Basic Principles of Radiation and Calibration of Therapy Units

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Layout

- Radiotherapy beams and sources
- Basic characteristics of photon and electron beams
- Calibration of radiotherapy beams
- Calibration of brachytherapy sources
Radiotherapy
[Treatment (cancer) using radiation]
sealed radioactive sources

Teletherapy
(source is **away** from the patient)
source strength is very high
remote operated

Brachytherapy
(source is **in contact**)
source strength is low
manual/remote operated
Radiotherapy

Beam therapy
- γ-rays
- X-rays
- Electrons
- Protons
- Neutrons
- Heavy ions

Brachytherapy
- HE γ-rays
- LE γ/x-rays
- β-rays
- Neutrons

Conventional/conformal/IM

Single source/multiple source
LDR/MDR/HDR

γ-rays a principal modality of cancer therapy

high and homogenous dose to tumour

Low dose to normal tissue and OAR
kV Therapy Units: First Phase of External Beam Therapy
Telegamma Units

OLD COBALT UNITS

MODERN COBALT UNIT
Telegamma Units (Modern Phase)
Bhabhatron: Indigenous Telecobalt Unit

**Bhabhatron-I**

Prototype version
0x0 to 35x35 cm² field size
NTD = 80 cm

**Bhabhatron-II**

- 0 X 0 Field size
- 3 X 3 Treatable Field
- Fully Computer Controlled
- Carbon Fiber Table Top
- Motorized Wedge
- Asymmetric Collimation
- Remote diagnosis
- Battery Backup
Beam Therapy Delivery Devices

- Gamma Knife
- Conventional Linac
- FFF LINAC
- Hi-Tech Linac
- Hi-Tech Linac
SRS by Gamma Knife
SRS by X-Knife
Brachytherapy

- Clinical use of small encapsulated radioactive sources at a short distance from the target volume for treatment of malignant/benign tumours

- It plays an important role in the management of cancers of several anatomical sites

- Recently, there is a growing interest in using BT for reducing restenosis after treatment for vascular diseases.
Forms of Brachytherapy

Depending on the method of placing the sources
- Interstitial
- Intracavitary
- Surface moulds
- Intraluminal
- Ocular
- Vascular

Depending on the treatment dose rate
- LDR
- MDR
- HDR
- PDR

Temporary
Permanent
Implants
HDR Brachytherapy

- High dose rate (HDR) refers to a dose rate greater than
  - 0.2 Gy/min (ICRU 38, 1985)
  - 0.5 Gy/min (AAPM TG 56, 1997)

- In the past few decades, HDR brachytherapy has been developed as an alternative to LDR brachytherapy.
# Brachytherapy Sources and Delivery Devices

<table>
<thead>
<tr>
<th>γ Emitter</th>
<th>β Emitter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{137}\text{Cs}$</td>
<td>$^{32}\text{P}$</td>
</tr>
<tr>
<td>$^{60}\text{Co}$</td>
<td>$^{90}\text{Sr}/^{90}\text{Y}$</td>
</tr>
<tr>
<td>$^{192}\text{Ir}$</td>
<td>$^{186}\text{Re}$</td>
</tr>
<tr>
<td>$^{125}\text{I}$</td>
<td>$^{188}\text{Re}$</td>
</tr>
<tr>
<td>$^{103}\text{Pd}$</td>
<td>$^{106}\text{Ru}$</td>
</tr>
</tbody>
</table>
Integrated Brachytherapy Unit

Imaging and planning while the patient remains in the treatment position.
Physical characteristics of commonly used $\gamma$ emitting brachytherapy sources

