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

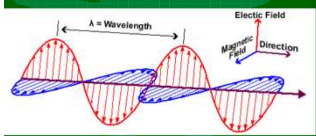
Safety Considerations

- Radiation protection

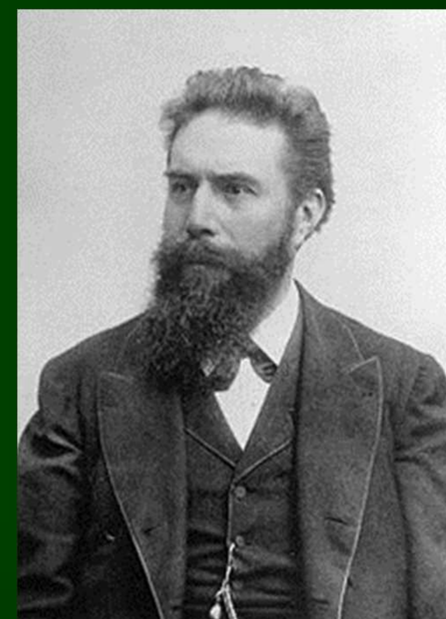
Cost Considerations

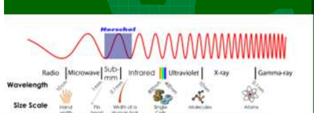
Additional Features

Introduction

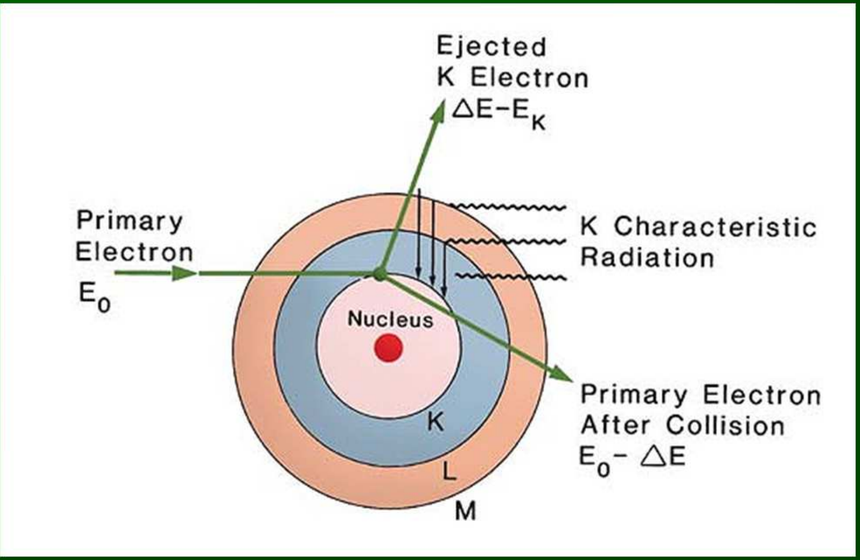


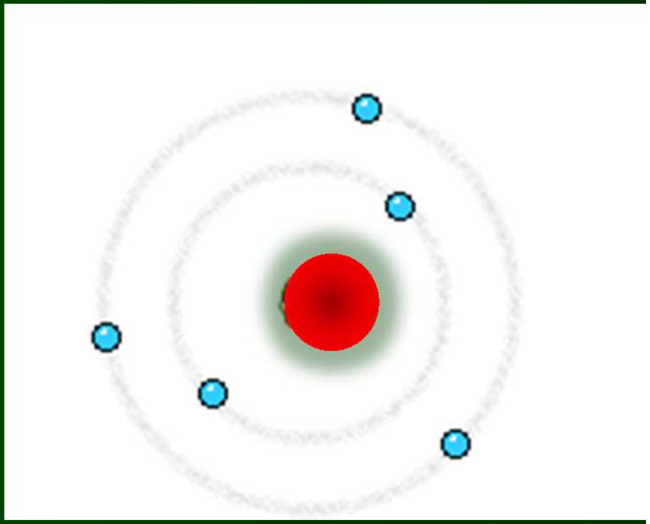
- What is Linac?
  - X-rays, Electron
- What is x-rays?
- Incidental discovery!
- How x-rays are produced?
- Physics of x-rays





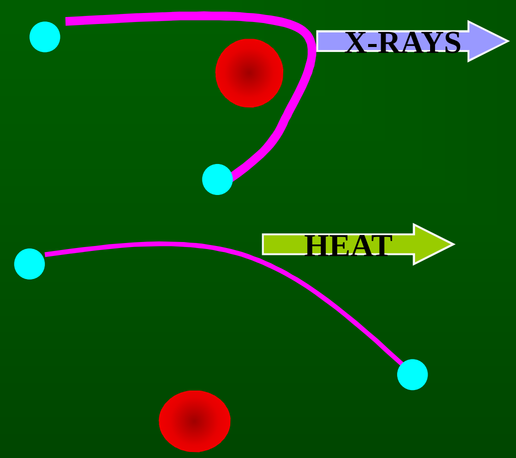
Characteristic X-rays

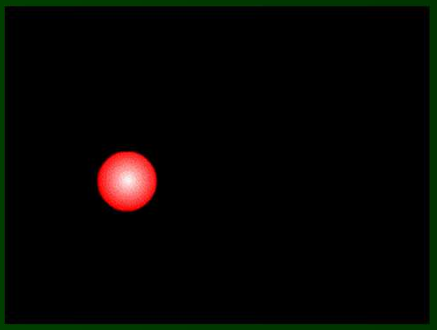




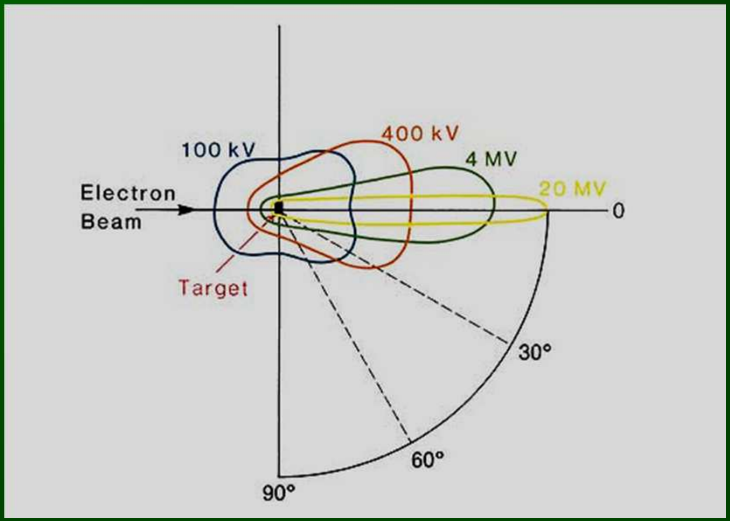
from Faiz Khan

Bremsstrahlung X-rays





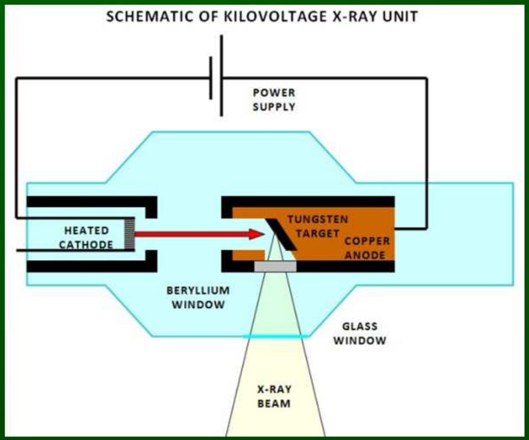
Angular Distribution

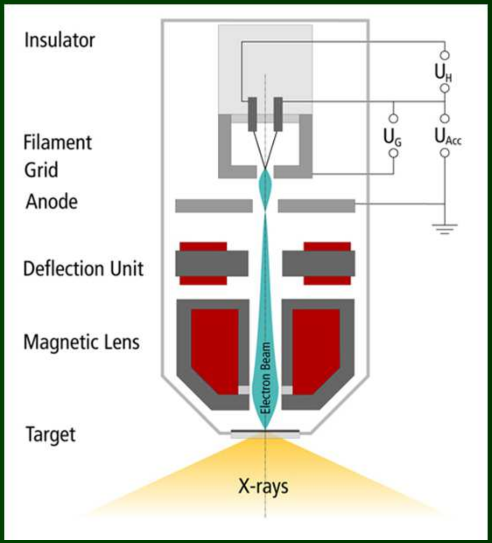


from Faiz Khan

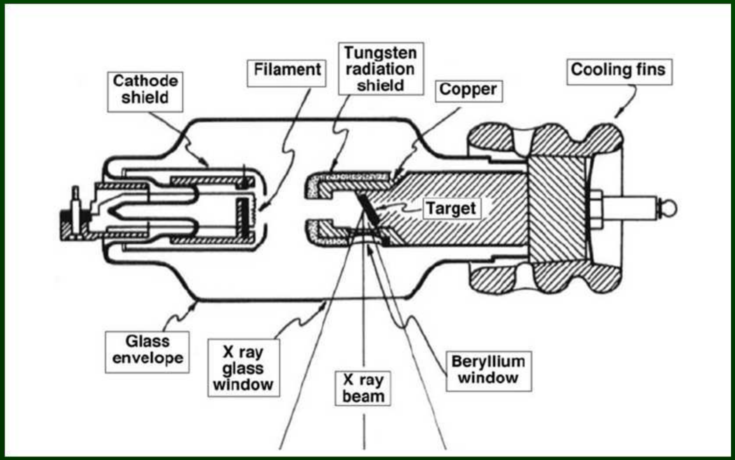
✶ Angular distribution becomes more "forward peaked" as the electron energy increases

