Megavoltage Radiotherapy Machines

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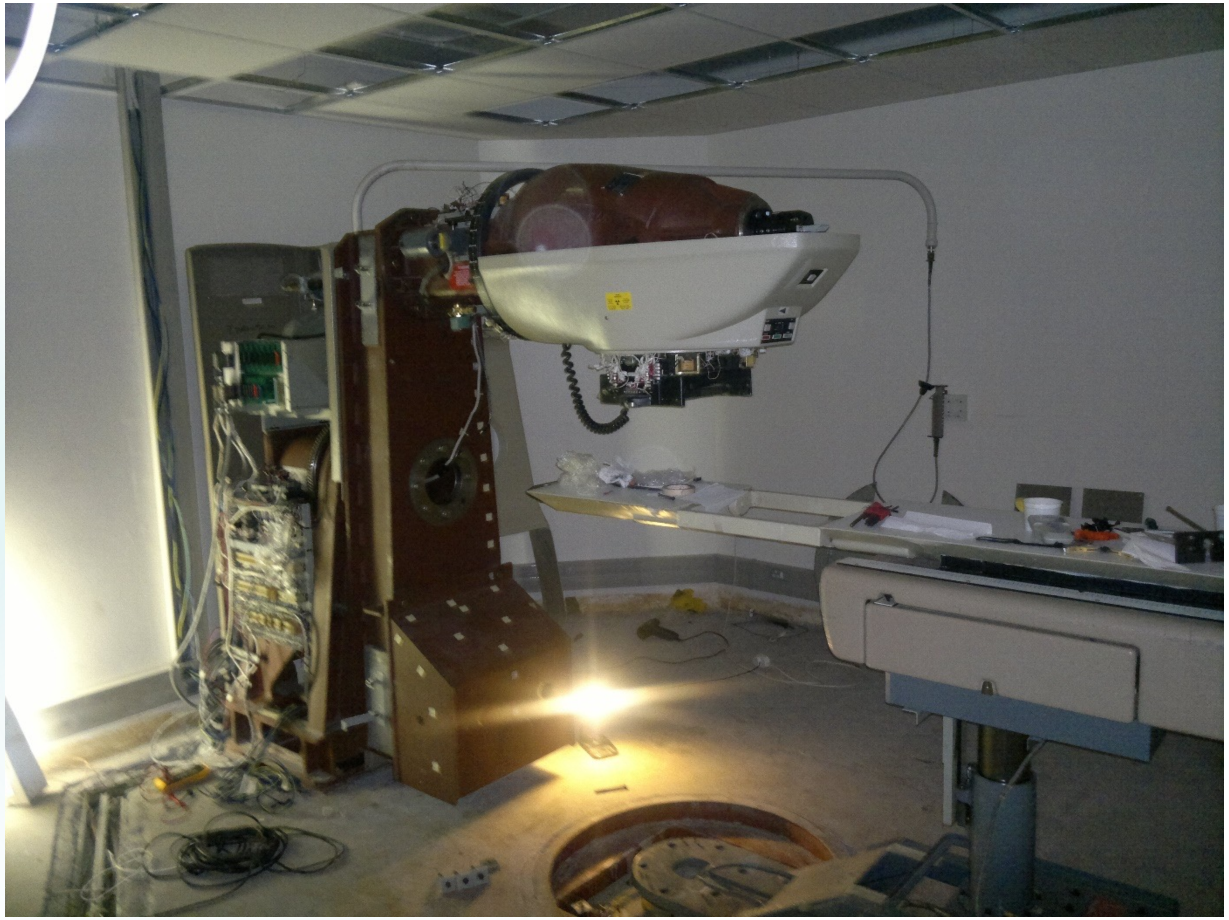
Two broad classes

- Radionuclide – Co-60 teletherapy or afterloader
- OR
- X-ray or electron beam – linear accelerator

Co-60

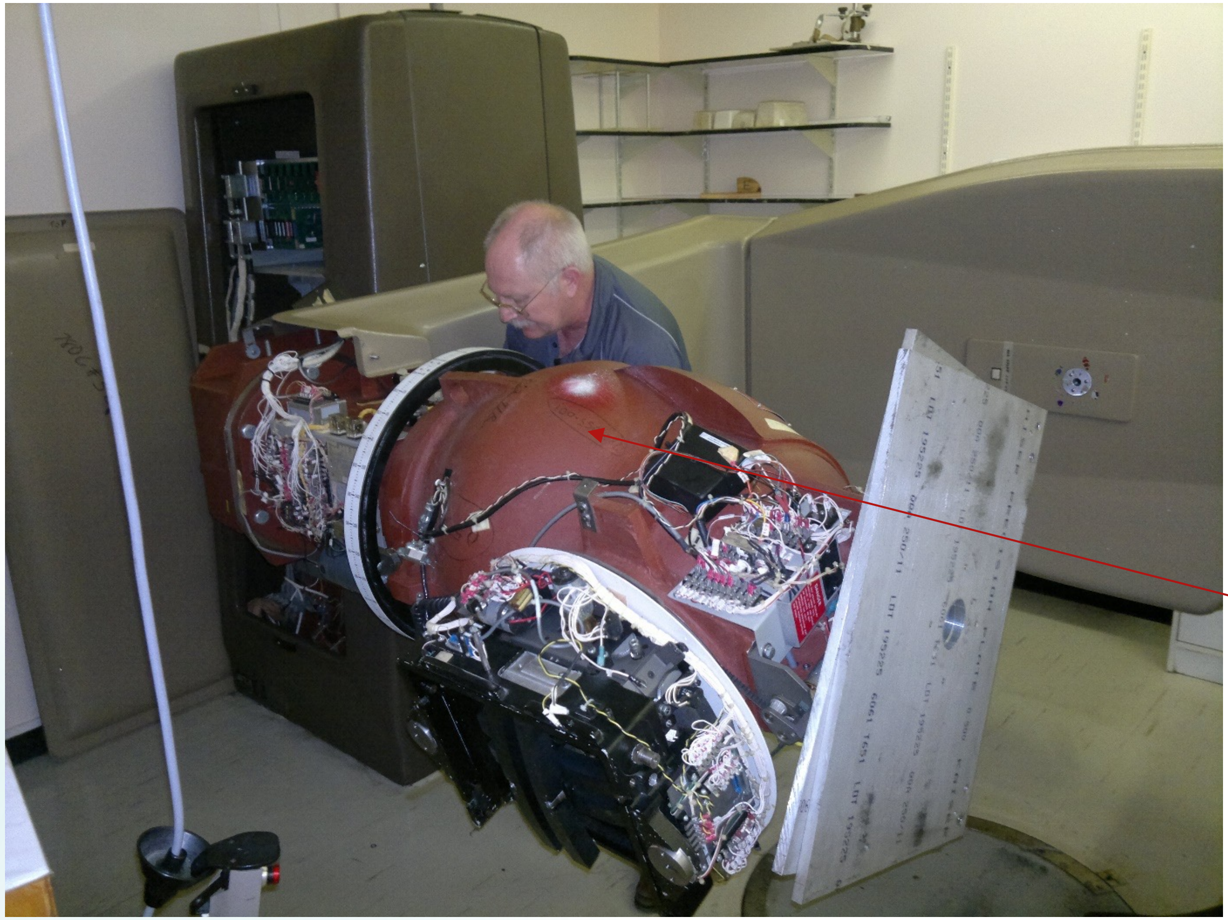
- Has a halflife of 5.26 years
- Manufactured in a nuclear reactor
- Radioactive decay has two gamma rays at 1.17 and 1.33 MeV
- These are used for radiotherapy

- Tiny source: around 1 cm x 1.5 cm cylinder
- 300 TBq or so



Similar Geometry as a Linac:

Gantry
Collimator
Treatment Couch
all rotate around isocenter



Lead Shielding

- Co-60: Halflife of 5.26 years
- Initial doserate about 2 Gy / min

- Need to replace source


RADIOACTIVE III
7
RQ
OP-1
RAD-MONITOR™
Radiation/Contamination Survey Meter
ALARM
AC POWER

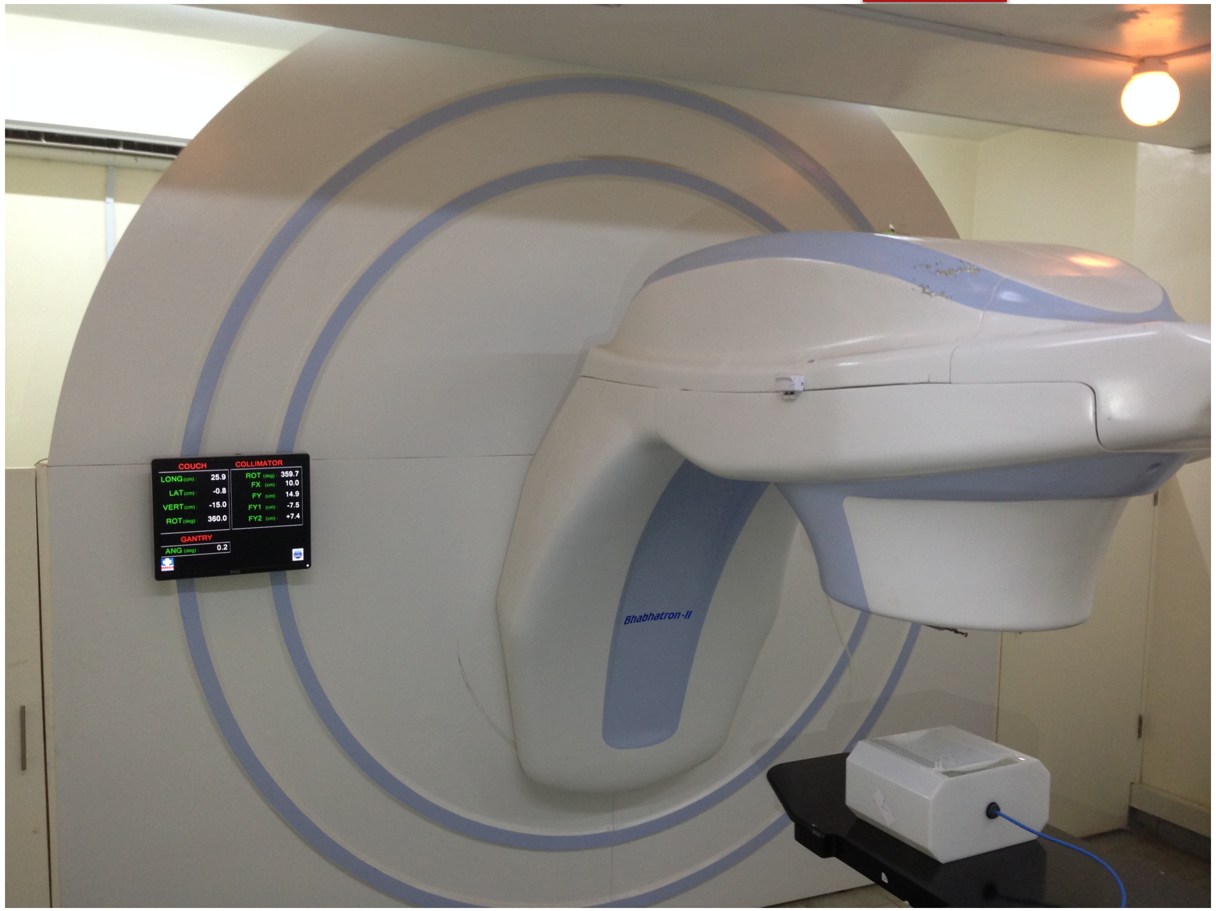
Co-60 source change

- Co-60 not used routinely any more in most departments
- Single energy
- Often smaller SSD, which only allows for SSD treatments and not SAD treatments
- Security concerns – stolen sources

But:

- Not so affected by power cuts
- Needs less power


healthcare for everyone
TeamBest
Your True Partner
UTRGV
COME JOIN OUR TEAM!


