Monte Carlo dose modelling of embedded beta/gamma emissions from DaRT alpha-emitters brachytherapy seeds using GEANT4.

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INTRODUCTION

This work presents dosimetric calculations of the dose distribution of embedded beta-emitters and isomeric transition emissions (gammas & internal conversion electrons) coming from diffusing alpha-emitters radiation therapy (DaRT) seeds.

MATERIAL & METHODS

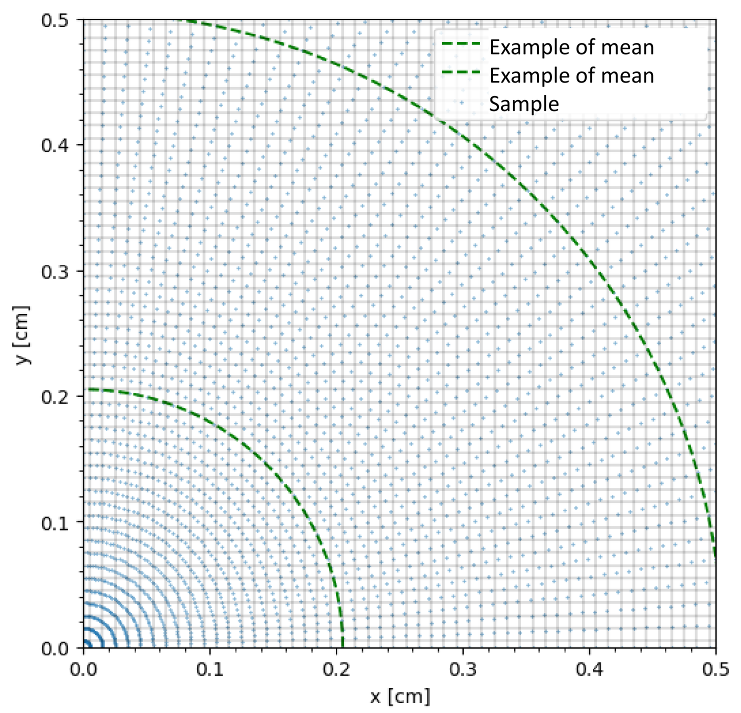

Figure 1: The blue dots represent the interpolated points of a slice in the Z direction. The green arcs are examples of how the 3D data is averaged over a 2D distribution.

- A DaRT brachytherapy seed of 1 cm was modelled using GAMOS[1], a GEANT4-based framework using a stainless-steel cylindrical geometry.
- The Radiactive Decay module from GEANT4 was used to generate daughter particles of ^{224}Ra ions, based on data from the Evaluated Nuclear Structure Data File (ENSDF).[2]
- Desorption probabilities of ^{220}Rn and ^{212}Pb were 0.38 and 0.5 respectively.
- An initial ^{224}Ra activity of 20 Bq (n = 9 million histories) was simulated explicitly and extrapolated to a clinically relevant activity of 111 kBq (3 µCi).
- 2D dose distributions deposited in the upper right quadrant of the seed were scored in a 2 x 2 x 2 cm^3 soft tissue-equivalent phantom with 0.1 mm voxels.
- Using the cylindrical symmetry of the seed, a mean 2D dose distribution (r, z) was obtained by averaging 360 dose distributions sampled from θ = 0° to θ = 179° using a bilinear interpolation.