<table>
<thead>
<tr>
<th>Sources</th>
<th>$T_{1/2}$</th>
<th>Energy (MeV)</th>
<th>$\Gamma_x$</th>
<th>$\Gamma_k$</th>
<th>HVL in Water (cm)</th>
<th>HVL in Lead (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Gamma</td>
<td>Beta</td>
<td>Rcm$^2$h$^{-1}$mCi$^{-1}$</td>
<td>$\mu$Gym$^2$h$^{-1}$MBq$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>Co-60</td>
<td>5.26 y</td>
<td>1.25</td>
<td>0.31</td>
<td>13.07</td>
<td>0.308</td>
<td>10.8</td>
</tr>
<tr>
<td>Cs-137</td>
<td>30 y</td>
<td>0.662</td>
<td>0.51-1.17</td>
<td>3.26</td>
<td>0.077</td>
<td>8.2</td>
</tr>
<tr>
<td>Ir-192</td>
<td>73.84 d</td>
<td>0.38 (0.14-1.06)</td>
<td>0.67</td>
<td>4.69</td>
<td>0.111</td>
<td>6.3</td>
</tr>
<tr>
<td>I-125</td>
<td>59.4 d</td>
<td>0.028</td>
<td>-----</td>
<td>1.46</td>
<td>0.034</td>
<td>2.0</td>
</tr>
<tr>
<td>Pd-103</td>
<td>17 d</td>
<td>0.021</td>
<td>-----</td>
<td>1.48</td>
<td>0.035</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Interaction of photon & electron beams

- Interaction of x-rays & gamma rays with matter
  - Photoelectric interaction
  - Compton interaction (scattering)
  - Pair production

- Interaction of beta rays (electrons) with matter
  - Interaction with atomic electrons
  - Interaction with atomic nuclei
Photon Beams: General Description

- All photon beams used for external beam therapy are characterized by the same physical parameters irrespective of their origin, means of production and energy;

- Physical parameters used to describe photon beams are:
  
  Photon fluence and fluence rate
  Energy fluence and fluence rate
  Dose rate in a given condition, etc.
Inverse Square Law & Beam Divergence

- Photon beam sources are assumed to be point sources
- Beams produced are divergent

\[ b = a \left( \frac{f_b}{f_a} \right) \]
Passage Through a Medium

\[ Z_{\text{max}} = \text{depth of dose maximum (} d_m \text{)} \]

\[ D_{\text{max}} = \text{Dose maximum} \]

\[ Z_{\text{ex}} = \text{depth at exit surface (} d_{\text{ex}} \text{)} \]

\[ D_{\text{ex}} = \text{Exit dose} \]

\[ D_{s} = \text{Surface dose} \]
Scattered photons from - collimator, flattening filter and air
Back scattered photons
Secondary electrons - collimator, air & phantom/ patient

Percent Surface Dose of 6 & 18 MV X-rays
Build Up Region:
6 & 18 MV X-rays

(Due to long range of secondary electrons produced by photons)
Depth of dose maximum ($d_m$) and $D_{ex}$

$d_m$ depends on:
Beam energy & Field size
- dependence on beam energy is more pronounced

$D_{ex}$
Dose at exit surface
Depends on beam energy

<table>
<thead>
<tr>
<th>Beam</th>
<th>$d_m$ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>0.5</td>
</tr>
<tr>
<td>4 MV</td>
<td>1.0</td>
</tr>
<tr>
<td>6 MV</td>
<td>1.5</td>
</tr>
<tr>
<td>10 MV</td>
<td>2.5</td>
</tr>
<tr>
<td>15 MV</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Percentage Depth Dose, PDD

\[ P = \frac{D_d}{D_{d_0}} \times 100 \]

\[ d_0 = d_m \]

\[ P = \frac{D_d}{D_{\text{max}}} \times 100 \]
\[ P = \frac{D_d}{D_{\text{max}}} \times 100 \]

**PDD:**
Dependence on SSD

\[ F = \left( \frac{f_2 + d_m}{f_1 + d_m} \right)^2 \times \left( \frac{f_1 + d}{f_2 + d} \right)^2 \]
TPR and TMR

\[ TPR(d, r_d) = \frac{D_d}{D_{t0}} \]

For TPR, \( t_0 = d_{10} \)
For TMR, \( t_0 = dm \)
Properties of TMR

TMR is independent of SSD, increases with energy and field size.

\[ TMR(d, r_d) = \frac{TAR(d, r_d)}{BSF(r_d)} \]

\[ TMR(d,0) = e^{-\mu(d-t_0)} \]

is caused entirely by the primary beam

TMR data for 10 MV x-ray beams

Depth in water
Collimator Scatter Factor ($S_c$)

