Principles of Teletherapy units in Radiation Therapy

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Learning Objectives

- Teletherapy units / External beam therapy units
- History and basic characteristics of Teletherapy units
- Understanding of the different mechanism and its function of various type of Teleisotope units
- Other type of external beam therapy units

External beam radiotherapy approaches

➢ Superficial X Rays	- 40 to 120kVp
➢ Orthovoltage X Rays	- 150 to 400kVp
➢ Telecurie / Tele istope units	- Cs-137 and Co-60
➢ Megavoltage X Rays	- Linear Accelerators
➢ Electrons	- Linear Accelerators
➢ Charged particles	- Protons, C
➢ Others	- Neutrons, pions

Definition of Teletherapy unit

- **Teletherapy or External beam radiotherapy** (**EBRT**) is the most common form of radiotherapy
- Tele means “Far”

TELETHERAPY

- Source of radiation is at a distance from the patient

ISOTOPIC TELETHERAPY

- Treatment machines incorporating γ ray sources for use in external beam radiotherapy

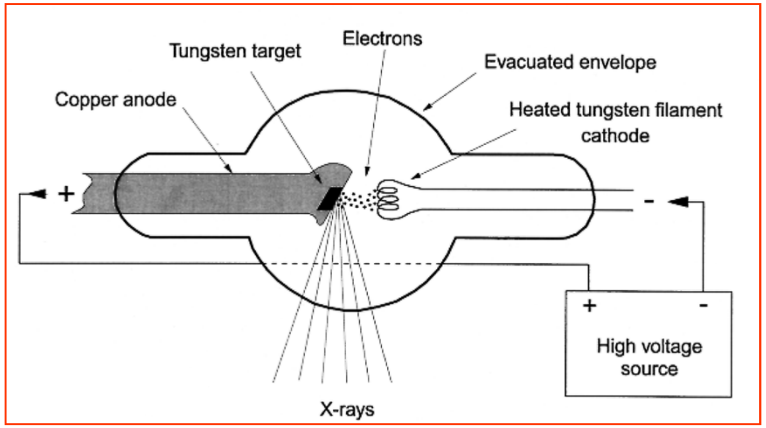
- External beam radiotherapy

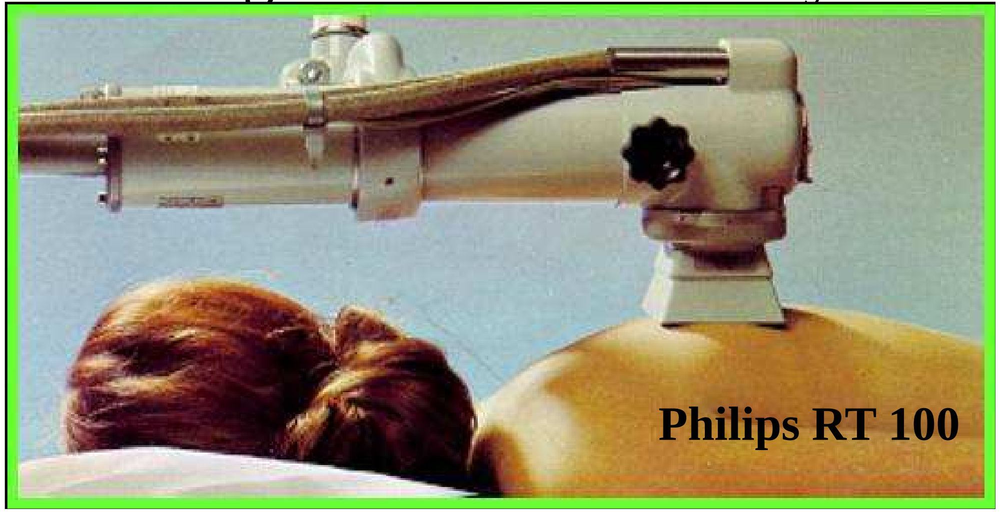
  (X rays +/- Electrons)

- Tele-Isotope units
  - Radium bomb
  - Telecesium unit
  - Telecobalt unit
- Linear accelerator
- Gamma Knife
- MRI Guided LINAC / Coblat (View Ray)
- Tomotherapy
- Cyber knife
- Proton Accelerator

Superficial radiotherapy

- 50 to 120kVp - similar to diagnostic X Ray qualities
- Low penetration
- Limited to skin lesions treated with single beam
- Typically small field sizes
- Applicators required to collimate beam on patient's skin
- Short distance between X Ray focus and skin
- The dose of radiation used to be measured in "skin erythema units"
- Increase in radiation increases reddening of the skin – not very accurate



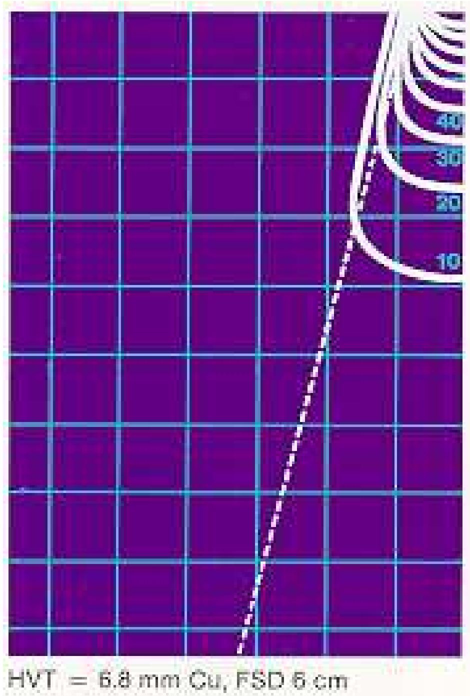


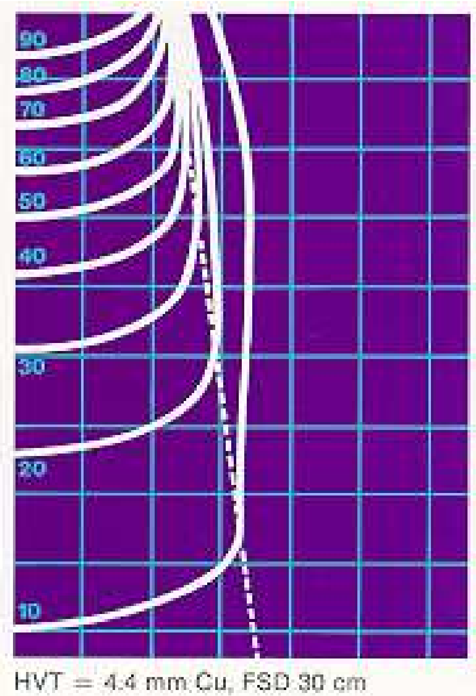
Superficial radiotherapy issues

- Due to short FSD high output and large influence of inverse square law
- Calibration difficult (strong dose gradient, electron contamination)
- Dose determined by a timer - on/off effects must be considered
- Photon beams may be contaminated with electrons from the applicator

Orthovoltage therapy

- 150 - 400kVp
- Penetration sufficient for palliative treatment of bone lesions relatively close to the surface (ribs, spinal cord)
- Largely replaced by other treatment modalities
- Depth dose affected by FSD





FSD 6cm, HVL 6.8mm Cu

FSD 30cm, HVL 4.4mm Cu

Superficial versus Orthovoltage

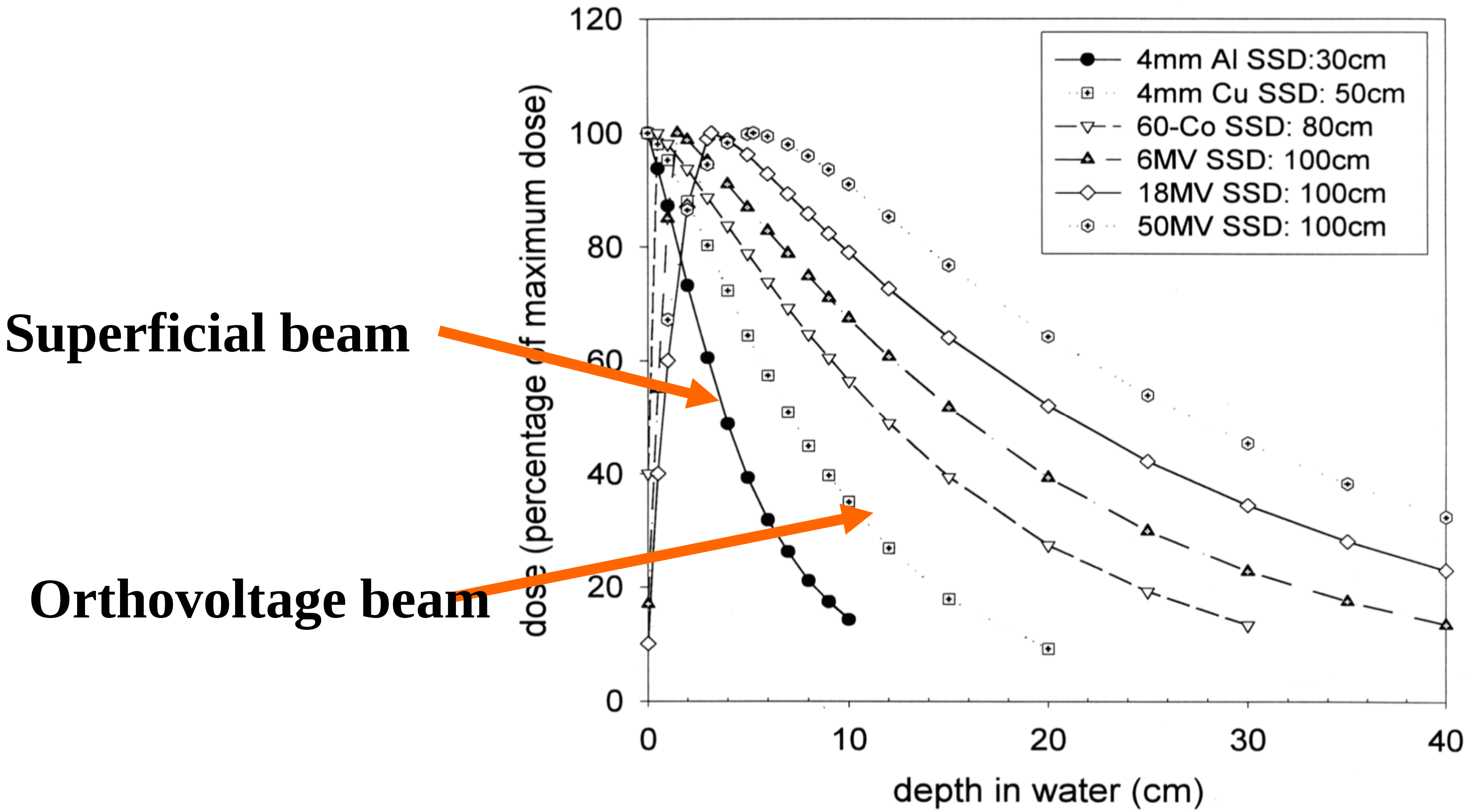
<u>Superficial</u>

- 40 to 120kVp
- small skin lesions
- maximum applicator size typically < 7cm
- typical FSD < 30cm
- beam quality measured in HVL aluminium (0.5 to 8mm)

<u>Orthovoltage</u>

- 150 to 400kVp
- skin lesions, bone metastases
- applicators or diaphragm
- FSD 30 to 60cm
- beam quality in HVL copper (0.2 to 5mm)

Photon percentage depth dose



Tele Isotope unit – Radium bomb

Until 1951, all isotope machines produced were teleradium units (radium bomb).The source to skin distance was usually not greater than 10 cm in these machines. Major drawbacks of these machines were high risk of radiation hazard due to radon gas leak produced as a by product, high cost of radium, large self absorption, low γ ray constant and low output.

Bryant Symons radium "bomb" at Westminster Hospital, London, England, in the 1930s.

Kilovoltage therapy

Telecaesium Unit
with applicators

- “Cesium 137 Teletherapy unit”
- Energy - 660 KeV, HF – 30 yrs
- Source of very high specific activity (~ 250 curie/gm) and high source strength (~10 kilo curie)
- Less build-up dose and skin dose was more

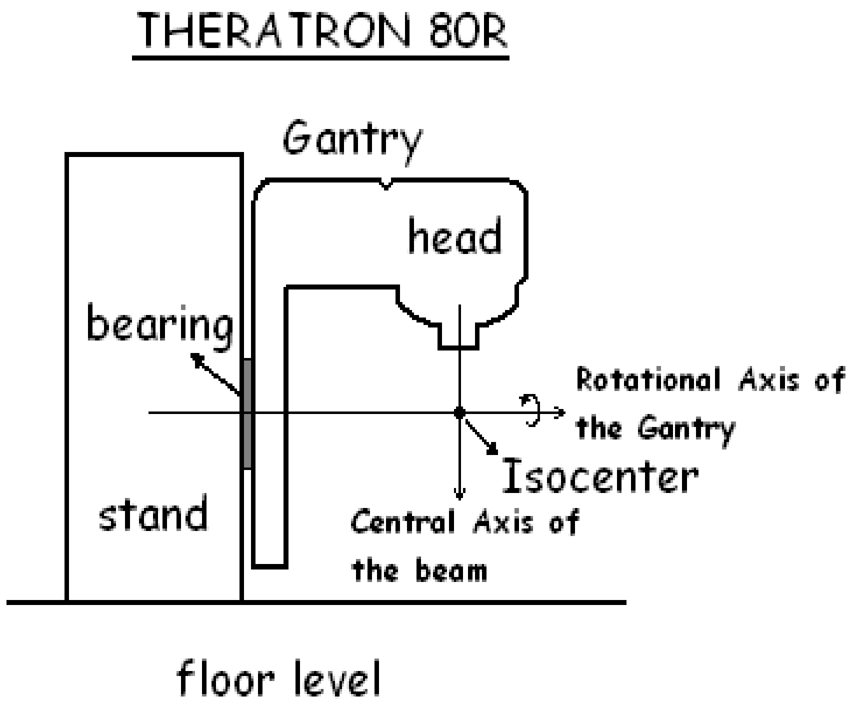
- Good for treating parallel opposing head and neck treatment.
- The source to skin distance is 20cm to 40cm.
- They have not been very popular because of relatively low γ ray constant and low specific activity.

Types of Teletherapy units

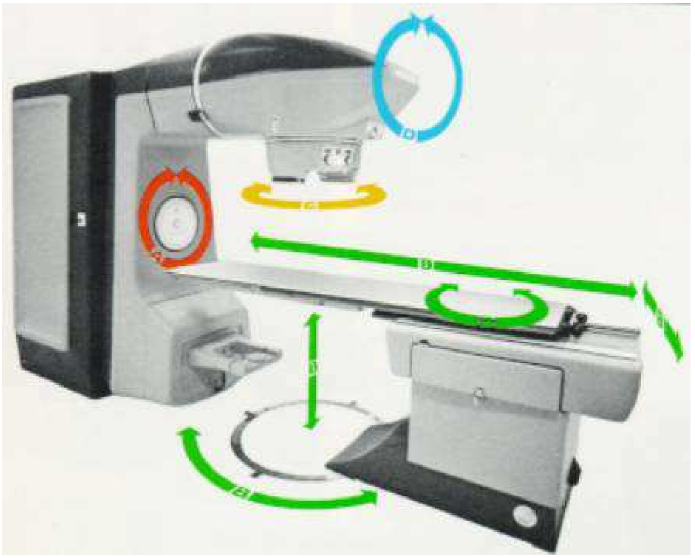
Stationary Type

- Fixed head
- SSD Technique

Rotational type



Isocentric Teletherapy units



- The axis of rotation of three structures:

  Gantry

  Collimator

  Couch

  coincide at a point known as the Isocenter.

  Isocentric set-up allows movement of all components around the same centre

- Isocentric Mounting

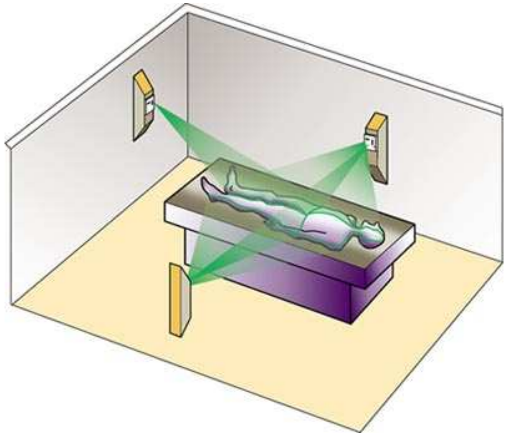
  1. Enhances accuracy.

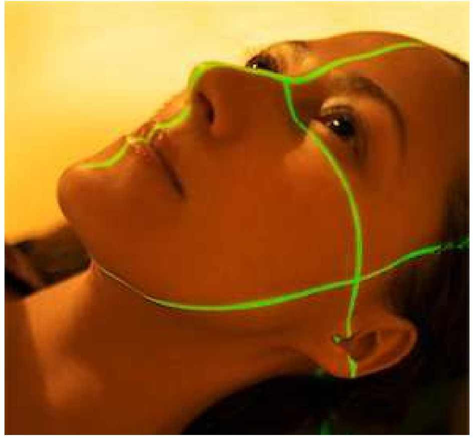
  2. Allows faster setup and is more accurate than older non isocentrically mounted machines.

  3. Makes setup transfer easy from the simulator to the treatment machine.

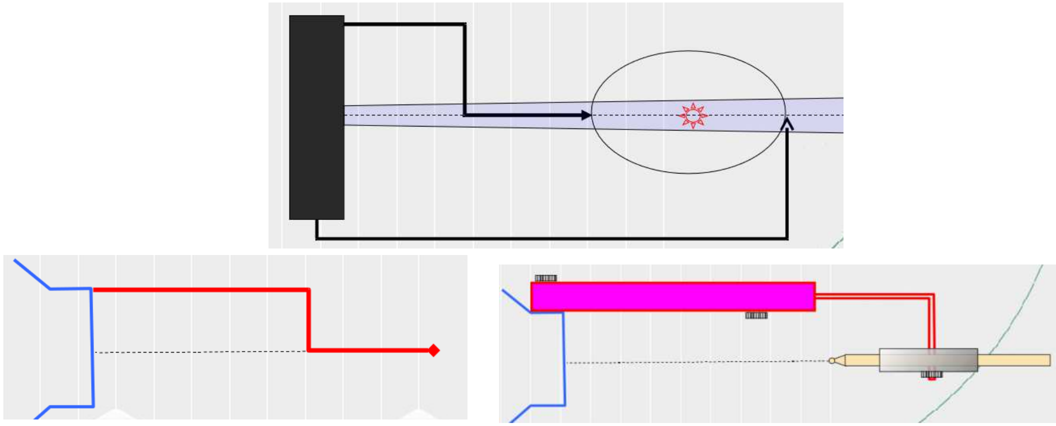
Isocentric Teletherapy units

- Lasers





- SSD mechanical distance indicator



- Front and Back pointers

- Optical distance indicator (ODI)

Megavoltage radiotherapy

- 60-Cobalt (energy 1.25MeV)
- Linear accelerators (4 to 25MVp)
- Skin sparing in photon beams
- Typical focus to skin distance 80 to 100cm
- Isocentrically mounted

Megavoltage radiotherapy

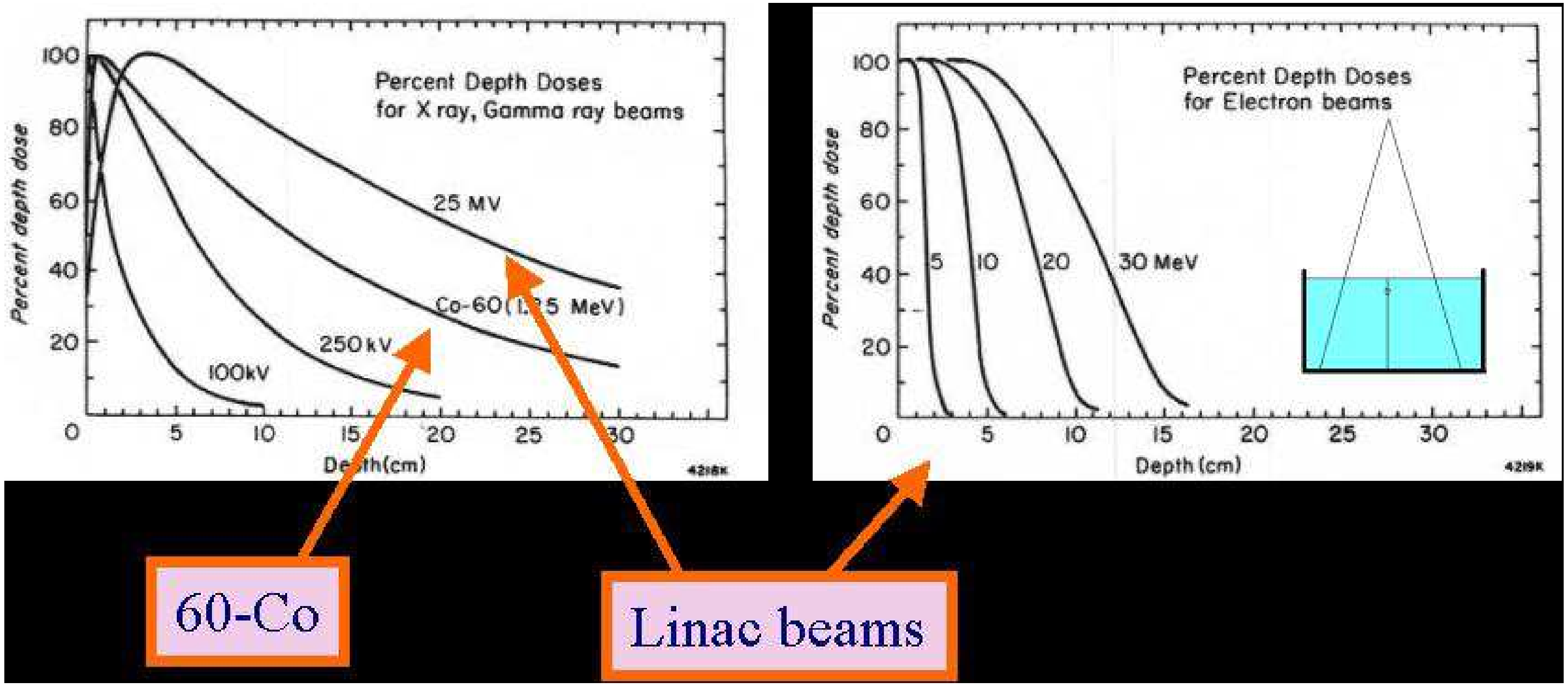
- Also called “Telecobalt therapy unit”
- Much more energetic and penetrating
- Used for treatment of deep seated tumours
- The maximum dose of radiation is deposited below the skin surface (skin sparing effect → increases with energy)
- Source of very high specific activity (~ 250 curie/gm) and high source strength (~10 kilo curie)
- Advantages:
  - Skin sparing effect (Deep seated tumours)
  - Less complex (training of manpower)
- Cobalt-60 units are more suitable than LINAC, considering the cost and maintenance issues. More than 50% of all human cancers were treated by Cobalt therapy units.

