<u>RADITATION THERAPY INSTRUMENTS</u>: Radioisotopes in medicine, COBALT-60, LINAC, Gamma Camera, Nuclear scintigraphy, ISODOSE Chart.

Radioisotopes in medicine

The field of nuclear medicine uses radiation to provide diagnostic information about the functioning of humans or information on how to treat them. Tens of millions of nuclear medicine procedures are performed each year and the demand for radioisotopes for medical use is increasing rapidly.

Areas of Medicine where radioisotopes used:

Sterilization of medical products

- Today, over half of all medical equipment used in modern hospitals is sterilized using radiation. New drug testing
- Over 80% of all new drugs are tested with radioactive tagging before approval.

Medical Imaging

- Approximately 68 million CT scans are performed in the U.S according to the National Council on Radiation (NCRP).

Therapy

- Approximately 10% of medical procedures use radiation to treat a variety of diseases, including many types of cancers, heart disease, gastrointestinal, endocrine, neurological disorders and other abnormalities within the body.
- 85% of all nuclear medicine examinations use Mo/Tc Generators for diagnostics of liver, lungs, and bones. Out of 5 Mo-99 generating nuclear reactors are nearing the ends of their service life and will be decommissioned or need extensive overhauls in the next few years.
- Non-reactor technetium can be produced in small quantities from cyclotrons and accelerators, in a cyclotron by bombarding a Mo-100 target with a proton beam to produce Tc-99m directly, or in a linear accelerator to generate Mo-99 by bombarding a Mo-100 target with high-energy X-rays.

Radiation in medical therapy was first applied to the treatment of thyroid cancer. The patient drinks a determined amount of the solution spiked with radioactive iodine-131. This radioisotope preferentially lodges in the thyroid. The beta emissions of this radioisotope subsequently target and destroy the cancer in the thyroid.

External radiation therapy uses an external beam of radiation to focus on cancerous growths. An incident beam of x-rays or protons is moved around the patient in a precise manner so that the beam remains focused on the tumor minimizing the length of time the penetrating radiation beam doesn't remain on any of the healthy cells for very long.

Internal radionuclide therapy can be administered by planting a small radiation source, usually a gamma or beta emitter in the target area(s). Iridium 192 implants are used often in the brain and breast regions. They are produced in wire form and are introduced through a catheter to the target area. After administering the correct dose, the implant wire is removed.

Boron Neutron Capture Therapy (BNCT): In this procedure boron is injected into the patient to preferentially concentrate at the tumor site. A neutron beam is then focused on the boron. Neutrons react with the boron to produce alpha particles that destroy the malignant cells in the immediate vicinity of the concentrated boron. Since alpha particles are stopped at a very short distance from their point of origin, intense radiation damage is localized.

Therapy

Gamma Knife Radio surgery (Cyber Knife)

Minimizing injury to healthy cells, radiation therapy involves rotating an external radiation beam around the patient. The radiation from the radioactive source is delivered from many directions, with the beam continually focused on the target abnormality with only small amounts of radiation passing through healthy tissue.

Brachytherapy is a form of internal radio therapy where a radiation source is placed inside or next to the area requiring treatment. Brachytherapy involves the precise placement of short-range radioisotopes directly at the site of the cancerous tumor. These are enclosed in a protective capsule or wire that allows the ionizing radiation to escape. The radiation treats and kills surrounding tissue, but prevents the charge of radioisotopes from moving or dissolving in the body fluids. The capsule may be removed later, or with some isotopes, it may be allowed to remain in place for prolonged treatment. A key feature of brachytherapy is that the radiation affects a localized area around the radiation source. In addition, if the patient moves, or if there's any movement of the tumor within the body during treatment, the radiation source retains its correct position in relation to the tumor.

There is no doubt that medical research will find more ways to use radiation and radioisotopes to improve our lives.

