Calibration of Therapy Level Ionization Chamber at ^{60}Co Teletherapy Beam Used for Radiation Therapy

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Abstract. The accuracy and traceability of absorbed dose to water measurement of radiotherapy beam is a critical issue to achieve the curative outcome of cancer patients. The current dosimetry protocols for radiotherapy beams TRS-398, TG-51 and DIN-6800-2 are based on the calibration factor of ionization chamber in terms of absorbed dose to water for ^{60}Co beam. The accuracy of the calibration factor of ionization chamber as well as output of radiotherapy beam is the primary requirements of precisional dose deliver to the tumor which is the QA part of radiotherapy dosimetry. In the present study, we have calibrated 9 different ionization chambers (8 thimbles and 1 parallel plate) of various active volumes for ^{60}Co beam against reference standard NE2571 and compared with manufacturer's values. The Percentage Depth Dose (PDD) and Output Factors (OF) of two cobalt units were measured with standard calibration system by following IAEA dosimetry protocol TRS-398 and compare with 6 MV photon beam from medical linear accelerator. The traceability of the dosimetry was verified by the participation of postal dose IAEA/WHO intercomparison program. The aim of the participation was to investigate uncertainties involved in the calibration of Ionization Chamber (IC) and absorbed dose measurement. The percentage of deviation relative to IAEA mean dose was found to be -0.2% (traceable limit $\pm 5\%$), which shows an excellent agreement of calibration of beam as well as ionization chamber with international standard. The deviation of $N_{D,W}$ factors of ionization chambers between the measured and manufacturer's values were found within 0.07-2.81% with an uncertainty of $\pm 1.5\%$ ($k=1$).

Introduction

Radiotherapy involves the delivery of a large amount of radiation dose to the cancer tumor. A high degree of accuracy, reliability and reproducibility is essentially required for safe and effective radiation treatment of cancer patients. This ensures confidence in both the dose delivery to the tumor as well as saving the normal tissue from adverse effects such as secondary cancer induction and genetic mutation. The maximum control of tumors with minimum complications to the normal tissue depends on various factors especially on the accuracy of absorbed dose [1]. The ICRU report-24 (1976) recommended for at least accuracy of $\pm 5\%$ in the delivery of absorbed dose to the target volume of the treatment tumor [2-3]. The tolerance value of accuracy in dose delivery of $\pm 3.5\%$ at one standard deviation level is proposed by Brahme [4] and $\pm 3\%$ by Mijnheer *et al.* [5] to reduce the acceptable complication of tissue in risk. The above tolerance limit includes absorbed dose measurement, patient data acquisition, treatment planning, and execution of planning of prescribed dose to the tumor. This implies that accuracy of each contributing stages must be better than a tolerance value of accuracy in order to achieve the curative outcome of the treatment. Hence, QA program have increasingly important roles as radiotherapy technology. Absorbed-dose-to-water calibrations are important to the medical community to facilitate the accurate dose delivered to tumors during external-beam cancer therapy.

The primary important parameter of QA involves in the accuracy and reliability of absorbed dose measurement that mainly includes; (i) calibration of ionization chamber as per international

recommendation, (ii) application of dosimetry protocol used for absorbed dose measurement for reference condition. The current international protocols TRS-398 (IAEA), TG-51 (AAPM), and DIN-6800-2 (German) for absorbed dose to water determination are based on the calibration factor of the ionization chamber in-terms of $N_{D,W}$ with ^{60}Co quality. To maintain the precisional dosimetry of radiotherapy centers a Secondary Standard Dosimetry Laboratory (SSDL) at BAEC is designed and equipped with reference standard dosimetry system which acts as a link between the field oncology centers in Bangladesh and International Atomic Energy Agency (IAEA). As per the national regulation the ionization chamber should be calibrated in a regular interval of 1 year. In the present study, 9 ionization chambers (8 thimbles and 1 parallel plate) of different hospitals are calibrated with ^{60}Co radiation qualities in terms of absorbed dose to water calibration factor ($N_{D,W}$) that satisfies the current international protocols [6-10]. The traceability of the reference system as well as dosimetry could be achieved by intercomparison program with other international organizations. Intercomparison is designed to establish the accuracy of measurement of absorbed dose to water and to reduce uncertainty involve in the total system of dosimetry such as chamber calibration factor, dosimetry protocol and other relevant components. The QA parameters of dosimetry acts to assess consistency of measurement system between the centers in comparison with standard measurement.

