SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – I - RADIO IMAGING AND THERAPEUTICS– SBMA1404

UNIT-1

I ELEMENTS OF RADIATION

Radioactive elements and Radioisotopes in medicine, Radioactivity, General properties of alpha, beta and gamma rays - Laws of radioactivity, Radioactive decay - alpha decay, beta decay, positron decay, decay energy and half-life. Radiation units-Roentgen, Rad - rem - sievert. Radiation sources - Natural and artificial radioactive sources.

1.1 Radiology

Radiology is a branch of medicine that employs the use of imaging to to diagnose and treat diseases seen within the body. A variety of imaging techniques such as X-ray radiography, ultrasound, computed tomography (CT), nuclear medicine including positron emission tomography (PET), and magnetic resonance imaging (MRI) are used to diagnose and/or treat diseases. Interventional radiology is the performance of (usually minimally invasive) medical procedures with the guidance of imaging technologies.

Radiology can be categorized for different organs or regions of body like chest radiology, cardiovascular radiology, fetal radiology, GI radiology, Nuclear medicine, pediatrics radiology etc.

Radiology is also known as Roentgenology after William Conrad Rontgen who discovered X- rays.

Roentgenology: Radiology, the science of radiation and, specifically, the use of both ionizing (like X-ray) and nonionizing (like ultrasound) modalities for the diagnosis and treatment of disease.

Roentgenology is named for Wilhelm Conrad Roentgen who discovered X-rays. Roentgen, a professor of physics in Germany, wanted to prove his hypothesis that cathode rays could penetrate substances besides air. When he saw that he could film his thumb and forefinger and their bones on a screen, the story goes that he replaced the screen with a photographic plate and X-rayed his wife's hand. Roentgen's report of his findings, "On a New Kind of Rays," was published by the Physical-Medical Society of Wurzburg in December 1895.

Radiations:

Radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium

OR Radiation is the Energy emitted from the sources or an energy that can be transported or propagated through space of matter.

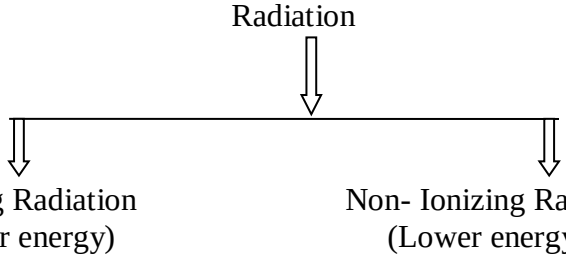
Eg. : - Electromagnetic waves, Microwaves from oven, heat or light, X-ray, γ- rays from radioactive elements

Radiation exhibit "wave like" behavior in these interactions with matter (diffraction, Rasmussen, etc)

Radiation includes:

- **Electromagnetic Radiation**, such as radio waves, visible light, x-rays, and gamma radiation (γ)
- **Particle Radiation**, such as alpha radiation (α), beta radiation (β), and neutron radiation (particles of non-zero rest energy)
- **Acoustic radiation**, such as ultrasound, sound, and seismic waves(dependent on a physical transmission medium)
- **Gravitational radiation**, radiation that takes the form of gravitational waves, or ripples in the curvature of space-time.

Radiations are of two types depending on the energy of the radiated particles:



Ex: α, β, or γ radiation, X-rays, UV-rays

Ex: visible light, infrared light, microwaves, radio waves and UV- rays

Ionizing radiation:

Ionizing radiation carries more than 10 eV, which is enough to ionize atoms and molecules, and break chemical bonds. This is an important distinction due to the large difference in harmfulness to living organisms. A common source of ionizing radiation is radioactive materials that emit α, β, or γ radiation, consisting of helium nuclei, electrons or positrons, and photons, respectively. Other sources include X-rays from medical radiography examinations and muons, mesons, positrons, neutrons and other particles that constitute the secondary cosmic rays that are produced after primary cosmic rays interact with Earth's atmosphere. Gamma rays, X-rays and the higher energy range of ultraviolet light constitute the ionizing part of the electromagnetic spectrum.

Radiation with sufficiently high energy can ionize atoms; that is to say it can knock electrons off atoms and create ions. Ionization occurs when an electron is stripped (or "knocked out") from an electron shell of the atom, which leaves the atom with a net positive charge. Because living cells and, more importantly, the DNA in those cells can be damaged by this ionization, exposure to ionizing radiation is considered to increase the risk of cancer. Thus "ionizing radiation" is somewhat artificially separated from particle radiation and electromagnetic radiation, simply due to its great potential for biological damage. While an individual cell is made of trillions of atoms, only a small fraction of those will be ionized at low to moderate radiation powers. The probability of ionizing radiation causing cancer is dependent upon the absorbed dose of the radiation, and is a function of the damaging tendency of the type of radiation (equivalent dose) and the sensitivity of the irradiated organism or the tissue's (effective dose).

If the source of the ionizing radiation is a radioactive material or a nuclear process such as fission or fusion, there is particle radiation to consider. Particle radiation is subatomic particles accelerated to relativistic speeds by nuclear reactions. Because of their momenta they are quite capable of knocking out electrons and ionizing materials, but since most have an electrical charge, they don't have the penetrating power of ionizing radiation. The exception is neutron particles; see below. There are several different kinds of these particles, but the majorities

are alpha particles, beta particles, neutrons, and protons. Roughly speaking, photons and particles with energies above about 10 electron volts (eV) are ionizing (some authorities use 33 eV, the ionization energy for water). Particle radiation from radioactive material or cosmic rays almost invariably carries enough energy to be ionizing.

Much ionizing radiation originates from radioactive materials and space (cosmic rays), and as such is naturally present in the environment, since most rock and soil has small concentrations of radioactive materials. The radiation is invisible and not directly detectable by human senses; as a result, instruments such as **Geiger counters** are usually required to detect its presence. In some cases, it may lead to secondary emission of visible light upon its interaction with matter, as in the case of Cherenkov radiation and radio-luminescence.

Application of Ionizing radiation:

Ionizing radiation has many practical uses in medicine, research and construction, but presents a health hazard if used improperly. Exposure to radiation causes damage to living tissue; high doses result in Acute radiation syndrome (ARS), with skin burns, hair loss, internal organ failure and death, while any dose may result in an increased chance of cancer and genetic damage; a particular form of cancer, thyroid cancer, often occurs when nuclear weapons and reactors are the radiation source because of the biological proclivities of the radioactive iodine fission product, iodine-131. However, calculating the exact risk and chance of cancer forming in cells caused by ionizing radiation is still not well understood and currently estimates are loosely determined by population based on data from the atomic bombing in Japan and from reactor accident follow-up, such as with the Chernobyl disaster. The International Commission on Radiological Protection states that "The Commission is aware of uncertainties and lack of precision of the models and parameter values", "Collective effective dose is not intended as a tool for epidemiological risk assessment, and it is inappropriate to use it in risk projections" and "in particular, the calculation of the number of cancer

deaths based on collective effective doses from trivial individual doses should be avoided."

1.2 Types of Ionizing Radiation:

1) Ultraviolet radiation (UV)

Ultraviolet, of wavelengths from 10 nm to 125 nm, ionizes air molecules, causing it to be strongly absorbed by air and by ozone (O3) in particular. Ionizing UV therefore does not penetrate Earth's atmosphere to a significant degree, and is sometimes referred to as vacuum ultraviolet. Although present in space, this part of the UV spectrum is not of biological importance, because it does not reach living organisms on Earth.

There is a zone of the atmosphere in which ozone absorbs some 98% of non-ionizing but dangerous UV-C and UV-B. This so-called ozone layer, starts at about 20 miles (32 km) and extends upward. Some of the ultraviolet spectrum that does reach the ground (the part that begins above energies of 3.1 eV, a wavelength less than 400 nm) is non-ionizing, but is still biologically hazardous due to the ability of single photons of this energy to cause electronic excitation in biological molecules, and thus damage them by means of unwanted reactions. An example is the formation of pyrimidine dimmers in DNA, which begins at wavelengths below 365 nm (3.4 eV), which is well below ionization energy. This property gives the ultraviolet spectrum some of the dangers of ionizing radiation in biological systems without actual ionization occurring. In contrast, visible light and longer-wavelength electromagnetic radiation, such as infrared, microwaves, and radio waves, consists of photons with too little energy to cause damaging molecular excitation, and thus this radiation is far less hazardous per unit of energy.

2) X-ray:

X-rays are electromagnetic waves with a wavelength less than about 10−9 m (greater than 3x1017 Hz and 1,240 eV). A smaller wavelength corresponds to a higher energy according to the equation E=hc/λ. ("E" is Energy; "h" is Planck's constant; "c" is the speed of light; "λ" is wavelength.) When an X-ray photon

collides with an atom, the atom may absorb the energy of the photon and boost an electron to a higher orbital level or if the photon is very energetic, it may knock an electron from the atom altogether, causing the atom to ionize. Generally, larger atoms are more likely to absorb an X-ray photon since they have greater energy differences between orbital electrons. Soft tissue in the human body is composed of smaller atoms than the calcium atoms that make up bone; hence there is a contrast in the absorption of X-rays. X-ray machines are specifically designed to take advantage of the absorption difference between bone and soft tissue, allowing physicians to examine structure in the human body.

X-rays are also totally absorbed by the thickness of the earth's atmosphere, resulting in the prevention of the X-ray output of the sun, smaller in quantity than that of UV but nonetheless powerful, from reaching the surface.

3) Gamma radiation:

Gamma (γ) radiation consists of photons with a wavelength less than $3x10^{-11}$ meters (greater than 1019 Hz and 41.4 keV).[3]Gamma radiation emission is a nuclear process that occurs to rid an unstable nucleus of excess energy after most nuclear reactions. Both alpha and beta particles have an electric charge and mass, and thus are quite likely to interact with other atoms in their path. Gamma radiation, however, is composed of photons, which have neither mass nor electric charge and, as a result, penetrates much further through matter than either alpha or beta radiation.

Gamma rays can be stopped by a sufficiently thick or dense layer of material, where the stopping power of the material per given area depends mostly (but not entirely) on the total mass along the path of the radiation, regardless of whether the material is of high or low density. However, as is the case with X-rays, materials with high atomic number such as lead or depleted uranium add a modest (typically 20% to 30%) amount of stopping power over an equal mass of less dense and lower atomic weight materials (such as water or concrete). The atmosphere absorbs all gamma rays approaching Earth from space. Even air is capable of absorbing gamma rays,

halving the energy of such waves by passing through, on the average, 500 ft (150 m).

4) Alpha radiation (Alpha decay):

Alpha particles are helium-4 nuclei (two protons and two neutrons). They interact with matter strongly due to their charges and combined mass, and at their usual velocities only penetrate a few centimeters of air, or a few millimeters of low density material (such as the thin mica material which is specially placed in some Geiger counter tubes to allow alpha particles in). This means that alpha particles from ordinary alpha decay do not penetrate the outer layers of dead skin cells and cause no damage to the live tissues below. Some very high energy alpha particles compose about 10% of cosmic rays, and these are capable of penetrating the body and even thin metal plates. However, they are of danger only to astronauts, since they are deflected by the Earth's magnetic field and then stopped by its atmosphere.

Alpha radiation is dangerous when alpha-emitting radioisotopes are ingested (breathed or swallowed). This brings the radioisotope close enough to sensitive live tissue for the alpha radiation to damage cells. Per unit of energy, alpha particles are at least 20 times more effective at cell-damage as gamma rays and X-rays. See relative biological effectiveness for a discussion of this. Examples of highly poisonous alpha-emitters are all isotopes of radium, radon, and polonium, due to the amount of decay that occur in these short half-life materials.

5) Beta radiation Beta decay:

Beta-minus (β−) radiation consists of an energetic electron. It is more penetrating than alpha radiation, but less than gamma. Beta radiation from radioactive decay can be stopped with a few centimeters of plastic or a few millimeters of metal. It occurs when a neutron decays into a proton in a nucleus, releasing the beta particle and an antineutrino. Beta radiation from linacaccelerators is far more energetic and penetrating than natural beta

radiation. It is sometimes used therapeutically inradiotherapy to treat superficial tumors.

Beta-plus (β+) radiation is the emission of positrons, which are the antimatter form of electrons. When a positron slows to speeds similar to those of electrons in the material, the positron will annihilate an electron, releasing two gamma photons of 511 keV in the process. Those two gamma photons will be traveling in (approximately) opposite direction. The gamma radiation from positron annihilation consists of high energy photons, and is also ionizing.

6) Neutron radiation and Neutron temperature:

Neutrons are categorized according to their speed/energy. Neutron radiation consists of free neutrons. These neutrons may be emitted during either spontaneous or induced nuclear fission. Neutrons are rare radiation particles; they are produced in large numbers only where chain reaction fission or fusion reactions are active; this happens for about 10 microseconds in a thermonuclear explosion, or continuously inside an operating nuclear reactor; production of the neutrons stop almost immediately in the reactor when it goes non-critical.

Neutrons do not ionize atoms in the same way that charged particles such as protons and electrons do (by the excitation of an electron), because neutrons have no charge. It is through their absorption by nuclei which then become unstable that they cause ionization. Hence, neutrons are said to be "indirectly ionizing." Even neutrons without significant kinetic energy are indirectly ionizing, and are thus a significant radiation hazard. Not all materials are capable of neutron activation; in water, for example, the most common isotopes of both types' atoms present (hydrogen and oxygen) capture neutrons and become heavier but remain stable forms of those atoms. Only the absorption of more than one neutron, a statistically rare occurrence, can activate a hydrogen atom, while oxygen requires two additional absorptions. Thus water is only very weakly capable of activation. The sodium in salt (as in sea water), on the other hand, need only absorb a single neutron to become Na-24, a very intense source of beta decay, with half-life of 15 hours.

7) Cosmic radiation or Cosmic rays:

There are two sources of high energy particles entering the Earth's atmosphere from outer space: the sun and deep space. The sun continuously emits particles, primarily free protons, in the

solar wind, and occasionally augments the flow hugely with coronal mass ejections (CME).

The particles from deep space (inter- and extra-galactic) are much less frequent, but of much higher energies. These particles are also mostly protons, with much of the remainder consisting of helions (alpha particles). A few completely ionized nuclei of heavier elements are present. The origin of these galactic cosmic rays is not yet well understood, but they seem to be remnants of supernovae and especially gamma-ray bursts (GRB), which feature magnetic fields capable of the huge accelerations measured from these particles. They may also be generated by quasars, which are galaxy-wide jet phenomena similar to GRBs but known for their much larger size, and which seem to be a violent part of the universe's early history.

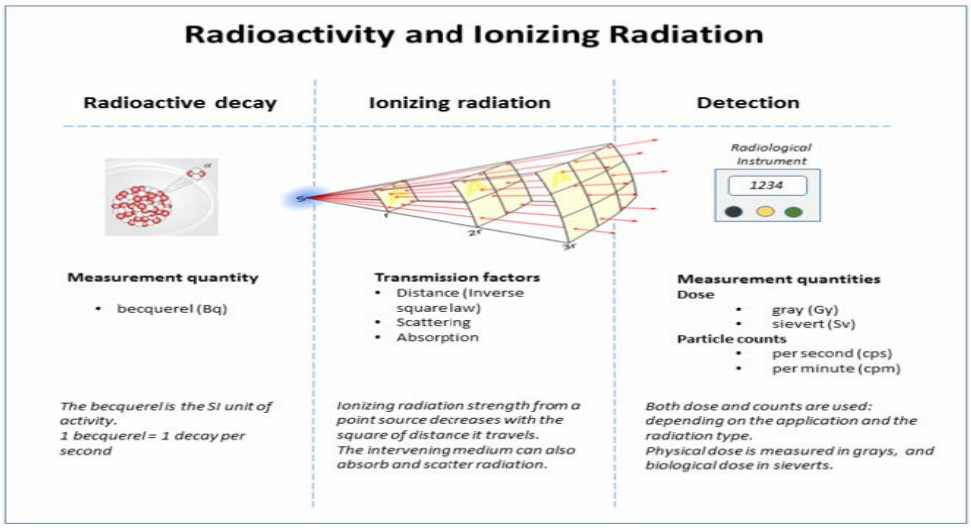


Fig.1.1: Non- Ionizing radiation and Electromagnetic radiation

Non- Ionizing radiation and Electromagnetic radiation:

The lower-energy, longer-wavelength part of the spectrum effect when interacting with tissue is heating, it includes visible light, infrared light, microwaves, and radio waves as non-ionizing radiation. This type of radiation only damages cells if the intensity is high enough to cause excessive heating. Ultraviolet radiation has some features of both ionizing and non-ionizing radiation. While the part of the ultraviolet spectrum that penetrates the Earth's atmosphere is non-ionizing, this radiation does far more damage to many molecules in biological systems than can be accounted for by heating effects, sunburn being a well-known example. These properties derive from ultraviolet's power to alter chemical bonds, even without having quite enough energy to ionize atoms.

The word radiation arises from the phenomenon of waves radiating (i.e., traveling outward in all directions) from a source. This aspect leads to a system of measurements and physical units that are applicable to all types of radiation. Because such radiation expands as it passes through space, and as its energy is conserved (in vacuum), the intensity of all types of radiation from a point source follows an inverse-square law in relation to the distance from its source. This law does not apply close to an extended source of radiation or for focused beams.

The kinetic energy of particles of non-ionizing radiation is too small to produce charged ions when passing through matter. For non-ionizing electromagnetic radiation, the associated particles (photons) have only sufficient energy to change the rotational, vibrational or electronic valence configurations of molecules and atoms. The effect of non-ionizing forms of radiation on living tissue has only recently been studied. Nevertheless, different biological effects are observed for different types of non-ionizing radiation. Even "non-ionizing" radiation is capable of causing thermal-ionization if it deposits enough heat to raise temperatures to ionization energies. These reactions occur at far higher energies than with ionization radiation, which requires only single particles to cause

ionization. A familiar example of thermal ionization is the flame-ionization of a common fire, and the browning reactions in common food items induced by infrared radiation, during broiling-type cooking.

The electromagnetic spectrum is the range of all possible electromagnetic radiation frequencies. The electromagnetic spectrum (usually just spectrum) of an object is the characteristic distribution of electromagnetic radiation emitted by, or absorbed by, that particular object.

The non-ionizing portion of electromagnetic radiation consists of electromagnetic waves that are not energetic enough to detach electrons from atoms or molecules and hence cause their ionization. These include radio waves, microwaves, infrared, and visible light. The lower frequencies of ultraviolet light may cause chemical changes and molecular damage similar to ionization, but is technically not ionizing. The highest frequencies of ultraviolet light, as well as all X-rays and gamma-rays are ionizing.

The occurrence of ionization depends on the energy of the individual particles or waves, and not on their number. An intense flood of particles or waves will not cause ionization if these particles or waves do not carry enough energy to be ionizing, unless they raise the temperature of a body to a point high enough to ionize small fractions of atoms or molecules by the process of thermal-ionization (this, however, requires relatively extreme radiation intensities).

1.3 Types of Non-Ionizing Radiation:

1) Ultraviolet light radiation:

As noted above, the lower part of the spectrum of ultraviolet, called soft UV, from 3 eV to about 10 eV, is non-ionizing. However, the effects of non-ionizing ultraviolet on chemistry and the damage to biological systems exposed to

it (including oxidation, mutation, and cancer) are such that even this part of ultraviolet is often compared with ionizing radiation.

2) Visible light radiation:

Light, or visible light, is a very narrow range of electromagnetic radiation of a wavelength that is visible to the human eye, or 380–750 nm which equates to a frequency range of 790 to 400 THz respectively. More broadly, physicists use the term "light" to mean electromagnetic radiation of all wavelengths, whether visible or not.

3) Infrared radiation:

Infrared (IR) light is electromagnetic radiation with a wavelength between 0.7 and 300 micrometers, which corresponds to a frequency range between 430 and 1 THz respectively. IR wavelengths are longer than that of visible light, but shorter than that of microwaves. Infrared may be detected at a distance from the radiating objects by "feel." Infrared sensing snakes can detect and focus infrared by use of a pinhole lens in their heads, called "pits". Bright sunlight provides an irradiance of just over 1 kilowatt per square meter at sea level. Of this energy, 53% is infrared radiation, 44% is visible light, and 3% is ultraviolet radiation.

4) Microwave radiation:

Microwaves are electromagnetic waves with wavelengths ranging from as short as one millimeter to as long as one meter, which equates to a frequency range of 300 GHz to 300 MHz. This broad definition includes both UHF and EHF (millimeter waves), but various sources use different other limits.[3] In all cases, microwaves include the entire super high frequency band (3 to 30 GHz, or 10 to 1 cm) at minimum, with RF engineering often putting the lower boundary at 1 GHz (30 cm), and the upper around 100 GHz (3mm).

5) Radio waves:

Radio waves are a type of electromagnetic radiation with wavelengths in the electromagnetic spectrum longer than infrared light. Like all other electromagnetic waves, they travel at the speed of light. Naturally occurring radio

waves are made by lightning, or by certain astronomical objects. Artificially generated radio waves are used for fixed and mobile radio communication, broadcasting, radar and other navigation systems, satellite communication, computer networks and innumerable other applications. In addition, almost any wire carrying alternating current will radiate some of the energy away as radio waves; these are mostly termed interference. Different frequencies of radio waves have different propagation characteristics in the Earth's atmosphere; long waves may bend at the rate of the curvature of the Earth and may cover a part of the Earth very consistently, shorter waves travel around the world by multiple reflections off the ionosphere and the Earth. Much shorter wavelengths bend or reflect very little and travel along the line of sight.

6) Very low frequency radiation:

Very low frequency (VLF) refers to a frequency range of 30 Hz to 3 kHz which corresponds to wavelengths of 100,000 to 10,000 meters respectively. Since there is not much bandwidth in this range of the radio spectrum, only the very simplest signals can be transmitted, such as for radio navigation. Also known as the myriameter band or myriameter wave as the wavelengths range from ten to one myriameter (an obsolete metric unit equal to 10 kilometers).

7) Extremely low frequency radiation:

Extremely low frequency (ELF) is radiation frequencies from 3 to 30 Hz (108 to 107 meters respectively). In atmosphere science, an alternative definition is usually given, from 3 Hz to 3 kHz.[3] In the related magnetosphere science, the lower frequency electromagnetic oscillations (pulsations occurring below ~3 Hz) are considered to lie in the ULF range, which is thus also defined differently from the ITU Radio Bands. A massive military ELF antenna in Michigan radiates very slow messages to otherwise unreachable receivers, such as submerged submarines.

8) Thermal radiation (heat):

Thermal radiation is a common synonym for infrared radiation emitted by objects at temperatures often encountered on Earth. Thermal radiation refers not only to the

radiation itself, but also the process by which the surface of an object radiates its thermal energy in the form black body radiation. Infrared or red radiation from a common household radiator or electric heater is an example of thermal radiation, as is the heat emitted by an operating incandescent light bulb. Thermal radiation is generated when energy from the movement of charged particles within atoms is converted to electromagnetic radiation.

9) Black-body radiation:

Black-body radiation is an idealized spectrum of radiation emitted by a body that is at a uniform temperature. The shape of the spectrum and the total amount of energy emitted by the body is a function the absolute temperature of that body. The radiation emitted covers the entire electromagnetic spectrum and the intensity of the radiation (power/unit-area) at a given frequency is described by Planck's law of radiation. For a given temperature of a black-body there is a particular frequency at which the radiation emitted is at its maximum intensity. That maximum radiation frequency moves toward higher frequencies as the temperature of the body increases. The frequency at which the black-body radiation is at maximum is given by Wien's displacement law and is a function of the body's absolute temperature. A black-body is one that emits at any temperature the maximum possible amount of radiation at any given wavelength. A black-body will also absorb the maximum possible incident radiation at any given wavelength. A black-body with a temperature at or below room temperature would thus appear absolutely black, as it would not reflect any incident light nor would it emit enough radiation at visible wavelengths for our eyes to detect. Theoretically, a black-body emits electromagnetic radiation over the entire spectrum from very low frequency radio waves to x-rays, creating a continuum of radiation.

1.4 RADIOACTIVE ELEMENTS:-

1) PROTACTINIUM (Pa):

Origin of the name: The name is derived from the Greek 'protos', meaning first, as a prefix to the element actinium, which is produced through the radioactive decay of proactinium

Group	Actinides	**Melting point**	1572°C, 2862°F, 1845 K
Period	7	**Boiling point**	4000°C, 7232°F, 4273 K
Block	f	**Density (g cm^{-3})**	15.4
Atomic number	91	**Relative atomic mass**	231.036
State at 20°C	Solid	**Key isotopes**	^{231}Pa
Electron configuration	[Rn] $5f^2 6d^1 7s^2$	**CAS number**	7440-13-3

USES AND PROPERTIES:

Image explanation : The icon is based on the Japanese monogram for 'ichi' – number one. This reflects the origin of the element's name from the Greek 'protos', meaning first.
Appearance : A silvery, radioactive metal.
Uses : Protactinium is little used outside of research.
Biological role : Protactinium has no known biological role. It is toxic due to its radioactivity.
Natural abundance :Small amounts of protactinium are found naturally in uranium ores. It is also found in spent fuel rods from nuclear reactors, from which it is extracted.

2) PLUTONIUM (Pu):

Origin of the name: Plutonium, is named after the then planet Pluto, elements uranium and neptunium. following from the two previous

Group	Actinides	**Melting point**	640°C, 1184°F, 913 K
Period	7	**Boiling point**	3228°C, 5842°F, 3501 K

Block	f	**Density (g cm^{-3})**	19.7
Atomic number	94	**Relative atomic mass**	[244]
State at 20°C	Solid	**Key isotopes**	^{238}Pu, ^{239}Pu, ^{240}Pu
Electron	[Rn] $5f^6 7s^2$	**CAS number**	7440-07-5

USES AND PROPERTIES:

Image explanation :
The image is inspired by Robert Oppenheimer's quote, following the first atomic bomb test in the Nevada desert. 'We knew the world would not be the same. A few people laughed, a few people cried. Most people were silent. I remembered the line from the Hindu scripture, the Bhagavad-Gita. Vishnu is trying to persuade the Prince that he should do his duty and to impress him takes on his multi-armed form and says, "Now I am become Death, the destroyer of worlds." I suppose we all thought that, one way or another.'
Appearance : A radioactive, silvery metal.
Uses : Plutonium was used in several of the first atomic bombs, and is still used in nuclear weapons. The complete detonation of a kilogram of plutonium produces an explosion equivalent to over 10,000 tonnes of chemical explosive.

Plutonium is also a key material in the development of nuclear power. It has been used as a source of energy on space missions, such as the Mars Curiosity Rover and the New Horizons spacecraft on its way to Pluto.
Biological role : Plutonium has no known biological role. It is extremely toxic due to its radioactivity.
Natural abundance : The greatest source of plutonium is the irradiation of uranium in nuclear reactors. This produces the isotope plutonium-239, which has a half-life of 24,400 years.

Plutonium metal is made by reducing plutonium tetrafluoride with calcium.

