Experimental determination of dosimetric characteristics of Best® 125 I brachytherapy source

Ali S. Meigooni, Darren M. Gearheart, and Keith Sowards

Citation: Medical Physics 27, 2168 (2000); doi: 10.1118/1.1289256
View online: http://dx.doi.org/10.1118/1.1289256
View Table of Contents: http://scitation.aip.org/content/aapm/journal/medphys/27/9?ver=pdfcov
Published by the American Association of Physicists in Medicine

Articles you may be interested in

Experimental and theoretical determination of dosimetric characteristics of IsoAid ADVANTAGE™ 125 I brachytherapy source
Med. Phys. 29, 2152 (2002); 10.1118/1.1500395

Experimental determination of the TG-43 dosimetric characteristics of EchoSeed™ model 6733 125 I brachytherapy source
Med. Phys. 29, 939 (2002); 10.1118/1.1470210

Dosimetric characteristics of the Best® double-wall 103 Pd brachytherapy source
Med. Phys. 28, 2568 (2001); 10.1118/1.1414007

Empirical dosimetric characterization of model I125-SL 125 Iodine brachytherapy source in phantom
Med. Phys. 27, 2796 (2000); 10.1118/1.1323980

Dosimetric characteristics of a new 125 I brachytherapy source
Med. Phys. 27, 2278 (2000); 10.1118/1.1290486
Experimental determination of dosimetric characteristics of Best® 125I brachytherapy source

Ali S. Meigooni, a) Darren M. Gearheart, and Keith Sowards
Department of Radiation Medicine, University of Kentucky Medical Center, Lexington, Kentucky 40536

(Received 24 February 2000; accepted for publication 16 June 2000)

125I brachytherapy sources are used for interstitial implants in tumor sites such as the prostate. Recently, the Best® 125I source became commercially available for interstitial brachytherapy treatment. Dosimetric characteristics (dose rate constant, radial dose function, and anisotropy function) of this source were determined, following the AAPM Task Group 43 recommendations, and were related to the NIST 1999 calibration assigned to this source. Measurements were performed in Solid Water® phantom using LiF thermoluminescent dosimeters. The results indicated a dose rate constant, \( \lambda \), of 1.01 ± 0.08 cGy h\(^{-1}\) U\(^{-1}\) for the new source. The radial dose function, \( g(r) \), of the new source was measured at distances ranging from 0.5 to 10.0 cm. The anisotropy function, \( F(r, \theta) \), of the new source was measured at distances of 2, 5, and 7 cm from the source center. These data compare favorably with those from the Nycomed/Amersham Models 6711 and 6702 sources. The anisotropy constant, \( \phi_{an} \), of the Best® 125I source was found to be 0.982. Complete dosimetric parameters of the new source are presented in this paper. © 2000 American Association of Physicists in Medicine. [S0094-2405(00)01709-0]

Key words: 125I, dosimetry, thermoluminescent dosimeter, brachytherapy

I. INTRODUCTION

125I and 103Pd brachytherapy sources are being used for interstitial implants in various tumor sites, such as the prostate. 125I sources are used in part because their low-energy photon emissions allow a rapid decrease in dose with increasing distance, and hence minimize the dose to normal tissue. The practice of using ultrasound-guided brachytherapy seed implants for prostate cancer has increased greatly in the last few years. The primary reasons for this increase can be attributed to the ease of the procedure for the patient, reduced side effects compared to radical prostatectomy, and great cost effectiveness.1–4 Because of an increase in the frequency of this procedure, a shortage of available seeds became apparent. To meet the rising demand, several manufacturers, including Best Medical International (7643 Fullerton Road, Springfield, VA) developed 125I and 103Pd sources. Nath and Mellillo studied one such 125I source, the Model 2300.5

Recently, the National Institute of Standards and Technology calibrated a newly introduced 125I source, (Best® 125I source, Model 2301) to the 1999 standard. Our goals of this project were to experimentally determine the dose distribution around the Best® 125I brachytherapy source, and to intercompare with earlier versions of this model and other commercially available sources. These determinations were performed according to the methodology outlined in AAPM Task Group No. 43 (TG-43)6,7 and in accordance with the American Association of Physicists in Medicine’s recommendations for source calibration.8,9

