Overview

• Math Concepts
• Definitions
• MU Calculations
What are we calculating?

- Divergence Formula – spreading out of the radiation beam
  - calculates the **SIZE** of the radiation field

- Inverse Square Formula – helps us calculate the **INTENSITY** (dose/quantity) of a radiation beam
Increasing Distance from Source

- **Increase Field Size** --- Direct Proportion
- **Decrease Intensity** --- Indirect Proportion

**Divergence Formula**

(Direct Proportion)

\[
\begin{align*}
\text{Field width}_1 &= \text{distance}_1 \\
\text{Field width}_2 &= \text{distance}_2 \\
\text{Field length}_1 &= \text{distance}_1 \\
\text{Field length}_2 &= \text{distance}_2
\end{align*}
\]
If the field size is 10x15 at 100cm, what is it on a port film at 125cm?

**Divergence**

Field Size on portal film at 125cm

\[
\begin{align*}
\text{Field width}_1 &= \frac{\text{distance}_1}{100} \times 125 \\
\text{Field width}_2 &= \frac{\text{distance}_2}{125} \\
\text{Field length}_1 &= \frac{\text{distance}_1}{100} \times 125 \\
\text{Field length}_2 &= \frac{\text{distance}_2}{125}
\end{align*}
\]

\[x = 12.5 \quad y = 18.75\]

Setup for Entire Femur

*Largest field length at 100cm is 40cm*

- Need 50cm length
- What would be the SSD required?
Setup for Entire Femur

Largest field length at 100cm is 40cm

- Need 50cm length
- What would be the SSD required?

\[
\frac{40\text{cm}}{50\text{cm}} = \frac{100\text{cm}}{??} \]

?? = 125cmSSD

Divergence

Skin surface

Overlap
Gap Problem

\[ \text{Gap} = \left( \frac{\text{field size}_1 \times \text{depth}}{2 \text{ SSD}} \right) + \left( \frac{\text{field size}_2 \times \text{depth}}{2 \text{ SSD}} \right) \]

(***This formula “uses” symmetric jaws dimensions***)

What is the gap needed between two adjacent fields to a depth of 6cm. The field lengths of the fields are 8cm and 20cm, respectively at 100cm SSD?

\[
\text{Gap} = \left( \frac{8 \times 6}{2 \times 100} \right) + \left( \frac{20 \times 6}{2 \times 100} \right) \\
= \left( \frac{4 \times 0.06}{100} \right) + \left( \frac{10 \times 0.06}{100} \right) \\
= 0.24 + 0.6 \\
= 0.84\text{cm}
\]

(Image from Stanton & Stinson p 242
*Applied Physics for Radiation Oncology* Revised Edition)

Feathering
Initial Plan

2nd Plan - Feathered 1cm inferiorly

3rd Plan - Feathered additional 1cm inferiorly

Feathering - CSI

NO Feathering

Green = 3000cGy

Used w/ permission TJU Graduate MD Student
Inverse Square Law
states that the intensity is inversely proportional to the square of the distance from the source.
**Dose at Another Distance**

**Inverse Square Formula**

\[
\frac{\text{Intensity}_1}{\text{Intensity}_2} = \frac{(\text{Distance}_2)^2}{(\text{Distance}_1)^2}
\]

OR

\[
\frac{(\text{Distance where Intensity is KNOWN})^2}{(\text{Distance where Intensity is UNKNOWN})^2} \times \text{Intensity}
\]

If the Intensity at 100cm is 200cGy, what is the Intensity at 50cm?
Inverse Square Problem

• If the Intensity at 100cm is 200cGy, what is the Intensity at 50cm?

\[
\frac{\text{Intensity}_1}{\text{Intensity}_2} = \left(\frac{\text{Distance}_2}{\text{Distance}_1}\right)^2
\]

\[
\frac{200\text{cGy}}{x} = \left(\frac{50}{100}\right)^2
\]

Intensity at 50cm = 800cGy
Inverse Square Problem

- If the Intensity at 100cm is 200cGy, what is the Intensity at 50cm?

\[
\frac{\text{Intensity}_1}{\text{Intensity}_2} = \left(\frac{\text{Distance}_2}{\text{Distance}_1}\right)^2
\]

\[
200\text{cGy} = \frac{(50)^2}{(100)^2} \times \text{Intensity at 50cm} = 800\text{cGy}
\]

\[
\frac{(100)^2}{(50)^2} \times 200\text{cGy} = \text{Intensity at 50cm} = 800\text{cGy}
\]
Definitions

Basic Concepts

Equivalent Square

Isocenter

Point around which a gantry rotates
Intersection of the collimator axis and the axis of rotation
Point within the patient or on the patient’s skin
SSD

