Electron Beam Output Measurement of a Medical Linear Accelerator

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To measure the electron beam output of a medical linear accelerator.

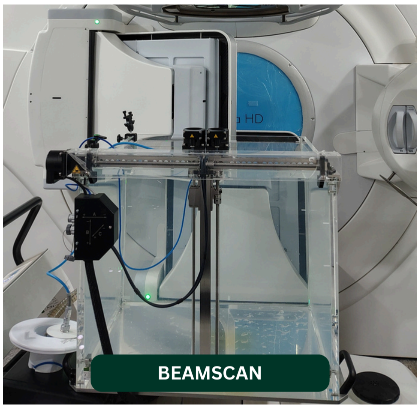
2 | Apparatus

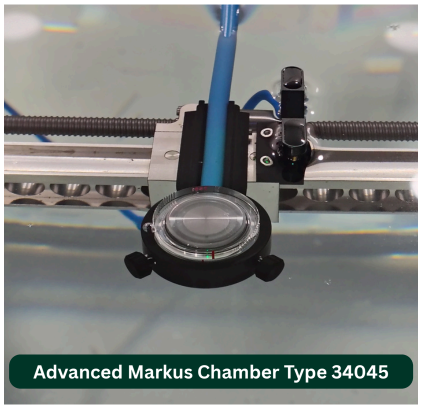
- Medical Linear Accelerator
- Water/ Slab Phantom
- Ionization Chamber
- Electrometer and Connecting cables
- Thermometer and Barometer

BEAMSCAN Water Phantom System

The BEAMSCAN system (PTW, Freiburg) is a modern, fully motorized three-dimensional water phantom designed for beam data acquisition in radiotherapy. It is widely used for commissioning, quality assurance, and beam characterisation of linear accelerators.

- **Purpose:** High-precision scanning of photon and electron beams for dosimetric measurements.
- **Design:** Large-volume water tank with three orthogonal motorised axes (X, Y, Z) for detector positioning.
- **Automation:** Fully computer-controlled scanning with high reproducibility and sub-millimetre positioning accuracy.
- **Detectors:** Compatible with ionisation chambers, diodes, and other field detectors for depth-dose and profile measurements.
- **Applications:** Beam commissioning, reference dosimetry, treatment planning system (TPS) data input, and periodic QA of radiotherapy machines.
- **Advantages:** High mechanical stability, waterproof detector holders, automated setup, and integration with dedicated software for data analysis.





Plane parallel chamber

Plane-parallel ionization chambers, also known as parallel-plate chambers, are specialized detectors used in radiation dosimetry, particularly for electron beams. Unlike extrapolation chambers, they feature a fixed but narrow electrode spacing of approximately 2 mm, which helps minimize cavity perturbations in the radiation field. This design is crucial for accurate dose measurements at shallow depths, where conventional cylindrical chambers—with their larger sensitive volumes—can distort electron fluence. The entrance window of a plane-parallel chamber is made of ultra-thin materials such as Mylar, polystyrene, or mica (typically 0.01 to 0.03 mm thick), allowing near-surface measurements with minimal attenuation. By layering phantom material over the chamber, one can study dose variation as a function of depth. The small electrode spacing in a plane-parallel chamber minimizes cavity perturbations in the radiation field. This material may be protected by copyright.These chambers are especially valuable in high-precision electron beam dosimetry and are available in various commercial models with differing specifications for sensitive volume, window thickness, guard ring width, and overall accuracy. A notable example is the Advanced Markus Electron Chamber, which is optimized for high dose-per-pulse scenarios and shallow depth profiling.

Feature	**Description**
Model	Advanced Markus Chamber Type 34045
Type	Plane-parallel ionization chamber
Application	Dosimetry of high-energy electron beams, especially for high dose-per-pulse scenarios
Sensitive Volume	0.02 mL, vented
Entrance Window	Thin entrance window(0.03 mm thick graphite-coated polyethylene membrane) for near-surface measurements; waterproof protection cap included
Guard Ring	Wide guard ring (2 mm width) design to minimise perturbation effects and scattered radiation influence
Energy Response	Flat energy response across relevant electron beam energies
Spatial Resolution	Small size enables high spatial resolution in dose distribution measurements

