Modeling Radiation Therapy Dose Deposition

Raisa Guisado

May 11, 2025

Abstract

Radiation therapy is a cancer treatment in which a precise dose of radiation is delivered to destroy cancerous tissue/cells without damaging healthy cells. In this project, I simulated how radiation decreases with tissue depth using the Beer–Lambert law. By generating noisy data and plotting the exponential dose decay curves for soft tissue and bone material, I compared how their different attenuation coefficients affect radiation penetration. This comparison shows the importance of considering tissue composition in radiation therapy planning, as bones can significantly reduce dose delivery to deeper regions.

Introduction

One of the most common treatments for cancer is radiation therapy. In this treatment, high-energy photons, electrons, or protons are used to damage the DNA of tumor cells. Radiation is absorbed differently depending on the tissues in the body, so understanding how the dose attenuates as it penetrates different tissues is essential.

The physics law that best describes the attenuation is the Beer-Lambert Law:

$$I(x) = I_0 e^{-\mu x}$$

where:

- $I(x)$ is the radiation intensity at depth x
- I_0 is the surface intensity (initial dose/intensity)
- μ is the attenuation coefficient (in cm^{-1}), which varies with the tissue type
- x is the depth into tissue (in cm)

Attenuation coefficients at therapeutic photon energies (1 MeV) are approximately 0.03 cm^{-1} for lung, 0.15 cm^{-1} for soft tissue, and 0.30 cm^{-1} for bone.

Methods

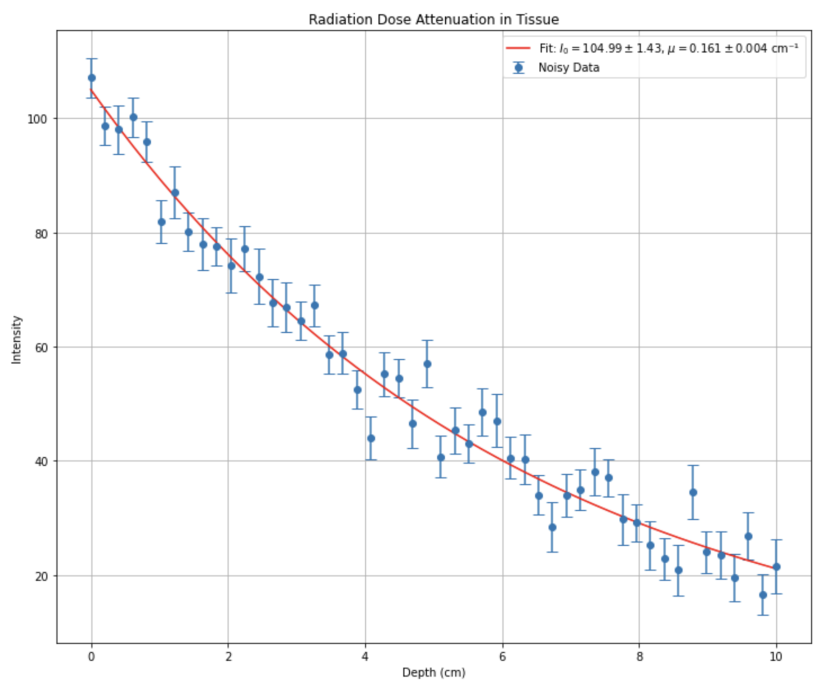
In this project, I generated radiation dose data based on the exponential attenuation model. Using NumPy, I simulated 50 depth points from 0 to 10 cm with an initial intensity $I_0 = 100$.

For soft tissue, I used a μ value of 0.15 cm^{-1}, while for bone I used $\mu = 0.30$ cm^{-1}. I then added noise to my data to simulate experimental uncertainty.

Once I had all the data with noise, I used Matplotlib to plot the radiation dose decay for the soft tissue and the bone. Then, I created a comparison plot and added a horizontal threshold line (shows where the intensity drops to 50%). This visually showed where each curve crosses that threshold and that bone attenuates radiation faster than soft tissue.

Results

The first figure shows the simulated soft tissue data and the best-fit exponential curve.




```
Fitted Parameters:
I0 = 104.99 ± 1.43
mu = 0.1606 ± 0.0040 cm^-1
```

Figure 1: Simulated radiation intensity vs. depth in soft tissue. Error bars represent uncertainty.

The second figure shows the simulated done tissue data and the best-fit exponential curve.

