A COMPARISON OF IN-AIR AND IN-WATER CALIBRATION OF A DOSIMETRY SYSTEM USED FOR RADIATION DOSE ASSESSMENT IN CANCER THERAPY

by

Waheed ARSHED[1*], Khalid MAHMOOD[1], Ikramullah QAZI[1], Asad ULLAH[1], Perveen AKHTER[1], Syed Salman AHMAD[1], and Zeeshan JAMIL[2]

[1]Health Physics Division, PINSTECH, Islamabad, Pakistan
[2]Chemical Plant Complex, Dera Ghazi Khan, Pakistan

Short paper
UDC: 615.849.5:621.386.82
DOI: 10.2298/NTRP1001051A

An accurate calibration of the therapy level radiation dosimetry system has a pivotal role in the accuracy of dose delivery to cancer patients. The two methods used for obtaining a tissue equivalent calibration of the system: air kerma calibration and its conversion to a tissue equivalent value (absorbed dose to water) and direct calibration of the system in a water phantom, have been compared for identical irradiation geometry. It was found that the deviation between the two methods remained within a range of 0% to 1.7% for the PTW UNIDOS dosimetry system. This means that although the recommended method is in-water calibration, under exceptional circumstances, in-air calibration may be used as well.

Key words: absorbed dose calibration, kerma to absorbed dose conversion

INTRODUCTION

The use of radiation is very common in our everyday lives. One of its major uses is in the health sector where radiation is utilized not only as diagnostic tool, but also as a therapeutics agent in the treatment of tumours. Radiation doses involved in the treatment of tumours are usually rather high. An optimal radiation dose to the tumour, dose fractionation and the prevention of healthy tissue receiving undue radiation doses are fundamental elements of treatment planning. Dose delivery and dose determination depend upon careful calibration of the dosimetry system which consists of an ionization chamber and an electrometer assembly [1-4]. The quantity of interest for the hospital physicist is the absorbed dose to the water, since water is a tissue equivalent material. The dosimetry system at a radiotherapy centre, therefore, needs to have an absorbed dose to water calibration factor, $N_{D,W}$. This calibration is provided by the Secondary Standard Dosimetry Laboratory (SSDL), which has its own dosimetry standard calibrated to a primary dosimetry system in a Primary Standard Dosimetry Laboratory (PSDL) [5].

Primary calibrations in absorbed doses to water are not provided by many standard laboratories worldwide and, because of that, dosimetry measurements rely upon the air kerma standard. Although the use of the direct absorbed dose to water calibration is the recommended method, in its absence, air kerma calibration can be converted to the absorbed dose to water calibration, using data provided by the IAEA standard protocols [6, 7].

In the present work, the two methods, direct absorbed dose to water calibration and calculation of the absorbed dose to water through air kerma calibration have been compared through the PTW UNIDOS dosimetry system which is a field instrument. The two said methodologies have been compared for various calibration geometries, using the Co-60 therapy level standard source.

MATERIALS AND METHODS

The PTW UNIDOS dosimetry system consists of a graphite thimble ionization chamber, type 30004, with an active volume of 0.6 cm^3 inside the graphite thimble and a body made of aluminum. The build-up cap of the chamber, with wall thickness of 4.55 mm, is made of poly methyl methacrylate (PMMA). The chamber's response to Co-60 gamma radiation (1.25 MeV) is independent of the direction of the beam incidence when used with a build-up cap. The

* Corresponding author; e-mail: warshed@pinstech.org.pk

measuring assembly is UNIDOS, a microprocessor controlled dosemeter with measurement modes available in terms of charge, doses, and dose rates [8]. The chamber was calibrated by a secondary standard (working standard), that of the SSDL Health Physics Division PINSTECH, consisting of an ionization chamber, type NE-2561, and a measuring assembly, type NE-2560, calibrated against the primary standard of the IAEA dosimetry laboratory (Seibersdorf, Vienna, Austria), both in terms of air kerma and the absorbed dose to water.

The schematic diagram used for air kerma calibration is shown in fig. 1, that for the absorbed dose to water calibration in fig. 2. The centre of the chamber was aligned with the centre of the Co-60 gamma ray beam using a laser alignment system, while the calibration was performed by the substitution method, using the SSDL standard. The source to chamber distance (SCD) was 100 cm, 150 cm, and 200 cm. At each SCD setting, field sizes at the chamber position of 10 × 10 cm^2, 15 × 15 cm^2, 20 × 20 cm^2, 30 × 30 cm^2, and 40 × 40 cm^2 were selected. Normal calibration geometry uses a 100 cm SCD and 10 × 10 cm^2 field size. We increased both parameters, starting with a standard setting, in order to see the effects of scattering. For air kerma measurements, the irradiation was performed in open air with the chamber inside the build-up cap, where as for the absorbed dose to water calibration, the chamber was inserted in an IAEA standard water phantom of 30 × 30 × 30 cm^3. The chamber was kept in a 3.45 mm thick PMMA sleeve, at a standard depth of 5 cm from the front face of the phantom.

