Linear Accelerator Technology

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Selection -Teletherapy Machine

Radiation Beam Characteristics

- Beam edge sharpness (penumbra) , Beam penetration (energy)

Machine Characteristics

- Dose rate, Patient collimator distance
- Isocentre height, Radioactive source versus x-rays

Service/Maintenance Issues

Safety Considerations

- Radiation protection

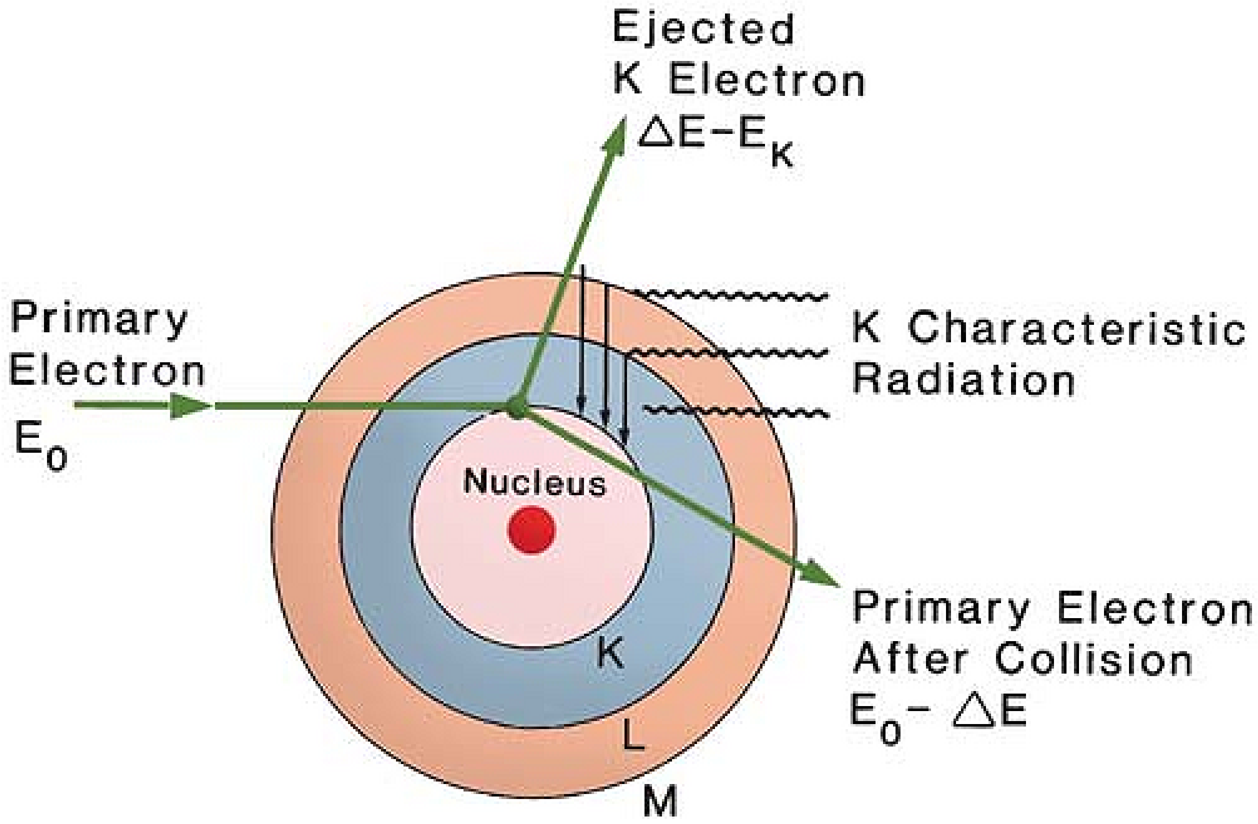
Cost Considerations

Additional Features

Introduction

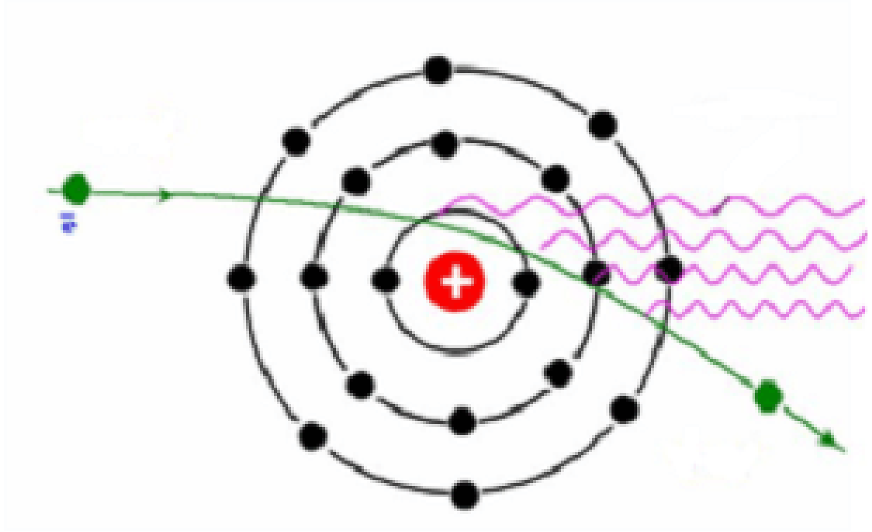
- What is x-rays?
- Incidental discovery!
- How x-rays are produced?
- Physics of x-rays

