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A dose kernel superposition approach for 2D lattice dosimetry of Alpha DaRT (^{224}Ra) sources

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INTRODUCTION

Diffusing alpha-emitters Radiation Therapy (DaRT) is an emerging brachytherapy modality that allows highly localized tumor cell killing using high-LET alpha particles from the ^{224}Ra decay chain. Accurate dose calculation for Alpha DaRT sources requires accounting for the spatial superposition of dose contributions from multiple implanted sources arranged in a regular lattice geometry [2]. In this work, we implemented a two-dimensional dose superposition algorithm for an array of Alpha DaRT sources based on a single-source dose kernel derived from GEANT4 simulations [2]. This approach enables an efficient evaluation of absorbed dose distributions for clinically relevant lattice configurations.

METHODS AND MATERIALS

We first consider an array of N parallel Alpha DaRT sources implanted in tissue. Let the coordinates of the i-th source axis be denoted by $R_i = (x_i, y_i)$. For an arbitrary point in the tissue, r = (x, y) and the radial distance from the i-th source axis is:

$$r_i = \| \mathbf{r} - \boldsymbol{R}_i \| = \sqrt{(\mathrm{x}-\mathrm{x}_i)^2 + (\mathrm{y}-\mathrm{y}_i)^2}$$

Let the radial dose distribution of a single Alpha DaRT source, calculated using GEANT4 Monte Carlo simulations, be described by a kernel function $K(r_i)$. Under the assumption of linear superposition, the total equivalent dose at the point r, resulting from all N implanted sources and M radiation components (i.e. alpha particles, beta particles, recoil nuclei, IC electrons, and secondary gamma rays), can be expressed as:

$$\begin{cases} K(r_i) = \sum_{j=1}^{M} RBE_j(r_i) \times D_j(r_i) \\ \mathrm{D_{TE}}(\mathrm{r}) = \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{w_i} \mathrm{K}(\mathrm{r_i}) \end{cases}$$

Where $K(r_i)$ [Gy] is the radial dose kernel of a single 1 cm source (obtained from GEANT4 calculations) calculated with a standard activity of 111 kBq, r_i is the radial distance between the point of interest and the i-th source, M is the total number of radiation components, N is the number of implanted sources, and w_i is the relative weighting factor for the i-th source. It is proportional to the initial activity of that source and is defined as the ratio of the activity of the i-th source to the kernel source activity (111 kBq).

RESULTS

To determine the radius at which the absorbed physical dose from alpha particles reaches 20 Gy, an isodose analysis was performed around a single Alpha DaRT source. Figure 1 shows the 2D isodose representing the spatial distribution of the alpha particle and the physical dose in the XY plane surrounding the source. From this analysis, the radius of the high-dose region exceeding 20 Gy is found to be R_{20} = 2.21 mm (or can be set to an equivalent dose 100 Gy for all emissions combined, R_{100} = 2.23 mm). This radius corresponds to half of the lattice spacing in a hexagonal arrangement of Alpha DaRT sources.

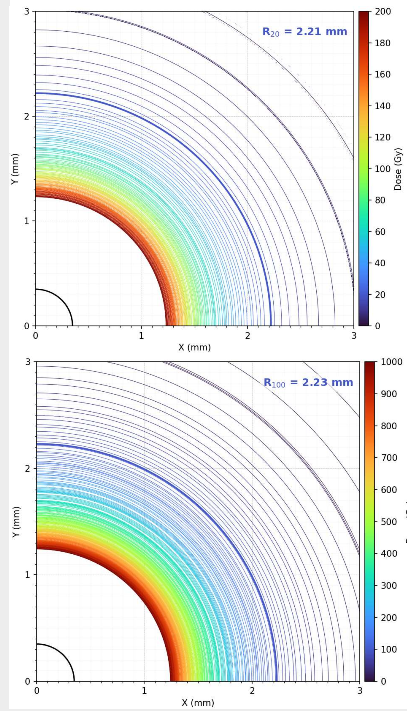

Figure 1: Two-dimensional isodoses representing the spatial distribution of the alpha particle dose surrounding a single source (up), for the total equivalent dose of all emissions (down).

Using this value of R_{20}, isodose curves were subsequently calculated for a hexagonal Alpha DaRT source lattice using reference diffusion parameters: L_{Rn} = 0.3 mm, L_{Pb} = 0.6 mm, P_{leak} = 0.5, $L_{Bi} = 0.1 \cdot L_{Pb}$, $P_{des}(Rn)$ = 0.45, and $P_{des}^{eff}(Pb)$ = 0.55. The resulting dose distributions for an array of Alpha DaRT sources with a lattice spacing of a = 4.4 mm are shown in Figure 2.

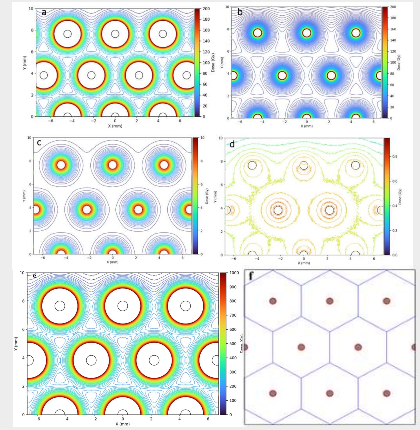

Figure 2: Maps of isodoses for a hexagonal Alpha DaRT source lattice with a lattice spacing of a = 4.4 mm: (a) alpha particles, (b) beta particles, (c) internal conversion electrons, (d) gamma rays, (e) total equivalent dose, and (f) the schematic of a hexagonal lattice geometry.

DISCUSSION

The results show that the 20 Gy alpha-particle threshold (R_{20} ≈2.21mm) serves as a key parameter for source arrangement. Using linear superposition of GEANT4-derived dose kernels, with a hexagonal lattice spacing of a=4.4 ($2 \times R_{20}$), provides effective dose coverage while accounting for the diffusion of ^{224}Ra progeny. Also, secondary emissions (beta, gamma, and recoil nuclei) contribute only marginally to the overall R_{100} radius. These findings support the use of R_{20} as a robust planning parameter for optimizing source geometry and minimizing cold spots within the tumor volume.

CONCLUSIONS

A two-dimensional dose superposition method based on a single-source dose kernel was developed to calculate absorbed dose distributions for arrays of Alpha DaRT sources. The analysis identified a 100 Gy-Eq isodose radius of R_{100} = 2.23 mm for the equivalent dose of all emissions from a single source, which corresponds to an optimal lattice spacing of 4.46 mm in a hexagonal source arrangement. Using reference diffusion parameter values, we demonstrated the algorithm's capability to compute dose distributions for multiple radiation components. This superposition approach enables near real-time dose calculation of Alpha DaRT lattice geometries, making it practical for clinical use.

REFERANCES

1. Heger G, Roy A, Dumančić M and Arazi L. Alpha dose modeling in diffusing alpha-emitters radiation therapy. Part II: Lattice studies *Med. Phys.* 2023; 50(3): 1812-1823.
2. Mowlavi AA, Kamio Y, Jia SB, Shamsabadi R, Carrier JF. Calculation of dose contributions from alpha particles, low-LET radiation and recoiled nuclei from an Alpha DaRT source (Ra-224) using GEANT4 including modeling of diffusion and leakage processes *Med Phys.* 2025; 52(8): 43.