Geant4 for Brachytherapy

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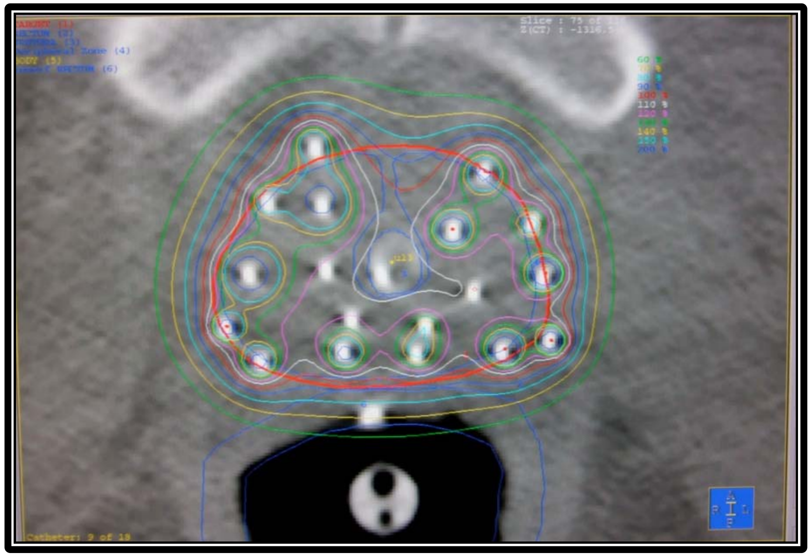
Why Monte Carlo For Brachytherapy

- Quality assurance
  - Plan checking



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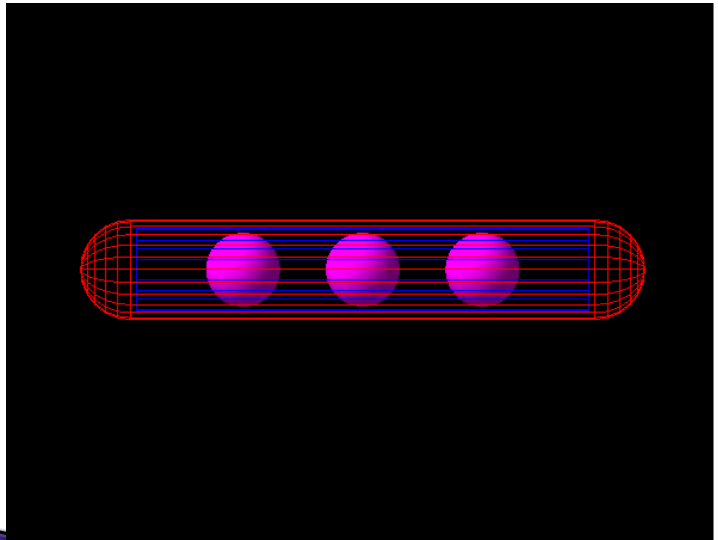
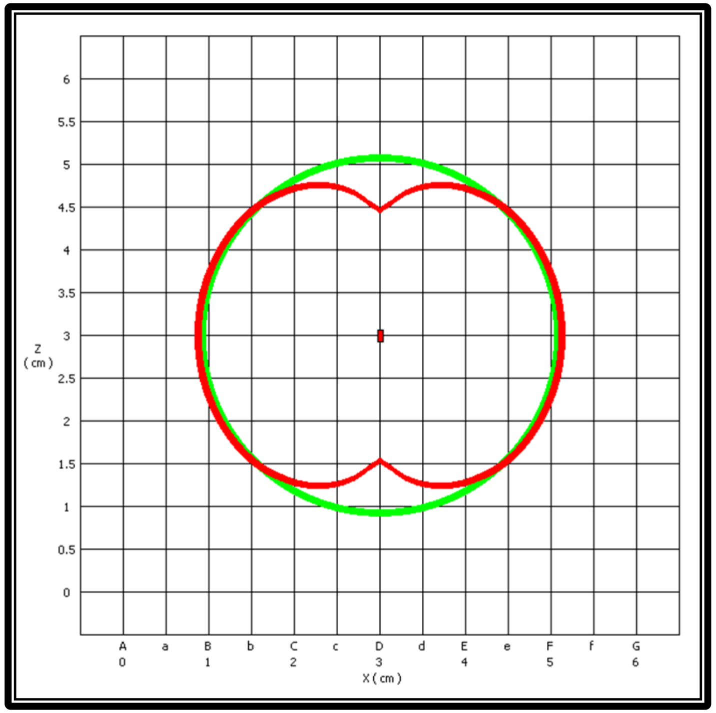
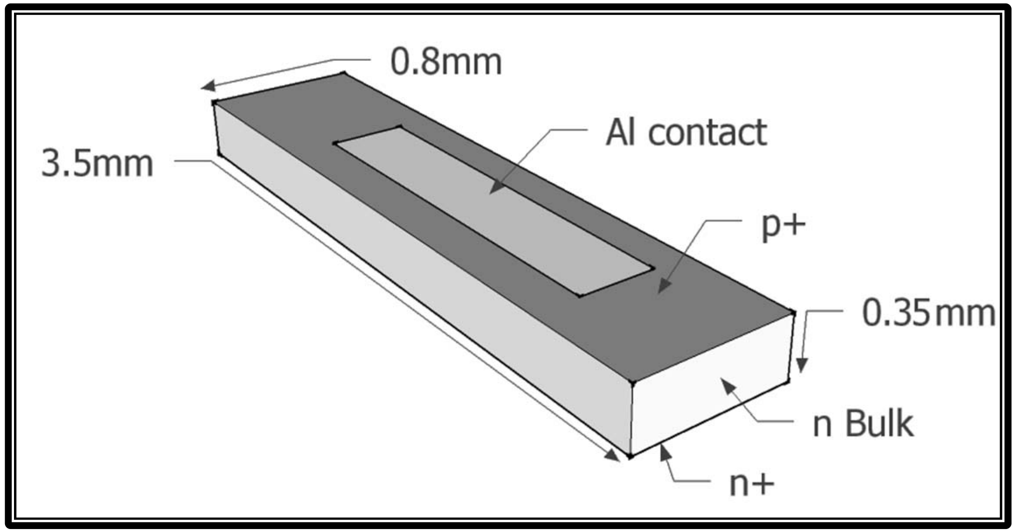
- Source modelling
  - TG-43 data