Characteristic X-rays



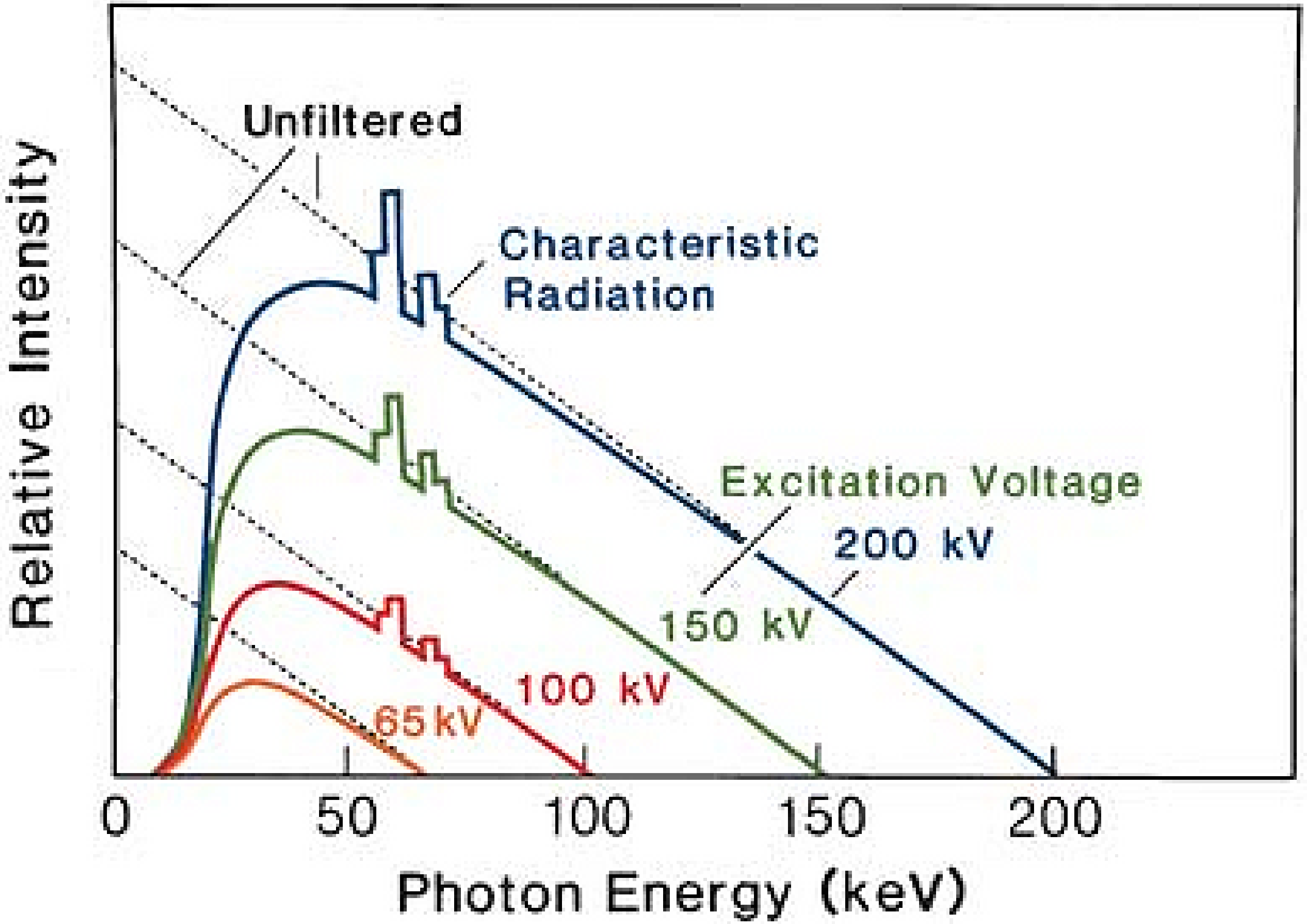
from Faiz Khan

Bremsstrahlung X-rays

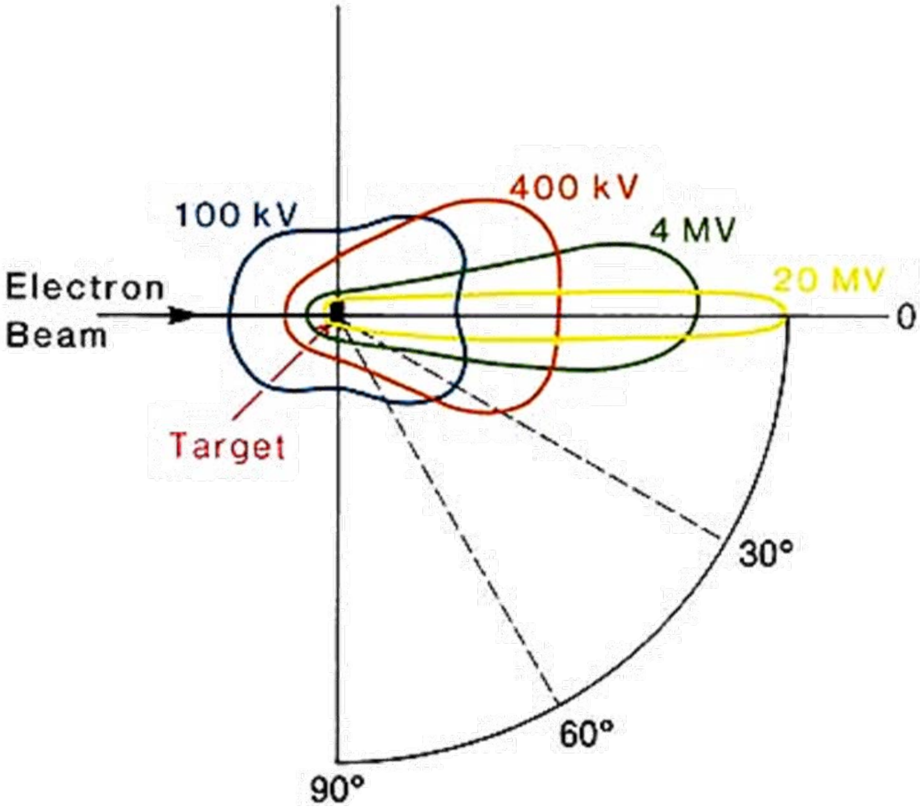


X-rays Spectrum

Thick tungsten target



Angular Distribution

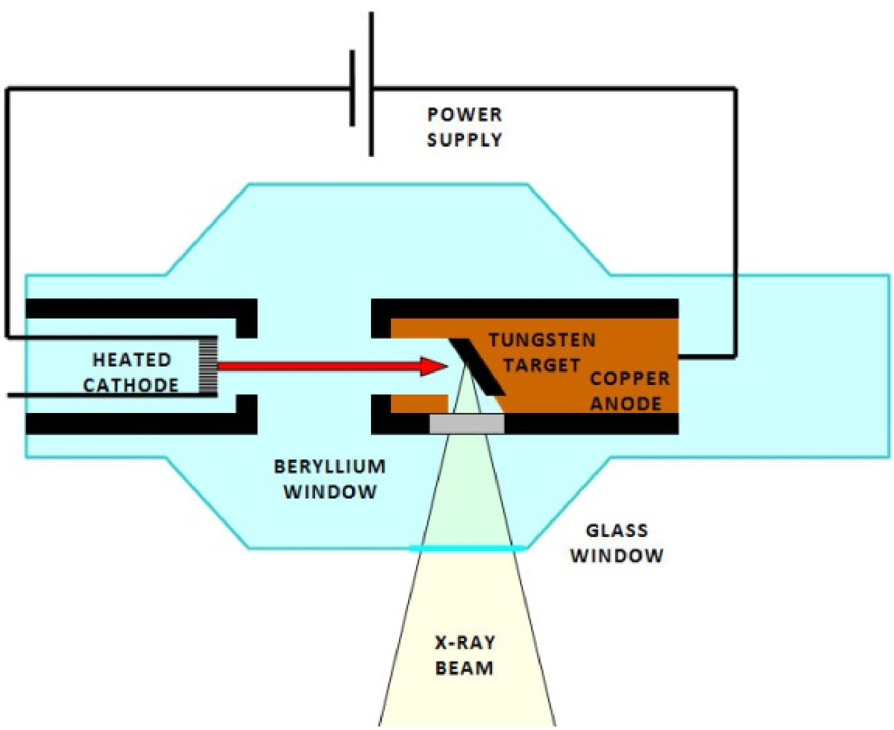


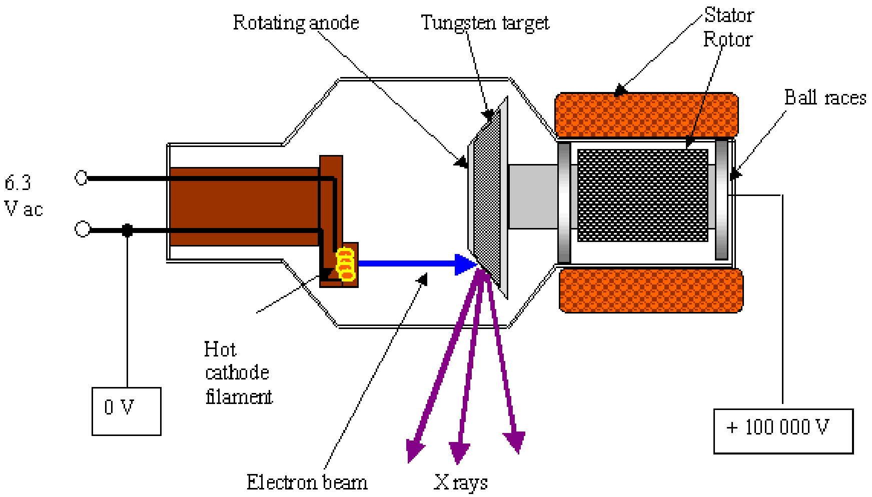
from Faiz Khan

Angular distribution becomes more “forward peaked” as the electron energy increases

X-Ray Tube

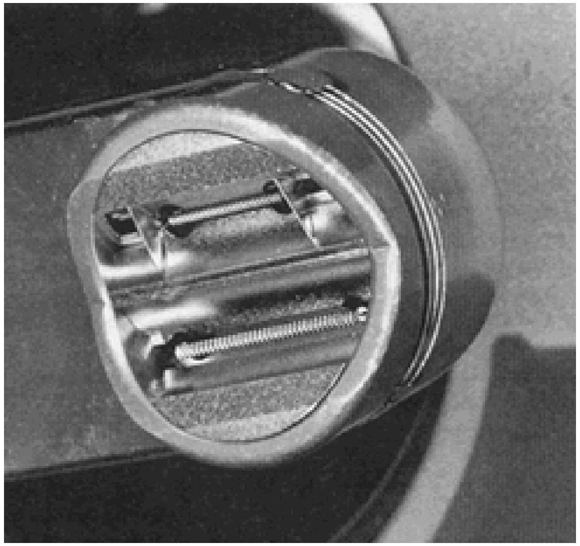
SCHEMATIC OF KILOVOLTAGE X-RAY UNIT





Cathode

- Tungsten filament (3370 ° C)
- Thermionic emission
- Focusing cup
- Dual filaments



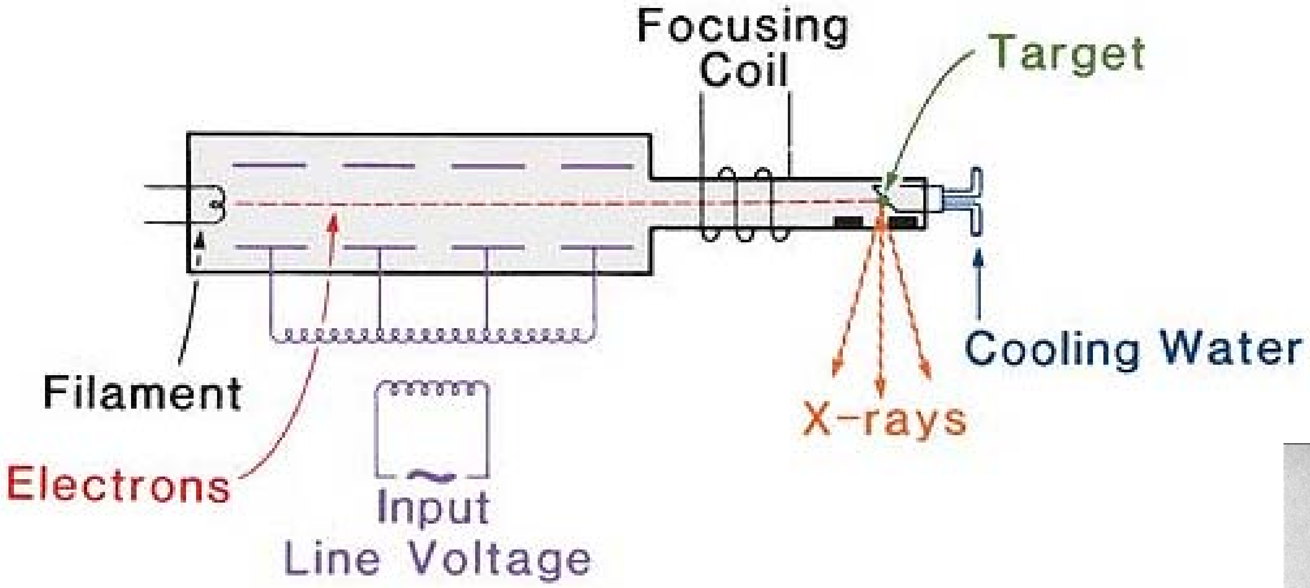
Anode

- Tungsten target
  - High melting point
  - High Z (74) , X-ray α Z^2
- Heat dissipation
  - Copper anode
  - Rotating anode /Stationary
- Anode hood – copper and tungsten shields intercept stray electrons and x rays

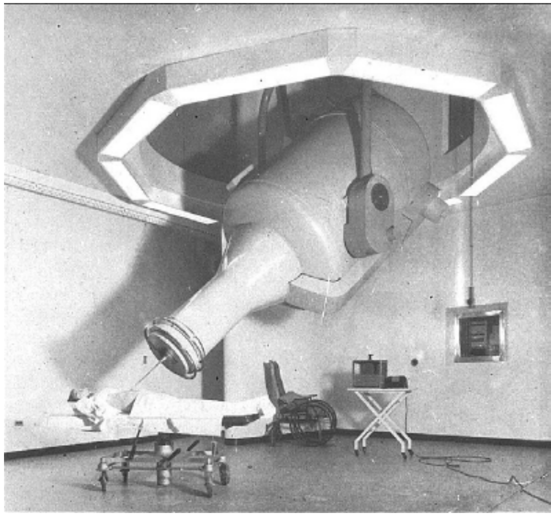
Limitations of X-ray Tube

- High voltage
- Millions of volts cannot be held in single gap

Resonant Transformer



300 to 2,000 kV



Require More space, bulky insulation

From Khan

Clinical Radiation Generators

Grenz rays	< 20 kVp
Contact Therapy	40-50 kVp
Superficial Therapy	50-150 kVp
Orthovoltage	150-500 kVp
Supervoltage	500-1000 kVp
Megavoltage	> 1000 kVp

Medical Linac?

A device in which electron beam is accelerated in linear path with the help of high frequency microwaves to produces high energy photon or electron beam

Basic Linac

Low energy

★4-8 MV

- Straight-through beam
- No Bending
- fixed flattening filter
- external wedges
- symmetric jaws
- isocentric mounting

(High end features are optional)

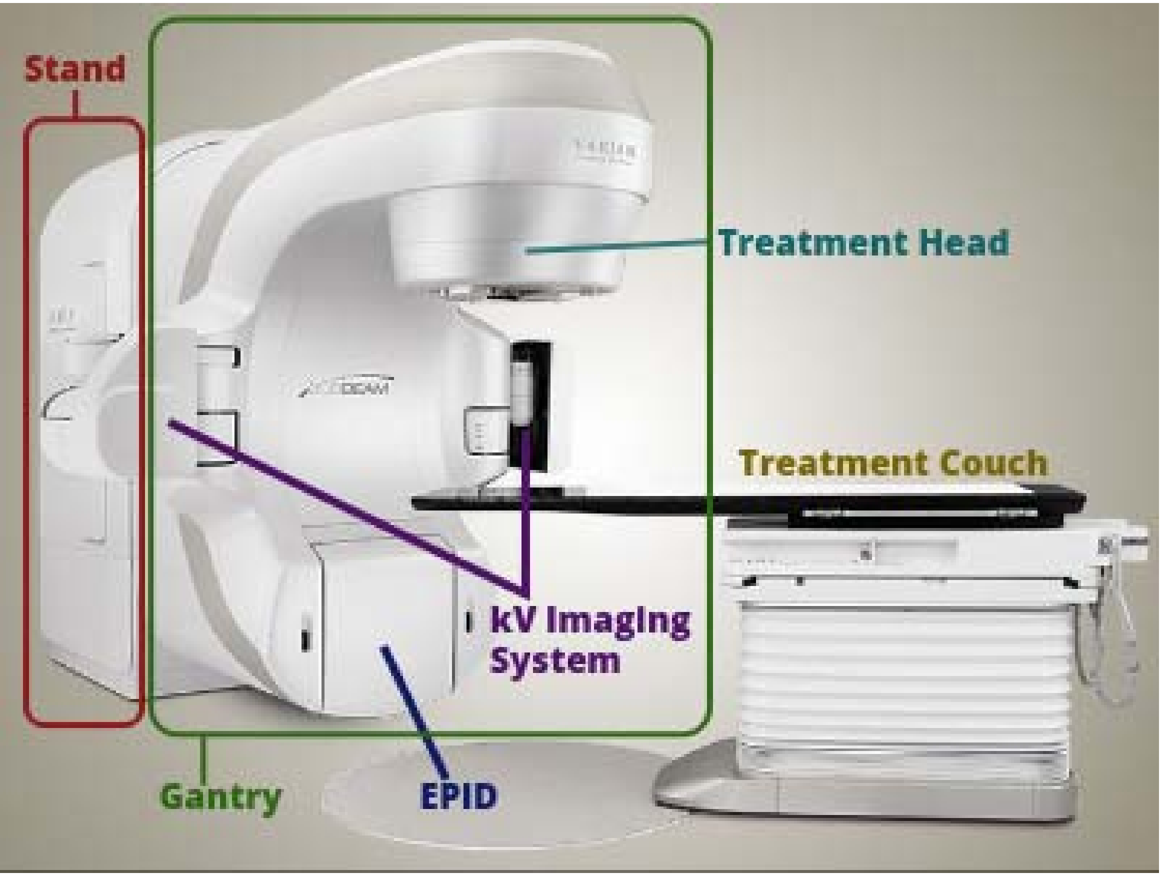
Medium/High Energy

- 10-25 MV
  - Dual photon energy and multiple electron energies
  - Achromatic bending
  - dual scattering foils or scanned electron pencil beam
  - Dynamic wedge
  - Asymmetric jaws.
- Advanced features
  - EPID, MLC
  - IMRT, IGRT

Basic Accelerator Technology

- Sophisticated & complex
- Mechanical, Electrical, electronics, Radiation, Optics, Microwave
- Microwave Power sources
- Acceleration structures
- Beam transport systems
- Support structures

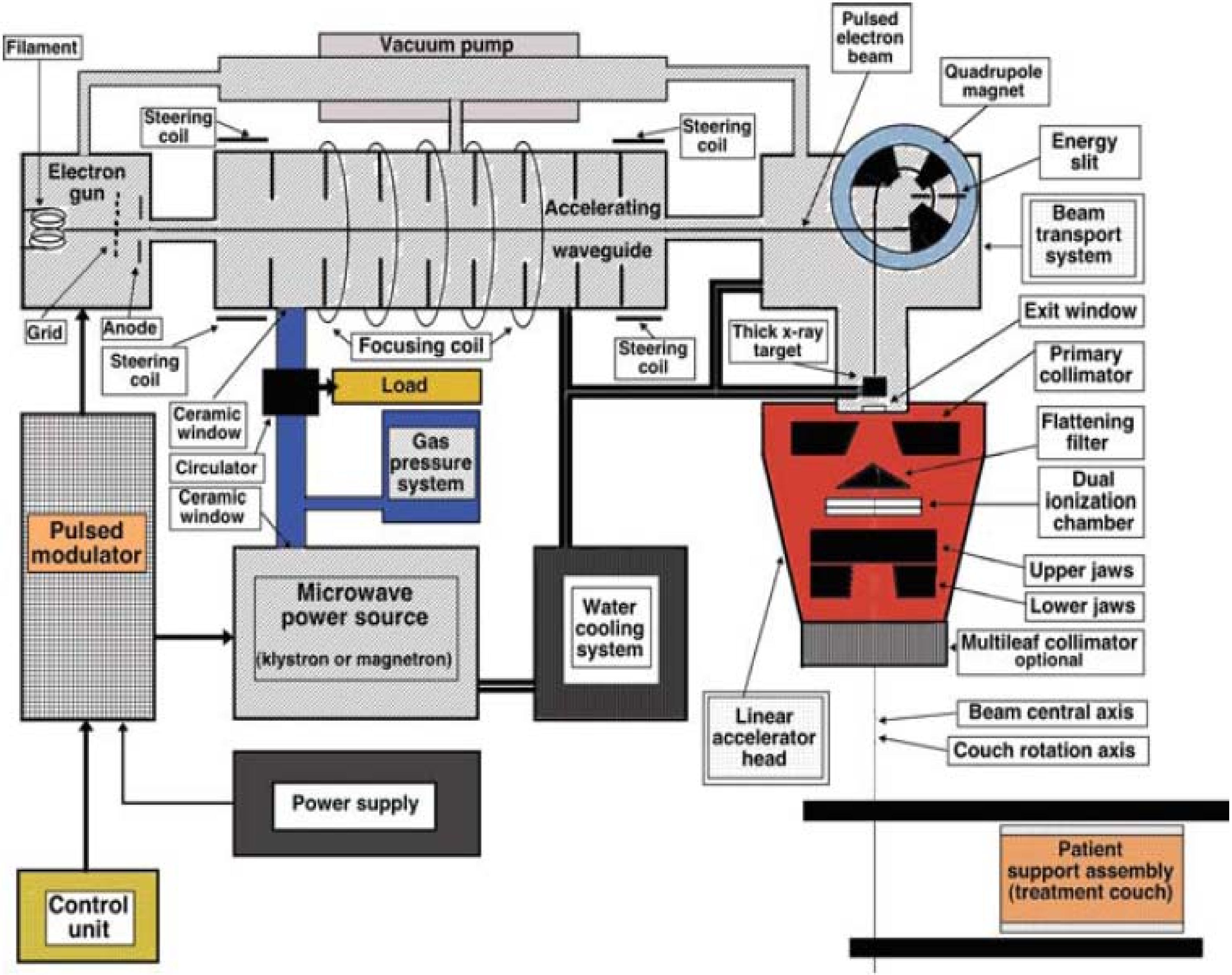
Major Parts



Treatment Console

Major Components

- Modulator
- Magnetron or Klystron
- Electron Gun
- Wave Guide system
- Accelerator Tube
- Bending Magnet
- Treatment Head (Straight Beam/(Bent Beam)
- Treatment Couch
- Control Console (operational and imaging)


Filament
Vacuum pump
Pulsed electron beam
Quadrupole magnet
Steering coil
Steering coil
Energy slit
Electron gun
Accelerating waveguide
Beam transport system
Grid
Anode
Steering coil
Focusing coil
Steering coil
Thick x-ray target
Exit window
Primary collimator
Ceramic window
Load
Flattening filter
Circulator
Gas pressure system
Ceramic window
Dual ionization chamber
Pulsed modulator
Microwave power source
(klystron or magnetron)
Water cooling system
Upper jaws
Lower jaws
Multileaf collimator optional
Linear accelerator head
Beam central axis
Couch rotation axis
Power supply
Patient support assembly (treatment couch)
Control unit

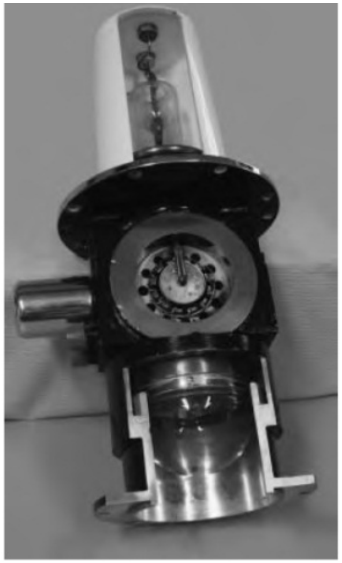
Modulator Cabinet

The combination of high voltage source, PFN, HV switch, and pulse transformer is known as "*modulator*"

- Power distribution system
- High Voltage pulses to gun & RF Generator
- Power supplies
- High voltage pulses from the modulator are fed to RF source and electron gun.

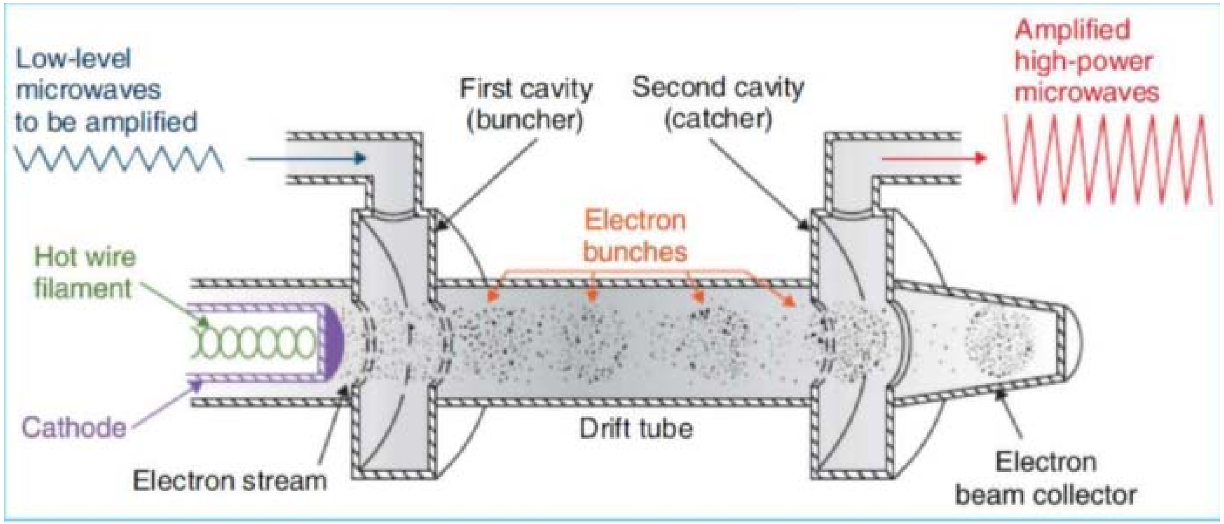
Magnetron

- A static magnetic field is applied perpendicular to the plane of the cross section of the cavities
- Pulsed DC is applied between cathode & anode.
- The electrons from cathode are accelerated toward anode due to pulsed DC electric field.
- The electrons move in complex spirals toward the resonant cavities & radiate energy in the form of microwaves.
- Low energy accelerators
- Less costly
- Smaller least complicated
- Less reliable
- shorter lifespan
-



