Iran. J. Radiat. Res., 2009; 7 (3): 135-140

Simulation of the shielding effects of an applicator on the AAPM TG-43 parameters of CS-137 Selectron LDR brachytherapy sources

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Background: The dose rate distribution delivered by a low dose rate ^{137}Cs pellet source, a spherical source used within the source trains of the Selectron gynecological brachytherapy system, was investigated using the MCNP4C Monte Carlo code. ***Materials and Methods:*** The calculations were performed in both water and Plexiglas and the absolute dose rate distribution for a single pellet source and the AAPM TG-43 parameters were computed. A spherical phantom with dimensions large enough (60 cm) was used to provide full scattering conditions. In order to score dose at different distances from the source centre, this sphere was divided into a set of 600 concentric spherical shells of 0.05 cm thickness. The calculations were performed up to a distance of 10 cm from the source centre. To calculate the effect of the applicator and dummy pellets on dose rate constant and radial dose function, a single pellet source was simulated inside the vaginal applicator, and spherical tally cells with radius of 0.05 cm were used in the simulations. The F6 tally was used to score the absolute dose rate at a given point in the phantom. ***Results:*** The dose rate constant for a single active pellet was found to be 1.102±0.007 $cGyh^{-1}U^{-1}$, and the dose rate constant for an active pellet inside the applicator was 1.095±0.009 $cGyh^{-1}U^{-1}$. The tabulated data and 5th order polynomial fit coefficients for the radial dose function along with the dose rate constant are provided for both cases. The effect of applicator and dummy pellets on anisotropy function of the source was also investigated. ***Conclusion:*** The error resulting from ignoring the applicator was reduced using the data of a single pellet. The results indicate that F(r, θ) decreases towards the applicator. **Iran. J. Radiat. Res., 2009; 7 (3): 135-140**

Keywords: *AAPM TG-43, brachytherapy, applicator, dose rate constant, MCNP.*

INTRODUCTION

Low dose rate (LDR) brachytherapy ^{137}Cs sources have been traditionally used for gynecological implants. These sources are still being used by many institutions even though ^{192}Ir high dose rate brachytherapy sources offer other clinical alternatives. The Nucletron Selectron LDR remote afterloading unit is mainly used for the treatment of gynecological malignancies, delivering the prescribed dose via a preselected sequence of active (Cs-137 sources) and inactive (stainless steel spacers) pellets loaded into applicator sets, usually made of stainless steel (1). This system is widely used in cervix, endometrium and vaginal treatments either exclusively or as a complement to external beam radiotherapy. Monte Carlo codes have been used as a reliable tool in determining dose distribution around brachytherapy sources.

In recent years many investigators have used MC calculations in determining dosimetry parameters of different brachytherapy sources (2-6). In contrast to some other brachytherapy sources, there is a shortage of dosimetric data suitable for use in treatment planning systems for Selectron ^{137}Cs sources, although some investigators have previously studied the shielding effect of applicators on dose rate distributions around brachytherapy sources (1, 2, 6, 7).

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The major goal of this study was to obtain dosimetric data suitable for treatment planning systems including ^{137}Cs sources. The dosimetric parameters such as dose rate constant, radial dose function and anisotropy functions of one active pellet source have been obtained following the AAPM TG-43 (American Association of Physicists in Medicine, Task Group 43) recommendations[8,9]. In this paper, absolute dose rate distributions in water are calculated for distances up to 10 cm from the source center at different angles using 3D Monte Carlo simulations. Then the results were used to obtain the dosimetric parameters of different combinations of active and inactive pellets by superposition principle, and it is not necessary to do a separate Monte Carlo simulation for each typical clinical configuration.

