ELSEVIER

Brachytherapy 1 (2002) 227–232

BRACHYTHERAPY

A Monte Carlo evaluation of the dosimetric characteristics of the EchoSeed™ Model 6733 ^{125}I brachytherapy source

Keith T. Sowards, Ali S. Meigooni*

Department of Radiation Medicine, University of Kentucky Chandler Medical Center, Lexington, KY, USA

Abstract

Purpose: Recently a new design of a ^{125}I brachytherapy source was introduced for interstitial seed implants, particularly for prostate seed implants. This new source is the EchoSeed™Model 6733 ^{125}I brachytherapy source. Due to the differences in source design and manufacturing process from one new source to the next, their dosimetric parameters should be determined according to the American Association of Physicists in Medicine (AAPM) TG-43 guidelines.

Methods and Materials: As per AAPM recommendation, it is required to perform at least one experimental study and one Monte Carlo simulation, preferably done by two independent investigators. Other investigators have experimentally determined the dosimetric parameters of this new source. In this project, the Monte Carlo simulated dosimetric parameters of the EchoSeed™ Model 6733 source have been provided.

Results: The results of this evaluation indicate the value of the dose rate constant of 0.97 $\pm$ 3% $cGyh^{-1}U^{-1}$ in liquid water, which is in good agreement with the measured value of 0.99 $\pm$ 8% $cGyh^{-1}U^{-1}$ reported by Meigooni *et al*. The anisotropy constant of the EchoSeed™ ^{125}I brachytherapy source was found to be 0.960 in liquid water.

Conclusions: The Monte Carlo Simulated TG-43 dosimetric parameters of the EchoSeed™ were determined and the results were compared with the published measured data.

Keywords: Dosimetry, Brachytherapy, ^{125}I, TG-43, Monte Carlo simulation

Introduction

Before 1987, a free-hand interstitial implant (1) was one of the techniques used to treat prostate cancer. This technique was performed in a few institutions by a limited number of radiation oncologists. However, the advent of the use of an ultrasound-guided technique during the prostate seed implant has greatly increased the demand for this procedure (2). Due to the increase in the number of patients treated with this procedure worldwide, a number of new sources have recently become available. One such source is the EchoSeedT™Model 6733 ^{125}I brachytherapy source, designed and manufactured by Nycomed/Amersham[1]. This design enhances the visualization of the seeds for interstitial prostate implants. The external surface of this source has several circular grooves, which improves the ultrasound signature of the source over a wider range of angular orientation.

As recommended by Williamson *et al*. (3), two independent investigators should evaluate dosimetric characteristics of the new ^{125}I and ^{103}Pd sources, using experimental and Monte Carlo methods. Meigooni *et al.* (4) has published an experimental evaluation of the dosimetric parameters of the EchoSeed™Model 6733 ^{125}I source, using thermoluminescent detectors (TLDs). However, to date no investigator has published a Monte Carlo evaluation of this source.

The goal of this study is to provide an independent Monte Carlo simulation of the dosimetric characteristics of the EchoSeed™ Model 6733 ^{125}I source. These parameters include the dose rate constant, radial dose function, a fifth order fit to the radial dose function, anisotropy function, anisotropy factors, and anisotropy constant.

Methods and materials

Source

The EchoSeed™ Model 6733 ^{125}I source is shown in Fig. 1. The source has a physical length of 4.5 mm and an outer diam-

Received 19 June 2002; received in revised form 25 November 2002; accepted 29 November 2002.

* Corresponding author. University of Kentucky, A.B. Chandler Medical Center, Department of Radiation Medicine. 800 Rose Street, Lexington, KY 40536-0084. Tel.: +1-859-323-0284; fax: +1-859-257-4931.

E-mail address: alimeig@uky.edu (A.S. Meigooni).

[1]Amersham Place, Little Chalfont, Buchinghamshire, HP7 9NA, United Kingdom.

