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Standard calibration of ionization chambers used in radiation therapy dosimetry and evaluation of uncertainties

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Background: Absolute dosimetry of external beam radiotherapy is carried out by the use of ionization chambers. These chambers must be calibrated at a standard dosimetry laboratory before any use in clinical dosimetry. The secondary standard dosimetry laboratory of Iran (SSDL) has the duty of calibrating the ionization chambers used in radiotherapy centers in Iran. ***Materials and Methods:*** The present work has described traceability of SSDL radiation measurement standards to relevant international standards, and calibration of therapy level ionization chambers in terms of air kerma and absorbed dose to water against ^{60}Co gamma radiation, as well as uncertainty evaluation of calibration coefficients. ***Results:*** The expanded uncertainties in the determination of air kerma and absorbed dose to water are estimated to be 2% and 2.3% at approximately 95% confidence level, respectively. ***Conclusion:*** In order to maintain the requirement of ±5% accuracy in the dose delivery, the combined standard uncertainty of the other factors in the dose delivery; i.e., dose measurement set-up, dose calculations, treatment planning, patient set-up, etc, should be less than 2.3%. **Iran. J. Radiat. Res., 2010; 8 (3): 195-199**

Keywords: *Dosimetry, ionization chamber, calibration, uncertainty.*

INTRODUCTION

A properly calibrated ionization chamber is a prerequisite for absorbed dose determination in external beam radiotherapy. The use of an ionization chamber having a calibration coefficient for ^{60}Co gamma rays is a common characteristic of all dosimetry protocols and codes of practice for high energy photons and electrons. These documents, introduced by national and international organizations, provide medical physicists with a systematic approach to the dosimetry of external radiotherapy beams [1-4]. Calibration coefficient of an ionization chamber is expressed usually in terms of exposure X, air kerma K_{air} or absorbed dose to water D_w, traceable to a standard dosimetry laboratory.

The various steps between the calibration of an ionization chamber in terms of air kerma at the standard dosimetry laboratories and determination of absorbed dose to water at hospitals using air-kerma based dosimetry protocols, introduce undesirable uncertainties into the realization of D_w. Many factors are involved in the dosimetric chain that starts with a calibration coefficient in terms of air kerma, N_K, measured in air using a ^{60}Co beam and ends with the absorbed dose to water, measured in water in clinical beams. Uncertainties associated with the conversion of N_K to absorbed dose to air chamber calibration coefficient, $N_{D,air}$ (or N_{gas}) mean that in practice, the starting point of the calibration of clinical beams already involves a considerable uncertainty.

The well established procedures to determine absorbed dose to water; i.e., the ionization method, chemical dosimetry, and water and graphite calorimetry, have considerably improved at primary standard dosimetry laboratories (PSDLs) in recent years. These developments lend to provide ionization chambers with calibration

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coefficients in terms of absorbed dose to water, $N_{D,w}$, for use in radiotherapy beams.

Many PSDLs already provide $N_{D,w}$ calibrations at ^{60}Co gamma ray beams and some laboratories have extended these calibration procedures to high energy photon and electron beams. Intercomparisons of primary standards of air kerma and absorbed dose to water generally give agreement within 0.2 – 0.3% at ^{60}Co gamma ray quality (1).

MATERIALS AND METHODS

Traceability to International Standards

At secondary standard dosimetry laboratories (SSDLs), calibration coefficients from a PSDL or from BIPM are transferred to hospital users. The dosimetry laboratory of the International Atomic Energy Agency (IAEA) is distinguished to act as a link between primary standards and members of the IAEA/WHO network of SSDLs. Indeed, calibration of all reference standard ionization chambers of the SSDL of Iran, as well as many other SSDLs, is traceable to the BIPM or a PSDL via the IAEA. Intercomparisons of secondary standards of absorbed dose to water are organized annually by the IAEA at ^{60}Co gamma ray and high energy X-rays through TLD postal dose audit program. Excellent results are reported by the IAEA in recent years. The results of the intercomparisons for the SSDL of Iran for the years 2000 to 2009 are shown in figure 1.