RESULTS

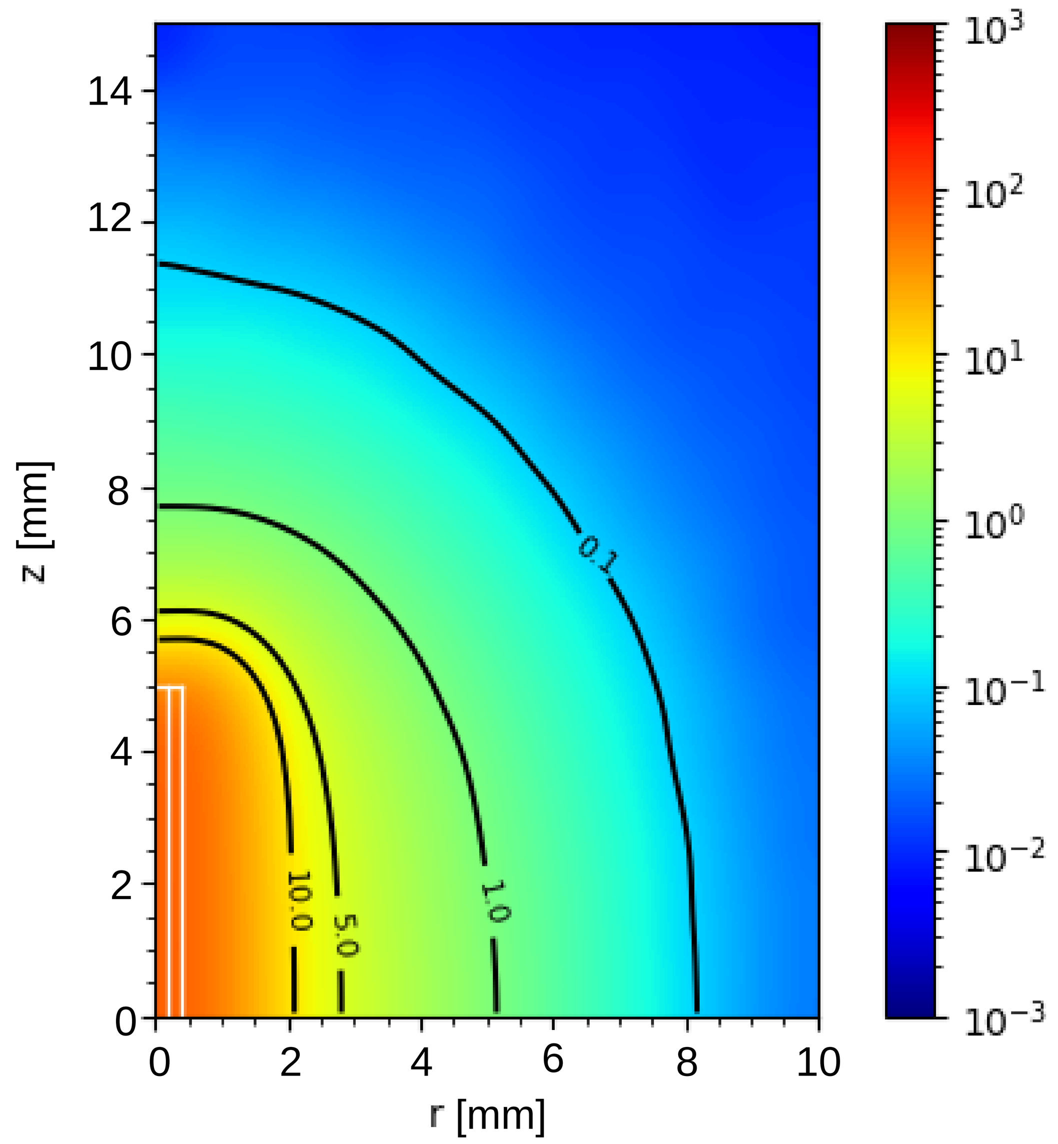

Figure 2: 2D (r, z) dose distribution from embedded beta-emitters and isomeric transition emissions for a single DaRT source (3 µC).

