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Radioactivity & Radiation

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1st lecture in Medical Chemistry

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Some Key Definitions Before We Move on

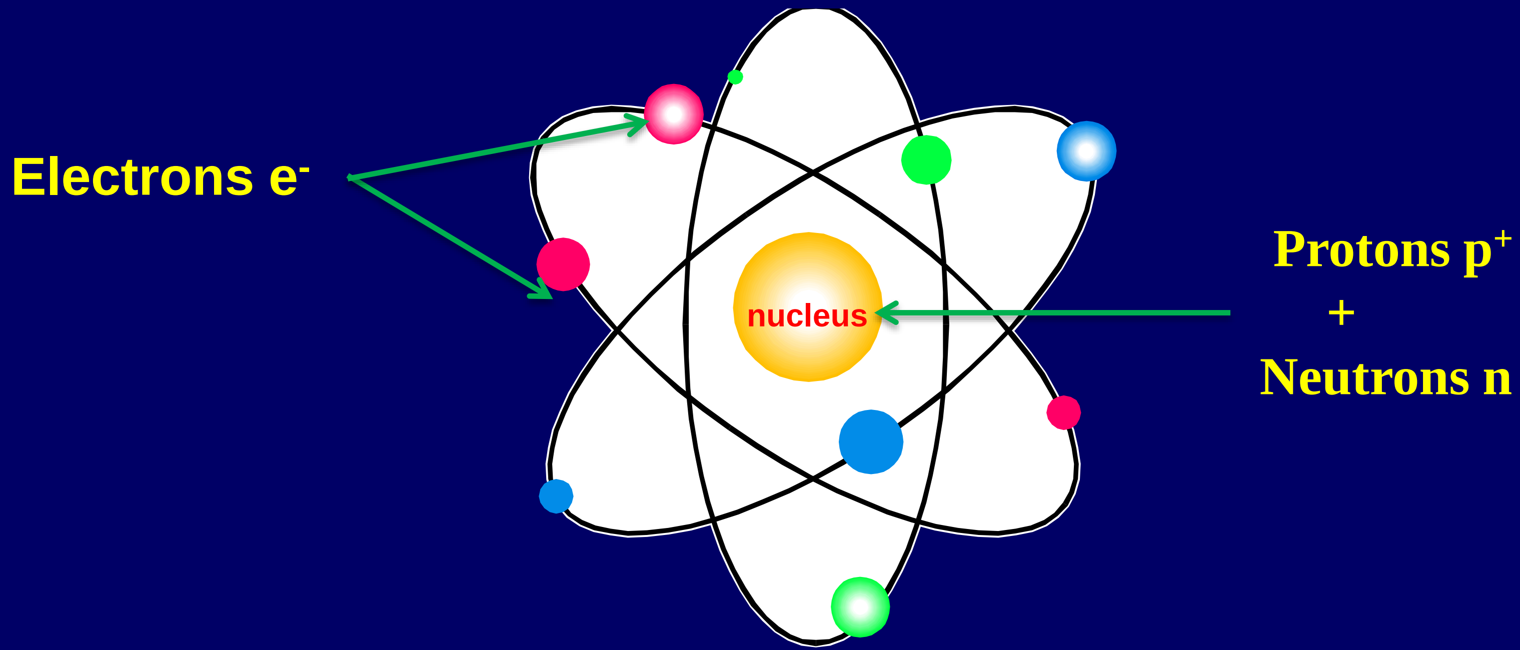
Z = The Atomic Number. It's the Number of Protons in the nucleus of an Atom.

Nucleus: It's where the Protons and Neutrons are located in an Atom.

Protons: Positively Charged Particles in the Nucleus of the atom. Mass = (approx) 1 AMU

Neutrons: Neutrally charged particles in the nucleus of an atom Mass = (approx) 1 AMU

Mass Number of an atom: Number of Protons + Number of Neutrons



- An atom is neutral
- The net charge is zero
- Number of protons = Number of electrons
- Atomic number = Number of electrons

mass number 11

Na

atomic number 23

sodium-23

p^+ = 11
n = 12
e^- = 11

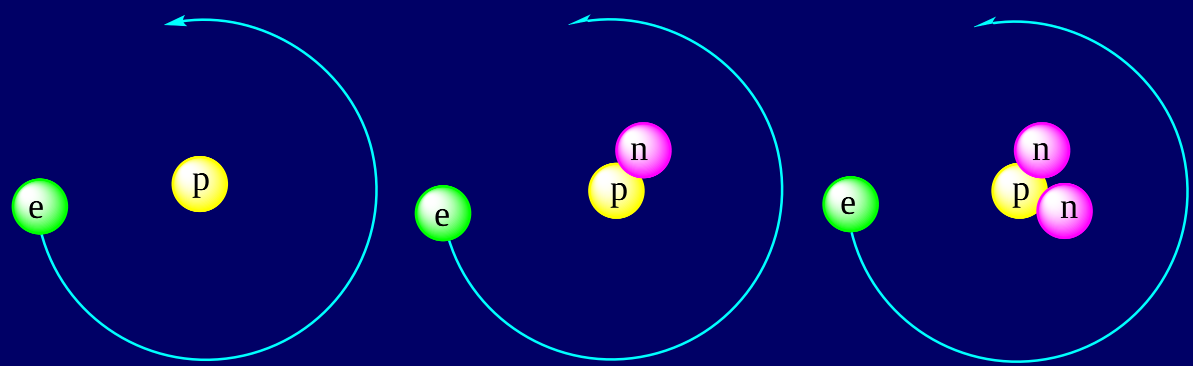
- **Isotopes are atoms with the same number of protons, but different numbers of neutrons.**
- **Isotopes are atoms of the same element (same atomic number) with different mass numbers**

