# Beam Modifying Devices and

# Beam Modulation

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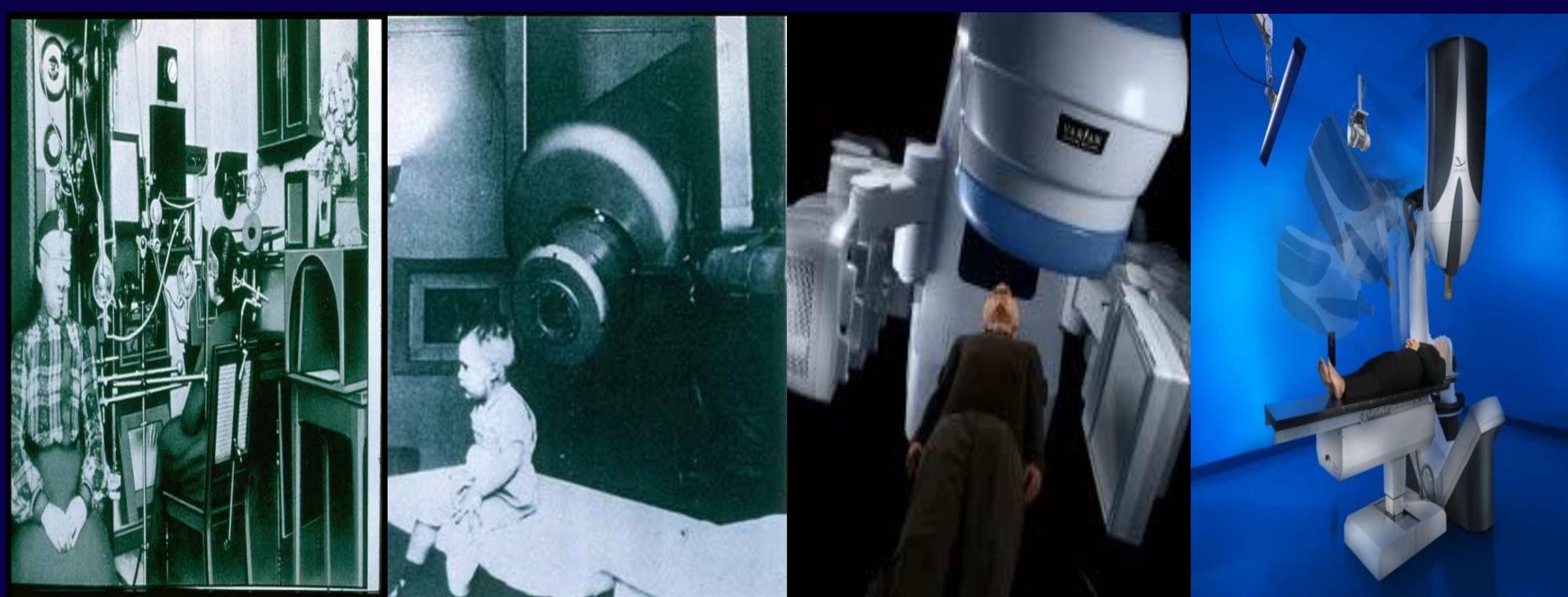
# Beam modification?

- Defined as **desirable** modification in the **spatial** distribution of radiation - within the patient - by insertion of any material in the beam path.



# Types of bean modification

- Four types of beam modification:

  - **Shielding**:

    To eliminate radiation dose to some special parts of the zone at which the beam is directed.

  - **Compensation**:

    To allow **normal** dose distribution data to be applied to the treated zone, when the beam enters a or obliquely through the body or where different types of tissues are present.

  - **Wedge filtration**:

    Where a special tilt in isodose curves is obtained.

  - **Bolus**:

    Used to increase the dose to the skin

# Other modification devices

- Beam flattening filter
- Multi-leaf collimator
- Beam spoilers
- Breast cone
- Penumbra trimmers
- Electron beam cone

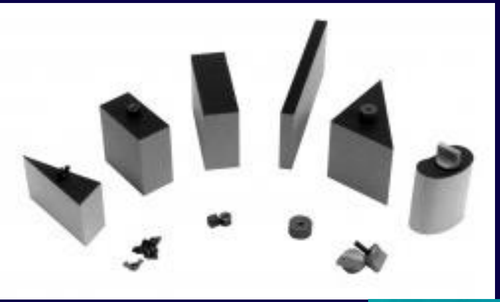
# Shielding

To protect the critical structures around the treatment volume by using various devices

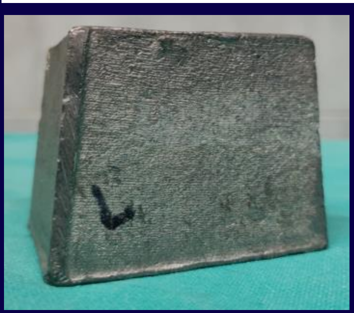
- The aims of shielding are:
  - To protect critical organs
  - Avoid unnecessary irradiation to surrounding normal tissue
  - Matching adjacent fields
- Is should have following characteristics
  - High atomic number
  - High density
  - Easily available
  - Inexpensive

# Beam blocking and shaping devices

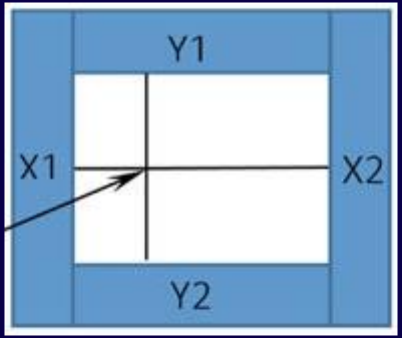
- Shielding (Standard) blocks



- Custom (Divergent) blocks

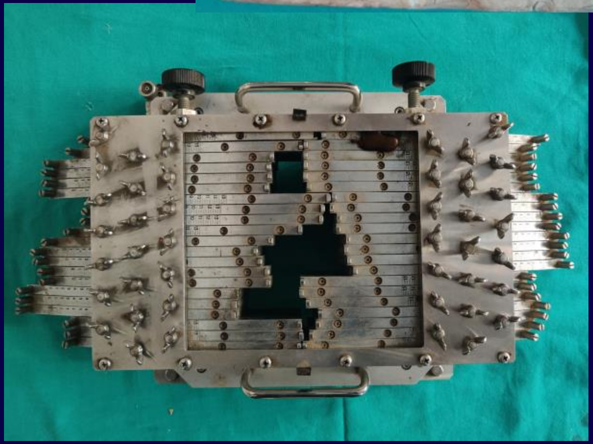


- Asymmetrical jaws





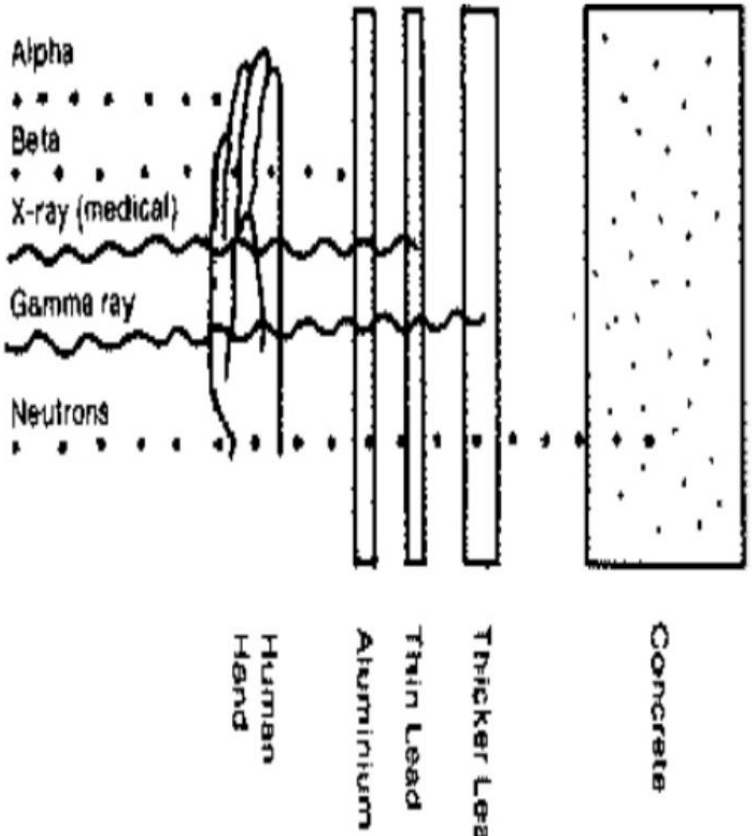
- Multileaf collimators



# Shielding

## Lead as a shielding material

- Choice of shielding is also dictated by the type of beam being used.



# Need to use shielding blocks

- Complex fields shapes including the following restrictions
  - Target volume with adequate margin
  - Presumed occult spread
  - Avoid normal tissue outside this volume / Shielding OAR
  - **A rational system of field shaping is necessary**
- Characteristics :
  - High atomic No & density, available, Inexpensive
  - lead (commonly)
  - Acceptable transmission is 5%

# Block Thickness

- **It's thickness depends on**
- *Attenuation of shielding material*
  - Half-value layer is defined as the thickness of an absorber required to attenuate the intensity of beam to half its original value.
- For practical purposes, the shielding material which reduces beam transmission to **5%** of its original is considered acceptable
- *The number of* ***HVL (n)***

**$1/2^n$ = 5%** or 0.05

Thus, $2^n = 1/0.05 = 20$ .OR, $n \log 2 = \log 20$.

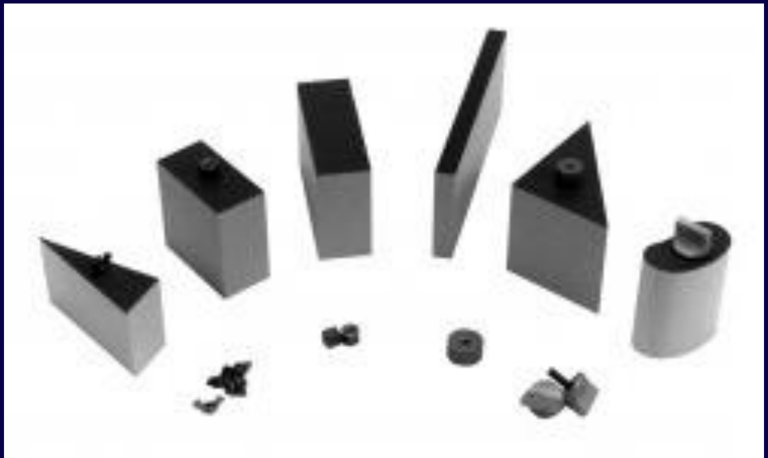
n = **4.32**

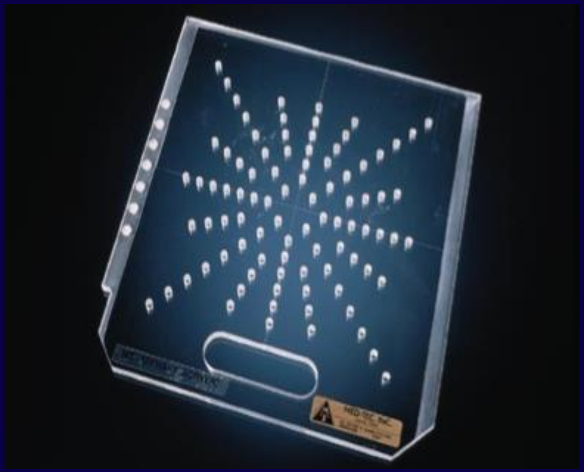
# Block Thickness

- Recommended of block thickness = 4.5 – 5 HVL
- Relationship holds for mono energetic x-ray beams
- Further increase of block thickness is not significant
  - » The predominance of scattered radiation from the adjoining open areas of the field

## Recommended Minimum Thickness of Lead for Shielding

| Beam Quality | Required Lead Thickness |
|---|---|
| 1.0 mm Al HVL | 0.2 mm |
| 2.0 mm Al HVL | 0.3 mm |
| 3.0 mm Al HVL | 0.4 mm |
| 1.0 mm Cu HVL | 1.0 mm |
| 2.0 mm Cu HVL | 2.0 mm |
| 3.0 mm Cu HVL | 2.5 mm |
| 137 Cs | 3.0 cm |
| 60Co | 5.0 cm |
| 4 MV | 6.0 cm |
| 6 MV | 6.5 cm |
| 10 MV | 7.0 cm |
| 25 MV | 7.0 cm |





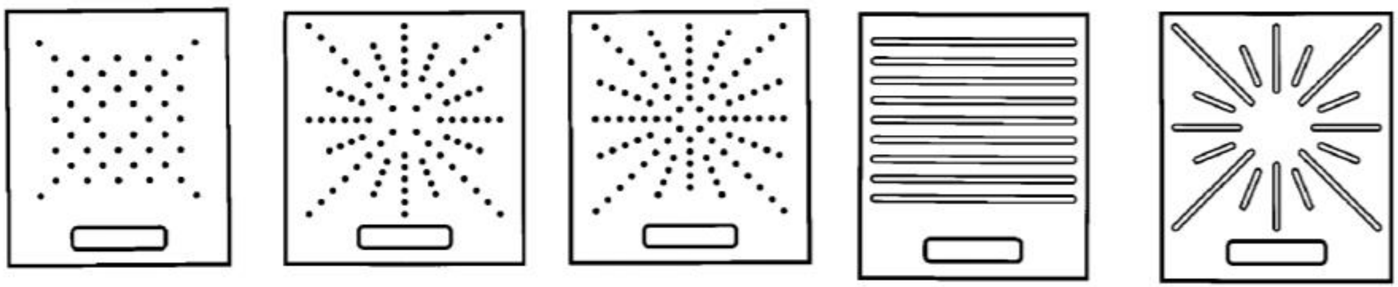
* Approximate values to give ≦5% primary transmission

# Shadow tray

## BLOCK ROOM PRODUCTS AND ACCESSORIES

### Hole and Slot Pattern (CC)

Hole Diameters available in 1/4", 3/8", or custom. Slot Widths available in 1/4", 7/32", or custom. Hole patterns available in 44 holes, 88 holes, 96 holes, or custom)



| | | | | |
|---|---|---|---|---|
| **16 - 44 Holes 1/4" Dia.** | **18 - 88 Holes 1/4" Dia.** | **20 - 96 Holes 1/4" Dia.** | **40 - 9 Slots 7/32" W** | **44 - 16 Slots 7/32" W** |
| **17 - 44 Holes 3/8" Dia.** | **19 - 88 Holes 3/8" Dia.** | **21 - 96 Holes 3/8" Dia.** | **41 - 9 Slots 1/4" W** | **45 - 16 Slots 1/4" W** |

### Block Tray Material and Thickness (D)

1/4" and 3/8" thick trays are most common. For very heavy blocks you may want to use 3/8" or 1/2" thick trays. Thicker trays are machined along the edges to fit the slots of the tray holder.