Why Monte Carlo For Brachytherapy

- Quality assurance
  - Plan checking
- Source modelling
  - TG-43 data
- Detector optimisation
  - Geometry
  - Materials

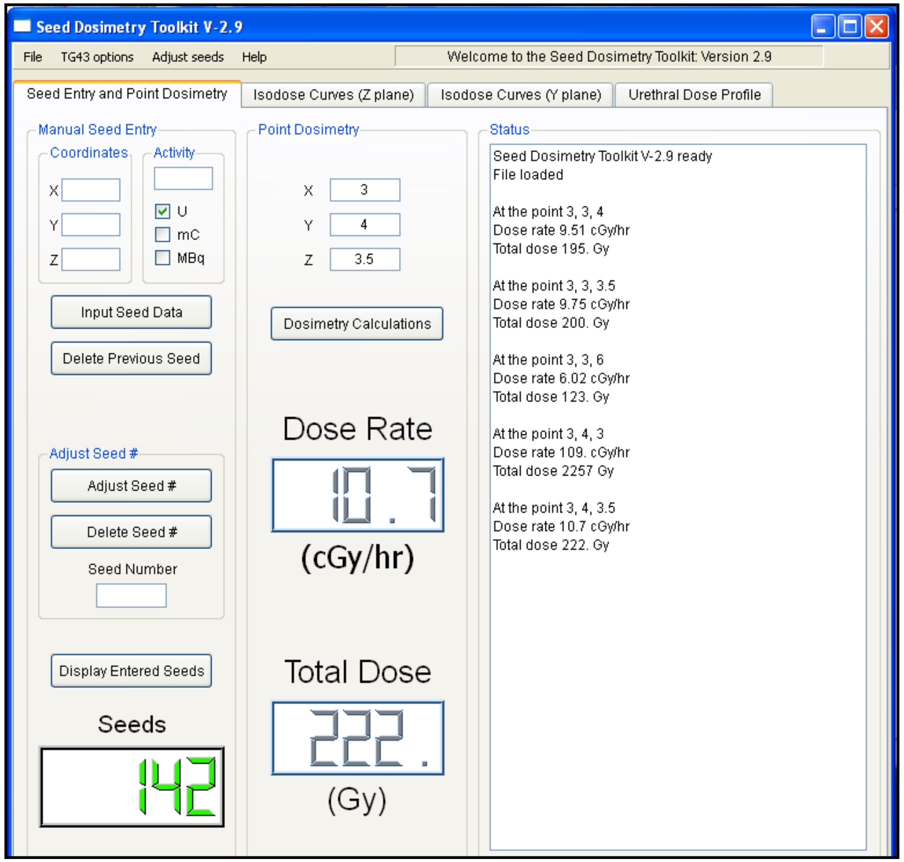


Geant4 for Brachytherapy

- We have used Geant4 for brachytherapy in the applications of
  - Low/high dose rate brachytherapy dosimetry
  - Low/high dose rate brachytherapy source characterisation
  - Low/high dose rate brachytherapy detector optimisation
  - Eye plaque brachytherapy dosimetry
  - Eye plaque brachytherapy detector design and optimisation

