Romanian Reports in Physics **69**, 606 (2017)

LONG TERM STABILITY OF THE PERFORMANCE OF A CLINICAL LINEAR ACCELERATOR AND Z-SCORE ASSESSEMENT FOR ABSORBED DOSE TO WATER QUANTITY

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Received December 15, 2015

Abstract. Assessment of the *z*-score was used to evaluate the long term stability of the performance of a clinical linear accelerator. The absorbed dose to water in high energy photon beam was determined at the linear accelerator owned by the clinical dosimetry laboratory in the radiotherapy department of the "Coltea" Clinical Hospital. The z-score was calculated for the absorbed dose measurements made at reference conditions according to IAEA-398 standard, in 2011 and in 2015 following repairs made to the linear accelerator. The measurements were conducted using water proof ionization chambers in a water equivalent phantom at the reference point for a 10 cm × 10 cm field size and at SSD = 1 m. For each ionization chamber the reference points, were determined according to radiation beam quality. The measurements were performed in a photon beam at reference points of 5 g cm^{-2} and 10 g cm^{-2}. *z*-score assessment for absorbed dose to water quantity was evaluated according to ISO 13528:2005. The values obtained were found to be in the limits of statistical performance, z = [–2; 2], concluding that laboratory performance is satisfactory.

Key words: clinical dosimetry, radiotherapy, LINAC stability, *z*-score.

1. INTRODUCTION

A clinical linear accelerator is an important apparatus used in radiotherapy departments worldwide [1, 2] where high accuracy of the delivered absorbed dose, is required. The measurements of the absorbed dose are performed according to international approved standards developed by IAEA [2, 3].

Absorbed dose to water measurements were performed at the Siemens MEVATRON Primus, a clinical linear accelerator, that belongs to the Department of Radiation Oncology from the "Coltea" Clinical Hospital in Bucharest. The laboratories involved in the determinations of absorbed dose to water were: the

High Energy Secondary Standard Dosimetry Laboratory STARDOOR, INFLPR [4] (National Institute for Laser, Plasma and Radiation Physics) and the Department of Radiation Oncology of the "Coltea" Clinical Hospital, Bucharest [2]. The ionization chambers used by both laboratories for measurements were cylindrical type and each ionization chamber was connected to the corresponding dosimeter owned by each laboratory. The measurements for the absorbed dose to water in reference point were performed for high energy photon beams with nominal energies of: 6 MeV and 15 MeV.

Unlike industrial linear accelerators, that are used mainly for providing large radiation doses (in the order of kGy) suitable for studying the interaction of radiation with matter, in medicine a single radiotherapy session usually involves a dose of about 2 Gy spread over a sufficiently long time frame, to allow for healthy cell regeneration [5–7].

The assessment of the absorbed dose to water quantity was made using the *z*-score, determined according to the International Standard ISO 13528 [8]. The measurements were performed at "Coltea" Hospital in 2011 and repeated in 2015.

2. MATERIALS AND METHODS

The determination of absorbed dose delivered to a patient during radiotherapy treatment, is based on the measurement of absorbed dose to water, because water is the equivalent material to soft tissue used in dosimetry [9]. Besides this method, another way for determining the dose absorbed by the patient is the method that use dosimetric film [10, 11], but the most relevant is the first one mentioned.

The equipment used for determining the long term stability of the accelerator in this experiment was: the Siemens MEVATRON Primus clinical linear accelerator, two ionization chambers, two UNIDOS dosimeters and a equivalent water phantom.

The clinical linear accelerator, that belongs to the "Coltea" Hospital, supplies electron beams with energies: 5 MeV, 7 MeV, 10 MeV and 12 MeV and photon beams with energies: 6 MeV and 15 MeV. The experiments presented in this paper were performed in photon beams at energies of 6 MeV and 15 MeV.