**Acrylic**
Acrylic is more rigid and scratch resistant than Lexan, however, it will break if dropped. Acrylic block trays will discolor from large amounts of radiation and may become brittle. Cracked trays should be removed from patient use, however, they could be used in the block room as set-up trays.

**Acrylic Density:** 1.17 to 1.20 g/cm$^3$

**Polycarbonate (Lexan)**
Polycarbonate (Lexan) is virtually unbreakable, scratches easily and will flex more under a heavy load.

**Polycarbonate (Lexan) Density:** 1.2 g/cm$^3$

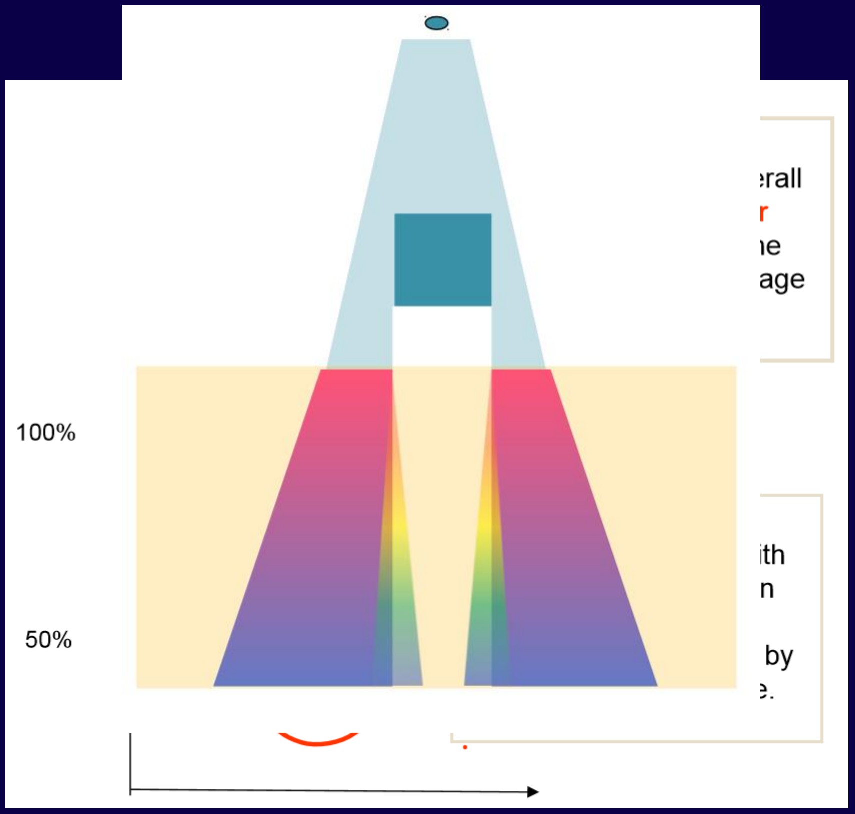
| Thickness | 1/4" | 3/8" | 1/2" |
|---|---|---|---|
| Acrylic | 1 | 3 | 5 |
| Polycarbonate (Lexan) | 2 | 4 | 6 |

# Challenges with shielding blocks

- Radiation reaching any point → primary & scattered photons

- The phenomena scattering results in an “blurring” of the effect of the beam modification

- Scattering is more in kilovoltage radiation than in megavoltage radiation therapy



# Challenges with shielding blocks

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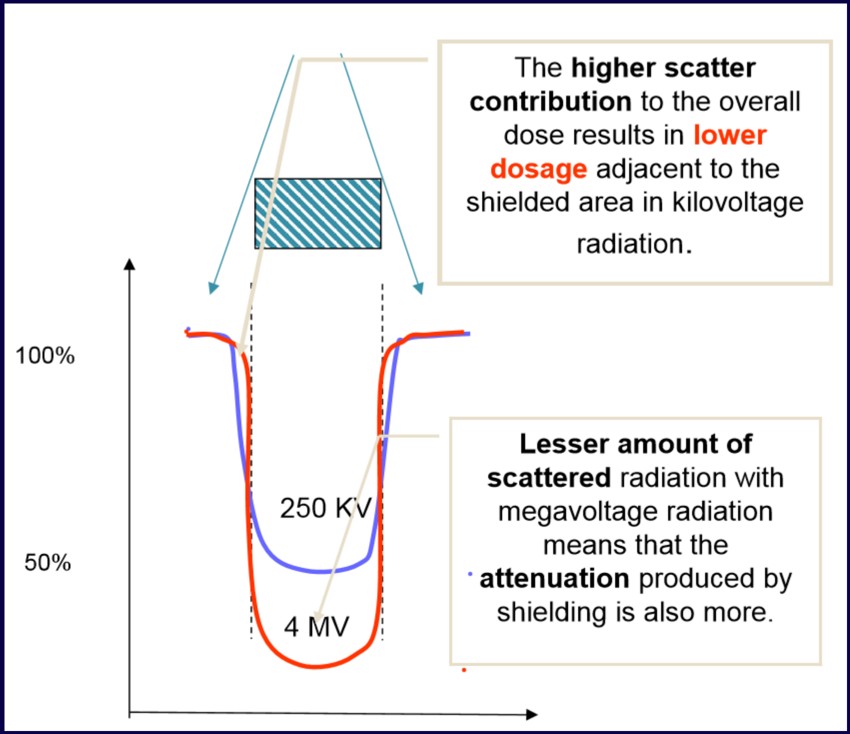
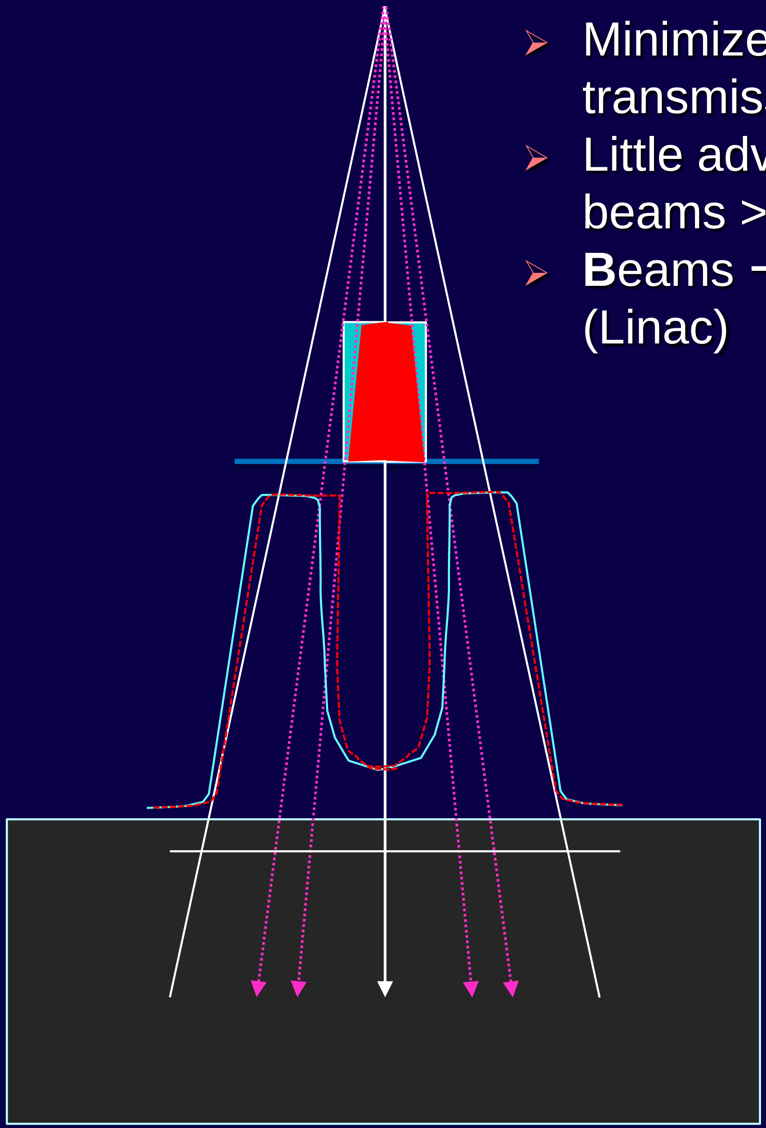
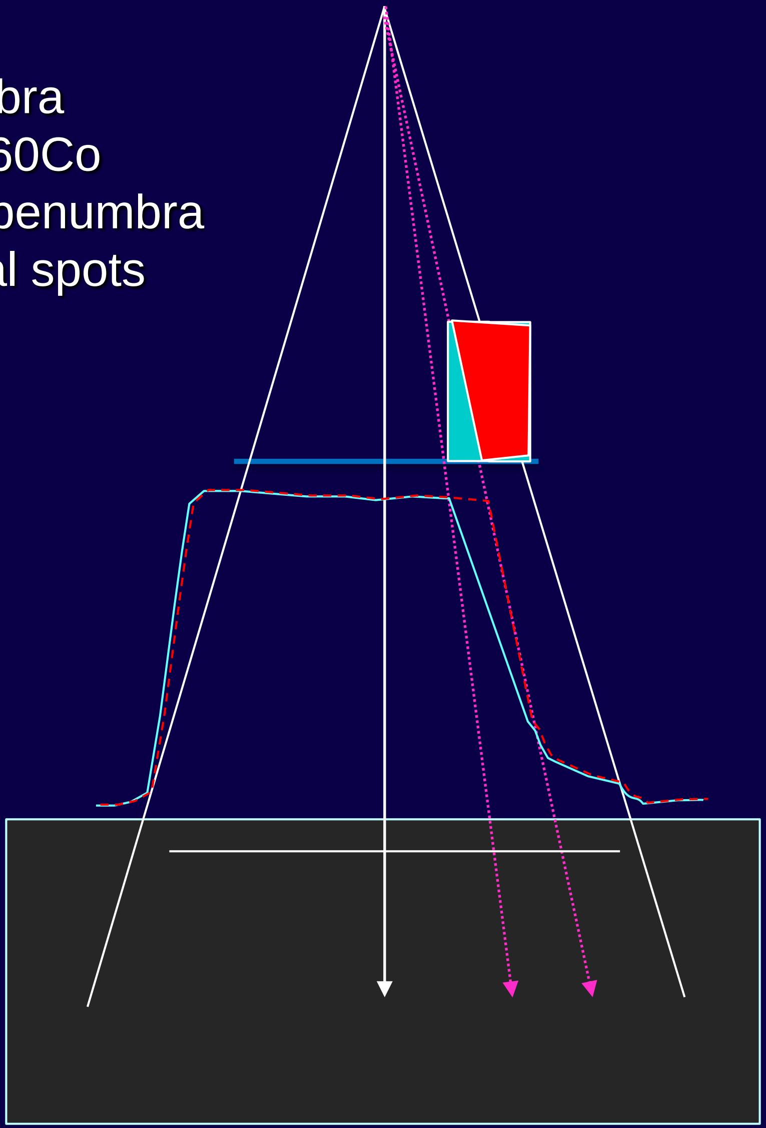


# Shielding blocks: Standard vs Divergent

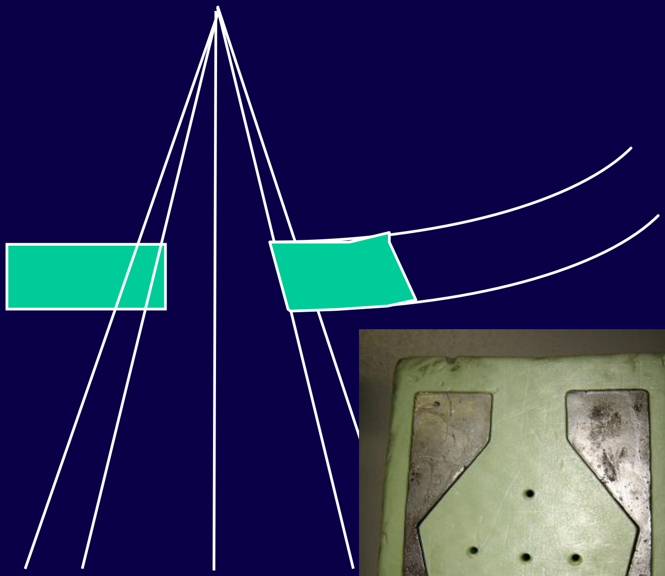


- Minimized the block transmission penumbra
- Little advantage for 60Co beams > geometric penumbra
- **B**eams → small focal spots (Linac)