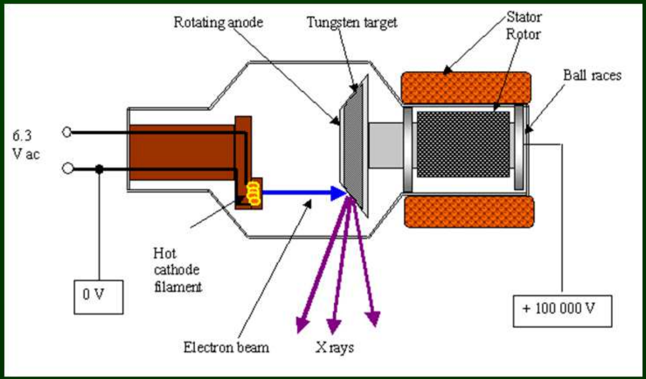
X-Ray Tube





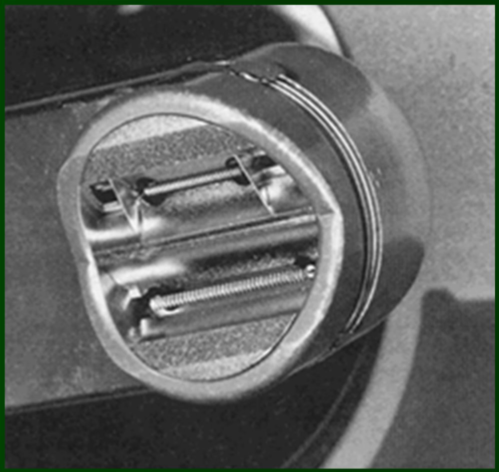
microfocus x-ray tubes (NDT)





Cathode

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



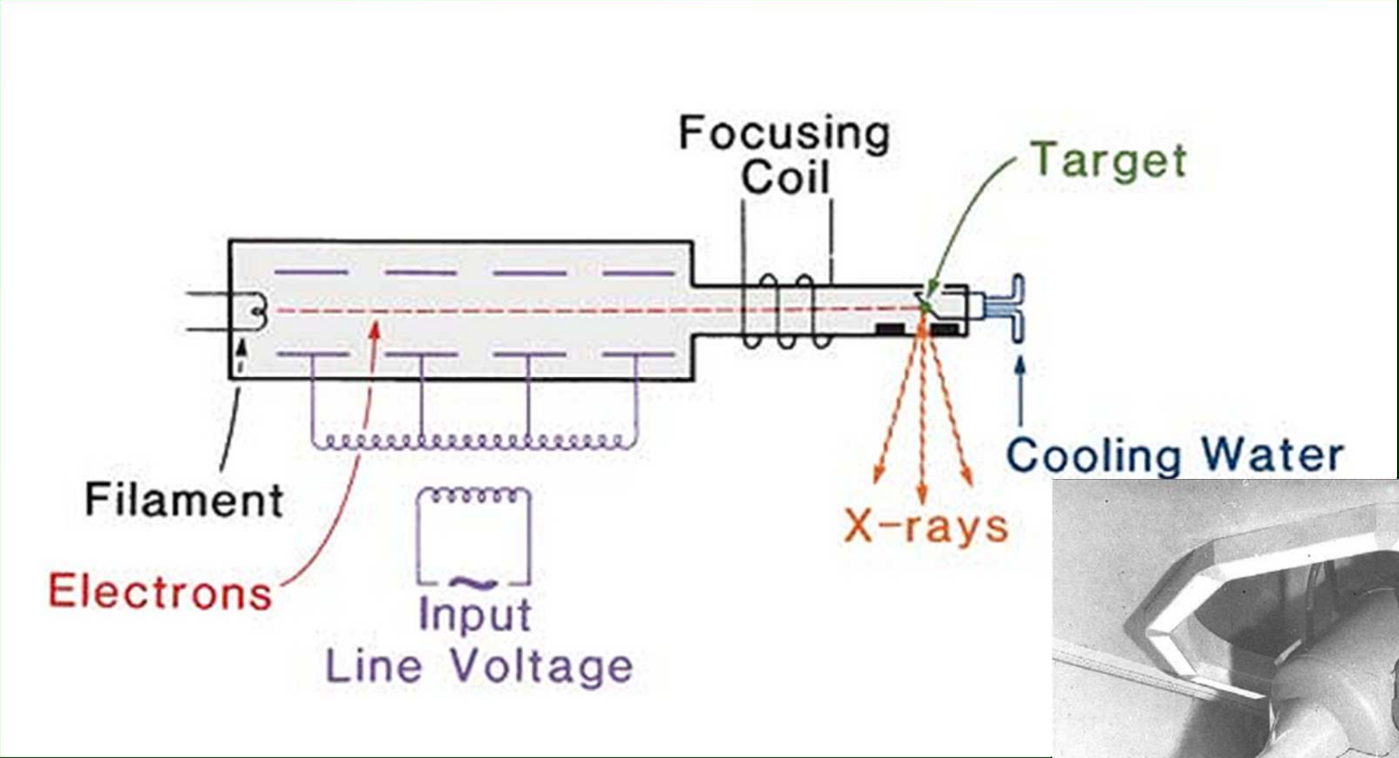
Anode

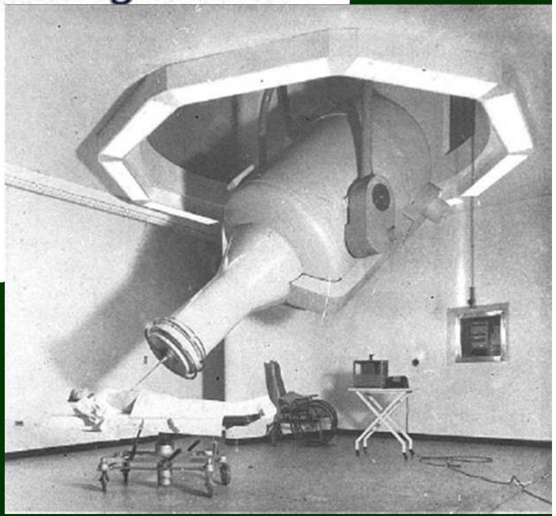
- Tungsten target
  - High melting point
  - High Z (74) , X-ray α Z^2
- Heat dissipation
  - Copper anode
  - Rotating anode /Stationary
- Anode hood – copper and tungsten shields intercept stray electrons and x rays

Limitations of X-ray Tube

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

Resonant Transformer





From Khan

300 to 2,000 kV

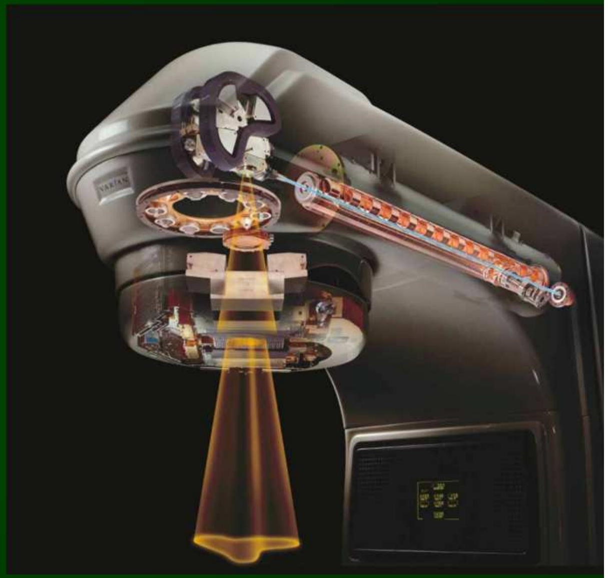
Require More space, bulky insulation

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

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



History

- Linacs were developed concurrently by two groups:
  - W.W. Hansen's group at Stanford University in the U.S.A.
  - D.D. Fry's group at Telecommunications Research Establishment in the U.K.
- Both groups - interested in Linacs for research
- Feasible - radar technology developed during World War II

Basic Linac

Low energy

✶ 4-8 MV

- Straight-through beam
- No Bending
- fixed flattening filter
- external wedges
- symmetric jaws
- single ionisation chamber
- isocentric mounting.

Medium/High Energy

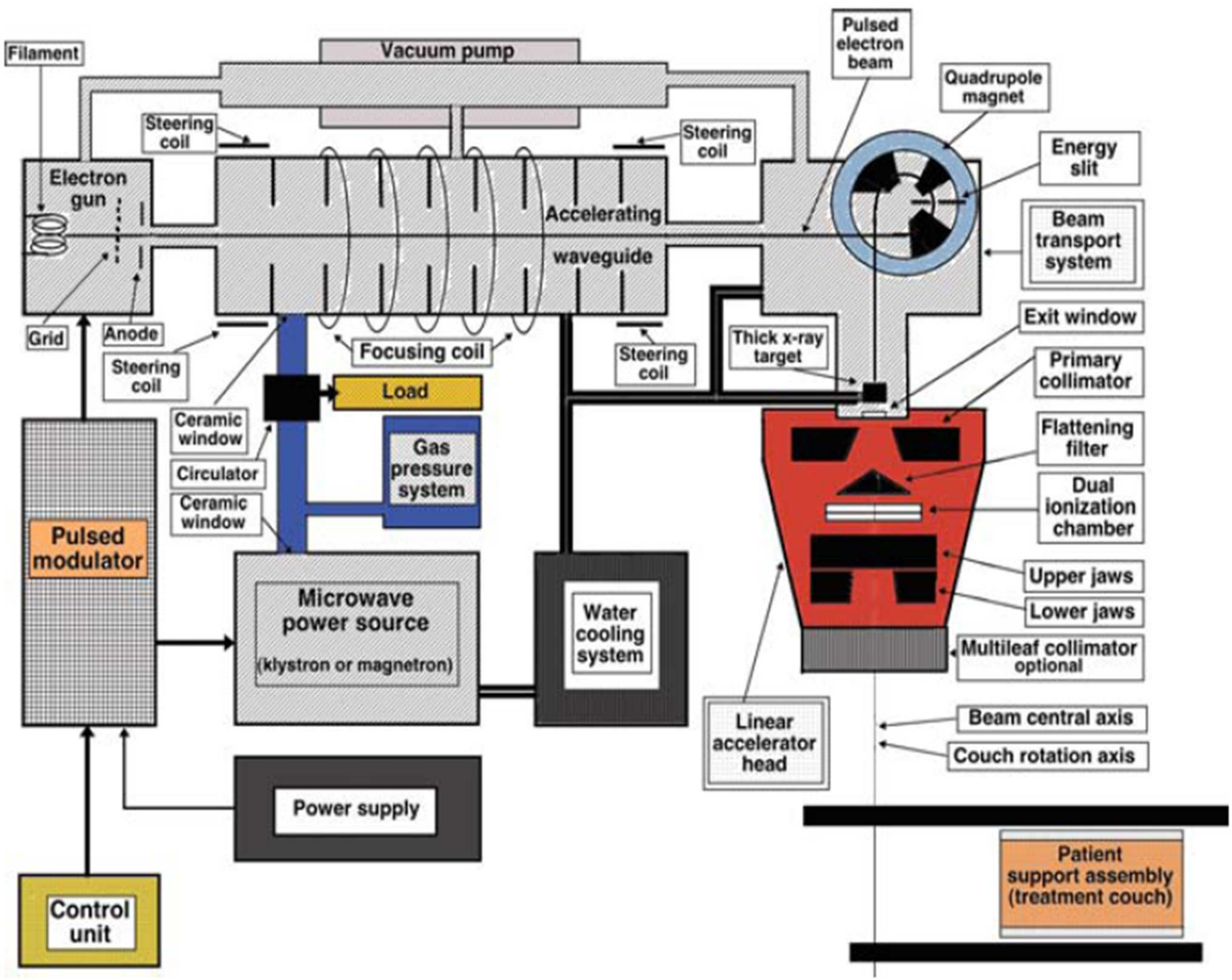
- 10-25 MV
  - Dual photon energy and multiple electron energies
  - Achromatic bending
  - dual scattering foils or scanned electron pencil beam
  - motorized wedge
  - Asymmetric jaws.
- Advanced features
  - EPID, MLC
  - IMRT, IGRT

