IJPST - S1(3), 2019; 42-47

Indonesian Journal of Pharmaceutical Science and Technology
Journal Homepage : http://jurnal.unpad.ac.id/ijpst/

Software Development to Calculate The Absorbed Dose Rate Distribution Using TG-43 Formula

Ismet Isnaini, Wahyuni Z Imrana

Nuclear Engineering Facility Center (PRFN BATAN), Kawasan PUSPIPTEK Serpong, Tangerang Selatan

Submitted 23 February 2019; Revised 10 May 2018; Accepted 11 May 2019; Published 13 May 2019
*Corresponding author: ismeth@batan.go.id

Abstract
Radioisotope applications have become widespread in many fields, such as medical. For the optimal treatment using radioisotope, an accurate absorbed dose rate distribution calculation is required to provide the optimal dose for each patient. A program has been designed to calculate this absorbed dose rate distribution so that paramedics would know whether the absorbed dose rate distribution emitted from that particular source is sufficient or not. Using the TG-43 formula derived by American Association of Physicist in Medicine (AAPM), the calculation was performed based on the information given from the manufacturer of the Ir-192 source, which is commonly used for Brachytherapy equipment, and the function which involves the geometric position between the source and a calculation point. The results of this calculation which were viewed using the *ImageJ* software, have shown that the absorbed dose rate located in the center of any volume was getting larger near the source location but has decreased drastically within the source location itself. This is due to the unavailability of anisotropic data from the source manufacturer for radius less than 2.5 mm. As for absorbed dose rate distribution emitted from several sources, the dose rate accumulated and reached the maximum in the middle. It has also formed some sort of shape depending on the location of the source, which also shows the isodose lines or curves.

Keywords: TG-43 Formula, absorbed dose rate

1. Introduction

The American Association of Physicist in Medicine (AAPM) has formulated a formula called TG-43 to determine the characteristics of a source [1]. Each source has a different specification so that it requires precise calculations based on the geometry of each source. Although there are still deficiencies in the formula [2], the formula is still the most valid formula in calculating the dosage to date [3].

When manufacturers produce an isotope, at the same time they will issue characteristic data of the source, such as the anisotropic function, the dose rate constant, the Air Kerma Strength constant and so on[4]. This characteristic can be done experimentally [5,6] by performing various kinds of dose or absorption rates measurements and can also be done using simulation software such as MCNP [3].

In addition, for the purposes of dose verification, several studies have produced methods to determine whether the dose rate produced by a source in practice is in accordance with empirical calculations [7,8].

The University of Valencia of Spain has transformed the calculations using TG-43 formula into a tabular calculation form using Excel, especially in relation to the applications of the Brachy Therapy Treatment Planning System (TPS), to facilitate the

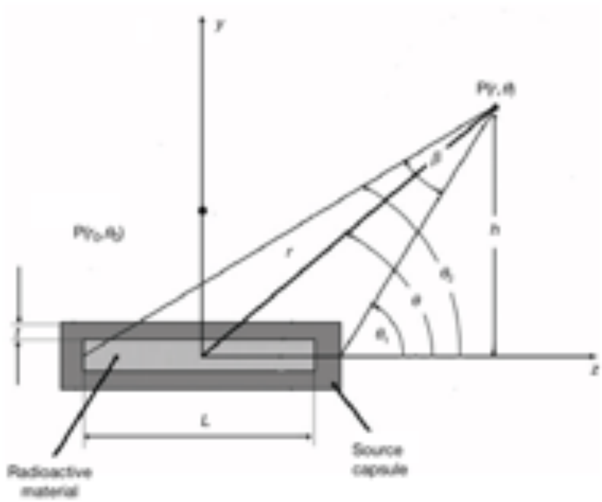

Figure 1. Geometric location for source and point calculation of absorbed dose rate distribution