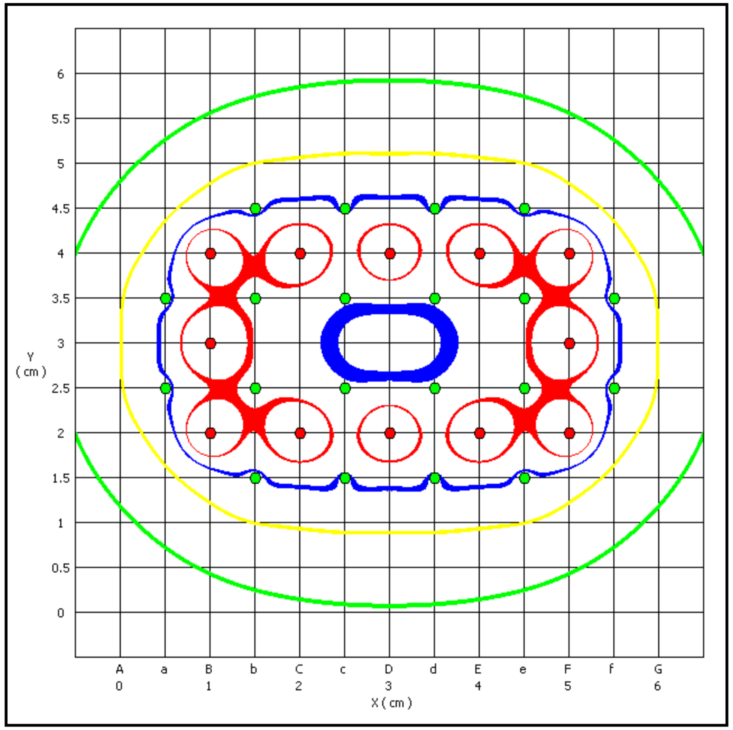
The Seed Dosimetry Toolkit

- Performs dosimetry calculations of seed arrays using any required dose calculation formalism (TG43, point source)
- May be used to calculate the dose rate or total treatment dose at any required coordinate of a treatment plan
- Is very flexible allowing for TG43 parameter and function modifications and comparisons

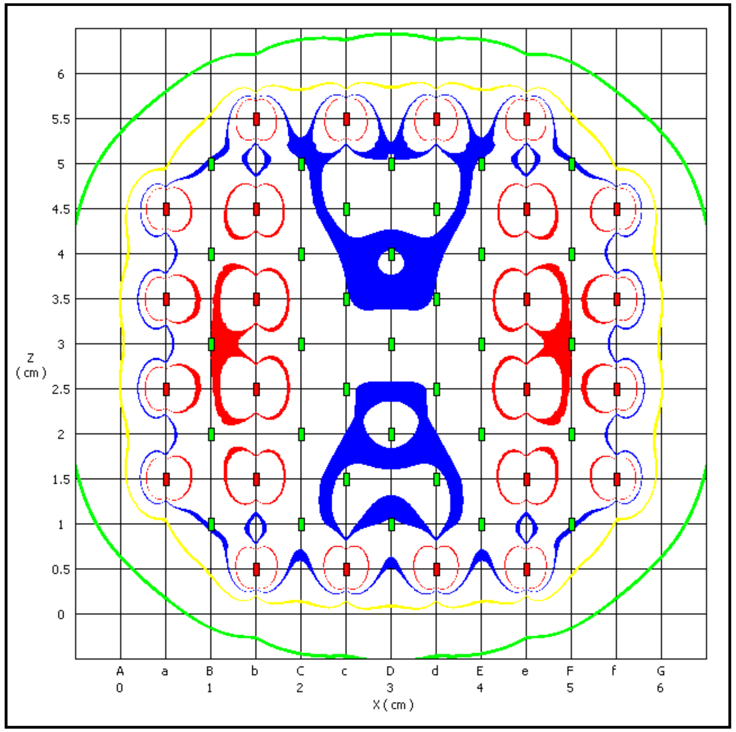


The Seed Dosimetry Toolkit

- May generate isodose representations in multiple orthogonal planes, DVHs, as well as dose profiles along predefined coordinates representing critical structures (urethra, rectum)