Basic Accelerator Technology

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

Major Components

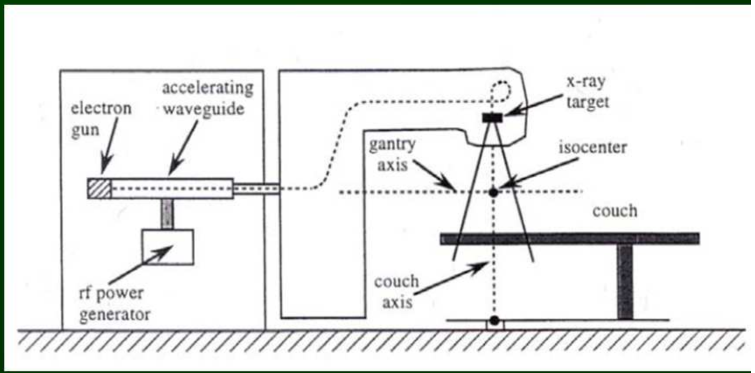
- Control Console
- Power Supply
- Modulator
- Magnetron or Klystron
- Electron Gun
- Wave Guide system
- Accelerator Tube
- Bending Magnet
- Treatment Head (Straight Beam/(Bent Beam)
- Treatment Couch


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
Load
Ceramic window
Gas pressure system
Flattening filter
Circulator
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

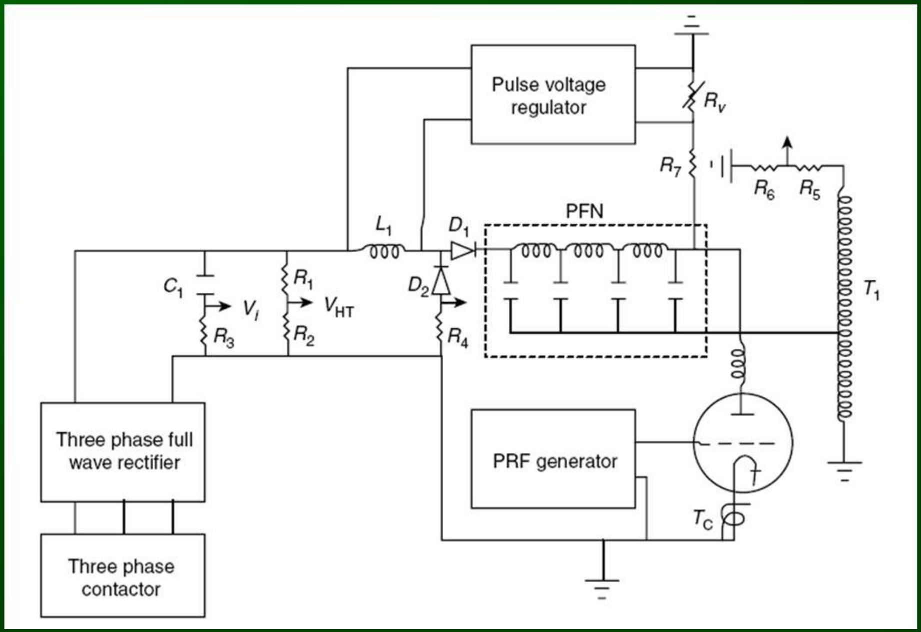
Modulator Cabinet

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 suppliers



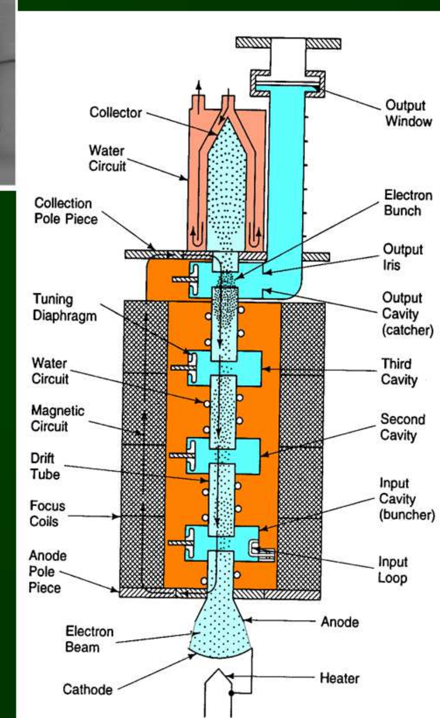
PFN



- The modulator supplies high-voltage pulses lasting a few microseconds to the microwave source and electron gun.
- The PRF (pulse repetition frequency) is set by the PRF generator connected to the thyratron grid and is usually adjustable in the range 50 Hz to 1000 Hz.

Microwave Source

- Magnetron
  - Low energy accelerators
  - Less costly
  - Smaller least complicated
  - Less reliable
  - shorter lifespan
- Klystron
  - Stable at higher energies
  - Costly & Complex
  - Bulky

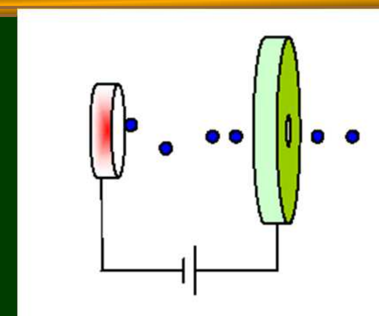


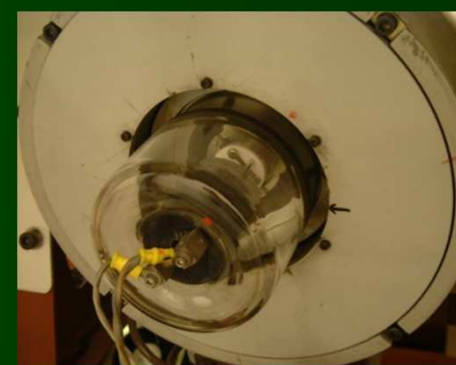
Classification as per RF fields

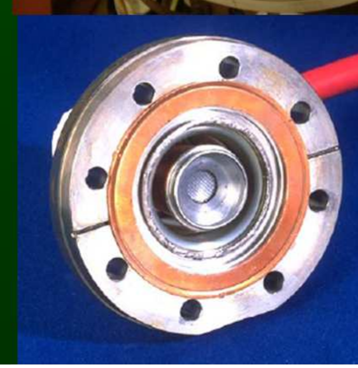
- L band - 10^3 MHz
  - physically larger but capable of beam powers considerably above 20 kW
- S band - 2856 MHz
  - more compact but limited to beam powers below 20 kW
- X band - 10^4 MHz
  - Tomotherapy
  - robotic arm mounting, miniature form
  - Mobetron (IORT system)

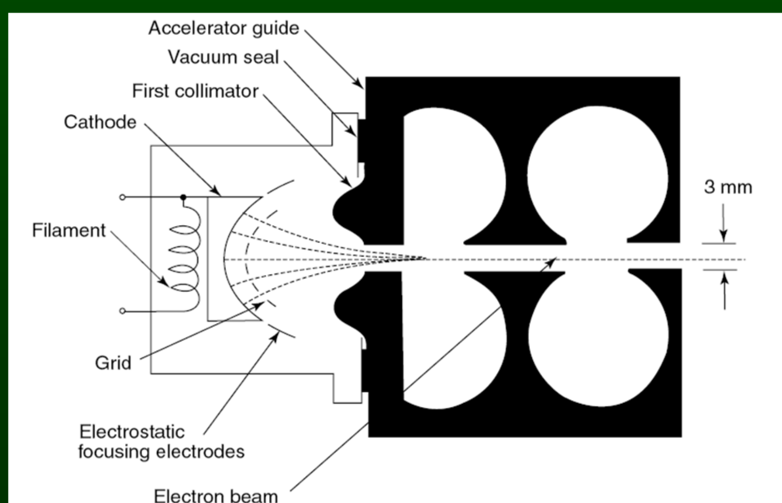
Electron Gun

- Source of the electrons
- Produced thermionically
- Injected onto the central axis of the waveguide.







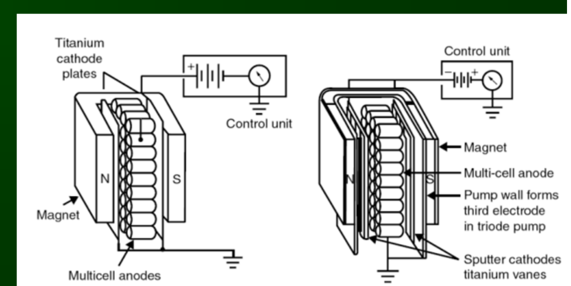


Vacuum & Cooling

- 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.