COUCH
LONG 25.9
LAT -0.8
VERT -15.0
ROT 360.0
COLLIMATOR
ROT 359.7
FX 10.0
FY 14.9
FY1 -7.5
FY2 +7.4
GANTRY
ANG 0.2
Bhabhatron-II

Main components

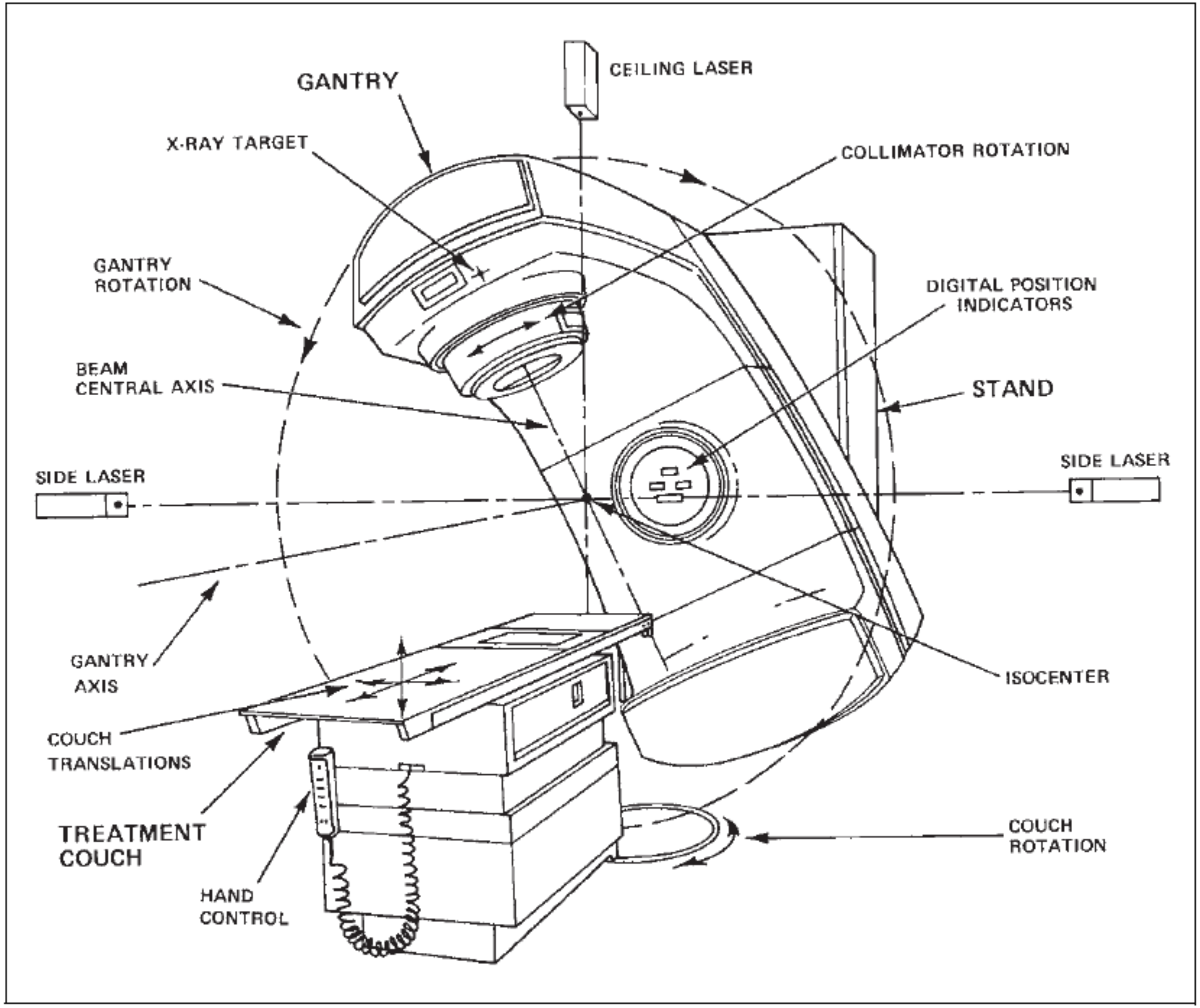
- Radioactive source
- Source housing, including beam collimator and source movement mechanism
- Gantry and stand
- Patient bed
- Machine control console

Linear Accelerator

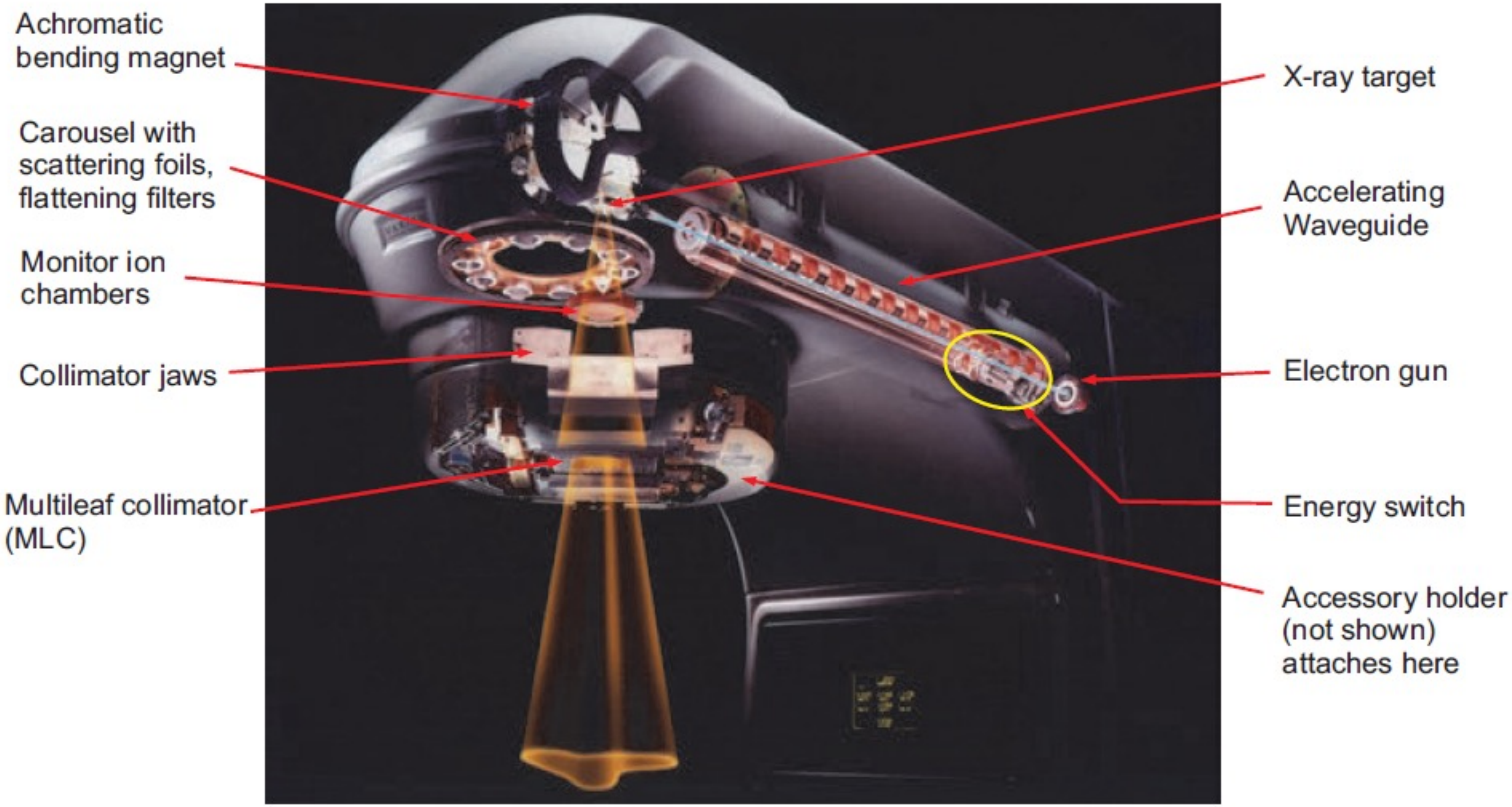

MNR. GENE LOUW

Linac is mounted isocentrically

- Five major components
  - Gantry
  - Gantry stand and support
  - Modulator cabinet
  - Patient support assembly
  - Control console

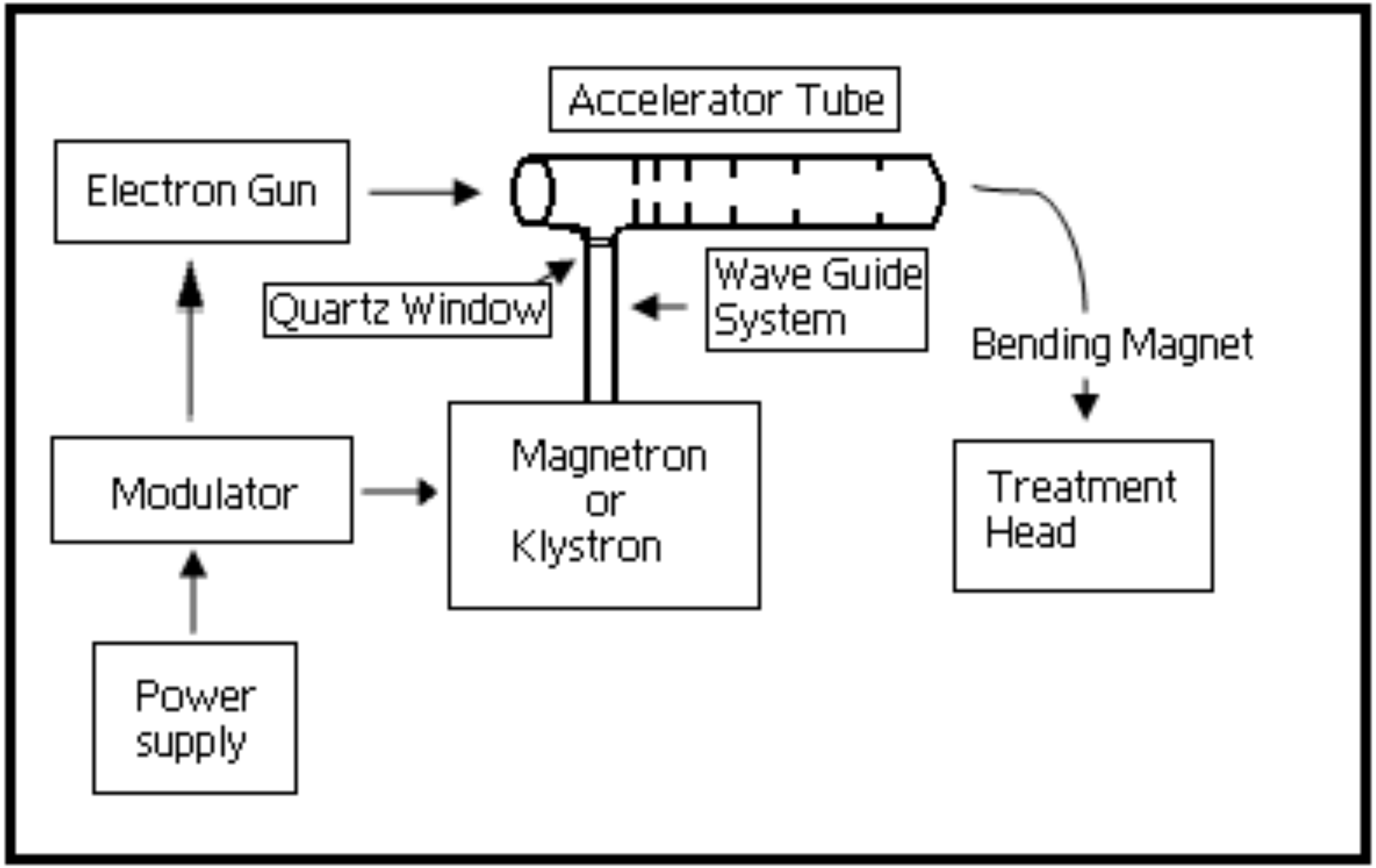


GANTRY
CEILING LASER
X-RAY TARGET
COLLIMATOR ROTATION
GANTRY ROTATION
DIGITAL POSITION INDICATORS
BEAM CENTRAL AXIS
STAND
SIDE LASER
SIDE LASER
GANTRY AXIS
ISOCENTER
COUCH TRANSLATIONS
TREATMENT COUCH
COUCH ROTATION
HAND CONTROL

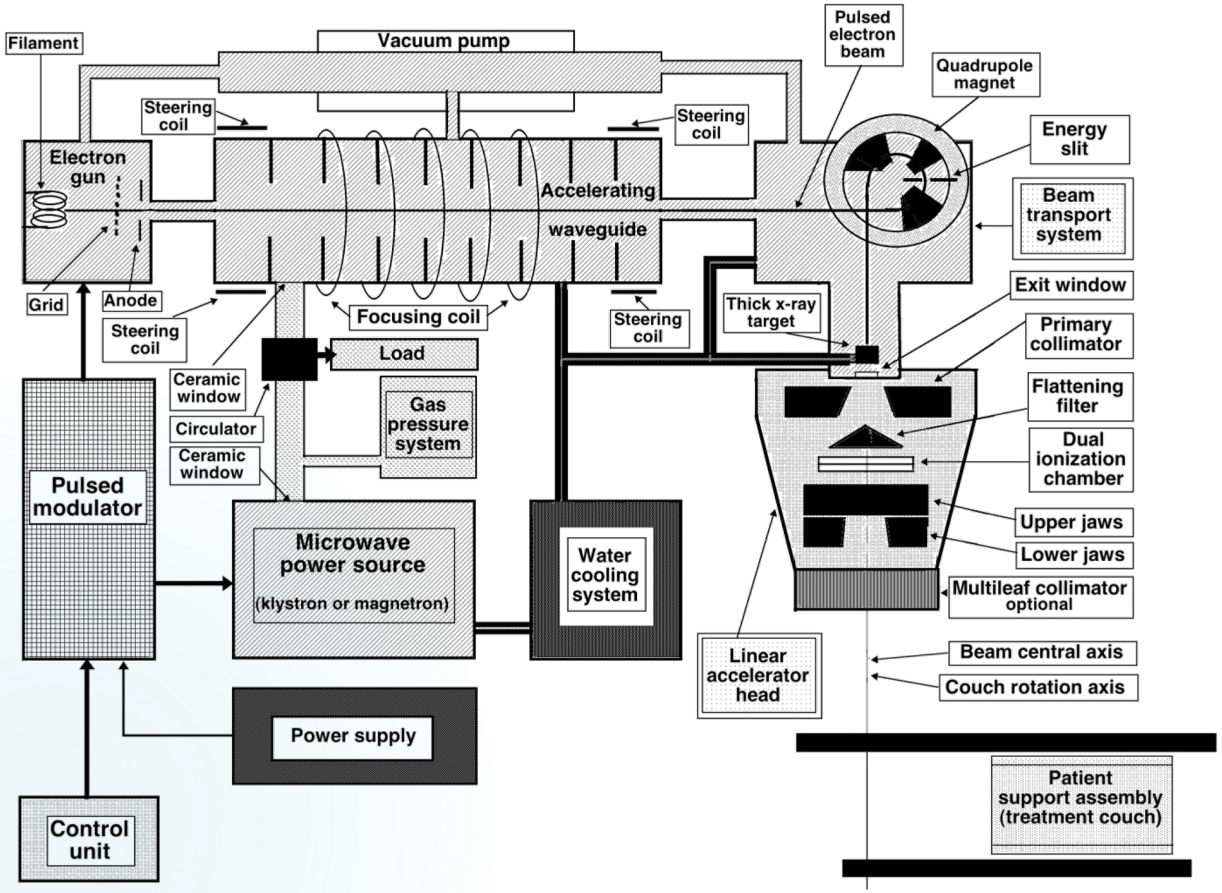

Achromatic bending magnet
Carousel with scattering foils, flattening filters
Monitor ion chambers
Collimator jaws
Multileaf collimator (MLC)
X-ray target
Accelerating Waveguide
Electron gun
Energy switch
Accessory holder (not shown) attaches here

Beam forming components

- Injection system
- RF power generation system
- Accelerating waveguide
- Auxiliary system
- Beam transport system
- Beam collimation and monitoring system



The RF from the magnetron travels at a velocity that is too high to synchronize with the electrons from the gun
An input mode transformer slows the RF to about 0.4c to match the velocity of the electrons from the gun.

