Evaluation of the performance of an ionization chamber cylindrical (PTW) by the ELEKTA linear accelerator: Case of pulsed radiation

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Abstract. The performance evaluation of cavity cylindrical ionization chamber dosimeters is the basis for the evolution of radiotherapy treatment processes. Studies focused on the statistical and physical performances of the ionization chamber dosimeter used in the radiotherapy department at the hospital oncology CHU-Fez-Morocco. This allowed having a qualitative and quantitative critical view, which is based on previous studies and works. The diagnostic of the dispersion results was calculated between measurements that were taken by the same dosimeter under different test conditions. These tests were then rechecked against two different operators. The general purpose of our study is to optimize measurement and treatment processes, with the desired level of quality according to international standards and protocols. The evaluation of this dosimeter is made by a source of pulsed radiation. This evaluation is carried out using an ELEKTA linear accelerator, using photon beams (6, 10 and 18 Mev). Experimental Results confirmed that the response of the cylindrical ionization chamber depends on several parameters, which influence the performance of the device/machine. The study reveals a total dosimeter uncertainty of the order 3.25 %, which is in the international standards. Even, this can cause an effect on the performance of the ionization chamber detector.

Keywords: Dosimeter, Cylindrical Ionization Chamber, ELEKTA Linear Accelerator, Performance evaluation, Dosimetry, Radiotherapy.

1. Introduction

The use of ionizing radiation in various applications such as radiotherapy and brachytherapy, is currently the subject of several very important studies. This studies focus on related tools that lead to optimal use of ionizing radiation, such as linear accelerators, computer tools, or measuring instruments.

The Cavity theory allows the measurements of the environments absorbed dose from the dose in the sensitive volume of the cavity ionization chamber detector [12, 13, 14, 17, 31, and 42]. The most used dosimeters in radiotherapy and brachytherapy are the ionization chambers [5]. These dosimeters are mainly recommended for the dosimetry of high energy electrons and photons [21, 38]. It is therefore necessary to know the essential characteristics and performance of each ionization chamber. For an optimal operation of the cylindrical ionization chamber in the clinic, it is strongly recommended to evaluate the performance parameters. These parameters are characterized by dose
response, dose rate, beam energy, radiation quality, radiation beam direction, and dosimeter stability at high temperature and humidity.

The objective of this work is to quantitatively and qualitatively evaluate the physical and statistical performance of the PTW-type cylindrical ionization chamber which is used in the radiotherapy department at the oncology hospital CHU -Fez-Morocco. The diagnostic of the dispersion results was calculated between measurements that were taken by the same dosimeter under different test conditions.

2. Material and Methods

2.1. Material

The evaluation of ionization chamber dosimeter (ICD) is performed by a pulsed source of radiation. This is done using an ELEKTA linear accelerator. Ionizing radiation pulses are used in the treatment by radiotherapy. The ELEKTA Linear Accelerator has two irradiation beam paths, namely photons and electrons. We carried out the irradiations using clinical beams of photons (6, 10 and 18 MV) at the oncology hospital radiotherapy Center CHU-Fez [39, 40].

We used a T41014 water phantom, which is used in absolute dosimetry (www.ptw.de). Water is recommended in the International Atomic Energy Agency as a reference medium for measuring the absorbed dose of photon beams [1, 2, 12, and 42]. The T41014 phantom is sized about 20 cm x 20 cm x 10 cm, which is covered by the (PMMA) plates. This phantom is filled with approximately 4 litters of water by a sealed filler cap (Fig.1). The wall thickness of the phantom is of the order of three millimetres. For its depth of measurement, it is constant is about 50 millimetres.

![Figure 1. Phantom 20 cm x20 cm x 10 cm in PMMA at the oncology hospital radiotherapy Center CHU-Fez.](image)

A cylindrical ionization chamber used in radiotherapy of CHU-Fez. Its characteristics are detailed in Table 1.

| Detector Characteristics | Characteristics |
|--------------------------|-----------------|
| Type                     | Cylindrical ionization chamber PTW |
| Particular design        | type 30010 : not waterproof |
| characteristics          | Guard ring       |
| Measuring quantities     | Air kerma and Air kerma rate |
| Radiation quality        | Absorbed dose to water and absorbed dose |
| Nominal sensitive volume | 0,6 mm3          |
| Nominal response         | 20 Nc/Gry        |
The collected charge produced in the ICD is very small. Measuring the dose requires a very sensitive machine called the electrometer [42]. This electrometer must have sufficient sensitivity for the measured responses. The stability of the associated electrometer must ensure that the leakage current is negligible.