Klystron

- It is a microwave amplifier and needs low-power microwave oscillator
- Stable at higher energies
- Costly & Complex
- Bulky in comparison to Magnetron



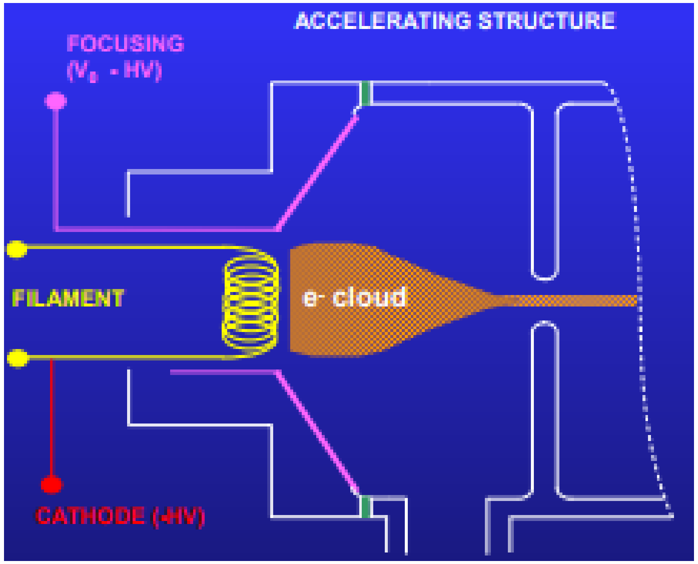
Classification as per RF fields

- L band - 10^3 MHz
  - physically larger but capable of beam powers considerably above 20 kW
- S band - 2856 MHz
  - more compact but limited to beam powers below 20 kW
- X band - 10^4 MHz
  - Tomotherapy
  - robotic arm mounting, miniature form
  - Mobetron (IORT system)

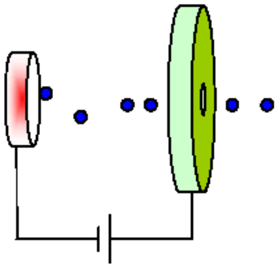
Electron Gun

- Diode electron Gun - used in simple, low energy machines and has limitations.
  - Radiofrequency is required to turn beam on or off (slow)
- Triode electron gun - Commonly used
  - More flexibility than a diode gun can
  - For a given beam energy any beam current can be achieved and vice versa.
  - Few hundred volts need to be switched to turn on or off the beam. (fast)
  - Triode guns used in multiple energy linacs

Electron Gun

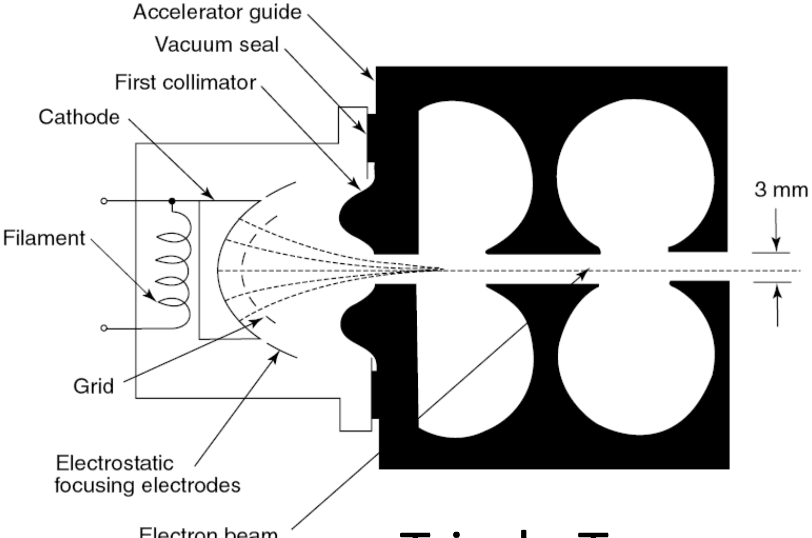


Diode Type

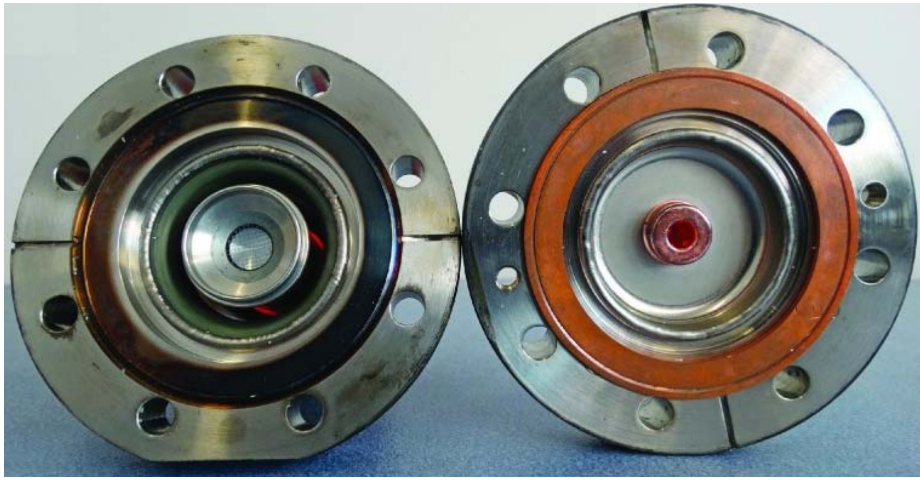


Cathode

Anode



Triode Type

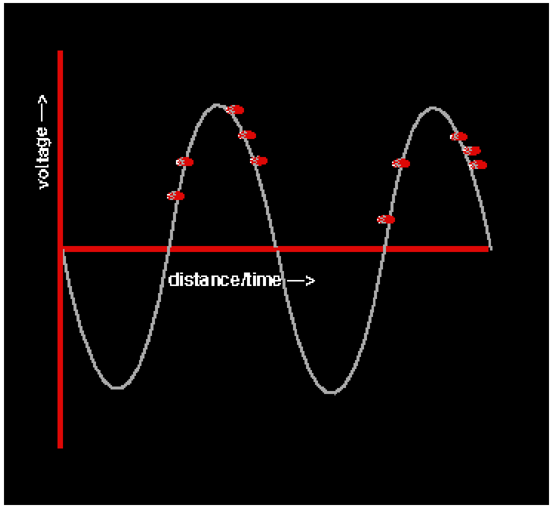


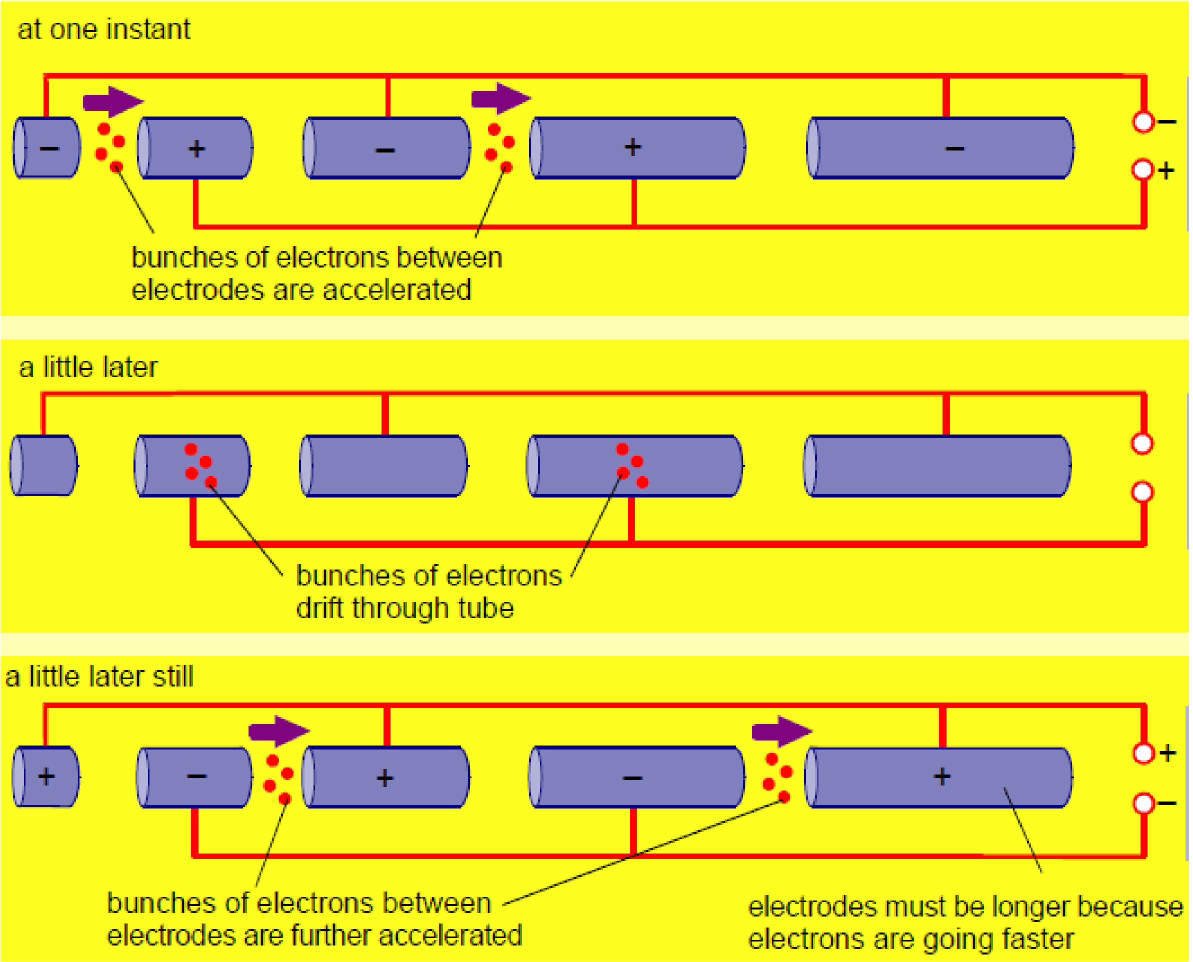
Whelan B et al 2016, Med Phys

Vacuum & Cooling

- The vacuum system
  - Maintains required low pressures
  - required for operation of WG, Gun and bending magnets.
  - Prevents breakdown of the high electric fields required during accelerator operation.
- The water cooling system
  - Required to establish a stable operating temperature.

