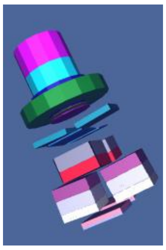
WORKING GROUP6 : COMPUTATIONAL DOSIMETRY

(coordinator G. Gualdrini, Gianfranco.gualdrini@enea.it)

Task 2

Standard Monte Carlo Modelling of a Medical Linear Accelerator



Proposed by :

- **Loïc de Carlan (CEA-LIST, France), loic.decarlan@cea.fr**
- **Jean-Marc Bordy (CEA-LIST, France), jean-marc.bordy@cea.fr**
- **Robert Price (City University, United Kingdom), R.Price@city.ac.uk**

Participants who intend to propose a solution to this action are kindly asked to send an e-mail to Loïc de Carlan, loic.decarlan@cea.fr

Final results should be also send to loic.decarlan@cea.fr

I) general aspects

Scope of the Proposal

Radiation Therapy has become more complex over the past few years with the use of new techniques like IMRT (Intensity Modulated Radiation therapy) and stereotactic treatments. Moreover optimisation of the treatment has become a critical point in the overall planning and delivery process due to the trend in dose-escalation with these new techniques and the real potential for damage to healthy tissue. Typically in techniques such as IMRT the dose distribution includes steep dose gradients with complex concave patterns. In order to calculate such complex three-dimensional distributions and deliver the proper dose to the tumour, the treatment planning system (TPS) has to perform complex calculations (usually in a short time) based on varying approximations to the radiation transport process. Monte Carlo (MC) simulations can be beneficial in such circumstances – either as a means of undertaking the whole calculation (although this is still not often used in practice) or for validating the results achieved with a commercial TPS. Moreover, MC calculations are commonly used in the establishment of the primary standards when determining correction factors not reachable by experimental means.
The exercises presented herein are aimed at developing a Monte Carlo simulation model of a well characterised medical linear accelerator (LINAC) that is used for primary measurements; measured data taken using the LINAC will be used as the benchmark for calibrating and testing the MC model..

This standard model can be used to help users to develop the skills needed to build and calibrate a Monte Carlo simulation and perform a dosimetric analysis.

Short Description of the Work:
The exercise is split into two tasks that should be performed in succession. Information on code used to build the MC models; the physics implemented; data used and methodology etc should be clearly described by the participants in their final report.

Task 1:
The first task is to model the head of the LINAC (a Saturne 43 at CEA LIST LNHB). All relevant geometry and material data is provided as will be limited information pertaining to the electron source and target. The information provided will be typical of that normally obtainable from the LINAC manufacturers and so provides a realistic scenario. Once the model geometry is constructed the participant is required to make adjustments to the electron source parameters related to the electron spot for a 12 MV photon beam, namely the spot size, shape and energy distribution for a single energy and a single field (12 MV photon; 10x10 cm² field at 100 cm from the source; 10 cm depth in water). This adjustment will be performed by comparing the simulated data calculated in a homogeneous water phantom (~~3~~40x~~3~~40x~~3~~40 cm^3) by the participant and the experimental ones provided by LNHB.
For participants who are not familiar with this kind of simulation, the procedure to tune the energy and spot size of the incident electrons is based on Depth Dose Curve (DDC) and profiles calculations. First, the primary energy of the incident electrons is set according to the manufactory specifications. This energy is tuned until the calculated DDC matches the measured one. Second, with that energy, the incident electron spot size is changed until calculated profiles match the measured ones – care should be taken to match the build-up region and the bremsstrahlung tail.

The "quality index" of the parameterization is based on the gamma index. A spread sheet is provided to enable a standard gamma index calculation to be performed by all participants. Depth-dose curve and beam profile plots are provided for a 10 x 10 cm^2 field to enable model calibration. Once this step is achieved, a phase-space file (PSF) can be recorded to be used in the second step of the exercise – the participant should expect this file to be very large.

Task 2:
The second task is dedicated to the calculation of relative absorbed dose in a water phantom including tissue equivalent heterogeneities (lung and/or bone) for 4 different configurations. Geometric and material data are provided. This task is based on the model calibration designed in the first task. Participants are asked to provide the relative absorbed dose at specific points in the phantom to facilitate the analysis of the results. For analysis purposes, the participants are asked to provide information on how the PSF was used, if it is the case (i.e. how many times it has been resampled, if it has been rotated, etc...). The authors will compare the calculations results to the experimental ones performed at LNHB using gamma index.