3) URANIUM (U):

Origin of the name: Uranium was named after the planet Uranus.

Group	Actinides	**Melting point**	1135°C, 2075°F, 1408 K
Period	7	**Boiling point**	4131°C, 7468°F, 4404 K
Block	f	**Density (g cm^{-3})**	19.1
Atomic number	92	**Relative atomic mass**	238.029
State at 20°C	Solid	**Key isotopes**	^{234}U, ^{235}U, ^{238}U
Electron configuration	[Rn] 5f^{3}6d^{1}7s^2	**CAS number**	7440-61-1

USES AND PROPERTIES:

Image explanation
The image is based around the common astrological symbol for the planet Uranus.
Appearance :A radioactive, silvery metal.
Uses : Uranium is a very important element because it provides us with nuclear fuel used to generate electricity in nuclear power stations. It is also the major material from which other synthetic transuranium elements are made.

Naturally occurring uranium consists of 99% uranium-238 and 1% uranium-235. Uranium-235 is the only naturally occurring fissionable fuel (a fuel that can sustain a chain reaction). Uranium fuel used in nuclear reactors is enriched with uranium-235. The chain reaction is carefully controlled using neutron-absorbing materials. The heat generated by the fuel is used to create steam to turn turbines and generate electrical power.

In a breeder reactor uranium-238 captures neutrons and undergoes negative beta decay to become plutonium-239. This synthetic, fissionable element can also sustain a chain reaction.
Uranium is also used by the military to power nuclear submarines and in nuclear weapons.
Depleted uranium is uranium that has much less uranium-235 than natural uranium. It is considerably less radioactive than natural uranium. It is a dense metal that can be used as ballast for ships and counterweights for aircraft. It is also used in ammunition and armour.

Biological role : Uranium has no known biological role. It is a toxic metal.
Natural abundance : Uranium occurs naturally in several minerals such as uranite (pitchblende), brannerite and carnotite. It is also found in phosphate rock and monazite sands. World production of uranium is about 41,000 tonnes per year.
Extracted uranium is converted to the purified oxide, known as yellow-cake. Uranium metal can be prepared by reducing uranium halides with Group 1 or Group 2 metals, or by reducing uranium oxides with calcium or aluminium.

4) IODINE 131 (I^{131}):

Origin of the name: The name is derived from the Greek 'iodes' meaning violet.

Group	17	**Melting point**	113.7°C, 236.7°F, 386.9 K
Period	5	**Boiling point**	184.4°C, 363.9°F, 457.6 K
Block	p	**Density ($g\ cm^{-3}$)**	4.933
Atomic number	53	**Relative atomic mass**	126.904
State at 20°C	Solid	**Key isotopes**	^{127}I
Electron configuration	[Kr] $4d^{10}5s^25p^5$	**CAS number**	7553-56-2

USES AND PROPERTIES:

Image explanation: The image is of seaweed. Many species of seaweed contain iodine.
Appearance: A black, shiny, crystalline solid. When heated, iodine sublimes to form a purple vapour.
Uses : Photography was the first commercial use for iodine after Louis Daguerre, in 1839, invented a technique for producing images on a piece of metal. These images were called daguerreotypes.

Today, iodine has many commercial uses. Iodide salts are used in pharmaceuticals and disinfectants, printing inks and dyes, catalysts, animal feed supplements and

photographic chemicals. Iodine is also used to make polarising filters for LCD displays.

Iodide is added in small amounts to table salt, in order to avoid iodine deficiency affecting the thyroid gland. The radioactive isotope iodine-131 is sometimes used to treat cancerous thyroid glands.

Biological role

Iodine is an essential element for humans, who need a daily intake of about 0.1 milligrams of iodide. Our bodies contain up to 20 milligrams, mainly in the thyroid gland. This gland helps to regulate growth and body temperature.
Normally we get enough iodine from the food we eat. A deficiency of iodine can cause the thyroid gland to swell up (known as goitre).

Natural abundance

Iodine is found in seawater, as iodide. It is only present in trace amounts (0.05 parts per million); however, it is assimilated by seaweeds. In the past iodine was obtained from seaweed.
Now the main sources of iodine are iodate minerals, natural brine deposits left by the evaporation of ancient seas and brackish (briny) waters from oil and salt wells. Iodine is obtained commercially by releasing iodine from the iodate obtained from nitrate ores or extracting iodine vapour from the processed brine.

5) COBALT 60 (Co^{60}):

Origin of the name: The name is derived from the German word 'kobald', meaning goblin.

Group	9	**Melting point**	1495°C, 2723°F, 1768 K
Period	4	**Boiling point**	2927°C, 5301°F, 3200 K
Block	d	**Density ($g\ cm^{-3}$)**	8.86
Atomic number	27	**Relative atomic mass**	58.933
State at 20°C	Solid	**Key isotopes**	^{59}Co

Electron configuration [Ar] $3d^7 4s^2$ **CAS number** 7440-48-4

USES AND PROPERTIES:

Image explanation: The image shows a goblin or 'kobold' (often accused of leading German miners astray in their search for tin). In the background is some early Chinese porcelain, which used the element cobalt to give it its blue glaze.
Appearance: A lustrous, silvery-blue metal. It is magnetic.
Uses: Cobalt, like iron, can be magnetised and so is used to make magnets. It is alloyed with aluminium and nickel to make particularly powerful magnets.
Other alloys of cobalt are used in jet turbines and gas turbine generators, where high-temperature strength is important.
Cobalt metal is sometimes used in electroplating because of its attractive appearance, hardness and resistance to corrosion.
Cobalt salts have been used for centuries to produce brilliant blue colours in paint, porcelain, glass, pottery and enamels.
Radioactive cobalt-60 is used to treat cancer and, in some countries, to irradiate food to preserve it.
Biological role
Cobalt is an essential trace element, and forms part of the active site of vitamin B12. The amount we need is very small, and the body contains only about 1 milligram. Cobalt salts can be given to certain animals in small doses to correct mineral deficiencies. In large doses cobalt is carcinogenic.
Cobalt-60 is a radioactive isotope. It is an important source of gamma-rays. It is widely used in cancer treatment, as a tracer and for radiotherapy.
Natural abundance
Cobalt is found in the minerals cobaltite, skutterudite and erythrite. Important ore deposits are found in DR Congo, Canada, Australia, Zambia and Brazil. Most cobalt is formed as a by-product of nickel refining.

A huge reserve of several transition metals (including cobalt) can be found in strange nodules on the floors of the deepest oceans. The nodules are manganese minerals that take millions of years to form, and together they contain many tonnes of cobalt.

6) FANCIUM (Fr):

Origin of the name: Francium is named after France.

Group	1	**Melting point**	21°C, 70°F, 294 K
Period	7	**Boiling point**	650°C, 1202°F, 923 K
Block	s	**Density (g cm^{-3})**	Unknown
Atomic number	87	**Relative atomic mass**	[223]
State at 20°C	Solid	**Key isotopes**	^{223}Fr
Electron configuration	[Rn] $7s^1$	**CAS number**	7440-73-5

USES AND PROPERTIES:

Image explanation: The image reflects the ancient cultural 'Gallic' iconography of France, the country that gives the element its name.

Appearance: An intensely radioactive metal.

Uses: Francium has no uses, having a half life of only 22 minutes.

Biological role : Francium has no known biological role. It is toxic due to its radioactivity.

Natural abundance : Francium is obtained by the neutron bombardment of radium in a nuclear reactor. It can also be made by bombarding thorium with protons.

7) ACTINIUM (Ac):

Origin of the name: The name is derived from the Greek 'actinos', meaning a ray.

Group	Actinides	**Melting point**	1050°C, 1922°F, 1323 K
Period	7	**Boiling point**	3200°C, 5792°F, 3473 K
Block	d	**Density (g cm^{-3})**	10
Atomic number	89	**Relative atomic mass**	[227]
State at 20°C	Solid	**Key isotopes**	^{227}Ac
Electron configuration	[Rn] $6d^1 7s^2$	**CAS number**	7440-34-8

USES AND PROPERTIES:

Image explanation: The Greek symbol 'alpha' and metallic 'rays' are representative of the element as a source of alpha radiation, and also the origin of its name.

Appearance : Actinium is a soft, silvery-white radioactive metal. It glows blue in the dark because its intense radioactivity excites the air around it.
Uses :Actinium is a very powerful source of alpha rays, but is rarely used outside research.
Biological role : Actinium has no known biological role. It is toxic due to its radioactivity.
Natural abundance: Actinium used for research purposes is made by the neutron bombardment of radium-226. Actinium also occurs naturally in uranium ores.

1.5 RADIOACTIVE DEACAY:

Radioactive decay is the spontaneous breakdown of an atomic nucleus resulting in the release of energy and matter from the nucleus. Remember that a radioisotope has an unstable nucleus that does not have enough binding energy to hold the nucleus together. Radioisotopes would like to be stable isotopes so they are constantly changing to try and stabilize. In the process, they will release energy and matter from their nucleus and often transform into a new element. This process, called **transmutation**, is the change of one element into another as a result of changes within the nucleus. The radioactive decay and transmutation process will continue until a new element is formed that has a stable nucleus and is not radioactive. Transmutation can occur naturally or by artificial means.

In radioactive processes, particles or electromagnetic radiation are emitted from the nucleus. The most common forms of radiation emitted have been traditionally classified as alpha (α), beta (β), and gamma (γ) radiation. Nuclear radiation occurs in other forms, including the emission of protons or neutrons or spontaneous fission of a massive nucleus.

Of the nuclei found on Earth, the vast majority are stable. This is so because almost all short-lived radioactive nuclei have decayed during the history of the Earth. There are approximately 270 stable isotopes and 50 naturally occurring

radioisotopes (radioactive isotopes). Thousands of other radioisotopes have been made in the laboratory.

Application of Radiology:

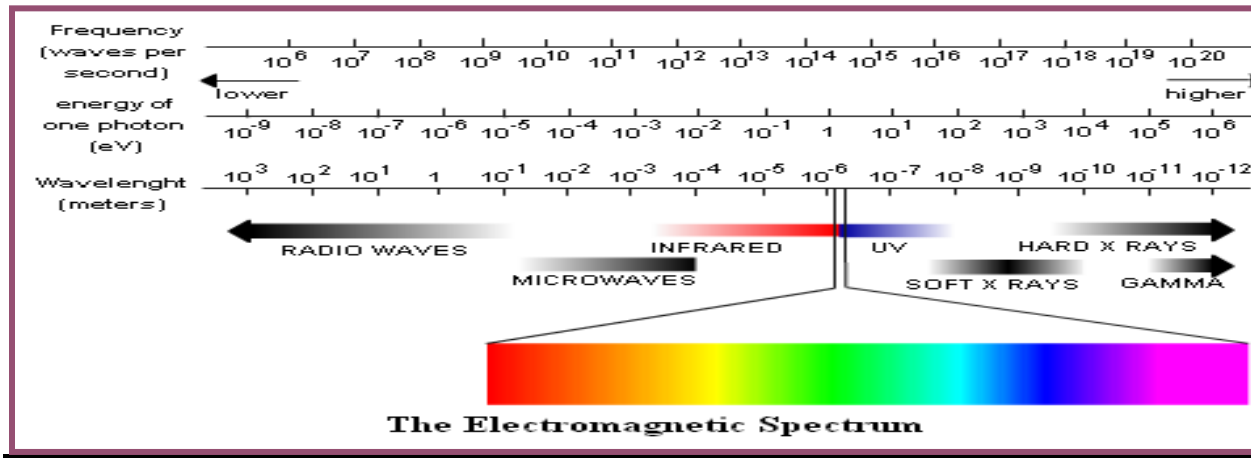
Radiology is concerned with the application of radiation to the human body for diagnostically and therapeutically purposes.
This requires an understanding of:

- **the basic nature of radiation**
- **interaction between radiation and matter**
- **radiation detection**
- **biological effects of radiation**

To evaluate the advantages and disadvantages of the various medical applications of radiation and its limitations

Nature and Origin of Radiation:

There are various kind of radiation which can be classified in electromagnetic radiation (EM) and particle radiation (p). The X-rays and γ-rays are part of the electromagnetic spectrum; both have a wavelength range between 10^{-4} and 10^{1} nm, they differ only in their origin.



The Electromagnetic Spectrum

When interacting with matter EM-radiation shows particle like behavior

The 'particles' are called photons. The energy of the photon and the frequency *u* (or wavelength λ) of the EM-radiation are determined by the Planck constant h:

$h=6.62^{-34}$ J ·s = $4.12 \cdot 10^{-21}$ MeV·s

$$E = h \cdot \nu = h \cdot \frac{c}{\lambda}$$

The photon energy for X-rays and γ-rays is in the eV to MeV range.

Types of Decay:

α – Particles:

- Heavily charged particles having 2 positive charges that are deflected by electric and magnetic fields
- Harmful to biological cells and can cause total burns when suddenly stopped due to heating effect
- They have short penetrating power

Alpha Decay:

- In this decay, an atomic nucleus emits an α – Particle (2 protons and 2 neutrons) and transforms into an atom with a mass no. than 4 and 2

- Ex: $_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4}{}^{2+}$

OR

$_{92}U^{238} \longrightarrow {}_{90}Th^{234} + \alpha$

β – Particles:

- They are high energy electrons and ionize in air
- They have more penetrating power
- β – Particles Causes external radiation hazard to skin and internal hazard occur if the atom the atoms with β – Particles are ingested to body.

Beta Decay:

- A type of radioactive decay in which a beta particles (e^- or positron) is emitted
- In case of e^- emission, it is β^- decay
- In case of positron emission, it is β^+ decay
- Positron is positive decay

β^- decay

- The weak interaction converts a neutron into a proton while emitting an electron and antineutrino
- Neutrinos do not carry electric charge. Because neutrinos are electrically neutral
- But Antineutrino carries the electric charge
- $n^0 \longrightarrow p^+ + e^- + \nu_e^-$
- Fundamental particles inside neutrons and protons are quarks
- There are two types of quarks i.e, up quarks and down quarks
- Up quarks are those charges are more than +2/3
- And down quarks are those charges are less than -1/3
- Quarks arrange themselves in set of 3 to form protons and neutrons.
- Quarks can charge from up quark to down quark and this changing cause's beta radiation.
- β^- Decay is caused due to conversion of a down quark to an up quark.

Positron Decay or β^+ decay

- Energy is used to convert a proton into an neutron, a positron and a neutrino (ν_e)
- energy + $p^+ \longrightarrow n^0 + e^+ + \nu_e$
- Positron emission occurs when an up quark changes into a down quark
- It does not occur in isolation as it needs energy and it occurs inside the nuclei when absolute value of the binding energy of daughter nuclei is higher than that of mother nucleus.
- Ex: Isotopes of Carbon-11, Po-40, N-13, O-15, etc
  $_6C^{11} \longrightarrow {}_5B^{11} + e^+ + \nu_e$

Electron Capture:

- Electron Capture means when an atomic e^- is captured by a nucleus with the emission of a neutrino.
- energy + $p^+ + e^- \longrightarrow n^0 + \nu_e$
- This is also called inverse beta decay.
- Ex: $_{19}K^{40} + e^- \longrightarrow {}_{18}Ar^{40} + \nu_e$
- $_{19}K^{40}$ undergoes all 3 types of beta decay with a half life of 1.277×10^9 years
- Some nuclei undergo double beta decay ($\beta\beta$ decay) where charge of nucleus changes by 2 units. But it is very rare.

γ – Particles or Gamma Rays:

- They are electromagnetic radiation of high frequency with short wavelength
- It produced by sub atomic particles interactions.
- They have frequency above 10^{19}Hz and wavelength less than 10 picometers and energy above 100 KeV
- They have high penetrating power and cause damage throughout the body
- Gamma rays can be used to kill living organisms like sterilization
- It is used to treat cancerous cell and CT
- It is used in cyber knife

Cluster Decay:

- A nuclear process in which a radioactive atom emits a cluster of neutrons and protons heavier than an alpha particles.
- It occurs only in a small percentage of decay
- It is limited to heavy radioisotopes that have enough nuclear energy to expel a portion of its nucleus.
    - Ex: $U^{235} \longrightarrow Ne^{24}$, Ne^{25}, Mg^{28}, Mg^{29}
- Tritons and deuterons are occasional radioactive decay products.

Decay Energy:

- The **decay energy** is the energy released by a radioactive decay.
- Radioactive decay is the process in which an unstable atomic nucleus loses energy by emitting ionizing particles and radiation.
- This loss of energy is called decay energy
- This decay, or loss of energy, results in an atom of one type, called the parent nuclide transforming to an atom of a different type, called the daughter nuclide.

Decay calculation

The energy difference of the reactants is often written as Q:

$$Q = (\text{Kinetic energy})_{\text{after}} - (\text{Kinetic energy})_{\text{before}},$$
$$Q = \left((\text{Rest mass})_{\text{before}} \times c^2\right) - \left((\text{Rest mass})_{\text{after}} \times c^2\right).$$

Decay energy is usually quoted in terms of the energy units **MeV** (million electron volts) or **keV** (thousand electron volts).

Types of radioactive decay include

- Gamma Ray
- Beta Decay (decay energy is divided between the emitted electron and the neutrino which is emitted at the same time)
- Alpha Decay

$$W = dm \times \left(\frac{A}{M}\right).$$

or

$$W = E \times \left(\frac{A}{M}\right).$$

- The decay energy is the mass difference ***dm*** between the parent and the daughter atom and particles.
- It is equal to the energy of radiation ***E***.
- If ***A*** is the radioactive activity, i.e. the number of transforming atoms per time, ***M*** the molar mass, then the radiation power ***W*** is:

Example: ^{60}Co decays into ^{60}Ni. The mass difference *dm* is 0.003u. The radiated energy is approximately 2.8 MeV. The molar weight is 59.93. The half life *T* of 5.27 year corresponds to the activity A=(N*(-ln(2)))/T, where N is the number of atoms per mol. Taking care of the units the radiation power for ^{60}Co is 17.9 W/g

Radioactive Isotopes:

Radioactive elements are unstable. They decay, and change into different elements over time.
Not all elements are radioactive.

Radioactive Decay and Half Life:

- The time required for one half the atoms of a given amount of a radioactive substance to disintegrate and is also called biological half-life.

- Half life is the period of time it takes for an atom undergoing decay to decrease by half.
- Pharmacologically the time required for the activity of a substance taken into the body to lose one half its initial effectiveness.
- If N_0 is the number of atoms present at any instant t=0, then the time in which $N_0/2$ atoms are disintegrated is called half life.
- The half-life of an element is the time it takes for half of the material you started with to decay.
- Each element has it's own half-life
- Radioactive element decays into a new element. Example C^{14} decays into N^{14}
- The half-life of each element is constant. It's like a clock keeping perfect time.
- We can use half-life to determine the age of a rock, fossil or other artifact.

Exponential decay

An exponential decay can be described by any of the following three equivalent formulas:

$$N(t) = N_0 \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$$

$$N(t) = N_0 e^{-\frac{t}{\tau}}$$

$$N(t) = N_0 e^{-\lambda t}$$

Where:

- N_0 is the initial quantity of the substance that will decay (this quantity may be measured in grams, moles, number of atoms, etc.),
- $N(t)$ is the quantity that still remains and has not yet decayed after a time t,
- $t_{1/2}$ is the half-life of the decaying quantity,
- τ is a positive number called the mean lifetime of the decaying quantity,
- λ is a positive number called the decay constant of the decaying quantity.

The three parameters t1⁄2, τ, and λ are all directly related in the following way:

$$t_{1/2} = \frac{\ln(2)}{\lambda} = \tau \ln(2)$$

Where ln (2) is the natural logarithm of 2 (approximately 0.693).

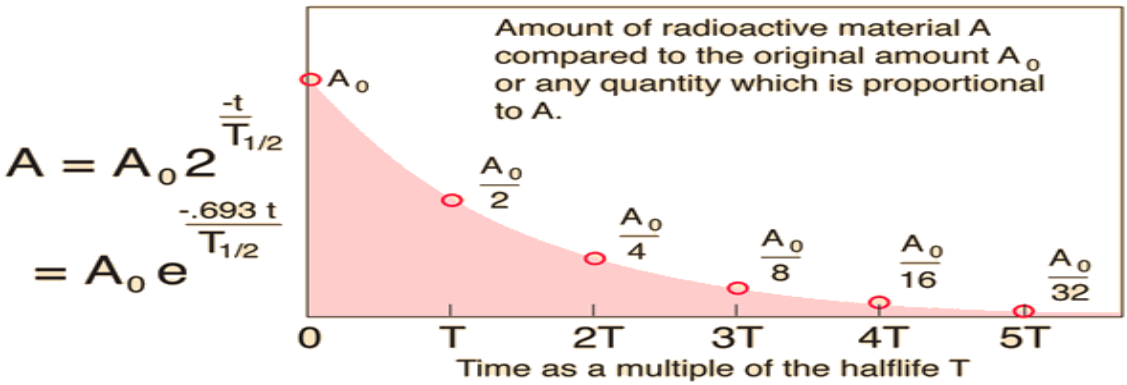
Therefore **$T_{1/2} = 0.693/\lambda$**

If disintegration constant λ is known then half-life can be easily calculated.

$$N(t) = N_0 \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}} = N_0 2^{-t/t_{1/2}}$$
$$= N_0 e^{-t \ln(2)/t_{1/2}}$$
$$t_{1/2} = \frac{t}{\log_2(N_0/N(t))} = \frac{t}{\log_2(N_0) - \log_2(N(t))}$$
$$= \frac{1}{\log_{2^t}(N_0) - \log_{2^t}(N(t))} = \frac{t \ln(2)}{\ln(N_0) - \ln(N(t))}$$

Regardless of how it's written, we can plug into the formula to get

- $N(0) = N_0$ as expected (this is the definition of "initial quantity")
- $N\left(t_{1/2}\right) = \frac{1}{2} N_0$ as expected (this is the definition of half-life)
- $\lim_{t \to \infty} N(t) = 0$; i.e., amount approaches zero as *t* approaches infinity as expected (the longer we wait, the less remains)



1.6 Heisenberg Uncertainty Principle

- The uncertainty principle states that the position and velocity cannot both be measured, exactly, at the same time (actually pairs of position, energy and time)
- Uncertainty principle derives from the measurement problem, the intimate connection between the wave and particle nature of quantum objects
- The change in a velocity of a particle becomes more ill defined as the wave function is confined to a smaller region
- The wave nature to particles means a particle is a wave packet, the composite of many waves
- Many waves = many momentums, observation makes one momentum out of many
- Exact knowledge of complementarities pairs (position, energy, time) is impossible
- Complementarities also means that different experiments yield different results (e.g. the two slit experiment)
- Therefore, a single reality cannot be applied at the quantum level
- The mathematical form of the uncertainty principle relates complementary to Planck's constant
- Classical physics was on loose footing with problems of wave/particle duality, but was caught completely off-guard with the discovery of the uncertainty principle.
- The uncertainty principle also called the Heisenberg Uncertainty Principle, or Indeterminacy Principle, articulated (1927) by the German physicist Werner Heisenberg, that the position and the velocity of an object cannot

both be measured exactly, at the same time, even in theory. The very concepts of exact position and exact velocity together, in fact, have no meaning in nature.

- Ordinary experience provides no clue of this principle. It is easy to measure both the position and the velocity of, say, an automobile, because the uncertainties implied by this principle for ordinary objects are too small to be observed. The complete rule stipulates that the product of the uncertainties in position and velocity is equal to or greater than a tiny physical quantity, or constant (about 10^{-34} joule-second, the value of the quantity h (where h is Planck's constant). Only for the exceedingly small masses of atoms and subatomic particles does the product of the uncertainties become significant.
- Any attempt to measure precisely the velocity of a subatomic particle, such as an electron, will knock it about in an unpredictable way, so that a simultaneous measurement of its position has no validity. This result has nothing to do with inadequacies in the measuring instruments, the technique, or the observer; it arises out of the intimate connection in nature between particles and waves in the realm of subatomic dimensions.
- Every particle has a wave associated with it; each particle actually exhibits wavelike behavior. The particle is most likely to be found in those places where the undulations of the wave are greatest, or most intense. The more intense the undulations of the associated wave become, however, the more ill defined becomes the wavelength, which in turn determines the momentum of the particle. So a strictly localized wave has an indeterminate wavelength; its associated particle, while having a definite position, has no certain velocity. A particle wave having a well-defined wavelength, on the other hand, is spread out; the associated particle, while having a rather precise velocity, may be almost anywhere. A quite accurate measurement of one observable involves a relatively large uncertainty in the measurement of the other.
- The uncertainty principle is alternatively expressed in terms of a particle's momentum and position. The momentum of a particle is equal to the product of its mass times its velocity. Thus, the product of the uncertainties in the momentum and the position of a particle equals h/(2) or more. The principle applies to other related (conjugate) pairs of observables, such as energy and time: the product of the uncertainty in an energy measurement and the

uncertainty in the time interval during which the measurement is made also equals h/(2) or more. The same relation holds, for an unstable atom or nucleus, between the uncertainty in the quantity of energy radiated and the uncertainty in the lifetime of the unstable system as it makes a transition to a more stable state.

- The uncertainty principle, developed by W. Heisenberg, is a statement of the effects of wave-particle duality on the properties of subatomic objects. Consider the concept of momentum in the wave-like microscopic world. The momentum of wave is given by its wavelength. A wave packet like a photon or electron is a composite of many waves. Therefore, it must be made of many momentums. But how can an object have many momentums?
- Of course, once a measurement of the particle is made, a single momentum is observed. But, like fuzzy position, momentum before the observation is intrinsically uncertain. This is what is know as the uncertainty principle, that certain quantities, such as position, energy and time, are unknown, except by probabilities. In its purest form, the uncertainty principle states that accurate knowledge of complementarity pairs is impossible. For example, you can measure the location of an electron, but not its momentum (energy) at the same time.
- A characteristic feature of quantum physics is the principle of complementarity, which "implies the impossibility of any sharp separation between the behavior of atomic objects and the interaction with the measuring instruments which serve to define the conditions under which the phenomena appear." As a result, "evidence obtained under different experimental conditions cannot be comprehended within a single picture, but must be regarded as complementary in the sense that only the totality of the phenomena exhausts the possible information about the objects." This interpretation of the meaning of quantum physics, which implied an altered view of the meaning of physical explanation, gradually came to be accepted by the majority of physicists during the 1930's.
- Mathematically we describe the uncertainty principle as the following, where `x' is position and `p' is momentum:

$$\Delta x \Delta p > \frac{h}{2\pi}$$

- This is perhaps the most famous equation next to $E=mc^2$ in physics. It basically says that the combination of the error in position times the error in momentum must always be greater than Planck's constant. So, you can measure the position of an electron to some accuracy, but then its momentum will be inside a very large range of values. Likewise, you can measure the momentum precisely, but then its position is unknown.
- Notice that this is not the measurement problem in another form, the combination of position, energy (momentum) and time are actually undefined for a quantum particle until a measurement is made (then the wave function collapses).
- Also notice that the uncertainty principle is unimportant to macroscopic objects since Planck's constant, h, is so small (10^{-34}). For example, the uncertainty in position of a thrown baseball is 10^{-30} millimeters.
- The depth of the uncertainty principle is realized when we ask the question; is our knowledge of reality unlimited? The answer is no, because the uncertainty principle states that there is a built-in uncertainty, indeterminacy, unpredictability to Nature.