SSD – SOURCE TO SKIN DISTANCE
Field size is defined at SKIN surface

SAD

SAD – SOURCE TO AXIS DISTANCE
SSD + depth = SAD  Field size is defined at Isocenter
92 + depth = 100
Bolus

- Tissue Equivalent Material

- Same density

- Same Z

- Examples:
  Water, rice, wax, brass mesh, superflab, superstuff

Half Value Layer

- **Half Value Layer** - HVL – 1913 – used to describe *quality of x-rays*

- Some thickness of material which will decrease the beam *intensity* by HALF
Can Swing Over Short

- **Grenz Ray**—≤ 10-15 KvP  HVL in mm AL
- **Contact Therapy**—40-50 KvP  HVL mm AL
- **Superficial**—50-150 KvP  HVL in mm AL
- **Orthovoltage**—1921  150-500 KvP  HVL in mm Cu

uses Thoreaus filter – Tin, Copper, Aluminum from tube to patient

- **Supervoltage**—500-1000 KvP
- **Megavoltage**—1961 ≥ 1000 KvP  HVL in mm Pb

---

**D/Max** — depth of maximum ionization

![Diagram showing D/Max](image)

**Figure 9.03.** Simplified diagram showing the comparative electron buildup regions for radiation of various energies.

Image from Selman’s “The Basic Physics of Radiation Therapy” 2nd edition
Some D/Max Depths to Know

<table>
<thead>
<tr>
<th>Beam Energy</th>
<th>D/Max Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt 60</td>
<td>.5cm</td>
</tr>
<tr>
<td>4Mv</td>
<td>1.0cm</td>
</tr>
<tr>
<td>6Mv</td>
<td>1.5cm</td>
</tr>
<tr>
<td>10Mv</td>
<td>2.5cm</td>
</tr>
<tr>
<td>18Mv</td>
<td>3.5cm</td>
</tr>
</tbody>
</table>

Remember: D/max Depth is Primarily dependent on **Beam Energy**

---

**f Factor**

- Roentgen (exposure in air) to cGy (absorbed dose) conversion factor
- Dependent on: **Beam Energy and density of material**

<table>
<thead>
<tr>
<th>Description</th>
<th>Photon Energy</th>
<th>f&lt;sub&gt;med&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional x-rays</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gen-X rays</td>
<td>0.909</td>
<td>0.912</td>
</tr>
<tr>
<td>30 keV</td>
<td>0.883</td>
<td>0.914</td>
</tr>
<tr>
<td>100 keV</td>
<td>0.956</td>
<td>0.956</td>
</tr>
<tr>
<td>Co-137</td>
<td>0.971</td>
<td>0.962</td>
</tr>
<tr>
<td><strong>Megavoltage x-rays</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 MeV</td>
<td>0.970</td>
<td>0.961</td>
</tr>
<tr>
<td>Co-60</td>
<td>0.967</td>
<td>0.958</td>
</tr>
<tr>
<td>1.5 MeV</td>
<td>0.973</td>
<td>0.962</td>
</tr>
<tr>
<td>5 MeV</td>
<td>0.938</td>
<td>0.948</td>
</tr>
<tr>
<td>10 MeV</td>
<td>0.945</td>
<td>0.933</td>
</tr>
<tr>
<td>100 MeV</td>
<td>0.888</td>
<td>0.873</td>
</tr>
</tbody>
</table>
f factor Problem

- For 100Kev photons, what is the dose delivered to muscle if the exposure to that muscle is 100R?

\[
\text{Dose}_{\text{muscle}} = \text{Exposure} \times f_{\text{muscle}}
\]

\[
= 100 \text{R} \times 0.956
\]

\[
= 95.6 \text{ cGy}
\]
Monitor Unit Calculations

• MU = Unit of Output Measure for Linear Accelerator

• Specific number of MUs needed for EACH patient’s treatment

• Dependent on: Machine
  - dose - Field Size - depth - Beam Energy - MLC

• Data for the Machine is given in SQUARE field sizes

Equivalent Square

Find the equivalent square for a rectangular treatment field

\[
\text{Sterling's Formula} \quad FS_{eq} = 4 \cdot \frac{\text{Area}}{\text{Perimeter}}
\]
Example 1

\[ FS_{eq} = 4 \cdot \frac{\text{Area}}{\text{Perimeter}} \]

\[ L \times W \]

\[ \text{or sum of sides} \]

\[ \frac{10 \times 14}{2(10 + 14)} = \frac{140}{48} = 2.917 \]

\[ 4 \times 2.917 \]

\[ FS_{eq} = 11.667 \text{ cm} \]

