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Dosimetric characterization of an encapsulated interstitial brachytherapy source of ^{125}I on a tungsten substrate

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Abstract

Purpose: Recently, a new design of an encapsulated ^{125}I source using a tungsten substrate has been introduced by Best Medical International and named as Best Model 2301 source. In contrast to model 6711 source that uses silver as substrate, the model 2301 source does not yield fluorescent x rays (22.1 keV and 25.5 keV) in the energy range of dosimetric interest. This changes the dosimetric characteristics of the source and experimental determination of these characteristics is needed.

Methods and Materials: In this work, the dosimetric characteristics of the tungstenbased ^{125}I source were measured using LiF TLDs in a Solid Water™ phantom. The dose rate constant as well as the radial dose function and anisotropy function were measured.

Results: The dose rate constant for the tungsten-based source was determined to be 1.02 ± 0.07 cGy h^{-1} U^{-1} in contrast to the previously reported value of 0.98 for the silver-based model 6711 source. The radial dose function for the tungsten-based model 2301 source decreases slightly less rapidly with distance than that for the silver-based model 6711 source. Considerable differences in the anisotropy functions between the two sources were observed.

Conclusions: Dosimetric parameters of the Model 2301 source, based on AAPM TG-43 formalism, have been experimentally determined. © 2002 Elsevier Science Inc. All rights reserved.

Keywords: ^{125}I source; Prostate seed implant; Interstitial brachytherapy; Dosimetry

Introduction

In 1991, a double-walled encapsulated source of radioactive ^{125}I on a tungsten substrate was developed for interstitial brachytherapy (model 2300; Best Medical International, Springfield, VA) (1). The double-walled encapsulation design was intended to provide thinner and more uniformly thick walls at the ends of the source so that the corresponding angular distributions are more isotropic. In contrast, the commonly used model 6711 source (Nycomed/Amersham, Arlington Heights, IL) uses a silver substrate that also serves as the radiographic X-ray marker for source localization in the patient. The atomic number of tungsten is 74, compared with 47 for silver. The K characteristic X-rays from tungsten have energies from 57.4 to 69.5 keV, and the L characteristic X-rays from tungsten have energies from 7.4 to 11.7 keV (2). The K-edge characteristic photon energies of tungsten are too high for the photons emitted by ^{125}I to produce (lower than 35.5 keV), and L-edge characteristic photons from tungsten are readily absorbed in the encapsulation and do not contribute significantly to the dose to tissue at the reference distance of 1 cm. In contrast, the silver K X-rays have energies of 21.7 and 25.5 keV (1), which are well within the range of photon energies from ^{125}I. Thus, the effective photon energy from a silver-based source is lower (approximately 27.4 keV) compared with that for the ^{125}I source on a tungsten substrate (approximately 28.4 keV). The model 2300 source also introduced double encapsulation made of titanium and used loading of radioactivity on the flat ends of the tungsten rod substrate. The source was designed to produce a more uniform angular dose distribution around the source, and we reported this in a previous study (3).

In 1999, the manufacturer introduced a commercial product based on the earlier design of the model 2300, which has been designated as the model 2301 source. The newly designed Best model 2301 ^{125}I seed has a nominal physical length of 5.0 mm and an outer diameter of 0.8 mm. The ^{125}I radionuclide was infused in the organic matrix, which was coated on a tungsten rod with a nominal length of 3.95 mm and a diameter of 0.25 mm. Recently, Meigooni *et al.* (4)

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published their study on the dosimetry of the same type of source. In this study, the 1999 primary standard of the air kerma strength of the Best source, based on the wide-angle free air ionization chamber (WAFAC) at the National Institute of Standards and Technology (NIST), was used. Subsequently, an error of approximately 3.5% for the Best model 2301 source was shown in the 1999 standard, and a year 2000–corrected standard was issued (5). This directly affects the dose-rate constant reported by Meigooni *et al.* (4).

These recent developments necessitated a reevaluation of the dosimetry parameters of the model 2301 source for clinical implementation. Moreover, the American Association of Physicists in Medicine (AAPM) requires that the dosimetric characteristics of a new brachytherapy source be determined by at least two independent investigations, which are reported in peer-reviewed literature (6). In this article, we present the results of a measurement of the AAPM Task Group (TG) No. 43 (7) parameters of the model 2301 source by using the year 2000–corrected 1999 NIST standard and compare the dosimetric characteristics of this source with those for the model 6711 source. We also present a comparison with the earlier work of Meigooni *et al.* and a recommended set of TG-43 parameters for the clinical implementation of a model 2301 source.