MATERIALS AND METHODS

Source model and vaginal applicator set

The Selectron unit pellets are 2.5 mm diameter and the Cs-137 sources are encapsulated in 0.5 mm stainless steel material with a 1.5 mm diameter active core of borosilicate glass. In this study, the dose distribution around one active pellet source is simulated with and without the applicator and dummy pellets. The Selectron 20 cm vaginal stainless steel applicator, which can be used for treatment of cancers of the vagina, cervix, endometrium and rectum was used in this study to investigate the TG -43 dosimetry parameters of the Cs-137 pellet source [1]. The composition of each part of the source and the applicator by weight and density of the materials is given in table 1.

Dose calculation formalism

The AAPM TG-43U1 [4] recommendations were adopted to derive dose parameters for a single pellet of Cs-137 source from the calculated and measured dose rate distribution D(r, θ) and air kerma strength SK.

Table 1. Density and composition of the different parts of the Selectron vaginal applicator set [1,3].

Material	Density (g cm^{-3})	Composition%
Borosilicate glass (active core)	2.9	Si(26.18) Ti(3.00) Al(1.59) B(3.73) Mg(1.21) Ca(2.86) Na(12.61) Cs(0.94) O(47.89)
Stainless steel 316L (active core encapsulation, inactive pellets, straight tube)	7.8	C(0.026) Mn(1.4) Si(0.42) P(0.019) S(0.003) Cr(16.8) Mo(2.11) Ni(11.01) Fe(68.21)
Polyethelene	0.93	H(33.33) C(66.67)

According to this protocol, the absorbed dose rate distribution around a sealed brachytherapy source can be determined using the following formalism:

$$\dot{D}(r,\theta) = \Lambda S K \frac{G_L(r,\theta)}{G_L(r_0,\theta_0)} g_L(r) F(r,\theta) \qquad (1)$$

Where Λ is the dose rate constant; G_L(r, ϴ) is the geometry function; g_L(r) is the radial dose function; F(r, ϴ) is the anisotropy function and SK is the initial source air kerma strength at the start of the measurement. The above quantities are defined and discussed in detail in TG-43U1 protocol [9]. In the following, methods to determine these parameters for a single pellet source are briefly described. The radial dose function, g(r), describes the attenuation of photons in the transverse plane of the source.

$$g_X(r) = \frac{\dot{D}(r,\theta_0)}{\dot{D}(r_0,\theta_0)} \frac{G_X(r_0,\theta_0)}{G_X(r,\theta_0)} \qquad (2)$$

The subscript X indicates whether a point source "P" or linear source "L" was used in the calculations. The radial dose function data obtained for the pellet source without the applicator, (point source approximation, $g_P(r)$) have been determined using the following formalism:

$$g_P(r) = \frac{\dot{D}(r,\theta_0)}{D(r_0,\theta_0)} \frac{r^2}{r_0^2} \quad (3)$$

The radial dose function data in presence of the applicator, (linear source approximation, $g_L(r)$), were obtained as follows:

$$g_L(r) = \frac{\dot{D}(r,\theta_0)}{D(r_0,\theta_0)} \frac{G_L(r_0,\theta_0)}{G_L(r,\theta_0)} \quad (4)$$

Where $G_L(r, \Theta)$ is the geometry function for the linear source with length L:

$$G_L(r,\theta) = \begin{cases} \dfrac{\beta}{Lr\sin\theta} if \quad \theta \neq 0 \\ (r^2 - L^2/4)^{-1} if \quad \theta = 0 \end{cases} \quad (5)$$

MCNP4C Monte Carlo code

The Monte Carlo N-particle Transport Code version 4C (MCNP4C) [(10)] was used to calculate the dose rate distribution in water and plexiglas (also called perspex, lucite, PMMA) around the Cesium source. This code is able to consider photoelectric, coherent, Compton and pair production interaction processes. There are many different tally types available in MCNP for scoring diverse physical characteristics. In this work, the F6 tally was used to score the dose rate and kerma rate to obtain the absolute dose rate at a given point in the phantom. In these simulations, both the photon and electron energy cut-offs were set to 10 keV.

