RESEARCH ARTICLE

CONSISTENCY OF CALIBRATION FACTOR OF RADIOTHERAPY DOSIMETERS AND REFERENCE DOSIMETRY OF HIGH ENERGY X-RAY BEAM USING TWO DIFFERENT IAEA DOSIMETRY PROTOCOLS

1,*Rahman, M. S.,²Islam, M. R., ³Sharmin, M. N., ²Parvez, M. S., ²Khan, H. R.,⁴Hossain, M. M., ¹Siddiqua, T. and ⁵Ali, M. Y.

¹Secondary Standard Dosimetry Laboratory (SSDL), Bangladesh Atomic Energy Commission, Dhaka, Bangladesh
²Physics Discipline, University of Khulna, Khulna, Bangladesh
³Cancer Center, Khwaja Yunus Ali Medical College and Hospital, Sirajgonj, Bangladesh
⁴University of Chittagong, Chittagong, Bangladesh
⁵University of Rajshahi, Rajshahi, Bangladesh

ARTICLE INFO

ABSTRACT

The outcome of the radiotherapy depends on how precisional dose deliver to the treatment volume which should not be exceeded more that ±5% of the prescribed dose. Among the several factors that effects on accurate dose delivery to the tumor, the absorbed dose measurement plays a major role. For the accuracy of dose measurement, several national and international protocols such as TRS-277, TRS-398, TG-51 and DIN-6800-2 are currently being used for the dosimetry of photon, electron and ion beams. The IAEA protocols TRS-277 (air Kerma, N_k) and TRS-398 (absorbed dose to water, $N_{D,W}$) are familiar and popular that are used worldwide. The purpose of this work is to study on (a) periodical consistency of calibration factors of ionization chamber, (b) accuracy that involved in absorbed dose determination in the IAEA protocols TRS-277 and TRS-398 for high energy X-ray beam and (c) traceability of the dose measurement by participating IAEA/WHO TLD intercomparison program. A total number of 13 ionization chambers of which 12 thimble and 1 parallel plate are calibrated with ^{60}Co in-terms $N_{D,W}$ factor against the reference standard of SSDL, Bangladesh. The deviation of calibration factor by manufacturer's stated value and present measurement lies in between 0.13-3.38% with an uncertainties of ±1.4% (coverage factor *k=1*). The average deviation of absorbed dose measurement between two different dosimetry protocols TRS-277 and TRS-398 were found within±1.59% for 4 MV and 15 MV LINAC photon beams which shows an excellent agreement with other measurement in the literature. The results obtained by the participation of IAEA/WHO intercomparison program ensures the traceability of present work with excellent agreement with IAEA standard.

INTRODUCTION

A high degree of precision, accuracy, reliability and reproducibility become an important issue for safe and effective radiotherapy of cancer patients. Clinical data showed that around two-third of all cancer patients require radiation therapy as unique or in conjunction of other treatment modalities (Gianfaldoni *et al.*, 2017).

Corresponding author: **Rahman, M. S.,**
Secondary Standard Dosimetry Laboratory (SSDL), Bangladesh Atomic Energy Commission, Dhaka, Bangladesh.

According to ICRU report-24 (1976), the accuracy of dose delivered to the tumor should meet within ±5% of the prescribed value (ICRU, 1976). (Brahame *et al.* 1988; Brahme, 1984) and (Mijnheer *et al.* 1987) proposed the tolerance value of delivering dose should be within ±3.5% and ±3% respectively for reducing complication including all types of uncertainty such as; accuracy of tumor detection, dose measurement, treatment planning, patient positioning etc. Incompleteness of these requirements may result in the failure of treatment. This requirement implies that dose measurement should be accurate and should be lies within ±2.0%.