Electron applicator

An electron applicator is a detachable device used in a linear accelerator (Linac) during electron beam therapy to shape and direct the electron beam toward the treatment area. It is mounted to the treatment head when the machine operates in electron mode and ensures that the beam is properly collimated to deliver a uniform dose across the target while minimizing exposure to surrounding healthy tissues. The applicator is usually made of lightweight materials such as aluminum and consists of a series of collimators and side walls that define the treatment field. Different applicators provide standard field sizes, typically ranging from 6×6 cm^2 to 25×25 cm^2, and customized cutouts can be inserted to match the shape of the tumor. Each applicator is designed for specific electron energies, since higher energies require longer or differently shaped applicators to control scatter effectively. Accurate positioning of the applicator is essential to maintain dose uniformity and achieve precise treatment delivery in radiotherapy.

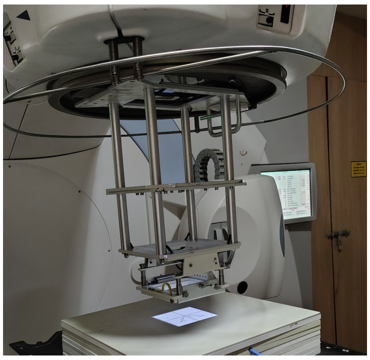


Figure 2.1: Electron applicator

3 | Theory

Medical LINACs are linear accelerators that accelerate electrons to a certain amount of kinetic energy using RF fields. In a LINAC, the electrons are accelerated following straight trajectories in special evacuated structures called accelerating waveguides. Electrons follow a linear path through the same, relatively low, potential difference several times. The high-power RF fields used for electron acceleration in the accelerating waveguides are produced through the process of decelerating electrons in retarding potential in special evacuated devices called magnetrons and klystrons. These accelerated electrons are targeted to the high-Z material(Tungsten) to produce X-ray Photons for treatment. Before the treatment, the output of the LINAC must be determined accurately. and it must also be verified regularly during clinical use to ensure accurate delivery of the prescribed dose to the patient.
The protocol, which is followed for LINAC output measurement, is TRS-398 (Technical Reports Series No. 398 "Absorbed Dose Determination in External Beam Radiotherapy" [2]) is the recommended international protocol for measuring output from a medical linear accelerator. The protocol and formalism for the measurement of output are described here.

Beam Quality Index (R_{50})

For electron beams, the beam quality index is defined as the half-value depth in water, denoted by R_{50}. This is the depth in water (in g/cm^2) at which the absorbed dose falls to 50% of its maximum value. Measurements are taken at a constant source-to-surface distance (SSD) of 100 cm with a field size of:

- At least 10×10 cm^2 for $R_{50} \leq 7$ g/cm^2 ($E_0 < 16$ MeV)
- At least 20×20 cm^2 for $R_{50} > 7$ g/cm^2 ($E_0 > 16$ MeV)

Absorbed Dose to Water Equation

The absorbed dose to water at a point is given by:

$$D_{W,Q} = N_{D,w,Q} \cdot M_Q \cdot k_{Q,Q_0}$$

Where:

- $N_{D,w,Q}$: Calibration coefficient provided in the chamber's calibration certificate
- M_Q: Corrected meter reading (includes all relevant correction factors)
- k_{Q,Q_0}: Beam quality correction factor

3.1 | Beam Quality Correction Factor (k_{Q,Q_0})

The factor k_{Q,Q_0} accounts for differences between the actual beam quality Q and the reference beam quality Q_0 used during chamber calibration. Values for k_{Q,Q_0} for various chambers and R_{50} values are tabulated in Table 18 of the IAEA TRS-398 protocol.

3.2 | Correction for Temperature, Pressure, and Humidity

Since the ionization chamber used to measure output is open to ambient air, the mass of the air in the cavity volume will be affected by the surrounding temperature, pressure, and humidity. No correction for humidity is applied if the humidity range is within 20-80%. The correction due to temperature and pressure is given by

$$K_{T,P} = \left(\frac{273.15 + T}{273.15 + T_0}\right)\left(\frac{P_0}{P}\right) \tag{3.1}$$

- T = Temperature at the time of measurement
- P = Pressure at the time of measurement
- T_0 = Reference temperature (20°C)
- P_0 = Reference pressure (1013.15 mbar)

