Physics of Radiation Therapy

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Radiotherapy or radiation therapy is treatment using ionizing radiation, mostly we treat cancer.

Ionizing radiation is made up of photons, subatomic particles or ions having enough energy to remove electrons from atoms or molecules.

Ionizing radiation is needed to kill cancer cells.

We use photons, electrons, protons and other particles for radiotherapy.

In Georgia in radiotherapy we have only photons and electrons. Absolute majority of patients are irradiated using photons.

Interaction of ionizing radiation with mater

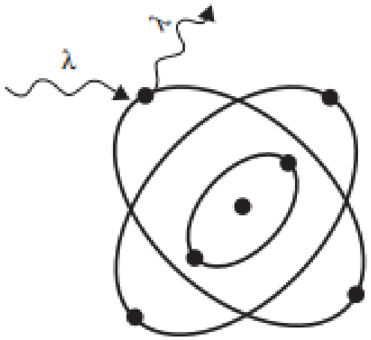
Directly ionizing radiation: charged particles (electrons, protons, alpha particles,…) having enough energy

Indirectly ionizing radiation: neutral particles (photons, neutrons)

Interaction of photons with matter

1. Coherent scattering (classical scattering or Rayleigh scattering)
2. Photoelectric effect
3. Compton scattering
4. Pair production
5. Photodisintegration

1. Coherent scattering

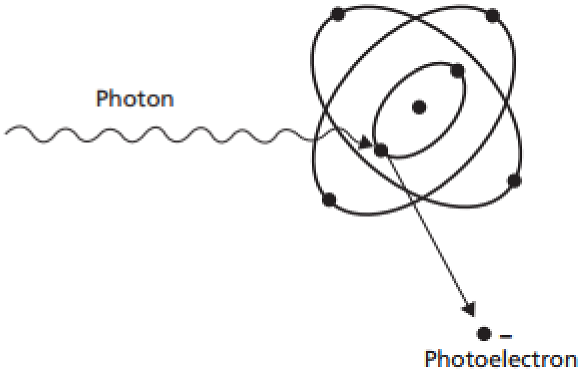


Incident and scattered photons have the same wave length so no energy is absorbed in the medium

More probable with low energy photons and in high atomic number materials

Not important in radiotherapy

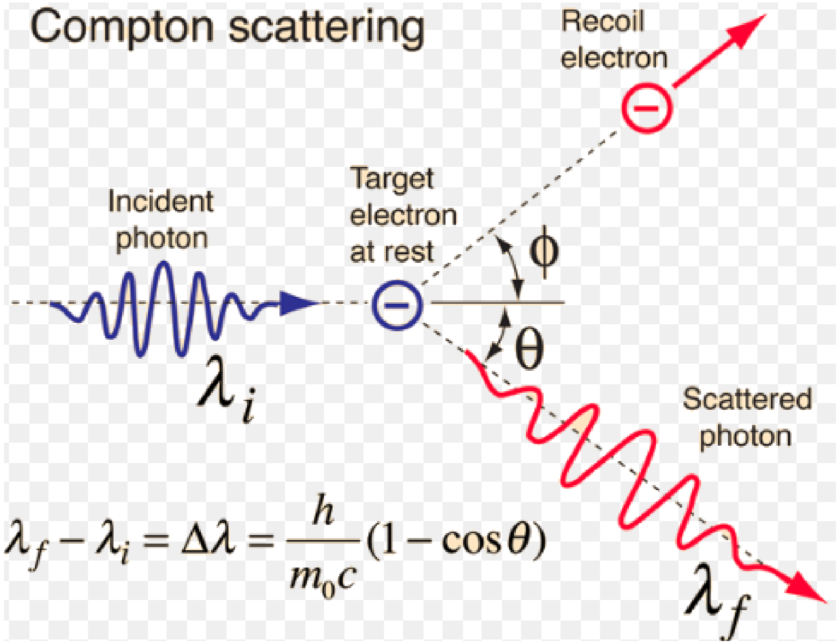
2. Photoelectric effect



Photon is absorbed by an atom and an orbital electron is ejected. All energy is transferred to the electron $K_e = h\nu - E_B$ the atom becomes ionized