# Advantage of Custom / Divergent block

- Standard blocks are used to shield corners / OAR (penumbra is large and ↑ as a function of OCR
- Custom blocks used for customized shielding (OAR)
- Ability to shape conformal beams
- Advantage is that the penumbra is uniform as a function of OCR and customized



# Custom Block (Divergent)

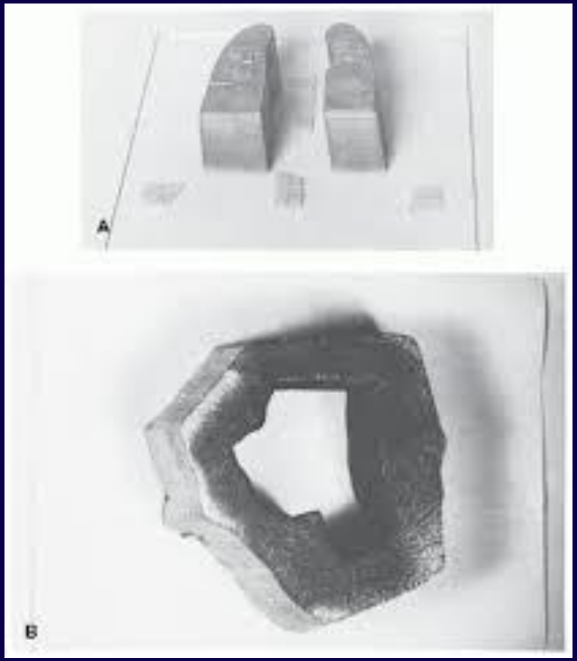
- Lipowitz metal (Cerrobend®)
  - A low melting point alloy
  - Density: 9.4g / $cm^3$ at 20℃ (83% of lead)
  - Consist of : ❶ bismuth (50%), ❷ lead (26.7%), ❸ tin (13.3%), ❹ cadmium (10%)
- Main advantage
  - Melting point: 70℃ (c.f. 327℃ of lead)
  - Harder than lead in room temperature
- Common thickness of block (Cerrobend®) used in 4 MV photon
  - Density ratio relative to lead (∼lead thickness × 1.21)
  - 7.5cm (Equivalent to 6 cm of pure lead)

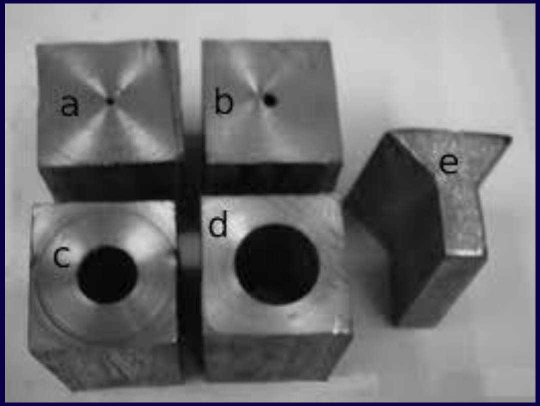
# Field Shaping : Custom blocks

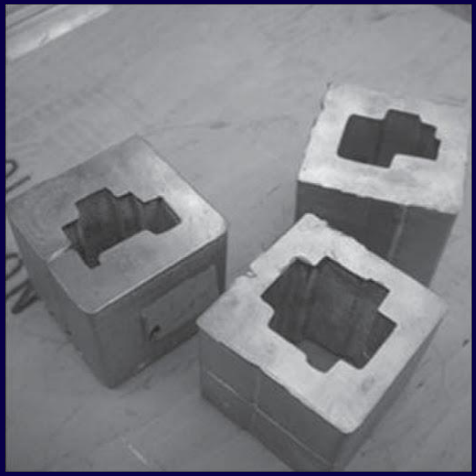
- Shielding blocks can be of two types
  - Positive blocks

    Create blocks to shield → align w.r.t field center
  - Negative blocks

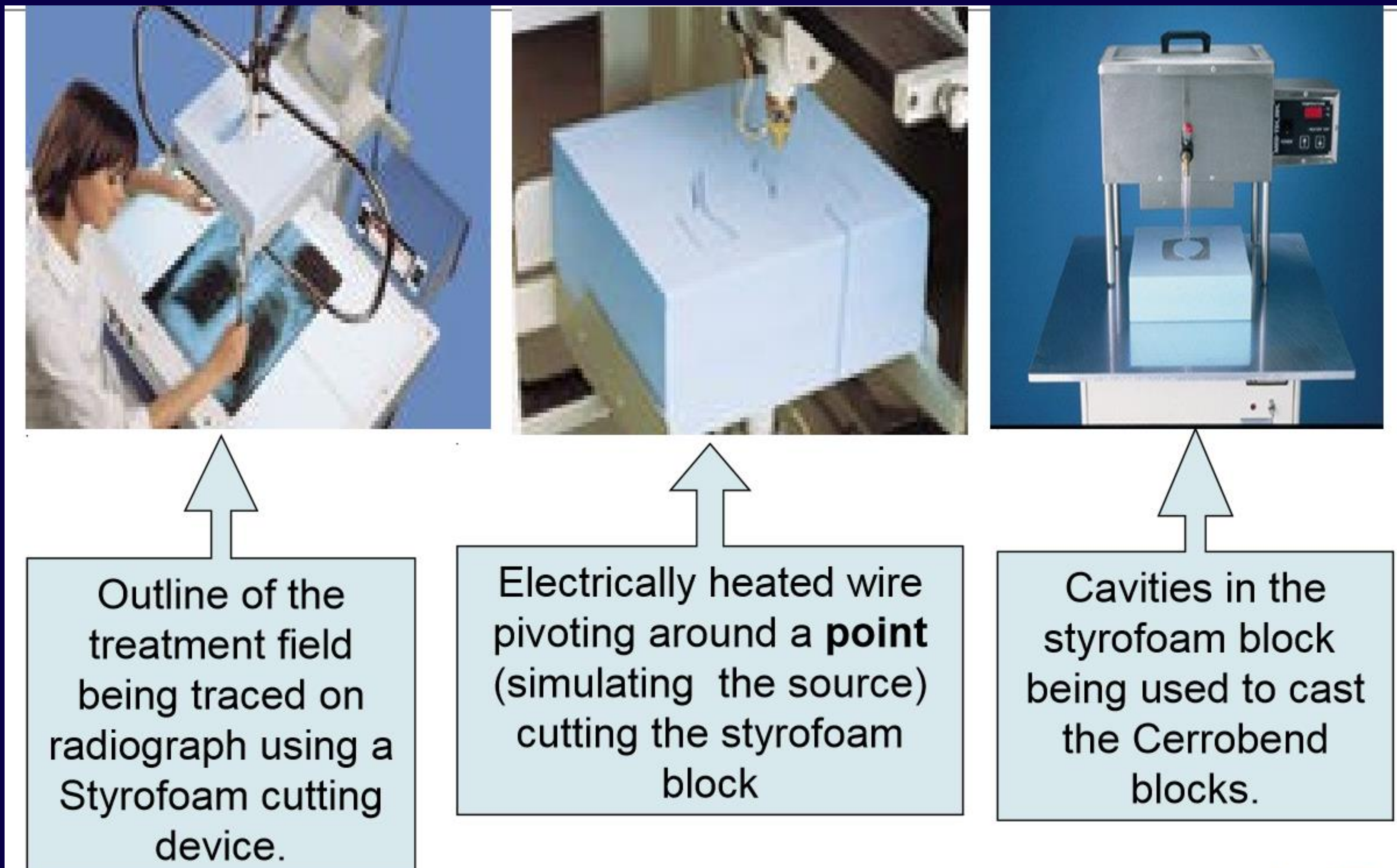
    Create opening for beam with shielding around w.r.t field center



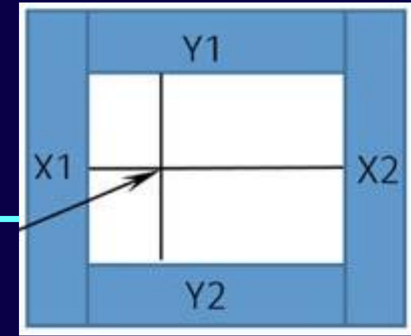



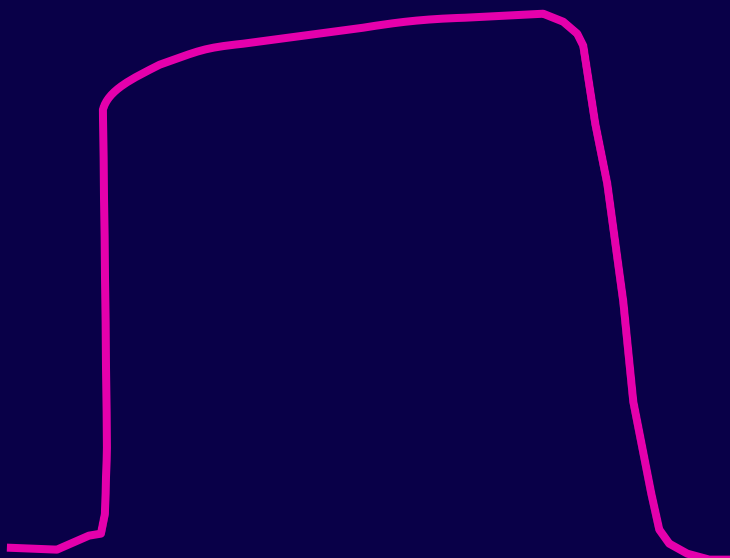
# Construction of Cerrobend block

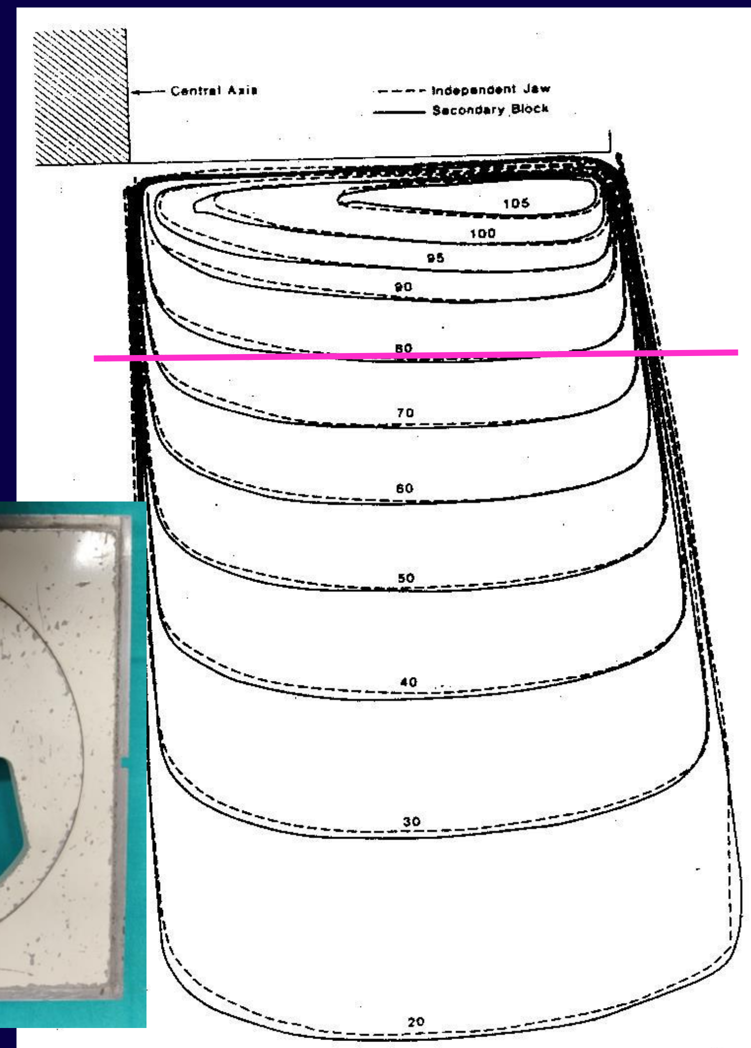


# Independent Jaws

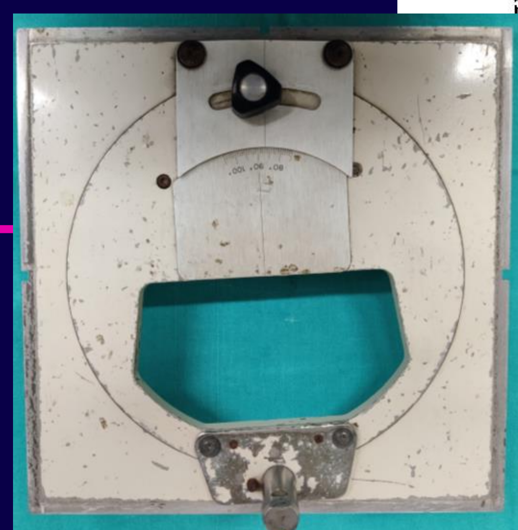



- Blocking off a part of the field without changing the position of the isocenter