T_0 and P_0 are the temperature and pressure respectively at which the chamber is calibrated, and it is mentioned in the calibration certificate.
In the above discussion it would be necessary to specify the temperature and pressure of the gas, since this determine its density. The mass, $m(T, P)$ of a given volume of air at temperature T and pressure P is related to its mass $m(0, 1013.2)$ at 0 °C and 1013.2 mbar pressure by:

$$m(T, P) = m(T_0, P_0)\left(\frac{273.15 + T_0}{273.15 + T}\right)\left(\frac{P}{P_0}\right) \tag{3.2}$$

the first bracketed term corrects for the expansion of the gas with increased temperature and second for changes due to changes in pressure. Since the mass of the gas appears in the denominator in dose calculation formula from Bragg-Gray Cavity Theory, The correction factor K_{TP} that must be applied to the dose determination is:

$$K_{T,P} = \left(\frac{273.15 + T}{273.15 + T_0}\right)\left(\frac{P_0}{P}\right) \tag{3.3}$$

3.3 | Correction for Ion Recombination/ Saturation

This error is introduced due to the incomplete charge collection inside the ionization chamber. The two-voltage method, suggested by J.W. Boag and J. Currant, is usually applied to calculate the recombination error. The protocol recommends that the ratio to be at least 2. Recombination factor correction factor(K_s) is the reciprocal of a chamber's collection efficiency and appears as a multiplicative factor in the dose calculation.

3.3.1 | Efficiency Correction Factor for Pulsed Radiation

The formula for collection efficiency f for a chamber exposed to pulsed radiation, suggested by Boag and Currant is

$$f = \frac{1}{u} ln(1 + u) \tag{3.4}$$

where

$$u = \frac{(\alpha/e)}{(k_1 + k_2)}(\frac{\rho d^2}{V}) \tag{3.5}$$

or,

$$\mu = \frac{(\alpha/e)}{(k_1 + k_2)} \tag{3.6}$$

- $\alpha =$ Ionic Recombination Coefficient
- $e =$ Electronic Charge
- $d =$ Electrode Spacing
- $k_1, k_2 =$ Mobilities of positive and negative ions respectively.
- $\rho =$ Initial charge density of positive and negative ions created by the pulse.

The two voltage technique suggested provides a relationship between collected charges, bias voltages and u given by,

$$\frac{q_1}{q_2} = \frac{V_1}{V_2}\frac{\ln(1 + u)}{\ln(1 + u\frac{V_1}{V_2})} \tag{3.7}$$

3.3.2 | Numerical solution for pulsed radiation

Now a program can be written to provide numerical solution to equation 3.7 for any voltage ratio . This equation was solved for u using the method of Newton Raphson. The value of u thus obtained was substituted in equation 3.4 to yield f , the reciprocal of which is k_s
Approximation for k_s were constructed in the form of quadratic equations. For a given voltage ratio,the alogorithm described above can produce a data pairs. These data pairs were used to obtain quadratic fits of K_s to Meter reading ratio.The fitted function took the form.

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_3\left(\frac{M_1}{M_2}\right)^2 \tag{3.8}$$

Voltage ratio	a_0	a_1	a_2
2.00	2.79977	-4.50337	2.70513
2.50	1.46830	-1.57525	1.10746
3.00	1.11751	-0.72733	0.60982
3.50	1.04426	-0.47813	0.43044
4.00	0.95461	-0.24098	0.28634
4.50	0.95134	-0.18368	0.23255
5.00	0.93661	-0.16959	0.20625
5.50	0.91052	-0.04487	0.13433
6.00	0.92763	-0.05490	0.12720
6.50	0.97077	-0.11459	0.14488
7.00	0.93554	-0.03546	0.10000
7.50	0.91955	0.00655	0.07400
8.00	0.94682	-0.03502	0.08812
8.50	0.92533	0.01140	0.06048
9.00	0.95805	-0.03868	0.00808
9.50	0.92112	0.03691	0.01409
10.00	0.92323	0.03937	0.03730

Table 3.1: Voltage Ratio and Coefficients [1]

This table consists value of k_s for pulsed beam determined by the Boag and Currant by solving transcendental equation, and as determined from the quadratic fit.

3.4 | Polarity Correction

The electrometer reading changes when the polarity of the bias voltage applied to the ionization chamber is reversed. The correction factor for change in meter readings due to polarizing potentials of opposite polarity is given by.