Units of Radioactivity:

- The number of decays per second, or activity, from a sample of radioactive nuclei is measured in becquerel (Bq), after Henri Becquerel.
- One decay per second equals one becquerel.
- An older unit is the curie, named after Pierre and Marie Curie.
- One curie is approximately the activity of 1 gram of radium and equals (exactly) 3.7×10^{10} becquerel.
- The activity depends only on the number of decays per second, not on the type of decay, the energy of the decay products, or the biological effects of the radiation

Explained: rad, rem, sieverts, becquerels:

Sometimes it must seem as though reports on releases of radioactive materials from Japan's Fukushima Daiichi nuclear powerplant in the wake of the devastating earthquake and tsunami are going out of their way to confuse people. Some reports talk about **millisieverts while others talk about rem or becquerels,** when what most people really want to know is much simpler: Can I drink the milk? Is it safe to go home? Should people in California be worried?

There are a number of reasons for the confusion. In part, it's the usual disparity between standard metric units and the less-standard units favored in the United States, added to the general confusion of reporters dealing with a fast-changing situation (for example, some early reports mixed up microsieverts with millisieverts — a thousandfold difference in dose). Others are more subtle: The difference between the raw physical units describing radiation emitted by a radioactive material (**measured in units like curies and becquerels**), versus measurements designed to reflect the different amounts of radiation energy absorbed by a mass of material (**measured in rad or gray**), and those that measure the relative biological damage in the human body (**using rem and sieverts**), which depends on the type of radiation. (**Rem, rad and gray are all used as the plural as well as the singular form for those units**).

"Just knowing how much energy is absorbed by your body is not enough" to make meaningful estimates of the effects, explains Jacquelyn Yanch, a senior lecturer in MIT's Department of Nuclear Science and Engineering who specializes in the biological effects of radiation. "That's because energy that comes in very close together," such as from alpha particles, is more difficult for the body to deal with than forms that come in relatively far apart, such as from gamma rays or x-rays, she says.

Because x-rays and gamma rays are less damaging to tissue than neutrons or alpha particles, a conversion factor is used to translate the **rad** or gray into other units such as **rem** (from Radiation Equivalent Man) or sieverts, which are used to express the biological impact.

Some things are clear: A radiation dose of 500 millisieverts (mSv) or more can begin to cause some symptoms of radiation poisoning. Studies of those exposed to radiation from the atomic bomb blast at Hiroshima showed that for those who received a whole-body dose of 4,500 mSv, about 50 percent died from acute radiation poisoning. By way of comparison, the average natural background radiation in the United States is 2.6 mSv. The legal limit for annual exposure by nuclear workers is 50 mSv, and in Japan that limit was just raised for emergency workers to 250 mSv.

The highest specific exposures reported so far were of two workers at the Fukushima plant who received doses of 170 to 180 mSv on March 24 — lower than the new Japanese standard, but still enough to cause some symptoms (reports say the men had rashes on the areas exposed to radioactive water).

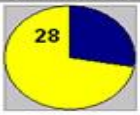
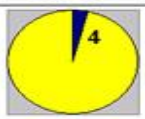
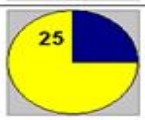
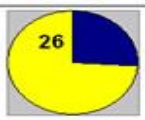
"Everything we know about radiation suggests that if you get a certain dose all at once, that's much more serious than if you get the same dose over a long time," Yanch says. The rule of thumb is that a dose spread out over a long period of time is about half as damaging as the same dose delivered all at once, but Yanch says that's a conservative estimate, and the real equivalence may be closer to one-tenth that of a rapid dose.

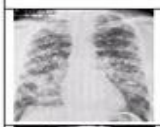
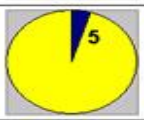
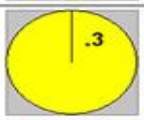
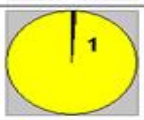
Basic conversions:

1 gray (Gy) = 100 rad
1 rad = 10 milligray (mGy)
1 sievert (Sv) = 1,000 millisieverts (mSv) = 1,000,000 microsieverts (μSv)
1 sievert = 100 rem
1 becquerel (Bq) = 1 count per second (cps)
1 curie = 37,000,000,000 becquerel = 37 Gigabecquerels (GBq)

For x-rays and gamma rays, 1 rad = 1 rem = 10 mSv
For neutrons, 1 rad = 5 to 20 rem (depending on energy level) = 50-200 mSv
For alpha radiation (helium-4 nuclei), 1 rad = 20 rem = 200 mSv

Effects of Radiation

Natural Sources		Annual Dose (mrem/year)
	Cosmic rays (radiation from the sun and outer space)	
	Building materials	
	The human body	
	The earth	

Manmade Sources		Annual Dose (mrem/year)
	Medical (primarily from diagnostic X-rays)	
	Fallout from atomic bombs	
	Nuclear power production	
	Consumer products (mostly from color TV sets)	

QUESTION BANK:

PART-A

1. Define radiology and mention few imaging techniques in radiology.
2. Write the sources of radiation.
3. Define electromagnetic and neutron radiation.
4. Define isotope and give two examples.
5. Define radioactivity and dose.
6. Name few radioactive elements.
7. Write a note on radioactive decay and its types.
8. Define double decay.
9. Give the equation of decay energy and radiation power.
10. Mention the units of radiation.

Explain radioactive elements in detail.

PART-B

1. Classify radioactive decay and its type in detail.
2. Describe half-life period and derive its equation.
3.Write a note on • Plutonium • Iodine • Cobalt
4. Write in detail about radiation and its types.
5.Write a note on • Radioactivity • General properties of, alpha, beta and gamma rays.
6. Enumerate the type of radiation sources.
7. Illustrate beta decay and its types in detail.
8. Explain alpha decay in detail.
9. Summarize positron decay in detail.

References:

1. Thomas S. Curry, III, James E. Dowdey, Robert C. Murry J R., Christensen the Physics of Diagnostic Radiology Lea & Febiger, 6 th Edition 2008.
2. Faiz M.Khan, The Physics of Radiation Therapy, 4th Edition, 2009

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – 2 - RADIO IMAGING AND THERAPEUTICS– SBMA1404

UNIT-2

II RADIATION GENERATORS

Particle Accelerators- Cyclotron, Klystron, Magnetron, Cascade generator, Van De Graff generator X ray films, X ray film processing, X Ray cassettes, Intensifying screens-New phosphor technology, Photostimulable phosphor imaging. collimators, grids - bucky grids, Body section radiography, Xeroradiography.

2.1 PARTICLE ACCELERATOR

- A particle accelerator is a machine that accelerates elementary particles, such as electrons or protons, to very high energies.
- On a basic level, particle accelerators produce beams of charged particles that can be used for a variety of research purposes.
- There are two basic types of particle accelerators:
- linear accelerators and
- Circular accelerators.
- Linear accelerators propel particles along a linear, or straight, beam line where as Circular accelerators propel particles around a circular track.
- Linear accelerators are used for fixed-target experiments, whereas circular accelerators can be used for both colliding beam and fixed target experiments.

WORKING PRINCIPLE OF PARTICLE ACCELERATOR

It use electric fields to speed up and increase the energy of a beam of particles, which are steered and focused by magnetic fields. The particle source provides the particles, such as protons or electrons that are to be accelerated. The beam of particles travels inside a vacuum in the metal beam pipe. The vacuum is crucial to maintaining an air and dust free environment for the beam of particles to travel unobstructed. Electromagnets steer and focus the beam of particles while it travels through the vacuum tube.

Electric fields spaced around the accelerator switch from positive to negative at a given frequency, creating radio waves that accelerate particles in bunches. Particles can be directed at a fixed target, such as a thin piece of metal foil, or two beams of particles can be collided. Particle detectors record and reveal the particles and radiation that are produced by the collision between a beam of particles and the target.

ACCELERATORS CONTRIBUTED TO BASIC SCIENCE

Particle accelerators are essential tools of discovery for particle and nuclear physics and for sciences that use x-rays and neutrons, a type of neutral subatomic particle. Particle physics, also called high-energy physics. Over the last four decades, light sources -- accelerators producing photons, the subatomic particle responsible for electromagnetic radiation -- and the sciences that use them have made dramatic advances that cut across many fields of research. Today, there are now about 10,000 scientists in the United States using x-ray beams for research in physics and chemistry, biology and medicine, Earth sciences, and many more aspects of materials science and development.

PARTICLE ACCELERATORS USED IN MEDICAL APPLICATIONS

- Tens of millions of patients receive accelerator-based diagnoses and therapy each year in hospitals and clinics around the world.
- There are two primary roles for particle accelerators in medical applications:
- the production of radioisotopes for medical diagnosis and therapy, and
- As sources of beams of electrons, protons and heavier charged particles for medical treatment.
- The wide range of half-lives of radioisotopes and their differing radiation types allow optimization for specific applications.
- Isotopes emitting x-rays, gamma rays or positrons can serve as diagnostic probes, with instruments located outside the patient to image radiation distribution and thus the biological structures and fluid motion or constriction (blood flow, for example).
- Emitters of beta rays (electrons) and alpha particles (helium nuclei) deposit most of their energy close to the site of the emitting nucleus and serve as therapeutic agents to destroy cancerous tissue.
- Radiation therapy by external beams has developed into a highly effective method for treating cancer patients.
- The vast majority of these irradiations are now performed with microwave linear accelerators producing electron beams and x-rays.
- Accelerator technology, diagnostics and treatment technique developments over the past 50 years have dramatically improved clinical outcomes.

- Today, 30 proton and three carbon-ion-beam treatment centers are in operation worldwide.

2.2 Cyclotron-

Principle, Construction, Working and Limitations of Cyclotron

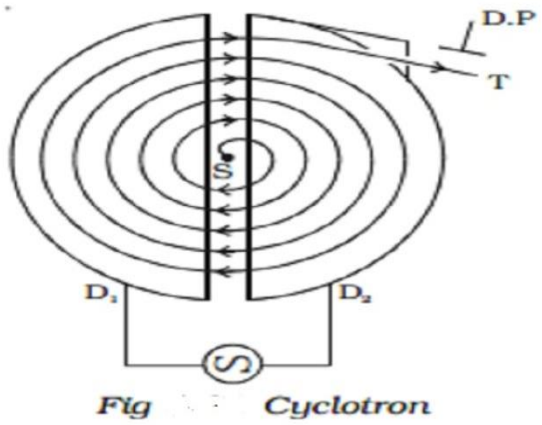


Fig:1 Cyclotron

Cyclotron- Principle, Construction, Working and Limitations of Cyclotron Cyclotron :

- Cyclotron is a device used to accelerate charged particles to high energies. It was devised by Lawrence.

Principle

- Cyclotron works on the principle that a charged particle moving normal to a magnetic field experiences magnetic lorentz force due to which the particle moves in a circular path.

Construction

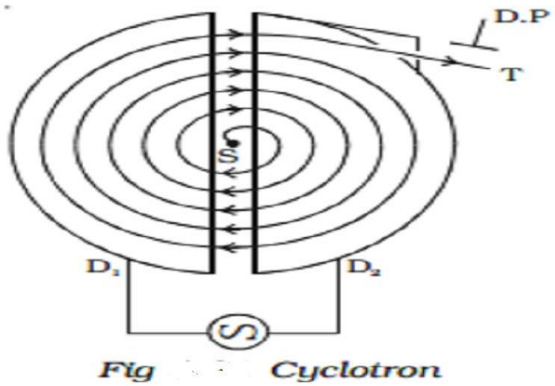


Fig:2-Cyclotron

- It consists of a hollow metal cylinder divided into two sections D1 and D2 called Dees, enclosed in an evacuated chamber.
- The Dees are kept separated and a source of ions is placed at the centre in the gap between the Dees.
- They are placed between the pole pieces of a strong electromagnet.
- The magnetic field acts perpendicular to the plane of the Dees. The Dees are connected to a high frequency oscillator.

Working:

- When a positive ion of charge q and mass m is emitted from the source, it is accelerated towards the Dee having a negative potential at that instant of time.
- Due to the normal magnetic field, the ion experiences magnetic lorentz force and moves in a circular path.
- By the time the ion arrives at the gap between the Dees, the polarity of the Dees gets reversed.
- Hence the particle is once again accelerated and moves into the other Dee with a greater velocity along a circle of greater radius.
- Thus the particle moves in a spiral path of increasing radius and when it comes near the edge, it is taken out with the help of a deflector plate (D.P).
- The particle with high energy is now allowed to hit the target T.

When the particle moves along a circle of radius r with a velocity v, the magnetic Lorentz force provides the necessary centripetal force.

$Bqv = v\ m\ 2/\ r$

$\therefore v/r = Bq/m = \text{constant} \ldots(1)$

The time taken to describe a semi-circle

$t = v\ \pi\ r \ldots(2)$

Substituting equation (1) in (2),

$t = \pi\ m/\ Bq \ldots(3)$

It is clear from equation (3) that the time taken by the ion to describe a semi-circle is independent of

(i) the radius (r) of the path and (ii) the velocity (v) of the particle

Hence, period of rotation

$T = 2t \therefore T = 2\ \pi/\ m\ Bq = \text{constant} \ldots(4)$

So, in a uniform magnetic field, the ion traverses all the circles in exactly the same time. The frequency of rotation of the particle,

$\upsilon = 1/T = Bq\ 2\ m\pi \ldots(5)$

If the high frequency oscillator is adjusted to produce oscillations of frequency as given in equation (5), resonance occurs.

Cyclotron is used to accelerate protons, deutrons and α - particles.

Limitations

- Maintaining a uniform magnetic field over a large area of the Dees is difficult.
- At high velocities, relativistic variation of mass of the particle upsets the resonance condition.
- At high frequencies, relativistic variation of mass of the electron is appreciable and hence electrons cannot be accelerated by cyclotron.

2.3 KLYSTRON

- Klystron is a specialized linear-beam vacuum tube which is used as an amplifier for high radio frequencies.
- It was invented in 1937 by American electrical engineers Russell and Sigurd Varian.
- It operates by the principle of velocity and current modulation.

CONSTRUCTION

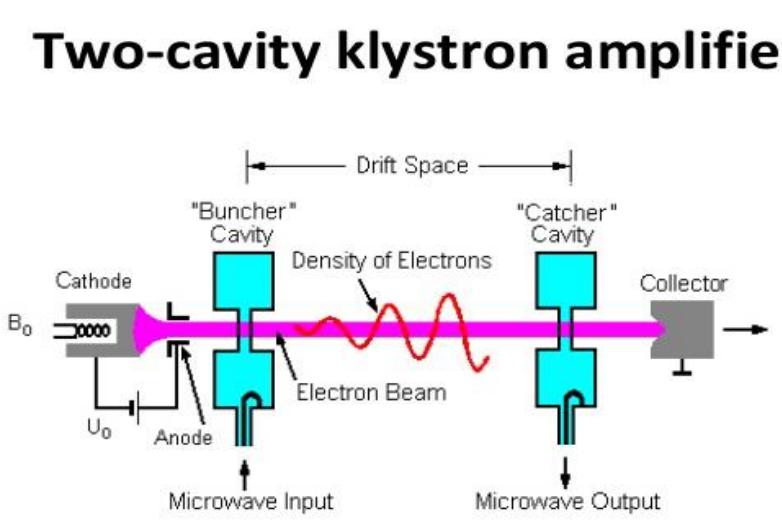


Fig:3- Klystron

It consists of three main components and they are:-

- An electron beam
- Two metal boxes known as cavity resonators.
- A collector

In a klystron, an electron beam interacts with radio waves as it passes through resonant cavities, metal boxes along the length of a tube. The electron beam first passes through a cavity to which the input signal is applied.In this tube there are two microwave cavity resonators, the "catcher" and the "buncher". When used as an amplifier, the weak microwave signal to be amplified is applied to the buncher cavity through a coaxial cable or waveguide, and the amplified signal is extracted from the catcher cavity.After passing through the catcher and giving up its energy, the lower energy electron beam is absorbed by a collector electrode.

WORKING

- The electron beam produces flow of electrons. The electrons are emitted by the cathode with high kinetic energy.
- The cavity resonator is similar to resonance circuit and it depends on the input signal frequency. In the first cavity, the bunching cavities regulate the speed of the electrons so that they reach as bunches at the output cavity.
- Alternating electric field makes the electrons to accelerate and decelerate.
- In second cavity, the bunches arrives at intervals corresponding to the frequency the first cavity oscillates.
- The bunches of electrons excite the microwaves in the output cavity of the klystron.

- The magnetic field produced in the cavity is linked with the cable and thus initiates amplified output signal.
- The microwaves flow into the waveguide which transports them to the accelerator. The electrons are absorbed in the collector

APPLICATION

- Radar
- Satellite
- In High power communications
- In particle accelerators

2.4 MAGNETRON

- The magnetron is a self-oscillating device as it requires no external elements other than a power supply. It is used to generate microwaves of high power.
- Its working principle is based on the interaction between electron stream and magnetic field.
- The Magnetron Tube works on Direct Current power.

CONSTRUCTION

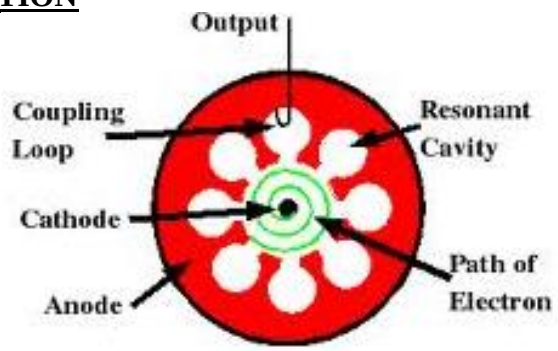


Fig:4- magnetron

- Magnetron tube is constructed of a vacuum tube having two electrodes.
- The permanent magnet and both electrodes are placed in such a way so that the magnetic field of permanent magnet and electric field of cathode are perpendicular to each other.
- The cathode is in center of the chamber or cylinder. There are cylindrical cavities open along their length and connect the common cavity space.
- The anode is constructed of a highly conductive material, almost always copper, so these differences in voltage cause currents to appear to even them out.

- Since the parallel sides of the cavities acts as a capacitor and the anode block provides a inductive analog. Hence the cavities are called as resonance cavities as they act as resonance circuit.

WORKING

The working principle of a magnetron is depending upon the relative strength of the magnetic and electric field the electrons released from the cavity move that towards the anode will navigate through the interacting space.

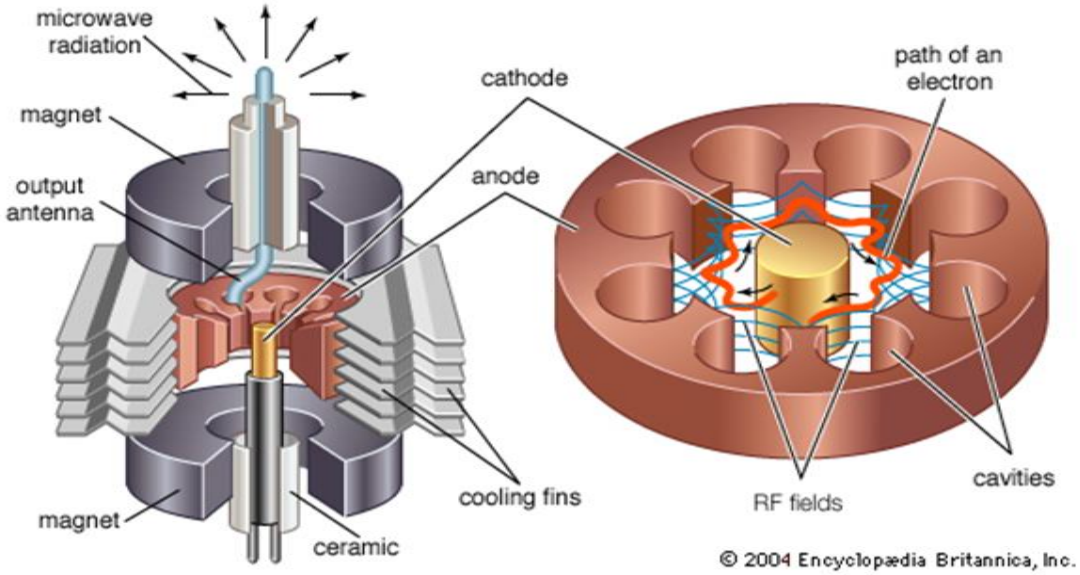


Fig: 5- magnetron

- High negative potential at cathode is created with high voltage DC power.
- Cathode emits electrons; path depends on strength and direction of Magnetic and Electric Field.
- When both fields are existing in that case the electron may have dissimilar path depending upon the strength of E and H.
  If E>H, the electrons reach at the anode but the path will be bend because of small magnetic field.
  If H>E, the electrons return back to the cathode.
- The magnetic field causes the electrons to get attracted towards positive anode and starts to spiral in a circular path.
- Then they sweep past the openings of the cavities which are open along their length.
- Then these electrons induce high frequency radio field in the cavity due to which electrons get bunched into groups.

- Then this field goes into output coupling loop which in turns connected to wave guide or antenna depending on the output requirement.

ADVANTAGE

It is a fairly efficient device.

DISADVANTAGES

- Frequency cannot be controlled
- As there is an increase in the number of cavities, the cost of the device also increases. Hence, the device is expensive.

APPLICATIONS

- Radars
- Heating(Microwave Oven)
- Lighting (Sulphur lamp)

2.5 GENERATORS

VAN DE GRAAFF GENERATOR:

Van de Graaff generator is designed by Robert J. Van de Graaff in 1929. It is an electrostatic machine that produces a large electrostatic potential difference of 10^7 V.

Principle:

1. Electrostatic induction:

It is possible to obtain charges without any contact with another charge. They are known as induced charges and the phenomenon of producing induced charges is known as electrostatic induction. For example when a negatively charged plastic rod is brought close to the uncharged metallic sphere, the free electrons move away due to repulsion and near end becomes positively charged due to deficit of electrons.

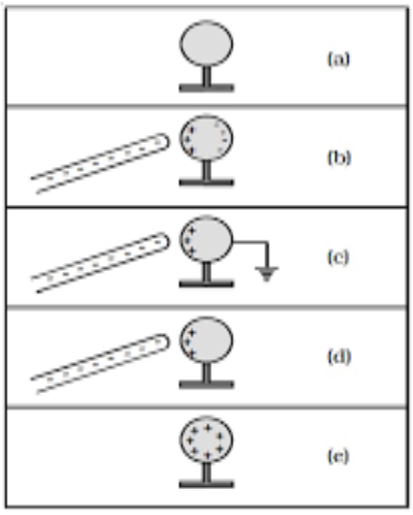


Fig Electrostatic Induction

Fig: 6- Electrostatic induction

2. Action of points:

The charges accumulate maximum at the pointed end where the curvature is maximum or the radius is minimum. It is found experimentally that a charged conductor with sharp points on its surface loses its charge rapidly.

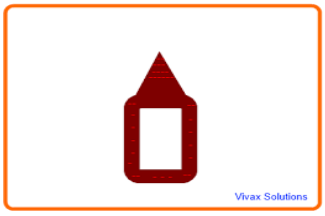


Fig: 7- Action of Points

Construction:

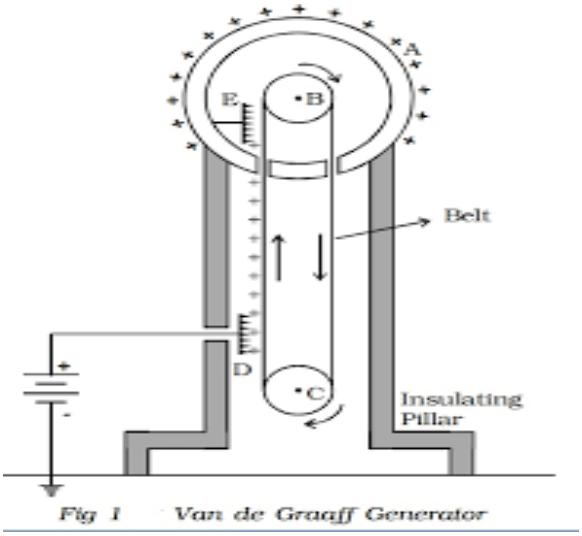


Fig: 8- Van de Graaff generator

- A hollow metallic sphere A is mounted on insulating pillars.
- A pulley B is mounted at the centre of the sphere and another pulley C is placed at the bottom.
- A belt made of silk moves over the pulleys.
- The pulley C is driven continuously by an electric motor.
- Two comb shaped conductors D and E having number of needles, are mounted near the pulleys.
- The comb D is maintained a positive potential of the order of 10^4 volt by a power supply.
- The upper comb E is connected to the inner side of the hollow metallic sphere.

Working:

- Because of the high electric potential near the comb D, the air gets ionised due to the action of points.
- So the negative charges in the air move towards the needles and positive charges are repelled on towards the belt.
- These positive charge stick to the belt, move up and reaches near comb E.
- As a result of electrostatic induction, the comb E acquires negative charge and the sphere acquires positive charge.
- The acquired positive charge is distributed on the surface of the sphere.
- The high electric field at the comb E ionises the air.
- Hence, the negative charges are repelled to the belt, neutralizes the positive charge on the belt before the belt passes over the pulley.

- Therefore the descending belt will be left uncharged.
- Thus the machine continuously transfers the positive charge to the sphere.
- As a result the potential of the sphere keeps increasing till it attains a limiting value.
- After this stage no more charges can be placed on the sphere, it starts leaking to the surrounding due to ionisation of air.

Advantages:

- It can be used as a particle accelerator
- It can produce high voltage at very low current.
- It is useful tool in the fundamental physics research.

Disadvantages:

- It has to be enclosed in a gas filled steel chamber at a very high pressure, to reduce the leakage of charge from the sphere.

Applications:

- It is used to accelerate protons and deuterons.
- It is used to produce very high potential.

2.6 CASCADE GENERATOR (Cockcroft-Walton generator):

The Cockcroft-Walton generator is an electronic circuit that produces high Dc voltage.

Principle:

It generates a high DC voltage from a low AC voltage or pulsing DC input.