Various Quality Assurance (QA) and Quality Control (QC) parameters are necessary for the success of tumor eradication. The dose measurement includes calibration of radiotherapy dosimeters (ionization chamber) with high accuracy and uses of dosimetry protocol to reduce the uncertainty of absorbed dose water measurement. To reduce the uncertainty and increase the accuracy of absorbed dose to water measurement several international organization recommended various protocols (International Atomic Energy Agency, 2020; International Atomic Energy Agency, 1987; International Atomic Energy Agency, 1997; American Association of Physicists in Medicine, 1999; Deutsches Institut fur Normung, 2006). Among them, International Atomic Energy Agency (IAEA) recommended the code of practices TRS-277, TRS-381 and TRS-398 are adopted by most of the member states of IAEA. The latest international Code of Practice for radiotherapy dosimetry co-sponsored by several international organizations has been published by the IAEA, TRS-398 which is replaced by previous protocols (TRS-381 and TRS-277). The new protocol TRS-398 is based on the calibration factor of the ionization chamber in terms of absorbed dose to water ($N_{D,W}$) whereas the TRS-381 and TRS-277 are based on the calibration factor of ionization chamber in terms of air Kerma (N_k). In all cases of international code practices the ionization chamber should have to be calibrated in-terms of ^{60}Co radiation quality. Ionization chamber plays a vital role for the dosimetry of radiotherapy beam which should be calibrated once a year to observe the consistency of its calibration factor. In the present study, 13 ionization chamber (12 thimble and 1 parallel plate) are calibrated with ^{60}Co beam in-terms of absorbed dose to water ($N_{D,W}$) against reference standard of SSDL, Bangladesh Atomic Energy Commission (BAEC) that satisfies the current international protocols (IAEA, 2000). A dosimetry comparison has been conducted for the IAEA protocols (IAEA, 2000; IAEA, 1987) TRS-398 and TRS-277 for high energy X-ray beam using the LINAC of Cancer Center at Khwaja Yunus Ali Medical College & Hospital, Sirajganj, Bangladesh. To verify the measured output and to get traceability of this study, the present measured values of output were tested by the participation of TLD postal dose intercomparison program arranged by IAEA/WHO. The above research outputs presented in this article are being performed at Secondary Standard Dosimetry Laboratory (SSDL), BAEC, Dhaka, National Cancer Research Institute and Hospital (NIRCH), Mohakahli, Dhaka and at the Cancer Center of Khawja Yunus Medical College and Hospital (KYAMCH), Sirajgonj, Bangladesh.

METHODS AND MATERIALS

I. IAEA dosimetry protocol TRS-277 and TRS-398

• IAEA protocol TRS-277:

Absorbed dose to water at the effective point $D_{w,Q}(P_{eff})$ of the chamber at users radiation quality Q can be expressed as;

$$D_{w,Q}(P_{eff}) = M_C . N_{D,air} . (S_{w,air})_Q . P_u . P_{cel.gb} \qquad (1)$$

Where, $N_{D,air} = N_k(1 - g)k_m . k_{att}$

Where, $S_{W,air}$- Stopping power ratio from water to air at user's radiation quality, P_u- perturbation correction factor accounts for non-equivalence of wall of the chamber with water, $P_{cl,gb}$-

global correction factor that account for non-water equivalence of chamber central electrode in any medium of measurement, g- faction of the energy of secondary charge particles converted to bremsstrahlung in air, k_{att}- attenuation correction factor for chamber wall, k_m- factors for non-equivalence of chamber wall and build-up cap for air Kerma measurement. Absorbed dose to water at reference depth in water (5 cm) is then calculated from which is related with effective point of measurement and chamber center by so-called displacement correction factor; $Z_{eff} - Z_p = 0.6r$, where r is the radius of the chamber. Hence, Eq[n] (1) can be reformed to;

$$(5 \ gm.cm^{-2}) = D_w(P_{eff}).P_{dis} \qquad (2)$$

The details of the correction factors stated above are given in ref. (IAEA, 1987).

The dose at maximum depth (0.5 cm for ^{60}Co) in water can be calculated by the equation given below;

$$D_{max} = \frac{D_{W,Q}(Z_{ref})}{\% \ DD} \times 100 \qquad (3)$$

Where, D_{max} is the maximum dose at 0.5 cm depth in water phantom, $D_{W,Q}(Z_{ref})$ be the measured dose at 5 cm depth and %DD be the depth dose at 5 cm depth in water phantom.

