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# Measurement of Absorbed Dose in Water Using Co-60 gamma source Teletherapy Units According to IAEA Dosimetry Protocols

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**Abstract**

Modern radiotherapy facilities like 3-Dimensional conformal radio therapy (3DCRT), Intensity Modulated Radiotherapy (IMRT), were recently suggested in Co-60 machine with Multi-leaf Collimator (MLC). In this study, two reference chambers NE-2571#1205 and NE2581#537 were used for absolute dose measurement in Equinox accelerator. A comparison of dose measurement by two different IAEA protocols TRS-277 and TRS-398 has been studied. Analyzing TRS-398, a common shaped empirical formula was developed for the four Co-60 units of four Medical Colleges in Bangladesh with fitting parameters. It was found that an average discrepancy in the determination of absorbed dose in water among the two different protocols TRS-277 and TRS-398 were 1.33 % for the chamber NE-2571#1205 and 0.65 % for the chamber NE2581#537 with combined uncertainty ±1.59 % ($k=1$). A good convergence has been obtained in the concepts and methods in this study.

**Keywords:** Co-60 Teletherapy Units, Technical Report Series (TRS), Absorbed Absolute Dose.

## Introduction

Proper utilization of ionizing radiation is used for the treatment of cancer. About 60 % of cancer patients are referred for radiotherapy in conjunction with chemotherapy **[1]. T**he most commonly used equipment in this field is Co-60 teletherapy machine which produces 1.25 MeV energy gamma rays 1.25 MeV **[2]**. The requirement for accuracy of 5 % **[3]** in the delivery of absorbed dose would correspond to a combined uncertainty of 2.5 % at the level of one standard deviation. To promote the compatibility methods applied for dosimetry in order to achieve uniformity of measurement throughout the world, International Atomic Energy Agency (IAEA) published a code of practice TRS-277 in 1987 for absorbed dose determination of photon and electron beams. In this code, measurements based on calibration in terms of air kerma require chamber dependent conversion factors to determine absorbed dose in water; these conversion factors increase the uncertainty of the determination of absorbed dose to water **[2,3]**. An updated protocol TRS-398 had been established by the

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IAEA (IAEA 2000) to reduce the uncertainty in the absorbed dose in water determination **[4,5]**. In TRS-398, absorbed dose in water is the interest of radiation therapy, since water is equivalent to the human body. In this protocol, there are no chamber dependent conversion factors, so the uncertainty associated with the corresponding correction factors is reduced.
In this work, an attempt has been made to measure the absolute dosimetry and find out an empirical formula for four Co-60 gamma source teletherapy units newly installed at four government medical colleges in Bangladesh. The work has been performed with the dosimetric facility, available at the Secondary Standard Dosimetry Laboratory (SSDL), Institute of Nuclear Science and Technology (INST), Atomic Energy Research Establishment (AERE), Savar, Dhaka, Bangladesh.

**Methods and materials:**

The restrained dosimetry of this work is based on the IAEA code of practice TRS-277 **[4]** and TRS-398 **[5]**. The reference cylindrical ionization chambers were NE-2571-1205 **[6,7]** and NE-2581#537 **[8]** coupled with electrometer PTW UNIDOS 10005-50231 **[9,10]**. The absorbed dose in water from $^{60}$Co gamma beam was carried out in a standard IAEA water phantom of dimension 30 cm × 30 cm × 30 cm. The ionization chamber was placed in the water phantom at the required depth (5 cm). The reference point of the chamber was positioned on the central axis of the $^{60}$Co beam. In this arrangement, Source to Surface Distance (SSD) of the phantom was 100 cm, Source to the Chamber Distance (SCD) was 105 cm or at 5 cm depth in water with different field sizes at the surface of the phantom. A standard barometer and thermometer were used for environmental corrections. Several correction factors such as those due to polarity, ion-recombination, pressure and temperature were calculated as per standard procedure given in TRS-398 & TRS-277. Table 1 shows a brief description of the teletherapy units with source activity in Bangladesh.

