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Dose Study Utilizing Ag Containing Markers in ^{125}I Seed for Eye Brachytherapy

Osman Gunay[1], Roya Boudaghi Malidarreh,[2] Seher Polat[3], Vladimir Yurivich Ivanov[2], Parisa Boodaghi Malidarreh[4]*, Iskender Akkurt[5],

[1]Yildiz Technical University, Istanbul, Turkiye

[2]Institute of Physics and Technology, Ural Federal University, Yekaterinburg, Russia

[3] Institute of Physics and Engineering, Sakarya University, Sakarya, Turkiye

[4] Department of Computer Science, University of Texas at Arlington, Texas, USA

[5]Physics Department, Suleyman Demirel University, Isparta, Turkiye

* Corresponding Author: pboodaghi@gmail.com

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Abstract:

Background: *Radionuclide therapy (encapsulating beta or gamma radionuclides close to or inside the tumor) for ocular benign growth or malignant melanoma presents as an efficacious treatment modality in the realm of cancer management. This research endeavours to establish a comprehensive protocol for treatment of ocular malignancies, specifically employing iodine-125, (^{125}I) radionuclide. In this study, novel cylinder markers composed of Ag/Ag+Al_2O_3 were employed to assess the distribution of doses within the tumor region of an eye phantom;* ***Methods:*** *To scrutinize the dose distributions within the tumor, we conducted the study employing the FLUKA Monte Carlo (MC) Environment. In this work, the Ag marker in the ^{125}I new seed has been modeled at the center of the Titanium (Ti) coating;* ***Results:*** *By increasing the depth (distance from the source), the absorbed dose values decrease. These values in 1 mm drop from 1 cGy/h to 0.079 in a 10 mm depth.* ***Conclusions:*** *The obtained results validate the effectiveness of the MC method in eye plaque brachytherapy.*

1. Introduction

Ocular plaque brachytherapy, which employs small sealed radioactive seeds, is a modern therapeutic strategy employed for treating malignant melanoma and benign growths in simulated eye models. Originally conceptualized by Pierre Curie in 1901, brachytherapy serves as a primary modality in radiation therapy. This technique involves the permanent placement of radionuclides in close proximity to or within the tumor site. In accordance with guidelines established by the Collaborative Ocular Melanoma Study (COMS) [1], the choice of appropriate radionuclides is contingent upon factors such as tumor depth and dimensions. Radionuclides such as ^{103}Pd, ^{125}I, ^{137}Cs, and ^{192}Ir are considered suitable for treating medium- and large-sized tumors due to their specific characteristics. Conversely, radionuclides like $^{90}Sr/^{90}Y$ (developed in the UK), ^{90}Y (produced by LV company), and $^{106}Rh/^{106}Ru$ beta emitters are deemed suitable for smaller tumors, primarily due to their beta dose falloff properties [2-4]. Compared to external radiotherapy, brachytherapy, particularly when employing beta emitters, offers a more straightforward, cost-effective, and less invasive alternative that enhances radiation protection for both medical personnel and patients [5]. Moreover, brachytherapy demonstrates superior efficacy in sparing normal tissues. ^{125}I, characterized by a half-life of approximately 60 days and emitting photons with an energy of 27 keV, has garnered considerable attention among gamma 29the use of ^{125}I brachytherapy for pelvic, prostate, thoracic, head and neck, brain tumors, and cervix

treatment for both benign growth and malignant tumors. This development in ^{125}I brachytherapy has primarily been driven by a focus on optimizing dose delivery accuracy. In this method, the seed remains affixed until the requisite dosage is delivered to the target organs. It is noteworthy that the active core composition of ^{125}I seeds, which is characterized as Low Dose Rate (LDR) radionuclide, may vary among different manufacturers. Certain ^{125}I seeds incorporate the use of $Ag/Ag+Al_2O_3$ within their active cores. These compositions, when utilized as rods, serve as effective carriers for the ^{125}I radionuclide and are capable of generating dose maps comparable to those produced by conventional ^{125}I seeds. Various models such as COMS (consisting of 8 seeds with a diameter of 12 mm), OSU-Nag (with 8 seeds with a diameter of 16 mm), and ROPES (also comprising 10 seeds with a diameter of 15 mm), among others, manufacture distinct plaques for ^{125}I eye brachytherapy, featuring diverse seed configurations and spatial distributions. In this study, we opted to investigate the influence of marker compositions by exclusively simulating a single sealed ^{125}I radionuclide on top of the eye phantom-like product generated by the COMS company. Accordingly, ^{125}I seed has been simulated using FLUKA code and the FLAIR environment. The active core of the radionuclide consists of Ag and $Ag+Al_2O_3$ with different wt.%, and the effect of the provided active core has been estimated. This simulation tool has shown promise for medical use, specifically in the field of eye brachytherapy. The obtained results in this work have been validated with the data in previous literature [2-4].