• **IAEA Protocol TRS-398:**

The basic of use of this protocol require the calibration factor of the ionization chamber in terms absorbed dose to water ($N_{D,W}$). The absorbed dose to water at reference position in water with a beam quality, Q_0 can be expressed by the equation;

$$D_{W,Q} (Z_{ref}) = M_u \times N_{D,W_{Q_0}} \times k_{Q,Q_0} = M_u \times k_{tp} \times k_{elec} \times k_{pol} \times k_s \times N_{D,W_{Q_0}} \times k_{Q,Q_0} \qquad (4)$$

k_{tp}, the correction factors for ambient temperature and pressure, $k_{pol,}$ polarity, and k_s, ion-recombination corrections, k_{Q,Q_0} is the beam quality correction factor are calculated as per standard procedure described in ref (IAEA, 2000).

For high energy photon, the beam quality correction factor can be obtained by the equation;

$$k_{Q,Q_0} = \frac{TPR_{20}}{TPR_{10}} \qquad (5)$$

This correction factor can also be measured from Percentage Depth Dose (PDD) curve by the equation (IAEA, 2000);

$$TPR_{20,10} = 1.2661 \ PDD_{20,10} - 0.0595 \qquad (6)$$

Calibration of ionization chamber: Clinical reference dosimetry in all protocols are based on air Kerma (N_k) or in absorbed dose to water ($N_{D,W}$) calibration factor of ionization chamber at ^{60}Co quality. The absolute dosimetry at reference position for ^{60}Co teletherapy unit (Elite-100) of National Institute of Cancer Research and Hospital (NICRH), Bangladesh is conducted in terms of absorbed dose to water by IAEA dosimetry protocol TRS-398. The reference standard cylindrical lionization chamber NE2571-1205 (coupled with electrometer PTW Unidos 10005-50231) is placed at 5 cm depth inside IAEA 30 cm × 30 cm × 30 cm water phantom for

a field size 10 cm × 10 cm and Source to Surface Distance (SSD) 100 cm. The chamber was protected by a PMMA sleeve of 1 mm wall thickness and is placed in water phantom, so as to perpendicular to the central axis of the beam.
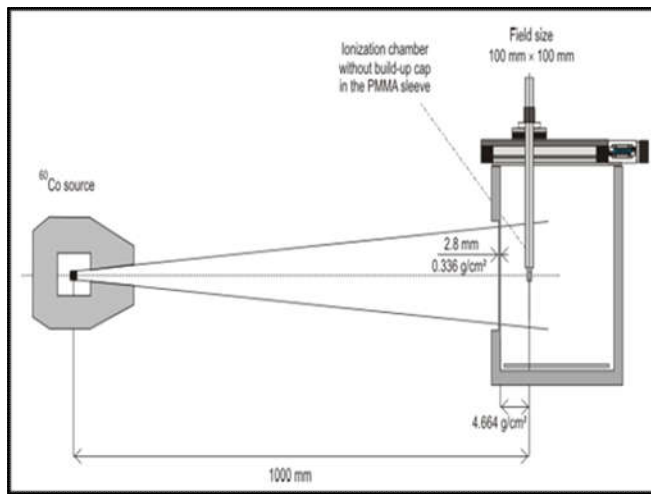

Fig. 1. Set-up for calibrations in terms of absorbed dose to water

In the present study, ionization chambers to be calibrated were placed at the same position inside the water phantom by substitution method (IAEA, 1994) with reference standard. It is mentioned here that the reference standard NE-2571 was calibrated at NPL, UK. The set-up of dosimetry and calibration arrangement is shown in Fig. 1.