The two cylindrical ionization chambers used for the measurements were both type TN 31010 (cavity volume 0.125 cm^3): one belonging to "Coltea" Hospital and the other belonging to the STARDOOR laboratory. Each of the ionization chambers was connected to their corresponding UNIDOS dosimeter. The dosimetric system that belongs to the STARDOOR laboratory is calibrated at primary standard at PTB-Braunschweigh (German Federal Institute of Physics and Metrology).

The measurements made in photon beams were carried out using a water phantom with dimensions: 60 cm × 50 cm × 40.75 cm, purchased from PTW, Germany. The environmental conditions were monitored with an OPUS 10 TPR thermo-barometer and were kept within standard required limits, during the experiments.

The method for determining the absorbed dose to water was selected considering IAEA-TRS 398 recommendations, employing the relation [3, 12, 13]:

$$D_{w,Q} = N_{D,w,Q_0} \cdot M_{cor} \cdot k_{Q,Q_0} \quad (1)$$

where, N_{D,w,Q_0} is the ionizing chamber calibration coefficient for Q_0 radiation beam determined in water; for the index quality of photon beam, the TRS 398 recommend measurement of tissue phantom ratio at depths of 10 cm and 20 cm ($TPR_{20,10}$) for the field size of 10 × 10 cm.

k_{Q,Q_0} is the factor considering the difference between the Q_0 beam quality used in calibration and Q radiation beam quality used in measurements [3, 14].

M_{cor} is the value read on the reference dosimeter corrected for the influence magnitudes, determined to be the product of the following factors [3, 12, 13]:

$$M_{cor} = M_{inst} \cdot k_{elec} \cdot k_{TP} \cdot k_{pol} \cdot k_s , \quad (2)$$

where M_{inst}, k_{elec}, k_{TP}, k_{pol} and k_s are given in reference standard IAEA TRS-398. The uncertainty for measurement of the absorbed dose to water, for each of the used energies, was 1.0 % and 3.13 %.

In most clinical situations the measurement conditions do not match the reference conditions used in the standards laboratory. This may affect the response of the dosimeter and it is then necessary to differentiate between the reference conditions used in the standards laboratory and the clinical measurement conditions [3].

The statistical performance was calculated as *z*-score by the below formula according to ISO 13528:2005 [8]:

$$z = \frac{x - X}{\sigma} , \quad (3)$$

where x is the average value, X is the assigned value or the conventional true value and σ is the standard deviation for proficiency assessment [8]. The *z*-score value should lie in the range of statistical performance, z = [–2; 2], when laboratory performance is satisfactory.

The conventional true value of a quantity is the value attributed to a particular quantity and accepted, sometimes by convention, as having an uncertainty appropriate for a given purpose. At a given laboratory or hospital, the value realized by a reference standard may be taken as a conventional true value and, frequently, the mean of number of results of measurements of a quantity is used to establish a conventional true value [3].

3. EXPERIMENTAL SET-UP

In this paper, both laboratories have measured absorbed dose to water in photon beams at a clinical linear accelerator at the reference depths, at 6 MeV and 15 MeV energies. The measurements were performed according the requirements of IAEA-TRS 398 standard [3]. All influence quantities, were considered included in the absorbed dose to water values.

For measuring the absorbed dose in a photon beam, the ionization chambers were placed at the reference depth perpendicular to the direction of propagation of the radiation beams. The absorbed dose to water was measured in water phantom at a constant source-surface-distance of 100 cm and the filed size of 10 cm × 10 cm at the plane of the ionization chamber. The reference point was calculated according to photon beams quality ($TPR_{20,10}$). The distance and field sizes were measured using a laser system. All distances and field sizes were checked through rigorous measurements.

For each ionization chamber that was used, the reference depth was determined according to the radiation beam quality used. The measurements were performed in the photon beam at reference depth equal to 5 g cm^{-2} for energy 6 MeV and 10 g cm^{-2} at energy 15 MeV.

The pressure and temperature were monitored and recorded for each measurement. No correction was made for air humidity, because this parameter doesn't have any influence to the measurements. Correction for leakage and ion-recombination effect was applied and the uncertainty for measuring of absorbed dose to water was calculated in conformity with reference standards.