Methods and materials

The dose-rate constant and dose distributions around the Best model 2301 ^{125}I source were measured with micro LiF thermoluminescence dosimeters (TLDs) (1 × 1 × 1 mm) and regular LiF TLDs (3.1 × 3.1 × 0.8 mm) in a water-equivalent solid phantom (Solid Water; Radiation Measurement, Inc., Middleton, WI). The regular TLDs, which are larger, were used for the points relatively far away from the source so that adequately high responses could be obtained. The measurements were performed in three types of experimental setup, as shown in Fig. 1. The Solid Water phantom was machined to accommodate a Best model 2301 ^{125}I source and TLDs. In all of the measurements, at least 10 cm of phantom materials was placed around the source and TLDs.

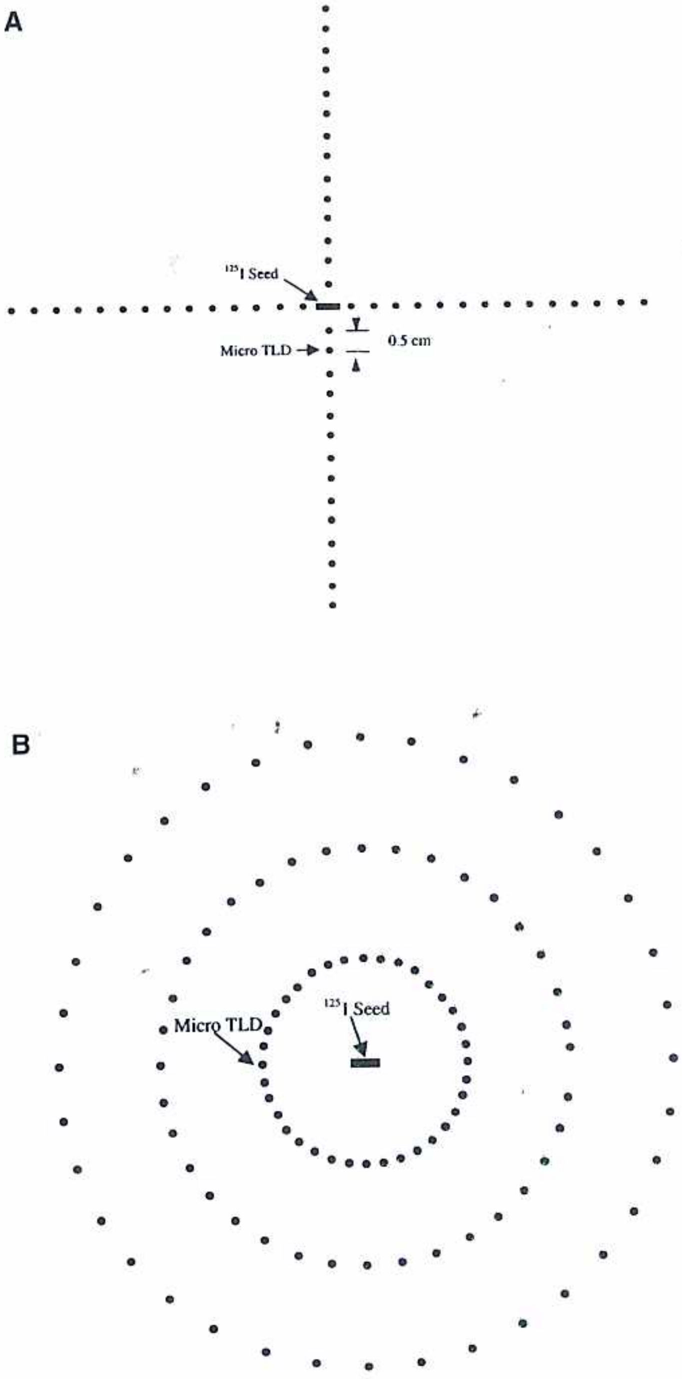

Fig. 1. Measurement setup for (A) dose rate constant and radial dose function and (B) anisotropy function. TLD = thermoluminescence dosimeter.