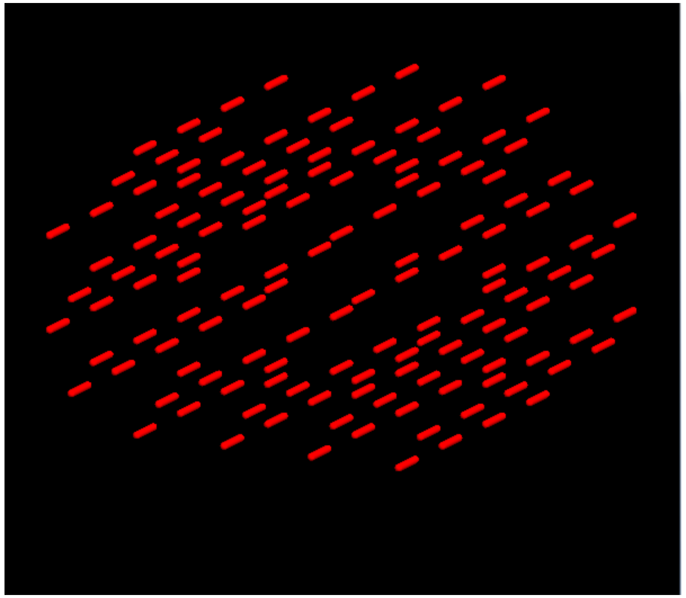
Axial view, centre of array

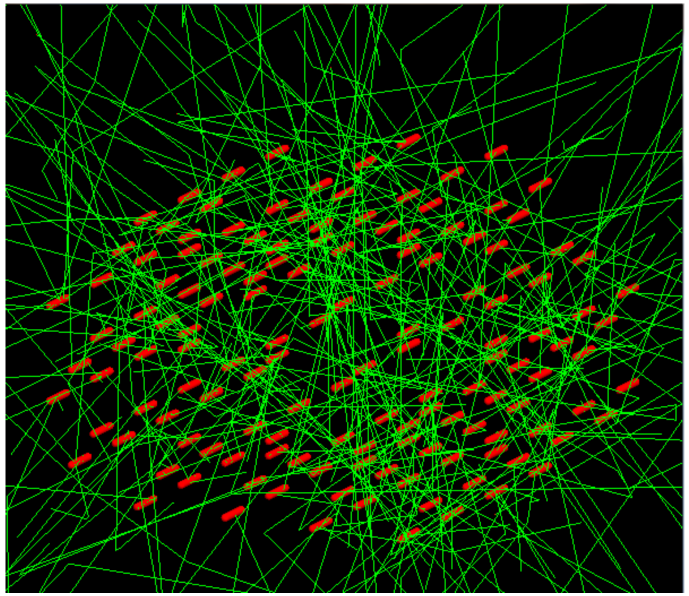


Coronal view, centre of array

BrachyPlot

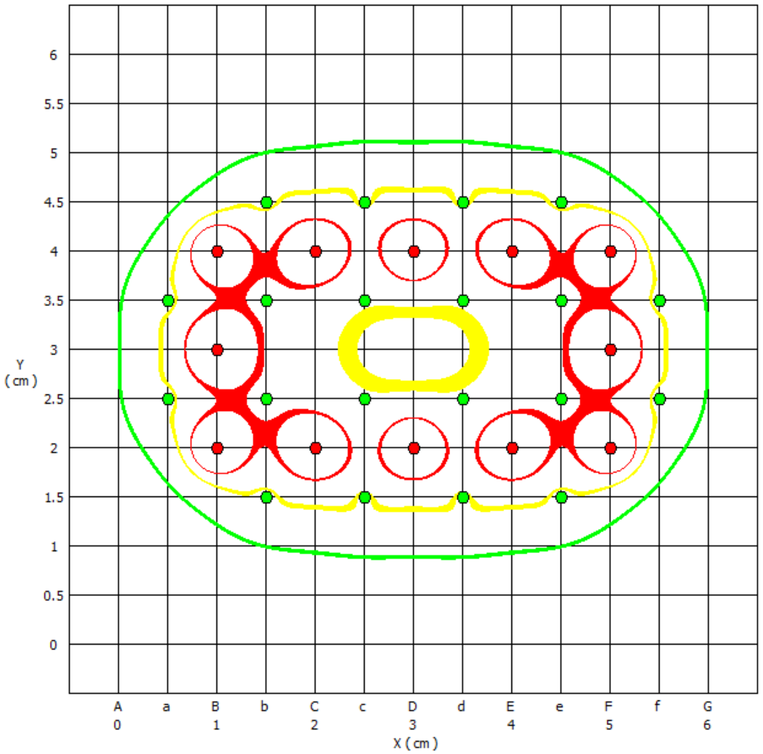
- Geant4 application for the simulation of LDR brachytherapy treatment plans
- Uses the seed locations provided by the seed dosimetry toolkit array files