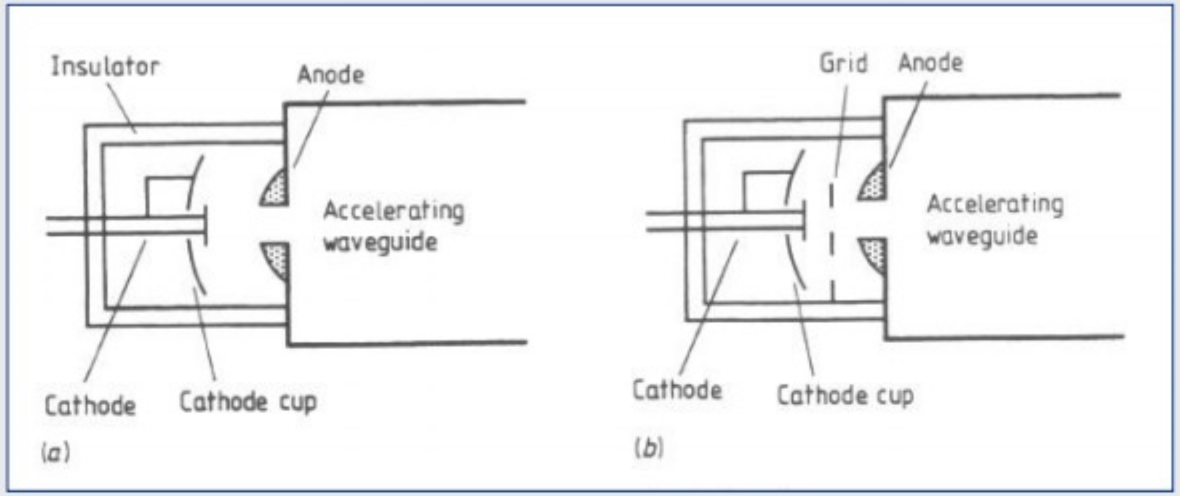


From IAEA slidepack

Injection system - Electron gun

Electron gun

Electron gun



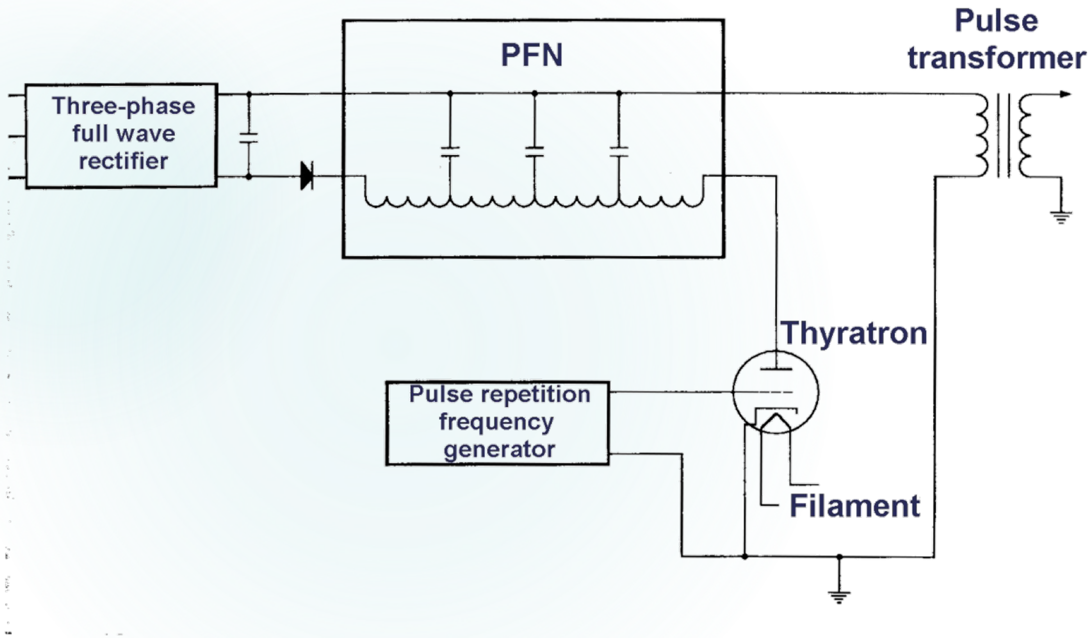
- The gun is the source of the electrons that will be accelerated
- The gun fires as the modulator gives a pulse to the microwave generator

RF Power Generation

- Two components:
  - RF power source – magnetron or klystron
  - Pulsed modulator

Modulator

- PFN – pulse forming network
- Includes the thyratron, which acts like a little switch to form pulses that are sent to the electron gun and the magnetron
- High voltage pulses, high current, short duration pulses

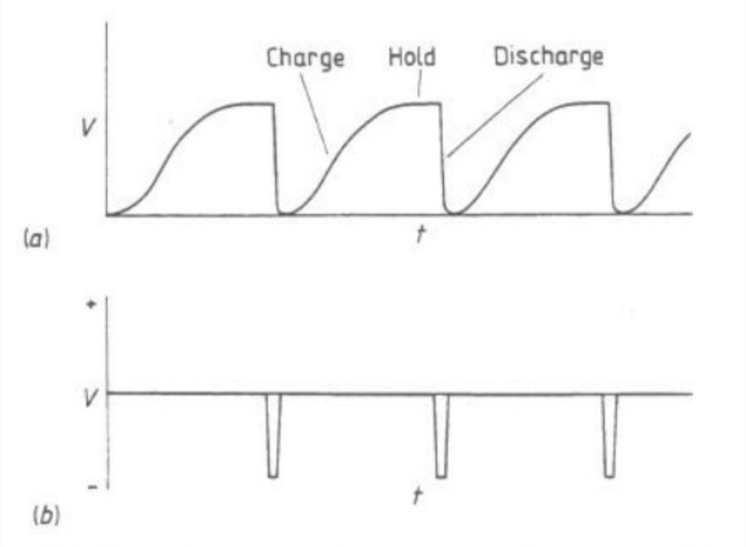


a) The voltage in the PFN as a function of time

b) The resulting current is fed to the primary windings of the pulse transformer, T_1

Pulse lengths of 3 to 6 ms are common, and peak currents of 500 A flow through the thyratron

The PRF is set by the PRF generator connected to the thyratron grid and is usually adjustable in the range 50 Hz to 1000 Hz.



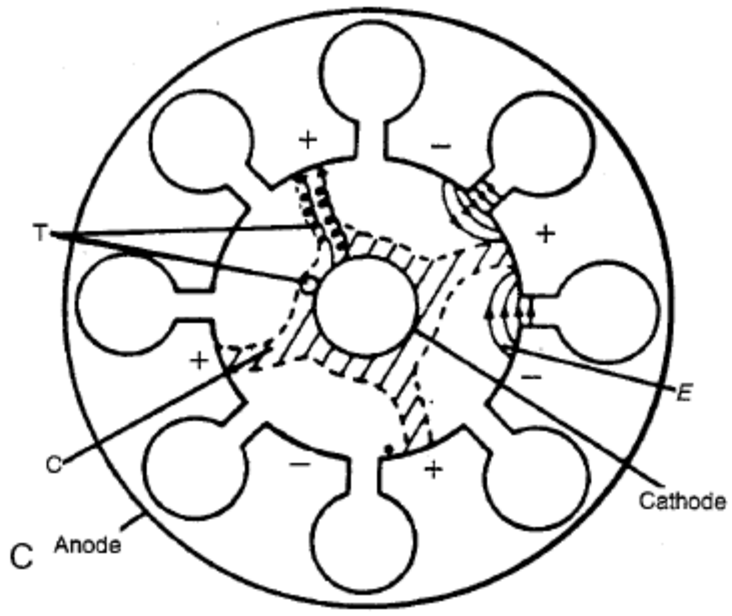
- Power supply provides direct current to a modulator
- High voltage pulses from the modulator are delivered to the electron gun, as well as the magnetron or klystron, which produce microwaves. The thyratron acts as a switch to deliver these high voltage pulses.

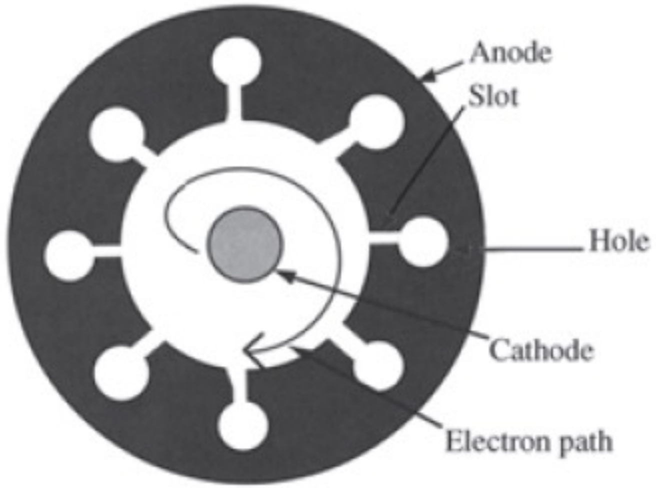
Magnetron

A magnetron produces microwaves.
It functions as a high-power oscillator with a repetition rate of several hundred pulses per second.
The frequency of the microwaves is about 3000 MHz.

Cylindrical construction: Central cathode and an outer anode with resonant cavities, made of copper. Static magnetic field is applied.
The electrons emitted by thermionic emission are accelerated towards the anode. Under the simultaneous influence of the magnetic field, the electrons move in complex spirals towards the resonant cavities, radiating energy in the form of microwaves.

- Magnetron: produces microwaves ~ 3000 MHz
- Central cathode, outer anodes in a static magnetic field: electrons released by thermionic emission, accelerated in spiral patterns through cavities to anode, radiating energy in the form of microwaves
- 2 MW or so





A cross section through a magnetron illustrating the principle of operation. Electrons emitted by the cathode spiral toward the anode in a magnetic field that is perpendicular to the page. As the electrons pass the cavities consisting of the holes and the slots, they induce oscillations at microwave frequencies. This is analogous to the sound waves that are produced by blowing air across the top of a soda bottle. (Adapted from Stanton, R., and D. Stinson, *Applied Physics for Radiation Oncology*, Fig. 9.6. © 1996, with permission from Medical Physics Publishing.)

Waveguide

- Two types of waveguide are used in linacs:
  - Radiofrequency power transmission waveguides (gas filled) for transmission of the RF power from the power source to the accelerating waveguide.
  - Accelerating waveguides (evacuated to about 10^{-6} tor) for acceleration of electrons.

- Power supply provides direct current to a modulator
- High voltage pulses from the modulator are delivered to the electron gun , as well as the magnetron or klystron, which produce microwaves. The thyratron acts as a switch to deliver these high voltage pulses.

- These microwaves are injected into the accelerator via a waveguide system, which is filled with gas.
- Electrons are pulsed in the system at the right moment, but can only be accelerated in a vacuum, so a window separates the gas under pressure from the vacuum in the accelerating waveguide

Waveguide

CONCEPT #1: EM WAVE PROPAGATION

- We start with Maxwell's equations for electrodynamics:

$$\text{(i)}\ \vec{\nabla}\cdot\vec{E}=0 \qquad \text{(iii)}\ \vec{\nabla}\times\vec{E}=-\frac{\partial\vec{B}}{\partial t}$$

$$\text{(ii)}\ \vec{\nabla}\cdot\vec{B}=0 \qquad \text{(iv)}\ \vec{\nabla}\times\vec{B}=\mu_0\epsilon_0\frac{\partial\vec{E}}{\partial t}$$

- These can be solved to give the equations for EM waves in a vacuum

$$\tilde{\vec{E}}(z,t)=\tilde{\vec{E}}_0 e^{i(kz-\omega t)}$$

$$\tilde{\vec{B}}(z,t)=\tilde{\vec{B}}_0 e^{i(kz-\omega t)}$$

where

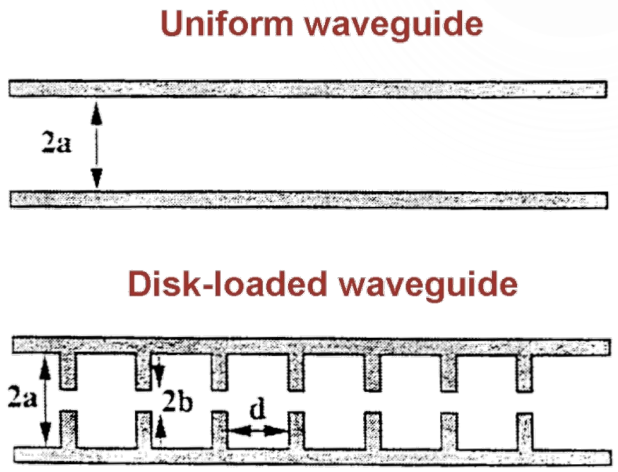
$$v=\omega/k \qquad v_g=d\omega/dk \qquad k=2\pi/\lambda \qquad \omega=2\pi f$$

Apply certain boundary conditions for rectangular or cylindrical waveguides and solve

EM waves reflected at conducting surfaces

- Travelling waveguide
  - Energy flows smoothly in and out at opposite ends (Elekta)
- Standing waveguide
  - Energy is reflected at the ends of the system (Varian) – more compact

- Accelerating waveguide is obtained from a cylindrical uniform waveguide by adding a series of disks (irises) with circular holes at the centre, placed at equal distances along the tube to form a series of cavities.
- The accelerating waveguide is evacuated to allow free propagation of electrons.
- The cavities serve two purposes:
  - To couple and distribute microwave power between cavities.
  - To provide a suitable electric field pattern for electron acceleration.