Therapy level ionization chambers in Iran are calibrated in comparison with the response of the SSDL reference and working standard ionization chambers in the ^{60}Co gamma ray beam of a teletherapy unit. All of the SSDL ionization chambers used for calibrations are themselves calibrated at the IAEA dosimetry laboratory (5). However, uncertainties associated with the calibration coefficients, together with other sources of uncertainties in the calibration process, usually lead to an expanded uncertainty of more than 2% in the calibration coefficients of hospital dosimeters.

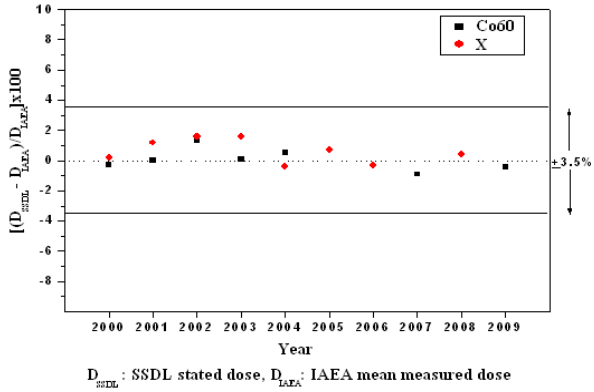

Figure 1. The results of IAEA/WHO TLD radiotherapy level audit for the SSDL of Iran for the years 2000 to 2009.

Ionization Chambers

Six therapy level ionization chambers were used for this investigation. Two of them are of NPL type secondary standard NE 2561 (UK) and NE 2611 ionization chambers, which were used as reference chambers at calibration laboratories. The other four chambers are well known 0.6 cc farmer type chambers (NE Technology (UK) and Physikalisch- Technische Werkstätten (PTW, Germany)) which were used both as working standards and field ionization chambers. These chambers are all calibrated at the IAEA dosimetry laboratory at ^{60}Co gamma radiation in terms of air kerma and absorbed dose to water. The calibration coefficients are reported in the IAEA certificates with both IAEA and SSDL (when available) electrometers. However, the differences between them for each one of the chambers are always less than their reported uncertainties.

Calibration of ionization chambers at SSDL

Calibration of the ionization chambers used in radiotherapy, were performed in comparison with the SSDL reference or working standard ionization chambers using substitution method. Calibrations were carried out in terms of both air kerma and absorbed dose to water, at ^{60}Co gamma ray beam of a ^{60}Co Picker V9 teletherapy unit. When calibrating in terms of air kerma, the chamber with its ^{60}Co buildup cap, was positioned free in air, so that its reference point was on the central axis of the beam and the chamber axis was perpendicular to it. The distance from the source to the reference point of the chamber was 80 cm. The radiation field size at reference plane was 10 cm × 10 cm figure 2 shows the configuration set-up.

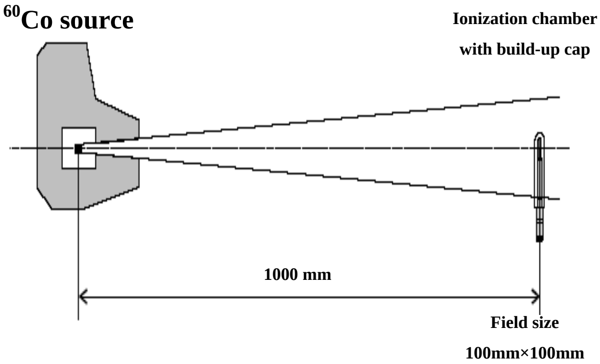

Figure 2. Reference conditions for calibration in terms of air kerma for ^{60}Co gamma radiation.

When calibrating in terms of absorbed dose to water, the chamber protected by a PMMA sleeve, was positioned in a 30 cm × 30 cm × 30 cm water phantom so that its reference point was on the central axis of the beam. The chamber axis was perpendicular to the central axis of the beam and the distance from the source to the reference point of the chamber is 80 cm. The reference point of the chamber was at 5 cm water depth and the size of the radiation field (50% isodose level) at the reference plane was 10 cm × 10 cm. Figure 3 shows the configuration set-up for calibration in terms absorbed dose to water.