$S_c = \frac{D(r)}{D(10)}$

**Reference field**

**Build-up cap**

**Mini phantom**

**Square field length (cm)**

$S_{c,\text{open}}$

- 6 MV, $d = 1.5$ cm
- 6 MV, $d = 10$ cm

- 15 MV, $d = 3.0$ cm
- 15 MV, $d = 10$ cm
Phantom Scatter Factor ($S_p$)

$$S_p = \frac{S_{c, p}(r)}{S_c(r)}$$

Graphs showing the total scatter factor ($S_{c, p}$) for different conditions with varying side lengths and SAD.
Photon Beam Penumbra

6 & 18 MV X-rays
Photon Beam: Flatness and Symmetry

- **Flatness**
  - within ±3% over 80% of the field

- **Symmetry**
  - within ±2% over 80% of the field

\[ S = 100 \times \frac{\text{area}_{\text{left}} - \text{area}_{\text{right}}}{\text{area}_{\text{left}} + \text{area}_{\text{right}}} \]
Photon Beam: Isodose Chart

Beam quality

Collimation and flattening filter

Source size, SSD, and SDD

Field size

- $^{60}\text{Co}$, SSD = 80 cm
- 4 MV, SSD = 100 cm
- 10 MV, SSD = 100 cm
Electron Beam: CADD Curves

- Rapid dose fall i.e. very high gradient (G)
- X-ray contamination (0.5 – 5%)
- 90% → E/4 cm   80% → E/3 cm
- Dmax does not follow a linear relationship with energy; depends on machine design and accessories
- The percent surface dose for electrons increases with energy.
- In clinical practice, isodose distributions for an individual machine, cone, and/or field size is required.
\[
\frac{I_0}{I_g} = \left( \frac{f + d_m + g}{f + d_m} \right)^2
\]

\[
\sqrt{\frac{I_0}{I_g}} = \frac{g}{f + d_m} + 1
\]

**SSD_{\text{eff}}**: distance between virtual source position to isocentre

**SSD_{\text{eff}}**: Function of beam energy and field size

ISL can be used to correct absorbed dose for small variations in air gaps between the patient surface and the applicator.
Electron Beam: Range and Energy

\[ G = \frac{R_p}{(R_p - R_q)} \]

\[ E_{p,0} = 0.22 \times 1.98 R_p + 0.0025 R_p^2 \]

\[ \bar{E}_o = C R_{50} \]

\[ \bar{E}_z = \bar{E}_o \left(1 - \frac{z}{R_p}\right) \]

\[ C = 2.33 \text{ MeV cm}^{-1} \]

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>( R_{90} ) (cm)</th>
<th>( R_{80} ) (cm)</th>
<th>( R_{50} ) (cm)</th>
<th>( R_p ) (cm)</th>
<th>( \bar{E}_0 ) (MeV)</th>
<th>Surface dose %</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1.7</td>
<td>1.8</td>
<td>2.2</td>
<td>2.9</td>
<td>5.6</td>
<td>81</td>
</tr>
<tr>
<td>8</td>
<td>2.4</td>
<td>2.6</td>
<td>3.0</td>
<td>4.0</td>
<td>7.2</td>
<td>83</td>
</tr>
<tr>
<td>10</td>
<td>3.1</td>
<td>3.3</td>
<td>3.9</td>
<td>4.8</td>
<td>9.2</td>
<td>86</td>
</tr>
<tr>
<td>12</td>
<td>3.7</td>
<td>4.1</td>
<td>4.8</td>
<td>6.0</td>
<td>11.3</td>
<td>90</td>
</tr>
<tr>
<td>15</td>
<td>4.7</td>
<td>5.2</td>
<td>6.1</td>
<td>7.5</td>
<td>14.0</td>
<td>92</td>
</tr>
<tr>
<td>18</td>
<td>5.5</td>
<td>5.9</td>
<td>7.3</td>
<td>9.1</td>
<td>17.4</td>
<td>96</td>
</tr>
</tbody>
</table>
Electron Beam: Isodose Curves

- Depends on the energy, field size, and collimation

- For the low-energy beams
  - All the isodose curves show some expansion

- For the higher energies
  - Only the low dose levels bulge out
  - Higher isodose levels tend to lateral constriction, which becomes worse with decreasing field size.
The flatness changes with depth