Simulations without the applicator

In order to obtain the absorbed dose or collision kerma rates for the pellet source, a single active pellet was placed at the center of a 30 cm radius spherical water phantom. Collision kerma and absorbed dose are independent of polar angle, because of the spherical symmetry of the pellet source. Because of this symmetry, 0.05 cm diameter spherical shells were considered in the water phantom, the origin being at the center of the pellet source, similar to the methodology used by Pe´rez-Calatayud et al. The active core of the source and its stainless steel are shown together with the tally cells in figure 1.

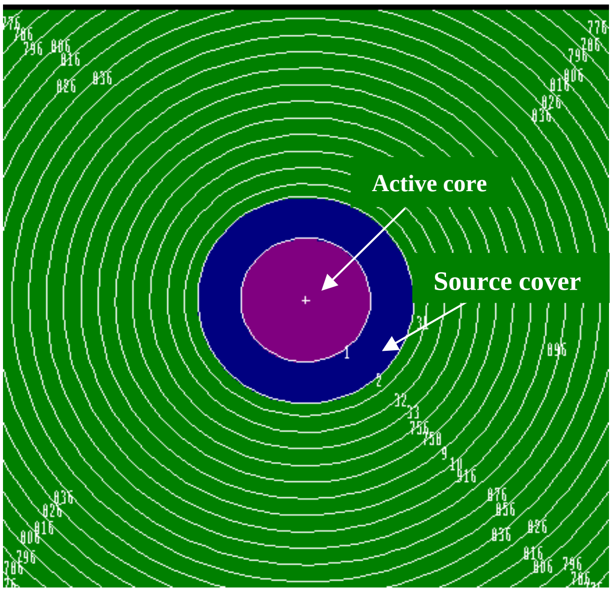

Figure 1. Geometry used for simulation of the parameters g(r) and Λ without the applicator.

The air-kerma strength *SK* is a measure of brachytherapy source strength which is used in this simulation to normalize the absorbed dose. It is defined as the product of air-kerma rate at a calibration distance along the transverse axis of the source, *d*, in free space, $\dot{K}_{air}(d)$, measured along the transverse bisector of the source, and the square of the distance, that is, $S_K=\dot{K}_{air}.\ d^2$ in U units (1 U =1 cGy cm^2 h^{-1}). In order to estimate the air-kerma strength, the pellet source was located in an air-filled spherical volume with 4m radius. The cells used in this case to score air-kerma were 0.05 cm diameter spherical shells. The air-kerma strength of the pellet source was determined according to TG-43U1 recommendations and a cutoff energy of 10 keV was used in the calculations in order to exclude low energy contaminant photons.

Simulations with the applicator

Monte Carlo simulations were performed by placing a single active pellet at the centre of a 60 cm diameter spherical volume of water and Plexiglas phantom. The spherical tally cells of 0.05 cm diameter and a centre corresponding to the distance between the calculation point and the source centre were employed to score dose rate. For the calculations of the radial dose functions and dose rate constant, the tally cells were placed on the transverse bisector plane of the source. The geometry used in simulation of F(r, Θ), g(r) and Λ is shown in figure 2.

After determination of dosimetry parameters of a single source, a computer program was written to evaluate the dose rate distribution around different combinations of active and dummy pellets by adding the dose from individual active sources.

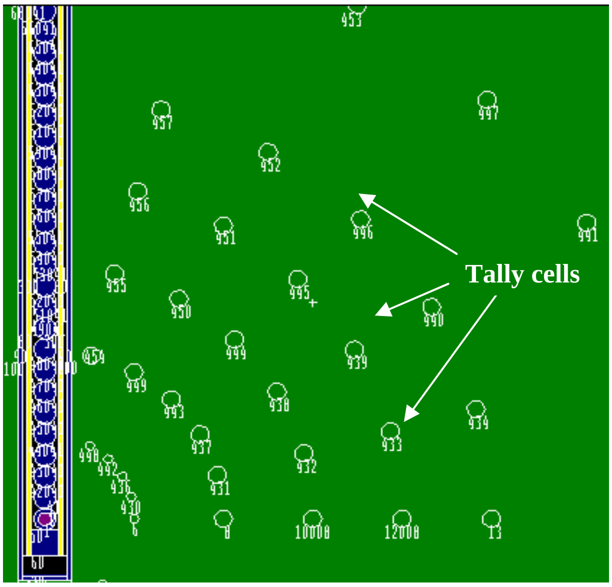

Figure 2. Geometry used for simulation of the parameters g(r), F(r, θ) and Λ in the presence of the applicator and dummy pellets.