II. MATERIALS AND METHODS

A. 125I source

Best Medical International designed the Best® 125I source with a physical length of 5 mm and an outer diameter of 0.8 mm. This source was manufactured using a 3.8 mm long by 0.25 mm diameter tungsten rod, coated with a 0.1 mm thick organic matrix containing 125I, encapsulated in double titanium capsules. Laser welding seals the two capsules. The double encapsulation is designed to provide thinner walls at the ends of the source, relative to other sources, such as the Model 6711. This design will improve the anisotropy function near the ends of the source. The improvement is due to less self-absorption at the end of the source due to the lesser thickness. This source is manufactured and distributed by Best Medical International with activities ranging from 0.2 up to 10 mCi. A total of nine Best® 125I sources, received in three separate shipments, were evaluated during the course of this project. The air kerma strength of these seeds were measured based on the Wide Angle Free AIR Chamber (WAFAC) calibration of the seeds at NIST in 1999.

B. Thermoluminescent dosimeters

Dose distributions around the Best® 125I source were measured in a Solid Water® phantom (Radiation Measurements Inc., RMI, Middletown, WI) using LiF thermoluminescent dosimeters (TLD-100, Harshaw/Bicron 6801 Cochran Rd., Solon, OH 44139). For these measurements, slabs of Solid Water® phantom material were machined to accommodate the source and LiF TLD chips of dimensions (3.1 × 3.1 × 0.8 mm\(^3\)) and (1.0 × 1.0 × 1.0 mm\(^3\)). Figure 1 shows the schematic diagram of the experimental setup for measurements of the dose rate constant and radial dose function. The position of the TLDs within the phantom was selected in order to minimize interference of any one TLD to the absorbed dose of any other TLD chip. Figure 2 shows the phantom that was designed and constructed for the measurement of the anisotropy function of a brachytherapy source.
This phantom accommodates LiF TLD chips in concentric circles relative to the source center. The TLD positions ranged from 0° through 360° in 10° degree intervals relative to the source axis. The source was held in position in a specially designed removable Solid Water™ phantom plug. This design allowed for measurement of any other sources by replacing the removable plug. Small Solid Water™ plugs were made to fill any TLD position not used during measurements. The source and the TLD chips were surrounded with at least 10 cm of Solid Water™ phantom material in order to provide full scattering conditions. Each measurement consists of data from at least eight TLD chips. The TLD chips were read using a Harshaw TLD reader (Model 3500) and they were annealed using a standard technique. The TLD responses from this irradiation were used to determine the dosimetric data that are described below.

\[
\frac{D(r, \theta)}{S_K} = \frac{R}{S_K \varepsilon TE(r) F_{\text{lin}}},
\]

where \( R \) is the TLD response, corrected for the physical differences of the TLD chips using the predetermined chip factors, \( T \) is the experimental time (hours), \( S_K \) is the measured source strength at the time of measurement, and \( \varepsilon \) is the calibration factor for the TLD response (nC/cGy) measured with a 6 MV x-ray beam from a linear accelerator (Clinac 2100C/D, Varian Oncology Systems, 3045 Hanover Street, Palo Alto, CA). \( E(r) \) in Eq. (1) is the correction factor for the energy dependence of the TLD between the calibration beam and the \( ^{125}\text{I} \) photons. A value of 1.4 was used for \( E(r) \) in this project. \( F_{\text{lin}} \) is the nonlinearity correction of the TLD response for the given dose. In these measurements, the experimental times were selected such that the absorbed doses ranged from 10–100 cGy, the range over which the TLD response is linear.