The use of the thermometer and the barometer were used for the determination of air density correction factors [42]. For this, these devices must be calibrated to neglect their assignment on the ICD measurements (Fig. 2).

2.2. Experimental method
For a good handling, it is necessary to refer to the international protocols quoted by the IAEA, specific to calibrated ICDs. This is to determine the dose absorbed by the photon beams in any medium [1, 2, and 42].

The characteristics and performances corresponding to the ionization chamber are classified according to the international standards IEC [3]. Measurements are made by placing the sensitive volume ICD at the beam axis of the linear accelerator ELEKTA in a water phantom under reference conditions [1, 2, 20, and 42].

The irradiation field is ten centimetres long, ten centimetre’s wide and five centimetres deep. The dose rate is 100 UM. The photon beam is 6 Mev.

2.3. Purpose of study
In this study, several types of tests were performed. We calculated the uncertainty of variation for repeatability and reproducibility. The dispersion of an ICD can be estimated from a repeatability and reproducibility test [5, 7]. We have also performed the dependence of the response as a function of the applied voltage, the direction and the energy of the beam. We studied the linearity and sensitivity of the response as a function of dose rate. Before carrying out ICD dosimeter test, it must be ensured that

| Property            | Value                                      |
|---------------------|--------------------------------------------|
| Polarizing Voltage  | ± (100…400) V                              |
|                     | Nominal : 400 V                           |
|                     | Maximal : ± 500 V                          |
| Temperature         | +10° C … +40° C                            |
| Humidity            | 10 % ... 80 % , max : 20g/m3               |
| Wall material       | 0.335 mm, PMMA                             |
|                     | 0.09 mm, graphite                          |
| Central electrode   | Ray, Al = 1.1 mm                           |
the ionization chamber is energized for at least 20 minutes [5]. No radioactive elements are required near the ionization chamber. This is to avoid the uncertainties generated during practical work.

### 3. Results and Discussion

#### 3.1. Results

The results obtained have been verified according to international recommendations and protocols [1, 2, and 3].

#### 3.1.1 The stability of the ionization chamber according to the voltage

The purpose of this test is to verify the polarization voltage of the ionization chamber in positive and negative voltages [6, 28]. The stability test was performed using a linear accelerator (6 Mev). This is done one minute per each measurement.

![Saturation curve of the ionization chamber using a linear accelerator (6MeV).](image)

**Figure 3.** Saturation curve of the ionization chamber using a linear accelerator (6Mev). Response represents the collected charge in 60 seconds. The maximum deviation was 0.52 %.

The response of the chamber depends on the voltage applied between the electrodes; it varies slightly depending on the voltage (Fig. 3). We found a relative asymmetry along the voltage axis and the response axis. The operating region (or the level of use) of the ICD is between the voltages of 50 V and 400 V [6, 16, 21, 28].

The response reaches a saturation regime in which almost all the charges produced are collected by an efficiency of 99, 98 %. The recombination effect of the charges is low about 0.2 %. This present result is small than the value of 1 %, recommended by IEC (2011).

#### 3.1.2. Response Linearity as a function of dose rate

The linearity of the ICD response was evaluated by measuring the charge produced by the dosimeter for different dose rates in UM [6]. From a clinical point of view, it is important that the response of a dosimeter is independent of the dose rate.
Figure 4. The linearity of the response of an ionization chamber as function of dose rate. The correlation coefficient obtained was 1.00.

The response of the ICD varies linearly with the dose rate (Fig. 4). The linear correlation coefficient $R^2$ was approach really 1.00. From the linearity, it is possible to determine the sensitivity of the ICD. It is present of order of 15 nC / Gy for the dose rate between 1 UM and 5 UM. For the dose rate between 10 and 600 MU, it is of order 15,375 Nc/Gy [15,16,17,18,25,29,30,31,32,33].

3.1.3. Dependence of the response of an ionization chamber according to the direction

Several measurements have been made on ICD at the different angle that varies from 0° to 360°, whose field size is 10x10 cm² [24,27,30]. Knowing that, the detector geometry is symmetrical with respect to the beam axis.

Figure 5. Dependence of the response of an ionization chamber according to the direction.
The maximum deviation was 0.66 %.

The uncertainty difference at the reference point (100% normalized response at 0 °) is 0 % for the measurement made from 0 ° to 45 °. This difference is from 0.33 % to 0.66 % for angulations of 90 ° to 360 ° (Fig.5), [12, 24, 25, 29, 33, and 43].