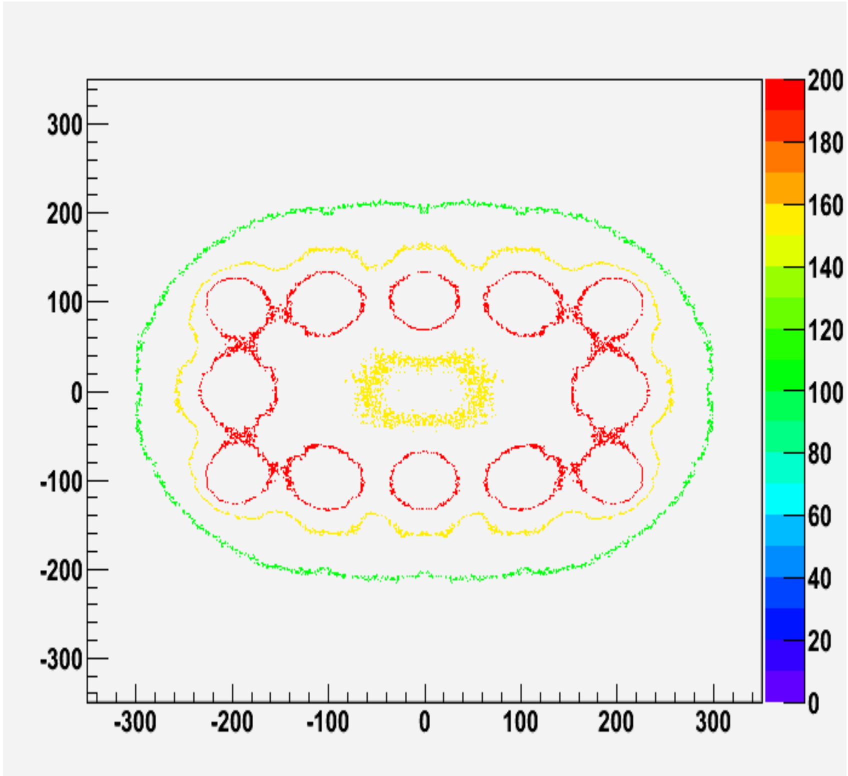


BrachyPlot

- Outputs isodose and dose colour wash curves



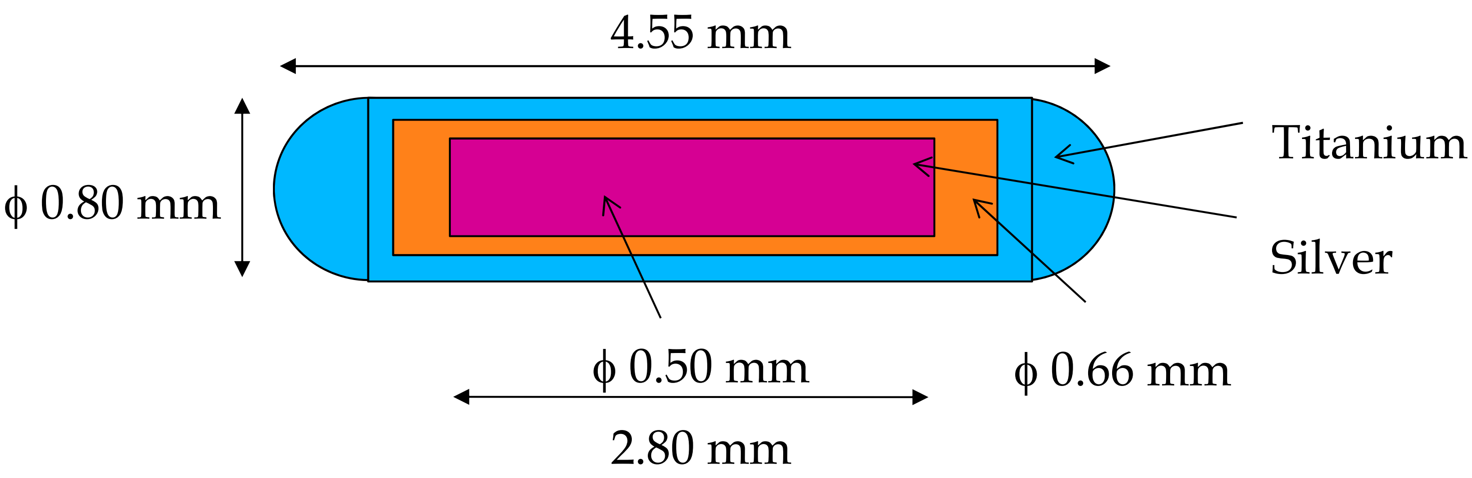
Seed Dosimetry Toolkit generated isodose curves



