Dosimetric Investigation of ^{106}Ru/^{106}Rh eye Plaque Brachytherapy model CCB Using GATE Monte Carlo Simulation

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Abstract

Knowledge of the exact dose distributions in tumor and each organ at risk is a critical matter in eye plaques brachytherapy for uveal melanoma treatment. In this regard, a simple water eye with a concave applicator, ^{106}Ru/^{106}Rh CCB manufactured by BEBIG were modeled using the GATE Monte Carlo simulation code. For validation purposes, the energy spectrum of ^{106}Ru/^{106}Rh and plaque central axis depth dose in the water phantom were calculated using GATE and compared with available data. Furthermore, the difference between the energy deposition in the water and eye material phantom has been evaluated. The results show an excellent agreement between our simulation results and available data. Moreover, the dose in the eye material phantom is approximately similar to that of the water phantom.

Keywords: ^{106}Ru/^{106}Rh, Eye plaque, Brachytherapy, Melanoma**,** GATE**.**

Introduction

Brachytherapy is an effective technique in clinical radiotherapy in which an encapsulated radionuclide as the radiation source is placed within or close to a tumor inside the patient's body [1]. One of the three kinds of uvea melanoma (choroidal, ciliary body, and iris melanoma) is choroidal melanoma which is the most common primary malignant intraocular tumor in adults [2]. Brachytherapy using removable ophthalmic plaques for the treatment of eye melanomas is a suitable superseded to enucleation, because of the ease of access and not expensive [3]. Brachytherapy with ^{106}Ru beta emitter eye plaques is the most common treatment for uveal melanomas with small to medium size. On the other hand, the Monte Carlo method is generally used to investigate dose distribution around the eye plaques [4]. The purpose of this study was to validate the ^{106}Ru beta emitter eye plaque model CCB using GATE Monte Carlo code. Moreover, the variation of dose deposition in the water, as a standard medium, and eye material has been studied.

Source specifications

The ^{106}Ru is a β^- emitter source with maximum beta energy of E = 39.4 keV, with a half-life of $T_{1/2}$ = 368.2 d. This source decays to ^{106}Rh with $T_{1/2}$ = 29.80s, before decaying to ^{106}Pd (stable) with maximum beta energy of 3.54 MeV [4]. The ^{106}Rh beta spectrum used in the simulations was taken from ICRU Report 72 [5].

^{106}Ru/^{106}Rh applicator specifications

The ^{106}Ru/^{106}Rh beta emitter eye plaque model CCB simulated in this work, produced by the BEBIG Eckert & Ziegler BEBIG GmbH. The mathematical model of this plaque consists of an entrance window with a thickness of 0.1 mm and a layer on the back of the active layer (made of silver) with a thickness of 1 mm [6]. The CCB plaque (Figure 1a) was simulated in this study by use of the GATE 8.2 Monte Carlo code, as shown in Figure 1b.

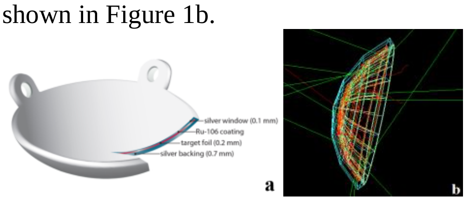

Figure 1. Schematic model of a CCB plaque (a) and simulated CCB plaque by GATE 8.2 code (b).

Monte Carlo simulation

In this work, simulations were performed using version 8.2 of the GATE (GEANT4 Application for Emission Tomography) Monte Carlo code. All GATE simulations were performed with the GEANT4 standard electromagnetic package. 2×10^8 electron histories were used to assure minimal statistical uncertainties for calculations.

Results and discussion

At first, the ^{106}Ru/^{106}Rh source was simulated as an isotropic point source centered in a spherical water phantom with a radius of 20 cm. Figure 2 shows a comparison of the ^{106}Ru/^{106}Rh energy spectrum in the water phantom, which is calculated by GATE code, with the data presentd by ICRU-72 [3]. There is a good agreement between our simulation results and ICRU data, with a the average difference about 2%.

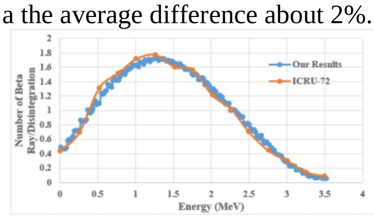

Figure 2. Energy spectrum of ^{106}Ru/^{106}Rh calculated using GATE.

To validate the results of dose distribution around the CCB eye plaque, a simple water phantom was simulated. The diameter of the eyeball was assumed to be 24 mm , and the plaque was placed in front of it. In the next step, a spherical eyeball with vitreous material was considered and the results were calculated.

Figure 3a shows the depth dose (DD) curves along the central axis direction of the plaque. In this figure, our results are compared to the data obtained by Mostafa et al. [3]. According to the results, there is a good agreement between our simulation results for DD of CCB eye plaque and previously reported data, with a mean difference of 3%.

Figure 3b shows the percent DD curve for the concave CCB eye plaque in both water and eye material phantoms (without the presence of the tumor). The material compositions of eye have been taken from Asadi et al. study [7]. In this Figure, results were normalized to the dose value at 1 mm depth. These results show an agreement between the two sets of data for all the points. Based on the similarity between the elemental composition of the vitreous body and water, it is clear that the dose in the vitreous is approximately similar to that of the water. The average difference between results is about 10%

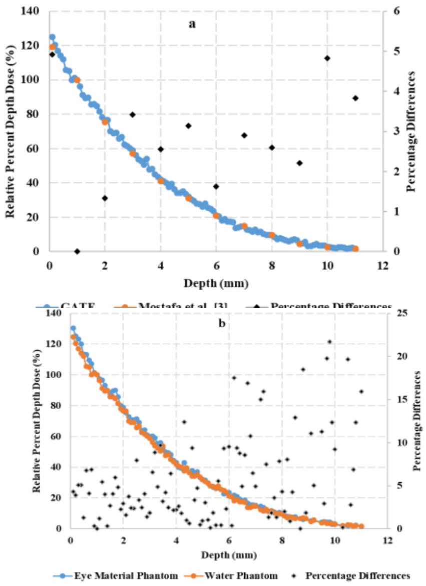

Figure 3. Comparison of the plaque central axis DD in the water phantom (a), The plaque central axis DD curves in the water and the eye material phantom (b).

Figure 4 presents the central cross-section of the eye phantom, for a CCB eye plaque. As shown in this Figure, the maximum dose is distributed within the base of the phantom, and with increasing the distance from the center of the plaque, the dose distribution decreases rapidly.

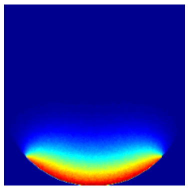

Figure 4. Central cross-section of the eye phantom

Conclusions

In this study, a CCB β^- emitter eye plaque was simulated and a water phantom was used to investigate the dose distribution around the plaque. the $^{106}Ru/^{106}Rh$ energy spectrum was verified by simulating a combined $^{106}Ru/^{106}Rh$ and compared with these offered by the ICRU-72. The percent depth dose curves along the central axis direction of the plaque, was determined and compared to the results presented by others. Results showed good agreement with values specified by the Mostafa et al. simulations. Furthermore, based on the similarity between the elemental composition of the vitreous body and water, the dose in the vitreous is approximately similar to that of the water.

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