2 isotopes of chlorine

$^{35}\text{Cl}_{17}$ chlorine - 35

$^{37}\text{Cl}_{17}$ chlorine - 37

3 isotopes of hydrogen



^{1}H Protium

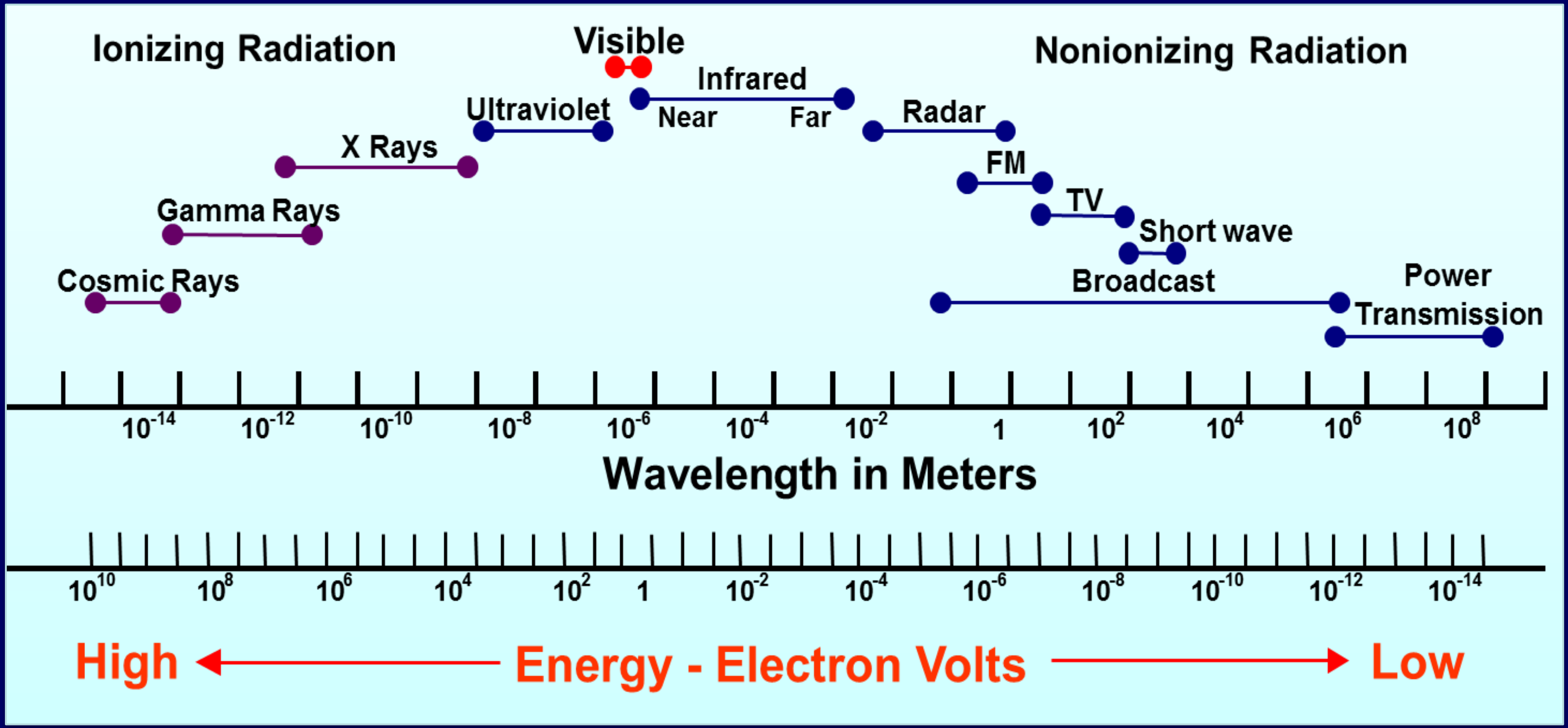
^{2}H Deuterium

^{3}H Tritium

Radiation

Radiation is energy emitted from a substance. There are two types of radiation:

1. Nonionizing Radiation
2. Ionizing Radiation



Electromagnetic Spectrum

1. Nonionizing

- **Radiation that does not have enough energy to break chemical bonds but can vibrate atom is referred to as "Non-ionizing Radiations"**

Everyday examples of non-ionizing radiation are:-

- Ultraviolet: sun light . fluorescent lamps, electric arc Germicidal lamps
- Visible: energy between 400 and 750 nm.
- Infrared: energy between 750 nm to 0.3 cm.
- Microwaves: energy between 0.1 cm to 1 kilometer
- radio & TV: Varity of industrial and home uses for heating information transfer (radio, TV, mobile phones)
- power transmission: highest level of exposure from generation and distribution system (high voltage power system – magnetic imaging.

Effects Nonionizing Radiation

- High ultraviolet – kills bacterial and other infectious agents (ultraviolet).
- High dose causes - sun burn – increased risk of skin cancer (ultraviolet)
- Pigmentation that results in suntan (ultraviolet).
- Suntan lotions contain chemicals that absorb UV radiation (ultraviolet)
- Reaction in the skin to produce Vitamin D that prevents rickets (ultraviolet)
- Can damage – cornea, iris, retina and lens of the eye (infrared radiation, ultraviolet)
- Acute health effects – shock (electrical power).
- Accelerates aging process (ultraviolet).
- Sunburn – acute cell injury causing inflammatory response (erythema) (ultraviolet).

2. Ionizing radiation

- **Radiation that has enough energy to break chemical bonds is referred to as 'ionizing radiation,**

- **Radiation capable for producing ions when interacting with matter – in other words enough energy to remove an electron from an atom.**

- These types of energy can cause chemical changes to living exposures to ionizing radiation may damage cells or tissues.