1538-4721/03/$ – see front matter
doi:10.1016/S1538-4721(02)00102-2

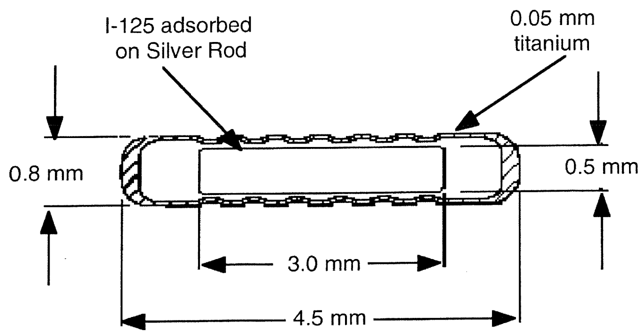

Fig. 1. A schematic diagram of the EchoSeed™Model 6733 ^{125}I Brachytherapy Source.

eter of 0.8 mm. The source was manufactured by placing a 3.0 mm long and 0.5 mm diameter silver cylinder coated with ^{125}I inside a titanium tube with walls 0.05 mm thick. The outer capsule is "threaded" like a screw with 6 "threads." The two ends of the outer cylindrical tube are laser welded. The source is available in activities of 0.2 mCi to 5.0 mCi.

Monte Carlo Simulation Method

The Monte Carlo computer simulation technique has become an invaluable tool in the dosimetry of brachytherapy sources in the last several years. Various investigators currently use several different Monte Carlo codes for dosimetry in the brachytherapy field. In this project, we have used the PTRAN Version 7.43 Monte Carlo code developed by Williamson and described in detail in several publications (5–8). In these publications, Williamson (5) has shown that by introducing the precise internal and external geometric and chemical compositions of the source to the PTRAN Monte Carlo code, one can accurately reproduce the experimental data for any brachytherapy source. The PTRAN code simulates photoelectric absorption followed by K and L shell characteristic X-ray emission as well as coherent and incoherent scattering. The photon cross section used in these simulations was DLC-99 (Data Library Code-99) (9) that was distributed by the Radiation Sciences Information Computing Center (RSICC) at Oak Ridge National Laboratory. The mass energy absorption coefficients used were obtained from Hubbell and Seltzer (10) and the primary ^{125}I spectrum was obtained from NCRP 58 (11). With this code, one can calculate the collisional kerma at a point located in the phantom material in units of cGy/mCi-hr. In these calculations, the activity of a given isotope is estimated by dividing the total number of photons that was used in the simulation to the number of photons per disintegration. A quotient of the calculated collisional kerma in a medium to air eliminates the role of source activity in these calculations, and the final dose rate at a given distance is expressed in units of cGy $h^{-1}U^{-1}$, where $1U = 1cGy\ cm^2\ h^{-1}$. For low-energy emitters such as ^{125}I, charged particle equilibrium can be assumed at the point of the calculation. This assumption implies that the collisional kerma closely approximates absorbed dose.

In this project the dose distribution of the EchoSeedT™ Model 6733 ^{125}I source was calculated using the PTRAN code in Solid Water™ and liquid water following TG-43 recommendation (12). Simulations were performed for a total of 2,100,000 histories divided into 65 batches. This number of histories combined with the use of the distance and attenuation averaged bounded next flight point kerma estimator (7), resulted in standard errors about the mean (67% confidence intervals) ranging from 1.5% (near the source: $r < 3$ cm) to 5–6% (far from the source: $r > 5$ cm). The phantom size in these simulations was comparable with the experimental setups. The composition of the Solid Water™ and their percent by weight were H: 8%, C: 67.2%, N: 2.4%, O: 19.8%, Ca: 2.3%, Cl: 0.1% (13). Density of the Solid Water™ was 1.015 g cm^{-3}.

Dose distributions were calculated in both Solid Water™ and water phantom materials, comparable with the TLD measurement technique. To verify the accuracy of the simulated source geometry, the simulated data in Solid Water™ were compared with the experimental data published by Meigooni *et al.* (4). Once the Monte Carlo simulations in Solid Water™ were shown to be in good agreement with the TLD data (4), the calculations were performed in liquid water.

Dosimetry technique

The dose rate constant, Λ, of the brachytherapy source is defined in the AAPM TG-43 (12) report as the dose rate per unit air kerma strength (S_K) at a reference point along the trans-

Table 1
A comparison of the calculated and measured dose rate constant (Λ) of the EchoSeed™ Model 6733 ^{125}I brachytherapy source

Reference	Method	Medium	Dose rate constant (Λ) ($cGyh^{-1}U^{-1}$)
This work	Monte Carlo	Solid Water™	0.94
This work	Monte Carlo	liquid water	0.97
EchoSeed™ Model 6733 ^{125}I (3)	TLD	Solid Water™	0.95
EchoSeed™ Model 6733 ^{125}I (3)	TLD	liquid water	0.99*
Model 6711 (5)	Monte Carlo	liquid water	0.98
MED3631 A/M ^{125}I (15)	Monte Carlo	liquid water	1.07
PharmaSeed™ (BT-125-I) (16)	Monte Carlo	liquid water	0.95

TLD = thermoluminescent dosimeter.
*Determined by applying a 1.05 correction factor to the TLD measured data in Solid Water™ (5).