Brachy_plot generated isodose curves

Commissioning the seed

Oncura Model 6711

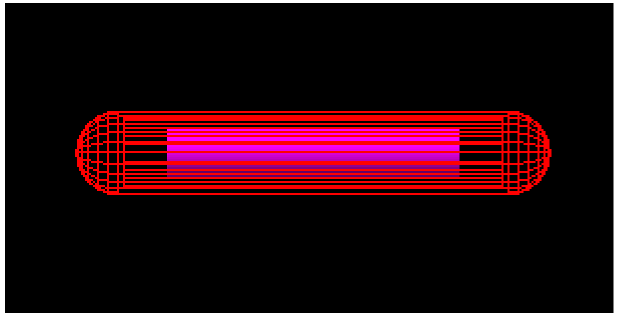


I-125 generated as a radioactive coating on silver core, 1-3 μm depth

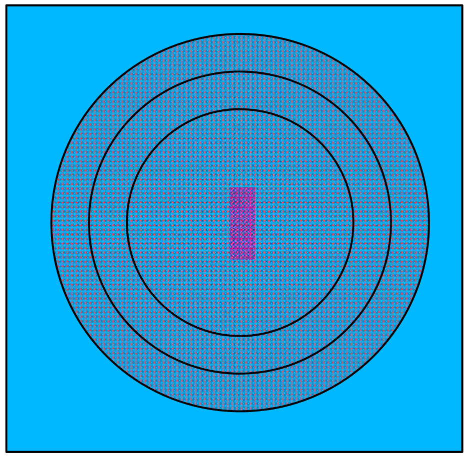
J. Dolan, et al, "Monte Carlo and experimental dosimetry of an 125I brachytherapy seed", Med. Phys. 33, 2006

The Model

- Seeds placed at centre of 30x30x30 cm^3 liquid water phantom



- Seeds located at centre of 25 concentric spherical shells
- Shells from 1mm to 100 mm radius
- Shells of thickness 0.05 mm



- Any energy deposition within a spherical shell is sent to a scoring routine

The Scoring Routine

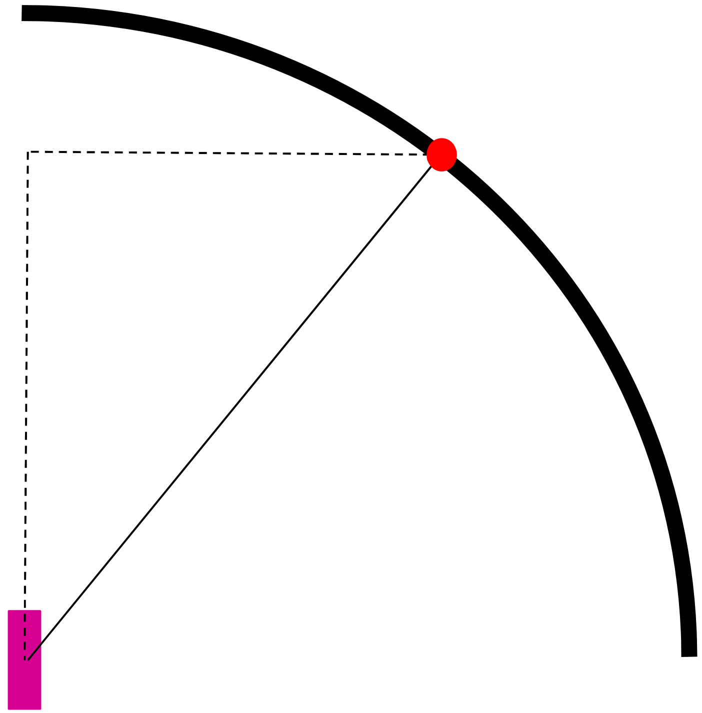
- Used to tabulate the data in the required format (r,θ)
  - Scoring array [25][19]