Construction:

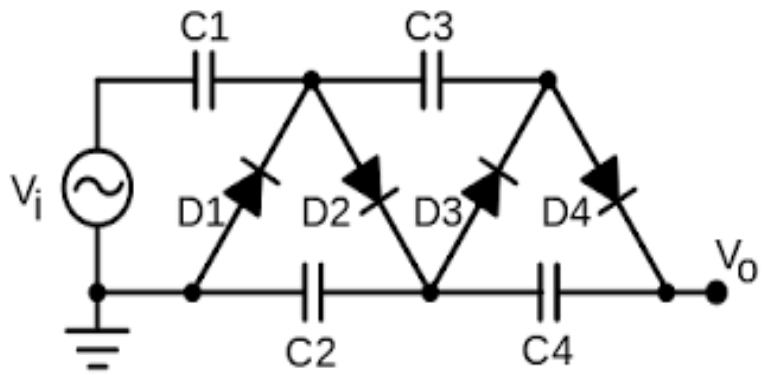


Fig:9- Cockcroft-Walton generator

- It is made up of voltage multiplier ladder network of capacitors and diodes to generate high voltages.
- The two stage cascade generator has four capacitors namely C1, C2, C3 and C4.
- It has four diodes namely D1, D2, D3 and D4.
- Its input voltage is Vi and output voltage is Vo

Working:

- Assume that the circuit is powered by an alternating voltage Vi with a peak value Vp.
- After the input voltage is turned on and when it reaches its negative peak value -Vp , current flows through the diode D1.
- This will charge capacitor C1 to a voltage Vp.
- When Vi reverses polarity and reaches its positive peak +Vp it adds to the capacitor voltage to produce a voltage of 2Vp on C2 because of two diodes D1 and D2.
- When Vi reverses polarity again, current from capacitor C2 flows through diode D3, charging capacitor C3 also to voltage of 2Vp.
- When Vi reverses polarity again, current from capacitor C3 flows through diode D4, charging capacitor C4 also to voltage of 2Vp.
- With each change in input polarity, current flows up the stack of capacitors through the diodes, until they are all charged.
- All the capacitors are charged to a voltage of 2Vp, except for C1 which is charged to Vp.
- The key to the voltage multiplication is that while the capacitors are charged in parallel, they are connected to the load in series.
- Since C2 and C4 are in series between the output and the ground, the total output voltage is

$$\mathbf{Vo = 4Vp}$$

This circuit can be extended to any number of stages. The output voltage is twice the peak input voltage multiplied by the number of stages N.

$$\mathbf{Vo = 2NVp}$$

The number of stages is equal to the number of capacitors in series between the output and the ground.

Advantages:

- It can be extended to any number of stages.
- Its output voltage is twice peak as input voltage.
- It is lighter and cheaper than transformers.

Disadvantages:

- As the number of stages increases, the voltages of the higher stages begin to "sag", mainly due to the electrical impedance of the capacitors in the lower stages.
- The voltage ripple increases as the number of stages is increased.

Applications:

- LCD backlighting
- Ion pumps
- Particle accelerators
- Oscilloscopes
- Air ionisers
- Cathode ray tube
- Television set
- Electrostatic systems
- X-ray systems
- Photocopiers.

2.7 X-RAY FILM

- The media on which the radiographic images of objects are recorded
- Images are stored as an unseen (latent) image that will be changes to a seen image by processing the film.
- X-ray film is a gelatine- covered polyester base. An emulsion coating both sides of the film contains tiny silver halide crystals that are sensitive to such things are visible light, x-rays, gamma rays, heat, moisture and pressure
- X-ray film should not be used if it is out dated
- The composition of x-ray film is similar to that of a photographic film
- Radiation sensitive emulsion is coated on both sides of a transparent base

2.8 THE STRUCTURE OF X-RAY FILM

If an undeveloped x-ray film is examined in daylight it will be found to consist of a flexible base of either cellulose acetate or polyester plastic coated on both sides with thin layers of apple-green photographic emulsion

TYPES OF FILMS

- Basis of coating

-Single emulsion
-Double emulsion

- Based on use of screens
  -Non screen type
  -Screen type
  -Single screen & Double screen
- Based on sensitivity
  -Blue sensitive films
  -Green sensitive films
  -Panchromatic films

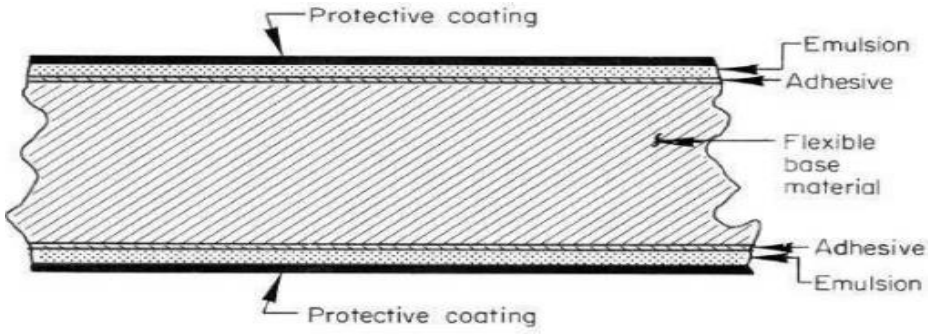


Fig: 10- x-ray film

TINTED BLUE FILM

- Triacetate and polyester are clear and colourless.
- Blue tint was added to the x-ray film in efforts to produce a film that was "easier" to look at.
- Causes less eye strain
- Blue that can be added to either to the base or to the emulsion
- All present x-ray films are blue tinted.

EMULSION

-Photosensitive layer of the film
-Thickness not more than 0.5mils more
-It is the mixture 2 or more liquid those are normally immiscible

BASE

It support the fragile photographic emulsion

FILM BASE REQUIREMENTS

*clear with low light absorption–should not produce visible pattern on the radiography

*Strength, thickness and flexibility of the base must allow for case of developing

*Must have dimensional stability maintain size and shape during processing, handling and storage

*Low flammability

TYPES OF BASES

1) Glass plates
2) Cellulose Nitrate
3) Cellulose tri acetate
4) Polyester

- GLASS PLATES: It is a thin layer of emulsion on one side
- CELLULOSE NITRATE: Inflammable

- Caused fire accidents
-Used in 1914

- CELLULOSE TRIACETATE: Non inflammable
- POLYESTER: Better dimensional stability and colourless

-Dimethyl terepthalate (DMT) and ethylene glycol are brought together under low pressure and high temperature to form molten polymer, stretched into sheets Eg1 Gonex

ADHESIVE LAYER

It is the attachment b/w emulsion layer and film base

Guard's integrity during processing and fixing

SUPER COATING

Thin layer of gelatine

Protects the emulsion from mechanical damage

Prevents scratches and pressure marks

Makes the film smooth and slick

X-RAY PROCESSING

Processing transforms latent image to visible image several producers:

1) Exposure:- latent heat created
2) Development:- converts latent image to black metallic Ag,
3) Wash (stop bath):- removes Ecem developer
4) Fixing & hardening
5) Washing
6) Dry

1) LATENT IMAGE FORMATION

- It is the ionization of the exposed silver bromide crystals (by photon energy theta emerges from the patient) Occurring in the layers before processing occurs

Ag+X-ray photons=Ag+Br

- The latent image is formed by deposits of free Ag ions.
- It remains in the emulsion of the x-ray film until it is changed into a variable image by chemical processing producers

2) DEVELOPMENT Converts latent image –black metallic Ag

- After latent image format, the film should be processed as soon as possible
- Developer solute- 1st solute to which film is placed
- The developer chemically reduces the energized ionised AgBr crystals by donating e-, removing the halides and precipitating Ag .
- The precipitation compounds to black array of the radiography.

DEVELOPER(REDUCING AGENT)

1) Hydroguinone:-

2) Alkalizer:- (acularation Na_2CO_3) provides alkaline medium in which the reducer reacts.

It softens and swelth the emulsion and attract the exposed AgBr crystals

3) PRESEVATIVE (Na sulphite):-

It preserves the strength of the other chemicals

If not present, the strength of other chemicals would rapidly weaken.

4) RESTRAINES (Potassium Bromide):-

The developing agent will deposit Ag in the unexposed crystals in the emulsion

Charging Ag deposit (fogging) on the film if restrains is not added

5) VECHICLE (water);- Provides a means for the chemicals in the development to react (ionize) and Water helps soften gelatine

6) FUNGICIDE ADDED;- To prevent growth of fungi

7) BUFFER;- Maintain pH

3) WASHING /STOP BATH

When the film is removed from the developer , gelatine emulsion is soften and swollen and contains chemicals which are removed by placing the film in a water bath.

*By rising the chemical with H_2O the soluble chemical are removed

*The development reaction is stopped

*Alkalinity of the residual of developer is reduced

*The unexposed Silver halide crystals are not water soluble and will not be washed away

4) FIXING

*The acidic fixing solution removes the unexposed and under develop silver bromide crystals from the film emulsion and re-hardens the emulsion that has soften during development process

FIXING SOLUTION;-

1) Fixing agent (Sodium thiosulphate)
   *removes unexposed crystals
   *Ammonium thiosulphate all crystals
2) Preservative (sodium sulphate)
   *prevents deterioration of solution
3) Hardening agent (potassium Alum)
   *shrinks and hardness the gelatine
4) Acidifier (acetic acid)
   *Alum reacts better in acid medium it provides acid mud
   *Stop developing process
5) Vehicle-water

5) FINAL WASH

*To remove residual fixer chemicals that is acid Ammonium thiosulphates and Ag salts from the film. Insufficient washing results in film turning grout as all the chemicals have not been washed away

6) DRYING:-Dark room –Hanging 1) Fans
2) Fans + heating element –cabinet dryers

PHOTO-STIMULABLE PHOSPHOR IMAGING

The photo-stimulable phosphor (PSP) stores absorbed x-ray energy in crystal structure “traps” and is sometimes referred to as a storage phosphor. This trapped energy can be released if stimulated by additional light energy of the proper

wavelength by the process of photo-stimulated luminescence (PSL). Acquisition and display of the PSP image can be considered in five generalized steps in the figure.

PSP Image acquisition & processing

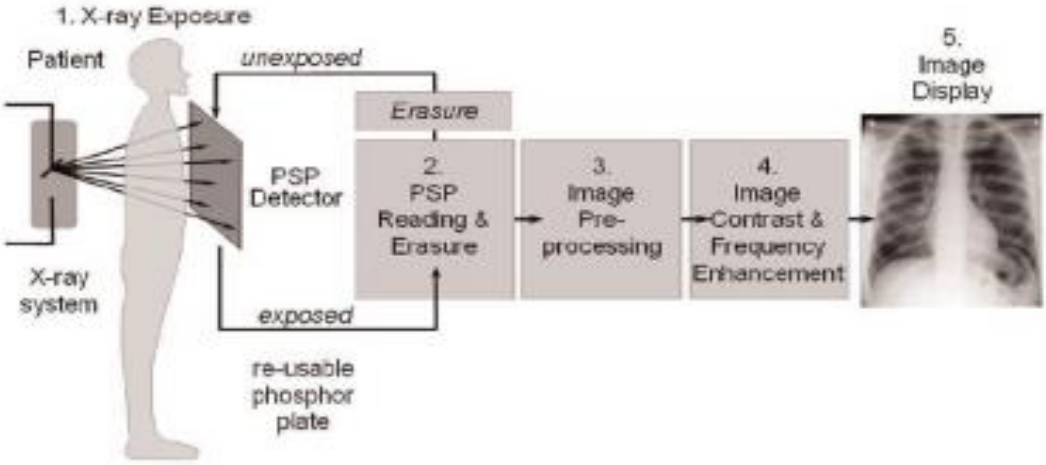


Fig: 11- PSP Image acquisition & processing

Fig.1 The unexposed PSP detector, placed a cassette, replaces the receptor.

Using x-ray imaging techniques similar to screen-film imaging, an electronic latent image in the form of trapped electrons is imprinted on the PSP receptor by absorption of the photons transmitted through the object. At this point, the unobservable latent image is processed by placing the PSP cassette into an image reader, where the image receptor is extracted from the cassette and raster – scanned with a highly focused laser light of low energy. A higher photo-stimulated luminescence (PSL) signal is emitted, intensity of which is proportional to the number of x-ray photons that were absorbed in the local area of the receptor. The PSL signal is channelled to a photo-multiplier tube, converted to a voltage, digitized with an analog to digital converter and stored in a digital image matrix. After PSP detector is totally scanned analysis of the raw digital data locates the pertinent areas of the useful image. Scaling of the data with well – defined computer algorithms creates a gray scale image that mimics the analog film. Finally the image is recorded

on film, or viewed on a digital image monitor. In terms of acquisition the PSP system closely emulates the conventional screen film detector paradigm. As this report will detail, however, there are also several important differences and issues that the user must understand and be aware of to take full advantages of PSP imaging capabilities.

NEW PHOSPHOR TECHNOLOGY

LASER PHOSPHOR DISPLAY(LPD)

- It is a large format display technology.
- This is similar to the CRT(Cathode Ray Tube)
- LPD uses the laser instead of electron gun to activate the phosphor that creates the images.

CONSTRUCTION

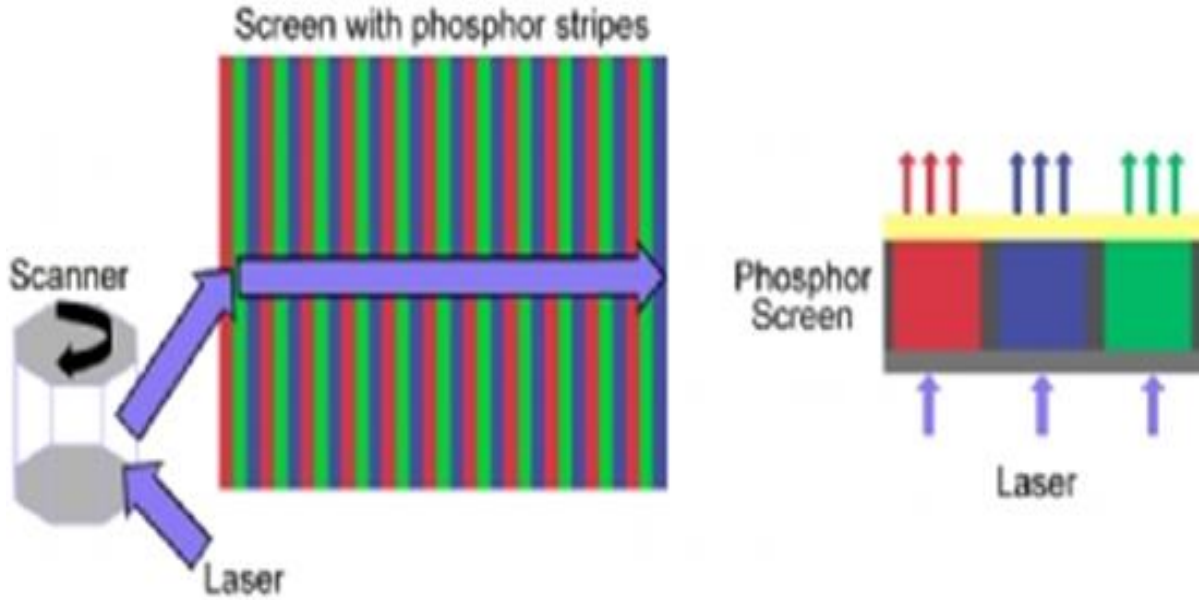


Fig: 12- Laser Phosphor Display

The laser phosphor display consists of two prominent components in them and they are:-

- Set of movable mirrors:- These movable mirrors helps in directing the light from several ultra violet laser onto a screen.
- Screen:- It is made up of plastic glass and a hybrid material coated with color phosphor stripes.

WORKING

- Laser scans the screen line by line from top to bottom.
- The energy emitted from the laser light activates the phosphor coated on the screen.
- The activation of the phosphor causes the emission of photons, hence creating the image.

ADVANTAGES

- Uses less power than LCD and LED.
- Completely recyclable components.
- 180 degree viewing angle.

DISADVANTAGES

- The displays are deeper.

APPLICATIONS

- Televisions.
- Monitors

PHOTOSTIMULABLE PHOSPHOR(PSP)

- A photostimulable phosphor (PSP) is a type of phosphor that can store information generated by X-rays.
- When a photostimulable phosphor is excited by X-rays, electrons and holes are generated.

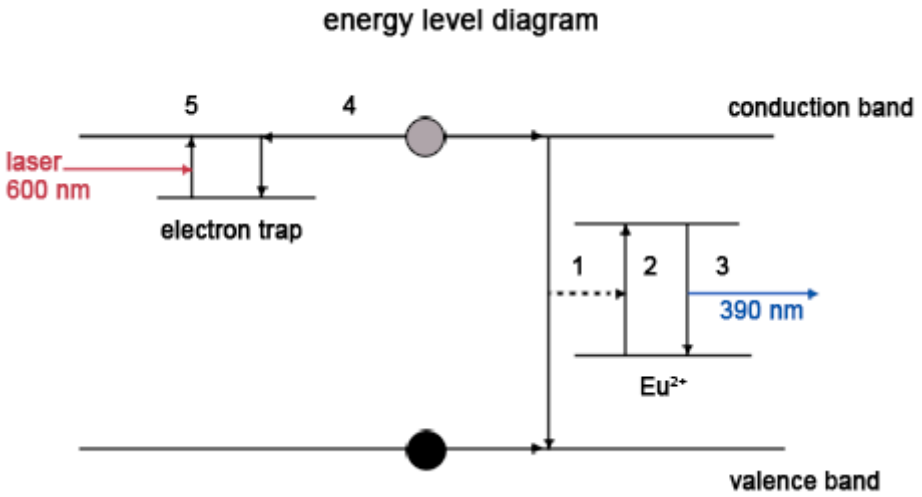


Fig: 13- computed radiography

- A computed radiography (CR) system uses the stimulated light emitted from the photostimulable phosphor. A red laser with adequate power and the correct wavelength scans the surface of the phosphor screen.
- The stimulated light emerging from the screen surface can be collected by a photomultiplier tube and converted to a digital signal for diagnostic purposes.

QUESTION BANK

PART-A

1. Define particle accelerators and give examples.
2. What are the types of particle accelerators?
3. How does accelerator works?
4. Write a short note on self-oscillating device.
5. What is a generator?
6. Give the applications of accelerators.
7. What are intensifying screens?
8. Give the types of X-ray films.
9. What is phosphor imaging?

10. Write the steps involved in X ray film processing.

11. Give two examples of developing and fixing solutions.

PART-B

1. Summarize the particle accelerator with an example.

2. Write notes on

- Magnetron
- Klystron
- cyclotron

3. Describe the principle of generators and write notes on cascade and Van de Graaff generator.

4. Explain in detail about X-ray film processing.

5. Illustrate phosphor technology in detail and add notes on photostimulable and phosphor imaging.

6. Write notes on

- Cyclotron
- Cockcroft Walton generator

7. Enumerate Cyclotron in detail with neat diagram.

8. Explain Magnetron in detail with neat diagram.

9. Explain Klystron in detail with neat diagram.

10.Explain Van de Graaff generator in detail with neat diagram.

References:

1. Gopal,B.Saha , Physics & Radiology of nuclear medicine, Springer 2nd Edition, 2006.
2. Khandpur R.S., Handbook of Biomedical Instrumentation, Tata McGraw Hill Publishing Company Ltd., New Delhi and revised edition, 2007.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERIN

UNIT – 3- RADIO IMAGING AND THERAPEUTICS– SBMA1404

UNIT -3

III- RADIO DIAGNOSIS

Fluoroscopy – Digital Fluoroscopy. Angiography, Cine Angiography, Digital subtraction Angiography. Mammography and Dental x-ray unit. Digital radiography, Angiography, Image intensifier, PET, SPECT.

3.1 Fluoroscopy:

Fluoroscopy is a study of moving body structures--similar to an X-ray "movie." A continuous X-ray beam is passed through the body part being examined. The beam is transmitted to a TV-like monitor so that the body part and its motion can be seen in detail.

The components included in a modern fluoroscopic imaging system. Some components are similar to those included in systems used exclusively for radiography, whereas others are unique to fluoroscopy. Typically, additional apparatus are attached to allow for image recording, such as a spot- film device, film changer, photospot camera, cine camera, or analog-to-digital converter. The following section contains a description of the function of each component.

Fluoroscopic Imaging Chain

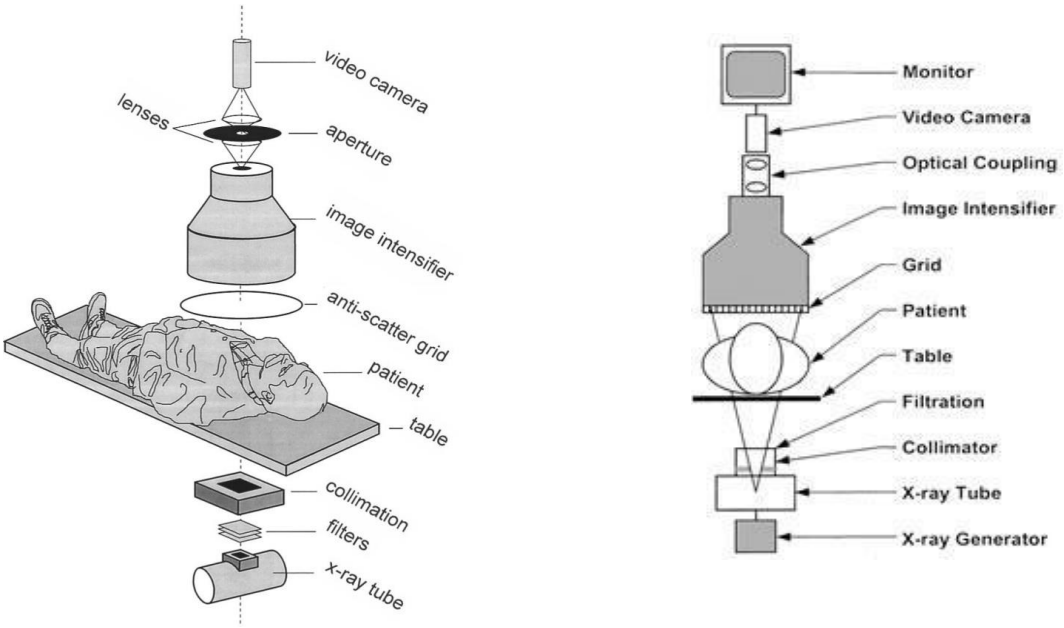


Fig: 1- Fluoroscopic Imaging Chain

3.2 X-ray Generator

An **X-ray generator** is a device used to generate X-rays. It is commonly used by radiographers to acquire an x-ray image of the inside of an object (as in medicine or non-destructive testing) but they are also used in sterilization or fluorescence. The x-ray generator allows selection of kilovolt peak (kVp) and tube current (mA) that is delivered to the x-ray tube. Two methods are used to energize the x-ray tube for fluoroscopy: continuous and pulsed exposure.

For continuous fluoroscopy, the generator provides a steady tube current while the fluoroscope is activated. Images are acquired at a rate of 30 frames per second, resulting in an acquisition time of 33 msec per image. For pulsed fluoroscopy, the exposure is delivered in short pulses, 3–10 msec in length. Typically, a pulse rate of 30 pulses per second is used, with some units allowing the selection of lower pulse rates (15 or 7.5 pulses per second). One advantage of pulsed fluoroscopy is improvement in temporal resolution. Motion blur occurring within each image is reduced because of the shorter acquisition time, making pulsed fluoroscopy useful for examining rapidly moving structures such as those seen in cardiovascular applications. In addition, pulsed fluoroscopy can be used as a method of reducing radiation dose, particularly when the pulse rate is reduced.

Another important feature of a fluoroscopic x-ray generator is ABC, which acts to keep the overall image brightness seen on the monitor at a constant level as the image intensifier is panned over body parts of differing thickness and attenuation. Constant brightness is achieved by automatically adjusting the kVp and mA settings as needed to maintain the x-ray exposure level at the entrance to the image intensifier.

X-ray Tube

The x-ray tube converts electrical energy provided by the generator into an x-ray beam. Within the x-ray tube, electrons are produced by a heated filament and accelerated toward a positively charged tungsten anode. The interaction of the electrons with the anode results in the emission of x rays. The entire assembly is placed within an evacuated envelope and shielded housing. The area of the anode that is struck by electrons is referred to as the focal spot. A small focal spot size is desirable so that geometric unsharpness is minimized.

Collimator

The collimator contains multiple sets of radiopaque shutter blades that define the shape of the x-ray beam. Two sets of blades are generally present within the collimator: round and rectangular. A round iris conforms the x-ray beam to the circular FOV. Rectangular blades can be brought in manually to further reduce the beam size. Collimation reduces the exposed volume of tissue, resulting in reduced scatter production and improved image contrast.

Most fluoroscopy systems used for angiography and interventional applications also contain equalization filters. These filters, also called contour or wedge filters, are partially radiolucent blades used to provide further beam shaping in addition to collimation. Equalization filters reduce glare from unattenuated radiation near the edge of the patient and equalize light exposure to the video camera.

As a result, they improve operation of the ABC system. The filters are made from tapered lead-rubber or lead-acrylic sheets.

Filters

Filtration material is added to attenuate low-energy x rays from the beam. Low-energy x rays are absorbed in patient tissue without being transmitted to the image receptor, contributing to patient dose with little improvement in image quality. Aluminum is the most common added filtration material. Copper can also be used for improved low-energy x-ray filtering. The use of copper filtration material has become more prevalent in fluoroscopy systems used for high-dose procedures such as angiography and interventional applications.

Patient Table and Pad

Patient tables for fluoroscopic systems must provide adequate strength to support large patients and, at the same time, result in minimal x-ray attenuation. Carbon fiber composite material satisfies both these requirements. Patient support pads should also be made of a material that provides minimal x-ray attenuation. Thin foam pads are generally acceptable, but thick gel pads have been found to result in excessive attenuation.

Grid

Anti-scatter grids are used to improve image contrast by reducing the scattered x rays that reach the image receptor. However, use of grids requires an increase in radiation exposure. The grid ratios for fluoroscopy range from 6:1 to 10:1, which is generally lower than common radiographic grid ratios (8:1 to 16:1). For fluoroscopy, removal of the grid may be desirable to reduce patient dose when the amount of scatter produced is low.

Image Intensifier

The image intensifier converts incident x rays into a minified visible light image and, in the process, amplifies the image brightness by about 10,000 times for better visibility to the viewer. The major components of an image intensifier include an input layer to convert x rays to electrons, electron lenses to focus the electrons, an anode to accelerate them, and an output layer to convert them into a visible image. All the components are contained within an evacuated bottle.

Optical Coupling

The optical coupling system distributes light from the image intensifier output window to a video camera and other image recording devices. The optical distributor may include a partially silvered, beam-splitting mirror, which directs a portion of the light from the image intensifier output window to an accessory device for image recording and passes the remainder to the video camera. A circular aperture is also included to set the proper light level required by the video camera. As a result, the ABC system increases the radiation exposure to maintain the light level at the camera,

producing a fluoroscopic image with low noise. Alternatively, when the aperture is set wide open, the radiation exposure level is low and more image noise is apparent.

Television System

A closed-circuit television system is used to view the image intensifier output image. The television system consists of a video camera that converts the image to a voltage signal and a monitor that receives the signal and forms the image display. In addition, fluoroscopic units can be equipped with an analog-to-digital converter to digitize the video camera voltage signal for additional processing and electronic image recording.