2. Material and Methods

MC Codes are well-suited for full dosimetry of complicated physical processes, enabling the potential use of any devices in the preclinical stage. Their capacity for high accuracy and precision facilitates the establishment of correlation between input files and outcomes. Accordingly, in this work, ^{125}I seed utilizing FLUKA Monte Carlo simulation code, operating within the FLAIR graphical interface, has been simulated. This code proves adept at generating a comprehensive dataset necessary for the implementation of the treatment planning system [4, 6]. The detailed geometry encompasses the $Ag/Ag+Al_2O_3$ rod marker and ^{125}I radionuclides at the center of it, which are encapsulated with a Ti cylinder. The space between the marker cylinder and the Ti is filled with air. In addition, an eye phantom with realistic compositions has been simulated, encompassing a lens, an oval tumor at the corner of the vitreous, and its volume. The real compositions of an eye phantom have been derived from refs. 7, 8 (see Table 1). A schematic of the ^{125}I novel seed for melanoma treatment and an eye phantom with realistic compositions have been represented in Figure 1.

Table 1. *The elemental mass fractions of the vitreous and tumor in eye phantom [8,9].*

Elements	*Vitreous*	*Tumor*	*Lens*
H	*0.1109*	*0.0940*	*0.1010*
C	*0.0*	*0.2120*	*0.1110*
N	*0.0*	*0.0560*	*0.0262*
O	*0.8804*	*0.6150*	*0.7620*
Na	*0.0038*	*0.0025*	*00000*
P	*0.0*	*0.0051*	*00000*
Si	*0.0*	*0.0064*	*00000*
Cl	*0.0045*	*0.0039*	*00000*
K	*0.0003*	*0.0051*	*00000*
Density (g.cm^{-3})	*1.0071*	*1.0400*	*1.0500*

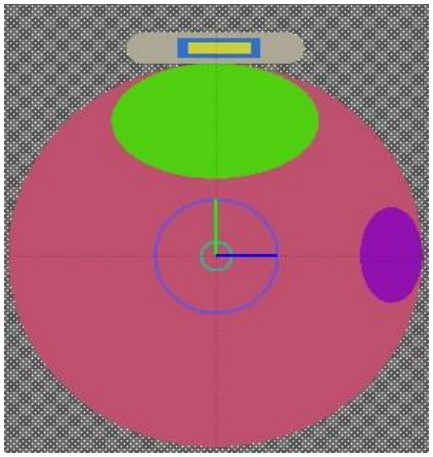

Figure 1. *The simulated ^{125}I seed and real compositions of an eye phantom encompassing lens (**purple**), tumor (**green**), and vitreous (**dark pink**) regions. Ti capsule (**gray**), $Ag+Al_2O_3$ (**blue**), ^{125}I (**yellow**).*

In an input file, extracting the absorbed dose, the AUXSCORE card has been used utilizing the

AMB74 library [6]. This configuration encompasses the entire eye phantom and source geometry. The start card specifies a total of 10^7 primaries. Additionally, 5 cycles are designated to execute the program, aiming to achieve minimal absolute errors within each energy range.

3. Results and Discussions

The dosimetric data in Figure 2 demonstrates the expected rapid attenuation of photon radiation from a brachytherapy source, governed by the inverse square law and medium interactions. The measured dose rate falls from 1.00 cGy/h at 1 mm to 0.079 cGy/h at 10 mm, consistent with geometric falloff. The notably steeper gradient within the first few millimeters is not solely due to distance but is significantly influenced by the proximal source geometry and filtration effects. In this region, the radiation field traverses multiple material boundaries—including the titanium capsule, any internal marker, and the surrounding medium—where photoelectric absorption and scattering are heightened due to the higher energy fluence and the transition between materials of differing density and atomic number. This compounded attenuation mechanism results in a more rapid initial dose reduction than would be predicted by distance alone.

