IN PHANTOM DOSIMETRY OF BRACHYTHERAPY SOURCE

CENTER FOR MEDICAL AND RADIATION PHYSICS

AIM:

1. To determine various dosimetry parameters such as Geometry Function G(r,θ), Radial Dose Function g(r), & Anisotropy Function (F(r,θ)) of TG-43 formalism using phantom dosimetry of brachytherapy source.
2. Find out the factors on which these parameters depends.

EQUIPMENT REQUIRED:

1. HDR Brachytherapy Unit (Microselectron Ir-192 Brachy source)
2. Solid Slab Phantom (IPD phantom)
3. Transfer Tube (Tube compatible with Interstitial Implant plastic catheters)
4. TLD capsules ($CuSO_4$: Dy)
5. TLD Reader (TL/OSL Research reader)

THEORY:

Dose measurement in Brachytherapy can be challenging due to several factors, such as dosimetry for a small dimension source, self-attenuation within the source, complex geometry, tissue heterogeneity, inverse square law, and high dose rates. Specialized dosimeters, careful calibration procedures, and sophisticated computational dose calculation models are used to overcome these hurdles. Consequently, the dosimetry of brachytherapy applications relies heavily on theoretical calculations. The traditional method of calculating dose in a medium had many demerits, and hence, to resolve such issues, AAPM published a protocol report named Task Group-43 (TG-43). It was comprehensive, simple formalism, accurate and versatile, so it was recommended as the standardized protocol for brachytherapy dosimetry.

TG-43 Formalism:

The TG-43 Formalism provides a methodology to calculate the dose rate in a tissue-equivalent medium for an actual source. The quantities used in the formula can be calculated and measured for specific types of sources, considering source construction and geometry in addition to primary photon fluence. The dose calculation formalism allows for 2D dose calculation around cylindrical sources in terms of polar coordinates (r, ϴ). So as per TG-43, the dose rate $\dot{D}$ (r, ϴ), at a point P with polar coordinate (r, ϴ) in a medium from the center of the source of Air Kerma strength S_k is given below:

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

Where,

r = distance (in centimetres) from the centre of the active source to the point of interest.

r_0 = Reference distance specified to be 1 cm in this protocol.

θ = The polar angle specifying the point-of interest.

θ_0 = The reference angle, source transverse plane, and is specified to be 90° or π/2 radians.

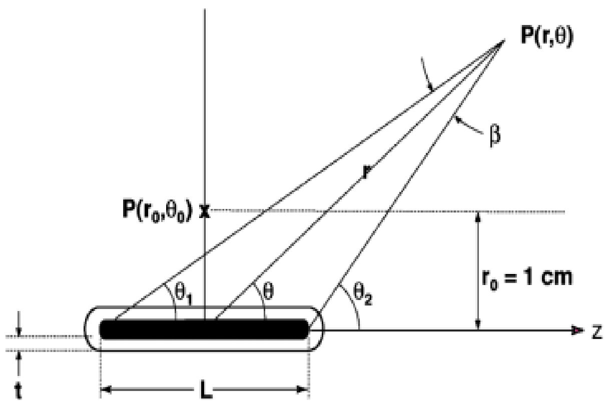


Fig:1: Coordinate system used for brachytherapy dosimetry calculations. L is the active length of the source. θ is the angle subtended by the active length of the source with the point of interest.

S_k: Air Kerma Strength

Air-kerma strength, S_k expressed in μGym^{2}h^{-1}*, is the air-kerma rate, $\dot{K}_\delta(d)$ at a distance d, in vacuum due to the photons of energy greater than δ, multiplied by the square of this distance, d.*

Mathematically:

$$S_k = \dot{K}_\delta(d) \times d^2$$

Where $\dot{K}_\delta(d)$ is usually inferred from transverse plane air-kerma rate measurements performed in a free-air geometry at distances large in relation to the maximum linear dimensions of the detector and source, typically of the order of 1 meter. The quantity d is the distance from the source center to the point of measurement of $\dot{K}_\delta(d)$ that is located on the transverse plane of the source. The energy cutoff, δ, is intended to exclude low-energy or contaminant photons (like characteristic x-rays originating in the outer layers of steel or titanium source cladding) that increase $\dot{K}_\delta(d)$ without contributing significantly to the dose at distances beyond 0.1 cm in tissue.

"In Vacuum" means the measurements should be corrected for photon attenuation and scattering in air and any other medium interposed between the source and detector, as well as photon scattering from nearby objects, including walls, floors, ceilings, etc.

Λ: Dose Rate Constant:

It is the ratio of dose rate at the reference position, P (r_0, θ_0) and S_k.

$$\Lambda = \frac{\dot{D}(r_0, \theta_0)}{S_k}$$

The dose rate constant depends on the radionuclide and the source model. The dose rate constant converts the air Kerma Strength to the Dose rate in the medium.