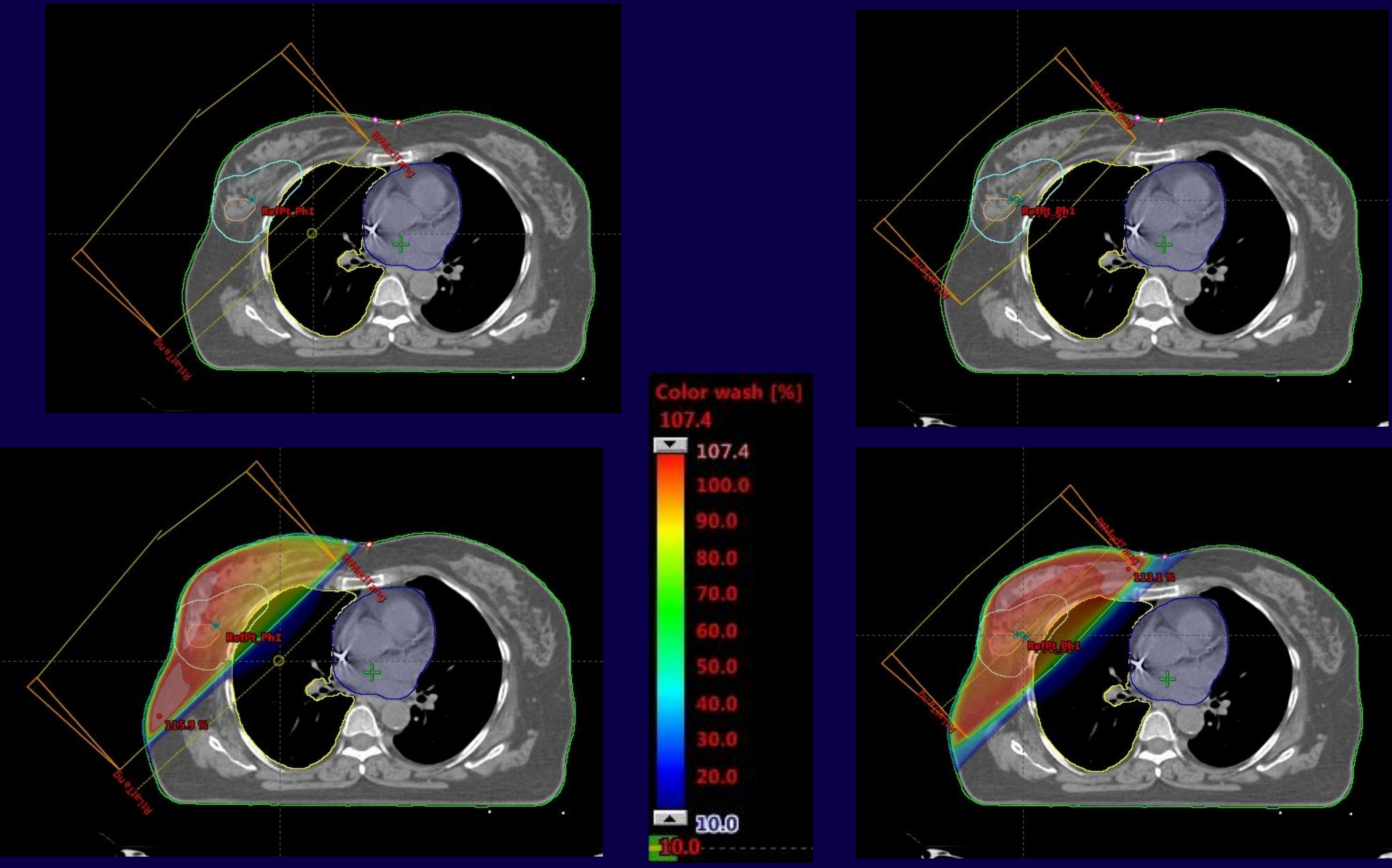




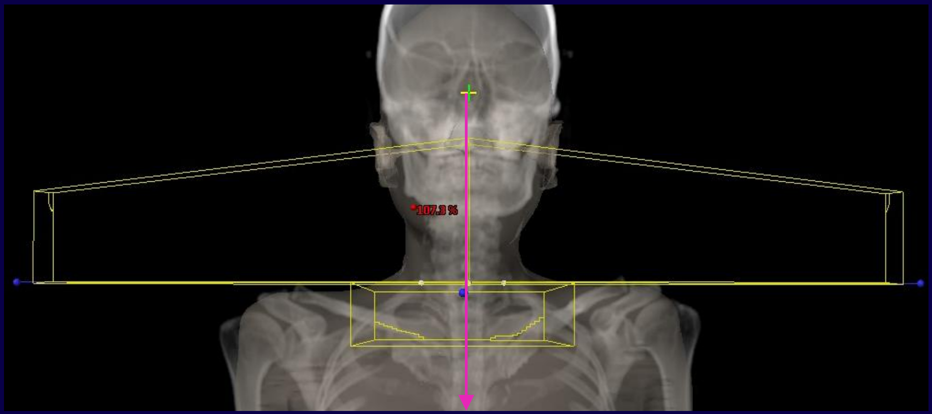

- Beam flatness
- Dose calculation (MU)

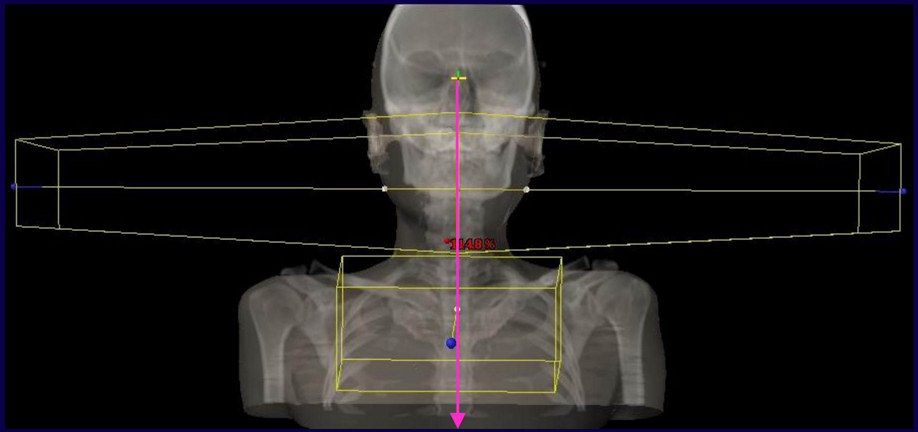


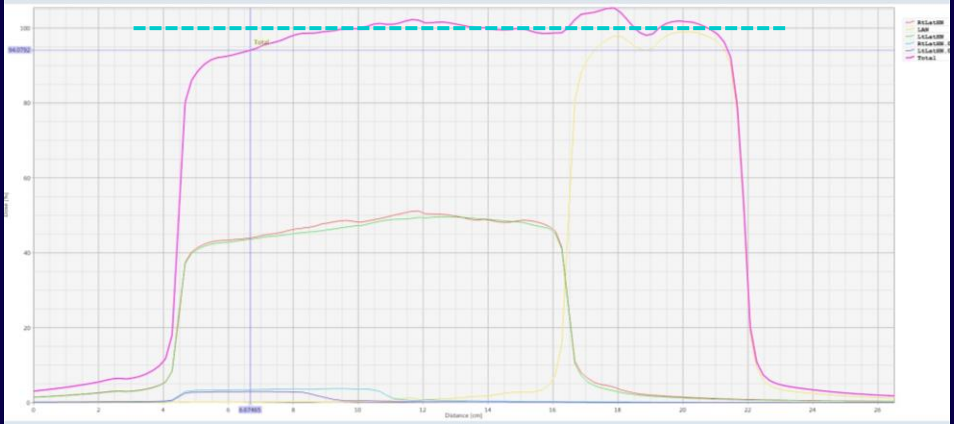
# Asymmetric vs symmetric Jaws

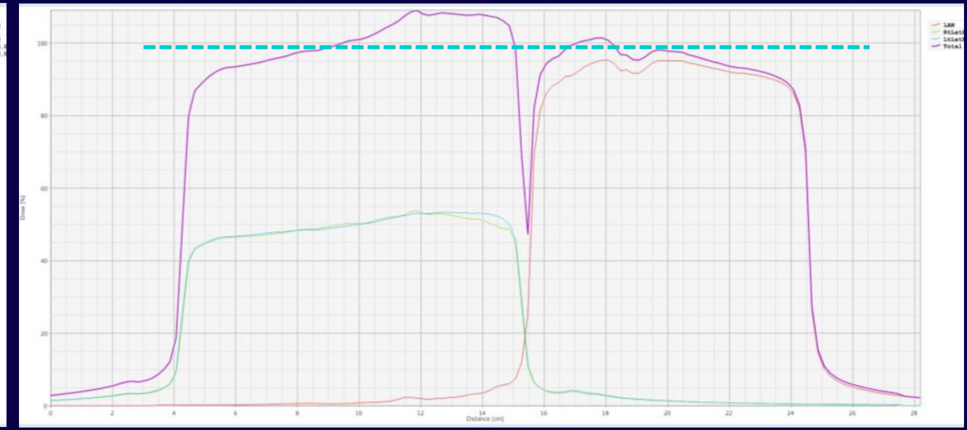


# Asymmetric vs symmetric Jaws



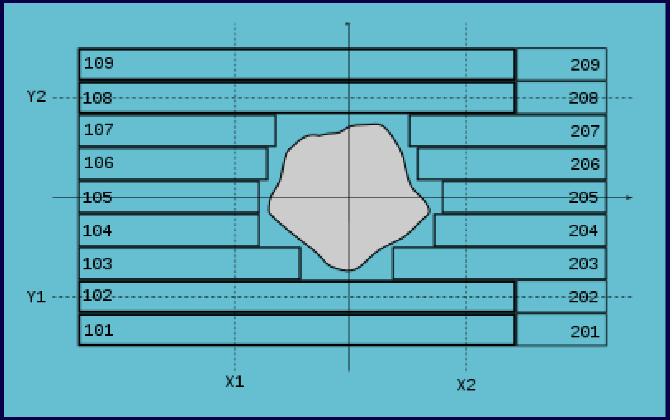





# Multileaf Collimators

- **MLC** is a collimator or beam-limiting device that is made of individual "leaves" of a high atomic numbered material, usually tungsten, that can move independently in and out of the path of a radiotherapy beam in order to shape it and vary its intensity.




- Provide conformal shaping of beams is place of custom blocks
- Cost effective solution for implementation of conformal RT
- Allows to match the borders of the target tumour
- IMRT treatments the leaves of a MLC can be moved across the field to create non-uniform fluence modulation

# Multileaf Collimators

- 40 pairs of leaves or more having a width of 1 cm on less (projected at the isocenter)
- 60 pairs / 120 millennium MLC / 160 pairs Agility MLC

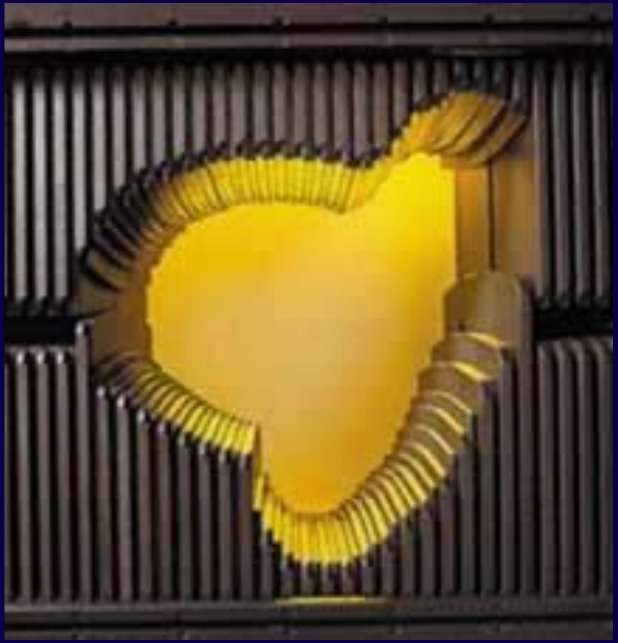
- Thickness = 6 – 7.5 cm
- Made of a tungsten alloy
- Density of 17 - 18.5 g/cm3
- Primary x-ray transmission:

  Through the leaves < 2%

  Interleaf transmission < 3%

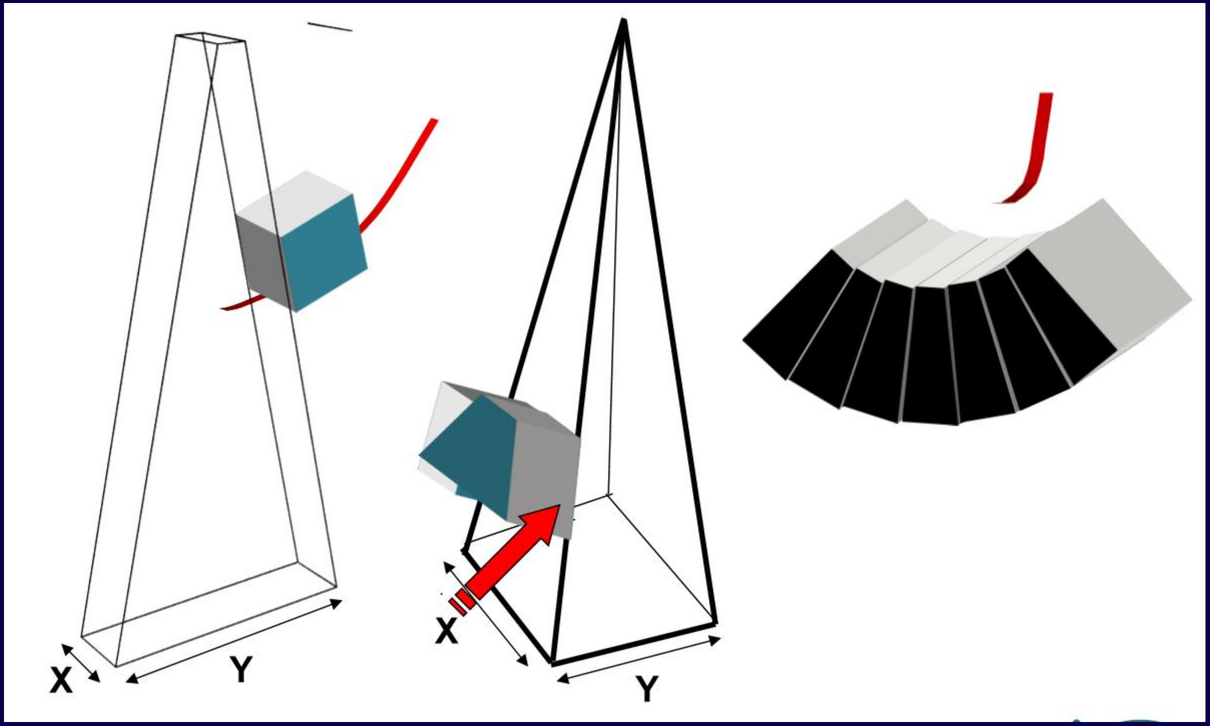
  For jaws 1%

  Cerrobend blocks 3.5%



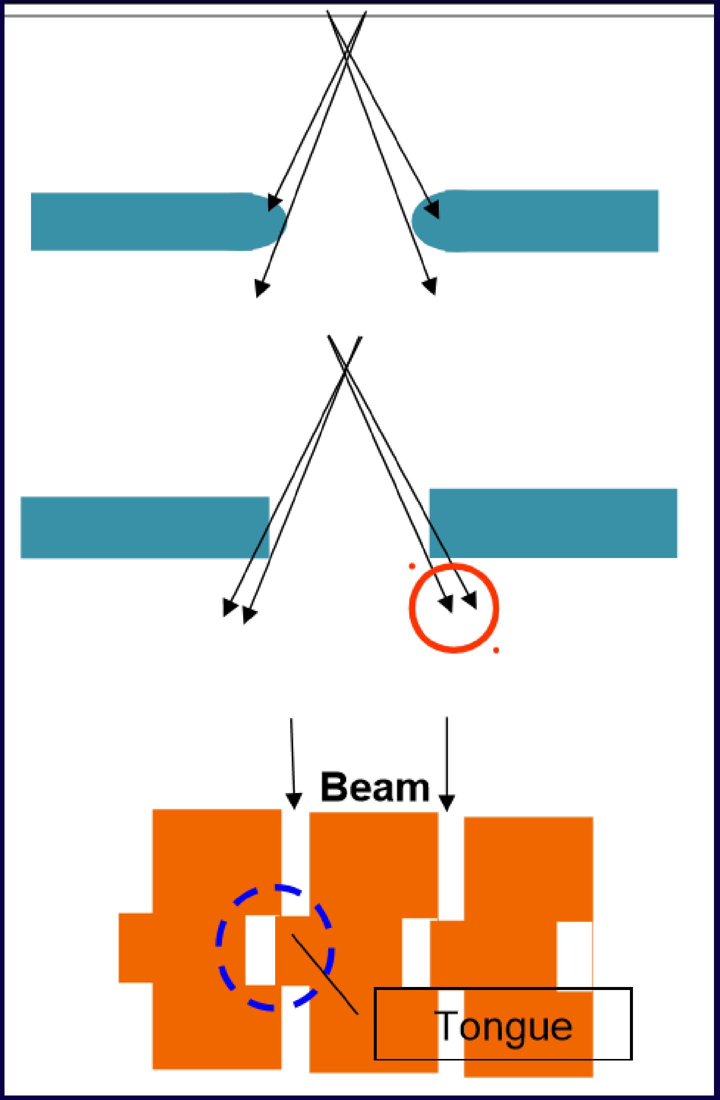
# Types : Multileaf Collimators

- MLC systems may have single or double focus leaves
- Single focus: Moves in a trajectory of provide beam divergence or uniform penumbra
- Double focus: Shaped to match the radiation beam along the Y axis only as the upper end is narrower than the lower



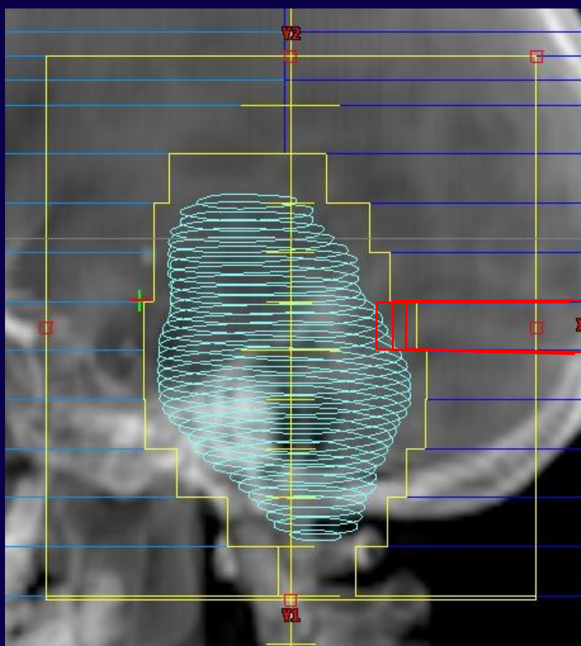
# Multileaf Collimators

- Single focus leaves are also rounded at the ends.
- This can lead to significant beam transmission (20%) when the leaves abut each other
- Both designs are to ensure a sharp beam cut off at the edge
- In order to allow fast interleaf movement, while reducing radiation transmission a tongue and groove design is often used

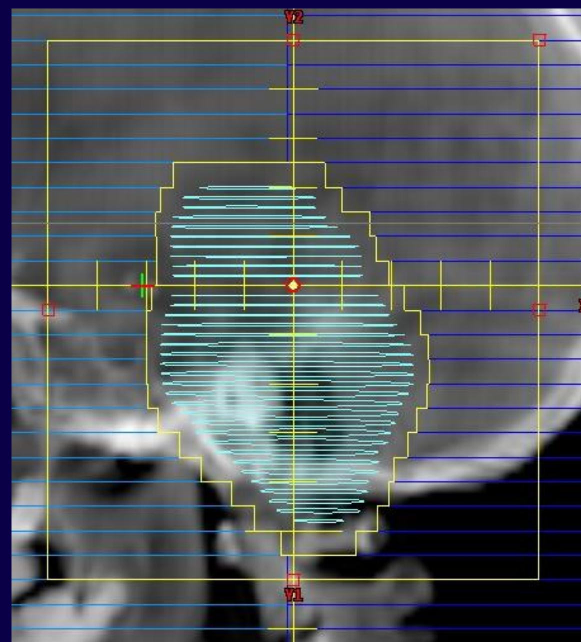


# Leaf resolution : MLC

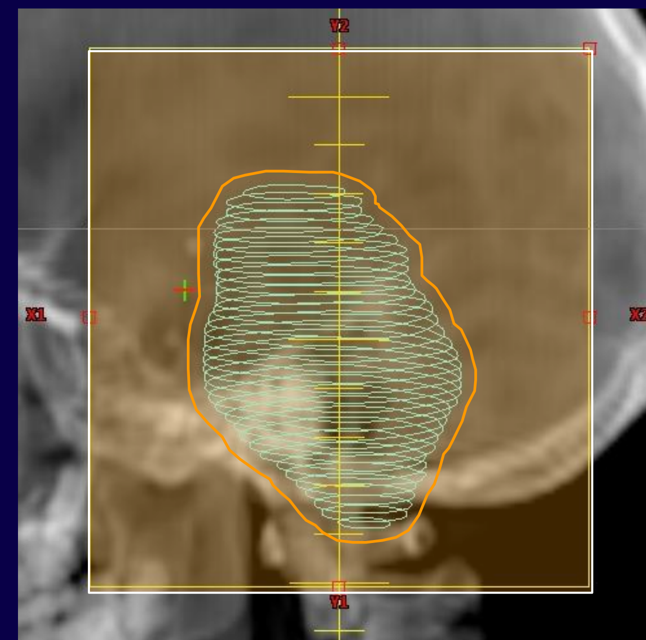
- What is ideal leaf resolution for beam shaping ?
- Outbound, Inbound and cross-bound




10mm MLC

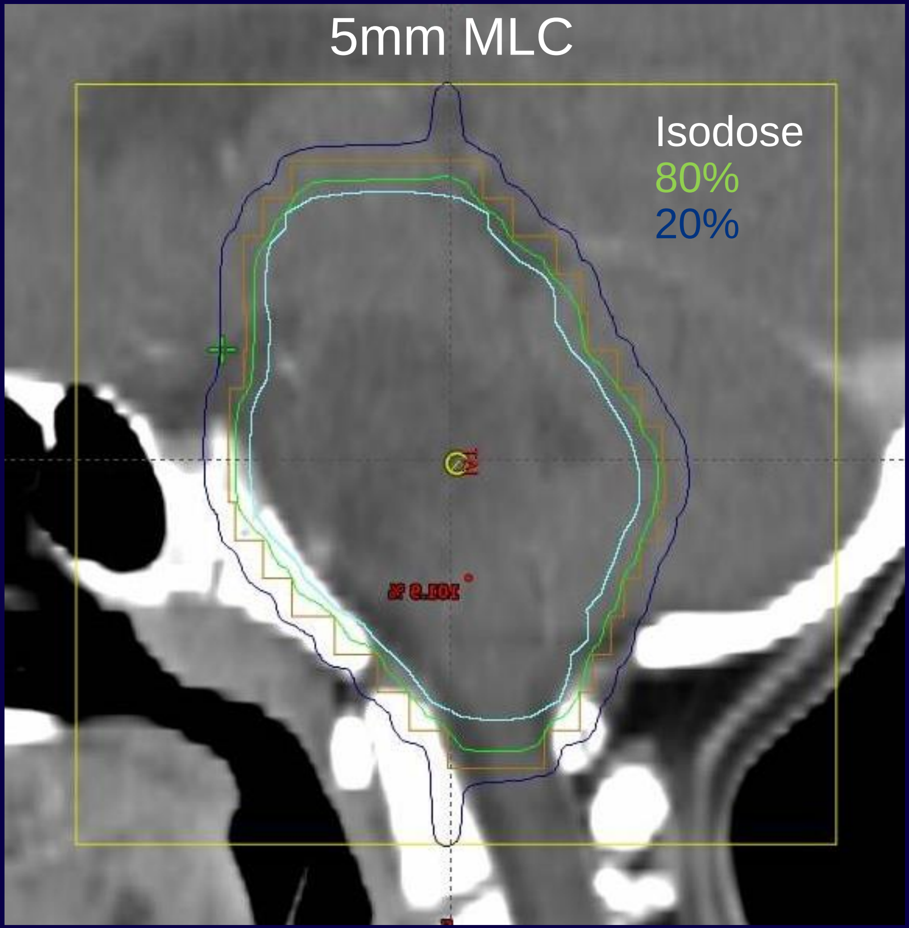


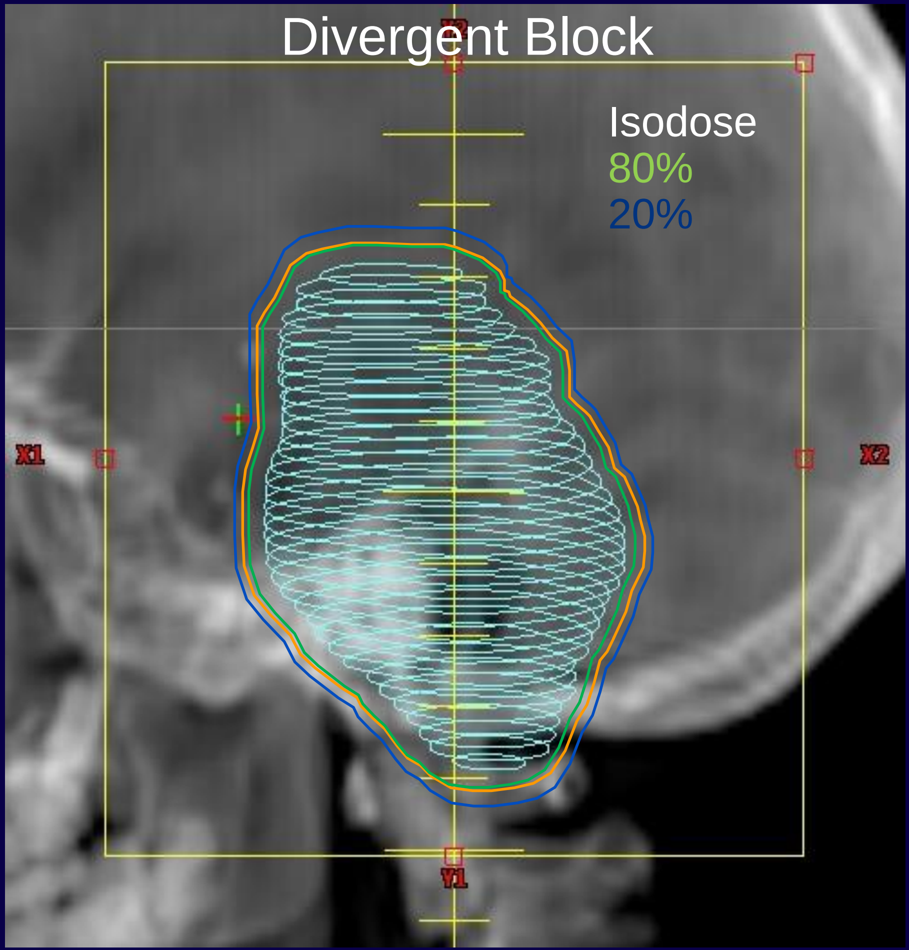

5mm MLC




Divergent Block

# MLC vs Divergent Block : Penumbra




- Field boundary is continuous whereas jagged stepwise boundary –MLC
- Degree of conformity → only depends of projected leaf width, but also Shape, Target volume and Optimization of MLC fitting and rotation