The absorbed dose to water at reference position (FS: 10 cm × 10 cm, SSD=100 cm and 5 cm depth in water phantom) has been calculated with Eq^n (4). The chamber calibration factor ($N_{D,W}$) is then calculated by equation given below;

$$N_{D,W} = \frac{D_W(Z_{ref})}{M_Q} \text{ (Gy/c)} \tag{7}$$

Where $D_W(Z_{ref})$ is the measured absorbed dose to water (Gy/min) at reference position by reference standard ionization chamber, and M_Q be the measured charge (nC/min) collected by the electrometer coupled with the chamber to be calibrated including all correction factors recommended by protocol TRS-398.

III. Participation of IAEA/WHO TLD intercomparison Program:

A set of three TLDs, one of them is a control (capsulated LiF powder) was irradiated with 2 Gy of absorbed dose to water. A special type of holder feasible to set with the IAEA standard phantom of size 30 × 30 × 30 cm^3 that made with perspex sheath. The irradiations were carried at a depth of 10 cm (for LINAC beam) for a field size of 10 × 10 cm^2 at Source to Surface Distance (SSD) 100 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. The holder is made of perspex which supports for the irradiation of TLDs by geometry of horizontal set up. The deviations Δ of stated and measured absorbed dose were then calculated according to the formula recommended by the IAEA;

$$\Delta = \frac{D_P - \bar{D}}{\bar{D}} \tag{8}$$

Where $\bar{D}$ is the mean absorbed dose measured by the TLD system of IAEA and D_P is the irradiated TLD dose.

RESULTS AND DISCUSSION

Calibration of ionization chamber: In the present measurement, 13 ionization chambers (12 thimble and 1 parallel plate) has been calibrated at ^{60}Co quality. The chambers are calibrated against the reference standard NE2571, which was calibrated at National Physical Laboratory (NPL), UK and compared with the values measured by NE2581 that calibrated from the SSDL of International Atomic Energy Agency (IAEA). The comparison of dose measurement by these two chambers were found within ±0.3%. The field chambers of various radiotherapy centers (Dhaka Medical College and Hospital, National Institute of Cancer Research and Hospital, Dhaka, Square Hospital Ltd, Dhaka, Khawja Yunus Ali Medical College and Hospital, Sirajganj and SSDL, BAEC) were calibrated and reported in this study. The details of the calibration factors obtained from this study are summarized in Table 1 with manufacturer values. It is seen that the deviation between manufacturer values and present measurement lies within 0.14 % to 3.38% with a maximum uncertainty of ±1.4% (coverage factor $k=1$). From the Table 1, it is also seen that, the calibration coefficients of the ionization chamber is highly depended on chamber volume. Hence, to understand the effect of calibration factors on the volume, an empirical relation have been developed which is shown in Fig. 2. It is seen that the calibration factor follows an exponential behavior with chamber volume; the details of the equation with fitting parameters are given below;

$$Y = Y_0 + A_1 \exp\left(-\frac{x - x0}{t1}\right) \tag{9}$$

Where, $Y_0 = 5.08256$, $x0 = 0.12051$, $A_1 = 25.36275$, t1= 0.1084, $R^2 = 0.97827$

Measurement of absorbed dose with TRS-277 and TRS-398: The aim of this work is to compare the above protocols for high energy X-rays with reference standard NE2571 of Secondary Standard Dosimetry Laboratory (SSDL), which was calibrated at National Physical Laboratory (NPL), UK. The dose is measured with standard procedure under reference condition set-forth by protocol recommendation. The PDD is measured using water proof ionization camber TW31010 and PTW MP3-M Water Phantom at 100 cm SSD and 10 cm × 10 cm FS. The PDD curve for various X-rays with energies 4 MV, 6 MV (2 beams), 15 MV (2 beams) from Eleckta Synergy Platform and Eleckta Synergy S are shown in Fig. 3**.** The beam quality correction factor was calculated from PDD values by Eq^n (6). The absorbed dose to water is measured at the reference position discussed earlier and by the recommendation given in (IAEA, 2000; IAEA, 1987) followed by the Eq^n (1,2,4). The details of the measurement of absorbed dose to water by two different dosimetry protocols TRS-277 and TRS-398 is summarized in Table 2. From Table 2, it is seen that the deviation of TRS-277 compared to TRS-398 for the photon energy 4 MV to 15 MV were found within ±1.59% with an uncertainty of ±1.4% which meets an agreement with other literature values (Fourie, 2008). The average ratio of the absorbed dose to water between two different protocols TRS-398 and TRS-277 was found 1.016.