$D(r,\theta) = Sk.\ \Lambda.(G_L(r,\theta)/G(r_0,\theta_0)).g(r).F(r,\theta)$

Where :
$D(r,\theta)$ = absorbed dose rate distribution at the point of calculation in air
$P(r_0,\theta_0)$ = reference point at 1 cm above the center of the source (that is r_0 = 1 cm and $\theta_0 = \pi/2$)
r = distance from the calculation point P to the center of source
θ = angle formed between point P and the source axis
θ_0 = transverse plane of the source equal to π/2 radian
S_k = Air Kerma Strength constant of the source ($mGy \cdot m^2 \cdot h^{-1}$).
Λ = dose rate constant in air
$G_L(r,\theta)/ G(r_0,\theta_0)$ = geometric function
g(r) = dosis function based on radial
$F(r,\theta)$ = anisotropic function

calculation of Absorption Dose Rate [9]. Similar calculations using the same formula have also been performed, but it was limited to a few calculation points only [10]. Based on the tabular calculation, a software has been developed to calculate in real time the rate of dose of one or several sources, which can then be developed to determine the lines of isodose generated from the source.

The calculation principle of the absorbed dose rate distribution can be observed in Figure 1. For a point P in a coordinate, the magnitude of the absorbed dose rate at that point is determined by several things such as source activity, source length, geometric location of the point to the source and others. There are also several constant factors that influence it, namely Air Kerma Strength and dose rate constant.

The formula below known as TG-43, used in calculating the absorbed dose rate distribution at a certain point P with distance r from the midpoint of the source and formed an angle θ with the axis of the source.

In order to apply the linear source model and accurately calculate the anisotropic function, it is necessary to determine the source orientation relative to the calculation point/dose calculation, for each source position specified in the applicator, or in other words, a polar angle θ. The source axis, in each position, is the tangent axis with the direction of the source in the applicator, so that the polar angle θ = 0º goes to the distal position or the end of the applicator. This direction is a vector that connects two source positions in a row. Polar angle θ is obtained by using a scalar product between vectors a and r, which is a vector between the source center and the calculation point. Whereas the angles θ1 and θ2, which are determined by both ends of the source, are calculated in the same way. With a method like this, the curvature of the catheter is taken into account. The dose calculation also does not depend on the origin or the orientation of the Cartesian axis system which is used to determine the coordinates of the source position and the point of calculating the dose.

While calculating GL(r,θ) the following formula can be used:

$$G_L(r,\theta) = \begin{cases} \dfrac{\beta}{L \cdot r \cdot \sin\theta} & \text{if} \quad \theta \neq 0, \pi \\ \dfrac{1}{r^2 - \dfrac{L^2}{4}} & \text{if} \quad \theta = 0, \pi \end{cases}$$

Where L is the source length and β is the angle formed between the calculation point and the two ends of the source as can be seen in Figure 1. Other calculation factors such as F (r, θ) and G (r_0, θ_0) was obtained from the table which is usually published by the source manufacturer.

2. Methods

In order to calculate the absorbed dose rate distribution from a source around it, the first volume of the universe is determined for the calculation of the dose. In this stage, a cube volume has been chosen with a distance from the source that can be determined according to the desired level of accuracy. Because the anisotropic function available in the literature is only for a radial distance of r less than 5 cm, this program has chosen the cube calculation volume with each side of 10 cm. If the selected volume is too large, the calculation will be longer but it will provide higher accuracy. For each of this volume, it is also determined the point density calculation of the distribution or the magnitude of the pixel in each volume. In this case, a pixel width of 2.5 mm has been chosen so that it produces 41x41x41 calculation points in each cube.