Cobalt 60 Machine

- 1950 introduced to medical use. Hard metal substance-atomic mumber-27, At Wt-58.93% of mass density-8900 kgm^{-3}, units at 1500^{o}C source of radiation-pellet of radioactive cobalt isotopes.
- Half life-5.26years-when id decays ityields 28 rays of energy 1.17 and 1.33 MeV equal high penetration.
- Production of ^{60}C source: any material placed within neutron radiation field of a muclear reaction will become radioactive. To produce source of strength 4000 ci cobalt remains for 2 years in reactor. In practice sources are made into capsule to a selection of specific activities. Pellets are loaded into cylinder and inserted into another cylinder and cold welded shut. All these operations are carried out remotely in a hot cell.

Construction

1. Cobalt source head
2. Head mounts
3. Collimator
4. Treatment table
5. Control console and safety interlocks

Cobalt source head

-Heart of the system cobalt source. It is placed in lead filled steel container.

- Source is mounted in a heavy metal like tungsten wheel that is rotated thro' 180^{o} to carry it from "off" to "on" position. Motor drive and torque spring is used for this source is mounted in a scudding pury or which carries source from on to off.

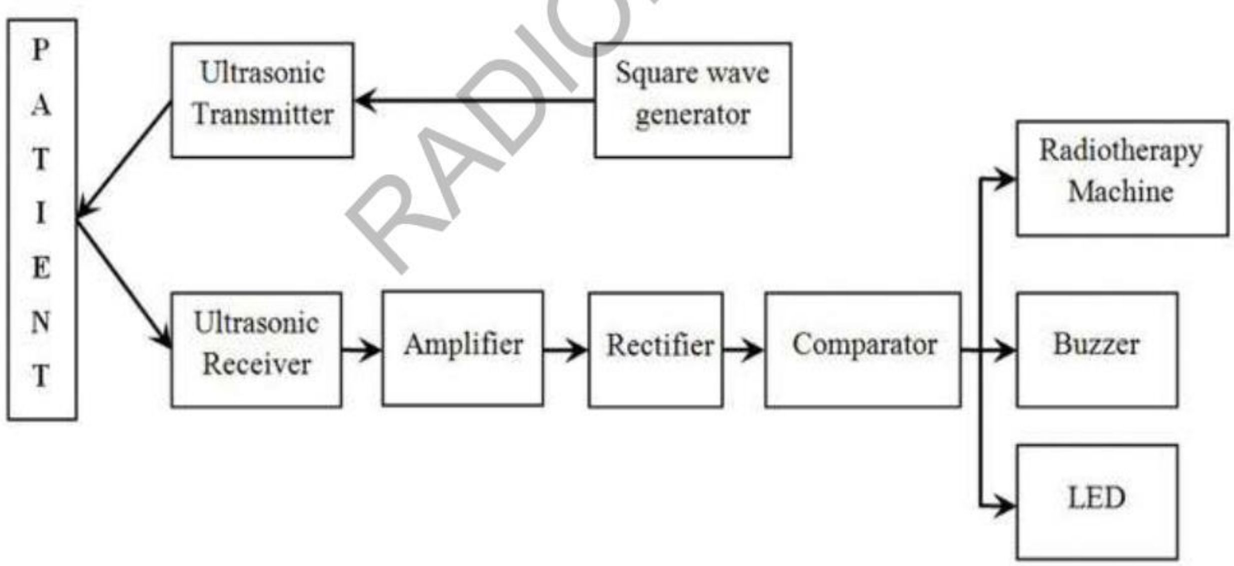
- Fail safe system is arranged, duriy poles failure it should return to off position.

- Lead filled container is 25cm thick in all direction. Leakage radiation should not cause any harm to others.

Mounts 2 types

- Head of unit is mounted on yoke which is mounted up and down or back and forth of rotated. This motion of mount allows the unit it place end of treatment applicator against skin at prescribed location. SSD-Distance from source to skin -80cm. Head mount is suspended from ceiling unit is mounted on vertical column-isocentric or fixed source axis distance (SAD) provides vibration free movement.
- Collimators-has set of bars that can produce radiation beam with rectangular cross-section. Rotates 360^{o}, position is locked by rotary knob.
- It has four sets of flat, inter-leaved lead vanes with angulated inner tungsten trees for continuously variable field size(3x3, 35x35)

