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Dosimetric Parameters Estimation for I-125 (model 6711) Brachytherapy Source

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Determining dose distribution around the applied sources in brachytherapy, especially ones with low-energy is so crucial in treatment designing. In this study dosimetric parameters of a brachytherapy source I-125 (model6711) were calculated using Monte Carlo simulation method.A homogeneity water phantom with dimensions of 30´30´30 cm^3 were simulated with MCNPX(2.6.0) code. A brachytherapy source I-125 (model6711) considering its details (materials, dimensions and its emitted spectrum) was located in the center of phantom. Positioning the source inside the vacuum sphere its air kerma strength, S_k, was calculated. Recommended dosimetric parameters were calculated by AAPM, TG-43 protocol in this phantom.The air kerma strength of the source I-125 (model 6711)was estimated equal to 0.557 cGycm^{2}h^{-1}mCi^{-1} in activity unit anddose rate constant was 0.885 cGyh^{-1}U^{-1}. The Radial dose function with 5 degree equation and correlation coefficient of 0.9989 was estimated by $g(r)=-0.0001r^4+0.0026r^3-0.0178r^2-0.0970r+1.0995$. Numerical amounts of the anisotropy dose functions and related equations were calculated and compared with the reported data.In spite of low-energy emission photons and high dose gradients with radial distance, dosimetric parameters of source I-125 (model 6711)can be calculated by MCNPX Monte Carlo code with an acceptable accuracyand this can be used in brachytherapy treatment planning.

Key words: Brachytherapy, Source I-125 (model 6711), Radiation dosimetry, Monte Carlo simulation.

I-125 source is widely used for brachy therapy treatment of prostate permanent implant, eye malignant tumor, brain temporary implant and other types of cancers[1,2]. In this method, several sources are usually placed around the target in order to deliver the highest dose to the tumor target and the lowest dose to the surrounding tissue[3,4].

Accurate knowledge about dose distribution around the source is important for precise treatment, due to lower average energy and sharp dose reduction with distance from the source I-125. Determining the source dosimetry is problematic because of different factors such as, the lack of complete equivalency between tissue and dosimeters, absence of resolution in dose report due to the large size of current dosimeters in radiotherapy parts, energy dependence of these dosimeters, lack of coordination between tissues and solid phantom (such as PE) and etc. Therefore, Monte Carlo simulation method can lead to desired results because of its high

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potentialin particle transport and not dealing with the practical problems of dosimetry for the evaluation of diametric parameters along with practical measurements[3, 5].

Accordingly, Group TG-43 of Medical Physics Society of America AAPM proposed a protocol to determine the necessary parameters for using radioactive sources in brachytherapy which is almost applied in all treatment planning software today[6,7]. It is essential to enter accurate dosimetry parameters outlined in the AAPM TG-43 protocol in this software in order to correctly calculate the dose distribution; therefore in this study, mentioned parameters for sourceI-125 (model 6711), will be calculated using MCNPX (2.6.0) simulation code.

MATERIALS AND METHODS

Monte Carlo simulation code MCNPX (2.6.0),F6 and *F8 talies were used in this study to simulate and calculate the kerma and absorbed dose in order to obtain desired results[8]. Cutoff energy for photon and electron was considered 5 and 10kev, respectively[9,10]. Results with a maximum error less than 5% have been reported for the transport of 10^9 photons from the source. No other lowering technical errors have been considered in programs.Output results by MCNPX code (MeV or MeV / gr) were turned into dose, by multiplying the conversion factor units and also considering Iodine source constant decay and photon radiation frequency in each attempt per m Ciactivity.

I-125 source (Model 6711)was used in this study to design the source with a silver cylindrical marker (density of 10.5 g/cm^3, length of 2.8 mm and a radius of 0.254mm) coating with a combination of bromide Iodine (density 6.245 g/cm^3 Br5I$_2$with a thickness of 2µm).Effective source length which is under a convex angle of 45 degrees source is 2.8mm. This set is placed in a titanium capsule with a density of 4.54 g/cm^3 filling by argon gas (density 1.784mg/cm^3) and the end is limited with a hemisphere (Figure 1). The average energy of I-125source equals to 28.37 kev and its half-life is 59.4 days [11].

Photon spectrum of I-125 source used in this study according to AAPM TG-43 that is shown in Table 1 (6).

Based on the AAPM, TG 43 recommendations[6], the dose rate at a certain point, (r, θ), relative to the center of the source, D (r, q), is obtained by the following equation:

(1)

$$\dot{D}(r,\theta) = S_k \Lambda \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta)$$

whereR is the radial distance from the center source, θ is polar angle between r and the axis of the source, S_k is air kerma power, E is dose rate constant, G (r, θ) is geometric function of spatial dose distribution, F (r, θ) is anisotropy function for dosespatial distribution in different angles and radiuses and g (r) is dose radial function of the distance perpendicular to the axis of the source. Point (r_0, θ_0) is the reference of point (r_0 = 1 cm, ¸0 = π / 2) and is considered for dose calculations.

