Calculated dosimetric parameters of the IoGold ^{125}I source model 3631-A

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Basic dosimetric parameters as recommended by the AAPM Task Group No. 43 (TG-43) have been determined for recently available IoGold ^{125}I brachytherapy seeds. Monte Carlo methods (MCNP) were used in the calculation of these parameters in water, and results compared with soon to be published experimental parameters also for ^{125}I IoGold seeds as well with parameters for model 6702 and 6711 ^{125}I seeds. These parameters were the radial dose function, anisotropy factor and constant, and the dose rate constant. Using MCNP, values for the radial dose function at 0.5, 2.0, and 5.0 cm were 1.053, 0.877, and 0.443, respectively. The anisotropy factor was 0.975, 0.946, 0.945, and 0.952 at 0.5, 1.0, 2.0, and 5.0 cm, respectively, with an anisotropy constant of 0.95. The IoGold dose rate constant was determined by excluding the low energy titanium characteristic x rays produced in the IoGold titanium capsule. Using this post TG-43 revised NIST air kerma methodology, the IoGold dose rate constant was 0.96 cGy h^{-1} U^{-1}. These calculatively determined parameters for IoGold seeds were compared with those determined experimentally for IoGold seeds, and also compared with parameters determined for model 6702 and 6711 seeds as presented in TG-43. [S0094-2405(98)02011-2]

Key words: iodine-125, brachytherapy, Monte Carlo, dosimetry

I. INTRODUCTION

Recently, the FDA approved a new type of ^{125}I seed, the IoGold model 3631-A, which is produced by North American Scientific, Inc. Basic dosimetric properties of the IoGold seeds have been evaluated experimentally by Wallace and Fan[1] using thermoluminescent dosimeters (TLDs) in a tissue-equivalent (TE) plastic, B-material, developed at Lawrence Livermore National Laboratory. Also, radiographic and spectral analysis as well as QA procedures for the first batch of IoGold seeds have been studied.[2] In this paper, the dosimetry parameters as outlined in TG-43[3] have been determined for IoGold seeds in water using MCNP.

II. MATERIALS AND METHODS

Transport calculations to determine dosimetric parameters for the IoGold seeds were performed on our distributed Monte Carlo N-Particle (MCNP) system comprised of Silicon Graphics workstations (R3000/R4000) and LINUX boxes.[4–6] The number of particles transported exceeded 10^8 in order to provide relative errors (1 σ) of less than 0.1%.

The Monte Carlo technique used herein determined energy absorbed in water within volume elements (voxels) surrounding a single IoGold seed. The ^{125}I photon spectrum of Browne and Firestone was used.[7] Absorbed dose to water was then determined by dividing energy absorbed by voxel mass. Though absorbed dose was averaged within the voxel, the size of each voxel was chosen such that the variation in absorbed dose within the voxel did not exceed $\pm$0.2%. The change in average absorbed dose within each voxel due to the radiation dose gradient did not exceed 0.1%. The IoGold seed was positioned at the center of a spherical water phantom of 10 cm radius. A sampling space comprised of spheres subdivided into conics was employed to determine the absorbed dose in each voxel.

The radial dose function, anisotropy factor, and anisotropy constant were all determined in the aforementioned spherical water phantom. The air kerma rate in free space was calculated for derivation of the dose rate constant. Here, the dose rate constant was determined by the ratio of the reference dose rate to air kerma strength where the reference dose rate is defined as the absorbed dose in water at a radius, r, of 1 cm and an angle, θ, with respect to the source long axis, of 90°.[3] Calculation of air kerma strength was performed on the transverse axis at a distance of 1 m in free space as recommended by TG-43.[3]

Geometric elements of the actual source (e.g., encapsulation length, diameter, thicknesses) were modeled instead of the more commonly employed point-wise determination.

TABLE I. Radial dose function, $g(r)$, for ^{125}I seeds.