Before measurements, a group of the same type of TLDs was annealed at 400°C for 1 h and then was kept at room temperature for 45 min, followed by 80°C heating for 24 h. These TLDs were then irradiated uniformly with a large-cavity ^{137}Cs irradiator for biomedical research (Shepherd Mark I-68A CS-137 Irradiator, Mark, IL) so that the relative sensitivities (chip factors) of the individual TLDs were established. The annealing process was then repeated for the TLDs and after each measurement. The TLDs were calibrated with a 6-MV X-ray beam of a Varian 2100 C/D linear accelerator (Varian Medical Systems, Inc., Palo Alto, CA). The X-ray beam was calibrated with a PTW 0.6-ml Farmer-type cylindrical chamber (Physikalisch-Technische Werkstatten, Freiburg, Germany) according to AAPM TG-21 protocol (8). Because the response of TLD is energy dependent, a correction factor of 1.41 was used to correct the dependence of TLD sensitivity to ^{125}I photon energy (9). The measurements were performed by leaving a ^{125}I source in the source location for a certain amount of time so that the TLD at 1 cm away from the source center along the source central transverse axis received a dose of an estimated value in the range of 100–200 cGy. Because the energy spectra of the model 2301 ^{125}I source are closer to the model 6702 ^{125}I source, on the basis of Monte Carlo simulation by Williamson (10), a correction of approximately 3.6% is needed to derive the dose-rate constant of the ^{125}I

Table 1
Measured radial dose function of the Best ^{125}I source (model 2301)

Radial distance (cm)	$G(r,\pi/2)\times r^2$ (this work)	Correction factor converting the radial dose function in Solid Water to that in liquid water	Radial dose function: This work (in water)	Radial dose function: Meigooni *et al.*(4) (in Solid Water)	Radial dose function: Recommended
0.5	0.952	0.9789	1.046	1.048	1.047
1.0	0.987	0.9650	1.000	1.000	1.000
1.5	0.994	0.9548	0.938	0.899	0.919
2.0	0.997	0.9415	0.876	0.824	0.850
2.5	0.998	0.9207	0.773	—	0.773
3.0	0.999	0.9204	0.693	0.683	0.688
3.5	0.999	0.9038	0.596	—	0.596
4.0	0.999	0.8872	0.528	0.522	0.525
4.5	0.999	0.8759	0.458	—	0.458
5.0	0.999	0.8647	0.406	0.358	0.382
5.5	1.000	0.8525	0.371	—	0.371
6.0	1.000	0.8403	0.311	0.287	0.299
6.5	1.000	0.8280	0.286	—	0.286
7.0	1.000	0.8158	0.240	0.208	0.224
8.0	1.000		—	0.159	0.159
9.0	1.000		—	0.115	0.115
10.0	1.000		—	0.083	0.083

source in water from the measured dose-rate constant in Solid Water. Similarly, a radial distance-dependent correction factor is needed to derive the radial dose function in liquid water from the Solid Water measurements (10). The values of the correction factor are listed in Table 1. In this study, these correction factors were applied to account for the use of Solid Water instead of water.

The air kerma strength of ^{125}I, traceable to the NIST 1999 standard, was provided by the manufacturer. It was subsequently corrected by NIST in 2000. The year 2000–corrected values were used in this study. Six sources were used in approximately 15 measurements. Assuming that the nominal dose measured with TLD at a point of interest (r,θ) was $D(r,\theta)$, that the air kerma strength was S_{ko} at a reference time T_o, that the measurement starting time was T_i, and that the measurement finishing time was T_f (the time when the source was removed from the Solid Water phantom), then the initial dose rate per unit air kerma strength in water at the point of interest was calculated as

$$\dot{D}(r,\theta) = \frac{1.036\times D(r,\theta)}{1.41\times S_{ko}\times e^{-\lambda(T_i-T_o)}\times\frac{1}{\lambda}\times(1-e^{-\lambda(T_f-T_i)})}, \qquad (1)$$

where λ is the decay constant of ^{125}I and equals ln2/59.6 (per day) or ln2/1430.4 (per hour).

On the basis of Eq. 1 and the recommendation of AAPM TG-43 (7), the dose-rate constant of the Best model 2301 ^{125}I source was calculated as

$$\Lambda = \frac{1.036\times D\left(r_o,\frac{\pi}{2}\right)}{1.41\times S_{ko}\times e^{-\lambda(T_i-T_o)}\times\frac{1}{\lambda}\times(1-e^{-\lambda(T_f-T_i)})}. \qquad (2)$$