3.4.1 | Reason for Polarity Effect

Polarity effects in ionization chambers are caused by a radiation-induced current, also known as the Compton current, which arises as a charge imbalance due to charge deposition in the chamber's electrodes. This current originates from the emission of secondary electrons predominantly in the direction of incident photons as a result of Compton interactions occurring in the chamber wall and electrode. Any difference in potential between the guard electrode and the collector may distort the electric field significantly, causing asymmetry in the polarity.

3.4.2 | General Discussion

One can eliminate the polarity effect by making measurements at two different polarities. The term "polarity effect" has been used to refer to the ratio of readings with positive M_+ and negative M_- polarity;that is, the polarity effect $= \frac{M_+}{M_-}$. M is the reading obtained with the polarity used at the chamber.
The polarity correction factor K_{pol} is thus given by the following relationship:

$$K_{pol} = \frac{|M_+| + |M_-|}{2|M|} \tag{3.9}$$

M_+ = Meter reading with positive bias voltage
M_- = Meter reading with negative bias voltage
M = Meter reading with the usual bias voltage (used for daily output measurement purposes)

3.5 | Electrometer Calibration

Usually, the ionization chamber and measuring electrometer are calibrated as a single unit. In that case, the electrometer calibration factor k_{elec} is unity. If the electrometer is calibrated separately, the electrometer calibration factor must be multiplied by the uncorrected meter reading (M_{Qunc}) to calculate the corrected meter reading (M_Q). The corrected meter reading after applying all the correction factors is given below.

$$M_{Q_c} = M_{Qunc} \times K_{T,P} \times K_{Pol} \times K_s \tag{3.10}$$

Table 3.2: Reference Conditions for the Determination of Absorbed Dose in Electron Beams (IAEA TRS-398 Table 17)

Influence Quantity	Reference Value or Characteristic
Phantom Material	For $R_{50} \geq 4$ g/cm^2: water; For $R_{50} < 4$ g/cm^2: water or plastic
Chamber Type	For $R_{50} \geq 4$ g/cm^2: plane-parallel or cylindrical; For $R_{50} < 4$ g/cm^2: plane-parallel only
Measurement Depth z_{ref}	$z_{\text{ref}} = 0.6R_{50} - 0.1$ g/cm^2
Reference Point of the Chamber	Plane-parallel: inner surface of the entrance window; Cylindrical: central axis at the center of the cavity volume
Position of Reference Point	Plane-parallel: at z_{ref}; Cylindrical: 0.5 z_{cyl} deeper than z_{ref}
Source-to-Surface Distance (SSD)	100 cm
Field Size at Phantom Surface	10×10 cm^2 or the size used for output factor normalization, whichever is larger

4 | Observation in Acharya Harihar Post Graduate Institute of Cancer

4.1 | Tabulation for 6MeV electron

Bias Voltage	M_{Q1}	M_{Q2}	M_{Q3}	Average (M_{Qunc})
+300 V	1.831 nC	1.834 nC	1.836 nC	1.8336 nC
+150 V	1.821 nC	1.824 nC	1.829 nC	1.8246 nC
-300 V	-1.847 nC	-1.851 nC	-1.853 nC	-1.8503 nC

Table 4.1: Tabulation for 6 MeV

Correction for Temperature, Pressure, and Humidity

$$k_{T,P} = \left(\frac{273.15 + T}{273.15 + T_0}\right)\left(\frac{P_0}{P}\right) \tag{4.1}$$

where $T = 21.2^o$C, $T_0 = 20^o$C, $P_o = 101.3$ kPa and $P = 100.3$ kPa.
So, after putting in the value, $\boxed{k_{TP} = 1.014}$.

Correction for Ion Recombination/ Saturation:

$$k_s = a_0 + a_1 \left(\frac{M_1}{M_2}\right) + a_3 \left(\frac{M_1}{M_2}\right)^2 \tag{4.2}$$

Where $a_0 = 2.79977$, $a_1 = -4.50337$, $a_2 = 2.70513$ for a voltage ratio of 2, and the values for M_1 and M_2 are the averages of the meter readings for +300 volts and +150 volts, respectively. So, $M_1 = 1.8336$ and $M_2 = 1.8246$.
After calculating , $\boxed{k_s = 1.00606}$.