The basic video camera consists of a vacuum tube cylinder (approximately 2.5 cm in diameter) with a photoconductive target and a scanning electron beam. In recent years, Charge coupled device (CCD) cameras consist of a solid-state array of light sensors, which store the image as pixels until they are read out as voltage pulses representing the two-dimensional image. Compared with traditional video cameras, CCD cameras are smaller, are more rugged, require less power, and have a longer lifetime.

Image Recording

A fluoroscopic imaging system may include additional devices to record images during an examination. Recording methods include spot film devices, film changers, photospot cameras, cine cameras, and digital photospots.

3.3 Digital Fluoroscopy

A fluoroscope produces a video x-ray. During a fluoroscopic exam, a continuous X-ray beam is used to view an organ or part of the body in real time. The live images are displayed on a computer screen or television monitor. Fluoroscopes are used for interventional procedures such as guiding the placement of a catheter during an arteriography, for assessing stomach and bowel movement and function, and for detecting obstructions in the airway or blood vessels. A contrast agent may also be used to enhance the images.

Fluoroscopy is most often used to view the upper GI tract, which includes the stomach, esophagus, duodenum, and the upper small intestine. It is also used to view the lower GI tract.

How fluoroscopy works

The fluoroscope is a type of x-ray machine that can use either a continuous or a pulsing x-ray beam. The x-ray machine has an x-ray tube that is constructed of glass or metal and has a vacuum seal inside. It generates x-rays by converting electricity from its power line (AC current of 120-480 volts) into electricity that falls into the 25-150 kilo volt range. This creates a stream of electrons that are shot against a tungsten target. When the electrons hit this target (called an anode) the atomic structure of the tungsten stops the electrons, causing a release of x-ray energy. This energy is focused by the x- ray tube onto the area of the body to be imaged.

X-ray image intensifiers for fluoroscopy

The x-ray image intensifier converts the transmitted x rays into a brightened, visible light image. Within an image intensifier, the input phosphor converts the x-ray photons to light photons, which are then converted to photoelectrons within the photocathode. The electrons are accelerated and focused by a series of electrodes striking the output phosphor, which converts the accelerated electrons into light photons that may be captured by various imaging devices. Through this process, several thousand light photons are produced for each x-ray photon reaching the input phosphor. Most modern image intensifiers use cesium iodide for the input phosphor because it has a high absorption.

These very energetic electromagnetic waves can pass through the body and create images of internal structures. Because the different tissues within the body are of different densities, those waves are attenuated (weakened) at differing rates as they pass through. Bone, for example, is very dense and absorbs a lot of the x-rays, while the tissues surrounding the bone are less dense and absorb less of the x-ray.

It is this difference in the absorption of the waves that creates variations in the exposures and allows the detail of the image to be formed.

With a fluoroscope, when the beam passes through the body it hits an image intensifier that increases the brightness of the image many times (e.g. x1000 to x5000) so that it can be viewed on a display screen. The image intensifier itself is coupled to a video camera that captures and encodes the two- dimensional patterns of light as a video signal from the x-ray machine. The signal is converted back into a pattern of light seen as the image on the monitor. The camera output can be digitized for computer image enhancements.

The fluoroscope produces a low dose of radiation, slightly higher than a regular x-ray so it is very important that you let the doctor know if you are pregnant or think you might be.

What to expect when you have fluoroscopic imaging:

Fluoroscopic imaging is painless. Before the imaging you will need to remove any jewelry or clothing that are in the area being scanned. For GI studies, you will usually need to drink barium, or have a barium enema. The barium provides the contrast needed to produce a clear image that can detect polyps and other abnormalities or obstructions.

You will then lie on a table or stand depending on the purpose and area being imaged. The camera will be moved to a position above or in front of you in order to get the proper angle for the images. The procedure will take anywhere from a few minutes to an hour depending on the purpose of the imaging. For example, fluoroscopy is often used in interventional radiology to aid the positioning of a needle for a biopsy or other procedure.

IMPORTANT: *If you are pregnant, or if you think you MIGHT be pregnant, tell the technician or radiologist. While x-rays are safe for you, they are not safe for the developing embryo*

efficiency and thus decreases patient dose. Image intensifiers come in various sizes, most having more than one input image size or magnification mode. Modern image intensifiers are specified by conversion factors, which is the measure of how efficiently an image intensifier converts x rays to light. Because of design restrictions, image intensifiers are subject to inherent and induced artifacts that contribute to image degradation. Both spatial and contrast resolution gradually decrease during the lifetime of the image intensifier because the brightness gain of an image intensifier decreases with time as the phosphor ages. A well-run quality control program for the image intensifier is needed to detect the inevitable changes in settings before they appear on clinical images.

Early fluoroscopic procedures produced visual images of low intensity, which required the radiologist's eyes to be dark adapted and restricted image recording. In the late 1940s, with the rapid developments in electronics and borrowing the ideas from vacuum tube technology, scientists invented the x-ray image intensifier, which considerably brightened fluoroscopic images. Commercial x-ray systems with image intensifiers were introduced in the mid 1950s. The x-ray image intensifier enabled the radiologist to visualize the output image without dark adaptation. The intensified visual image could be easily captured by film and television camera tubes. When the image intensifier was first introduced, it had a small input size and a glass vacuum case. Modern image intensifiers have input field sizes up to 57 cm in diameter with little image distortion, and the vacuum cases are usually made of metal.

An x-ray image intensifier has two major functions: (*a*) to intercept the x-ray photons and convert them into visible light photons and (*b*) to amplify or intensify this light signal. The image intensifier creates a large gain (or intensification) in luminance at the output screen compared with that at the input screen. The output screen image can be viewed with closed-circuit television or recorded with film.

Construction and Principles of Operation

In a modern fluoroscopy system, the image intensifier is located opposite the x-ray tube. The image intensifier is contained in a cylindrical protective case because it is a very delicate device under high vacuum and needs to be handled with care. At the entrance end of this protective case, there is usually a mechanical sensory device to prevent the image intensifier from pushing too hard on the patient or other objects, which may cause damage to the image intensifier. Image intensifiers come in various sizes depending on the specific application. Usually, the larger the image intensifier the higher the cost.

The operational principles of an image intensifier can be briefly described as follows. X-ray photons penetrate the input window of the vacuum case. The input phosphor absorbs the x-ray photons and

converts them into optical photons (a phenomenon called luminescence). These optical photons are converted to photoelectrons at the photocathode. The photoelectrons are accelerated by the electric field produced by the strong electric potential difference of the image intensifier and are collected at the output phosphor. Each accelerated electron produces many optical photons at the output phosphor.

Image Intensifier Components

An image intensifier consists of the following major components: an input window, an input phosphor and photocathode, several electrostatic focusing lenses, an accelerating anode, an output phosphor screen, and a protective vacuum case.

Input Window

The shape and choice of material for the input window results from a compromise among many factors, such as minimizing patient distance, x-ray absorption, x-ray scatter, manufacturing cost, and mechanical strength of materials. The input side of the image intensifier usually has a convex shape and is generally made of aluminum ($Z = 13$). The convex shape not only minimizes the patient distance thus maximizing the useful entrance field size, but it also gives the image intensifier better mechanical strength under atmospheric pressure. This aluminum input window is approximately 1 mm in thickness.

Input Phosphor and Photocathode

X rays transmitted through the input window are converted into fluorescent light photons by the input phosphor. The input screen is a substrate made of aluminum coated with a phosphor layer, an intermediate coupling layer, and finally the photocathode layer. The thickness of the input phosphor layer is a compromise between spatial resolution and x-ray absorption efficiency. A thicker phosphor layer has higher x-ray absorption efficiency, which means more x-ray photons can be absorbed and converted to light photons in the phosphor layer. A thicker phosphor layer requires fewer x-ray photons to generate the same amount of light photons at the image intensifier output window, thus reducing patient dose. However, with a thicker input phosphor layer, more light photons are scattered laterally within the phosphor layer, thus reducing the spatial resolution. Currently, the thickness of an input phosphor layer typically measures between 300 and 450 μm,

depending on the image intensifier type and technology used.

To maximize the conversion efficiency from x-ray photons to photoelectrons, the mass attenuation coefficient of the input phosphor material should be matched with the spectrum of the x rays emerging from the patient. Ideally, the light spectrum of the input phosphor should also match the sensitivity profile of the photocathode. The initial phosphor used in early image intensifiers was zinc- cadmium sulfide (ZnCdS), whereas the current phosphor of choice is cesium iodide (CsI:Na). There are several reasons for replacing ZnCdS with CsI:Na as the input phosphor material. First, the mass attenuation coefficient of CsI:Na better matches the x-ray spectrum of the radiation transmitted from the patient. The mass attenuation coefficients of the two phosphors in relation to the relative spectral distribution of the transmitted radiation from the patient. The mass attenuation peaks in CsI:Na,

compared with those of ZnCdS, are more closely matched to the transmitted x-ray spectrum, thus increasing the absorption of the transmitted x-ray photons. As mentioned, increasing the absorption efficiency decreases the patient's dose. A second advantage for using CsI:Na as the phosphor is that it has a high atomic number from Cs (Z = 55) and I (Z = 53), which also results in higher x-ray absorption. Consequently, most modern image intensifiers use CsI:Na for the input phosphor material.

The photocathode layer is made of antimony-cesium ($SbCs_3$). To maximize the conversion efficiency from light photon to photoelectron, light emitted from the input phosphor should match the sensitivity spectrum of the photocathode. CsI:Na has a better spectral match to the antimony-cesium compound ($SbCs_3$). This is another reason why CsI:Na is a better input phosphor material than ZnCdS. The photocathode has a thickness of about 20 nm and a photoelectron production efficiency of 10%–15%. Approximately 200 photoelectrons will be created for a single 60-keV x-ray photon absorbed in the input phosphor.

In addition to its high absorption efficiency, CsI:Na can be evaporated onto the substrate in crystal needle form. These needles act like light pipes, in a manner similar to the light propagation in a fiber- optic faceplate, thus reducing cross scatter inside the phosphor screen and yielding better spatial resolution. A cross-sectional diagram of the input screen. The CsI:Na needles are approximately 5 μm in diameter. Input phosphor screens in modern image intensifiers are

approximately 300–500 μm in thickness and absorb 60%–70% at 60 keV. Because of the crystalline structure of the needles, the surfaces of the crystals, and the reflectivity of the substrate, approximately 2,600 luminescence photons are generated from each 60-keV x-ray quantum. Of these 2,600 luminescence photons, approximately 1,600 reach the photocathode.

Electron Optics

Photoelectrons are accelerated from the photocathode to the output phosphor by the anode. The accelerated photoelectrons are focused down to the size of the output phosphor by a series of electrostatic focusing electrodes. The number of photoelectrons within the image intensifier will not increase: Only the speed of the photoelectrons will increase. The total current produced by these photoelectrons is approximately 600 nA (600×10^{-9} A).

The focusing electrodes are very sensitive to external electrical and magnetic fields. Extraneous electrical and magnetic fields (even the earth's magnetic field) may cause image distortions in the image intensifier. This effect must be monitored and controlled for fluoroscopes operated near magnetic resonance imaging units. Furthermore, the high voltages on the electrodes must be kept very stable to guarantee the image quality, since ripple in the voltage will be noticed as periodic variation in image diameter.

On the vacuum side of the output phosphor surface, the anode of the electron optics system has a thin aluminum film coating. This aluminum film allows electrons to pass through, but it is opaque to light photons generated on the fluorescent screen. It stops these photons from being scattered back into the image intensifier and exposing the photocathode. The film also serves as a reflector to increase the output luminance.

Output Phosphor and Window

The output phosphor of the x-ray image intensifier, which typically is called P20, is a fluorescent compound made of silver-activated zinc-cadmium sulfide (ZnCdS:Ag). The emission spectrum of P20 is at a maximum around 530 nm (green light). The P20 layer is very thin, having a thickness of 4–8 μm, and is deposited on the glass output window. Approximately 2,000 luminescence photons are generated for every accelerated 25-keV photoelectron. Because every electron was produced by one light photon, this represents a luminescence gain of 2,000. The output window is carefully designed so that the fluorescent photons reflected back to the input screen are minimized. The luminescence decay time of the output phosphor determines the temporal resolution of the

image intensifier.

Image Intensifier Housing

The x-ray image intensifier is enclosed in a metal housing consisting of lead to absorb scattered radiation, mu-metal to shield the electron optics from extraneous magnetic fields, and an outer aluminum shell. On the input side of the housing, the aluminum shell protects the input window of the image intensifier. Although the housing will provide some shielding from external electromagnetic fields, the presence of strong magnetic or electrical fields too close to the image intensifier will degrade image quality.

Physical Characteristics

The input size, brightness gain, conversion factor, contrast ratio, magnification mode, and spatial resolution characterize an image intensifier. The size of an image intensifier is obviously the most visible property, and the larger the image intensifier, the larger the field of view. A large field of view allows one to visualize a larger area, which can be very helpful in some clinical procedures. However, a larger image intensifier is more difficult to make and thus more expensive.

Brightness Gain and Conversion Factor

The brightness gain comes from two sources that are completely unrelated: the minification gain and the flux gain. The minification gain is defined as the ratio of input area to the output area of the image intensifier. Because the number of photoelectrons leaving the photocathode is equal to the number striking the output phosphor, the number of photoelectrons per unit area at the output phosphor increases. The minification gain does not improve the statistical quality of the fluoroscopic image. It will not change the contrast of the image, but it will make the image appear brighter. A smaller output window size will just compress more photons into a smaller area, producing a smaller but brighter image.

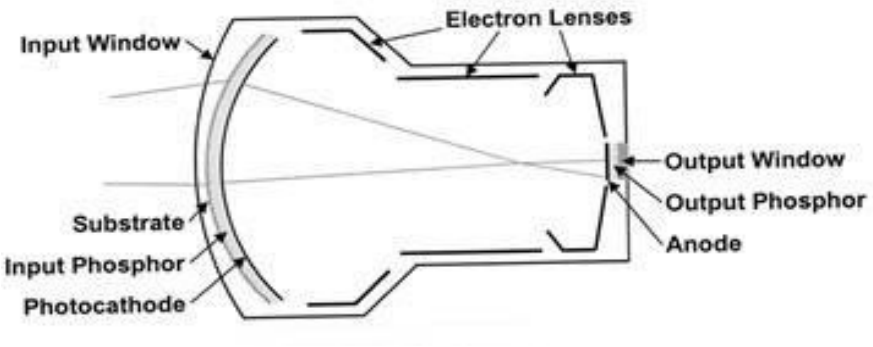
Flux gain is defined as the number of photons generated at the output phosphor for every photon generated at the input phosphor. The flux gain results from the acceleration of photoelectrons to a higher energy so that they generate more fluorescent photons at the output phosphor. Each light photon generated at the input phosphor will generate approximately 100 photons at the output phosphor, resulting in a flux or luminance gain of 100. The total brightness gain of the image intensifier is the product of minification gain and flux gain (total brightness gain = flux gain × minification gain).

The size of the output window of an image intensifier is usually between 1.5 and 6.0 cm in diameter. The minification gain for a 23-cm image intensifier with an input entrance field size of 22 cm (380 cm^2) and a 2-cm output window (3.14 cm^2) is approximately 120. With a flux gain of approximately

100, the total brightness gain for this image intensifier would be approximately 12,000.

The original definition of brightness gain is the output luminance level (or brightness) of an image intensifier divided by the output luminance level of a Patterson B-2 fluoroscopic screen when both are exposed to the same quantity of radiation. The Patterson B-2 fluoroscopic screen was typically used for fluoroscopy before image intensifiers were introduced. If the image intensifier gives 5,000 times brighter output than the Patterson B-2 fluoroscopic screen, the brightness gain is 5,000. The drawback of using this definition is the lack of reproducibility of the Patterson B-2 screen.

The International Commission on Radiological Units and Measurements (ICRU) has recommended another method of evaluation called the conversion factor. Today, most x-ray image intensifiers are specified by the conversion factor. The conversion factor is defined as the output luminance level of an image intensifier divided by its entrance exposure rate. It is a measure of how efficiently an image intensifier converts the x rays to light. Conversion factors have units of candela per square meter per milliroentgen per second ([cd/m^2]/[mR/sec]). A typical 23-cm image intensifier has a conversion factor of approximately 200 cd/m^2/mR/sec. The conversion factor usually equals to 1% of the brightness gain in value. Conversion factors tend to deteriorate (decrease) as image intensifiers age, resulting in higher patient dose for older image intensifiers. The higher the conversion factor, the more efficient the image intensifier.



3.2 Cross sectional schematic of an image intensifier shows its major components

- Medex Gamma camera has crystal upto 500 mm in diameter, 6.4mm or 9.6 mm thick with an array of 61, 75 or 93 PMTs.
- The no of gamma rays received by an region on the crystal is directly and to amount of nudide located directly below the region.

- Only 0.01% of rays emitted are detected and used for image formation.
- A Polaroid camera mounted on top of escilloscope photograph 50,000 dots on the screen.

Benefits/Risks

Fluoroscopy is used in a wide variety of examinations and procedures to diagnose or treat patients. Some examples are:

- Barium X-rays and enemas (to view the gastrointestinal tract)
- Catheter insertion and manipulation (to direct the movement of a catheter through blood vessels, bile ducts or the urinary system)
- Placement of devices within the body, such as stents (to open narrowed or blocked blood vessels)
- Angiograms (to visualize blood vessels and organs)
- Orthopedic surgery (to guide joint replacements and treatment of fractures)

Fluoroscopy carries some risks, as do other X-ray procedures. The radiation dose the patient receives varies depending on the individual procedure. Fluoroscopy can result in relatively high radiation doses, especially for complex interventional procedures (such as placing stents or other devices inside the body) which require fluoroscopy be administered for a long period of time. Radiation-related risks associated with fluoroscopy include:

- radiation-induced injuries to the skin and underlying tissues ("burns"), which occur shortly after the exposure, and
- radiation-induced cancers, which may occur sometime later in life.

The probability that a person will experience these effects from a fluoroscopic procedure is statistically very small. Therefore, if the procedure is medically needed, the radiation risks are outweighed by the benefit to the patient. In fact, the radiation risk is usually far less than other risks not associated with radiation, such as anesthesia or sedation, or risks from the treatment itself. To minimize the radiation risk, fluoroscopy should always be performed with the lowest acceptable exposure for the shortest time necessary.

Information for Patients

Fluoroscopy procedures are performed to help diagnose disease, or to guide physicians during certain treatment procedures. Some fluoroscopy procedures may be performed as outpatient procedures while the patient is awake – for example, upper gastrointestinal series to examine the esophagus, stomach and small intestine, or a barium enema to examine the colon.

Other procedures are performed as same-day hospital procedures or sometimes as inpatient procedures, typically while the patient is sedated – for example, cardiac catheterization to examine

the heart and the coronary arteries that supply blood to the heart muscle. Still other fluoroscopy procedures may be performed under general anesthesia during surgery – for example to help align and fix fractured bones.

The clinical benefit of a medically appropriate X-ray imaging exam outweighs the small radiation risk. The FDA encourages patients and parents of pediatric patients to engage in a discussion with their health care provider about the benefits and risks of fluoroscopy procedures (see the Medical X- ray Imaging webpage for advice on questions to ask your health care provider).

Extensive information is available on fluoroscopy, diseases and conditions where fluoroscopy is used for diagnosis or treatment, and on the risks and benefits of fluoroscopy. In addition to the patient information links on the Medical X-ray Imaging webpage, more specific information on procedures conducted using fluoroscopy is provided below:

- Patient Information on interventional radiology procedures from the Society of Interventional Radiology
- Information on heart disease and cardiology procedures, including cardiac catheterization and coronary artery stenting can be found at the Society for Cardiovascular Angiography and Interventions
- The Heart Rhythm Society's Patient Information addresses heart disease, abnormal heart rhythms and treatment of abnormal heart rhythms
- The Society of Vascular Surgery's Vascular Conditions, Tests, Treatments contain information on diagnosis and treatment of abnormalities of blood vessels

Resources for patients on concerns about radiation from fluoroscopy include:

- The Alliance for Radiation Safety in Pediatric Imaging: The Step Lightly campaign for interventional radiologyand the Pause and Pulse campaign for fluoroscopy
- International Atomic Energy Agency (IAEA) Radiation Protection of Patients (RPOP): Information for Patients: Interventional Procedures
- National Cancer Institute of the National Institutes of Health on Interventional Fluoroscopy: Reducing Radiation Risks for Patients and Staff

Digital radiography :

Digital radiography is a form of X-ray imaging, where digital X-ray sensors are used instead of traditional photographic film. Advantages include time efficiency through bypassing chemical processing and the ability to digitally transfer and enhance images. Also, less radiation can be used to produce an image of similar contrast to conventional radiography. Instead of X-ray film, digital radiography uses a digital image capture device. This gives advantages of immediate image preview and availability; elimination of costly film processing steps; a wider dynamic range, which

makes it more forgiving for over- and under-exposure; as well as the ability to apply special image processing techniques that enhance overall display quality of the image.

Detectors

There are two major variants of digital image capture devices: flat panel detectors (FPDs) and high-density line-scan solid state detectors.

Flat Panel Detectors

1. **Indirect FPDs** Amorphous silicon (a-Si) is the most common material of commercial FPDs. Combining a-Si detectors with a scintillator in the detector's outer layer, which is made from caesium iodide (CsI) or gadolinium oxysulfide (Gd_2O_2S), converts X-rays to light. Because of this conversion the a-Si detector is considered an indirect imaging device. The light is channeled through the a-Si photodiode layer where it is converted to a digital output signal. The digital signal is then read out by thin film transistors (TFTs) or fiber-coupled CCDs. The image data file is sent to a computer for display.

2. **Direct FPDs**. Amorphous selenium (a-Se) FPDs are known as "direct" detectors because X-ray photons are converted directly into charge. The outer layer of the flat panel in this design is typically a high-voltage bias electrode. X-ray photons create electron-hole pairs in a-Se, and the transit of these electrons and holes depends on the potential of the bias voltage charge. As the holes are replaced with electrons, the resultant charge pattern in the selenium layer is read out by a TFT array, active matrix array, electrometer probes or microplasma line addressing.

High-density Line-scan Detectors A **high-density line-scan solid state detector** is composed of a photostimulable barium fluorobromide doped with europium (BaFBr:Eu) or caesium bromide (CsBr) phosphor. The phosphor detector records the X-ray energy during exposure and is scanned by a laser diode to excite the stored energy which is released and read out by a digital image capture array of a CCD.

Digital Radiography in Medical Uses

Digital Radiography is replacement of the former Analog methods of detection, with the almost instantaneous development of images on a digital display, instead of the former methods of film and the associated delay in time and chemistry consumption.

At present there are two distinct methods of Digital Radiography.

1. Computed radiography (CR); This resembles the old analogue system of a light sensitive film sandwiched between two x-ray sensitive screens, the difference being the analogue film has been replaced by an imaging plate, which records the image to be read by an image reading device, which transfers the image usually to a Picture archiving and communication system (PACS)

2. Direct radiography (confusingly also abbreviated to DR). A direct radiography system has a sealed imaging cassette; this contains an imaging system not entirely unlike the CCD in a digital camera. The image is recorded then transmitted wirelessly direct to the PACS (hence the name Direct Radiography)

CR vs DR

Computed radiography (CR)	Direct radiography (DR)
Initially CR was the system of choice	early DR systems were expensive (each cassette costs around Rupees 24 Lakhs to 40 Lakhs)
CR system were initially cheaper	Costly and prone to damage
less likely to critical failure	DR systems have been developed the cassettes have become cheaper
more similar to previous analogue systems	newer more durable and now incorporate wireless technology
No Integration	integrated DR x-ray systems
CR is becoming the 'old' technology	the DR systems are proving faster, more efficient and producing higher quality radiographs

Image intensifier

- Image intensifier tubes (IITs) are optoelectronic devices that allow many devices, such as night vision devices and medical imaging devices, to function.
- They convert low levels of light from various wavelengths into visible quantities of light at a single wavelength.
- An **image intensifier** or **image intensifier tube** is a vacuum tube device for increasing the intensity of available light in an optical system, which allow to use under low-light conditions, such as at night, to facilitate visual imaging of low-light processes, such as fluorescence of materials in x-rays or gamma rays (x-ray image intensifier), or for conversion of non-visible light sources, such as near-infrared or short wave infrared to visible.
- They operate by converting photons of light into electrons, amplifying the electrons (usually with a microchannel plate), and then converting the amplified electrons back into photons for viewing.
- They are used in devices such as night vision goggles.

Operation:

- **Image intensifiers** convert low levels of light photons into electrons, amplify those electrons, and then convert the electrons back into photons of light. Photons from a low-light source enter an objective lens which focuses an image into a photocathode.
- The photocathode releases electrons via the photoelectric effect as the incoming photons hit it. The electrons are accelerated through a high-voltage potential into a microchannel plate (MCP).
- Each high-energy electron that strikes the MCP causes the release of many electrons from the MCP in a process called secondary cascaded emission.
- The MCP is tilted to encourage more electron collisions, thus increasing the amount of emission of secondary electrons.

- The electrons all move in a straight line due to the high-voltage difference across the plates, which preserves collimation, and where one or two electrons entered, thousands may emerge.
- A separate (lower) charge differential accelerates the secondary electrons from the MCP until they hit a phosphor screen at the other end of the intensifier, which releases a photon for every electron.
- The image on the phosphor screen is focused by an eyepiece lens.
- The amplification occurs at the microchannel plate stage via its secondary cascaded emission.
- The phosphor is usually green because the human eye is more sensitive to green than other colors and because historically the original material used to produce phosphor screens produced green light (hence the soldiers' nickname 'green TV' for image intensification devices).

History:

- The idea of an image tube was first proposed by G. Holst and H. De Boer (Netherlands) in 1928 , but early attempts to create one were not successful.
- It was not until 1934 that Holst, working for Philips, created the first successful infrared converter tube.
- This tube consisted of a photocathode in proximity to a fluorescent screen. Using a simple lens, an image was focused on the photocathode and a potential difference of several thousand volts was maintained across the tube, causing electrons dislodged from the photocathode by photons to strike the fluorescent screen.
- This caused the screen to light up with the image of the object focused onto the screen, however the image was non-inverting. With this image converter type tube, it was possible to view infrared light in real time, for the first time.

Principle:

- Photons from a low-light source enter the objective lens (on the left) and strike the photocathode (gray plate).

- The photocathode (which is negatively biased) releases electrons which are accelerated to the higher-voltage microchannel plate (red).
- Each electron causes multiple electrons to be released from the microchannel plate. The electrons are drawn to the higher-voltage phosphor screen (green).
- Electrons that strike the phosphor screen cause the phosphor to produce photons of light viewable through the eyepiece lenses.

