Micro Monte Carlo

Due April 15, 2013

IN CLASS

In this project you will write a Monte Carlo program that models energy deposition in a spherical cavity proportional counter of tissue equivalent material. Any programming language that contains a random number generator class will suffice for this project.

Background

First proposed by Rossi and Rosenweig [1-2], this type of detector is used for measurements of LET spectra from neutron radiation. A spherical cavity makes an ideal micro-dosimeter because its response is independent of the direction and angular distribution of the incident neutron radiation, its chord length distribution is simple and known, and the energy losses in the cavity is important for understanding of the biological effects of neutron radiation. A theoretical description of neutron with a spherical cavity has been proposed by Caswell [3]. Caswell grouped energy losses from recoil particles into four different categories, "insiders", "starters", "stoppers" and "crossers". A diagram and description of each of these categories is provided in Figure 1.

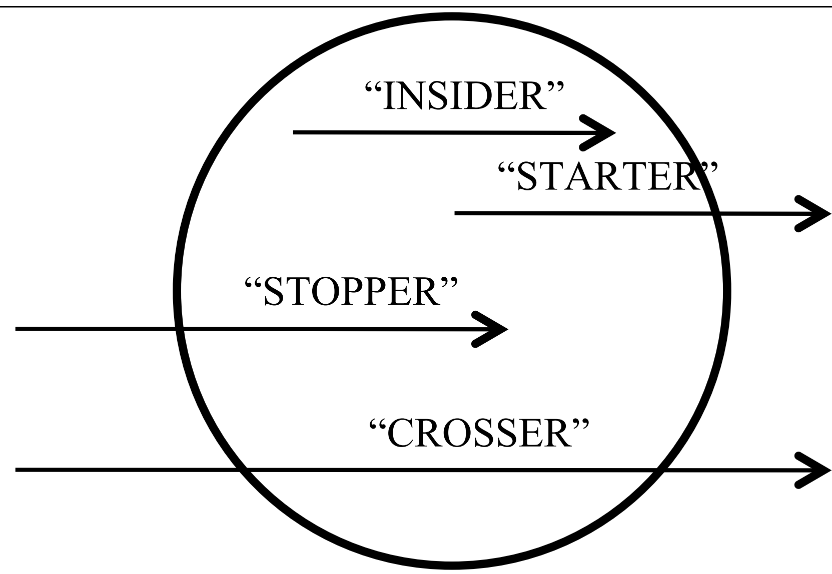

Figure 1. Caswell's description of energy loss in a spherical cavity. An inside is a recoil particle that is created and completely stopped in the sphere. A starter is a recoil particle that is created in the sphere, but only deposits partial energy in the sphere. A stopper is a particle that is created outside the sphere, but deposits some of its energy in the sphere before stopping. And finally a crosser is a recoil particle that is created outside of the cavity and completely crosses the sphere, depositing some energy, before stopping outside of the cavity.

Caswell's theoretical treatment used chord length distributions to determine lineal energy distributions for a parallel beam of neutrons for several different energies. The lineal energy is defined as the quotient of ε by $\overline{\ell}$, where ε is the energy imparted to the matter in a volume by a single energy deposition event and $\overline{\ell}$ is the mean chord length in that volume,

$$y = \frac{\varepsilon}{\overline{\ell}} \qquad (1)$$

Typical units of linear energy is keV μm^{-1}. Given that the lineal energy is a stochastic quantity, the lineal energy distribution is a probability density function and is described by,

$$f(y) = \frac{dF(y)}{dy} \qquad (2)$$

We will repeat Caswell's calculations using a "hybrid" Monte Carlo method. Consider the simulation geometry outlined in Figure 2. A parallel, monoenergetic neutron beam of cross sectional area A is incident on a spherical micro-chamber filled with tissue-equivalent gas surrounded by a solid shell made of polyethylene. The radius of the chamber is R. We will assume that only neutron elastic scattering takes place within the solid and the gas and that the recoil particle always travels in the same direction as the incident neutron. We will consider 1 and 10 MeV neutrons in this project. The radius of the micro-chamber is 0.5 μm.

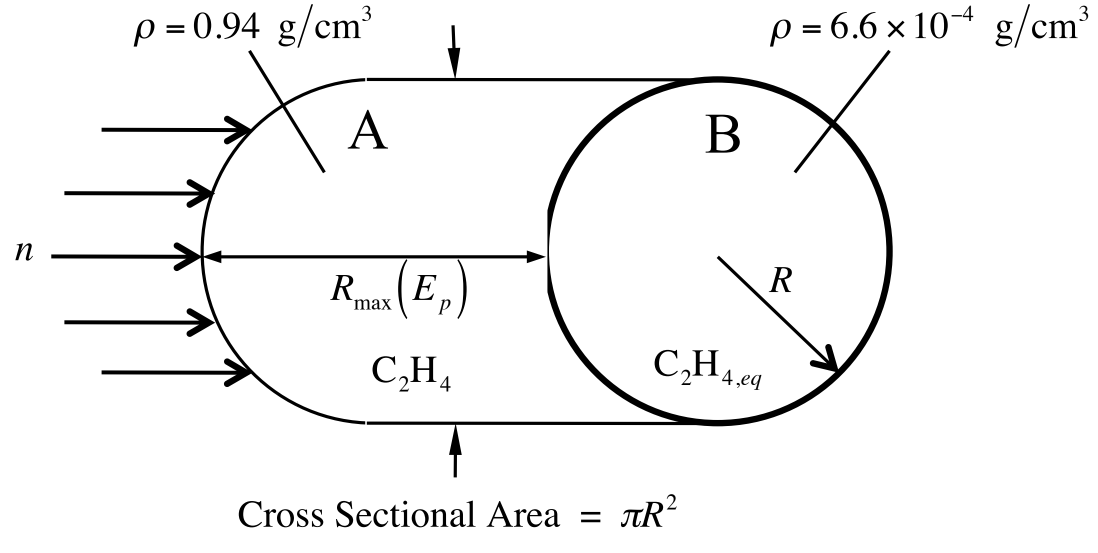

Figure 2.

