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Original Article

Determination of Dosimetric Characteristics of IrSeed ^{125}I Brachytherapy Source

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Abstract

Introduction
Low dose rate brachytherapy sources have been widely used for interstitial implants in tumor sites, particularly in prostate. Dosimetric characteristics of a new IrSeed ^{125}I brachytherapy source have been determined using the LiF thermoluminescent dosimeter (TLD) chips.
Materials and Methods
Dose rate constant, radial dose function, and anisotropy function around the IrSeed ^{125}I source were measured in a plexiglass phantom using TLD-100 chips. A plexiglass slab phantom with dimensions of $30\times30\times7.3$ cm^3 was used to measure dose distribution around the source.
Results
Dose rate constant was measured to be equal to 0.965±0.006 cGyh^{-1}U^{-1}. Radial dose function, anisotropy function, and geometry function have been presented as tabulated data for the IrSeed source.
Conclusion
Basically, the dosimetric parameters presented here for this new IrSeed source have clinical and treatment planning applications.

Keywords: ^{125}I; Brachytherapy; Dosimetry; TG-43; TLD.

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1. Introduction

^{125}I brachytherapy source is being used for interstitial implants in various anatomical sites, particularly for prostate cancers. This form of therapy plays an important role in treatment of cancers of several sites, including brain, head and neck, and prostate[1,2]

There are two main forms of brachytherapy: intracavitary irradiation using radioactive sources that are placed in body cavities in close proximity to tumors; and interstitial brachytherapy using radioactive seeds implanted directly into tumor volume. Both theoretical and experimental methods have been widely used to characterize two-dimensional dose distributions around brachytherapy sources (especially interstitial sources) in water or solid water medium. The common sources which are widely used for interstitial implantation are ^{125}I, ^{192}Ir, and ^{103}Pd. Monte Carlo simulation and thermoluminescence dosimetry (TLD) are used for determination of dose distribution around sources in different media. Atomic Energy Organization of Iran, a new source which produces IrSeed ^{125}I called that dosimetry parameters have not been fully investigated yet. In this research, TL dosimeters (TLD-100) were used for measurement of dosimetric parameters around a new IrSeed ^{125}I seed source. The dosimetric data obtained in this work were being presented, discussed and compared with other published work.[3,4,5]

2. Materials and Methods

2.1. IrSeed ^{125}I brachytherapy source

^{125}I decays with a half-life of 59.408 days, by electron capture to the first excited state of ^{125}Te, which undergoes internal conversion 93% of the time and otherwise emits a 35.5 keV gamma ray.[6] ^{125}I is available for interstitial implants commercially in the form of small "seeds". Figure 1 shows a schematic diagram of ^{125}I source manufactured by Nuclear Science and Technology Institute of Atomic Energy Organization of Iran.

The source is 4.7 mm long, 0.8 mm in diameter, and has a 0.06 mm thick titanium wall. This model is available in air kerma strengths up to 1.143 U, Where U is the unit of air kerma strength of the source and environment (equivalent to an apparent activity of 0.9 mCi).

2.2. TG-43 parameters

Dosimetric characteristics of the IrSeed ^{125}I source were determined experimentally following recommendations published in the Task Group 43 (TG-43) of the American Association of Physicists in Medicine (AAPM) report. Following this protocol, dose rate around a sealed brachytherapy source can be determined using the following formula:

$$\dot{D}(r,\theta) = S_k \Lambda \frac{G(r,\theta)}{G(1,\frac{\pi}{2})} g(r) F(r,\theta) \quad (1)$$

where S_k is air kerma strength of the source; Λ is dose rate constant; $G(r, \theta)$ is geometry function; $g(r)$ is radial dose function, and $F(r, \theta)$ is anisotropy function.[7]

The above quantities were defined and discussed in details in TG-43U1 report.[8] In the following sections, our methods of determination of these parameters have been briefly described. We restrict our consideration to cylindrical symmetric source geometry as shown in Figure 2.

