Determination of Absorbed Dose To Water From Common Targeted Radionuclide Therapy Agents

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Introduction

- Targeted radionuclide therapy (TRT) has historically been used in primarily palliative treatments of metastatic diseases such as metastatic bone cancer[1].
- Recent developments, such as immune checkpoint inhibitor (ICI) therapy, have sparked renewed interest in using TRT to aid in curative treatments[2].
- Traditionally, high levels of dosimetric confidence are achieved in radiation therapy due to well established protocols, traceable calibrations to standards, and widely researched treatment planning system algorithms.
- Current dosimetry for TRT is largely based on injected activity and calculated through idealized biokinetic models such as OLINDA/EXM.
- Patient specific dosimetry is replacing traditional approaches through Monte Carlo simulation and kernel-based methods. There is a need to benchmark the accuracy of these techniques.

Aim

- This work aims to determine the absorbed dose to water from common beta-emitting radionuclide therapy agents (^{131}I and ^{90}Y) from a given injected activity in a custom phantom. Special attention is given to surface dose measurements and comparison to Monte Carlo simulations.

Methods

- Check source-sized phantoms were designed and constructed in-house for the purpose of obtaining surface dose measurements from liquid solutions of various short-ranged TRT agents.
- The disposable phantoms were constructed of a PMMA shell consisting of two needle compatible fill ports and fitted with a 7 µm thick polyimide window illustrated in figure 1.

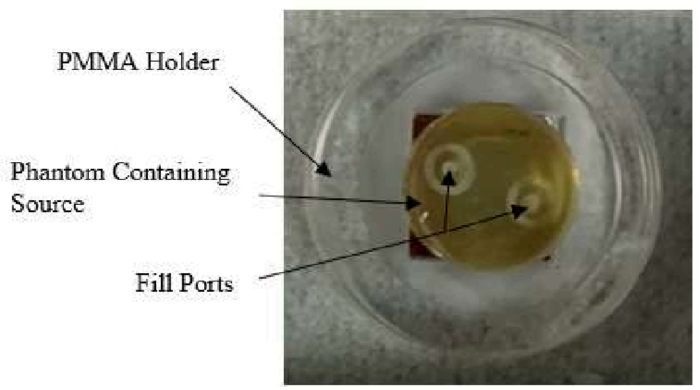

Fig. 1: Experimental setup with the phantom in the center, placed over a film and virtual water stack held in place by an acrylic holder.

- Unlaminated gafchromic EBT3 film (® Ashland Inc. Covington, KY) was chosen to measure absorbed dose to water near the surface of the phantom due to its exposed active layer, near water equivalence, and minimal attenuation of emitted betas. The film was cut into half-inch squares and calibrated for absorbed dose to water using a NIST traceable, 250 kVp x-ray beam
- Two separate ^{90}Y trials were conducted each using 5 phantoms with activities of 23.4 µCi for 26 hours and 25 µCi for 25 hours. Additionally, 5, 60 µCi solutions of ^{131}I were used to irradiate 5 film stacks for 51 hours.
- The setups for the two radionuclides varied slightly due to the difference in penetration between the higher and lower energy beta emissions.
- Change in net optical density (OD) of the film was measured using an EPSON EXPRESSION 10000 XL flatbed scanner and NIST OD filters for reference.
- Measured film doses were compared to decay corrected Monte Carlo simulations modelled in EGSnrc depicted in figure 2.
- The simulated source was modelled as an isotropically emitting volume source in the egs_chamber user code.

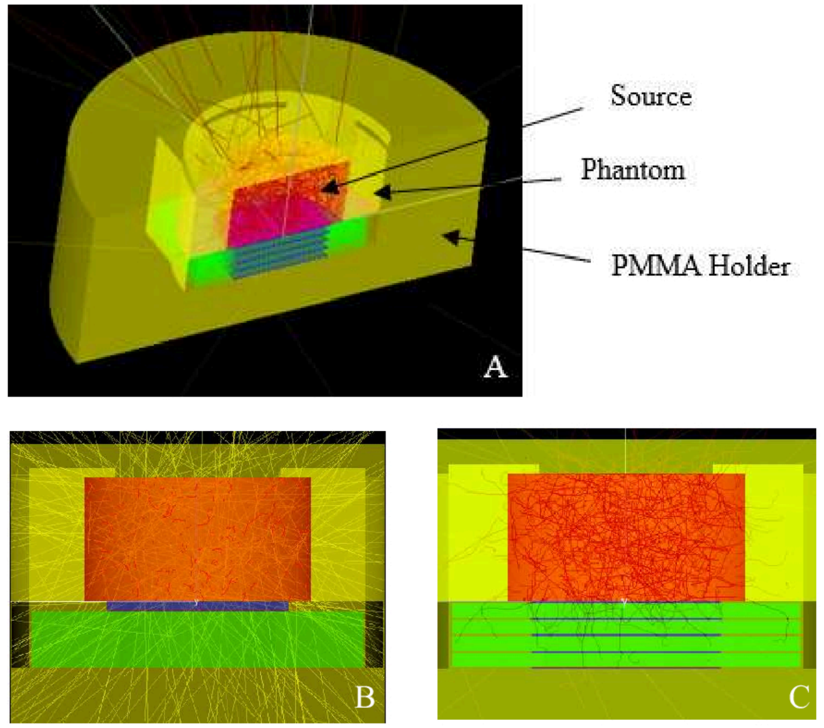

Fig. 2: (A) Screen capture of EGSnrc simulation. (B). Depiction of experimental setup for ^{131}I with film stack in blue and virtual water stack in green. (C) Depiction of setup for ^{90}Y. Film is represented in blue and virtual water in green.