Linear Accelerator (LINAC) and Modern therapy units

- Is the device most commonly used for external beam radiation treatments
- Delivers high energy x-rays and electrons
- 4 MV – 18 MV x-ray photons; 4 MeV to 20 MeV electrons
- Advantages
  - Higher energy to treat deep seated tumour
  - High dose rate (constant) → Less treatment time
  - Sharp penumbra (Field junction)
- Disadvantages
  - Maintenance issue (Needs air-condition with air exchanges)
  - Qualified / Skilled manpower
  - Frequent dosimetry and Quality assurance

Photon percentage depth dose

- **PHOTONS**
- **ELECTRONS**

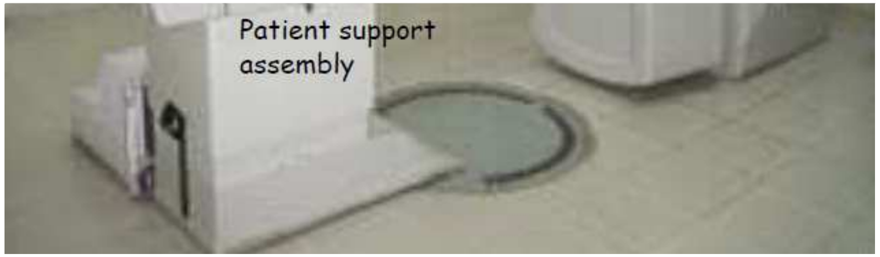


TELE COBALT UNIT

Cobalt-60 teletherapy machine, Theratron-780, AECL (now MDS Nordion), Ottawa, Canada

Teletherapy : Components

- Radioactive / X-ray source
- A source housing, including beam collimator and source movement mechanism
- A gantry and stand in isocentric machines or a housing support assembly in stand-alone machines
- Patient support assembly; and
- Machine console.



Characteristics of Radionuclides : Teletherapy units

- Characteristics of radionuclides useful for external beam radiotherapy are:
  - High gamma ray energy (of the order of 1 MeV).
  - High specific activity (of the order of 100 Ci/g).
  - Relatively long half life (of the order of several years).
  - Large specific air kerma rate constant.

- Of over 3000 radionuclides known only 3 meet the required characteristics and essentially only cobalt-60 is currently used for external beam radiotherapy.

Coblat 60 v/s Radium 226 and Cesium 137

Radionuclide	Half-life	γ-Ray Energy	Exposure Rate Constant	Specific Activity
Radium	1622 yrs	0.83 MeV (average)	0.825 $Rm^2Ci^{-1}h^{-1}$	0.98 Ci/g
Cesium-137	30 yrs	0.66 MeV	0.326 $Rm^2Ci^{-1}h^{-1}$	50 Ci/g
Cobalt-60	5.26 yrs	1.17 MeV 1.33 MeV	1.30 $Rm^2Ci^{-1}h^{-1}$	200 Ci/g

Telecobalt machines

- Cobalt-60 teletherapy machine depicted on a postage stamp issued by Canada Post in 1988
  - In honor of Harold E. Johns, who invented the cobalt-60 machine in the 1950s.

Telecobalt sources

- Telecobalt sources are cylinders with height of 2.5 cm and diameter of 1, 1.5, or 2 cm
  - The smaller is the source diameter, the smaller is the physical beam penumbra and the more expensive is the source.
  - Often a diameter of 2.0 cm is chosen as a compromise between the cost and penumbra.
- Typical source activity: of the order of 5 000 – 10 000 Ci (185 – 370 TBq).
- Typical dose rates at 80 cm from source: of the order of 100 – 200 cGy/min

Telecobalt sources

- The Cobalt-60 source is produced by irradiating ordinary, stable ^{59}Co with neutrons in a nuclear reactor. The nuclear reaction is represented as

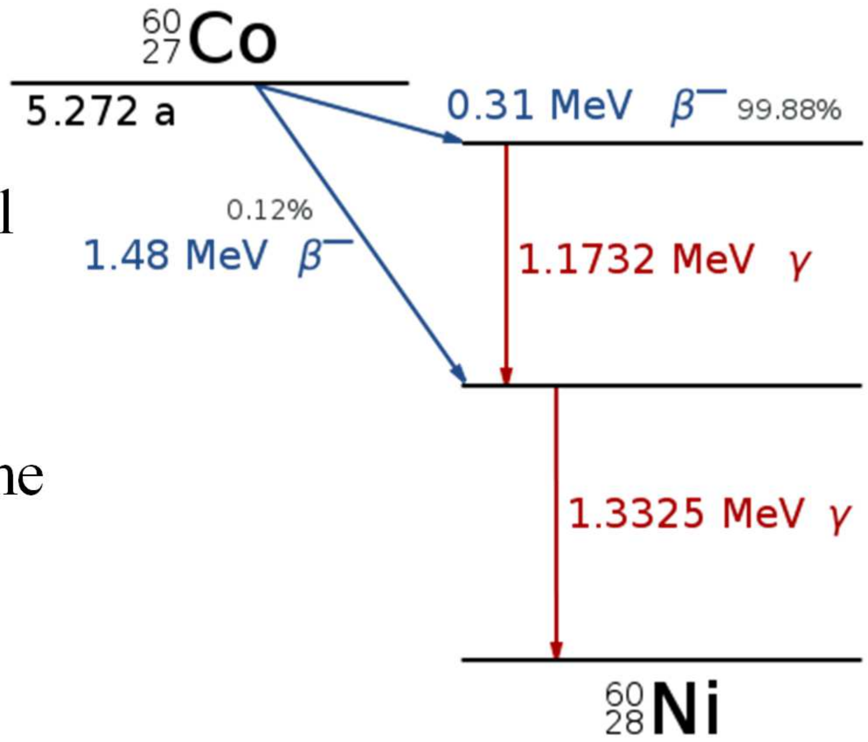
$$^{59}_{27}Co + ^{1}_{0}n \rightarrow ^{60}_{27}Co \rightarrow ^{60}_{28}Ni + ^{0}_{-1}e + \gamma \text{ (photon)}$$

- The resultant isotope ^{60}Co is a radioactive one and it decays to $^{60}_{28}Ni$ by means of β emission. The maximum energy of β rays is 0.32 MeV.
- The nuclei of ^{60}Ni will be in the excited states following this decay and the de-excite to the ground state by emitting two γ ray photons of energy 1.17 MeV and 1.33 MeV in cascade.
- The decay half-life is 5.26 years and the average photon energy is 1.25 MeV.

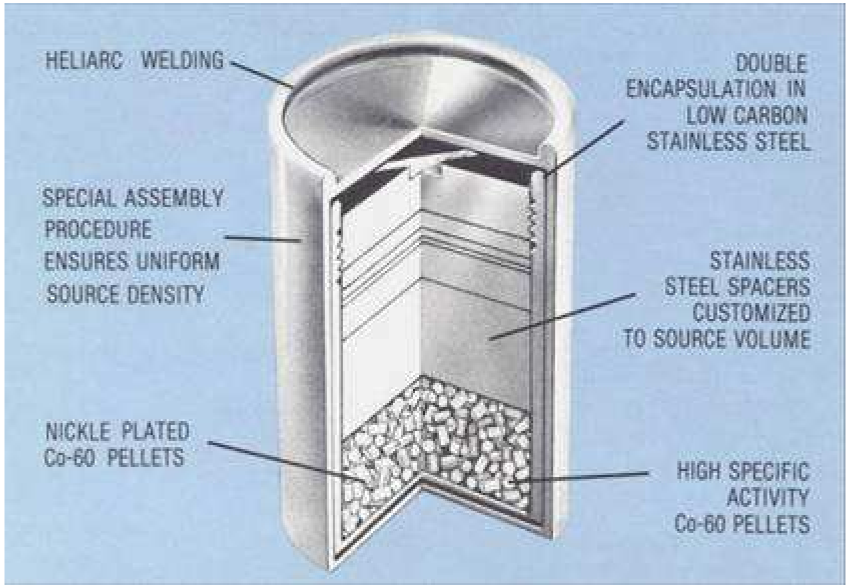
Telecobalt sources

- These γ rays constitute the useful treatment beam.

- The β particles are absorbed in the cobalt metal and stainless steel capsules.



The source



Typical ^{60}Co source displaying the interior with a large amount of pellets

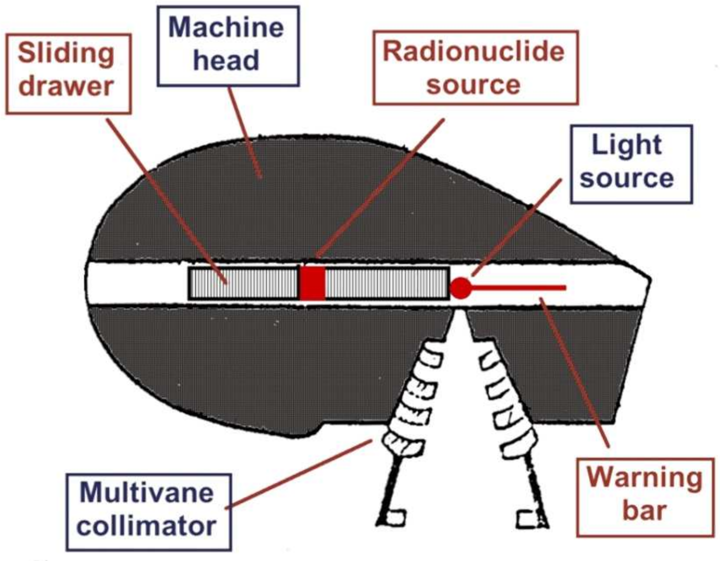
Teletherapy source housing

Steel shell with lead for shielding purposes

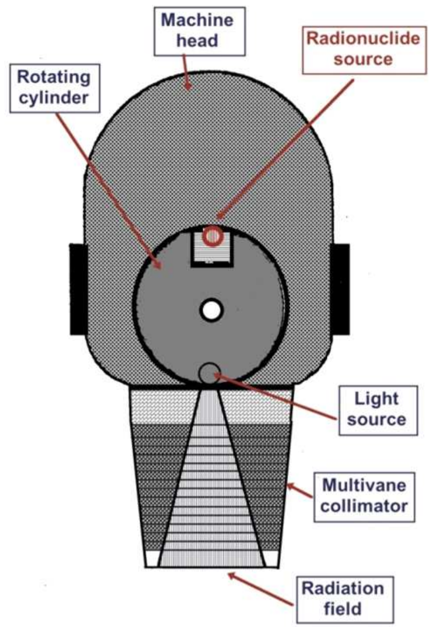
Mechanism for bringing the source in front of the collimator opening to produce the clinical gamma ray beam.

- Methods for moving the teletherapy source from the BEAM-OFF into the BEAM-ON position and back:

Source on a sliding drawer



Source on a rotating cylinder



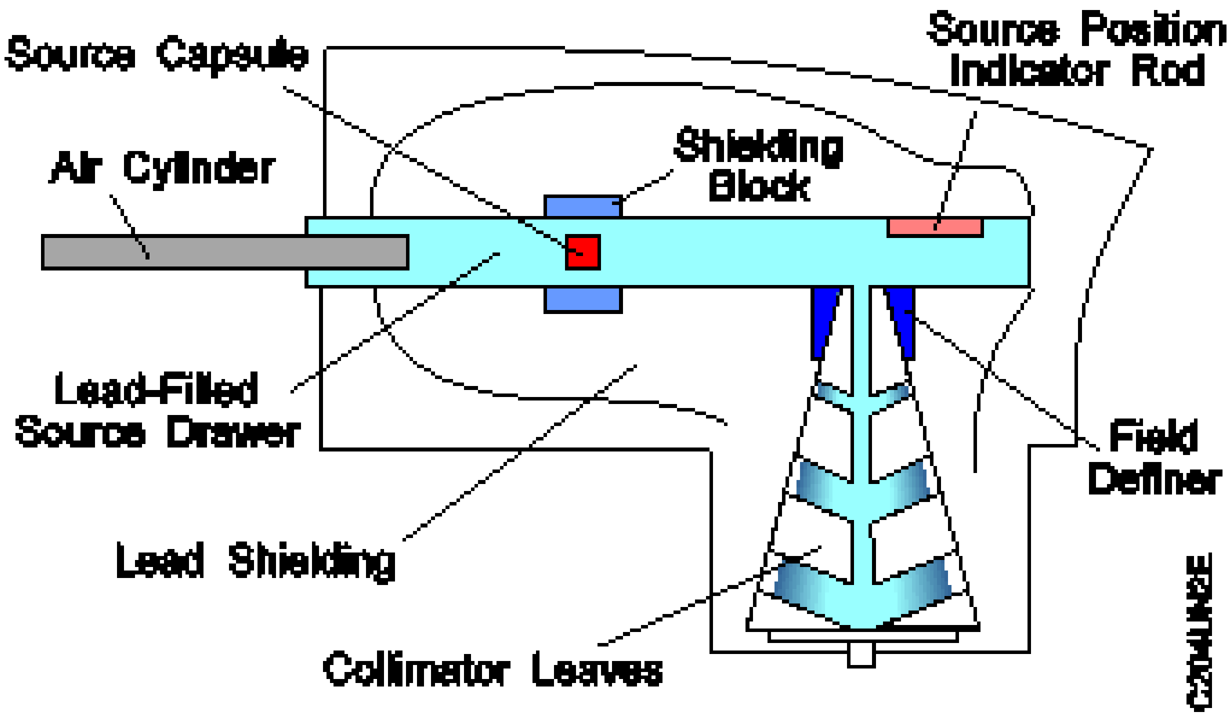


Figure 3. Basic head design of a cobalt radiotherapy unit

Teletherapy source housing

- Some radiation (leakage radiation) will escape from the teletherapy machine even when the source is in the BEAM-OFF position.

- Head leakage typically amounts to less than 2 mR/h (0.02 mSv/h) at 1 m from the source.

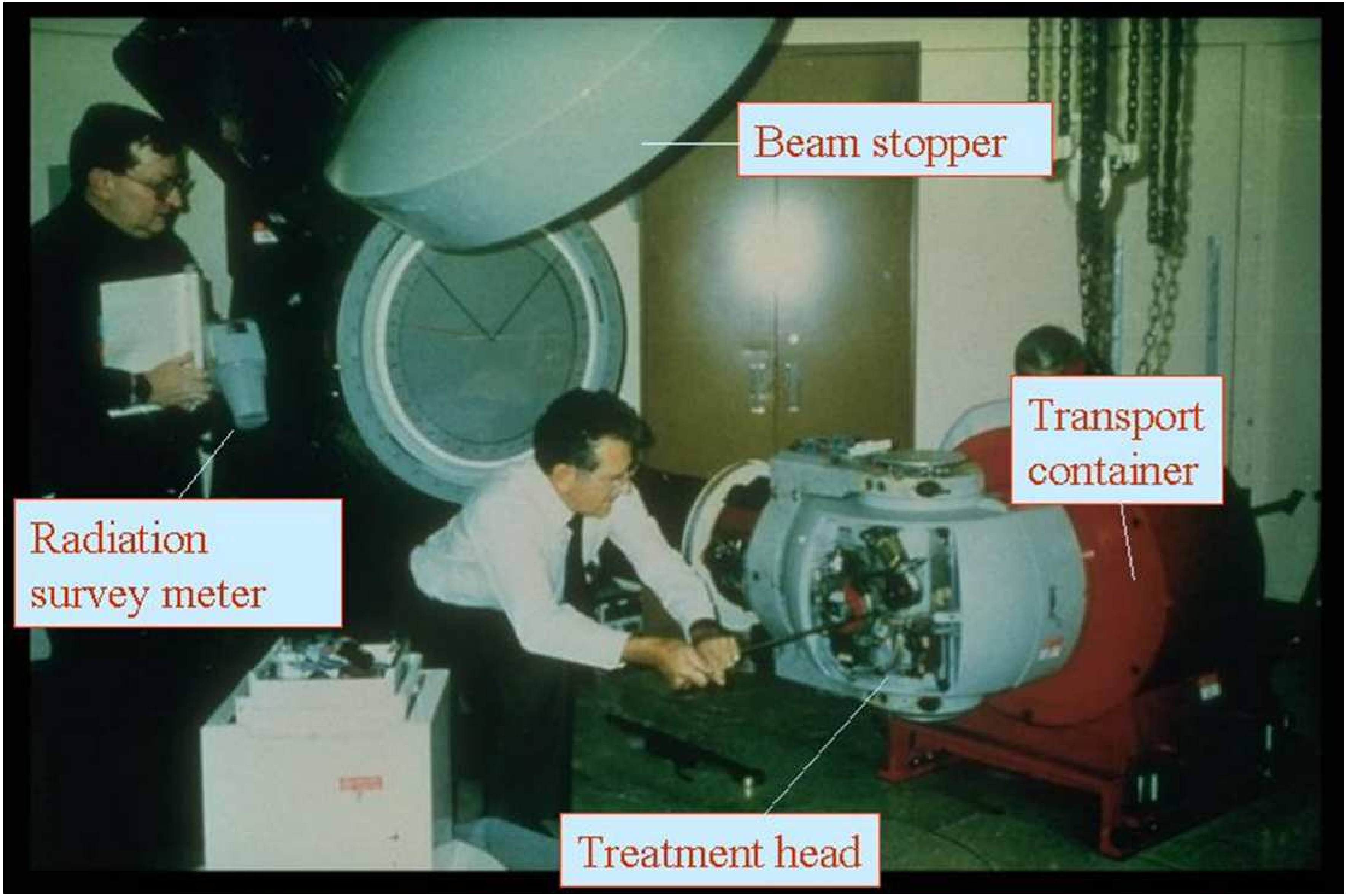
Teleisotope unit : Source decay

- Limited half life: 60-Co 5.26years
- Source change recommended every 5 years to maintain output