To calculate the air kerma power of the source, first the air kerma rate $\dot{K}(d)$ was calculated at different distances (5 to 100cm), in a dry air phantom and multiplied by the square of the distance (d^2); which result is as follow:

$$S_k = \dot{K}(d)\, d^2 \quad (9, 12) \qquad \text{...(2)}$$

In order to calculate dose radial function, radioactive source is centering in a cylindrical phantom containing water, and concentric rings with different thicknesses (thickness increase according to increasing the radial distance) are positioned around it[3]. Rings are set to 0.05 thicknesses in distances less than 0.03 cm to source center,0.1 thicknesses in 0.03 to 1 cm distances,0.5 thicknesses for distance between 1cm to 0.03 and 1 cm thickness for distances more than 10 cm. The dose radial function is calculated by the following equation[3, 12-15].

$$g(r) = \frac{\dot{D}(r,\theta_0) G(r_0,\theta_0)}{\dot{D}(r_0,\theta_0) G(r,\theta_0)} \qquad \text{...(3)}$$

$$g(r) = \frac{\dot{D}(r,\theta_0) G(r_0,\theta_0)}{\dot{D}(r_0,\theta_0) G(r,\theta_0)} \qquad \text{...(4)}$$

Dose rate constant is obtained by dividing dose rate at distance of 1cm, perpendicular to the source axis (r_0 = 1cm, θ_0 = π/2) into air kerma power S_K(1, 13, 16).

$$\Lambda = \dot{D}(r_0,\theta_0)/S_k \quad ...(5)$$

One of the dosimetric parameters for cylindrical source is anisotropy function. Considering the cylindrical geometry of the sources, being aware of the dose distribution at different angles and radiuses relative to the axis of the source, is important to accurately estimate the dose.To obtain this parameter, radioactive source was placed in the center of a 30 × 30 × 30 cm^3 phantom containing water and the anisotropy dose function at a certain point of (r, θ) was calculated by placing the radioactive source at various angles and distances using spheres with radius of 0.05cm and its center at the point of (r, θ)

$$F(r,\theta) = \frac{\dot{D}(r,\theta)G(r,\theta_0)}{\dot{D}(r,\theta_0)G(r,\theta)} \quad ...(5)$$

RESULTS

The air kerma power of the I-125 source (model 6711) per activity unit was calculated by averaging air kerma power from source at 10cm distance: S_K=0.557 $cGycm^2h^{-1}mCi^{-1}$. To calculate this parameter specified produced X-ray from titanium shield was considered.

Dose rate constant, E, was calculated $cGyh^{-1}U^{-1}$0.885, based on the results from Mont Carlo and applying Eq. 3.

Numeric values of dose geometric function for I-125 source (model 6711) in water phantom was calculated for distances from 1 to 15 cm which is indicated in table 2.

Numeric values of anisotropy function F(r, θ) for I-125 source (model 6711) is indicated for angles of 0 to 85 degrees in table 3 with a 5 degree difference and at distances of 1 to 10 cm.

DISCUSSION

Considering the generated specified X-ray from the titanium shield source, air kerma power of I-125 source (Model 6711) per activity unit equals to 0.557 cGycm2h-1mCi-1.Air kerma power of I-125 source (model 6711) considering produced X-ray from source capsule was reported 0.557 cGycm2h-1mCi-1, by Rodriguez *et al.*(2005) in evaluating Penelope code for low energy sources, which exactly equal to the results of the present study[3].

According to the mentioned study, ignoring the lack of specified X-ray can lead to unacceptable error inair kerma calculation, because in this situation,calculated air kerma power is 0.679 cGycm2h-1mCi-1, indicating 22% reduction in air kermapower.

Accordingly, as recommended in the revised standard by NIST, all old data related to air kerma, especially in terms of low-energy sources must be revised in order to considering the impact of producing specified X-ray in capsule source. However Hedtjarn *et al.* (2000), reported 2 to 3% increase in source I-125 (model 6702) taking into consideration the revised factors recommended by NIST[17].