The radial dose function of the source was calculated as

$$g(r) = \frac{\dot{D}(r,\pi/2)\times G(r_o,\pi/2)\times R(r_o)}{\dot{D}(r_o,\pi/2)\times G(r,\pi/2)\times R(r)}, \qquad (3)$$

where $\dot{D}(r,\pi/2)$ and $\dot{D}(r_o,\pi/2)$ were the measured initial dose rates at radial distances r and r_o along the central transverse axis of the source, respectively. The reference distance r_o was taken to be 1.0 cm. $R(r)$ and $R(R_o)$ are the correction factors listed in Table 1 at radial distances r and r_o, respectively. $G(r,\pi/2)$ and $G(r_o,\pi/2)$ were the geometry functions at a radial distance of r and r_o along the central transverse axis of the source, respectively. The geometry functions were calculated by assuming that the source was a line source with a length of L and as

$$G(r,\theta) = \frac{\tan^{-1}\left(\frac{r\cos\theta+L/2}{r\sin\theta}\right)-\tan^{-1}\left(\frac{r\cos\theta-L/2}{r\sin\theta}\right)}{Lr\sin\theta} \qquad (4)$$

when $90^\circ \geq \theta > 0$ and as

$$G(r,\theta) = \frac{\frac{1}{r-L/2}-\frac{1}{r+L/2}}{L} \qquad (5)$$

when $\theta = 0$. In Eqs. 4 and 5, L is the active length of the source and was taken as 3.95 mm in this study. Because the source was constructed to be symmetric to the central transverse axis, the geometry functions at θ angles other than $90^\circ \geq \theta \geq 0$ can be easily derived from the previous two equations (Table 1).

Anisotropy function accounts for the variation of dose rate around the source at each distance and was calculated on the basis of the formalism in AAPM TG-43 as

$$F(r,\theta) = \frac{\dot{D}(r,\theta) \times G(r,\pi/2)}{\dot{D}(r,\pi/2) \times G(r,\theta)}. \tag{6}$$

Because in the clinical applications, the radioactive sources are often considered as point sources for dosimetry calculation, a quantity anisotropy factor is used in the place of anisotropy function to simplify dose calculation. The anisotropy factor is the ratio of the dose rate at distance r, averaged with respect to solid angle, to dose rate on the central transverse axis at the same distance. It usually changes slightly with radial distance and can be calculated as

$$\begin{aligned}\phi_{an}(r) &= \int_0^{4\pi} \frac{G(r,\theta)F(r,\theta)}{4\pi G(r,\theta_o)} d\Omega = \int_0^{\pi} \frac{G(r,\theta)F(r,\theta)}{2G(r,\theta_o)} \sin\theta d\theta \\ &= \frac{\int_0^{\pi} \dot{D}(r,\theta) \sin\theta d\theta}{2\dot{D}(r,\pi/2)}.\end{aligned} \tag{7}$$

To further simplify the dose calculation, the anisotropy factor can be replaced with a distance-independent constant, the anisotropy constant θ. The anisotropy constant was computed as

$$\bar{\phi}_{an} = \frac{\sum D(r)\phi_{an}(r)}{\sum D(r)}. \tag{8}$$

After radial dose function, anisotropy function, anisotropy factor, and anisotropy constant were determined, the dose rate at any point by the same type of source can then be calculated as

$$\begin{aligned}\dot{D}(r,\theta) &= S_k \Lambda \frac{G(r,\theta)}{G(r_o,\theta_o)} g(r) F(r,\theta) \\ &\approx S_k \Lambda \frac{G(r,\theta_o)}{G(r_o,\theta_o)} g(r) \phi_{an}(r) \\ &\approx S_k \Lambda \frac{G(r,\theta_o)}{G(r_o,\theta_o)} g(r) \bar{\phi}_{an}.\end{aligned} \tag{9}$$

Results

Dose-rate constant

The average value of the dose-rate constant from our measurements of the Best ^{125}I source (model 2301), after being converted to that in water, was 1.02 cGy·h^{-1}·U^{-1}.

Radial dose function

The radial dose function of the Best ^{125}I source (model 2301) was measured from a radial distance of 0.5 cm up to 7.0 cm with a step size of 0.5 cm (Fig. 1A). The measured results, converted to those in water, are presented in Table 1. Our data are in excellent agreement with those of Meigooni *et al.* (4). Therefore, we recommend the use of an average of our data and those of Meigooni *et al.* The recommended radial dose function was fitted to a fifth-order polynomial function as

$$g(r) = a_0 + a_1 r + a_2 r^2 + a_3 r^3 + a_4 r^4 + a_5 r^5, \tag{10}$$

where $a_0 = 1.0579$, $a_1 = 0.01768$, $a_2 = -0.09673$, $a_3 = 0.02159$, $a_4 = -0.001972$, and $a_5 = 0.00006649$. The polynomial function should be used only for distances of 0.5 to 10 cm.

Anisotropy function, anisotropy factors, and the anisotropy constant

The anisotropy function of the Best ^{125}I source (model 2301) was measured at radial distances of 2, 4, and 6 cm and at different θ angles from 0 to 90° at 10° intervals (Fig. 1B). Because sources were assumed to be symmetric relative to the central axes, the results were averaged relative to the central axes. The measured anisotropy functions are listed in Table 2. The derived anisotropy factor based on Eq. 7 is presented in Table 3. The anisotropy constant was computed according to Eq. 8, and an average value was obtained for distances from r = 2.0 cm to r = 6.0 cm. The dose-weighted average value of the anisotropy constant was 0.96.

