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Monte Carlo Simulation and Experimental Determination of Tissue Phantom Ratio for Megavoltage Photon Beam

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ABSTRACT: *According to IAEA TRS-398 protocol the Tissue Phantom Ratio, $TPR_{20,10}$, is used as a quality index for the megavoltage photon beam in external beam radiotherapy. This work presents a calculation of $TPR_{20,10}$, in two high energy photon modes using FC65-G thimble type cylindrical ionization chambers with the help of Monte Carlo method. The MCNP (version MCNP5) code was used for the simulation of photon beams delivered by Varian-2300CD Clinac accelerator head. The $TPR_{20,10}$ values were also measured experimentally using the same chamber. The calculation of $TPR_{20,10}$ using MC simulation showed good agreement with our experimentally determined values. The $TPR_{20,10}$ discrepancies of Monte Carlo and experimental values were found within 3.12% and 2.7% for 6 MV and 10 MV photon beams respectively. As MCNP simulated values showed good agreement with experimentally determined values, so this simulation technique should be applicable for the further research in reference dosimetry.*

Keywords: Photon beam, Tissue Phantom Ratio (TPR), TRS-398 protocol, Monte Carlo N particles (MCNP).

1. INTRODUCTION

Cancer is responsible for over 12% of all causes of death around the world. More than 7 million people die of this disease annually. Radiotherapy is the most important and effective technique of local treatment of cancer with ionizing radiation [01-04]. The primary objective in radiation therapy is to deposit dose from ionizing radiation to the affected cell while sparing the surrounding healthy tissue. The accuracy of radiotherapy treatments depends on the calibration of radiation sources (e.g. Clinac) known as reference dosimetry. There are two main types of radiation therapy, external beam radiotherapy and internal beam radiotherapy.

In external beam radiation therapy, the radiation source is at a certain distance from the patient and the target within the patient is irradiated with an external radiation beam. More than half radiotherapy patients are treated with external beam radiotherapy. Most external beam radiotherapy is carried out with photon beams, some with electron beams and a very small fraction with more exotic particles such as protons, heavier ions or neutrons. There are many different types of external radiotherapy namely, 3DCRT, IMRT, IGRT, IORT etc. The type of external radiotherapy is actually depends on the type of cancer and its position in the body.

In internal beam radiotherapy a radioactive source is put inside body or near the tumor. It is also known as brachytherapy. It is usually used for skin cancer, tongue cancer, cheek cancer, breast cancer etc. The various dosimetric physical quantities, like wall correction factor, stopping power ratio, central electrode correction factor, beam quality correction factor etc., depend upon photon or electron beam energy. Thus the beam quality needs to be specified for dosimetric calculations. In the megavoltage photon energy range, the main beam quality indices are $TPR_{20,10}$, $PDD(10)_x$, and d_{80} etc. Most recent dosimetry protocols based on absorbed dose to water calibration of ion chambers use the tissue phantom ratio, $TPR_{20,10}$, as the high energy photon beam quality specifier (IPEM, IAEA TRS 398, etc.) [05-09]. The parameter $TPR_{20,10}$ is defined as the ratio of absorbed dose to water at depth of 20 and 10 cm in a water phantom obtained with constant source to chamber (SCD) distance of 100 cm and a field size of 10 cm × 10 cm at the position of the chamber. The most important characteristics of the beam quality index $TPR_{20,10}$ is its independent of the electron contamination in the incident beam. It is also a measure of the effective attenuation coefficient describing the approximately exponential decrease of a photon depth dose curve beyond the depth of maximum dose [10]. Now according to definition, $TPR_{20,10}$ is expressed as

$$TPR_{20,10} = \frac{D_{w,20,Q}}{D_{w,10,Q}} \quad (1)$$

The absorbed dose to water in high energy photon beam is obtained by the following expression [11-12]

$$\begin{aligned} D_{w,Q} &= M_Q \, N_{D.w,Q_0} \, k_{Q,Q_0} \\ &= M_{raw,Q} \; K_{TP} \, K_{elec} \, K_{pol} \, K_s \, N_{D,w,Q_0} \, k_{Q,Q_0} \end{aligned} \quad (2)$$

Plugging equation (2) into equation (1), we obtain

$$TPR_{20,10} = \frac{M_{raw,20,Q}}{M_{raw,10,Q}} \quad (3)$$

Where M_{raw} is the uncorrected charge reading in nC from electrometer.