On the other hand, dosimetric parameters such as PDD and OF play an important role in the patient treatment. Being unstable it decays of ^{60}Co continuously into ^{60}Ni with half-life of 5.27 years thereby resulting in the decrease of its activity and hence dose rate (output). As a part of ongoing studies of dosimetry and QA the Percentage Depth Dose (PDD) of tele-cobalt units which is independent of source strength but dependent on field size, Source to Surface Distance (SSD) and OF a key characteristic of beam quality have been measured for two cobalt units. The whole research output presented in this article is performed at Secondary Standard Dosimetry Laboratory (SSDL), BAEC, Dhaka, and National Cancer Research Institute and Hospital, Mohakahli, Dhaka and Delta Hospital Ltd, Mirpur, Dhaka.

Materials and Method

The standardization and dosimetry of ^{60}Co radiotherapy beam has multiple stages. The present research article consists of three different parts:

(a) Dosimetry of Teletherapy Units:

Absorbed dose to water (D_w) of two different Teletherapy units; Theratronics, Elite 100 (11989 Ci on 06th January 2012) of National Institute of Cancer Research and Hospital (NIRCH) and ALCYON II P (6974 Ci on 01st June 2013) of Delta Hospital Ltd. (DHL) was measured using IAEA dosimetry protocol TRS-398 with standard procedure. Reference ionization chamber NE2571 coupled with electrometer PTW Unidos 10005 and IAEA reference water phantom $30 \times 30 \times 30 \text{ cm}^3$ were used for dosimetric assessment of the teletherapy units. The correction factors for the influence of ambient pressure and temperature was measured with Prazisions barometer and a GTH 175/PT thermometer. The PDD of ^{60}Co beam was measured for different depth by placing the ionization chamber from 2.5 cm to 27.5 cm at a horizontal geometry. The chamber was placed at reference depth in water phantom (5 cm), SSD 80 cm (ALCYON II P) and SSD 100 cm (Theratronics, Elite 100) for reference field $10 \text{ cm} \times 10 \text{ cm}$. To understand the trend of PDD and OF of tele-cobalt source (^{60}Co), we also have measured the PDD and output factor of 6 MV photon beam from Clinac 2300C/D was measured with the same procedure. The schematic diagram of experimental setup with phantom arrangement for absorbed dose to water measurement is shown in Fig. 1.

Figure 1. Experimental set up of chamber-phantom arrangements for absorbed dose to water measurement of ^{60}Co beam.

The PDD for different depth was calculated by equation given in eqn. (1)

$$PDD \text{ at a point} = \frac{\text{Dose at this point}}{\text{Dose at maximum distance}} \times 100 \quad (1)$$

The measurement was carried out for various field sizes ($4 \times 4 \text{ cm}^2$ to $25 \times 25 \text{ cm}^2$) using reference ionization chamber NE2571 coupled with electrometer Unidos PTW 10005 and determine the Output Factor (OF) with reference $10 \times 10 \text{ cm}^2$ field size.

The general formalism for the calculation of absorbed dose water by TRS-398 protocol at reference point $D_{W,Q}(Z_{ref,w})$ for high energy photon beam can be calculated by the equation given below

$$D_W(Z_{ref,w}) = M_Q N_{D,W} k_{Q,Q_0} \quad (2)$$

where

$$M_Q = m_u \times k_{tp} \times k_{elec} \times k_{pol} \times k_s,$$

where, m_u is charge rate in nC/min corrected for the ambient conditions, k_{tp} (pressure and temperature), correction factors for electrometer k_{elec} , ($k_{elec} = 1$ if the chamber was calibrated with the same electrometer), polarity, k_{pol} and k_s , ion recombination, $N_{D,W}$ be the calibration factor of the ionization chamber for Q_0 quality, and k_{Q,Q_0} is the beam quality correction factor (in case of ^{60}Co , $k_{Q,Q_0} = 1$ as the chamber is calibrated in terms of ^{60}Co beam). The details of the ambient correction (k_{tp}), polarity correction factor (k_{pol}), and ion-recombination correction factor (k_s) are described elsewhere [6]. The Output Factor (OF) is then calculated from the ratio of absorbed dose to water at any field size to the reference field size.

