Calibration of Electron Beams for the Synergy Linac

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Abstract:

Aim: This study aims to calibrate the electron beams produced from the Synergy Linac available at Tripoli University Hospital.

Material and Methods: The Calibration procedures were carried out using PTW Advanced Markus plane-parallel ionization chamber and PTW UnidoseE electrometer, 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 electron beams the beam quality index is the half-value depth in water R_{50}. This is the depth in water (in g cm^{-2}) at which the absorbed dose is 50% of its value at the absorbed-dose maximum, measured with a constant SSD of 100 cm and a field size at the phantom surface of at least 10 cm x 10 cm for $R_{50} < 7$ g cm^{-2} ($E_0 < 16$ MeV) and at least 20 cm x 20 cm for $R_{50} > 7$ g cm^{-2} ($E_0 > 16$ MeV). As noted in TRS- 381 [6], some accelerators at high electron energies have an intrinsic poor homogeneity at large field sizes which may improve at smaller field sizes as a result of electrons scattered from

the collimator (or applicator, cones, etc). In such cases a field size smaller than 20 cm x 20 cm may be used provided that R_{50} does not change by more than around 0.1 g cm^{-2} from the value measured for a 20 cm x 20 cm field.

1.1.2. Measurement of beam quality

The reference conditions including the phantom materials, chamber types, reference point of chamber and its position, values of SSD and Field size used to determine of electron beam quality are summarized at table 1.1.

Table 1.1. Reference conditions for the determination of electron beam quality (R50) [1]

Influence quantity	Reference value or reference characteristics
Phantom material	For $R_{50} \geq 4$ g cm^{-2} , water For $R_{50} < 4$ g cm^{-2} ($E_0 < 10$ MeV) , water or plastic†
Chamber type	For $R_{50} \geq 4$ g cm^{-2} ($E_0 > 10$ MeV), plane-parallel or cylindrical For $R_{50} < 4$ g cm^{-2}, plane parallel
Reference point of chamber	For plane-parallel chambers, on the inner surface of the window at its centre. For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	For plane-parallel chambers, at the point of interest. For cylindrical chambers, 0.5 r_{cyl} deeper than the point of interest
SSD	100 cm
Field size at phantom surface	For $R_{50} \geq 7$ g cm^{-2}, at least 10 cm x 10 cm. For $R_{50} > 7$ g cm^{-2}, at least 20 cm x 20 cm[a]

[a] A field size smaller than 20 cm x 20 cm may be used provided that R_{50} does not change by more than around 0.1 g cm^{-2} from the value measured for a 20 cm x 20 cm field.

† If a plastic phantom is used, all depths must be scaled according to the recommendation of TRS-398 [1]

When using an ionization chamber, the measured quantity is the half-value of the depth-ionization distribution in water, $R_{50,ion}$. This is the depth in water (in g cm^{-2}) at which the ionization current is 50% of its maximum value. The half-value of the depth-dose distribution in water R_{50} is obtained using [7] [1]

$$R_{50} = 1.029\, R_{50,ion} - 0.06 \text{ g cm}^{-2} \quad (R_{50,\,ion} \geq 10 \text{ g cm}^{-2}) \quad \textbf{(1.1}$$

$$R_{50} = 1.059\, R_{50,\,ion} - 0.37 \text{ g cm}^{-2} \quad (R_{50,\,ion} > 10 \text{ g cm}^{-2})$$

As an alternative to the use of an ionization chamber, other detectors (for example diode, diamond, etc.) may be used to determine R_{50}. In this case the user must verify that the detector is suitable for depth-dose measurements by test comparisons with an ionization chamber at a set of representative beam qualities. **[1]**

1.2. Determination of absorbed dose to water

1.2.1. Reference conditions

The reference conditions for determination of absorbed dose to water in electron beams are given in Table 1.2. Because the precise choice of field size is not critical [6], a convenient choice for the reference field size is that which is used for the normalization of output factors, subject to the constraint that it should not be less than 10 cm x 10 cm at the phantom surface [1]. The reference depth z_{ref} is given by [8]

$$z_{ref} = 0.6\, R_{50} - 0.1 \text{ g cm}^{-2} \quad (R_{50} \text{ in g cm}^{-2}) \qquad \textbf{(1.2)}$$

This depth is close to the depth of the absorbed-dose maximum z_{max} at beam qualities $R_{50} < 4$ g cm^{-2} ($E_o < 10$ MeV), but at higher beam qualities is deeper than z_{max}.

