Determination of Absorbed Dose to Water for the DaRT Brachytherapy Source in Monte Carlo

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Diffusing alpha-emitters Radiation Therapy (DaRT) is a ^{224}Ra brachytherapy source currently undergoing clinical trials in the United States for treatment of Squamous Cell Carcinoma (SCC). The source strength determination currently used for the DaRT source is activity-based, which has no direct correlation to energy deposition in tissue. Previous work has shown that a windowless extrapolation chamber can measure absorbed dose to water for alpha-emitting sources. Source preparation and geometry of the DaRT source does not permit use of a windowless chamber, because of the curvature and encapsulation of the source. This work shows preliminary work for an absorbed dose to water formalism for the DaRT source using Monte Carlo, shown in Table 1, using an extrapolation ionization chamber with a thin aluminized mylar entrance window. Future physical measurements with the DaRT source will validate this model.

For this work, the only correction factor investigated was k_{MC}, the Monte Carlo (MC) correction factor, shown in Table 2. The expected signal and the k_{MC} are the main determining factors in defining the geometry for these absorbed dose to water measurements. TOPAS was used to estimate signal and correction factor magnitudes for measurements of a 3 μCi DaRT source in a windowed extrapolation chamber geometry. Geometry optimization was performed by adjusting the size of the collecting electrode, source to mylar distance, mylar thickness, and distance between the mylar and collecting electrode (air gap).

Optimal correction factor magnitude was found for a 2 mm by 3 mm rectangular collecting electrode, 450 um source to mylar distance, 3 um aluminized mylar thickness, and 300-500 um air gaps. The expected signal output for this geometry and air gap distances is 2.87±0.22 pA. The magnitude and uncertainty in the Monte Carlo correction factors are shown in Table 2.

A method for measurement of absorbed dose to water for the DaRT source has been determined and optimized. An absorbed dose to water characterization would provide a much more clinically relevant quantity of source strength for the DaRT source. Future validations of this model and geometry will be done with physical measurements of an alpha-emitting brachytherapy source.

Table 1. Absorbed Dose to Water Formalism for the DaRT source with descriptions and equations for correction factors in a windowed extrapolation ionization chamber.

$$\dot{D}_{water} = \frac{\left(\frac{\bar{W}}{e}\right)_{air} \cdot \bar{S}_{air}^{water}}{\rho_0 \cdot A_{eff}} \cdot (I_{raw} \cdot \boldsymbol{k_{tp}} \cdot \boldsymbol{k_{pol}} \cdot \boldsymbol{k_{recom}} \cdot \boldsymbol{k_{elec}} \cdot \boldsymbol{k_{backscatter}} \cdot \boldsymbol{k_{div}} \cdot \boldsymbol{k_{window}} \cdot \boldsymbol{k_{vol}})$$

Correction Factor	Description	Equation
$\boldsymbol{k_{tp}}$	Temperature and pressure	$k_{tp} = \frac{273.2 + T}{273.2 + 22} \cdot \frac{101.33}{P}$
$\boldsymbol{k_{recom}}$	Initial and general recombination	$k_{recom} = \frac{1}{Q} = \left(\frac{1}{Q_{sat}} + \frac{\alpha}{V} + \frac{\beta}{V^2}\right) e^{-\gamma V}$
$\boldsymbol{k_{pol}}$	Polarity	$k_{pol} = \left\lvert \frac{M^+ - M^-}{2M^-} \right\rvert$
$\boldsymbol{k_{backscatter}}$	Backscatter from collecting electrode	$k_{backscatter}(l) = \frac{D_{vol,air,air}(l)}{D_{vol,air,copper}(l)}$
$\boldsymbol{k_{div}}$	Accounts for loss of particles as air gap changes in extrapolation	$k_{div} = \frac{D_{vol,air,air}(l \rightarrow 0)}{D_{vol,air,air}(l)}$
$\boldsymbol{k_{window}}$	Entrance window attenuation	$k_{window} = \frac{D_{vol,air,copper}(l)}{D_{vol,mylar,copper}(l)}$
$\boldsymbol{k_{vol}}$	Conversion from volume dose to point dose	$k_{vol} = \frac{D_{point,air,air}(vol \rightarrow 0)}{D_{vol,air,air}(l \rightarrow 0)}$

Table 2. Correction factors results for the windowed extrapolation ionization chamber at a fixed source to mylar distance.

Correction Factor	$\boldsymbol{k_{ion\ chamber}}$			$\boldsymbol{k_{MC}}$			
Air Gap (um)	$\boldsymbol{k_{tp}}$	$\boldsymbol{k_{recom}}$	$\boldsymbol{k_{pol}}$	$\boldsymbol{k_{backscatter}}$	$\boldsymbol{k_{div}}$	$\boldsymbol{k_{window}}$	$\boldsymbol{k_{vol}}$
300 µm	**Obtained During Physical Measurements**			1.002 (0.13%)	1.303 (0.14%)	1.073 (0.12%)	1.231 (0.91%)
325 µm				1.002 (0.13%)	1.331 (0.14%)	1.072 (0.12%)	
350 µm				1.002 (0.13%)	1.357 (0.14%)	1.072 (0.12%)	
375 µm				1.002 (0.11%)	1.384 (0.13%)	1.071 (0.11%)	
400 µm				1.002 (0.11%)	1.410 (0.13%)	1.071 (0.11%)	
425 µm				1.002 (0.11%)	1.438 (0.13%)	1.070 (0.11%)	
450 µm				1.002 (0.11%)	1.465 (0.13%)	1.069 (0.11%)	
475 µm				1.001 (0.11%)	1.491 (0.13%)	1.068 (0.11%)	
500 µm				1.002 (0.11%)	1.517 (0.13%)	1.068 (0.11%)	