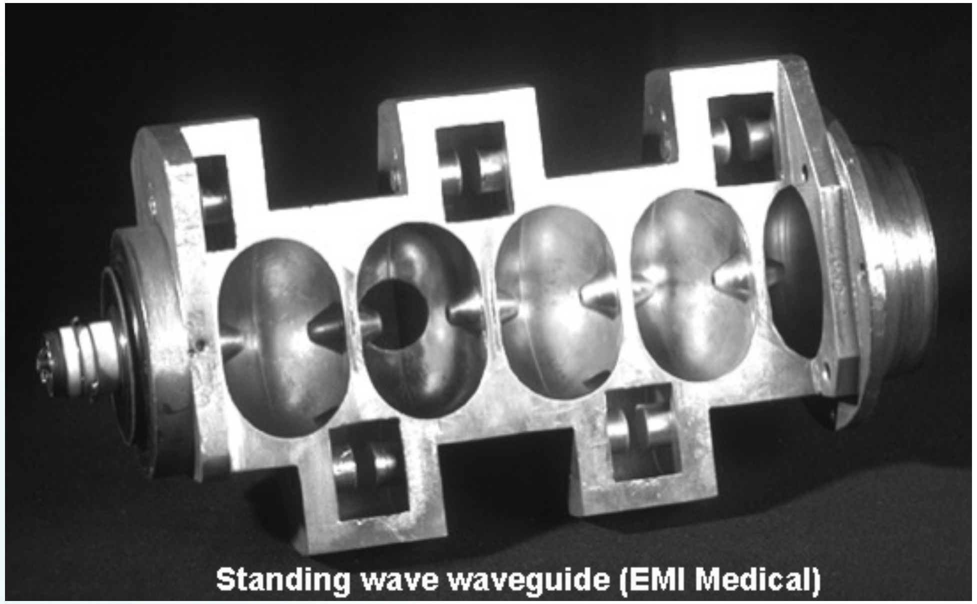
- The role of the disks (irises) is to slow the phase velocity of the RF wave to a velocity below the speed of light in vacuum to allow acceleration of electrons.

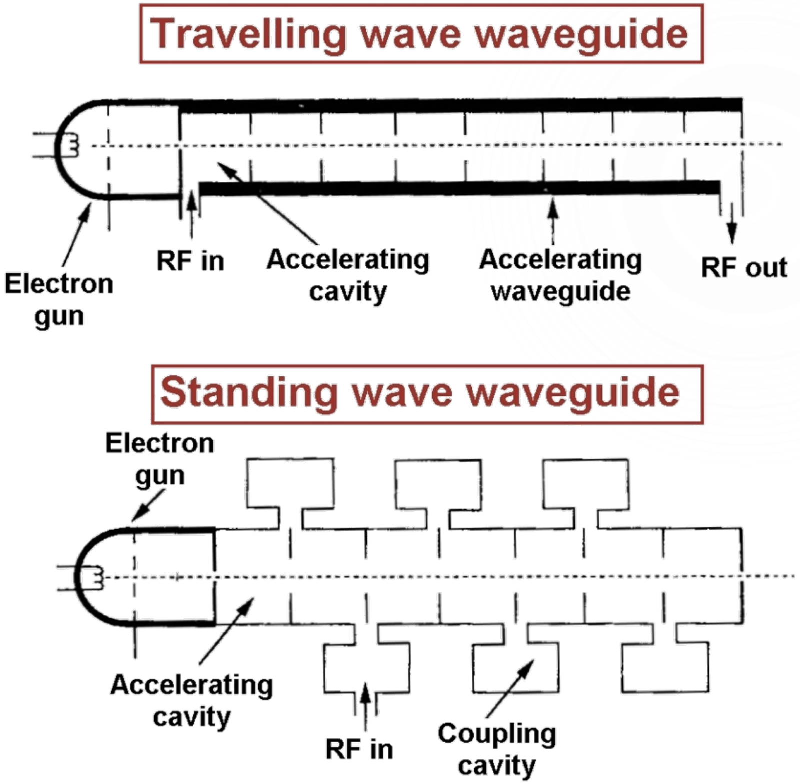
- The accelerating waveguide is evacuated (10^{-6} tor) to allow free propagation of electrons.

- The cavities serve two purposes:

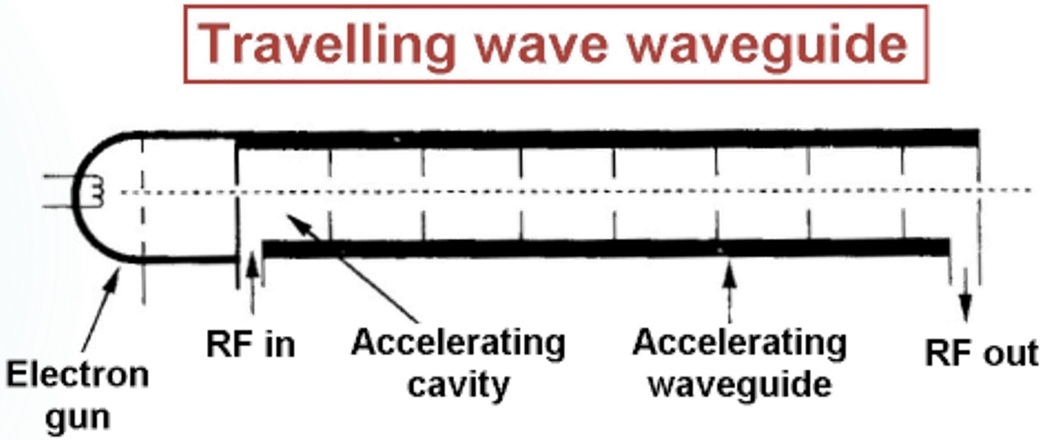
  - To couple and distribute microwave power between adjacent cavities.
  - To provide a suitable electric field pattern for electron acceleration.

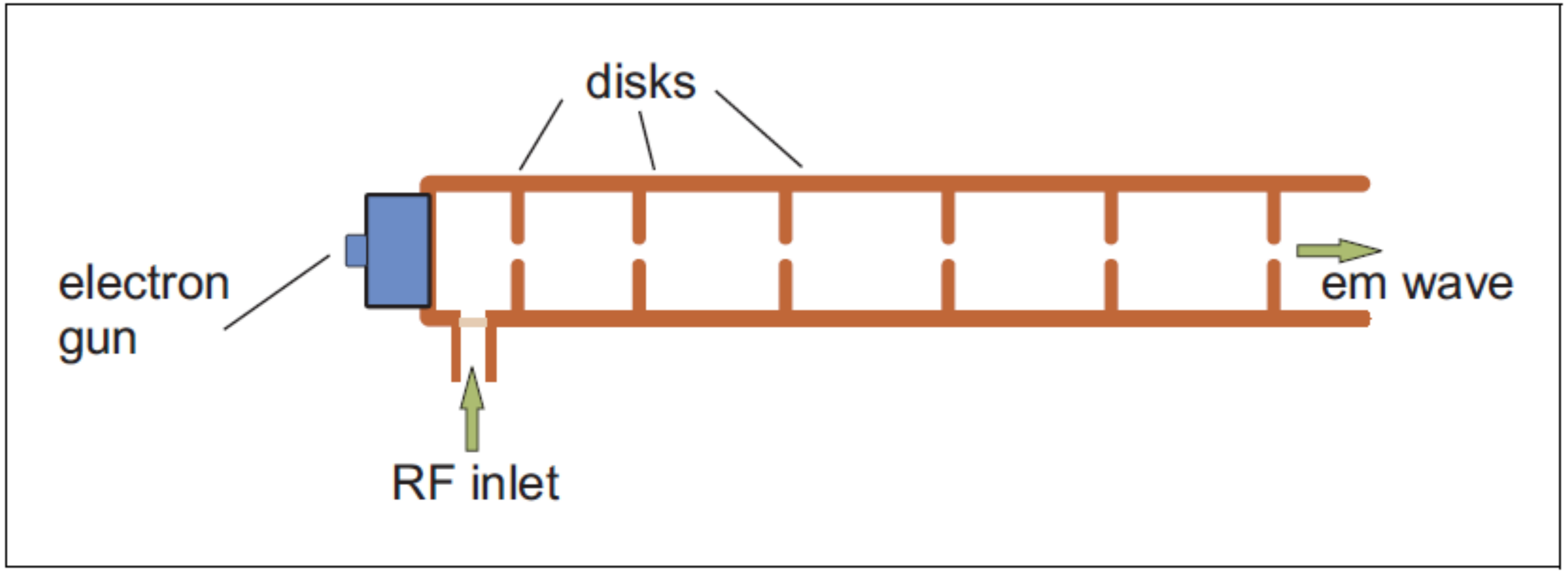
- Two types of accelerating waveguide are in use:
  - Traveling wave structure
  - Standing wave structure





- In the travelling wave accelerating structure the microwaves enter on the gun side and propagate toward the high energy end of the waveguide.

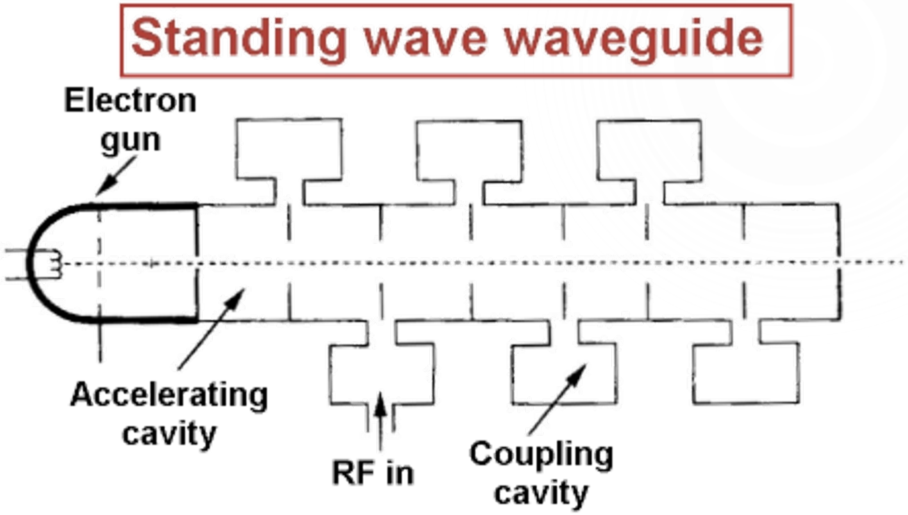




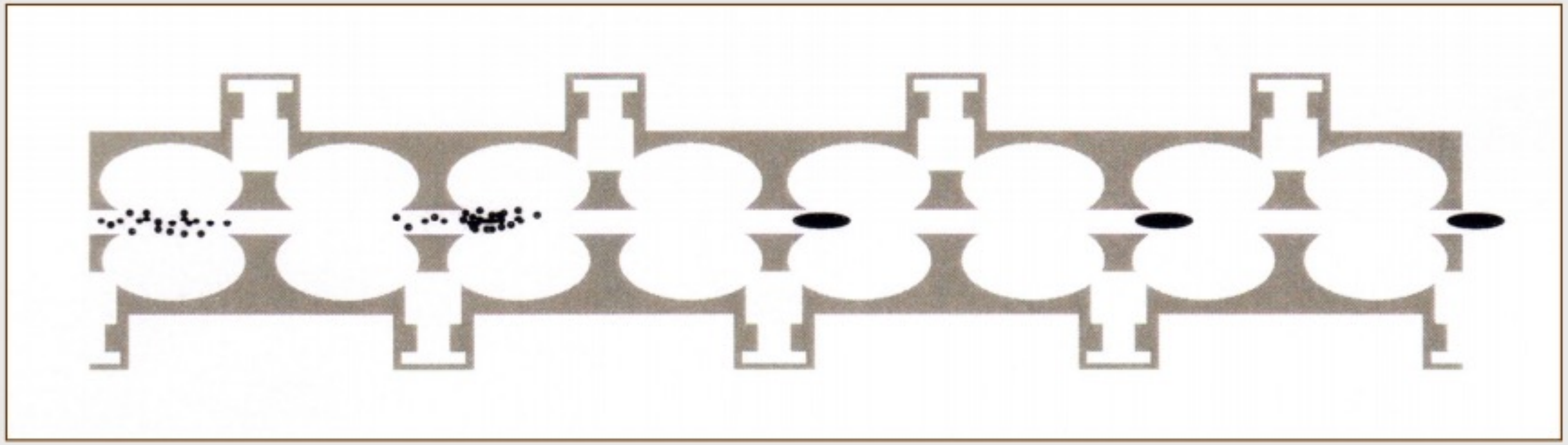
A cross section of an accelerating waveguide for a traveling wave linear accelerator. The waveguide is disk loaded to slow down the microwave electromagnetic waves so that bunches of electrons may "surf" on these waves down the guide from left to right. The electron gun injects electrons into the waveguide.

- The "holes" (irises) provide resistance to the travel of the radiowaves, effectively slowing them down. The closer the irises and the tinier the opening, the slower the wave will travel.

