Overview

The microbeam example simulates the microbeam cellular irradiation beam line installed on the AIFIRA electrostatic accelerator facility located at CENBG, Bordeaux-Gradignan, France. This setup is mainly used to investigate the effects of low dose irradiation on living cells. The microbeam line allows irradiation of individual biological living cells in culture medium in single ion mode, with an exact control of the delivered dose to a particular cell among the cell population. This Geant4 example simulates the microbeam line in a configuration of irradiation with 3 MeV incident alpha particles and allows the calculation of the dose deposited by the incident particles in the cell cytoplasm and in the cell nucleus, which are inaccessible by experimental measurements. For the first time in Monte Carlo microdosimetry, the simulation includes a realistic cell phantom obtained from confocal microscopy and from ion beam analysis techniques.

For more information on this irradiation facility, please visit: [http://www.cenbg.in2p3.fr](http://www.cenbg.in2p3.fr)
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Description

The beam is emitted just before the 10° switching magnet taking into account experimental beam parameters measurements; the main elements simulated are:

- **A switching dipole magnet with fringing field**, to deflect by 10° the 3 MeV alpha beam generated by the electrostatic accelerator into the microbeam line, oriented at 10 degrees from the main beam direction;

- **A circular object collimator**, defining the incident beam size at the microbeam line entrance; the collimator has been simulated from realistic electron microscopy images;

- **A quadrupole based magnetic symmetric focusing system** allowing equal transverse demagnifications of 10. Fringe fields are calculated from *Enge's model*.

- **A dedicated cellular irradiation chamber setup**, taking into account all the elements encountered by the incident beam (diaphragm, gas detector, isobutane, beam extraction window, air, culture foil, culture medium, cell dish…);

- **A set of horizontal and vertical electrostatic deflecting plates** which can be turned on or off to deflect the beam on target;

A realistic human keratinocyte voxelized cellular phantom observed from confocal microscopy and taking into account realistic nucleus and cytoplasm chemical compositions. The phantom uses the G4PVParameterised class.

Collimator geometry implemented in Geant4 as embedded cones
Confocal microscopy image of a HaCat cell showing the cytoplasm (red) and the nucleus (purple)

Corresponding Geant4 phantom showing incident alpha particles penetrating the cell phantom

Low energy electromagnetic processes (for alphas, electrons, photons) and hadronic elastic and inelastic scattering for alphas are activated by default. In the proposed Physics list (which uses Physics builders), standard electromagnetic processes replace low energy electromagnetic processes above 1 GeV. This shows to users how to implement a combined Physics list between low energy electromagnetic models and standard electromagnetic models.

How to run the example

The example can be compiled with cmake and make. It uses multithreading mode by default. The macro file microbeam.mac allows simulation control.

Results and future developments

The output consists in a ROOT file (http://root.cern.ch) created directly in the microbeam directory. It contains:

• the total deposited dose in the cell nucleus and in the cell cytoplasm for each incident alpha particle;
• the average dose deposited per voxel per incident alpha particle;
• the final stopping (x,y,z) position of the incident alpha particle within the irradiated medium (cell or culture medium)
• the actual stopping power dE/dx of the incident alpha particle just before penetrating into the targeted cell;
• the beam transverse position distribution (X and Y) just before penetrating into the targeted cell;

The ROOT macro plot.C gives the following graphical output, obtained for 20000 incident alpha particles. These files are merged and analyzed using the provided ROOT macro file plot.C. Type ‘root plot.C’ after the run is terminated. This macro gives the following graphical output:
TOP row
- left plot: nucleus voxel intensity (0-255) distribution, two density zones have been isolated in the simulation
- middle left plot: alpha dose deposit in nucleus
- middle right plot: nucleus voxel intensity projected on cell transverse section
- right plot: beam transverse (X) position distribution on target. The sigma of the Gaussian fit is compatible with the measured experimental value.

MIDDLE row
- left plot: cytoplasm voxel intensity (0-255) distribution, two density zones have been isolated (one for pure cytoplasm in red, the other for nucleoli in yellow)
- middle left plot: alpha dose deposit in cytoplasm
- middle right plot: cytoplasm voxel intensity projected on cell transverse section
- right plot: beam transverse (Y) position distribution on target. The sigma of the Gaussian fit is compatible with the measured experimental value.

BOTTOM row
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- left plot: beam stopping power dE/dx distribution at cell entrance
- middle left plot: 3D distribution of alpha particle range in cell or medium
- middle right plot: projected mean energy deposit per voxel (transverse, z axis is in eV)
- right plot: projected mean energy deposit per voxel (longitudinal, z axis is in eV).

References

Refer to Geant4-DNA publications (http://geant4-dna.org) and in particular to:


