Calibration of Photon Beams for the Synergy Linac

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Abstract:

Aim: This study aims to calibrate the photon beams produced from the Synergy Linac available at Tripoli University Hospital.
Material and Methods: The Calibration procedures were carried out using FC- 65G cylindrical ionization chamber and DOSE 1electrometer, the measurements were performed in water, weekly prior to the clinical use of the Machine.
Results: The calibration results for March 2023 is shown in this work

1. Introduction

To achieve the main aim of the radiotherapy of delivering the highest homogenise dose to the target volume and lowest dose to the surrounding normal tissue, the output of the external beam radiotherapy machines should be well calibrated prior to its clinical use. However, the output calibration of the external radiotherapy machine beams represents one of the weekly quality control procedures.
The External Beam radiotherapy machine should be calibrated to that: 1 MU (Monitor Unit) is delivering 1 Gy of dose. In below the details of requirements of the output calibrations and how to should be performed following the recommendations of IAEA code of practice TRS-398 [1]

1.1. Beam quality specification

1.1.1. Choice of beam quality index

For high-energy photons produced by clinical accelerators the beam quality Q is specified by the tissue-phantom ratio, $TPR_{20,10}$. This is the ratio of the absorbed doses at depths of 20 cm and 10 cm in a water phantom, measured with a constant source-chamber distance (SCD) of 100 cm and a field size of 10 cm x 10 cm at the plane of the chamber. **[1,2]**
As $TPR_{20,10}$ is obtained as a ratio of doses, it does not require the use of displacement correction factors at two depths when cylindrical chambers are used. Furthermore, $TPR_{20,10}$ is in most clinical set ups not affected by small systematic errors in positioning the chamber at each depth, as the settings in the two positions will be affected in a similar manner.**[1]**

1.1.2. Measurement of beam quality

The experimental set up for measuring $TPR_{20,10}$ is shown in Figure. 1 The reference conditions of measurements are given in Table 1. [1]
Although the definition of $TPR_{20,10}$ is made in terms of ratios of absorbed dose, the use of ionization ratios provides an acceptable accuracy due to the slow variation with depth

of water/air stopping-power ratios and the assumed constancy of perturbation factors beyond the depth of dose maximum. **[1]**

Table 1. Reference conditions for the determination of photon beam quality ($TPR_{20,10}$) [1]

Influence quantity	Reference value or reference characteristics
Phantom material	water
Chamber type	cylindrical or plane-parallel
Measurement depths	20 g cm^{-2} and 10 g cm^{-2}
Reference point of chamber	or cylindrical chambers, on the central axis at the centre of the cavity volume. For plane-parallel chambers, on the inner surface of the window at its centre
Position of reference	for cylindrical and plane-parallel chambers, at the measurement depths
SCD	100 cm
Field size at SCD	10 cm x 10 cm [a]

[a] The field size is defined at the plane of the reference point of the detector, placed at the recommended depths in the water phantom.

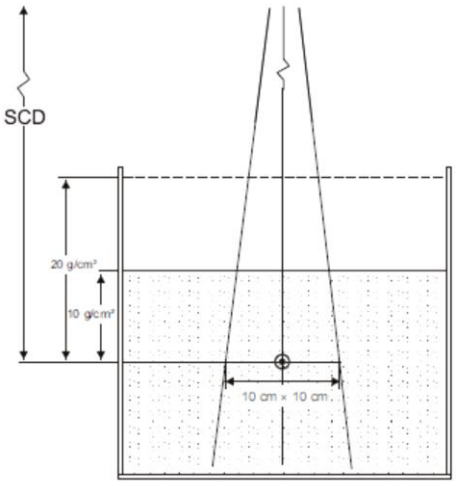

Fig. 1. Experimental set-up for the determination of the beam quality index Q ($TPR_{20,10}$). The source-to chamber distance (SCD) is kept constant at 100 cm and measurements are made with 10 g cm^{-2} and 20 g cm^{-2} of water over the chamber. The field size at the position of the reference point of the chamber is 10 cm x 10 cm. Either a cylindrical or a plane-parallel ionization chamber can be used. **[1,2]**

1.2. Determination of absorbed dose to water under reference conditions

1.2.1. Reference conditions

The reference conditions for determination of absorbed dose to water are surmises in Table 2.

Table 2 Shows reference conditions for the determination of absorbed dose to water in high-energy photon beams. [1]

Influence quantity	Reference value or reference characteristics
Phantom material	water

Chamber type	cylindrical
Measurement depth z_{ref}	for $TPR_{20,10} < 0.7$, 10 g cm^{-2} (or 5 g cm^{-2}) for $TPR_{20,10} \geq 0.7$, 10 g cm^{-2}
Reference point of chamber	on the central axis at the centre of the cavity volume
Position of reference point of chamber	at the measurement depth z_{ref}
SSD/SCD	100 cm*
Field size	10 cm x 10 cm**

* If the reference dose has to be determined for an isocentric set up, the SAD of the accelerator shall be used even if this is not 100 cm.

****** The field size is defined at the surface of the phantom for a SSD type set-up, whereas for a SAD type set-up it is defined at the plane of the detector, placed at the reference depth in the water phantom at the isocentre of the machine.

1.2.2. Formalism

The absorbed dose at the reference depth z_{ref} in water, in a photon beam of quality Q and in the absence of the chamber, is given by

$$D_{w,Q} = M_Q N_{D,w,Q_0} K_{Q,Q_0} \qquad Eq1.1 \qquad [1,2]$$

Where:

M_Q: is the reading of the dosimeter with the reference point of the chamber positioned at z_{ref} in accordance with the reference conditions given in Section 1.2.1 and corrected for the influence quantities temperature and pressure, electrometer calibration, polarity effect and ion recombination as described in below (Section 1.2.3). [1,2]

$N_{D,w,Qo}$: is the calibration factor in terms of absorbed dose to water for the dosimeter at the reference quality Qo. (This factor can be found at the chamber certificate)

$k_{Q,Qo}$: is a chamber-specific factor which corrects for the difference between the reference beam quality Qo and the actual quality being used, Q. **[1,2]**

1.2.3. Correction of Influence quantities

Influence quantities are defined as quantities not being the subject of the measurement, but yet influencing the quantity under measurement. They may be of different nature as, for example, pressure, temperature and polarization voltage; they may arise from the dosimeter (e.g. ageing, zero drift, warm-up), or may be quantities related to the radiation field (e.g. beam quality, dose rate, field size, depth in a phantom). [1]

It is possible to correct for the effect of these influence quantities by applying appropriate factors. Assuming that influence quantities act independently from each other, a product of correction factors can be applied, Π_{ki} , where each correction factor k_i is related to one influence quantity only. [1]

A departure from the reference beam quality Q_o used to calibrate an ionization chamber can also be treated as an influence quantity. Measurements at radiation qualities other than the reference quality Q_o therefore require a correction factor. This is treated explicitly by the factor $k_{Q,Qo}$ which is not included in the k_i above; the correction for the radiation beam quality is described in detail below (section 1.2.3.5). **[1]**

1.2.3.1. Pressure, temperature and humidity

As all chambers recommended are open to the ambient air, the mass of air in the cavity volume is subject to atmospheric variations. The correction factor

$$k_{t,p} = \frac{(273.2+T)}{273.2+T_0}\frac{P_0}{P} \qquad \text{Eq. 1.2} \quad [1]$$

should be applied to convert the cavity air mass to the reference conditions. P and T are the cavity air pressure and temperature at the time of the measurements, and P_o and T_o are the reference values (generally 101.3 kPa and 20° C). The temperature of the air in a chamber cavity should be taken to be that of the phantom, which should be measured; this is not necessarily the same as the temperature of the surrounding air. For measurements in a water phantom, the chamber waterproof sleeve should be vented to the atmosphere in order to obtain rapid equilibrium between the ambient air and the air in the chamber cavity. **[1]**

No corrections for humidity are needed if the calibration factor was referred to a relative humidity of 50% and is used in a relative humidity between 20% and 80%. If the calibration factor is referred to dry air a correction factor should be applied for ^{60}Co calibrations $k_h = 0.997$. **[1]**

1.2.3.2. Electrometer calibration

When the ionization chamber and the electrometer are calibrated separately, a calibration factor for each is given by the calibration laboratory. The electrometer calibration factor k_{elec} is treated as an influence quantity and is included in the product Π_{ki} of correction factors. Typically, the calibration factor $N_{D,w}$ for the ionization chamber will be given in units of Gy/nC and that for the electrometer k_{elec} either in units of nC/rdg or, if the electrometer readout is in terms of charge, as a dimensionless factor close to unity (effectively a calibration in units of nC/nC). **[1]**

If the ionization chamber and the electrometer are calibrated together, then the combined calibration factor $N_{D,w}$ will typically be given in units of Gy/rdg or Gy/nC (depending on the electrometer readout) and no separate electrometer calibration factor k_{elec} is required. In this case, a value for k_{elec} of unity (dimensionless) should be recorded in the Worksheets. [1]

1.2.3.3. Polarity effect

The effect on a chamber reading of using polarizing potentials of opposite polarity must always be checked on commissioning. For most chamber types the effect will be negligible in photon beams, a notable exception being the very thin window chambers used for low-energy x-rays. In charged particle beams, particularly electrons, the effect may be significant. **[1]**

When a chamber is used in a beam that produces a measurable polarity effect, the true reading is taken to be the mean of the absolute values of readings taken at both polarities. For the routine use of a given ionization chamber, a single polarizing potential and polarity is normally adopted. However, the effect on the chamber reading

of using polarizing potentials of opposite polarity for each user beam quality Q can be accounted for by using a correction factor: **[1]**

$$k_{pol} = \frac{|M_+|+|M_-|}{2M} \qquad \text{Eq.1.3} \quad [1]$$

Where:

M_+ and M_- are the electrometer readings obtained at positive and negative polarity, respectively, and M is the electrometer reading obtained with the polarity used routinely (positive or negative).

The readings M+ and M— should be made with care, ensuring that the chamber reading is stable following any change in polarity (some chambers can take up to 20 minutes to stabilize).

When the chamber is sent for calibration, a decision is normally made, either by the user or by the calibration laboratory, on the polarizing potential and polarity to be adopted for the routine use of the chamber. The calibration should be carried out at this polarizing potential (and polarity, if only one polarity is used for the calibration), or if not, clearly stated in the calibration certificate. **[1]**

1.2.3.4. Ion Recombination

The incomplete collection of charge in an ionization chamber cavity due to the recombination of ions requires the use of a correction factor k_s. Two separate effects take place; (i) the recombination of ions formed by separate ionizing particle tracks, termed general (or volume) recombination, which is dependent on the density of ionizing particles and therefore on the dose rate, and (ii) the recombination of ions formed by a single ionizing particle track, referred to as initial recombination, which is independent of the dose rate. Both effects depend on the chamber geometry and on the applied polarizing voltage. For beams other than heavy ions, initial recombination is generally less than 0.2%. **[1]**

In pulsed radiation, and especially in pulsed-scanned beams, the dose rate during a pulse is relatively high and general recombination is often significant.

For pulsed beams, it is recommended in Code of Practice TRS- 398 [1] that the correction factor ks be derived using the two-voltage method [4]. In this method, the recombination correction factor k_s at the normal operating voltage V_1 is obtained from**: [3,4]**

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_1\left(\frac{M_1}{M_2}\right)^2 + a_2\left(\frac{M_1}{M_2}\right)^2 \quad Eq.1.4 \quad [1]$$

Where:

The constants a_i are given in Table 3 for pulsed and for pulsed-scanned radiation.

M_1 and M_2 are the measured values of the collected charges at the polarizing voltages V_1 and V_2, respectively, measured using the same irradiation conditions. V_1 is the normal operating voltage and V_2 a lower voltage; the ratio V_1 / V_2 should ideally be equal to or larger than 3. [1,3,4]

Table 3. Quadratic fit coefficients, for the calculation of k_s by the "two voltage" technique in pulsed and pulsed-scanned radiation, as a function of the voltage ratio v1/v2 [4]

	Pulsed			Pulsed scanned		
V1/V2	a_0	a_1	a_2	a_0	a_1	a_2
2	2.337	-3.636	2.299	4.711	-8.242	4.533
2.5	1.474	-1.587	1.114	2.719	-3.977	2.261
3	1.198	-0.875	0.677	2.001	-2.402	1.404
3.5	1.080	-0.542	0.463	1.665	-1.647	0.984
4	1.022	-0.363	0.341	1.468	-1.200	0.734
5	0.975	-0.188	0.214	1.279	-0.750	0.474

1.2.3.5. Values for k_{Q,Q_0}

1.2.3.5.1. Chamber calibrated in ^{60}Co

When the reference quality Q_o is ^{60}Co, k_{Q,Q_0} is denoted by k_Q and N_{D,w,Q_0} is denoted by $N_{D,w}$.

Calculated values for the factor k_Q are given in Table 6.III at the code of practice TRS-398 [1] for a series of user qualities Q (i.e., $TPR_{20,10}$) and for a number of chamber types. These values can be used at the reference depths given in Table 1.2. A sleeve of PMMA 0.5 mm thick has been used in the calculations for all the chambers which are not waterproof; for sleeve thicknesses up to 1 mm the change in k_Q is not greater than about 0.1%. Values of k_Q for non-tabulated qualities may be obtained by interpolation. **[1]**

1.2.3.5.2. Chamber calibrated in a series of photon beam qualities

For a chamber calibrated in a series of photon beam qualities, the data from the calibration laboratory will ideally be presented in the form of a single calibration factor N_{D,w,Q_0} and a set of measured factors k_{Q,Q_0}. From the latter, a value for k_{Q,Q_0} at the user quality Q may be derived by interpolation. N_{D,w,Q_0} and the resulting k_{Q,Q_0} are then used directly in Equation (1.1).**[1]**

When the calibration laboratory provides a series of calibration factors N_{D,w,Q_0}, data must first be converted to the above format by choosing one of the photon beam qualities used by the calibration laboratory as reference quality, Q_o. The k_{Q,Q_0} factors are evaluated using**:[1]**

$$K_{Q,Q_0} = \frac{N_{D,W,Q}}{N_{D,W,Q_0}} \qquad Eq\ 1.5$$

Interpolation to determine k_{Q,Q_0} at the user quality Q then proceeds as above.

Once experimental values for N_{D,w,Q_0} and k_{Q,Q_0} are obtained for a particular chamber, it may not be necessary for the user to calibrate the chamber every time at all qualities Q, but only at the single reference quality Q_o. In this case the new calibration factor N_{D,w,Q_0} should be used in conjunction with the existing values for k_{Q,Q_0} and the quality dependence of that chamber (k_{Q,Q_0} values) needs to be verified every third calibration cycle of the chamber or if the user suspects that the chamber has been damaged. The single calibration does not need to be performed at the same laboratory where the experimental k_{Q,Q_0} values were measured. Note, however, that this procedure should

not be repeated more than twice in succession; the chamber should be re-calibrated at all qualities at least every six years. [1]

2. Material and Methods

Synergy linear accelerator output is calibrated at its potential energies of 6MV and 10MV using the dosimetry system of FC65-G cylindrical ionization chamber (SN: 3588) and electrometer DOSE 1 (SN: 24343), and by using the following setup: irradiation time is 100 MU, with Field size (10 x 10 cm^2), SSD = 100 cm, where the ionization chamber is placed at the reference depth of 10 cm, in the Wellhofer water phantom (42cm x 36 cm x 34 cm); (type WP305/SN: 104), and the reference point of chamber is on the central axis at the centre of the cavity volume; see figure 2.1 for the setup example. However, the entire measurements were performed in the department of medical and radiation physics, at the Tripoli University Hospital.

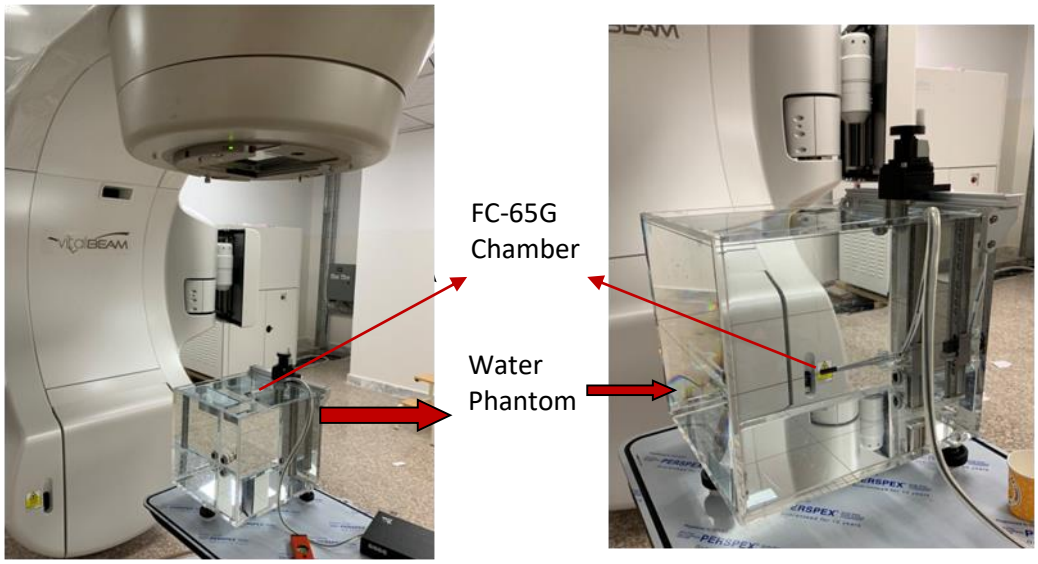

Fig. 2: shows the setup of photon beam output calibration measurements

2.1. Measurement of beam quality

The beam quality of The $TPR_{20,10}$ is measured using the set up shown in Figure 1.1 for both energies potential of 6 MV and 10 MV. The SCD should be kept fixed of 100 cm, the field size of (10 x 10 cm^2) is at the position of the reference point of chamber. Starting with acquiring five measurements at depth of 10 cm (i.e. SSD = 90 cm) to obtain TPR_{10} , then fill-in water to have the chamber at the 20 cm depth (i.e SSD = 80 cm) to obtain TPR_{20} with keeping the SCD fixed to 100 cm.

2.2. The value of k_{Q,Q_0}

Using of the values of beams quality measured previously for 6 MV and 10 MV photon energies, the values of k_{Q,Q_0} can be interpolated from the table 6.III available in the Code of practice TRS-398 [1] for the ionization chamber FC65-G.

2.2.1. Measurements of Correction of Influence quantities:

All measurements were performed by using the same set-up explained at section 2

2.2.1.1. Temperature and Pressure correction factor ($K_{t,p}$)

Temperature is measured using the mercury thermometer placed into the water, the temperature is measured before and post the radiation and taking the average. The value of pressure is measured using the barometer.

2.2.1.2. Polarity effect (K_{pol})

Three electrometer charge readings are obtained at the positive polarity (normal operating voltage) of + 400 V , and other three electrometer charge reading at the negative polarity of - 400 V, the average are calculated for each group. Then apply at the Equation 1.3 to obtain K_{pol}

2.2.1.3. Ion Recombination (K_s)

Three electrometer charge readings are obtained at the half of the operating voltage (+ 200 V) and at the normal operating voltage (+ 400 V), then apply in the Equation 1.4 to obtain K_s

2.3. Calibration of synergy linear accelerator photon beams

The absorbed dose to water at the reference depth z_{ref} of 10 cm in water for 6 MV and 10 MV is measured using the set-up and dosimetry system explained in section 2 and with SSD = 100 cm. Whereas, The average of three charge electrometer reading values at least is obtained, and with applying the corrections of influence quantities those measured above, the absorbed dose for both potential can be acquired by using of the Equation 1.1. Then the output can be calculated using the following formulae:

$$\boldsymbol{output}\ \% = \boldsymbol{D_{W,Q} \times K_{T,P} \times K_s \times K_{pol} \times K_{elec} \times \frac{1}{PDD} \times 100} \quad \textbf{Eq. 2.1}$$

Or simply:

$$\boldsymbol{output}\ \% = \boldsymbol{M_Q \times N_{D,W} \times K_{Q,Q_0} \times K_{T,P} \times K_s \times K_{pol} \times K_{elec} \frac{1}{PDD} \times 100} \quad \textbf{Eq. 2.2}$$

If the output is equal to (100 ± 2), no calibration is required if not the machine has to be calibrated using its software and the doses measurements is repeated until the output become (100 ± 2), which means that each 100 MU is delivering to 1 Gy (100 cGy).

3. Results:

3.1. Values of beam quality ($TPR_{20,10}$) and k_{Q,Q_o}

Table 4 shows the average of electrometer's readings at depth 10 cm (SSD = 90 cm) and at depth 20 cm (SSD = 80 cm), the values of beam quality, and k_{Q,Q_o} for 6 MV and 10 MV Synergy photon beams.

Table 4: Beam quality ($TPR_{20,10}$) and k_{Q,Q_o} values for 6 MV and 10 MV beams produced from Synergy linac

E (MV)	Average of Reading of electrometer (nC) at depth = 10 cm, SSD= 90cm	Average Reading of electrometer (nC) at depth = 20 cm, SSD= 80cm	$TPR_{20,10}$	k_{Q,Q_0}
6	82.26	56.83	0.691	0.985
10	89.55	66.29	0.740	0.9915

3.2. Polarity Effect factor (K_{pol})

Table 5 contains the values of the average of electrometer's readings of M+ and M- obtained at polarities of +400 and -400, respectively for 6 MV and 10 MV. Also, the values of $\mathbf{K_{pol}}$ which was calculated using the Equation 1.3 is included in the table 3.2.

Table 5: Polarity values (K_{pol}) for 6 MV and 10 MV beams produced from Synergy linac

(MV)	M_+ (nC) with V= +400	M_- (nC) with V= -400	K_{pol}
6	68.085	68.035	0.9996
10	73.80	73.775	0.9998

3.3. Ion Recombination (K_s)

The average of electrometer's reading M_1 and M_2 at the polarizing voltages of V_1 = +400 and V_2 = +200, respectively, and the values of $\mathbf{K_s}$ for 6 MV and 10 MV photon beams were calculated from the Equation 1.4 is summarized at table 3.3. However, the values of a_0, a_1, and a_2 are equal to 2.337, -3.636 and 2.299 respectively; the a_i values were interpolated from table 6.

Table 6: Ion Recombination values (K_s) for 6 MV and 10 MV beams produced from Synergy linac

E (MV)	M_1 (nC) with V_1= +400	M_2 (nC) with V_2= +200	K_s
6	68.085	67.845	1.0034
10	73.80	73.530	1.0036

3.4. Output calibration of photon beams produced from Synergy Linac

Here is the output calibrations summary for 6 MV and 10 MV beams during the March 2023 measured for the Synergy Linac in the Department of Medical and Radiation Physics at Tripoli University Hospital.