It should be noted that by recommending that reference dosimetry at higher energies be conducted at a depth beyond z_{max}, the uncertainty arising from cavity perturbation effects for cylindrical chambers may be larger. In the worst case, around $R_{50} = 5$ g cm^{-2} (E_0 around 12 MeV) the increased uncertainty is approximately 0.3%. [1]

1.2.2. Determination of absorbed dose to water under reference conditions

The absorbed dose to water at the reference depth z_{ref} in water, in an electron beam of quality Q and in the absence of the chamber, is given by [1,2].

$$D_{W,Q} = M_Q N_{D,W,Q_0} K_{Q,Q_0} \qquad (.1.3)$$

Where:

M_Q: is the reading of the dosimeter corrected for the influence quantities temperature and pressure, electrometer calibration, polarity effect and ion recombination as described in below (Section 1.2.4). The chamber should be positioned in accordance with the reference conditions, as given in Table 1.2. [1,2]

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

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

Table 1.2 reference conditions for the determination of absorbed dose to water in electron beams [1]

Influence quantity	Reference value or reference characteristics
Phantom material	For $R_{50} > 4$ g cm^{-2}, water. For $R_{50} < 4$ g cm^{-2}, water or plastic
Chamber type	For $R_{50} > 4$ g cm^{-2}, plane-parallel or cylindrical. For $R_{50} < 4$ g cm^{-2}, plane parallel
Measurement depth z_{ref}	0.6 R_{50} – 0.1 g cm^{-2}
Reference point of chamber	For plane-parallel chambers, on the inner surface of the window at its centre. For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	For plane-parallel chambers, at z_{ref}. For cylindrical chambers, 0.5 r_{cyl} deeper than z_{ref}
SSD	100 cm
Field size at phantom surface	10 cm x 10 cm or that used for normalization of output factors, whichever is larger

1.2.3. Absorbed dose at z_{max}

Clinical normalization most often takes place at the depth of the dose maximum z_{max} which, in the Code of Practice TRS-398, does not always coincide with z_{ref}. To determine the absorbed dose at z_{max} the user should, for a given beam, use the measured central-axis depth-dose distribution to convert the absorbed dose at z_{ref} to that at z_{max}. [1]

1.2.4. 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,Q_o} which is not included in the k_i above; the correction for the radiation beam quality is described in detail below (section 1.2.5). **[1]**

1.2.4.1. 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 [1].

$$k_{t,p} = \frac{(273.2+T)}{273.2+T_0}\frac{P_0}{P} \qquad (1.4)$$

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]**

1.2.4.2. 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].

1.2.4.3. 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]**

$$k_{pol} = \frac{|M_+|+|M_-|}{2M} \qquad (1.5)$$

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]**

1.2.4.4. 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]**

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_1\left(\frac{M_1}{M_2}\right)^2 + a_2\left(\frac{M_1}{M_2}\right)^2 \qquad (1.6)\ [1]$$

Where:

The constants a_i are given in Table 1.3 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 1.3. 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

1.2.5. Values for k_{Q,Q_o}

1.2.5.1. Correction for the radiation quality of the beam, k_{Q,Q_o}

When a dosimeter is used in a beam of quality Q different from that used in its calibration, Q_o, the absorbed dose to water is given by Eq. (1.3) above:[1]

$$D_{W,Q} = M_Q \, N_{D,W,Q_0} K_{Q,Q_0}$$

Where:

The factor k_{Q,Q_o} corrects for the effects of the difference between the reference beam quality Q_o and the actual user quality Q, and the dosimeter reading M_Q has been corrected to the reference values of influence quantities, other than beam quality, for which the calibration factor is valid. [1]

The beam quality correction factor k_{Q,Q_o} is defined as the ratio, at the qualities Q and Q_0, of the calibration factors in terms of absorbed dose to water of the ionization chamber

$$K_{Q,Q_0} = \frac{N_{D,W,Q}}{N_{D,W,Q_0}} = \frac{D_{W,Q}/M_Q}{D_{W,Q_0}/M_{Q_0}} \qquad (.1.7)$$

1.2.5.2. Chamber calibrated in ^{60}Co

When the reference quality Q_o is ^{60}Co, the factor k_{Q,Q_o} is denoted by k_Q. Calculated values for k_Q are given in Table 7.III at the IAEA code of practice TRS-398 [1] for a series of user qualities Q (i.e R_{50}) and for a number of chamber types; values for non-tabulated qualities may be obtained by interpolation. [1]

1.2.5.3. Chamber calibrated in a series of photon beam qualities

For a chamber calibrated in a series of electron beam qualities, the data from the calibration laboratory will ideally be presented in the form of a single calibration factor N_{D,w,Q_o} determined in a reference electron beam of quality Q_o and a set of measured factors k_{Q,Q_o} corresponding to the other calibration qualities Q. **[1]**

However, if the calibration data are in the form of a set of calibration factors $N_{D,w,Q}$ then one of the calibration qualities should be chosen as the reference calibration quality Q_o. The corresponding calibration factor is denoted N_{D,w,Q_o} and the remaining calibration factors $N_{D,w,Q}$ are expressed as a series of factors k_{Q,Q_o} using the relation **:[1]**

$$K_{Q,Q_0} = \frac{N_{D,W,Q}}{N_{D,W,Q_0}} \qquad Eq\ 1.8$$

If the quality of the user beam Q does not match any of the calibration qualities, the value for k_{Q,Q_o} to be used in Eq. (1.3) can be obtained by interpolation. [1]

A chamber calibrated at a series of beam qualities may be subsequently recalibrated at only the reference calibration quality Qo. In this case, the new value for N_{D,w,Q_o} should be used in conjunction with the values for k_{Q,Q_o} measured previously. Note, however,

that this procedure should not be repeated more than twice in succession; the chamber should be recalibrated at all qualities at least every six years [9] or if the user suspects that the chamber has been damaged. [1]

2. Material and Methods

Synergy linear accelerator output is calibrated at its electron potential energies of 4, 6, 8, 10, 12, and 15 MeV using the dosimetry system of PTW Advanced Markus plane-parallel ionization chamber (SN: 34045) and electrometer PTW UnidoseE (SN: 1008-80547), and by using the following setup: irradiation time is 100 MU, with applicator (10 x 10 cm^2), SSD = 100 cm, where the ionization chamber is placed at depth equal to the Z_{ref} (see table 1.2), 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 inner surface of the windows at its centre; 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.

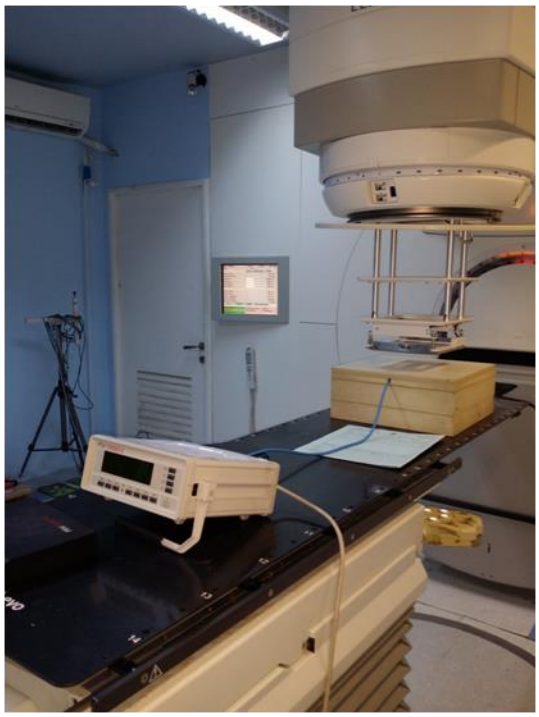

Fig. 2.1: shows the setup of electron beam output calibration measurements, when a solid water phantom in used. The picture shows the ionization chamber inside the phantom connecting with the UnidoseE electrometer, and 10 x10 cm^2 applicator was in use