**Table 1**: Brief description of the calibrated GUCO teletherapy units with source activity

| Model | Source Activity | User |
|---|---|---|
| **Equinox, Theratronics#2133** | 440.6 TBq (11908 Ci) | Dhaka Medical College & Hospital,Dhaka (DMCH) |
| **Equinox, Theratronics#2135** | 444.9 TBq (12025 Ci) | Chitagong Medical College & Hospital, Chottogram (CMCH) |
| **Equinox, Theratronics#2134** | 449.7 TBq (12153 Ci) | Rajshahi Medical College & Hospital, Rajshahi (RMCH) |
| **Equinox, Theratronics#2136** | 438.2 TBq (11842 Ci) | Osmani Medical College & Hospital, Sylhet.(OMCH) |

The gamma radiation from the cobalt-60 source entered the chamber through the chamber wall via the water of the phantom. This radiation interacted with the air of the chamber wall and produced charges. The ion chamber collected these charges that were obtained as an electrometer reading mentioned as Monitor Unit (MU) **[4]** in the following formalism. The charges depended on the exposure time and the projected field size(s) at the surface of the phantom. The accumulated charges (MU) in the air cavity of the ionization chamber were measured for several square and rectangular field sizes ranging from 4 cm × 4 cm to 25 cm × 25 cm.

**Absorbed dose in water measurement using IAEA dosimetry protocol TRS-277 [4]:**

The absorbed dose in water at the position of the effective point of measurement of the ionization chamber $D_W(P_{eff})$ in unit of gray is given by:

$$D_W(P_{eff}) = M_u \cdot N_{D,air} \cdot S_{W,air} \cdot P_u \cdot P_{cel} \quad (1)$$

Where: $M_u$ is the reading of the ionization chamber, $S_{w,air}$ is the water to air stopping power ratio, equal to 1.133 for Co-60, $P_u$ is the perturbation factor, $P_{cel}$ is a factor that corrects the response of an ionization chamber and $N_{D,air}$ is the absorbed dose in air chamber calibration factor in unit Gray per charge, which can be calculated by the following formula:

$$N_{D,air} = N_K \,.\, (1-g) \,.\, K_m \,.\, K_{att} \quad (2)$$

Where: $N_K$ is the air kerma calibration factor of the ionization chamber; $g$ is the fraction of the energy of secondary charge particles lost into bremsstrahlung (g = 0.003 Gray for Co-60 gamma radiation) **[4]**; $K_m$ is the factor to take into account for non-air equivalence of the chamber wall and build-up cap during the calibration of the chamber walls. The absorbed dose in water at the position of the effective point of measurement and at the center of the chamber can be related by the so called displacement correction factor $P_{dis}$:

$$D_W(5\ g.cm^{-2}) = D_W(P_{eff})\,.P_{dis} \quad (3)$$

Where: $P_{dis} = 1 - 0.004r$, $r$ is the internal radius of the ionization chamber in mm. The distance between $P_{eff}$ and the center of the chamber is equal to 0.6r for the cylindrical chamber. The peak absorbed dose on the central axis is called maximum dose ($D_{max}$) in unit of Gray, which can be calculated by using the following equation **[4]**:

$$D_{max} = \frac{D_W\,(5\ g.cm^2)}{P} \times 10 \quad (4)$$

Where: $P$ is the central axis percentage depth dose (PDD) for SSD and tissue maximum ratios (TMR) for SAD set-ups.

**Absorbed dose in water measurement using IAEA dosimetry protocol TRS-398 [5]**

The absorbed dose in water at the reference depth, $Z_{ref}$, in water for a reference beam of quality Q is given by the simple relationship:

$$D_{w,Q}(Z_{ref}) = M_Q \times N_{D,W,Q0} \times K_Q \quad (5)$$

Where: $M_Q$ is the reading of the dosimeter corrected for the influence quantities and $N_{D,W,Q}$ is the calibration factor (Gray per coulomb) in terms of absorbed dose in water.