Example 2

\[ FS_{eq} = 4 \cdot \frac{\text{Area}}{\text{Perimeter}} \]

\[ \text{L} \times \text{W (of whole rectangle)} - \text{(area of blocks)} \]

\[ \frac{2(L + W)}{2(L + W) \text{ or sum of sides}} \]

\[ \text{Area} = (10 \cdot 14) - (2 \cdot 2) - (3 \cdot 3) \]

\[ \text{Perimeter} = 8 + 2 + 2 + 12 + 7 + 3 + 3 + 11 \]

\[ FS_{eq} = 4 \cdot \frac{127}{48} \]

\[ FS_{eq} = 10.58 \text{ cm} \]
### Calculations

#### Monitor Unit

- PDD
- TAR / TMR

#### Irregular Field

- Irregular Field (Clarkson)

---

**Percentage Depth Dose (PDD or %DD)**

Ratio of Dose at Depth compared to the dose at D/Max expressed as a percentage

![Diagram of Percentage Depth Dose](image)
PDD at D/Max for ANY field Size, SSD, Beam Energy is 100% = 1.00 (decimal form)

Percentage Depth Dose (PDD or %DD)
Ratio of Dose at Depth compared to the dose at D/Max expressed as a percentage

What IF:
220cGy at D/max depth
What is PDD value?
220cGy/220cGy = 1.00
Factors Affecting PDD

- Beam Energy - \( \uparrow \) Energy \( \rightarrow \) PDD
- Field Size – \( \uparrow \) FS \( \rightarrow \) PDD
- Source to Skin Distance - \( \uparrow \) SSD \( \rightarrow \) PDD

(Mayneord’s F Factor)

- Go deeper into patient \( \downarrow \) PDD
# Table 11-7

## Increasing FS -> Increases PDD

### PDD Table for 6Mv

<table>
<thead>
<tr>
<th>Beam Energy</th>
<th>dmax(cm)</th>
<th>PDD d10</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25 MeV</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1.25 MeV</td>
<td>0.5</td>
<td>56</td>
</tr>
<tr>
<td>4 MV</td>
<td>1.0</td>
<td>60</td>
</tr>
<tr>
<td>6 MV</td>
<td>1.5</td>
<td>67</td>
</tr>
<tr>
<td>10 MV</td>
<td>2.5</td>
<td>73</td>
</tr>
<tr>
<td>18 MV</td>
<td>3.5</td>
<td>80</td>
</tr>
</tbody>
</table>

---

**Beam Energy**

- **Beam Energy**: The energy of the beam used in radiation therapy.
- **dmax(cm)**: The depth at which the maximum dose is delivered.
- **PDD d10**: The percentage depth dose at 10 cm SSD.
### Percentage Depth Dose

(PDD or %DD)

Ratio of Dose at Depth compared to the dose at D/Max expressed as a percentage

---

#### Source of radiation

D<sub>max</sub>

---

#### Depth

**Increasing depth in patient $\rightarrow$ Decreases PDD**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>PDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>100.0%</td>
</tr>
<tr>
<td>0.1</td>
<td>99.7%</td>
</tr>
<tr>
<td>0.2</td>
<td>99.5%</td>
</tr>
<tr>
<td>0.3</td>
<td>99.3%</td>
</tr>
<tr>
<td>0.4</td>
<td>99.1%</td>
</tr>
<tr>
<td>0.5</td>
<td>98.9%</td>
</tr>
<tr>
<td>0.6</td>
<td>98.7%</td>
</tr>
<tr>
<td>0.7</td>
<td>98.5%</td>
</tr>
<tr>
<td>0.8</td>
<td>98.3%</td>
</tr>
<tr>
<td>0.9</td>
<td>98.1%</td>
</tr>
<tr>
<td>1.0</td>
<td>97.9%</td>
</tr>
</tbody>
</table>

**Ion Chamber is MOVED at different distances from radiation source**

---

**Table 11-7**

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>PDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>100.0%</td>
</tr>
<tr>
<td>0.1</td>
<td>99.7%</td>
</tr>
<tr>
<td>0.2</td>
<td>99.5%</td>
</tr>
<tr>
<td>0.3</td>
<td>99.3%</td>
</tr>
<tr>
<td>0.4</td>
<td>99.1%</td>
</tr>
<tr>
<td>0.5</td>
<td>98.9%</td>
</tr>
<tr>
<td>0.6</td>
<td>98.7%</td>
</tr>
<tr>
<td>0.7</td>
<td>98.5%</td>
</tr>
<tr>
<td>0.8</td>
<td>98.3%</td>
</tr>
<tr>
<td>0.9</td>
<td>98.1%</td>
</tr>
<tr>
<td>1.0</td>
<td>97.9%</td>
</tr>
</tbody>
</table>

---

**Figure 11-7**

**Percentage Depth Dose (PDD or %DD)**

Ratio of Dose at Depth compared to the dose at D/Max expressed as a percentage.

