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(RESEARCH ARTICLE)

Assessment of calibration coefficient $N_{D,W}$ in terms of absorbed dose-to-water of some ionization chambers

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Abstract

The absorbed dose-to-water calibration coefficients $N_{D,W}$ of some ionization chambers were determined in terms of the secondary standard chambers in ^{60}Co gamma-ray beam based on the TRS-398 protocol. The reference absorbed dose-to-water D_w were measured using secondary standard ionization chambers of model NE 2781#0537 (0.60 cm^3 volume) and NE 2771#1205 (0.69 cm^3 volume) which are traceable to the dosimetry laboratory of the International Atomic Energy Agency (IAEA). This study mainly focuses on the comparative assessment of the determined $N_{D,W}$ coefficients of twenty cylindrical ionization chambers from various user groups. The determined $N_{D,W}$ coefficients were compared with the manufacturer provided $N_{D,W}$ coefficients. The observed percentage of deviation between the measured and the manufacturer's $N_{D,W}$ coefficients among all the chambers were found to be in the range of 0.019% and -2.263% as the least and highest, respectively. The observed percentage of deviations for studied chambers were found within the IAEA's acceptance limit of 1.5% with an exception for three chambers. This observed discrepancy with the IAEA's acceptance limit for the three chambers out of the twenty chambers, indicates the calibration necessity before using chambers in routine reference dosimetry. In $N_{D,W}$ measurement, the uncertainty U_c is reported with the coverage factor k=1 that providing a level of confidence of approximately 68%.

Keywords: Calibration; Absorbed dose-to-water; Dosimetry; Radiotherapy; Karma; Ionization chamber.

1. Introduction

A precisely calibrated ionization chamber is a prerequisite for accurate absorbed dose-to-water determination in external beam radiotherapy [1]. Absorbed dose-to-water calibration coefficients $N_{D,W}$ are important to the radiotherapy medical community to facilitate the accurate determination of doses delivered to tumors during external-beam cancer therapy. The method of measurement of absorbed dose-to-water for high-energy photon beams by means of ionization chamber is based on different dosimetry protocols recommended by several international organizations. Advances in radiation dosimetry is being continued to improve the accuracy of calibrating photon and electron beams for radiation therapy. Since 1976 it has been recognized that an accuracy of ±5% in the delivery of an absorbed dose to a target volume is needed for successful therapy treatment [2]. Recent studies have shown that for certain types of tumors, the combined standard uncertainty in dose delivery should be smaller than ±3.5%. When the calibration of the reference dosimeter is carried out in the ^{60}Co beam of a SSDL, the combined standard uncertainty in absorbed dose-to-water D_w is estimated to be typically about 1.5% [3].

Ionization chamber is an important part of absorbed dose measurement, but without calibration, its use is meaningless. Calibration is defined as the quantitative determination under a controlled set of standard conditions of the indication

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given by a radiation measuring instrument as a function of the value of the quantity that the instrument is intended to measure. It is necessary to calibrate ionization chambers in terms of absorbed dose-to water to standardize the instruments by the easier and latest protocol. International Atomic Energy Agency published an international code of practice TRS-277 in 1987 [4] for absorbed dose determination in photon and electron beams and to achieve uniformity in dosimetry throughout the world. This protocol has certain limitations in meeting the needs of the broader radiation oncology community such as radiation metrology standards of the absorbed dose-to-water under reference conditions and is not easy to follow in different environment [5]. On the other hand, there is a large possibility of human errors to follow so many parameters of this protocol. To overcome such kind of problem, IAEA had added some corrections in this protocol in 1997 [6], published an international code of practice for dosimetry in high-energy electron & photon beams using plane parallel ionization chambers [7] and finally published a new international code of practice TRS-398 in 2000. This new international code of practice has drawn useful information available within the current national protocols and is intended to provide the user with a document that is clear and understandable and is easy to follow in rather different environments. This protocol is based on radiation metrology standards of absorbed dose-to-water and provides a systematic and internationally unified approach for the determination of the absorbed dose-to- water under reference conditions or calibration, with most kinds of radiotherapy beams. The previous IAEA protocol TRS-277 [4] was based on the air kerma calibration factor i.e. N_k.

