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Estimation of Energy Spectrum and Energy Deposition of Photons Emitted from Brachytherapy ^{125}I Seed

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Abstract

Objective: The objective of the current study was to estimate the energy spectrum and energy deposition of the photons emitted from ^{125}I seed model 6711 with and without the presence of titanium capsule using Monte-Carlo N-Particle code (MCNP) in order to investigate whether the titanium capsule attenuates photons and how much would be the attenuation. **Materials and Methods:** Two models were built and simulated using MCNPX code, in the first model, the simulation was performed assuming the geometry of ^{125}I seed provided by the manufacturers. Whereas in the second model, the simulation was performed assuming that ^{125}I seed without titanium encapsulation. For both models, the energy and energy deposition of the photons were estimated. **Results:** MCNPX computations showed that the energy spectrum released from ^{125}I seed with the presence of the capsule was lower than that released without the presence of the capsule for all energies in the spectrum by approximately 19 %. Further, the energy deposition computed with the presence of titanium capsule was lower than that computed without the presence of titanium capsule by nearly 31%. **Conclusion:** The titanium capsule has an impact on the energy spectrum as well as energy deposition of the photons emitted by ^{125}I seed. According to the MCNPX results, titanium capsule attenuates the energy and energy deposition of the radiation emerged from the seed by nearly 19% and 31% respectively.

Keywords: Brachytherapy, Energy Deposition, Energy Spectrum, 125I Seed, Model 6711, MCNP

1. Introduction

Interstitial brachytherapy using permanent radioactive implants is a common choice for most patients with prostate cancer[1-3]. Iodine-125 (^{125}I) has been widely used for permanent implants in prostate brachytherapy[2,4-6]. The advantages of ^{125}I over gold-198 and radon are; its lower photon energy results in requiring less shielding[2,5], and its longer half-life (59.4 days) makes it an appropriate for storage. However, the dosimetry of ^{125}I is more complicated than the conventional interstitial sources[5].

Iodine-125 seeds are classified according to the design of sealed radioactive sources[7]. Three commercial models of ^{125}I seed have been manufactured, which are 6701, 6702, and 6711. These models are similar in encapsulation and size but different in the design of active source[5]. In the current study, model 6711 has been selected to estimate the energy spectrum and energy deposition of the photons emitted from ^{125}I seed. The encapsulation of this seed composed of titanium tube of 0.05mm thickness welded at both ends to shape a cylindrical capsule which has outer diameter of 0.8 mm and length of 4.5 mm[5,7]. Model 6711 seed contains a silver rod (3 mm length) where ^{125}I is adsorbed on its surface[7-8]. Figure 1 shows the schematic diagram of ^{125}I seed model 6711.

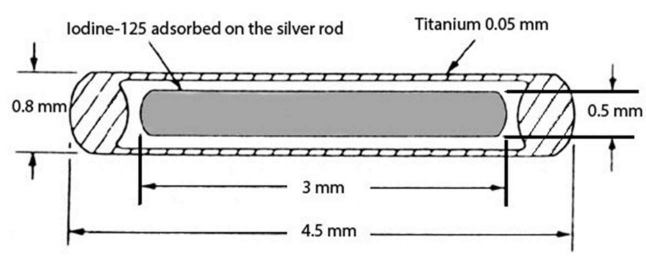

Figure 1. Schematic diagram of ^{125}I seed model 6711. The geometry of this figure is not drawn to scale. The information of this figure is derived from references[5,7,14].

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Iodine-125 is one of the man-made radioisotopes produced in the nuclear reactor. "^{125}I is produced mainly in a neutron activation process, through xenon-124 (^{124}Xe) gas target to give rise to ^{125}Xe. In turn, ^{125}Xe decays into ^{125}I by electron-capture (EC) transition. The half-life of the ^{125}Xe is 16.9 hours. ^{125}I also decays by EC into an excited state ^{125}Te*, producing the maximum photon energy of 35.5 keV by gamma decay (6.7% of the time) See Figure 2. In addition, the transition leads to characteristic x-rays of energy between 27.2 to 31.7 keV (K-shells) as a result of internal conversion (93.3%). Also, very low-energy x-ray of 3.8 keV is also possible (15%) but in practice very low energy photons are attenuated within the source capsule"[9].The production and decay processes of ^{125}I are shown in the equations below[9].

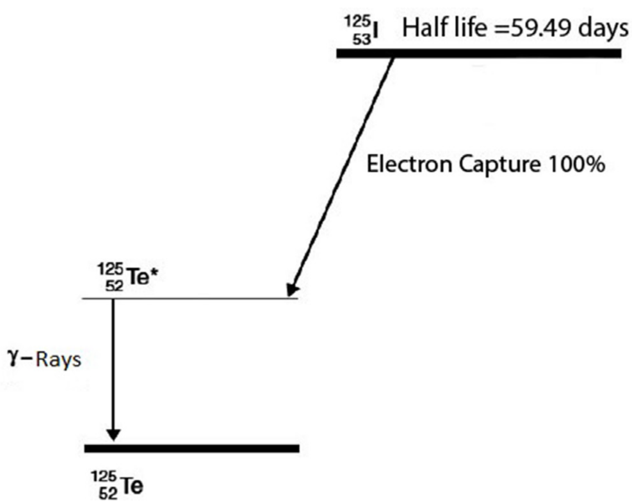

Figure 2. Decay scheme of ^{125}I. It was drawn according to the information from (6).