Ion Pump

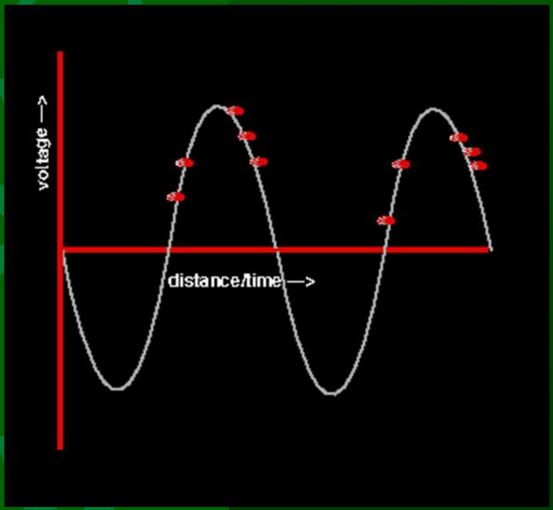
- Electric field to accelerate and traps ions
- Solid electrodes in pump usually made from Titanium.
- Ion Pumps have no moving parts and use no oil

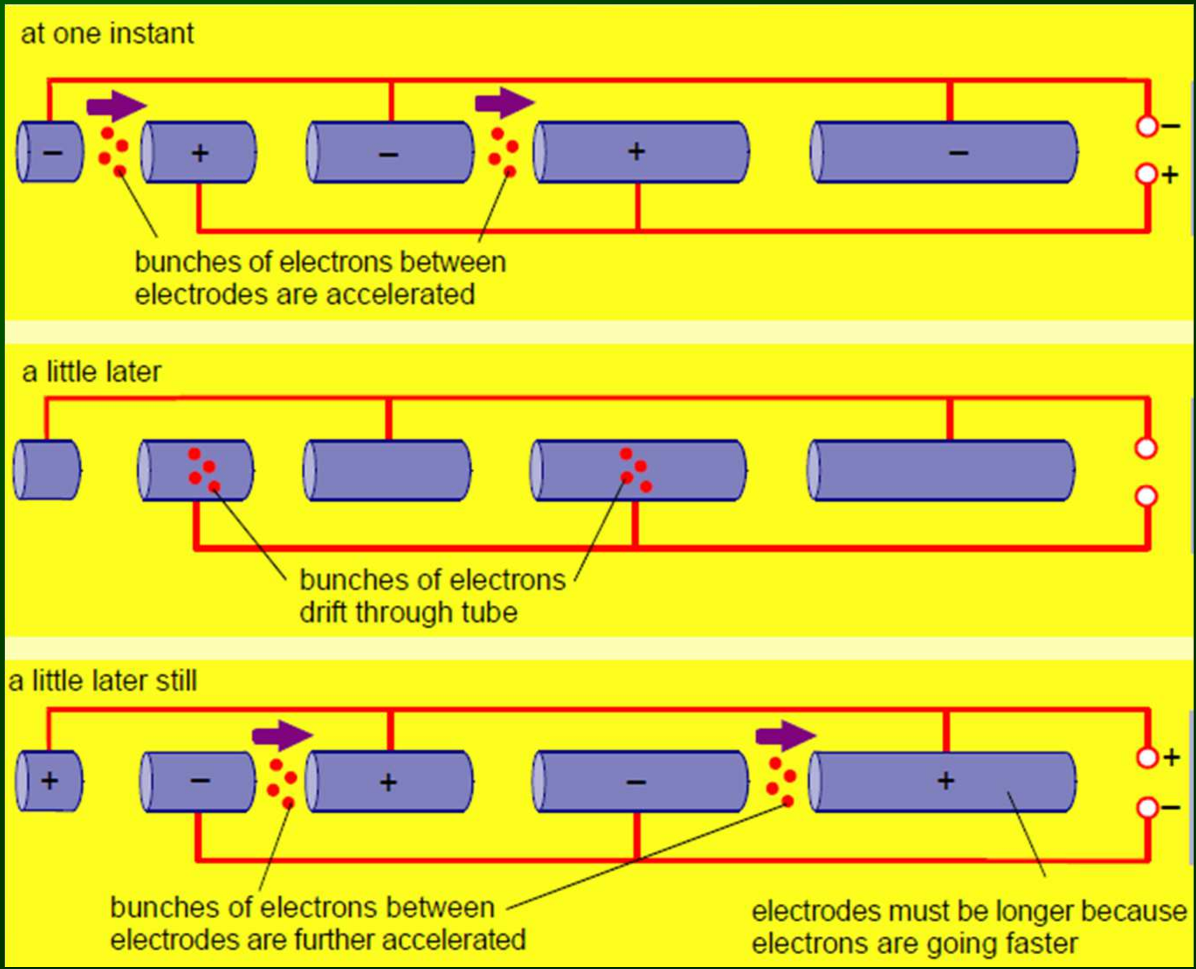


Ion pump schematics

(a) Diode pump (b) Triode pump

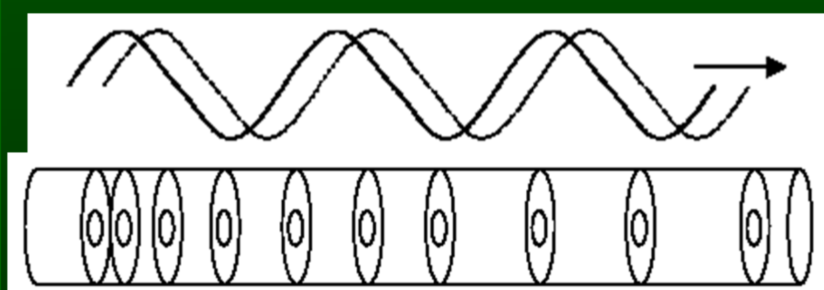
Electron Acceleration



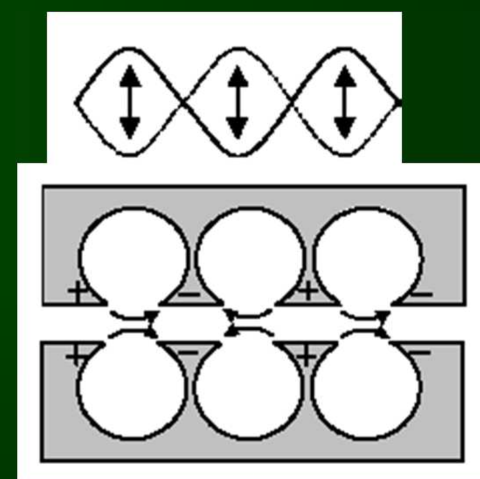


Accelerator Structures

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



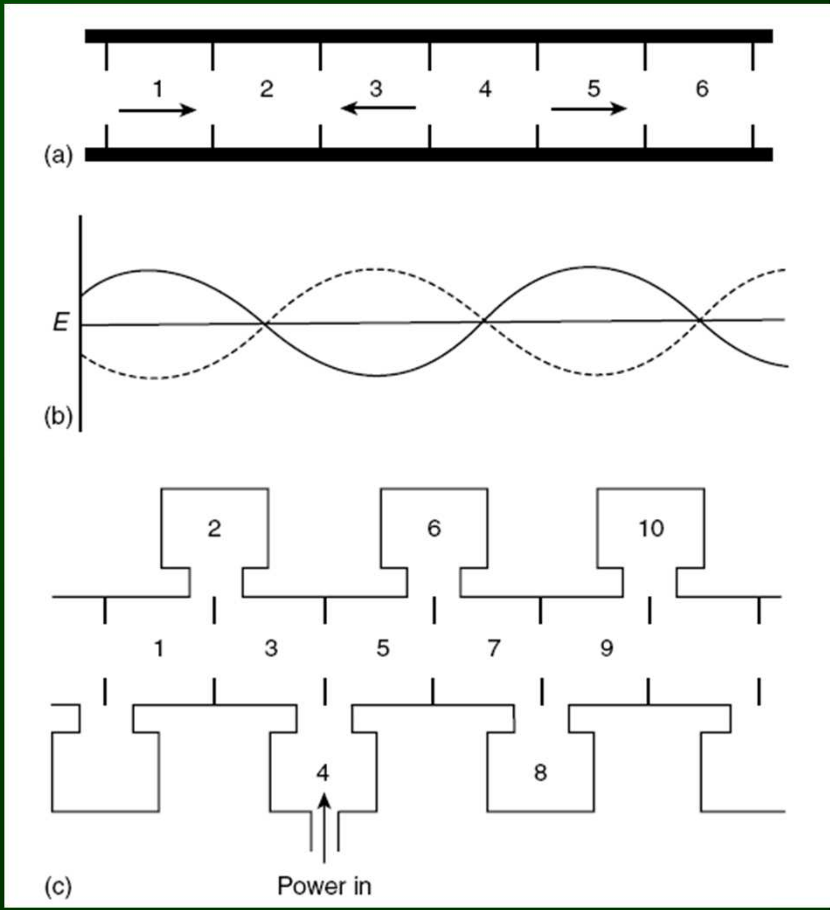
Standing Wave

Standing wave

(a) Arrangement of the waveguide.