C. Dosimetry technique

Characteristics of the Best® \( ^{125}\text{I} \) source were determined experimentally according to TG-43.® Following this protocol, the dose distribution around a sealed brachytherapy source can be determined using the following formalism:

\[
\frac{D(r, \theta)}{S_K} = \frac{\Lambda G(r, \theta)}{G(r_0, \pi/2)} g(r) F(r, \theta),
\]

where: \( S_K \) is the air kerma strength of the source, \( \Lambda \) is the dose rate constant, \( G(r, \theta) \) is the geometry factor, \( g(r) \) is the radial dose function, \( F(r, \theta) \) is the anisotropy function, and \( r_0 = 1 \) cm.

The above quantities are defined and discussed in detail in AAPM TG-43.® However, they are briefly reviewed here together with our technique of measurement.

D. Dose rate constant, \( \Lambda \)

The dose rate constant, \( \Lambda \), is defined as the dose rate per unit air-kerma strength at a reference point along the transverse axis of the source. This quantity is expressed in units of cGy h\(^{-1}\) U\(^{-1}\), where U is the unit of the air-kerma strength of the source, which is defined as 1 U = 1 Gy m\(^2\) h\(^{-1}\) = 1 cGy cm\(^2\) h\(^{-1}\). The dose rate constant of the Best® \( ^{125}\text{I} \) source was measured using LiF TLD chips. The dose rate constant of the Best® \( ^{125}\text{I} \) in Solid Water™ phantom material was obtained from the rearrangement of Eq. (2) as shown below:
where $r_0$ is a reference distance and usually is defined to be 1 cm, as is the case in this project. $G(r, \theta)$ is known as the geometric factor, which takes into account the effect of the distribution of radioactive material inside the source on the dose distribution at a given point. The geometric factor is defined by the AAPM as

$$G(r, \theta) = \frac{D(r, \pi/2)G(r_0, \pi/2)}{D(r_0, \pi/2)G(r, \pi/2)}, \quad (4)$$

where $D = (r, \pi/2)$ and $D = (r_0, \pi/2)$ are the dose rates measured at distances of $r$ and $r_0$, along the transverse bisector of the source. $r_0$ is a reference distance and usually is defined to be 1 cm, as is the case in this project. $G(r, \theta)$ is known as the geometric factor, which takes into account the effect of the distribution of radioactive material inside the source on the dose distribution at a given point. The geometric factor is defined by the AAPM as

$$G(r, \theta) = \begin{cases} 
\frac{1}{r^2} & \text{point source approximation,} \\
\tan^{-1}\left(\frac{x+L/2}{y}\right) - \tan^{-1}\left(\frac{x-L/2}{y}\right) & \text{linear source approximation.}
\end{cases} \quad (5)$$

As seen in Eq. (4), the value of the radial dose function is equal to 1 at the reference point along that source’s transverse bisector. An active length of 4.0 mm was used in the calculation of the geometry factor.

The TLD measurements were performed using the Solid Water™ phantom material shown in Fig. 1. The pattern of the TLD locations was selected to minimize the interference of any one TLD to the absorbed dose of other TLD chips. The measurements were performed from 0.5 to 10 cm at 0.5 and 1 cm increments. The larger TLD chips were used for distances greater than 2 cm and the smaller chips were used at distances of 2 cm or less. This range was divided into three regions in order to minimize attenuation along inner radii and to limit TLD doses to a zone of linear response. TLD responses were converted to absorbed dose using Eq. (1) and the radial dose function was extracted using Eq. (4). The TLD data at each distance was obtained from the average of at least eight TLD chips with a combined uncertainty (1σ) of about ±5%.