2.1. Measurement of beam quality

The beam quality of R_{50} is obtained from the commissioning measurement data, obtained for all Synergy electron energies for 10 x10 cm^2 field size and SSD = 100 cm in water.

2.2. The value of k_{Q,Q_o}

Using of the values of beams quality obtained previously for the electron energies of 4, 6, 8, 10, 12, 15 MeV, the values of k_{Q,Q_o} can be interpolated from the table 7.III available in the IAEA Code of practice TRS-398 [1] for PTW Advanced Markus plane-parallel ionization chamber.

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. From values of temperature and pressure the $\mathbf{K_{t,p}}$ can be calculated from Eq. (1.4)

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 1.5 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 1.6 to obtain K_s

2.3. Calibration of synergy linear accelerator electron beams

The absorbed dose to water at the reference depth z_{ref} in water for 4, 6, 8, 10, 12, and 15 MeV 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 the all electron potential can be acquired by using of the Equation 1.3. Then the output can be calculated using the following formulae:

$$output\ \% = D_{W,Q} \times K_{T,P} \times K_s \times K_{pol} \times K_{elec} \times \frac{1}{PDD} \times 100 \qquad (2.1)$$

Or simply:

$$output\ \% = M_Q \times N_{D,W} \times K_{Q,Q_0} \times K_{T,P} \times K_s \times K_{pol} \times K_{elec} \frac{1}{PDD} \times 100 \qquad (2.2)$$

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

3. Results:

3.1. Values of beam quality (R_{50}) and k_{Q,Q_o}

Table 3.1 shows the values of Z_{ref} that was calculated using Eq. (1.2), R_{50} and the values of k_{Q,Q_o} for the entire Synergy electron beam potentials.

Table 3.1: Beam quality (R_{50}), Z_{ref} and k_{Q,Q_o} values for electron beams produced from Synergy linac

E (MeV)	Z_{ref} (mm)	R_{50} (mm)	k_{Q,Q_o}
4	9.6	17.63	0.927
6	13.9	24.83	0.920
8	18.9	33.23	0.914
10	24.8	42.95	0.908
12	29	50	0.904
15	35.4	60.68	0.899

3.2. Polarity Effect factor (K_{pol})

Table 3.2 contains the values of the average of electrometer's readings of M+ and M- obtained at polarities of +400 and -400, respectively for 4, 6, 8, 10, 12,15 MeV. Also, the values of K_{pol} are included in the table 3.2.

Table 3.2: Polarity values (K_{pol}) for electron beams produced from Synergy linac

(MeV)	Z_{ref} (mm)	M_+ (nC) with V= +400	M_- (nC) with V= -400	K_{pol}
4	9.6	0.770	0.783	1.008
6	13.9	0.776	0.772	0.997
8	18.9	0.775	0.771	0.997

10	24.8	0.773	0.779	1.004
12	29	0.780	0.785	1.003
15	35.4	0.784	0.783	0.999

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 4, 6, 8, 10, 12, 15 MeV electron beams are 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 1.3.

Table 3.3: Ion Recombination values (K_s) for electron beams produced from Synergy linac

(MeV)	Z_{ref} (mm)	M_1 (nC) with V_1= +400	M_2 (nC) with V_2= +200	K_s
4	9.6	0.770	0.772	0.998
6	13.9	0.776	0.774	1.003
8	18.9	0.775	0.773	1.003
10	24.8	0.773	0.773	1.000
12	29	0.780	0.779	1.002
15	35.4	0.784	0.784	1.000

3.4. Output calibration of photon beams produced from Synergy Linac

Here is the output calibrations summary for the entire Synergy linac electron beam potentials during March 2023 measured in the Department of Medical and Radiation Physics at Tripoli University Hospital.