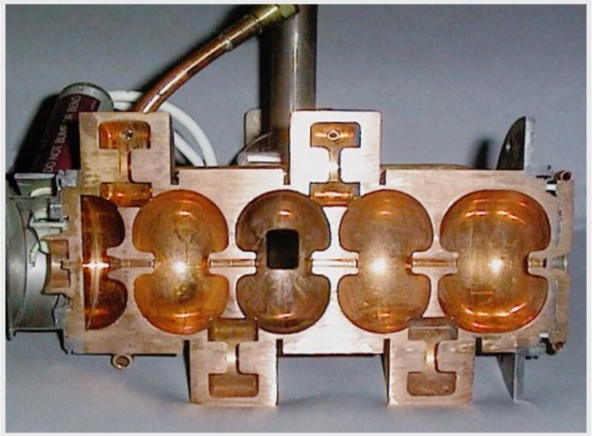
- In the standing wave accelerating structure each end of the accelerating waveguide is terminated with a conducting disk to reflect the microwave power producing a standing wave in the waveguide.
- Every second cavity carries no electric field and thus produces no energy gain for the electron (coupling cavities).



Bunching



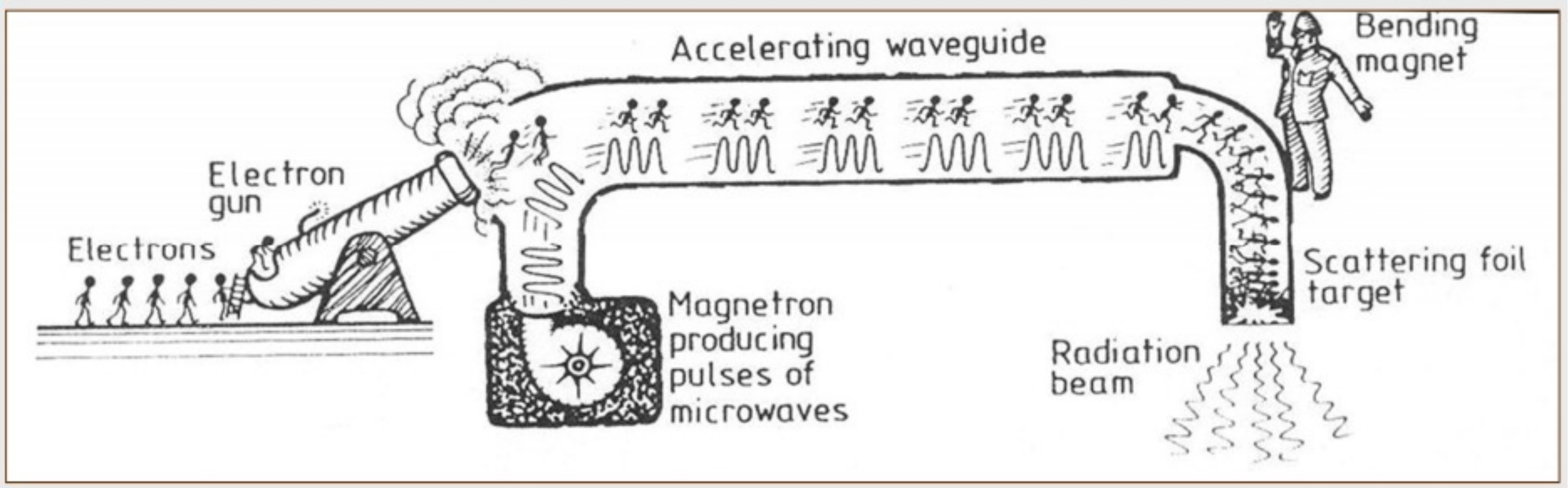
The electrons is bunched such way that every pulse have particles with the same energy



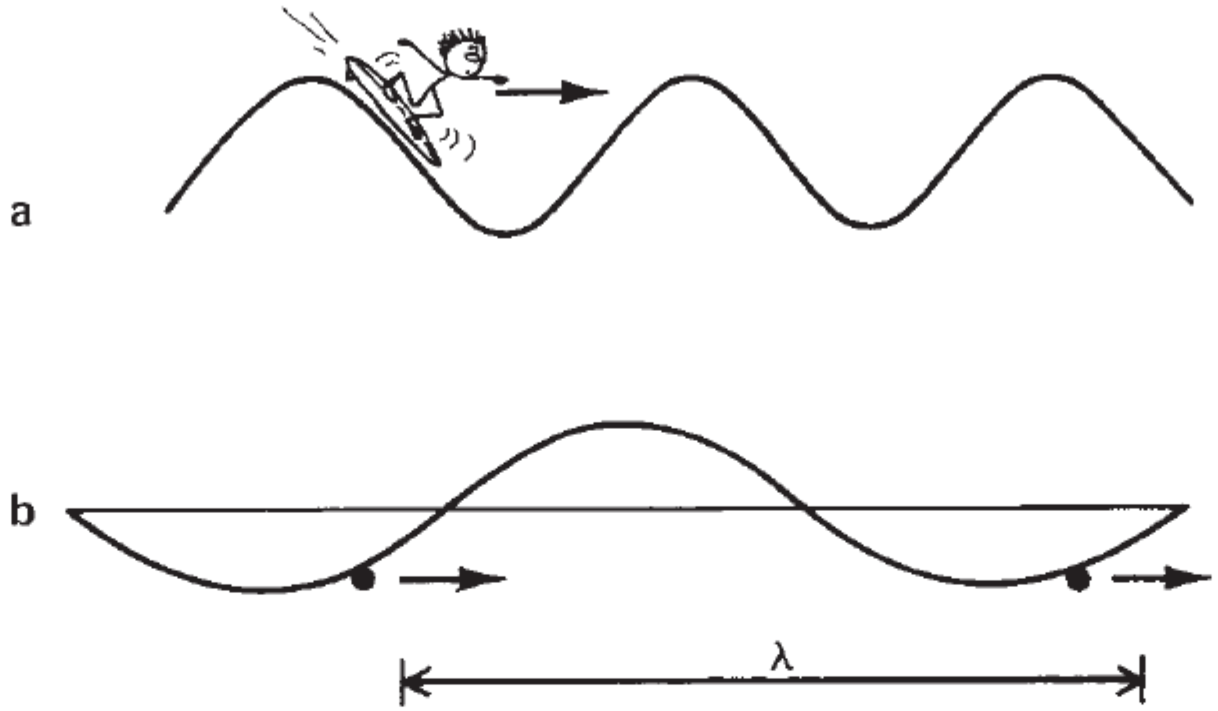
Microwave power transmission

- The microwave power produced by the RF generator is carried to the accelerating waveguide through rectangular uniform waveguides usually pressurized with a dielectric gas (freon or sulphur hexafluoride SF_6).

- Between the RF generator and the accelerating waveguide is a circulator (isolator) which transmits the RF power from the RF generator to the accelerating waveguide but does not transmit microwaves in the opposite direction.

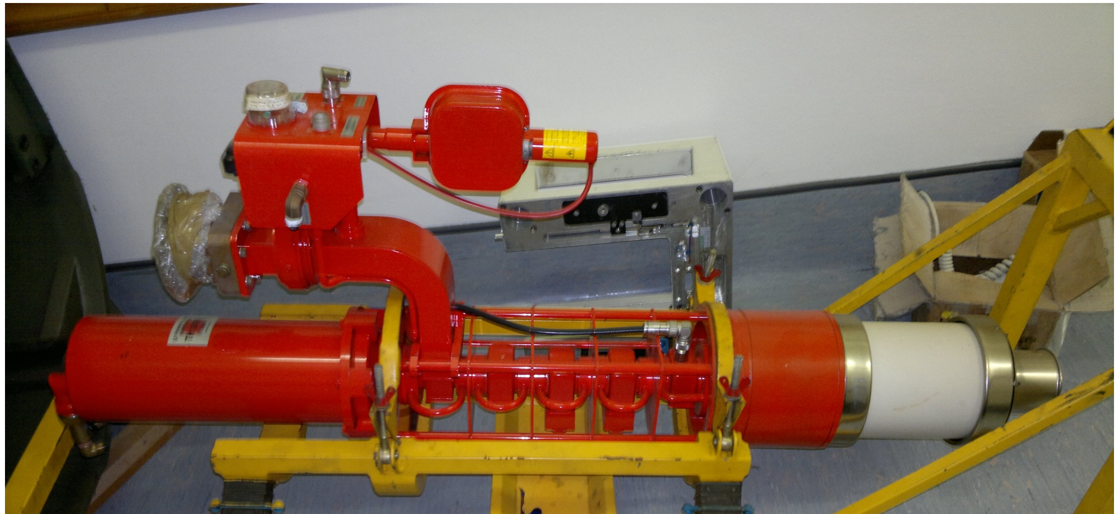


Accelerating waveguide
Bending magnet
Electron gun
Electrons
Scattering foil target
Magnetron producing pulses of microwaves
Radiation beam


a
b
λ

Waveguide

Standing vs
travelling waveguide

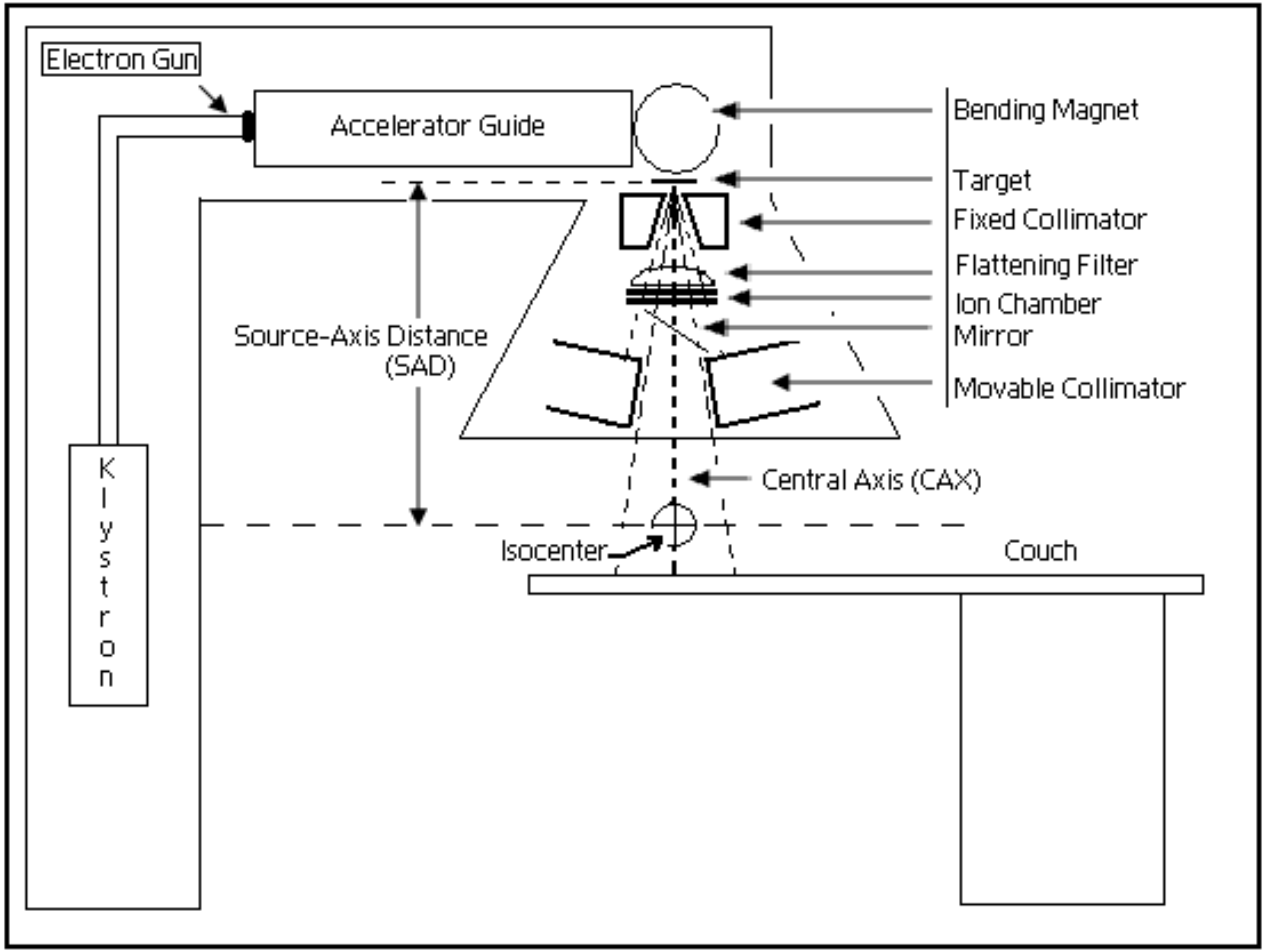


Microwaves are absorbed at the end of the waveguide, or fed back to the input

Microwaves reflect from the distal surface to produce a standing wave

Auxiliary systems

- Auxiliary service consists of four systems that are not directly involved with electron acceleration:
  - Vacuum pumping system producing high vacuum in the accelerating waveguide.
  - Water cooling system for cooling the accelerating waveguide, target, circulator and RF generator.
  - Air pressure system for pneumatic movement of the target and other beam shaping components.
  - Shielding against leakage radiation produced by target, beam transport system and RF generator.