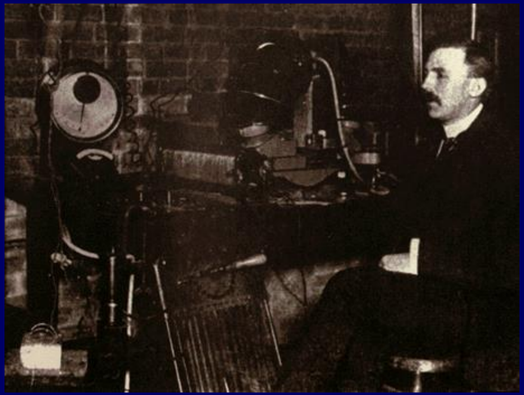
- Real-life examples of ionizing radiation are:-

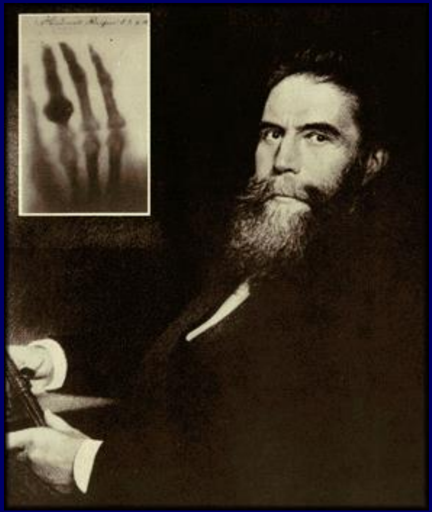
1. X-ray machines.
2. **Radioactive material produce alpha, beta, and gamma radiation,** used in biomedical research.
3. **Cosmic rays from the sun and space.**

Early Pioneers in Radioactivity

Rutherford:

Discoverer Alpha and Beta rays 1897



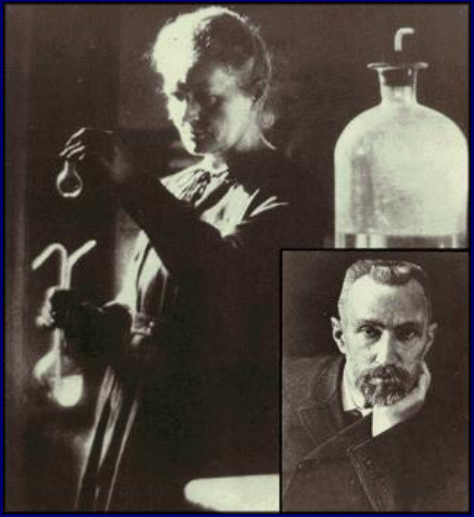


Roentgen:

Discoverer of X-rays 1895

The Curies:

Discoverers of Radium and Polonium 1900-1908

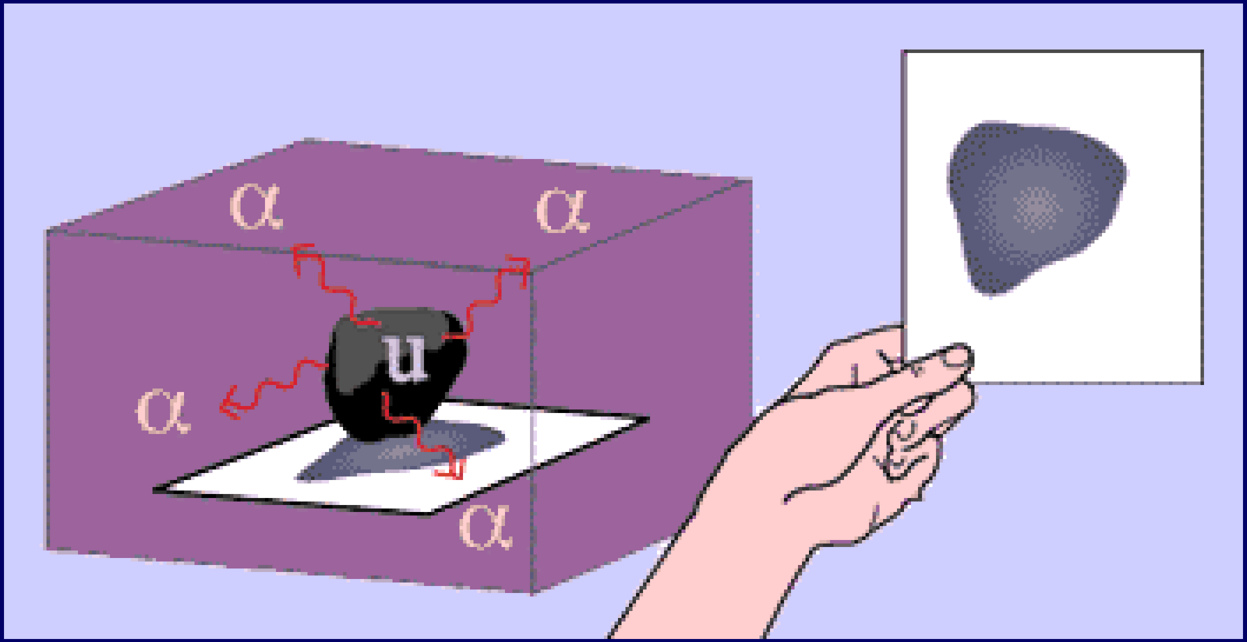


Becquerel:

Discoverer of Radioactivity 1896

The Discovery of Radioactivity

Antoine Henri Becquerel (1852-1908)



Radioactive Material

- Either natural or created in nuclear reactor or accelerator
- Radioactive material is unstable nucleus and emits energy in the form of (particles or electromagnetic waves) in order to return to a more stable state .
- Half-life – time for radioactive material to decay by one-half