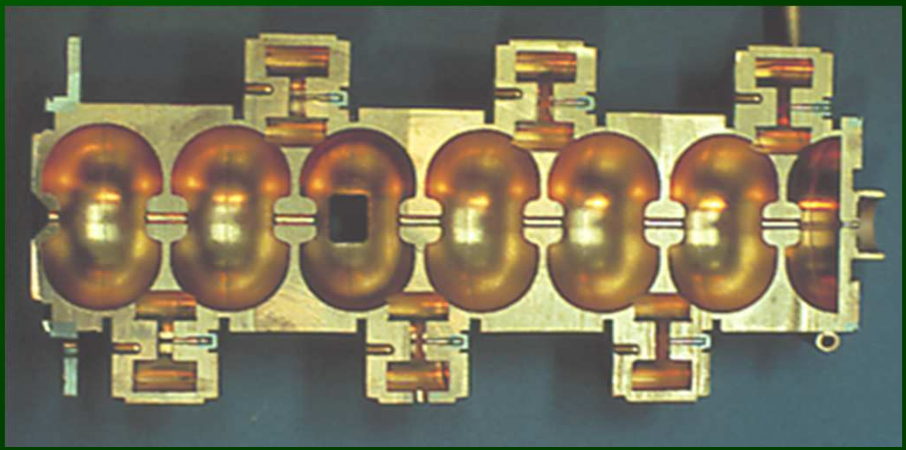
(b) Standing waves.

(c) Shows a side-coupled cavity.



From Greene and Williams

Section of SW accelerator



Comparison

Travelling Wave

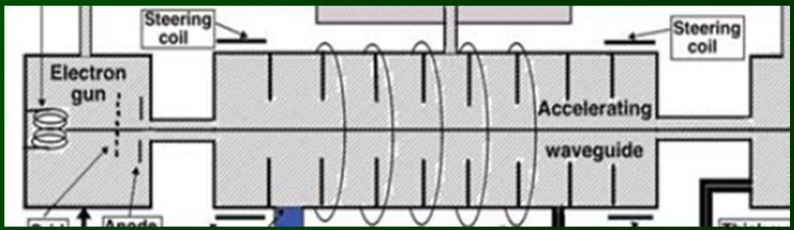
- Longer structure
- Short fill time
- Circulator not required
- High accelerating beam capacity
- Spectrum insensitive to accelerating field
- Bunching less sensitive to accelerating field
- Generally low vacuum requirement

Standing Wave

- Shorter structure
- Longer fill time
- Circulator required
- Low accelerating beam capacity
- Spectrum sensitive to accelerating field
- Bunching highly sensitive to accelerating field
- High vacuum requirement

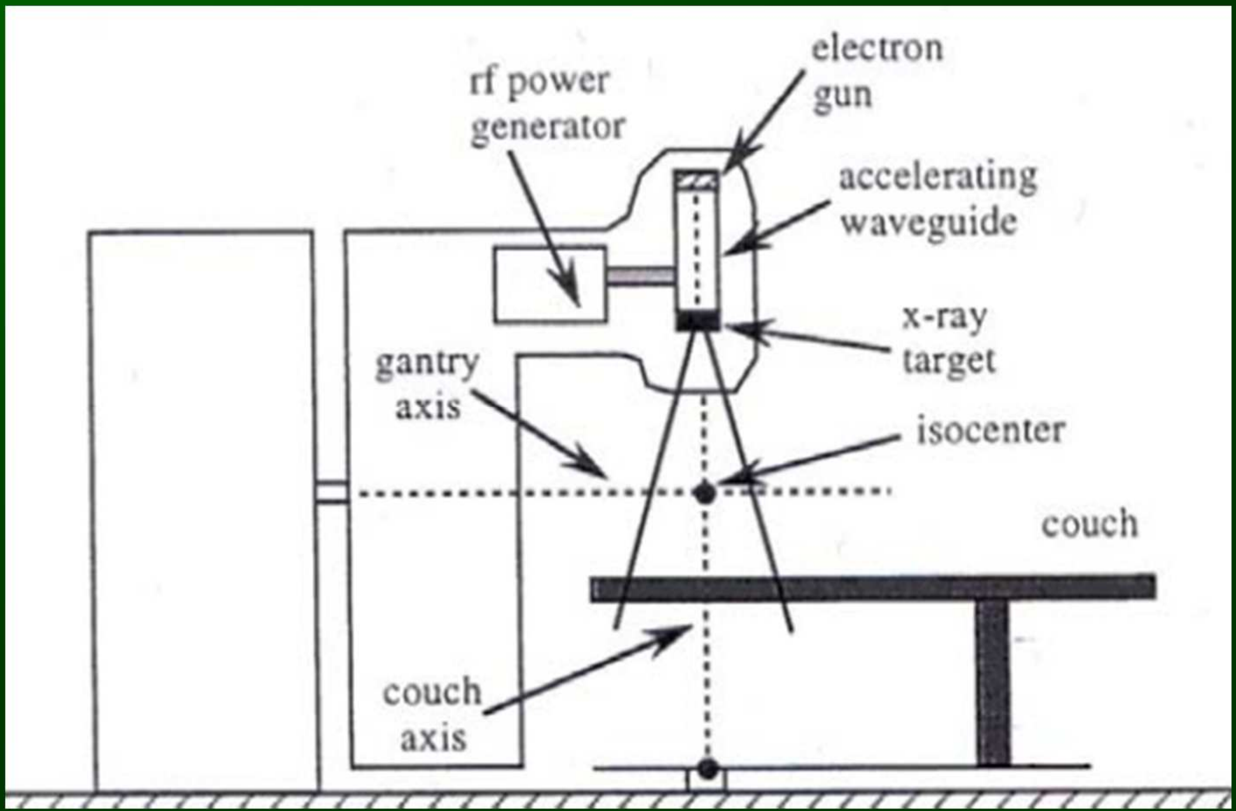
Focusing

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



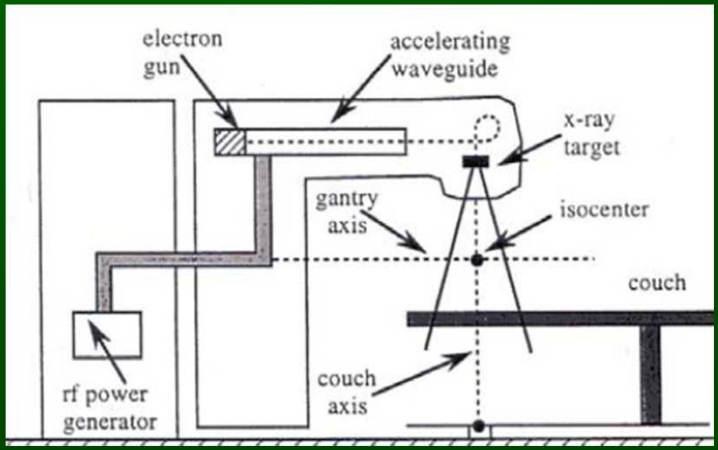
- Steering coils
  - Independently of focusing coils
  - Ensure, electron beam is at the centre of WG
  - Entrance and exit electron beam as desired

Position of WG



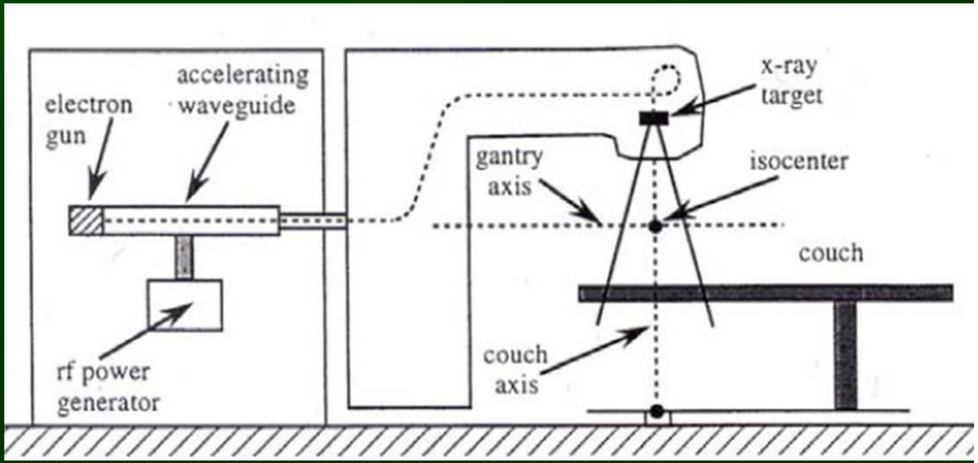
Wave guide in Head

Position of WG



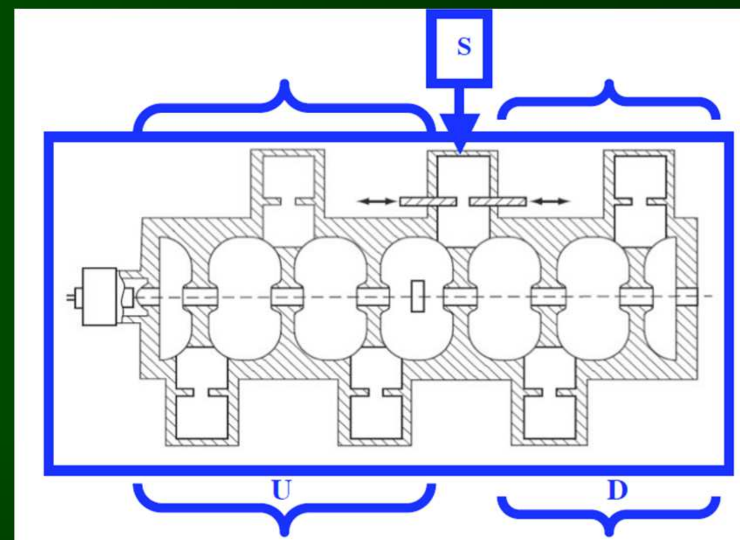
Wave guide Gantry

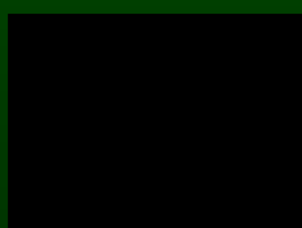
Wave guide in Gantry Stand



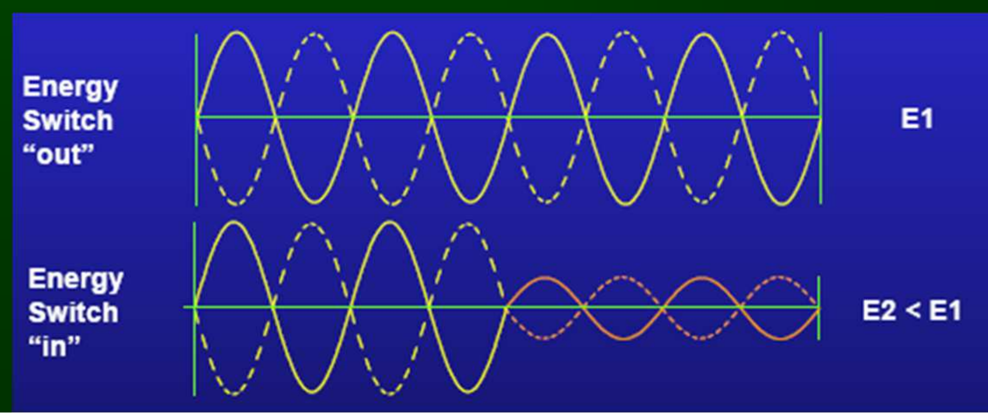
Energy Change?

