Cross-calibration of a Therapy level Dosimeter

Aim:

To calibrate a therapy-level field chamber against a reference field chamber.

Equipment Required:

1. Teletherapy Unit
2. Water/ Slab Phantom
3. Ionization Chamber (Field Chamber)
4. Ionization Chamber (Reference Chamber)
5. Electrometer and Connecting cables
6. Thermometer and Barometer
7. Levelling tool (Spirit level)

Theory:

Most of the Radiotherapy centers are equipped with more than one type of ionisation chamber. These ionization chambers vary in size, shape, and in sensitive volume. The use of these chambers depends on the type of Dosimetry being performed. For measurements in smaller field sizes, small-volume chambers are recommended. The calibration certificates provided with the chamber are valid for 2 years. After the expiry of the calibration certificate, these chambers needed to be calibrated against a reference chamber either from a calibration Laboratory or can be cross-calibrated at the user end. The user can cross-calibrate it against a reference chamber that has a valid calibration certificate from an Accredited Calibration Laboratory. This method is called cross-calibration of field chambers. There are two set-ups available for the cross-calibration of ionisation chambers.

Sequential/Substitution Method: The chambers are compared by placing them at the point z_{ref} inside the water phantom sequentially. The reference ionisation chamber readings are repeated to ensure the radiation beam's stability with time and the stability of the chamber. The tolerance between the initial and repeated measurements is 0.5%.

Side-by-side setup: The ionization chambers are compared by placing them side by side at the same depth in the water phantom and at the same time. The field size selected should be such that there should be at least a 3cm gap from each chamber to the field edge. The chambers need to be swapped in this method, and average reading should be used. This is done to remove the dependencies on the flatness of the beam.

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 $\times$ 10 cm at the plane of the chamber. The measurement depth can be chosen based on the TPR$_{20, 10}$ value as given in the table below.

For the cross-calibration purpose, it is recommended to use the beam quality which is used to calibrate the reference ionisation chamber. If it is not available, then any other beam quality can be used.

The calibration factor in terms of absorbed dose to water for the field chamber is given by

$$N_{D,w,Q_0}^{field} = \frac{D_{w,Q}(z_{ref})}{M_Q^{field} \ k_{Q,Q_0}^{field}} = \frac{\overline{M}_Q^{ref} \ N_{D,w,Q_0}^{ref} \ k_{Q,Q_0}^{ref}}{M_Q^{field} \ k_{Q,Q_0}^{field}}$$

N_{D,w,Q_0}^{field} = The calibration factor/coefficient for the field chamber

N_{D,w,Q_0}^{ref} = The calibration factor/coefficient as provided in the calibration certificate

$\bar{M}_Q^{ref}$ = Average meter reading of the reference ionisation chamber before and after field chamber measurement.

M_Q^{field} = Meter reading of the field ionization chamber (Corrected for all factors)

k_{Q,Q_0}^{ref} = Beam quality factor of reference chamber for beam quality Q_0

k_{Q,Q_0}^{field} = Beam quality factor of field chamber for beam quality Q_0

There are two special cases for which $k_{Q,Q_0}^{ref} = 1$, and $k_{Q,Q_0}^{ref} = 1$.

1. Chamber is cross-calibrated at the same beam quality (Q_0) as the reference chamber.
2. If both the field and reference chamber have the same model number, whatever be the beam quality $k_{Q,Q_0}^{ref} = 1$, and $k_{Q,Q_0}^{ref} = 1$.
3. The above equation reduces to

$$N_{D,w,Q_0}^{field} = \frac{D_{w,Q}(z_{ref})}{M_Q^{field}} = \frac{\bar{M}_Q^{ref} \ N_{D,w,Q_0}^{ref}}{M_Q^{field}}$$

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
$\quad$ T_0 = Reference temperature (20^0C)
$\quad$ P = Pressure at the time of measurement
$\quad$ 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.

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). If you are using the same electrometer for both the chamber, this factor is not needed

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

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

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)

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.

$$k_s = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)}$$

For pulsed beam from a Linear Accelerator the following formula needs to be used.

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

The corrected meter reading after applying all the correction factors is given below.

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

Table for cross-calibration in High Energy Photon beams

Influence Quantity	Reference Value or Characteristics
Phantom material	Water
Chamber type	Cylindrical or plane parallel
Measurement depth, z_{ref}	5 g/cm² (or 10 g/cm²)

Reference point of the chamber	For cylindrical chambers, on the central axis at the center of the cavity volume. For plane-parallel chambers, on the inner surface of the window at its center
Position of the reference point	For cylindrical and plane-parallel chambers, at the measurement depth z_{ref}
SSD or SCD	80 cm or 100 cm
Field size	10 cm $\times$ 10 cm

Procedure:

Here we will use Co-60 based teletherapy unit for the cross-calibration purpose.

