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Determination of dosimetric characteristics for ^{125}I seed source with FLUKA code*

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This work determined a new Monte Carlo code (FLUKA) that can be used to calculate the dosimetric characteristics of seed sources. Dosimetric parameters (dose rate constant, radial dose function, and anisotropy function) of model 6711 ^{125}I seed source were calculated with FLUKA. The results were compared to the relative data recommended by AAPM TG43U1: dose rate constant with FLUKA was in agreement with 2.041%; radial dose functions with FLUKA for distances ranging from 0.5 cm to 10 cm, the deviation was less than 5%. Therefore the FLUKA code can be used to calculate the dosimetric characteristics of seed sources.

Keywords: FLUKA, Dosimetric parameters, ^{125}I seed source

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I. INTRODUCTION

The permanent implantation of ^{125}I brachytherapy sources has been used for treating cancer, particularly for prostate cancers. Due to their low-energy photon emission, the radiation dose is largely localized to the tumor, which reduces unnecessary radiation to the surrounding normal tissue. Radioactive seed implants can reduce the pain for patients. As a result, seed sources have became more and more widely used for treating cancer in recent years. In order to reduce the risk to surrounding normal tissue, it is important to evaluate the dose distribution of the seed source in a tumor. The dosimetric characteristics of a seed source can be used to evaluate the dose distribution. Developing an accurate and reliable method for calculating the dosimetric characteristics of a seed source is necessary. Recently, various Monte Carlo (M-C) codes have been used to calculate the dosimetric characteristics of seed sources, such as Cazeca *et al*. [1], Medich *et al*. [2], Saidi *et al*. [3] and Hosseini *et al*. [4], using MCNP5 to calculate the dosimetric characteristics of seed source. Reniers *et al*. [5] and Taylor *et al*. [6] used EGSnrc to calculate the dosimetric characteristics of a seed source. Ballester *et al*. [7] and Taschereau *et al*. [8] used GEANT4 to calculate the dosimetric characteristics of seed source, etc. MCNP is a business software and not an open-source program, so the use of MCNP is limited in some respects. EGSnrc is restricted in construction to the geometry model and GEANT4 is complex to use. So finding a free, open-source program, simple and reliable M-C code to calculate the dosimetric characteristics of seed source is necessary. The FLUKA code meets conditions above. FLUKA code is rarely used, so the main objective of this project was to calculate the dosimetric characteristics of 6711 Model ^{125}I seed source with FLUKA and to evaluate the applicability of FLUKA code to calculating dosimetric characteristics of seed sources.

II. MATERIALS AND METHODS

The diagram of the 6711 Model ^{125}I seed source is shown in Fig. 1. The physical length of the source is 0.45 cm and the outer diameter is 0.08 cm. The silver marker at the center of the source is 0.3 cm in length and 0.05 cm in diameter.

Phantom materials include the seed source, air, and water. Photon spectra for the ^{125}I seed source come from Ref. [9]. The densities of the materials used in this study are as follow [10]: Ag (density is 10.5 g/cm^3), Ti (density is 4.54 g/cm^3), dry air (density is 0.001 205 g/cm^3) composed of C (weight fraction is 0.000 124), N (weight fraction is 0.755 268), O (weight fraction is 0.231 781), Ar (weight fraction is 0.012 827), and liquid water (density is 1 g/cm^3) composed of H (weight fraction is 0.111 898), O (weight fraction is 0.888 102). The source was placed at the centre of a cylindrical phantom. To ensure full scattering conditions, the cylinder was constructed to have a radius of 30 cm and a height of approximately 20 cm.

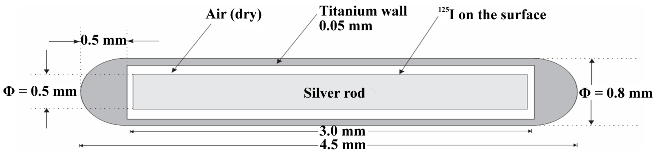

Fig. 1. Longitudinal view of 6711 Model ^{125}I seed source.

III. PARAMETERS CALCULATING FORMULAS

The formula to calculate seed source dose recommended by the AAPM Task group is [11]

$$\dot{D}(r,\theta) = S_k \Lambda \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta), \tag{1}$$

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where $\dot{D}(r,\theta)$ is the dose rate; S_k is the air kerma strength of the source; Λ is the dose rate constant; $G(r,\theta)$ is the geometry factor; $g(r)$ is the radial dose function and $F(r,\theta)$ is the anisotropy function. In order to be consistent with the traditional practice for dose calculation in a medium, the reference point ($r_0 = 1$ cm, $\theta_0 = 90°$) is selected. Λ, $g(r)$ and $F(r,\theta)$ have been calculated with FLUKA.

IV. MONTE CARLO CALCULATIONS

A. Air-kerma strength and dose rate constant

The air-kerma has been calculated in a vacuum phantom with a radius of 1 m surrounded by an air-filled ring detector made by an intersecting of two spherical shells with an inner and outer radius of 96 cm and 104 cm, respectively. The P_{cut} is set to 5 keV for the purpose of excluding low-energy or contaminant photons (such as characteristic X-rays originating in the outer layers of titanium source cladding) and increasing S_k without contributing significantly to the dose at distances greater than 0.1 cm in tissue [9]. After setting histories as 1×10^{11}, the result of air-kerma was estimated to be 4.151×10^{-14} Gy/one beam particle. $D(r_0,\theta_0)$ was calculated by separating the input file of which geometry reference is in Section IV B. $D(r_0,\theta_0)$ was estimated 3.924×10^{-14} Gy/one beam particle. The dose rate constant was obtained from Eq. (2):

$$\Lambda = \frac{\dot{D}(1\,\text{cm},\pi/2)}{S_k}. \quad (2)$$

The value of the dose rate constant, Λ, obtained for the ^{125}I seed source is 0.945 cGy/(h U). This result was in good agreement with the value recommended by AAPM TG43U1 [9] (0.965 cGy/(h U)) with a deviation of 2.041%.