$$^{124}\mathrm{Xe} + {}^{1}\mathrm{n} \longrightarrow {}^{125}\mathrm{Xe} + \gamma \quad (1)$$
$$^{125}\mathrm{Xe} + {}^{-}\mathrm{e} \longrightarrow {}^{125}\mathrm{I} + \nu \quad (2)$$
$$^{125}\mathrm{I} + \mathrm{e} \longrightarrow {}^{125}\mathrm{Te}^{*} + \gamma\ (6.7\%) + \text{X-rays}\ (93.3\%) \quad (3)$$

Iodine-125 emits gamma and x-photons with spectrum of energies ranges from 3.3 to 35.5 Kev[10]. In ^{125}I seed used in brachytherapy, the radioactive source of ^{125}I is encapsulated by titanium material with a thickness of 0.05 mm[5,7], and so the photons released from ^{125}I source must pass through the titanium material before reaching the tissue. The current study was designed to estimate the energy spectrum and energy deposition of the photons emitted from ^{125}I source with and without the presence of titanium capsule using Monte-Carlo N- Particle code (MCNP) in order to investigate whether the titanium capsule attenuates photons.

2. Materials and Methods

2.1 Source Description

Iodine-125 seed model 6711 was used for MCNP simulations in the current study. Simple geometrical model of this seed was built according to the geometry of the seed provided by the manufacturers (See Figure 1) in which the design consists of a cylindrical core made of silver that has a length of 0.3 cm and diameter of 0.05 cm, onto which very thin layer of ^{125}I has been uniformly adsorbed. The silver core is encapsulated within a cylindrical titanium housing of diameter 0.08 cm, length 0.45 cm, and thickness 0.005 cm, with rounded titanium welds at each end. The space between the silver core and titanium capsule assumed to be filled with air. Physical properties of the materials used in ^{125}I seed are tabulated in Table 1.

Table1. Physical properties of ^{125}I seed model 6711components[2]

Material	Mass Density (g/cm^3)	Atomic Number	Physical State
Iodine (^{125}I)	4.933	53	Sold
Silver (Ag)	10.49	47	Sold
Titanium (Ti)	4.5	22	Sold
Air	0.00129	7.62	Gas

2.2 MCNP Simulation

MCNP simulation is a robust and beneficial technique in brachytherapy measurements. Currently, there are several versions of MCNP code exist; in the present study, MCNPX code, version 2.7.0 was utilized to estimate the energy spectrum and energy deposition of the photons emitted from brachytherapy ^{125}I seed used for prostate cancer treatment.

Herein, two models were simulated using MCNPX, the first model was implemented by assuming the geometry of ^{125}I seed as shown in Figure 1 with adding an imaginary air sphere with radius of 10 cm surrounds titanium capsule. Whereas the second model was performed by assuming that ^{125}I seed without titanium encapsulation (i.e. removing titanium encapsulation from ^{125}I seed), and also assuming an imaginary air sphere with radius of 10 cm surrounds silver cylinder. For both models, the energy spectrum and energy deposition of the photons were estimated at the surface of air sphere in order to investigate the impact of the encapsulation on the energy spectrum and energy deposition of photons emitted from ^{125}I source and how much would attenuate the photons. As it was mentioned earlier, ^{125}I emits photons of gamma and x-rays with a spectrum of energies ranges from 3.3 to 35.5 KeV, the very low-energy photons are attenuated within the capsule. Therefore, only photons with energies ranging from 27- 35.5KeV were included in the present MCNPX simulation. The photon energies used for the current simulation are listed in Table 2.

Table 2. The spectrum of ^{125}I energies included in MCNP simulation

Energy (MEV)	Weight (%)
0.0272	17.9245
0.0275	33.4681
0.0310	11.6352
0.0355	30.0090

In this current study, the source was supposed to have cylindrical shape with a radius similar to that of the silver rod because radioactive ^{125}I is adsorbed homogenously on the surface of cylindrical silver rod. Computationally MCNP F1 and F6 tallies were utilized to estimate the energy spectrum and energy deposition of the photons that are emitted by the ^{125}I seed.

3. Results and Discussions

MCNP code has many advantages that makes it suitable for use in brachytherapy field, for instance, it can transport the electrons and photons in the range of energy from 1KeV-100 MeV, which is a very important feature because brachytherapy uses low energy sources. In addition, this code is able to model precisely the complex geometry of the sources used in brachytherapy[2]. Further, MCNP computations provide precise results because they simulate each physical process taking place inside the target. The number of simulated particles must be extremely large for the results to be statistically reliable[11].