F. Anisotropy function, $F(r, \theta)$

The anisotropy function, $F(r, \theta)$, represents the variation of dose distribution around a brachytherapy source due to the distribution of radioactivity within the source, self-absorption, and oblique filtration of the radiation in the capsule material. From AAPM TG-43, the anisotropy function is defined as

$$F(r, \theta) = \frac{\bar{D}(r, \theta)G(r_0, \pi/2)}{\bar{D}(r, \pi/2)G(r, \theta)}. \quad (6)$$

The measurements were performed at distances of 2, 5, and 7 cm from the source center using a Solid Water™ phantom that was accurately machined to accommodate the TLD chips. Anisotropy was measured for individual radii at angles ranging from 0° through 360° at 10° degree intervals relative to the source axis (Fig. 2). The results of individual dose rates measured at various angles were folded into the first quadrant. At least eight TLD chips were exposed for each data point. Exposures were scheduled for individual radii to minimize interference of TLD chips at any one radius to the response of TLD chips at any other radius. TLD responses were converted to absorbed dose using Eq. (1) and then the anisotropy functions were extracted using Eq. (6). The anisotropy factor, $\phi_{an}(r)$, at each radial distance was calculated following the TG-43 recommendation as

$$\phi_{an}(r) = \frac{\int \bar{D}(r, \theta) d\Omega}{4\pi \bar{D}(r, \pi/2)}. \quad (7)$$

The anisotropy constant, $\bar{\phi}_{an}$, of the new source was determined by averaging of the individual anisotropy factors for a given medium.

III. RESULTS

The dose rate constant, $\Lambda$, of the Best® 125 I source was measured in Solid Water™ as 0.961 ± 0.07 cGy h⁻¹ U⁻¹. The error propagation for this experiment is shown in Table I. In this table, “Type A” errors are the statistical fluctuations in data obtained by repeating measurements. “Type B” errors are based on the uncertainty of the information that is used in the data analysis for which the investigator has no control of the magnitude of these errors. Total error is a quadrature combination of these two types of errors. A correction factor, accounting for attenuation differences between water and Solid Water™, of 1.0512 was used to obtain a dose rate constant in water of 1.01 ± 0.08. This value is for clinical application, as recommended by TG-43. A comparison of these values with other commercially available sources can be found in Table II.

The radial dose function, $g(r)$, of the Best® 125 I source was measured at distances ranging from 0.5 to 10 cm using two different sizes of LiF TLD chips. Figure 3 shows a comparison of the radial dose function of the Best® 125 I source in Solid Water™ with other commercially available sources. The final TLD data in Solid Water™ are presented in Table III. For clinical application of these data the measured data in the range of 0.5–10 cm was fitted to a fourth-order polynomial function as follow:

$$g(r) = a_0 + a_1 r + a_2 r^2 + a_3 r^3 + a_4 r^4,$$
where \( a_0 = 1.10, \ a_1 = -9.01 \times 10^{-2}, \ a_2 = -3.33 \times 10^{-2}, \ a_3 = 5.77 \times 10^{-3}, \) and \( a_4 = -2.56 \times 10^{-4}, \) with \( R = 0.9995. \)

The anisotropy function, \( F(r, \theta), \) of the Best\textsuperscript{\textregistered} 125 I was measured with LiF TLD chips at distances of 2, 5, and 7 cm from the source center in Solid Water™. Figure 4 shows the result of these measured anisotropy functions. The uncertainty of the measured data is ±5%. Figure 5 shows the comparison of the anisotropy function of the Best\textsuperscript{\textregistered} 125 I source with several other commercially available sources. No significant differences were observed between Best\textsuperscript{\textregistered} 125 I and other commercially available sources. From the anisotropy functions the anisotropy factors, \( f_{am}(r), \) and anisotropy constants, \( \Phi_{an}, \) of the Best\textsuperscript{\textregistered} 125 I were extracted [Eq. (7)]. Table IV shows the tabulated anisotropy functions, anisotropy factors, and anisotropy constants for the Best\textsuperscript{\textregistered} 125 I in Solid Water™. The anisotropy constant of the Best\textsuperscript{\textregistered} 125 I in Solid Water™ was found to be 0.982.

**IV. DISCUSSIONS AND CONCLUSIONS**

A double encapsulated 125 I source has been designed and fabricated by Best Medical International for interstitial brachytherapy seed implant. Dosimetric characteristics [i.e., dose rate constant, \( L, \) radial dose function, \( g(r), \) and anisotropy function, \( F(r, \theta) \)] of the Best\textsuperscript{\textregistered} 125 I have been measured in Solid Water™ using LiF TLD chips. These measurements were performed following the AAPM TG-43 task group recommendation.