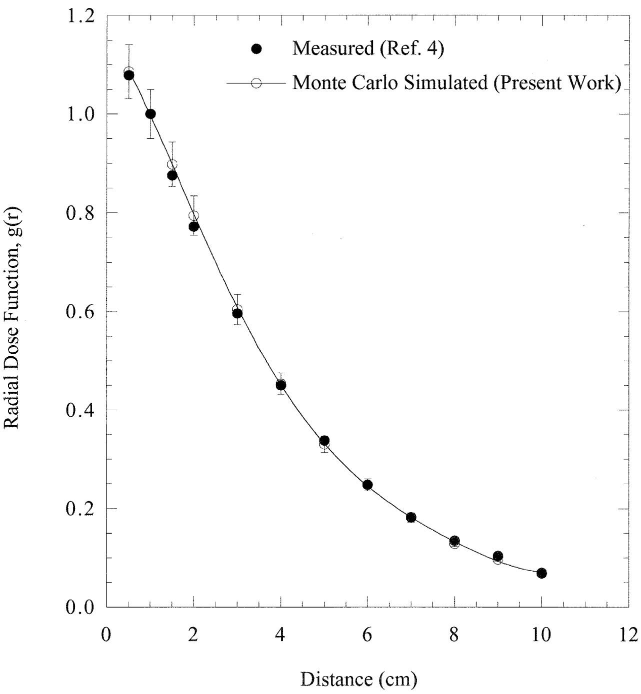

Fig. 2. A comparison of the calculated and measured radial dose functions of the EchoSeed™ Model 6733 ^{125}I Brachytherapy Source, in Solid Water™. The solid curve is a fifth-order polynomial fit to the present data.

verse bisector of the source. The unit of the dose rate constant is $cGyh^{-1}U^{-1}$, where U is the air kerma strength of the source and is defined as $1U = 1\mu Gym^2h^{-1} = 1cGycm^2h^{-1}$. The dose rate constant is calculated as follows:

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

The Monte Carlo simulated dose rate constant was obtained by calculating the kerma rate to water at the reference point (1 cm, π/2) in a medium and dividing that by the simulated air kerma strength of the source. S_K was determined by calculating air kerma rate at 5 cm (to closely simulate the NIST measured value) distance and correcting for the inverse square of the distance to obtain the value at 1 cm.

$$S_K = \dot{K}_{air}(1\ \text{cm}) = \dot{K}_{air}(5\ \text{cm}).5^2 \quad (2)$$

This calculation was repeated for several distances up to 25 cm from the source center, and no significant differences from the 5 cm data were found. For the simulations in air, the titanium characteristic X-ray production was suppressed within the code.

The radial dose function, g(r), is defined in AAPM TG-43 (12) as:

$$g(r) = \frac{\dot{D}(r, \pi/2) \cdot G(1\ \text{cm}, \pi/2)}{\dot{D}(1\ \text{cm}, \pi/2) \cdot G(r, \pi/2)} \quad (3)$$

Where $\dot{D}(r, \pi/2)$ and $\dot{D}(1\ \text{cm}, \pi/2)$ are the dose rates calculated at distances of r and 1 cm, respectively, along the transverse bisector of the source. G (r, π/2) is the geometry factor of the source calculated using linear source approximation. This factor takes into account the effect of the distribution of the radioactive material along the source. The active length used to calculate the geometry factor of the EchoSeed™ Model 6733 ^{125}I source was 3.0 mm.