RESULTS

The dose rate constant, Λ, of a single active pellet was calculated in a liquid water phantom. The dose rate constant of 1.095±0.009 in absence of the applicator was in good agreement with the dose rate constant 1.102, determined by Pe´rez-Calatayud *et al.*, and the Monte Carlo calculated value of 1.101±0.007 in presence of applicator in liquid water.

The calculated radial dose functions, g(r), of an active pellet, with and without the applicator, in water and Plexiglas phantoms are compared in figure 3. These results are also shown in table 2.

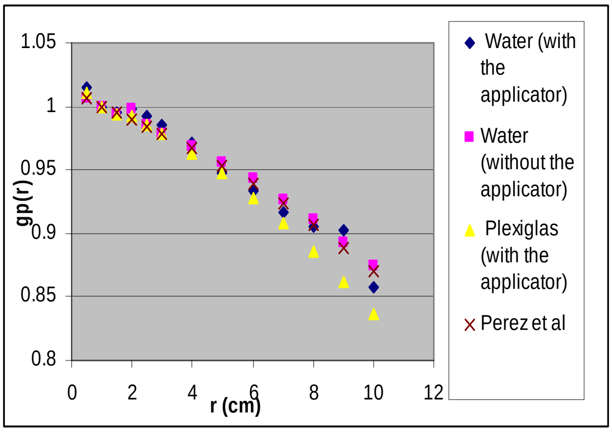

Figure 3. Comparison of the radial dose function of a single pellet source with and without the applicator in water and plexiglas phantoms.

Table 2. Radial dose function in water and plexiglas for the Cs-137 source in presence of applicator and dummy pellets, and without them.

r (cm)	g_p (r), Water with applicator	g_P (r), Water without applicator	g_p (r), Plexiglas with applicator	Perez *et al.*
0.5	1.015	1.007	1.010	1.007
1.0	1.000	1.000	1.000	1.000
1.5	0.995	0.994	0.994	0.995
2.0	0.998	0.998	0.993	0.989
2.5	0.992	0.985	0.986	0.984
3.0	0.985	0.979	0.978	0.978
4.0	0.971	0.968	0.963	0.967
5.0	0.947	0.956	0.947	0.953
6.0	0.934	0.943	0.928	0.939
7.0	0.917	0.927	0.908	0.923
8.0	0.906	0.911	0.888	0.907
9.0	0.902	0.893	0.862	0.889
10.0	0.857	0.874	0.836	0.870

The water data for the pellet without the applicator was fitted to a 5th order polynomial function as follows:

$g_p(r) = a_0 + a_1 r + a_2 r + a_3 r^3 + a_4 r^4 + a_5 r^5$
Where a_0=1.0092, a_1= - 0.0055, a_2=- 0.0023, a_3= 0.0005, a_4=- 0.00005, a_5=0.000002.

The anisotropy function, F(r, θ), of the source was measured and calculated at 15° angle increments relative to the source axis at distances of 1, 2, 3, 5, and 7 cm from the source centre in the water phantom. Figure 4 shows a comparison between the calculated F (r, θ) at different distances from the source centre in water. As shown in figure 5, the values of F(r, θ) increase at angles near 180 degrees.

