MONTE CARLO SIMULATION OF AN Ir-192 BRACHYTHERAPY SOURCE SPECTRA, GEOMETRY AND ANISOTROPY FACTORS USING GEANT4 CODE

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ABSTRACT

In brachytherapy cancer treatments, methods of calculation of dose delivered to tumours and organs have been continuously improved. The goal of calculations is the maximization of dose deposition in the target volume, while minimizing the deposition in the healthy tissues. The use of interstitial brachytherapy sources follows the recommendations of AAPM REPORT Nº 51. The present work is based on Monte Carlo simulations with GEANT4 code for the transport of subatomic particles in matter. This code incorporates a number of physical processes, presenting many important characteristics for medical applications, due to its precision in the treatment of geometries, materials, particle trajectories inside the volumes, particle fields, energy range, visualization of events, etc. Iridium–192 MicroSelecron HDR source was simulated and the geometry of dose deposition in media and primary spectra were obtained. Calculations also include photon-fluence distributions at two radial distances and accumulated air Kerma. A matrix of radial and angular coordinates was constructed, obtaining the Geometry Factor G(r,θ), the Anisotropy Function F(r,θ) and the Radial Dose Function g(r,θ) needed for dosimetry calculations, adopting the AAPM REPORT Nº 51 recommendations.

1. INTRODUCTION

Recently, many works in brachytherapy have studied the dose distributions around of radioactive sources. Monte Carlo codes, like MCNP and EGSnrc, was specifically constructed for to simulate the charge particles transport and the radiation interaction with matter, in energy levels used in medical physics.

The Geant4 Code [1], originally constructed for High Energy Physics experiments, has been used in many applications like Nuclear Physics, Medical Physics and Space Sciences, and
allowing simulation of low energy particles, it extended also to applications used in Medical Physics. In this work is presented the results from the simulation of a brachytherapy source using the Geant4 code. Was simulated an iridium-192 source MicroSelectron-HDR (high dose rate) model, used in brachytherapy, the mediums where the source deposit the dose (a water equivalent medium), the primary photons spectrum and was reproduced the photon-fluence spectrums to 5 cm of the source, the accumulated air kerma, the geometry Factor and the radial dose and anisotropy functions.

Results are presented according to the AAPM TG-43 dosimetric formalism [2]. The results of this study are also compared to previously published MC data for the MicroSelectron-HDR.

2. METHODS AND MATERIALS

2.1. $^{192}$Ir Brachytherapy Source

The model source studied in this work is the iridium-192 MicroSelectron-HDR, described by BORG, J. et al [3]. The source geometry was modeled by a cylindrical iridium core ($\rho = 22.42$ g/cm$^3$) surrounded by the encapsulation and cable of the source, both of the stainless steel ($\rho = 8.02$ g/cm$^3$). Fig. 1 (a) shows the actual geometry of the source and the fig. 1 (b) shows the model used in the Geant4 simulation.

![Figure 1](image.png)

Figure 1. MicroSelectron-HDR $^{192}$Ir source. a) Actual geometry b) Geometry used in the simulation.

2.2. Monte Carlo Simulation

Monte Carlo calculations were performed using the GEANT4 code [1]. The GEANT4 simulation toolkit is a C++ code that simulates the passage of particles through matter.

Photon interactions simulated in this work include the photoelectric effect, Compton scattering, pair production and Rayleigh scattering. In our simulation electron transport was
considered.

The longitudinal axis of the source was chosen as the polar axis. The origin of the system of coordinates is the center of the active source. For collection of particles generated in the source, two different geometries were defined. The first one, to collect particles of the bare Iridium spectrum and to calculate the photon fluence and kerma distribution, consists of a ring lying in a transverse plane to the source axis and centered in the origin. The second geometry of collection consists of concentric spherical shells, centered in the origin, each one 5 cm thick, to collect particles for the calculation of the geometry factor, radial dose and the anisotropy function.

Data analysis was done with the OpenScientist [4] package implementation of AIDA (Abstract Interface for Data Analysis) [5] for histograms and n-tuples construction. Visualization was done with the OpenInventor [6] package.

2.3. Determination of the Photon-fluence Distribution and Kerma

Fluence of photons was calculated in accordance with ICRU 60 formalism [7] in the distances of 5 cm and 10 cm of the source.

The accumulated air kerma was calculated at a distance of 5 cm of the source. The total Kerma for photon-fluence in discrete form was calculated in accordance with BORG, J. et al [3]

2.4. Determination of Geometry Factor, Radial Dose Function and Anisotropy Function

The linear source approximation geometry factor, \( G(r, \theta) \), was used for the calculations of radial dose function, \( g(r) \), and anisotropy function, \( F(r, \theta) \), according to the formalism proposed by AAPM TG-43 [2]

The source and spherical shells, mentioned above, are immersed in water. For the calculation of the absorbed doses, \( D(r, \theta) \), the medium was segmented in spherical shells with respect to radial distance, \( r \), and polar angle, \( \theta \). The segmentation with respect to \( r \) was performed, with \( \Delta r = 0.4 \) cm intervals, while all shells were split in 2° intervals with respect to polar angle \( \theta \).

The radial dose Function and anisotropy Function have their reference values for polar angle and radial distance \( \theta_o = 90^\circ \) and \( r_o = 1 \) cm, respectively.

3. RESULTS AND DISCUSSION

3.1. \( ^{192}\text{Ir} \) Source Simulation

Fig. 3, shows the visualization of the simulated source.
The fig. 4 shows the bare iridium spectrum, generated in the simulation.

3.2. Photon-fluence Distribution and Kerma

Fig. 5 shows the photon-fluence spectrum at 5 cm of the source and fig. 6 shows the result for the accumulated air kerma, both obtained in the Geant4 simulation and the results obtained by BORG, J. et al [3].
Figure 6. Accumulated air kerma at 5 cm of the source. The picture at right shows the BORG, J. et al [3] results and at left the results obtained in simulation.

3.5. Radial Dose Function and Anisotropy Function

Fig. 7 presents the results for radial dose function of the simulation compared to results of AAPM TG-43 [2] and fig. 8 present our simulation results for anisotropy function.

Figure 7. Radial Dose Function obtained with Geant4 and proposed for AAPM TG-43[2]
3. CONCLUSIONS

This work reproduced satisfactorily the Ir-192 geometry, bare spectrum and photon-fluence. The accumulated air kerma was also obtained according to BORG, J. et al [3]. A matrix of radial and angular coordinates was constructed. The Geometry Factor $G(r,\theta)$, the Anisotropy Function $F(r,\theta)$ and the Radial Dose Function $g(r,\theta)$ was obtained according to AAPM REPORT Nº 51 recommendations. The calculations are consistent with published results. The implementation of the phantoms tissue equivalents and attenuation interseed calculation is also foreseen.

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REFERENCES