

Cross-calibration of a Therapy level Dosimeter

(Lab Report)



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1. Aim

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

2. Apparatus Required

- Water/ Slab Phantom
- Ionization Chamber (Field Chamber)
- Ionization Chamber (Reference Chamber)
- Electrometer and Connecting cables
- Thermometer and Barometer

3. Theory

SSDLs (Secondary Standard Dosimetry Laboratories) are places that make sure the radiation measurement tools used in medical treatments are accurate. These tools, like ionization chambers, can vary in size and sensitivity. To make sure these tools give consistent and reliable results, a process called cross-calibration is used. This means comparing different tools to a reference standard to ensure they all measure radiation similarly. Over time, these tools can change, so cross-calibration helps monitor and correct these changes. It's crucial in medical treatments, like radiation therapy, where delivering the right dose is important.

The recommendation is to calibrate these tools in the same conditions as the original calibration. Users can also cross-calibrate their tools using reference chambers with valid calibration certificates. There are two ways to set up this cross-calibration: one involves using the same kind of radiation used in the original calibration, and the other allows users to use available radiation beams at their level. Both methods help ensure that these tools stay accurate over time.

Sequential/Substitution Method: The chambers are compared by placing them at the point z_{ref} inside the water phantom sequentially. The reference ionization 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 3 cm gap from each chamber to the field edge. The chambers need to be swapped in this method, and an average reading should be used. This is done to remove the dependencies on the flatness of the beam.

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

$$N_{D,w,Q_0}^{field} = \frac{D_{w,Q}(z_{ref})}{M_Q^{field} k_{Q,Q_0}^{field}} = \frac{\bar{M}_Q^{ref} N_{D,w,Q_0}^{ref} k_{Q,Q_0}^{ref}}{M_Q^{field} k_{Q,Q_0}^{field}} \quad (1)$$

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

Here, Q_0 is the beam quality used for initial calibration of the chamber and which is Co-60 beam for the chambers used as per their calibration certificates. Q is the user beam quality used for performing the experiment.

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

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

$$k_{Q,Q_0} = \frac{N_{D,w,Q}}{N_{D,w,Q_0}} \quad (2)$$

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.

Here, $TPR_{20,10}$ 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.

So, the calibration factor for the field chamber in terms of absorbed dose to water for user beam quality is given by,

$$N_{D,W,Q_0}^{field} \times k_{Q,Q_0}^{field} = \frac{\bar{M}_Q^{ref} N_{D,W,Q_0}^{ref} k_{Q,Q_0}^{ref}}{M_Q^{field}}$$

$$N_{D,W,Q}^{field} = \frac{\bar{M}_Q^{ref} N_{D,W,Q_0}^{ref} k_{Q,Q_0}^{ref}}{M_Q^{field}} \quad (3)$$

Reference Conditions:

Table 1: Reference conditions for cross-calibration of dosimeters.

Influence Quantity	Reference value or reference characteristics
Phantom material	PMMA (slab phantom)
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 of the chamber	At the measurement depth z_{ref}
SSD/SCD	100 cm
Field Size	10 cm × 10 cm

Air temperature, pressure, and humidity effects ($K_{T,P}$):

Ion chambers used in measuring the absorbed dose are generally vented ion chambers. Thus, the mass of the air inside the sensitive volume of the chamber varies with respect to the density (ρ) and volume (V) i.e. $m = \rho V$. As the volume of the chamber remains constant, the density varies with respect to pressure and temperature.

- If the pressure increases, the density of air increases (by Boyel's law), and the mass of air inside sensitive volume increases; hence, more interaction occurs. This results in more charge collection. The dose measured in this case is overestimated from that measured in standard conditions.

- If the temperature increases, the density of the air inside the sensitive volume decreases (by Charle's law), and the mass of air inside the sensitive volume decreases. This results in less charge collection.