# Benefits : Multileaf Collimators

- Potential applications of the MLC systems
  - Replacement of custom Cerrobend blocking
  - Automatic beam shaping for multiple fields
  - Dynamic conformal RT (beam shaping during rotation of the gantry)
  - Modifying dose distributions within the field (computer-controlled dwell time of the individual leaves)

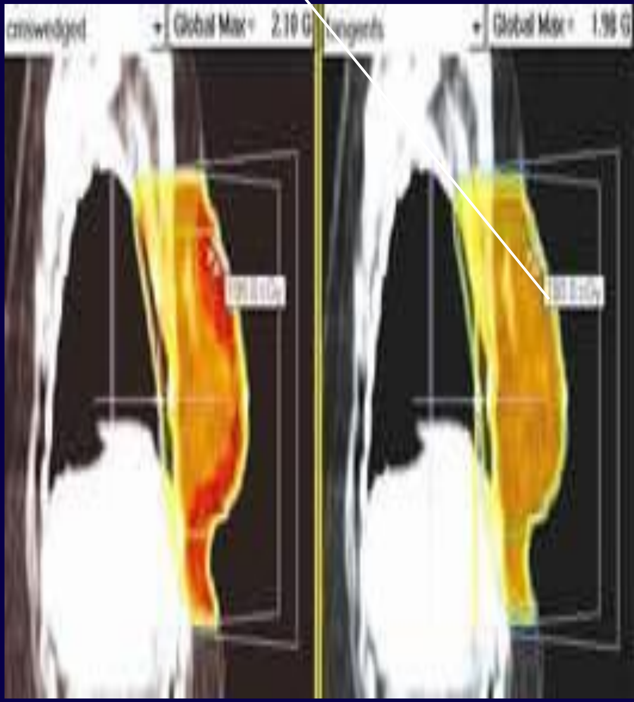
# Tissue compensators

- Beam modifying device which evens out the skin surface contours, while retaining the skin-sparing advantage

- It allows normal depth dose data to be used for such irregular surfaces

- Compensators can also be used for
  - To compensate for tissue heterogeneity
  - To compensate for dose irregularities arising due to reduced scatter near the field edges

*Notice the reduction in the hot spot*

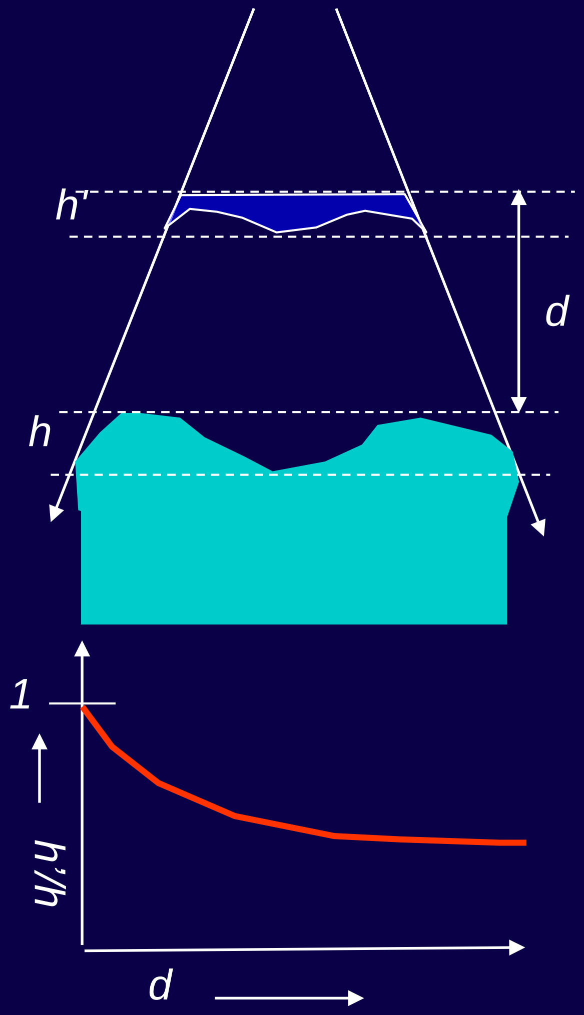


# Tissue compensators

- The **dimension and shape** of a compensator must be adjusted to account for :
  - Beam **divergence**.
  - **Linear attenuation coefficients** of the filter material and soft tissue.
  - **Reduction** in scatter at various depths due to the compensating filters, when it is placed at the distance away from the skin.

- To compensate for these factors a tissue compensator is always has **an attenuation less** than that required for primary radiation.

- As the distance between the skin and compensator increases the **thickness ratio** (h'/h) decreases.



# Tissue compensators

- The **thickness ratio** depends on:
  - Compensator to surface distance
  - Thickness of the missing tissue
  - Field size
  - Depth
  - Beam quality

- Of these, the **distance** is the most important factor when d is ≤ 20 cm.

- Therefore, a fixed value of **thickness ratio** ($\tau$) is used for most compensator work (~ **0.7**).

- The formula used for calculation of compensator thickness is given by: **TD x ($\tau/\rho_c$)**, where **TD** is the tissue deficit and $\rho_c$ is the density of the compensator.

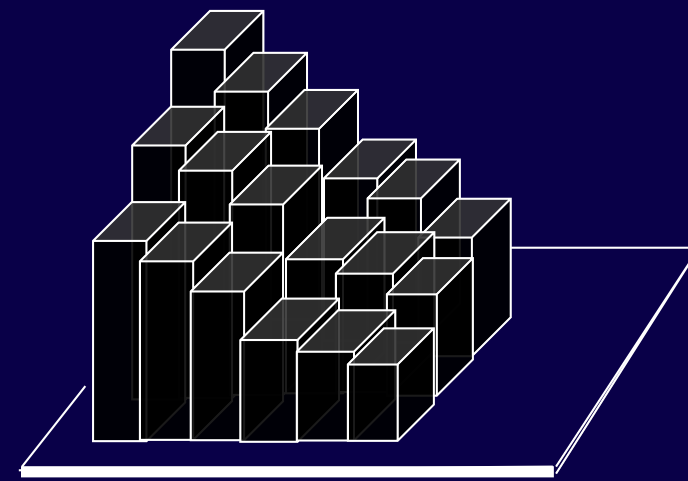
- The term $\tau/\rho_c$ can be directly measured by using phantoms.

- The term **compensator ratio** is the inverse of the thickness ratio. ($\rho_c/\tau$).

# 2-D compensators

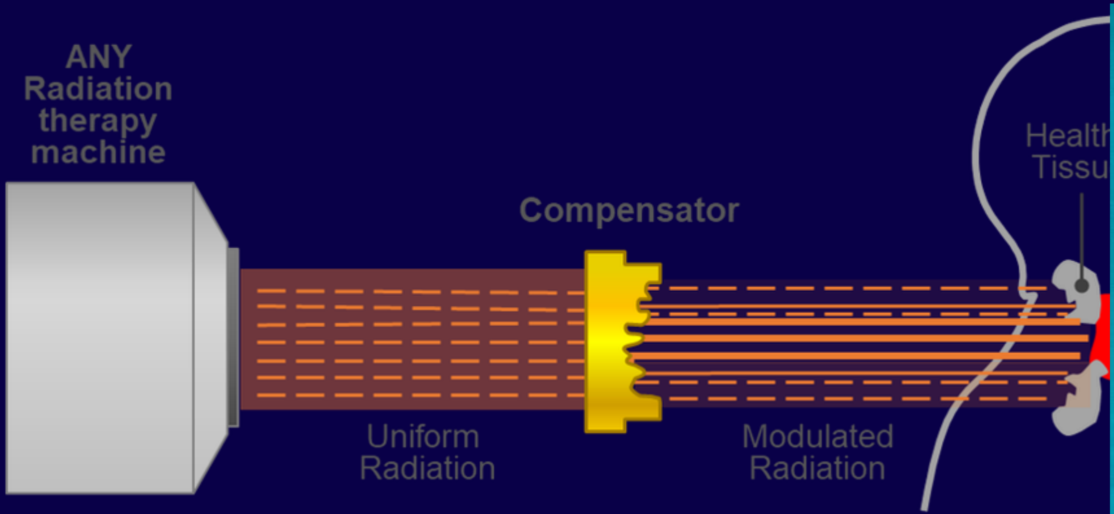
**Two-dimensional compensators**

- Thickness varies, along a single dimension only.
- Can be constructed using thin sheets of lead, lucite or aluminum. This results in production of a **laminated** filter.



# 3-D compensators

- 3D compensators are designed to measure tissue deficits in both transverse and longitudinal cross sections
- Cavity produced in the Styrofoam block is used to cast compensator filters

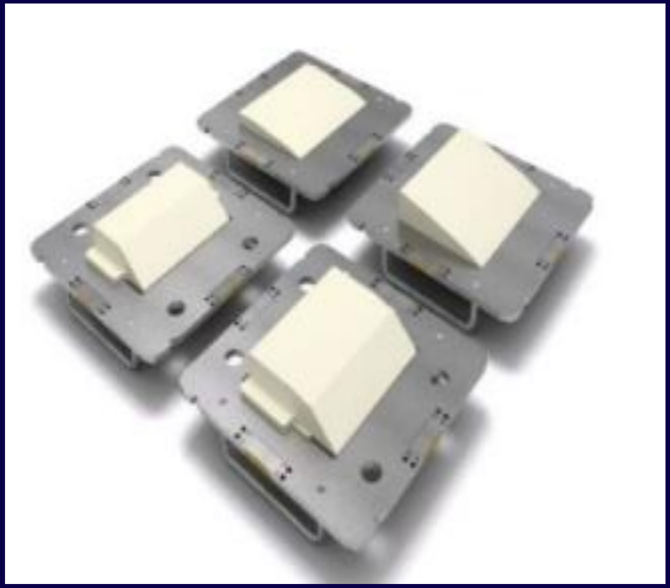



# Wedge Filters

- **Wedge shaped absorber** causes a progressive decrease in intensity **across** the beam resulting in tilting the isodose curves from their normal positions.
- Degree of the tilt depends upon the slope of the wedge filter.
- Material: **tungsten, brass. Lead or steel.**
- Usually wedges are mounted at a distance of **15 centimeters** from the skin surface.

# Wedge Filters

- The sloping surface is made either straight or sigmoid in shape.
- A sigmoid shape produces a **straighter** isodose curve.
- Mounted on trays which are mounted on to the head of the gantry.

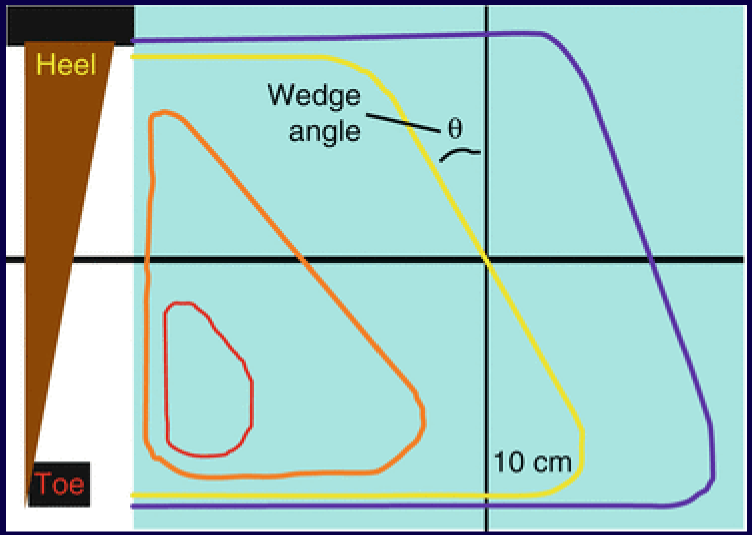


# Wedge filters

- The wedge isodose angle (θ) is the **complement** of the angle through which the isodose curve is tilted with respect to the **central ray** of the beam at any specified depth.

- This depth is important because the angle will **decrease** with increasing depth.

- The choice of the reference depth varies:
  - **10 centimeters.**
  - 1/2 - 2/3$^{rd}$ of the beam width.
  - At the 50% isodose curve (kV).



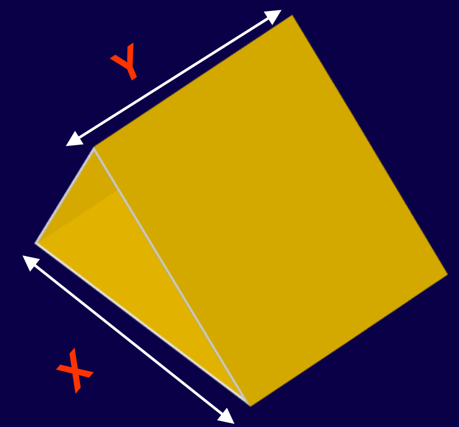
# Type of Wedge filters

- Types of wedge systems:
  - **Physical wedges**
    - » **Individualized**
    - » **Universal**
    - » **Motorized**
  - **Dynamic wedges**
  - **Enhanced Dynamic wedges**

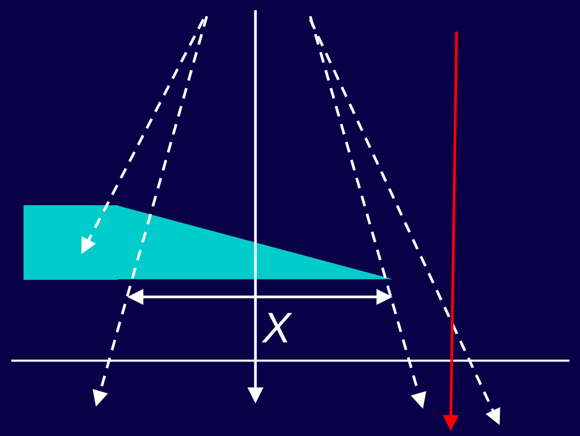
- The two dimensions of wedges are important – "**X**" or width and "**Y**" or length.