Flatness $< \pm 5\%$ ($\pm 3\%$) over an area confined within lines 2 cm inside the geometric edge of fields

Symmetry $< 2\%$

- Dose difference between points located symmetrically opposite on cross beam profile in the reference plane $< 2\%$
Co-60 Gamma rays: 1.25 MeV

High Energy X-rays: 4, 6, 10, 15, 18 MV

High Energy electrons: 4 - 22 MeV

Proton Beams: All energies

Protocol: IAEA TRS-398

Dosimeter: Ionization chambers
The absorbed dose to water at the reference depth $z_{\text{ref}}$ in water for a reference beam of quality $Q_o$ and in the absence of the ionisation chamber is given by

$$D_{w,Q_0} = M_{Q_0} N_{D,w,Q_0}$$  \hspace{1cm} (1)

where,

$$M_{Q_0} = \text{dosimeter reading under reference conditions}$$

(PRACTICAL CONDITIONS - SAME AS STANDARDS LAB)

$$N_{D,w,Q_0} = \text{absorbed dose to water calibration factor of the dosimeter obtained from standards laboratory}$$

However, other than reference beam quality

$$D_{w,Q} = M_{Q} N_{D,w,Q_0} k_{Q,Q_0}$$  \hspace{1cm} (2)

$$k_{Q,Q_0} = \text{beam quality correction factor (BQCF)}$$
General Practical Considerations

♠ Chamber sleeve: PMMA, Wall thickness ≤ 1.0 mm; Air gap: 0.1-0.3 mm
* sleeve should not be left in water longer than is necessary to carry out the measurements
* The use of a thin rubber sheath is not recommended,

♠ Verify stability of the dosimeter system using a check source

♠ Enough time should be allowed for the dosimeter to reach thermal equilibrium

♠ Mains powered electrometers should be switched on at least two hours before use to allow stabilisation

♠ Pre-irradiate the ionisation chamber with 2 - 5 Gy to achieve charge equilibrium in the different materials

♠ Operate the measuring system under stable conditions whenever the polarity or polarising voltage are modified

♠ Measure the leakage current before and after irradiation(< 0.1%)
Evaluation of Influence Quantities

♦ Atmospheric variations:

* No correction for humidity, if $N_{D,w}$ is referred to a relative humidity (RH) of 50% and is used in 20 - 80% of RH

* If $N_{D,w}$ is referred to dry air, apply $k_h = 0.997$ ($Q_o = ^{60}\text{Co}$)

♦ Polarity effect ($k_{pol}$): true reading is taken to be the mean of the absolute values of readings taken at both polarities

For routine use of a single potential and polarity

Where,

$M = \text{electrometer reading obtained with the polarity used routinely (} + \text{ or } -$)

⇒ For most chamber types, $k_{pol}$ is negligible for photon beams
Evaluation of Influence Quantities

♠ Ion Recombination\( (k_s) \): (two voltage method)

For pulsed beams (Linac X-rays and electrons),

(Based on linear dependence of \( 1/M \) on \( 1/V \))

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

Where,

\( M_1 = \) electrometer reading at polarising voltage \( V_1 \) (Normal Voltage)
\( M_2 = \) electrometer reading at polarising voltage \( V_2 \) (Lower Voltage)
(\( M_1 \) and \( M_2 \) are corrected for \( k_{pol} \) at their respective voltages)
\( a_0, a_1 \) and \( a_2 \) = quadratic fit co-efficients

Ideally, \( V_1/V_2 = 3 \)
Evaluation of Influence Quantities

For continuous radiation ($^{60}$Co gamma rays),

(Based on linear dependence of $1/M$ on $1/V^2$)

\[
k_s = \frac{(V_1 / V_2)^2 - 1}{(V_1 / V_2)^2 - (M_1 / M_2)}
\]
### Reference Conditions