Table 1. Calibration factor of the chambers at ^{60}Co radiation quality

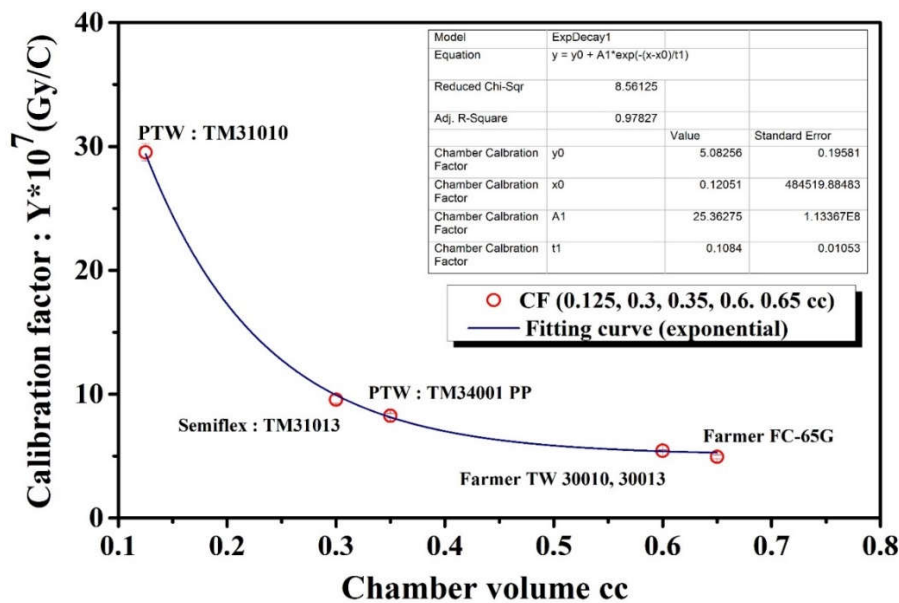| Chamber	Volume of the chamber (cc)	Manufacturer Measurement: Absorbed dose to water Calibration factor (CF), $N_{D,W}$ (Gy/C)	Manufacturer Calibration date and calibration laboratory	Present Measurement: Absorbed dose to water Calibration factor (CF), $N_{D,W}$ (Gy/C)	Deviation of CF (%)
TM31010#1225	0.125	2.955×10^8	5-Apr-2005 PTB, Germany	2.951×10^8	0.14
TM31010#1227	0.125	2.934×10^8	5-Apr-2005 PTB, Germany	2.920×10^8	0.48
TM31013#1471	0.3	9.393×10^7	15-Sept-2009 PTB, Germany	9.407×10^7	0.15
TM31013 #1472	0.3	9.418×10^7	15-Sept-2009 PTB, Germany	9.339×10^7	0.85
TM34001#01615	0.35	8.248×10^7	15-Sept-2009 PTB, Germany	8.537×10^7	3.38
W30013#0364	0.6	5.343×10^7	29-Aug-2002 PTB, Germany	5.416×10^7	1.35
TM31010#012	0.3	9.710×10^7	29-Aug-2002 PTB, Germany	9.917×10^7	2.08
TW30013#4922	0.6	5.374×10^7	9-Aug-2010 PTB, Germany	5.442×10^7	1.25
TW30010#4774	0.6	5.408×10^7	14-June-2010 PTB, Germany	5.483×10^7	1.37
TW31010#1888	0.125	3.013×10^8	16-Aug-2010 PTB, Germany	3.050×10^8	1.21
TW31010#2211	0.125	2.882×10^7	16-Aug-2010 PTB, Germany	2.889×10^7	0.24
TM30010 #0392	0.6	5.360×10^7	5-Apr-2005 PTB, Germany	5.369×10^7	0.17
IBA FC-65G#938	0.65	4.935×10^7	9-March-2010 Scanditronnix-Wellhofer GmbH, Germany	5.007×10^7	1.3