Air kerma strength is a measure of brachytherapy source strength, which is specified in terms of air kerma rate at point located at 1 m distance along the transverse axis of the source in free space.[9,10]

With considering the units of μGy, h and m, for kerma, time and distance, respectively, the unit of S_k will be μGym^2 h^{-1} as recommended in TG-43U1 report, which is denoted by symbol of U [11].

$$1\,U = 1\mu\,Gym^2h^{-1} = 1\,cGycm^2h^{-1} \quad (2)$$

Dose rate constant (cGyh^{-1}U^{-1}) represents the dose rate to medium (plexiglass) at the reference point r=1 cm along the transverse axis θ=π/2 of the source per air kerma strength.

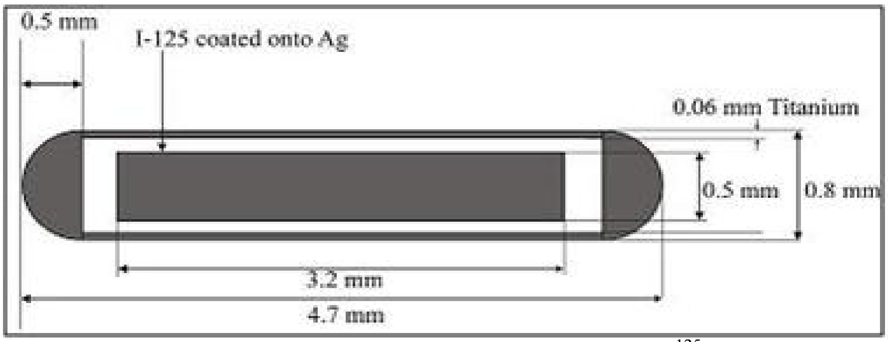

Figure 1. Schematic diagram illustrating the geometry of the IrSeed ^{125}I brachytherapy source

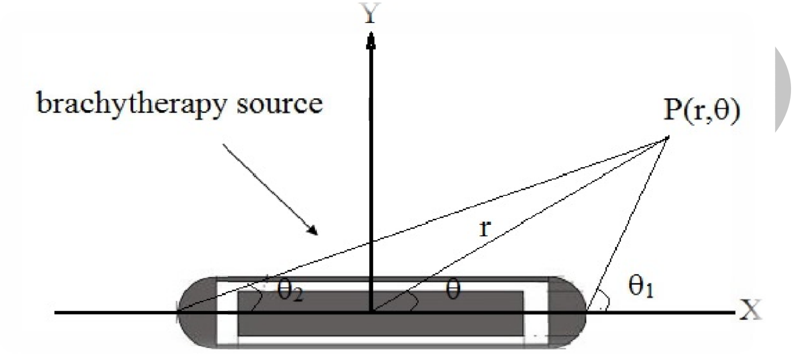

Figure 2. A schematic diagram of geometry assumed in the TG-43U1 dose calculation formalism for a brachytherapy source.

Since $g(r)$ and $F(r, \theta)$ are equal to unity at the distance of 1 cm and an angle of $\pi/2$, using Eq. (1) one can obtain:

$$\Lambda=\frac{\dot{D}(1,\frac{\pi}{2})}{S_k} \quad (3)$$

The dose rate at the distance of 1 cm from the center of the source and angle of $\pi/2$ was measured using TL dosimeters.

$G(r, \theta)$ is known as the geometry function which takes into account the effect of the physical shape of the interior geometry of source on dose distribution at a given point. The geometry function is defined by the TG-43U1 as:

$$G(r,\theta)=\begin{cases}\frac{1}{r^2} & \text{point source approximation}\\ \frac{\tan^{-1}(\frac{x+L/2}{y})-\tan^{-1}(\frac{x-L/2}{y})}{Ly} & \text{line source approximation}\end{cases} \quad (4)$$

where L is the active length of the source as shown in Figure 1, $x= r\cos\theta$, and $y= r\sin\theta$.