Source transport container

Treatment unit head

Telecobalt Source Exchange

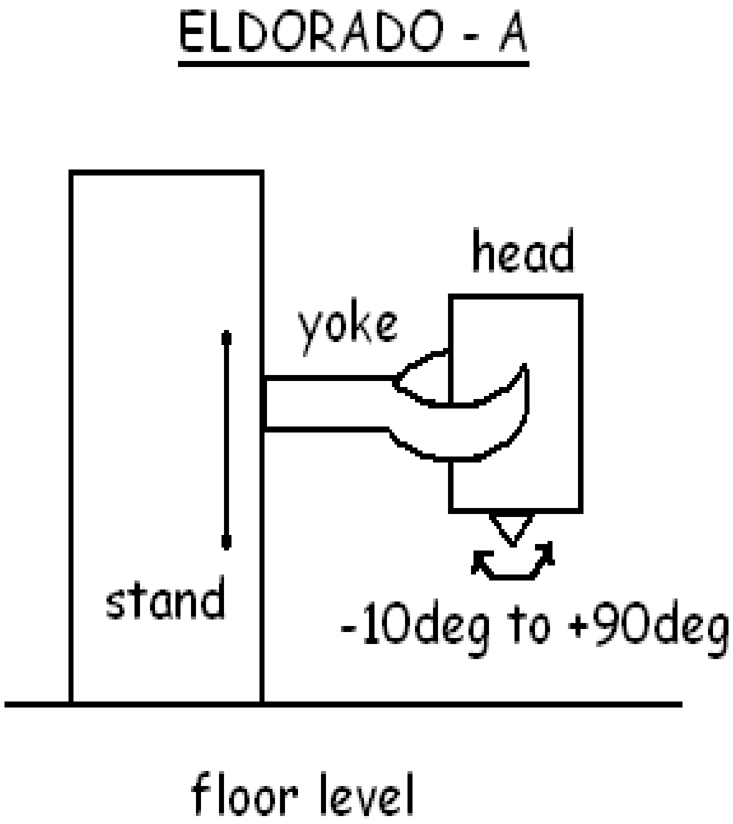


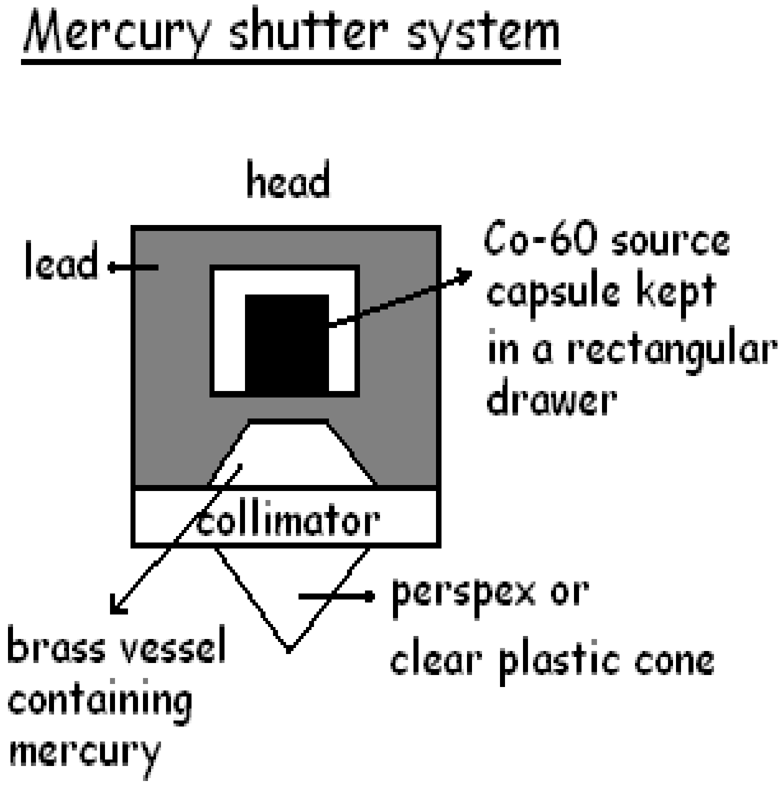
Shutter mechanisum

- Mercury Shutter System
- Pneumatic Shutter System
- Rotational Shutter System
- Mechanical Shutter System
- Currently, two methods are used for moving the Tele-therapy source from the BEAM-OFF into the BEAM-ON position and back:
  - Source on a sliding drawer
  - Source on a rotating cylinder

Mercury Shutter System:

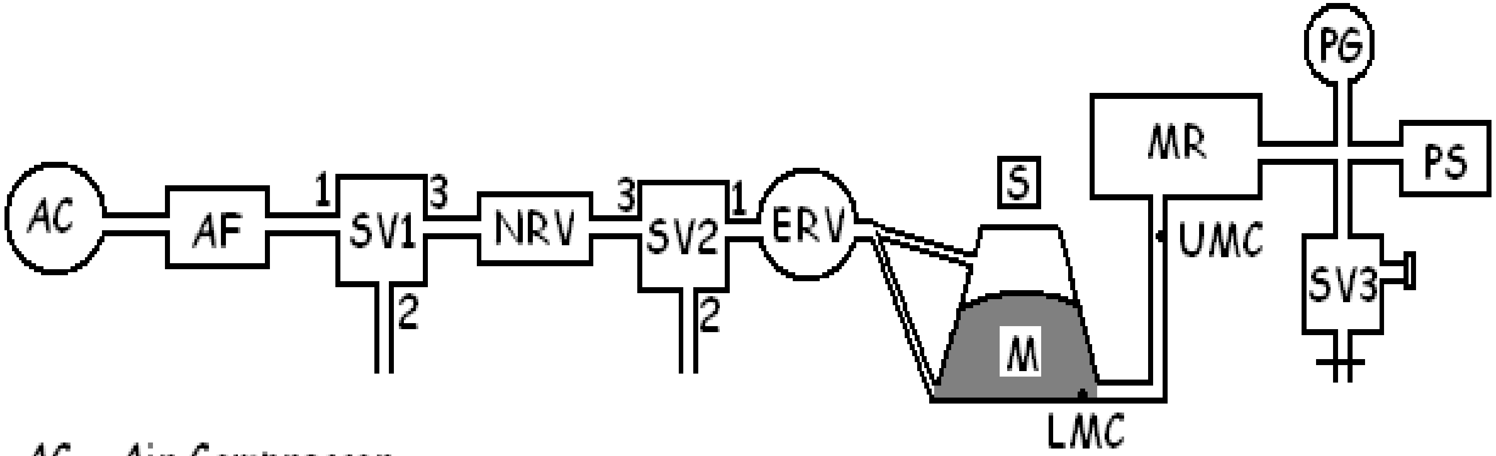
Mercury is allowed to flow into a container immediately below the source to shut OFF the beam.





Mercury Shutter System…

Mercury shutter system - schematic diagram



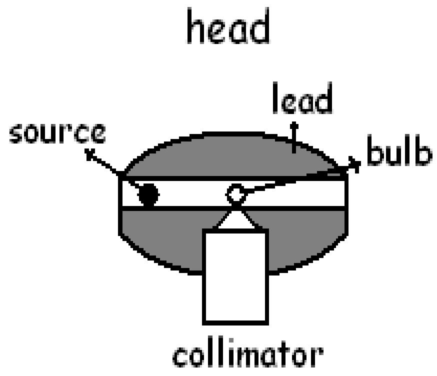
AC - Air Compressor
AF - Air Filter
SV - Solenoid Valve
NRV - Non-return Valve
ERV - Emergency Release Valve
S - Source

UMC - Upper mercury contact
LMC - Lower mercury contact
M - Conical vessel containing mercury
MR - Mercury Reservoir
PG - Pressure Gauge
PS - Pressure Switch

Mercury Sutter System…

- The disadvantages of MSS are:
  - Beam ON and OFF times are longer, compared to other systems (7 sec).
  - Production of mercuric oxide, blocks the airways and mercury pipe lines. Also the mercuric oxide mixes with atmosphere during release of pressure and is poisonous.
  - Due to presence of mercury the head rotation is restricted.

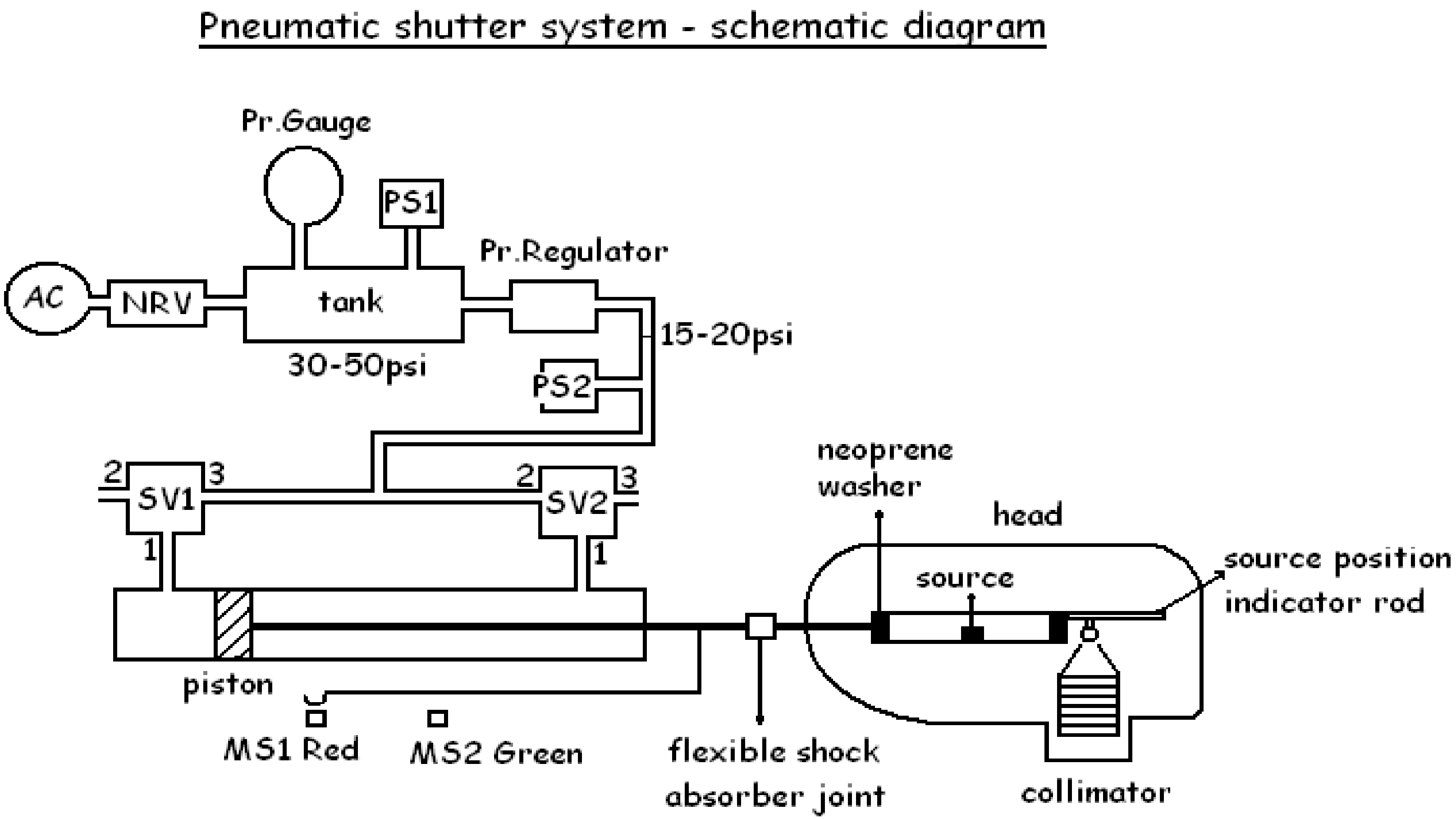
Pneumatic Shutter System



Source mounted on a heavy metal drawer is moved horizontally by pneumatic system through a hole running through the source head

- Since mercury shutter system had its own disadvantages pneumatic shutter system was introduced by AECL (Atomic Energy Canada Ltd).
- An air compressor fills air in a tank through a NRV (Non return valve).The pressure inside the tank is maintained between 30 – 50 psi (pounds per sq.inch) with the help of a pressure gauge and pressure switch.
- The air from tank goes through a pressure regulator which reduces the pressure to be between 15 – 20 psi.
- The air lines are attached to a cylinder with a piston through 2 solenoid valves (SV1 & SV2).

Pneumatic Shutter System…



Pneumatic Shutter System…

- When the source exactly ON, micro switch MS2 will be activated with the help of a metal strip attached to the piston, which will in turn arrest the movement of piston.

- When the treatment time is over, the supply to the solenoid valves are cutoff, this increases the pressure at the front of the piston and moves it backward and source comes to safe. The micro switch MS1 will now be activated and will arrest the movement of piston.

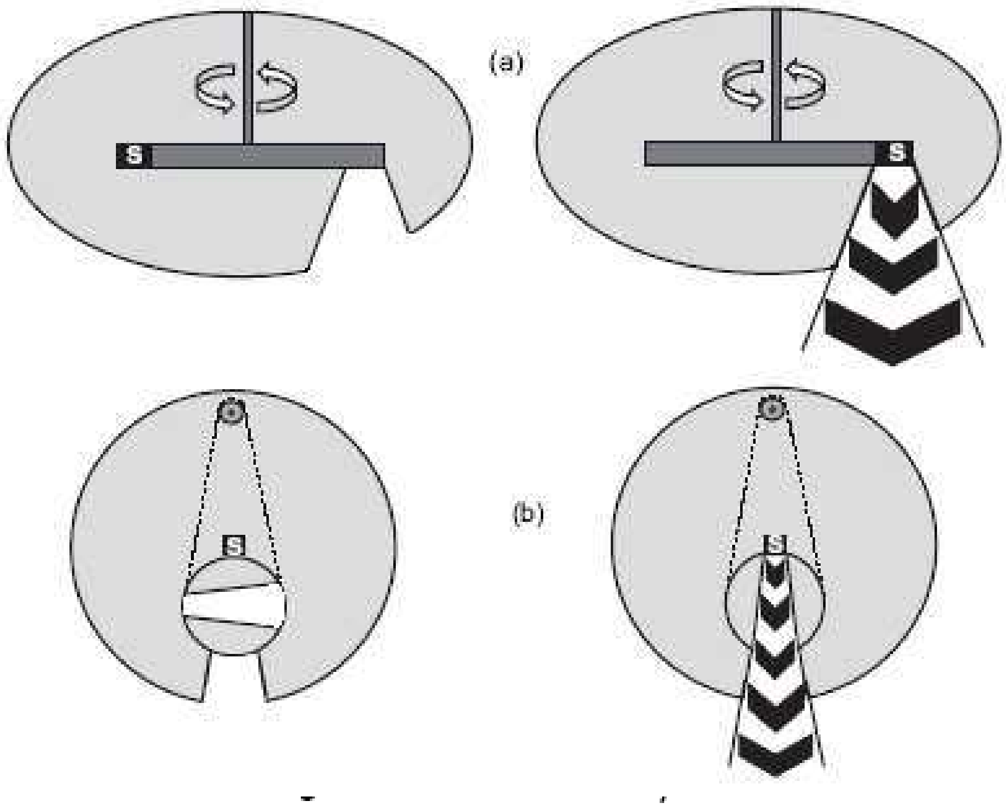
- The MS1 and MS2 are responsible for the supply to Red lamp and Green lamp respectively.

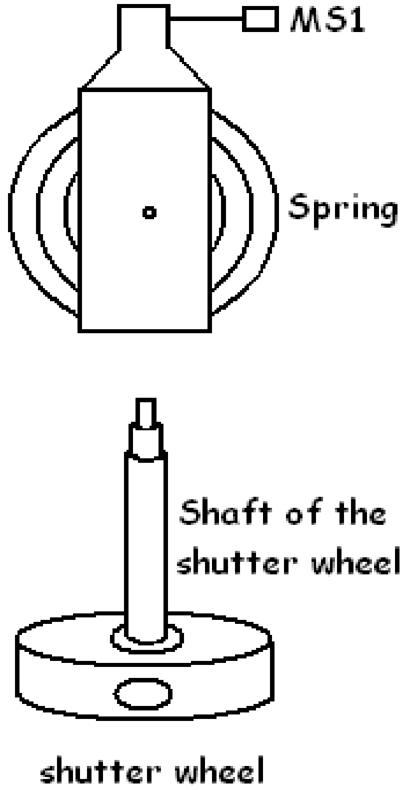
- Pneumatic system is fails safe.

- When power is OFF both solenoids are open, which pushes the piston backward along with the source.

Rotational Shutter System

Source mounted on a rotating wheel inside the source head to carry the source from OFF to On position





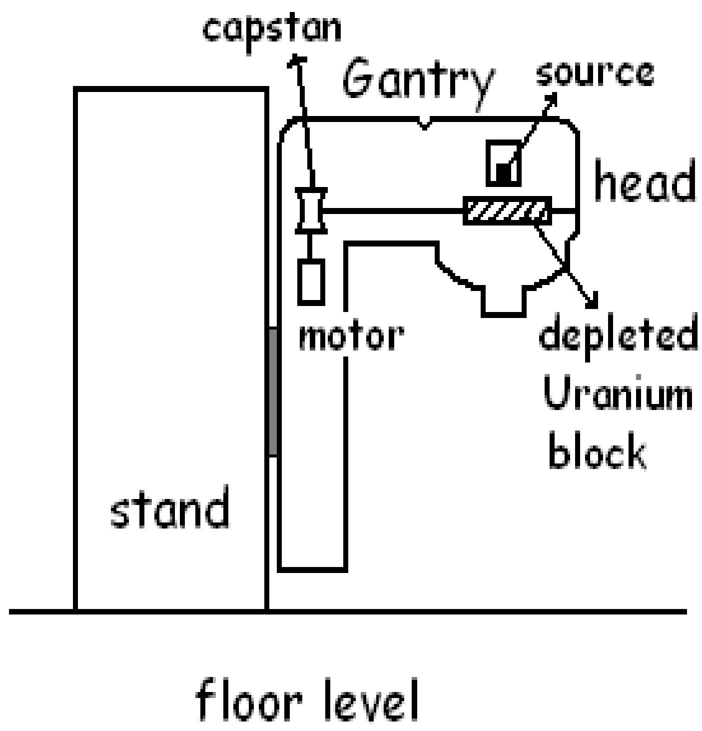
Rotational Shutter System

- The shutter wheel turns through 180^{o} and is mechanically stopped by a steel bolt and the radiation comes out of the machine.
- The motor rotates continuously to maintain the magnetic field to keep the shutter wheel in ON position against the spring tension.
- When the set time is over, the power to the motor is switched OFF and the spring brings shutter wheel back to safe position.

Mechanical Shutter System

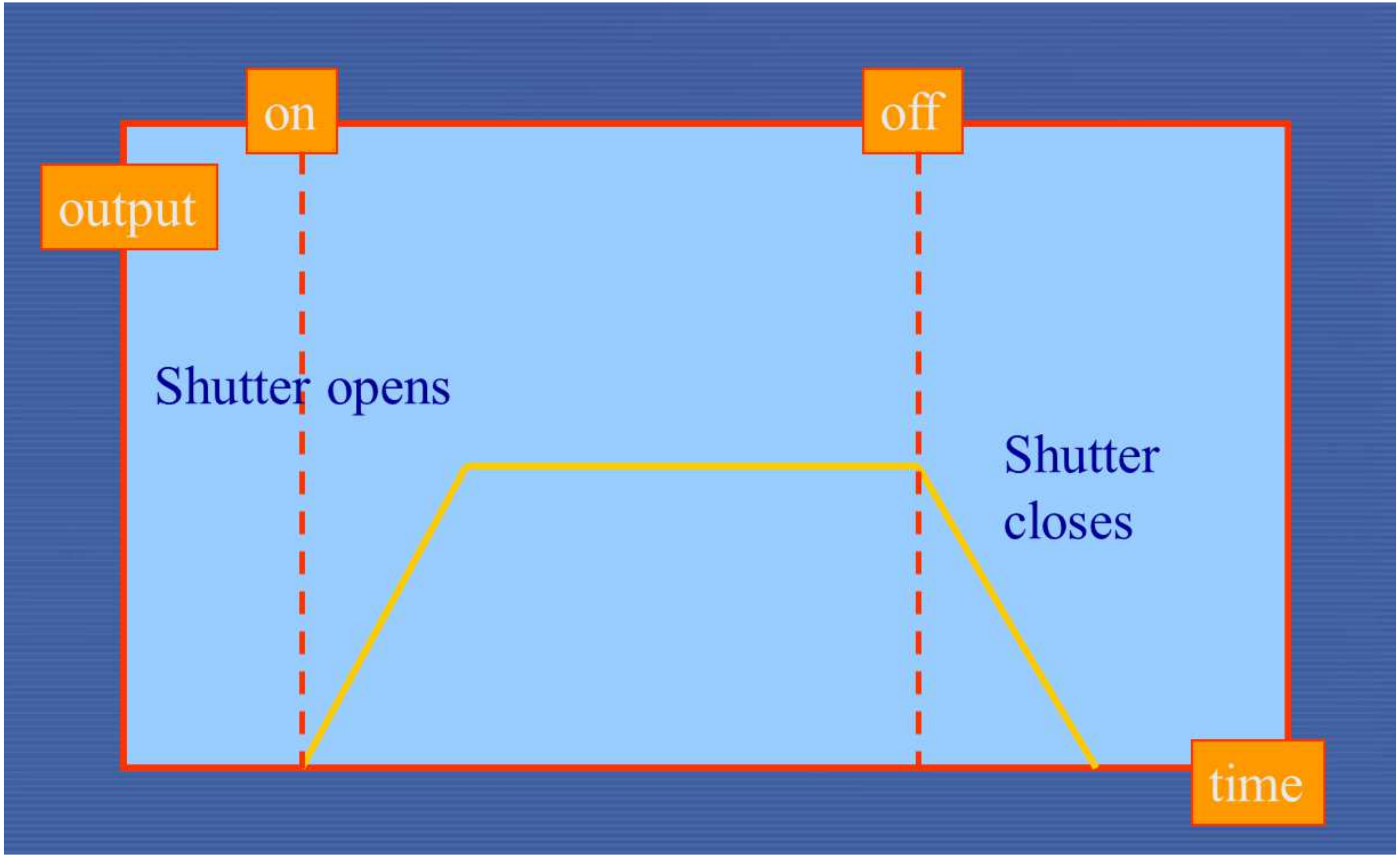
Source is fixed in front of the aperture and the beam can be turned ON and OFF by a shutter consisting of heavy metal jaws

- Consists of a block of depleted Uranium with springs and capstan with magnetic clutch assembly and motor.
- When motor rotates, the capstan pulls the depleted Uranium block towards it and radiation ON
- The uranium block is stopped by micro switch MS2.
- After treatment set time is over, the power OFF and the block is brought back to the original position at safe.