3.1.4. Dependence of the response as function of photon energy
we measured the dependence of the response as a function of the energy of the beam of photons (6, 10 and 18 Mev) of the cylindrical ICD by the accelerator ELEKTA CHU-Fez.

![Figure 6. Dependence of the response as a function of the energy of the beam of photons (6, 10 and 18 Mev) of the cylindrical ICD by the accelerator ELEKTA. The maximum deviation was 3.2 %.

The result shows that the ICD response is affected by a large energy dependence of an average variation factor of 3.20 % (Fig.6) [24, 30].

3.1.5. Repeatability and reproducibility
The repeatability studied the deviation of the Farmer PTW cylindrical ICD response according to several repeated manipulations under the same test conditions.
With respect to reproducibility, we checked the variation gap of handling conditions. These tests were then rechecked against two different manipulators, using the full method described by Maurice Pillet (The Method Six Sigma) [7, 8, 9, 10, 30, 44, 45, 46, 47].
We conducted two sets of different measurements, each of which has 13 photons beam of energy 6 Mev. These measurements are performed under the reference irradiation conditions of the ICD response.
Figure 7. Repeatability & Reproducibility of the response of an ionization chamber type Farmer. The maximum deviation was 0.054 %.

The result of this test gives a coefficient of variation, which is below the fixed limits of 1 % compared to international standards on 13 measures (Fig. 7). That is, the uncertainty of evolution of all these measurements is very low with a coefficient of variation of the order of ± 0.054 % [7,29,32,41].

3.2. Discussion
The evaluation of these dosimeters already carried out using a continuous energy source [6]. In this work, we used a source of pulsed radiation. This was done to minimize the dispersion of the results, and to know the sources of measurement disturbance using the ionization chamber dosimeters. These disrupters take the origin of the effect of temperature and the effect of recombination, material, methodology, labor. These agitators are fixed according to international standards and protocols [1,2]. Table 2 summarizes the results obtained by the cylindrical ionization chamber dosimeter type Farmer PTW.

Table 2 summarizes the results obtained by the cylindrical ionization chamber dosimeter type Farmer PTW.

| Characteristics and performances | Results |
|----------------------------------|---------|
| Radiation quality                | Photons |
| Chamber voltage                  | ± (50…400) V |
|                                  | The maximum uncertainty was 0.52 % |
| The ion collection efficiency    | 99.98 % |
| The recombination effect of the charges | 0.2 % |
| Repeatability                    | Low dispersion 0.031 % |
| Reproducibility                  | Very low dispersion 0.0055 % |
| Linearity of response as function of dose rate | The correlation coefficient was 1.00 |
| Sensitivity                      | 15 (nC/Gy) to 15.375 (nC/Gy) |
| Directional response in water    | 0.33 % < 1 % for rotation up to an angle |
In this study, the experiments carried out made it possible to specify that the response of the cylindrical ionization chamber used in the oncology hospital-radiotherapy department CHU-Fez Morocco depends on several parameters. These parameters influence the performance of the ionization chamber.

These ionization chambers are detectors which statistically capable in terms of repeatability and reproducibility [44, 45, 46]. The temperature and humidity have remarkable effects. The response of the ionization chamber varies linearly with the absorbed dose and its rate. The response of the cylindrical ionization chamber is affected by a large energy dependence with an uncertainty of 3.2 %. The response is almost constant in the different angles. The comparison between our results and that of calibration certificate shows that our results are following the international standards. Hence the interest of this study which reveals a total uncertainty of dosimeter of 3.25 %, which is in the standards, however, has an effect on the performances [29, 32].

4. Conclusion
The ICD is of great importance in radiotherapy treatment in humans. Our study evaluated the performance of ICD cylindrical type Farmer PTW. Using a physical and statistical study, we focused on calculating the disturbing effects on the measurement with a total uncertainty of the dispersion of the results. Our results show that the difference in uncertainties obtained can be due to the variation of certain manipulative conditions, or to the enclosure of the device. These uncertainties will have negative effects on radiotherapy treatment processes. In order to minimize this dispersion uncertainty, the device must optimize measurement processes to a desired level of quality according to international standards and protocols. Generally, there are several technology of detection and measurement of ionizing radiation in the medical field for dosimetry. Each technology has its advantages and disadvantages. This must take into consideration the following selection criteria: the cost of manufacture, calibration frequency compared to primary laboratories, range of use, irradiation conditions, the effect of environmental conditions and dosimeter dimensions [41, 48, and 49]. So, there is not an ideal system, but the only guarantee of the measures is the optimization of the use of the systems according to the norms and the international protocols.

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