X-Ray Image Intensifier (XRII):

- An x-ray image intensifier (XRII) is an image intensifier that converts x-rays into visible light at higher intensity than mere fluorescent screens do. Such intensifiers are used in x-ray imaging systems (such as fluoroscopes) to allow low-intensity x-rays to be converted to a conveniently bright visible light output.
- The device contains a low absorbency/scatter input window, typically aluminum, input fluorescent screen, photocathode, electron optics, output fluorescent screen and output window.
- These parts are all mounted in a high vacuum environment within glass or more recently, metal/ceramic.
- By its intensifying effect, It allows the viewer to more easily see the structure of the object being imaged than fluorescent screens alone, whose images are dim.
- The X-ray II requires lower absorbed doses due to more efficient conversion of x-ray quanta to visible light. This device was originally introduced in 1948.

3.3 Generation 0: early infrared electro-optical image converters

- Development continued in the US as well during the 1930s and mid-1930, the first inverting image intensifier was developed at RCA. **RCA Corporation**, founded as the **Radio Corporation of America**, was an American electronics company in existence from 1919 to 1986. General Electric took over the company in late 1985. This tube used an electrostatic inverter to focus an image from a spherical cathode onto a spherical screen.

- Unlike later technologies, early Generation 0 night vision devices were unable to significantly amplify the available ambient light and so, to be useful, required an infra-red source.
- These devices used an S1 photocathode or "silver-oxygen-caesium" photocathode, discovered in 1930, which had a sensitivity of around 60 μA/lm (Microampere per Lumen) and a quantum efficiency of around 1% in the ultraviolet region and around 0.5% in the infrared region. Of note, the S1 photocathode had sensitivity peaks in both the infrared and ultraviolet spectrum and with sensitivity over 950 nm was the only photocathode material that could be used to view infrared light above 950 nm.

Generation 1: significant amplification

- With the discovery of more effective photocathode materials, which increased in both sensitivity and quantum efficiency, it became possible to achieve significant levels of gain over Generation 0 devices.
- In 1936, the S-11 cathode (cesium-antimony) was discovered by Gorlich, which provided sensitivity of approximately 80 μA/lm with a quantum efficiency of around 20%; this only included sensitivity in the visible region with a threshold wavelength of approximately 650 nm.

Generation 2: micro-channel plate

- Second generation image intensifiers use the same multi alkali photocathode that the first generation tubes used, however by using thicker layers of the same materials, the S25 photocathode was developed, which provides extended red response and reduced blue response, making it more suitable for military applications.
- It has a typical sensitivity of around 230 μA/lm and a higher quantum efficiency than S20 photocathode material.
- Oxidation of the cesium to cesium oxide in later versions improved the sensitivity in a similar way to third generation photocathodes.

Generation 3: high sensitivity and improved frequency response

- While the third generation of tubes was fundamentally the same as the second generation, they possessed two significant differences.
- Firstly, they used a GaAs—CsO—AlGaAs photocathode, which is more sensitive in the 800 nm-900 nm range than second-generation photocathodes.
- Secondly, the photocathode exhibits negative electron affinity (NEA), which provides photoelectrons that are excited to the conduction band a free ride to the vacuum band as the Cesium Oxide layer at the edge of the photocathode causes sufficient band-bending.
- This makes the photocathode very efficient at creating photoelectrons from photons. The Achilles heel of third generation photocathodes, however, is that they are seriously degraded by positive ion poisoning.

- Due to the high electrostatic field stresses in the tube, and the operation of the MicroChannel Plate, this led to the failure of the photocathode within a short period - as little as 100 hours before photocathode sensitivity dropped below Gen2 levels.
- To protect the photocathode from positive ions and gases produced by the MCP, they introduced a thin film of sintered aluminium oxide attached to the MCP.
- The high sensitivity of this photocathode, greater than 900 μA/lm, allows more effective low light response, though this was offset by the thin film, which typically blocked up to 50% of electrons.

Collimators:

A collimator is a device that narrows a beam of particles or waves. The necessary shaping of the x ray beams are done by these. Collimators are used in neutron, X-ray, and gamma-ray optics because it is not yet possible to focus radiation with such short wavelengths into an image through the use of lenses as is routine with electromagnetic radiation at optical or near-optical wavelengths. Collimators are also used with radiation detectors in nuclear power stations for monitoring sources of radioactivity. To narrow can mean either to cause the directions of motion to become more aligned in a specific direction (i.e., make collimated light or parallel rays), or to cause the spatial cross section of the beam to become smaller (beam limiting device). Collimator consists of a shutter made from a heavy metal like lead with a rectangular hole or Collimators (beam limiting devices) are used in linear accelerators used for radiotherapy treatments. They help to shape the beam of radiation emerging from the machine and can limit the maximum field size of a beam.

Grids / Bucky Grids:

Grids are placed between the patient and the X-ray film to reduce the scattered radiation (produced mainly by Compton Effect) and thus improve image contrast. They are made of parallel strips of lead with an interspace having an aluminium or organic spacer. The strips can be oriented either linear or crossed in their longitudinal axis. As the scatter radiation is increased in "thicker" patients and at larger field sizes, grids are useful in such scenarios to improve image contrast. The working ability of a grid is described by the grid ratio, which is the ratio of height of the lead strips to the distance between two strips (the interspace). The higher the grid ratio, the better the image contrast but at a cost of increased patient dose. Grid ratio of 8:1 is generally used for 70-90 kVp technique and 12:1 is used for >90 kVp technique.

Radiographic Grid

- Used to reduce scatter radiation from reaching the image receptor (IR) through absorption
- Cleans up scatter radiation
- Inherent part of bucky, placed between the patient and IR
- Table or upright bucky usage – >60 kVp, 10 cm tissue
- When primary x-rays interact with the patient, x-rays are scattered from the patient in all directions.

Types:

- Focused grids (most grids): strips are slightly angled so that they focus in space
- Parallel grid: used for short fields or long distances

- Moving grids (also known as Potter-Bucky grids): eliminates the fine grid lines that may appear on the image when focused or parallel grids are used.

Uses:

Grids are commonly used in radiography, with grid ratio available in even numbers, such as 4:1, 6:1, 8:1, 10:1 or 12:1. Generally used where the anatomy is >10 cm:

- Abdomen
- Skull
- Spine (except lateral cervical)
- Contrast studies
  - IVU
  - RGU
  - MCU
  - barium studies (including lateral cervical)
- Breast (mammography): uses 4:1 grid ratio
- A bucky is typically used for table or wall mounted x-ray systems and holds the x-ray cassette and grid. A bucky, is a device found underneath the exam table, a drawer like device that the cassette and grid is slid into before shooting x-ray.
- The most common bucky size grids are 17 1/4 x 18 7/8, 17 1/4 x 17 3/4, and 18 x 18. Buckys are found in both medical and veterinarian offices. There is nothing special about a bucky grid other than its size.
- A reciprocating bucky is a device that moves the grid while the x ray is being taken. The motion keeps the lead strips from being seen on the image. The finer the lead strips, the less movement is needed.

Grid Frequency

- Number of strips or grid lines per inch or cm – 25 – 45 lines/cm, 60 – 110 lines/in – 25 – 80 lines/cm, 60 – 200 lines/in
- Higher grid frequency requires higher technique – Less grid lines appear in image – Often used in mammography
- 80 lines/cm, 200 lines/in
- Typically higher frequency grids have thinner lead strips.

BODY SECTION RADIOGRAPHY

Body section radiography involves taking radiographs of layers of the body, that is, a series of x-rays taken at different depths in order to define images of desired areas. The desired image is brought sharply into focus while blurring out the other areas. These types of radiograms are used to locate lesions accurately in places like the lungs and bones. They are referred to as tomograms, laminograms, and planograms.

Tomography

A special x-ray technique to show the detail images of structures lying in a predetermined plane of tissue, while blurring or eliminating detail images of structures in other planes (Same as Laminography)

Laminography

X-ray of a selected layer of the body made by Laminography (Picker Ultrasonic Laminograph). In the early 1970's, computerized tomography (CT) was introduced into clinical medicine and revolutionized the field of diagnostic imaging.

Digital Radiography

A system which uses computers to convert the lighter and darker areas of the radiographic image into numbers and then translate these numbers into an image on a cathode ray (television) tube

Xeroradiography

The term xeroradiography; 'xero' meaning dry in Greek. It requires more radiation exposure.

Xeroradiography is a type of X-ray imaging in which a picture of the body is recorded on paper rather than on film. In this technique, a plate of selenium, which rests on a thin layer of aluminium oxide, is charged uniformly by passing it in front of a scorotron. The process was developed by engineer Dr. Robert C. McMaster in 1950.

As X-ray photon impinges on this amorphous coat of selenium, charges diffuse out, in proportion to energy content of the X-ray. This occurs as a result of photoconduction. The resulting imprint, in the form of charge distribution on the plate, attracts toner particles, which is then transferred to reusable paper plates. In contrast to conventional X-rays, photographic developers are not needed. Xeroradiography was used first in mammography prior to the advent of digital mammography and called Xeromammography.

3.4 SINGLE PHOTON EMISSION COMPUTER TOMOGRAPHY (SPECT)

Single-photon emission computed tomography (**SPECT**, or less commonly, **SPET**) is a nuclear medicine tomographic imaging technique using gamma rays.[1] It is very similar to conventional nuclear medicine planar imaging using a gamma camera.[2] However, it is able to provide true 3D information. This information is typically presented as cross-sectional slices through the patient, but can be freely reformatted or manipulated as required.

The technique requires delivery of a gamma-emitting radioisotope (a radionuclide) into the patient, normally through injection into the bloodstream. On occasion, the radioisotope is a simple soluble dissolved ion, such as an isotope of gallium(III). Most of the time, though, a marker radioisotope is attached to a specific ligand to create a radio ligand, whose properties bind it to certain types of

tissues. This marriage allows the combination of ligand and radiopharmaceutical to be carried and bound to a place of interest in the body, where the ligand concentration is seen by a gamma camera.

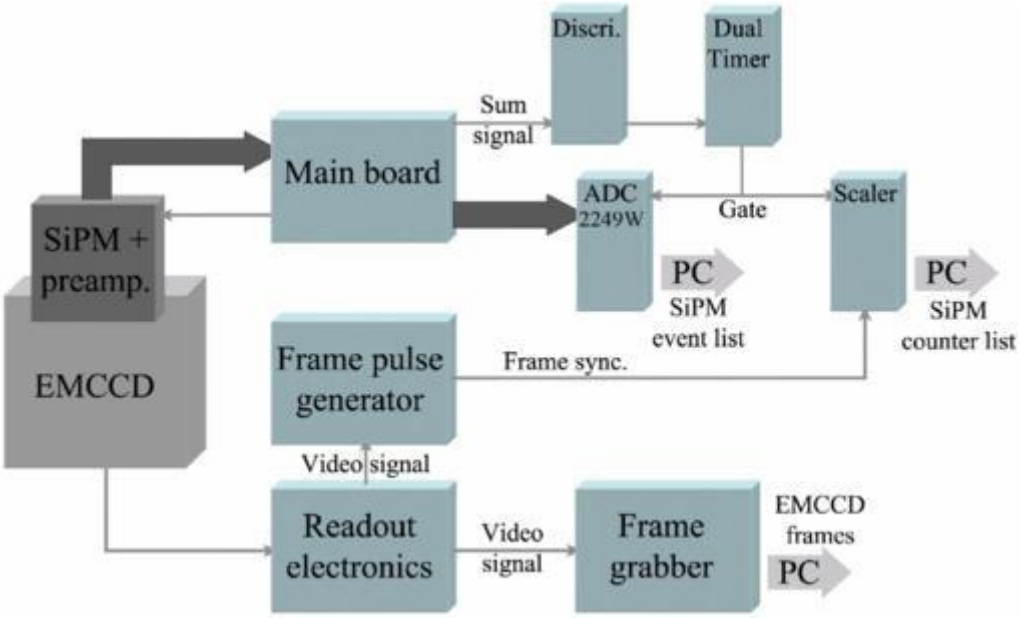
- SPECT is a nuclear medicine technique used to create a 30 image of the distribution of the adminsted radio pharmaceutical.
- SPECT cameras detect only radion that produce a cascaded emission of single photons.
- Rgs of SPECT radionuctides are TC-99m, Ti-201, I-123, 7n-111, and Xe-133.
- Main component is a single gamma camera movement on a specialized mechanical gentry that automatically rotates the camera 360^0 around the patient.
- SPECT acquire data is a series of multiple projection at cncrincents of 2 or more degrees. Camera is moved a limited no of times (Usually 6)n in limited angle systems.
- Image is reconstructed by filtered back projection algorithm.
- Once non target data are filtered off, the reconstructed 3D image is derived from back projection which will have multi angled; 2D views and projects them onto a computer monitor.
- Transverse slias (axial or trans axial) are obtained by combining the projected data.
- SPECT can one multiple camera heads.
  - Dual Head system 2, 180^O opposed camera heads.

Accusation time reduced by half Triple

Head System Improves Sensitivity

- Sensitivity of SPECT is determined by the total area of detector surface that is viewing the organ of interest.
- Detector to improve sensitivity.
  - Bank of dis detectors, stationary ring of detectors and a unique ten beam collimator that rotates in front of the stationary detectors. (highly sensitive)
  - Another method uses a set of 12 and ventilation detectors coupled with a complex scanning motion to produce tomographic images.

Camera based SPECT



- A pallet (to reduce gamma ray alteration) supports the patient B/W 2 Scintillation cameras (radeally adjustable form 22-66cm detector surface to surface)
- Adjustable range allows the collimators to be in close proximity to patient.
- Data collected using contneus gantry during 360^{O} rotation.
- Acquisition time is 2-26 mins.
- 2 Na (71) crystals c FOV 40.6cm, are 9.5 mm thick.
- Detectors coupled to an array of 37 PMT's.
- Electronic circuitry includes circuit for positioning non-levearties and regional rensitivity variations.
- During acquisition, each X-Y pair of Gamma ray event coordinate digitized into a 128x 64 storage array in fuffer memory, together with detector identifying bit energy window identifying bit.
- A secondary window is used to reached events that have undergoes Compton scattering within the patient.
- The fast and common evaluation method for reconstruction of images is SPECT is by filtered back projection.
- Nowadays iterative algorithms or reconstruction method are used to prevent disturbances of artefacts.
- Parallel hole collimators is used for imaging organs like livers, lungs, and heart, for brain , fan beam collimators are used to increase sensitivity.
- Image display is dove on a system interfaced to a computer. 256x256 image format with 256 slides of gray with windowing and background subjection is available.
- Colors monitors are also provided and display station is also interfaced to a film recorder to

obtain prints.

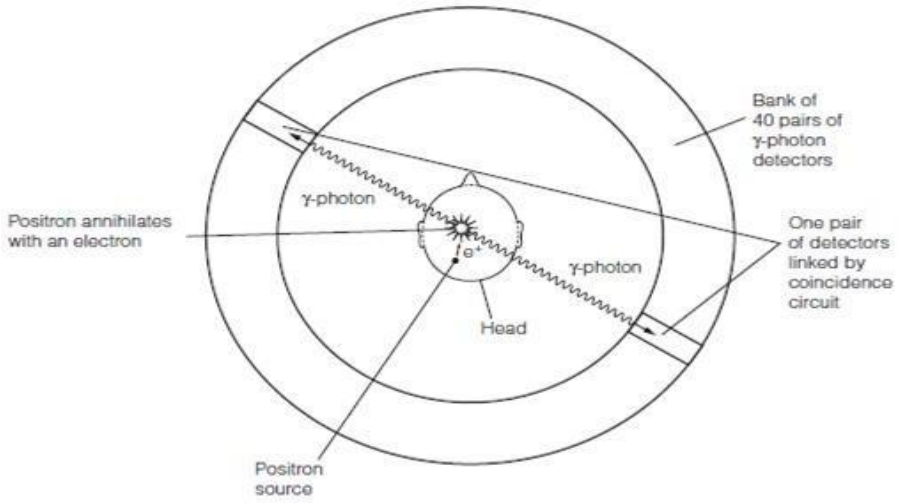
- An ECG gate can also be interfaced, to obtain end diastolic and end system SPECT images of the heart.
- Many were dyed image processing tools are used in the software. Some general also applications are image smoothing, interpolation, image addition or subtraction, background subtraction, contrast enhancements.

3.5 POSITRON EMISSION TOMOGRAPHY (PET)

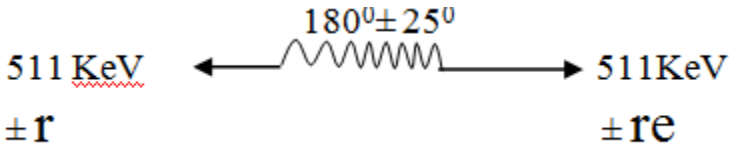
An imaging technique for obtaining invivo cross sectional images of positions emitting isotopes that demonstrate biological function, physiology or pathology

Principle:-

- A chemical compound with the desired biological activity is labelled with a radioactive isotope that decays by emitting a positron.
- This emitted positron immediately combines with an electron and the two are naturally annitralated with the emission of 2 gamma rays.
- These 2 gamma rays travel in the opposite directions penetrate the surrounding tissue and are recorded outside the subjects by a circular array of detectors.



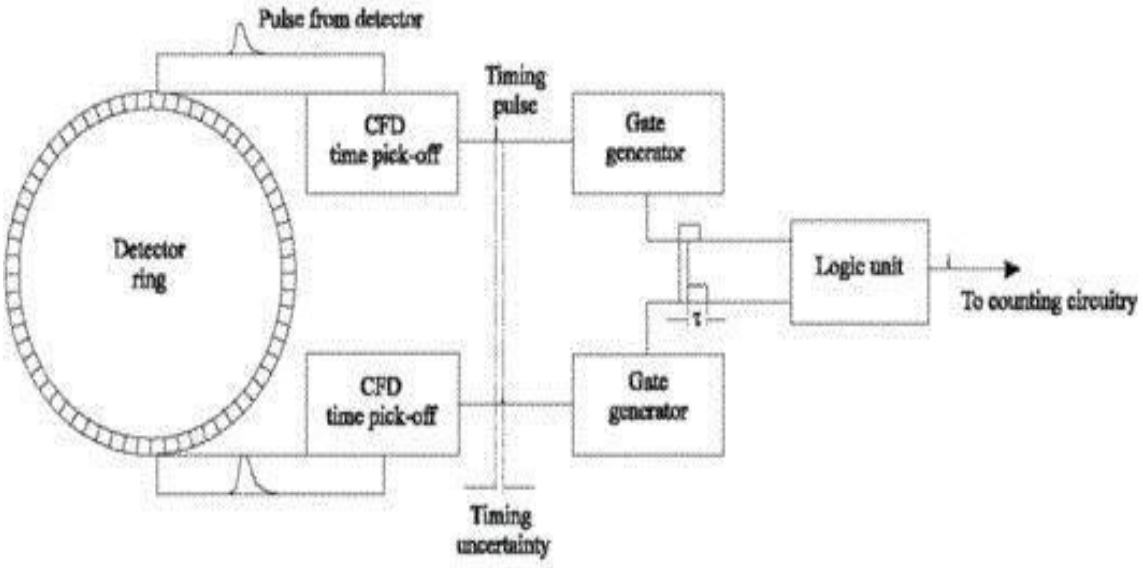
- A mathematical algorithm apptred by the computer rapidly reconstructs the apatial distribution of the radioactivity within the subject for a selected plane and displays resulting image on the monitor.
- The position (β^+) emitted from the proton such nucleus has a variable amount of KE.
- The β^+ combines with a free electron β^- and the masses are transmitted to two 511KeV gamma Rays which are emitted at $180^0 \pm 25^0$ to one another to satisfy conservation of momentum.



The isotopes used are ^{11}C, ^{13}N, ^{15}O and ^{18}F Two design types of PET's are

1) Large area detectors which require rotation around the patient to provide necessary degree of angular sampling
2) Multiple individual crystal detector surrounding the patient in a circular or hexagonal array. Collimators are not usually required and pulse processing needs to be faster.

Hoffmann PET System



- Gantry has large opening and can image brain and torso
- Detector system can be filtered to obtain oblique section.
- Scintillation crystals used are bismuth germinate (BGO) and they detect the 511KeV annilirilation eadration.
- Detectors arranged in circular ring geometry with 512 detectors per ring. Has 2 rings and produces 2 scanning plaves. Detectors are agganged in buckets C 16 detector packages. Each package contains 2 crystals and 2 PMT's. The bucket also contains amplifiers/dis cricimotors and few front end processing electronics.

<u>Original PET Scanners</u>

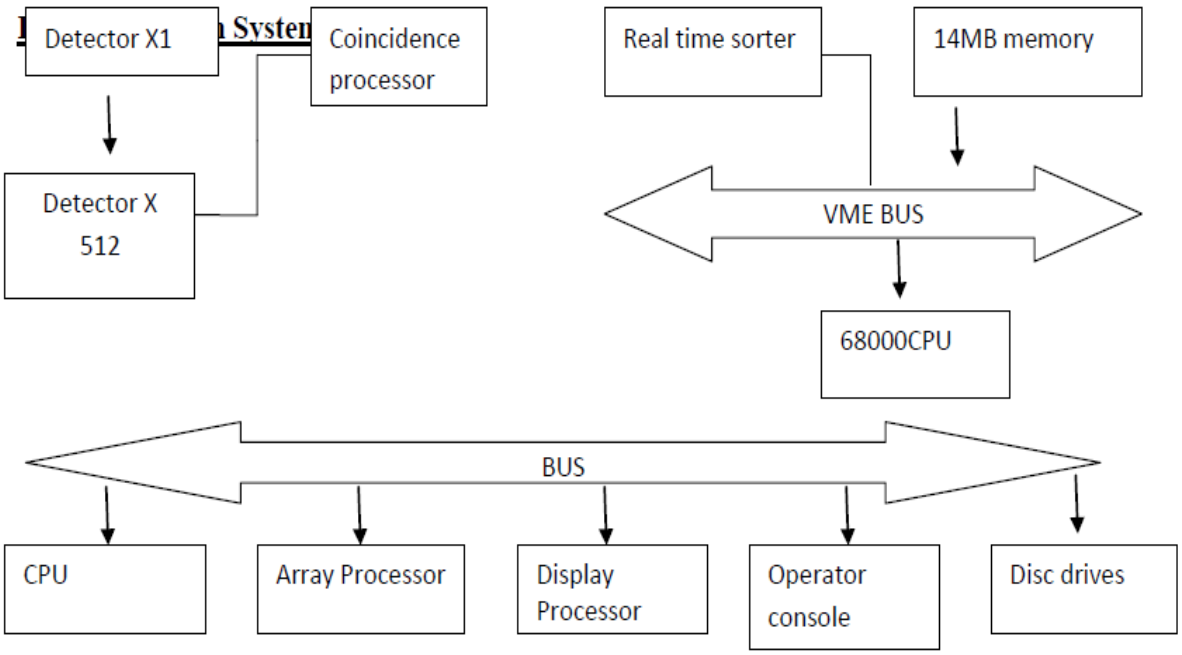
Thallium dropped scdium iodide detectors.

Advantages are high efficiency

- Ease of fabrication
- Low cost

Disadvantage

Decreasing detection efficiency (smaller crystal for higher resolution)



- Many processors are used throughout the system to maximize speed for simultaneous data collection.
- Individual and average detector signals are amplified.
- Constant fraction discriminator-deternunes thine of interaction.
- Time encoder- converts events into 14 bit word with detector no and event time within 8Hrs.
- Coincidence processor-14 bit word sent here every 22 Hrs.
- Energy window controlled by MP in every bucket.
- Threshold of 220 KeV is used to detect scattered gamma rays.
- Fan beam geometry used.
- Main processor- motors + Controls the various processing jobs.
- Array processor- used to perform primary reconstruction
- Peripheral devices- display processor, controls, desk divices.
- <u>GE 4096 PET System</u>
- High resolution scanning system
- 4096 individual crystals are arrange in 8 rings of 512 crystals each. 2 PMT's attached to each set of 16 crystals (to increase position sampling). Crystal used in Bismuth generate.
- 30 slices obtained in a single acquisition interval.
- Patient port is 57cm that allows for large patient scanning
- Positioning accomplished by triple laser positioning system.
- Horizontal or acial table positioning controlled manually.
- 2 pin shaped Ge sources are used for transmission requirements, adjustment of gain and normalization of detector efficiencies.

- DAP (Data acquisition processor) uses a 68030 processor and dual lutel i960 RISC processor. This controls the real time acquisition of data for the system

3.6 ANGIOGRAPHY

Angiography or **arteriography** is a medical imaging technique used to visualize the inside, or lumen, of blood vessels and organs of the body, with particular interest in the arteries, veins, and the heart chambers. The word itself comes from the Greek words ἀνγεῖον *angeion*, "vessel", and γράφειν *graphein*, "to write" or "record". The film or image of the blood vessels is called an *angiograph*, or more commonly, an *angiogram*. This is traditionally done by injecting a radio- opaque contrast agent into the blood vessel and imaging using X-ray based techniques such as fluoroscopy.

Technique:

Depending on the type of angiogram, access to the blood vessels is gained most commonly through the femoral artery, to look at the left side of the heart and at the arterial system; or the jugular or femoral vein, to look at the right side of the heart and at the venous system. During an angiogram, a thin tube called a catheter is placed into a blood vessel in the groin (femoral artery or vein) or just above the elbow (brachial artery or vein). The catheter is guided to the area to be studied. Then an iodine dye (contrast material) is injected into the vessel to make the area show clearly on the X-ray pictures. This "dye, " properly called contrast, makes the blood flowing inside the blood vessels visible on an x-ray. The contrast is later eliminated from your body through your kidneys and your

urine. This method is known as conventional or catheter angiogram. The angiogram pictures can be made into regular X-ray films or stored as digital pictures in a computer.

Reasons:

An angiogram to diagnose a variety of vascular conditions, including:

- Blockages of the arteries outside of your heart, called peripheral artery disease (PAD)
- Enlargements of the arteries, called aneurysms
- Kidney artery conditions, called renovascular conditions
- Problems in the arteries that branch off the aorta, called aortic arch conditions
- Malformed arteries, called vascular malformations
- Problems with your veins, such as deep venous thrombosis (DVT) or blood clots in the lungs called pulmonary emboli

Applications:

One of the most common angiograms performed is to visualize the blood in the coronary arteries. A long, thin, flexible tube called a catheter is used to administer the X-ray contrast agent at the desired area to be visualized. The catheter is threaded into an artery in the forearm, and the tip is advanced through the arterial system into the major coronary artery. X-ray images of the transient radio contrast distribution within the blood flowing inside the coronary arteries allows visualization of the size of the artery openings. Presence or absence of atherosclerosis or atheroma within the walls of the arteries cannot be clearly determined.

Neuro-vascular angiography

Another increasingly common angiographic procedure is neuro-vascular digital subtraction angiography in order to visualise the arterial and venous supply to the brain. Intervention work such as coil-embolisation of aneurysms and AVM gluing can also be performed.

Peripheral angiography

Angiography is also commonly performed to identify vessel narrowing in patients with leg claudication or cramps, caused by reduced blood flow down the legs and to the feet; in patients with renal stenosis (which commonly causes high blood pressure) and can be used in the head to find and repair stroke. These are all done routinely through the femoral artery, but can also be performed through the brachial or axillary (arm) artery. Any stenoses found may be treated by the use of atherectomy.