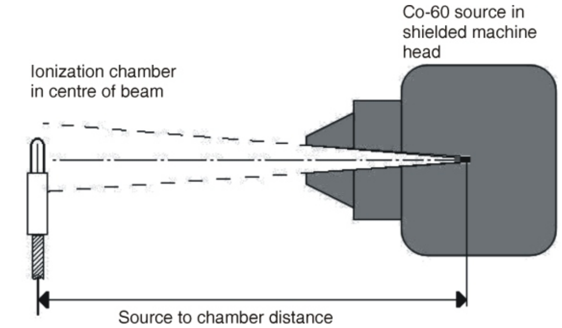

Figure 1. Experimental set-up used for air kerma calibration

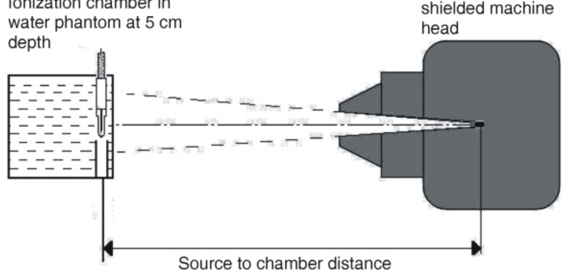

Figure 2. Experimental set-up used for absorbed dose to water calibration

In the direct method, measurements were made in the water phantom. The absorbed dose to water calibration factor $N_{D,W}$ was determined by the following relation

$$N_{D,W} = \frac{D_W\,(5\mathrm{cm})}{M} \tag{1}$$

where D_W(5 cm) is the dose at a depth of 5 cm in the water phantom, as measured by the SSDL working standard, and M is the PTW UNIDOS dosemeter reading in charge mode, corrected for ambient conditions.

In this method, the absorbed dose to water calibration factor D_W(5 cm) was derived from the experimentally determined air kerma calibration factor N_K for PTW chamber type 30004 connected with a PTW UNIDOS dosemeter (measuring assembly). The formalism for the indirect determination of D_W(5 cm) has been discussed in detail in the IAEA dosimetry protocol TRS-277 [6]. Using this formalism, the absorbed dose to air calibration factor $N_{D,air}$ was derived from N_K through following equations

$$N_K = K_{air}\,/\,M \tag{2}$$

$$N_{D,air} = N_K\,(1 - g)\,k_m k_{att} \tag{3}$$

where K_{air} corresponds to the mean absorbed dose to air inside the cavity of the chamber, g is the fraction of the secondary electron energy lost to bremsstrahlung in the air, k_m – the correction factor for non-air equivalence of the chamber wall, and k_{att} – corrects for the attenuation and scattering of photons in the chamber wall (graphite) and build-up cap (PMMA). The absorbed dose to water calibration factor was calculated from

$$N_{D,W} = N_{D,air}\,(S_{W,air})\,P_c \tag{4}$$

where $S_{W,air}$ is the water-to-air stopping power ratio and P_c is the overall perturbation correction factor of the ionization chamber for phantom measurement at Co-60 quality. Following values of various correction factors have been used [6, 9, 10]:

g = 0.003 for Co-60, therefore,
1 – g = 0.997,
$k_m k_{att}$ = 0.975 for 0.6 cm^3, PTW chamber type 30004,
$S_{W,air}$ = 1.133 for Co-60 average gamma energy (1.25 MeV), and
P_c = 0.993 for Co-60 radiation quality.

