Electron Beam Output Measurement of a Medical Linear Accelerator

Aim:

To measure the Electron Beam output of a Medical Linear Accelerator.

Equipment Required:

1. Medical Linear Accelerator
2. Water/ Slab Phantom
3. Ionization Chamber
4. Electrometer and Connecting cables
5. Thermometer and Barometer
6. Levelling tool (Spirit level)

Theory:

A medical linear accelerator is a treatment unit that accelerates electrons to very high energy using high-frequency electromagnetic waves. This highly energetic electron beam is nearly monoenergetic and spread over an area of around a circle of 2mm diameter. To use these electron beams for the patient treatment, the area of the beam needs to be increased to the size of the tumour. After being extracted from the accelerating structure these electrons are allowed to hit a scattering foil to spread the beam. Electron Applicators are externally mounted to the gantry to collimate the electron beams to the target. Before the treatment, the output of this beam should 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 electron beam output of a medical Linac is the absorbed dose rate to water measured in units of cGy/MU (MU: Monitor Units) at a reference depth in water for a reference field size (e.g., 10cm X 10cm) defined by the Electron Applicator. The output measurement is one of the Quality Assurance tests performed to ensure that the absorbed dose to water is within acceptable tolerance as recommended by the competent authority (AERB).

The procedures for performing output measurement of a clinical photon or electron beam produced by a radiotherapy machine are prescribed in international, national, and regional radiation dosimetry protocols or dosimetry codes of practice. IAEA TRS 398- "Absorbed Dose Determination in External Beam Radiotherapy" 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 ($\boldsymbol{R_{50}}$):

For electron beams the beam quality index is the half-value depth in water $\boldsymbol{R_{50}}$. 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 field size at the phantom surface of at least 10 cm × 10 cm for $R50 \leq 7$ g/cm^2 ($E_0 < 16$ MeV) and at least 20 cm × 20 cm for $\boldsymbol{R_{50}} > 7$ g/cm^2 ($E_0 \geq 16$ MeV).

The formula gives the absorbed dose to water at a point:

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

N_{D,w,Q_0} = The calibration factor/coefficient as provided in the calibration certificate
M_Q = Corrected meter reading (The various correction factors on which the meter reading depends are discussed below)
k_{Q,Q_0} = Beam quality correction factor.

Beam Quality Correction factor (k_{Q,Q_0}):

The beam quality correction factor is used when the measurement beam differs from the reference beam where the chamber is calibrated. The values of this correction factor for various chambers and the beam quality (R_{50}) are available in Table 18 of IAEA TRS 398.

Correction for Temperature, Pressure, and Humidity ($k_{T,P}$):

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

$$k_{TP} = \frac{(273.2+T)}{(273.2+T_o)}\frac{P_o}{P}$$

Where T = Temperature at the time of measurement
T_0 = Reference temperature (20^0C)
P = Pressure at the time of measurement
P_0 = Reference pressure (1013.2 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.

Correction for Ion Recombination/ Saturation (k_s):

This error is introduced due to the incomplete charge collection inside the ionization chamber. The two-voltage method is usually applied to calculate the recombination error. The protocol recommends that the ratio to be at least 2.

$$k_s = a_o + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2$$

The constants a_0, a_1, and a_2 can be found in Table 9 (for pulsed beams) of the IAEA TRS 398.

Polarity Correction (k_{pol}):

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

$$k_{\text{pol}} = \frac{|M_+| + |M_-|}{2M}$$

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)

Electrometer Calibration (k_{elec}):
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.

$$M_Q = M_{Qunc}\, k_{T,P}\, k_{pol}\, k_s\, k_{elec}$$

TRS 398 Protocol for Output Measurement:

Influence Quantity	Reference Value or Characteristics
Phantom material	For $R50 \geq 4$ g/cm^2, water For $R50 < 4$ g/cm^2, water or plastic
Chamber type	For $R50 \geq 4$ g/cm^2, plane parallel or cylindrical For $R50 < 4$ g/cm^2, plane parallel
Measurement depth, z_{ref}	0.6 $R50$ – 0.1 g/cm^2
Reference point of the 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 the reference point	For plane-parallel chambers, at z_{ref} point of the chamber For cylindrical chambers, $0.5r_{cyl}$ deeper than z_{ref}
SSD or SCD	100 cm
Field size	10 cm × 10 cm or that used for normalization of output factors, whichever is larger

Procedure:

There are various types of water and slab phantoms available commercially. The design of the phantoms varies from one another. Here we have given the generalized procedures for absolute dosimetry.