(b) Calibration of ionization chamber

The calibration of ionization chamber in terms of absorbed dose to water is made with ^{60}Co gamma radiation. The chamber was protected by a PMMA sleeve of 1 mm wall thickness, is positioned in the water phantom, so that its reference point is on the central axis of the beam. The chamber axis is perpendicular to the central axis of the beam. The serial number of the chamber on the stem is set so as to point towards the radiation source. The distance from the source to the reference point of the chamber is 1 m. The reference point of the chamber is at 5 g/cm^2 water depth. The size of the radiation field (50 % isodose level) at the reference plane is $10 \text{ cm} \times 10 \text{ cm}$ is the same set-up as shown in Fig. 1. The absorbed dose to water was measured with standard ionization chamber by equation (2) for reference condition. Hence, the chamber to be calibrated in terms of absorbed dose to water is placed at the same position described above and collected charge (nC) is measured by connecting with the same electrometer. The chamber calibration factor ($N_{D,W}$) is then calculated by equation given below

$$N_{D,W} = \frac{D_W(Z_{ref})}{M_Q} (\text{Gy/C}) \quad (3)$$

where $D_W(Z_{ref})$ is the measured absorbed dose to water (Gy/min) at reference position by reference ionization chamber, and M_Q be the measured charge (nC/min) collected by the electrometer coupled with the chamber to be calibrated including the correction factor for ambient condition, polarity and ion recombination.

(c) Participation of IAEA/WHO TLD intercomparison Program

A set of three TLDs, one of them is a control (capsulated LiF powder) was sent for the irradiation with 2 Gy of absorbed dose to water. A special type of holder feasible to set with the IAEA standard phantom size of $30 \times 30 \times 30 \text{ cm}^3$ and some water tank made of perspex sheath was used in this study. The irradiations were carried at a depth of 10 cm for a field size of $10 \times 10 \text{ cm}^2$ at source to surface distance (SSD) 80 cm.

The dose for irradiation is fixed at 2 Gy of absorbed dose to water because this value is approximately equal dose to the patient at each fractionation of treatment. A set of TLD irradiation holder made of perspex which supports for the irradiation of TLDs by geometry of horizontal and vertical set up. The deviations Δ of reported and measured absorbed dose were calculated according to the formula recommended by the IAEA.

$$\Delta = \frac{D_p - \bar{D}}{\bar{D}} \quad (4)$$

where $\bar{D}$ is the absorbed dose measured by the TLD system of IAEA and D_p is the irradiated TLD by present study.

Results and Discussion

The experimental values of PDD for reference field size $10 \text{ cm} \times 10 \text{ cm}$ of ALCYON IIP (SSD 80 cm) and Elite 100 (SSD 100 cm) in compared with BJR-25 data [11] is shown in Fig. 2 (a) and 2 (b) respectively. It is seen that experimental data meets an excellent in agreement with BJR supplement 25 that satisfy 3rd order polynomial fitting functions, presented by the dashed and full lines, which refer to experimental and BJR-25 fittings respectively. To understand the effect depth dose in water, we have compared PDD for photon beam from ^{60}Co teletherapy unit (Elite 100) and 6 MV photon beam from Clinac 2300C/D which is shown in Fig. 3. From Fig. 3, it is seen that PDD values of 6 MV photon beam is higher than ^{60}Co which is obvious due higher energy and follows the same trend of decrease in increasing the depth of water.

Figure 2. The comparison of experimental and BJR-25 data for percentage depth dose curve of (a) ALCYON IIP (80 cm SSD) and (b) Elite 100 (100 cm SSD) for ^{60}Co radiation for reference field size $10\text{ cm} \times 10\text{ cm}$.