Target
Primary scatter filter
Primary collimator
Secondary flattening filter
Ion chamber
Wedge
Diaphragm

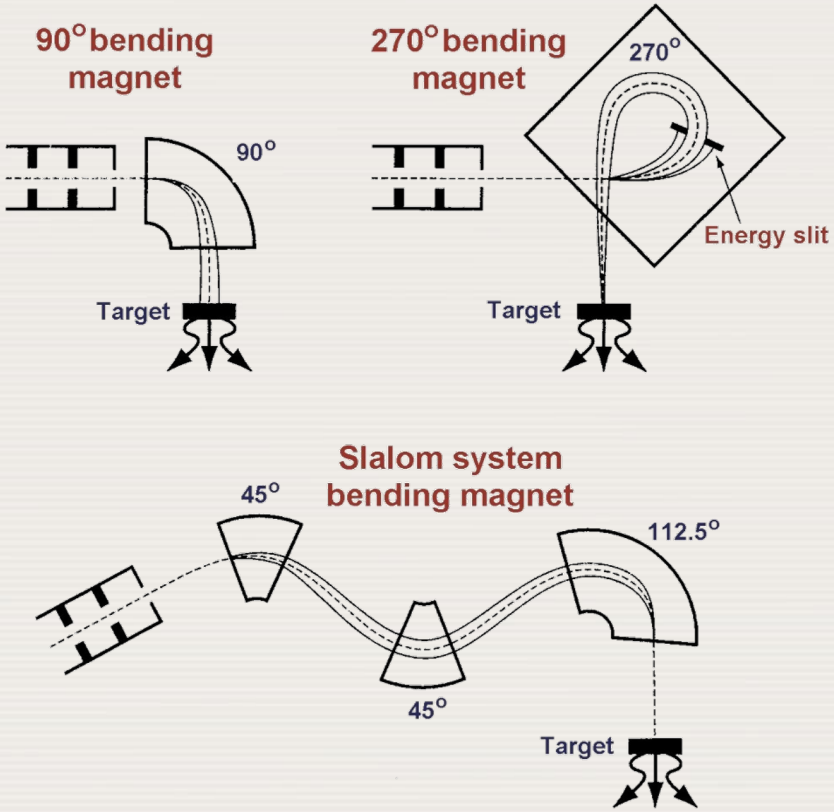
Electron beam transport

- Beam transport system consists of:

- Drift tubes
- Bending magnets
- Steering coils
- Focusing coils
- Energy slits

Electron beam transport (from IAEA slidepack)

- Three systems for electron beam bending have been developed:
  - 90^o bending
  - 270^o bending
  - 112.5^o (slalom) bending



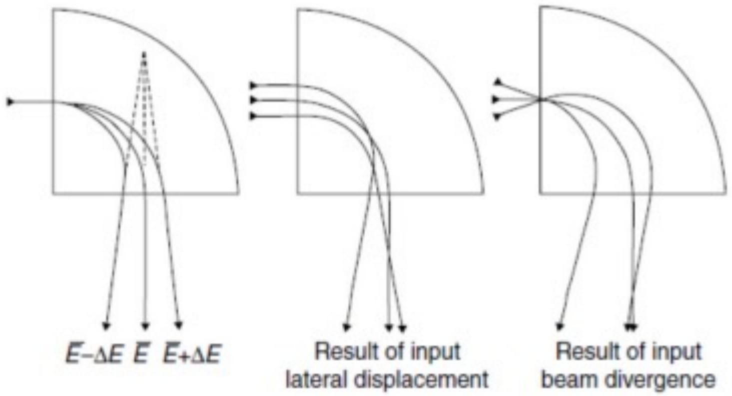
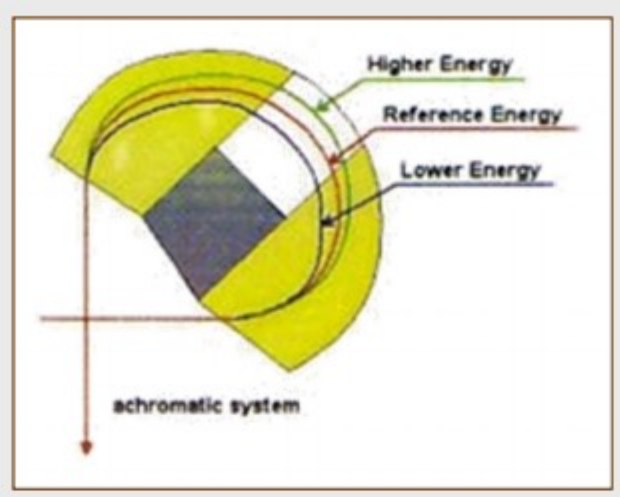
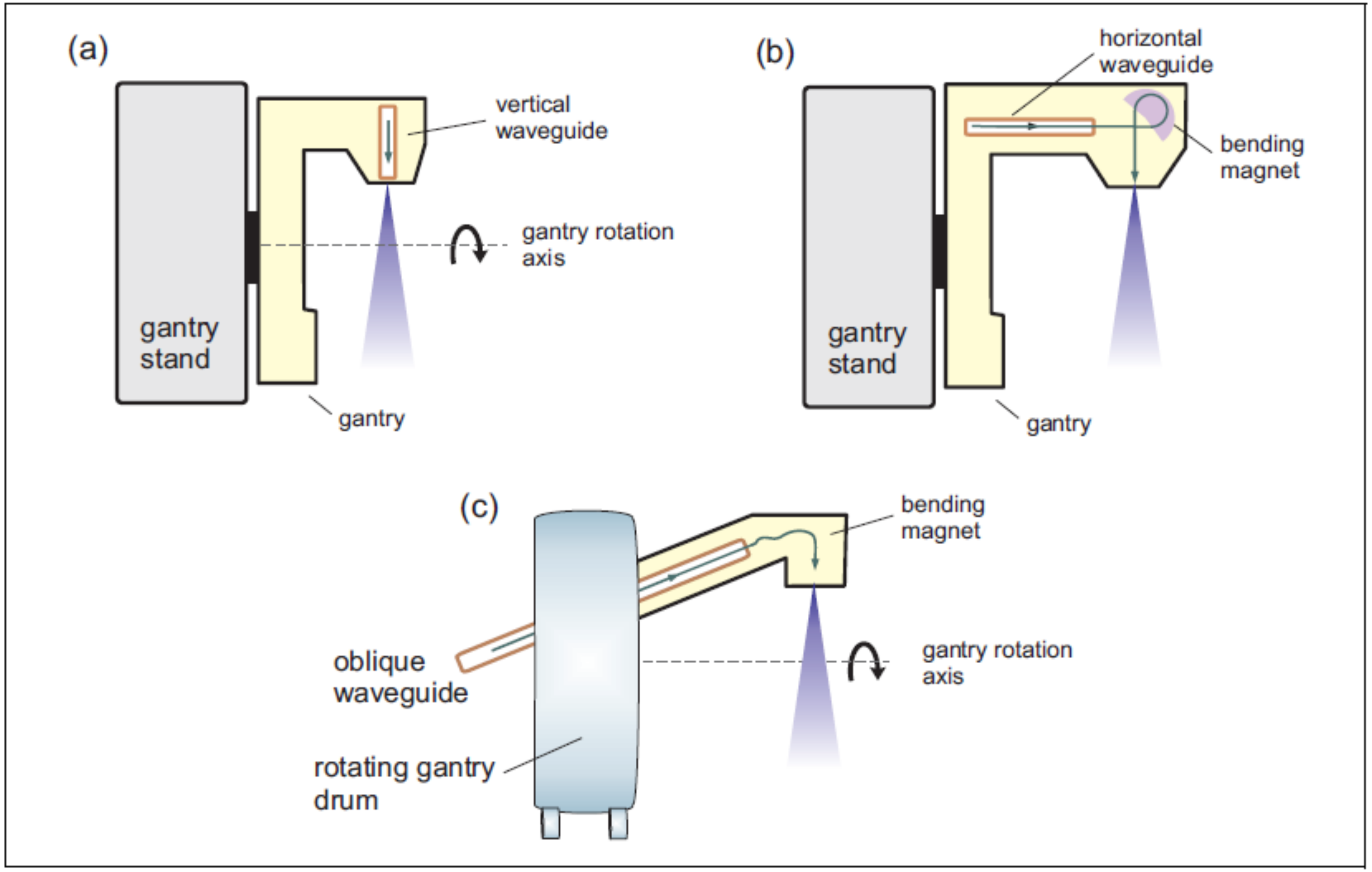
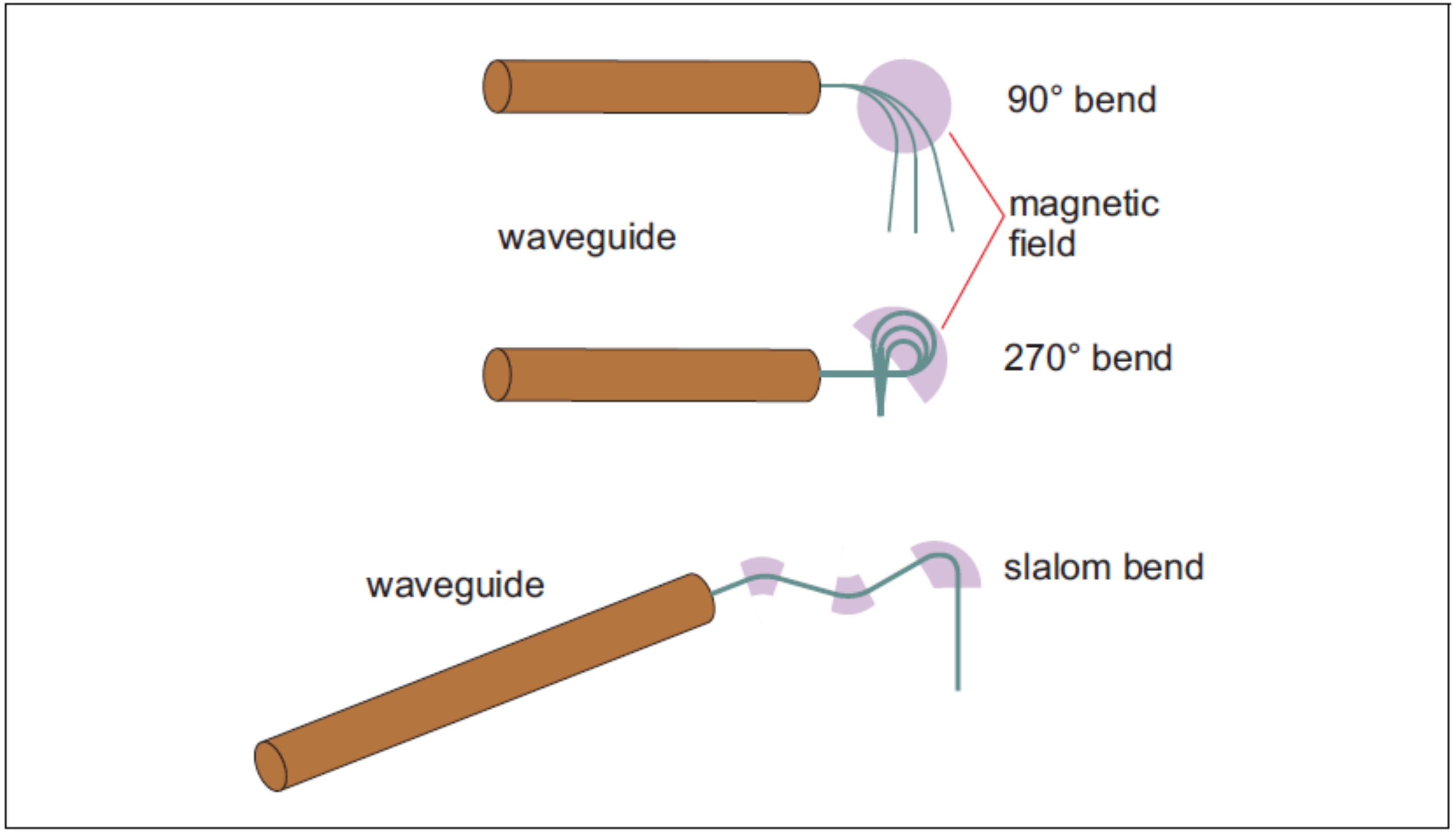


FIGURE 11.14
Simple 90° non-achromatic bending system.

