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On the shape of the Task Group 43 anisotropy factor for linear brachytherapy sources at short distances

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ABSTRACT

PURPOSE: To investigate the peak shown by the American Association of Physicists in Medicine (AAPM) Task Group 43 1D anisotropy function at short distances from the source.

METHODS AND MATERIALS: The 1D anisotropy function of an ideal nonencapsulated photon linear source is calculated. A simple analytical model developed to evaluate the dose because of photon point−like sources has been applied. Previously, the model has been tested by comparing the values obtained for the various Task Group 43 dosimetric functions with those calculated with the Monte Carlo code PENELOPE for three different photon energies.

RESULTS: The model is able to reproduce the behavior of the 1D anisotropy function, describing the maximum that appears at a distance between 1 and 2 mm from the source. The reason for this behavior has been identified in terms of the contributions of the source activity inside and outside the scoring sphere.

CONCLUSIONS: Although it is not usually shown in reference data, this behavior should be taken into account for accurate dosimetric calculations.

Keywords: Photon dose models; Photon linear sources; Monte Carlo simulation; TG-43; PENELOPE

Introduction

Task Group 43 (TG-43) protocol (1, 2) defines the necessary physical quantities for brachytherapy dose calculations establishing both 1D and 2D formalisms. In the case of the 1D formalism, the anisotropy factor, also called 1D anisotropy function, $\phi_{an}(r)$, is considered. This is defined as

$$\phi_{an}(r) = \frac{\dot{D}_{ave}(r)}{\dot{D}(r,\theta_0)}, \quad (1)$$

where

$$\dot{D}_{ave}(r) = \frac{1}{2}\int_0^{\pi} d\theta \sin\theta\, \dot{D}(r,\theta), \quad (2)$$

is the solid angle weighted dose rate, averaged over the complete 4π steradian space; $\dot{D}(r,\theta)$ is the dose rate at the point (r,θ) and $\theta_0 = 90°$. Figure 1 shows the coordinate system.

In two recent works, it was pointed out that the 1D anisotropy function calculated for three ^{125}I sources, the 9011 and 6711 (both seeds; Oncura, a Unit of GE Healthcare, Chalfont St Giles, UK) (3) and the selectSeed (Nucletron, an Elekta company, Elekta AB, Stockholm, Sweden) (4), behaves at distances close to the source as shown in Fig. 2. In these works, two different procedures to determine $\phi_{an}(r)$ were used. Rivard (3) calculated $\phi_{an}(r)$ by integrating over solid angle, the dose rates obtained in a Monte Carlo (MC) simulation performed with MCNP5 (5). Juan-Senabre *et al.* (4) determined the 1D anisotropy function by calculating directly the spherical average dose rate in an MC calculation done with the PENELOPE code (version 2006) (6). As we can see, $\phi_{an}(r)$ presents a maximum at $r = 0.1$ cm, close to, but outside, the Ti capsule of the sources. However, this behavior is not indicated in the databases for dosimetry parameters currently available (7−9), in which the 1D anisotropy function is usually given for distances larger than 0.2 cm (from 0.1 cm in Ref. (9)). The first of these databases (7) includes the data obtained in various MC calculations performed by the authors, whereas the

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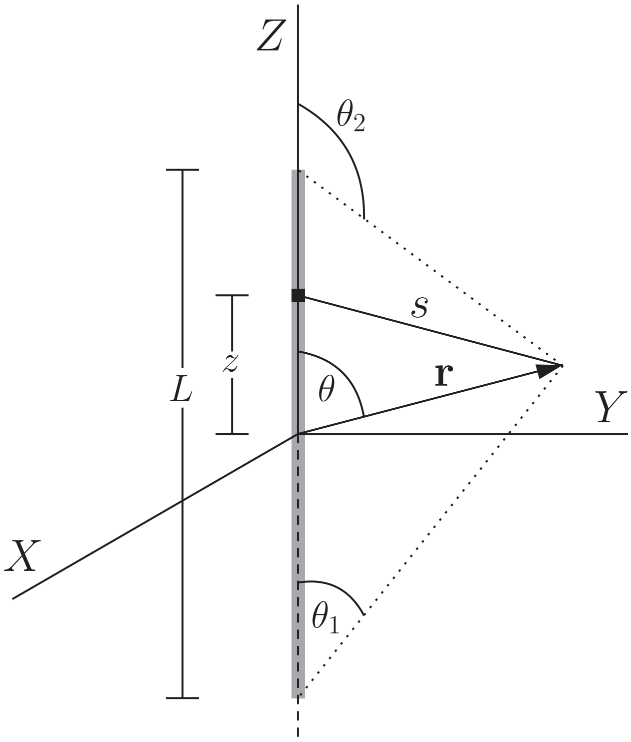

Fig. 1. Coordinate system for a one-dimensional linear source of length L located at the z-axis.