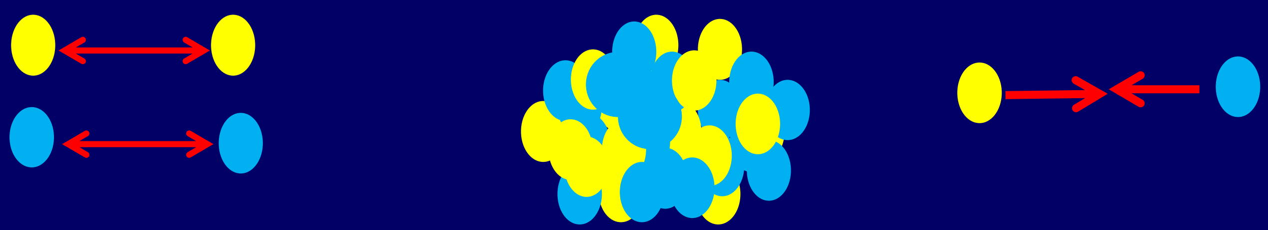
The general idea:

An unstable nucleus releases energy to become more stable

Is all of the atomic nucleus unstable and decomposed?

$^{35}_{17}Cl$	$^{36}_{17}Cl$	$^{37}_{17}Cl$
Stable	Unstable	Stable

- A mysterious strong forces holding the nucleus (protons & neutrons) together



- Unstable atoms when there are too many protons or neutrons because the bad combination between P^+ & n^0
- Stability depend on a ration of protons to neutrons

Radioactive Decay (Emissions)

- Radioactive decay is the process in which an unstable **atomic nucleus** loses energy by **emitting radiation** in the form of particles **or** electromagnetic waves **to be more stable.**

- There are numerous types of radioactive decay.

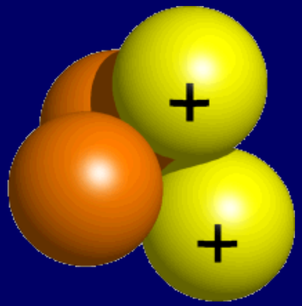
Summary of Radioactive Decay Processes			
Type of Radioactive Decay	Particle Emitted	Change in Mass Number	Change in Atomic Number
Alpha Decay	Helium Nuclei	Decreases by 4	Decreases by 2
Beta Decay	Beta Particle	No Change	Increases by 1
Gamma Emission	Energy	No Change	No Change

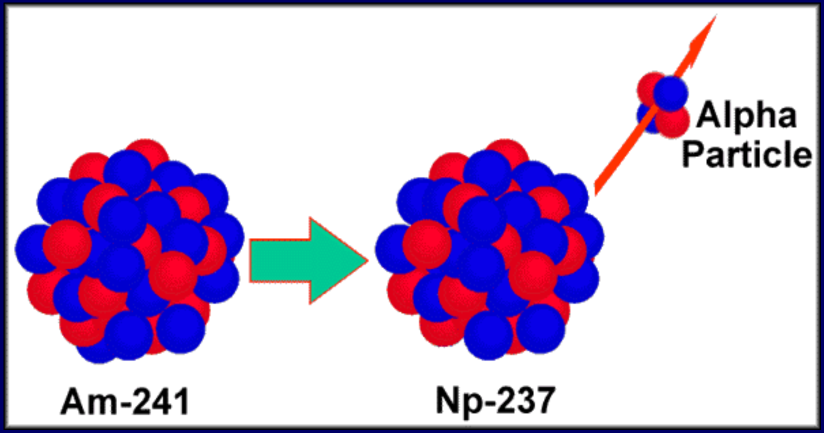
Types Radioactive Decay

1. Alpha Decay

- Emission of alpha particles α
- Helium nuclei
- Two protons and two neutrons
- Can be stopped by a sheet of paper, clothing.
- They are a minimal health risk to people unless ingested or inhaled.
- Amercium-241 used in smoke detectors is an α-emitter

$^{4}_{2}He$



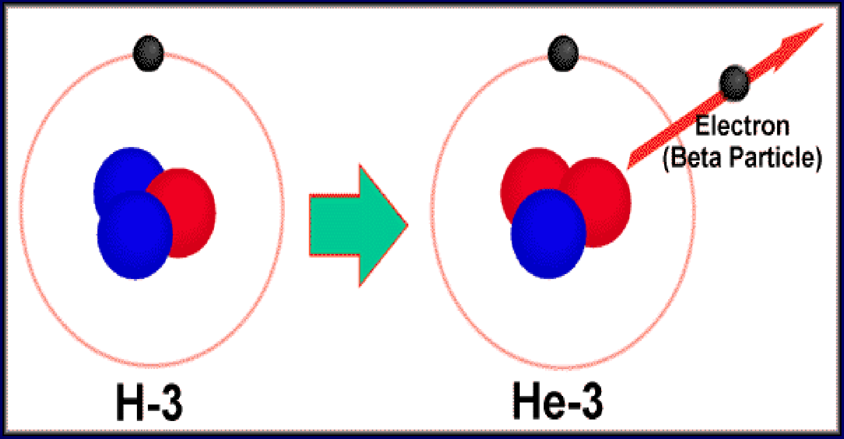


2. Beta Decay

- Emission of beta particles β
- Formed by the disintegration of a neutron into a proton and electron.