- Place the water phantom (without water) on the treatment couch and perform the necessary alignments by matching phantom markings with the crosshair of the machine and external lasers.
- Adjust the tilt of the phantom with the help of spirit level, placing it on the walls and corners of the phantom.
- Fill the phantom with distilled water carefully without disturbing the phantom.
- Insert the ionization chamber into the slot given in the phantom.
- Adjust the ionisation chamber to align the equipment crosshair with the markings of the ionization chamber.

- Move the ionization chamber to the reference depth/measurement depth (z_{ref}) from the surface of the water.
- Adjust the SSD to 100 cm with the help of ODI/Lasers and open the field size to 10cm X 10cm with the help of a 10x10 electron applicator. (The sample calculation shown below is for SSD setup).
- Place the thermometer and barometer inside/near the water phantom away from the irradiation field (10cm X 10cm). Note down the temperature and pressure before irradiation.
- Set the bias voltage on the electrometer to the voltage mentioned in the calibration certificate.
- Before starting the measurement, eliminate any leakage current that might be present in the connecting cables by pressing the Zeroing button on the electrometer and warm up the ionization chamber by irradiating the chamber to a dose of at least 2 Gy. After completion of the irradiation, press the Zeroing button on the electrometer.
- Irradiate the chamber for 100 MU and tabulate the meter readings (Charge collected) as given below. Take at least three readings to minimize the statistical uncertainty in the measurement.
- Calculate the various correction factors $\boldsymbol{k_{T,P}}$, $\boldsymbol{k_s}$, $\boldsymbol{k_{pol}}$, $\boldsymbol{k_{elec}}$ using the formula given above.
- Repeat the measurement for other available electron energies and calculate the output.
- The sample tabulation is given below.

Tabulation and Calculation:

Bias Voltage (V)	M_{Q1} (nC)	M_{Q2} (nC)	M_{Q3} (nC)	Average (M_{Qunc})(nc)
+300	1.928	1.927	1.927	1.9273
+150	1.926	1.925	1.924	1.925
-300	-1.933	-1.933	-1.932	-1.9326

* M_{Qunc} = Uncorrected meter reading.

The details of the calculation given in the next page. The worksheet given below can be found in 7.10. worksheet of IAEA TRS 398. All the data in Sr. 2 of the worksheet given below can be found in the calibration certificate provided by the SSDL/ADCL.

From the datasheet given below, we found the following:

Output measured = 1.0015 cGy/MU

Standard Output = 1 cGy/MU

$$Error\ (\%) = \frac{Measured - standard}{Standard}\ X\ 100$$

= 0.15 % (Tolerance = 2%)

Precautions:

- Carefully handle the ionization chamber, phantom, and other accessories.
- Do not touch the connecting cables when a bias voltage is set on the electrometer.
- Do not irradiate the ionization chamber while zeroing the electrometer.
- Do not step on the connecting cables.

7.10. WORKSHEET

Determination of the absorbed dose to water in an electron beam

User: Radiation Therapy Department Date: _____

1. Radiation treatment unit and reference conditions for $D_{w,Q}$ determination

Accelerator: Medical LINAC Nominal energy: 4 MeV
Nominal dose rate: 400 MU/min Measured R_{50}: 23.98 g/cm²
Reference phantom: ☑ water ☐ plastic obtained from ☐ ionization ☑ dose curves
Reference field size: 10×10 cm × cm Reference SSD: 100 cm
Beam quality, Q ($R_{50,w}$): 23.98 g/cm² Reference depth $z_{ref,w} = 0.6\,R_{50} - 0.1$: 13.4 g/cm²

2. Ionization chamber and electrometer

Ionization chamber model: MPlane Parallel Serial No.: 13456 Type: ☑ pp ☐ cyl
Chamber wall/window material: _____ thickness: _____ g/cm²
Waterproof sleeve/cover material: PMMA thickness: 0.88 g/cm²
Phantom window material: _____ thickness: _____ g/cm²
Absorbed dose to water calibration factor[a] N_{D,w,Q_0} = 0.5558 ☑ Gy/nC ☐ Gy/rdg
Calibration quality Q_0: ☑ ^{60}Co ☐ electron beam Calibration depth: _____ g/cm²
If Q_0 is electron beam, give R_{50}: _____ g/cm²
Reference conditions for calibration P_0: 101.32 kPa T_0: 20 °C Rel. humidity: 50 %
Polarizing potential V_1: 300 V Calibration polarity: ☑ +ve ☐ –ve ☐ corrected for polarity effect
User polarity: ☑ +ve ☐ –ve