<table>
<thead>
<tr>
<th>Influence quantity</th>
<th>Reference value/characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phantom material</td>
<td>Water</td>
</tr>
<tr>
<td>Chamber type</td>
<td>Cylindrical or plane parallel (PP)</td>
</tr>
<tr>
<td>Measurement depth, $z_{\text{ref}}$</td>
<td>5 or 10 g/cm²</td>
</tr>
<tr>
<td>Reference point of the chamber</td>
<td>For cylindrical chambers, on the central axis at the centre of the cavity volume. For pp chambers, on inner surface of the window at its centre</td>
</tr>
<tr>
<td>Position of the reference point of the chamber</td>
<td>At the measurement depth $z_{\text{ref}}$</td>
</tr>
<tr>
<td>SSD or SCD</td>
<td>80/100 cm</td>
</tr>
<tr>
<td>Field size</td>
<td>10 cm × 10 cm</td>
</tr>
</tbody>
</table>
$^{60}$Co $\gamma$-Rays: Reference Dosimetry

Experimental Set-up: SSD

- 80 cm (SSD)
- 5 cm (depth)
- 10 x 10 cm$^2$

- Electro-meter
- Water Phantom
- Water
- Ion chamber
The absorbed dose to water at $z_{\text{ref}}$ in water, in the user 60Co beam and in the absence of the chamber

$$D_w(z_{\text{ref}}) = MN_{D,w} \quad \text{Gy/min}$$

where,

$$M = \text{reading of the dosimeter corrected for temperature and pressure, electrometer calibration, polarity effect, ion recombination and timer error}$$

$$= M_{\text{unc}} k_{\text{TP}} k_{\text{elec}} k_{\text{pol}} k_{\text{s}} / (t \pm \delta t) \quad t = \text{time of irradiation (min)}$$

Absorbed dose at $z_{\text{max}}$:

For SSD Set-up, $$D_w(z_{\text{max}}) = D_w(z_{\text{ref}}) \times 100 / \text{PDD}(z_{\text{ref}})$$

For SAD Set-up, $$D_w(z_{\text{max}}) = D_w(z_{\text{ref}}) / \text{TMR}(z_{\text{ref}})$$
### $^{60}$Co $\gamma$-Rays: Uncertainty $D_w(z_{\text{ref}})$

<table>
<thead>
<tr>
<th>Physical quantity/ procedure</th>
<th>Rel. Std. uncertainty (%) - typical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{D,w}$ calibration of secondary standard at PSDL</td>
<td>0.5 (A1)</td>
</tr>
<tr>
<td>Long term stability of secondary standard</td>
<td>0.1 (A2)</td>
</tr>
<tr>
<td>$N_{D,w}$ calibration of user dosimeter at SSDL</td>
<td>0.4 (A3)</td>
</tr>
<tr>
<td><strong>Combined uncertainty in $N_{D,w}$ calibration of user dosimeter at SSDL (quadrature sum of A1 to A3)</strong></td>
<td>0.6 (A)</td>
</tr>
<tr>
<td>Long term stability of user dosimeter</td>
<td>0.3 (B_{48})</td>
</tr>
</tbody>
</table>
## Reference Conditions

<table>
<thead>
<tr>
<th>Influence quantity</th>
<th>Reference value/characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phantom material</td>
<td>Water</td>
</tr>
<tr>
<td>Chamber type</td>
<td>Cylindrical</td>
</tr>
<tr>
<td>Measurement depth $z_{\text{ref}}$</td>
<td>For $\text{TPR}_{10}^{20} &lt; 0.7, 10 \ (\text{or 5}) \ \text{g/cm}^2$</td>
</tr>
<tr>
<td></td>
<td>For $\text{TPR}_{10}^{20} = 0.7, 10 \ \text{g/cm}^2$</td>
</tr>
<tr>
<td>Reference point of the chamber</td>
<td>On the central axis at the centre of the cavity volume</td>
</tr>
<tr>
<td>Position of the reference point of the chamber</td>
<td>At the measurement depth $z_{\text{ref}}$</td>
</tr>
<tr>
<td>SSD/SCD</td>
<td>100 cm</td>
</tr>
<tr>
<td>Field size</td>
<td>$10 \ \text{cm} \times 10 \ \text{cm}$</td>
</tr>
</tbody>
</table>
Experimental Set-up: SSD

100 cm (SSD)