The correction due to temperature and pressure is given by

$$K_{T,P} = \frac{(273.2 + T)}{(273.2 + T_o)} \frac{P_o}{P} \quad (4)$$

Where,

T = Temperature at the time of measurement

T_o = Reference temperature (20°C)

P = Pressure at the time of measurement

P_o = Reference pressure (1013.2 mbar)

T_o and P_o are the temperature and pressure, respectively, at which the chamber is calibrated, and it is mentioned in the calibration certificate.

Here, 273.2 is added to T & T_o to convert °C to kelvin.

Polarity Correction (k_{pol}):

Under identical irradiation conditions, using opposite polarity polarizing potentials in an ionization chamber may result in dissimilar meter readings, known as the polarity effect. With the chamber operating under saturation conditions, major causes of the polarity effects include the following:

- High-energy electrons, like Compton electrons expelled by high-energy photons from the central electrode, form an independent current, the Compton current. This current can increase or decrease the collector current based on electrode polarity. Some electrons might halt in the collector, potentially causing an imbalance not fully offset by recoil electrons. Thinning the collector electrode reduces these effects. For parallel-plate chambers with close electrode spacing, errors from these phenomena are notable. Nevertheless, in such cases, determining the actual ionization current involves averaging two currents achieved by reversing chamber polarity.
- The *extracameral* current collected outside the sensitive volume of the chamber may cause the polarity effect. Such a current may be collected at inadequately screened collector circuit points. In cases where a measurable polarity effect is observed in a chamber used with a specific beam, the real meter reading is determined by calculating the average of the modulus of the values of meter readings taken at the two polarities.

$$K_{pol} = \frac{|M_+| + |M_-|}{2M} \quad (5)$$

M_+ = Electrometer reading with positive bias voltage

M_- = Electrometer reading with negative bias voltage

M = Electrometer reading with the usual bias voltage (used for daily output measurement purposes)

Correction for Ion Recombination/ Saturation (k_s):

An error is introduced due to the incomplete charge collection inside the ionization chamber. The ionic recombination correction factor k_s accounts for the loss of ions in the chamber-sensitive volume due to initial recombination, general recombination, and diffusion against the electric field.

As the voltage difference between the electrodes of an ion chamber exposed to radiation increases, the ionization current increases at first almost linearly and later more slowly. The ionization curve finally approaches a saturation value for the given exposure rate. The initial increase of ionization current with voltage is caused by incomplete ion collection at low voltages. The negative and the positive ions tend to recombine unless they are quickly separated by the electric field. This recombination can be minimized by increasing the field strength. If the voltage is increased much beyond saturation, the ions, accelerated by the electric field, can gain enough energy to produce ionization by collision with gas molecules. This results in a rapid multiplication of ions, and the current, once again, becomes strongly dependent on the applied voltage. The chamber should be used in the saturation region so that small changes in the voltage do not result in changes in the ionic current.

To calculate this correction factor, the two-voltage technique is employed. This method relies on the assumption of a linear relationship between $1/M$ and $1/V$ and involves measuring collected charges,

M_1 and M_2 , at two distinct polarizing voltages, V_1 and V_2 . These measurements are taken under identical irradiation conditions, with V_1 typically representing the standard operating voltage and V_2 being a lower voltage value. It's important to note that for ideal results, the ratio V_1/V_2 should ideally be equal to or greater than 3, although in this particular experiment, the ratio is equal to 2.

For a continuous beam, the formula is:

$$k_s = \frac{(V_1/V_2)^2 - 1}{(V_1/V_2)^2 - (M_1/M_2)} \quad (6)$$

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

$$K_s = a_0 + a_1 \left(\frac{M_N}{M_L} \right) + a_2 \left(\frac{M_N}{M_L} \right)^2 \quad (7)$$

Where M_N and M_L are the chamber signals obtained with the normal applied potential V_N and low applied potential V_L , respectively, and the ratio V_N/V_L was taken to be 2.

