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Application of the MCNP5 code to the Modeling of vaginal and intra-uterine applicators used in intracavitary brachytherapy: a first approach

I. Gerardy[2], J. Rodenas[1], M. Van Dycke[3], S. Gallardo[1], F, Tondeur[2]

[1] Departamento de Ingeniería Química y Nuclear, Universidad Politécnica de Valencia, Apartado 22012, E-46071 Valencia (Spain)

[2] Institut Supérieur Industriel de Bruxelles, 150, Rue Royale, B-1000 Brussels (Belgium)

[3] Clinique Saint Jean, Bld du Jardin Botanique, B-1000 Brussels (Belgium)

gerardy@isib.be

Abstract. Brachytherapy is a radiotherapy treatment where encapsulated radioactive sources are introduced within a patient. Depending on the technique used, such sources can produce high, medium or low local dose rates. The Monte Carlo method is a powerful tool to simulate sources and devices in order to help physicists in treatment planning. In multiple types of gynaecological cancer, intracavitary brachytherapy (HDR Ir-192 source) is used combined with other therapy treatment to give an additional local dose to the tumour. Different types of applicators are used in order to increase the dose imparted to the tumour and to limit the effect on healthy surrounding tissues. The aim of this work is to model both applicator and HDR source in order to evaluate the dose at a reference point as well as the effect of the materials constituting the applicators on the near field dose. The MCNP5 code based on the Monte Carlo method has been used for the simulation. Dose calculations have been performed with *F8 energy deposition tally, taking into account photons and electrons. Results from simulation have been compared with experimental in-phantom dose measurements. Differences between calculations and measurements are lower than 5%.The importance of the source position has been underlined.

1. Introduction.

In multiple cases of gynaecological cancer, vaginal or intra-uterine, the use of brachytherapy techniques in combination with other treatments provides an additional dose to the tumour. Those treatments are mainly based on external radiotherapy using photons provided by linear accelerators. In high dose rate (HDR) techniques, the source (i.e. Ir-192) produces a high local dose rate with a high spatial dose gradient. Different applicators can be used depending on the localization of the tumour in order to guide the source into the patient. These devices allow to increase the dose to the tumour while the exposition of the healthy tissues is limited. Materials constituting applicators are mainly stainless steel and polymer.

The treatment should deliver an accurate dose to the tumour. Therefore, it is necessary to estimate as exactly as possible the dose rate produced by the source into the body. The influence on the delivered dose of both source and applicator materials should also be analysed. The Monte Carlo method is a powerful tool to simulate sources and devices in order to help physicists in treatment planning.

In the present work, both applicator and HDR source have been modelled using the MCNP5 code to simulate the irradiation process. In order to validate the model doses have been calculated at a reference point and results have been compared with experimental measurements performed in a water phantom using an ionization chamber.

2. Instrumentation and method.

The MCNP5 [1] code based on the Monte Carlo method has been used for the simulation of the source, applicators and dosimetric devices. The source considered in this work is an HDR Ir-192 Microselectron of Nucletron

2.1. Modeling of the source and anisotropic function evaluation.

A model of the source including its capsule and guiding cable has been developed. In order to validate it, an anisotropy function has been evaluated using different MCNP tallies: fluence (F2) and energy deposition (F6, *F8**)** at different distances (1, 2, 4, 5 and 10 cm) of the source centre and different angles relative to the cable (from 0º to 180º by steps of 15º)**.** For MCNP calculations, 10^9 particles have been launched and energy cutoff has been set to 1 keV for photons, and 20 keV for electrons. Results obtained have been compared with data from literature [2, 3]. A first evaluation for this kind of source was performed in a previous work [4].

2.2. Modeling of the applicator.

An applicator is used for the right positioning of the HDR source and for the protection of healthy tissues. The applicator consists in two parts: an intra-uterine tube and a vaginal applicator. The intra-uterine part consists in a metallic tube with a 15° inclination of the end part. The vaginal applicator is formed by two plastic cylinders of 2 cm diameter and 2.5 cm length. An evaluation of relative isodose curves around the source has been obtained using the F4MESH tally of MCNP5. In this calculation, the fluence (F4) has been evaluated in a 4 cm side cube divided into 5 mm length voxels, the source being in the centre of the cube. A sensitivity analysis of the dose evaluation, taking into account the geometrical uncertainties of the source position into the tube, has been performed. An uncertainty of 1 mm in the length of the guiding cable as well as the maximal radial movement of the source into the intra-uterine tube (±0.5 mm) have been considered.