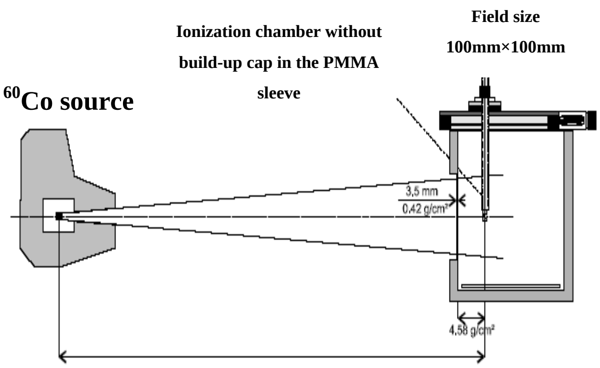

Figure 3. Reference conditions for calibration in terms of absorbed dose to water for ^{60}Co gamma radiation.

RESULTS AND DISCUSSION

Absorbed dose to water, which is the quantity of interest in radiotherapy, is preferably determined by direct measurement in a phantom but it also may be calculated by an air kerma measurement in a ^{60}Co gamma ray beam free in air. The mean value of the absorbed dose rate at a reference point in a water phantom, determined at the same date by $N_{D,w}$ formalism [(2)], N_K formalism [(1)] and in air measurement formalism [(6)], using all six calibrated chambers mentioned in materials and methods section, were in agreement within 1.8% at 95% confidence level (figure 4).

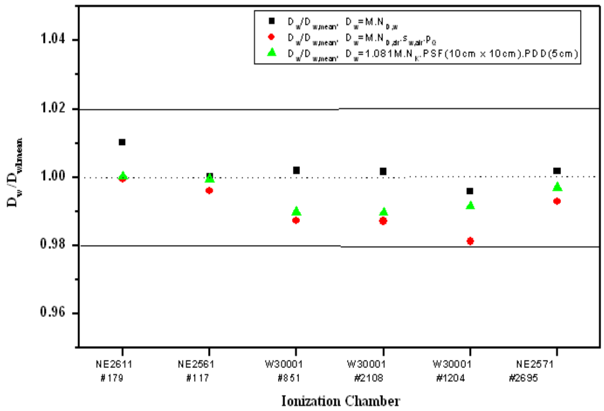

Figure 4. Results of absorbed dose rate Variation at a reference point in a ^{60}Co radiotherapy beam as determined by three formalisms using IAEA calibrated chambers. The reference point was located on the central axis of the beam, at 5 cm depth in a 30 cm × 30 cm × 30 cm water phantom. The distance from the source to the phantom surface was 80 cm and the field size at this distance was 10cm × 10cm.

Calibration coefficient of a chamber under calibration is obtained from:

$$N^{U} = \frac{N^{SSDL} \times M^{SSDL}}{M^{U}}$$

where N^U is the calibration coefficient (to be determined) and M^U is corrected electrometer reading of the user chamber. Also, N^{SSDL} is the calibration coefficient and M^{SSDL} is corrected electrometer reading of the SSDL chamber. The uncertainties in the SSDL calibration coefficients corresponding to one standard deviation are reported in the IAEA certificates to be 0.4% to 1%. The electrometer readings M_0^{SSDL} and M_0^{U} should be corrected for several factors including scale reading, recombination loss, leakage, radiation background, distance, air density, field homogeneity and humidity. The uncertainty contributions of these factors must be evaluated in the determination of N^u.

Scale reading is the only factor that has statistical contribution to overall uncertainty, the so called type A, uncertainty. Contribution of other factors to the uncertainty may be regarded as systematic, the so called type B uncertainty.

The standard deviation of the electrometer reading of well behaved therapy level ionization chambers does not exceed 0.5%. Thus the uncertainty in both readings, M_0^{SSDL} and M_0^{U} , is overestimated to be 0.5%.

Recombination loss for secondary standard instruments and most other therapy level dosimeters is small in a ^{60}Co beam and the uncertainty is considered to be negligible.

Leakage currents including radiation induced leakage have been small for secondary standard dosimeters and for field ionization chambers with possible larger volumes may be considered to vary with an uncertainty of not more than 0.2%.

Radiation background for therapy level ionization chambers was negligible with negligible uncertainty [7].

Ionization chambers were used at the same source-chamber distance, 80 cm, but this value did not enter the uncertainty calculation. The difference between the positions of the chamber centers could be as much as 1 mm. The percent uncertainty must have been doubled owing to the inverse square law.