  For 25 shells, 19 angles
- The radius in mm is simply the shell number
- The angle is calculated using the coordinate of deposition

$$\theta = \cos^{-1}(|z|/r)$$

rounded to nearest 5°

Energy deposition added to deposition array at $[r-1][\theta/5]$



Model Output

- At the end of the simulation
  - Output the dose per particle for each component of the radius-angle array to file

  - Calculate TG43 formalism functions from obtained array data for correlation with standard values

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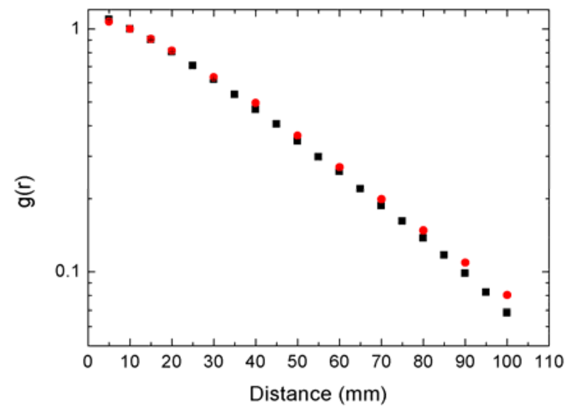
$$G(r,\theta)=\frac{\sin^{-1}\left(\frac{L^{*}\sin(\tan^{-1}\{[r^{*}\sin(\theta)]/[r^{*}\cos(\theta)-L/2]\})}{\sqrt{[r^{*}\sin(\theta)]^{2}+[r^{*}\cos(\theta)+L/2]^{2}}}\right)}{L^{*}r^{*}\sin(\theta)}.$$

$$g_X(r)=\frac{\dot{D}(r,\theta_0)G_X(r_0,\theta_0)}{\dot{D}(r_0,\theta_0)G_X(r,\theta_0)} \qquad F(r,\theta)=\frac{\dot{D}(r,\theta)G_L(r,\theta_0)}{\dot{D}(r,\theta_0)G_L(r,\theta)}$$

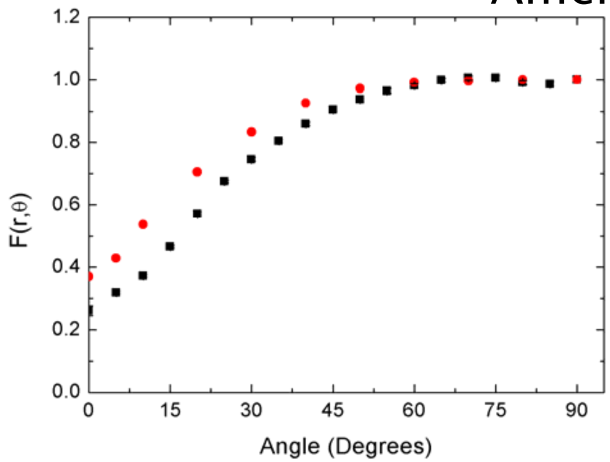
Model Commissioning

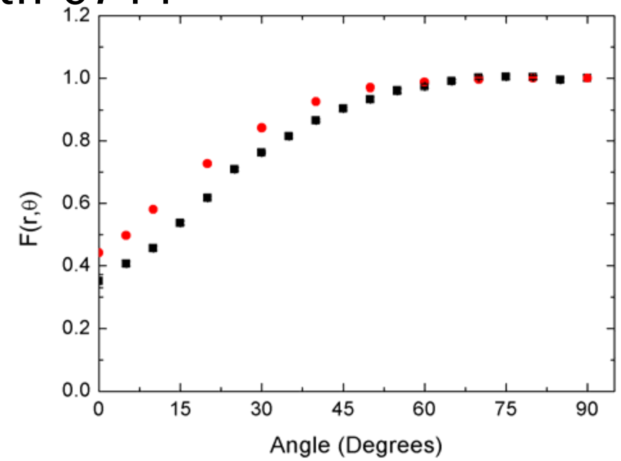
- To test the validity of the model
- Radial dose function and anisotropy function plotted



