to the real data.

References

1. Bonate, P.L. A (2001). Brief Introduction to Monte Carlo Simulation.
2. Paliwal, B., et al. (2009). Advances in Radiation Therapy Dosimetry.
3. N. Reynaert, et al. (2006) Monte Carlo Treatment Planning.
4. Shapiro, J (2002). Radiation Protection: A Guide for Scientists, Regulators, and Physicians 4th ed., *Harvard University Press*.

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