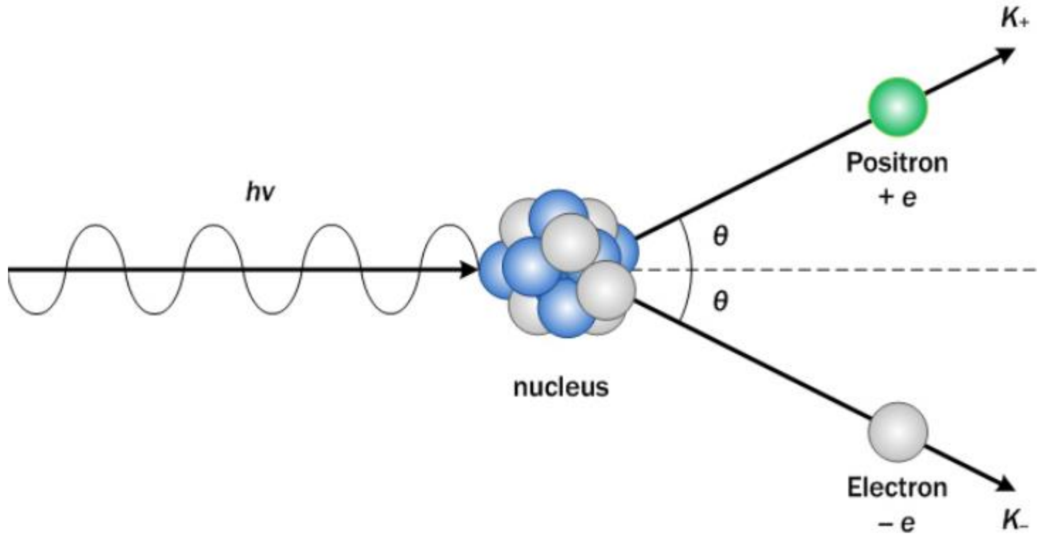
Photoelectric effect is significant in diagnostic radiology (relatively small photon energies)

3. Compton scattering



Compton effect is dominant in radiotherapy !!!

4. Pair production



Energy threshold for photon is 1.02Mev

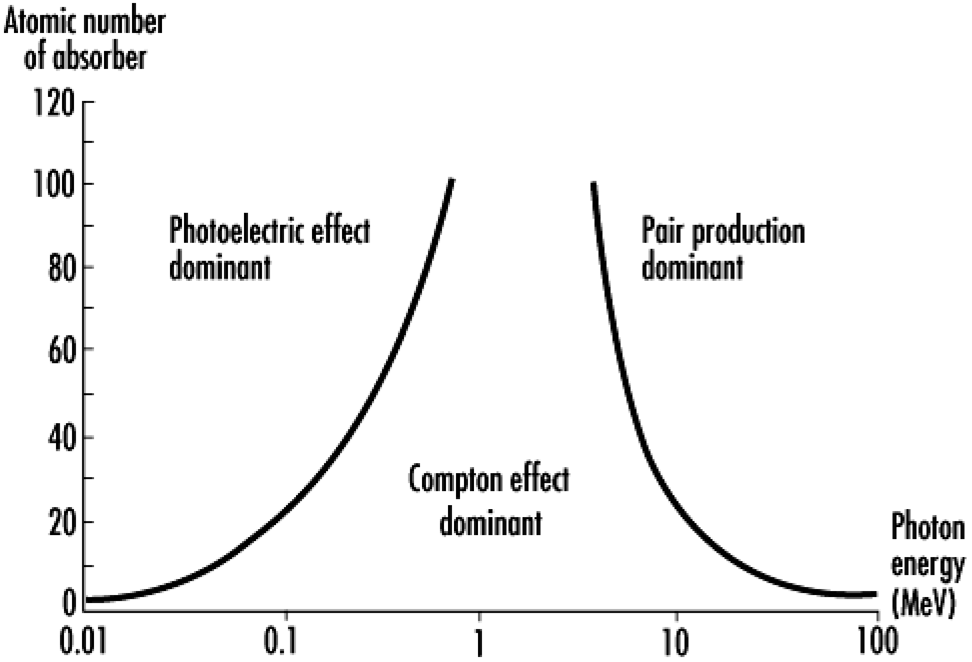
Does not play significant role in radiotherapy

5. Photo disintegration

Occurs when a high-energy photon is absorbed by an atomic nucleus. The nucleus splits into lighter elements, releases neutron, proton or alpha particle.