The dose rate constant, \( L, \) of the Best\textsuperscript{\textregistered} 125 I source in Solid Water™ was measured to be 0.961 ± 0.07 cGy h\textsuperscript{-1} U\textsuperscript{-1}. Table II shows a comparison of the
The table below shows the experimentally determined radial dose function, $g(r)$, of the Best® 125I source in Solid Water™.

<table>
<thead>
<tr>
<th>Distance from source center (cm)</th>
<th>Radial dose function, $g(r)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>1.048</td>
</tr>
<tr>
<td>1.00</td>
<td>1.000</td>
</tr>
<tr>
<td>1.50</td>
<td>0.899</td>
</tr>
<tr>
<td>2.00</td>
<td>0.824</td>
</tr>
<tr>
<td>3.00</td>
<td>0.683</td>
</tr>
<tr>
<td>4.00</td>
<td>0.522</td>
</tr>
<tr>
<td>5.00</td>
<td>0.358</td>
</tr>
<tr>
<td>6.00</td>
<td>0.287</td>
</tr>
<tr>
<td>7.00</td>
<td>0.208</td>
</tr>
<tr>
<td>8.00</td>
<td>0.159</td>
</tr>
<tr>
<td>9.00</td>
<td>0.115</td>
</tr>
<tr>
<td>10.00</td>
<td>0.083</td>
</tr>
</tbody>
</table>

The radial dose function, $g(r)$, of the Best® 125I source was measured in 0.5 cm increments in the range of 0.5–2.0 cm and 1 cm increments for distances between 2.0–10 cm using two different sizes of LiF TLD chips. The results indicate that the measured radial dose function for the Best® 125I source is in excellent agreement (within experimental uncertainty) with the radial dose function of Models 6711 and Model 6702 as reported in TG-43,6 Model 2300 as measured by the solid line represents a fourth-order polynomial fit to the measured data for the Best® 125I source. The dashed lines are connected data points for other data. The error bars represent ±5%.
Nath and Mellilo, and IoGold as measured by Wallace and Fan. The anisotropy function, $F(r, \theta)$, of Best® 125I was measured at angles ranging from 0°–360° at 10° intervals relative to the source axis (Fig. 2) at distances of 2, 5, and 7 cm using LiF TLD. Through the application of Eq. (7), the anisotropy factor, $\phi_{\text{an}}(r)$, and anisotropy constant, $\phi_{\text{an}}^*$, of the Best® 125I was extracted from measurements in Solid Water™. The anisotropy constant of the Best® 125I in Solid Water™ was found to be 0.982. This value is an improvement when compared to the published value of 0.95 for the IoGold source by Wallace and Fan, contrary to the data published by Nath and Mellilo for the model 2300 125I source, no significant variation of the anisotropy function with depth were observed for the Best® 125I source. In conclusion, dosimetric characteristics of the Best® 125I source for interstitial brachytherapy were experimentally determined based on TG-43 recommendations. The parameters for the Best® 125I source recommended for use in clinical applications are 1.01 cGy h$^{-1}$ U$^{-1}$ for the dose rate constant, 0.982 for the anisotropy constant, and the tabulated radial dose function in Table III. The coefficient for a fourth-order polynomial fit to the radial dose function is also given within the text. These values are comparable to the reported values for other commercially available sources.

ACKNOWLEDGMENTS

This project was partially supported by Best Medical International. The authors would like to thank Ms. Mahnaz Qamar and Mr. Michael Staryszak for their assistance during the TLD measurements and data analysis.

Author to whom correspondence should be addressed. Ali S. Meigooni, Ph.D., University of Kentucky Medical Center, Department of Radiation Medicine, 800 Rose St., Lexington, Kentucky 40536. Telephone (606) 323-6486; fax: (606) 257-4931; electronic mail: alimeig@pop.uky.edu