Thus, the main purpose of the present study was to calibrate some cylindrical ionization chambers (20 chambers) in terms of the absorbed dose-to-water calibration coefficient $N_{D,W}$ based on the TRS-398. Then, the determined $N_{D,W}$ coefficients, of the ionization chambers taken under calibration, were compared with the manufacturer's $N_{D,W}$ values with a view to find out whether the deviation among the $N_{D,W}$ coefficients are within the IAEA's acceptance limit of 1.5% [8].

2. Material and methods

In the present study, twenty cylindrical ionization chambers from various user groups were taken under calibration. This study incorporated the cylindrical chambers with a wide range of sensitive volumes ranged from 0.004 mm^3 - 0.65 cm^{-3} to evaluate the chamber response dependence on the chamber's sensitive volumes. In the course of determining the $N_{D,W}$ coefficients, at the first step, the reference absorbed dose-to-water at 5 cm $D_W(5g.cm^{-2})$ was measured, as described in the subsequent section 2.1. Then, at the second step, the experimental setup was arranged for the ccalibration of the ionization chambers, as described in the subsequent section 2.2.

2.1. Determination of the absorbed dose-to-water based on TRS-398 protocol

The reference absorbed dose-to-water $D_W(5g.cm^{-2})$ at the reference depth Z_{ref}(5g.cm^{-2}) in water was determined for a ^{60}Co gamma ray beam as per the TRS-398 [3], applying the following Equation:

$$D_W(5g.cm^{-2}) = M_u \cdot N_{D,W} \quad (1)$$

where $D_W(5g.cm^{-2})$ is the absorbed dose-to-water in the user ^{60}Co gamma ray beam in the absence of the chamber, M_u is the reading of the dosimeter corrected for the influence quantities; and $N_{D,W}$ is the absorbed dose-to-water calibration coefficient of reference ionization chamber at ^{60}Co gamma ray beam.

In the present study, the absorbed dose-to-water D_w were measured at reference condition using the secondary standard ionization chambers of model NE 2781#0537 and NE 2771#1205 coupled with the PTW Unidos electrometer 10002#20718. The IAEA reference water phantom after being filled up with water was placed on the couch of the teletherapy machine. Thereafter, ionization chamber was inserted into the hole of amplification of PMMA waterproof holder. Then, the PMMA holder was placed at 5 cm depth from the front window of the phantom. The gantry of the machine was set at ninety-degree (90^0) alignment to ensure the position of radiation beam as horizontal. The collimator was adjusted to the 10cm × 10cm field size. The ionization chamber inside the holder was set at 90-degree alignment with the central axis of the beam. The couch position was adjusted to keep the source to water surface distance (SSD) at 100 cm. The schematic diagram of the experimental setup with Phantom arrangement for dose measurement is shown in Fig.1. The measured absorbed doses-to-water D_w with the secondary standard ionization chambers NE 2781#0537 and NE 2771#1205 were compared. The dose deviation between these two chambers was found to be 0.859%, which is within the IAEA acceptable limit of ±1.5% [3] and can reasonably be a good agreement between the measured absorbed doses. Thus, the absorbed dose measured by the ionization chamber NE 2781#0537 was considered as the reference dose for calculating $N_{D,W}$ of the twenty ionization chambers under calibration.

2.2. Ionization Chamber Calibration

Calibration can be carried out either directly with primary standard in the primary standard dosimetry laboratory (PSDL) or with secondary standard in the SSDL. In Bangladesh, radiotherapy ion dosimeters are calibrated against secondary standard dosimeters. The present calibration work in terms of the absorbed dose-to-water calibration coefficient $N_{D,W}$ was carried out in comparison with the secondary standard dosimetry system of the SSDL, Bangladesh Atomic Energy Commission, which is traceable to the IAEA's dosimetry laboratory (Seibersdorf, Austria). The SSDL having a secondary standard dosimeter often calibrates the dosimeters at other radiotherapy centres in the country.

