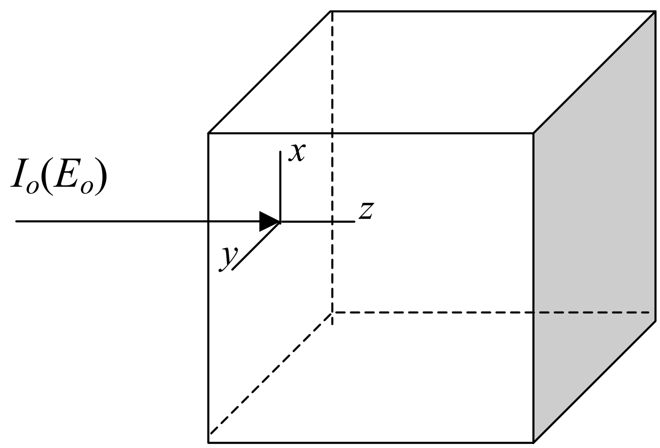
EP 471 -- Engineering Problem Solving II
Default Project: NE Majors/Radiation Science Track

Monte Carlo simulation of shielding problem

In NEEP 408, you typically do some "back-of-the-envelope" shielding problems where (for instance) a mono-energetic, mono-directional beam is incident on one side of a slab, and you wish to find the build-up flux on the other side so you can estimate a dose or dose-equivalent.



In the sketch above, the *x* and *y* directions are intended to extend to infinity, so that the only finite dimension is in the direction of the shield thickness, *z*. Suppose we have an incident beam of 1 MeV photons on one side of an iron slab, and the shield is ten mean-free-paths thick (on the basis of the initial 1 MeV energy). The purpose of this problem is to use Monte Carlo analysis to determine a spectrum on the far side of the shield and therefore provide an alternative to the simplistic build-up flux and build-up factors used in NEEP 408.

You already have many of the elements you'll need for this problem from the Monte Carlo exercises we've encountered in class. You'll need a single loop that runs for the number of particles you're going to sample (let's say 10^7). The form of the loop should consist of a decision-making process that works like this:

(1) Determine the penetration depth. If this is negative (particle has departed backwards through the incident surface) or is positive and exceeds the shield thickness (particle has successfully penetrated the shield), terminate this particle's history and record results.
(2) Based on the current unit vector describing the particle's orientation, determine where the next interaction occurs. (This is based on the exponential attenuation PDF we examined in class.) Decide whether or not to continue based on the additional penetration, as outlined in step (1).

(3) Determine whether the interaction is a scattering event (particle continues to survive) or an absorption event (history is terminated). The fraction of RNG-space occupied by the absorption events increases as the photon energy decreases. You will need a semi-empirical model of the photoelectric effect's energy dependence in order to estimate this. There is a closed-form expression for Compton scattering, so its energy dependence is known. This part of the process is quite simple. Having generated a random number ξ, the particle is declared absorbed if $\xi < \mu_a/(\mu_s + \mu_a)$, otherwise it survives.

(4) If the event is declared to be a scattering event, determine two scattering angles, an azimuthal angle (equally likely in all directions) and a polar angle (rejection technique, as in class). Define a new particle orientation based on these new angles. The new orientation is defined from the old orientation through the rotational transformation,

$$\begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix}_{\text{new}} = \begin{bmatrix} \cos\theta\cos\varphi & -\sin\theta & \cos\theta\sin\varphi \\ \sin\theta\cos\varphi & \cos\theta & \sin\theta\sin\varphi \\ -\sin\varphi & 0 & \cos\varphi \end{bmatrix} \begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix}_{\text{old}}$$

Here θ is the azimuthal angle defined off the local x-axis and φ is the polar angle defined off the local z-axis. From the figure on the previous page, the initial unit vector describing particle orientation is [0 0 1].

(5) Determine the new photon energy from the polar scattering angle in step (4) and return to step (1).

Every case will terminate in either an absorption event in the shield or a penetration through the shield (forward or backward). Once you've completed the loop, you should have records of the number and energy of the penetrating particles. You can use the hist utility to plot the spectrum of energies on the far side of the shield. Integrate the product of particle energy and absorption coefficient to determine the dose. Compare your result to a "back-of-the-envelope" calculation from NEEP 408.