Dose delivery with teleisotope units

ON /OFF effect



Dose delivery with teleisotope units

- The prescribed dose is delivered to the patient with the help of two treatment timers: primary and secondary.
  - The primary timer actually controls the treatment time and turns the beam off upon reaching the prescribed beam-on time.
  - The secondary timer serves as a backup timer in case of the primary timer's failure to turn the beam off.

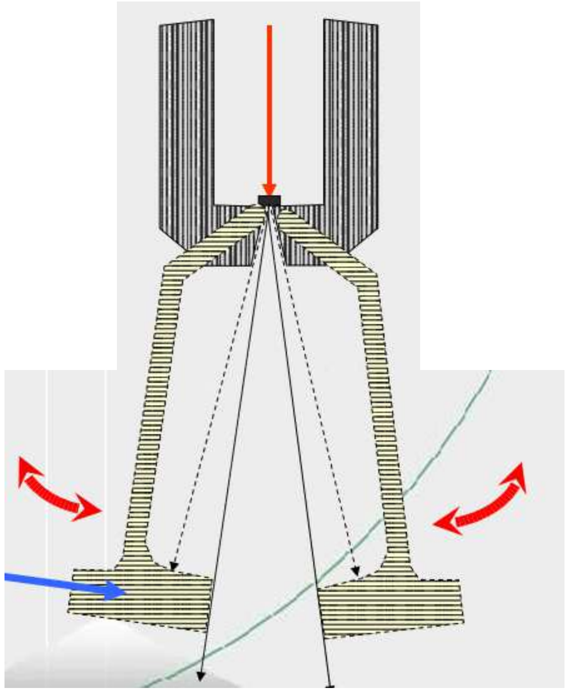
- The set treatment time should incorporate the shutter correction time to account for the travel time of the source from the BEAM-OFF to the BEAM-ON position at the start of the irradiation and for the reverse travel at the end of irradiation.

- Source ON/OFF Indicator –

  Red- ON   Green- OFF   Amber- TRANSIT

Collimators

- Reduce the beam diameter for the treatment of lesions of various sizes, special field-limiting devices such as cones, diaphragms and lead shield



- Collimators provide beams of desired shape and size.

- Collimators of teletherapy machines provide square and rectangular radiation fields typically ranging from 5×5 to $35 \times 35\ cm^2$ at 80 cm from the source.

- The rotational movement of the collimator is continuous, and it can rotate 360° about its own axis. The collimator system can move to any position when the gantry is rotated.

Collimators

The different types of collimators are:

1. Single plane collimator

   4 blocks of steel container having lead is used for this purpose and are moving in a single plane.

2. Multivane collimator

   Multiple blocks of lead in the form of vane are used to control the size of the beam.

3. John-Mackay collimator

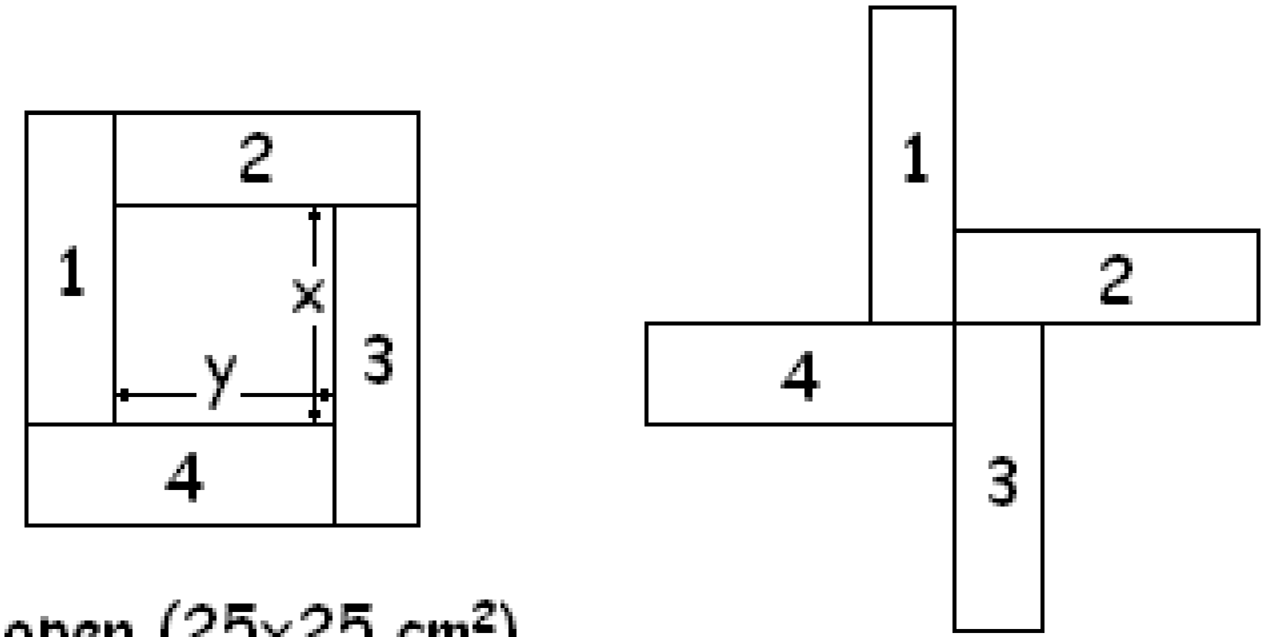
   Moving lead blocks are used for collimation.

4. Jaw type collimator

   2 pairs of lead blocks are fixed one above the other and are moved independently to obtain a square or rectangle-shaped field.

Collimators…

<u>Single plane collimator</u>

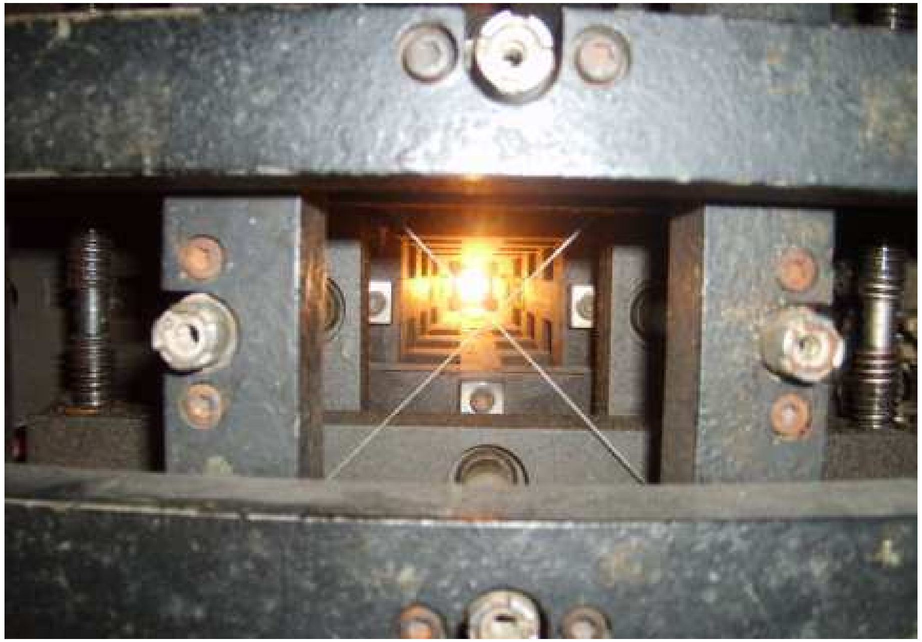


fully open (25x25 cm²)

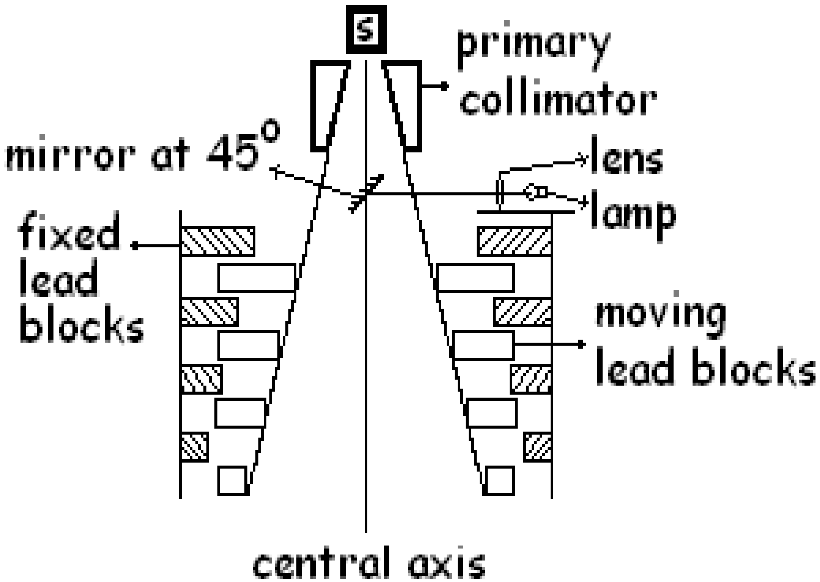
fully closed (0x0 cm²)

Collimators…

Multivane Collimator



John-Mackay collimator



BHABHATRON-II

- Source Head Capacity:250 RMM
- Minimum Collimator $3x3cm^2$ at 80cm Iso-centre
- Maximum Collimator Field Size $35x35cm^2$
- Automatic Collimator closure
- Arc Treatment
- Auto set up of Collimator
- Computerized Control Console
- Auto collision detection
- Computerised motorised wedge
- Asymmetric Collimator

Penumbra

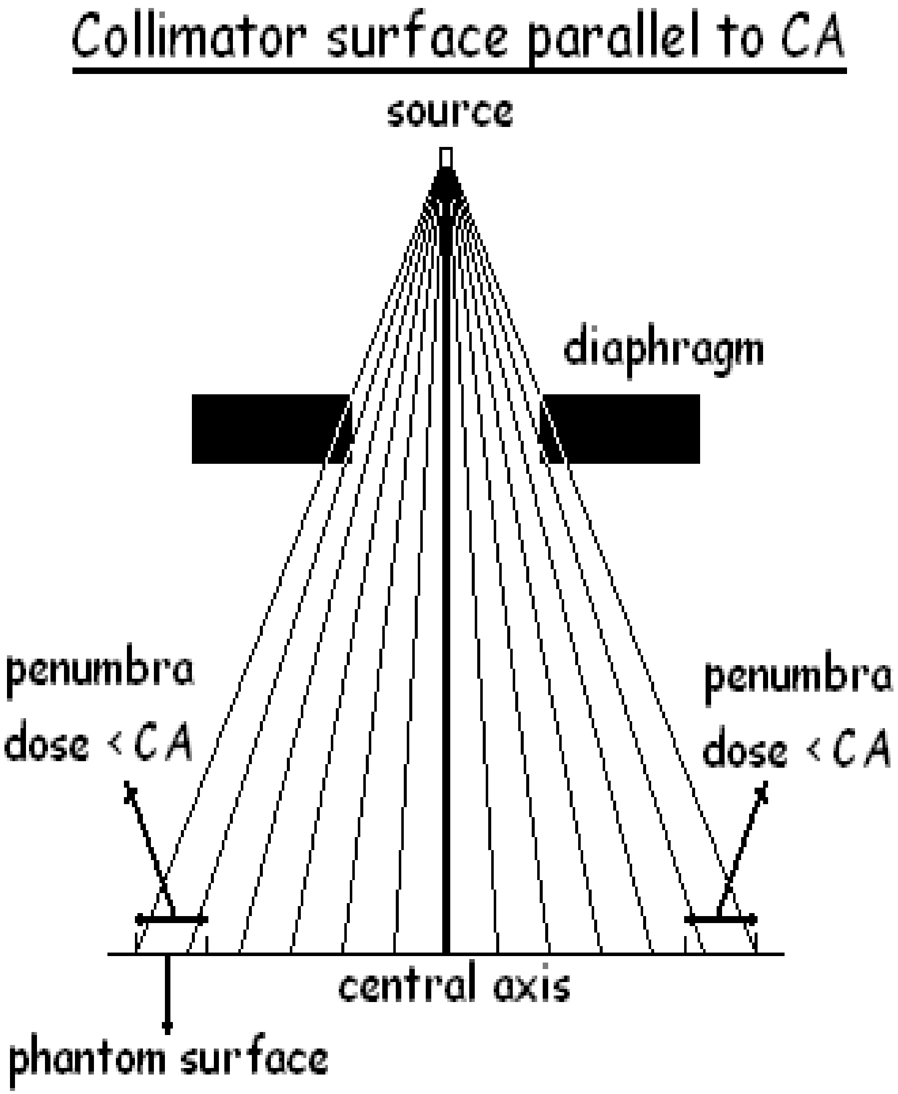
Umbra – full shadow

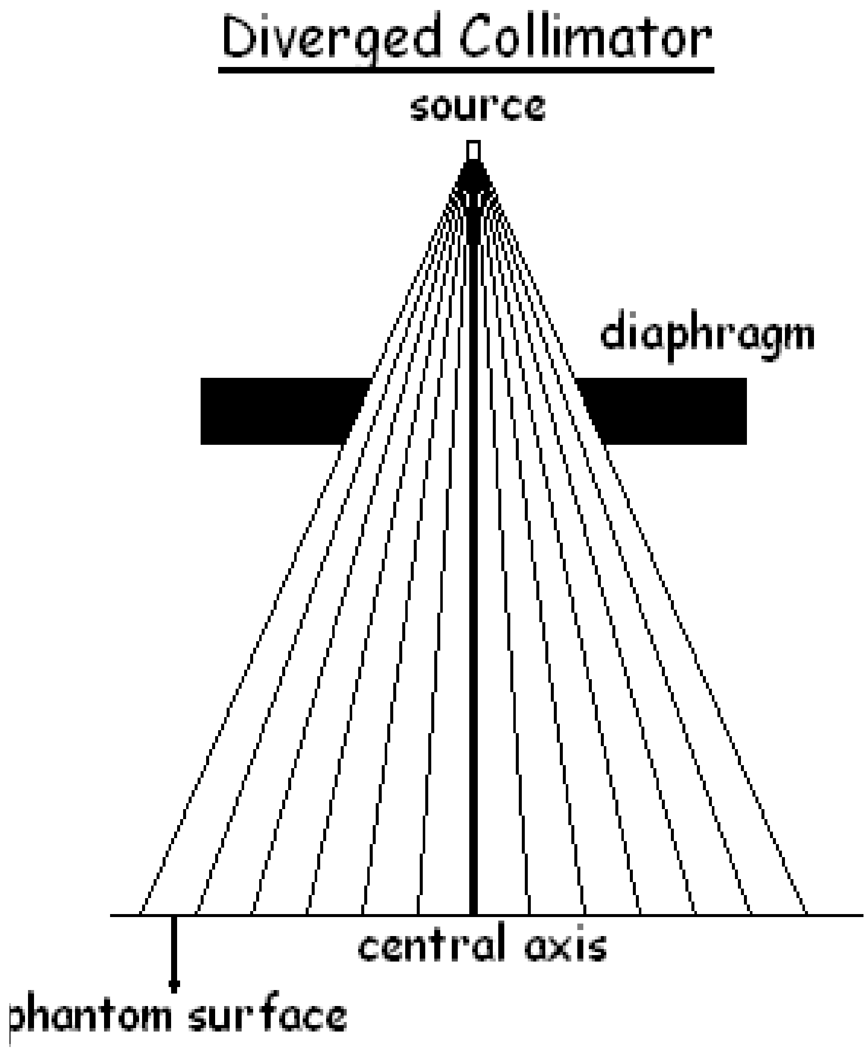
Penumbra – partial shadow

- Penumbra means, the region at the edge of a radiation beam, over which the dose rate changes rapidly as a function of distance from the beam axis.

- If the inner surface of the blocks is made parallel to the central axis of the beam, the radiation will pass through the edges of the collimating blocks. This transmission radiation is known as ***transmission penumbra.***

Penumbra


Collimator surface parallel to CA
source
diaphragm
penumbra
dose < CA
penumbra
dose < CA
central axis
phantom surface

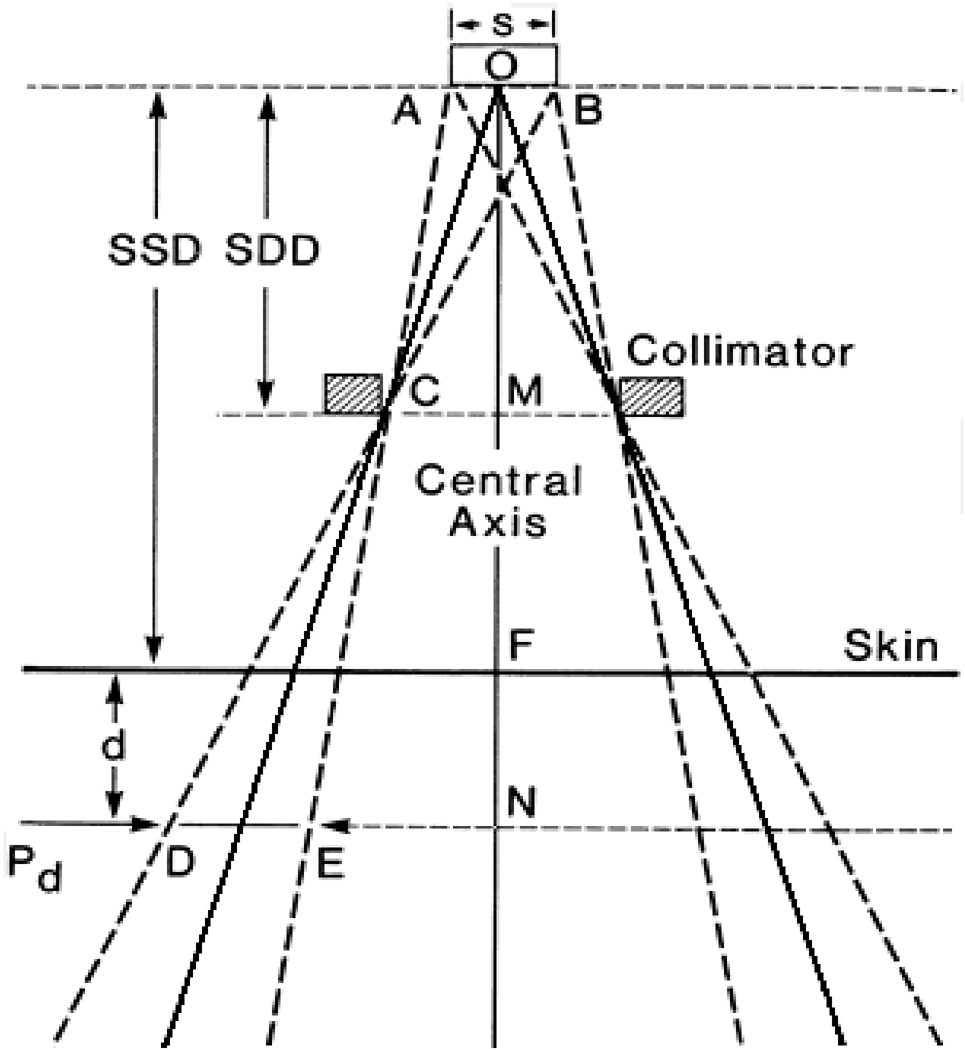

Diverged Collimator
source
diaphragm
central axis
phantom surface

Penumbra

- The extent of this penumbra is more pronounced for larger collimator openings because of greater obliquity of the rays at the edges of the blocks.
- This effect has been minimized in some designs by shaping the collimator blocks so that the inner surface of the blocks remains always parallel to the edge of the beam.
- The transmission penumbra can be minimized with such an arrangement; it cannot be completely removed for all field sizes.

Penumbra…

- Another type of penumbra arises from geometric reasons, known as the ***geometric penumbra***



Determination of geometric penumbra width (P_d) at any depth d from the surface of a patient:

From simillar triangles, ABC and DEC

$$\frac{DE}{AB} = \frac{CE}{CA} = \frac{CD}{CB} = \frac{MN}{OM} = \frac{OF + FN - OM}{OM}$$

DE = P_d, penumbra width

AB = s, the source diameter

OM = SDD, the source to diaphragm distance

OF = SSD, the source to surface distance

FN = d, depth from the skin

Penumbra…

The penumbra width (DE) at depth d is given by:

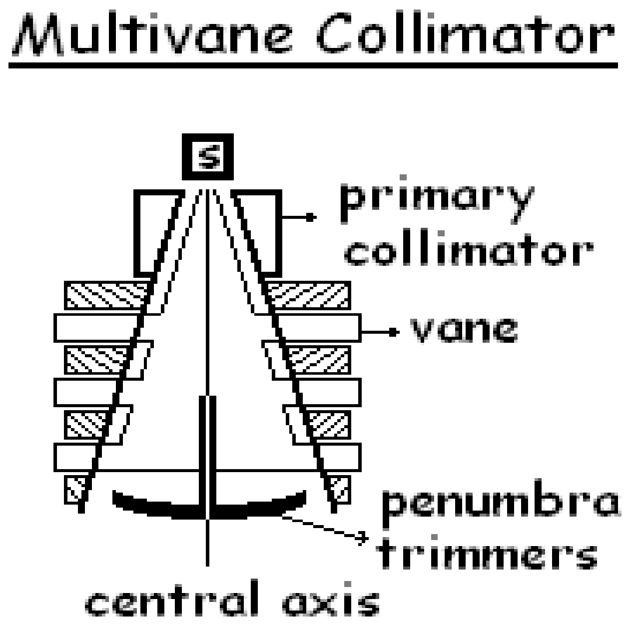
$$P_d = \frac{s\,(SSD + d - SDD)}{SDD}$$

The penumbra width at surface can be calculated by substituting d = 0 in the above equation.

