Iodine-125 Brachytherapy Seed Benchmark

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INTRODUCTION

In this paper, dose-related values obtained from a Monte Carlo model simulation of the Amersham model 6711 ^{125}I brachytherapy seed are compared with similar values obtained from a recent publication [1] that includes both experimental and calculation analysis results. An uncertainty analysis that combines computational and experimental uncertainties is also presented. This uncertainty analysis is required as a basis to determine the extent to which results derived from simulations and experiments should agree in order for a successful benchmark to be established. Dose-related values presented in this publication include the dose-rate constant, the radial dose function, and the two-dimensional (2D) anisotropy function, all of which are quantities defined and standardized by the American Association of Physicists in Medicine (AAPM) TG-43 protocol [2]. The AAPM recommends the dose-rate protocol and source-specific dosimetry data to be adopted by all end users for planning clinical treatment with low-energy brachytherapy interstitial sources (^{125}I and ^{103}Pd seeds only).

DESCRIPTION OF EXPERIMENT

Seed Description

The Amersham model 6711 seed geometry description was obtained from [1]. Its geometry configuration includes nominal dimensions and uncertainties (standard deviations of the mean derived from 18 measurements), which are shown in a schematic in Fig. 1. The source is a right circular cylindrical silver rod, beveled on each end at an angle of 45° ± 10% and coated with a radioactive layer consisting of AgBr and AgI in a molecular ratio of 2.5:1. The thickness of the radioactive coating varies from approximately 1.0 to 2.5 μm and its density is estimated to have an uncertainty of 0.5%. The silver rod is located within a cylindrical titanium shell. Although the nominal configuration shows the rod centered within the titanium shell, in practice it may be shifted to one end and/or to one side or tilted as much as 3° as allowed by the available void space. Also, the ends, though shown as hemispherical on the outside and flat on the inside, may assume different shapes and may also be convex or concave on the inside.

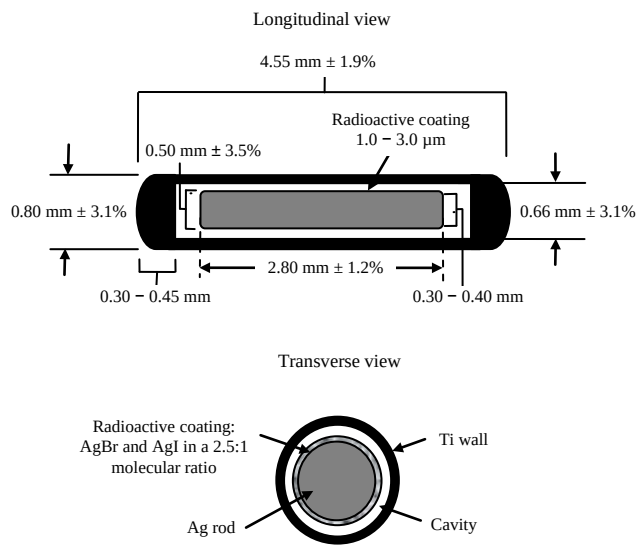

Fig. 1. Geometric structure and dimensions of the Amersham model 6711 ^{125}I seed.

Experiment Description

Dose measurements as described in [1] were performed using LiF thermoluminescent dosimeters (TLDs) within a polymethylmethacrylate (PMMA) phantom of high purity. The measurement results obtained in the PMMA phantom were converted to equivalent results (absorbed dose) in pure water. Dose measurements include uncertainties in a variety of TLD parameters (i.e., position, sensitivity correction factors, relative energy response, and nonlinearities). Uncertainties described above were integrated into the total measurement uncertainty. The reported measurement uncertainty for the dose rate constant was 6.1%. For the radial dose function, reported measurement uncertainties were 10.0, 4.7, 2.4, 3.1, and 5.8% at distances of 0.2, 0.5, 1.0, 5, and 10 cm, respectively. For the 2D anisotropy function, the experimental uncertainties were 11, 8, 7, 7, 6, 7, and 6% at distances of 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, and 5.0 cm, respectively.

DESCRIPTION OF THE ACTUAL WORK

Benchmark calculations were performed with MCNP5 V1.50 [3] and the default photoatomic data sets based on ENDF/B-VI.8. The MCNP model used to

determine the radial dose function and the 2D anisotropy function consisted of the seed surrounded by pure water. The model includes cells in the water region defined by conical and spherical surfaces and used for cell-tally (F6 tally) calculations. These tally cells are azimuthally symmetric. Each cell defines an angular region of 1° width and a thin radial thickness of 0.005 to 0.05 cm, depending on distance from the center of the seed. A cell angular width of 1° was determined to be large enough for adequate run statistics yet small enough for minimal geometry effect. Tallies were located at radial distances and angles consistently with the experimental locations. The MCNP model used to determine air-kerma strength approximates the wide-angle free-air chamber measurement configuration described in and recommended by TG-43. The model included the seed, surrounding void, and a thin (0.1-cm) disk cell-tally region at the 30-cm radius with its center on the seed transversal axis. Air was added to the material in the model, but as a tally material only (F4 tally).

The effects of geometry parameter uncertainties (see Fig. 1) were evaluated by performing simulations and calculating the dose-related quantities of interest (air-kerma strength and dose-rate constant, radial dose function, and 2D anisotropy function), with each geometry parameter individually set to the maximum and minimum value. Also the effects of tilt of the silver rod as well as axial and radial displacements of the rod within the titanium shell were examined. Total geometric uncertainty was estimated by adding the individual uncertainties in quadrature according to Eq. 1 below:

$$\sigma_y^2 = \sum_{i=1}^{N} \left(\frac{y(x_{\max,i}) - y(x_{\min,i})}{2p_i} \right)^2 , \qquad (1)$$

where, y is a dose-related quantity of interest, $x_{\max,i}$ and $x_{\min,i}$ are the maximum and minimum values of geometry parameter i, respectively, and p_i is either 1 for the normally distributed values or is equal to $\sqrt{3}$ for the uniformly distributed values [4].

MCNP calculations were also performed using photoatomic interaction data libraries based on ENDF/B-IV, which are distributed with MCNP5, to evaluate the impact of uncertainties that may exist in the photoatomic interaction data. A combined uncertainty includes the geometry, photoatomic data, and experimental uncertainties.

RESULTS

A comparison of the MCNP simulated dose-rate constant value with the experimental value shows a difference of ~4%, which is less than the experimental uncertainty alone.

Comparison of values from this analysis with the experimental values for the radial dose function shows a gradual increase in the difference from 0 to 6.49% for distances ranging from 1 to 10 cm. The worst-case difference from this analysis (6.49%) appears to be better than the 9.41% obtained by the comparison of the simulated and experimental values from [1]. The benchmark calculated values for the radial function agree with the reported experimental values well within the estimated combined uncertainties for all distances.

Comparison of MCNP simulated values with the experimental values for the 2D anisotropy function shows that differences typically increase either as the distance increases or as the angle decreases. For angles from 80° to 30° from the seed longitudinal axis, the maximum difference is ~6%. For angles less than 30°, the maximum difference is ~10%, which occurs for θ = 15° and r = 0.5 cm. Results for the 2D anisotropy function also showed agreement with the experimental values within the estimated combined uncertainties for all angles and distances for which experimental values were available.

On the basis of these results, it is concluded that a viable benchmark model has been established.

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