The values of the Z_{ref}, K_i factors, $N_{D,W}$ and PDDs used to obtain the output are summarized in the table 3.4

Table 3.4: The measured, calculated and standard values used in obtaining the output of electron beams for Synergy Linac

E (MeV)	Z_{ref} (mm)	$K_{Q,Q0}$	$K_{t.p}$*	K_{elec}**	K_s	K_{pol}	$N_{D,W}$ (Gy/c)	PDD (Z_{ref})
4	9.6	0.927	/	1.000	0.998	1.008	139.9 x10^7	99.58
6	13.9	0.920	/	1.000	1.003	0.997	139.9 x10^7	99.73
8	18.9	0.914	/	1.000	1.003	0.997	139.9 x10^7	98.73
10	24.8	0.908	/	1.000	1.000	1.004	139.9 x10^7	99.8

12	29	0.904	/	1.000	1.002	1.003	139.9 x10^7	99.7
15	35.4	0.899	/	1.000	1.000	0.999	139.9 x10^7	97.67

* 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 3.5 – 3.8 Show the weekly quality control electron beam output calibrations for the synergy linear accelerator.

Table 3.5: Electron beams weekly output calibration for synergy linac (1st week of March 2023)

1st week		Before calibration			After calibration		
E(MeV)	**$K_{t.p}$**	**M_Q (nC)**	**output**	**%Error**	**M_Q (nC)**	**output**	**%Error**
4	1.0009	0.757	99.3	0.7	**No calibration is required**		
6	1.0009	0.777	100.4	0.4			
8	1.0009	0.773	100.2	0.2			
10	1.0009	0.770	98.5	1.5			
12	1.0009	0.789	100.7	0.7			
15	1.0009	0.776	99.9	0.1			

Table 3.6: Electron beams weekly output calibration for synergy linac (2nd week of March 2023)

2nd week		Before calibration			After calibration		
E(MeV)	**$K_{t.p}$**	**M_Q (nC)**	**output**	**%Error**	**M_Q (nC)**	**output**	**%Error**
4	1.0003	0.770	100.9	0.9	**No calibration is required**		
6	1.0003	0.784	101.2	1.2			
8	1.0003	0.780	101	1			
10	1.0003	0.772	98.7	1.3			
12	1.0003	0.792	101	1			
15	1.0003	0.779	100.2	0.2			

Table 3.7: Electron beams weekly output calibration for synergy linac (3rd week of March 2023)

2nd week		Before calibration			After calibration		
E(MeV)	**$K_{t.p}$**	**M_Q (nC)**	**output**	**%Error**	**M_Q (nC)**	**output**	**%Error**
4	1.013	0.742	98.4	1.6	**No calibration is required**		
6	1.013	0.760	100.1	0.1			
8	1.013	0.761	99.8	0.2			
10	1.013	0778	100.7	0.7			
12	1.013	0.770	99.4	0.6			
15	1.013	0.755	98.4	1.6			

Table 3.8: Electron beams weekly output calibration for synergy linac (4th week of March 2023)

4nd week		Before calibration			After calibration		
E(MeV)	**$K_{t.p}$**	**M_Q (nC)**	**output**	**%Error**	**M_Q (nC)**	**output**	**%Error**
4	1.0003	0.763	100	0	**No calibration is required**		
6	1.0003	0.782	101	1			
8	1.0003	0.778	100.8	0.8			
10	1.0003	0.772	98.7	1.3			
12	1.0003	0.791	100.9	0.9			
15	1.0003	0.779	100.2	0.2			

4. Conclusion

The output calibration for the electron beams of 4, 6, 8, 10, 12, and 15 MeV potentials of synergy linear accelerator at Tripoli University Hospital were carried out using dosimetry system of PTW Advanced Markus plane-parallel ionization chamber and PTW UnidoseE 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 . The output calibration for electron beams was performed in this work for March 2023, no calibration was required as the output was within ± 2%

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