The anisotropy function of the source is defined as:

$$F(r, \theta) = \frac{\dot{D}(r, \theta) \cdot G(r, \pi/2)}{\dot{D}(r, \pi/2) \cdot G(r, \theta)} \quad (4)$$

Monte Carlo simulations were performed in Solid Water™ at angles ranging from 0° to 180° in intervals of 10° and distances of 2, 3, 5 and 7 cm from the source. These results were then compared to the published data measured in Solid Water™. A good agreement (i.e., within the experimental uncertainty) between the measured and calculated anisotropy function was assumed to indicate the correct source geometry during the Monte Carlo simulations. Therefore, Monte Carlo simulations were repeated in liquid water at distances ranging from 1 to 7 cm from the source and angles

Table 2
A comparison of the calculated and measured radial dose function of the EchoSeed™ Model 6733 ^{125}I brachytherapy source

Distance, r (cm)	Measured, solid water™ (4)	Calculated, solid water™	Calculated, liquid water
0.10			1.050
0.15			1.076
0.20			1.082
0.25			1.085
0.30			1.090
0.40			1.081
0.50	1.078	1.086	1.069
0.60			1.058
0.70			1.055
0.75			1.045
0.80			1.036
0.90			1.018
1.00	1.000	1.000	1.000
1.50	0.875	0.898	0.912
2.00	0.772	0.794	0.821
2.50			0.731
3.00	0.596	0.604	0.656
3.50			0.568
4.00	0.450	0.453	0.495
4.50			0.430
5.00	0.338	0.330	0.379
5.50			0.327
6.00	0.248	0.248	0.285
6.50			0.241
7.00	0.182	0.181	0.214
7.50			0.186
8.00	0.134	0.128	0.155
8.50			0.137
9.00	0.104	0.097	0.119
9.50			0.096
10.0	0.068	0.070	0.084

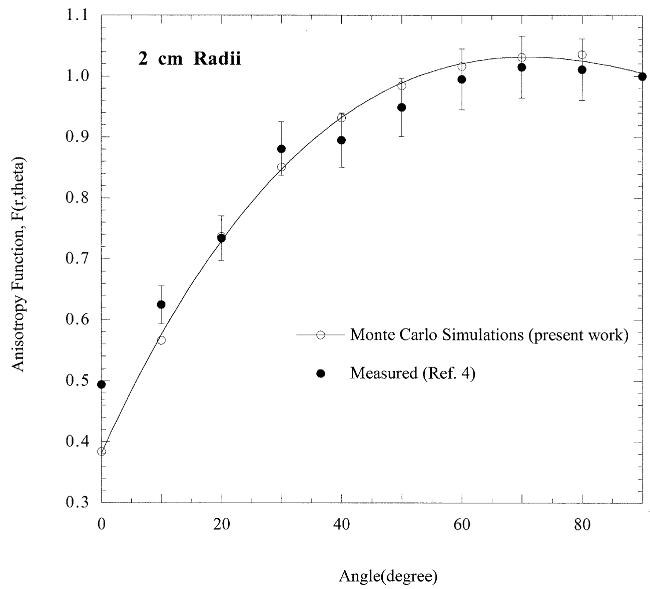

Fig. 3. A comparison of the calculated and measured anisotropy function in Solid Water™ at 2 cm distance for the EchoSeed™ Model 6733 ^{125}I Brachytherapy Source. The solid curve is a fourth-order polynomial fit to the present data.

ranging from 0° to 180° in intervals of 5°. The anisotropy factors, ϕ_{an} (r), at each radial distance were calculated from the simulated dose rate distributions as a function of angle, in both water and Solid Water™ following the TG-43 recommendation (12). The anisotropy constant, $\overline{\phi}_{an}$, was determined by averaging of the individual anisotropy factors for a given medium.

Results and discussion

Monte Carlo simulated TG-43 parameters for the EchoSeed™ Model 6733 ^{125}I have been determined as per AAPM requirements for new low-energy brachytherapy sources. Table 1 shows a comparison between the Monte Carlo simulated dose rate constant of this source and the published values for this source as well as other commercially available sources (5, 15, 16). The simulated Λ in Solid Water™ was found to be 0.94 ± 3% $cGyh^{-1}U^{-1}$. The value for the Model 6733 seed was in excellent agreement with the measured dose rate constant of 0.95 ± 8% $cGyh^{-1}U^{-1}$ by Meigooni *et al.* (4) As per TG-43 recommendations (12) dose rate constant of the EchoSeed™ Model 6733 ^{125}I source was simulated in water and it was found to be 0.97 ± 3% $cGyh^{-1}U^{-1}$. This value is in excellent agreement

Table 3
A comparison between the measured and calculated anisotropy functions of the EchoSeed™ Model 6733 ^{125}I brachytherapy source in Solid Water™ phantom material