Most photodisintegration interactions are either (γ, n) or (γ, p)

Less important in radiotherapy.



Interaction of charged particles with matter

Charger particles interact with matter by **Coulomb force**; particles attract or repel each other.

Most charged particle interactions with matter are interactions with the electrons that surround the nucleus. the charged particles impart a small portion of their kinetic energy to secondary electrons.

In tissue an electron loses about 30 electron volt energy in each interaction.

For example 3Mev energy electron will undergo about 100 000 interactions before loosening all its kinetic energy.

The main difference between Photon and Electron interactions

A beam of electrons loses energy but the number of charged particles (intensity) does not change. Energy is lost in a continuous manner until the charged particles stop. So the energy deposited (dose) by a charged particles in a first approximation is constant from the patient's skin to a maximum depth of penetration.

A photon may eject an electron along with a photon of lower energy. The initial photon is absorbed and a new, scattered photon is ejected. Consequently, the photon entering an interaction is attenuated (removed from the beam) and a secondary electron, and possibly a secondary photon, is produced.
The photon beam intensity decreases with depth of penetration, whereas the photon beam energy, at least for a monochromatic beam, does not change.

quantities and units in radiotherapy

Radioactivity:

Definition: 1 decay per second is 1 Bq.

Radioactivity unit is **Becquerel (Bq)**

1 Ci=3.7·10^10 Bq

Radiation Expose:

Definition: dQ/dm

Exposure is a measure of ionization produced **in air** by photons.

International Commission on Radiation Units and Measurements (ICRU) adopted Roentgen as a unit for measuring X and gamma rays.

The unit of radiation exposure is **Coulomb per kilogram - C/kg**

Old unit is **Roentgen (R)**

1R=2.58 · 10^-4 C/kg

Absorbed Dose

Definition: the amount of energy absorbed per unit weight of the matter

Unit of absorbed dose is **Gray (Gy)**

1Gy =1 Joule radiation energy absorbed per kilogram .

Old unit is **rad. 1Gy=100 rads**

Equivalent Dose

Definition: absorbed dose · radiation weighting factor

Unit of Equivalent Dose is Sievert (Sv) and measured in Joule per kilogram

Equal doses of different types of radiations are not equally harmful. To take this into account radiation dose is expressed as "equivalent dose" in units of **Sievert (Sv)**

Old unit is rem – Roentgen equivalent for men 1Sv=100 rem

Radiation type and energy range		W_R
Photons (X-rays and gamma-rays) all energies		1
Electrons, all energies		1
Neutrons		
	<10 keV	5
	10-100 keV	10
	>100 kev to 2 MeV	20
	2-20 MeV	10
	>20 MeV	5
Protons	>20MeV	5
Alpha-particles, fission fragments		20

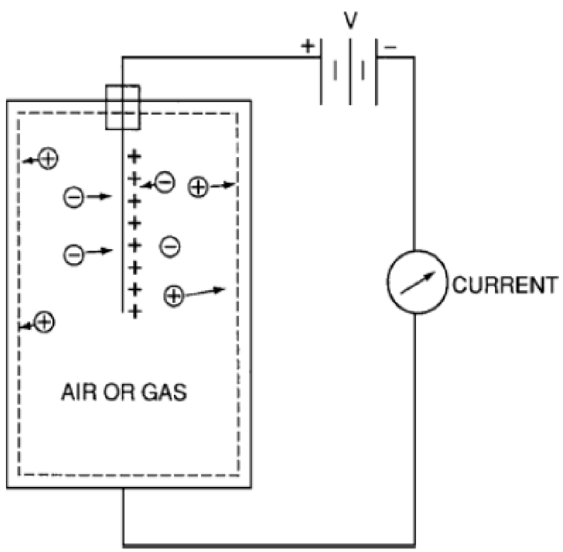
Detection of ionizing radiation

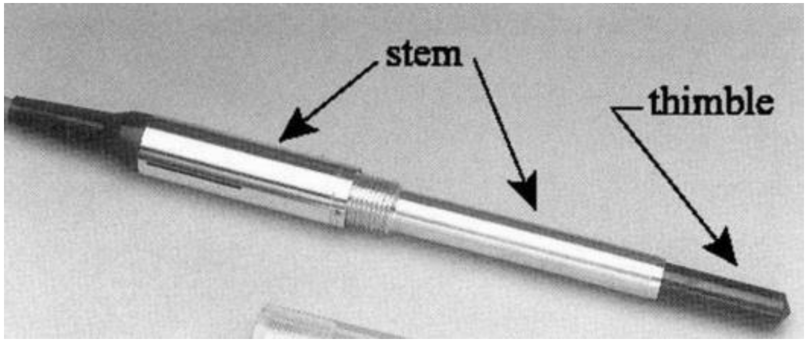
We need to detect ionizing radiation for:

1. Research applications
2. Personal protection
3. Estimation of radiation dose in treatment of patients
4. Calibration of treatment machines and isotopes etc…

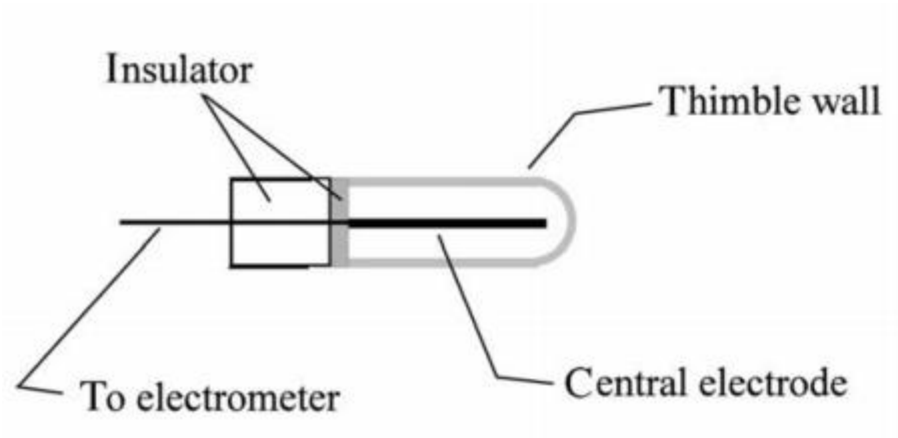
Ionizing radiation detectors used in radiotherapy