End of the action:
A workshop will be organised and Proceedings may be published in a scientific journal with reviewing process in 2012.

Agenda:
Proposal disseminated in May 2010
Results provided to the authors by October~~June~~ 2011
Workshop – June 2012

II) Description of the problem

Geometry

A general view of the geometry of the LINAC and the water phantom is given in Fig1.

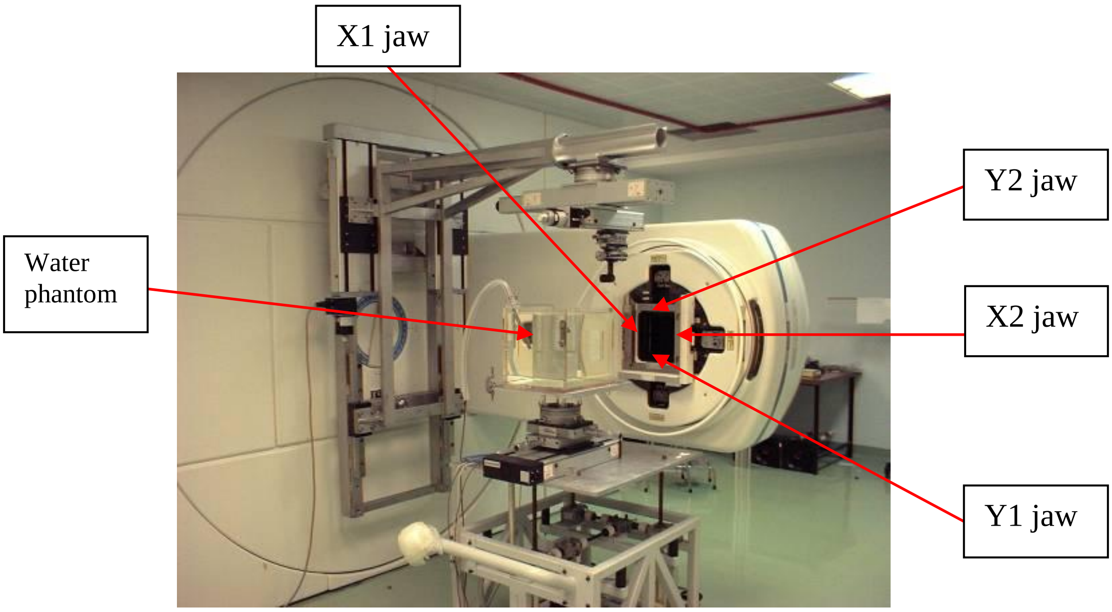


Fig 1 : Overview of the LINAC and the water phantom

The complete description of the geometry and materials is given in the files described below. It corresponds to the simulation of the **12 MV beam in photon mode (10x10 cm^2)**.

1 "various field sizes.pdf" : view cuts (not at the same scale) of 4x4, 10x10, 40x40 cm^2 fields in X and Y cut. This file is given only as a guide to show the final geometry of the head. The participant should compare simulated results with one or several plots given in this file.

2 "linac-drawing1.pdf" : gives the main dimensions of the head. The origin of the geometry is the centre of the upper part of the target see also file **"Titanium-window-and-target.pdf"**. this origin is also considered as the initial point of photon emission whereas the upper part of the titanium window is the initial point of emission of electrons for which it is asked to optimize the energy, position… All the surrounding material is taken to be air even if above the titanium window it is in reality vacuum.

3 "linac-drawing2.pdf" : gives dimensions of the head and the materials of each component.

4 "Collimator diameter.pdf" gives the different diameters that are not given in the in files 2 & 3.

5 "Titanium-window-and-target.pdf" : gives the detailed description of the output section, namely the titanium window and the target.

6 "flattening filter.pdf" : gives the detailed description of the flattening filter.

7 "Monitor chamber.pdf" : gives the detailed description of the monitor chamber and the materials.

8 "water-phantom.pdf" : gives the detailed description of the water phantom. At the front of it, the thickness of PMMA crossed by the beam is 4 mm (15 mm for the all other walls of the phantom). The distance from the top of the target to the external entrance window of the water phantom is 90 cm. The depth in water is expressed from the external side of the entrance window of the phantom. Thus a measurement of 10 cm depth means 4 mm of PMMA plus 9.6 cm of water. Depth in water is **always expressed in cm**, but for comparison of task II (in different heterogeneities), this depth will be converted into equivalent depth in water **expressed in g/cm²**.