	Meigooni *et al.* (4) (measured)				This Project (simulated)			
θ (deg)	2 cm	3 cm	5 cm	7 cm	2 cm	3 cm	5 cm	7 cm
0	0.494	0.510	0.518	0.525	0.384	0.446	0.516	0.541
10	0.625	0.611	0.631	0.700	0.566	0.609	0.659	0686
20	0.734	0.728	0.776	0.801	0.737	0.757	0.784	0.770
30	0.881	0.836	0.854	0.845	0.851	0.860	0.868	0.855
40	0.895	0.885	0.931	0.888	0.932	0.933	0.938	0.899
50	0.949	0.935	0.968	0.943	0.984	0.980	0.984	0.934
60	0.995	0.974	0.954	0.969	1.016	1.015	1.012	0.986
70	1.015	0.989	0.980	0.982	1.031	1.031	1.029	0.985
80	1.011	0.987	0.985	0.995	1.035	1.028	1.024	1.018
90	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
ϕ_{an} (r)	0.955	0.936	0.946	0.943	0.964	0.965	0.969	0.942
$\overline{\Phi}_{an}$	0.95 ± 5%				0.96 ± 3%			

Table 4
Monte Carlo calculated anisotropy function of the EchoSeed™ Model 6733 ^{125}I brachytherapy source in liquid water

θ (deg)	1 cm	2 cm	3 cm	4 cm	5 cm	6 cm	7 cm
0	0.305	0.397	0.451	0.502	0.533	0.551	0.565
5	0.386	0.468	0.510	0.557	0.586	0.595	0.611
10	0.507	0.570	0.609	0.634	0.660	0.669	0.685
15	0.621	0.663	0.680	0.712	0.717	0.726	0.719
20	0.714	0.738	0.743	0.774	0.769	0.779	0.785
25	0.787	0.800	0.801	0.830	0.824	0.819	0.819
30	0.848	0.851	0.849	0.873	0.859	0.860	0.880
35	0.900	0.897	0.888	0.905	0.893	0.894	0.918
40	0.944	0.933	0.918	0.932	0.921	0.912	0.924
45	0.977	0.961	0.946	0.955	0.941	0.934	0.932
50	0.999	0.985	0.969	0.983	0.953	0.965	0.949
55	1.017	1.005	0.980	0.992	0.972	0.978	0.971
60	1.029	1.015	0.995	1.012	0.985	1.003	0.982
65	1.035	1.026	1.010	1.016	0.994	0.996	0.979
70	1.038	1.033	1.015	1.022	1.001	0.994	1.019
75	1.039	1.033	1.019	1.032	1.013	0.997	1.002
80	1.026	1.034	1.014	1.026	1.009	0.999	1.000
85	1.000	1.020	1.009	1.019	1.010	1.012	0.997
90	1.000	1.000	1.000	1.000	1.000	1.000	1.000
ϕ_{an} (r)	0.967	0.964	0.953	0.966	0.953	0.948	0.955
$\overline{\Phi}_{an}$			0.96 ± 3%				