Part A. The Birth of a Recoil Nucleus

We will not model neutron transport directly. However, we need to determine the location of the birth of the recoil nucleus within our simulation geometry. We will assume that the probability of creating a recoil nucleus in region A over region B is equal to the ratio of masses of the two regions m_A and m_B. Determine the probability of creating a recoil nucleus in region A and B given that recoil nuclei can only be created in A or B. Be mindful of the laws of probability. Show all derivations.

Part B. How Many "Insiders", "Starters", "Stoppers" and "Crossers"?

Next, we will model proton transport inside our simulation geometry. We will assume that the incident neutrons only collide with hydrogen atoms creating recoil protons. Given the scale of the problem we are able model individual proton interactions without the use of a multiple scattering theory. We will ignore angular deflections and assume that the protons will travel in a straight path after creation (i.e. no straggling) as well as that the inelastic cross section of the proton is constant along the path (i.e. one velocity treatment).

Please use the following sampling recipe to model proton transport:

i. Devise a sampling scheme to determine whether the proton is created in region A or B. Note, that the proton has equal probability of being created at any location within each region – just not between regions.

ii. Next, determine the energy of the proton by sampling the recoil energy probability distribution assuming isotropic neutron scattering off of hydrogen, which can be determined from derivations in our class notes. Once the energy of the recoil is sampled, determine the distance to the next collision using,

$$x = -\frac{1}{\mu}\ln(1-r) \qquad (3)$$

where r is a random number between [0,1] and μ is the probability of proton inelastic collision per unit pathlength that is given by,

$$\mu\left(\times 10^{6}\ \mathrm{cm^2 g^{-1}}\right) = 4.94T^{-0.821} \qquad (4)$$

where T is the proton energy in MeV.

iii. Next determine the distance to the next boundary t. If $x < t$ then move on to the next step. If $x > t$ then repeat step ii for the proton located at the boundary. The fact that the particle has survived a certain distance in a medium has no bearing at all on the probability of how much further it will travel before colliding.

iv. Next determine the energy lost in the collision using the average energy lost $\overline{W}$ (in eV) by a proton per inelastic collision which is given by,

$$\overline{W} = 57.14T^{0.045} \qquad (5)^{1}$$

For now we will assume the energy lost in the collision is deposited locally at the interaction site. <u>Keep track of all energy losses in region B</u>.

v. Determine the remaining proton energy after the interaction and repeat steps ii and iii until all of the proton energy is dissipated in region A or B or the proton exits region B.

Produce a total lineal energy distribution in region B as a function of lineal energy for all protons as well as lineal energy distributions for "insiders", "starters", "stoppers" and "crossers" from recoils produced from 1 and 10 MeV neutrons.

<u>Part C. What About Ionization Electrons?</u>

Next we will also attempt to include the contribution of electrons. Instead of local energy deposition we will use an analytical approach to account for any energy losses due to high energy ionization events. Therefore we will need to slightly modify step iii from the recipe above. A proton collision can result in either an excitation or ionization where the excitation cross section is 1/3 of the total ionization cross section. The amendment to step iii is as follows,

i. iii. Next determine the energy lost in the collision using the average energy lost $\overline{W}$ (in eV) by a proton per inelastic collision which is given by,

$$\overline{W} = 57.14T^{0.045} \qquad (6)$$

where T is in MeV. Devise a sampling scheme to determine if an excitation or ionization reaction occurs. If an excitation reaction occurs deposit this energy locally. If an ionization reaction occurs an electron is created with energy $\overline{W}$. Assume this electron travels in the same direction as the proton. Neglecting radiative losses, use the following extrapolated range energy relationship to determine the energy loss of the electron during transport,

$$R_e(T) = 1.264 \times 10^{-6}T^2 + 1.225 \times 10^{-5}T - 1.6045 \times 10^{-5} \qquad (7)$$

---

[1] It follows that the mass stopping power is given by,

$$\frac{dE}{\rho dx} = \mu\overline{W}$$

where T is in keV and R is in g cm^{-2}. Make sure to keep track of the boundaries between each region as well as all energy losses in region B.

Produce a total lineal energy distribution in region B as a function of lineal energy for all protons as well as lineal energy distributions for “insiders”, “starters”, “stoppers” and “crossers” from recoils produced from 1 and 10 MeV neutrons.

Presentation of Data

You do not need to write a detailed report for this project. Please provide the derivation from part A and the plots of distributions from part B and C. Also, please turn in a copy of your source code.

References

1. H.H. Rossi and W. Rosenzweig, A device for the measurement of dose as a function of specific ionization. Radiology 64, 404 (1955)
2. H.H. Rossi and W. Rosenzweig, Measurements of neutron dose as a function of linear energy transfer. Radiation Res. 2, 417 (1955)
3. R.S. Caswell, Deposition of energy by neutrons in spherical cavities. Radiation Res. 27, 92 (1966)