- The geometric penumbra is independent of field size when the movement of diaphragm is in one plane (SDD stays constant with increase in field size).
- The penumbra width increases with increase in source diameter, SSD & depth but decreases with an increase in SDD, which is an important parameter in determining penumbra width.

Penumbra…

- Heavy metal bars are used as penumbra trimmers to increase the SDD distance, which will attenuate the beam at the penumbra region and thus sharpening the field edges.



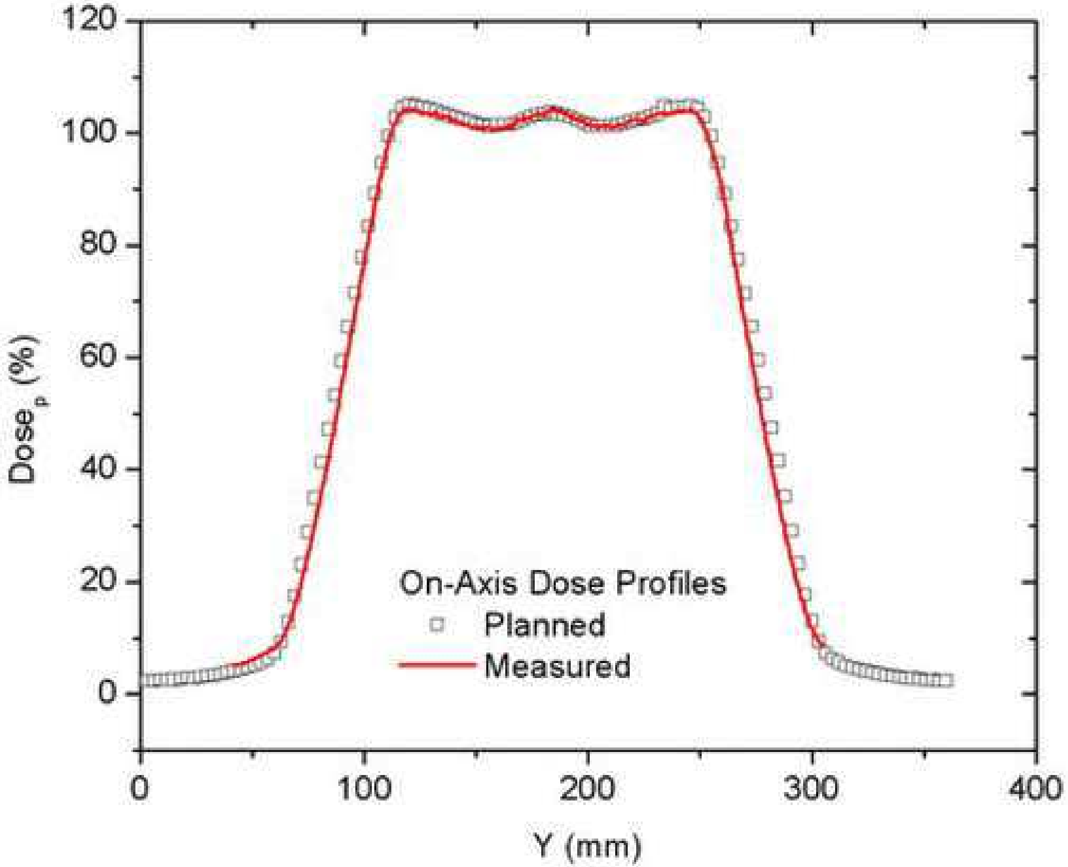
- **An alternative way of reducing the penumbra is to use secondary blocks, placed close to patient, for redefining or shaping the field.**

Penumbra

Penumbra Trimmers consist 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).

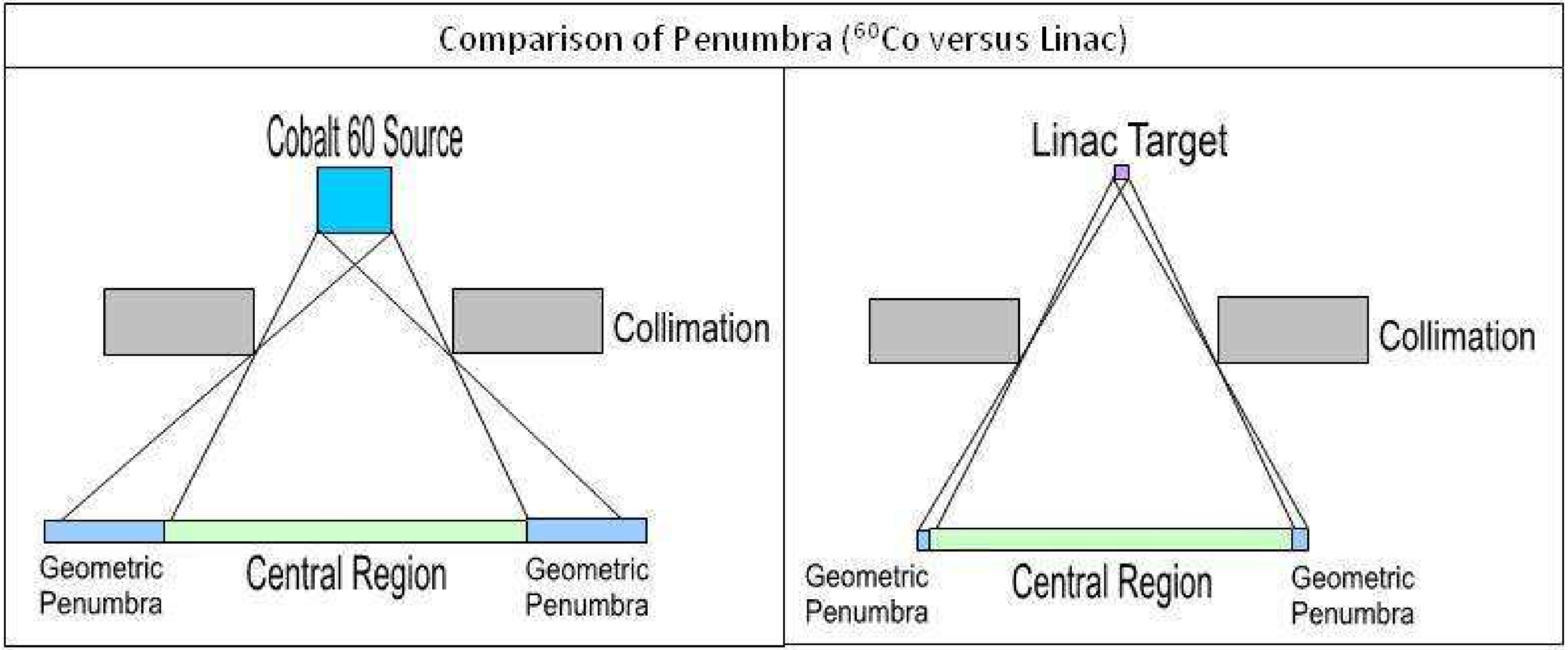


Penumbra

➢Penumbra width depends upon:

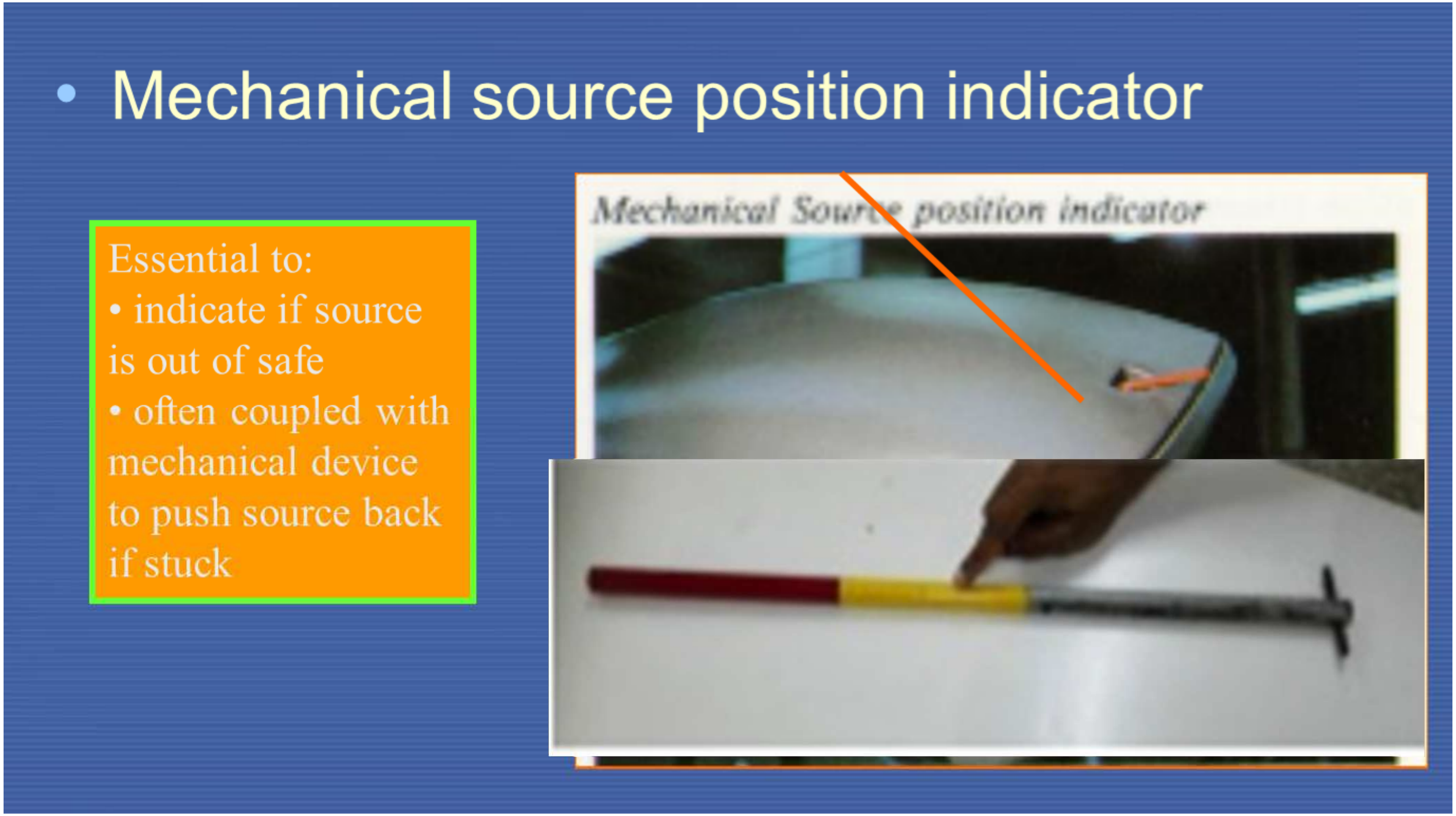
1. Source diameter.
2. SSD.
3. Depth below skin.
4. Source to diaphragm distance (inversely)

$$P_d = \frac{s\,(SSD + d - SDD)}{SDD}$$



Emergency situation in telecobalt

- There are chances that the source drawer may not go back fully to ***'Off'*** position or **'remain stuck' in partially retracted position.**



Emergency source handling procedure

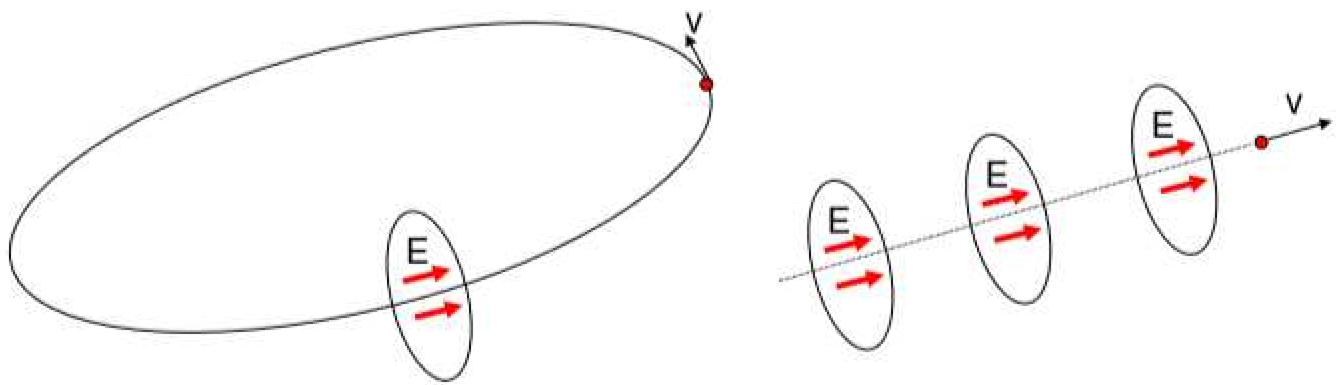
If source gets stuck in cobalt unit:-

- Stop the irradiation using emergency key / button
- Close collimators to a minimal field size
- **Rotate ganty/table so patient is removed from the primary beam**
- Enter the room (route to enter should be chosen logically), remove the patient safely and quickly from the room.
- Push the source back to the safe position with the help of T-rod
- One person should stay outside and make a note of the time taken for all the steps
- Person entering room should have personnel dosimeter
- **The RSO should be contacted, the room door closed and a warning sign hung on the door**

Types of Accelerators

- Acceleration by repeated applications of time-varying accelerating fields

  - Two approaches for accelerating with time-varying fields



Circular Accelerators

Use one or a small number of Radio-frequency accelerating cavities and make use of repeated passage through them. This approach is realized in circular accelerators: Cyclotrons, synchrotrons and their variants

Linear Accelerators

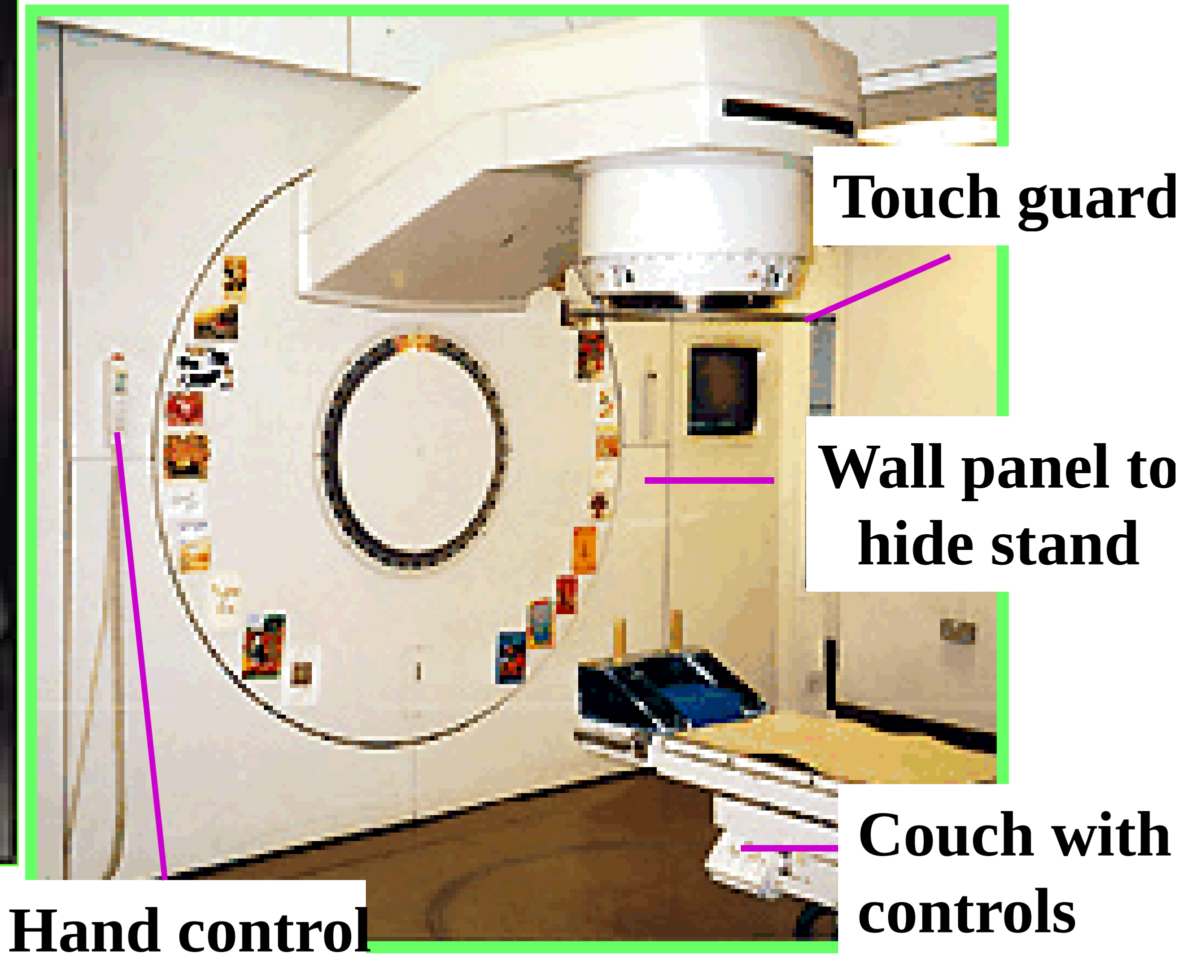
Use many accelerating cavities through which the particle beam passes once:

These are linear accelerators

Types of Accelerators

- Van de Graaff **Accelerators**
- The **Linear Accelerator** (Linac)
- The Cyclotron
- The Betatron
- The Microtron
- The Synchrocyclotron
- The Synchrotron

Linear Accelerator

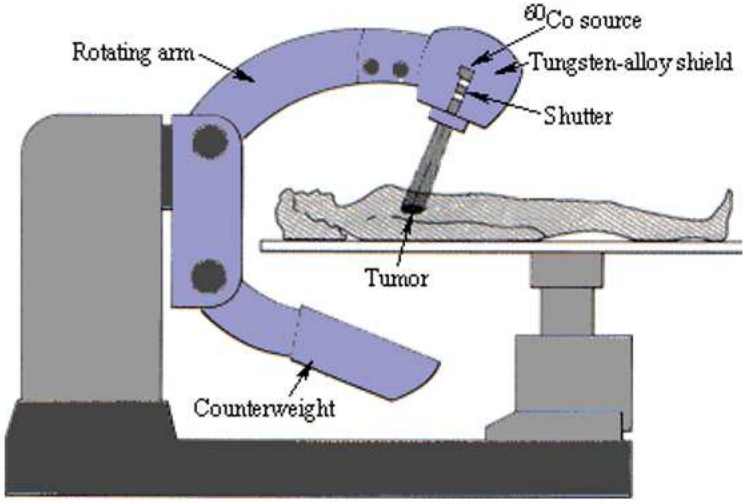


Evolution of Gamma knife

Components

Stand in isocentric machines

Housing support assembly in stands that focus the radiation at one point

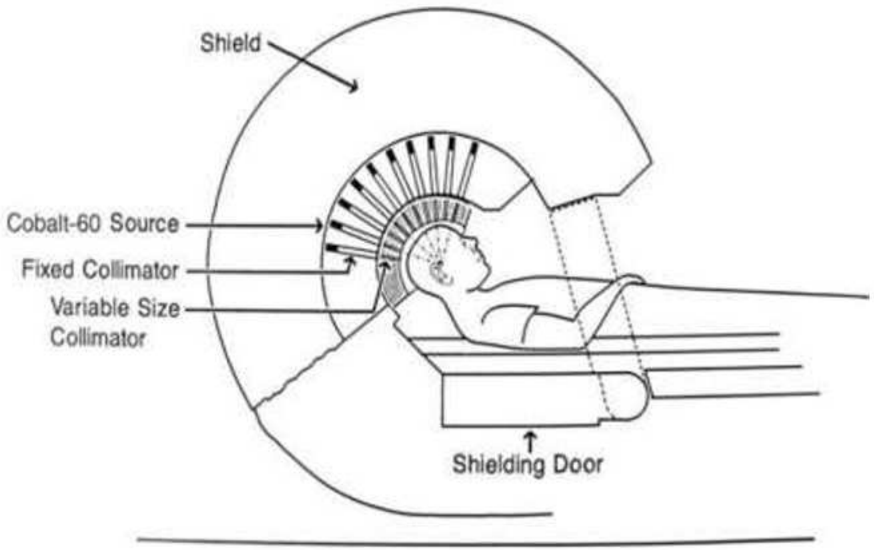


Gantry

Allows Gamma rays by the rotating source around a fix position.