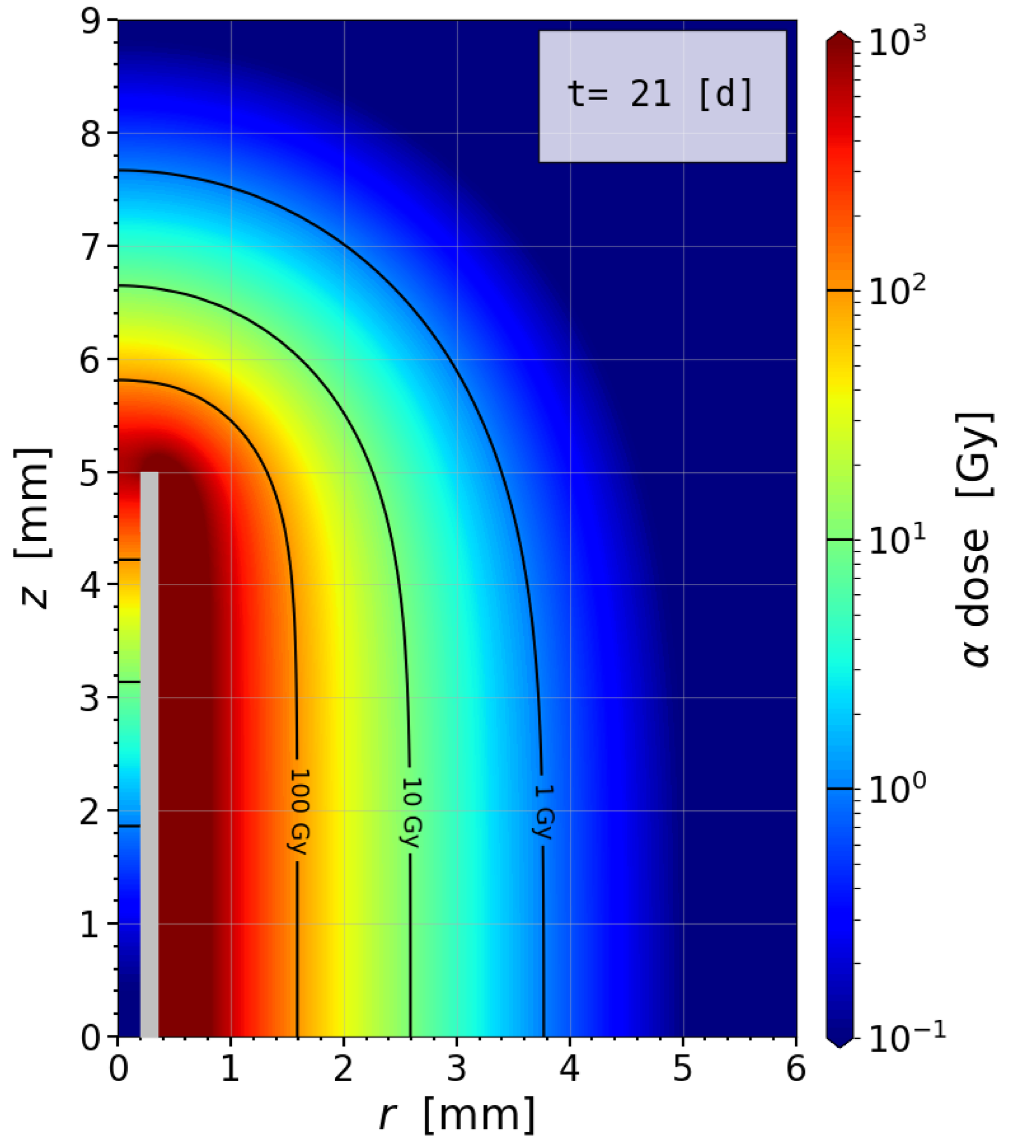

Figure 3: 2D (r, z) dose distribution from alpha-particles for a single DaRT source (3 µC).[3]