Results

- Figures 3 and 4 show the absorbed dose to water vs depth measured from film and calculated through Monte Carlo simulation for ^{90}Y. Figure 5 shows the analogous depth-dose curve for the ^{131}I experiment.

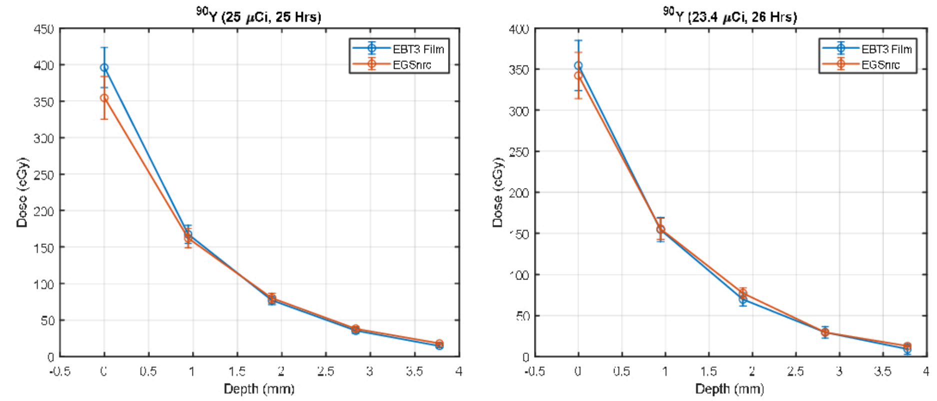

Fig. 3 and 4: Absorbed dose to water vs depth in film stack as measured by film and calculated via EGSnrc for ^{90}Y. Uncertainty bars represent calculated uncertainty at k=1.

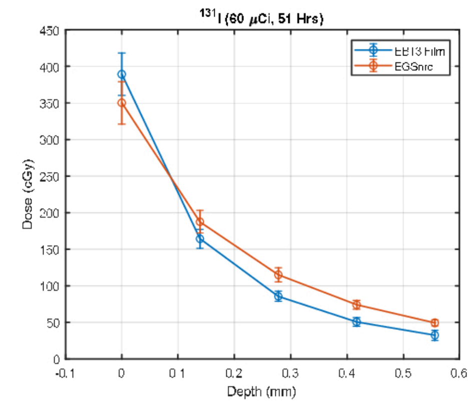

Fig. 5: Absorbed dose to water vs depth in film stack as measured by film and calculated via EGSnrc for ^{131}I. Uncertainty bars represent calculated uncertainty at k=1.

Uncertainty

- Uncertainty was calculated through incorporation of type A and type B uncertainties for both the EGSnrc simulation and the measured dose.
- Components of uncertainty evaluated for film measurements include standard deviation between corresponding pieces of film in each film stack, standard deviation of pixel values contained in the analyzed ROIs, positional alignment of film within the stack, and film calibration.
- Components of uncertainty evaluated for Monte Carlo simulations include statistical standard deviations, geometry uncertainties, and uncertainty in the actual injected activity contained within the source volume.

Conclusions

- Agreement between the measured absorbed dose to water from film and the calculated absorbed dose to water from EGSnrc simulations at the k=1 level can be seen in figures 3 and 4 at all depths for both trials conducted with ^{90}Y.
- Results from the ^{131}I experiment show agreement within k=1 uncertainty for the two measurements closest to the surface. The difference between the two curves falls out of agreement at depths beyond 200 µm.
- The lack of agreement between the two curves is believed to be caused by non-uniformity in the distribution of the ^{131}I within the source volume. This was likely caused by settling of the radionuclide due to the increased exposure time. Evidence of this effect was seen in the film samples through a non-uniform film optical density across the ROI.
- The experiments show good agreement between experimental measurements and Monte Carlo simulations. Despite this, further measures should be taken to assure uniform distribution of the radionuclide throughout the solution for the duration of the exposure.
- Future work will include refining experimental technique and analysis of more radionuclides used in TRT.
- The results show a promising foundation for future benchmarking of various Monte Carlo based TRT dosimetry and treatment planning systems.

Acknowledgments

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References

1. Lewington, V. Targeted Radionuclide Therapy for Bone Metastases. European Journal of Nuclear Medicine, 1993, 20, 66-74
2. Choi J, Beaino W, Fecek R, Kellsye F, Laymon C, Kurland B, Storkus W, Anderson C. Combined VLA-4-Targeted Radionuclide Therapy and Immunotherapy in a Mouse Model of Melanoma. Journal of Nuclear Medicine, 2018, 59, 1843-1849