According to TRS-398, for $V_N/V_L = 2$, the values of a_0 , a_1 & a_2 are

$$a_0 = 2.337,$$

$$a_1 = -3.636,$$

$$a_2 = 2.299$$

So, Using all these correction factors, the corrected meter readings can be written as,

$$M_Q = M K_{T,P} K_{pol} K_s \quad (8)$$

4. Chamber Specifications

- **Farmer Ionization chamber**

It is a 0.6 cm³ ionization chamber by PTW. The reference point on the chamber axis is 13 mm from the chamber tip.



Materials and Measures

Nominal Sensitive Volume: 0.6 cm³

Acrylic wall, graphited

Aluminum central electrode

Dimensions of sensitive volume : radius

3.05 mm,

Length

23.0 mm

Central electrode

: Al

99.98,

Diameter 1.15 mm

Build-up Cap

: PMMA,

Thickness 4.55 mm

Figure 1: Farmer ionization chamber with its specifications on the right-hand side.

- **Semiflex Ionization Chamber**

It is an ionization chamber with a sensitive volume of 0.07 cm^3 by PTW.



Materials and Measures

Sensitive volume: 0.07 cm^3

Acrylic wall, graphited

Aluminum central electrode

Dimensions of sensitive volume :
radius 2.4 mm,

Length 4.8 mm

Central electrode : Al
99.98,

Diameter 0.8 mm

Build-up Cap :

PMMA,

Thickness 3 mm

Figure 2: Semiflex ionization chamber with its specifications on the right-hand side.

- **Pinpoint Ionization Chamber**

It is an ionization chamber with a sensitive volume of 0.015 cm^3 by PTW.



Figure 3: Pinpoint ionization chamber by PTW dosimetry.

5. Observations

Phantom: Slab phantom

Reference Depth, $z_{\text{ref}} = 10 \text{ g/cm}^2$

Source to surface distance, SSD = 100 cm

Field Size = $10 \text{ cm} \times 10 \text{ cm}$

Photon beam energy: 6MV

Calibration factor of Farmer chamber, $N_{D,w,Q_0} = 5.372 \times 10^7 \text{ Gy/C}$

Farmer chamber beam quality correction factor, $K_{Q,Q_0} = 0.9912$

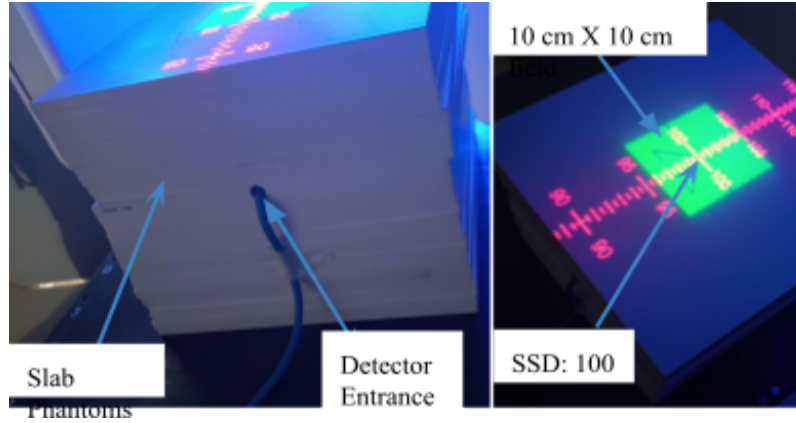


Figure 3: Slab phantom setup for the cross-calibration experiment, a 10 cm x 10 cm field was used for measurements at 100 cm SSD.

Table 2: Observation condition for meter readings collected for reference and field detectors.

Chamber	Voltage (V)	M_1 (nC)	M_2 (nC)	M_3 (nC)	Avg. meter reading (nC)
Reference (Farmer chamber)	400	12.11	12.11	12.11	12.11
	200	12.09	12.1	12.1	12.097
	- 400	-12.13	-12.14	-12.14	-12.137
Field Chamber-1 (Pinpoint chamber)	400	0.282	0.282	0.282	0.282
	200	0.281	0.281	0.281	0.281
	- 400	- 0.284	- 0.285	- 0.285	- 0.2847
Field Chamber-2 (Semi-flex)	400	1.133	1.133	1.133	1.133
	200	1.13	1.131	1.131	1.1307
	- 400	-1.128	-1.128	-1.128	-1.128

Table 3: Table for correction factors and corrected meter readings for reference and field chambers.