Gas-filled chamber





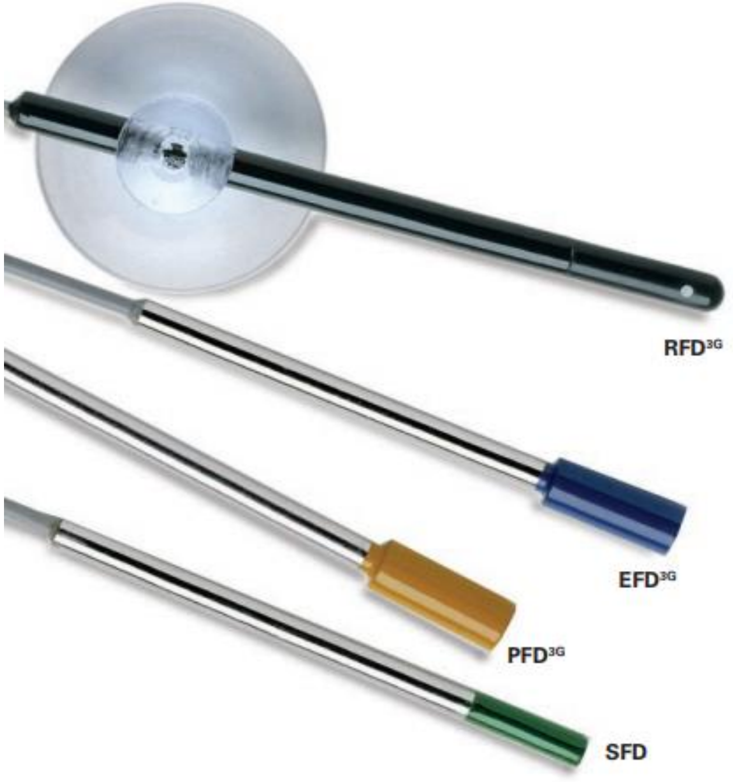
Farmer chamber



Solid-state detectors

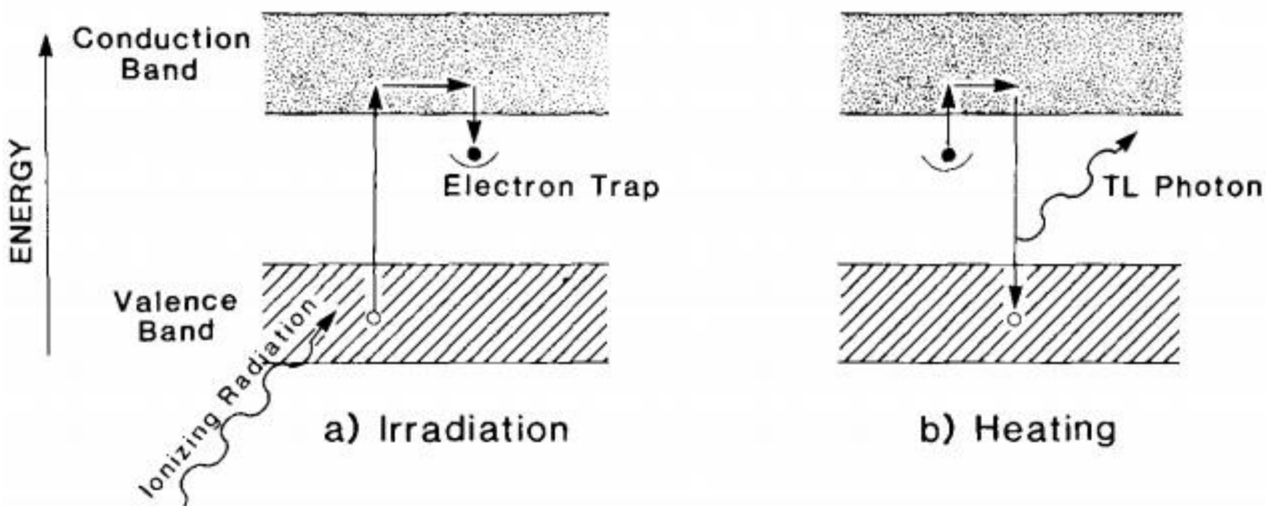
Diode detectors

Based on p-n junction of a semiconductor materials, when ionizing radiation falls on it ion pairs are created at the junction thus producing a current which is then measured.



Thermoluminescent (TLD) and Optically stimulated luminescence (OSL)

A fraction of electrons that are excited by ionizing radiation are trapped in excited states. We can release these electrons by heating (TLD) or by exposure to light(OSL). When these electrons fall to low energy state they emit light.



TLD

Teletherapy (external beam radiation therapy) is most common form of radiotherapy in the world.

Teletherapy means that patient is irradiated from “some distance” outside of the patient’s body.

While Brachytherapy means that patient is irradiate from inside the body or the irradiation source is very close (almost touches) the body.

Production of ionizing radiation

Ionizing radiation can came from radioisotopes or can be generated by linear accelerators.