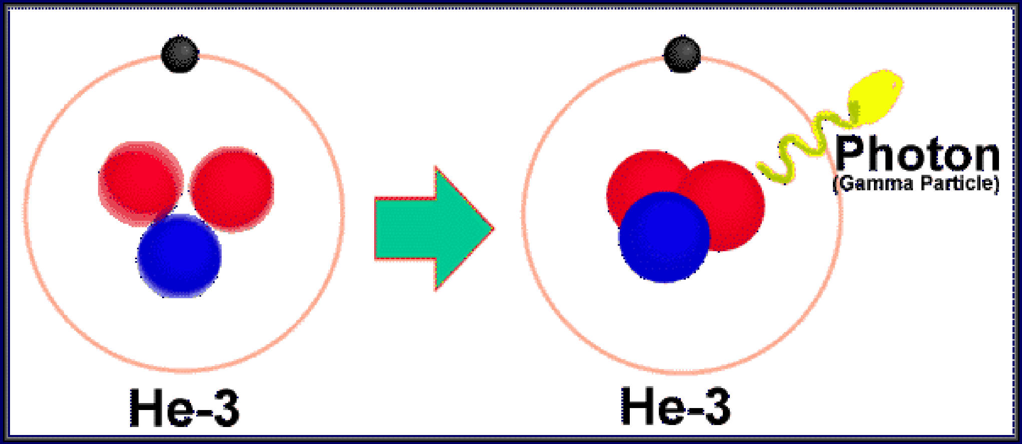
$$n \qquad p^{+} + e^{-}$$

- Proton stays in nucleus – mass no. stays the same
- Atomic number is increased by 1
- Electrons emitted in a fast moving stream
- Higher penetration than α-particles, 2-3mm of aluminium foil
- Stopped by skin, harmful if they get inside the body
- Carbon-14 used for age determination



3. Gamma Decay

- Emission of gamma radiation γ
- Gamma rays are electromagnetic waves.
- They have no mass.
- Gamma radiation has no charge.
- Most Penetrating, can be stopped by 1m thick concrete or a several cm thick sheet of lead.
- Beta emission can be a significant health risk.
- Cobalt 60 – cancer treatment and food irradiation



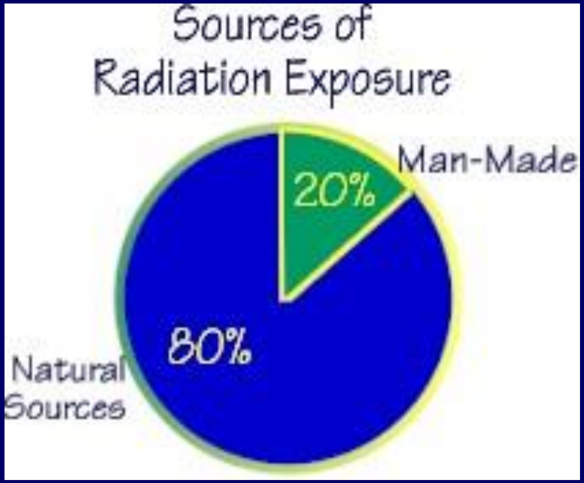
X-rays

- Overlap with gamma-rays
- Electromagnetic photons or radiation Produced from or free electrons – usually machine produced.
- Since X-rays are emitted by electrons, they can be ray tube, a vacuum tube that uses a high voltage to electrons released by a hot cathode to a high velocity. electrons collide with a metal target, the anode, creating
- Emitted with various energies & wavelengths (0.01 to 10
- Highly penetrating – extensive shielding required
- X-ray photons carry enough energy to ionize atoms and molecular bond. This makes it a type of ionizing radiation therefore harmful to living tissues.

Sources of Radioactivity

1. **Naturally Occurring Sources:**
   - **Radon from the decay of Uranium and Thorium**
   - **Potassium -40 – found in minerals and in plants**
   - **Carbon 14 – Found in Plants and Animal tissue**

2. **Manmade Sources:**
   - **Medical use of Radioactive Isotopes**
   - **Certain Consumer products –(e.g. Smoke detectors)**
   - **Fallout from nuclear testing**
   - **Emissions from Nuclear Power plants**



Chemical reaction Vs Nuclear reaction

Chemical reaction

- Elements combine to form other compounds
- Compounds break up into their constituent elements
- Elements in compounds rearrange to form different compounds

$K + S_8 \longrightarrow K_2S$ (ionic)

$Ca + O_2 \longrightarrow CaO$ (ionic)

$Al + I_2 \longrightarrow AlI_3$ (ionic)

$H_2 + O_2 \longrightarrow H_2O$ (covalent)

Nuclear reaction

- Cause changes in the nucleus involving protons and neutrons
- Cause elements to change into other elements

Example Nuclear Reactions

α decay $\quad {}^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

β decay $\quad {}^{131}_{53}I \longrightarrow {}^{131}_{54}Xe + {}^{0}_{-1}e$

γ decay $\quad {}^{234}_{90}Th^{*} \longrightarrow {}^{234}_{90}Th + \gamma$

Units of Radiation

Different units of measure are used depending on what aspect of radiation is being measured:

Becquerel (Bq) and curie(Ci):

The units used to measure the amount of radiation being given off, or emitted, by a radioactive material

Rad & gray (Gy):

