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A Monte Carlo evaluation for effects of probable dimensional uncertainties of low dose rate brachytherapy seeds on dose

*Berkay Camgöz**, *Mehmet N. Kumru*[1]

Ege University, Institute of Nuclear Sciences, 35100 Bornova, Izmir, Turkey

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ABSTRACT

The aim of this study is to determine effects of size deviations of brachytherapy seeds on two dimensional dose distributions around the seed. Although many uncertainties are well known, the uncertainties which stem from geometric features of radiation sources are weakly considered and predicted. Neither TG-43 report which is not completely in common consensus, nor individual scientific MC and experimental studies include sufficient data for geometric uncertainties. Sizes of seed and its components can vary in a manufacturing deviation. This causes geometrical uncertainties, too. In this study, three seeds which have different geometrical properties were modeled using EGSnrc-Code Packages. Seeds were designed with all their details using the geometry package. 5% deviations of seed sizes were assumed. Modified seeds were derived from original seed by changing sizes by 5%. Normalizations of doses which were calculated from three kinds of brachytherapy seed and their derivations were found to be about 3%–20%. It was shown that manufacturing differences of brachytherapy seed cause considerable changes in dose distribution.

1. Introduction

Monte Carlo (MC) simulations are popular and relatively reliable for brachytherapy. TG-43 (Task Group) report of the AAPM (the *American Association of Physicists in Medicine*) collects both experimental and MC data and evaluates them. The uncertainty of data of applied dose is momentous for medical-dosimetric studies because of human life. It is aimed that optimum dose value must be acquired in cancerous tissue to treat it in radiotherapy (brachytherapy is specialized radiotherapy). There are several uncertainties of dose and they must be determined completely to decide an optimum value in treatment planning.

Low dose rate (LDR) brachytherapy sources are commonly used for cancer treatment especially for prostate cancer. The dose distribution around a brachytherapy seed source is calculated in a formalism that is suggested in AAPM Task Group 43 Report for the treatment planning. As the TG-43 formalism the dose is calculated as follows:

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

* *Corresponding author*. Tel.: +90 5553734911; fax: +90 2323886466.
E-mail addresses: berkay.camgoz@ege.edu.tr, lachry@gmail.com (B. Camgöz), mehmet.nurullah.kumru@ege.edu.tr (M.N. Kumru).
[1] Tel.: +90 2323112501; fax: +90 2323886466.

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at a point specified by r and θ variables where Λ is dose rate constant and S_k is air kerma strength. Radial dose function $g(r)$ and anisotropy function $F(r,\theta)$ are calculated using analytical dose values. This formalism requires the usage of a number of dosimetry parameters for the calculation of dose value at a certain point around a brachytherapy source. It is also assumed that a brachytherapy source has an ideal geometry (announced manufacturer specifications). Eq. (1) was performed by partitioned functions. Uncertainties of each expression which perform main dose value have a contribution on total uncertainties. Although individual uncertainties are assumed small as they can be omitted they are effective on total uncertainties. As it is understood from the equation, dosimetric functions and main dose $D(r,\theta)$ quantity is directly dependent on geometrical variables. Components of a brachytherapy seed have specific sizes.[1] Seed models vary from one another with their general shape, material thickness, length, radius, radioactivity carrier properties, kind of radio-opaque material and radioactive material. All of these properties directly affect and change analytical dose value around the source.[1] Accurate knowledge of source geometry and details of its physical structure are especially important for Monte Carlo modeling.[1] Monte Carlo simulations are independent from detector-source geometry and detector response artifacts. Smaller estimated uncertainty can cause artifact-free dose-rate estimates at distances shorter or longer than those accessible by TLD (Thermo Luminescence Dosimeter) methods. Few Monte Carlo studies have been conducted to determine the effects of geometric uncertainties, internal component mobility, size variations of sources, and on the uncertainty of dose distributions.[1] Geometrical changes will contribute with an external uncertainty over other known uncertainties on dosimetric parameters in Eq. (1) which results in the analytical dose value. Estimation of geometric uncertainty, $\%\sigma_{\Lambda|G}$, is complex and not well understood.[1] Each source design is characterized by numerous and unique geometric parameters, most of which have unknown and potentially correlated probability distributions. However, a few studies in the literature report parametric studies in which the sensitivity of dosimetric parameters to specified sources of geometric variability is published.[1] For example, Williamson[4] has shown that the distance between the two radioactive spherical pellets of the Drax Image (Jubilant DraxImage Incorporated. 16751 Trans-Canada Highway Kirkland, Québec, Canada H9H 4J4) ^{125}I source varies from 3.50 to 3.77 mm. This leads to a source-orientation dependent variation of approximately 5% in calculated dose-rate constant. Rivard[2] published similar findings for the NASI (North American Scientific) model MED3631-A/M (Brachytherapy Services Incorporated (BSI) 7643 Fullerton Road, Springfield, VI 22153, USA) ^{125}I source.