Table 2
Measured anisotrophy function of the Best ^{125}I source (model 2301)

		Angle θ (°)									
Variable	r (cm)	90	80	70	60	50	40	30	20	10	0
This work	2	1.000	1.039	1.020	0.974	0.980	0.915	0.882	0.779	0.706	0.972
	4	1.000	0.998	0.979	0.993	0.947	0.905	0.850	0.807	0.757	0.993
	6	1.000	1.023	1.014	0.933	1.003	0.904	0.868	0.858	0.770	0.960
Meigooni *et al.* (4)	2	1.000	1.038	1.010	0.998	1.016	0.919	0.892	0.829	0.828	0.850
	5	1.000	1.045	1.018	1.019	0.986	0.980	0.930	0.821	0.792	0.911
	7	1.000	1.016	1.007	1.008	0.964	0.943	0.942	0.804	0.750	0.944
Recommended	2	1.000	1.039	1.015	0.986	0.998	0.917	0.887	0.804	0.767	0.911
	4	1.000	0.998	0.979	0.993	0.947	0.905	0.850	0.807	0.757	0.993
	5	1.000	1.045	1.018	1.019	0.986	0.980	0.930	0.821	0.792	0.911
	6	1.000	1.023	1.014	0.933	1.003	0.904	0.868	0.858	0.770	0.960
	7	1.000	1.016	1.007	1.008	0.964	0.943	0.942	0.804	0.750	0.944

Table 3
Anisotropy factor of the Best ^{125}I source (model 2301)

	Anisotropy factor		
Radial distance (cm)	This work	Meigooni *et al.*(4)	Recommended
2	0.96	0.99	0.98
4	0.94	—	0.94
5	—	0.99	0.99
6	0.96	—	0.96
7	—	0.97	0.97
Anisotropy constant	0.96	0.98	0.97

Discussion

Uncertainty analysis

In the determination of the dose-rate constant of the Best model 2301 ^{125}I source, there were two major categories of uncertainty: uncertainty in the measurement of dose by using TLDs and uncertainty in the measurement of air kerma strength at the calibration laboratory. It was estimated that the uncertainty in the measurement of air kerma strength was approximately 0.5%. The various sources of uncertainties in dose measurement with TLDs and their estimates are summarized in Table 4. The statistical uncertainty (type A) resulting from repetitive TLD measurements was approximately 3% in our measurement. The type B uncertainty (systematic uncertainties) resulting from the misplacement of sources in the phantom was approximately 1%. The type B uncertainty in the calibration of TLDs was approximately 3%, which included the uncertainty in the calibration of the 6-MV X-ray beam. The uncertainty in the energy dependence of LiF TLDs was approximately 5%, and the uncertainty in the factor that converts dose from Solid Water to water was approximately 3%. Therefore, the overall uncertainty in the determination of dose was estimated to be approximately 7%. Because the uncertainty in the measurement of air kerma strength (0.5%) was much smaller than 7%, the overall uncertainty in the determination of the dose-rate constant was also estimated to be 7%. Thus, the dose-rate constant of the Best model 2301 ^{125}I source determined in our measurement was 1.02 ± 0.07 cGy·h^{-1}·U^{-1}. In the determination of radial dose function and anisotropy function, the statistical uncertainty in the measurement was approximately 4%. The type B uncertainty due to misplacement of sources was approximately 2%. The uncertainty in the chip factors of TLDs was approximately 2%. Conversion from Solid Water to water introduced approximately 3% uncertainty. Because the measurement of radial dose function and anisotropy function was relative, the 6-MV beam calibration and TLD energy dependence did not contribute to the uncertainty. Therefore, the overall uncertainty in the determination of radial dose function and anisotropy function was approximately 6%.

Table 4
Uncertainties in dose-rate measurement using TLDs (1SD)

Component	Type A uncertainty (%)	Type B uncertainty (%)
Repetitive TLD measurements (n = 11 seeds)	3%	—
Seed and TLD positioning	—	1%
TLD dose calibration	—	3%
Correction of energy dependence of LiF (factor 1.41)	—	5%
Correction for Solid Water to liquid water (factor 1.036)	—	3%
Combined uncertainty		7%

TLD = thermoluminescence dosimeter.