Figure 3. A comparison of percentage depth dose curve of Elite 100 (^{60}Co beam) and 6 MV photon beam from Clinac 2300C/D at 100 cm SSD for reference field size $10\text{ cm} \times 10\text{ cm}$.

On the other hand, the output factors of the two machines were measured by for various field size(s) normalized to $10\text{ cm} \times 10\text{ cm}$. The output factors (OF) for different field size(s) as measured for the two machines are plotted in the Fig. 4. As can be seen from Fig. 4, the differences of respective output factors between the two machines are very small at lower field size up to 200 cm^2 and almost negligible. At higher field size (s) above 200 cm^2 , OF decreases with increasing SSD that might be due to Linear Energy Transfer (LET) and scattering factors. It can be seen from Fig. 4, the OF of 6 MV photon beam from medical linear accelerator is higher than the same of ^{60}Co ($E_{\text{eff}} = 1.25\text{ MeV}$) at field size lower than $10 \times 10\text{ cm}^2$ and decreases with increasing field size (s). The larger the photon energy the lower the surface dose. At high energy photon beam, z_{max} shift at higher depth hence OF increases than cobalt beam. On the other hand, at larger field (s) size scattering contribution of high energy photon beam is lower than the cobalt beam, which leads the

lower OF. The data of OF for the both machines are fitted with 5th order polynomial function ($y = y_0 + B1x^1 + B2x^2 + B3x^3 + B4x^4 + B5x^5$) shows an excellent in agreement with fitting function. The fitting parameters are given in Table. 2

Figure 4. Experimental values of Output Factor (OF) of Elite-100 (SSD = 100 cm), ALCYON IIP (SSD = 80 cm) ⁶⁰Co teletherapy units and Clinac 2300C/D 6 MV photon beam (SSD = 100 cm) from electron linac.

Table 1. Polynomial fitting parameters for the output factor determination of two different ⁶⁰Co teletherapy units and a 6 MV photon beam from Clinac 2300C/D.

Fitting parameters values	Elite-100 ⁶⁰ Co teletherapy unit		ALCYON IIP ⁶⁰ Co teletherapy unit		Clinac 2300C/D 6 MV photon beam	
	Value	Standard Error	Value	Standard Error	Value	Standard Error
Y0 (Intercept)	0.8406	0.00408	0.85541	0.01122	0.89441	0.00369
B1	0.00287	1.61683E-4	0.00248	4.50127E-4	0.00206	2.06587E-4
B2	-1.79027E-5	2.03716E-6	-1.35565E-5	5.49125E-6	-1.40112E-5	2.95585E-6
B3	6.49344E-8	1.07313E-8	4.22695E-8	2.7943E-8	5.12927E-8	1.65468E-8
B4	-1.17055E-10	2.45255E-11	-6.62518E-11	6.21807E-11	-9.15895E-11	3.89494E-11
B5	8.12266E-14	2.00545E-14	4.07149E-14	4.99024E-14	6.27673E-14	3.22955E-14
R ²	0.99949		0.99608		0.99707	

The calibration of ionization chamber in terms of absorbed dose to water ($N_{D,W}$) is conducted at reference condition (FS: 10 cm × 10 cm, 5 cm depth in water phantom). The measured calibration factors are compared with the manufacturer's values which are given in Table 2. The uncertainties were calculated as the combined uncertainties U_c ($k=1$) due to Type A and Type B. The components of Type A was calculated on the basis of random error due to charge measurement by the electrometer (0.1-0.4%), temperature (0.6%) and pressure (0.5%). On the other hand, the type B uncertainties were estimated on the basis systematic parameters due to the uncertainties of the calibration factor of ionization chamber ($\pm 1.1\%$), Source to Surface Distance (0.2%), field size (0.3%) and depth in water phantom (0.2%). The calculated uncertainties of Type A and Type B were 0.9% and 1.2% respectively. Three different measurements were taken in each cases, hence combined uncertainty were within $\pm 1.5\%$ for coverage factor of $k=1$. The percentage of deviations

between measured and manufacturer's calibration coefficients $N_{D,W}$ were calculated according to the formula recommended by the IAEA [8].