First of all, a source position and a calculation point in the universe of the volume are determined as explained in the previous figures. From these two points, a radial distance (vector r) and vector a, which is a vector that connects the position of the source to the next position are determined. From these two vectors, we can get the angle θ as shown in Figure 1, using the equation below it. Then, with the same method, the angle θ_1 can be calculated using the scalar multiplication between vector a and vector r proximal (between calculation points with the position of the nearest source tip), and the angle θ_2 can be calculated using the multiplication between the vectors a and the distal r vector (between the calculation points and the farthest end of the source position). The next step is to get the angle β, which is the sum of the angles θ_1 and θ_2. The angle β is then used to calculate G_L(r,θ), which then results are used to calculate g(r), F(r,θ) and finally D(r,θ). Furthermore, calculations will be performed to calculate the distribution of absorbed dose rate from the source in the next position for the same calculation point. It continued until all source positions end, the calculation is done for another calculation point. The flowchart of all these processes can be seen in Figure 2. The calculation resulted from each of this calculation point P are then stored in a binary document that can be displayed with the help of software such as ImageJ. The next step is to calculate the absorbed dose rate distribution with a single source and several sources at various locations (in the middle position and several other positions that are adjacent but still in one axis) with the characteristics as listed in table 1.

3. Result

The result of the program was stored in a file with the format of binary, were viewed using an Image Reader software called *ImageJ*. Some imaging results have been obtained with a different type of source activities and locations. In figure 3 it can be seen that the intensity of the dose rate in the initial slices is still low, but increases in the

Table 1. Source characteristics used in the calculation of absorbed dose rate distribution

Source Characteristics	
Type of Source	Ir-192
L (Source Length)	3.6 cm
Air Kerma Constant (RAKR)	9906 U (mGy/h at 1 meter in Air)
Dose Rate Constant	1.108 cGy(h.U)

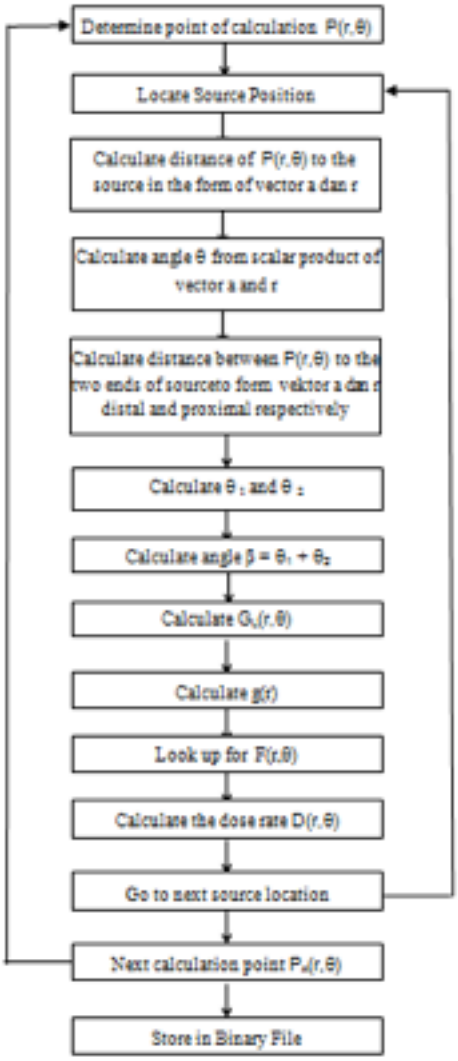

Figure 2. Flow Chart of Dose Rate Calculation

mid-slices so that they reach the maximum in the middle slice where the source is located. However, it can be noted that in slice 21, there are some 'blank spot' in which by calculation the value of absorbed dose rate in such location is zero. This phenomenon due to two factors first is the unavailability of anisotropic function for r less than 2.5 mm. Another factor is the geometric factor, where an angle formed between the source and the point of calculation is zero, hence resulting in a zero result.

Figure 5 depicts a 3-dimensional absorbed dose rate distribution profile for a source with the pixel size of 41x41. In slice 1 and 41 (the furthest from the source), the dose rate distribution has not been seen yet. But as it gets closer to the location of the source, the dose rate distribution getting higher. The results confirm the previous calculation of the absorbed dose rate distribution reaching its peak in the middle slice, while at the location of the source (slice 21) it has decreased dramatically.

