MCNEG Workshop 2016 - Part 1.

Monte Carlo modelling of targets and radiation leakage with FLUKA

Introduction

FLUKA is a sophisticated Monte Carlo code that can model the full gamut of particles traditionally encountered in the radiation protection context, i.e. photons, electrons, positrons, neutrons, protons and alpha-particles. It has a flexible geometry interface and materials editor. The aim of this practical is to familiarise with the basic functionality of FLUKA, applying the code to several common-place examples. Click on 'New' to start a new project.

Getting started

Type in 'flair' at the console. The graphical interface for FLUKA, called Flair, will appear

Click on the Input tab and note the several essential aspects to setting up a Monte Carlo problem, the radiation beam description, the geometry and material assignments.

BEAM:
Switch from momentum to energy description of the beam. Choose an electron of energy, E, of 20 MeV and the beam-width and height, Δx and Δy, of 0.1 cm. [Note that FLUKA uses the units GeV and cm]

BEAMPOS:
This will default to the electron travelling in the Z direction

RCC:
The geometry defines a cylindrical COPPER target. Reduce the thickness and diameter of the target to 1 cm. Check the geometry viewer and insure you understand what you are seeing.

ASSIGNMA:
Change the assigned material of the target to TUNGSTEN and the assigned material for the Void to AIR. We will look at the products of the interaction of these electrons with the target and display the distribution of these products in the surrounding air. [As you are allowing interactions in the void region it is sensible to reduce the radius of SPH void to 10 cm]

Add scoring components USRBIN with an X-Y-Z arrangement for electron, photon and neutron fluence, selecting a unique BIN for each output file. Define a cube that encompasses the target and extends to include 1 cm of air on all sides. The overall cube should be 3x3x3 cm^3 in dimension. Choose 30 voxels in each of these directions.

Create a folder and save the input file and project in the folder, with a sensible choice of folder and filename.

Click Run and Start button to start the calculation. The calculation is performed in 5 batches and should take about a minute.

Click on the data sub-tab and Scan (for newly created files) and Process (to form one single set of 3D data. You need to click on the Runs sub-tab to run new simulations.

Click on the Plot tab and add a USRBIN plot. Load each of the bnn (binary format) files and reflect on the fluence distributions generated for the three particles.

Calculating fluence spectra for a typical LINAC target

Create small test masses of AIR (spheres of 1 cm radius) and place them 5 cm before, 5 cm after (i.e. Z direction) and 5 cm perpendicularly off-axis (i.e. in X or Y direction) from the target. You will need to add three SPH REGIONS and adjust ASSIGNMA accordingly. The SPH will occupy volume in the Void region so this definition will also need to be changed.

Add three USRTRACK scoring components to calculate the bremsstrahlung spectrum for photons. These can all be placed in ASC file with a single unit.

Run the simulation again and download the *.out files and the *_fort.24 associated with your run. There should be 5 of them.

Examine one of the *.out files, which contains a lot of information about the batch, much of which is not relevant to the particular calculation you have performed. Look for the energy deposited in the Void, the Target and the three spherical test masses, the number of histories used and the time taken towards the end of the file.

Extract the energy deposited from all 5 *.out files. Calculate a mean dose and the standard deviation for each of the regions per incident electron. [Hint you will need to determine the density of the AIR used and the volumes of your test masses.]

Calculate the figure of merit for each detector:

$$\text{f.o.m.} = 1 / (\text{CPU time} * \text{standard\_deviation}^2)$$

Extract the photon fluence spectra for each detector from each of the 5 batches. Calculate a mean and standard deviation. Plot these with error bars.

Comment on the issues associated with shielding a 20 MeV LINAC beam in order to minimise leakage from the back and side of the device.

Creating suitable shielding and an enclosure

Enlarge the radius of the void to 2 m and move the test masses to 1 m from the target for which we will determine leakage doses. Increase the diameter of the spheres to 20 cm. This time fill the test masses with water to ensure reasonable electronic equilibrium is achieved. Modify your USRBIN plots to cover a 5x5x5 m^3 region.

Assuming a treatment dose-rate of 1 Gy/s, what is the dose-rate at 1 m in the other two directions in the absence of LINAC head shielding.

Try to determine a suitable thickness of lead (Pb) to ensure that only 10 mGy/s level of leakage from photons escape from the back and sides during operation of the machine. The TVL (tenth-value-layer) for Pb at megavoltage energies is usually taken as 5.7 cm.

Construct an outer shield from two nested rectilinear parallelepipeds (RPP) within the void with an outer walls at 0.5 m from the target with a thickness determined from the figure you estimated above. You might want to add a third RPP of air to create a 20x20 cm^2 aperture in the front surface to model a collimator system.

Calculate the dose in each of the detectors and compare it to your prediction above.

Move the two test masses at the side and rear of the target to a distance of 5 m. Run the simulation. Observe the photon fluence distribution and dose recorded in the output files. Once again determine the dose relative to the dose at isocentre.

How long a simulation would be required to get an accurate result? What is wrong with this approach? [Hint: In shielding problems we aim the reduce the number of photons reaching or regions of interest, however this reduces the probability of photons interacting with the test masses and effects the quality of the calculation.]