- 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



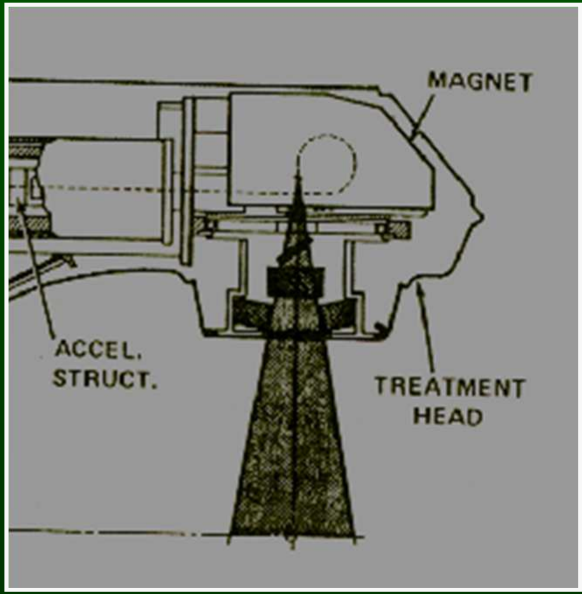


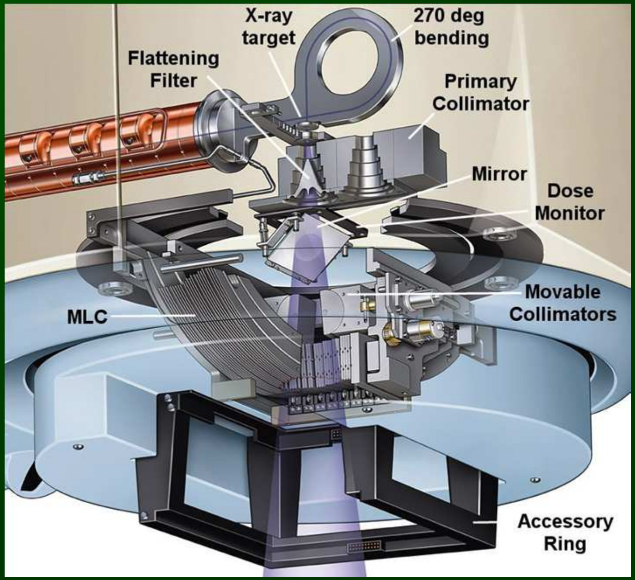
Video



Treatment Head

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



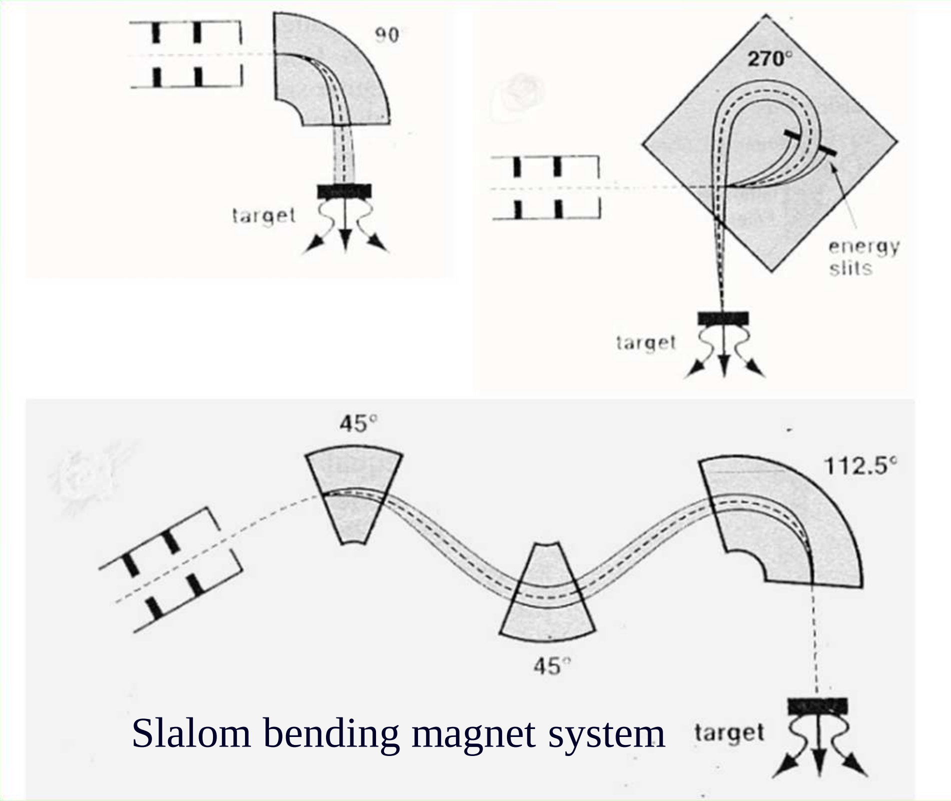


Components in Head

- 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

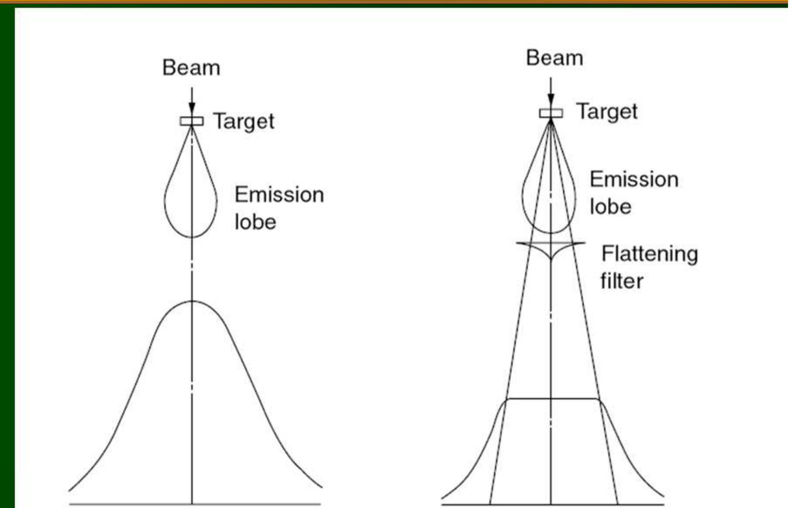
- Limiting the radiation beam
- Primary/fixed collimation
  - Cone-shaped, defines maximum field size
  - Depleted uranium/Tungsten
  - Transmission <0.2%
- Secondary/movable collimator
  - Transmission <2%
  - mounted on either side of the central axis
- Symmetric or asymmetric collimator

Multileaf collimators

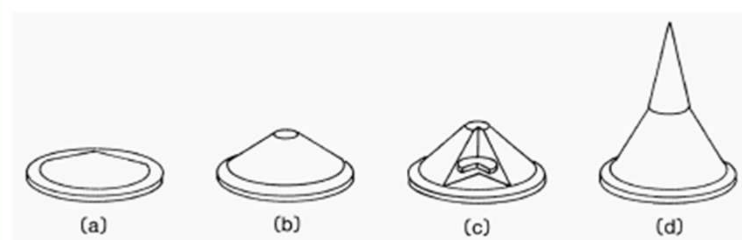
- Many independent collimators
- Allow irregular field sizes
- to be delivered from the linear accelerator.
- 40–80 pairs of independent collimators
- Each leaf has its own motor

Flattening Filter

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



- PB - Low energies
- Pb and/or W up to 15 MeV
- Fe and Pb core 20-25 MeV
- Al or Fe for higher energies

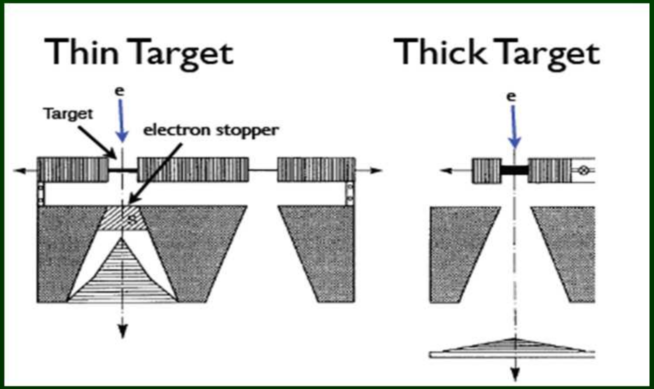


Flattening Filter Free Linac

- 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.

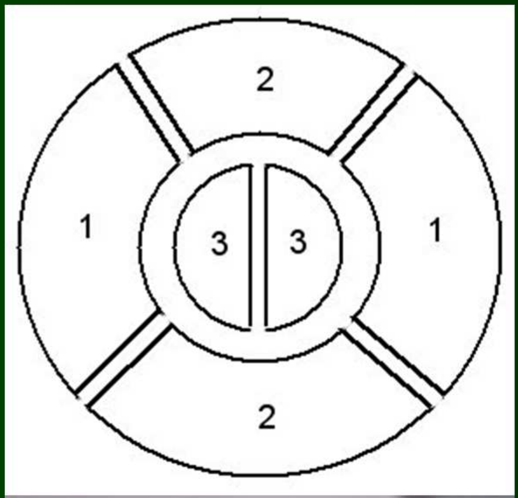
X-ray target

- 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.

