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Abstract

This work determined a new M-C 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 125I 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.

Full Text

Determination of Dosimetric Characteristics for 125I Seed Source with FLUKA Code

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Abstract. This work establishes FLUKA, a new Monte Carlo code, for calculating the dosimetric characteristics of seed sources. Dosimetric parameters—including the dose rate constant, radial dose function, and anisotropy function

—were calculated for the model 6711 125I seed source using FLUKA. The results were compared against AAPM TG43U1 recommended data: the FLUKA-calculated dose rate constant agreed within 2.041%, while radial dose functions for distances ranging from 0.5 cm to 10 cm showed deviations of less than 5%. These findings demonstrate that FLUKA can be reliably employed to calculate the dosimetric characteristics of seed sources.

Keywords: FLUKA, Dosimetric parameters, 125I seed source
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INTRODUCTION

Permanent implantation of 125I brachytherapy sources has become an increasingly widespread treatment modality for cancer, particularly prostate cancer. The low-energy photon emission from these sources localizes the radiation dose primarily to the tumor volume, thereby minimizing unnecessary exposure to surrounding healthy tissue. This targeted approach reduces patient discomfort and improves clinical outcomes. Accurate evaluation of dose distribution within tumors is essential for minimizing risks to adjacent normal tissues, and the dosimetric characteristics of seed sources provide the foundation for such evaluations. Consequently, developing accurate and reliable methods for calculating these characteristics is of paramount importance.

In recent years, various Monte Carlo codes have been employed for this purpose. Cazeca et al. [1], Medich et al. [2], Saidi et al. [3], and Hosseini et al. [4] utilized MCNP5 to calculate seed source dosimetric characteristics. Reniers et al. [5] and Taylor et al. [6] applied EGSnrc for similar calculations, while Ballester et al. [7] and Taschereau et al. [8] used GEANT4. However, MCNP is commercial software with restricted accessibility, EGSnrc has limitations in geometry modeling, and GEANT4 is complex to implement. These constraints highlight the need for a free, open-source, user-friendly, and reliable Monte Carlo code—criteria that FLUKA satisfies. Despite its potential, FLUKA has been rarely applied in this domain. The primary objective of this study was to calculate the dosimetric characteristics of the 6711 model 125I seed source using FLUKA and to evaluate its applicability for brachytherapy dosimetry calculations.

MATERIALS AND METHODS

The geometry of the 6711 model 125I seed source is illustrated in [Figure 1: see original paper]. The source has a physical length of 0.45 cm and an outer diameter of 0.08 cm, with a silver marker positioned at its center measuring 0.3 cm in length and 0.05 cm in diameter. Phantom materials consisted of the seed source itself, air, and water. The photon spectrum for the 125I seed source was obtained from Ref. [9]. Material densities and compositions used in this study were as follows [10]: silver (Ag) with density 10.5 g/cm^3; titanium (Ti) with density 4.54 g/cm^3; dry air (density 0.001205 g/cm^3) composed of C (weight fraction 0.000124), N (0.755268), O (0.231781), and Ar (0.012827);

and liquid water (density 1 g/cm^3) composed of H (0.111898) and O (0.888102). The source was positioned at the center of a cylindrical phantom with a radius of 30 cm and height of approximately 20 cm to ensure full scattering conditions.

PARAMETERS CALCULATING FORMULAS

The dose calculation formula recommended by the AAPM Task Group is [11]:

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

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. To maintain consistency with traditional dose calculation practices in a medium, the reference point was selected at ($r_0 = 1$ cm, $\theta_0 = 90°$). The parameters Λ, $g(r)$, and $F(r,\theta)$ were calculated using FLUKA. Scoring regions in the simulation were defined with radial and axial thicknesses of approximately 1 mm × 1 mm, covering distances from 0.5 cm to 10 cm.

MONTE CARLO CALCULATIONS

Air-Kerma Strength and Dose Rate Constant

Air kerma was calculated in a vacuum phantom with a 1 m radius, surrounded by an air-filled ring detector formed by the intersection of two spherical shells with inner and outer radii of 96 cm and 104 cm, respectively. The Pcut parameter was set to 5 keV to exclude low-energy or contaminant photons (such as characteristic X-rays originating from the outer titanium cladding layers) that increase S_k without contributing significantly to tissue dose at distances greater than 0.1 cm [9]. After simulating 1×10^{11} histories, the air kerma was determined to be 4.151×10^{-14} Gy per source particle. $D(r_0, \theta_0)$ was calculated using a separate input file with the geometry described in the Materials and Methods section, yielding 3.924×10^{-14} Gy per source particle. The dose rate constant was obtained from:

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

The resulting dose rate constant Λ for the 125I seed source is 0.945 cGy/(h · U), which agrees well with the AAPM TG43U1 recommended value [9] of 0.965 cGy/(h · U), corresponding to a deviation of 2.041%.

Radial Dose Function

The radial dose function was calculated in a cylindrical water phantom with a radius of 30 cm and height of approximately 20 cm. compares the FLUKA-calculated $g(r)$ values at a polar angle of 90° for various distances from 0.5 cm to 10 cm against reference data. The results are also illustrated in [Figure 2: see original paper]. Compared to TG43U1, EGSnrc, and MCNP5 values, FLUKA results show good agreement with TG43U1 (deviation $< 5\%$) across the entire distance range, with only one exception. The FLUKA results also demonstrate good consistency with EGSnrc and MCNP5 data.

A fifth-order polynomial fit to the simulated $g(r)$ values in water from 0.5 cm to 10 cm was determined using:

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

The fitted coefficients are: $a = 0.58855$, $b = 2.17767$, $c = -1.23502$, $d = 0.50367$, $e = -0.07002$, $f = 0.00370$, $k = 0.67741$, with $R^2 = 0.99983$ and SSE $= 0.00020$.

Anisotropy Function

The anisotropy function was calculated in the cylindrical phantom described in Section II, with scoring regions distributed from 0.5 cm to 5 cm radially and from 0° to 90° angularly. The $F(r, \theta)$ results are presented in . Compared to TG43U1 recommended values, FLUKA results show good agreement, with deviations less than 17% for distances of 0.5–1 cm and less than 7% for distances of 2–5 cm.

DISCUSSION AND CONCLUSION

Simulation results obtained with FLUKA demonstrate excellent conformity with TG43U1 recommended values. The code exhibits high precision and can be implemented following standard protocols comparable to MCNP and EGSnrc. Therefore, FLUKA serves as a valuable alternative tool for calculating dosimetric characteristics of novel brachytherapy sources.

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Note: Figure translations are in progress. See original paper for figures.