In the present study, substitution method of calibration was followed to calibrate the ionization chambers. In the first step, the absorbed dose-to-water was measured using the secondary standard ionization chambers, NE 2781#0537 and NE 2771#1205 connected with the electrometer PTW Unidos 10002#20781. The IAEA reference water phantom of dimension 30cm×30cm×30cm was placed on the couch of the teletherapy machine after being filled up with water. Thereafter, ionization chamber(s) was inserted into the hole of PMMA waterproof holder, which was placed at 5 cm depth from the front window of the phantom. The holder (wall thickness < 1 mm) was used to ensure the fixed position of the chamber in the phantom, and to protect the non-waterproof ionization chambers. The gantry of the machine was set at ninety-degree (90^0) position to ensure the horizontal radiation beam. The source to phantom surface distance (SSD) was fixed at 100 cm and the field size at the chamber position was 10cm × 10cm. The schematic diagram of the experimental setup for the absorbed dose-to-water calibration coefficients determination is shown in Fig. 1.

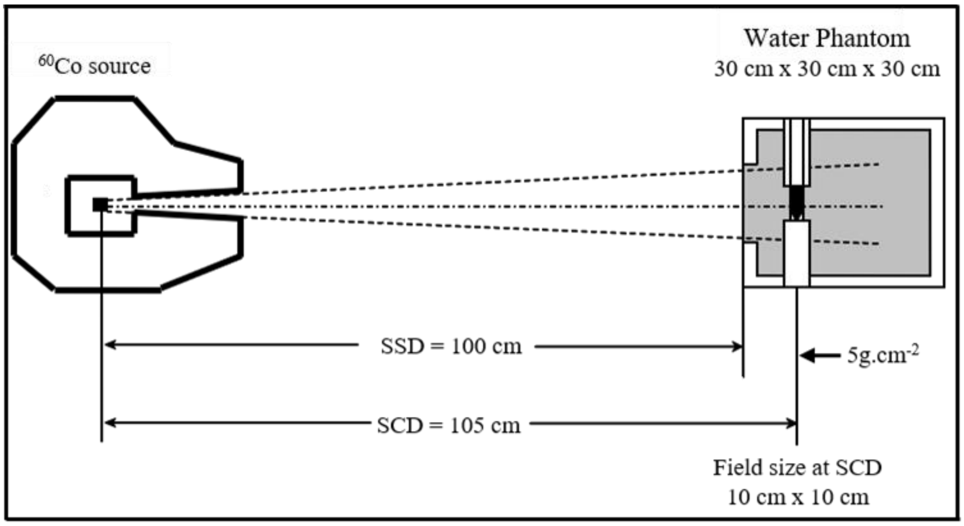

Figure 1 Experimental setup for absorbed dose-to-water calibration coefficient measurement**.**

In the second step, ionization chambers under calibration were placed one by one at this reference depth with the same geometry and beam quality. Electrometer readings were taken for each ionization chamber for five times to reduce measuring uncertainty and then the electrometer readings were corrected for influence quantity, i.e. temperature & pressure, ion recombination and polarity effect. The absorbed dose-to-water calibration coefficient, $N_{D,W}$ of the ionization chambers under calibration were determined by using the following equation [3]

$$N_{D,W} = \frac{D_W\left(5g.cm^{-2}\right)}{M} \qquad (2)$$

Where, $D_W(5g.cm^{-2})$ is the absorbed dose-to-water, measured by using the reference ionization chamber and applying the protocol Technical Report Series-398 (TRS-398); M is the electrometer reading corrected for influence quantities in order to correspond to the reference condition for the chamber under calibration.

3. Results and discussion

Prior to determine the $N_{D,W}$ coefficients, a reference absorbed dose-to-water at 5 cm $D_W(5g.cm^{-2})$ was measured with reference condition using the secondary standard ionization chambers of model NE 2781#0537 and NE 2771#1205 coupled with the PTW Unidos electrometer 10002#20718. The dose deviation between the above two secondary standard chambers was found to be 0.859%, which is within the IAEA acceptable limit of (±1.5%), hence a good agreement between measured doses and was used as the reference D_w for the determination of $N_{D,W}$. Thus, the absorbed dose measured by the ionization chamber NE 2781#0537 was considered as the reference dose for calculating the $N_{D,W}$ of the twenty ionization chambers under calibration.