Radial dose function, $g(r)$, describes the attenuation of the photons emitted from the brachytherapy source in tissue. The radial dose function is defined as:

$$g(r)=\frac{\dot{D}(r,\frac{\pi}{2})G(r_0,\frac{\pi}{2})}{\dot{D}(1,\frac{\pi}{2})G(r,\frac{\pi}{2})} \quad (5)$$

where $\dot{D}(r,\frac{\pi}{2})$ and $\dot{D}(1,\frac{\pi}{2})$ are the measured dose rates, $G(1,\frac{\pi}{2})$ and $G(r,\frac{\pi}{2})$ are the geometry functions at distances of 1 cm and r cm, respectively, along the transverse axis of the source.[12]

Before measuring the radial dose function, it is necessary to obtain the dose rates and the geometry function around the source. For these measurements, an experimental setup was arranged by drilling holes on the upper side of the phantom. The holes were drilled along eight spiral lines diverging from the source center in the transverse bisector plane of the source as shown in Figure 3. a. TL dosimeters were located at each point at 1 cm intervals ranging from 0.5 to 7 cm in such a way to minimize perturbation of the radiation field by the other TL dosimeters. With this arrangement at each distance, eight simultaneous measurements could be made, an exception being at the distance of 0.5 cm, which contains four holes. Irradiation times for TLDs at different distances from the source were set at different time intervals ranging from 0.35 to 70.5 h.

The anisotropy function of IrSeed ^{125}I source was measured at distances of 2, 3, and 5 cm from the source center using a plexiglass phantom that was accurately machined to accommodate the TLD chips at 10 $^{\circ}$ angle increments relative to the source longitudinal axis (Figure3.b).

At least eight TLDs were exposed for each data point. From the measured dose distribution around the source at a given radius, the anisotropy function, *F*(*r*, *θ*), was calculated following the TG-43U1 recommendation as:

$$F(r,\theta)=\frac{\dot{D}(r,\theta)G(r,\frac{\pi}{2})}{\dot{D}(r,\frac{\pi}{2})G(r,\theta)} \quad (6)$$

Where $\dot{D}(r,\theta)$ and $\dot{D}(r,\frac{\pi}{2})$ are the dose rate measured at distance of *r* cm and angles of *θ* and *π*/2 relative to the longitudinal axis of the source, respectively. The anisotropy factor is defined following the TG-43U1 recommendations as:

$$\phi_{an}(r)=\frac{\int \dot{D}(r,\theta)\sin\theta d\theta}{2\dot{D}(r,\frac{\pi}{2})} \quad (7)$$

The anisotropy constant, φ_{an}, of the new source was determined by averaging the individual anisotropy factors in the given medium.

2.3. TLD calibration

A phantom correction factor was applied to TLD responses in measurements of the dose rate constant (Λ). In absolute measurement of the dose rate constant in the phantom, the correction factor was 0.985, calculated for the phantom material at 1 cm, and was applied to arrive at equal the dose rate constant inplexiglass . Correction factors that were applied to TLD response in the analysis of radial dose function are found elsewhere.

For all measurements, a single batch of TLD rods was selected with a uniform response in absolute range of mean ±2-3%. Regarding TLD constancy of the cobalt-60, reference calibration factors were within 4% of those for previous investigations. Prior to each exposure, the full batch of TLD rods was annealed at 400 $^{\circ}$C for 1 h, quenched to ambient room temperature in 30 min, and then heated at 80 $^{\circ}$C for 24 h. Annealing was repeated as necessary to complete all experiments. Thus, after each experiment, the heating process took place on the TLDs. [13]

2.4. TLD dose measurements

Dose distributions around the IrSeed ^{125}I source were measured in a plexiglass phantom using TLD-100 (LiF:Mg). TLD-100 chips, with dimensions of 3.1×3.1×0.9 mm^3, were used in all phantom measurements evaluating the IrSeed ^{125}I source, in Lucite build-up capsules using the ^{60}Co source. An automated TLD reader was used (Harshaw-Bicron, model 4500) and chips were placed in the phantom in a special pattern to minimize inter-rod effects.

Figure 3.a shows the schematic diagram of the experimental setup measurement of dose rate constant and radial dose function. Figure 3.b illustrates the phantom design that was used for measurement of source anisotropy function. The TLD data at each point was taken as the average values from the four measurements with an uncertainty of about 6% of standard deviation.