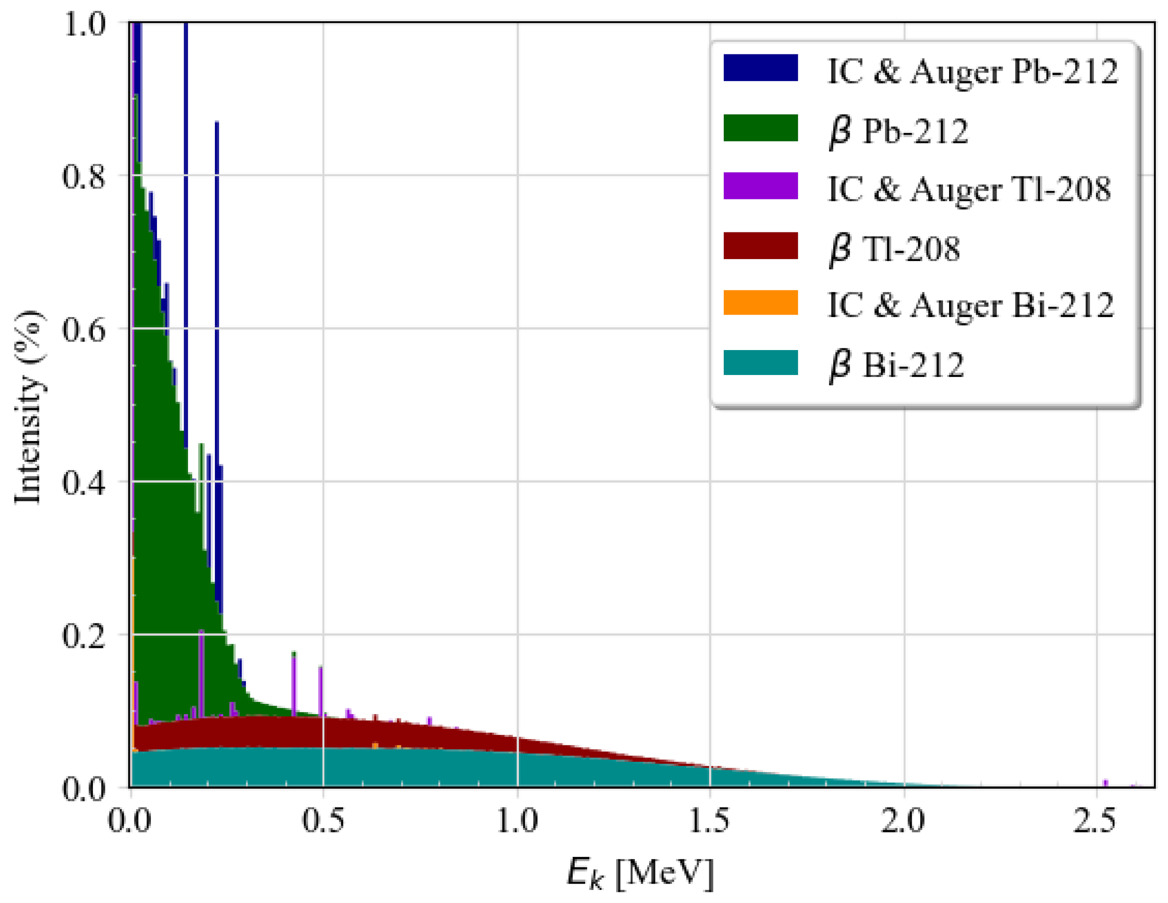

Figure 4: Energy spectra of electrons emitted by Beta decay, Auger and electrons from internal conversion from ^{212}Pb, ^{212}Bi and ^{208}Tl.