1. *For Reference Ionisation Chamber:*

- 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 (The markers are given in the build-up cap given with the chamber).
- Move the ionization chamber to the reference depth/ measurement depth (at 10 cm) from the surface of t water after removing the build-up cap (For variable depth type phantoms). For fixed-type phantoms, the slot is made at the reference depth.
- Adjust the SSD to 80 cm with the help of ODI/Lasers and open the field size to 10cm X 10cm. (Here, we have used 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.
- 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.
- Set the bias voltage on the electrometer to the voltage mentioned in the calibration certificate. Irradiate the chamber for 100 MU and tabulate the meter readings (Charge collected). Take at least three readings to minimize the statistical uncertainty in the measurement.
- Change the bias voltage and polarity and record the readings as shown in the table below.
- Calculate the various correction factors $k_{T,P}$, k_s, k_{pol}, k_{elec} using the formula given above.

2. *For Field Chamber:*
- Remove the reference chamber from the slot and insert the field chamber at the same position. If the chambers are of different size, then the depth of measurement, SSD should be checked.
- Repeat the steps given above and tabulate the readings.

3. *Reference Chamber:*
- Remove the field chamber from the slot and insert the reference chamber at the same position. Verify the SSD and depth of measurement and repeat the procedure as in Sr. No. 1 and tabulate the readings.

4. Calculate the absorbed dose to water for the reference chamber as given in worksheet of IAEA TRS398.

Tabulation:

Reference Chamber: $N_{D,W,Q_0} = 0.04194 \; Gy/nC, \; k_{Q,Q_0} = 1.0$

Bias Voltage (V)	M_{Q1}(nC)	M_{Q2}(nC)	M_{Q3}(nC)	Average (M_{Qunc})(nC)
+300	15.71	15.71	15.72	15.71
+150	15.37	15.38	15.37	15.37
-300	-15.97	-15.98	-15.97	-15.97

M_{unc}	$k_{T,P}$	k_{elec}	k_{pol}	k_s	M_Q
15.71	1.0097	1	1.008	1.0224	16.332

Field Chamber: (T = 23.6 °C, P = 101.7), $k_{Q,Q_0} = 1.0$

Bias Voltage (V)	M_{Q1}(nC)	M_{Q2}(nC)	M_{Q3}(nC)	Average (M_{Qunc})(nC)
+300	2.34	2.34	2.35	2.346
+150	2.32	2.31	2.32	2.326
-300	-2.36	-2.37	-2.37	-2.366

M_{unc}	$k_{T,P}$	k_{elec}	k_{pol}	k_s	M_Q
2.356	1.0085	1	1.0043	1.0084	2.396

Reference Chamber Repeat: (T = 23.5 °C, P = 101.7 kPa)

Bias Voltage (V)	M_{Q1} (nC)	M_{Q2} (nC)	M_{Q3} (nC)	Average (M_{Qunc})(nC)
+300	15.71	15.72	15.72	15.72
+150	15.36	15.37	15.37	15.37
-300	-15.98	-15.98	-15.99	-15.98

M_{unc}	$k_{T,P}$	k_{elec}	k_{pol}	k_s	M_Q
15.72	1.0082	1	1.008	1.0231	16.354

*M_{Qunc} = Uncorrected Meter Reading

*M_Q = Corrected Meter Reading

Calculation:

From the above tabulated data, the Calibration Factor for the field chamber can be calculated as given below.

$$\bar{M}_Q^{ref} = \frac{16.332 + 16.354}{2} = 16.343$$

$$N_{D,w,Q_0}^{field} = \frac{D_{w,Q}(z_{ref})}{M_Q^{field} \ k_{Q,Q_0}^{field}} = \frac{\bar{M}_Q^{ref} \ N_{D,w,Q_0}^{ref} \ k_{Q,Q_0}^{ref}}{M_Q^{field} \ k_{Q,Q_0}^{field}}$$

$$N_{D,w,Q_0}^{field} = \frac{16.343 \ X \ 0.04194 \ X \ 1}{2.396 \ X \ 1} = 0.286 \ Gy/nC$$

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.