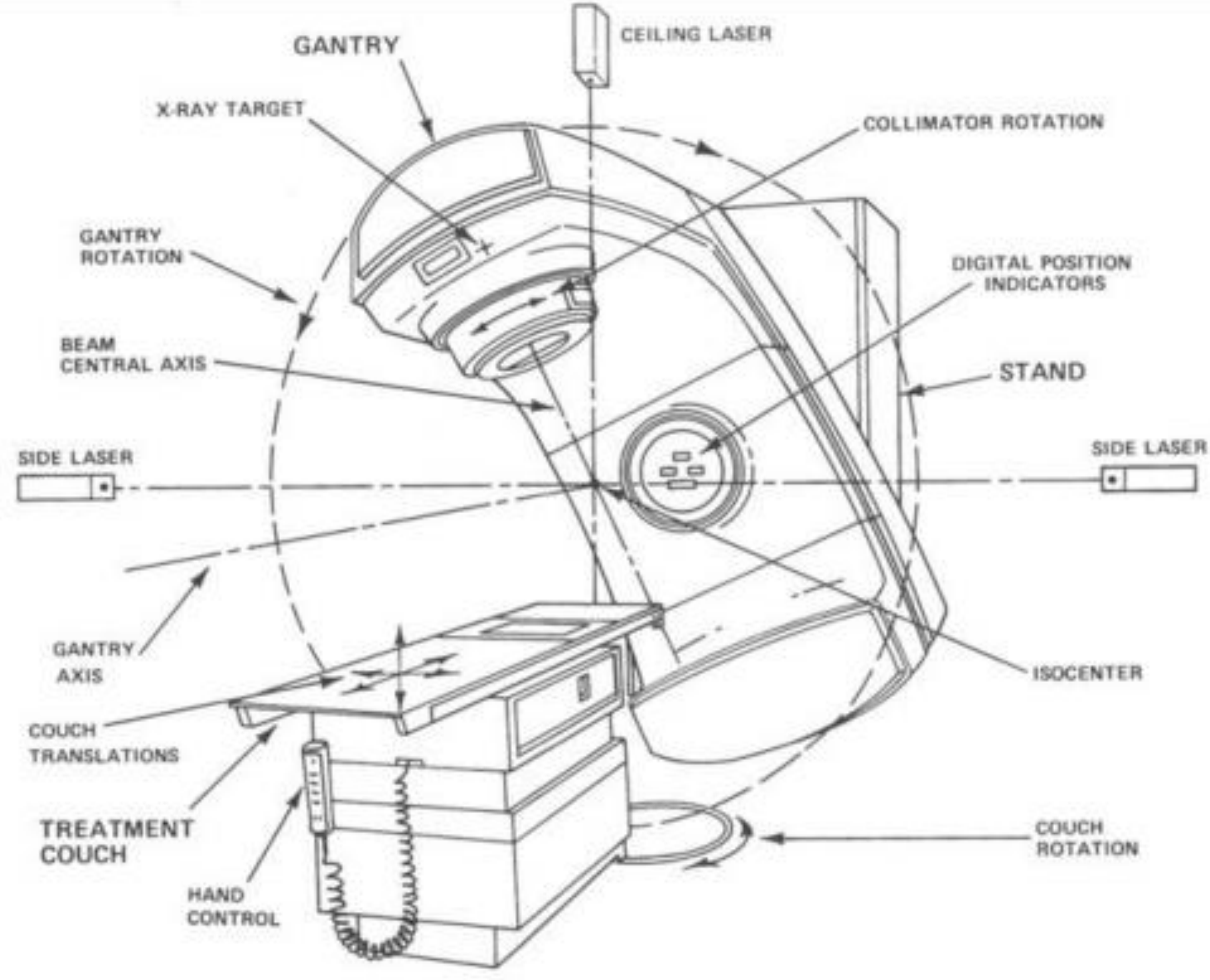
In teletherapy there are two types of machines linear accelerators and Co60 units

They started using cobalt 60 machines to treat cancer in 1950s, soon they started using medical accelerators.

From 1970s cobalt 60 units have been replaced by linear accelerators. Nowadays some clinics steel use cobalt units.