TABLE 1. Radial dose function $g(r)$

$r(cm)$	Radial dose functiona $g(r)$			
	FLUKA	TG43U1	EGSnrc [12]	MCNP5 [13]
0.50	1.017	1.071	1.074	1.071
1.00	1.000	1.000	1.000	1.000
2.00	0.781	0.814	0.820	0.831
3.00	0.636	0.632	0.640	0.658
4.00	0.501	0.496	0.488	0.514
5.00	0.394	0.364	0.366	0.399
6.00	0.271	0.270	0.271	0.298
7.00	0.191	0.199	0.202	0.229
8.00	0.140	0.148	0.148	0.169
9.00	0.108	0.109	0.109	0.128
10.00	0.081	0.080	0.078	0.093

B. Radial dose function

The radial dose function was calculated in a cylindrical phantom with a radius of 30 cm and a height of approximately 20 cm, which was filled with water. The dimension of the scoring regions in the simulation were chosen to have a radial thickness and axial thickness of about 1 mm × 1 mm and distance ranging from 0.5 cm to 10 cm. Table 1 shows the comparison of the results of $g(r)$ for a polar angle of 90° at various distances from 0.5 cm to 10 cm and the related data. The results of radial dose function for a polar angle of 90° at various distances from 0.5 cm to 10 cm are illustrated in Fig. 2, in comparison to related data.

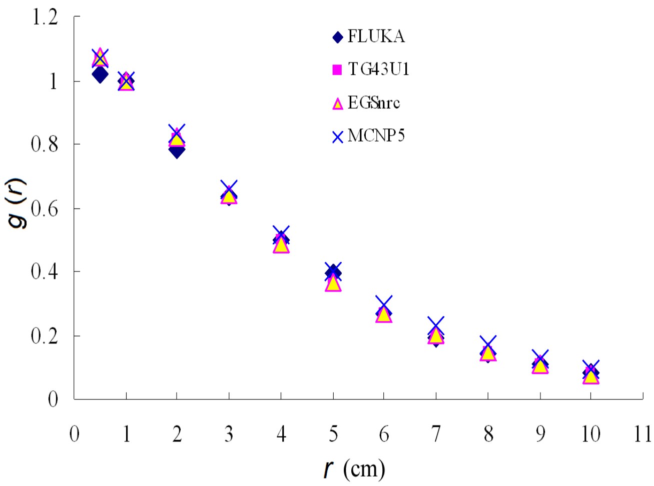

Fig. 2. (Color online) The results of $g(r)$ with FLUKA compared with related data.

Compared with the values recommended by TG43U1, EGSnrc, and MCNP5, the values for FLUKA are in good agreement with TG43U1 with a deviation of less than 5%, except for one value. The results of FLUKA are also in good agreement with EGSnrc and MCNP5.

TABLE 2. Anisotropy function $F(r,\theta)$

$\theta(^o)$	r (cm)					
	0.5	1	2	3	4	5
0	0.476	0.436	0.470	0.471	0.568	0.464
5	0.387	0.475	0.424	0.545	0.613	0.539
10	0.515	0.599	0.544	0.573	0.486	0.552
20	0.732	0.620	0.679	0.689	0.756	0.744
30	0.822	0.655	0.792	0.686	0.741	0.779
40	0.953	0.921	0.984	0.874	0.870	0.845
50	0.986	0.841	0.818	0.873	0.897	1.103
60	1.111	1.096	1.084	1.025	0.880	0.911
70	1.073	1.033	0.997	1.066	1.117	0.857
80	0.961	1.111	1.156	1.071	1.531	1.018
90	1.000	1.000	1.000	1.000	1.000	1.000

A fifth-order polynomial fit to the simulated $g(r)$ in water in the range of 0.5 cm to 10 cm has been determined using Eq. (3)

$$g(r) = (a + br + cr^2 + dr^3 + er^4 + fr^5)\mathrm{e}^{-kr}. \quad (3)$$

The coefficients of above polynomial are given as follows: $a = 0.58855$, $b = 2.17767$, $c = -1.23502$, $d = 0.50367$, $e = -0.07002$, $f = 0.00370$, $k = 0.67741$, and define $R^2 = 0.99983$, *SSE*$= 0.00020$.

C. Anisotropy function

The anisotropy function was calculated in the cylindrical phantom referenced in Section II. The distribution of the s-coring regions in the phantom: distance from the centre of the source ranged from 0.5 cm to 5 cm and angles ranged from 0° to 90°. The results of $F(r,\theta)$ are presented in Table 2.

Compared to the values recommended by TG43U1. The values of FLUKA are in good agreement with TG43U1. When the distance ranges from 0.5 cm to 1 cm, the deviation is less than 17%. When the distance ranges from 2 cm to 5 cm, the deviation is less than 7%.

V. DISCUSSION AND CONCLUSION

Simulation results using FLUKA code conform with the values recommended by TG43U1 very well. Actually, it seems that FLUKA code with a high quality of precision can be implemented in standard protocols procedures like MCNP and EGSnrc. Therefore, FLUKA can be applied as a valuable alternative tool to calculate dosimetric characteristics for novel brachytherapy sources.

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