For the DraxImage (Jubilant DraxImage Inc.) seed model[3] source $\%\sigma_{\Lambda|geo} = 1.4\%$. For the Theragenics Corporation Model 200 seed, Williamson has shown that L is relatively insensitive to Pd metal layer thickness or end weld configuration.[4] Thus 2% seems to be a reasonable and conservative estimate of $\%\sigma_{\Lambda|geo}$. The reported statistical precision of Monte Carlo Λ estimates ranges from 0.5% for Williamson's recent studies to 3% for Rivard's MED3631-A/M (Brachytherapy Services Inc.) study.[5] Thus for a typical Williamson study, one obtains a $\%\sigma_{\Lambda}$ of 2.5%. Using the $\%\sigma_{\Lambda|s}$ reported by each investigator along with the standard $\%\sigma_{\Lambda|geo}$ and $\%\sigma_{\Lambda|\mu}$ values, discussed above; $\%\sigma_{\Lambda}$ varies from 2.5% to 3.7% for the eight seeds described in this report. Thus, assuming a standard or generic $\%\sigma_{\Lambda}$ of 3% for all Monte Carlo studies seems reasonable.[1]

Mobit and Badragan[6] noted geometrical specifications of Amersham (Nycomed Amersham) Model 6711 (Oncura Incorporated, 3350 North Ridge Avenue, Arlington Heights, IL 60004, USA) Seed. Their measurements (Table 1) showed that all manufactured seeds are not equal to each other and producing specifics. In that data (Table 1) dimensional uncertainties in Table 1 between 1% and 4%". Table 1 provides reference data to limit deviation amounts of components of the seeds.

Goal of this study is to examine geometrical deviations of brachytherapy seeds on dosimetric distribution. In this study, three seeds which have different geometrical properties were modeled using EGSnrc-Code Packages. Seeds were designed in all their detail with the geometry package. 5% deviations of seed sizes were assumed. Modified seeds were derived from the original seed by changing sizes by 5%.

There are several kind of geometrical uncertainty sources for brachytherapy seeds.[7] MC investigators should be free from manufacturing specifics of a seed.[7] In this study hypothetical seeds which have been derived are used to characterize some of source geometry uncertainty. Probable deviation of seed dimensions[8] was selected as some of geometrical uncertainties.

2. Materials and methods

In the present study Amersham Model 6711 (Oncura Inc.), TheraSeed 200 (Theragenics Corporation, 5203 Bristol Industrial Way, Buford, GA 30518, USA) and Imagyin Seed (Imagyn Medical Technologies, Incorporated, 1 Park Plaza Ste 1100, Irvine, CA 92614, USA) were modeled using EGSnrc[9] Monte Carlo Code.

Scenarios of geometric variations of seeds reference seed that has ideal geometrical measurements published by commercials were simulated using this code. Every geometrical combination of seed component performed hypothetic seeds which had been derived from the commercial one. Dose was calculated by mathematical process of EGS Simulation as

$$D^j = K^j_{col} = \frac{\sum_i E_i t_i (\mu_{en}/\rho)}{V_j}$$

where D^j and K^j_{col} are the dose and collision kerma in the jth voxel, E_i is the energy of the ith photon, and t_i is the track length of that photon in the voxel. The mass-energy absorption coefficient corresponding to energy E_i is (μ_{en}/ρ) and V_j is the volume of the voxel.[10] Voxels were dimensioned (Fig. 1) with optimum volume values according to Taylor et al.[10]

2.1. Seed modeling

Designed seeds and their geometrical derivative seed models were identified by identification (ID) number. Derivative seed concepts were designed by changing seed dimensions[11] with 5% ratios (Tables 2–4). This size diversity supplies large probability for practical seed properties. It must be mentioned