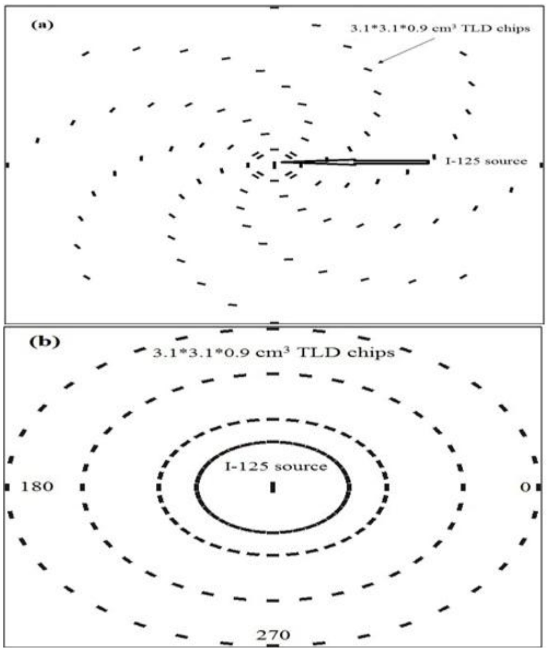

Figure 3. Schematic diagram of the plexiglass phantom design for measurement of (a) radial dose function and (b) anisotropy function using TLDs.

2.5. Phantom selection

In selection of calibration and dosimetric phantomnumber of key parameters are thickness for production of full scattering condition and the composition of tissue substitute must be taken into account. For photons, the effective atomic number of the material is important. Water, Acrylics, Polystyrene or similar low atomic number materials are appropriate for such phantoms. Polymethyl Methacrylate PMMA or plexiglass is one of such materials with low effective atomic number (Z_{eff}=6.5) that is found to be suitable for calibration and dose measurements. In this work a plexiglass slab phantom of 30×30×7.3 cm^3 dimensions was used to measure dosimetric parameters around the source. A number of holes were drilled, as appropriate, on the upper side of the phantom, the size of the each hole being just sufficient to accommodate the TLDs in vertical position.

Table 1. A comparison of dose rate constant of the ^{125}I IrSeed source those of commercially available ^{125}I sources.

Reference	Phantom	Method	Dose rate constant (Λ) cGyh^{-1}U^{-1}
BEST Iodine-125 (Meigooni, 2000)	Solid Water	TLD	0.961±6.8%
BEST Iodine-125 (Meigooni, 2000)	Water	MC	1.01±6.8%
IoGold MED3631-A/M (Solberg, 2002)	Water	TLD	0.949
Model 6711 (Williamson,1991)	Solid Water	MC	0.934
Model 6702 (Williamson ,1991)	Water	MC	0.973
ADVANTAGE (Solberg, 2002)	Plastic Water	TLD	0.96±0.05
Present Work	Plexiglass	TLD	0.965±0.006

Table 2. Values of the geometry function for seed source calculated for distances of 2, 3, and 5 cm and angles of 0-90,110,130,and 150

r(cm) Ө(deg)	2 cm	3 cm	5 cm
0	—	0.118	0.0446
10	0.591	0.117	0.0444
20	—	0.116	0.0439
30	0.359	0.114	0.0426
40	—	0.112	0.0422
50	0.262	0.111	0.0408
60	—	0.109	0.0399
70	0.222	0.105	0.0392
80	—	0.103	0.0390
90	0.211	0.102	0.0400
110	0.222	0.105	0.0392
130	0.262	0.111	0.0408
150	0.359	0.114	0.0426

During the measurements, another slab phantom with thickness of 7 cm was placed on top of the phantom for providing full scattering condition.

3. Results

3.1. Dose rate constant

Measured values of Λ for the seed sources were found to be 0.965±6% cGy h^{-1} U^{-1}. The obtained values are shown in Table 1 together with a comparison of these with published results by Solberg et al., Williamson et al. and Meigooni et al.[5,7,8]

3.2. Radial dose function

Values of this function were determined for distances of 0.5-7 cm (Table 2). Figure 4 shows a comparison of these with values reported by Meigooni et al., Solberg et al., and Nath et al. [5-7]. The figure shows that values of the radial dose function decrease in a relatively smooth fashion with increasing distance from the center of the source. Radial dose function values, $g(r)$, in a plexiglass medium for IrSeed were fitted to a polynomial explanation which is as below:

$$g(r)=a_0+a_1r+a_2r^2+a_3r^3+a_4r^4+a_5r^5 \qquad (8)$$

Where a_0=0.988, a_1=1.07456×10^{-1}, a_2=-1.65512×10^{-1}, a_3=3.92687×10^{-2}, a_4=-3.65409×10^{-3}, and a_5=1.23754×10^{-4}.