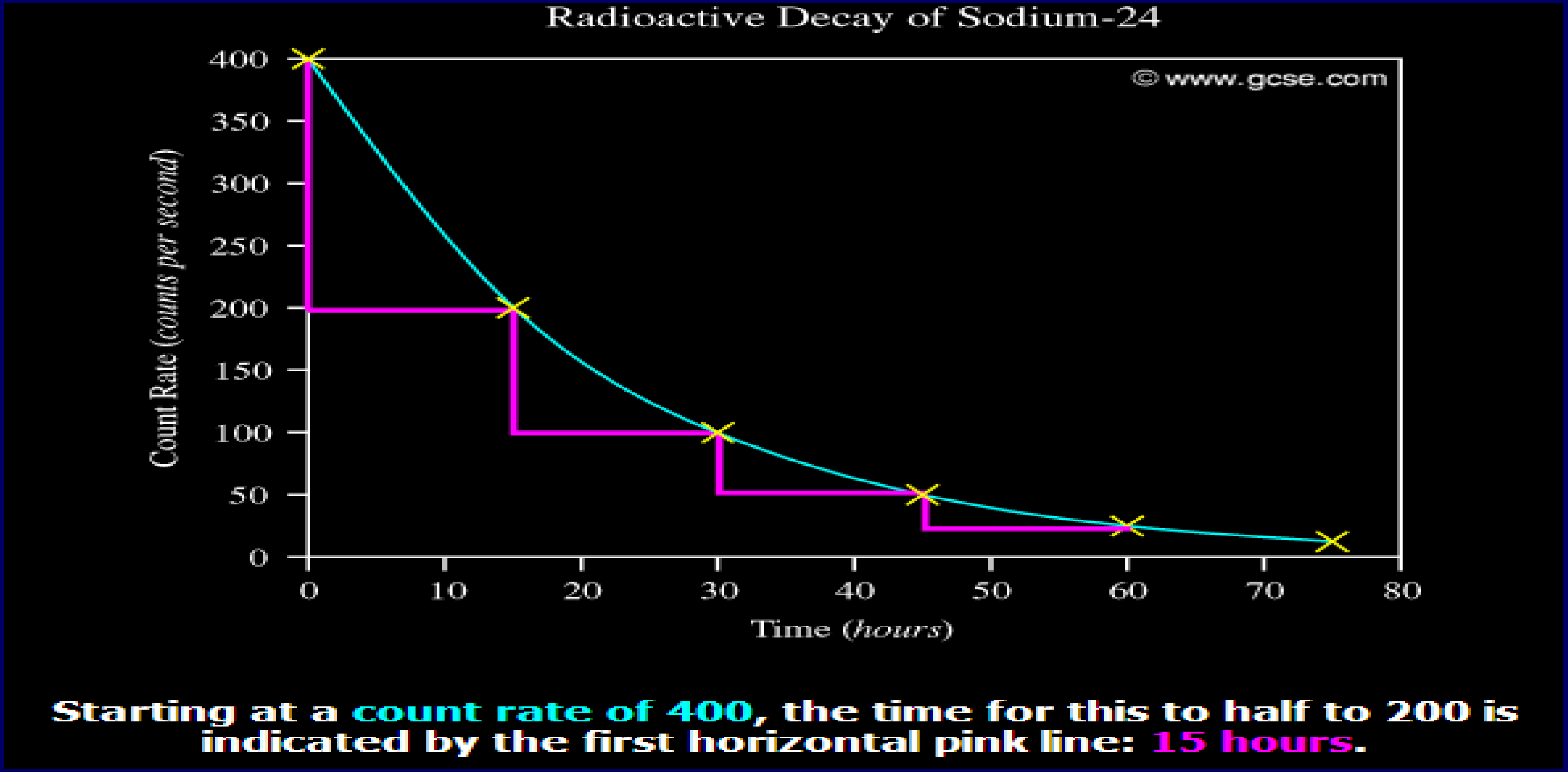
The units used to measure the radiation dose absorbed by a person (that is, the amount of energy deposited inhuman tissue by radiation)

Rem and Sievert (Sv)

The units used to measure the biological risk of exposure to radiation

Half-life of Radioactive Atoms

- The **half-life** of a radioactive substance, is the time required for one half of it to decay.
- Can vary from seconds to millions of years.
- E.g. Radium-214 has a half life of 20 minutes, Radium-226 has a half life of 1,620 years



The Effects of Ionising Radiation

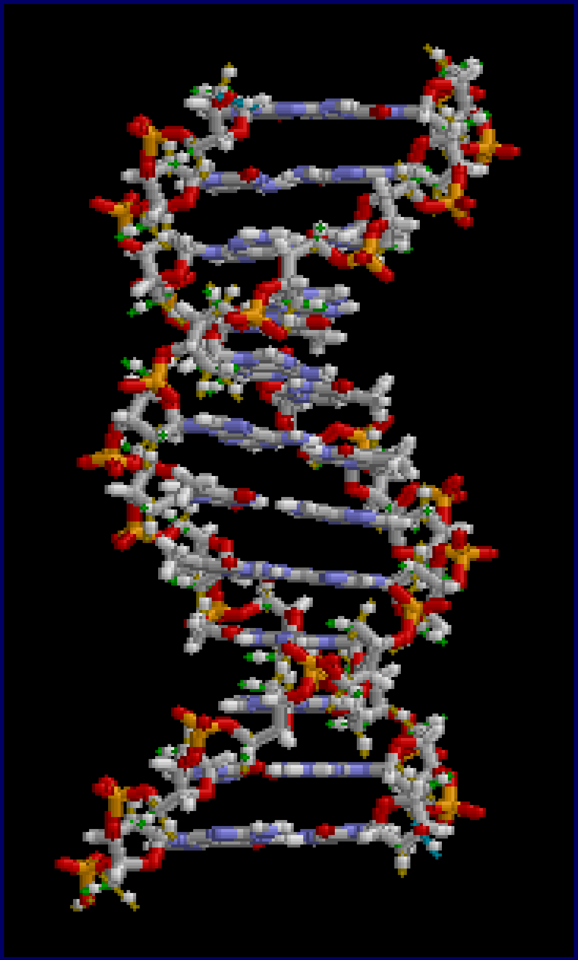
- The biological effect of radiation depends on:
  1. The type of radiation.
  2. The nature of tissue or body organ that absorbs the radiation.
  3. The total amount of energy absorbed

- The effects of the damage inflicted by the ionising radiation may take two categorise:
  1. Short-term effects: Which is usually occur when there's a large amount of exposure to radiation. This be severe and cause immediate effects.

  2. long-term effects of radiation which can be caused by much lower levels of radiation. One of the most important long-term. effects of radiation is that of cancer in various parts of the body the body.