Table 1. Photon spectrum I-125, according to AAPM, TG-43

Photon energy kev	Number of photons in each decay
27.202	0.4060
27.472	0.7570
30.980	0.2020
31.710	0.0439
35.492	0.0668

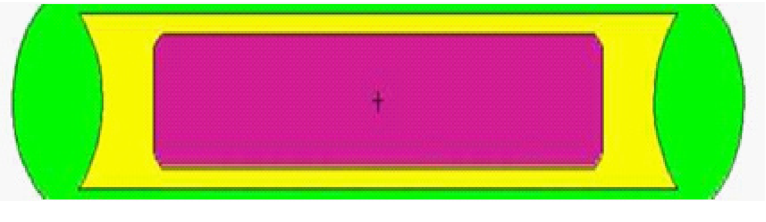
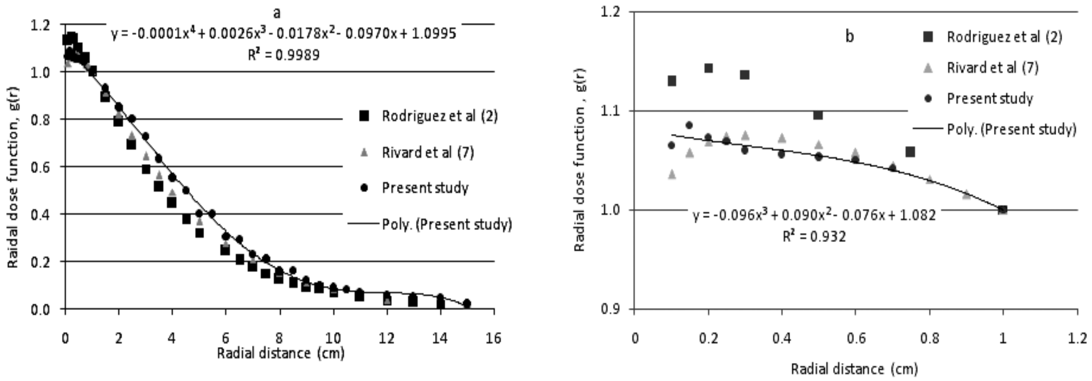
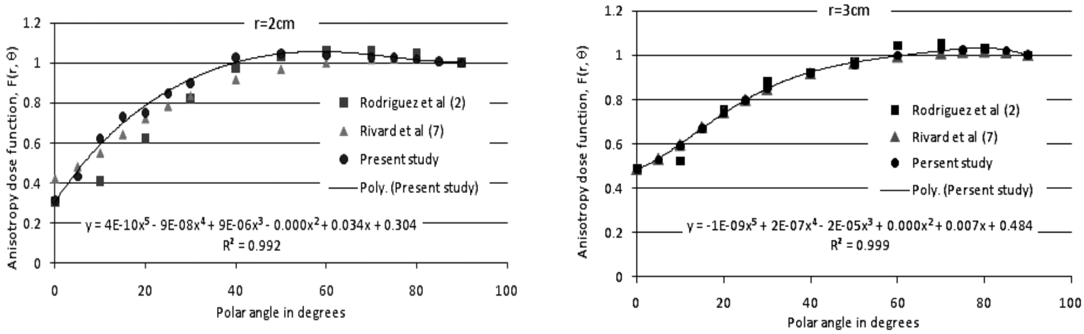


Fig. 1. I-12 5Source (Model 6711): Source length = 22mm, outer diameter = 0.774mm, inner diameter = 0.66mm, silver marker length= 2.8 mm, Silver Marker diameter = 0.508mm



Curve1. Radial dose values for I-125 source compared to Rivard *et al* (2009) (6) and Rodriguez *et al* (2005) (2). a) Radial distance to 15 cm, b) Radial distance to 1 cm



Curve 2. Anisotropy functions for I-125source (Model 6711), different radial distances from different angles comparing to other results

Compared to other studies,air kermapower produced in this study indicates more compatibility with reported value by Rivard *et al* (2005)[11]. Alsodose rateconstant, E, for I-125 source (model 6711) was evaluated cGyh-1U-1 885/0 which was compatible with reported data compared to other values reported in table 4 [3,11,18].

Data related to radial dose function are indicated in figure 2. Assuming linearity of the source, radial function has been calculated by geometric functions. As seen in Curve 1, radial dose function indicate more compatibility with data reported by Rivard *et al*. (2009)[11], rather than radial dose function presented by Rodriguez *et al.* (2005)[3].

This compatibility works well particularly in more radial distances (>8cm) and also less distances (<1cm), however calculation errors are increased upto %5, due to photonic flux reduction; a part of this difference is related to different interaction between cross section level applied between Penelope code which was used by Rodriguez *et al*. (2005) by means of mcnpx (2.6.0) code in this study[3].

The difference in factors might be related to difference in source materials and structure, different spectrum used for the source, inconsistent between photon and electron cutoff energies, inconsistent volume considered for tallies definition and etc. The differences are more according to Mont Carlo code used in this and the study by Rodriquez *et al*., (2005).g(r)= $-0.0001r^4+0.0026 r^3-0.0178 r^2$-The equation 0.0970 r+1.0995 was obtained by fitting equation degree 5 to the above correlation coefficient (regression, R^2), equal to 0.9989 on calculated data for radial dose function in all radial distances to 15 cm, g(r) which can be used for calculation of radial functions in terms of brachytherapy treatment software planning for I-125 source (model 6711).