The equation 2 was used to calculate the absorbed dose-to-water calibration coefficient $N_{D,W}$ for the 20 ionization chambers under calibration by applying the TRS-398 protocol. The calculated absorbed doses-to-water calibration coefficients $N_{D,W}$ of all ionization chambers and their percentage of deviation with the manufacturer's $N_{D,W}$ values are given in Table 1. From this table it is obvious, that the percentage of deviation of $N_{D,W}$ coefficients of all the ionization chambers taken under calibration were found within the IAEA's acceptance limit (i.e. 1.5%) except the three chambers (TW31010, S/N:03991, TW31010, S/N:03991 and TM 34001,S/N: 01615). The percentage of deviations between the measured and the manufacturer's $N_{D,W}$ values were calculated according to the formula recommended by the IAEA TRS-277 [4]

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

From the Table1 it is evident that the ionization chambers with relatively larger sensitive volume indicates relatively small percentage of deviation in $N_{D,W}$ than that of the smaller sensitive volumes one. Along with the percentage of deviation in $N_{D,W}$ evaluation, the measurement uncertainty of $N_{D,W}$ is presented in Table 1 as well. The reported combined uncertainty U_c assigned to the stated calibration coefficient is obtained as the combination of Type A and Type B uncertainty multiplied by the coverage factor k=1, providing a level of confidence of approximately 68%.

Apparently, the percentage of deviation in $N_{D,W}$ evaluation was found relatively large in the cases of smaller chamber volumes in comparison to the larger ones. This is because, the chamber sensitivity is proportional to its volume, and hence the effect of leakage on the measured charge is relatively greater for small chambers than that of the larger ones. Similarly, larger deviation in the evaluation of $N_{D,W}$ corresponds to the larger estimated range of U_c for smaller chambers and vice versa larger chambers.

Table 1 Assessed percentage of deviation between measured and manufacturer's $N_{D,W}$ for various chamber property.

Chamber Group	Chamber Model	Chamber S/N	Chamber Volume	Measured $N_{D,W}$ factor (Gy/C)	Manufacture's $N_{D,W}$ factor (Gy/C)	Deviation between manufacturer's and measured $N_{D,W}$	Uc (k=1) in $N_{D,W}$ measure-ment
1	TW 60019	122773	0.004 mm^3	1.285×10^9	1.271×10^9	1.089%	±1.7%
2	TN 31014	001273	0.015 cm^3	2.377×10^9	2.353×10^9	1.010%	±1.7%
3	TW 60017	001137	0.03 cm^3	1.089×10^8	1.089×10^8	0.918%	±1.7%
4	TW 31010	2211	0.125 cm^3	2.844×10^8	2.861×10^8	-0.599 %	±1.1%
5	TW 31010	1888	0.125 cm^3	3.012×10^8	3.016×10^8	-0.133 %	±1.1%
6	CC13	14663	0.13 cm^3	2.713×10^8	2.695×10^8	0.663%	*±1.3%*
7	CC13	14664	0.13 cm^3	2.707×10^8	2.693×10^8	0.517%	*±1.3%*
8	TW31010	03991	0.3 cm^3	2.899×10^8	2.958×10^8	-2.035%	*±1.4%*
9	TW31010	03992	0.3 cm^3	2.906×10^8	2.964×10^8	-1.996%	*±1.4%*
10	TM 34001	01615	0.35 cm^3	8.439×10^7	8.248×10^7	2.263%	±1.7%
11	TW30013	04904	0.6 cm^3	5.395×10^7	5.418×10^7	-0.426%	*±1.4%*
12	TW30013	009015	0.6 cm^3	5.359×10^7	5.351×10^7	0.149%	*±1.4%*
13	TW30013	009016	0.6 cm^3	5.359×10^7	5.347×10^7	0.224%	*±1.4%*
14	TN30013	04774	0.6 cm^3	5.406×10^7	5.405×10^7	0.019%	±1.4%
15	TM 31013	01472	0.6 cm^3	9.521×10^7	9.418×10^7	1.082%	±1.4%
16	FC65-P	3406	0.65 cm^3	4.814×10^7	4.807×10^7	0.145%	±1.1%
17	FC65-P	3407	0.65 cm^3	4.816×10^7	4.804×10^7	0.249%	±1.1%
18	FC65-G	938	0.65 cm^3	4.818×10^7	4.796×10^7	0.457%	*±1.3%*
19	FC65-G	1928	0.65 cm^3	4.817×10^7	4.848×10^7	-0.644%	*±1.3%*
20	FC65-G	3320	0.65 cm^3	4.823×10^7	4.796×10^7	0.560%	*±1.3%*