2.3. Comparison between MCNP evaluation and experimental measurements.

The global model has been validated by comparing results from the simulation using MCNP5 and experimental measurements, which have been performed in a water phantom using a RK-8305 0.12 cc ionization chamber from SCANDITRONIX. The chamber has been calibrated by comparison (in air) with a NE2571 chamber, calibrated and certified for Ir-192 by the manufacturer. The phantom is a 30 cm side cube contained in a Plexiglas box of 1 cm thick walls. Four different positions of the source into the intra-uterine tube have been considered in order to minimize the dependence of the source position. Position 1 is shown in the figure 4. The other positions have been obtained by moving the source 5 mm towards the vaginal applicator. Finally, a source train of 20 mm is measured instead of a single 3.5 mm source. Doses have been evaluated through the energy deposition tally *F8 of MCNP5.

3. Discussion and results.

3.1. Anisotropy function evaluation.

The source model is represented in figure 1. This model has been validated by calculating anisotropy functions.

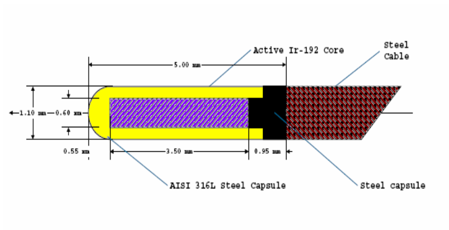

Fig. 1 Source model

The values obtained for different tallies (F2, F6 and *F8) show a good agreement with Williamson's data [2] and with Sharma's measurements [3] as it can be seen in figure 2 for the 1-cm distance, which represents the less favourable case. Differences never exceed 4% and they are located at extreme angles. These differences with Williamson's data could be attributed to differences in material composition for the cap side (316L stainless steel used in our case instead of 304) and to differences in material density on the cable side (5.28 g/cm³ in our study, 8.02 g/cm³ in [2])

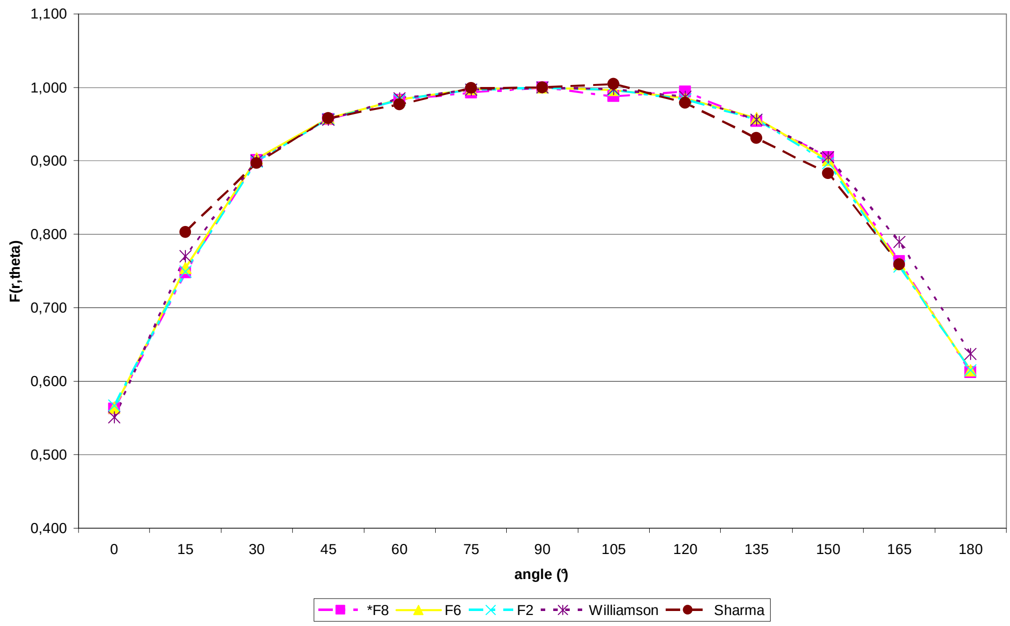

Fig. 2 Anisotropy function

3.2. Model of the applicator.

A view obtained with the SABRINA code [5] of the gynaecological applicator as well as the ionization chamber (small blue cylinder) can be seen in figure 3 while figure 4 represents a zoom showing the positioning of the source.

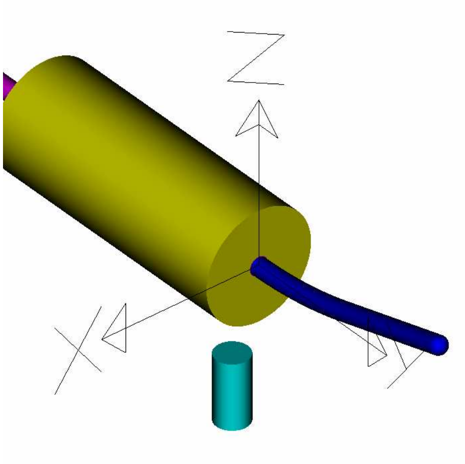

Fig. 3. Sabrina view of the applicator and ionisation chamber

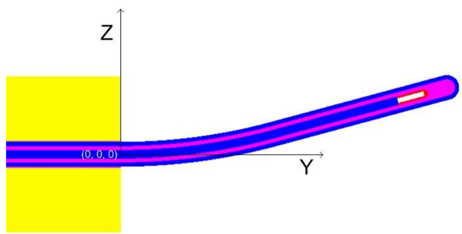

Fig. 4. Sabrina view of the source into the applicator (YZ plan at x= 0 source position 1)