In the case of multiple sources, the image would be similar except that the value is now accumulated. For example, the maximum value in the middle slice would reach a value of 5676 mGy for multiple sources while such value for a single source would be below 100 mGy.

The calculation of absorbed dose rate distribution will be very useful in determining the isodose lines/curves produces by the sources. The correct positioning of the sources, will create a certain shape of isodose lines/curves hence can give a correct dose for the targeted area, and at the same time avoided high dose for other healthy areas. Later on such dose can also be verified by different method [11].

4. Conclusion

A software has been made that to calculate the absorbed dose rate distribution for Ir-192 sources for a certain volume using the TG-43 formula. It has shown that the absorbed dose rate distribution rises around the source location and decreases in proportion to the distance from the source. However, for a distance less than 2.5 mm, these values cannot be calculated since there is no manufacturing information to support

Figure 3 The image of the value of absorbed dose rate distribution with 41x41x41 pixel point of calculation at slices 19 – 23. In the middle slice (21), it has reached the maximum rate

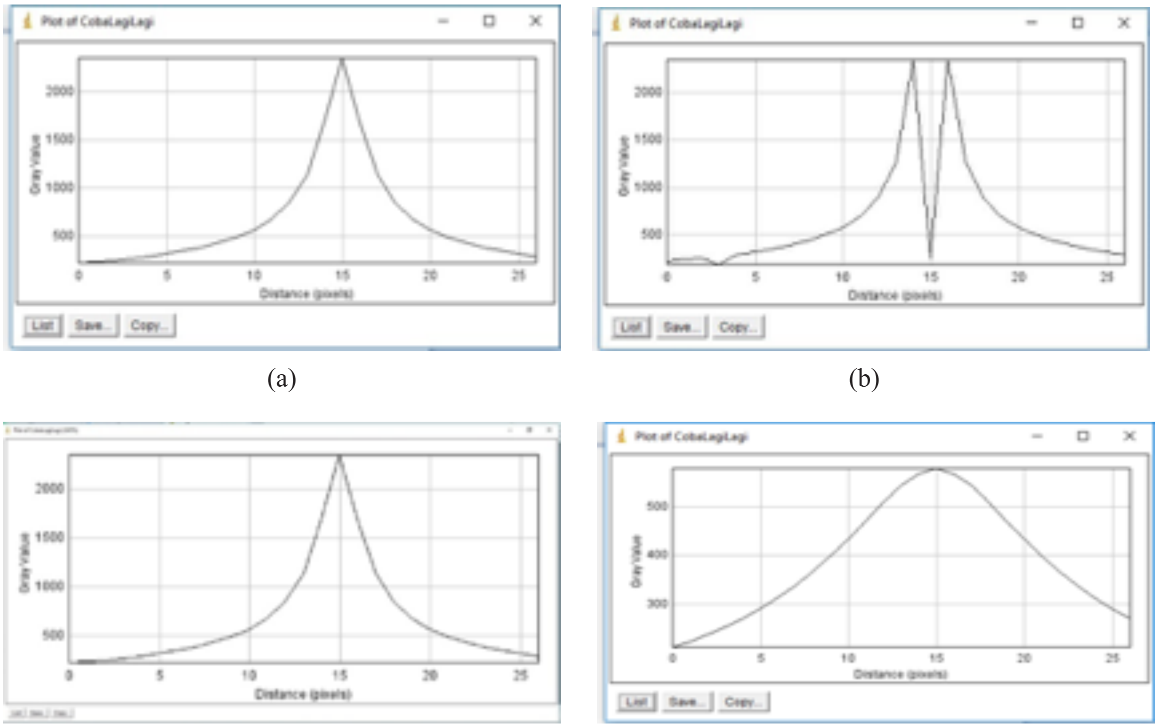

Figure 4 a-d Cross-section profile of each image slice with a size of 3x27 pixel at slice number 19, 20, 21 and 31 respectively. At the mid slice 21, the absorbed dose rate distribution reached its maximum