The goal of this work is to calculate the tissue phantom ratio directly through Monte Carlo simulation of necessary equipment (through MCNP code) for two-photon modes using FC65-G thimble type cylindrical ion chambers and also the experimental measurement of $TPR_{20,10}$.

2. MATERIALS AND METHODS

2.1 Monte Carlo simulation

MCNP is a general-purpose Monte Carlo N-Particle code that is used for analyzing the transport of neutrons and gamma rays by the Monte Carlo method. In the simulation of radiation transport using MC methods, the history of a particle is defined as a sequence of tracks where each tracks ends with an interaction event where the particle can change its direction, lose energy and occasionally produce secondary particles. The history ends when it leaves the region of interest or when its energy is lower than the predefined cutoff energy [13]. In the latter case, the remaining energy is deposited at the point where the transport of particle was stopped.

The MC simulation of the accelerator head of a Clinac was performed in MCNP (version MCNP5). The following sections describe the geometry of several components used in this simulation.

2.1.1 Accelerator geometry

The accelerator head of Varian Clinac 2300CD located at the National Institute of Cancer Research and Hospital (NIRCH), Bangladesh was simulated using MCNP5. Information about the geometry and the materials of the components of this Clinac were obtained from its manufacturer. The target of the Linac was defined as two cylinders, one made of tungsten and the other make copper. The primary collimator is made of tungsten, about 7.47 cm, located just below the x-ray target, used to collimate the x-rays in the direction of the treatment field. The conical- shaped flattening filter is made of OFE Cu (Oxygen- Free Electrons) provides uniform radiation intensity distribution across x-ray fields at any depth of treatment. The secondary collimators consist of two pairs of jaws, one above the other and these are labeled as X1, X2, and Y1, Y2. The pair of jaws is made of tungsten of about 7.77 cm and 7.80 cm high respectively.

Simulation geometries were drawn using the developed code into geometry plotting panel of Visual Editor (VE) of MCNPX Monte Carlo package.

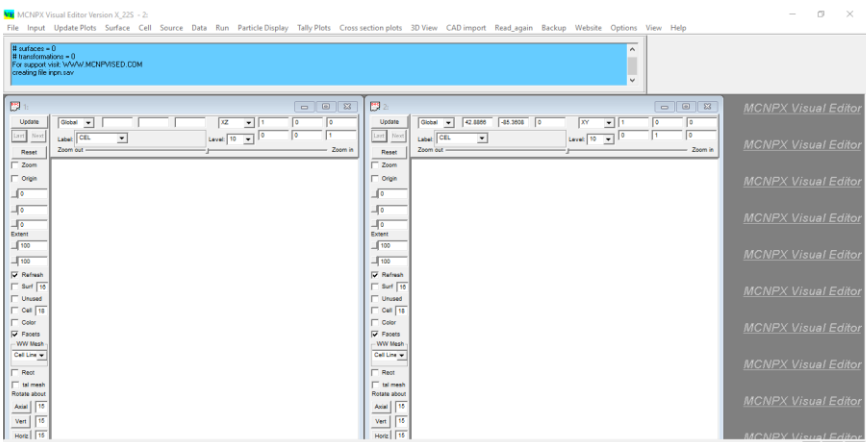


Fig. 1. Visual Editor (VE) display window.