	Radial dose function, $g(r)$			
Distance along transverse axis (cm)	Model 6711 experimental (Ref. 3) (Solid Water)	Model 6702 experimental (Ref. 3) (Solid Water)	IoGold experimental (Ref. 1) (TE plastic)	IoGold calculative (water)
0.5	1.04	1.04	1.064	1.053
0.75			1.028	1.022
1.0	1.000	1.000	1.000	1.000
1.5	0.926	0.934	0.929	0.934
2.0	0.832	0.851	0.848	0.877
3.0	0.632	0.670	0.676	0.724
4.0	0.463	0.511	0.523	0.575
5.0	0.344	0.389	0.401	0.443

While the three ^{125}I seed types currently available (IoGold, model 6702, and model 6711) have similar external appearance and are all encapsulated in titanium tubes with laser-welded ends, there are differences within each seed type which cause differences in their dosimetric parameters. The model 6711 seed has Ag^{125}I coated upon the surface of a silver wire. The active elements of the IoGold and model 6702 seeds consist of four resin beads impregnated with ^{125}I. A difference between the IoGold and model 6702 ^{125}I seed is that the laser-welded ends of the IoGold seed are 0.15 mm compared to the 0.5 mm ends of the model 6702 seed. Within the IoGold seed, but not within the model 6702 or 6711 seeds, are two nonradioactive spheres (40% gold, 60% copper) which are arranged between the ^{125}I resin beads to provide enhanced radiographic contrast. The gold and copper present in the IoGold seed, the silver present in the model 6711 seed, and the titanium encapsulation present for all seeds induce characteristic x rays. Consequently, differences in the dosimetric parameters for these three ^{125}I seeds are expected. The TE plastic phantom material used by Wallace and Fang[1] was comprised of H, C, N, O, and Ca (0.78% mass) with a mass density of 1.09 g/cm^3.

III. RESULTS AND DISCUSSION

A. Radial dose function

The radial dose function, $g(r)$, was calculated and experimentally[1] determined for radii of 0.5 to 5.0 cm for IoGold seeds. These results are presented in Table I in addition to those experimentally determined and recommended by TG-43[3] for ^{125}I model 6702 and 6711. Results of MCNP calculations were greater than the experimental results[1] for IoGold seeds by up to 10% at a distance of 5.0 cm. This may be due to the differences between water and TE plastic, since decreased attenuation is expected in the water phantom due to the presence of calcium in the TE plastic which increases the ^{125}I attenuation due to the photoelectric effect. In a Monte Carlo simulation study by Meigooni *et al.*,[8] values for $g(r)$, as recommended by TG-43,[3] were also determined in Solid Water, and similarly demonstrated a decrease in $g(r)$ values compared with our results determined in water for radii exceeding 1 cm, probably due to the photoelectric effect of calcium. Our calculated coefficient values for radial dose function results in water are fitted to a 5th order polynomial below to facilitate entry into treatment planning workstations.[9]

$$a_0 = 1.095; \quad a_1 = -7.48\times10^{-2};$$
$$a_2 = -2.11\times10^{-2}; \quad a_3 = 1.00\times10^{-3};$$
$$a_4 = 3.11\times10^{-4}; \quad a_5 = -2.2\times10^{-5}.$$

The impact of the Au/Cu spheres is not expected to significantly alter the radial dose function.

B. Anisotropy factors and constants

Anisotropy factors, $\phi_{an}(r)$, for several radii were determined through calculation of absorbed dose to water between two spherical shells enclosing the source, and dividing these values by the transverse axis absorbed dose; the average dose rate for a given radius was normalized to that on the transverse axis where r is the radius and θ_0 is 90° on the transverse axis to yield the anisotropy factor as in Eq. (1).

$$\phi_{an}(r) = \frac{\dot{D}(r)}{\dot{D}(r,\theta_0)}. \tag{1}$$

Table II presents the calculative results determined for the IoGold seeds, as well as experimental results[1] for IoGold seeds and experimentally determined TG-43[3] recommended values for model 6702 and 6711 ^{125}I seeds. Only the calculated results for IoGold seeds were determined in water, while all other results in Table II were determined in TE plastic[1] or Solid Water.[3] In comparing the anisotropy factors determined experimentally with those determined calculatively, it is clear that there is greater fluctuation in the results determined experimentally.