Beam collimator

Present in source housing and prevent unwanted radiation emission



Radioactive source

It is housed in capsule of metal to prevent contamination and dangerous emission

Specialized Telecobalt Machine: LGK

LGK 4C

Source to UCP Distance = 40 cm

- **LGK is a standard SRS device specifically designed for intracranial radiosurgery,**
- **Contains 201 ^{60}Co sources, distributed along five parallel cycles in a hemispherical surface of radius 40 cm**
- **Each source of nominal activity 30 ci contains 12 - 20 ^{60}Co cylindrical pellets.**
- **Radiation emitted by each source is collimated by three different collimators: first two are permanently installed in the central body and final collimation is achieved by one of the four interchangeable collimator helmets which define a beam dia of 4, 8, 14 or 18 mm at the focus or unit centre point (UCP).**
- **Patient couch- sliding cradle - helmet attached**
- **Collimator system is designed to produce a precise overlap of 201 individual beams at the UCP (x=y=z= 100 mm) - mechanical centre.**
- **Superimposition of 201 beams produces approx. spherical dose distribution at UCP**

Specialized Telecobalt Unit: LGK Perfexion

• Collimator system consists of 192 ^{60}Co sources, divided into 8 sectors that can be individually positioned to any of 4 states: 4 mm, 8 mm, 16 mm or OFF.

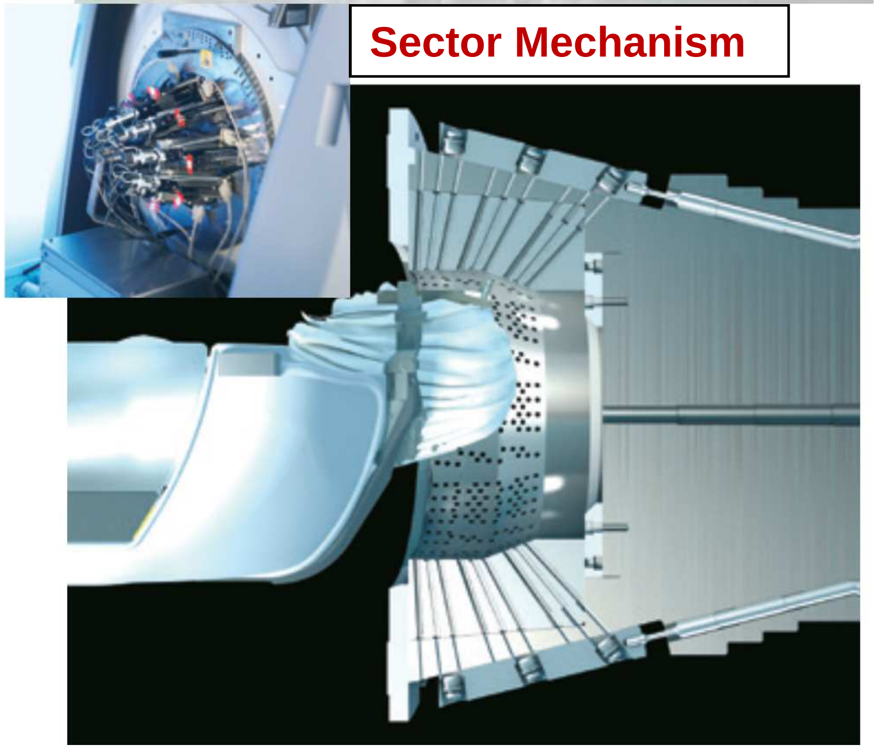
• During treatment these sources are positioned via the sector mechanism to generate the desired radiation beam and enable treatment to highly complex structures.

• Beam size can be changed dynamically by the sector.

• Individual sectors can be blocked for further shaping of each radiation shot.

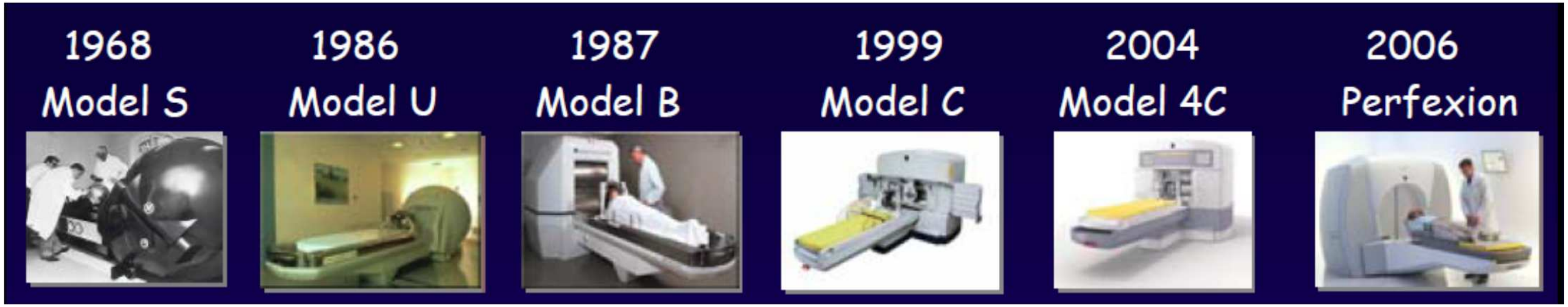
• Larger collimator bore

• Increased throughput, increased patient comfort and extended anatomical reach.



Sector Mechanism

Evolution of LGK



1968 – Model S

Prototype for clinical research

1986 – Model U

Decreased body dose

Computer dose planning

1987 – Model B

Improved collimator design

1999 – Model C

Semi-robotic patient positioning

Improved dose conformity

2004 – Model 4C

Improved software

Merger/fusion capability

2006 – Perfexion

Improved conformity

Large cavity

Very low body dose

Rapid treatment

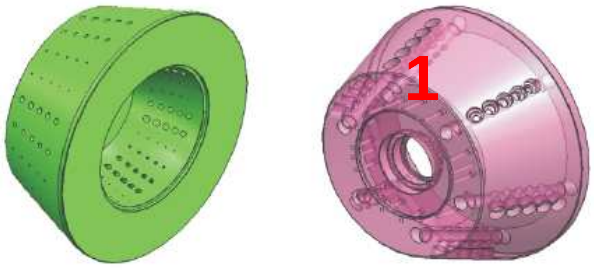
Full automation

Expert panel

Rotating Gamma Ray System INFINI

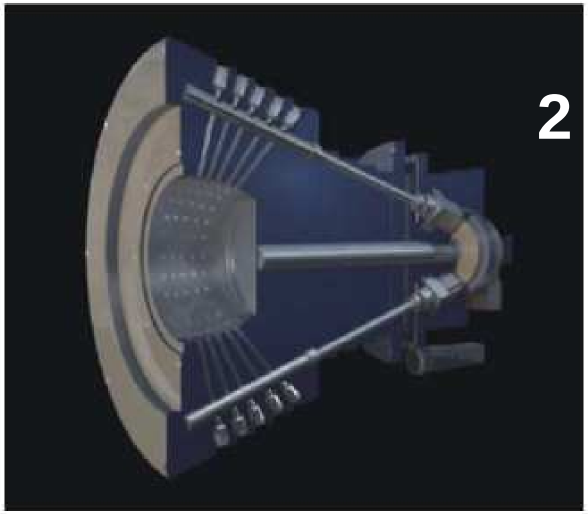
- **Contains 30 Co-60 Sources**
- **30 beams are focused on the focal point by collimators**
- **The distance from focal point to each source is different i.e. non-isometric**

Gantry Components of INFINI

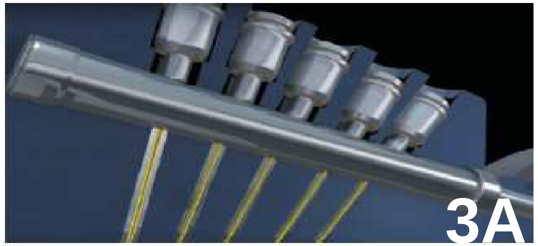


Collimator body

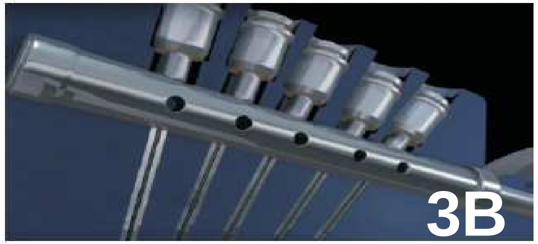
Source body



Beam on



Beam off



<u>Beam ON:</u>

- The Source Body turns to a position such that all Cobalt source align with Collimator holes
- Beam Switch turned ON (Fig. 3A)
- Gantry door open

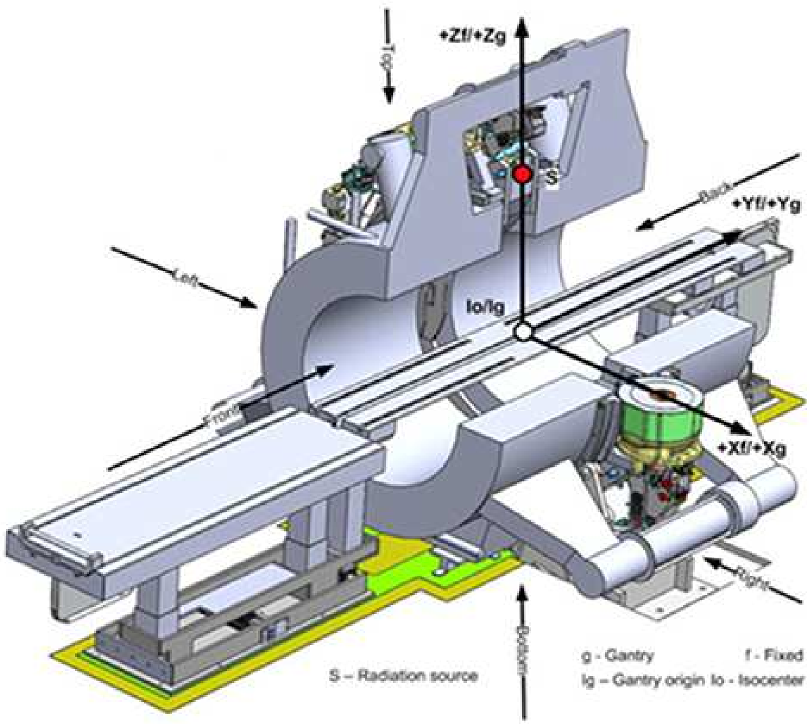
<u>Beam OFF:</u>

- The Source Body turns to a position that no Cobalt source aligns with any Collimator hole – all radiations blocked by collimator Body
- Beam Switch turned OFF (Fig.3B)
- Gantry door closed

Super Specialised Telecobalt Machine: ViewRay – MR IGRT System

- 0.35 T MRI, 70 cm bore, 50 cm FOV
- 3 ^{60}Co heads 120 degrees apart with divergent MLCs
- Conventional (3D), IMRT, and SBRT delivery
- Monte Carlo based dose calculation only
- Ability to track tissues at 4 frames per second
- On couch adaptive RT (image, contour, optimize, dose calculate, QA, treat)

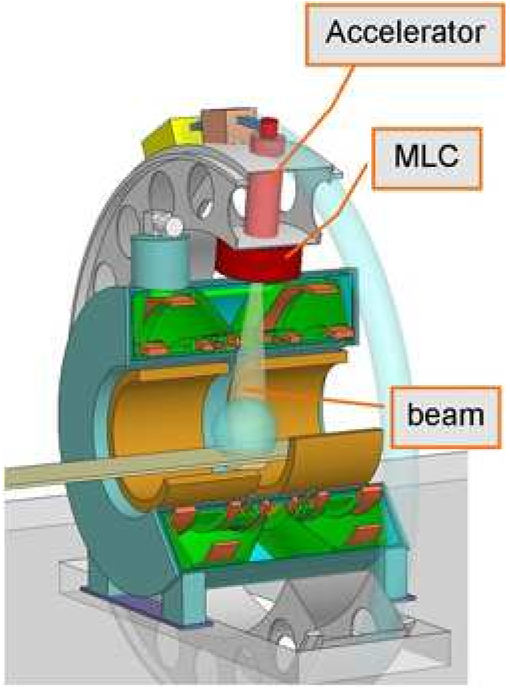
ViewRay (Co-60 based Tx Equipment)



Being used as

- MR-IGRT System
- On couch Adaptive Radiation Therapy
- MR Treatment Control (i.e. MR Gating)

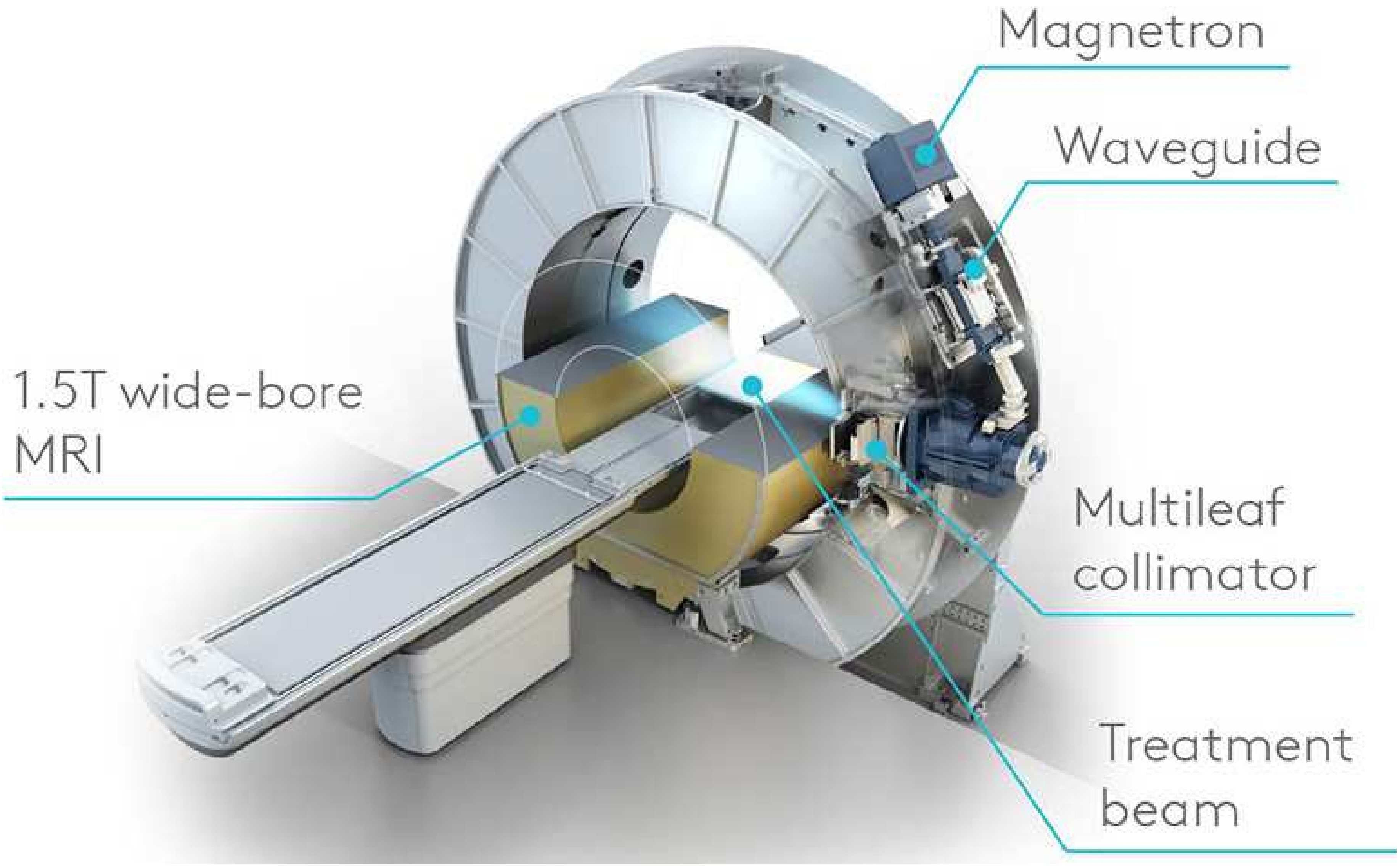
MRI Guided LINAC



Cut-away view of the MR-LINAC. The LINAC gantry and its peripherals are around the MRI. The light blue toroid indicates the low magnetic field zone outside the MRI created by adapting the active shielding to decouple the MRI and the accelerator.

- To improve delineation accuracy - better differentiation between target tissue (tumour) and non-target tissue (normal tissue/OAR) is required
- MRI offer superior soft-tissue contrast over CT
- Thus, clinicians can see tumour tissue more clearly and adapt the radiation dose while a patient is being treated.
- Escalated dose delivery to tumour, high precision and effective than ever before.
- It could also reduce the number of treatment sessions, providing more convenience for patients.
- Treatment for all types of cancer and specially suitable for moving tumour e.g. lung, pancreatic, liver, tumours of upper abdomen.

MR LINAC: Components (Elekta Unity)



Specialized LINAC: Tomotherapy

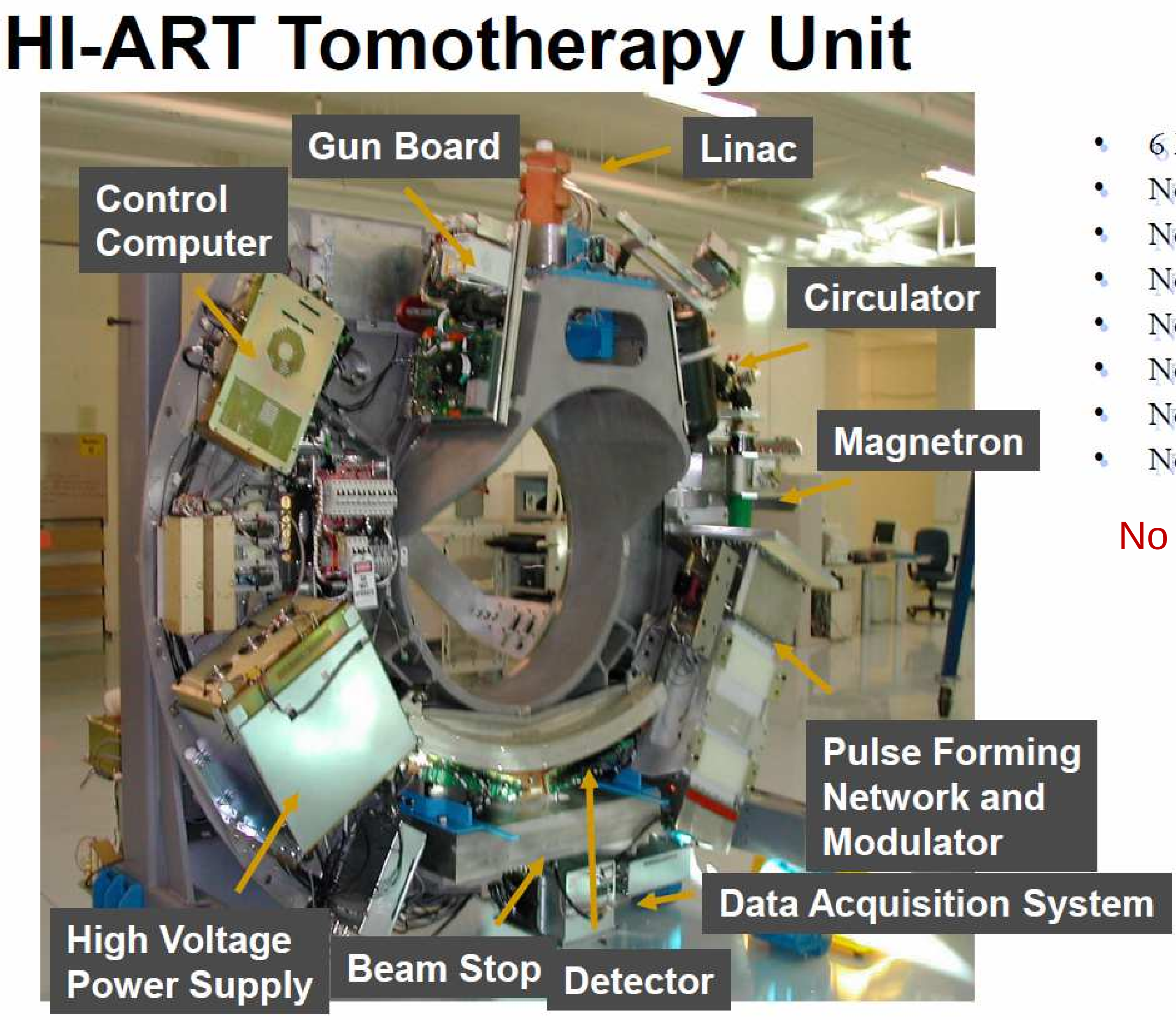
- Helical tomotherapy is IMRT delivery technique.
- Resembles Helical CT scanning
- 6 MV LINAC mounted on a slip ring gantry
- The beam passes through a primary collimator which is further collimated into a fan-beam shape by an adjustable jaw.
- A binary 64 leaf MLC is used to divide the fan beam in X-direction. MLC leaves travels in Y-direction
- During treatment, ring gantry continuously rotates while the patient is continuously translated through the rotating beam plane
- Dose is thus delivered in a helical fashion
- Ring gantry contain a detector system mounted opposite the accelerator which is used for MVCT data acquisition.
- Beam stopper – reduced shielding requirement

Imaging: 3 MVCT
Treatment: 6 MV (IMRT)