In the current work, two models were simulated using MCNPX code, in the first model, the MCNPX simulation was performed assuming the geometry of ^{125}I seed shown in Figure 1. Whereas in the second model, the simulation was performed assuming that ^{125}I seed without titanium encapsulation (i.e. removing titanium encapsulation from the seed). For both models, the energy and energy deposition of the photons were estimated. The simulations of two models and their results are depicted in the next sections.

3.1 MCNPX Simulation to Estimate Energy Spectrum for Both Models of 125I Seed

F1 Tally was performed to estimate the energy spectrum of the photons emerged from ^{125}I source for two models (with and without titanium capsule). F1 Tally is beneficial for verifying conservation of the number of particles and conservation of energy[12]. It is measured in unit of MeV[13]. The energy spectra for both models were measured at the surface of the imaginary air sphere with radius of 10 cm that surrounds the ^{125}I seed.

The simulation results to estimate energy spectrum of the photons emitted from ^{125}I seed for both models are shown in Figure 3 which represents a comparison between the energy spectra computed for these models. As seen from this figure, the energy spectrum released from ^{125}I seed with presence of the capsule was lower than that released without presence of the capsule for all energies in the spectrum. The data clearly shows that the titanium has an effect on energy spectrum emitted by ^{125}I source; it attenuates the energy spectrum by approximately 19 % in comparison with energy spectrum released from ^{125}I source and computed without titanium capsule.

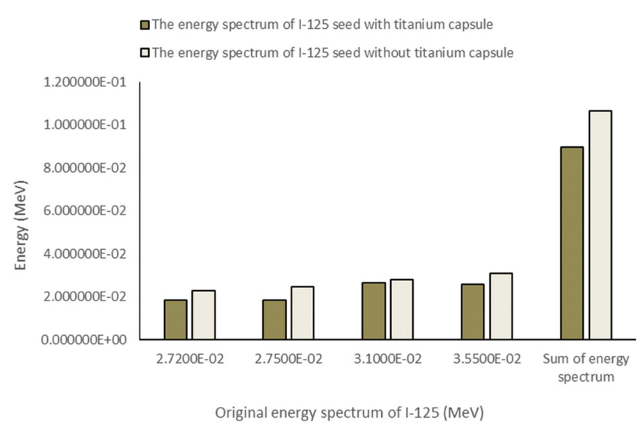

Figure 3. Comparison between the energy spectra of ^{125}I seed of two models (with and without titanium capsule).

3.2 MCNPX Simulation to Estimate Energy Deposition for Both Models of 125I Seed

F6 Tally was performed to estimate the energy deposition of the photons emerged from the ^{125}I source with and without passing through the titanium capsule. F6 tally is used to estimate energy deposition averaged over a cell and is measured in unit of MeV/g[13]. The energy deposition was measured at the surface of the imaginary air sphere with radius of 10 cm that surrounds the ^{125}I source.

The data was acquired to estimate energy deposition of ^{125}I seed with and without the presence of titanium capsule are plotted in Figure 4 which represents a comparison between the data of both models. It can be seen from this figure that the energy deposition computed with the presence of titanium capsule was less than that computed without presence of titanium capsule by nearly 31%. This result confirms that the titanium causes an attenuation to the radiation emitted from ^{125}I source.

The results of the current study indicated that the energy spectrum of the photons emitted by the ^{125}I source is attenuated by the titanium capsule as well as through the space between the source and the encapsulation. The present result could have a benefit in dosimetry and dose calculation and can be employed to calculate the absorbed dose accurately by taking in to account the attenuation of radiation by titanium capsule. However, more studies need to be performed to confirm the present results.

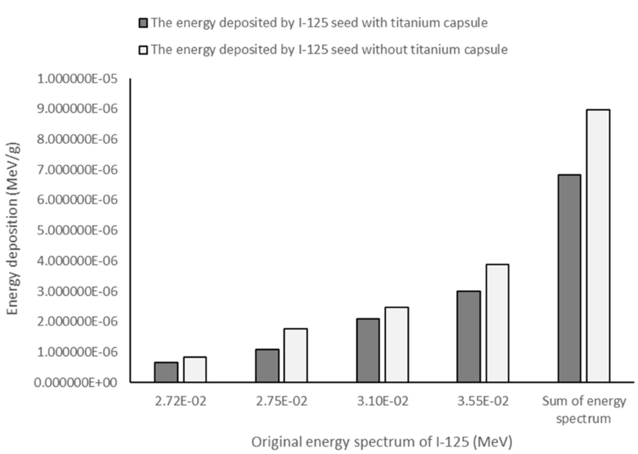

Figure 3. Comparison between the energy deposition of ^{125}I seed of two models (with and without titanium capsule).

4. Conclusion

The titanium capsule has an impact on the energy spectrum as well as energy deposition of the photons emitted by ^{125}I source. According to the current MCNPX results, titanium capsule attenuates the energy and energy deposition of the photons emerged from the seed by nearly 19% and 31% respectively. The percentage of attenuation occurred due to the titanium capsule should take into consideration when calculating the absorbed dose during the brachytherapy treatment using ^{125}I seeds.

5. Acknowledgements

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6. Author Disclosure Statement

The authors declare that have no conflicts of interest.

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