10 x 10 cm

Ion chamber

Water Phantom

Water

Electrometer

10 x 10 cm²
HE X-rays: Measurement of QI (TPR\textsuperscript{20,10})

### Reference Conditions

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<td>Water</td>
</tr>
<tr>
<td>Chamber type</td>
<td>Cylindrical or plane parallel (PP)</td>
</tr>
<tr>
<td>Measurement depths</td>
<td>20 and 10 g/cm\textsuperscript{2}</td>
</tr>
<tr>
<td>Reference point of the chamber</td>
<td></td>
</tr>
<tr>
<td>For cylindrical chambers, on the central axis at the centre of the cavity volume. For PP chambers, on the inner surface of the window at its centre</td>
<td></td>
</tr>
<tr>
<td>Position of the reference point of the chamber</td>
<td>At the measurement depths</td>
</tr>
<tr>
<td>SCD</td>
<td>100 cm</td>
</tr>
<tr>
<td>Field size at SCD</td>
<td>10 cm × 10 cm</td>
</tr>
</tbody>
</table>
Experimental Set-up for QI

SCD = 100 cm

Chamber

Water
HE X-rays: Reference Dosimetry

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

$$D_{w,Q}(z_{ref}) = M_Q N_{D,w} k_Q$$ \text{Gy/MU}

$M_Q = M_{unc} k_{TP} k_{elec} k_{pol} k_s$ = Corrected Electrometer reading

Absorbed Dose to water at $z_{max}$

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

$$D_{w,Q}(z_{max}) = 100 \frac{D_{w,Q}(z_{ref})}{TMR (z_{ref})}$$ \text{Gy/MU - SAD}
# HE X-rays: Uncertainty $D_{W,Q}(z_{ref})$

<table>
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<th>Physical quantity/ procedure</th>
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</thead>
<tbody>
<tr>
<td>$N_{D,w}$ calibration of user dosimeter at SSDL</td>
<td>0.6 (A)</td>
</tr>
<tr>
<td>Long term stability of user dosimeter</td>
<td>0.3 (B 1)</td>
</tr>
<tr>
<td>Establishment of reference conditions</td>
<td>0.4 (B 2)</td>
</tr>
<tr>
<td>Dosimeter reading relative to monitor chamber</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Uncertainty of $D_{W,Q}(z_{max})$ can be estimated by including uncertainty of PDD/ TMR.
**HE Electrons: Determination of BQ \( (R_{50}) \)**

**Reference Conditions**

<table>
<thead>
<tr>
<th>Influence quantity</th>
<th>Reference value/characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phantom material</td>
<td>water - ( R_{50} \geq 4 \text{ g/cm}^2 ) ( (E_o \geq 10 \text{ MeV}) )</td>
</tr>
<tr>
<td></td>
<td>water or plastic - ( R_{50} &lt; 4 \text{ g/cm}^2 )</td>
</tr>
<tr>
<td>Chamber type</td>
<td>PP or cylindrical - ( R_{50} \geq 4 \text{ g/cm}^2 )</td>
</tr>
<tr>
<td></td>
<td>Plane parallel (PP) - ( R_{50} &lt; 4 \text{ g/cm}^2 )</td>
</tr>
<tr>
<td>Reference point of the chamber</td>
<td>PP - on the inner surface of the window at its centre</td>
</tr>
<tr>
<td></td>
<td>Cylindrical - on the central axis at the centre of the cavity volume</td>
</tr>
<tr>
<td>Position of the reference point of</td>
<td>PP - at the point of interest</td>
</tr>
<tr>
<td>the chamber</td>
<td>Cylindrical : 0.5 ( r_{cyl} ) deeper than the point of interest</td>
</tr>
<tr>
<td>SSD</td>
<td>100 cm</td>
</tr>
<tr>
<td>Field size at phantom surface</td>
<td>10 cm ( \times ) 10 cm - ( R_{50} \leq 7 \text{ g/cm}^2 )</td>
</tr>
<tr>
<td></td>
<td>20 cm ( \times ) 20 cm - ( R_{50} &gt; 7 \text{ g/cm}^2 )</td>
</tr>
</tbody>
</table>
When using an ionisation chamber, the measured quantity is $R_{50,\text{ion}}$. The $R_{50}$ is obtained using

$$R_{50} = 1.029 \, R_{50,\text{ion}} - 0.06 \, \text{g/cm}^2 \quad (R_{50,\text{ion}} \leq 10 \, \text{g/cm}^2)$$
$$R_{50} = 1.059 \, R_{50,\text{ion}} - 0.37 \, \text{g/cm}^2 \quad (R_{50,\text{ion}} > 10 \, \text{g/cm}^2)$$