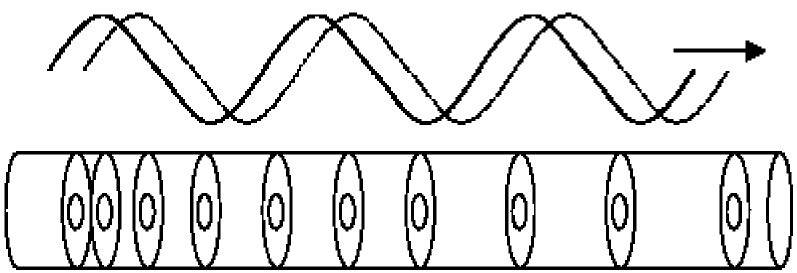
Electron Acceleration



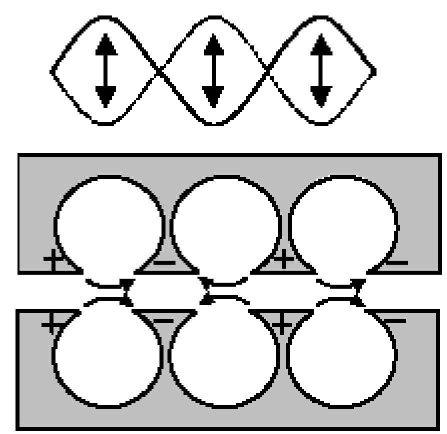


Accelerator Structures

A cylindrical tube in which electrons from electron gun, are accelerated by the amplified microwaves and exit the waveguide to enter the *treatment head.*



Travelling Wave



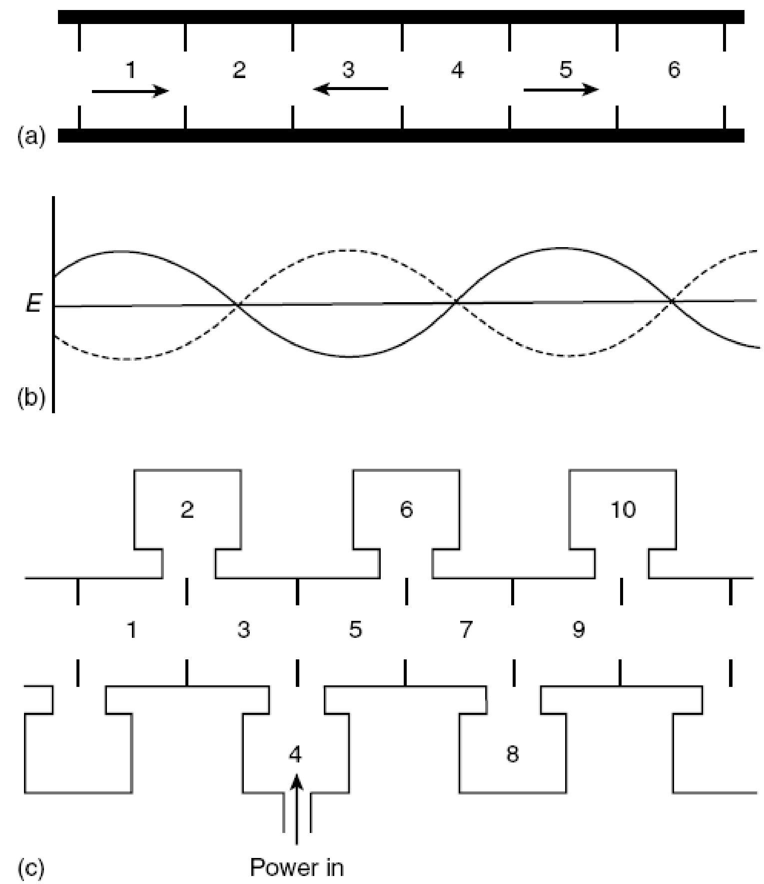
Standing Wave

Standing wave

(a) Arrangement of the waveguide.

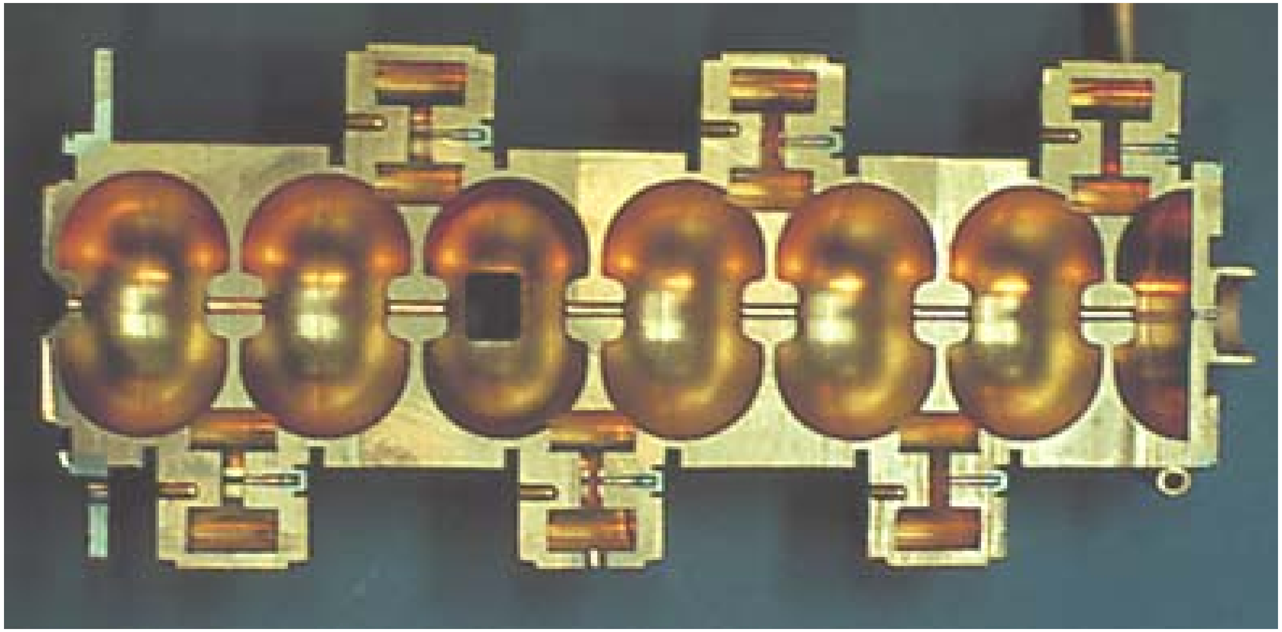
(b) Standing waves.

(c) Shows a side-coupled cavity.



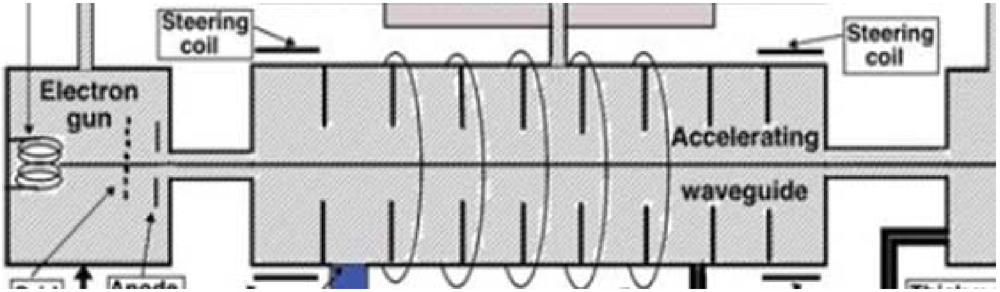
From Greene and Williams

Section of SW accelerator



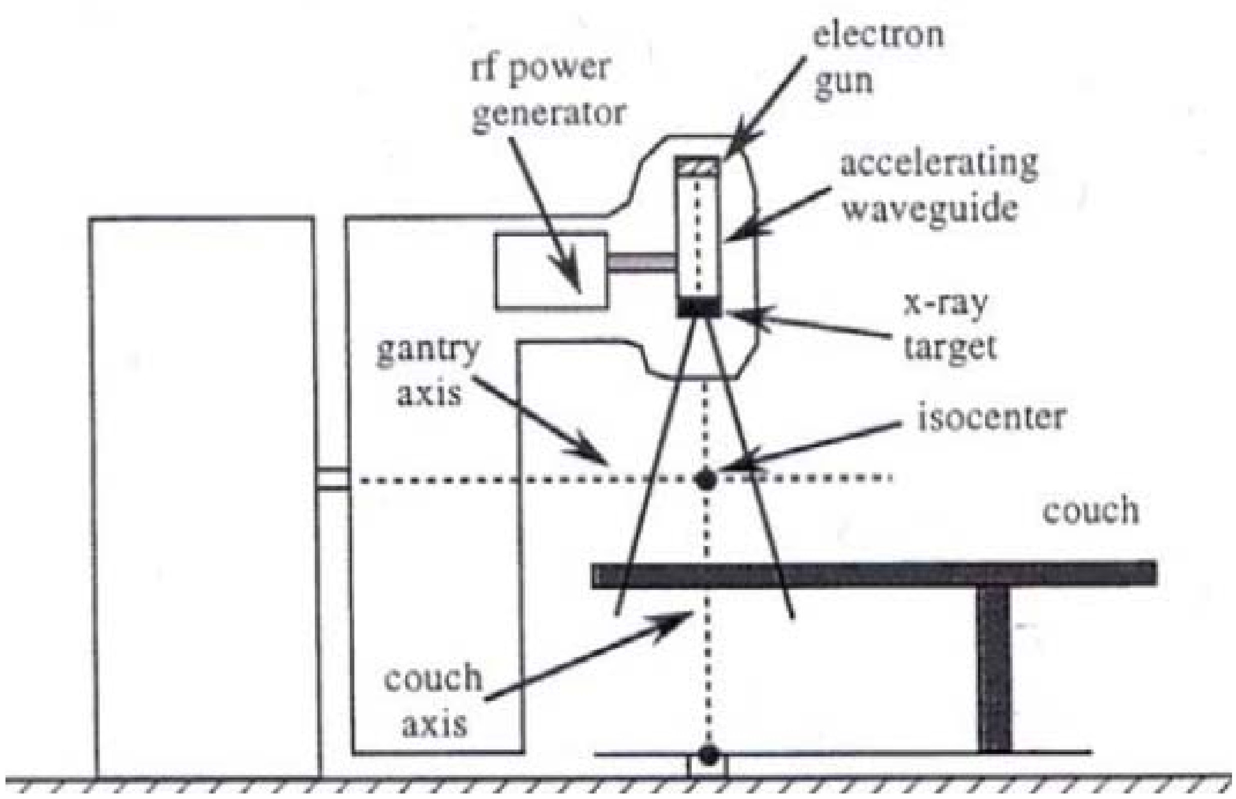
Focusing

- Focusing coils
  - Aligned along the exterior of the waveguide.
  - Magnetic fields parallel to the long axis of the waveguide.