---

**Legend**

- Ion Chamber is MOVED at different distances from radiation source.

---

**Note:**

- All values are approximate and subject to variation.

---

**Source:**

- [Reference](https://example.com)
Mayneord’s F Factor

Source to Skin Distance - \( \uparrow \) SSD \( \rightarrow \) \( \uparrow \) PDD  (Mayneord’s F Factor)

- This is used when there is a change in the SSD from the chart. It is an application of the **INVERSE SQUARE LAW** !

- \( F = \frac{(SSD \text{ from chart} + \text{depth})^2 \times (\text{Treatment SSD} + \text{D/Max})^2}{(SSD \text{ from chart} + \text{D/Max})^2 \times (\text{Treatment SSD} + \text{depth})^2} \) 

- \( F \times \%\text{DD value from chart} = \%\text{DD at Treatment SSD} \)

---

**Mayneord’s F Factor Problem for 6Mv**

- Calculate the adjusted PDD value for a Co machine using a treatment SSD of 110cm for a field size of 10x10 depth 5cm

****DO PROBLEM****
Mayneord’s F Factor Problem for 6Mv

Calculate the adjusted PDD value for a Co machine using a treatment SSD of 110cm for a field size of 10x10 depth 5cm.

Using Mayneord’s F Factor

15x15 at 8cm depth @125SSD =

\[ F = \frac{(108.0)^2}{(101.5)^2} \times \frac{(126.5)^2}{(133.0)^2} = 1.0242 \]

\[ F \times \%DD@100\text{cm SSD} = \%DD@125\text{cm SSD} \]

\[ 1.0242 \times 76.8 = 78.7 \]
Monitor Unit Calculations Using PDD

Monitor Unit =

Tumor Dose

Reference Dose Rate x Sc x Sp x PDD x (any other absorption factors) x (IDL)
(at distance of Rx SSD + D/Max)
Monitor Unit Calculations Using PDD

**SOURCE**

SSD

Reference Dose Rate at SSD + D/Max

Field Size measured on SKIN

**Reference Field Size generally 10x10**

---

**Scatter (Output) Factor**

- This factor adjusts the machine output when the Treatment Field Size is “different” than 10x10
- If the Field Size is greater than 10x10, the Output Factor will be GREATER than 1.0 (more scatter)
- If the Field Size is smaller than 10x10, the Output Factor will be Less than 1.0 (less scatter)
- The Output Factor can be subdivided into Collimator Scatter (Sc) and Phantom Scatter (Sp)

**Tumor Dose**

Reference Dose Rate $\times$ Sc $\times$ Sp $\times$ PDD $\times$ (any other absorption factors)

(at distance of Rx SSD + D/Max)
Monitor Unit Calculations Using PDD

Monitor Unit =

Tumor Dose

Reference Dose x Sc x Sp x PDD x (any other factors as needed)

Rate (at distance of Rx SSD + D/Max)
PDD Monitor Unit Problem for 6Mv Linear Accelerator

Calculate the MU necessary to deliver:
- 200cGy to a depth of 3cm
- (PDD value = 95.1%)
- 10x10 field size - 100cmSSD
- 6Mv Linear Accelerator
- Reference Dose Rate at 101.5cm from source is 1.0cGy/monitor unit

---

Scatter Factor Tables

10x10 Reference Field Size

Table 24-4

<table>
<thead>
<tr>
<th>Scattering Factor</th>
<th>(Sc, Sp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 MV</td>
<td>0.0001</td>
</tr>
<tr>
<td>18 MV</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

---

Table from Washington & Leaver
PDD Monitor Unit Problem for 6MV

200cGy

\[
\frac{200cGy}{MU} \times 1.0 \times 1.0 \times 0.951 = 210.3 \text{ MU}
\]
Dose to Another Point Using PDD

- To calculate the dose at some point along the central axis – use direct proportion.

\[
\text{Dose at Point A} = \frac{\text{Dose at Point B}}{\% \text{DD at Point A}} \\
\text{Problem: For a 6Mv beam, what is the dose to the depth of 5cm when the dose at 3cm is 200cGy?}
\]