From Table II, it is evident the variation of the experimentally measured anisotropy factors[1,3] is more for the IoGold and model 6702 seeds than that of the model 6711 seed. As the location of the Au/Cu spheres and ^{125}I resin beads within the IoGold seeds have been shown[2] to move, this variability in position may have complicated experimental measurements of the anisotropy factors for IoGold and model 6711 ^{125}I seeds. However, the differences between the

TABLE II. Anisotropy factors, $\phi_{an}(r)$, and anisotropy constants, ϕ_{an}, for ^{125}I seeds.

	Anisotropy factors, $\phi_{an}(r)$			
Distance along transverse axis (cm)	Model 6711 experimental (Ref. 3) (Solid Water)	Model 6702 experimental (Ref. 3) (Solid Water)	IoGold experimental (Ref. 1) (TE plastic)	IoGold calculative (water)
0.5				0.975
0.75				0.955
1.0	0.944	0.968	0.885	0.946
1.5				0.951
2.0	0.936	0.928	0.847	0.945
3.0	0.893	0.897	0.926	0.947
4.0	0.887	0.942	0.853	0.951
5.0	0.884	0.959	0.936	0.952
Anisotropy constants ϕ_{an}	0.93	0.95	0.90	0.95

calculative and experimentally[1] determined anisotropy factors are primarily attributed to variation in TLD response. Here, measurements using radiation-sensitive film may resolve this discrepancy.

A value of 0.95 was calculated for the anisotropy constant, $\phi_{an}(r)$, which is about 5% greater than that, 0.90, determined experimentally using TLDs.[1] The anisotropy constants for ^{125}I model 6702 and 6711 are also presented in Table II. While the calculated IoGold anisotropy constant was identical to that of the model 6702 ^{125}I seed,[3] direct comparison of $\phi_{an}(r)$ between the three seed types is of limited utility due to their dissimilar construction.

C. Dose rate constant

While the low energy, approximately 4 keV, titanium characteristic x rays from the ^{125}I encapsulation contribute to measurements of air kerma strength, they are relatively innocuous for *in vivo* dosimetry. Consequently, absorbed dose from these x rays was disregarded in calculation of the reference dose rate and also in calculation of air kerma strength in adherence to post TG-43 ^{125}I NIST calibration methods.[10] The dose rate constant calculated in such a way is 0.96 $\mathrm{cGy\,h^{-1}\,U^{-1}}$, but would be about 0.86 $\mathrm{cGy\,h^{-1}\,U^{-1}}$, approximately 10% less, if calculated using the previous (1985) NIST methodology.[10] The dose rate constant determined experimentally by Wallace and Fan[1] was 0.93 $\mathrm{cGy\,h^{-1}\,U^{-1}}$. As the experimentally determined dose rate constant employed the 1985 NIST methodology, the MCNP calculated dose rate constant (0.86 $\mathrm{cGy\,h^{-1}\,U^{-1}}$) using the 1985 NIST methodology[10] was about 7% less than that (0.93 $\mathrm{cGy\,h^{-1}\,U^{-1}}$) determined experimentally.[1] For comparative purposes, the revised dose rate constants for models 6702 and 6711 ^{125}I seeds are 0.93 $\mathrm{cGy\,h^{-1}\,U^{-1}}$ and 0.88 $\mathrm{cGy\,h^{-1}\,U^{-1}}$, respectively.[10] Quantitative comparison between the dose rate constant values of the three seed types (IoGold, model 6702, and 6711) is complicated by their differing construction (e.g., Au/Cu beads, Ag wire, encapsulation thickness).

IV. CONCLUSION

We recommend use of the ^{125}I IoGold dosimetry parameters determined herein as they were calculated in water using MCNP in strict adherence to TG-43 recommendations, and in accordance with the recently revised NIST ^{125}I source calibration methodology.[3,10] While these results should be confirmed with experimental measurements, the purpose of these calculations was to provide reference dosimetry parameters for IoGold ^{125}I seeds necessary for clinical treatment planning of interstitial brachytherapy implants.

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