9 "materials.pdf" : file containing all the materials of the problem and their density. The composition of each component of the materials are given in fraction by weight, expressed in %.

Dimensions are given in mm except when otherwise mentioned. All the data provided are as precise as possible. Nevertheless, participants are free to simplify some data if necessary. As an example, it is not mandatory to model the external part of the flattening filter since it is not crossed by the beam (fig 2).

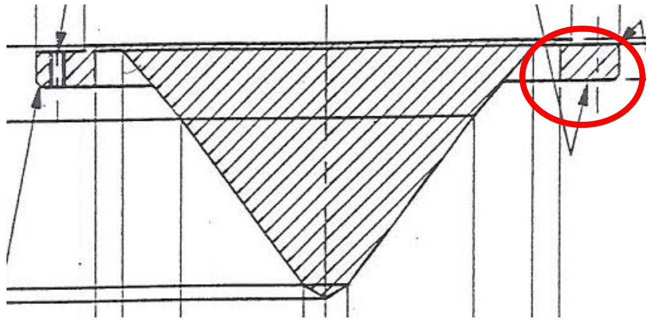


Fig 2 : Overview of the flattening filter at 12 MV.

III) Detailed Description of Task1

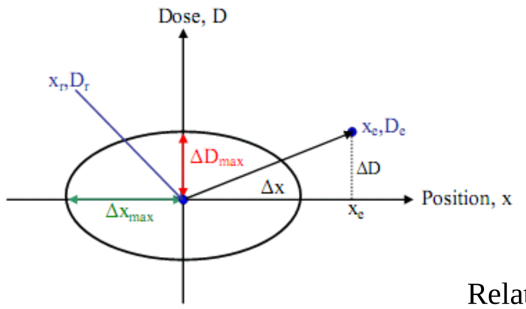
In this task, you are asked to adjust the energy spectrum, the size and the shape of the electron spot impinging **on the Titanium window**. Adjustment should be performed by comparing simulated results with the experimentally measured beam profile (profile has been averaged and symmetrised for the 4 jaws of the collimator) and the percentage depth dose (PDD) curve for a 10x10 cm² field. These data are provided in the excel file **"beam-data in water.xls"**.

It is proposed (but not mandatory) to use voxels with a size of 0.5x0.5x0.5 cm^3. The uncertainty given by the participant should be given in absolute value with a confidence level of **2 sigma** (usually codes give the results at one sigma only). Proposed target value for the relative uncertainty at 2 sigma is 1%.

In order to compare the results and to adjust the requested parameters (energy spectrum etc), the gamma index should be used (see fig 3). This index takes into account both the relative shift in terms of intensity and in terms of position.

One considers ΔDmax and Δxmax around the experimental value. The values ΔDmax and Δxmax define the axes of an ellipsoid in which one can accept the calculated point. For each point of the data of the simulation to be compared (Xe_i; De_i), one calculates the gamma value in comparison with the reference point measured (Xr_i; Dr_i). The gamma index for (Xr_i; Dr_i) is the minimum value of all the gamma values.

The calculation is repeated for each (Xr_i; Dr_i) value.



$$\Delta x = |x_e - x_r|$$

$$\Delta D = D_e(x_e) - D_r(x_r)$$

$$1 = \sqrt{\left(\frac{\Delta D}{\Delta D_{max}}\right)^2 + \left(\frac{\Delta x}{\Delta x_{max}}\right)^2}$$

$$\Gamma(x_e, D_e) = \sqrt{\left(\frac{\Delta x}{\Delta x_{max}}\right)^2 + \left(\frac{\Delta D}{\Delta D_{max}}\right)^2} \leq 1$$

$$\gamma(x_r) = \min[\Gamma(x_e, D_e)] \ \forall x_e$$

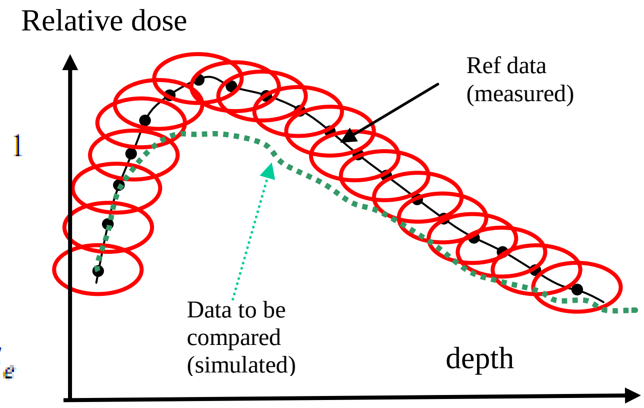


Fig 3 : Gamma index description.