For Co-60 gamma ray beam, the formula is **[5]:**

$$D_w(Z_{ref}) = M_u N_{D,W} \quad (6)$$

Where: $D_W(Z_{ref})$ is the absorbed dose in water at $Z_{ref}$ in the user Co-60 gamma ray in the absence of the chamber; $M_u$ is the reading of the dosimeter corrected for the influence quantities; $N_{D,W}$ is the absorbed dose in water calibration factor at C0-60 gamma ray beam; absorbed dose $Z_{max}$ is the peak absorbed dose on the central axis , called dose ($D_{max}$), which can be calculated by using following equation **[5]**:

$$D_{max} = \frac{D_w\, Z_{ref}}{P} \times 100 \quad (7)$$

Where: $P$ is the central axis percentage depth dose (PDD) for SSD set-up.

## Results

### The absolute absorbed dose in water determined according to IAEA dosimetry protocol TRS-398 and TRS-277:

Applying both TRS-398 and TRS-277 absorbed absolute doses in water at 5 cm depth and $D_{max.}$ is shown in Table 2 and Figure 1.

**Table 2:** Comparison of absorbed dose in water at 5 cm depth and $D_{max}$ in reference IAEA water phantom for field size of 10 cm × 10 cm using chambers NE-2571#1205 & NE-2581#537

| Name of Medical College and Hospital | Chamber Model and Sl. No. | Field Size ($cm^2$) | TRS – 398 | | TRS – 277 | |
|---|---|---|---|---|---|---|
| | | | $D_w$ (5 cm) in cGy/min at 100 cm SSD | $D_{max}$ (0.5 cm) rate in cGy/min at 100 cm SSD | $D_w$ (5 cm) in cGy/min at 100 cm SSD | $D_{max}$ (0.5 cm) rate in cGy/min at 100 cm SSD |
| **DMCH** | NE-2571# 1205 | 10 × 10 | 148.53 | 184.74 | 148.30 | 182.48 |
| | NE-2581 # 537 | | 147.84 | 183.83 | 147.53 | 183.5 |
| **CMCH** | NE-2571#1205 | 10 × 10 | 147.52 | 183.48 | 147.24 | 181.17 |
| | NE-2581 # 537 | | 146.59 | 182.33 | 147.75 | 181.80 |
| **RMCH** | NE-2571 #1205 | 10 × 10 | 146.45 | 182.15 | 145.91 | 179.54 |
| | NE-2581# 537 | | 145.29 | 180.71 | 147.35 | 179.75 |
| **OMCH** | NE-2571#1205 | 10 ×10 | 147.70 | 183.70 | 147 | 180.88 |
| | NE-2581# 537 | | 146.39 | 182.83 | 146.80 | 179.75 |