In order to obtain a first view of the dose distribution and to check the suitability of the device, a set of isodose curves has been calculated for the position 1 of the source into the intra-uterine tube, shown in figure 4. Fluence values (MeV/cm^2) around the applicator have been obtained using the tally F4MESH. Handling these values with the MATLAB code [6] relative isodose curves can be plotted. Figure 5 shows isodose curves, in a logarithmic scale, in the XY plane that contains the center of the source cylinder. The X and Y values refer to the general axis system showed on figure 3. Some distortion observed in isodose curves can be attributed to the effect of applicator materials such as stainless steel.

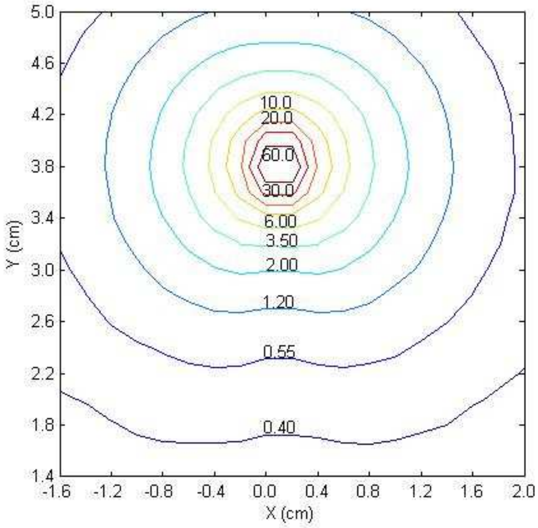

Fig. 5. Relative isodose curves (in %) around the applicator normalised in source centre

3.3. Sensitivity analysis.

A sensitivity analysis of the influence of geometrical uncertainties of the source position on the dose evaluation has been performed. The reference point for dose calculation has been located in the XY plane containing the axis of symmetry of the vaginal applicator, at 2 cm of the intra-uterine tube and 2 cm of the end of the vaginal applicator (see figure 3). This point represents the position of the ionization chamber in the water phantom. The scoring voxel has a volume (0.12 cc) equal to that of the ionisation chamber. 500 millions particles have been launched. Energy cutoffs for electrons and photons are the same as in the anisotropy calculation. At this distance, the maximum difference observed between results from dose calculations is about 8% (for a movement of 1mm of the source along the tube) while the uncertainty given by the MCNP code for the energy deposition calculation using tally *F8 is between 3 and 4 %. Therefore, this effect could be significant.

3.4. Comparison between simulation results and experimental measurements.

In order to validate the global model a comparison between results from the MCNP5 simulation and experimental measurements has been performed. Measurements have been performed in a water phantom using a RK-8305 ionization chamber. The final dose recorded by the ionisation chamber is the sum of partial doses given by each of the four positions of the source into the intra-uterine tube. This measurement sequence was repeated twice to improve the reproducibility of the obtained value. The values obtained were 75.0 and 75.5 cGy with the same uncertainty (1.5% given by the manufacturer). The reproducibility of both ionization chamber reading and source positioning (by the microselectron device) is within the predicted uncertainty [7].

The calculated value is a summation of results obtained from four MCNP runs, one for each source position, with 10^8 particles for each run; energy cutoffs being the same as above.

Calculated dose is 78.5 cGy (3 % uncertainty) while the mean value of measured dose is 75.25 cGy (1.5 % uncertainty), the difference being about 4%. Therefore, results of the applicator modeling are encouraging and it can be said that the model is good enough to continue the proposed research line.

4. Conclusions.

The MCNP5 code has been applied to simulate an HDR Ir-192 source and a gynaecological applicator used in intracavitary brachytherapy. Results of the simulation have been compared with experimental measurements performed using an ionization chamber.

Anisotropy functions calculated using different tallies, F2, F6 and *F8, show a good agreement with Williamson's data and Sharma's measurements for the HDR Ir-192 source considered. Discrepancies never exceed 4%. Therefore, the source model developed can be considered as being validated.

A sensitivity analysis of the influence of geometrical uncertainties of the source position on the dose evaluation show an effect that could be significant for the model developed; a great accuracy is necessary in the positioning of sources and measurement devices in order to permit a comparison between experimental measurements and MCNP simulations.

Small distortions can be seen in the isodose curves. They are attributed to the stainless steel constituting the applicator.

Finally, the comparison of estimated doses with experimental measurements shows discrepancies about 4%. Therefore, the developed global applicator model can be considered valid.

Acknowledgments

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