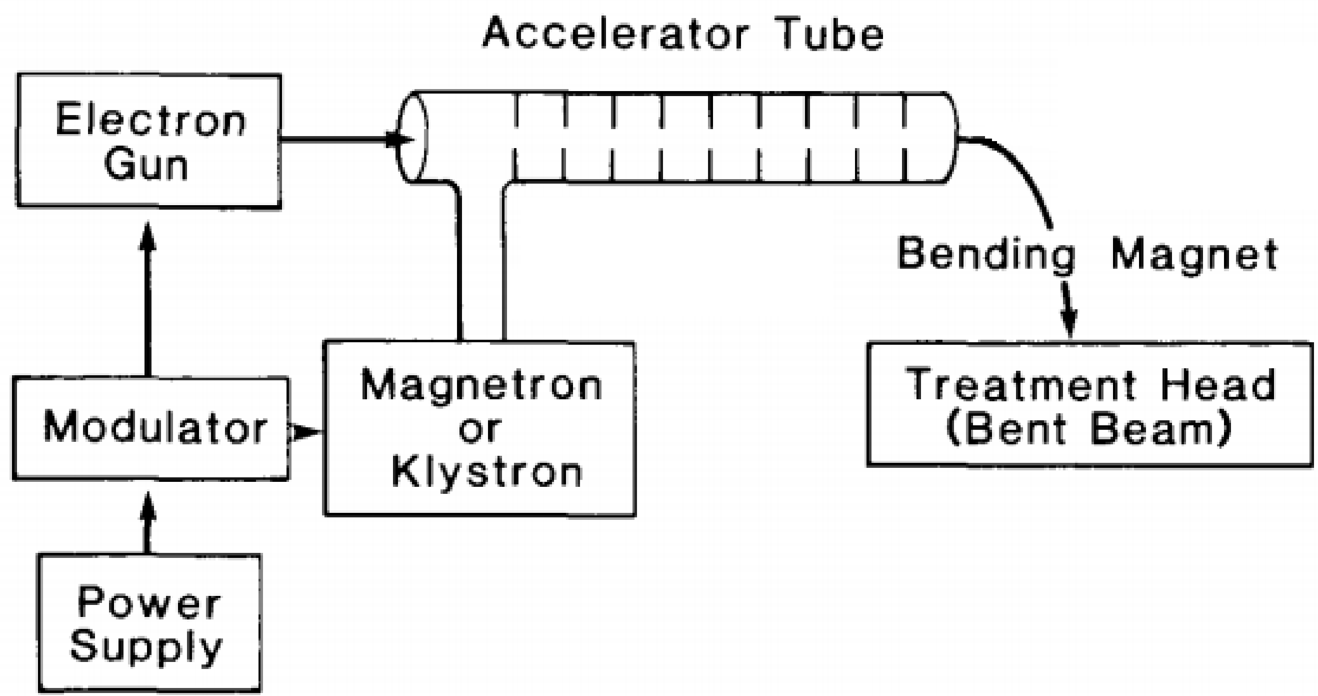
Cobalt 60 unit uses Cobalt-60 isotope which emits gamma rays of energy 1.17 and 1.33 Mev and its half life is 5.27 years