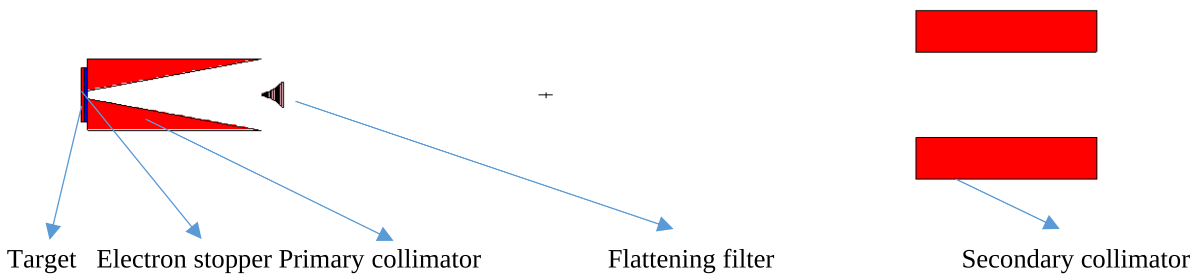
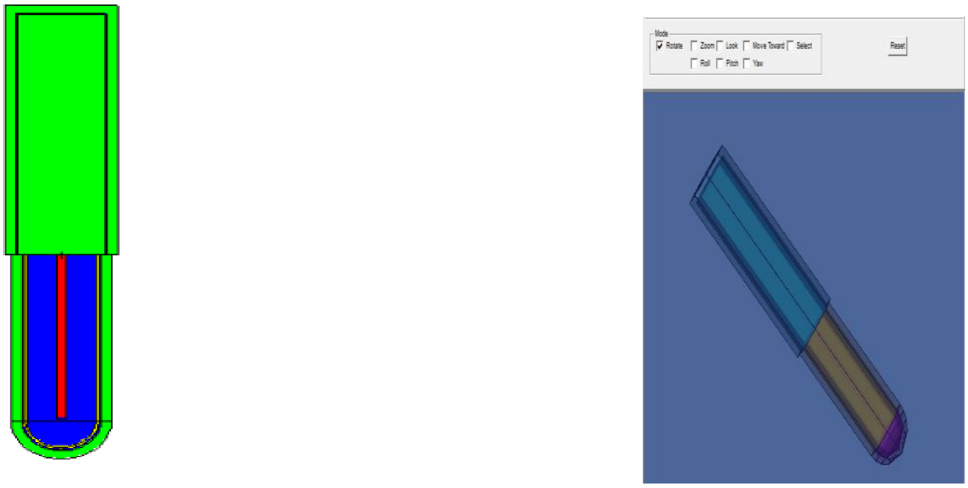


Fig. 2. Simulation geometries of Varian Clinac.

2.1.2 Ion chamber geometry

The 0.6 cm^3 FC65-G chamber was modeled by taking necessary materials and dimensions from IAEA TRS-398 protocols [10]. The chamber cavity has a diameter of 0.62 cm and a length of 2.31 cm and includes a 2.05 cm central electrode of aluminum with 0.1 cm diameter. The wall material is of Graphite with 0.065 g cm^{-2} thickness. The air gap of 0.1mm between the chamber wall and waterproofing sleeve was taken to allow the air pressure in the chamber to equilibrate.



(a) (b)

Fig. 3. Simulation geometries of FC65-G Farmer chamber, (a) 2-D and (b) transparent 3-D mode.

Besides ion chambers, IAEA standard water phantom of dimensions 30 × 30 × 30 cm^3 was also modeled. The complete geometry of photon dose calculations at the reference point of the ion chamber placed in the water phantom is illustrated in figure 4.

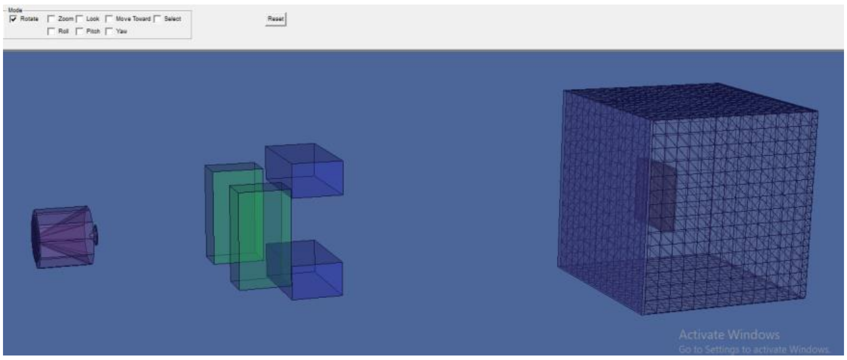


Fig. 4. Simulation geometries of FC65-G Farmer chamber for photon dose calculation.

2.1.3 Simulation strategy: calculation of $TPR_{20,10}$

The absorbed dose to water at particular depth was calculated using F4 cell tally. As the units of F4 tally is of average flux in cell, this is converted into the dose unit (Gy) by using appropriate FM4 tally multiplier card. Then the developed input files were executed for two depths 10 and 20 cm with NPS- 3000000 using coreI3 processor. After successful execution of input files, the ratio of doses for 20 cm and 10 cm is taken from output files which is the calculated value of Tissue Phantom Ratio for particular energy. After that, we repeated the above procedure for different energy.

2.2 Measurement approach of $TPR_{20,10}$

The experimental set –up for measuring $TPR_{20,10}$ is shown in figure 5.