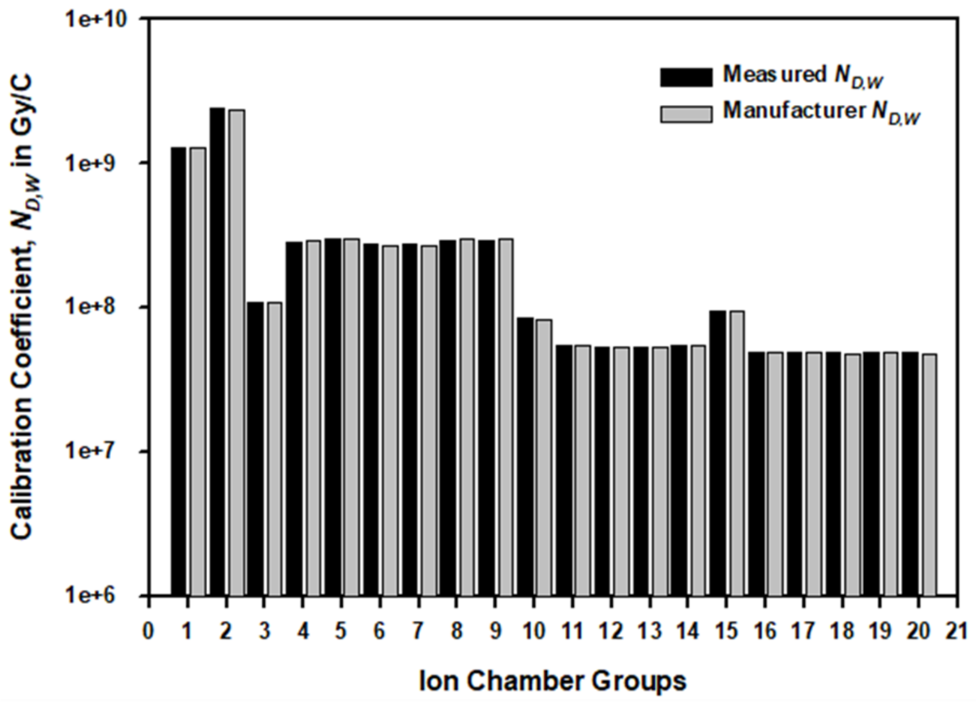

Figure 2 Comparison between measured and manufacturer's absorbed dose-to-water calibration coefficient $N_{D,W}$.

4. Conclusion

Absorbed dose-to-water calibration coefficients $N_{D,W}$ for twenty ionization chambers have been determined. The reference absorbed dose-to-water D_w was measured in reference condition of TRS-398 using two secondary standard ionization chambers of SSDL. The percentage of deviation of measured D_w was verified in reference to the IAEA acceptable limit (±1.5%), and found in a good agreement. This measured D_w was used as the reference depth dose for determining the $N_{D,W}$ coefficients of the ionization chambers under calibration. The determined $N_{D,W}$ coefficients of the twenty ionization chambers under calibration were compared with the manufacturer provided $N_{D,W}$ coefficients. The observed percentage of deviation between the measured and the manufacturer's $N_{D,W}$ value for all chambers were found to be in the range of 0.019% and -2.263% as the least and highest respectively. Apparently, the percentage of deviation of the $N_{D,W}$ coefficients of all the ionization chambers taken under calibration were found within the IAEA's acceptance limit (i.e. 1.5%) with an exception for three chambers The deviation of $N_{D,W}$ beyond the IAEA limit for the three chambers might have influenced due to the transport effect and ambient condition. Therefore, in some cases it is not reasonable to grossly rely on the manufacturer provided calibration coefficient, instead, it is obligatory to calibrate the ionization chamber once in every twice year to be used in dosimetry purposes. Therefore, regular calibration of ionization chamber is essential for the accurate determination of doses delivered to cancer patients during the external-beam cancer therapy.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest declared on this research article.

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