4. RESULTS AND DISCUSSION

The measurements in photon beam were performed in 2011 year and repeated in 2015. The measurements of absorbed dose to water were performed at reference depth at energy 6 MeV and 15 MeV for 2011, while in the 2015 year were performed at energy 6 MeV. The dosimetric equipment belongs to STARDOOR laboratory, used to measure the absorbed dose to water was described in the chapter 2 and also was respected the set-up experiment described in chapter 3.

The accumulated absorbed dose to water was measured three times for each energy for a preset time of 33 seconds, and the measurement uncertainty was calculated as equal to 1%. These measurements made in high energy photon beams, confirm the performance of the dosimetric system used, as reference equipment (Fig. 1).

In Fig. 1 it can be seen that statistic performance calculated for the two energies (6 MeV and 15 MeV) used in the three measurements is found in the range of [–2, +2].

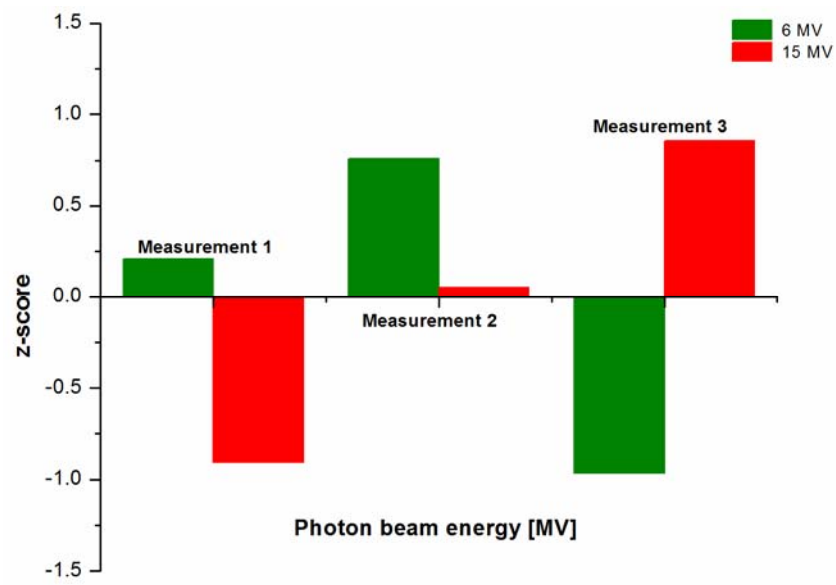

Fig. 1 – *z*-score for measurements results in 6 MeV and 15 MeV photon beam for absorbed dose to water.

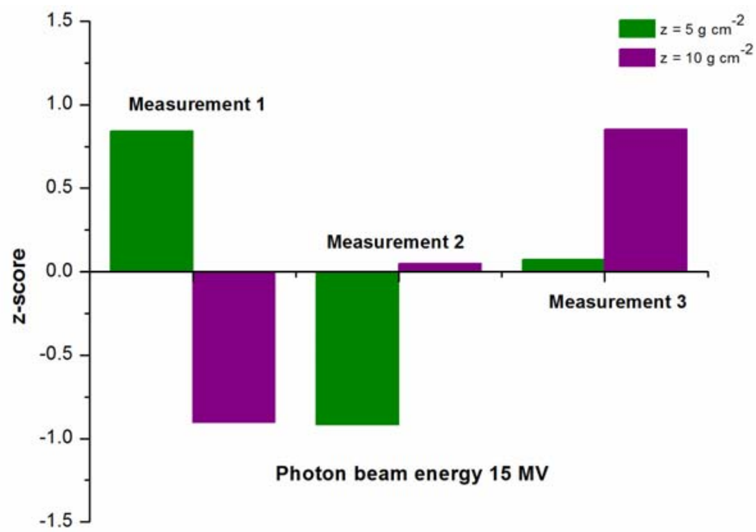

Fig. 2 – *z*-score for measurements results in 15 MeV photon beam for absorbed dose to water at depth 5 g cm^{-2} and 10 g cm^{-2}.