The values of the K_i factors, $N_{D,W}$ and PDDs used to obtain the output are summarized in the table 7

Table 7: the measured, calculated and standard values used in obtaining the output of 6 MV and 10 MV beams of Synergy Linac

E (MV)	$K_{Q,Q0}$	$K_{t.p}^{*}$	K_{elec}^{**}	K_s	K_{pol}	$N_{D,W}$ (Gy/c)	PDD
6	0.9915	/	1.000	1.0034	0.9996	4.829×10^7	67.43
10	0.985	/	1.000	1.0036	0.9998	4.829×10^7	73.36

* The values of $K_{t.p}$ are changed according to the pressure and temperature at the time of measurement.
/** K_{elec} equal 1.0 because the ionization chamber and electrometer are calibrated together.

Table 8 – 11 Show the weekly quality control of 6 MV and 10 MV photon beam output calibrations for the synergy linear accelerator.

Table 8: 6 MV and 10 MV beams weekly output calibration for synergy linac (1st week of March 2023)

1st week		Before calibration			After calibration		
E(MV)	$K_{t.p}$	M_Q (nC)	output	%Error	M_Q (nC)	output	%Error
6	1.0009	69.05	101.9	1.9	67.73	100	0
10	1.0009	75.9	102.3	2.3	74.23	100.1	0.1

Table 9: 6 MV and 10 MV beams weekly output calibration for synergy linac (2nd week of March 2023)

2nd week		Before calibration			After calibration		
E(MV)	$K_{t.p}$	M_Q (nC)	output	%Error	M_Q (nC)	output	%Error
6	1.00025	66.61	98.2	1.8	67.82	100	0
10	1.00025	72.68	97.9	2.1	74.25	100	0

Table 10: 6 MV and 10 MV beams weekly output calibration for synergy linac (3rd week of March 2023)

3rd week		Before calibration			After calibration		
E(MV)	$K_{t.p}$	M_Q (nC)	output	%Error	M_Q (nC)	output	%Error
6	0.9993	69.92	103.5	3.5	67.91	100.1	0.1
10	0.9993	76.39	102.8	2.8	74.31	100.1	0.1

Table 11: 6 MV and 10 MV beams weekly output calibration for synergy linac (4th week of March 2023)

4th week		Before calibration			Note
E(MV)	$K_{t.p}$	M_Q (nC)	output	%Error	
6	1.013	67.57	100.9	0.9	**No calibration is required**
10	1.013	73.40	100.2	0.2	

4. Conclusion

The output calibration for the photon beams of 6 MV and 10 MV potentials of synergy linear accelerator at Tripoli University Hospital were carried out using dosimetry system of cylindrical ionization chamber and DOSE1 electrometer at water phantom and at the standard setup following the recommendation of code of practice TRS-398. These measurements were

performed weekly at a part of quality control procedures and prior to the clinical use of the external beam radiotherapy machine. The output should be within ± 2 % , otherwise the machine requiring to be calibrated using its software .

5. Acknowledgement

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6. Reference

1. International Atomic Energy Egency, Absorbed Dose Determination in External Beam Radiotherapy, Technical Reports Series No. 398, IAEA, Vienna (2000)
2. KHAN, F. M. 2009. *The Physics of Radiation Therapy*, Lippincott Williams & Wilkins
3. Energy photon therapy dosimetry based on the NPL absorbed dose calibration service, Phys.Med. Biol. 35 (1990) 1355-1360.
4. BURNS, D.T., MCEWEN, M.R., Ion recombination corrections for the NACP parallel-plate(2001) chamber in a pulsed electron beam, Phys Med Biol 43 (1998) 2033-2045.
5. IAEA INTERNATIONAL ATOMIC ENERGY AGENCY, "The use of plane-parallel ionization chambers in high-energy electron and photon beams. An International Code of Practice for Dosimetry", Technical Report Series no. 381, IAEA, Vienna (1997).
6. ICRU INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS, Dosimetry of High-Energy Photon Beams based on Standards of Absorbed Dose to Water, ICRU Report 64, Bethesda, MD: ICRU (2000).