Calibration laboratory: _____ Date: _____
Electrometer model: _____ Serial No.: _____
Calibrated separately from chamber: ☐ Yes ☑ No Rating setting: _____
If yes, calibration laboratory: _____ Date: _____

3. Phantom

Water phantom window material: Water thickness: 1 g/cm²
Plastic phantom phantom material: _____ density: _____ g/cm³
depth scaling factor c_{pl}: _____ reference depth $z_{ref,pl} = z_{ref}/c_{pl}$: _____ g/cm²
fluence scaling factor[b]: h_{pl} = _____

4. Dosimeter reading[c] and correction for influence quantities

Uncorrected dosimeter reading at V_1 and user polarity: 1.9273 ☑ nC ☐ rdg
Corresponding accelerator monitor units: 100 MU
Ratio of dosimeter reading and monitor units: M_1 = 0.019273 ☑ nC/MU ☐ rdg/MU

(i) Pressure P: 1015.4 kPa Temperature T: 23.8 °C Rel. humidity (if known): 65 %

$$k_{TP} = \frac{(273.2+T)}{(273.2+T_o)}\frac{P_o}{P} = 1.0108$$

(ii) Electrometer calibration factor[d] k_{elec}: ☐ nC/rdg ☐ dimensionless k_{elec} = 1

(iii) Polarity correction[e] rdg at $+V_1$: M_+ = 1.9273 rdg at $-V_1$: M_- = -1.9326

$$k_{pol} = \frac{|M_+|+|M_-|}{2M} = 1.0014$$

(iv) Recombination correction (two voltage method)

Polarizing voltages: V_1 (normal) = 300 V V_2 (reduced) = 150 V

Readings[f] at each V: M_1 = 1.9273 M_2 = 1.925

Voltage ratio V_1/V_2 = 2 Ratio of readings M_1/M_2 = 1.0012

Use Table 9 for a beam of type: ☑ pulsed ☐ pulsed–scanned

a_0 = 2.337 a_1 = -3.636 a_2 = 2.299

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2 = 1.0012$$

Corrected dosimeter reading at the voltage V_1:

$M_Q = M_1 h_{pl} k_{TP} k_{elec} k_{pol} k_s$ = 1.9486 ☑ nC/~~MU~~ ☐ rdg/MU

5. Absorbed dose to water at the reference depth, z_{ref}

Beam quality correction factor for user quality Q:

If Q_o is ^{60}Co, Table 18 gives k_{Q,Q_o} = 0.921

If Q_o is electron beam, Table 19 gives $k_{Q,Q_{int}}$ = _____ $k_{Q_o,Q_{int}}$ = _____

$$k_{Q,Q_o} = \frac{k_{Q,Q_{int}}}{k_{Q_o,Q_{int}}} = \_\_\_\_\_$$

If k_{Q,Q_o} derived from series of electron beam calibrations k_{Q,Q_o} = _____

Calibration laboratory: _____ Date: _____

$D_{w,Q}(z_{ref}) = M_Q N_{D,w,Q_o} k_{Q,Q_o}$ = 0.99747 cGy/MU

6. Absorbed dose to water at the depth of dose maximum, z_{max}

Depth of dose maximum: z_{max} = _____ g/cm^2

Percentage depth dose at z_{ref} for a 10 cm × 10 cm field size: PDD(z_{ref} = 13.4 g/cm^2) = 99.6 %

Absorbed dose calibration of monitor at z_{max}:

$D_{w,Q}(z_{max}) = 100\, D_{w,Q}(z_{ref})/\mathrm{PDD}(z_{ref})$ = 1.0015 cGy/MU

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[a] Note that if Q_o is ^{60}Co, N_{D,w,Q_o} is denoted by $N_{D,w}$.

[b] If a water phantom is used, set the fluence scaling factor $h_{pl} = 1$.

[c] All readings should be checked for leakage and corrected if necessary.

[d] If the electrometer is not calibrated separately, set $k_{elec} = 1$.