Chamber	M_{uncorr} (nC)	k_s	k_{pol}	k_{elec}	M_Q (nC)
Farmer	12.11	1.001	1.0011	1	12.1354
Pinpoint	0.282	1.0035	1.0048	1	0.2843
Semi flex	1.133	1.002	0.9978	1	1.1328

6. Calculations

- For Field Chamber-1 (Pinpoint chamber)

Calibration factor of Farmer chamber, $N_{D,w,Q_0}^{ref} = 5.372 \times 10^7 \text{ Gy/C}$

Farmer chamber beam quality correction factor, $K_{Q,Q_0}^{ref} = 0.9912$

$$\overline{M}_Q^{ref} = 12.1354 \times 10^{-9} \text{ C}$$

$$\overline{M}_Q^{field} = 0.2843 \times 10^{-9} \text{ C}$$

$$N_{D,W,Q}^{field} = \frac{\overline{M}_Q^{ref} N_{D,W,Q_0} k_{Q,Q_0}}{\overline{M}_Q^{field}}$$

$$N_{D,W,Q}^{field} = \frac{12.1354 \times 10^{-9} \times 5.372 \times 10^7 \times 0.9912}{0.2843 \times 10^{-9}}$$

$$N_{D,W,Q}^{field} = 2.2729 \times 10^9 \text{ Gy/C}$$

- **For Field Chamber-2 (Semi-flex)**

Calibration factor of Farmer chamber, $N_{D,w,Q_0}^{ref} = 5.372 \times 10^7 \text{ Gy/C}$

Farmer chamber beam quality correction factor, $K_{Q,Q_0}^{ref} = 0.9912$

$$\overline{M}_Q^{ref} = 12.1354 \times 10^{-9} \text{ C}$$

$$\overline{M}_Q^{field} = 1.1328 \times 10^{-9} \text{ C}$$

$$N_{D,W,Q}^{field} = \frac{\overline{M}_Q^{ref} N_{D,W,Q_0} k_{Q,Q_0}}{\overline{M}_Q^{field}}$$

$$N_{D,W,Q}^{field} = \frac{12.1354 \times 10^{-9} \times 5.372 \times 10^7 \times 0.9912}{1.1328 \times 10^{-9}}$$

$$N_{D,W,Q}^{field} = 5.7042 \times 10^8 \text{ Gy/C}$$

7. Results

- The chamber calibration factor obtained for the Pinpoint Ionization chamber in user beam quality is

$$N_{D,w,Q} = 2.2729 \times 10^9 \text{ Gy/C}$$

- The chamber calibration factor obtained for the Semiflex Ionization chamber in user beam quality is

$$N_{D,w,Q} = 5.7042 \times 10^8 \text{ Gy/C}$$

8. Conclusion

The cross-calibration experiment done on therapy-level radiation measuring devices is crucial for making sure we get accurate and dependable measurements in medical settings. Creating a strong link between these devices and a reference standard is essential to ensure that different devices give

consistent results. This commitment to consistency is vital for maintaining top-notch standards in patient care and safety during radiation therapy.

9. Precautions

- Handle the ionization chamber, phantom, and associated accessories with care.
- Avoid touching the connecting cables when applying a bias voltage to the electrometer.
- Refrain from irradiating the ionization chamber while performing electrometer zeroing.
- Exercise caution to avoid stepping on the connecting cables.

10. References

- CMRP lab manual (3rd semester)
- Technical Reports Series, TRS-398, Absorbed Dose Determination In External Beam Radiotherapy. IAEA. 2006
- Khan FM, Gibbons JP. Khan's the Physics of Radiation Therapy. Fifth edition. Lippincott Williams & Wilkins/Wolters Kluwer; 2014.
- [PTW dosimetry](#)