Polarity Correction:

$$K_{pol} = \frac{|M_+| + |M_-|}{2|M|} \tag{4.3}$$

Putting the values $|M_+| = |M|$ and $|M_-|$ the K_{Pol} calculation, we get $\boxed{K_{Pol} = 1.005}$.

Corrected meter reading:

$$\begin{aligned} M_Q &= M' \times k_{pol} \times k_{sat} \times k_{TP} \\ &= 1.8336 \times 1.005 \times 1.006 \times 1.014 \\ &= \boxed{1.8797 \text{ nC}} \end{aligned}$$

Absorbed does to water at $Z_{ref} = 1.4$ cm depth:

Given, $k_{Q,Q_0} = 0.919$ and $N_{D,w} = 5.734 \times 10^8$ Gy/C

$$\begin{aligned} D'_{w,Q} &= M_Q \times N_{D,w} \times k_{Q,Q_0} \\ &= 1.8797 \text{ nC} \times 5.734 \times 10^8 \text{ Gy/C} \times 0.919 \\ &= \boxed{0.99055 \text{ cGy}} \end{aligned}$$

Dose at the depth of dose maxima, 100 cm SSD set up:

PDD at $Z_{ref} = 1.4$ cm for a 10 cm $\times$ 10 cm field size for a 6 MeV beam is *99.166* %.
Absorbed dose rate calibration at Z_{max}

$$\begin{aligned} D_{w,Q} &= \frac{0.99055 \times 100}{99.166} \\ &= \boxed{0.9988 \text{ cGy/MU}} \end{aligned}$$

Error calculation

- Output measured: 0.9988 cGy/MU
- Standard output: 1.0000 cGy/MU

$$\begin{aligned} \text{Error (\%)} &= \left(\frac{\text{Measured} - \text{Standard}}{\text{Standard}}\right) \times 100 \\ &= \left|\frac{0.9988 - 1.0000}{1.0000}\right| \times 100 \\ &= 0.12\% \text{ (Tolerance} = 2\%) \end{aligned}$$

4.2 | Tabulation for 12 MeV electron

Bias Voltage	M_{Q1}	M_{Q2}	M_{Q3}	Average (M_{Qunc})
+300 V	1.865 nC	1.869 nC	1.870 nC	1.868 nC
+150 V	1.851 nC	1.856 nC	1.86 nC	1.8556 nC
-300 V	-1.869 nC	-1.872 nC	-1.874 nC	-1.8716 nC

Table 4.2: Tabulation for 12 MeV

Correction for Temperature, Pressure, and Humidity

$$k_{T,P} = \left(\frac{273.15 + T}{273.15 + T_0}\right)\left(\frac{P_0}{P}\right) \tag{4.4}$$

where $T = 21.2^o$C, $T_0 = 20^o$C, $P_o = 101.3$ kPa and $P = 100.3$ kPa.
So, after putting in the value, $\boxed{k_{TP} = 1.014}$.

Correction for Ion Recombination/ Saturation:

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_3\left(\frac{M_1}{M_2}\right)^2 \tag{4.5}$$

Where $a_0 = 2.79977$, $a_1 = -4.50337$, $a_2 = 2.70513$ for a voltage ratio of 2, and the values for M_1 and M_2 are the averages of the meter readings for +300 volts and +150 volts, respectively. So, $M_1 = 1.868$ and $M_2 = 1.8556$.
After calculating , $\boxed{k_s = 1.0077}$.

Polarity Correction:

$$K_{pol} = \frac{|M_+| + |M_-|}{2|M|} \tag{4.6}$$

Putting the values $|M_+| = |M|$ and $|M_-|$ the K_{Pol} calculation, we get $\boxed{K_{Pol} = 1.001}$.

Corrected meter reading:

$$\begin{aligned} M_Q &= M' \times k_{pol} \times k_{sat} \times k_{TP} \\ &= 1.868 \times 1.001 \times 1.007 \times 1.014 \\ &= \boxed{1.9093 \text{ nC}} \end{aligned}$$

Absorbed does to water at $Z_{ref} = 2.7$ cm depth:

Given, $k_{Q,Q_0} = 0.919$ and $N_{D,w} = 5.734 \times 10^8$ Gy/C

$$\begin{aligned} D'_{w,Q} &= M_Q \times N_{D,w} \times k_{Q,Q_0} \\ &= 1.9093 \text{ nC} \times 5.734 \times 10^8 \text{ Gy/C} \times 0.919 \\ &= \boxed{1.0061 \text{ cGy}} \end{aligned}$$