- %Dd value at D3 = .951
- %Dd value at D5 = .871

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>PDD at D3</th>
<th>PDD at D5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>0.5</td>
<td>0.9924</td>
<td>0.9924</td>
</tr>
<tr>
<td>1.0</td>
<td>0.9951</td>
<td>0.9951</td>
</tr>
<tr>
<td>1.5</td>
<td>0.9974</td>
<td>0.9974</td>
</tr>
<tr>
<td>2.0</td>
<td>0.9992</td>
<td>0.9992</td>
</tr>
<tr>
<td>2.5</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
<tr>
<td>3.0</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
<tr>
<td>3.5</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
<tr>
<td>4.0</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
<tr>
<td>4.5</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
<tr>
<td>5.0</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
</tbody>
</table>

\[
\text{Table 11-7} \\
6 \text{ MV percentage depth dose at 100 cm SSD}
\]

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>PDD at D3</th>
<th>PDD at D5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>0.5</td>
<td>0.9924</td>
<td>0.9924</td>
</tr>
<tr>
<td>1.0</td>
<td>0.9951</td>
<td>0.9951</td>
</tr>
<tr>
<td>1.5</td>
<td>0.9974</td>
<td>0.9974</td>
</tr>
<tr>
<td>2.0</td>
<td>0.9992</td>
<td>0.9992</td>
</tr>
<tr>
<td>2.5</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
<tr>
<td>3.0</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
<tr>
<td>3.5</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
<tr>
<td>4.0</td>
<td>0.9999</td>
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</tr>
<tr>
<td>4.5</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
<tr>
<td>5.0</td>
<td>0.9999</td>
<td>0.9999</td>
</tr>
</tbody>
</table>
Dose at Another Depth

**Hint:** Since 5cm depth is further *away* from the source, the dose would be *less* than the dose at 3cm.

---

**Diagram:**
- Dose at 3cm: 200cGy, PDD = 0.951
- Dose at 5cm: ??cGy, PDD = 0.871

---

**Calculation:**
- PDD value at D3 = 0.951
- PDD value at D5 = 0.871

\[
\frac{200 \text{cGy}}{0.951} = \frac{x}{0.871}
\]

Solving for x:
- \( x = 183.176 \text{ cGy} \)
Dose at Another Depth

Hint: Since 5cm depth is further away from the source, the dose would be less than the dose at 3cm.

• Problem: For a 6Mv beam, what is the dose to the D/Max when the dose at 3cm is 200cGy?

• PDD value at D3 = .951

• Dose at D3 = Dose at D/Max
  PDD at D3 = PDD at D/Max
Dose at Another Depth

Hint: Since 1.5cm depth (D/max depth for 6MV) is closer \textbf{TOWARDS} the source, the dose would be \textbf{MORE} than the dose at 3cm.

\[ \text{PDD at D}_3 = 0.951 \]

\[ \text{PDD at D/Max} = 1.00 \]

\[ \frac{200\text{cGy}}{0.951} = \frac{x}{1.00} \]

\[ x = 210.305 \text{ cGy} \]
Dose at Another Depth

Hint: Since 1.5cm depth (D/max depth for 6MV) is closer to the source, the dose would be **MORE** than the dose at 3cm

![Diagram showing dose at different depths and SSD](image-url)
Tissue to Air Ratio (TAR)

- Developed by Johns to be used in Rotational Therapy - better skin tolerance
- Rotational Therapy has the gantry moving DURING the treatment – while the beam is ON.

- A full $360^0$ treatment is called a “Rotation”
- Any treatment $< 360^0$ is called an “arc”

In Rotational Treatments, SSD changes as Gantry rotates
Tissue Air Ratio (TAR)

TAR at D/Max is also called **Back Scatter Factor**

*Ratio of dose with scattering medium to dose at same point in “air” without a scattering medium*

**Factors Affecting TAR**

- Field Size – ↑FS →↑TAR
- Beam Energy - ↑Energy →↑TAR
- Go deeper into patient - ↓TAR
  - ****Source to Skin Distance **DOES NOT AFFECT** TAR (~2% accuracy)****
**6Mv TAR**

**Notice --- NO SSD label**

<table>
<thead>
<tr>
<th>0</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>22</th>
<th>24</th>
<th>26</th>
<th>28</th>
<th>30</th>
<th>32</th>
<th>35</th>
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<tbody>
<tr>
<td>1</td>
<td>2.0</td>
<td>2.4</td>
<td>2.8</td>
<td>3.2</td>
<td>3.6</td>
<td>4.0</td>
<td>4.4</td>
<td>4.8</td>
<td>5.2</td>
<td>5.6</td>
<td>6.0</td>
<td>6.4</td>
<td>6.8</td>
<td>7.2</td>
<td>7.6</td>
<td>8.0</td>
<td>8.4</td>
<td>8.8</td>
<td>9.2</td>
<td>9.6</td>
<td>10.0</td>
<td>10.4</td>
<td>10.8</td>
<td></td>
</tr>
</tbody>
</table>