When using detectors other ion chambers (e.g. diode, diamond, etc.) the measured quantity is $R_{50}$
## HE Electrons: Reference Dosimetry

### Reference Conditions

<table>
<thead>
<tr>
<th>Influence quantity</th>
<th>Reference value/characteristic</th>
</tr>
</thead>
</table>
| Phantom material         | water - $R_{50} \geq 4$ g/cm$^2$ ($E_o \geq 10$ MeV)  
                          | water or plastic - $R_{50} < 4$ g/cm$^2$ |
| Chamber type             | PP or cylindrical - $R_{50} \geq 4$ g/cm$^2$  
                          | Plane parallel (PP) - $R_{50} < 4$ g/cm$^2$ |
| Measurement depth $z_{ref}$ | $= (0.6 \, R_{50} - 0.1)$ g/cm$^2$ |
| Reference point of the chamber | PP - on the inner surface of the window at its centre  
                                   | Cylindrical - on the central axis at the centre of the cavity volume |
| Position of the reference point of the chamber | PP - at $z_{ref}$  
                                   | Cylindrical : $0.5 \, r_{cyl}$ deeper than $z_{ref}$ |
| SSD                      | 100 cm                        |
| Field size at phantom surface | $10 \times 10$ cm or that used for normalisation of output factors |
HE Electrons: Reference Dosimetry

Experimental Set-up : SSD

100 cm (SSD)

10 x 10 cm²

Electro-meter

Water Phantom

Water

PP chamber

\[ z_{\text{ref}} = (0.6 \, R_{50} - 0.1) \]
Absorbed dose to water at the reference depth $z_{\text{ref}}$

$$D_{w,Q}(z_{\text{ref}}) = M_Q N_{D,w} k_Q \quad \text{Gy/MU}$$

$$M_Q = M_{\text{unc}} k_T p k_{\text{elec}} k_{\text{pol}} k_s = \text{Corrected Electrometer reading}$$

Absorbed Dose to water at $z_{\text{max}}$

$$D_{w,Q}(z_{\text{max}}) = 100 \frac{D_{w,Q}(z_{\text{ref}})}{\text{PDD}(z_{\text{ref}})} \quad \text{Gy/MU - SSD}$$
The use of plastic phantom is strongly discouraged, as in general they are responsible for the largest discrepancies in the determinations of absorbed dose in electron beams.

Nevertheless, when accurate chamber positioning in water is not possible, or when no waterproof chamber is available, their use is permitted.

Plastic phantoms may only be used at beam qualities $R_{50} < 4 \text{ g/cm}^2$ ($E_0 < 10 \text{ MeV}$).

Depth scaling

$$z_w = z_{pl} \times c_{pl} \frac{\text{g/cm}^2}{z_{pl} \text{ in g/cm}^2}$$

BQI

$$R_{50,\text{ion}} = R_{50,\text{ion,pl}} \times c_{pl} \frac{\text{g/cm}^2}{R_{50,\text{ion,pl}} \text{ in g/cm}^2}$$

Reference Depth

$$z_{ref,pl} = z_{ref} / c_{pl} \frac{\text{g/cm}^2}{z_{ref} \text{ in g/cm}^2}$$

$D_w$

$$M_Q = M_{Q,pl} \times h_{pl}$$
**HE Electrons: Uncertainty $D_{W,Q}(z_{ref})$**

<table>
<thead>
<tr>
<th>Physical quantity/ procedure</th>
<th>Rel. Std. uncertainty (%)</th>
<th>Cyl. Chamber</th>
<th>PP Chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{D,w}$ calibration of user dosimeter at SSDL (A)</td>
<td></td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Long term stability of user dosimeter (B1)</td>
<td></td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Establishment of reference conditions (B2)</td>
<td></td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Dosimeter reading relative to monitor chamber (B3)</td>
<td></td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Correction for influence quantities (B4)</td>
<td></td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Uncertainty of $D_{W,Q}(z_{max})$ can be estimated by including uncertainty of PDD**