Dose at the depth of dose maxima, 100 cm SSD set up:

PDD at $Z_{ref} = 2.7$ cm for a 10 cm × 10 cm field size for a 6 MeV beam is *98.963* %.
Absorbed dose rate calibration at Z_{max}

$$\begin{aligned} D_{w,Q} &= \frac{1.0061 \times 100}{98.963} \\ &= \boxed{1.0166 \text{ cGy/MU}} \end{aligned}$$

Error calculation

- Output measured: 1.0166 cGy/MU
- Standard output: 1.0000 cGy/MU

$$\begin{aligned}\text{Error }(\%) &= \left(\frac{\text{Measured} - \text{Standard}}{\text{Standard}}\right) \times 100 \\ &= \left|\frac{1.0166 - 1.0000}{1.0000}\right| \times 100 \\ &= 1.66\% \text{ (Tolerance} = 2\%)\end{aligned}$$

5 | Observation in AIIMS

5.1 | Tabulation for 6 MeV electron beam

Bias Voltage	M_{Q1}	M_{Q2}	M_{Q3}	Average (M_{Qunc})
+300 V	683 pC	682 pC	681.5 pC	682.17 pC
+150 V	680 pC	679.5 pC	680.5 pC	680 pC
-300 V	-692.5 pC	-692.5 pC	-691.5 pC	-692.17 pC

Table 5.1: Tabulation for 6 MeV

Correction for Temperature, Pressure, and Humidity

$$k_{T,P} = \left(\frac{273.15 + T}{273.15 + T_0}\right)\left(\frac{P_0}{P}\right) \tag{5.1}$$

where $T = 23^o$C, $T_0 = 20^o$C, $P_o = 101.3$ kPa and $P = 101.1$ kPa.
So, after putting in the value, $\boxed{k_{TP} = 1.0122}$.

Correction for Ion Recombination/ Saturation:

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_3\left(\frac{M_1}{M_2}\right)^2 \tag{5.2}$$

Where $a_0 = 2.79977$, $a_1 = -4.50337$, $a_2 = 2.70513$ for a voltage ratio of 2, and the values for M_1 and M_2 are the averages of the meter readings for +300 volts and +150 volts, respectively. So, $M_1 = 682.17$ and $M_2 = 680$.
After calculating , $\boxed{k_s = 1.0044}$.

Polarity Correction:

$$K_{pol} = \frac{|M_+| + |M_-|}{2|M|} \tag{5.3}$$

Putting the values $|M_+| = |M|$ and $|M_-|$ the K_{Pol} calculation, we get $\boxed{K_{Pol} = 1.0073}$.

Corrected meter reading:

$$\begin{aligned}M_Q &= M' \times k_{pol} \times k_{sat} \times k_{TP} \\ &= 682.17\text{ pC} \times 1.0073 \times 1.0044 \times 1.0122 \\ &= \boxed{0.699\text{ nC}}\end{aligned}$$

Absorbed does to water at $Z_{ref} = 1.4$ cm depth:

Given, $k_{Q,Q_0} = 0.939$ and $N_{D,w} = 150.7$ cGy/nC

$$\begin{aligned} D'_{w,Q} &= M_Q \times N_{D,w} \times k_{Q,Q_0} \\ &= 0.699 \text{ nC} \times 150.7 \text{ cGy/nC} \times 0.939 \\ &= \boxed{98.913 \text{ cGy/ 100 MU}} \end{aligned}$$

Dose at the depth of dose maxima, 100 cm SSD set up:

PDD at $Z_{ref} = 1.4$ cm for a 10 cm × 10 cm field size for a 6 MeV beam is *98.893* %.
Absorbed dose rate calibration at Z_{max}

$$\begin{aligned} D_{w,Q} &= \frac{98.913}{98.893} \\ &= \boxed{1.0002 \text{ cGy/MU}} \end{aligned}$$

Error calculation

- Output measured: 1.0002 cGy/MU
- Standard output: 1.0000 cGy/MU

$$\begin{aligned} \text{Error (\%)} &= \left(\frac{\text{Measured} - \text{Standard}}{\text{Standard}}\right) \times 100 \\ &= \left|\frac{1.0002 - 1.0000}{1.0000}\right| \times 100 \\ &= 0.02\% \text{ (Tolerance} = 2\%) \end{aligned}$$