---

**BSF is NOT affected by SSD (readings at ion chamber)**

| 100cm | Dose in free space: 100cGy | Dose in phantom: 120cGy |
| 64cGy | BSF = 120/100 = 1.2 |
| 76.8cGy | BSF = 76.8/64 = 1.2 |
Monitor Unit Calculations Using **TAR**

**Machine Output AND Field Size measured at Treatment SAD**

TAR Monitor Unit Calculations for 6Mv Linear Accelerator

Calculate the Monitor Unit necessary to deliver:

- 180cGy to a 5cm depth   TAR at D5 = 95.2%
- 10x10 field size   100cmSAD
- 6Mv Linear Accelerator
- Machine output at 100cm from source is 1cGy/MU
Monitor Unit Calculation Using TAR

Monitor Unit =

Tumor Dose

\[
\text{TAR Monitor Unit Calculations for 6Mv Linear Accelerator}
\]

\[
\frac{180}{1.0 \text{cGy/MU} \times 1.0 \times .952 \times \text{TAR}} = 189.076 \text{ MU}
\]

(machine output at Rx SAD) \( S_e \) \( \text{TAR} \)
Tissue Maximum Ratio

- Because of Measurement difficulties, the TMR was developed.
- The SAME factors which influence TAR, affect TMR in the same way.

Tissue Air Ratio

Tissue Maximum Ratio
Factors Affecting TMR

- **Field Size** – ↑**FS** →↑**TMR**
- **Beam Energy** - ↑**Energy** →↑**TMR**
- Go deeper into patient - ↓**TMR**
  
  **DOES NOT AFFECT** TMR
  
  (~2% accuracy)***

**Notice --- NO SSD label**

<table>
<thead>
<tr>
<th>TABLE 23.9</th>
<th>Throat-maximum ratio for 6 MV</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FS</strong></td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Depth</strong></td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>TMR</strong></td>
<td>1.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>

(All SDs are in cm.)
Monitor Unit Calculations Using *TMR*

Calculate the Monitor Unit necessary to deliver:

- 180cGy to a 5cm depth  10x10 field size
- 100cmSAD       TMR = 97.7%
- 6Mv Linear Accelerator
- Machine output at 100cm from source is 1cGy/MU

Monitor Unit Calculation Using *TMR*

Monitor Unit =

\[
\text{Tumor Dose} \frac{\text{Machine output}}{\text{Sc} \times \text{Sp} \times \text{TMR} \times \text{(any other absorption factors)}} \text{ (at distance of Rx SAD)}
\]
TMR Monitor Unit Calculations for 6Mv Linear Accelerator

\[ \frac{180}{1.0 \text{ cGy/MU} \times 1.0 \times 1.0 \times 0.977} = 184.237 \text{ MU} \]

Factors Affecting PDD/TAR/TMR

<table>
<thead>
<tr>
<th>Factor</th>
<th>PDD</th>
<th>TAR</th>
<th>TMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase Beam Energy</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Increase Field Size</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Increase Depth in Patient (go deeper)</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Increase SSD (use Mayneord’s F Factor)</td>
<td>↑</td>
<td>NO Change</td>
<td>NO Change</td>
</tr>
</tbody>
</table>
Gantry Speed for Rotational Treatments

Speed of Gantry for Rotational Treatment

- To set speed of gantry during a moving field treatment

  Treatment Monitor units
  number of degrees of treatment rotation/arc
Problem for the Speed of the Gantry for Rotational Treatment

- What would be the monitor units per degree (aka speed of gantry) when

The monitor units is 255 for an anterior arc of 180 degrees?

\[
\text{Treatment Monitor units} \\
\text{number of degrees of treatment arc}
\]

\[
\frac{255}{180} = 1.4166 = 1.42 \text{ MU/degree}
\]

Where is the FINISHING angle for the arc?

- If the MU are 255 and the MU/degree is 1.42 and the gantry starts at gantry angle of 270, travels clockwise.....WHERE is the FINISHING (aka STOP) gantry angle for this treatment?
Where is the FINISHING angle for the arc?