Our results obtained for IrSeed source are closed to those reported by Rivard et al. for distances of 0.5-7 cm (difference ranging from 1.3% to 5%) [4].

3.3. Geometry function

The calculated values of $G(r, \theta)$ for seed are given in Table 3 which demonstrates that by increasing the distance from the source the, values of $G(r, \theta)$ become smaller. At angles which are symmetric relative to the transverse axis, the values are identical at each distance and the minimum value at each distance occurs on the transverse axis (angle 90˚).

3.4. Anisotropy functions

The calculated values of $F(r, \theta)$ for IrSeed ^{125}I source are given in Table 4. It is apparent from the figure that the anisotropy function depends strongly on the angle θ. At angles close to the axis of the source, $F(r, \theta)$ reaches the minimum of its value which at symmetric angles relative to the transverse or longitudinal axis of the source, $F(r, \theta)$ does not produce identical values.

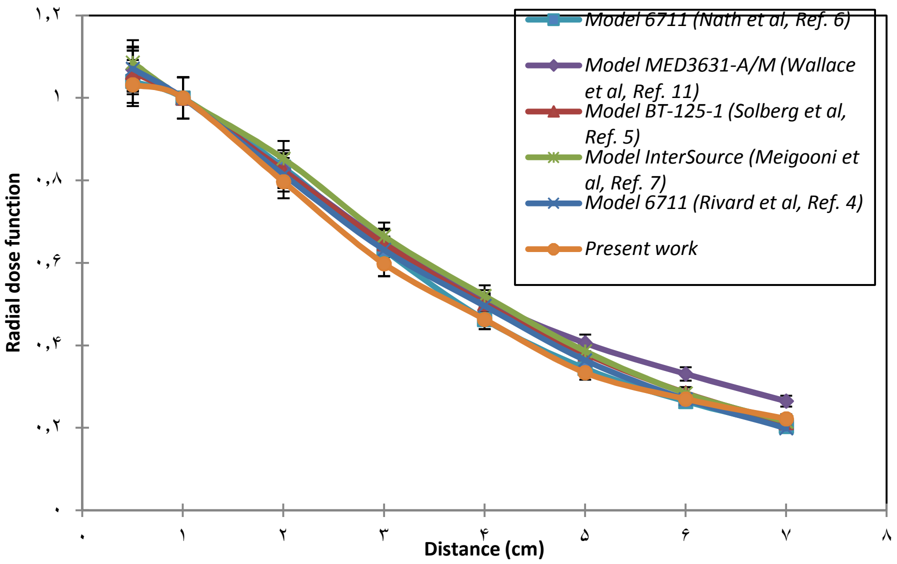

Figure 4. Comparison of radial dose function of the new IrSeed ^{125}I source in plexiglass with data those for other ^{125}I sources reported by Nath et al., Wallace et al., Solberg et al., and Migooni et al.[5,6,7,11]

Table 3. Values of the radial dose function measured for ^{125}I IrSeed source for distances *0.5-7* cm

Radial distance (cm)	Solberg (2002), BT-125-1L=3.25 mm	Meigooni (2002),InterSource ^{125}I, L=3.7 mm	Rivard (TG43UI, 2004), 6711,L=3 mm	Present Work(IrSeed) L=3.2 mm
0.5	1.062	1.086	1.071	1.011
1	1	1	1	1
2	0.823	0.853	0.814	0.803
3	0.647	0.665	0.632	0.612
4	0.501	0.52	0.496	0.478
5	0.380	0.386	0.364	0.352
6	0.285	0.284	0.270	0.270
7	0.213	0.215	0.199	0.208