RESULTS AND DISCUSSION

The values of the absorbed dose to water calibration factor $N_{D,W}$, determined using direct measurements in a water phantom and those calculated from the air kerma calibration factor, have been shown in tabs. 1, 2, and 3. The measurements were repeated for three different SCD values and five field sizes at each SCD setting. Overall, the results presented here reveal very good

Table 1. Comparison of $N_{D,W}$ for the PTW ionization chamber, type 30004, using air kerma formulation and direct measurements in a water phantom of SCD 100 cm

Field size at chamber position [cm^2]	$N_{D,W}$ from air kerma formulation, A [mGy/nC]	$N_{D,W}$ from direct measurement, B [mGy/nC]	Percent [%] difference 100 $(B - A)/B$
10 10	52.83	52.47	–0.69
15 15	52.63	52.38	–0.48
20 20	52.68	52.65	–0.06
30 30	53.45	52.68	–1.46
40 40	53.62	52.72	–1.71

Table 2. Comparison of $N_{D,W}$ for the PTW ionization chamber, type 30004, using air kerma formulation and direct measurements in a water phantom of SCD 150 cm

Field size at chamber position [cm^2]	$N_{D,W}$ from air kerma formulation, A [mGy/nC]	$N_{D,W}$ from direct measurement, B [mGy/nC]	Percent [%] difference 100 $(B - A)/B$
10 10	52.75	52.55	–0.38
15 15	52.67	52.41	–0.50
20 20	52.64	52.65	–0.02
30 30	52.69	52.60	–1.17
40 40	52.81	52.61	–1.38

Table 3. Comparison of $N_{D,W}$ for the PTW ionization chamber, type 30004, using air kerma formulation and direct measurements in a water phantom of SCD 200 cm

Field size at chamber position [cm^2]	$N_{D,W}$ from air kerma formulation, A [mGy/nC]	$N_{D,W}$ from direct measuremen,t B [mGy/nC]	Percent [%] difference 100 $(B - A)/B$
10 10	52.93	53.02	0.17
15 15	53.11	53.47	0.67
20 20	53.28	53.59	0.58
30 30	52.95	53.49	1.01
40 40	52.91	53.82	1.69

agreement between calibration factors obtained by the two methodologies. When the calibration factors obtained in these two ways are compared, it is seen that in most cases the difference is less than 1%, except for a few cases of field sizes higher than the standard field size of 10 × 10 cm^2. A difference of 1.5% in calibration factors obtained by the two methods has been quoted by Bjerke *et al.* [11]. McEvan *et al.* [12] have shown that the difference in calibration factors derived from the primary standard calorimeter differed from 1% to 2. This means that the data values for various correction factors which have been taken from the IAEA codes, as indicated in the previous section, can safely be used for the determination of the absorbed dose to water calibration factor through the air kerma calibration factor. Calibration factors obtained through air kerma measurements had a mean of 52.93 mGy/nC, with a standard deviation of 0.58%, while calibration f actors obtained by the direct absorbed dose to water have a mean value of 52.87 mGy/nC, with a standard deviation of 0.9% at a 95% confidence level. The percent deviation of absorbed dose to water calibration factors obtained through the air kerma conversion, as compared to the one obtained by direct measurement, is evenly distributed in the negative and positive direction, as indicated in fig. 3. This means that the deviation is a random phenomenon. A relatively higher deviation has been found for field sizes larger than 20 × 20 cm^2. This could be due to the penumbra, as much as to the increased scattering from surroundings, as indicated elsewhere [13].

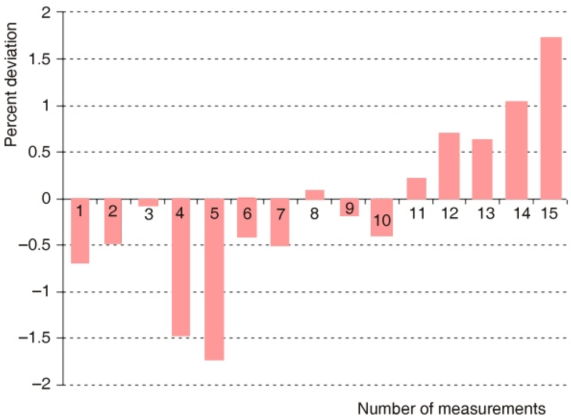

Figure 3. Extent of percent deviation of absorbed dose to water calibration factor obtained through air kerma conversion, as compared to those obtained by direct measurement

The overall error limit in dose delivery to cancer patients during radiation therapy is 5% [10,14]. Our findings indicate that if an ionization chamber at a therapy institute is calibrated for the absorbed dose to water indirectly, using the air kerma calibration factor, the error induced will not exceed that of 5% limit.

CONCLUSION

In the light of the presented study and its results, it may be concluded that, although the direct procedure for obtaining the absorbed dose to water calibration factor is recommended, in its absence, the determination of the absorbed dose to water calibration factor from the air kerma calibration factor works equally well for field sizes not greater than 20 × 20 cm^2.

ACKNOWLEDGEMENT

The authors would like to acknowledge the contribution of Mr. Anees Ahmad Farooqui and Mr. Zia Khurshid for the completion of the work presented here.