Fig.2. Relationship of chamber volume vs Calibration Factor of IC

Table 2: Variations of absorbed dose to water between two protocols TRS-398 and TRS-277

Medical Linac Unit	Photon beam energy (MV)	$TPR_{20/10}$	Absorbed dose to water for TRS-398 $D_W(Z_{ref})$ cGy/MU	Absorbed dose to water for TRS-277 $D_W(Z_{ref})$ cGy/MU	Deviation (%): $\dfrac{D_{w(398)} - D_{w(277)}}{D_{w(277)}} \times 100$	Ratio $= \dfrac{TRS-398}{TRS-277}$
Elekta Synergy Platform	6 MV	0.684	0.675	0.665	1.50	1.015
	15 MV	0.762	0.763	0.749	1.87	1.018
Elekta Synergy S	4 MV	0.630	0.628	0.618	1.62	1.016
	6 MV	0.687	0.674	0.665	1.35	1.013
	15 MV	0.762	0.756	0.744	1.61	1.016

Table 3. Results of participation of postal dose TLD intercomparison program from present measurement

Treatment Unit	TLD set	Photon Beam energy	Irradiated TLD Mean dose from present study (Gy)	Dose measured by the IAEA (Gy)	Ratio = IAEA Measured Value/Stated Value from present study	% of deviation*
Elekta Synergy Platform	263-14113	6 MV	1.999	2.00	1.00	0.2 %
	263-14114	15 MV	2.026	2.06	1.02	-1.6 %
Elekta Synergy S	2IR26203	4 MV	1.998	2.05	1.03	-2.6 %
	2IR26204	6 MV	1.997	2.01	1.01	-0.7 %
	2IR26205	15 MV	2.002	2.04	1.02	-1.8 %

*Agreement within ±5% between the stated dose and IAEA measured dose is considered satisfactory.
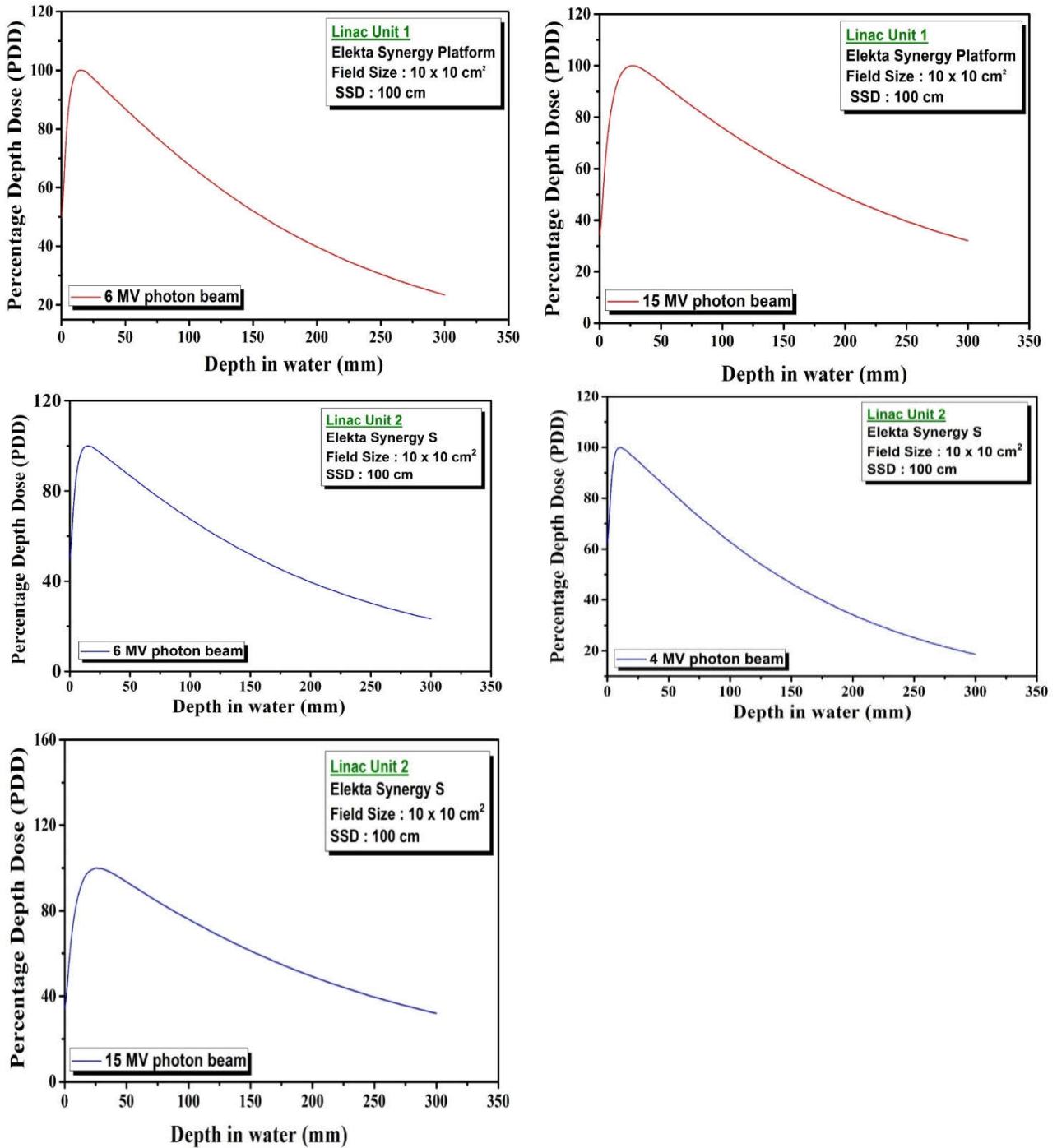