$G_x(r,\theta)$: Geometry Function:

The geometry function $G_x(r,\theta)$ accounts for the inverse square law and does not consider radiation absorption and scattering by traversing the medium. In the line-source approximation model, G also considers the approximate spatial distribution of radioactivity within the active core of the source. Geometry functions according to the point-source and line-source approximations are:

$$G_p(r,\theta) = r^{-2} \qquad \text{Point source approximation}$$

$$G_L(r,\theta) = \{\frac{\beta}{Lr\sin\theta},\ if\ \theta \neq 0^0\ \left(r^2 - \frac{r^2}{4}\right)^{-1}, if\ \theta = 0^0 \qquad \text{Line source approximation}$$

β is the angle, in radians, subtended by the tips of the hypothetical line source with respect to the calculation point, P (r, ɵ).

g_x (r): Radial Dose Function:

The radial dose function $\mathbf{g_x(r)}$ accounts for the dose rate change due to photon scattering and absorption in the medium along the transverse axis through the centre of the source. This excludes the geometrical fall-off effects modelled with $\mathbf{g_x(r)}$**.** Overall, $\mathbf{g_x(r)}$ is defined as:

$$g_x(r) = \frac{\dot{D}(r,\theta_0)}{\dot{D}(r_0,\theta_0)} \times \frac{G_x(r_0,\theta_0)}{G_x(r,\theta_0)}$$

F (r, θ): Anisotropy Function:

The 2D anisotropy function (F (r, θ)) describes the variation of dose as a function of polar angle θ relative to the transverse plane. For sources other than point sources, this angular variation is mainly due to self-filtration, scattering of photons within the source and oblique filtration of primary photons through the source encapsulation. F (r, θ) is given by

$$F(r,\theta) = \frac{\dot{D}(r,\theta)}{\dot{D}(r,\theta_0)} \times \frac{G_L(r,\theta_0)}{G_L(r,\theta)}$$

Measurement of these Factors:

The geometry function $G_x(r,\theta)$ depends on the source geometry, shape, etc. It can be easily calculated by knowing the dimensions and properties of the source. The determination of $g_L(r)$ and $F(r, \theta)$ relies on the measurement dose rates in the medium at the respective points. This dose rate can be measured by solid-state detectors, films, TLDS, OSLDs, etc. (Here, we will use TLDs). Both the quantities $g_L(r)$ and $F(r, \theta)$ are proportional to the ratio of the measured dose rates as given in the definition above. If we keep the measurement parameters and the source geometry constant, the dose rate is proportional to the counts in the TLD. So, while measuring with TLDs, this ratio of dose rates is simply the ratio of counts obtained from the respective TLDs. This approach eliminates the need for TLD calibration, as we solely focus on the ratio of TLD readings.

Hence

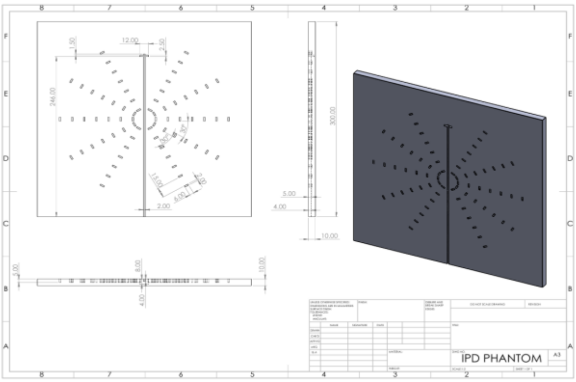
$$g_x(r) = \frac{\dot{D}(r,\theta_0)}{\dot{D}(r_0,\theta_0)} \times \frac{G_x(r_0,\theta_0)}{G_x(r,\theta_0)} = \frac{TLD\ Counts(r,\theta_0)}{TLD\ Counts(r_0,\theta_0)} \times \frac{G_x(r_0,\theta_0)}{G_x(r,\theta_0)}$$

$$F(r,\theta) = \frac{\dot{D}(r,\theta)}{\dot{D}(r,\theta_0)} \times \frac{G_L(r,\theta_0)}{G_L(r,\theta)} = \frac{TLD\ Counts(r,\theta)}{TLD\ Counts(r,\theta_0)} \times \frac{G_L(r,\theta_0)}{G_L(r,\theta)}$$

PHANTOM DESIGN:

The Phantom (called IPD phantom henceforth) used for this experiment was made up of Perspex of 10mm thickness. The dimension of the phantom is (30X30) cm^2. There is a central line of 2mm diameter grooved to insert the interstitial catheter (which has a button at one end and opened at the other to allow the insertion of a source through it). The top end containing the button is fixed within the slab phantom. The brachytherapy transfer tube can be connected to the other end for the movement of the source.

There are tiny groves of dimension (2X6.2) mm^2 at 15mm intervals from the central line placed along the perimeter of the circle on both sides of the central line to hold the TLD seeds within it. The angular separation of these groves is 30^0 (Refer to the figure 2 below).