Regarding the air density correction, the exact temperature and pressure do not enter uncertainty calculation. The temperature and pressure usually may differ between the measurement of two chambers by 0.5 °C in air (0.2 °C in water) and by 1mb respectively. The uncertainty due to air density correction is about 0.2% in air (0.1% in water).

Lateral displacement of the chambers during calibration is too small to cause any detectable difference in response owing to field non-uniformity.

Relative humidity in the SSDL laboratory is normally in the range of 20% to 50% during a year and is not high enough to cause leakage.

The uncertainties in the calibration of a therapy level ionization chamber in comparison with each one of the six calibrated SSDL chambers are summarized [8]:

Parameter	Uncertainty (%)
Uncorrected reading, M_0^{SSDL}	0.5
Uncorrected reading, M_0^{U}	0.5
SSDL calibration coefficient, N^{SSDL}	0.6 (N_K), 0.8 ($N_{D,w}$)
Leakage (user chamber)	0.2
Air density	0.2 (N_K), 0.1 ($N_{D,w}$)
Distance	0.3
Recombination loss	0.1 (SSDL), 0.1 (user)
Combined standard uncertainty	1.02 (N_K), 1.15 ($N_{D,w}$)
Expanded uncertainty (k=2)	2.04 (N_K), 2.3 ($N_{D,w}$)

CONCLUSION

Calibration of ionization chambers is an important first step in the dosimetry of radiation therapy beams. The SSDL of Iran, which is traceable to international standards of air kerma and absorbed dose to water via IAEA dosimetry laboratory, issues calibration certificates for ionization chambers used in radiotherapy centers in Iran. The certificates provide the ionization chambers with air kerma and absorbed dose to water calibration coefficients in ^{60}Co gamma radiation. Calibration coefficients are determined with an expanded uncertainty of 2% for air kerma and 2.3% for absorbed dose to water with a coverage factor k=2. According to ICRU [8-9], the available evidence for certain types of tumors points to the need for an accuracy of

±5% at 95% confidence level in the delivery of an absorbed dose to a target volume. This is interpreted as if it corresponds to approximately two standard deviations. Thus the requirement for accuracy of 5% in the delivery of absorbed dose corresponds to a combined standard uncertainty of 2.5% at the level of one standard deviation. Regarding the combined standard uncertainties for N_K and $N_{D,w}$, we may write

$$u_N^2 + u_r^2 \leq 2.5^2$$

where U_N is the combined standard uncertainty of N_K or $N_{D,w}$ and u_r is the combined standard uncertainty of the other factors in the dose delivery i.e. dose measurement set-up, dose calculations, treatment planning, patient set-up, etc. In order to maintain the requirement of ±5% accuracy in the dose delivery, u_r is estimated to be less than 2.3%.

REFERENCES

1. International Atomic Energy Agency(1997) Absorbed Dose Determination in Photon and Electron Beams: An International Code of Practice, Technical Report Series No. 277 IAEA, Vienna .
2. International Atomic Energy Agency (2000) Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water, Technical Report Series No. 398, IAEA, Vienna.
3. American Association of Physicists in Medicine(1999) Task Group 51: Protocol for Clinical Reference Dosimetry of High-Energy Photon and Electron Beams. *Med. Phys, **26:** 1847-1870.*
4. American Association of Physicists in Medicine(1983) Task Group 21: A protocol for the determination of absorbed dose from high-energy photon and electron beams. *Med Phys, **10:** 741-771.*
5. Meghzifene A and Short K (2007) The IAEA calibration and Measurement capabilities SSDL Newsletter, ***53:** 4-8.*
6. International Atomic Energy Agency (1994) Calibration of dosimeters used in radiotherapy, technical reports series No. 374, IAEA, Vienna.
7. Faiz M Khan (2003) Measurement of ionizing radiation, The physics of radiation therapy, Lippincott Williams & Wilkins, Philadelphia, USA.
8. International Atomic Energy Agency (2009) Calibration of Reference Dosimeters for External Beam Radiotherapy. Evaluating the uncertainty TRS No. ***469:** 57-61.*
9. International Comission on Radiation Units and Measurements(1976) Determination of absorbed dose in a patient irradiated by beams of X or gamma rays in radiotherapy procedures, ICRU Report 24, ICRU, Bethesda.