Source to rotation centre distance = 85 cm

Source to detector distance = 145 cm
FS: 40 cm x 5 cm (max)

Components of Tomotherapy Machine



- 6 MV photon beam
- No electrons
- No wedges
- No gantry angles
- No collimator angles
- No table angles
- No field size
- No field light

No flattening Filter

Main components of Tomotherapy

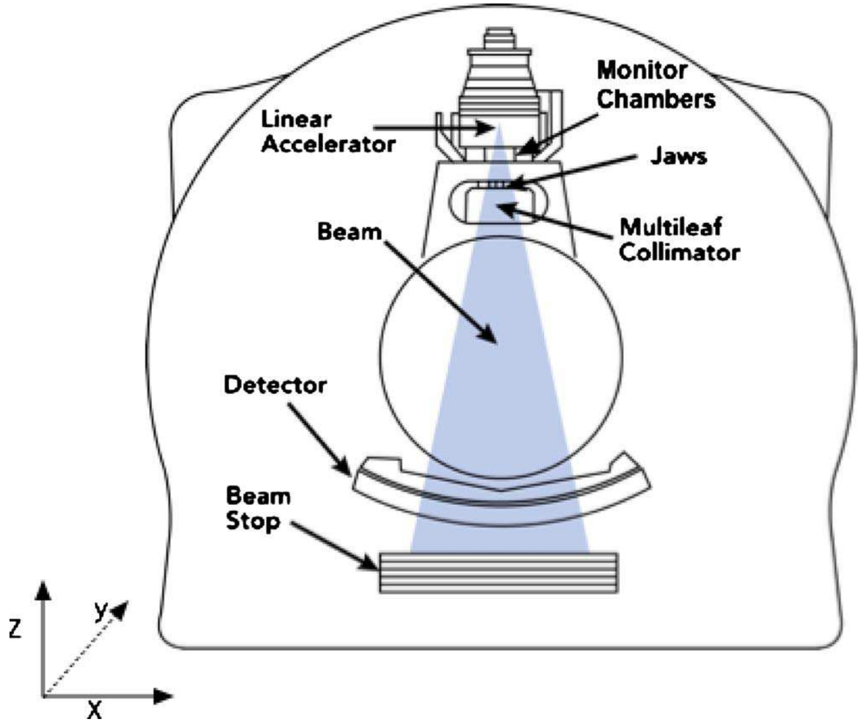


Fig.: Main components of tomotherapy unit

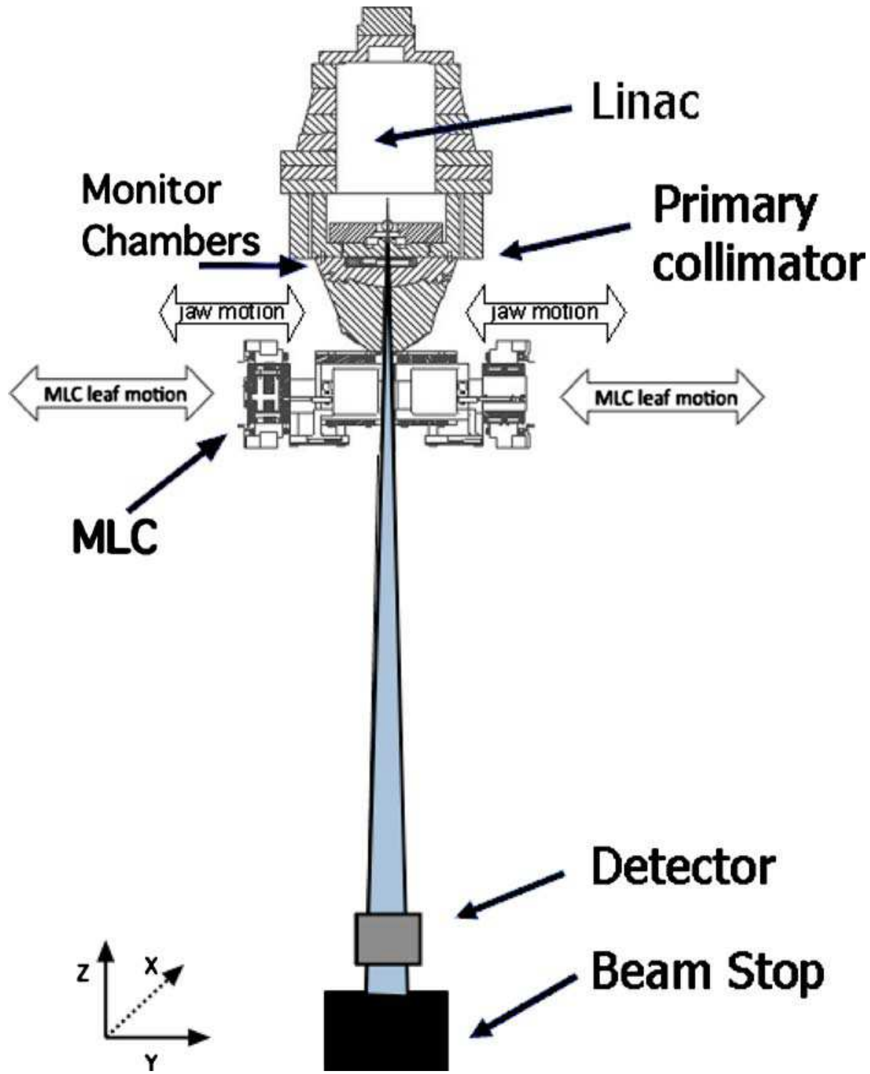


Fig.: Lateral View of beam collimation components

Specialized LINAC: Cyber Knife (CK M6)

- Cyber Knife is a robotic stereotactic radiosurgery system

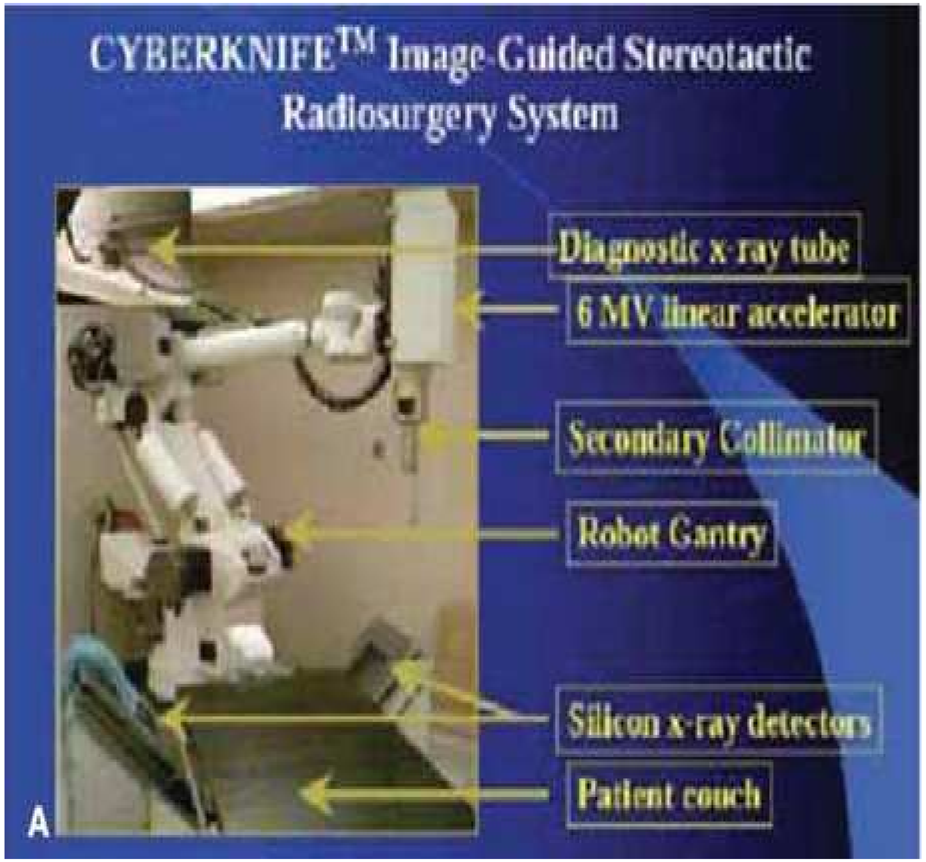
- LINAC attached to the end of robotic arm is free to rotate and translate with 6 degrees of freedom

- LINAC is capable of producing 6 MV photon beam

Cyber Knife – contd.

- Distance between target to isocentre can be varied anywhere between 60-120 cm
- Pseudo isocentre is defined for the purpose of definition of field sizes, output measurement and shielding calculation
- Distance between pseudo isocentre and target is taken at 80 cm
- Available treatment field sizes are circular in shape with diameters varies from 5 mm to 60 mm at pseudo isocentre

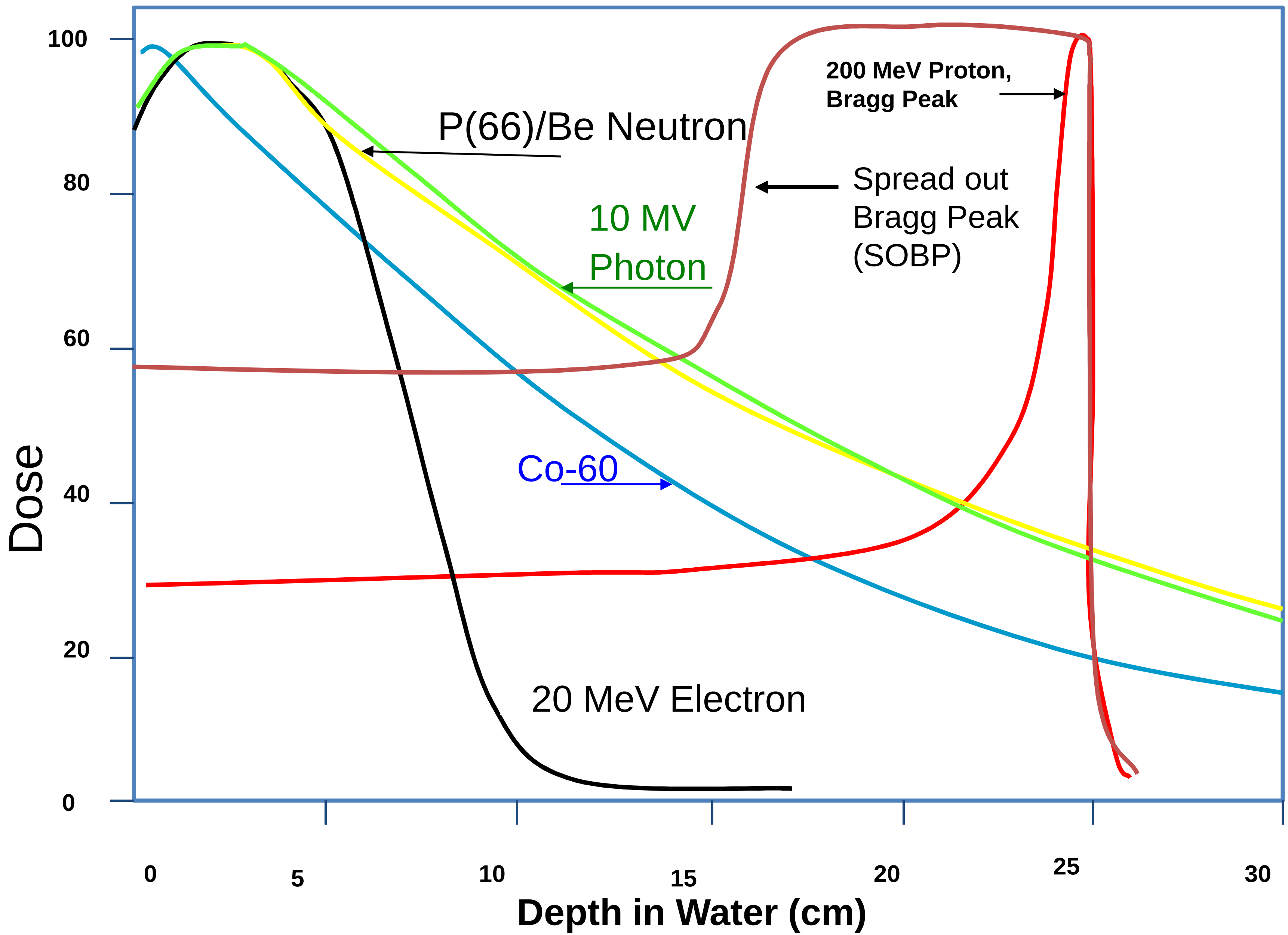
Cyber knife : Operational aspects



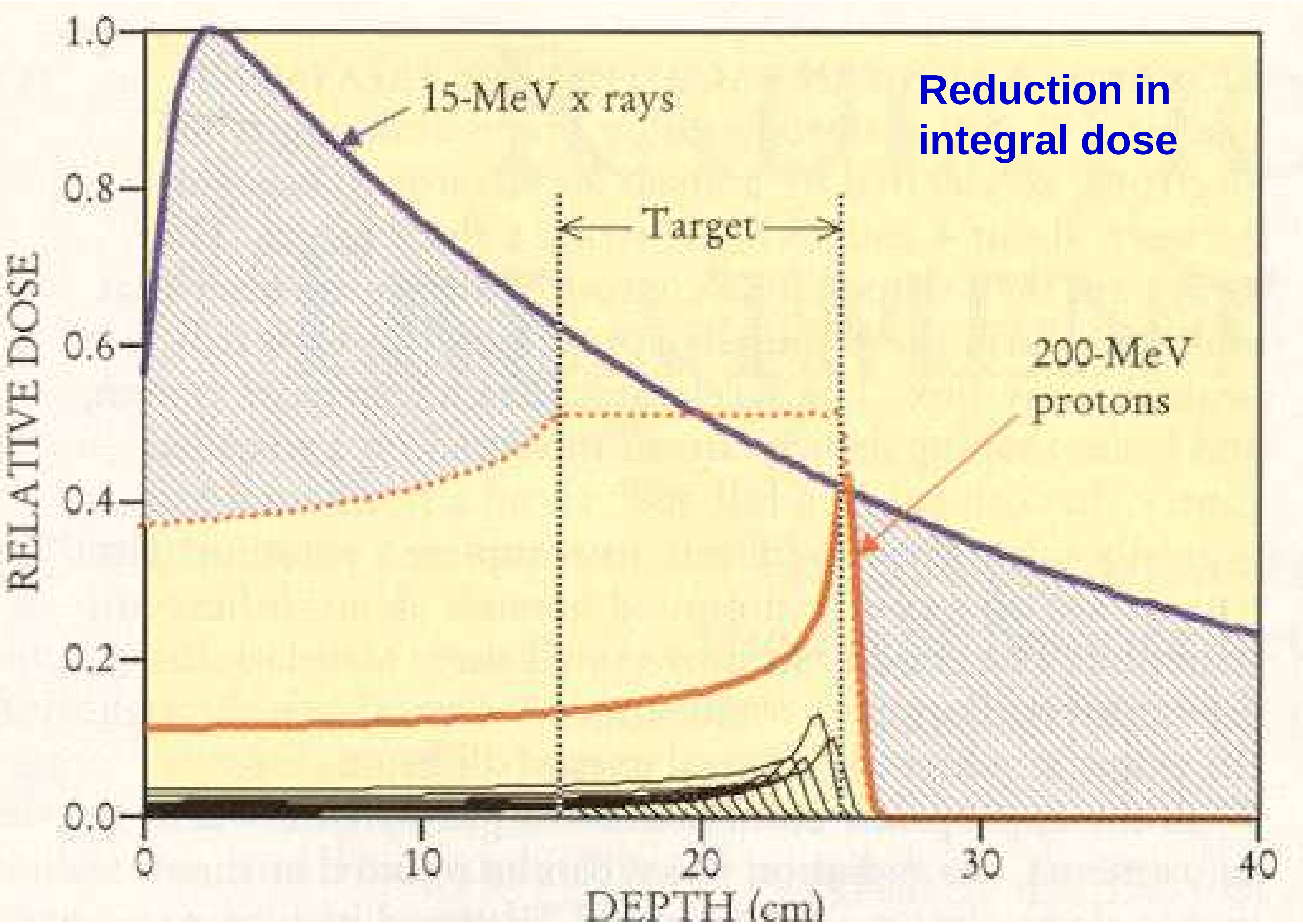
Cyber knife & Accessories: CK M6

Fixed circular cone collimator: 12 circular collimators (5 to 60 mm), can select up to three for a treatment.

Depth Dose Characteristics of Tx Beams



Superiority of P-Beam over HEX



Available Proton Accelerators

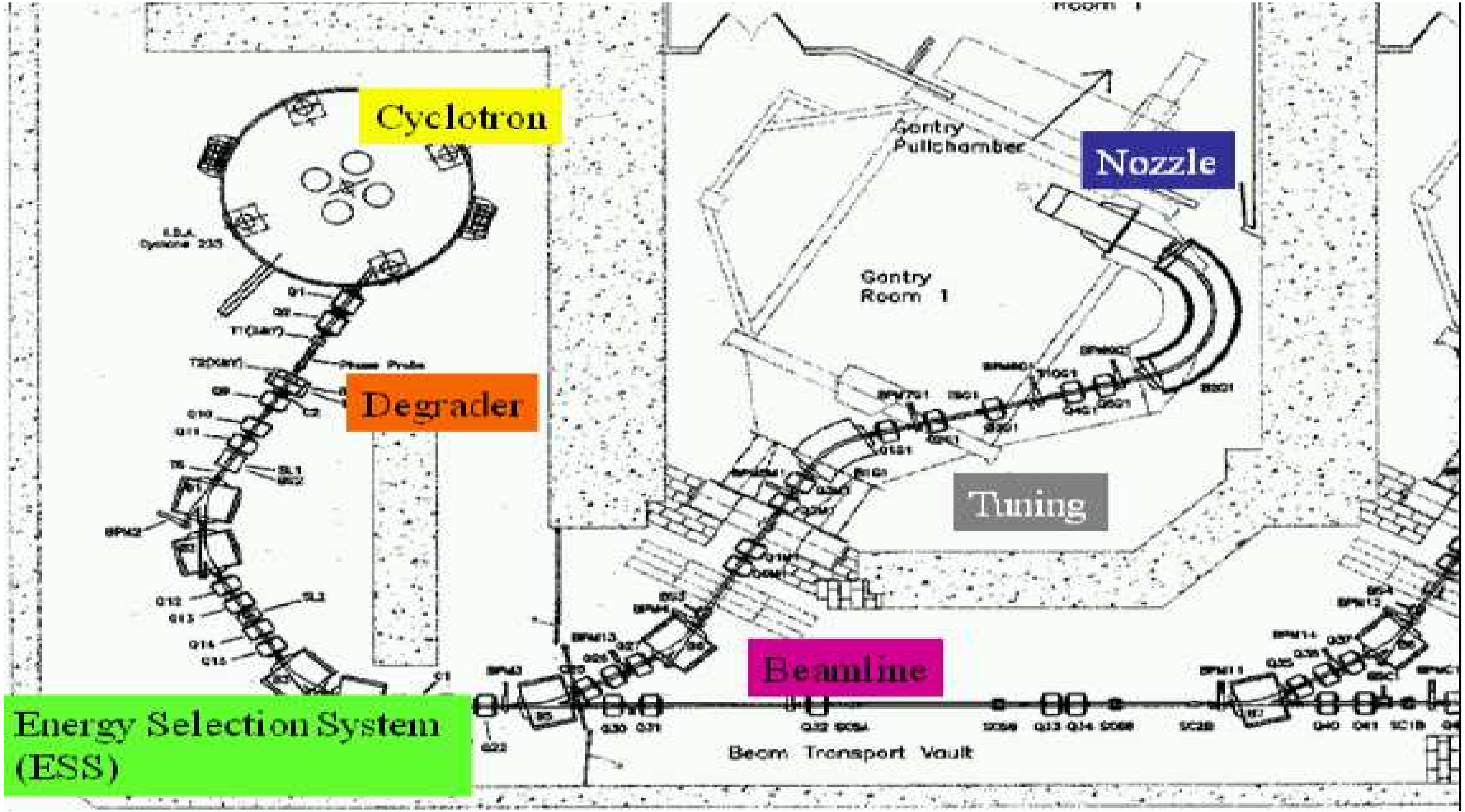
Cyclotron

- Consists of dipole magnets to produce uniform magnetic fields (straight sides are parallel but slightly separated),
- Particles injected into it move in a semi-circular path & acquire energy at the gaps,
- Isochronous or Synchrocyclotron and Semiconducting cyclotron
- Single frequency RF; fixed energy continuous beam