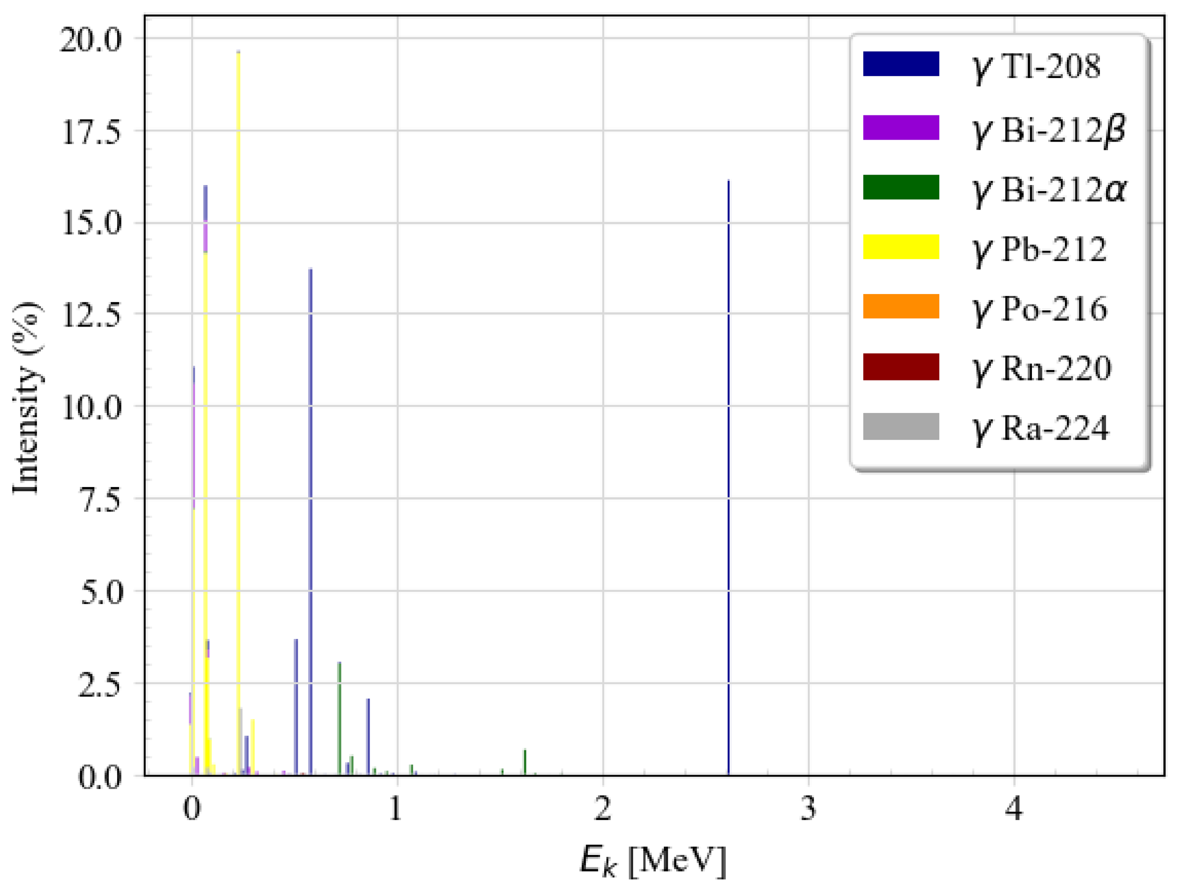

Figure 5: Energy spectra of gammas emitted from isomeric transitions by ^{224}Ra daughters.

DISCUSSION AND CONCLUSION

The appearance of the resulting isodoses were improved by smoothing them with a gaussian filter (σ = 4). A comparison was made against the dose distribution from the main diffusing alpha-emitters. Diffusing alpha-emitters contribute more significantly to the absorbed dose in the immediate vicinity of the seed with ~70 Gy (vs. ~10 Gy for embedded beta/gamma emissions) at a distance of r = 2.0 mm. However, their contributions become similar at a distance of r = ~3 mm (~5 Gy) and embedded beta/gamma emissions contribute more significantly to the dose further away with the 1 Gy isodose reaching a distance of r = 5 mm (vs. r = 3.8 mm for alpha-emitters) and 0.1 Gy at r = ~8 mm.

The electron spectra show that ^{212}Pb emits low-energy electrons, while ^{208}Tl and ^{212}Bi emit high-energy electrons. In the gamma spectrum, 15% of the spectrum is made up of photons over 2 MeV. These photons are not effective against the tumor, but can be used to verify the calibration of DaRT applicators.

In this work, we report dosimetric calculations of the dose distribution from embedded beta-emitters and their secondary emissions (gammas & IC electrons) coming from DaRT brachytherapy seeds. The total beta/gamma dose could be evaluated by summing the contribution from embedded emitters evaluated in this work to the contribution from diffusing emitters.

ACKNOWLEDGMENTS

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3. Chevé, P., Charbonneau, P., Carrier, J. F. and Kamio, Y. (2023) A finite volume approach to dosimetric calculations in diffusing alpha emitters radiation therapy. To be submitted.

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