- All wedges are aligned so that the central axis of the beam is at the central axis of the wedge.

- If the **X** dimension of **field** is longer then we can't use the wedge without risking a hot spot!!

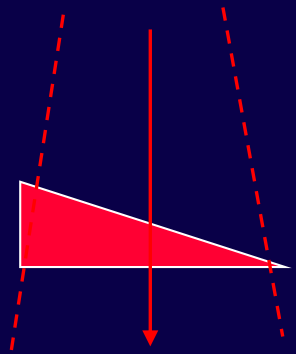



*This area will have a hot spot.*



# Wedge Filters

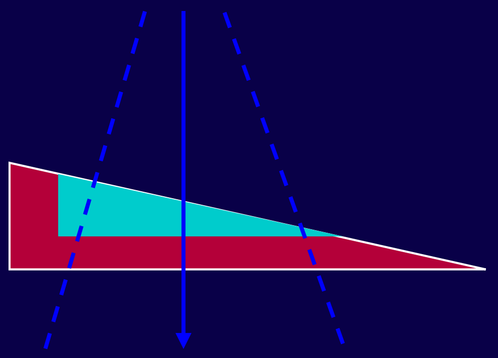
- **Individual wedges are useful in Cobalt beams**
- Using **bigger wedges** than necessary will reduce output of the machine → **increased treatment time.**
- The width (W) of the wedge is fixed and important.
- The same wedge can however be used for fields with lesser lengths or breadths.



- The wedge systems available are:
  - 6W ( x 15)
  - 8W ( x 15)
  - 10W ( x 15)
- All systems have the following four angles **15°, 30°, 45°, 60°.**

# Wedge Filters

- Universal wedges are designed so that the same wedge can be used with all field sizes.
- This is useful as it saves time.
- However not suitable for cobalt beams because of excessive reduction of beam output with smaller fields.



- Come in one size of 20 x 30 cms (except 60°).
- Wedge angles used are: 60°, 45°, 30° & 15°.

# Wedge filters

- The presence of the wedge **decreases** output of the machine.
- WTF = Dose with the wedge/ Dose without the wedge (at a point in the phantom, along the central axis of the beam).
- Usually measured at a suitable depth **below** the $D_{max}$ usually 5 -10 cms! This minimizes the error in calculation of PDD.
- The resultant reduction in output results in an **increase** in the treatment time.

# Wedge filters

- In some isodose charts used in cobalt machines the wedge transmission factor is already incorporated, and no further correction is necessary.

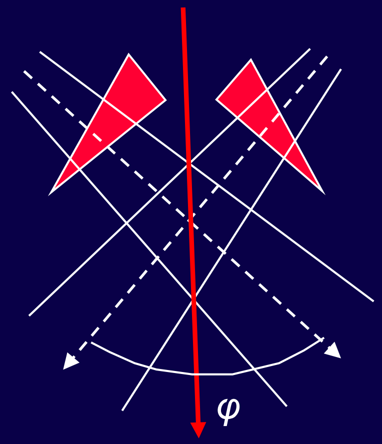
- Use of wedge will result in a preferential **hardening** - more pronounced in case of linear accelerators.

- This is because the Co 60 beam is mono energetic .
- For **small** depths (<10 cms) most of the calculation parameters however remain unchanged.

- At larger depths however, the PDD can be altered specially in case of linear accelerator beams.

# Wedge filters

- Wedged fields are generally used for relatively **superficial** tumors.
- Beams are usually directed from the **same** side of the patient.
- The **broad** edges of the wedges should be aligned together.
- The wedge angle chosen depends on the angle between the central rays of the two beams also called the **"hinge angle"(φ).**
- Wedges:
  - Reduce the hot spots at the surface
  - Rapid dose falloff beyond the region of overlap.
- The overlap region is also called the **"plateau region"**.

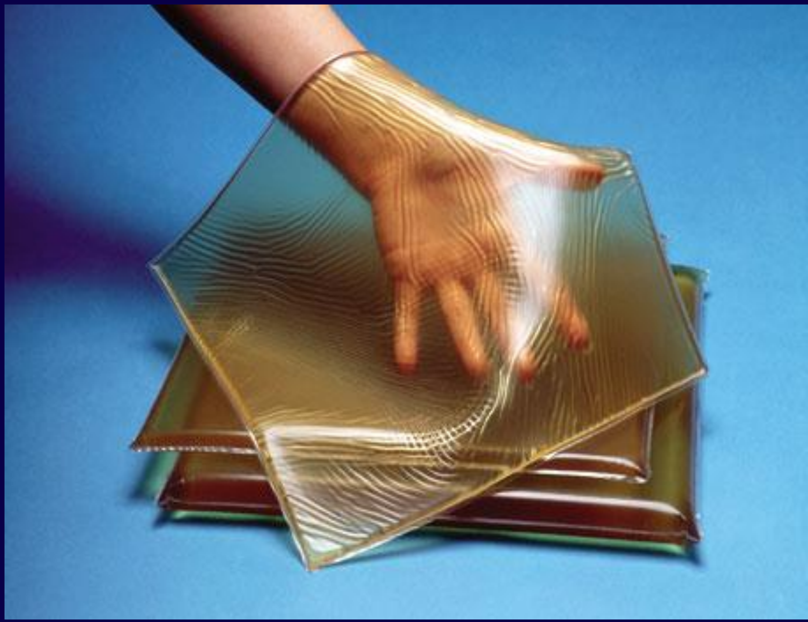



- Thus the 2 factors on which the wedge angle is choosen are:
  - The hinge angle.
  - The wedge separation.
- The wedge angle that will make the isodose curves parallel to each other and the hinge angle bisector is obtained using the equation.

$$\Theta = 90 - \varphi / 2$$

# Bolus

- A tissue equivalent material used to reduce the depth of the maximum dose ($D_{max}$).
- Better called a “build-up bolus”.
- A bolus can be used in place of a compensator for kilo voltage radiation to even out the skin surface contours.
- In megavoltage radiation bolus is primarily used to bring up the **buildup zone** near the skin in treating superficial lesions.



# Bolus

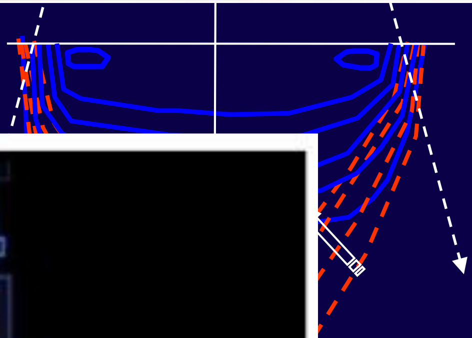
- The thickness of the bolus used varies according to the energy of the radiation.
- In megavoltage radiation:
  - **$Co^{60}$** : 2 - 3 mm
  - **6 MV** : 7- 8 mm
  - **10 MV** : 12 - 14 mm
  - **25 MV**: 18 - 20 mm
- Properties of an ideal bolus:
  - Same electron density and atomic number.
  - Pliable to conform to surface.
  - Usual specific gravity is 1.02 -1.03

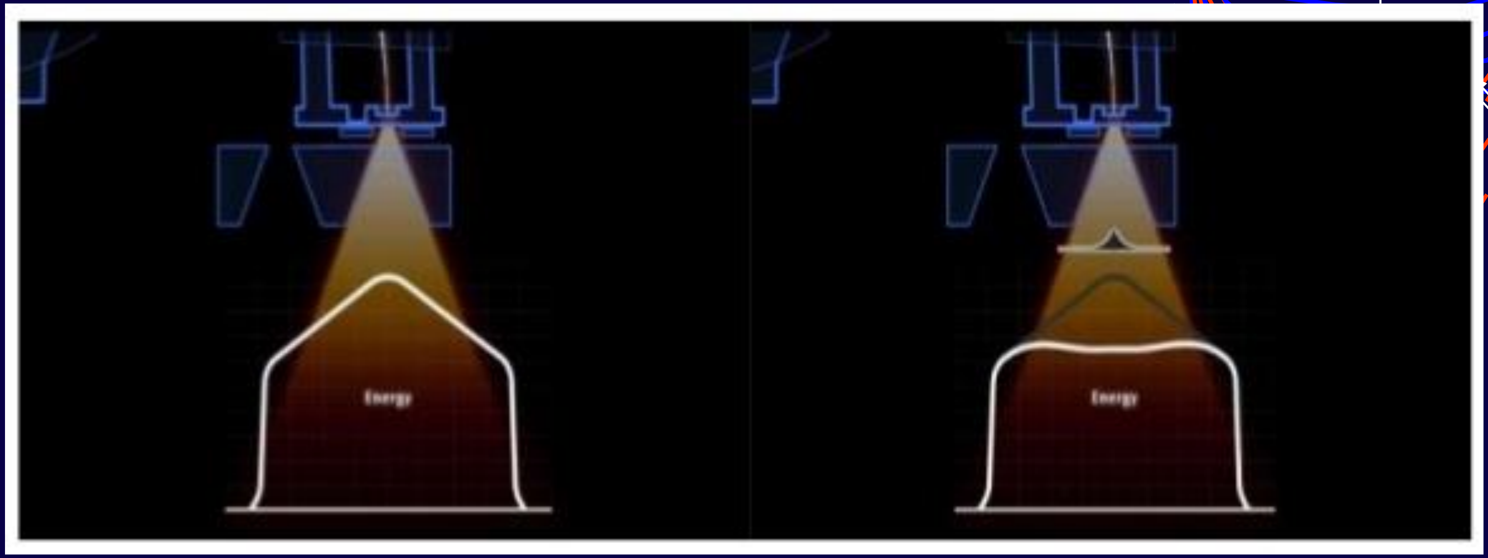
# Bolus

- Commonly used materials are:
  - Cotton soaked with **water**.
  - Paraffin wax.
- Other materials that have been used:
  - Mix- D (wax, polyethylene, mag oxide)
  - Temex rubber (rubber)
  - Lincolnshire bolus (sugar and mag carbonate in form of spheres)
  - Spiers Bolus (rice flour and sodium bicarbarconate)
- Commercial materials:
  - **Superflab**: Thick and doesn't undergo elastic deformation. Made of synthetic oil gel.
  - **Superstuff**: Add water to powder to get a pliable gelatin like material.
  - **Bolx Sheets**: Gel enclosed in plastic sheet.

# Beam flattening filter

- Intensity is more at central axis and decreases as we move away
- Non-uniform dose at any given depth
- FF is used to uniform it
- Usually made up of copper or brass.





# Flattening filters

- The beam flatness is specified at **10 centimeters**.
- The extent of flatness should be **± 3%** along the central axis of the beam at 10 centimeters.
- Should cover **80%** or more of the field, or reach closer than one centimeter from the edge.
- There is usually over flattening of isodoses, near the surface. This results in production of **"horns" or hot spots.**
- No point parallel to the surface should receive a dose **> 107%** of the central axis dose.
- Because of the thinner outer rim, the **average** beam energy is lower at the periphery as compared to the centre

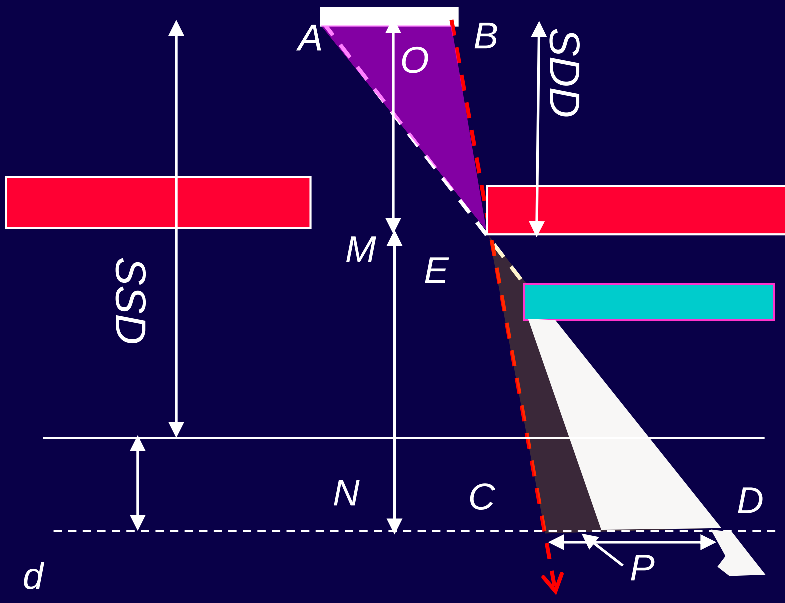
# Penumbra trimmers

- **Penumbra** :Refers to the region at the edge of the beam where the dose-rate changes rapidly as a function of distance from the beam axis.
- Types:
  - **Transmission penumbra**: Transmission through the edge of the collimator block.
  - **Geometrical penumbra** : Finite size of the source.
- **Physical penumbra**: Lateral distance between to specified isodose curves at a specific depth (90% & 20% at $D_{max}$).
- Takes scattered radiation into account.

- Penumbra width depends upon:
  - Source diameter.
  - SSD.
  - Depth below skin.
  - Source to diaphragm distance (inversely)

# Penumbra trimmers

- Consists of **extensible**, heavy metal bars to attenuate the beam in the penumbra region.
- Increase the source to diaphragm distance, reducing the geometric penumbra.
- Another method is to use secondary blocks placed close to the patient ( 15 – 20 cms).