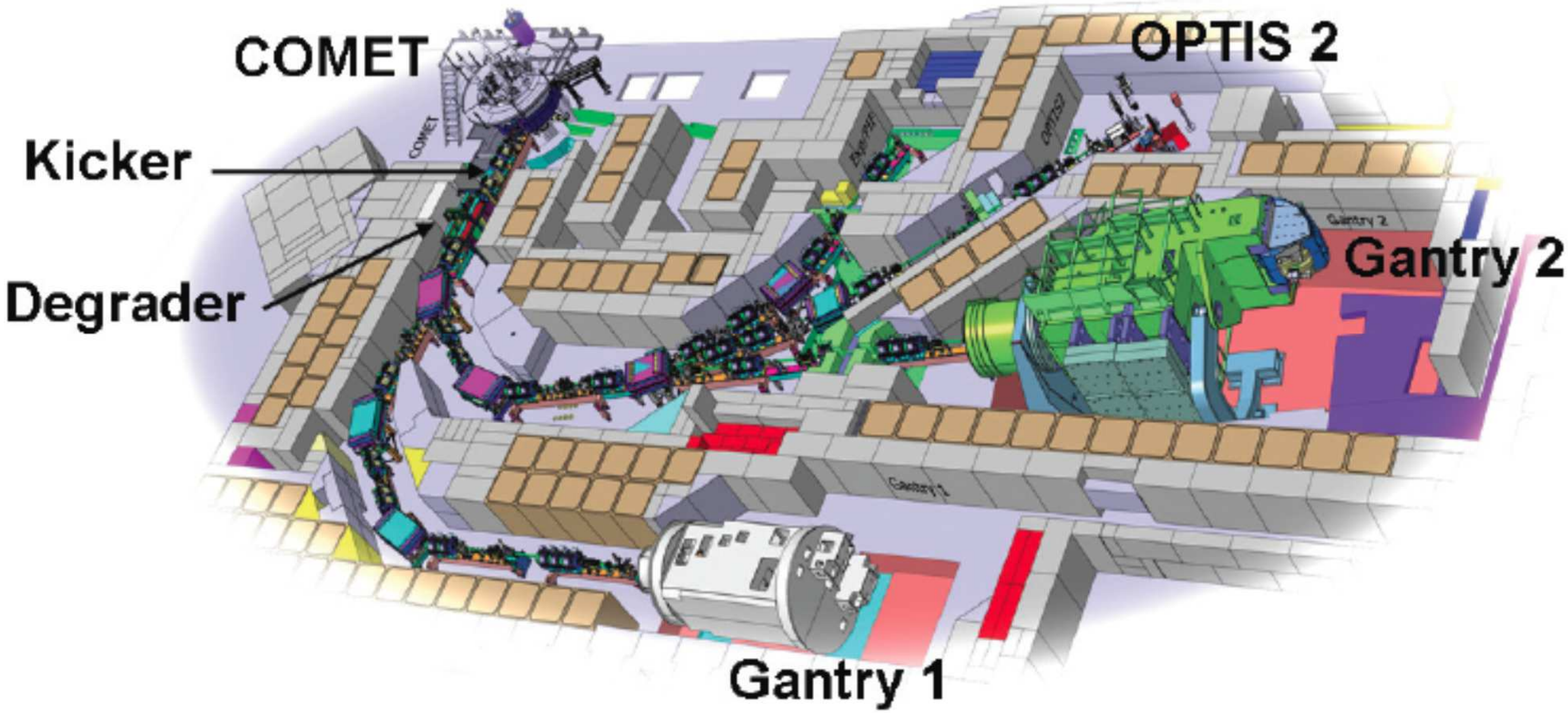
Synchrotron

- Circular accelerating ring
- EM resonant cavities around the ring accelerate the particles which moves in the same radius
- H field strength is increased with increase in particle energy – are in synchronization

Proton Beam Production & Transport



Proton Beam Production & Transport



Cyclotron

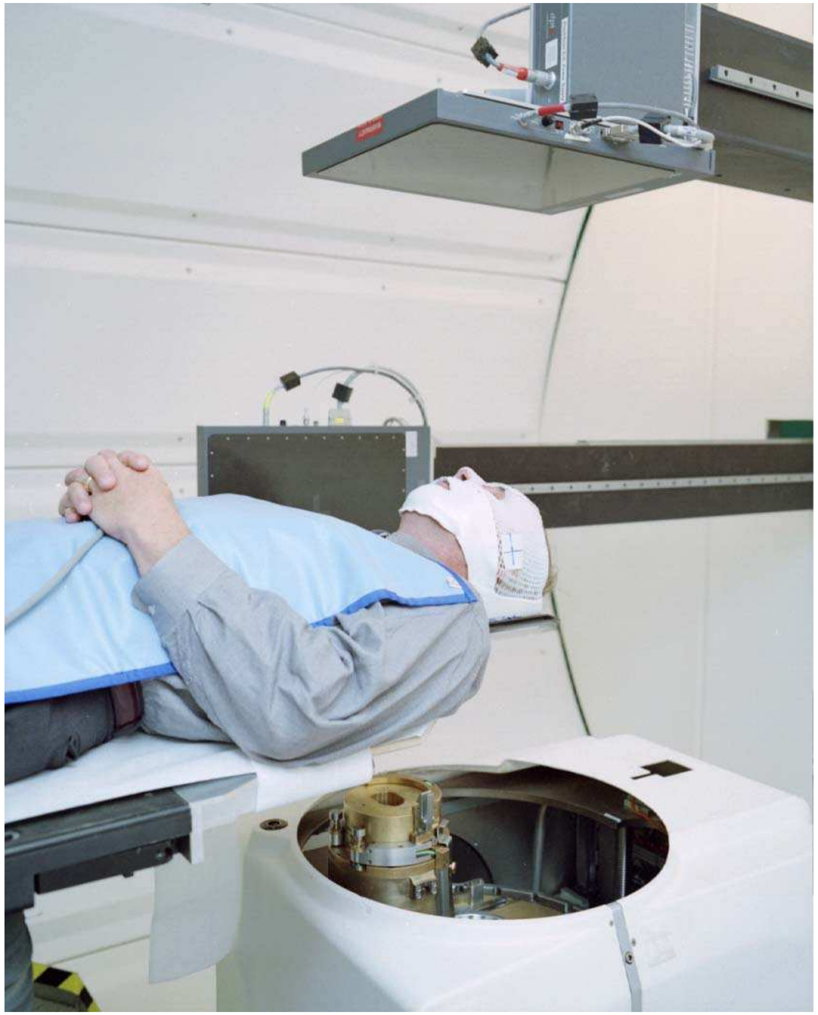
Through electrolysis, protons are taken from water and injected into the cyclotron (cylindrical structure at center) which accelerates protons to nearly the speed of light. The protons are guided through the beam line at right.

The protons travel through the beam line, guided by electromagnets, into treatment rooms.

Cyclotron: Proton Beam Transport

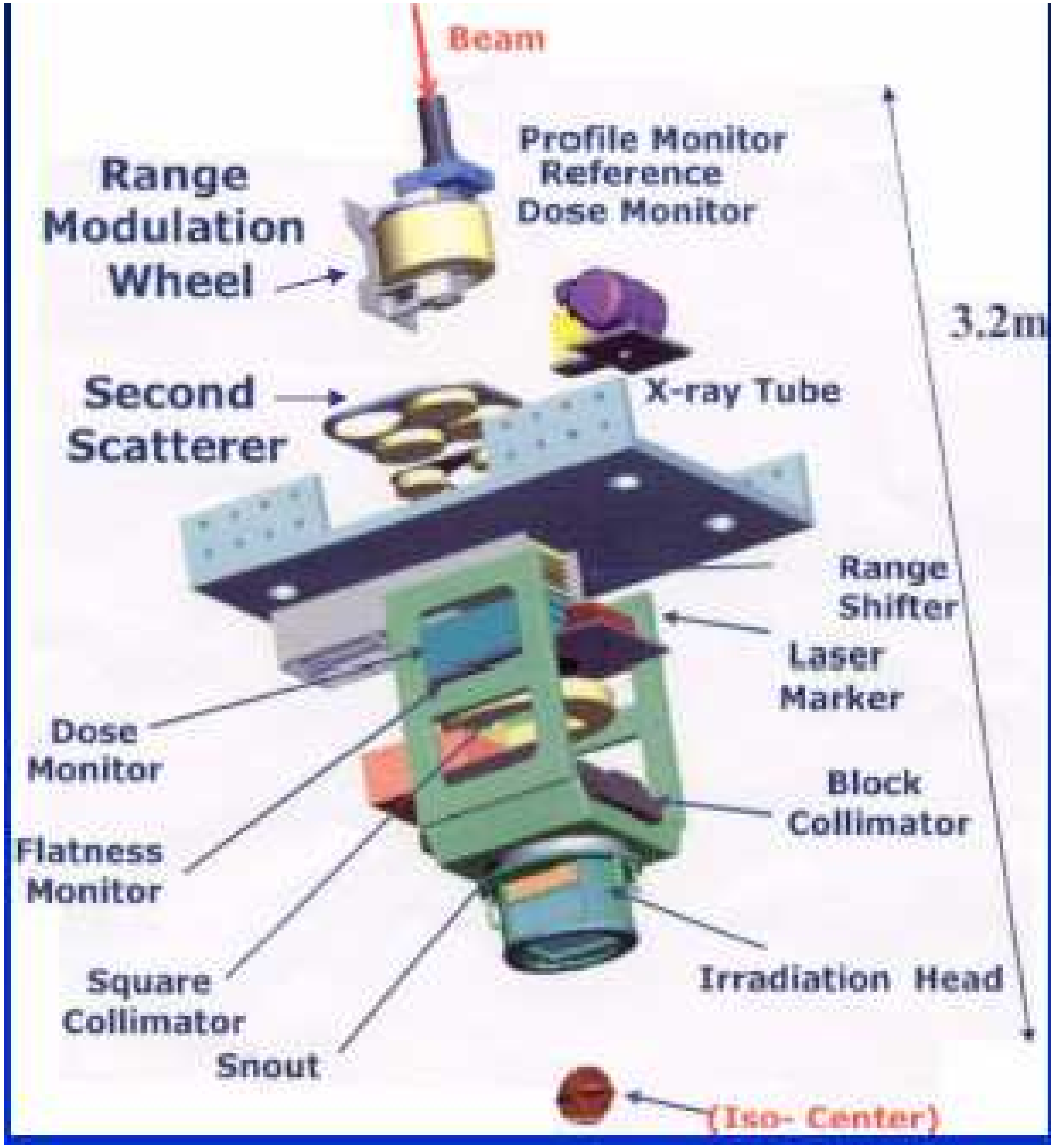
- Dipoles – Bend, guide the proton beam
- Quadrupoles – Focus the proton beam
- Steering Coils – Fine-tune direction of beam
- Beam Profile Monitors with beam stops – providing input to magnets

Proton Beam Gantry & Tx Nozzle



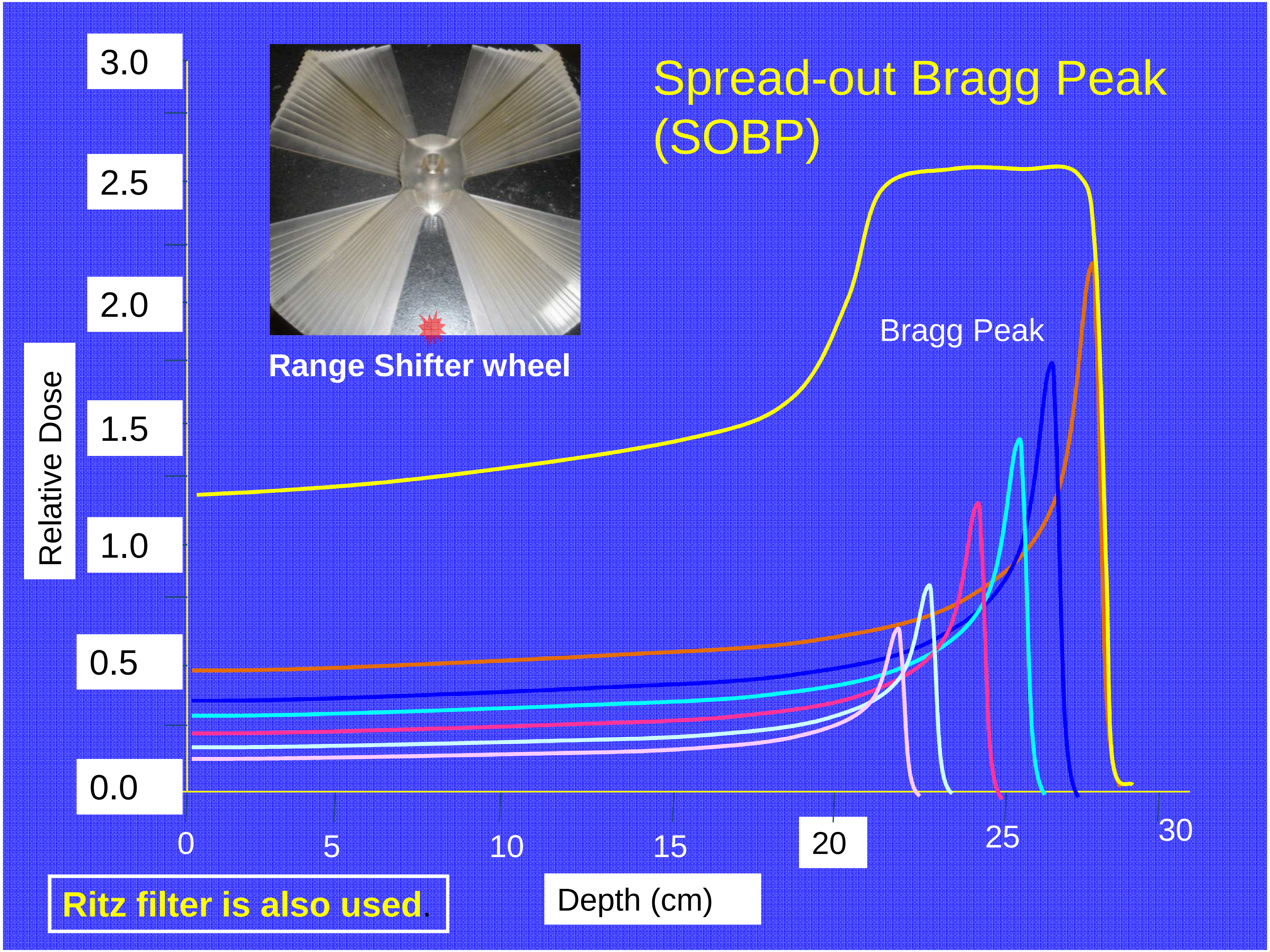
Proton therapy is delivered while the patient lie on the treatment table. The gantry rotates to deliver the treatment precisely to the tumor site.

Schematic Diagram of Nozzle



Nozzle of Proton beam accelerator is nothing but the treatment head,

Contains various components for beam shaping and beam monitoring.


Spread-out Bragg Peak (SOBP)
Range Shifter wheel
Bragg Peak
Relative Dose
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
Depth (cm)
Ritz filter is also used.

Helium Ion Therapy

- The beam penumbra of protons at larger depths is comparable to that of high energy photon beams.
- Helium ion possess sharper beam penumbra at all depths, a more pronounced Bragg-peak, and a steeper dose falloff beyond the Bragg-peak.
- The higher atomic number of helium ions compared to protons can result in break-up of primary beam particles, resulting in a fragmentation tail.
- Due to the lower atomic number of helium compared to carbon ions only a small percentage of the total dose is deposited beyond the Bragg-peak.
- It is reported that the use of helium ions results in further reduction of dose to surrounding normal tissues and organs at risk in comparison to proton beams.

Carbon Ion Therapy

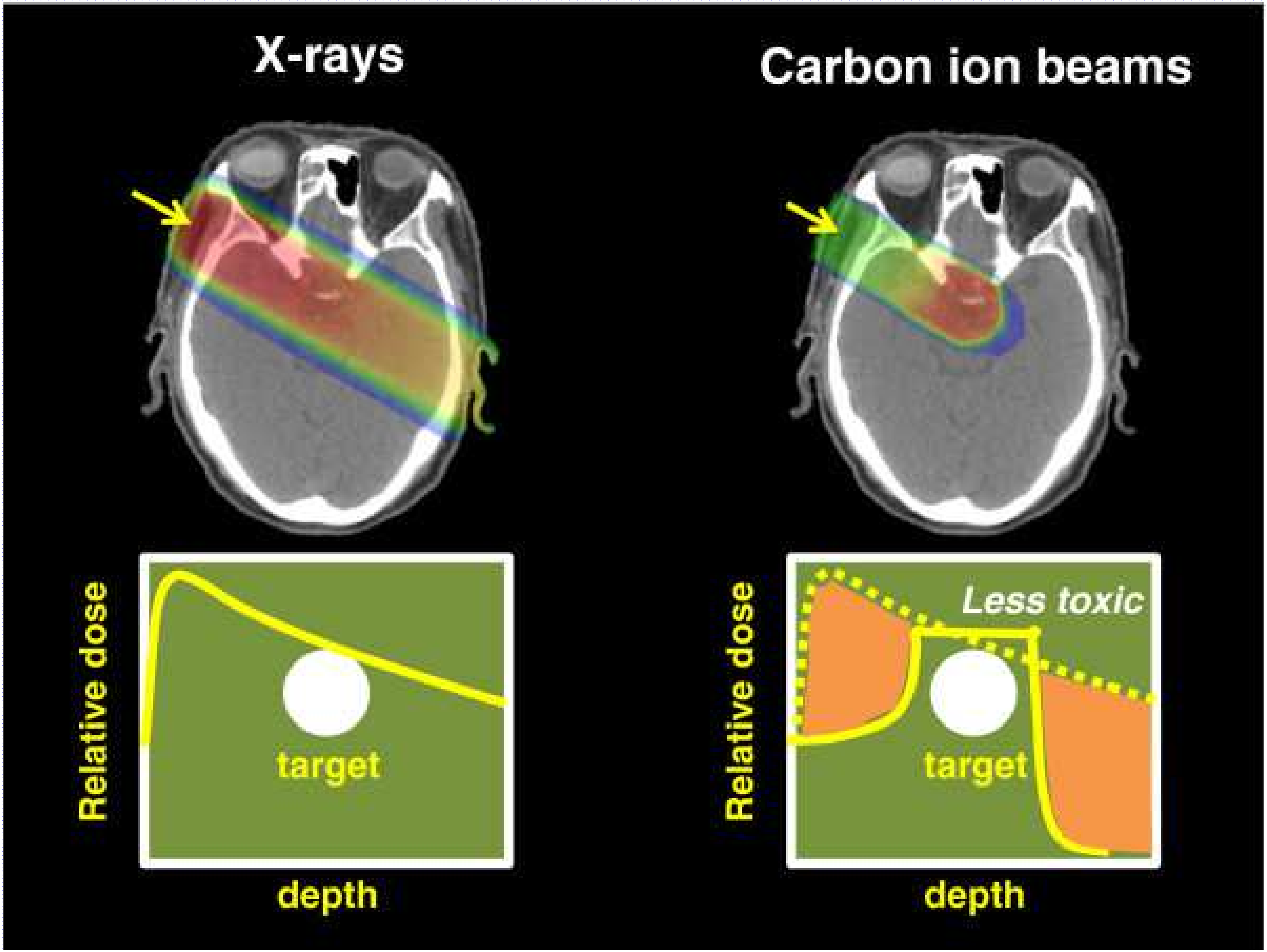
- Carbon (^{12}C) ion beam is now-a-days thought to be a better choice among proton and heavy ions due to higher LET and better dose localization.

- ^{12}C ions are heavier than protons and have been shown to be effective in the treatment of so-called radioresistant tumours.

- It has been shown that the differential radiosensitivity between poorly-oxygenated (radioresistant) and well-oxygenated (radiosensitive) cells is reduced with high LET radiation.

- Tumour sites that are prone to hypoxia might benefit most from high LET radiations (e.g. squamous cell head and neck cancer and non-small cell lung cancer).

Carbon Ion Therapy



Comparison: C-ion & Proton Beam

Statements	Proton Beam Therapy	Carbon Ion Therapy
Proton's Advantages over Carbon	• Lower cost • Able to be delivered via gantry, allowing multiple beam angles •More narrow range of RBE (1-1.1) and greater certainty leading to smaller variations in actual delivered dose. • Decreased risk of late normal tissue damage due to lower RBE.	•Higher cost (2-3 x proton therapy) •Usually delivered via a fixed beam, not permitting multiple angles •There are uncertainties in the RBE (1.5-3.4) which may cause large variations in the actual delivered dose. • Potential for increased risk of late normal tissue damage due to higher/variable RBE.
Carbon's Advantages over Proton	•RBE is similar to photon radiation and increased tumor control would not be expected. •Larger lateral penumbra which can cause greater dose to normal tissue structures than carbon ion.	•Higher RBE particularly at distal edge of Bragg peak which may permit greater tumor control. •Smaller lateral penumbra which may permit a more conformal dose laterally and limit normal tissue damage.
Similarities of Proton and Carbon ion beams	•Both proton and carbon ion limit the integral dose and therefore are predicted to reduce the risk of secondary malignancies over photon therapy, particularly in the pediatric population. •Both proton and carbon ion research is limited, largely consisting of small series of patients where definitive conclusions are difficult to make.	

Summary

- **Teletherapy /External Beam Radiotherapy :**

  Radium bomb, Caesium 137, Cobalt 60 Teleisotope/ Megavoltage external beam therapy, Linear Accelerator

- **Components of Teletherapy:**

  Source, Source Housing, Collimation and characteristics, shutter system

- **Linear Accelerator:**

  Kylstron/Magnetron, Wave guide, C arm / Rotating gantry and drum

- **Tomotherapy**

  Helical treatment with 6 MV and image guidance

- **Other type of teletherapy:**

  MR Linac/Coblat units, Proton