Photon Beam Output Measurement of a Medical Linear Accelerator

Aim:

To measure the Photon 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. The highly energetic electron beams are made to hit a target (usually made of Tungsten) to produce bremsstrahlung X-ray photons. These X-Rays are collimated to the precise tumour location inside the patient. Before the treatment, the output of ionizing radiation beams produced by external beam radiotherapy treatment machines 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 photon 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). The output measurement is one of the Quality Assurance tests performed to ensure that the absorbed dose to water for an equipment 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.

$\mathrm{TPR}_{20,10}$ is the ratio of the absorbed doses at depths of 20 and 10 cm in a water phantom, measured with a constant SCD of 100 cm and a field size of 10 cm × 10 cm at the plane of the chamber. The measurement depth can be chosen based on the $\mathrm{TPR}_{20,10}$ value as given in the table below.

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 beam qualities (**TPR$_{20,10}$**) are available in Table 14 of IAEA TRS 398. If both the reference beam (Where the chamber is calibrated) and measurement beam are the same then k_{Q,Q_0} is 1.

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.

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

TRS 398 Protocol for Output Measurement:

Influence Quantity	**Reference Value or Characteristics**
Phantom material	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 the chamber	On the central axis at the center of the cavity volume
Position of the reference point	At the measurement depth z_{ref}
SSD or SCD	100 cm
Field size	10 cm × 10 cm

Procedure:

Medical Linear Accelerators can produce different X-Ray photon energies. The most common energy used in Radiation Therapy are 6MV, 10MV, and 15MV. There are also 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 of 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 cylindrical ionization chamber into the slot given in the phantom.
- Adjust the ionisation chamber to align the equipment crosshair with the markers of the ionization chamber.
- Move the ionization chamber to the reference depth/measurement depth (at 5 cm or 10 cm) 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. (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.
- The sample tabulation is given below.

Tabulation: (For 6MV):

Bias Voltage (V)	M_{Q1} (nC)	M_{Q2} (nC)	M_{Q3} (nC)	Average (M_{Qunc})(nc)
+400	12.46	12.47	12.46	12.462
+200	12.44	12.44	12.43	12.436
-400	-12.48	-12.48	-12.47	-12.476

* M_{Qunc} = Uncorrected meter reading.

Calculation:

The details of the calculation are given in the next page. The worksheet given below can be found in 6.9. 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. The dosimetry for other available X-Ray photon energies can also be done based on the above procedure.

From the datasheet given below, we found the following:

Output measured = 0.9934 cGy/MU

Standard Output = 1 cGy/MU

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

= 0.66 % (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.

6.9. WORKSHEET

Determination of the absorbed dose to water in a high energy photon beam

User: Radiation Therapy Department Date:

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

Accelerator: Medical LINAC (Name) Nominal Acc. potential: 6 MV

Nominal dose rate: 600 MU/min Beam quality, Q ($TPR_{20,10}$): 0.67

Reference phantom: water Set-up: ☑ SSD ☐ SAD

Reference field size: 10 × 10 cm × cm Reference distance (cm): 100

Reference depth z_{ref}: 10 g/cm²

2. Ionization chamber and electrometer

Ionization chamber model: Farmer 0.6cc Serial No.: 12345

Chamber wall material: Graphite thickness: 0.08 g/cm²

Waterproof sleeve material: PMMA thickness: 0.5 g/cm²

Phantom window material: thickness: g/cm²

Absorbed dose to water calibration factor[a] N_{D,w,Q_o} = 0.05372 ☑ Gy/nC ☐ Gy/rdg

Calibration quality Q_o ☑ ^{60}Co ☐ photon beam Calibration depth: 10 g/cm²

If Q_o is photon beam, give $TPR_{20,10}$:

Reference conditions for calibration P_o: 101.32 kPa T_o: 20 °C Rel. humidity: 50%

Polarizing potential V_1: 400 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 Range setting:

If yes, calibration laboratory: Date:

3. Dosimeter reading[b] and correction for influence quantities

Uncorrected dosimeter reading at V_1 and user polarity: 12.462 ☑ nC ☐ rdg

Corresponding accelerator monitor units: 100 MU

Ratio of dosimeter reading and monitor units: M_1 = ☐ nC/MU ☐ rdg/MU

(i) Pressure P: 101.65 kPa Temperature T: 23.8 °C Rel. humidity (if known): %

$$k_{TP} = \frac{(273.2+T)}{(273.2+T_o)}\frac{P_o}{P} = 1.0097$$

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

(iii) Polarity correction[d] rdg at $+V_1$: M_+ = 12.462 rdg at $-V_1$: M_- = 12.474

$$k_{pol} = \frac{|M_+|+|M_-|}{2M} = 1.0005$$

(iv) Recombination correction (two voltage method)

Polarizing voltages: V_1 (normal) = 400 V V_2 (reduced) = 200 V

Readings[e] at each V: M_1 = 12.462 M_2 = 12.436

Voltage ratio V_1/V_2 = 2 Ratio of readings M_1/M_2 = 1.002

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

a_0 = 2.337 a_1 = −3.636 a_2 = 2.299

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2 = 1.002$$

Corrected dosimeter reading at the voltage V_1:

$M_Q = M_1\, k_{TP}\, k_{\text{elec}}\, k_{\text{pol}} k_s$ = 12.614 ☑ nC/MU ☐ rdg/MU

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

Beam quality correction factor for the user quality Q: k_{Q,Q_o} = 0.9912.

taken from ☐ Table 14 ☐ Other, specify: ________

$D_{w,Q}(z_{\text{ref}}) = M_Q\, N_{D,w,Q_o} k_{Q,Q_o}$ = 0.672 cGy/MU

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

Depth of dose maximum: z_{max} = 1.5 *g/cm²*

✓(i) SSD set-up

Percentage depth dose at z_{ref} for a 10 cm × 10 cm field size: PDD (z_{ref} = 10 g/cm²) = 67.61%

Absorbed dose calibration of monitor at z_{max}:

$D_{w,Q}(z_{\text{max}}) = 100\, D_{w,Q}(z_{\text{ref}})/\text{PDD}(z_{\text{ref}})$ = 0.9934 Gy/MU

(ii) SAD set-up

TMR at z_{ref} for a 10 cm × 10 cm field size: TMR (z_{ref} = ________ g/cm²) = ________

Absorbed dose calibration of monitor at z_{max}:

$D_{w,Q}(z_{\text{max}}) = D_{w,Q}(z_{\text{ref}})/\text{TMR}(z_{\text{ref}})$ = ________ Gy/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] All readings should be checked for leakage and corrected if necessary.

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

[d] *M in the denominator of k_{pol} denotes reading at the user polarity. Preferably, each reading in the equation* should be the average of the ratios of M (or M_+ or M_-) to the reading of an external monitor, M_{em}.
It is assumed that the calibration laboratory has performed a polarity correction. Otherwise k_{pol} is determined according to:
rdg at $+V_1$ for quality Q_o: M_+ = ________ rdg at $-V_1$ for quality Q_o: M_- = ________

$$k_{\text{pol}} = \frac{\left[\left(|M_+|+|M_-|\right)/|M|\right]_Q}{\left[\left(|M_+|+|M_-|\right)/|M|\right]_{Q_o}} = \_\_\_\_\_\_\_\_$$

[e] Strictly, readings should be corrected for polarity effect (average with both polarities). Preferably, each reading in the equation should be the average of the ratios of M_1 or M_2 to the reading of an external monitor, M_{em}.