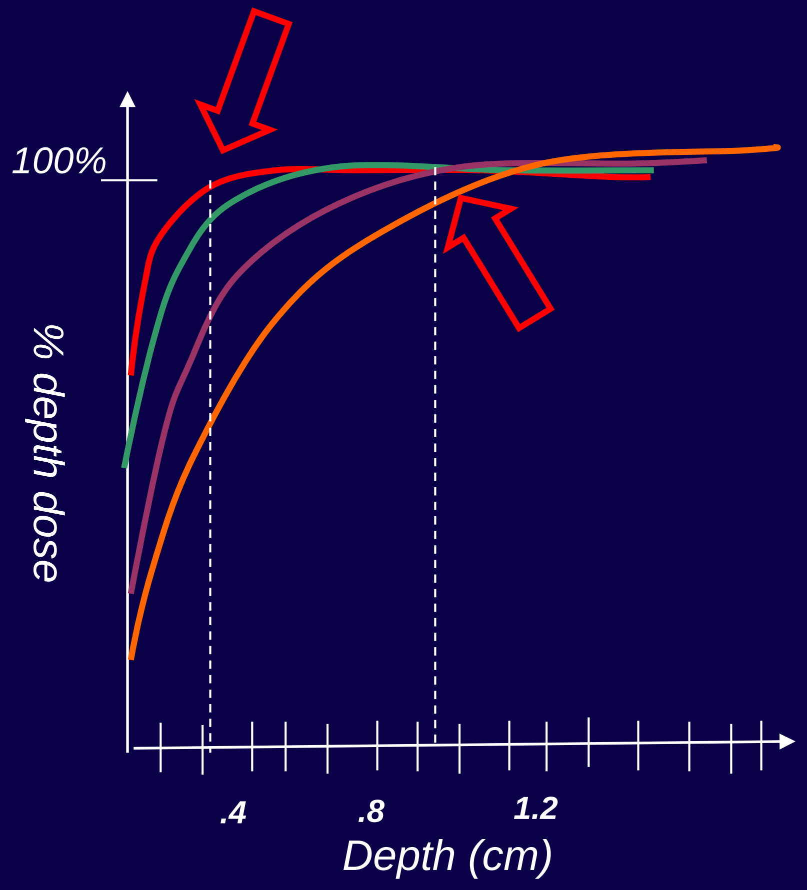

1. *CD/ AB = MN/ OM*

2. *CD/ AB = SSD + d – SDD / SDD*

3. ***P = AB ( SSD + d – SDD)/ SDD***

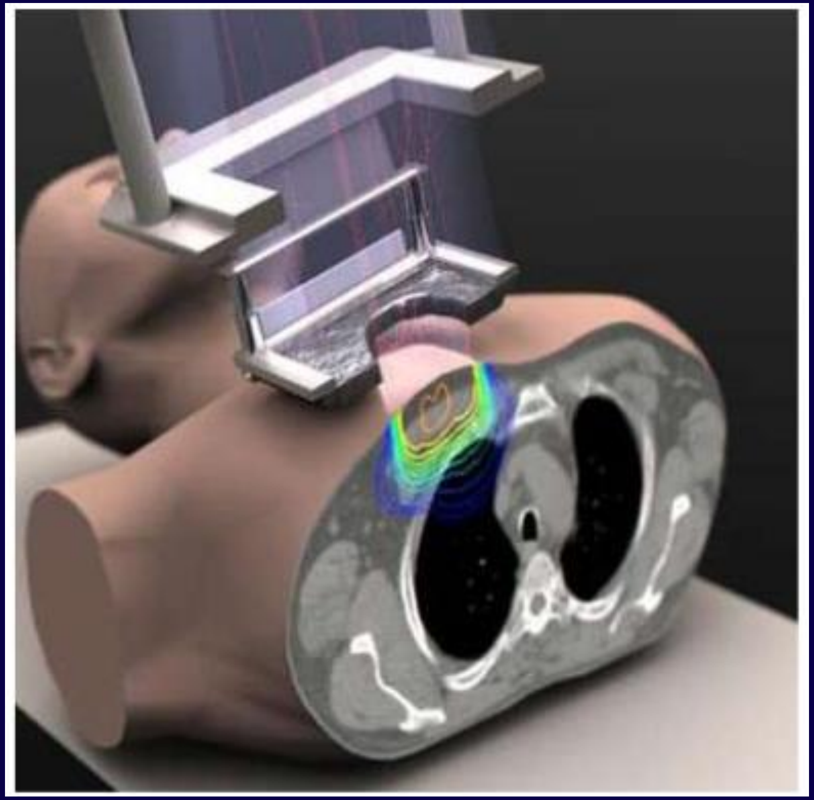
# Beam Spoilers

- Special beam modification device where **shadow trays** made from **Lucite** are kept at a certain distance from the skin.
- Based on the principle that **relative surface** dose increases when the surface to tray distance is **reduced**.
- First used by Doppke to **increase** dose to superficial neck nodes in head and neck cancers using 10 MV photon beams.



# Beam modification of Electrons

- Electron field shaping is done using lead cutouts.
- For a low-energy electrons (<10 MeV), sheets of lead, less than 6 mm thickness are used.
- The lead sheet can be placed **directly** on the skin surface.
- Shields can also be supported at the end of the treatment cone if too heavy at the cost of greater inaccuracies.
- Design is **easier**, because the size is same as that of the field on the patients skin.

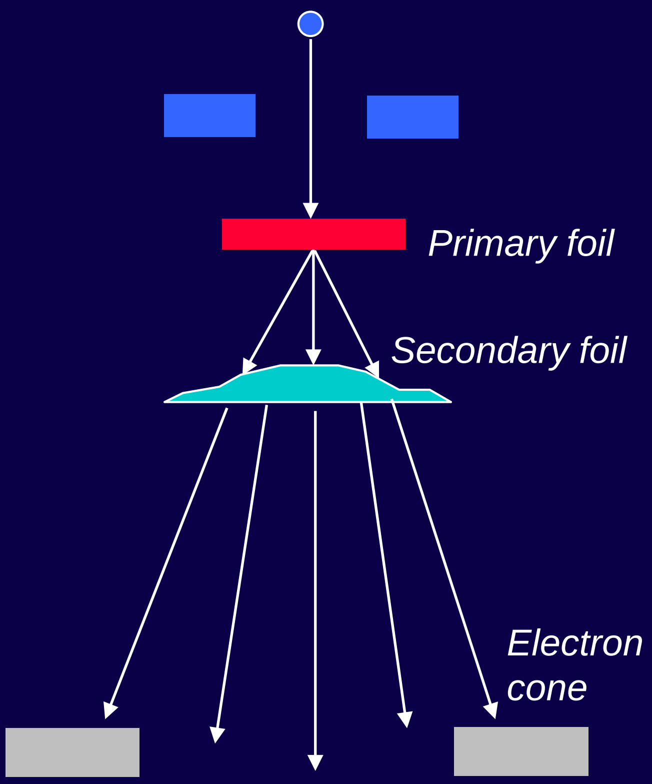


# Electron Beam

- To avoid variation in output and electron scatter, jaws cannot be used to collimate electron beams.
- An electron beam cone is therefore used to provide the collimation.
- A primary collimator is provided close to source – defines the maximum field size.
- A secondary collimator, near the patient defines the treatment field.

# Scattering foil

- A device to widen the thin pencil beam (3 mm) of electrons.
- Metallic plates of **tin, lead or aluminium** are used.
- Disadvantages:
  - Beam attenuation.
  - Generation of bremsstrahlung radiation.
- Advantages:
  - Less prone to mechanical errors.
  - Less expensive.
  - Requires less instrumentation.
- Nowadays **dual foil systems** are used, which compare well with scanning beam systems.

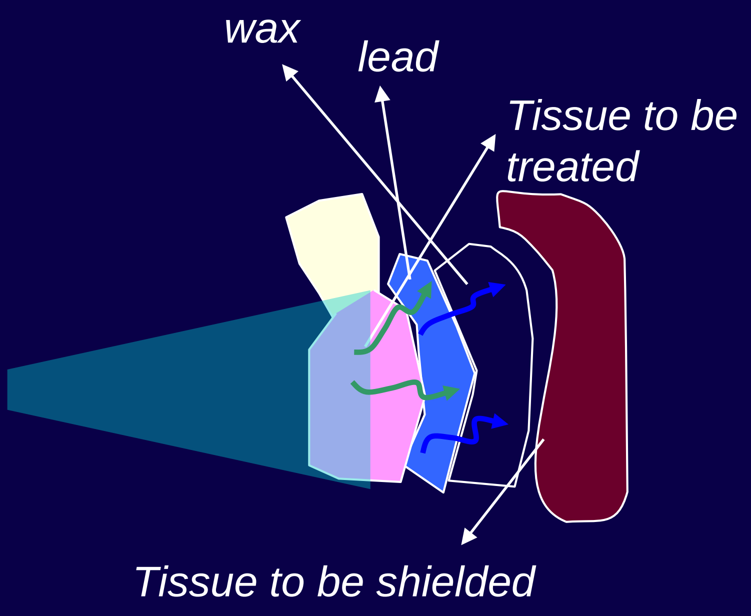


# Lead cut-outs

- For a low-energy electrons(<10MeV), sheets of lead, less than 6mm thickness are used
- Lead sheet can be placed directly on the skin surface
- Shields can also be supported at the end of the treatment cone if too heavy at the cost of greater inaccuracies
- Design is easier, because the size is same as that of the field on the patients skin

# Direct / Internal Shielding

- Used for electron beam shielding
- A **lead shield** can be placed where shielding of structures against backscatter electrons is required
- A **tissue equivalent** material is coated over the lead shield like wax/ dental acrylic/ aluminum
- Example of areas requiring these techniques are the buccal mucosa and eye lids

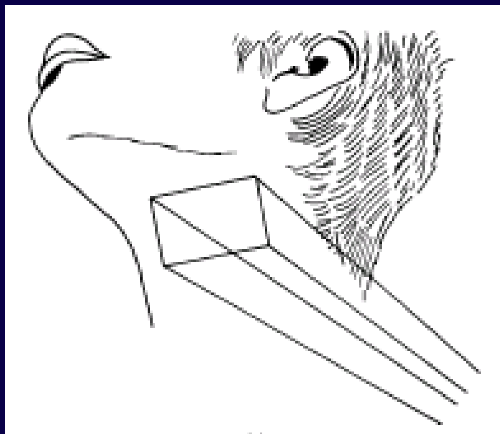


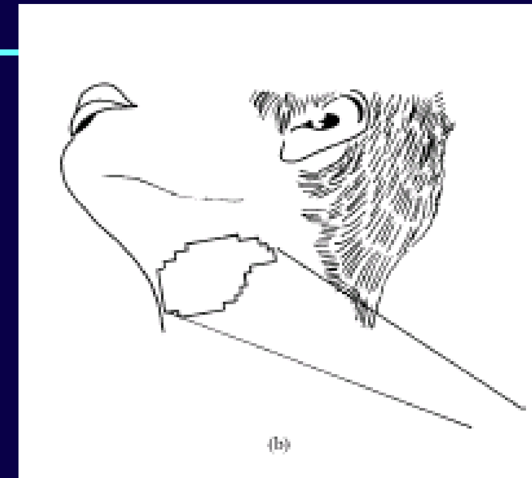
# Beam / intenstiy Modulation

- IMRT is the delivery of radiation to the patient via fields that have non-uniform radiation fluence

- Arguably the terminology has been incorrectly established because strictly it is fluence not intensity that is modulated

# Evolution of IMRT

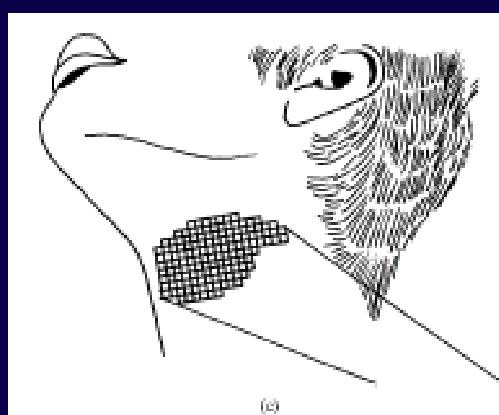




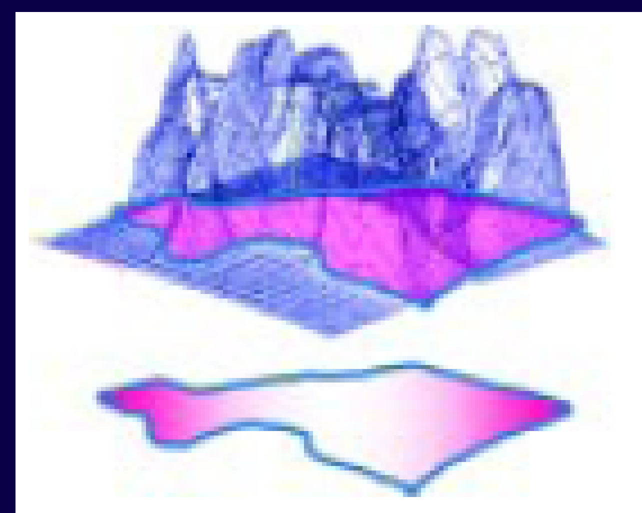

*Conventional RT*

*Uniform fluence*

*3D CRT*




*IMRT*



*Non uniform fluence*

# How intensity to be modulated?

Intensity can be modulated by any beam modifying device kept in the path of the beam

- Wedges
- Compensators
- Attenuating bars
- Binary MLC
- Multileaf collimators

# Conclusion

- Beam modification increases conformity allowing a higher dose delivery to the target, while sparing more of normal tissue simultaneously.
- Megavoltage radiotherapy is better suited for most forms of beam modification due to it’s favorable scatter profile.
- However any beam modification necessitates a close scrutiny of every phase of the planning and treatment process.