5.2 | Tabulation for 12 MeV electron

Bias Voltage	M_{Q1}	M_{Q2}	M_{Q3}	Average (M_{Qunc})
+300 V	718.5 pC	717.5 pC	718 pC	718 pC
+150 V	715.5 pC	715.5 pC	714 pC	715 pC
-300 V	-723.5 pC	-723 pC	-722.5 pC	-723 pC

Table 5.2: Tabulation for 12 MeV

Correction for Temperature, Pressure, and Humidity

$$k_{T,P} = \left(\frac{273.15 + T}{273.15 + T_0}\right)\left(\frac{P_0}{P}\right) \tag{5.4}$$

where $T = 23^oC$, $T_0 = 20^oC$, $P_o = 101.3$ kPa and $P = 101.1$ kPa.
So, after putting in the value, $\boxed{k_{TP} = 1.0122}$.

Correction for Ion Recombination/ Saturation:

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_3\left(\frac{M_1}{M_2}\right)^2 \tag{5.5}$$

Where $a_0 = 2.79977$, $a_1 = -4.50337$, $a_2 = 2.70513$ for a voltage ratio of 2, and the values for M_1 and M_2 are the averages of the meter readings for +300 volts and +150 volts, respectively. So, $M_1 = 718$ and $M_2 = 715$.
After calculating , $\boxed{k_s = 1.00538}$.

Polarity Correction:

$$K_{pol} = \frac{|M_+| + |M_-|}{2|M|} \tag{5.6}$$

Putting the values $|M_+| = |M|$ and $|M_-|$ the K_{Pol} calculation, we get $\boxed{K_{Pol} = 1.00348}$.

Corrected meter reading:

$$\begin{aligned} M_Q &= M' \times k_{pol} \times k_{sat} \times k_{TP} \\ &= 718 \times 1.00348 \times 1.00538 \times 1.0122 \\ &= \boxed{733.212 \text{ pC}} \end{aligned}$$

Absorbed does to water at $Z_{ref} = 2.7$ cm depth:

Given, $k_{Q,Q_0} = 0.909$ and $N_{D,w} = 150.7$ cGy/nC.

$$\begin{aligned} D'_{w,Q} &= M_Q \times N_{D,w} \times k_{Q,Q_0} \\ &= 0.733 \text{ nC} \times 150.7 \text{ cGy/nC} \times 0.909 \\ &= 100.41 \text{ cGy/ } 100 \text{ MU} \\ &= \boxed{1.0041 \text{ cGy/ MU}} \end{aligned}$$

Dose at the depth of dose maxima, 100 cm SSD set up:

PDD at $Z_{ref} = 2.7$ cm for a 10 cm $\times$ 10 cm field size for a 6 MeV beam is *98.963* %.
Absorbed dose rate calibration at Z_{max}

$$\begin{aligned} D_{w,Q} &= \frac{1.0041 \times 100}{98.963} \\ &= \boxed{1.0146 \text{ cGy/MU}} \end{aligned}$$

Error calculation

- Output measured: 1.0146 cGy/MU
- Standard output: 1.0000 cGy/MU

$$\begin{aligned} \text{Error (\%)} &= \left(\frac{\text{Measured} - \text{Standard}}{\text{Standard}}\right) \times 100 \\ &= \left|\frac{1.0146 - 1.0000}{1.0000}\right| \times 100 \\ &= 1.46\% \text{ (Tolerance} = 2\%) \end{aligned}$$

6 | Conclusion

This Output measurement of electron is a part of QA in any LINAC. All values calculated in the experiment are within the tolerance($< 2\%$) as suggested by AERB. This error should be as small as possible to operate for delivering a precise dose.

7 | References

[1] Souvik Das. Numerical solution for pulsed radiation using newton raphson method in python. https://colab.research.google.com/drive/1v28pI4fMtCMZGqr_qRu5STyYaFO_76bO?usp=sharing, 2025. Accessed: 2025-10-20.

[2] International Atomic Energy Agency. Absorbed dose determination in external beam radiotherapy: An international code of practice for dosimetry based on standards of absorbed dose to water. Technical Report Technical Reports Series No. 398, IAEA, 2024. Accessed: 2025-10-20.