Dose-rate constant comparisons

In 1999, NIST established air kerma strength standards for several designs of low-energy (^{103}Pd and ^{125}I) brachytherapy sources based on the WAFAC. In 2000, NIST determined that many of the low-energy source calibrations performed during 1999, including the newly designed Best model 2301 ^{125}I sources, were in error by 3% to 5% because of a malfunction of the WAFAC. The dose-rate constant reported in this study was derived on the basis of the year 2000–corrected air kerma strength for the Best model 2301 ^{125}I source, whereas the dose-rate constant 1.01 cGy·h^{-1}·U^{-1} reported by Meigooni *et al.* (4) (Table 5) was based on the NIST 1999 air kerma strength standard for low-energy photon sources before the correction occurred. If the dose-rate constant reported by Meigooni *et al.* is corrected for the NIST 1999 air kerma strength standard error, the dose-rate constant becomes 1.05 cGy·h^{-1}·U^{-1}. This is the value in current use for the Best model 2301 ^{125}I sources and is the reported value in the product information sheet prepared and distributed by Best Industries (11). Recently, Meigooni *et al.* reported a more accurate correction for the use of Solid Water in their experiments. They recommend a final corrected value of 1.03 cGy·h^{-1}·U^{-1} for the measured dose-

Table 5
Various values of the dose-rate constants for the Best model 2301 ^{125}I source

Study	Air kerma standard used	Method	Dose-rate constant (cGy·h^{-1}·U^{-1})
Meigooni *et al.*(4)	NIST 1999	Measurement	1.01
Meigooni *et al.*(11)	NIST 2000	Measurement	1.05
Meigooni and Sowards (12)	NIST 2000	Measurement	1.03
This study	NIST 2000	Measurement	1.02
Average of the measured values	NIST 2000	Measurement	1.025
Sowards and Meigooni (13)	NIST 2000	Monte Carlo	1.01
Averge of the measured and the calculated values	NIST 2000	Recommended	1.02

NIST = National Institute of Standards and Technology.

Table 6
Dose-rate constants for various ^{125}I sources

Source	Air kerma standard used	Study	Dose-rate constant ($cGy \cdot h^{-1} \cdot U^{-1}$)
Model 6711/ Nycomed(14)	NIST 1999	AAPM 1999	0.98
Model 6702/ Nycomed(14)	NIST 1999	AAPM 1999	1.04
Model 12501/ Imagyn(15)	NIST 2000	Nath and Yue 2000	0.95
Model 12501/ Imagyn(16)	NIST 1999	Gearheart *et al.* 2000	0.88
Model 2301/Best	NIST 2000	Recommended	1.02

NIST = National Institute of Standards and Technology; AAPM = American Association of Physicists in Medicine.

rate constant from their study (12). This is very similar to the dose-rate constant (1.02 $cGy \cdot h^{-1} \cdot U^{-1}$) reported in our study. Therefore, the average value for the two measured dose-rate constants of the Best ^{125}I model 2301 source is 1.025 $cGy \cdot h^{-1} \cdot U^{-1}$.

Recently, Sowards and Meigooni (13) reported a Monte Carlo calculated value of 1.01 $cGy \cdot h^{-1} \cdot U^{-1}$ for the Model 2301 ^{125}I source. AAPM recommends that the average of measured values and the average of calculated values be averaged with equal weight. This procedure then results in a recommended value of 1.02 $cGy \cdot h^{-1} \cdot U^{-1}$ for the dose-rate constant of model 2301 ^{125}I sources. The various dose-rate constants discussed are listed in Table 5.

Table 6 lists the dose-rate constants of several types of ^{125}I sources. The dose-rate constants of ^{125}I model 6711 and 6702 sources are 0.98 $cGy \cdot h^{-1} \cdot U^{-1}$ and 1.04 $cGy \cdot h^{-1} \cdot U^{-1}$, respectively (14). These dose-rate constants were measured and corrected on the basis of the NIST 1999 standard. The measured dose-rate constant of the Best ^{125}I model 2301 source falls in between the dose-rate constants of ^{125}I model 6711 and 6702 sources and is considerably higher than that of the ^{125}I Imagyn model 12501 source (Table 6) (15, 16). The measured dose-rate constant for the Best model 2301 ^{125}I source is closer to that of the ^{125}I model 6702 source than to the ^{125}I model 6711 source.

As pointed out previously, the effective photon energy from a silver-based ^{125}I source is expected to be lower than that for the ^{125}I source on a tungsten substrate, assuming similar encapsulations in source construction. As pointed out by Chen and Nath (17), the addition of the two low-energy fluorescent X-rays from the silver in the ^{125}I model source leads directly to a reduction in the dose-rate constant, and therefore it should be expected that the dose-rate constant of the Best model 2301 ^{125}I source is higher than that of the ^{125}I model 6711 source.