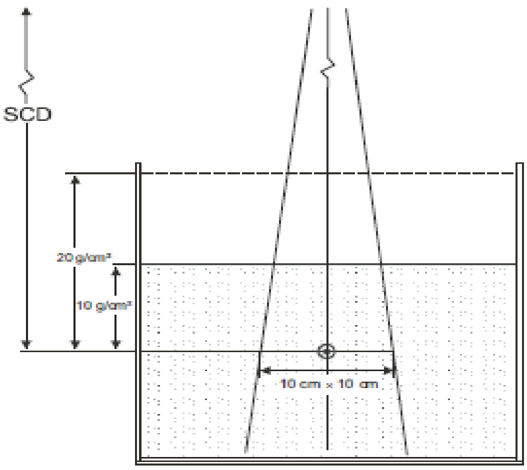


Fig. 5. Experimental set-up for the determination of beam quality index $TPR_{20,10}$ **[10].**

First, an ion chamber was placed at SCD (Source to Chamber Distance) 100 cm with 20 cm depth of water phantom. Exposing this arrangement to a photon beam of 6 MV, the charge reading (in nC) was taken from the dosimeter. The IBA dose-1 dosimeter was used in this work. The charge reading was also taken by changing the depth to 10 cm. Now using equation (3), the $TPR_{20,\ 10}$ values was calculated for this beam. The above procedure is also repeated for 10 MV photon beam. The reference conditions of measurement of $TPR_{20,10}$ are given in Table 1.

Table 1. Reference conditions for the determination of photon beam quality ($TPR_{20,10}$) **[10]**

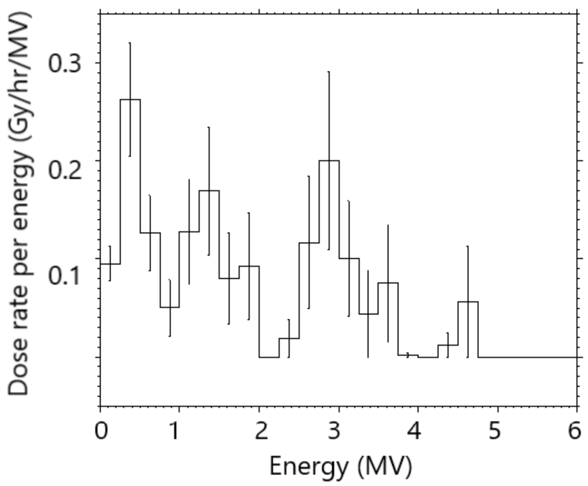
Influence quantity	Reference value or reference characteristics
Phantom material	Water
Chamber type	Cylindrical or plane parallel
Measurements depths	20 g/cm^2 and 10g/cm^2
Reference point of the chamber	For cylindrical chambers, on the central axis at the centre of the cavity volume. For plane-parallel chambers, on the inner surface of the window at its centre
Position of the reference point of the chamber	At the measurements depths for both chambers
SCD	100 cm
Field size at SCD	10 cm × 10 cm

3. RESULTS

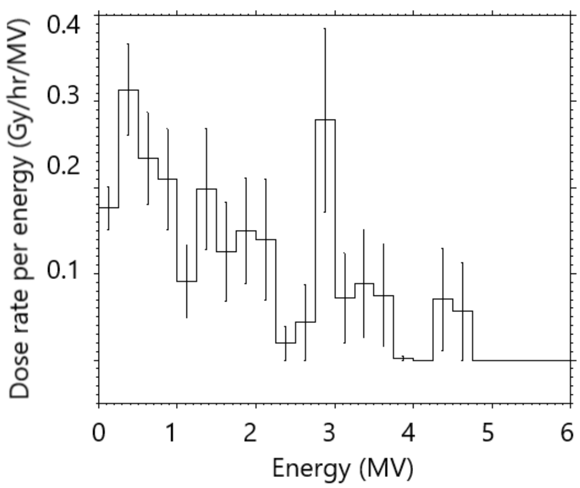
3.1 Monte Carlo calculated values of $TPR_{20,\ 10}$

The MC calculated dose- energy data were plotted (dose rate per unit energy vs. energy) for each photon mode using tally plotting facility of visual editor (VE) windows of MCNP code. The total dose rate at 20 cm and 10 cm depth of water phantom at the reference point of chamber were also taken from the MCNP output file for individual photon beam.