Table 2. Geometric dose function for I-125 source (model 6711)

Radial distance from source (cm)	Radial dose function
0.1	1.065
0.15	1.085
0.2	1.073
0.25	1.069
0.3	1.06
0.4	1.056
0.5	1.053
0.6	1.05
0.7	1.042
1	1
1.5	0.93
2	0.85
2.5	0.8
3	0.725
3.5	0.633
4	0.553
4.5	0.5
5	0.402
5.5	0.401
6	0.305
6.5	0.294
7	0.228
7.5	0.21
8	0.159
8.5	0.16
9	0.12
9.5	0.1
10	0.09
10.5	0.08
11	0.07
12	0.06
13	0.05
14	0.048
15	0.021

Table 3. Numeric values of anisotropy function F(r,,) for I-125 source (model 6711)

Radial	Angle(degree)			
distance (cm)	5	4	3	2
0.565	0.512	0.488	0.31	5
0.597	0.641	0.531	0.43	10
0.623	0.676	0.593	0.62	15
0.702	0.746	0.672	0.73	20
0.781	0.792	0.74	0.75	25
0.827	0.835	0.799	0.85	30
0.922	0.901	0.851	0.9	40
0.935	0.955	0.918	1.03	50
0.978	0.985	0.959	1.05	60
0.998	1.02	0.999	1.04	70
1.066	1.05	1.03	1.03	75
1.075	1.06	1.023	1.03	80
1.056	1.05	1.026	1.02	85

Table 4. Dose rate constant for I-125 source (Model 6711) compared with other researches results

Reference name	Source Model	$E(cGyh^{-1}U^{-1})$
Rivard(2009) (6)	6711	0.904
Rodriguez (2005) (2)	6711	0.867
Mainegra (1998) (12)	6711	0.81
Current research	6711	0.887

Anisotropy dose functions F (r, q), I-125 source (Model 6711) with the assumption of dose linearity compared to Rivard *et al*. (2009) (11) and Rodriguez *et al*. (2005)[3] are indicated for different distances in Curve2 (a-d). Calculated anisotropy functions for I-125 source (Model 6711) in this study respectively indicate 0.32% and 0.24%, 4.3%, and 8.4%, 2.7% and 8.1% difference for radial distances of 2, 3, 4cm compared to results by Rivard *et al*.(2009)[11] and Rodriguez *et al*. (2005)[3].

2.3% and 4.7% difference was obtained for radial distance of r= 5 in angle distances of 0 to 90 degree compared to results by Rivard *et al*. (2009)[11] and Rodriguez *et al*. (2005) [3], however the difference decreases with increasing the angle relative to the axis of the source. This suggests that with increasing the distance, various factors of the difference (mentioned in radial dose function section), have less impact on absorbed dose.

According to proposed AAPM, TG-43protocol[6], knowing the desired anisotropy dose functions F (r, q) in every angle relative to perpendicular axis to the central axis in different radial distances from source center is essential to calculate the dose in brachytherapy treatment systems using Eq. 1. Demonstration these data in form of mathematical equations, can provide an easier access to the information provided.

Therefore anisotropy functions were calculated using an equation of degree 5 and reporting the relevant correlation coefficient and the equations of anisotropy functions curves. Equation resulting from fitting obtained data using degree 5 equation and correlation coefficient of 0.9939 for radial distance of 5 cm as F(r, q)=-3e-09q^5+6e-07q^4-4e-05q^3+.0013q^2-0.0028q + 0.5684. dose rate can be calculated at any point around source I-125 (model 6711),using MCNPX simulation code.

The data can be used to work for treatment designing and writing systems based on Monte Carlo methods. Compared with the applications built solely on mathematics basis, Monte Carlo system, can specify dose distribution for each patient, taking into account the patient's specific anatomical condition.

CONCLUSION

Air kerma power,S_k, I-125 source (model 6711) per activity unit equals to S_K=0.557 cGycm^{2}h^{-1}mCi^{-1}and dose rate constant equals to Λ=0.887(cGyh^{-1}U^{-1}). Obtained equation for radial dose function of I-125 source (model 6711) was estimated r^2-0.0970 r+1.0995 g(r)= -.0001r^4+0.0026 r^3-0.0178by degree 5 equation and regression 0.9989.

Dosimetric parameters stated in The AAPM, TG-43 proposed protocol (6) for brachytherapy source I-125 (model 6711), can be calculated using MCNPX Mont Carlo computational code, considering low radiant energy and extreme dose changes related to distance.

Calculated values for source air kerma power, dose rate constant , radial dose function, g(r), anisotropy functions,f(r, q) can be used in brachytherapy I-125 source(model 6711) and treatment software designing. These data would be also beneficial for advanced treatment planning software based on Mont Carlo in future.

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