Fig. 3.The PDD curves for 4 MV, 6 MV and 15 MV photon beam of Elekta Synergy Platform and Elekta Synergy S

Participation of IAEA/WHO intercomparison program: The aim of this postal dose intercomparison program was carried in order to investigate the present measured values with international reference system set forth by IAEA. The intercomparison program was organized by the IAEA/WHO postal dose intercomparison network. In the present study, the TLDs were irradiated with the measured absorbed dose to water by TRS-398 protocol for 4 MV, 6MV (2 beam), 15 MV (2 beam) from two LINACs (Electa Synergy Platform and Elekta Synergy S). After irradiation, the TLDs were sent to IAEA standard laboratory for evaluation of doses measured with standard procedure. The measured values by IAEA and stated values from the present experiment is summarized in Table 3. From Table 3, it is found that the % of deviations between IAEA measured and present stated dose were lies from 0.2 to -2.6% that meets good agreement within IAEA limit (±5%) This results also indicate that the traceability of calibration factors of ionization chamber from present measurement meets excellent agreement with international standard.

Conclusion

The consistency of the calibration factor of ionization chambers measured by SSDL, BAEC shows an excellent agreement with reference standard by IAEA. Out of 13 chambers the calibration factors of 7 chamber meets an excellent agreement with manufacturer values (≤ ±1%) but among the other chambers, large deviation has been observed by Parallel Plate (PP) and Semi-flex chamber by 3.38% and 2.06% which shows the necessity of calibration of ionization chamber in a regular interval as a part of QA program in radiotherapy. The deviation between the two different IAEA dosimetry protocols TRS-277 and TRS-398 was found ±1.59% for high energy X-ray beams indicates the necessity of choosing protocol considering uncertainty involvement. The verification of the total measurement system was carried out by the participation of TLD intercomparison program organized by IAEA shows an excellent agreement. The study thus performed also shows the trend towards uniformity and traceable to the international system by SSDL, BAEC. The results obtained from this experiment could be important for the improvement of dosimetry QA and conceptual agreement for the future development of radiotherapy treatment of cancer patients.

Acknowledgement

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