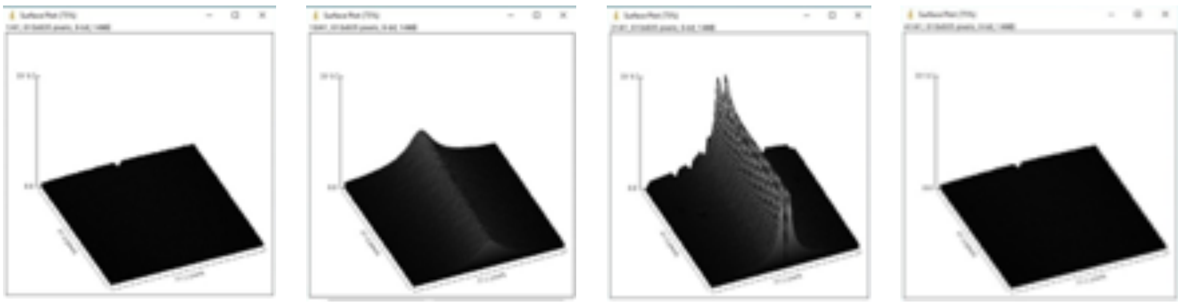

Figure 5 Several 3 dimension profile of absorbed dose rate distribution, showing an increase for slice 1 to slice 41 with the source located in the middle

this. For calculations using several sources, the values accumulated and hence form some sort of shape of isodose lines or curves.

Acknowledgment

We would like to give our gratitude towards our institution PRFN which has given us the opportunity to perform this research.

References

1. Rivard MJ, Coursey BM, DeWerd L a, Hanson WF, Huq MS, Ibbott GS *et al.* Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations. *Med Phys*. 2004; 31(3): 633–674.
2. Zehtabian M, Faghihi R, Si S. A Review on Main Defects of TG-43. In: *Brachytherapy*. InTech, 2012 doi:10.5772/34360.
3. Granero D, Vijande J, Ballester F, Rivard MJ. Dosimetry revisited for the HDR 192Ir brachytherapy source model mHDR-v2. *Med Phys*. 2011; 38(1): 487–494.
4. Herbert C, Morris WJ, Keyes M, Hamm J, Lapointe V, McKenzie M *et al.* Outcomes following iodine-125 brachytherapy in patients with Gleason 7, intermediate risk prostate cancer: A population-based cohort study. *Radiother Oncol*. 2012; 103(2): 228–232.

5. Saxena SK, Sharma SD, Dash A, Venkatesh M. Development of a new design 125I-brachytherapy seed for its application in the treatment of eye and prostate cancer. *Appl Radiat Isot*. 2009; 67(7–8): 1421–1425.
6. Rivard MJ, Ph D, Melhus C. Brachytherapy Dose Calculation Formalism , Dataset Evaluation , and Treatment Planning System Implementation. *System*. 2009; (June).
7. Smith RL, Haworth A, Millar JL, Panettieri V, Millar JL, Franich R. Treatment Delivery Error Trapping in HDR Brachytherapy. *Brachytherapy*. 2016; 15(August): S39.
8. Smith RL, Haworth A, Panettieri V, Millar JL, Franich RD. A method for verification of treatment delivery in HDR prostate brachytherapy using a flat panel detector for both imaging and source tracking. *Med Phys*. 2016; 43(5): 2435–2442.
9. Valencia U of. www.uv.es/braphyqs/. 2006.
10. Ramdhani S, Khotimah SN, Wardaya S, Haryanto DF. Perhitungan Laju Dosis Serap untuk Simulasi Terapi Kanker Serviks dengan Metode High Dose Rate Berdasarkan TG-43U1. *J Fis Himpun Fis Indones*. 2011; 11(1): 6–11.
11. Huckle A, Al-Qaisieh B, Bownes P. Methods of verifying the output of the treatment planning system used for high dose rate (HDR) prostate brachytherapy. *Radiother Oncol*. 2012; 103(2): 261–265.