- An optical device projects easy to read scale on patient's skin.
- Treatment table-patient lies on couch which can be raised/lowered, moved sideways so tumour is positioned at axis so beam will pass through the tumour.
- The focus of attention is now at the tumour rather than the surface. This mount is isocentric because axis of rotation of gantry intersects with central axis of beam so they both rotate at some axis.
- The carriage assembly consists of aluminium casting below table top. It includes bearing assembly and positioning control.
- It is provided with multiple safeguards to protect patient and therapist.
- Control console and safety interlocks-placed outside treatment room. It permits selection of treatment technique such as rotation.
- Oscillation Skip scanning or multi portal indexing, direction selector.
- Exposure timer counts down as treatment time diminishes and displayed in LED read out. Count up exposure time is displayed with progress of treatment.
- Entrance door interlock permits interconnection of safety switch at entrance door
- Exposure automatically terminates if entrance door is opened while source is 'ON'
- Cobalt unit is mechanically simple and its o/p is totally predictable and reliable. Used for short treatments.
- It is easy to make special filters and beam modifiers for individual treatment needs.
- Because of source decay, sources must be renewed at intervals of around five years.



Advantages- They has single electrical drives, saves money and power. They produce continues stream of particles at the target. So average power is high and It is very compact.

LINAC-Linear Accelerator Machine

- Linac is a precise reliable treatment instrument that was introduced in 1960's.
- Linear accelerator is a part of a system where e^- is accelerated to the required level of energy.
- It delivers mega voltage X-ray beam and has 3 main components