Risks:

Coronary angiography is a common medical test. It rarely causes serious problems. However, complications can include:

- Bleeding, infection, and pain at the catheter insertion site.
- Damage to blood vessels. Rarely, the catheter may scrape or poke a hole in a blood vessel as it's threaded to the heart.
- An allergic reaction to the dye that’s used during the test.

Other, less common complications include:

- Arrhythmias (irregular heartbeats). These irregular heartbeats often go away on their own. However, your doctor may recommend treatment if they persist.
- Kidney damage caused by the dye that’s used during the test.
- Blood clots that can trigger a stroke, heart attack, or other serious problems.

- Low blood pressure.
- A buildup of blood or fluid in the sac that surrounds the heart. This fluid can prevent the heart from beating properly.

As with any procedure involving the heart, complications can sometimes be fatal. However, this is rare with coronary angiography.

The risk of complications is higher in people who are older and in those who have certain diseases or conditions (such as chronic kidney disease and diabetes).

QUESTIO BANK

PART-A

1. What is the principle of fluoroscopy?

2. What is digital radiography?

3. Define optical coupling.

4. Draw a neat sketch of fluoroscopy.

5. Define image intensifier.

6. How an angiogram works?

7. Give the applications of PET.

8. Why is collimator used in fluoroscopy?

9. What are grids and give an example.

PART-B

1. Describe fluoroscopy and its different components with a neatly labeled diagram.

2. Summarize the angiography. Enumerate its application in detail.

3. Illustrate about the image intensifier and mention its need in the field of radiology.

4. Elaborate the different kinds of radiography.

5. Differentiate between PET and SPECT.

6. Examine about digital radiography.

7. Write in detail about bucky grids.

8. Explain PET with a neatly labeled diagram.

9. Explain SPECT with a neatly labeled diagram.

10. Explain in detail about xeroradiography

References

1. Faiz M.Khan, The Physics of Radiation Therapy, 4th Edition, 2009.

2. Gopal,B.Saha , Physics & Radiology of nuclear medicine, Springer 2nd Edition, 2006

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERIN

UNIT – 4- RADIO IMAGING AND THERAPEUTICS– SBMA1404

UNIT –IV
RADIOTHERAPHY

COBALT-60, Linac, Gamma camera, Nuclear scintigraphy, Brachytherapy, Cyber Knife, Gamma knife, Intraoperative radiotherapy

4.1 COBALT-60:

Cobalt 60 Machine

- Introduced in 1950 to medical use. Hard metal substance-atomic number-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 it yields 28 rays of energy 1.17 and 1.33 MeV equal high penetration.
- Production of 60C source: any material placed within neutron radiation field of a nuclear 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

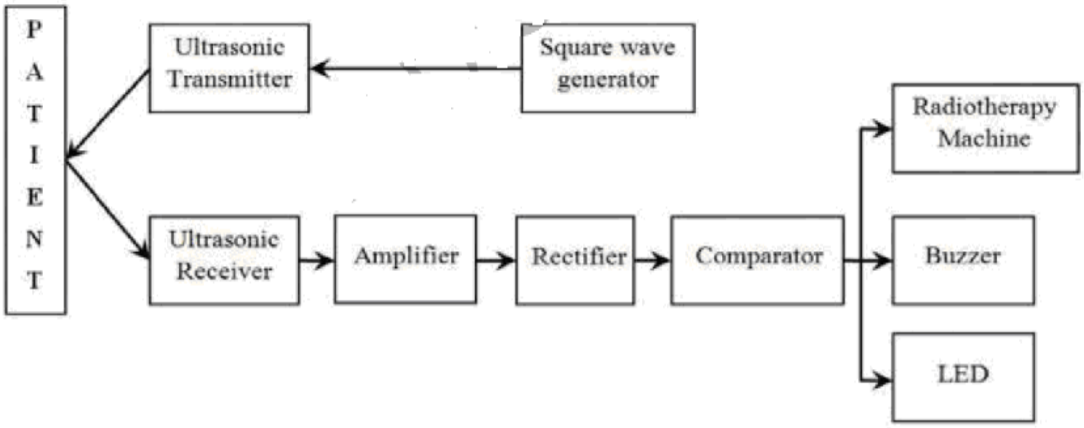
Cobalt source head

- ✓ 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‟ 180o to carry it from “off” to “on” position. Motor drive and torque spring is used for this source is mounted in a scudding pure 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
- It is very compact.

4.2 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

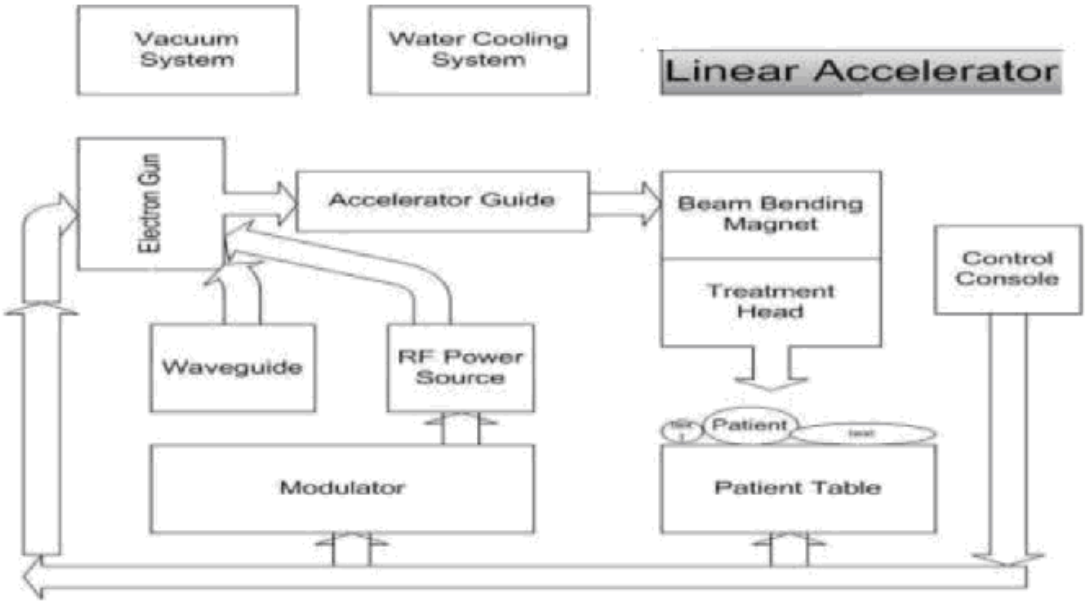
- Control console

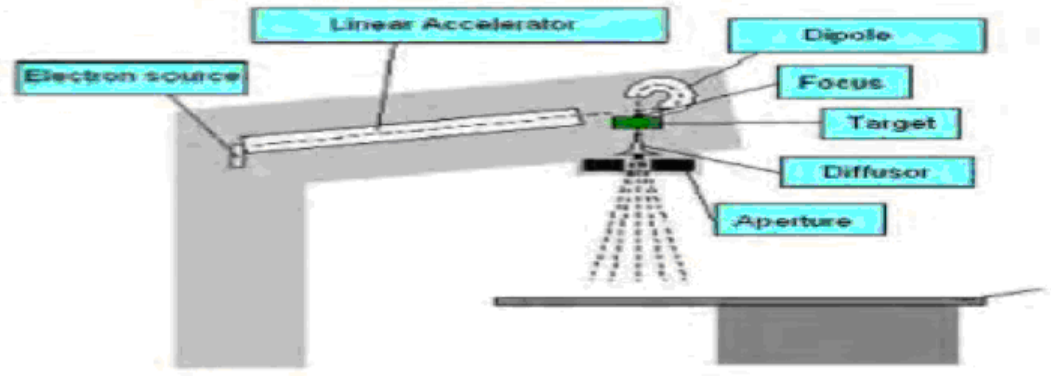
- The treatment beam is generated by a linear accelerator wave guide in the gantry and produces a photon beam of energy in the range 11-20 MeV.
- The accelerator accessibly is mounted in rotating gantry with 100 cm target axis distance. The gantry has X-Ray collimating system and also a display of for 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.

The Accelerator

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- is 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 Structure 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.

5) 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- have 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 finder 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 360o clockwise and counter clockwise.
- Rotation is provided by a drive shaft connected to a servo drive motor.

iii) Control console

- The Control the accelerator located outside the treat room. All control enable operation of the unit.
- 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.

iv) Patient Couch

- 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.

4.3 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.

Nuclear Scintigraphy:

4.4 Brachytherapy:

- 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.
- The advantages of Brachytherapy are 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.
- Brachytherapy is commonly used as an effective treatment for cervical, **prostate**, **breast**, and **skin cancer** and can also be used to treat tumours in many other body sites

Gamma Knife Radio surgery

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.

4.5 Cyber Knife:

- ✓ The **CyberKnife** is a frameless robotic radiosurgery system used for treating benign tumors, malignant tumors and other medical conditions.
- ✓ The system was invented by John R. Adler, a Stanford University professor of neurosurgery and radiation oncology, and Peter and Russell Schonberg of Schonberg Research Corporation.
- ✓ The CyberKnife system is a method of delivering radiotherapy, with the intention of targeting treatment more accurately than standard radiotherapy.

- ✓ **The two main elements of the CyberKnife are:**

1. The radiation produced from a small linear particle accelerator (linac)
2. A robotic arm which allows the energy to be directed at any part of the body from any direction

- **Difference between Gamma Knife** can only target brain or cervical spine cancer with a single treatment of high-dose radiation, while **CyberKnife** is able to treat cancer anywhere on the body in one to five radiation treatments.

4.6 INTRA-OPERATIVE RADIOTHERAPY (IORT):

Intra-operative radiation therapy (IORT) delivers a concentrated dose of radiation therapy to a tumor bed during surgery. This advanced technology may help kill microscopic disease, reduce radiation treatment times or provide an added radiation "boost."

Advantages of IORT

Typically, standard radiation therapy involves five days of treatment per week, for a total of five to six weeks for some patients. With IORT, our radiation oncologists can deliver a similar dose of radiation in a single treatment session, while also preserving more healthy tissue. This helps to reduce side effects and the time spent going back and forth to the hospital for radiation treatments.

Advantages of IORT:

- Maximum effect. IORT delivers a concentrated dose of radiation to a tumor site immediately after a tumor is removed, helping to destroy the microscopic tumor cells that may be left behind. The tumor site is typically at high risk for recurrence and traditional radiation therapy requires a recovery period after surgery, which leaves microscopic disease in the body for longer.
- Spares healthy tissues and organs. During IORT, a precise radiation dose is applied while shielding healthy tissues or structures, such as the skin, that could be damaged using other techniques. This allows a higher radiation dose to be delivered to the tumor bed, while sparing normal surrounding tissues. Critical organs within the radiation field, such as the lungs or heart, can also be protected.
- Shortened treatment times. IORT may help some patients finish treatment and get back to their lives quicker by reducing the need for additional radiation therapy, which is typically given over five to six weeks. The IORT treatment itself takes about four to five minutes.
- A "boost" for traditional radiation patients. Patients who must receive additional radiation therapy following surgery can receive a boost of radiation during IORT. After they have recovered from the surgical procedure, they can continue with their radiation treatments, with typically fewer complications.
- A patient must be a surgical candidate in order to be eligible for IORT. This treatment is generally reserved for individuals with early-stage disease.

QUESTION BANK

PART-A

1. How COBALT-60 is used in radiotherapy?

2. What is linac?

3. How does the gamma camera works?

4. What is nuclearscintigraphy?

5. Write a note on brachytherapy.

6. What is cyber knife?

7. Write a note on intraoperative radiotherapy.

8. What is gamma knife?

9. Write the applications of gamma camera.

10. Give the applications of cyber knife.

PART-B

1. Describe in detail about gamma camera and its application.

2. Enumerate the applications of COBALT-60 in radiotherapy.

3. Summarize radiotherapy in detail with example.

4. Write a brief note on nuclearscintigraphy.

5. Explain in detail about brachytherapy.

6. Enumerate the applications of gamma knife.

7. What is cyber knife and enumerate its applications.

8. Write in detail about intraoperative radiotherapy techniques.

9. Enumerate the applications of linac.

10. Explain in detail about nuclear medicine.

Reference:

1. Gopal,B.Saha , Physics & Radiology of nuclear medicine, Springer 2nd Edition, 2006.

2. Khandpur R.S., Handbook of Biomedical Instrumentation, Tata McGraw Hill Publishing Company Ltd., New Delhi and revised edition, 2007.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERIN

UNIT – 5- RADIO IMAGING AND THERAPEUTICS– SBMA1404

UNIT –V

RADIATION SAFETY MEASURES

Radiation Protection, Protective barrier-primary& secondary, Equivalent Dose, Biological effects of radiation, Somatic & genetic effects of radiation-LD 50/30, Effect of radiation on skin, blood forming organs, Personnel and area monitoring systems, Radiation measuring devices -dosimeter, survey meter.

5.1 Radiation Protection:

Radiation protection, sometimes known as radiological protection, is defined by the International Atomic Energy Agency (IAEA) as "The protection of people from harmful effects of exposure to ionizing radiation, and the means for achieving this". The IAEA also states "The accepted understanding of the term radiation protection is restricted to protection of people. Suggestions to extend the definition to include the protection of non-human species or the protection of the environment are still controversial".

Ionizing radiation is widely used in industry and medicine, and can present a significant health hazard. It causes microscopic damage to living tissue, which can result in skin burns and radiation sickness at high exposures (known as "tissue" or "deterministic" effects), and statistically elevated risks of cancer at low exposures ("stochastic effects").

Fundamental to radiation protection is the reduction of expected dose and the measurement of human dose uptake. For radiation protection and dosimetry assessment the International Committee on Radiation Protection (ICRP) and International Commission on Radiation Units and Measurements (ICRU) have published recommendations and data which is used to calculate the biological effects on the human body, and set regulatory and guidance limits.

Radiology is concerned with the application of radiation to the human body for diagnostically and therapeutically purposes. This requires an understanding of:

- The basic nature of radiation
- The basic nature of radiation
- Radiation detection
- Biological effects of radiation

To evaluate the advantages and disadvantages of the various medical applications of radiation and its limitations

Regulation of dose uptake

In most countries a national regulatory authority works towards ensuring a secure radiation environment in society by setting dose limitation requirements that are generally based on the recommendations of the International Commission on Radiological Protection (ICRP). These use the following overall principles:

- **Justification:** No unnecessary use of radiation is permitted, which means that the advantages must outweigh the disadvantages.
- **Limitation:** Each individual must be protected against risks that are far too large through individual radiation dose limits.
- **Optimization:** Radiation doses should all be kept as low as reasonably achievable. This means that it is not enough to remain under the radiation dose limits. As permit holder, you are responsible for ensuring that radiation doses are as low as reasonably achievable, which means that the actual radiation doses are often much lower than the permitted limit.

Recording personal radiation exposure

An employer must ensure that the exposure doses of radiation received are recorded for each employee to whom a personal monitoring dosimeter has been issued. These records must be reviewed at intervals usually not exceeding three months.

The record kept by an employer must contain the following information:

- The amount of radiation to which the person has been exposed as measured by the dosimeter. The dose should be recorded in sieverts.
- The results of any tests carried out by the employer to determine the amount of radiation to which the employee has been exposed.
  Records must contain the following particulars of the employee:
- full name, sex and date of birth
- current home address or if the person is no longer employed by the employer, the person's last known home address
- the date employment commenced and the date the employee ceased employment, if they are no longer employed there
- the kind of work performed by the employee
- details of the types of ionising radiation to which the employee may have been exposed in the course of their employment, including information about unsealed radioactive substances to which they may have been exposed
- details must be provided of any radiation accidents in which the employee has been involved or by which they may have been affected

- details of the PMD worn by the employee, which may include the type of monitor, where on the body the monitor was worn and the name of the PMD service provider
- the radiation exposure dose results for the employee.

When an employee leaves their place of employment, the employer must provide the following:

- A copy of their radiation exposure records. This must include all annual dose records and any subsequent periodic reports received after the employee has ceased employment. It may be necessary to send these to the current address of the former employee.
- An additional copy of the radiation exposure records must be provided to the new employer if requested by the employee. These records are required to be given to a new employer so that an assessment can be made of possible future doses that can be received to keep an employee under their annual limit.

An employer must ensure the following warning is included on copies of radiation exposure records provided to an employee.

‘**These records should be kept safely and permanently and be given to any future employer employing you as a radiation worker.**

An employer who is required to keep records of personal radiation exposure must ensure that an employee's records are available for them to see at a convenient time during normal working hours.

Managing employee dose rates

When a dose report is received from the dosimetry service provider, a review with previous reports should be made. This is to determine if the employee's previous 12-month and five-year dose rates are within the required limits of 20 mSv per year, averaged over a period of five consecutive calendar years.

The employer should make a note of any high dose rates received by employees. The PMD service provider should highlight these high dose rates. If the dose rate exceeds 400 microsieverts (µSv) in any week averaged over the period of monitoring, it is considered that the employee has received a high dose. For incidents where this has occurred, a letter may be required from the Environment Protection Authority (EPA) seeking an explanation from the employer as to why such a dose was received. A change in work practice or role should be considered to manage an employee's annual dose, if a high dose report has been received.

Personal radiation monitoring dosimeter service providers

The EPA must approve all PMDs and their providers used in NSW. A current listing of approved PMDs is provided under radiaiton monitoring.

The Chair of the EPA may impose conditions on the approval of a PMD.

Under the requirements of Division 2 of the Radiation Control Regulation employers are required to ensure that all monitoring devices that are issued or installed are checked, maintained and calibrated in accordance with the Guideline: Monitoring Devices (devices.pdf, 121KB)

5.2 Protective Barrier- Primary & Secondary:

The lead lined walls of ***Radiology*** department are referred to as ***protective barriers*** because they are designed to protect individuals located outside the X-ray rooms from unwanted radiation There are two types of ***protective barriers***.

(a) Primary Barrier: is one which is directly struck by the primary or the useful beam.

(b) Secondary Barrier: is one which is exposed to secondary radiation either by leakage from X-ray tube or by scattered radiation from the patient.

The shielding of X-ray room is influenced by the nature of occupancy of the adjoining area. In this respect two types of areas have been identified.

A) Primary barrier is the barrier in which the primary beam of the treatment machine falls (Linac, co-60 units) on it. The thickness of the primary is greater than the other barriers of room. Shielding materials for primary barrier as well as other barriers are same like concrete, lead, and steel etc.

Primary barrier thickness determination:

The required attenuation of the barrier B may be found according to a desired dose constraint that is derived from an occupational or public dose limit. Reference (1) uses the following expression to determine the attenuation required by the barrier.

Where,

P – is the allowed dose per week (Sv/week)outside the barrier.

D – is the distance from the isocentre to the outside of the barrier, in meters.

SAD – Source to Axis Distance in meters

W – is the workload, in Gy/week at 1meter.

U – is the use factor or fraction of time that the beam is likely to be incident on the barrier.

T – is the occupancy factor or the fraction of time that the area outside the barrier is likely to be occupied

The thickness of concrete required from attenuation graphs, or by the use of TVLs. The number of TVLs required to produce this attenuation is determined from:

The width of the primary will be calculated as follows,

The primary barrier width is made equal to the maximum to the maximum field size at the barrier plus 1foot (0.305m) on either side to prevent radiation from leaking through the secondary barrier that abuts the primary. Most of the linear accelerator has 40cm x 40cm as maximum field size at one meter from the target.

When the collimator is rotated to 45 degree, the above dimension becomes equal to its diagonal (56.6cm) then the horizontal barrier width (W) required is given by

$W = 0.556d + (0.305 \times 2)$

Where, d is the distance from the source to the barrier.

The image intensifier is a **primary barrier** against radiation coming from the tube located beneath the x-ray table. When the table is in the vertical position the image intensifier can be an effective means to protect the technologist from radiation. When the table is in the horizontal position and the technologist is required to be in the room for a procedure, occupational dose can be lessened by locating to a strategic location behind the image intensifier. As the primary beam exiting the patient strikes the image intensifier to produce images on the monitor, the image intensifier serves as a primary barrier. According to the regulations, the image intensifier must have a minimum absorption equivalency of 2.0 mm lead. Furthermore, the entire cross section of the useful beam should be intercepted by a primary protective barrier at all source-to-image distances (SID). Standing in front of the patient and therefore the image intensifier when the table is upright, along with wearing a lead apron will offer the technologist outstanding radiation protection.

B) Secondary barriers are the barrier in which the secondary beam will fall on it. However, it is not facing the primary radiation we need to shield against the scattered radiation as well as leakage radiation from the head. Shielding materials used for the secondary barrier is same as the primary barrier only example concrete, lead, and steel etc.

International protocol for the leakage radiation from the head of the linear accelerator must not exceed 0.5% of the primary beam, outside the useful beam at one meter from the path of the electron between the gun and target window and averaged over 100cm3. In the plane of the patient, the leakage must not exceed an average of 0.1% and it would be reasonable to assume this value when determining the required secondary barrier thickness.

The control booth, lead aprons, the x-ray tube housing are includes in types of secondary radiation barriers.

The required attenuation (BL) to shield against leakage radiation is as follows:
Where,

P - is the design dose limit.

Ds - is the distance from the isocentre to the point of interest in meter.

W - is the workload.

T – is the occupancy factor.

The use factor for the secondary barrier is always considered as 1 for the determining protection, because of that no need to write in the equation. In this case ds should be measured from the gun end of the wave guide to the point just outside this barrier since this barrier will be subjected to leakage radiation from the vicinity of the gun.

Barrier thickness to shield against scattered radiation:
The required barrier transmission (Bp) needed to shield against radiation scattered by the patient.
Where,

P, W and T have the same meaning as in the leakage radiation equation.

dsca – is the distance from the radiation source to the patient, in meter

dsec – is the distance from the patient to the point of interest, in meter

a - is the scatter fraction defined at dsca.

The scatter primary ratio (a) is dependent on the energy of the X ray beam and the scattering angle. These data
retabulated per 400 cm2 of irradiated field area for Co60, 6, 10, 18, and 24 MV X ray beams.

F – is the field area incident on the patient , in cm2

Scattered radiation from the patient or phantom is usually less than 0.1% of the incident radiation per 0.1 m2 area irradiated. For larger scatter angles, the energy of the scattered radiation will be degraded.

If the thickness required protecting from leakage differs from that required to protect from scatter by less than one TVL, use the greater thickness and add one HVL of shielding material for the energy of the leakage radiation. If the two thicknesses for leakage and scatter protection differ by more than one TVL use the greater thickness.

Equivalent Dose:

Equivalent dose is a dose quantity *H* representing the stochastic health effects of low levels of ionizing radiation on the human body. It is derived from the physical quantity absorbed dose, but also takes into account the biological effectiveness of the radiation, which is dependent on the radiation type and energy. In the SI system of units, the unit of measure is the sievert (Sv).

Application:

To enable consideration of stochastic health risk, calculations are performed to convert the physical quantity absorbed dose into equivalent dose, the details of which depend on the radiation type. For applications in radiation protection and dosimetry assessment the ICRP and the International Commission on Radiation Units and Measurements (ICRU) have published recommendations and data on how to calculate equivalent dose from absorbed dose.

Equivalent dose is designated by the ICRP as a "limiting quantity"; to specify exposure limits to ensure that "the occurrence of stochastic health effects is kept below unacceptable levels and those tissue reactions are avoided". This is a calculated value, as equivalent dose cannot be practically measured, and the purpose of the calculation is to generate a value of equivalent dose for comparison with observed health effects.

Calculation:

Equivalent dose H_T is calculated using the mean absorbed dose deposited in body tissue or organ T, multiplied by the radiation weighting factor W_R which is dependent on the type and energy of the radiation R.

The radiation weighting factor represents the relative biological effectiveness of the radiation and modifies the absorbed dose to take account of the different biological effects of various types and energies of radiation.

The ICRP has assigned radiation weighting factors to specified radiation types dependent on their relative biological effectiveness, which are shown in accompanying table.

Calculating equivalent dose from absorbed dose;

$$H_T = \sum_R W_R \cdot D_{T,R}$$

where,

H_T is the equivalent dose in sieverts (Sv) absorbed by tissue T

$D_{T,R}$ is the absorbed dose in grays (Gy) in tissue T by radiation type R

W_R is the radiation weighting factor defined by regulation

Thus for example, an absorbed dose of 1 Gy by alpha particles will lead to an equivalent dose of 20 Sv, and an equivalent dose of radiation is estimated to have the same biological effect as an equal amount of absorbed dose of gamma rays, which is given a weighting factor of 1.

To obtain the equivalent dose for a mix of radiation types and energies, a sum is taken over all types of radiation energy doses. This takes into account the contributions of the varying biological effect of different radiation types.

5.3 Biological Effects of Radiation:

There is no direct evidence of radiation-induced genetic effects in humans, even at high doses. Various analyses indicate that the rate of genetic disorders produced in humans is expected to be extremely low, on the order of a few disorders per million live BORN per REM of parental exposure. The potential biological effects and damages caused by radiation depend on the conditions of the radiation exposure.

It is determined by:

- quality of radiation
- quantity of radiation
- received dose of radiation
- exposure conditions (spatial distribution)

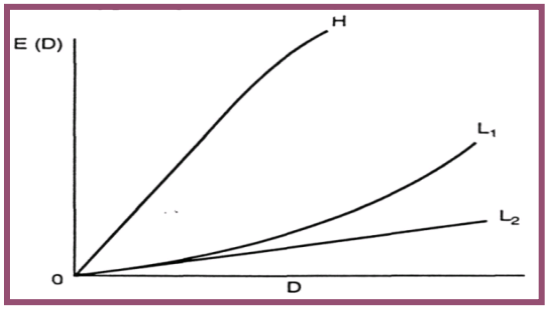
The different kinds of radiation have different energy loss effects *LET*.

$$LET = \frac{dE}{dx}$$

- Energy loss effects depends on nature and probability of interaction between radiation particle and body material.
- Particles with high energy loss effects cause typically greater damage.
- To normalize these effects as an empirical parameter the Relative Biological Effectiveness RBE of radiation for producing a given biological effect is introduced:

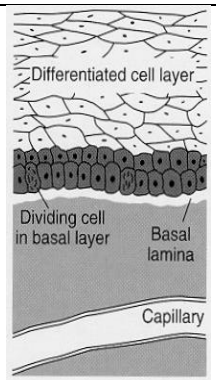
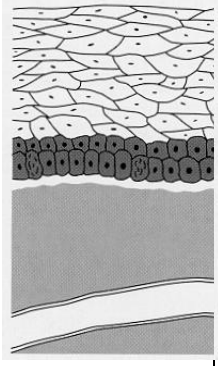
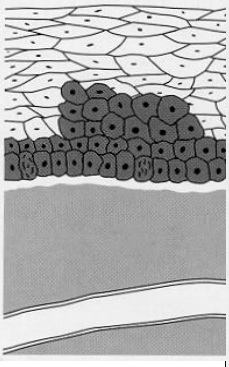
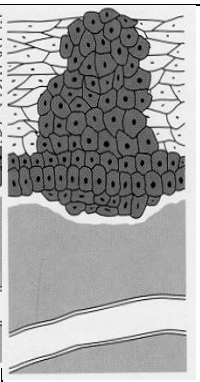
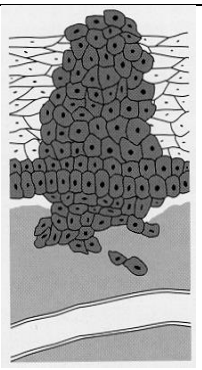
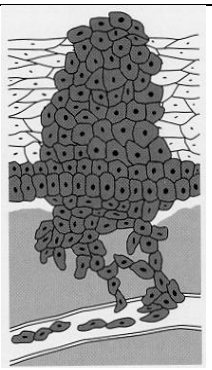
$$RBE = \frac{Dose\ of\ 150\ V\ X-rays\ required\ to\ cause\ effect\ x}{Dose\ of\ radiation\ required\ to\ cause\ effect\ x}$$

- The RBE for different kinds of radiation can be expressed in terms of energy loss effects LET.
- Radiation damage to body organs, tissue, and cells is a purely statistical effect
- As higher the radiation dose as more likely some effects will occur.
- As higher the *LET* and/or the *RBE* as more likely damage may occur.
- The effects are typically described by empirical **dose-response curves**.