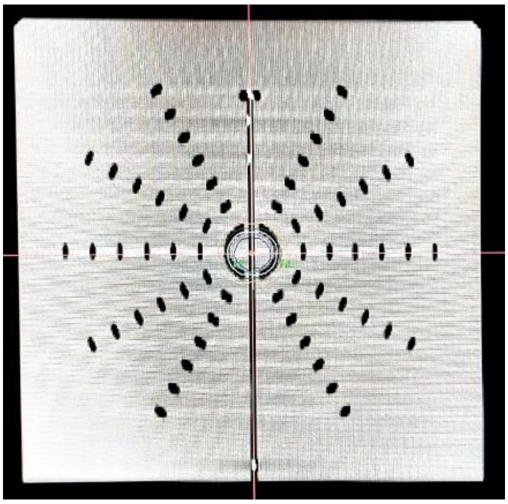


(Figure 2: Design of In-house IPD phantom)

PROCEDURE:

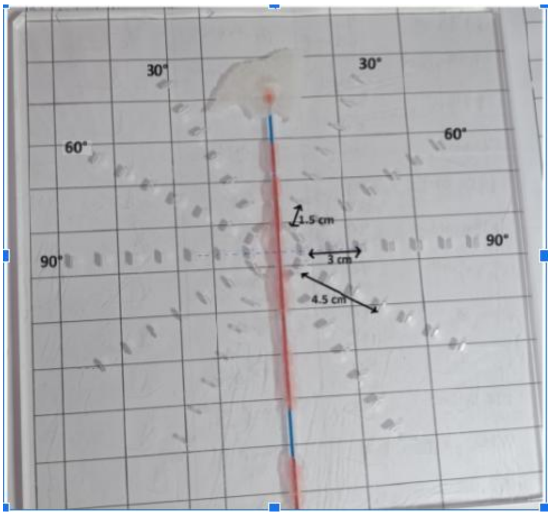
The various steps for the experiment are described below

1. Scan the IPD phantom in a CT scanner with proper fiducial on both ends of the central line.
2. Set the dwell position of the source at the centre of the inner circle of the phantom and create a plan with a prescription dose of 2Gy at 15mm from the source along the transverse line.



(Fig3: Scanned Phantom In TPS)

3. Place the TLD discs in the grooves of the phantom at different distances (i.e. 15mm, 30mm, 45mm etc) and at different angles (90^0, 60^0, 30^0). Place the TLD on both sides of the central line to have 2 TLDs for a particular angle and distance. These readings can be averaged out easily.



(Fig4: IPD phantom showing distance and angle difference between measurement points)

4. Connect the after-loader brachytherapy unit with the catheter of the phantom by a transfer tube, as shown in Figure 5 below.

(Fig5: Measurement Setup for In Phantom Dosimetry of Brachytherapy Source)

5. Expose the TLDs to the prescribed dose as mentioned above.
6. Remove the TLDs from their respective slots and store each in separate envelopes, marking the distance and angle at which the TLD is placed.
7. You can have many such envelopes corresponding to distance(r)=15mm, 30mm, 45mm and angles = 90^0, 60^0, 30^0 respectively.
8. Read all the TLDs individually with the help of a TL reader and tabulate the readings as shown below.

OBSERVATION:

1. TLD counts for different r and ɵ values from the TLD reader-

Distance In cm	Angles In Degrees	Counts 1	Counts 2	Average
1.5cm	30			
	60			
	90			
3.0cm	30			
	60			
	90			
4.5cm	30			
	60			
	90			

2. Calculated $G_L(r, \theta)$, g_x(r) and $F(r, \theta)$, value in the table below: -

r (cm)	Angle (θ) (deg)	β (Radians)	$G_L(r, \theta)$ *radians/cm*^{2}	$g_L(r)$	$F(r, \theta)$
1.5cm	30				
	60				
	90				
3.0cm	30				
	60				
	90				
4.5cm	30				
	60				
	90				

RESULT:

CONCLUSION:

PRECAUTION:

<u>During Irradiation of TLD</u>

1. Ensure the source is fully retracted before entering the treatment room.
2. Ensure the proper connection of the transfer tube both with the machine and applicator.

<u>For TL Reader</u>

3. Do not increase the PMT voltage beyond 1000 Volts.
4. Please ensure the correct mode (TL/ OSL) is selected.
5. Do not open the drawer while the measurement is going on.
6. Do not touch the planchet/ sample holder immediately after the readout. Wait till the temperature reduces below 40°C.
7. Switch on the TL/ OSL Reader power button after turning on the main supply.
8. Always wear gloves while handling the samples during the measurement and the annealing procedure

<u>References:</u>

- AAPM TG43 Report: https://www.aapm.org/meetings/04AM/pdf/14-2226-27835.pdf
- TL/OSL research reader manual by Nucleonix Systems Pvt. Ltd.