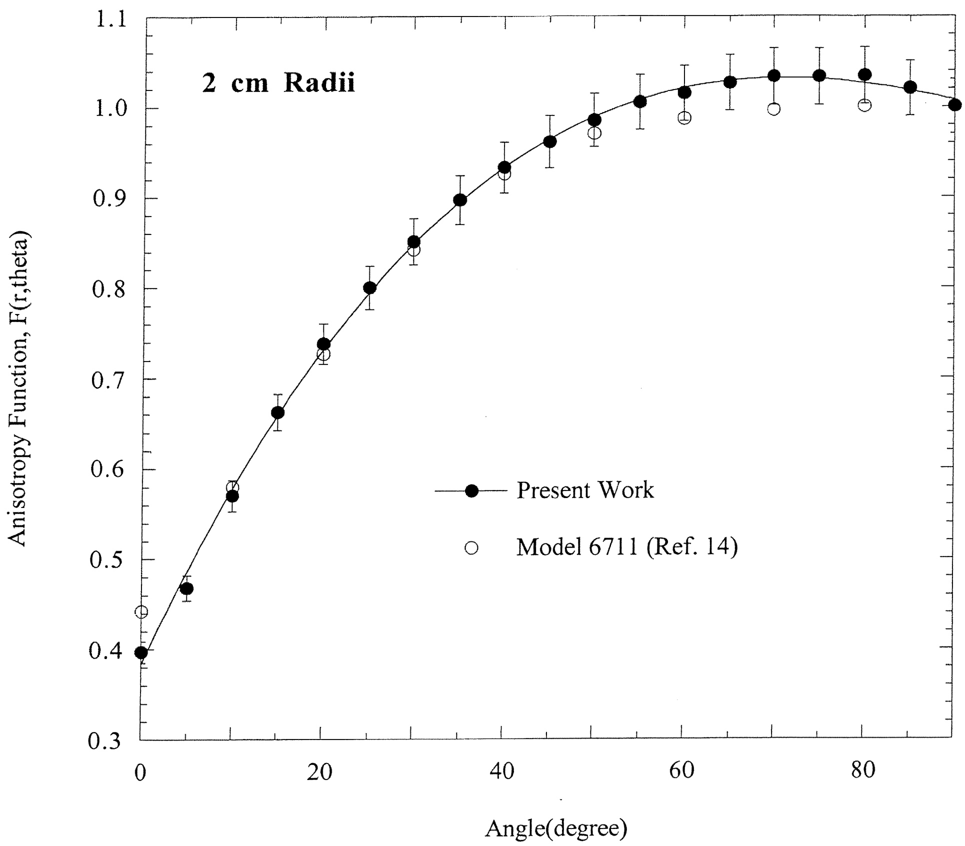

Fig. 4. A comparison of the calculated anisotropy function of the EchoSeed™ Model 6733 ^{125}I Brachytherapy Source in water with Model 6711 ^{125}I source, at 2 cm distance from the source center. The solid curve is a 4th order polynomial fit to the present data.

with the calculated Λ of 0.99 ± 8% $cGyh^{-1}U^{-1}$ in water by Meigooni *et al.* (4).

The radial dose function of the EchoSeed™ Model 6733 ^{125}I source was simulated in Solid Water™ at distances ranging from 0.5 cm to 10 cm at 0.5 cm increments. Figure 2 shows a good agreement between the simulated g(r) and the TLD measured data by Meigooni *et al.* (4). This agreement confirms that the source geometry used in the Monte Carlo simulations was accurate. Monte Carlo simulations were performed in water to obtain the clinically applicable dosimetric parameters. The Monte Carlo simulated g(r) for the EchoSeed™ Model 6733 ^{125}I source in Solid Water™ and water and the measured g(r) by Meigooni *et al.* are included in Table 2.

A fifth-order polynomial fit to the simulated g(r) in water in the range of 0.1 to 10 cm has been determined using the following equation.

$$g(r) = a_0 + a_1 r + a_2 r^2 + a_3 r^3 + a_4 r^4 + a_5 r^5$$

The coefficients of the polynomial fit are as follows:

$a_0 = 1.0834$; $a_1 = 5.8771E\text{-}3$;
$a_2 = -1.0699E\text{-}1$; $a_3 = 2.5401E\text{-}2$;
$a_4 = -2.3996E\text{-}3$; $a_5 = 8.2411E\text{-}5$

Anisotropy functions of the EchoSeed™ Model 6733 ^{125}I source were calculated in both Solid Water™ and liquid water phantom materials using the Monte Carlo simulation method. Figure 3 and Table 3 show, except at small angles (≤10°), a good agreement (less than 5%) between the Monte Carlo simulated anisotropy function of the EchoSeed™ Model 6733 ^{125}I source in Solid Water™ and the measured data by Meigooni *et al.* (4). This agreement reflects the use of the correct source geometry in the Monte Carlo simulations. Table 4 shows the Monte Carlo simulated anisotropy function of this source in water at distances ranging from 1 cm to 7 cm in 1 cm increments. Figure 4 shows a comparison of the simulated anisotropy function of the Model 6733 source with the simulated values of Model 6711 source performed by Weaver (14) at 2 cm distance in water. This figure shows an excellent agreement (less than 5%) between the two source Models. Table 3 also shows a good agreement between the measured anisotropy constant of 0.95 ± 5% by Meigooni *et al.* (4) and simulated data from this project of 0.96 ± 3% in Solid Water™. For clinical applications, the source aniso-tropy constant in water has been calculated and it was found to be 0.96.

Conclusion

The Monte Carlo simulated dosimetric parameters of the EchoSeed™ Model 6733 ^{125}I brachytherapy source were determined according to the AAPM TG-43 (12) protocol. Good agreements between the simulated data and published measured data have been observed. With these data, the dosimetric characteristics of the EchoSeed™ Model 6733 ^{125}I brachytherapy source will be in compliance with the AAPM recommendation.

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