REFERENCES

[1] Ahmad, S. S., Mahmood, K., Orfi, S. D., Comparison of Calibrated Absorbed Dose to Water Calibration and Direct Absorbed Dose to Water Calibration Coefficients of Farmer Type Ionization Chambers, *SSDL Newsletters, 48* (2003), pp. 19-23

[2] Khan, F. M., The Physics of Radiation Therapy, 3rd ed., Lippincott, William & Wilkins, Baltimore, Md., USA, 2003

[3] ***, International Commission on Radiation Units and Measurements, Measurement of Absorbed Dose Measured in a Phantom Irradiated by a Single Beam of X or Gamma Rays, Report No. 23, ICRU, Bethesda, Md., USA, 1973

[4] Andreo, P., Suentjens, J. P., Podgorsan, E. B., Calibration of Photon and Electron Beams, Radiation Onchology Physics, A Handbook for Teachers and Students, IAEA, Vienna, 2005, p. 301

[5] ***, International Atomic Energy Agency, Member Laboratories of the IAEA/WHO Network of SSDLs, SSDL Newslatter No. 45, IAEA Vienna, 2003, p. 33

[6] ***, International Atomic Energy Agency, Absorbed Dose Determination in Photon and Electron Beams, An International Code of Practice, Technical Reports Series No. 277, IAEA, Vienna, 1987

[7] ***, International Atomic Energy Agency, Review of Data and Methods Recommended in the International Code of Practice IAEA Technical Reports Series No. 277, Absorbed Dose Determination in Photon and Electron Beams, IAEA-TECDOC-897, IAEA, Vienna, 1996

[8] ***, Instruction Manual PTW-UNIDOS Universal Dosemeter, Firmware No. 2.20 D196.131.0/4, 1996

[9] ***, International Atomic Energy Agency, The Use of Plan Parallel Ionization Chamber in High Energy Electron and Photon Beams, An International Code of Practice, Technical Reports Series No. 381, IAEA, Vienna, 1997

[10] ***, International Atomic Energy Agency, Absorbed Dose Determination in External Beam Radiology, An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water, Vienna, Technical Report Series No. 398, 2000

[11] Bjerke, H., Järvinen, H., Grimbergen, T. W. M., Grindborg, J-E., Chauvenet, B., Czap, L., Ennow, K., Moretti, C., Rocha, P., Comparison of Two Methods of Therapy Level Calibration at ^{60}Co Gamma Beams, *Phys. Med. Biol., 43* (1998), 10, pp. 2729-2740

[12] McEvan, M. R., Williams, A. J., DuSautoy, A. R., Determination of Absorbed Dose Calibration Factors for Therapy Level Electron Beam Ionization Chambers, *Phys. Med. Biol., 46* (2001), 3, pp. 741-755

[13] Hatimbbhai, M., Singh, P., Iyer, P. S., Effect of Field Size on the Radiation Penumbra and Integral Dose for Telegamma Therapy Units, *Strahlentherapie, 151* (1976), 2, pp. 151-155

[14] ***, International Commission on Radiation Units and Measurements, Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma Rays in Radiotherapy Procedures, Report No. 24, ICRU, Bethesda, Md., USA, 1976

Received on August 31, 2009
Accepted on March 10, 2010

Вахид АРШЕД, Халид МАХМУД, Икрамулах ГАЗИ, Асад УЛАХ,
Первин АХТЕР, Сајед С. АХМАД, Зишан ЏАМИЛ

ПОРЕЂЕЊЕ КАЛИБРАЦИЈЕ У ВАЗДУХУ И ВОДИ ДОЗИМЕТРИЈСКОГ СИСТЕМА НАМЕЊЕНОГ ПРОЦЕНИ ДОЗЕ ЗРАЧЕЊА У ЛЕЧЕЊУ РАКА

Еталонирање система за дозиметрију зрачења који се користи у терапији, има водећу улогу у тачном одређивању дозе предате болесницима од рака. Две методе су коришћене и упоређене за ткивно-еквивалентну калибрацију система са истоветном геометријом озрачивања: калибрација преко керме у ваздуху и њене конверзије у вредност еквивалентну ткиву (апсорбована доза у води) и директна калибрација система у воденом фантому. Утврђено је да су одступања између две методе остала у граници од 0% до 1.7% за PTW UNIDOS дозиметријски систем. Овим је утврђено да се у посебним околностима калибрација у ваздуху може такође користити, мада је калибрација у води препоручена метода.

Кључне речи: калибрација, айсорбована доза, конверзија керме у айсорбовану дозу