Schematic representation of dose-response function *E(D)* at low doses D for high-LET (curve H) and low-LET (curve L_1,) radiations. L_2 is the extension of the linear beginning of L_1.

- Radiation can cause immediate effects (radiation sickness), but also long term effects which may occur many years (cancer) or several generations later (genetic effects).
- Biological effects of radiation result from both direct and indirect action of radiation.
- Direct action is based on direct interaction between radiation particles and complex body cell molecules, (for example direct break-up of DNA molecules)

Different stages of cell growth					
					
NORMAL TISSUE	**CELL INITIATION** **An initiating event** **creates a mutation in** **one of the basal cells**	**DYSPLASIA** **More mutations occurred.** **The initiated cell has gained proliferative** **advantages.** **Rapidly dividing cells begin to accumulate**	**BENIGN TUMOR** **More changes within** **the proliferative cell line lead to full tumor development.**	**MALIGNANT TUMOR** **The tumor breaks through the basal lamina. The cells are irregularly** **shaped and the cell line is immortal. They have an increased mobility and invasiveness.**	**METASTASIS** **Cancer cells break through** **the wall of a lymphatic** **vessel or blood capillary.They can now migrate** **throughout the body and** **potentially seed new tumors.**

		within the epithelium.			

5.4 DETERMINANTS OF BIOLOGICAL EFFECTS :

A. Rate of Absorption

The rate at which the radiation is administered or absorbed is most important in the determination of what effects will occur. Since a considerable degree of recovery occurs from the radiation damage, a given dose will produce less effect if divided (thus allowing time for recovery between dose increments) than if it were given in a single exposure.

B. Area Exposed

The portion of the body irradiated is an important exposure parameter because the larger the area exposed, other factors being equal, the greater the overall damage to the organism. This is because more cells have been impacted and there is a greater probability of affecting large portions of tissues or organs. Even partial shielding of the highly radiosensitive blood-forming organs such as the spleen and bone marrow can mitigate the total effect considerably. An example of this phenomenon is in radiation therapy, in which doses which would be lethal if delivered to the whole body are commonly delivered to very limited areas, e.g., to tumor sites. Generally when expressing external radiation exposure without qualifying the area of the body involved, whole-body irradiation is assumed.

C. Variation in Species and Individual Sensitivity

There is a wide variation in the radio sensitivity of various species. Lethal doses for plants and microorganisms, for example, are usually hundreds of times larger than those for mammals. Even among different species of rodents, it is not unusual for one to demonstrate three or four times the sensitivity of another. Within the same species, individuals vary in sensitivity. For this reason the lethal dose for each species is expressed in statistical terms, usually for animals as the LD50/30 for that species, or the dose required to kill 50 percent of the individuals in a large population in a thirty day period. For humans, the LD50/60 (the dose required to kill 50 percent of the population in 60 days) is used because of the longer latent period in humans (see section V). The LD50/60 for humans is estimated to be approximately 300-400 rad for whole body irradiation, assuming no treatment is given. It can be as high as 800 rad with adequate medical care. It is interesting to note that the guinea pig has a LD50 similar to humans.

D. Variation in Cell Sensitivity

Within the same individual, a wide variation in susceptibility to radiation damage exists among different types of cells and tissues. In general, those cells which are rapidly dividing or have a potential for rapid division are more sensitive than those which do not divide. Further, cells which are non-differentiated (i.e., primitive, or non-specialized) are more sensitive than those which are highly specialized. Within the same cell families, then, the immature forms, which are generally primitive and rapidly dividing, are more radiosensitive than the older, mature

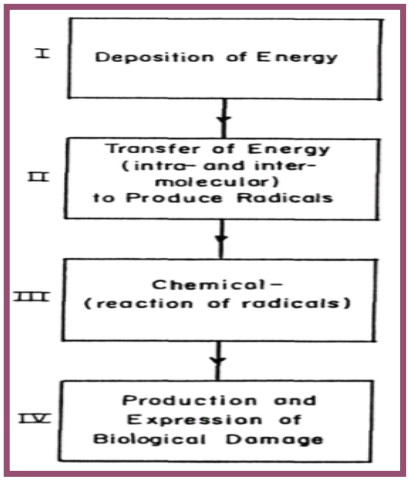
cells which have specialized in function and have ceased to divide. This radiosensitivity is defined as the "Law of Bergoniè and Tribondeau". One exception to this law is mature lymphocytes, which are highly radiosensitive. Based upon these factors, it is possible to rank various kinds of cells in descending order of radiosensitivity. Most sensitive are the white blood cells called lymphocytes, followed by immature red blood cells. Epithelial cells, which line and cover body organs, are of moderately high sensitivity; in terms of injury from large doses of whole-body external radiation, the epithelial cells which line the gastrointestinal tract are often of particular importance. Cells of low sensitivity include muscle and nerve, which are highly differentiated and do not divide.

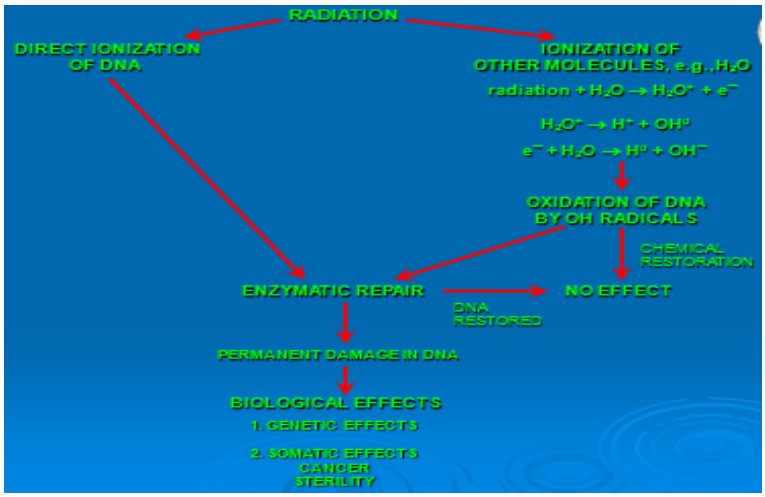
Somatic and Genetic Effects of Radiation- LD 50/30:

- Radiation can cause immediate effects (radiation sickness), but also long term effects which may occur many years (cancer) or several generations later (genetic effects).
- Biological effects of radiation result from both direct and indirect action of radiation.
- Direct action is based on direct interaction between radiation particles and complex body cell molecules, (for example direct break-up of DNA molecules)
- Indirect action is more complex and depends heavily on the energy loss effects of radiation in the body tissue and the subsequent chemistry.

1. Radiation deposits energy into the body tissue by energy loss effects
   - compton scattering, photo-excitation for g- and X-rays
   - scattering and ionization processes for a-, p, n-particles (LET)
2. Energy loss causes ionization and break-up of simple body molecules:

   $$H_2O \rightarrow H^+ + OH^-$$
3. OH^- radical attacks DNA-molecule.
4. Resulting biological damage depends on the kind of alteration and can cause cancer or long-term genetic alterations.





Categories of Effects of Exposure to Low Doses of Radiation:

1. **Genetic**
2. **Somatic**

There are three general categories of effects resulting from exposure to low doses of radiation. These are:

1. Genetic:

- Mutation of the reproductive cells passed on to the offspring of the exposed individual:
- The effect is suffered by the offspring of the individual exposed.
- Risks from 1 rem of radiation exposure to the reproductive organs are approximately 50 to 1,000 times less than the spontaneous risk for various anomalies.
- The Genetic Effect involves the mutation of very specific cells, namely the sperm or egg cells. Mutations of these reproductive cells are passed to the offspring of the individual exposed. Radiation is an example of a physical mutagenic agent. There are also many chemical agents as well as biological agents (such as viruses) that cause mutations. One very important fact to remember is that radiation increases the spontaneous mutation rate, but does not produce any new mutations.

Therefore, despite all of the hideous creatures supposedly produced by radiation in the science fiction literature and cinema, no such transformations have been observed in humans. One possible reason why genetic effects from low dose exposures have not been observed in human studies is that mutations in the reproductive cells may produce such significant changes in the fertilized egg that the result is a nonviable organism which is spontaneously reabsorved or aborted during the earliest stages of fertilization. Although not all mutations would be lethal or even harmful, it is prudent to assume that all mutations are bad, and thus, radiation exposure SHALL be held to the absolute minimum or **As Low As Reasonably Achievable (ALARA)**. This is particularly important since it is believed that risk is directly proportional to dose, without any threshold.

2. Somatic:

- Effect is suffered by the individual exposed Primary consequence is cancer:
- The effect is primarily suffered by the individual exposed. Since cancer is the primary result, it is sometimes called the Carcinogenic Effect. For radiation induced cancers, the risk estimate is small compared to the normal incidence of about 1 in 4 chances of developing any type of cancer. However, not all cancers are associated with exposure to radiation. The risk of dying from radiation induced cancer is about one half the risk of getting the cancer. - Somatic effects (carcinogenic) are, from an occupational risk perspective, the most significant since the individual exposed (usually the radiation worker) suffers the consequences (typically cancer). Radiation is an example of a physical carcinogenic, while cigarettes are an example of a chemical cancer causing agent. Viruses are examples of biological carcinogenic agents. Unlike genetic effects of radiation, radiation induced cancer is well documented. Many studies have been completed which directly link the induction of cancer and exposure to radiation.

The time scales for the short and long term effects of radiation are :

Time Frame for Effects of Ionizing Radiation

Times	Events
Physical stage $\lesssim 10^{-15}$ s	Formation of H_2O^+, H_2O^*, and subexcitation electrons, e^-, in local track regions ($\lesssim 0.1$ μm)
Prechemical stage $\sim 10^{-15}$ s to $\sim 10^{-12}$ s	Three initial species replaced by H_3O^+, OH, e^-_{aq}, H, and H_2
Chemical stage $\sim 10^{-12}$ s to $\sim 10^{-6}$ s	The four species H_3O^+, OH, e^-_{aq}, and H diffuse and either react with one another or become widely separated. Intratrack reactions essentially complete by $\sim 10^{-6}$ s
Biological stages	
$\lesssim 10^{-3}$ s	Radical reactions with biological molecules complete
$\lesssim 1$ s	Biochemical changes
Minutes	Cell division affected
Days	Gastrointestinal and central nervous system changes
Weeks	Lung fibrosis develops
Years	Cataracts and cancer may appear; genetic effects in offspring

LC 50/30

In toxicology, the **median lethal dose**, **LD_{50}** (abbreviation for "lethal dose, 50%"), **LC_{50}** (lethal concentration, 50%) or **LCt_{50}** is a measure of the lethal dose of a toxin, radiation, or pathogen. The value of LD_{50} for a substance is the dose required to kill half the members of a tested population after a specified test duration. LD_{50} figures are frequently used as a general indicator of a substance's acute toxicity. A lower LD_{50} is indicative of increased toxicity.

LD_{50} is usually determined by tests on animals such as laboratory mice. In 2011 the US Food and Drug Administration approved alternative methods to LD_{50} for testing the cosmetic drug Botox without animal tests. The LD_{50} is usually expressed as the mass of substance administered per unit mass of test subject, typically as *milligrams of substance* per *kilogram of body mass*, sometimes also stated as nanograms , micrograms, or grams per kilogram. Stating it this way allows the relative toxicity of different substances to be compared, and normalizes for the variation in the size of the animals exposed (although toxicity does not always scale simply with body mass). The choice of 50% lethality as a benchmark avoids the potential for ambiguity of making measurements in the extremes and reduces the amount of testing required. However, this also means that LD_{50} is *not* the lethal dose for all subjects; some may be killed by much less, while others survive doses far higher than the LD_{50}. Measures such as "LD_1" and "LD_{99}" (dosage required to kill 1% or 99%, respectively, of the test population) are occasionally used for specific purposes.

Lethal dosage often varies depending on the method of administration; for instance, many substances are less toxic when administered orally than when intravenously administered. For this reason,

LD_{50}figures are often qualified with the mode of administration,. The related quantities $LD_{50}/30$ or $LD_{50}/60$ are used to refer to a dose that without treatment will be lethal to 50% of the population within (respectively) 30 or 60 days. These measures are used more commonly within Radiation Health Physics, as survival beyond 60 days usually results in recovery.

A comparable measurement is **LCt_{50}**, which relates to lethal dosage from exposure, where C is concentration and t is time. It is often expressed in terms of mg-min/m^3. **ICt_{50}** is the dose that will cause incapacitation rather than death. These measures are commonly used to indicate the comparative efficacy of chemical warfare agents, and dosages are typically qualified by rates of breathing (e.g., resting = 10 l/min) for inhalation, or degree of clothing for skin penetration.

Limitations:

As a measure of toxicity, LD_{50} is somewhat unreliable and results may vary greatly between testing facilities due to factors such as the genetic characteristics of the sample population, animal species tested, environmental factors and mode of administration.

There can be wide variability between species as well; what is relatively safe for rats may very well be extremely toxic for humans (*cf*. paracetamol toxicity), and vice versa. For example, chocolate, comparatively harmless to humans, is known to be toxic to many animals. When used to test venom from venomous creatures, such as snakes, LD_{50} results may be misleading due to the physiological differences between mice, rats, and humans. Many venomous snakes are specialized predators on mice, and their venom may be adapted specifically to incapacitate mice; and mongooses may be exceptionally resistant. While most mammals have a very similar physiology, LD_{50} results may or may not have equal bearing upon every mammal species, such as humans, etc.

5.6 Effect of Radiation on Skin:

Skin reactions occur because external beam radiation travels through the skin to reach the area being targeted for treatment. Radiation to any area of the body can cause skin reactions. The equipment used to deliver radiation therapy does not usually cause major damage to the skin. Some people do not experience any skin reactions with radiation therapy.

Symptoms:

Radiation treatment may cause some general skin reactions, including:

- redness
- itching
- dryness or flaking
- moistness
- peeling
- tenderness or soreness

Most skin reactions occur within the first 2 weeks of receiving external beam radiation therapy. They usually go away 2–4 weeks after treatment is finished.

Sometimes skin changes occur after radiation is finished and become long-term (chronic) problems. The skin over the treated area can become thinner. It may also appear:

- darker or tanned (because the cells that produce skin pigment are affected)
- smooth, tight and shiny
- red or flushed (because small blood vessels are widened)

Radiation recall

Radiation recall is a skin reaction that can occur when certain chemotherapy drugs, such as doxorubicin (Adriamycin), are given after radiation therapy treatment. It usually appears in the area of skin where the radiation was given. The skin becomes red and tender, and it may peel or blister like a sunburn. Radiation recall can happen shortly after, a few months after or a year or more after radiation treatments. Radiation recall is treated like other skin reactions.

Prevention and management

Keeping skin clean, dry and moisturized during treatment can help reduce potential problems. Some areas of the body are more sensitive to the effects of radiation. For example, skin folds may be more sensitive because of increased warmth and moisture where skin surfaces rub together.

Skin care during radiation therapy

It is important to follow skin care instructions that the radiation oncologist or radiation therapy team give you. The following are general guidelines about skin care:

- Follow the bathing instructions suggested by the radiation therapy team.
    - Wash the area *gently* with warm water.
    - Rinse the area well after washing and pat it dry. Do not rub the area roughly with a washcloth or towel.
    - Use a mild shampoo, like a baby shampoo.
    - Allow the hair to air dry. Do not use a hair dryer.
- Ask the radiation therapy team to recommend products that will not irritate the skin or interfere with treatment. Do not use any powders, creams, perfumes, deodorants, body oils, ointments or lotions in the treatment area unless approved by someone on the team. These products can irritate skin that is more sensitive because of radiation treatment or may affect the dose of radiation treatment.
- Do not use aftershave or hair removal products on skin in the treatment area.
- Use an electric shaver rather than a razor to prevent cutting the skin in the treatment area.
- Protect treatment areas from rubbing, pressure or irritation by wearing loose, soft clothing next to the skin. Cotton and silk are less irritating on radiated skin than harsh fabrics like wool and denim.

- Don’t wear a bra when having radiation therapy to the breast area. If this is too uncomfortable, talk to the radiation therapy team about possible options. They may suggest wearing a soft, comfortable bra without underwire.
- Do not put anything hot or cold (such as heating pads or ice packs) on the treatment area.
- Do not squeeze or scratch pimples.
- Do not wash or scrub off any markings used to target radiation therapy until after the last treatment. Marks made by a pen will gradually fade away. If the marks need to be removed quickly after treatment, lotion can be applied to them. Marks made by permanent tattoo will not fade over time and can’t be removed by lotion.
- Rinse well after swimming in a swimming pool because chlorine can be drying to the skin.
- Skin in the treatment area will be sensitive to sunlight and may burn easily. Cover treated skin with a hat or clothing before going outside. Ask the radiation therapy team about using a sunscreen and when it is okay to start using it. **Protect the skin from the sun** for at least 1 year after radiation therapy.
- Talk to the radiation therapy team if skin in the treatment area gets cut or scraped. They will suggest ways to take care of cuts and scrapes. They can also tell you how to bandage cuts if needed, such as using tape made for sensitive skin and applying tape outside the treatment area.

It is important to report skin reactions to the healthcare team. Mild skin reactions do not usually need treatment. Severe reactions may require medical treatment or radiation therapy may be delayed to help the skin recover.

Skin irritation can continue for several weeks after treatment ends, so special care may be needed for a short time after radiation therapy.

Some people choose to use makeup or cosmetics to help hide or camouflage discoloured skin after completing radiation therapy. Check with the radiation therapy team about when it is okay to try this and what products you can use.

Blood Forming Organs:

Blood forming organ is an organ that synthesizes blood cell such as erythrocytes, leukocyte and platelets. The examples of blood forming organs are spleen and bone marrow. Blood forming organs are the most sensitive organs to radiation due to its rapid regeneration time. When blood forming organs are exposed to the radiation from radioactive component, early lethal effects that appear is hematopoietic syndrome. Hematopoietic syndrome presents due to ionizing radiation impairs hematopoiesis through a variety of mechanisms. Ionizing radiation exposures directly damages the hematopoietic stem cells and affects bone marrow in maintaining or supporting hematopoiesis in vivo and in vitro. Hematopoietic syndrome could cause death when body exposure at radiation doses <8 Gy (1 Gy = 1 Joule/Kg). Peak incidence of death occurs at about 30 day’s post-irradiation and also continues for up to 60 days. Exposure to ionizing radiation causes normal bone marrow and also spleen functions to be suppress with redistribution and apoptosis of mature formed

elements of the blood. Symptoms that usually are associated with hematopoietic syndrome are fatigue, internal bleeding, bacterial infections, fever, ulceration or anaemia. Death normally occurs unless receive bone marrow transplant.

Disease that is associated with blood forming organs caused by ionizing radiation exposure is leukemia. Leukemia is a cancer of white blood cells that begins in the bone marrow. When leukemia develops, it leads to an uncontrolled increase in the number of leukocytes. An increase in the number of leukocytes in human body can prevent healthy erythrocyte, platelets and mature leukocytes from being made. During the Second World War, two atomic bombs were dropped on Hiroshima and Nagasaki in Japan, there were 176 leukemia deaths among 50,113 survivors with significant exposures (>0.5 Gy). It was estimated that about 90 of these death are associated with radiation exposure. Symptoms that are associated with leukemia are anemia, bleeding, weight loss, night sweats, fever and easy bruising.

Personnel and Area Monitoring Systems:

Personal radiation monitoring devices or dosimeters (PMDs) are badges that detect various forms of radiation a worker may be exposed to. The dosimeter or badge detects the exposure of a person to x-rays, gamma radiation, neutron and beta particles. Workers are required to wear the dosimeters for periods of up to three months. The accumulated dose from the various types of radiation is measured by the dosimetry service provider and reported to the employer The radiation control regulation 2013 imposes responsibilities on employers to record and monitor all occupationally exposed persons in their employ who are involved in the use of ionising radiation for any one of the purposes listed in the Regulation (see below). Employees who are exposed to radiation as part of their occupation must be provided with an appropriate and approved PMD when using radioactive substances and radiation apparatus.
Employees issued with a PMD by their employer are required under the legislation to wear the personal monitoring dosimeters/devices while at work. Employers must ensure that all occupationally exposed employees using ionising radiation for the purposes listed in the Regulation are issued with a personal monitoring dosimeter. The dosimeter detects and measures an employee's cumulative dose of exposure to radiation. The employer should monitor the accumulated dose to ensure that the employee's work practices result in exposures well below 20 millisieverts (mSv) effective dose averaged over five consecutive calendar years or a maximum of 50 mSv in any single year.

Occupationally exposed persons requiring monitoring

A personal monitoring dosimeter must be issued to persons working with the following uses of radiation:

- radiotherapy
- industrial radiography
- nuclear medicine

- equine veterinary radiography,
- scientific research in laboratories classified as medium or high level laboratories where radioactive substances not contained in a sealed source device are used
- diagnostic or interventional radiology (other than dentistry, veterinary and chiropractic applications)
- neutron based detection, analysis and gauging when used in borehole logging
- servicing of ionising radiation apparatus or devices containing radioactive substances.

An employee's responsibilities

An occupationally exposed person who has been issued with a PMD by their employer must wear the monitor while using ionising radiation in the course of their employment.

An employee may be fined for not wearing the dosimeter when working with ionising radiation.

If an employee is required to wear a lead gown during the course of their duties, the PMD should be worn under the gown.

When a PMD has been issued to an employee, a control PMD must also be provided to measure background radiation received by the wearer. This control PMD must be stored in an area where only background radiation will be measured.

When the defined issuing period has passed, all PMDs including the control must be returned to the service provider for measurement. PMDs that have not been issued, or if issued have not been worn, must also be returned to the service provider.

Radiation Measuring Devices- Dosimeter:

A **radiation dosimeter** is a device that measures exposure to ionizing radiation. It has two main uses: for human radiation protection and for measurement of dose in both medical and industrial processes. Personal **radiation monitoring devices** or dosimeters (PMDs) are badges that detect various forms of **radiation** a worker may be exposed to. The dosimeter or badge detects the exposure of a person to x-**rays**, gamma **radiation**, neutron and beta particles. Whilst **Dosimetry** in its original sense is the measurement of the absorbed dose delivered by ionizing **radiation**, the term is better known as a scientific sub-specialty in the fields of health physics and medical physics, where it is the calculation and assessment of the **radiation** dose received by the human body.

Thermoluminescent **dosimeter** (TLD) A thermoluminescent **dosimeter** measures ionizing radiation exposure by measuring the intensity of visible light emitted from a crystal in the detector when heated. The intensity of light emitted is dependent upon the radiation exposure.

A variety of instruments are available for detecting and measuring radiation. Examples of radiation survey meters: This probe is used for the detection of alpha radiation. The most common type of radiation detector is a **Geiger-Mueller** (GM) tube, also called a Geiger counter.

The devices that can be used to detect nuclear radiation are:

- Geiger Mueller (GM) Detectors with Pancake Probes.
- Alpha Radiation Survey Meter.
- Dose Rate Meter.
- Newer Radiation Detection Devices.
- Personal Dosimeters.

Survey Meter:

Survey meters are portable radiation detection and measurement instruments used to check personnel, equipment and facilities for radioactive contamination, or to measure external or ambient ionizing radiation fields (to evaluate the direct exposure hazard). The hand-held survey meter is probably the most familiar radiation measuring device to society owing to its wide and highly visible use. The most commonly used hand-held survey meters are the scintillation counter, which sees use in the measurement of alpha, beta and neutron particles; the Geiger counter, widely used for the measurement of alpha, beta and gamma levels; and the ion chamber, which is used for beta, gamma and X-ray measurements.

The instruments are designed to be hand-held, are battery powered and of low mass to allow easy manipulation. Other features include an easily readable display, in counts or radiation dose, and an audible indication of the count rate. This is usually the "click" associated with the Geiger type instrument, and can also be an alarm warning sound when a rate of radiation counts or dose has been exceeded. For dual channel detectors such as the scintillation detector it is normal to generate different sounds for alpha and beta. This gives the operator rapid feedback on both the level of radiation and the type of particle being detected. These features allow the user to concentrate on manipulation of the meter whilst having auditory feedback of the rate of radiation detected.

Meters can be fully integrated with probe and processing electronics in one housing to allow single-handed use, or have separate detector probe and electronics housings, joined by a signal cable. This latter is preferred for checking of convoluted surfaces for radioactive contamination due to the ease of manipulating the probe.

QUESTION BANK

PART-A

1. What are the effects of radiation?

2. What are the radiation measuring devices?

3. Define radiation protection.

4. Write a note on personnel and area monitoring systems.

5. What are the effects of radiation-LD 50/30?

6. Write a note on protective barrier.

7. What are the effects of radiation on skin?

8. Define dosimeter.

9. Define equivalent dose.

10. Define survey meter.

PART-B

1. Describe the effects of radiation on the skin and blood forming organs.

2. What are the different types of effects caused due to radiation?

3. Enumerate the effects of radiation-LD 50/30.

4. Examine the radiation measuring devices.

5. Classify the somatic effects caused due to radiation.

6. Enumerate the genetic effects caused due to radiation.

7. What is radiation protection? Explain its need.

8. Elaborate the protective barrier.

9. Enumerate on the monitoring devices.

10. Differentiate between the somatic and genetic effects caused during radiation.

Reference:

1. Khandpur R.S., Handbook of Biomedical Instrumentation, Tata McGraw Hill Publishing Company Ltd., New Delhi and revised edition, 2007.

2. Thayalan K., Basic Radiological Physics, Jaypee Brothers Medical Publishers Pvt. Ltd., Revised Edition, 2005.