1. Determine the number of degrees in the arc

\[
\frac{\text{Treatment Monitor units}}{\text{gantry speed}} = \text{gantry speed number of degrees of treatment arc}
\]

\[
\frac{255}{???} = 1.42
\]

\[
255 / 1.42 = ??? = 180 \text{ degrees in the arc}
\]

2. Look at gantry angle orientation AND direction of the gantry movement

AND….the FINISHING angle is …………. 
Blocking/MLC

Kahn's 4th Edition
BLOCKS

• Shape the Radiation Field to shield/protect normal tissues

• Must be at least 5 HVL thick to allow < 5% transmission

• Made of *Cerrobind* – (Lipowitz’s metal)
  Bismuth, Lead, Tin & Cadmium

• Main Advantage – Low Melting Point

---

Half Value Layer

• *Half Value Layer* - HVL – 1913 – used to describe *quality of xrays*

- Some thickness of material which will decrease the beam *intensity* by *HALF*
Cerrobend Ratio to Lead

- Since cerrobend is a Lead alloy, we need MORE cerrobend to do the same shielding as Pure Lead
  ***1.25 cm Cerrobend ~ 1.00cm Pure Lead***
- Problem: How much cerrobend is needed for blocks to be used on a machine whose HVL = 1.1cm Lead?

- \(1.25 \times 1.1 = 1.375\) cm cerrobend x 5 = \(6.875\) cm
Half Value Layer

1 HVL decreases beam to 50%
2 HVL decreases beam to 25%
3 HVL decreases beam to 12.5%
4 HVL decreases beam to 6.25%
5 HVL decreases beam to 3.125%

Tray to Hold Blocks
Tray Factor

• Amount of *Transmission* through the plastic tray which holds the Cerrobend blocks

• Dose *With* Tray in place = 97cGy
• Dose *Without* Tray = 100cGy

• Transmission Factor = 97/100 = .97
  (Same concept can be applied to compensator/physical wedges)

Clarkson Calculation

Also called “*Irregular Field Calculation*” corrects for the *lack of scatter* due to shielding

• The Tissue Air Ratio value needed to calculate the Monitor Unit, is made up of contributions from both the Primary radiation - 0x0 field size (TAR₀) – *when e-hits target, photons produced = primary beam*
  added to scatter (SAR)
  \[
  \text{TAR} = \text{TAR}_0 + \text{SAR}
  \]
### 6Mv TAR

| TAR | \(0\) | \(4\) | \(5\) | \(6\) | \(7\) | \(8\) | \(9\) | \(10\) | \(11\) | \(12\) | \(13\) | \(14\) | \(15\) | \(16\) | \(17\) | \(18\) | \(19\) | \(20\) | \(22\) | \(24\) | \(26\) | \(28\) | \(30\) | \(32\) | \(35\) |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| TAR for 15x15 \(\text{open field}\) at 10cm depth | \(.844\) |
| TAR\(0\) for 0x0 at 10cm depth | \(.676\) |
| \(\text{TAR} = \text{TAR}\(0\) + SAR\) | \(.844\) \(+\) \(.676\) \(+\) SAR |
| \(.844 - .676\) | SAR |
| \(.168\) | SAR |

- TAR for 15x15 \(\text{open field}\) at 10cm depth = .844
- TAR\(0\) for 0x0 at 10cm depth = .676

\[ \text{TAR} = \text{TAR}\(0\) + SAR \]

\[ .844 = .676 + \text{SAR} \]

\[ .844 - .676 = \text{SAR} \]

\[ .168 = \text{SAR} \]
Clarkson Calculation

1. Divide Field into Segments
2. Look up SAR value for EACH Radius Length
3. Get Average SAR value
4. Add Average SAR value to TAR0
5. Use "adjusted" TAR value for MU Calculation

![Image from Bentel Radiation Therapy Planning 2nd Edition p.94]

What’s Up Next??

![Dog Image]
Beam Weighting

• When the dose from EACH beam is the same, the beams are said to be
  • Equally Weighted

• Different doses from EACH beam is called
  • Unequally Weighted

For example:
AP:PA :: 2:1 dose ratio

\[ 2x + 1x = 180\text{cGy} \]
\[ 3x = 180\text{cGy} \]
\[ x = 60\text{cGy} \]

Notice the higher isodose curves (ex 130) will be near the beam direction where MORE dose was given.
Wedges (Physical)

https://www.google.com/search?q=wedges+for+linear+accelerator&tbm=isch&ved=2ahUKEwi8m5vy4Pz-AhUiBVkFHfq8BpYQ2-cCegQIABAA&oq=wedges+for+linear+accelerator&gs_lcp=CgNpbWcQAzoKCAAQigUQsQMQQzoFCAAQgAQ6BwgAEIoFEEM6CAgAEIAEELEDOgsIABCABBCxAxCDAToGCAAQBRAeOgcIABAYEIAEUMsWWPJqYK1taABwAHgAgAFIiAGcDJIBAjMwmAEAoAEBqgELZ3dzLXdpei1pbWfAAQE&sclient=img&ei=oP5kZLzLB6KK5NoP-vmasAk&bih=745&biw=1481&rlz=1C1GCEB_enUS911US911#imgrc=VZk93Zq0W52obM
Wedges