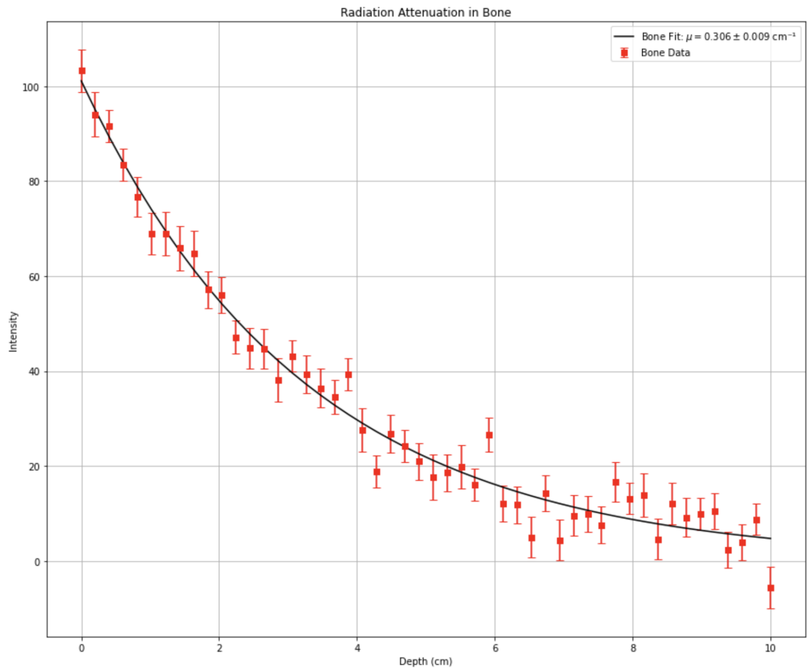


Figure 2: Simulated radiation intensity vs. depth in bone tissue. Error bars represent uncertainty.

Finally, the third figure compares the attenuation of radiation through soft tissue and bone. It also includes a horizontal threshold line that shows where the intensity drops to 50%. The radiation is attenuated more quickly in bone due to its higher linear attenuation coefficient.

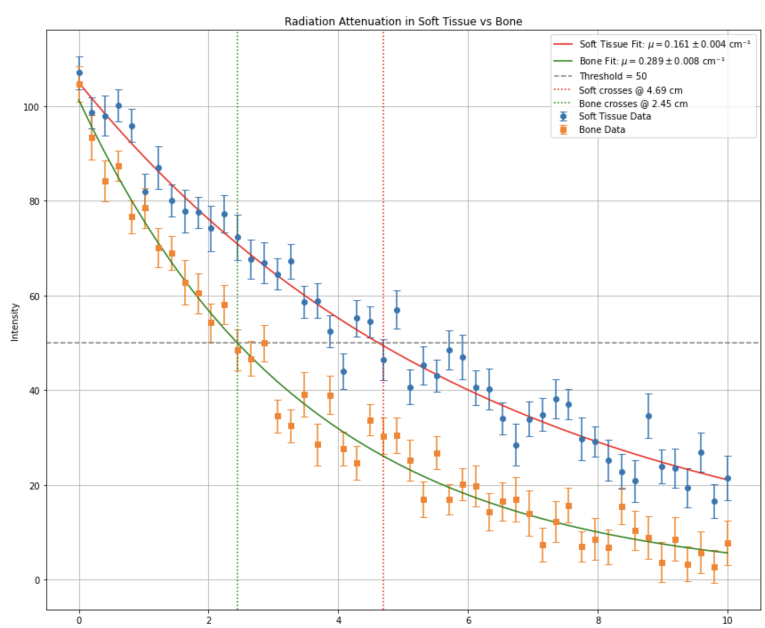


Figure 3: Comparison of radiation attenuation in soft tissue vs. bone.

Fitted values:

- Soft tissue: $I_0 = 104.99 \pm 1.43$, $\mu = 0.1606 \pm 0.0040$ cm^{-1}
- Bone: $I_0 = 101.13 \pm 1.93$, $\mu = 0.3062 \pm 0.0085$ cm^{-1}

The fitted and obtained values are close to the true parameters used in the project.

Conclusion

In this project, I was able to apply and use Beer–Lambert Law to model radiation dose deposition in different tissues. The results I obtained in the project highlighted the importance of considering how each material attenuates and absorbs radiation in treatment planning. As we saw, bone attenuated radiation is much more rapid than soft tissue, which needs to be accounted for in therapy planning. I think I will continue to expand on this project and try to simulate layered tissue models (skin $\rightarrow$ fat $\rightarrow$ bone) in where the attenuation coefficient changes or use other radiation energies. Finally, I found this project super interesting, fun, and challenging. I really liked researching radiation therapy and applying everything I learned throughout the semester to this project.

References

[1] Bielajew, Alex F. *Fundamentals of Radiation Dosimetry and Radiological Physics*. The University of Michigan, Department of Nuclear Engineering, 2005.

[2] Stabin, Michael. *Radiation Dosimetry in Nuclear Medicine*. Elsevier, 1999.

[3] NIST XCOM Photon Cross Section Database.

[4] Izewska, Joanna. *Radiation Dosimeters*. Citeseer, 2005.