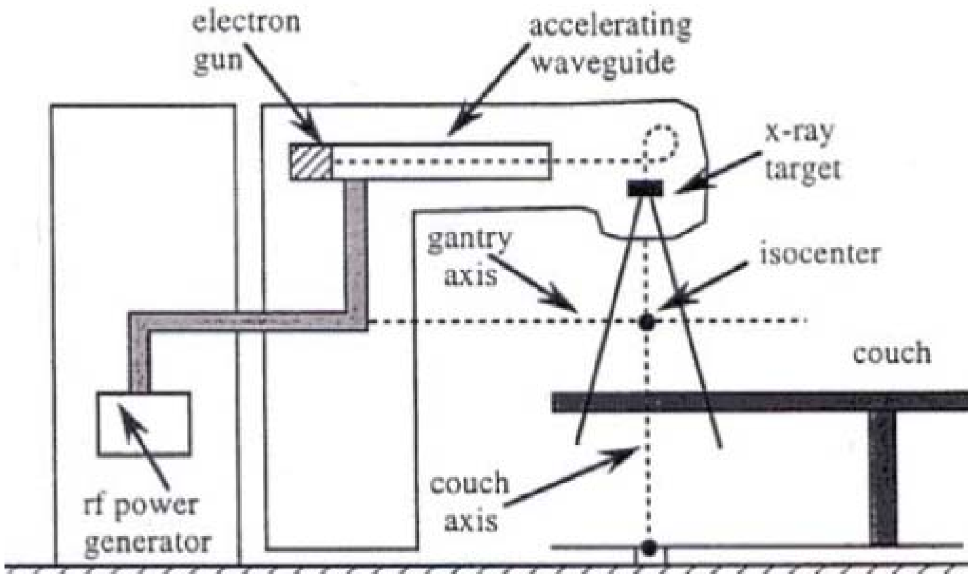
- Steering coils
  - Independently of focusing coils
  - Ensure, electron beam is at the centre of WG
  - Entrance and exit electron beam as desired

Position of WG



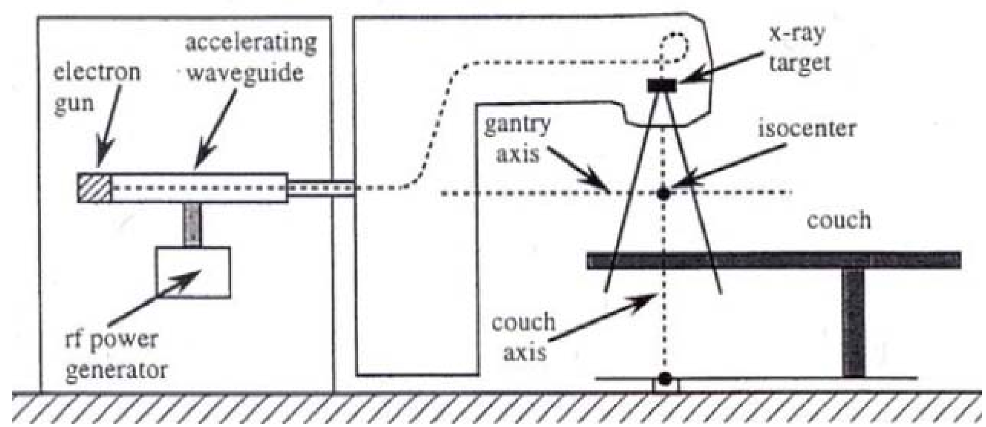
Wave guide in Head

Position of WG



Wave guide Gantry

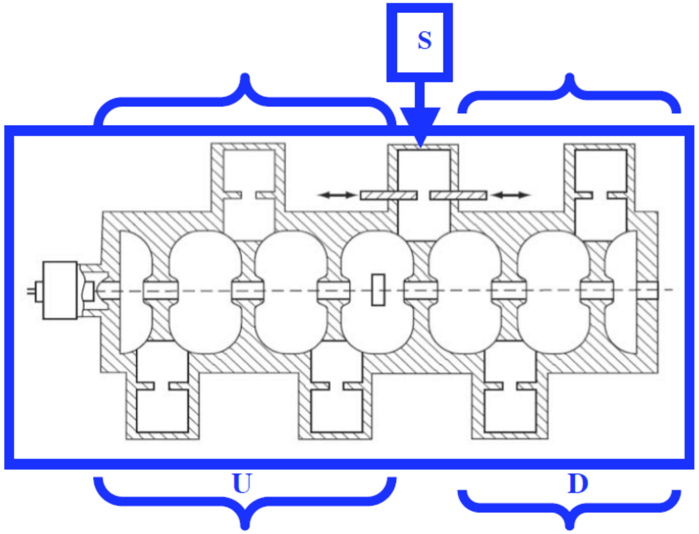
Wave guide in Gantry Stand

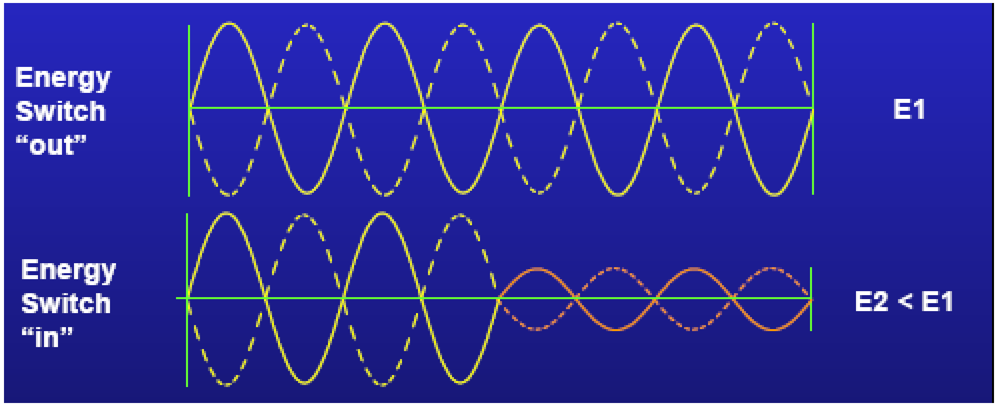


Energy Change?

Energy switch

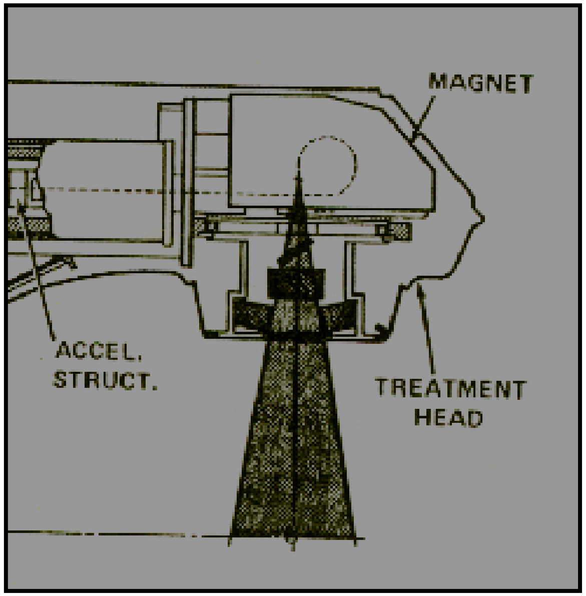
- fields in the accelerating cavities in section D may be varied in a controlled amount relative to the fields in the cavities in section U

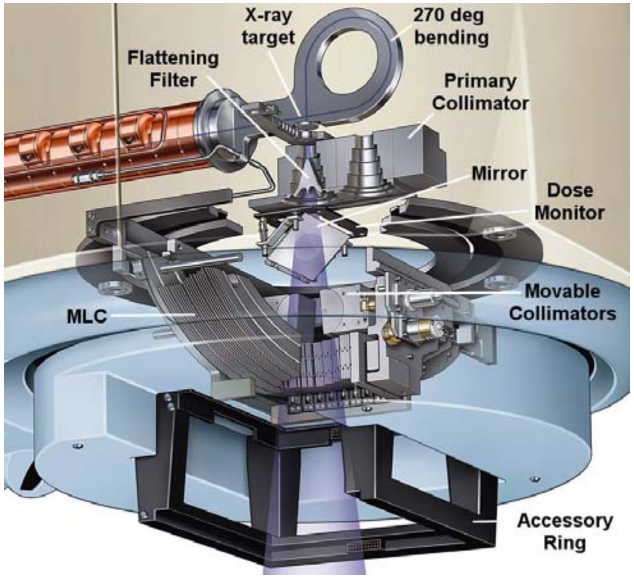




Treatment Head

- Contains the beam shaping, steering, and control components of the linear accelerator.





Components in Head

- Scattering Foils –to spread the beam
- Monitoring Chambers – to monitor
- Collimation System – fixed and movable
- X-Ray Target – transmission-type
- Flattening Filter –to produce a “flat” beam

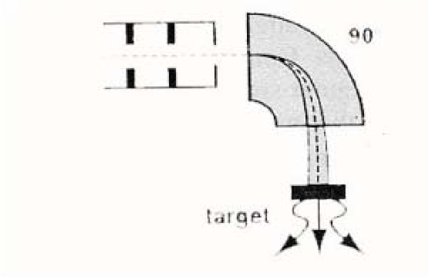
Bending magnet

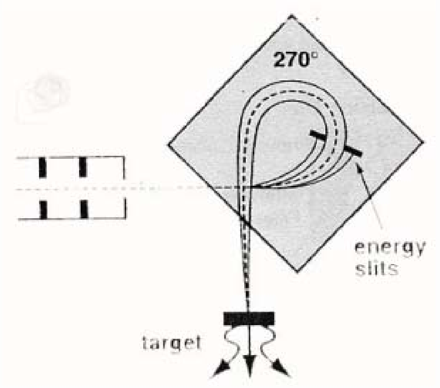
- projects the electron beam onto the target.

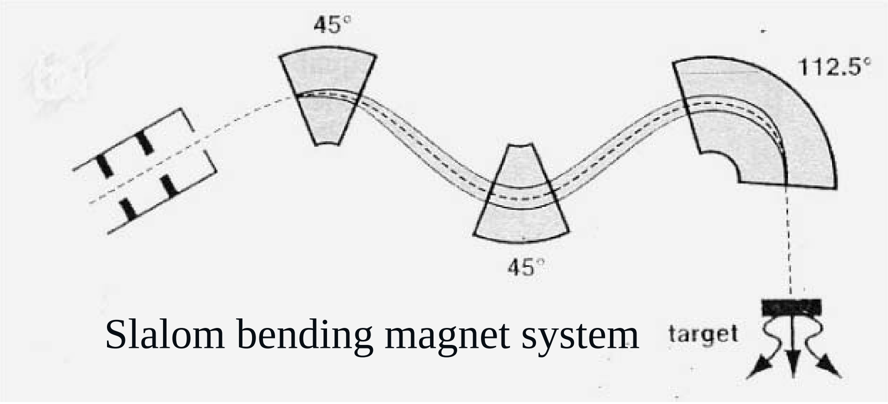
✶ 90^0 - Simple, but elliptical focal spot

✶ $270^{\,0}$ - small FS, energy accuracy ± 5%, but Bulky

✶ Salalom (112.5^0) – advantages of both , total bending 202.5^0.







