Equivalent dose calculation using simulated RBE for alpha particles from an Alpha DaRT source (^{224}Ra)

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2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

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INTRODUCTION

The calculation of the equivalent dose in Diffusing alpha-emitters Radiation Therapy (Alpha DaRT) is highly influenced by the spatial dose distribution and the radiobiological impact of emitted alpha particles [1-3]. Current practice in clinical treatment planning systems is to use a constant RBE value of 5 for the alpha dose.

In this study, the spatial distribution of all ^{224}Ra decay products surrounding an Alpha DaRT seed was simulated while accounting for their diffusion in tissues. The resulting DNA damage and RBE associated with these decay products were quantified, to systematically evaluate their influence on appropriate seed spacing.

METHODS AND MATERIALS

We calculated the atomic fractions of each alpha emitter (^{220}Rn–^{216}Po and ^{212}Bi–^{212}Po) as a function of radial distance from an Alpha DaRT source. Based on the alpha energy spectra associated with these atomic fractions, the RBE for DNA double-strand breaks (RBE_{DSB}) and single-strand breaks (RBE_{SSB}) was evaluated as a function of radial distance from the Alpha DaRT source using Geant4-DNA track-structure simulations. DNA damage was classified based on energy deposition and strand-break proximity. Depositions > 10.79 eV in sugar or phosphate groups were scored as SSBs, while opposing SSBs within 10 base pairs (~3.4 nm) were defined as DSBs. Chemical stages were modeled using G4EmDNAChemistry-option3.

We evaluated how the atomic fractions of ^{220}Rn and ^{212}Bi vary with radial distance *r*. At any radius, these fractions are given by:

$$F_{Rn}(r) = \frac{N_{Rn}(r)}{N_{Rn}(r)+N_{Bi}(r)} \tag{1}$$

$$F_{Bi}(r) = \frac{N_{Bi}(r)}{N_{Rn}(r)+N_{Bi}(r)} \tag{2}$$

The alpha particle energy spectrum can then be calculated at any radial distance *r* using these atomic fractions.

RESULTS

Figure 1(a) shows the variation in atomic fractions of ^{220}Rn and ^{212}Bi with distance from the source *r*, assuming a ^{212}Pb leakage probability of $P_{leak}(^{212}Pb) = 0.5$. Figure 1(b) illustrates the calculated values of RBE_{DSB} and RBE_{SSB} as functions of radial distance, with values within $4.84 < RBE_{DSB} < 5.34$ and $0.83 < RBE_{SSB} < 0.92$, respectively. The results indicate that RBE_{DSB} values remain consistently high across all radial distances r (4.84 - 5.34, < 1% statistical uncertainty), converging to approximately RBE_{DSB} = 4.84 at distances beyond r = 3.60 mm from the source. These findings are in good agreement with the results reported by Ballisat *et al.* [3]. Figure 2 shows the radial profiles of the alpha particle physical dose and equivalent dose, defined as:

$$D_{Eq}(r) = D(r) \times RBE(r) \tag{3}$$

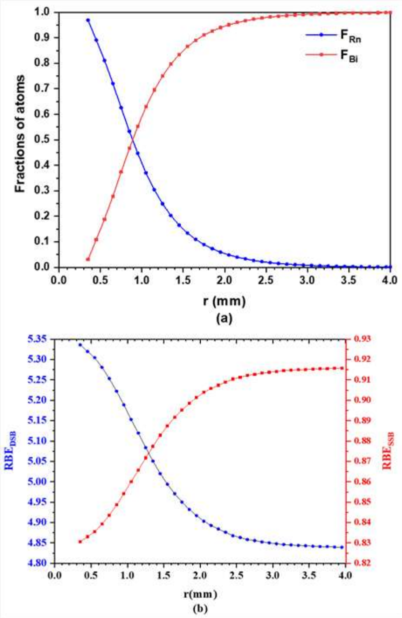

Figure 1: (a) Variation in atomic fraction of ^{220}Rn and ^{212}Bi as a function of radial distance *r* for $P_{leak}(^{212}Pb) = 0.5$, **(b)** Variations of RBE_{DSB} and RBE_{SSB} with radial distance from the source calculated using Geant4-DNA.

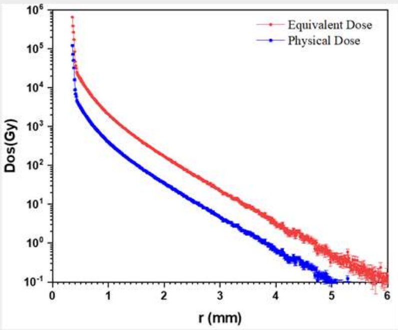

Figure 2: Radial profiles of the alpha particle physical dose and equivalent dose.

DISCUSSION

The results of Geant4-DNA track-structure simulations demonstrate that the RBE_{DSB} of alpha particles emitted from an Alpha DaRT source is a radially dependent quantity, varying from 5.34 to 4.84, rather than a uniform constant value. This variation is primarily driven by the radial diffusion of ^{220}Rn and ^{212}Bi, which alters the local alpha energy spectrum. Near the source, low-energy alpha particles maximize clustered DNA damage, peaking RBE_{DSB} at 5.34, but beyond 3.60 mm, RBE_{DSB} stabilizes at approximately 4.84.

Therefore, $RBE_{DSB}(r)$ for alpha particles emitted from a DaRT source should be considered a radially dependent function for equivalent dose calculations, rather than represented by a single fixed value of 5.

CONCLUSIONS

This study provides a framework for more precise modeling of the RBE of alpha particles in Alpha DaRT therapy. Incorporating $RBE_{DSB}(r)$ values into a dosimetric formalism based on TG-43 would significantly enhance the accuracy of clinical treatment planning based on equivalent dose calculations.

REFERENCES

1. Arazi L, Cooks T, Schmidt M, Keisari Y, Kelson I. The treatment of solid tumors by alpha emitters released from ^{224}Ra-loaded sources - internal dosimetry analysis. Phys Med Biol. 2010; 55(4):1203-1218.
2. Arazi L, Cooks T, Schmidt M, et al. First-in-human clinical trials with diffusing alpha-emitters radiation therapy (DaRT) for recurrent or unresectable skin cancer. *Int J Radiat Oncol Biol Phys.* 2021; 109(3):701-709.
3. Ballisat L, De Sio C, Beck LMG, Guatelli S, Sakata D, et al. Dose and DNA damage modelling of diffusing alpha-emitters radiation therapy using Geant4. *Phys Medica*. 2024; 121:103367.

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