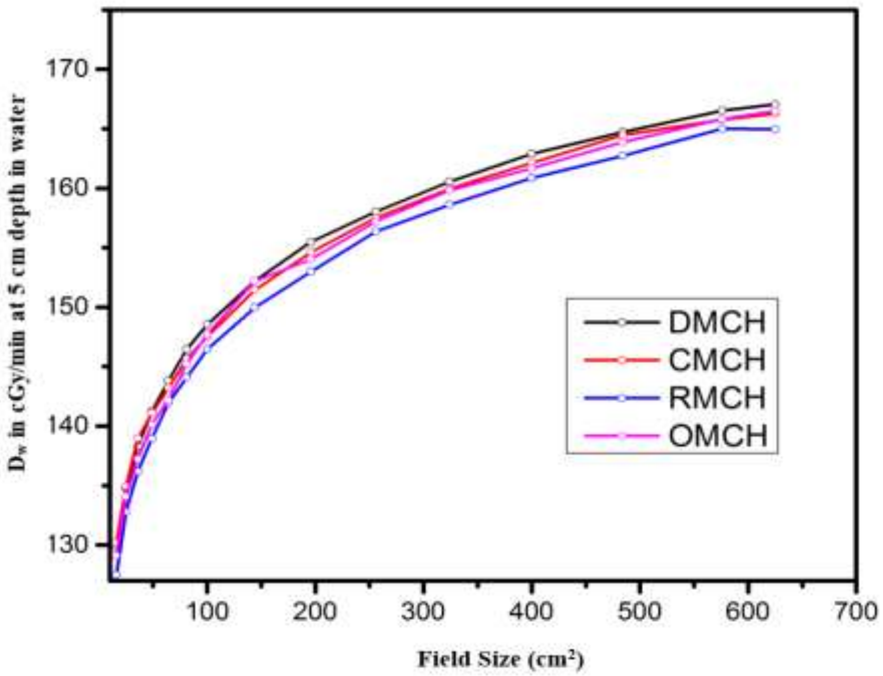


**Figure 1:** **A**bsorbed dose (Co-60 Teletherapy Units) in water as a function of field size ($cm^2$) using (IAEA TRS-398) at four government medical colleges in Bangladesh

From Figure 1, the developed best fitted empirical equation is the following:

$$Y = A_1 \times exp(-(X-X_0)/t_1) + A_2 \times exp(-(X-X_0)/t_2) + A_3 \times exp(-(X-X_0)/t_3) + Y_0 \quad (8)$$

Where: $Y$ = Absorbed Dose, $X$ = field size and $Y_o$, $X_o$, $A_1$, $t_1$, $A_2$, $t_2$, $A_3$ and $t_3$ are different numerical constants.
From Figure 1, values of different constants for the four Teletherapy Units Co-60 of government medical colleges of Bangladesh were determined and listed in Table 3.

**Table 3:** Values of different constants from best fitted curves for four different government medical colleges of Bangladesh

| Name of Medical Colleges | Regression Values of $R^2$ | Values of different constants | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $Y_0$ | $X_0$ | $A_1$ | $t_1$ | $A_2$ | $t_2$ | $A_3$ | $t_3$ |
| **DMCH** | 0.999 | 171.829 | 15.166 | -12.149 | 44.924 | -3.013 | 5.877 | -27.425 | 345.517 |
| **CMCH** | 1.000 | 171.829 | 21.981 | -10.439 | 44.918 | -26.980 | 345.517 | -0.095 | 5.877 |
| **RMCH** | 0.999 | 168.358 | 15.244 | -10.694 | 41.933 | -2.906 | 3.195 | -28.186 | 289.537 |
| **OMCH** | 1.000 | 171.829 | 21.581 | -1.011 | -40.921 | -26.921 | 345.516 | -10.533 | 44.923 |

From Figure 1, it is confirmed that the absorbed absolute dose rate increases with field size. Because when the field size is large, the contribution of the scattered radiation is high. That is actually absent at reference to larger field due to the negligible scattering effect at the center of field.

**Discussion:**

The same type of curve was obtained for each Co-60 teletherapy unit. TRS-277 involves air kerma factor ($N_k$) whereas TRS-398 involves the calibration of ionization chamber in terms of absorbed absolute dose in water which is the main difference of their measurement techniques. In TRS-277 a large number of correction factors are needed for absorbed dose in water determination due to air-kerma factor. So, the uncertainty using TRS-277 become large compared to TRS-398. It is mentioned here that the variation depends on the chamber which is experimentally found because of use of stopping power, perturbation correction factor, non-water equivalence correction factor, attenuation correction factor, radioactive correction factor etc. These correction factors vary with the chambers' construction materials. On the other hand, the absorbed dose measurement with TRS-398 mainly involves beam quality correction factor which is a function of energy. The absorbed dose depends on the source activity, beam energy, depth in the phantom, field size and beam collimation system. The numerical constants of Eq. 8 are not the same, which is mainly due to the different source activity of the units. The affecting factors such as beam energy, depth in the phantom, field size and SSD were taken analogous for each unit in this work. The other affecting factors such as beam collimation system, filter design, and measuring uncertainty might affect the numerical coefficients. The coefficients would be the same if these factors were taken equal for each unit.

**Conclusion:**

This research work showed that the percentage of deviation between two protocols were 1.33 % for the chamber NE-2571#1205 and 0.65 % for the chamber NE-2581#537. The measured absorbed dose in water for various field sizes was fitted with fitting function for each Co-60 teletherapy unit. Using such fitting equations, the absorbed dose in water can be determined for any field. A general equation for calculating the absorbed doses can be written based on the measured data as given in Eq. 8.

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