Radial dose function comparisons

Figure 2 shows the comparison of radial dose functions of different types of ^{125}I sources. The radial dose function measured by Meigooni *et al.* (4) for the Best model 2301 source is also displayed. All the radial dose functions are quite similar. However, it seems that the radial dose function of the Best

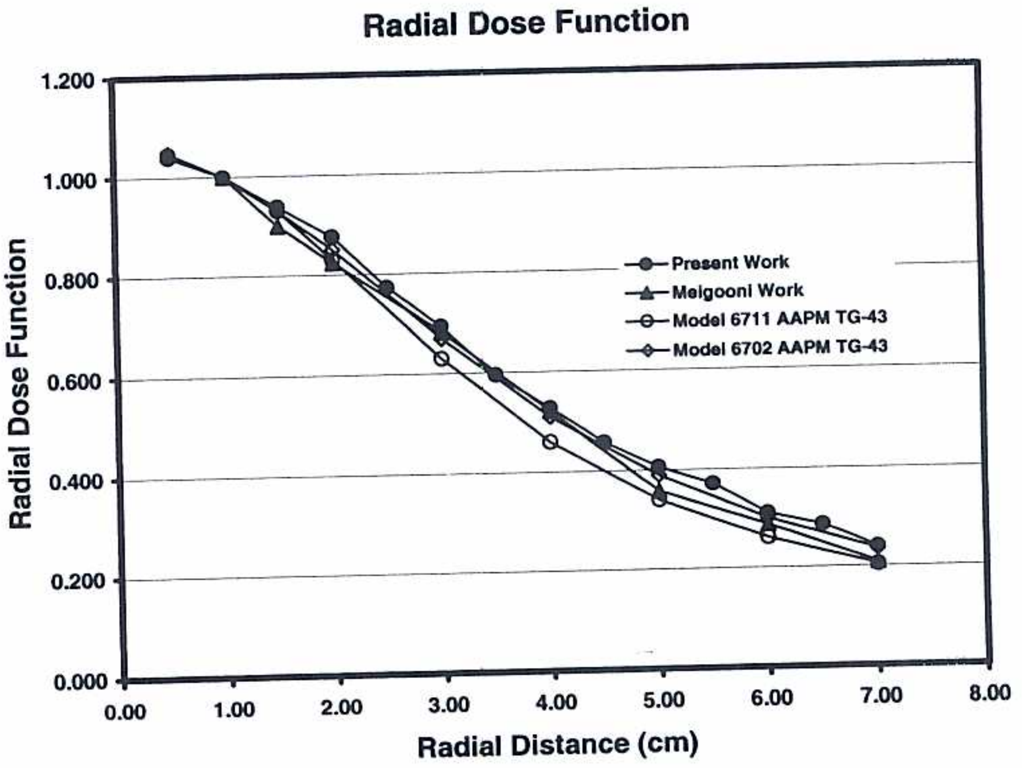

Fig. 2. Comparison of radial dose functions of different types of ^{125}I sources. AAPM = American Association of Physicists in Medicine.

model 2301 ^{125}I source is slightly higher than that of the model 6711 ^{125}I source at almost all distances and is fairly close to that of the model 6702 ^{125}I source.

Both the Best model 2301 ^{125}I source and the Nycomed ^{125}I model 6711 source contain a rod-type marker. However, the ^{125}I model 6702 source and the ^{125}I Imagyn model 12501 source use sphere-type markers, and ^{125}I radioisotope resides on the markers. As discussed in the study by Karaiskos *et al.* (18), a line source approximation in the calculation of the geometry factor could introduce significant errors for sources consisting of several active pellets if the radial distance is less than 3 mm. However, as radial distance increases beyond 5 mm, a line source is a good approximation (within 3%), not only for the source using rod-type markers, but also for the sources using sphere-type markers. In this study, all the points of interest are beyond 5 mm. Therefore, the line source approximation does not introduce significant errors.