Slalom bending magnet system

Collimation Systems

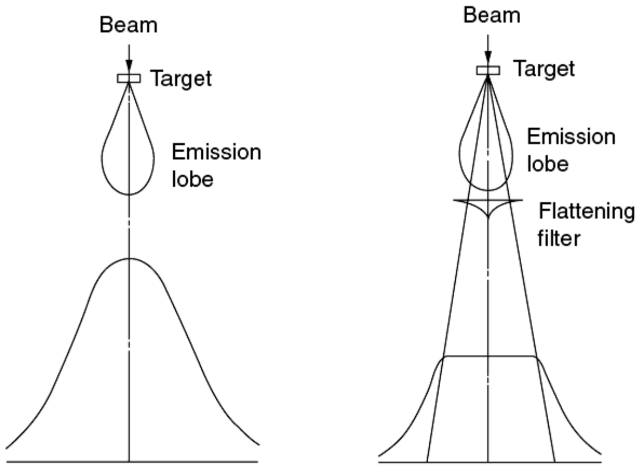
- Limiting the radiation beam
- Primary/fixed collimation
  - Cone-shaped, defines maximum field size
  - Depleted uranium/Tungsten
  - Transmission <0.2%
- Secondary/movable collimator
  - Transmission <2%
  - mounted on either side of the central axis
- Symmetric or asymmetric collimator

Multileaf collimators

- Many independent collimators
- Allow irregular field sizes
- to be delivered from the linear accelerator.
- 40–80 pairs of independent collimators
- Each leaf has its own motor

Flattening Filter

- Conical metal filter
  - situated between the target and the ionization chamber.
  - Produce a uniform intensity distribution
  - Reduces the output on the central axis of the beam



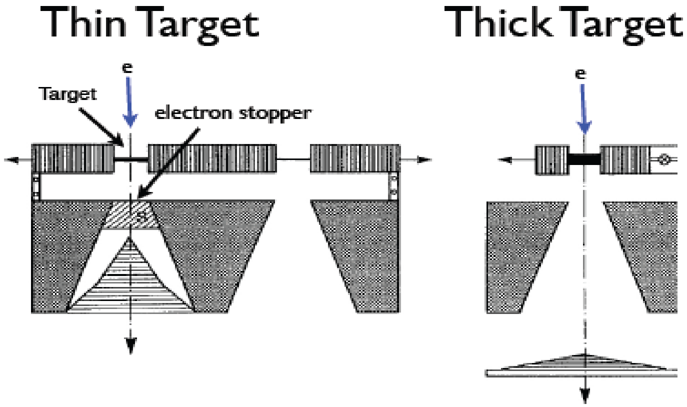
Flattening Filter Free Linac

Removal of the FF results

- Increase in dose rate (2 - 4 times higher)
- Softening of the x-ray spectra
- Shift in dmax
- Reduction in head scattered radiation
- Nonuniform beam profile.

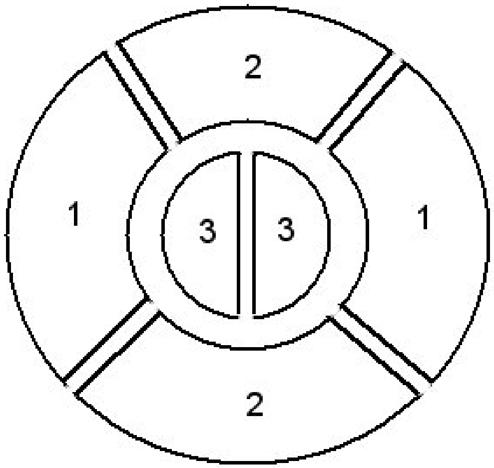
X-ray target

- X-ray production
- up to 10 MeV, a thick tungsten target is employed,
- Thick aluminum target being used for energies greater than this.
- Retractable for electron beam therapy.

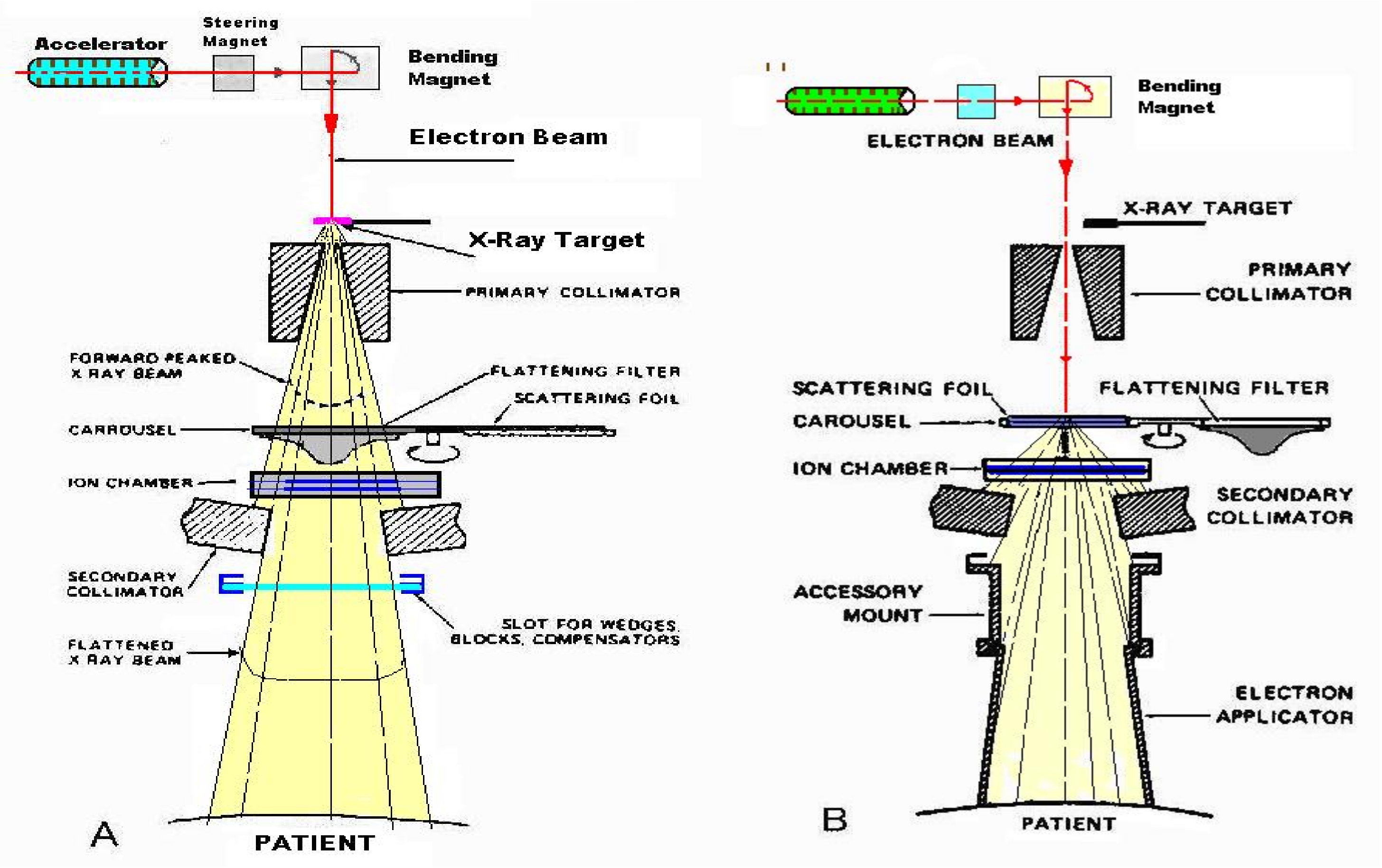


Ionization Chamber

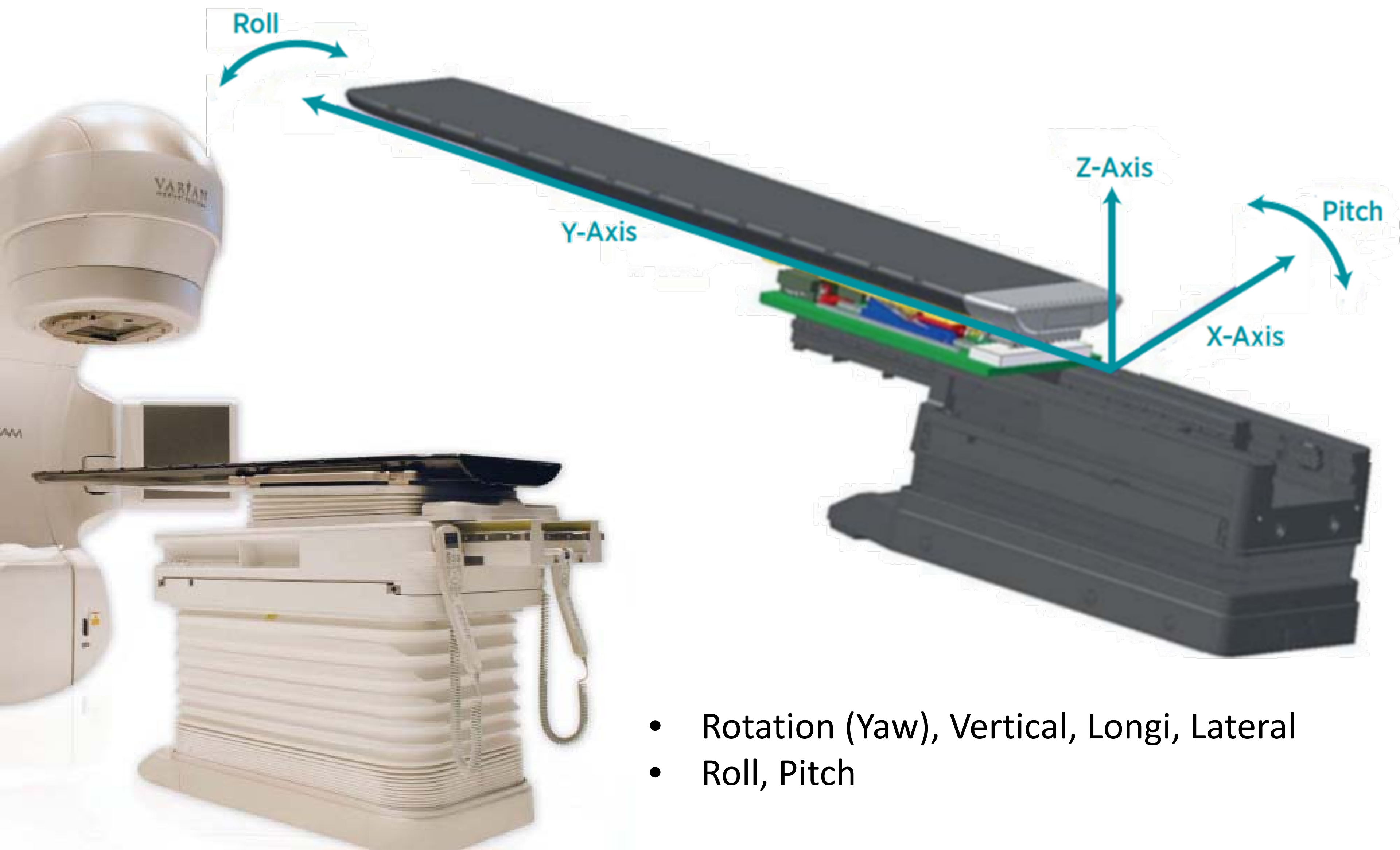
- Measures dose & Terminates the beam
  - After prescribed dose
  - if the energy, quality, flatness, or dose rate changes
  - Two chambers operate independently