For a better analysis of the data the absorbed dose to water at the energy of 15 MeV at depth of 5 g cm^{-2} (Fig. 2) was also measure and the *z*-score was calculate. Also, the absorbed dose to water values are within the limits of the measurement uncertainty. After comparing the results of the *z*-score for the two depths it was concluded that the statistic performance for the STARDOOR laboratory is satisfactory.

In 2015 the measurements were carried out at the energy of 6 MeV. The absorbed dose to water measurements made at clinical linear accelerator at the reference depth were measured using two cylindrical ionization chambers: a chamber belongs to the "Coltea" Hospital and other belongs to STARDOOR Laboratory.

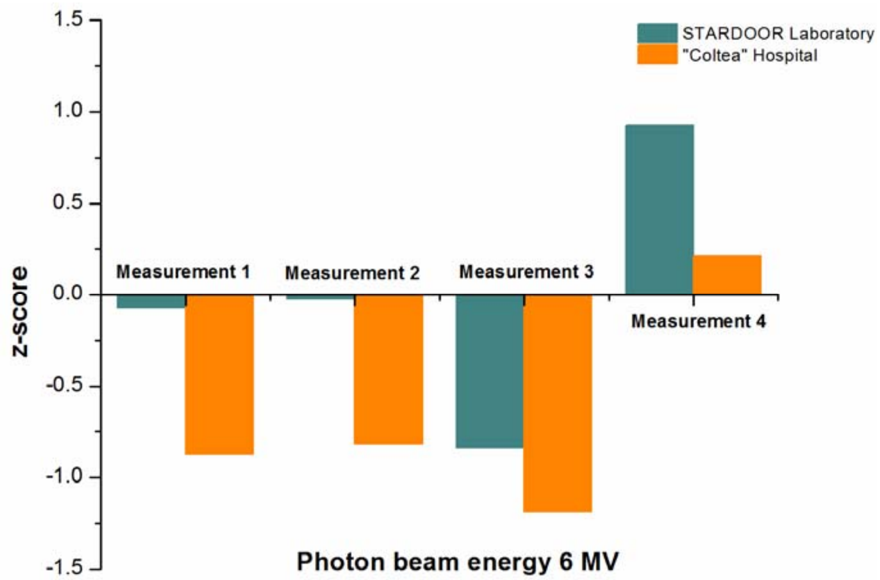

Fig. 3 – *z*-score for measurements results at 6 MeV photon beam for absorbed dose to water at reference depth of the 5 g cm^{-2}.

From the obtained data it was observed that for the two laboratories the absorbed dose to water values are within the limits of the measurement uncertainty (3.13 %). The *z* score values are within the range [–2, +2].

Analyzing Fig. 3 it can be see that when different ionization chambers are used in the same radiation beam, the values measured for the absorbed dose to water are almost equal. The accumulated absorbed dose to water was measured of four times for the 6 MeV energy at the present time of 10 seconds, and the uncertainty of measurement was calculated as equal to 3.13%. Positive and negative values of *z*-score are obtained within the range mentioned above and it can be said that the measurements made by the two ionization chambers are satisfactory.

5. CONCLUSION

The measurements for absorbed dose to water in photon beam, performed with two dosimetric systems (STARDOOR laboratory and "Coltea" Hospital) respect the uncertainty range limit required in specialized standards for the reference laboratory.

Z-score for each laboratory is included in range limits of [–2, +2], for absorbed dose to water quantity. Both participating laboratories demonstrate that their implemented quality assurance system proves high quality of their services.

Quality assurance of the results is also demonstrated through the long therm stability of the clinical linear accelerator. The measurements performed in different years show that, the measurement uncertainity is in the range given by dosimetry standards used for radiation therapy laboratories.

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