Combined uncertainty in $D_{W,Q}(z_{max})$ can be estimated by including uncertainty of PDD
Calibration of Brachytherapy Sources

Quantity: RAKR/ AKS

Method: IAEA TECDOC 1274

Detector: Ionization chamber
   - Well Type Chamber
   - Cylindrical Chamber
Source Strength Specification: BCRU/ ICRU

Reference Air Kerma Rate (RAKR)

Defined as Kerma Rate to air measured in air at a reference distance of 1 meter along the transverse bisector of the source corrected for air attenuation and scattering.

The recommended unit of RAKR is $\mu$Gy$h^{-1}$. 
Air Kerma Strength (AKS)

\[ S_k = K_{\text{air}}(d)d^2 \mu \text{Gy}m^2h^{-1} (\text{cGy}cm^2h^{-1}) = 1\text{U} \]

- RAKR does not have the dimensions of a Kerma rate - lead to confusion in teaching and clinical use

- Recommendations agree with BCRU and ICRU in that the source strength is specified directly in terms of AKR in free space at one meter (i.e. RAKR)
Methods of Source Calibration at Hospitals

(1) Well type ionization chamber

LDR sources ($^{137}$Cs, $^{192}$Ir wires/seeds, $^{125}$I seeds),

HDR sources ($^{192}$Ir, $^{60}$Co)

(2) Cylindrical ionization chamber

- in air
- in phantom

HDR sources ($^{192}$Ir, $^{60}$Co)
Calibration using well type chamber

\[ RAKR = M \, K_{t,p} \, K_{\text{recom}} \, N_{\text{elec}} \, N_{K,RAKR,s} \]

\[ AKS = M \, K_{t,p} \, K_{\text{recom}} \, N_{\text{elec}} \, N_{K,AKS,s} \]

\[ M = \text{Meter reading} = \text{Average current (or charge)} \]

\[ K_{t,p} = \text{Temperature & pressure correction factor} \]

\[ K_{t,p} = \frac{(273.15 + t) \times 1013.2}{(273.15 + t_0) \times P} \]
Calibration using well type chamber - contd.

\[ \frac{1}{k_{\text{recom}}} = \frac{4}{3} \left[ \frac{Q_1}{3 - Q_2} \right] \]

where

\( Q_1 \) = charge collected at higher voltage (300 V)
\( Q_2 \) = charge collected at lower voltage (150 V)

\( N_{\text{elec}} = \text{electrometer cal. factor} \)

\( N_{K,\text{RAKR},s} \left( N_{K,\text{AKS},s} \right) = \text{chamber cal. factor in terms of} \)

\( \text{RAKR (AKS) for the given source } s \)

\( \text{(given by Standard laboratory)} \)
HDR-1000 Well Type Ionization Chamber & Electrometer
Response Graphs: HDR Ir-192 and LDR Cs-137 tube (BARC)
Calibration of $\mu$-Selectron HDR $^{192}$Ir Source
## Uncertainty in RAKR Measurement of HDR Ir-192 Source: Well Chamber method

<table>
<thead>
<tr>
<th>Uncertainty component</th>
<th>Rel. Std. uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type A</td>
</tr>
<tr>
<td>RAKR calibration by the SSDL (1 σ)</td>
<td></td>
</tr>
<tr>
<td>Stability of the well type chamber</td>
<td>0.3</td>
</tr>
<tr>
<td>Electrometer reading relative to timer</td>
<td>0.3</td>
</tr>
<tr>
<td>Correction for influence quantities</td>
<td>0.2</td>
</tr>
<tr>
<td>Recombination correction</td>
<td></td>
</tr>
<tr>
<td>Half life of Ir-192 source</td>
<td></td>
</tr>
<tr>
<td>Square sum</td>
<td>0.47</td>
</tr>
<tr>
<td>Total Combined standard uncertainty (1 σ)</td>
<td></td>
</tr>
</tbody>
</table>
Questions

Thank you