  gantry and stavel

  Treatment couch

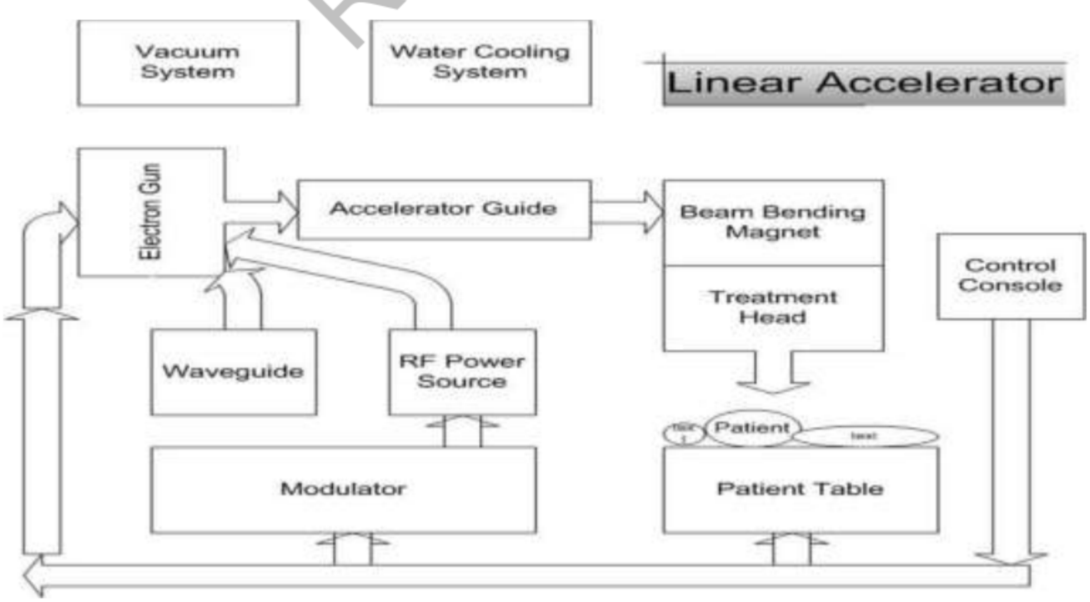
  Control console

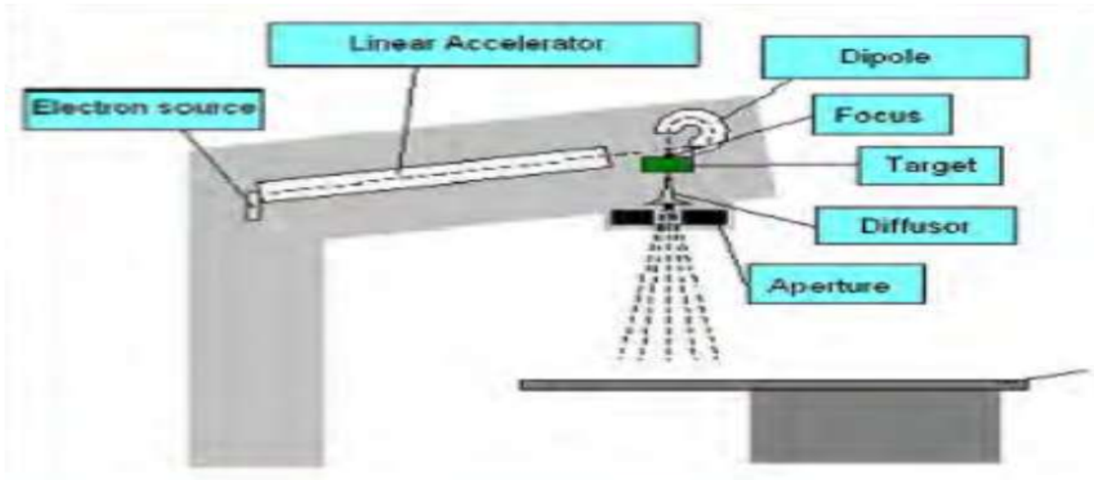
- The treatment beam is generated by a linear accelerator wave guide in the gantry and produces a photon beam of energy in the range 11-20 MeV.
- The accelerator accessibly is mounted in rotating gentry with 100 cm target axis distance. The gantry has X-Ray collimating system and also a display of for gantry, rotation angle. Collimator opening and collimator rotation angle.
- The stand supports the gantry and also contains electronic circuitry for motor control and high voltage power supply for microwaves source and e- gun.

<u>The Accelerator</u>

The heart of the linac the have 4 main components

1) Modulator
2) Electron gun
3) RF power source
4) Accelerator Guide





- The e- accelerator is a wave guide which is energized at microwave frequency, 3000 MHz. The radiation is supplied in short pulses, for few seconds long.
- These pulses are generated by supplying high voltage pulses of 5kv from the modulator to the microwave generator which is a magnetron valve.
- The e- gun is also pulsed so that high energy level e- are injected into accelerating wave guide.

1) **Modulator**

   Main function is to supply high voltage pulses to the microwave generator. Specialized circuitry steps up and produces high voltage pulses to the e- gun and RF power source.

   It contains a Thyratron which is a high power switching device which device the HV pulses to e- gun and RF power source.

   The dose rate from the accelerator guide is regulated by controlling the pulses the frequency.

   Modulator maybe located in either the gantry or stand and electrical connections to e- gun and source are made through HV cables.

2) **Electron gun:-**

   It is pulsed by modulator and injects pulses of e- into accelerator guide at energies of about 15-40 KeV and are further accelerated inside guide to required energy level.

   e- gun can be diode or triode

   All guns employ a heater or filament.

3) **RF Power source:-**

   Power source is either a magnetron (low-medium energy accelerator) or klystron (High energy accelerators)

   They employ a no of RF clarities either in circle (magnetron) or in a straight line (Klystron).

   The RF power source provides HF EM wave (3000MHz) that accelerate the e- injected from gun down the accelerator guide.

   Amplified RF power is fed into a wave guide special hollow metallic tube used to transport to microwave that is connected to the accelerator.

4) **Accelerator wave guide:-**

It is made up of a number of specially shaped copper microwave resonant cavities that are joined together to form a single structure. Length of Str is between 30cm -2.5 m

All accelerator structures are of 2 basic types- travelling wave (TW) or standing wave (SW). The SW system accelerates the e- in a field of content amplified which the field in TW system is attenuated as it moves along the guide.

Coaxial magnetic field supplied by coils steer the e- beam in required position and direction.

These guides get heated up and a water cooling system is provided in the form of a water jacket through which temperature controlled water is circulated.

An ion pump is used to rate vacuumed condition so that e- does not get deflected.