But in comparison with the without-seed and this specific marker, there is no significant difference (Rivard et al.) [10]. It can be stated that a seed lacking a high-density marker provides a baseline dose profile that is unaffected by internal metallic components. This means the radiation field is shaped exclusively by the Ti encapsulation, free from the localized spikes or dips caused by high-atomic-number materials. As a result, the calculated dose at any distance aligns perfectly with established TG-43 reference data, offering a theoretically ideal and predictable distribution. However, this dosimetric purity comes at a significant clinical cost: the seeds are extremely difficult to visualize on standard postoperative imaging. This low radiographic contrast introduces substantial uncertainty in verifying their final positions, with potential localization inaccuracies exceeding 1-2 mm. Such positional errors can propagate into the dose calculation for the tumor, creating an estimated dose delivery uncertainty of 5-15%. Thus, the major drawback is not in the dose distribution itself, but in the inability to confirm with high precision where that dose was actually Administered.

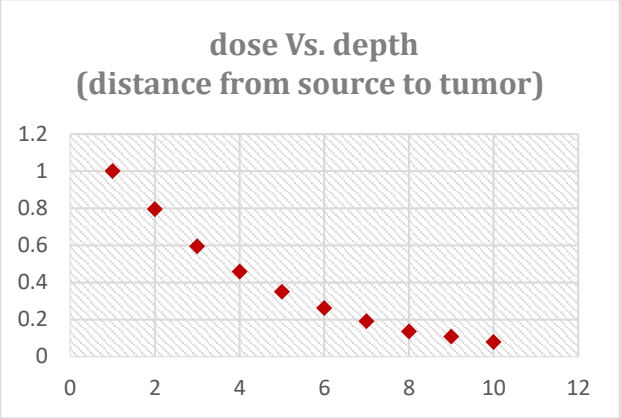

Figure 2. *Absorbed dose (cGy/h) versus depth (distance from source) in tumor region with irradiation of 0^0.*

The presence of a high-density marker induces a quantifiable, yet intensely localized, alteration to the radiation field. Computational modeling indicates that this component generates a sharp increase in absorbed dose of approximately 10-15% in the tissue immediately touching the marker (within 0.1 mm), a result of ejected photoelectrons. Conversely, it produces a modest reduction of about 5% in dose at a distance of 0.5 mm directly opposite it. These perturbations are, however, exceedingly limited in range. When considering therapeutic distances greater than 2 mm—particularly the standard 5 mm prescription depth for eye tumors—the aggregate influence of all seeds in a plaque on the total dose is clinically insignificant, falling below 0.5%. The principal advantage, therefore, lies not in modifying the therapeutic dose but in achieving superior imaging clarity. This allows for verification of seed placement with precision under one millimeter after surgery. Consequently, the margin of error in determining the actual dose received by the tumor is sharply decreased from a possible 5-10% range to a more reliable 1-2%, guaranteeing that the treatment delivered aligns accurately with the physician's original plan.

4. Conclusions

In conclusion, this work demonstrates that the integration of high-density silver-containing markers ($Ag/Ag+Al_2O_3$) within a novel ^{125}I brachytherapy seed for ocular plaques introduces only negligible dosimetric perturbations at clinically relevant distances. The primary and significant outcome is a dramatic enhancement in radiographic visibility, enabling sub-millimeter post-implant seed localization. This critical advancement reduces dose reconstruction uncertainty from a potential 5–15% to within 1–2%, thereby ensuring that the delivered

dose conforms precisely to the treatment plan. Thus, the design successfully reconciles the essential need for imaging fidelity with the strict requirement for dosimetric integrity in eye brachytherapy.

Data availability statement:

All data can be shared with journal.

Author Statements:

Not Applicable

Ethical approval:

The conducted research is not related to either human or animal use.

Conflict of interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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