Anisotropy function comparisons

Figure 3 shows the comparisons among anisotropy functions for different types of ^{125}I sources at 2, 4, and 6 cm, respectively. At 2 cm, when the angle θ is larger than 40°, the anisotropy functions are very similar for most types of sources (model 6711, model 6702, and Best model 2301). As θ becomes smaller and smaller, or, in other words, as the point of interest becomes closer to the central longitudinal axis, the anisotropy function of the Best model 2301 source starts to differ from the other types of ^{125}I sources. Instead of decreasing monotonically with θ, as do other types of sources, the anisotropy function of the Best model 2301 source reached its minimum at approximately 10° and then started to increase as θ decreased. At 4 and 6 cm, the anisotropy function of the Best model 2301 ^{125}I source showed similar characteristics. The unique characteristics in the anisotropy function of the Best model 2301 ^{125}I source are due to the special design in the source construction. The model 2301 source was made with double titanium encapsulation, and the double encapsulation was designed to provide thinner walls at both ends of the source. Also, there is radioactive material on the flat ends of the tungsten cylinder in the source. Such a design allows a higher dose along the longitudinal axis of a source than other types of sources.

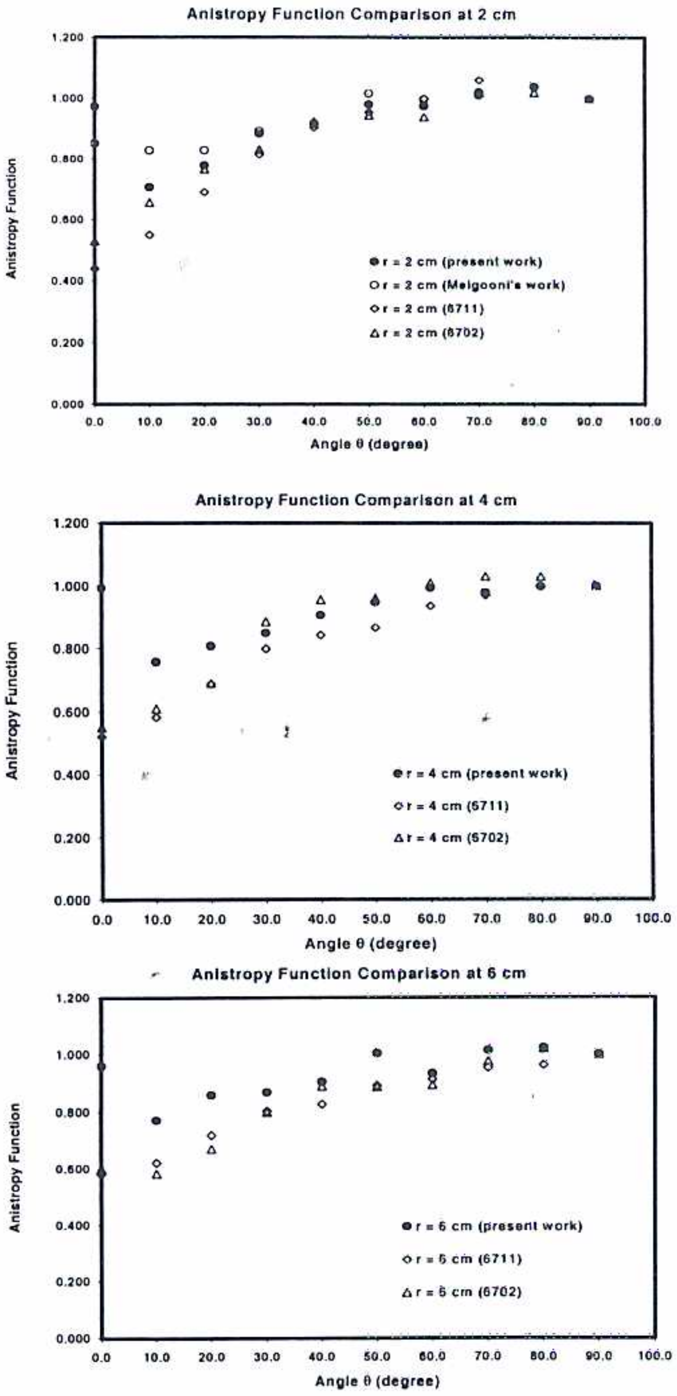

Fig. 3. Comparison of anisotropy functions of different types of ^{125}I source at radial distances of 2, 4, and 6 cm, respectively.

Conclusions

Dose distributions around a Best model 2301 ^{125}I source were measured with LiF TLD chips. The dosimetric characteristics of the sources were determined on the basis of the AAPM TG-43 formalism. It was found that the dose-rate constant of a Best model 2301 ^{125}I source was 1.02 $cGy \cdot h^{-1} \cdot U^{-1}$, and its radial dose function was slightly higher than that of the model 6711 ^{125}I source and similar to that of the model 6702 ^{125}I source. The anisotropy function of a Best model 2301 ^{125}I source was unique in that instead of decreasing monotonically with θ, it reached the minimum around θ = 10° and then increased as θ decreased to 0°.

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