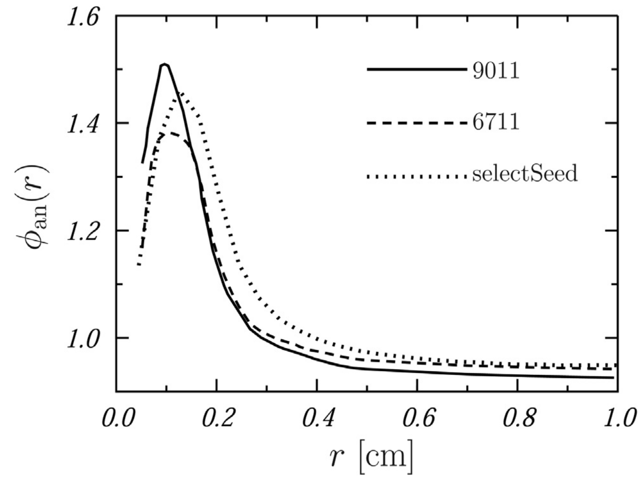

Fig. 2. 1D anisotropy functions, $\phi_{an}(r)$, corresponding to the ^{125}I sources 6711 and 9011 (Oncura-GE Healthcare), obtained by Rivard (3), and selectSeed (Nucletron, an Elekta company), calculated by Juan-Senabre *et al.* (4), as a function of the distance to the source center, r.

other two (8, 9) provide the AAPM recommended data from TG-43 (2, 10).

This work aims at investigating the reasons for this behavior of the 1D anisotropy function. To do that, a simplified ideal linear source emitting photons of different energies was considered. A statistical model developed in a previous work (10) to describe the dose because of a point source of monoenergetic photons embedded in a homogeneous medium was used for analyzing the r dependence of this factor. Besides, for checking the validity of the model, the dose deposited by the ideal source has been calculated by means of an MC simulation carried out with PENELOPE (6). In addition to $\phi_{an}(r)$, other dosimetry functions defined in the TG-43 protocol (1, 2), the radial dose $g(r)$ and the 2D anisotropy $F(r,\theta)$ functions, were also calculated for checking purposes.

Methods

The statistical model

In a previous work (11), the dose absorbed by a homogeneous medium from a point source of monoenergetic photons was described by means of simple functional forms that account for the energy deposited by unit length because of primary and scattered photons. These functions were obtained after applying a statistical model in which successive photon generations inside the medium were taken into account. Specifically, the energy deposited at a point situated at a distance s from the point source, per unit length and per initial particle, $e(s)$, is separated as

$$e(s) = e_0(s) + e_{sc}(s), \tag{3}$$

where $e_0(s)$ is the contribution of the primary photons emitted by the source, and $e_{sc}(s)$ labels the contribution of all the generations of scattered photons. The two terms in Eq. 3 were given by

$$e_0(s) = \begin{cases} A_0[1-\exp(-\mu_0 s)], & \text{if } s \le R_0 \\ A_0 \exp(-\mu_0 s)[\exp(\mu_0 R_0 - 1)], & \text{if } s > R_0 \end{cases}, \tag{4}$$

and

$$e_{sc}(s) = \sum_{k=1}^{2} C_k \left(\mu_k'\right)^{k+1} s^k \exp\left(-\mu_k' s\right), \tag{5}$$

where the parameters A_0, μ_0, R_0, C_k, and μ_k' were chosen to reproduce the results of MC simulations. Some of them have a physical meaning such as effective attenuation coefficients (μ_0 and μ_k') or an effective electron range (R_0).

Dose rate because of a photon linear source

We are interested in the 1D anisotropy function of an ideal one-dimensional photon linear source of length L embedded into a homogeneous medium and, as Eqs. 1 and 2 indicate, this requires calculating the dose rate $\dot{D}(r,\theta)$ produced by the source at a given point of coordinates (r,θ) (Fig. 1). Owing to the cylindrical symmetry of the problem, the dose depends on the distance to the source center $r \equiv |\mathbf{r}|$ and the polar angle θ. In addition, and because of the symmetry between θ and $\pi - \theta$, we restricted our calculation to the region $\theta \in [0, \pi/2]$.