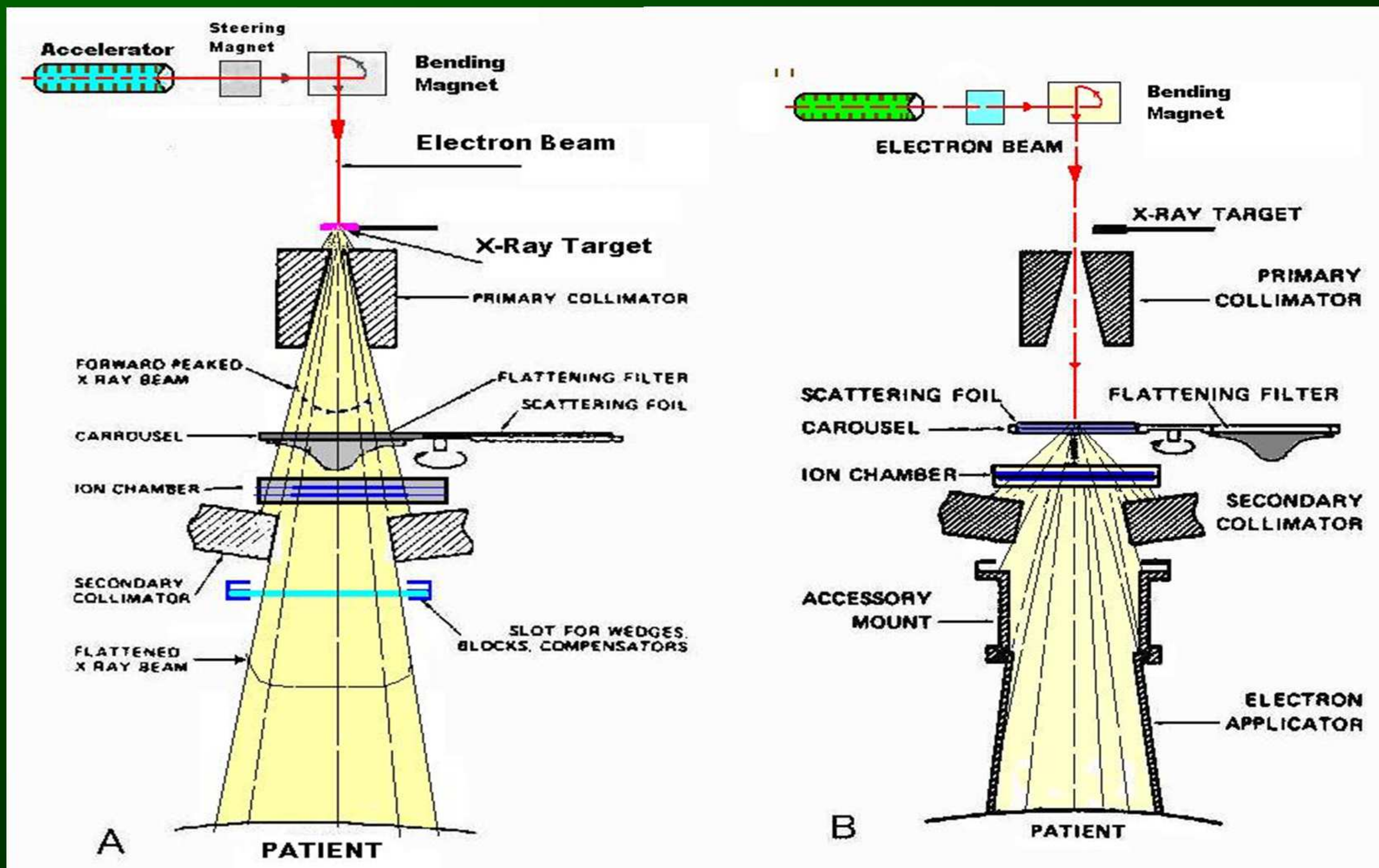


Ionization Chamber

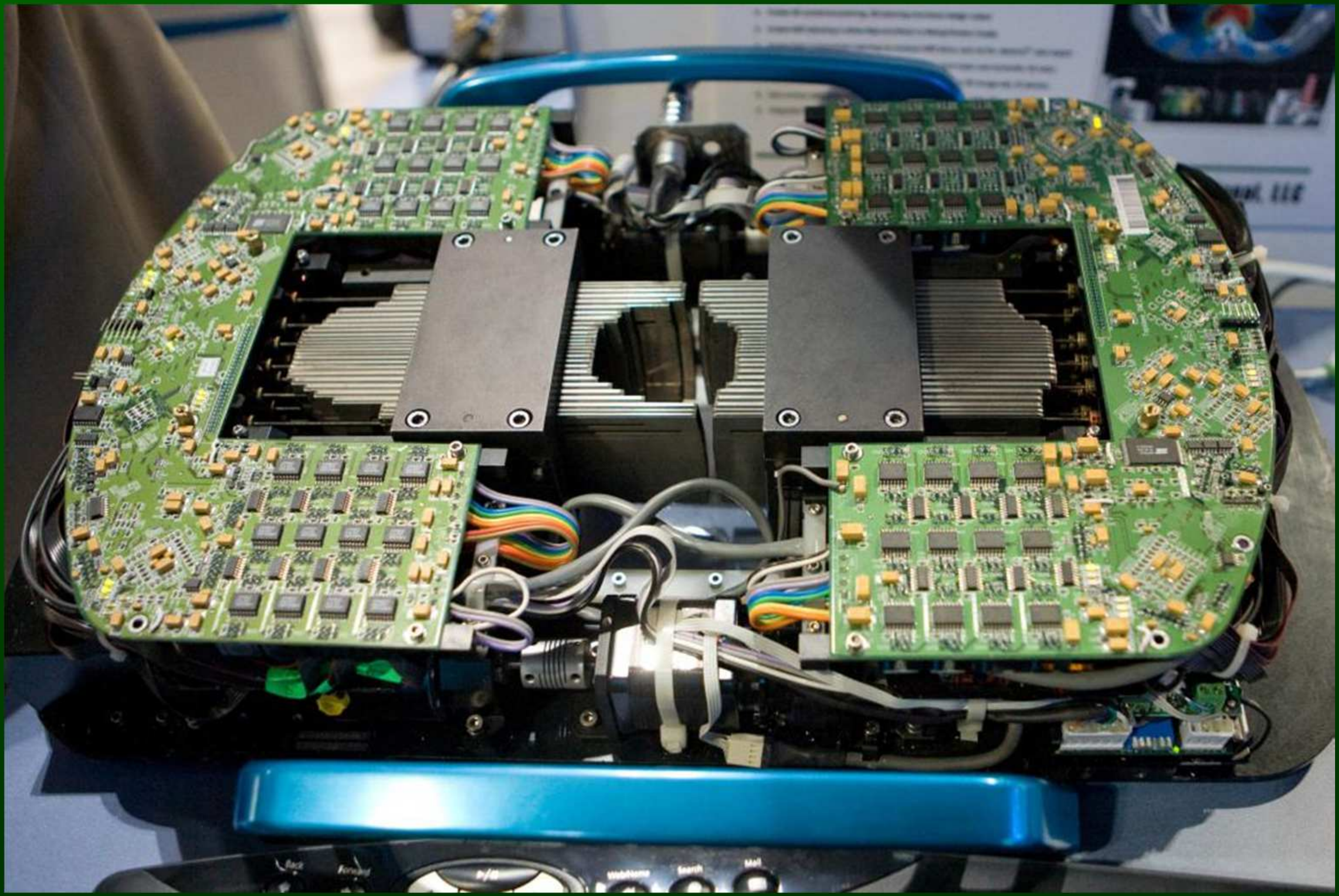
- Measures dose & Terminates the beam
  - After prescribed dose
  - if the energy, quality, flatness, or dose rate changes
  - Two chambers operate independently



X-rays & Electron Beam



MLC



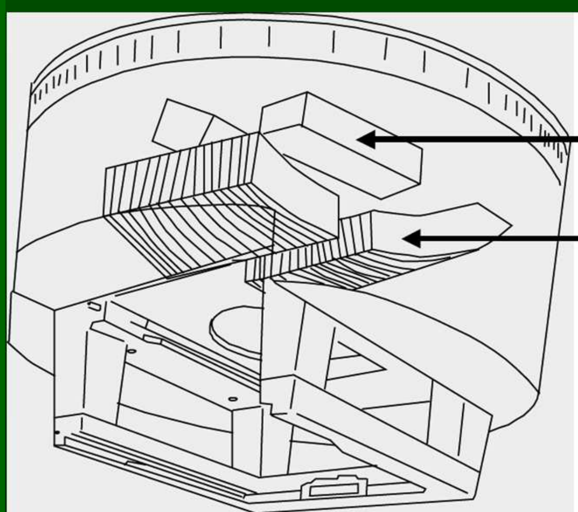
Types of MLC

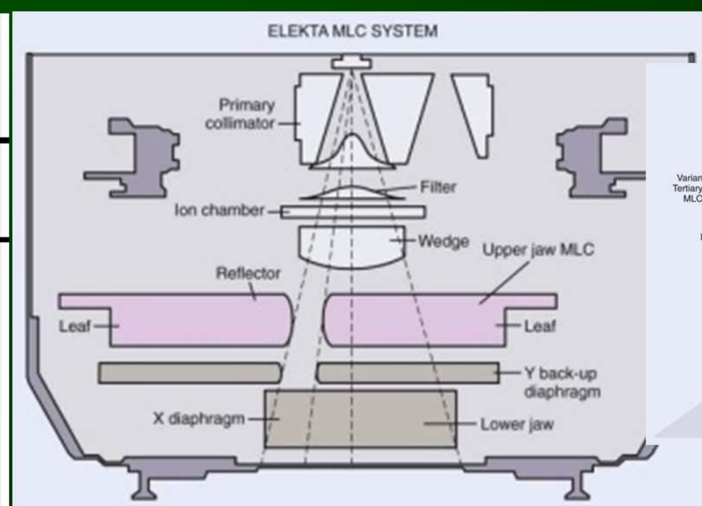
Three main types

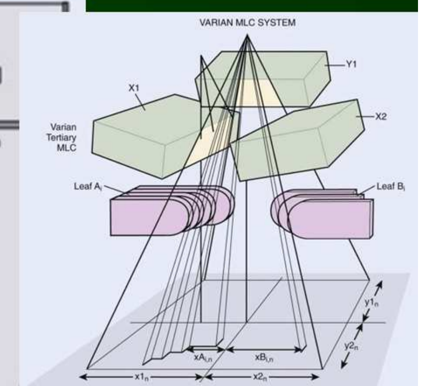
A - Siemens - retain upper but replaces lower Jaw