X-rays & Electron Beam

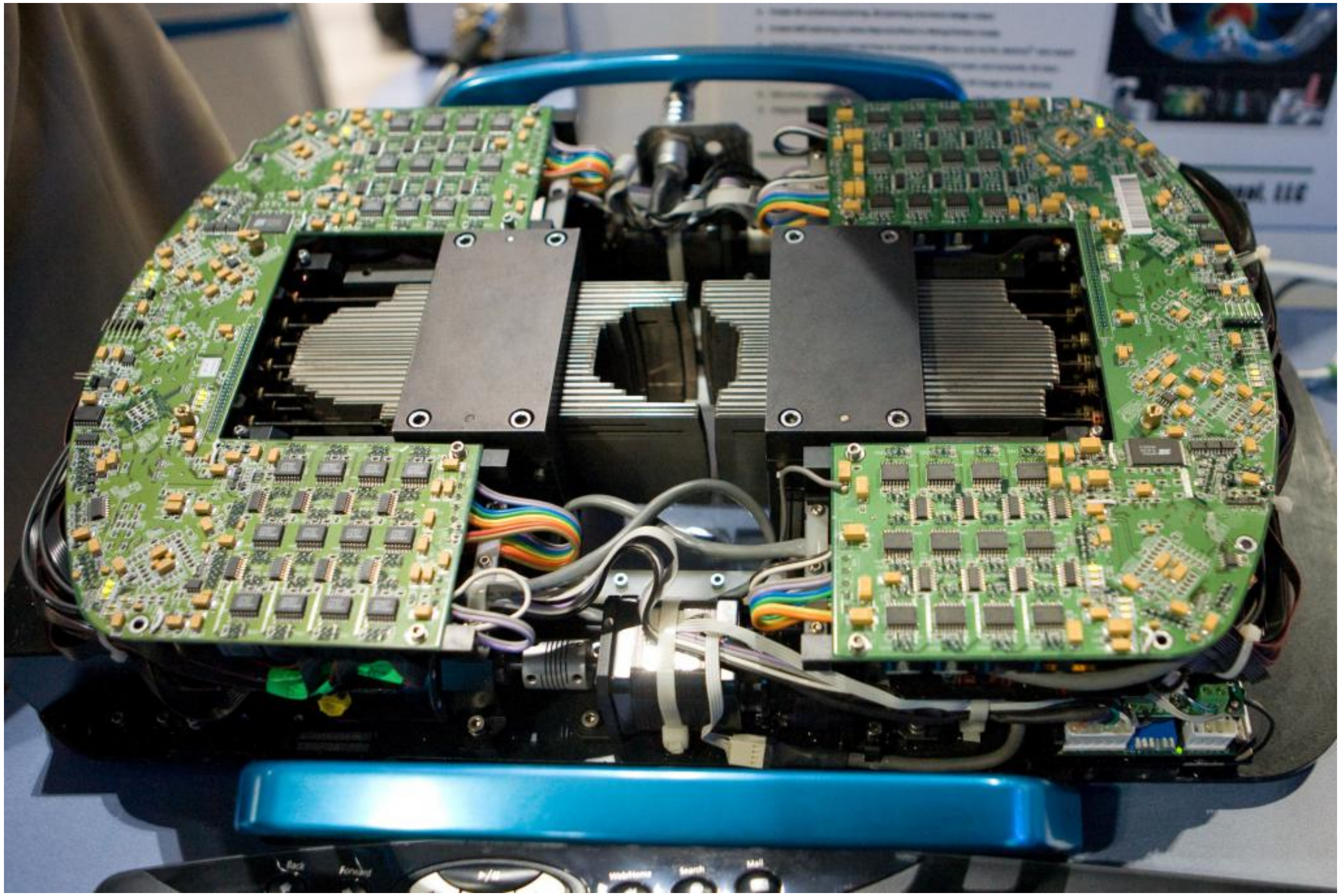


Couch



- Rotation (Yaw), Vertical, Longi, Lateral
- Roll, Pitch

MLC



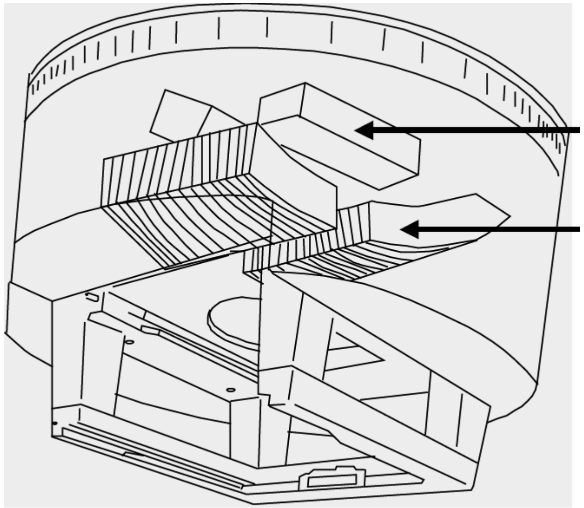
Types of MLC

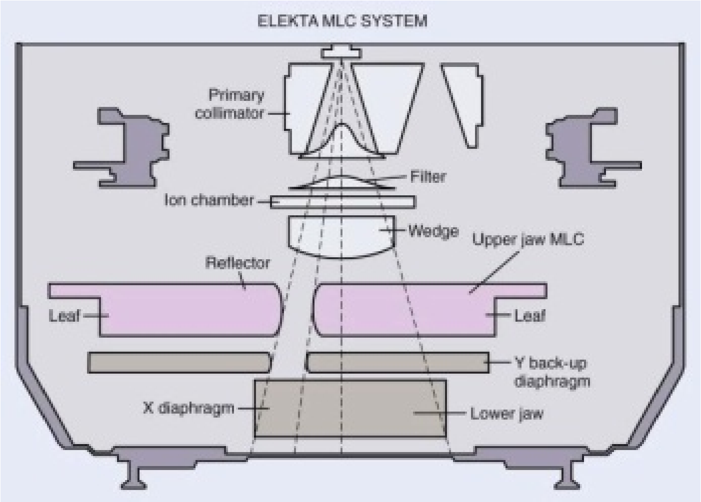
Three main types

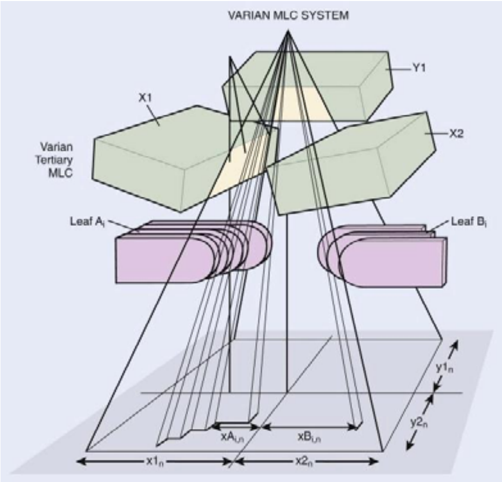
A - Siemens - retain upper but replaces lower Jaw

B - Elekta - retain lower jaw + backup collimators, replaces upper jaw

C – Varian - retain all jaws + MLC







Other facilities

- Electron cones
- Onboard imaging/EPID
- LASER
- Optical back pointer
- Shielding blocks
- Physical wedges, etc

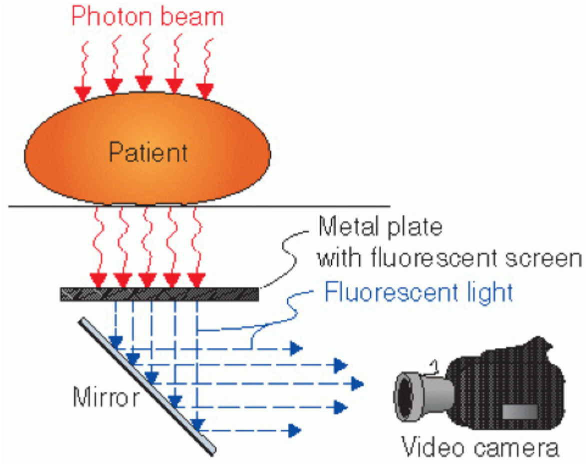
On Board Imaging

- CBCT mounted to the linac acquires images of the patient in the treatment position
- Planar projection images are obtained around the patient through 180 degrees
- 3 D images are reconstructed
- Imaging enables the localization of planned target volume and critical structures before each treatment.
- Images can be obtained by KV or MV radiation.

Electronic Portal Imaging

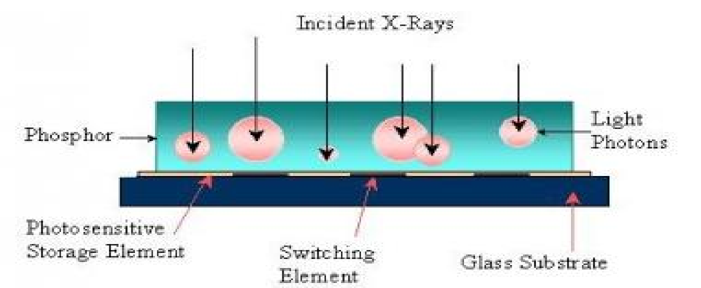
Video based

- Radiation passes through the patient
- Excites a metal fluorescent screen.
- Reflected by 90 degree into the video camera.



Flat-panel image detector

- The x-ray is converted into visible light by a scintillator which is detected by an array of photodiodes embedded on amorphous silicon panel.
- EPID is mounted on a retractable arm
- Flat panel is compact and give good quality image.



MV Imaging

- Higher noise and lower tissue resolution than those in the kVCT images
- We can have Fluoroscopic and CBCT images
- Images obtained are good to see bony anatomy
- Helpful in patient positioning
- Less metal artifacts
- Provide correct CT value in the region surrounding the metal implants.

KV Imaging

- KV CBCT images are obtained by a x-ray tube mounted on a retractable arm at 90^0 to therapy beam.
- Images with good contrast & spatial resolution.
- CT as well 2-D fluoroscopy images to verify portal accuracy and management of patient motion before treatment

Conclusion

- Choice of Equipment
- Complex, needs qualified and skilled staff
- Constantly developing to the needs of patients
- Uptime is high
- Require regulated power supply

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Thank you