Linear accelerator

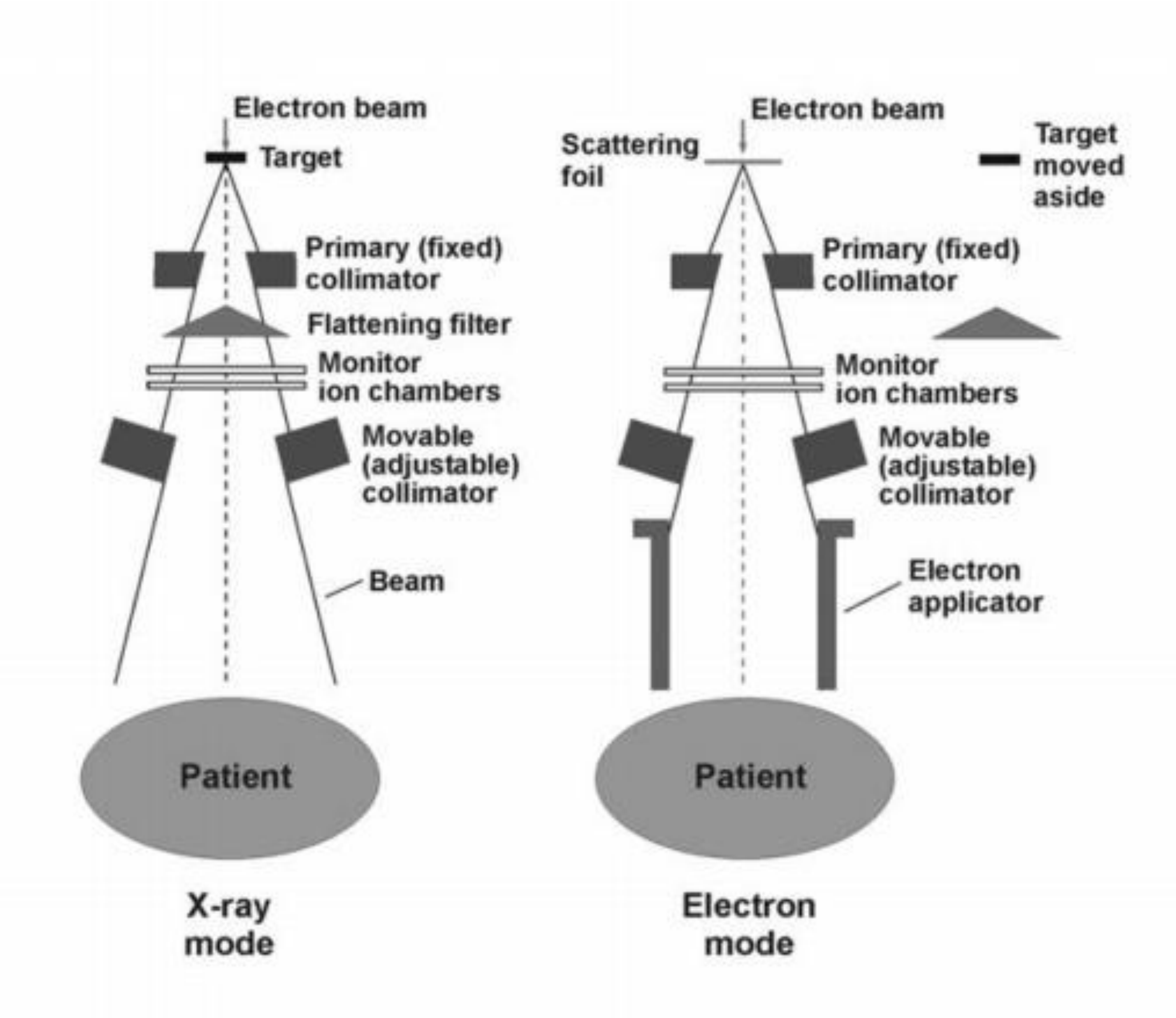


CEILING LASER
GANTRY
X-RAY TARGET
COLLIMATOR ROTATION
GANTRY ROTATION
DIGITAL POSITION INDICATORS
BEAM CENTRAL AXIS
STAND
SIDE LASER
SIDE LASER
GANTRY AXIS
ISOCENTER
COUCH TRANSLATIONS
TREATMENT COUCH
COUCH ROTATION
HAND CONTROL

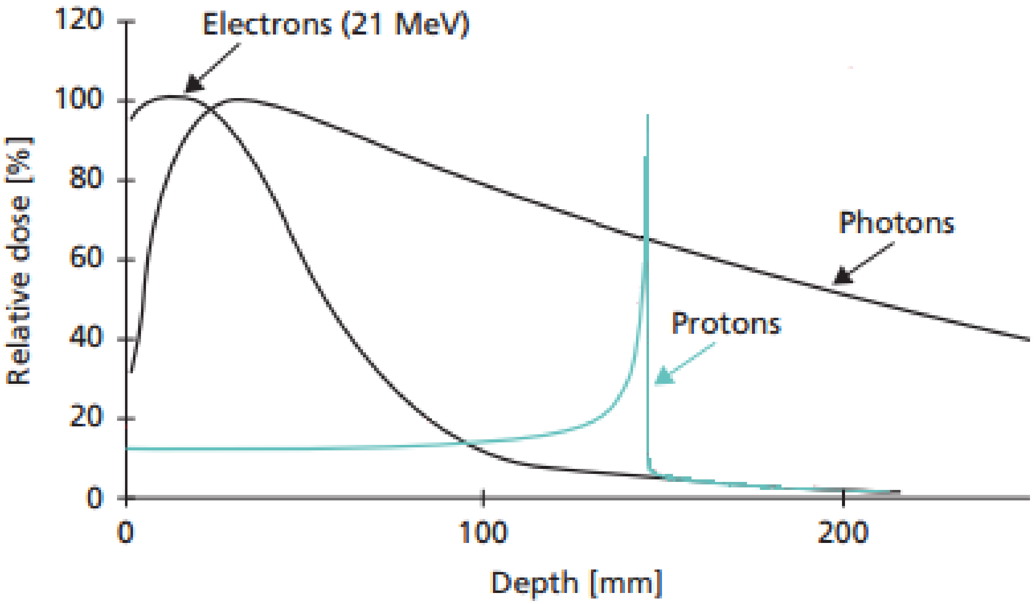
Electron acceleration



Treatment head



Beam Percentage Depth Dose (PDD)



Research Institute of Clinical Medicine (RICM)

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<u>Teletherapy</u>

Linear accelerators: two **TrueBeam** and **EDGE**

Photons: 6,10,15 (Mev)

Electrons 6,9,12,15,18 (Mev)

<u>Brachytherapy</u>

GammaMedPlus™ iX HDR

Ir-192 – 0.38Mev

I wish you never have cancer!

Thank you !