Model Commissioning

Anisotropy function, F(r,θ)
Amersham Health 6711





r = 1cm
TG43 – red
Monte Carlo - black

r = 2cm
TG43 – red
Monte Carlo - black

- Agreement within 5% for angles greater than 45°
- Under-response at small angles

Detector Construction Class

- Constructs a water phantom of dimensions 30x30x30 cm^3
- Constructs a sensitive region within the phantom of dimensions 7x7x7 cm^3
- Imports a seed location file
- Constructs a three dimensional array featuring x, y and z coordinates for the required number of seeds
- Performs a physical placement of the seed model in each location specified by the seed array

Primary Generator Class

- The Primary Generator Action class imports the seed numbers and locations from the seed array input file
- A random number generator is used in each event to select
  - The seed number to simulate the primary from
  - The location within the seed to set the x,y,z values of the primary gun (plus the x,y,z coordinate of the randomly chosen seed)
  - The energy of which to set the primary particle to based on the energy spectrum of I-125
  - The direction of which to fire the primary particle

Sensitive Detector Class

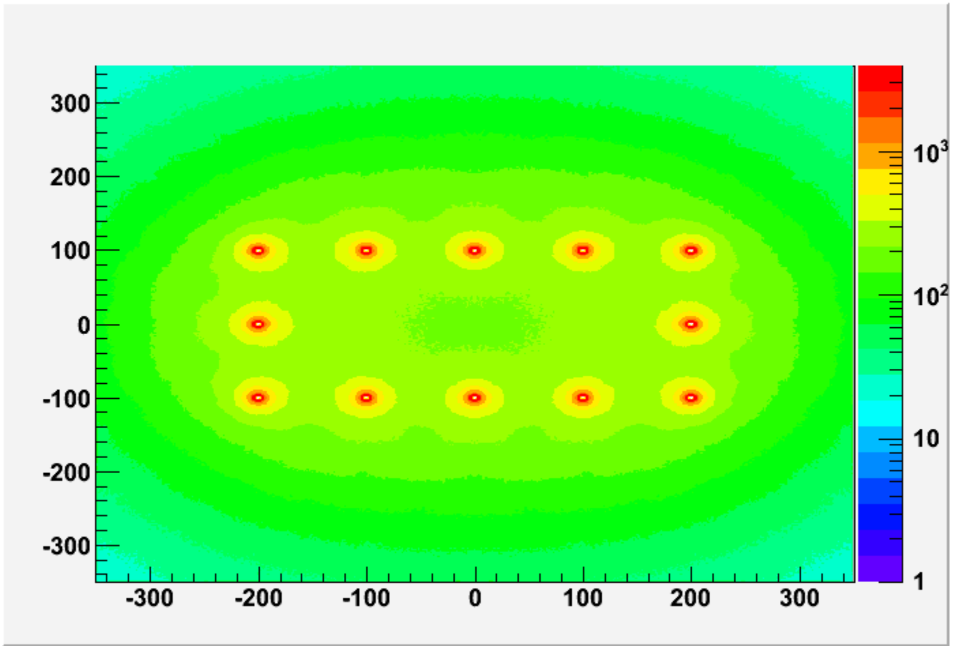
- Is called upon whenever a step occurs within the sensitive volume
- Creates virtual planes in the z direction
  - 2 mm thick
  - 5mm apart
- Checks to see whether energy is deposited in the step
- Checks to see if the interaction occurred in a scoring plane
- Splits each plane into a 700x700 grid representing x,y coordinates
- Passes on the (x,y,z) coordinates and energy deposited to the run action class

Run Action Class

- Contains an input function to receive energy deposition information from the sensitive detector class
  - Sums all of the x,y,z,eDep information passed on from each event into a three dimensional array [15][700][700]
- Contains a routine that is executed at the end of the simulation that takes the three dimensional scoring array and uses the ROOT analysis manager to build 15 2 dimensional histograms, representing the dose distribution on each plane

ROOT Analysis

- The ROOT analysis consists of a set of macro files which
  - Import the .root results file
  - Adjust the dose array values based on the
    - Number of seeds in the simulation
    - Number of events simulated
    - Calibration adjustment



ROOT Analysis

- The macro files are designed to
  - Create dose wash graphs for each plane
  - Create isodose curves for each plane
  - Compile the dose arrays for each plane to obtain dosimetric parameters
    - E.g. V100, D90, V150