The MC calculated dose rate from figure 6 of 6 MV photon beam at 20 cm and 10 cm depth for FC65-G chamber are *0.405732* ± *0.013000* [Gyhr^{-1}] and *0.585939* ± *0.103400* [Gyhr^{-1}] respectively. Using equation-2, $TPR_{20,\ 10}$ is obtained as *0.692* ± *0.182* for 6 MV photon beam.



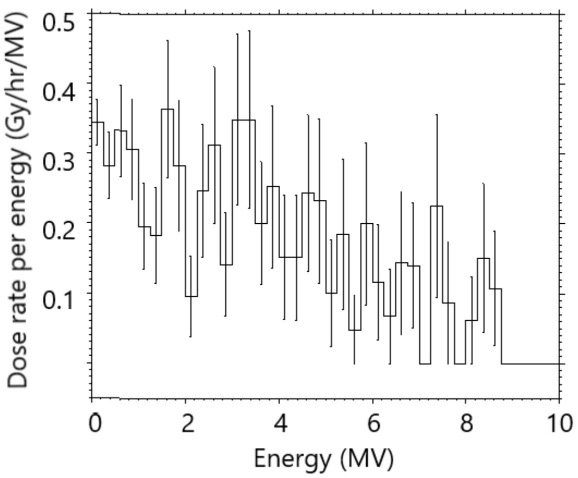
(a)



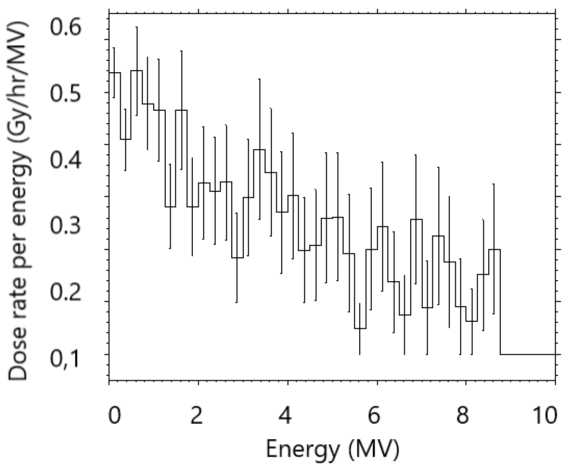
(b)

Fig. 6. Dose energy spectrum of 6 MV photon beam at (a) 20 cm depth and (b) 10 cm depth of water phantom using FC65-G Chamber.

The total dose rate of 10 MV photon beam from figure 7 are obtained as *1.67208* ± *0.09340* [Gyhr^{-1}] and *2.32234* ± *0.06610* [Gyhr^{-1}] for 20 cm and 10 cm depth of water phantom respectively. So the MC calculated tissue phantom ratio for 10 MV photon is 0.720 ± 0.027.



(a)



(b)

Fig. 7. Dose energy spectrum of 10 MV photon beam at (a) 20 cm depth and (b) 10 cm depth of water phantom using FC65-G Chamber.

3.2 Experimental values of $TPR_{20,10}$

Using photon beam from Varian 2300CD clinac and following IAEA TRS-398 protocol $TPR_{20,10}$ values were measured experimentally. Table 2 shows the comparison between experimental and MC calculated values of $TPR_{20,10}$.

Table 2. Comparison of experimental and calculated values of $TPR_{20,10}$

Chamber	Photon energy (MV)	Experimental values of $TPR_{20,10}$	Monte Carlo calculated values of $TPR_{20,10}$	Uncertainty
FC65-G	6	0.671	0.692	3.12%
	10	0.740	0.720	2.7%

4. DISCUSSIONS

The determined values of tissue phantom ratio show that it is mainly depend on the energy of incident photon beam. Values of $TPR_{20,10}$ increases with the increase of photon energy. The $TPR_{20,10}$ values vary with the material of ionization chamber. central electrode of ionization chamber type also. Particularly, wall material and central electrode have greater impact on the photon interactions and electron interactions produced in the surrounding medium (water). However, the variation of $TPR_{20,10}$ values with ion chamber is very small.

5. CONCLUSIONS

This paper presents a calculation of tissue phantom ratio for two photon modes using FC65-G cylindrical chambers with Monte Carlo simulations. The good agreement between MC calculated and experimentally measured values support the conclusion that both presented approaches to obtain $TPR_{20,10}$ are valid. It also encourages the use of MC calculated data if no experimental data is found with at least the same uncertainty.

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