A dedicated worksheet is provided in the file "**gamma-index.xls**". The default values for the tolerance are **1 mm** in position and **1 %** in relative dose. If the gamma index is less than or equal to unity, the comparison is accepted, if it is greater than unity, the point is rejected. **It is highly recommended to use the same position of calculated and measured data so that Xe=Xr. Positions are provided in "beam-data in water.xls" file.**

Participant may calculate a PSF in order to store the particles information at the exit of the head in order to avoid simulating again the particles inside the head, which is time consuming. Note that usually, the creation of the PSF file is also more time consuming than the simulation of the energy deposition for the same number of initial particles.
As a suggestion, a scoring plane could be located at 22 cm (just before the jaws) so to use the phase space data for different field sizes, even if in this exercise the field size is always 10x10 cm². It could be useful to have some tens of millions of particles in the phase space file.

You are also asked to calculate the spectral fluence distribution (cm^{-2}) in air (**without** the water phantom) at 90 cm from the source on the central beam axis (maximum volume of a few cm²). The required linear step in energy is 200 keV.

Summary task I :

- modelling of the LINAC according to provided data (geometry and materials).
- Adjustment of the electron-beam energy and its distribution; optimisation of the initial position of the source and its distribution. This work is performed using the gamma index.
- Calculation of the spectral fluence $\Phi(E)$ **emitted electron**
- Filling the "**beam-data in water.xls**" with calculated data and information about the source
- Provide the **dose/emitted-electron** value at 10 cm depth. This value will be used in task II for normalisation.

IV) Detailed Description of Task2

In the second task, using the parameters of the source determined in the first task, you are asked to calculate the relative absorbed dose in water, including tissue equivalent heterogeneities. As explained earlier, the depths for the calculation are expressed in **cm**. Nevertheless, for the comparison with the measured data (obtained in water only since the heterogeneities are made with solid phantoms), the comparison will be performed with the depth expressed in g/cm^2 in order to be able to compare the results with the "only water" case.
It is also highly recommended (see task I) to use the same position of calculated and measured data so that Xe=Xr. Positions are provided in "PDD and profiles in heterogeneities.xls" file.

Four configurations are proposed that include solid phantoms placed in the water phantom (see file **"heterogeneities.pdf"**).

A) lung only
B) bone only
C) bone and lung
D) two lungs

For each configuration the requested information are the following :
- cases A) to C) : PDD
- case D) : profiles (-10 cm to +10 cm) at 22 and 25 cm depth.

You are asked to provide for each result the absolute uncertainty. More information is given in the file "**PDD and profiles in heterogeneities.xls**".

<u>Very important note about the normalisation of the results:</u>
In order to compare the results obtained by calculation with the experimental data two important things are to be taken into account. The first is related to the fact that the depth in water is expressed in cm but automatically converted into water equivalent depth in g/cm^2 in the excel file as already mentioned. The second aspect is related to the normalisation of the results.

- For the cases A) to C) the results are given as the ratio of the dose/emitted-electron in heterogeneous case to the dose/emitted-electron at 10 cm depth on the central axis beam in the reference case (Task I).

$$\mathbf{PDD(z) = \frac{Dose(z)\ heterogeneous / emitted\ electron}{Dose(10cm)\ homogeneous / emitted\ electron}}$$

- for the case D), profiles are normalized to the central axis but not to unity. The central axis value is equal to PDD (z_1 or z_2) :

$$\mathbf{PDD(z1\ or\ z2) = \frac{Dose(z1\ or\ z2)\ heterogeneous / emitted\ electron}{Dose(10cm)\ homogeneous / emitted\ electron}}$$

In other words, for the case D), calculate the profiles at z1 and z2 are normalized on the central axis to the value of PDD(z1 or z2).

Note : The expression "**per emitted electron**" means also "**per electron hitting the Titanium window**" and if the electron source is oriented directly to the Titanium window, it is also similar to "**per starting particle**".