Treatment Head:-

The treatment head contains the X-ray target filtering system, beam monitor detectors and beam defining system.

The accelerator e- either are used to produce X-ray or used directly.

A flattening filter (cove shaped) is used to give energy dose over area of interest.

i) **Collimators**- has a primary collimator and 2 pair of movable secondary collimators. The opening is 40x40 cm. The collimator jaws should be able to close or open. It can be rotated about an axis. The assembly also has a light source that projector light in patient to dyine entry position of radiation. Range firder determines target skin distance.

Some linac's use dual x-ray energy level accelerator. They provide 2 x-ray energies.

Dose rates should be 200 Gy/min for all energies.

Sometimes are therapy is employed where there is rotation of gantry at constant speed.

ii) **Gantry**

The gantry houses the accelerating wave guide. The treatment head and radiation shielding

It is supported in a vertical stand that is fixed to a team.

It rotates 360° clockwise and counter clockwise.

Rotation is provided by a drive shaft connected to a servo drive motor.

<u>Control console</u>

Control the accelerator located outside the treat room.

All control enable operation of the unit.

The selection of the dose to be given for treatment and has interlock circuitry to protect patient and treatment unit.

Radiation on and off also can be done.

Interlocks shut the machine off in the event of malfunction in the whole system.

<u>Patient couch</u>

Motion is controlled by control located on side of couch or pendant (a device e- controls having from ceiling)
Should have adequate range of travel.
Head extension beam should be there for tall persons.

Nuclear Scintigraphy:-

Scint is latin means spark.
Nuclear scintigraphy is a form of magnetic test used in nuclear medicine whereas radio pharmaceuticals are taken internally and the emitted radiation is captured by external electron (gamma Cameras) to form 2D images.
Here external radiations are not passed through the body.
Nuclear scintigraphy is also known as bone scan, that provides a screening tool to locate areas of increased metabolic activity in soft tissue or bone which ray indicate a site of injury.

This process is normally done in hoses, where electronegative 99 tagged with phosphorous is inserted into body. 97% of traces is decayed in 30 hours.
Can be used to image areas that are difficult to access like back and upper limb
Scintigraphs can provide valuable information than ledregcaphs or ultra sound so in looks at metabolic activity than auatony.

Nuclear scintigraphy in medicine
Cholescintigraphy- scintigraphy of bilayer system
Used to diagnosis obstruction of bile ducts by gallstone tumour and also to evaluate the health and function of the gall bladder.
A radioactive lraces, 'technetium-99' is corrected through an accessible vein and allowed to circulate to liver where it is excreted into the binary system (bile ducts, gall bladder and intestine).
A gamma camera is placed on abdomen to picture these perfuse organs.
In the absence of the disease, gall bladder is visualized within 1 hour of injection leaces.
If gall bladder is not visualized within 4 hours after the injection, this indicates cystic duct obstruction.

Scintigraphy is normally done after on abdominal examination as test is more sensitive, opecific, costly and invasive.
Usually sensitivity is 95% and specificity is 90%.

Lung scintigraphy
Used to diagnosis pulmonary embolism evaluates lung transplantation, pre operative evaluation and evaluation of right to left shunts.
It mainly use ventilation / pesfusous scan.

In the ventilation phase of the scan, a gaseous electro nuclide 'xenon' or technitives DTPA (diethylene triamine penta acetic acid) in an aerosol form is inhaled by the patient through a mouthpiece that covers the nose and mouth.
In the perfusious phase an intravenous injection, radioactive technique macro aggregated albumin (Tc99m-MAA) is administered.
Gamma camera acquires the images of both the phase for study.

Bone Scintigraphy
A legaivel methylene diphosphate (MDP) is taken by the bone.
By chemically attaching technetium 99m to MDP, radioactivity can be transported and attached to bone (vla) hydroxyapatite for imaging.
Any physiological function (fracture in bone) will mean increased concentration of traces at the site.