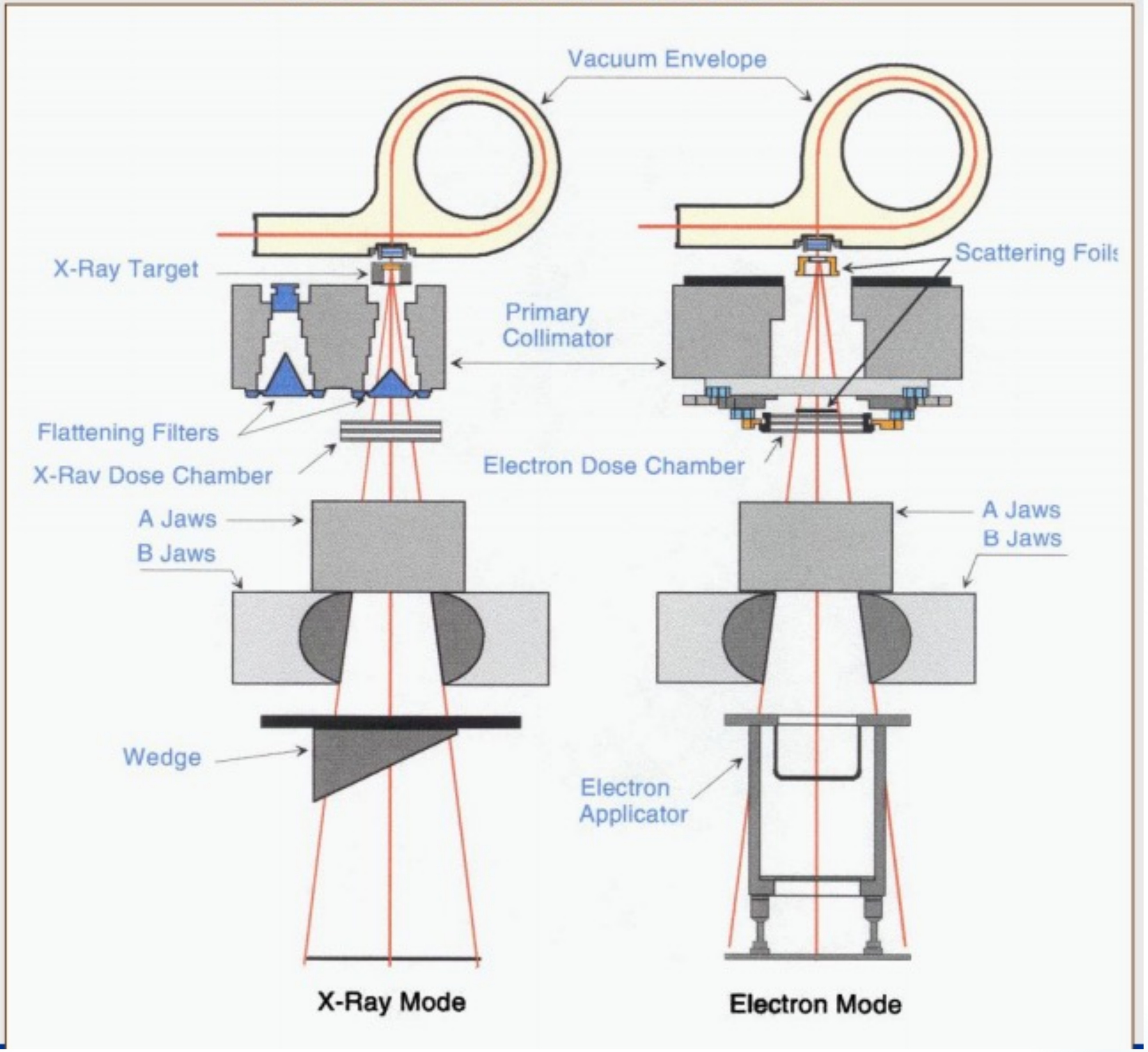


Bending magnets

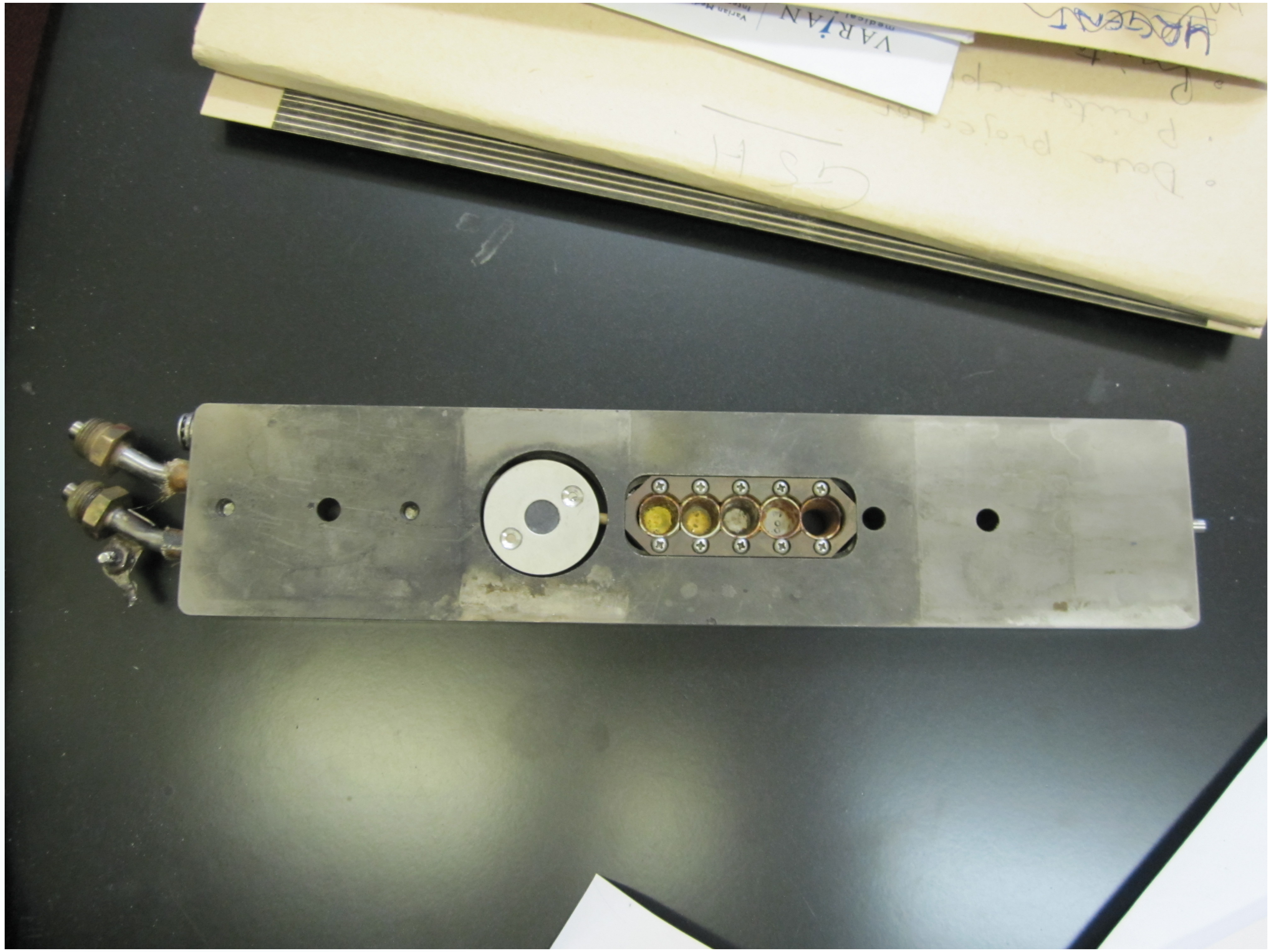



90° bend
waveguide
magnetic
field
270° bend
waveguide
slalom bend

Photons and electrons



Target



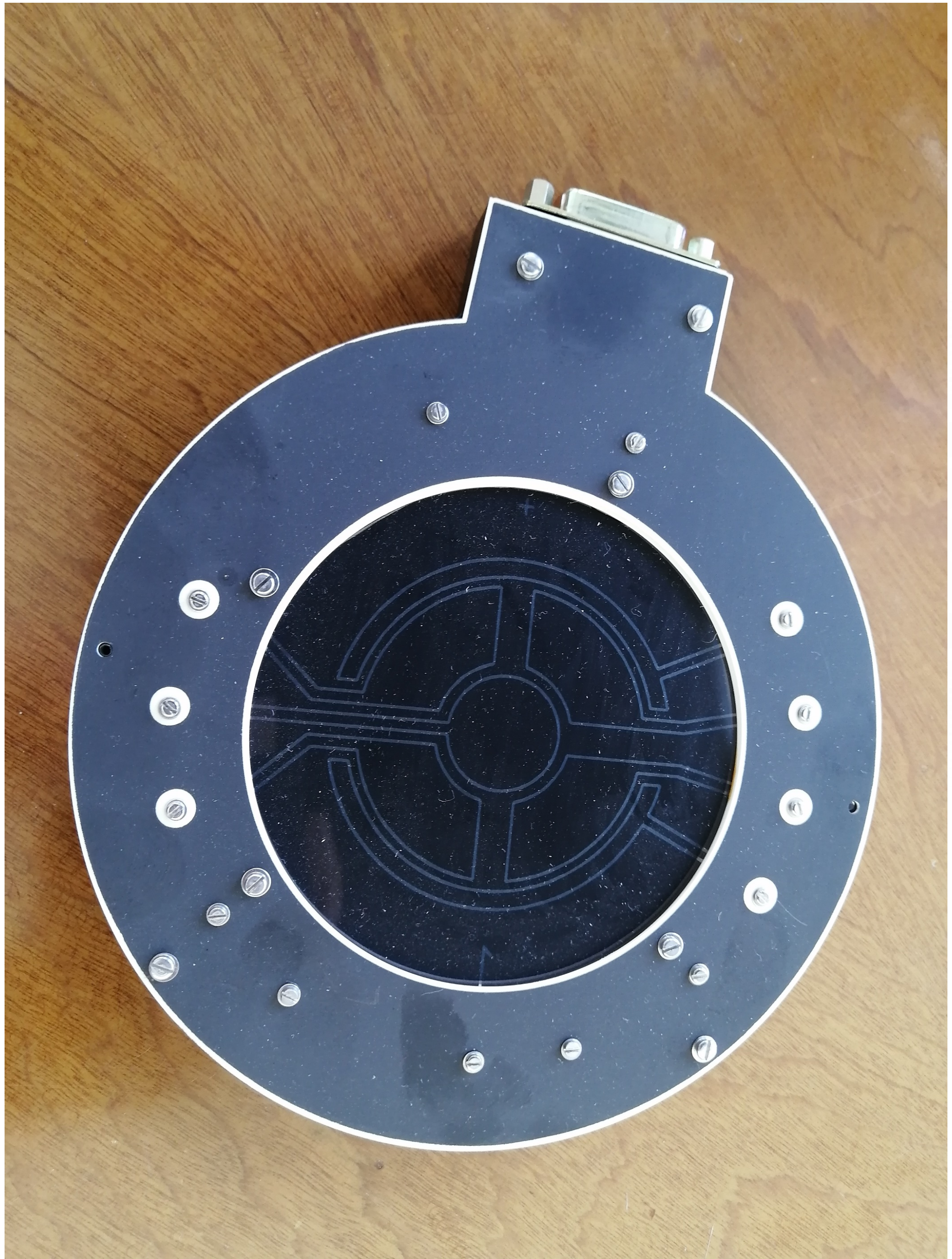
Flattening filter & Scattering Foils

Ion Chamber

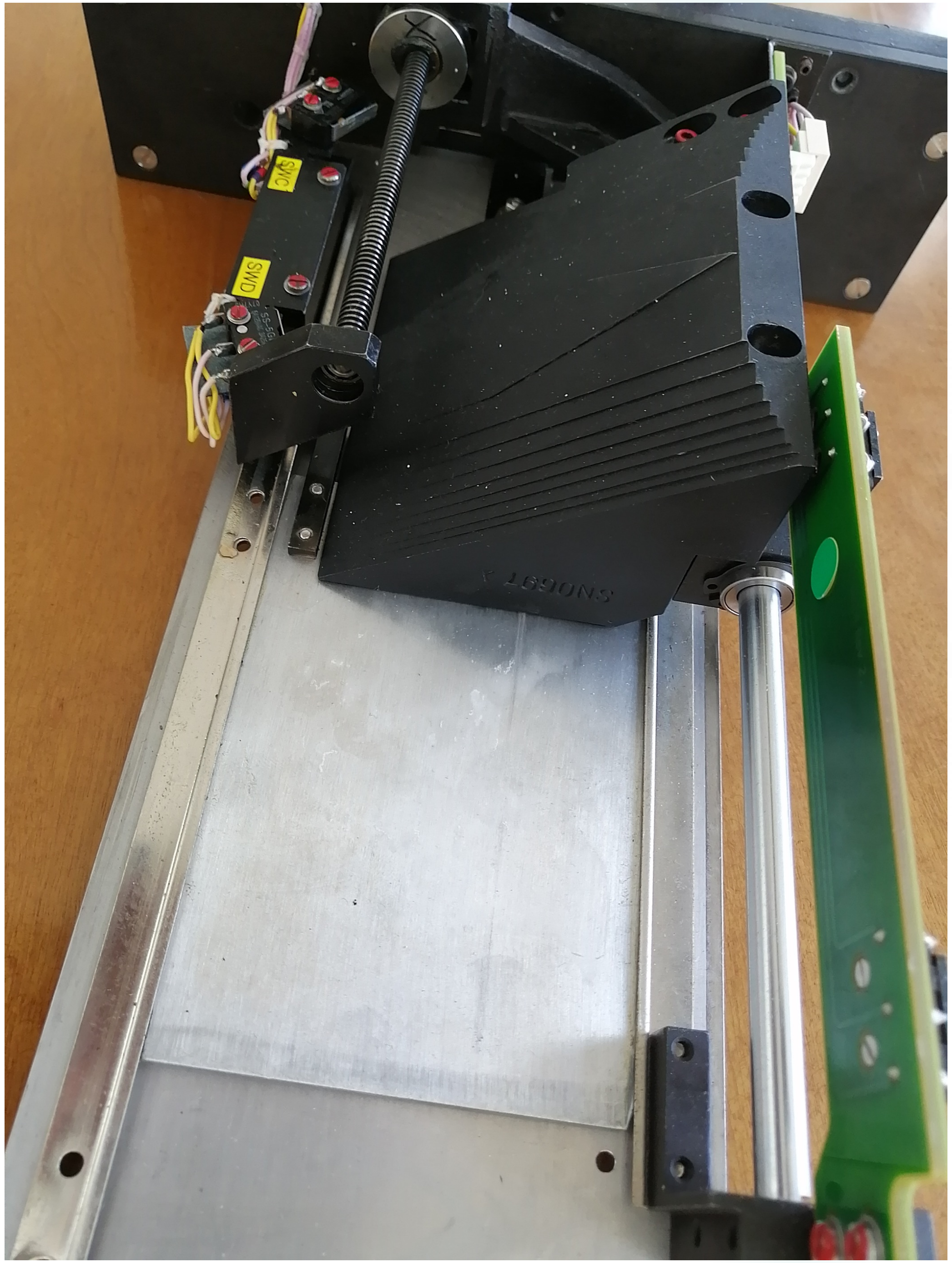
Monitors Dose
Dose Rate
Symmetry
Flatness

+Redundancy (MU2)