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

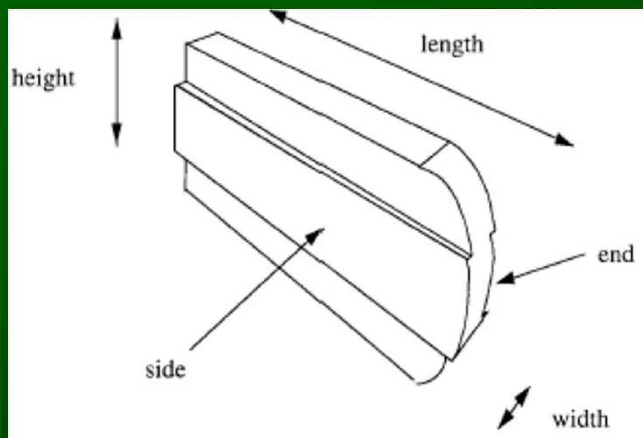
C – Varian - retain all jaws + MLC

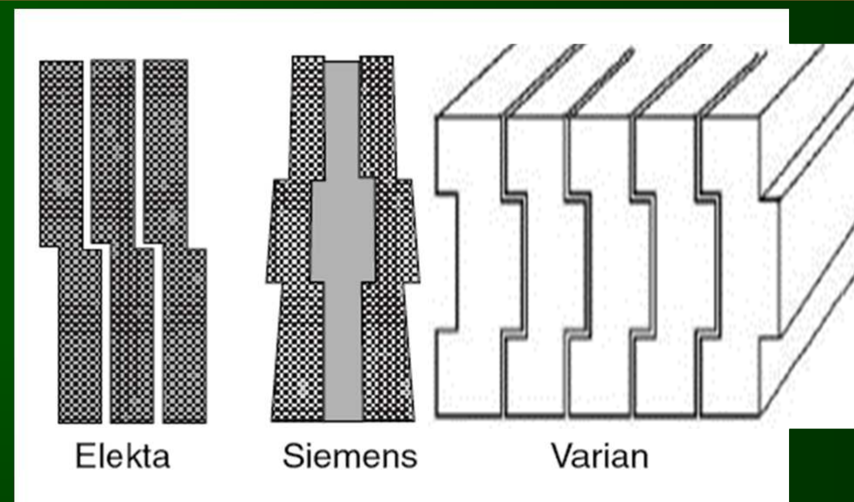






Comparison

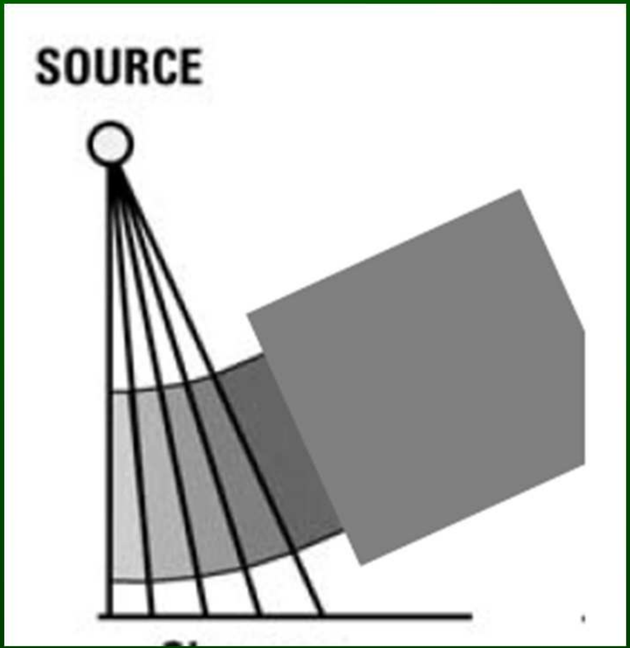


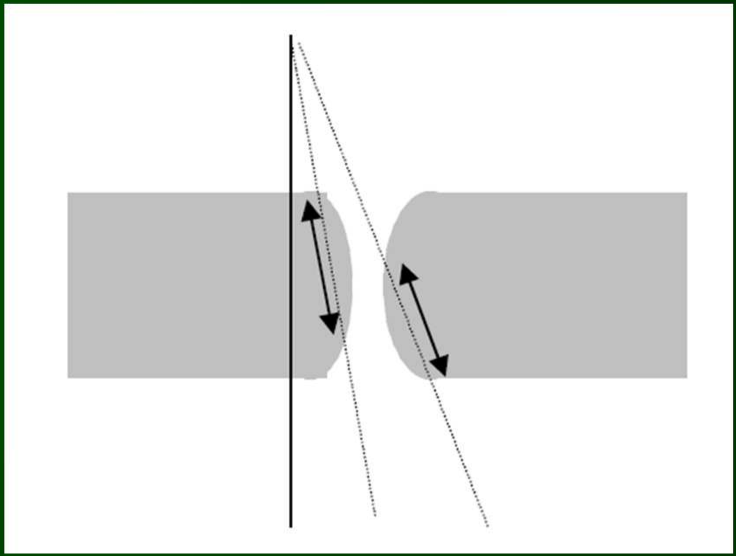


Stepped leaves to reduce leakage

	Upper jaw	Lower Jaw	Tertiary Collimator
Elekta	focused MLC	focused block	none
Varian	focused block	focused block	unfocused MLC
Siemens	focused block	focused MLC	none

Transmission





Focused
Maintains Divergence

Non-focused , rounded leaf ends
The penetration through curved leaves is independent of leaf position.

Other facilities

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

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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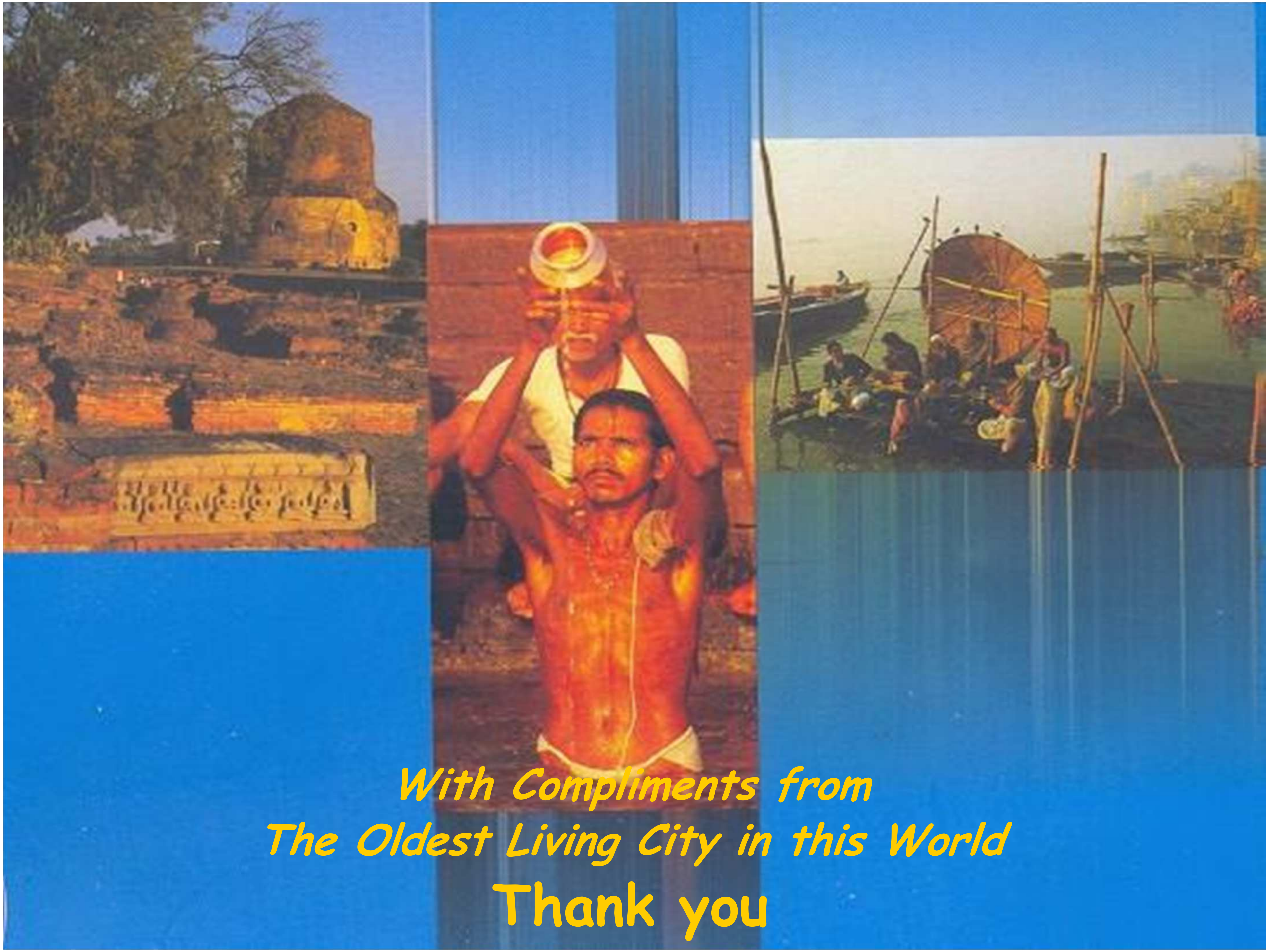
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