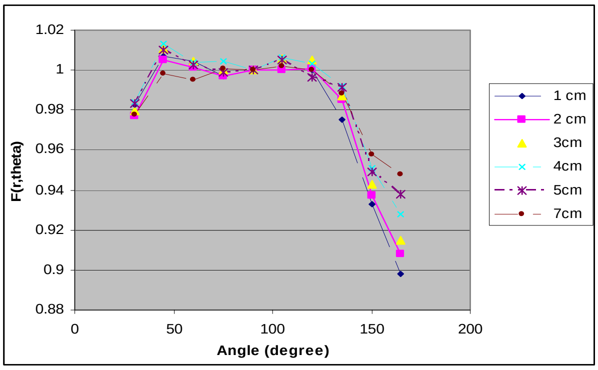

Figure 4. Comparison of the anisotropy function at different distances and angles from the source.

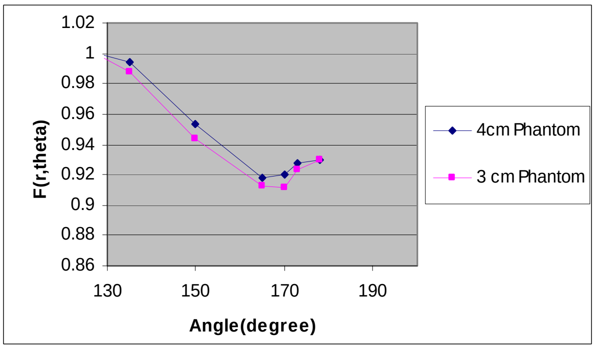

Figure 5. Comparison of the anisotropy function at angles near 180 degrees.

DISCUSSION

In previous studies, investigators have determined the impact of the applicators on dose rate distribution of typical combinations of pellets used in treatment of a specific tumour.

Pe´rez-Calatayud *et al.* determind the dosimetry characteristics of a single pellet of Cs-137 source without the presence of the applicator and showed that using the supperposition principle to obtain dose distribution around different compositions of 7 pellets will cause about 15% error in the presence of the tandem applicator [6]. Fragoso *et al* carried out a study on the Selectron vaginal applicator set, where the 3D dose distribution around the vaginal applicator was obtained and its attenuating effect assessed for a typical clinical application using gel dosimetry [1]. More recently, Tavakoli *et al.* determined dosimetric characteristics of the Cs-137 Selectron source by calculation of the dose distribution around 6 different active and inactive pellet combinations used in treatment of different kinds of tumours [7].

The results of dose calculation around a single Cs-137 pellet source indicate that the presence of the vaginal applicator set does not have a significant effect (less than 2%) on the dose rate constant and radial dose function of the Cs-137 Selectron pellet source. The effect of phantom type on the distribution was also investigated in this study. According to the simulations, the difference between g(r) in the Plexiglas phantom and g(r) in the water phantom increases with distance from the source centre. However, the results show that the phantom material has a small effect (2% at 10 cm radius) on the dosimetric parameters of 662 keV photons of Cs-137. The discrepancy between the dose rate of the single pellet source alone, and inside the applicator on the transverse axis of the pellet source, is small. But it should be noted that the presence of the applicator will cause the anisotropy of the dose distribution on the longitudinal plane of the source, so it is very important to take such an effect in to account. As shown in figure 5, the values of F(r, Θ) increase at angles near 180 degrees, which is due to the shape of the applicator tip.

After calculating the dose distribution around the single pellet inside the applicator the dose distribution around every combination of active and inactive pellets can be obtained by adding the dose from each active pellet in every point of the phantom. There is no need to do separate MC calculations for each of the configuration of the pellets because a MATLAB computer program has been written to obtain the dose distribution around different combinations of active and dummy pellets inside the applicator. According to the investigation reported by Pe´rez-Calatayud *et al.* [6], calculation of dose distribution around different combinations of pellets using the dosimetry data of a single source without the applicator, will cause significant error in dose calculations specially near the applicator tip. In this paper, this error was reduced using the data of a single pellet in presence of a typical applicator and by investigating the influence of the phantom material.

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