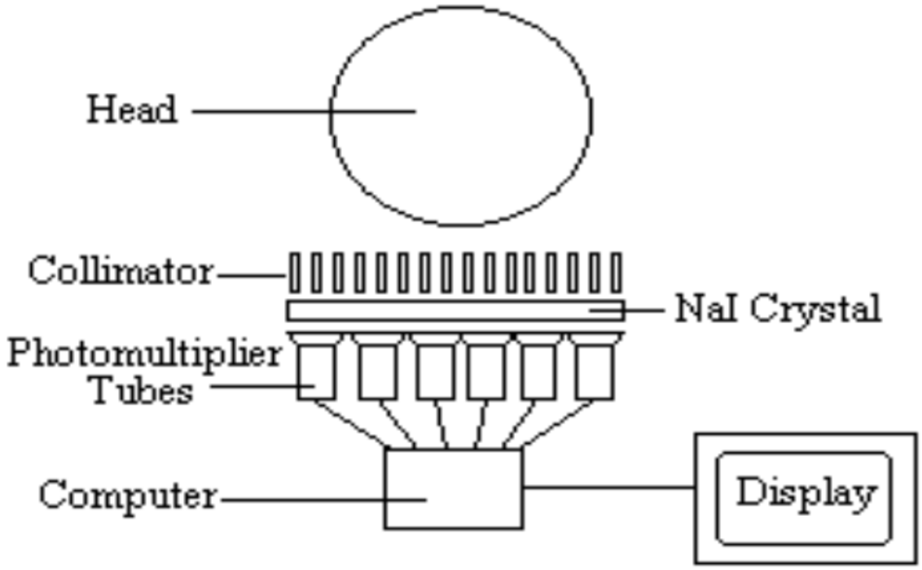
GAMMA CAMERA

The gamma camera is an imaging technique used to carry out functional scans of the brain, thyroid, lungs, liver, gallbladder, kidneys and skeleton.

Gamma cameras image the radiation from a tracer introduced into the patient's body.

The most commonly used tracer is technetium-99m, a metastable nuclear isomer chosen for its relatively long half-life of six hours and its ability to be incorporated into a variety of molecules in order to target different systems within the body. As it travels through the body and emits radiation the tracer's progress is tracked by a crystal that scintillates in response to gamma-rays.

The crystal is mounted in front of an array of light sensors that convert the resulting flash of light into an electrical signal. Gamma cameras differ from X-ray imaging techniques in one very important respect; rather than anatomy and structure, gamma cameras map the function and processes of the body.



This is an imaging device used in nuclear scanning. By far the most widely used gamma camera was invented by H. Anger in the 1960s and is often referred to as the **Anger** camera.

An Anger camera consists of a collimator, placed between the detector surface and the patient (the patient's head is depicted as a circle in the diagram to the left). This is made out of a highly absorbing material such as lead, serving to suppress gamma rays that deviate substantially from the vertical and so acting as a kind of "lens". The simplest collimators contain parallel holes.

Depending on the position of the radiation event, the appropriate phototubes are activated. The positional information is recorded onto film as an analogue image or onto a computer (coupled to the camera) in digital form.

This set-up yields relatively accurate positional information. The intrinsic resolution of two radiation sources placed immediately on the crystal surface without the collimator is in the order of 1 mm.

The Anger camera principle is used in one type of PET camera. PET (Positron Emission Tomography) imaging is a tomographic nuclear imaging procedure that uses positron emitters and that records the gamma rays produced by the ensuing positron-electron annihilations. Note: tomography is a general scanning technique that displays a plane cross-section, especially through the body (Greek 'tome' = a cutting).

Digital gamma cameras are currently under development that use arrays of small crystals digitally interfaced to a computer. It is too early to say how they will compare with the Anger camera principle in clinical practice.

ISODOSE CHART:

Within the area A each point at a certain depth d receives the same dose → **ISODOSE.** Isodose profiles are plotted in terms of the **percentage depth dose in % DD** because absolute dose measurements are difficult. The percentage depth dose is the absorbed dose at a given depth d expressed as a percentage of the absorbed dose at a reference depth d_{max} along the central axis of the beam.

$$\%DD = \frac{D(d)}{D(d_{max})} \cdot 100 \quad [\%]$$

Isodose charts are usually plotted in increments of 10 %. They depend on the beam geometry and the various absorption effects within the body tissue.