$$\text{Percentage of deviation (\%)} = \frac{N_{D,W}(\text{measured}) - N_{D,W}(\text{manufacturer})}{N_{D,W}(\text{measured})} \times 100\% \quad (5)$$

Calibration of six reference class (Farmer Type) ionization chamber in terms of absorbed dose to water ($N_{D,W}$) was studied by A. Solimanian et al. [12] and found agreement within 1.8%. In the present study, we have calibrated nine different reference and filed class ionization chamber and found within 2.8% with an uncertainty of 1.5%. From Table 2, calibration factors of all the chamber in the present studies meets good in agreement with the manufacturer's values except PTW chamber W31010. The large deviation of PTW W31010 chamber implies that the stability of the chamber is relatively poor.

Table 2. Comparison of $N_{D,W}$ factors between current measurements and manufacturer's stated values.

Chamber No.	Chamber Model # Sl. No.	Measured $N_{D,W}$ factor (Gy/C)	Manufacture's $N_{D,W}$ factor (Gy/C)	Deviation between manufacturer's and measured value of $N_{D,W}$
1	TW 31010 # 2211	2.852×10^8	2.861×10^8	-0.32%
2	TW 31010 # 1888	3.008×10^8	3.016×10^8	-0.27%
3	TN 30013 # 04774	5.409×10^7	5.405×10^7	0.07%
4	TM 31010 # 1227	2.890×10^8	2.951×10^8	-2.12%
5	TM 31010 # 1225	2.891×10^8	2.972×10^8	-2.81%
6	TM 30010 # 0392	5.324×10^7	5.331×10^7	-0.14%
7	TM 31013 # 10472	9.297×10^7	9.418×10^7	-1.30%
8	TM 31013 # 01471	9.305×10^7	9.393×10^7	-0.95%
9	TM 34001 # 01615	8.339×10^7	8.248×10^7	1.09%

For the traceability, the present measurement was compared with international system by the participation of the IAEA/WHO TLD postal dose intercomparison program. Two sets of TLD irradiated with a measured dose of 2 Gy and sent back to IAEA. The percentage deviation of locally measured dose relative to IAEA mean dose was found to be -0.2%, which was significantly small in compared with the allowed limit $\pm 5\%$. This small deviation between the stated and IAEA measured dose indicates highly satisfactory accuracy of the present dosimetry system. The uncertainty in the TLD measurement of the dose is presented in Table 3. The details of irradiated dose on TLD and IAEA measured dose are given in Table 3.

Table 3. Irradiation of TLDs by present measured values and evaluated values at IAEA standard laboratory.

Beam	Teletherapy Unit	Stated dose (Gy)	IAEA measured dose (Gy)	IAEA mean dose (Gy)	% of deviation	IAEA mean dose / Stated dose	Uncertainty
^{60}Co	ALCYON IIP	2.00	2.03	2.00	-0.2	1.00	1.8%
		2.00	1.95				(1 standard deviation)
		2.00	2.02				

Conclusion

For consistent performance of teletherapy unit within accepted tolerance level, Quality Assurance (QA) and Quality Control (QC) activities are highly required. The experimental values of PDD is compared with BJR-25 shows an excellent in agreement for both the Elite-100 and ALCYON II P ^{60}Co teletherapy units. The output factor for the aforementioned teletherapy units were found in an increasing trend with field sizes. The differences of respective output factors between the two machines are very small at field size (s) up to 200 cm^2 and could be considered to be negligible. Above field size (s) 200 cm^2 , the OF decreases with increasing due to Source to Surface Distance (SSD). The traceability of the present measurement was verified with international system in terms of TLD postal dose intercomparison program was found (-0.2%) to be within the IAEA acceptance limit of $\pm 3.5\%$. The results of this study could be used for precise dose measurement in radiotherapy treatment using ^{60}Co teletherapy unit.

Conflict of Interest

The authors declare that there is no conflict of interest.

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