Computational assignment 6

due on November 3, 2025

Proton pencil beam algorithm

Implement a proton pencil beam dose calculation algorithm. Write a function

`calculate_proton_pencil_beam_dose(angle,energy,latpos,raddepth)`

where the inputs are

`angle` the angle of the incident beam,
`energy` the initial proton energy,
`latpos` the lateral position of the beam's central axis relative to the isocenter,
`raddepth` the radiological depth matrix for that beam angle.

and the function should return a dictionary `pb` (for "pencil beam") with the following fields:

`pb.angle` the beam angle,
`pb.energy` the proton energy,
`pb.latpos` the lateral position of the beam's central axis,
`pb.dose` the dose distribution of the beam in the patient.

Pencil beam dose model

We assume a Gaussian model for the dose distribution of a pencil beam in water. For a proton beam in 3D in the beam coordinate system, for which the beam's central axis coincides with the z-axis, the dose distribution $D(x, y, z)$ is given by

$$D(x, y, z) = D_0(z_{rad}(z), E_0) \frac{1}{2\pi\sigma^2(z_{rad}(z), E_0)} \exp\left(-\frac{x^2 + y^2}{2\sigma^2(z_{rad}(z), E_0)}\right) \tag{1}$$

Thus we assume that the lateral spread of the beam σ is equal in x and y and that σ depends on depth. $\sigma(z, E_0)$ is the width of the beam at depth z in water for an initial proton energy E_0. $D_0(z, E_0)$ is the integral depth dose curve in water. Since we only work in two dimensions, you can set $y = 0$. For calculation of the radiological depth, you can use the same function that was used for photons.

To calculate the dose to a voxel, it is sufficient to calculate dose to the point in the center of the voxel according to the above formula. You do not have to subdivide the voxel in smaller volumes to average over dose values in the 2.5 by 2.5 mm volume.

Input data

We use tabulated data for $D_0(z, E_0)$ and $\sigma(z, E_0)$. This data was generated by Monte Carlo simulations, but you could equally think of it as measured data. The zip-file 'protondosedata.zip' contains D_0 and σ as a function of depth in water for various energies (files 'pbmcs*.dat'). The three columns in each file correspond to depth in mm, D_0, and σ, respectively. The file 'edata.dat' contains the available proton energies and 'rdata.dat' contains the corresponding ranges. Thus, the energies are chosen as to correspond to 5 mm range increments in water.