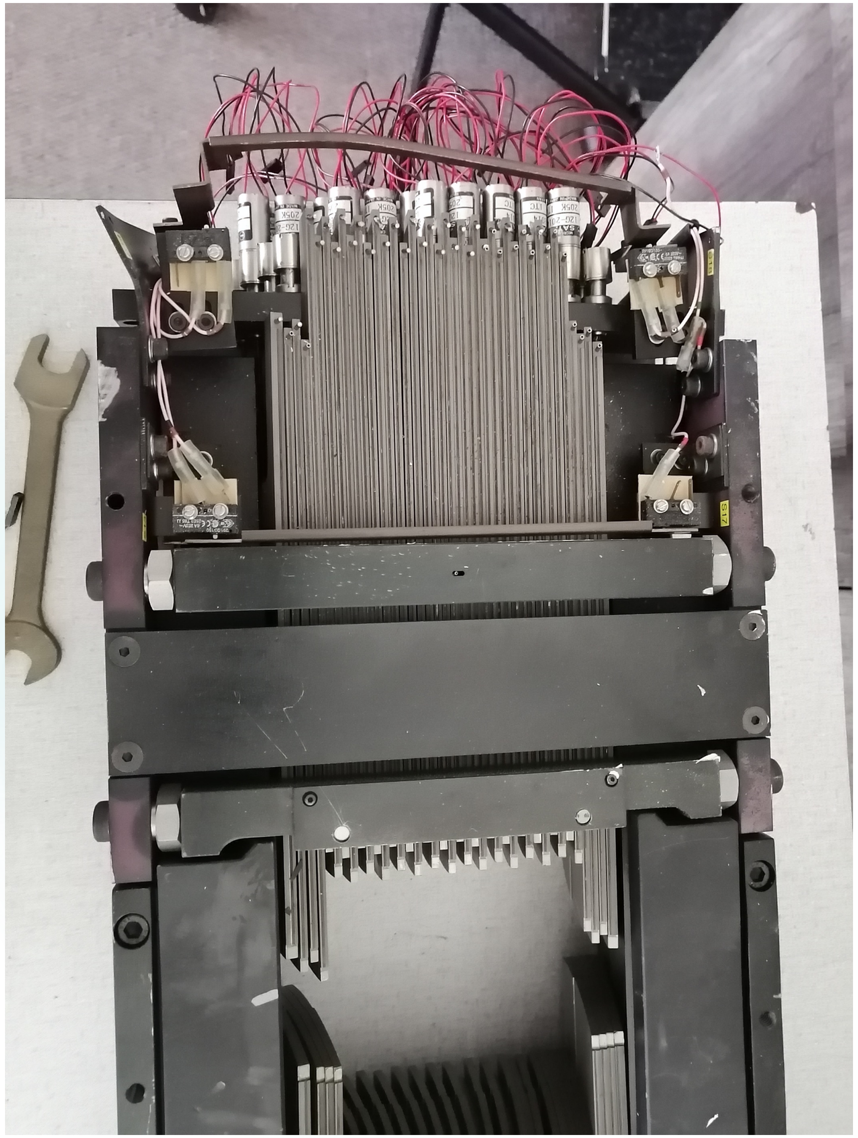
Either sealed or unsealed

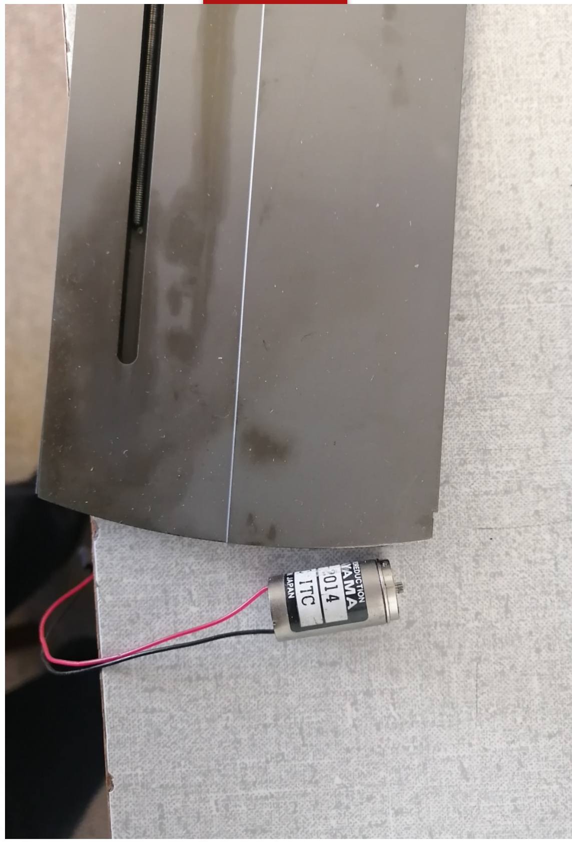


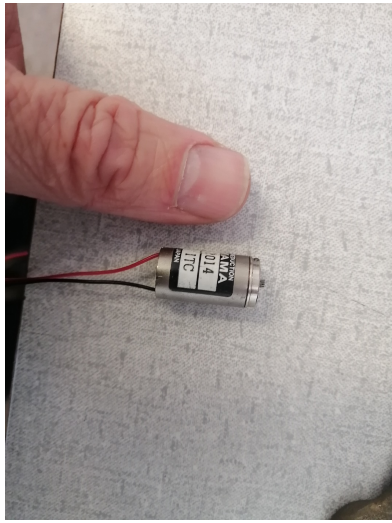
Elekta Wedge



MLC

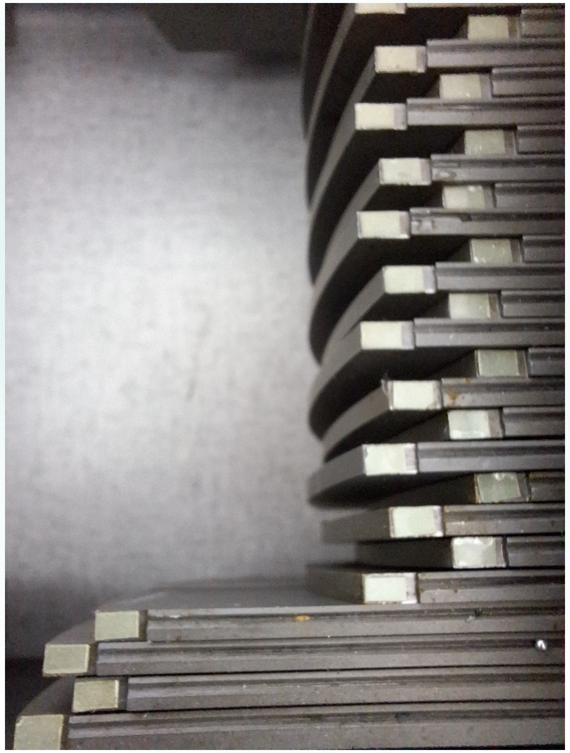


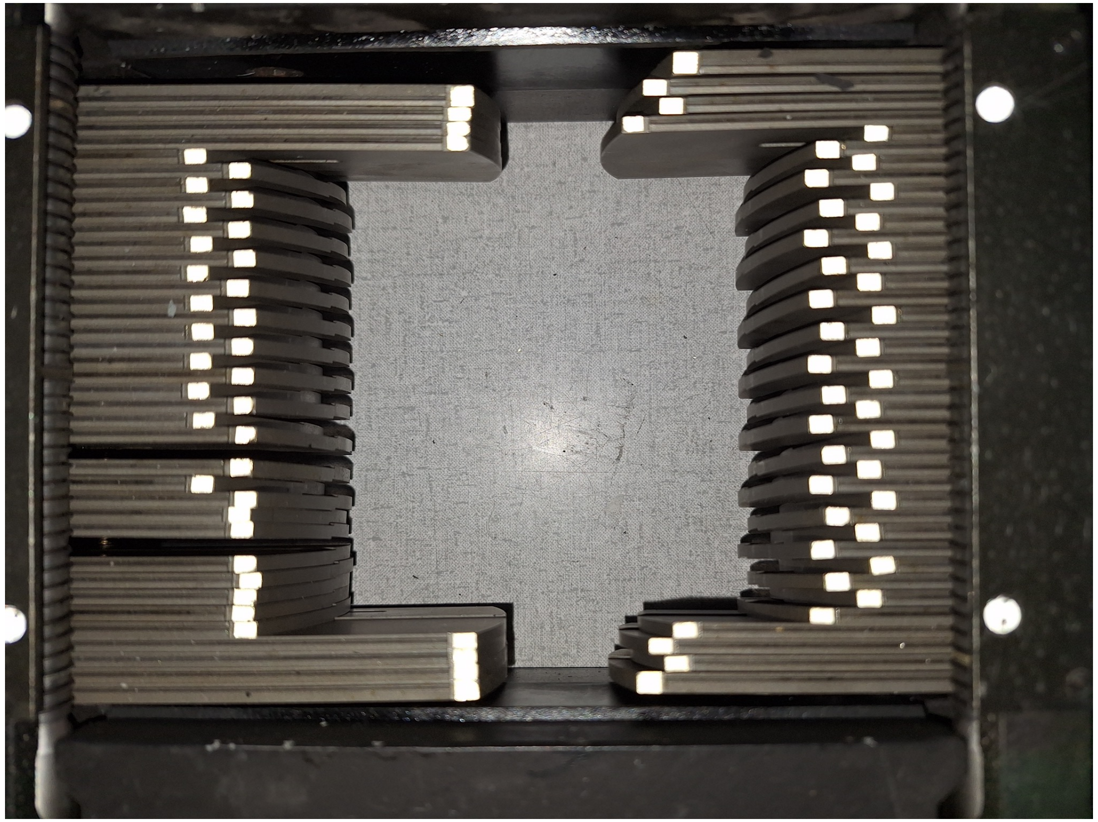




Field shaping

- Combination of jaws and / or MLC





5.5LINACS

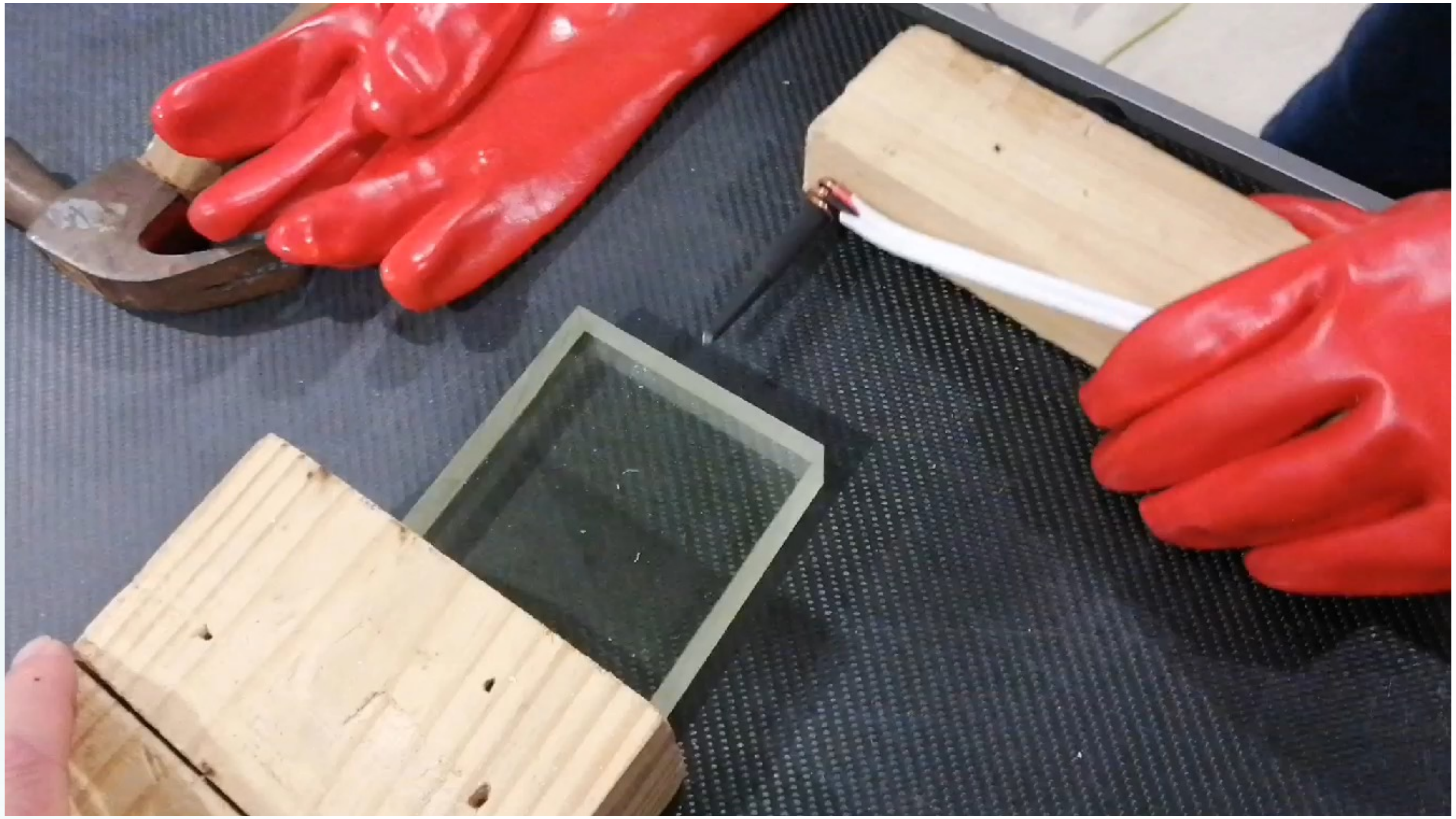
5.5.11 Linac treatment head

- Components of a modern linac treatment head:
  - Several retractable x-ray targets (one for each x-ray beam energy).
  - Flattening filters (one for each x-ray beam energy).
  - Scattering foils for production of clinical electron beams.
  - Primary collimator.
  - Adjustable secondary collimator with independent jaw motion.
  - Dual transmission ionization chamber.
  - Field defining light and range finder.
  - Retractable wedges.
  - Multileaf collimator (MLC).

Electron Tree

- Electric discharge patterns in transparent low-conductive materials due to very high instantaneous electron currents.

- A 2006 Elekta Synergy Platform linear accelerator was about to be replaced. In order to get an appropriate electron beam current, the bellows of the linac were fixed to allow an electron current that would usually be used for photon beam production to pass through the electron exit, but without hitting the bremsstrahlung target.
- The flattening filters and scattering foils were removed. These are not interlocked.
- The beam's ionization chamber had to be removed from the beam, but kept connected.
- The mylar field light mirror remained in place.





- Thank you!