The Effects of Ionising Radiation

- **The mechanisms for cancer occurring are poorly understood at the moment.**
- **Our DNA contains genetic instructions (cod) which control the operation and reproduction of the cells.**
- **If ionisations caused by ionising radiations alter these instructions (cod) in the DNA, there is a chance that cancer will develop.**



1. Ionising radiation affects the DNA material by.

2. Breakage of Chemical Bonds

2. Formation of New Chemical Bonds or Cross linkages

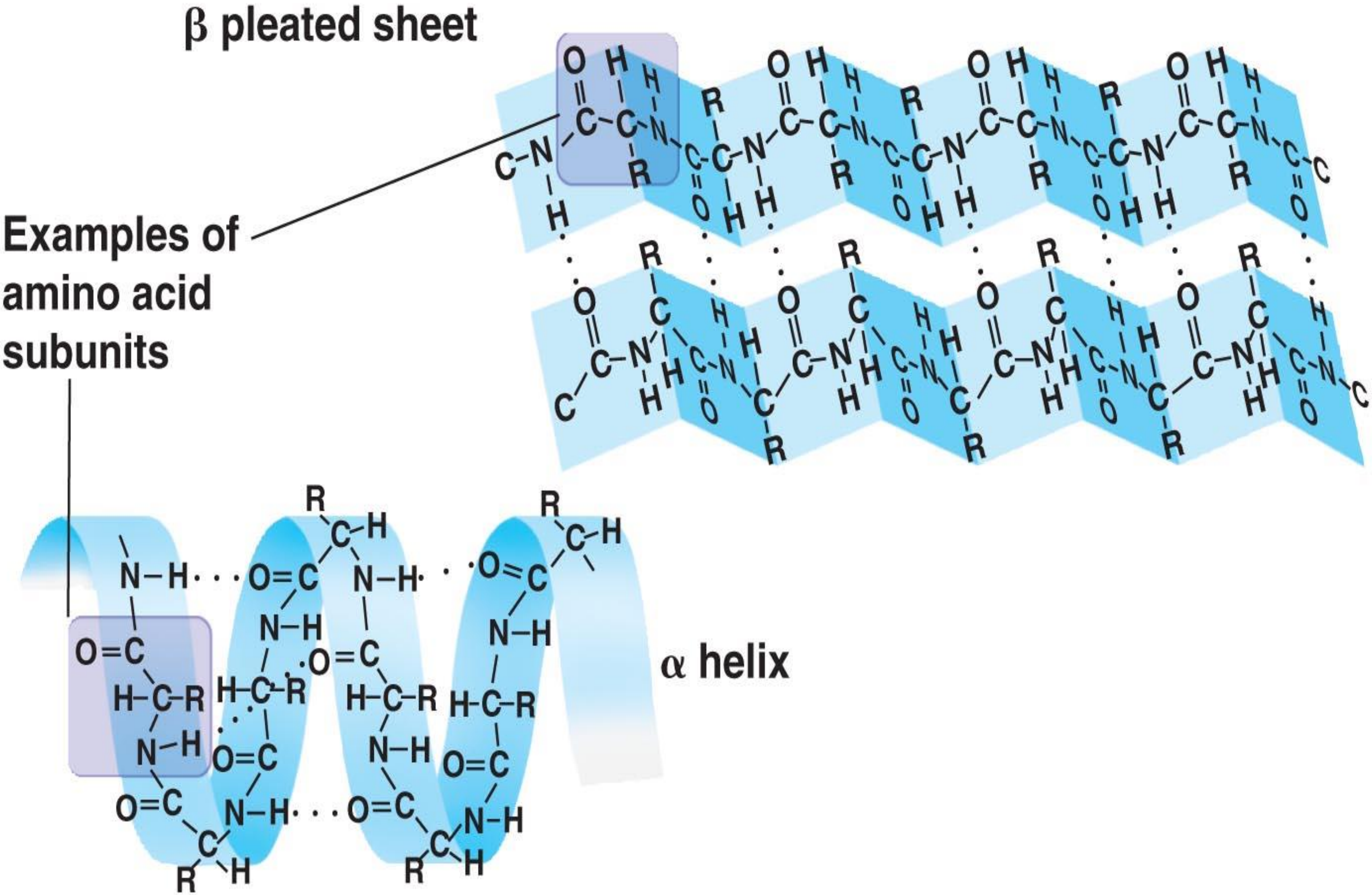
4. Damage to Macromolecules (DNA, RNA, Protein).

Protein).

5. Production of Free Radicals

- **Genetic damage can be caused to cells by radiation, including cells which are involved in reproduction.**

Secondary Structure



Uses of Ionizing Radiation in Medicine:

There are 3 main uses of ionizing radiation in medicine:

1. Treatment of cancer 2. Sterilization 3. Diagnosis

1. Treatment of cancer

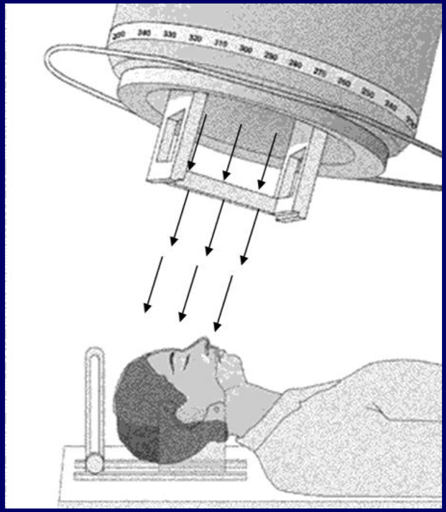
- The damage inflicted by radiation therapy causes the cancerous cells reproducing and thus the tumor shrinks.
- Unfortunately, healthy cells can also be damaged by the radiation.
- The amount of radiation given to the patient has to be accurately the damage is limited to the cancerous cells only.
- There are two techniques in radiation therapy that are used to treat ionizing radiation: Radiotherapy and Brachytherapy

a. Radiotherapy

Cancerous tumors can be treated using radiotherapy as follows

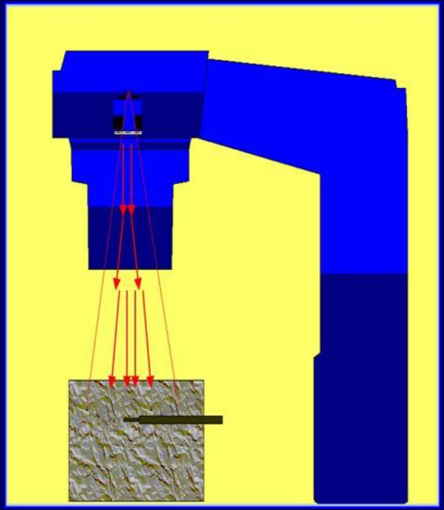
1) Irradiation using high energy gamma rays.
2) Irradiation using high energy x-rays.