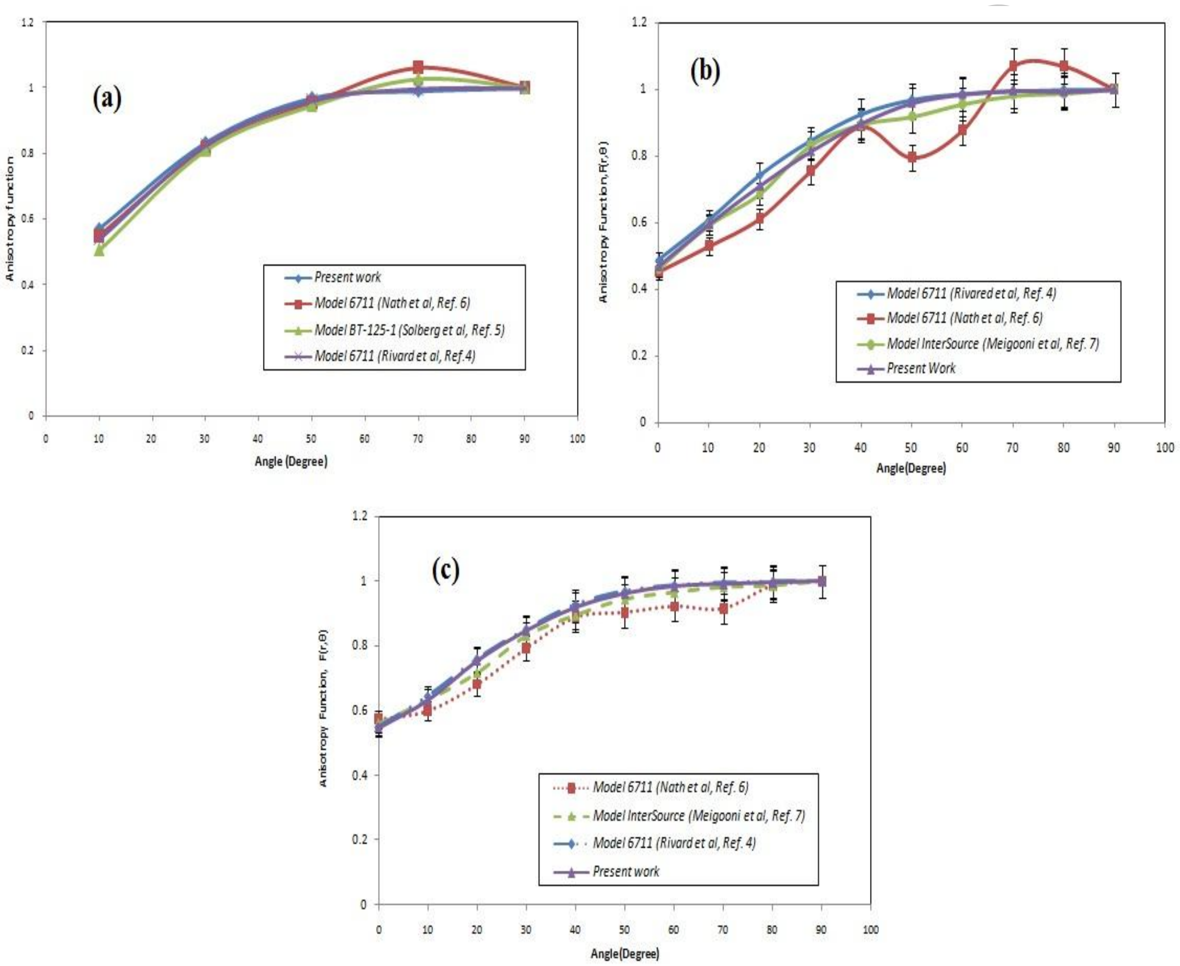

Figure 5. (a) Anisotropy function at distance of 2 cm, (b) Anisotropy function at distance of 3 cm, and (c) Anisotropy function at distance of 5 cm obtained from present work compared to those of previous studies in which solid core cylindrical sources were evaluated.