• The most **FREQUENTLY** used Beam Modifying Device

• The Physical wedges are shaped like a foot. Thick edge is called HEEL. Thin edge is called TOE

Dynamic Wedge

The upper collimator moves **DURING** the treatment – giving a “wedge effect”
Example of Treatment Machine Monitor

Angles used when talking about wedges

- **Wedge Angle**
  angle through which an isodose curve is tilted (**** *NOT* the angle of the triangular piece of metal of the physical wedge****)

- **Hinge Angle**
  angle between the central rays of two fields
Wedge Angle

- **Wedge Angle** – angle through which an isodose curve is tilted at the central ray of a beam at a specified depth. The range of wedge angles is generally **15-60 degrees**.

Kahn “wedge angle measurements recommended to be measured at 10 cm depth”
Hinge Angle

- **Hinge Angle** – angle between the central rays of two fields

![Diagram of Hinge Angle](image)

Figure 14.20

The hinge angle is the angle between the central rays of the two beams.

*Image from Stanton & Stanton, p242
Applied Physics for Radiation Oncology
Revised Edition*
Formulae to Calculate “Optimal Pairing of Wedges & Hinge Angles”

• **wedge angle formula** = 90 – (.5 x hinge angle)

• **optimum hinge angle** = 180 – (2 x wedge angle)

**Wedge Problems**

• Determine the wedge angle to be used with a 120° hinge angle
  
  **wedge angle formula** = 90 – (.5 x hinge angle)  
  = 90 – (.5 x 120)  
  = 90 – (60)  
  = 30° wedge angle

• Determine the optimum hinge angle to be used with 30° wedges
  
  **optimum hinge angle** = 180 – (2 x wedge angle)  
  = 180 – (2 x 30)  
  = 180 – (60)  
  = 120° hinge angle
### Wedge & Hinge Angles Table

<table>
<thead>
<tr>
<th>Wedge Angle</th>
<th>Hinge Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>150</td>
</tr>
<tr>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td>45</td>
<td>90</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

*Combinations of Wedge Angle with optimal Hinge Angle (in water phantom)*

*RED line = 100% IDL*
Electrons

- *Electrons* are “generally” used for boost treatments – not as penetrating as photons

  o *Therapeutic Range* - depth of an isodose curve which covers the treatment volume (frequently 80% or 90% isodose line)

  o *Practical Range* – depth of the 10% isodose line
Electron Breast Boost

6Mv Photons

12Mev Electrons
Electrons

To determine the approximate depth of an electron isodose line to cover the deepest part of a tumor, the following “rules of thumb” can be used:

- $\text{Mev}/3.2 \sim \text{depth of 90\% isodose line}$  \hspace{1cm} \text{Therapeutic Range}
- $\text{Mev}/2.8 \sim \text{depth of 80\% isodose line}$  \hspace{1cm} \text{(info as per Kahn’s 5th edition)}
- $\text{Mev}/2 \sim \text{depth of 10\% isodose line}$  \hspace{1cm} \text{Practical range}

Electron with “Tumor Volume”

deepest part of tumor to be covered by 90\% isodose line

Estimate depth $\text{Mev}/3.2$

- Determine the appropriate electron energy to treat a tumor at 2cm depth if the physician wants to treat to the 90\% isodose line.
Electron Problem
2cm to be covered by 90% IDL

• Available electron Energies:
  7MeV
  10MeV
  13MeV
  16MeV

Rule of Thumb
Mev/3.2 ~ depth of 90% isodose line

- 7MeV/3.2 = 2.19cm
- 10MeV/3.2 = 3.13cm
- 13MeV/3.2 = 4.06cm

Electron with “Tumor Volume”
deepest part of tumor to be covered by 80% isodose line

Estimate depth Mev/2.8

• Determine the appropriate electron energy to treat a tumor at 3.0cm depth if the physician wants to treat to the 80% isodose line.
## Electron Problem

3cm to be covered by 80% IDL

<table>
<thead>
<tr>
<th>Available electron Energies:</th>
<th>Rule of Thumb</th>
</tr>
</thead>
<tbody>
<tr>
<td>7Mev</td>
<td>Mev/2.8 ~ depth of 80% isodose line</td>
</tr>
<tr>
<td>10Mev</td>
<td>7Mev/2.8 = 2.50cm</td>
</tr>
<tr>
<td>13Mev</td>
<td>10Mev/2.8 = 3.57cm</td>
</tr>
<tr>
<td>16Mev</td>
<td>13Mev/2.8 = 4.64cm</td>
</tr>
</tbody>
</table>

Any Questions?

Contact
Shirley.Johnston@jefferson.edu