1) Irradiation using high energy gamma rays.



- Gamma rays are emitted from a cobalt-60 source – a radioactive form of cobalt.
- The cobalt source is kept within a thick, heavy metal container.
- This container has a slit in it to allow a narrow beam of gamma rays to emerge.

2) Irradiation using high energy x-rays.



- The x-rays are generated by a linear accelerator (linac).
- The linac fires high energy electrons at a metal target and when the electrons strike the target, x-rays are produced.
- The x-rays produced are shaped into a narrow beam by movable metal shutters

Treatments by radiotherapy are given as a series of small doses because cancerous cells are killed more easily when they are dividing, and not all cells divide at the same time – this reduces some of the side effects which come with radiotherapy.

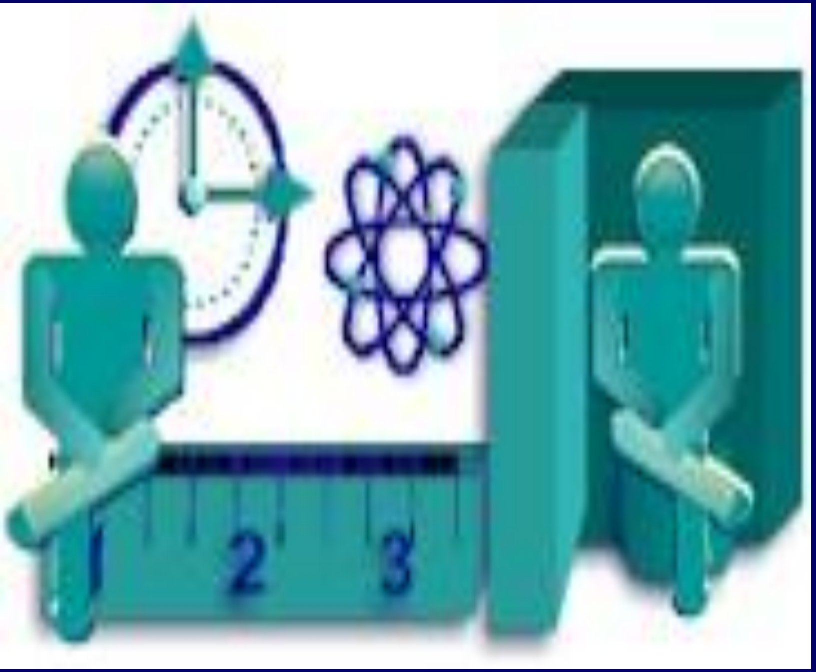
b. Brachytherapy

- This involves placing implants in the form of seeds, wires or pellets directly into the tumor.
- Such implants may be temporary or permanent depending on the implant and the tumor itself.
- The benefit of such a method is that the tumor receives nearly all of the dose whilst healthy tissue hardly receives any.

2. Sterilization

- Radiation not only kills cells, it can also kill germs or bacteria.
- Nowadays, medical instruments (e.g. syringes) are prepacked and then irradiation using an intense gamma ray source.
- This kills any germs or bacteria but does not damage the syringe, nor make it radioactive.

Reducing Exposure



1. Time

Reduce the spent near the source of radiation.

2. Distance

Increase the distance from the source of radiation.

3. Shielding

Place shielding material between you and the source of radiation.

Tracers

- **There are many uses of ionising radiation based on the fact that it is easy to detect. In such applications, the radioactive material is used in the form of a tracer.**

- **In nuclear medicine, a tracer is a radioactive substance which is taken into the body either, as an injection, or as a drink. Such a substance is normally a gamma emitter which is detected and monitored.**

- **This gives an indication of any problems that may be present in body organs or tissues by how much, or how little, of the substance has been absorbed.**

- **Such tracers consist of two parts:**
  1. A drug which is chosen for the particular organ that is being studied.
  2. A radioactive substance which is a gamma emitter.

Tracers Used in Nuclear Medicine

Pharmaceutical	Source	Activity (MBq)	Medical Use
Pertechnetate	^{99m}Tc	550 - 1200	Brain Imaging
Pyrophosphate	^{99m}Tc	400 - 600	Acute Cardiac Infarct Imaging
Diethylene Triamine Pentaacetic Acid (DTPA)	^{99m}Tc	20 - 40	Lung Ventilation Imaging
Benzoylmercaptoacetyltriglycerine (MAG3)	^{99m}Tc	50 - 400	Renogram Imaging
Methylene Diphosphonate (MDP)	^{99m}Tc	350 - 750	Bone Scans

Factors Affect the Choice of Tracer

Such tracers are chosen so that:-

- **They will concentrate in the organ, or tissue, which is to be examined.**
- **They will lose their radioactivity (short time).**
- **They emit gamma rays which will be detected outside the body.**
- **Gamma rays are chosen since alpha and beta particles would be absorbed by tissues and not be detected outside the body.**
- **Technitium-99m is most widely used because it has a half-life of 6 hours.**

Why is a half-life of 6 hours important?

A half-life of 6 hours is important because:

- A shorter half-life would not allow sufficient measurements or images to be obtained.
- A longer half-life would increase the amount of radiation the body organs or tissues receive.


Thank you for your attention