Table 4. Measured anisotropy function for the ^{125}I IrSeed brachytherapy source in Plexiglass phantom.

r(cm) Θ(degrees)	1cm	2 cm	3 cm	5 cm
0	0.325	—	0.469	0.549
10	—	0.571	0.596	0.634
20	0.685	—	0.711	0.755
30	—	0.834	0.814	0.848
40	0.832	—	0.898	0.919
50	—	0.970	0.959	0.962
60	0.956	—	0.985	0.984
70	—	0.991	0.996	0.991
80	0.985	—	0.993	0.996
90	1	1	1	1
$\Phi_{an}(r)$	0.938	0.940	0.942	0.944

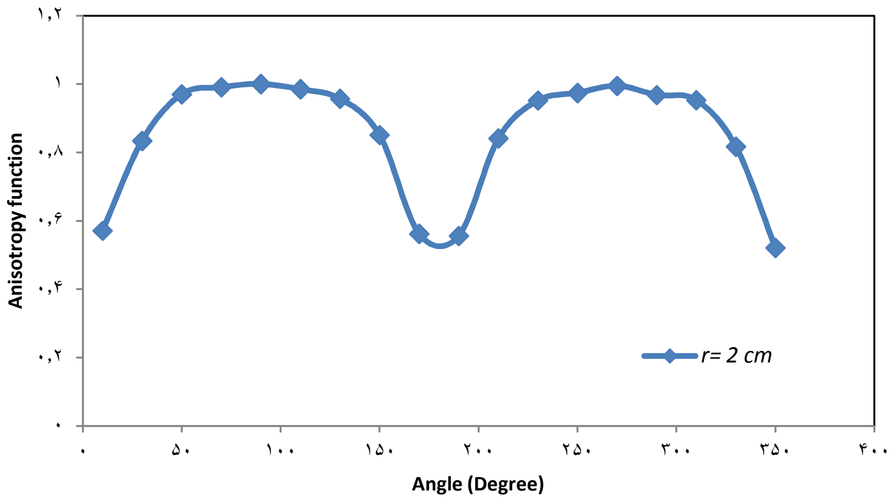

Figure 6. A anisotropy function obtained at different angles between 0 and 360° at a distance of 2 cm for new IrSeed ^{125}I brachytherapy source.

In Figures 5.a, 5.b, and 5.c values of the $F(r, \theta)$ function for the ^{125}I seed source at distances of 2, 3, and 5 cm are compared with those reported by Nath et al., Solberg et al., and Rivard et al..[4,5,6] The measured values of $F(r, \theta)$ for this seed source at distance of 2 cm and for angles between 0 and 360° are presented in Figure 6.

4. Discussion

In this study, dosimetric characteristics of the new IrSeed ^{125}I brachytherapy source which generated by AEOI review and has been determinated.

Dosimetric characteristics (i.e., dose rate constant, radial dose function, and anisotropy function) of a new IrSeed ^{125}I brachytherapy source have been determined using an experimental method. Measurements were performed in a plexiglass phantom using dosimeters (TLD-100).

The dose rate constant, Λ, was measured to be equal to 0.965±0.006 $cGyh^{-1}U^{-1}$ using LiF TLDs in plexiglass phantom. The radial dose function, $g(r)$, of IrSeed ^{125}I source was measured at 0.5 cm increments from 0.5 to 1 cm and 1 cm increments for distance between 1 and 7 cm using the LiF TLDs chips.

The anisotropy function, $F(r, \theta)$, of the IrSeed ^{125}I source was measured at 10° increments relative to the source axis (Figure 5) at distances 2, 3, and 5 cm using LiF TLDs. Good agreement is observed between the $F(r, \theta)$ obtained in this work and the data published by Nath et al., Solberg et al, and Rivard et al.. [4,5,6] The relatively small differences between the present values and previous findings are suggested to be due to differences between phantom materials, self filtration in the source, and differences between the active lengths of the sources.

5. Conclusion

Today, most of brachyherapy treatment planning systems are based on the recommendations of AAPM (TG-43) dose calculation formalism. The tabulated data including TG-43 parameters of the brachytherapy sources which are obtained experimentally or theoretically, are used as the input data of the treatment planning software. The TG-43 parameters are obtained by positioning the source at the center of a fixed volume homogeneous plexiglass phantom.

The dosimetric characteristics of the new IrSeed ^{125}I source which were experimentally determined based on TG-43 recommendations were found to be comparable to the values reported for other commercially available ^{125}I sources. As recommended by TG-43, the parameters determined in plexiglass phantom can be used for clinical applications.

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