5.8. WORKSHEET

Determination of the absorbed dose to water in a ^{60}Co γ ray beam

User: __Radiation Therapy Department__   Date: _____

1. Radiation treatment unit and reference conditions for D_w determination

^{60}Co therapy unit: __Tele cobalt Unit__

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

Reference field size: __10 × 10__ cm × cm   Reference distance: __80__ cm

Reference depth z_{ref}: __10__ g/cm^2

2. Ionization chamber and electrometer

Ionization chamber model: __Farmer 0.6cc__ Serial No.: __123456__ Type: ☑ cyl ☐ pp

Chamber wall/window   material: __Graphite__   thickness: __0.08__ g/cm^2

Waterproof sleeve/cover   material: __PMMA__   thickness: __0.5__ g/cm^2

Phantom window   material: _____ thickness: _____ g/cm^2

Absorbed dose to water calibration factor $N_{D,w}$ = __0.04194__   ☑ Gy/nC ☐ Gy/rdg

Reference conditions for calibration P_o: __101.32__ kPa T_o: __20__ °C Rel. humidity: __50__ %

Polarizing potential V_1: __300__ V Calibration polarity: ☑ +ve ☐ −ve ☑ corrected for polarity

                                    User polarity: ☑ +ve ☐ −ve   effect

Calibration laboratory: _____ Date: _____

Electrometer model: _____ Serial No.: _____

Calibrated separately from chamber: ☐ yes ☑ no   Range setting: _____

  If yes, calibration laboratory: _____ Date: _____

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

Uncorrected dosimeter reading at V_1 and user polarity: __15.71__   ☑ nC ☐ rdg

Corresponding time: __1.__ min

Ratio of dosimeter reading and time[b]: M_1 = __15.463__   ☐ nC/min ☐ rdg/min

(i) Pressure P: __1010.5__ kPa   Temperature T: __25.5__ °C   Rel. humidity (if known): _____ %

$$k_{TP} = \frac{(273.2 + T)}{(273.2 + T_o)} \frac{P_o}{P} = \underline{1.021}$$

(ii) Electrometer calibration factor[c] k_{elec}:   ☐ nC/dg ☐ dimensionless k_{elec} = __1.__

(iii) Polarity correction[d]   rdg at $+V_1$: M_+ = __15.71.__   rdg at $-V_1$: M_- = __15.97__

$$k_{pol} = \frac{|M_+| + |M_-|}{2M} = \underline{1.008}$$

(iv) Recombination correction (two voltage method)

Polarizing voltages: V_1 (normal) = __300__ V V_2 (reduced) = __150__ V

Readings[e] at each V: $M_1 =$ __15.71__ $M_2 =$ __15.37__

Voltage ratio $V_1/V_2 =$ __2__   Ratio of readings $M_1/M_2 =$ __1.022.__

$$k_s = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)} = \underline{1.007}$$

Corrected dosimeter reading at the voltage V_1:

$M = M_1/k_{TP}k_{elec}k_{pol}k_s = $ __16.025__   ☑ nC/min ❑ rdg/min

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

   $D_w(z_{ref}) = M N_{D,w} = $ __0.672__   Gy/min

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

   Depth of dose maximum: $z_{max} = $ __0.5__ g/cm^2

(i) SSD set-up

   Percentage depth dose at z_{ref} for a 10 cm × 10 cm field size: PDD ($z_{ref} = $ __10__ g/cm^2) = __57.74__%

   Absorbed dose rate calibration at z_{max}:

$$D_w(z_{max}) = 100\ D_w(z_{ref})/PDD(z_{ref}) = \underline{1.164}\ \text{Gy/min}$$

(ii) SAD set-up

   TMR at z_{ref} for a 10 cm × 10 cm field size: TMR ($z_{ref} = $ _____ g/cm^2) = _____

   Absorbed dose rate calibration at z_{max}:

$$D_w(z_{max}) = D_w(z_{ref})/\text{TMR}\ (z_{ref}) = \text{_____ Gy/min}$$

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

[b] The timer error should be taken into account. The correction at voltage V_1 can be determined according to

   M_A is the integrated reading in a time t_A $M_A = $ __15.71__ $t_A = $ __1__ min

   M_B is the integrated reading in n short exposures

   of time t_B/n each ($2 \le n \le 5$) $M_B = $ __15.956__ $t_B = $ __1__ min $n = $ __2__

   Timer error, $\tau = \dfrac{M_B t_A - M_A t_B}{n M_A - M_B} = $ __0.016__ min (the sign of τ must be taken into account)

   $M_1 = \dfrac{M_A}{t_A + \tau} = $ __15.463__ ☑ nC/min ❑ rdg/min

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

[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}.

[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}.

[f] It is assumed that the calibration laboratory has performed a recombination correction. Otherwise the factor $k_s' = k_s/k_{s,Q_o}$ should be used instead of k_s. When Q_o is ^{60}Co, k_{s,Q_o} (at the calibration laboratory) will normally be close to unity and the effect of not using this equation will be negligible in most cases.