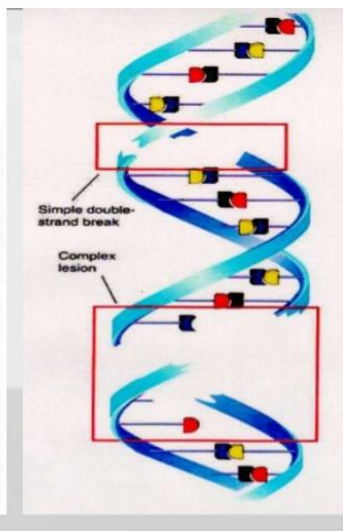
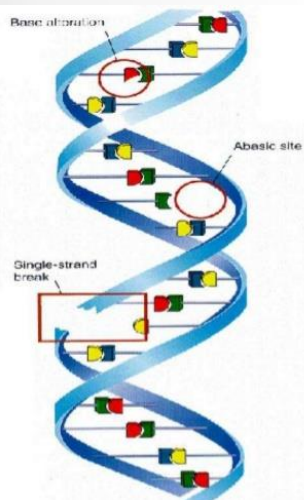
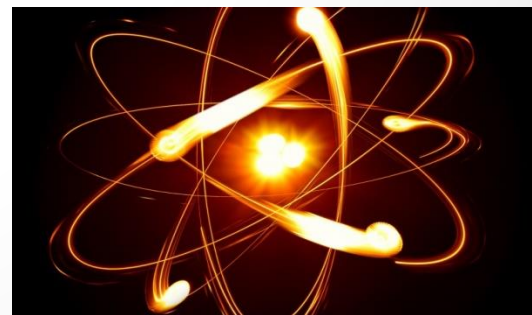


NUCLEAR CHEMISTRY



Soma Maji



Introduction

In any compound the electrons around the atom's nucleus are involved in various chemical reactions. Discovery of radiation emitted by uranium has expanded this field to nuclear changes. **Marie Sklodowska Curie** has initiated the study of radioactivity and contributed much to the study of nuclear changes.

Radiation and Nuclear Reactions

According to the theory proposed by Frederic Soddy "radioactivity is the result of a natural change of an isotope of one element into an isotope of a different element."

In chemical reactions the molecules are formed whereas due to the nuclear reactions there will be transmutation of one element into a different isotope or a different element altogether.

All elements heavier than bismuth (Bi) exhibit natural radioactivity and thus can "decay" into an altogether lighter elements. Normally the number of protons in an atom will determine a particular element. As the protons are changing in the nucleus due to radiation the atom of that element will also change.

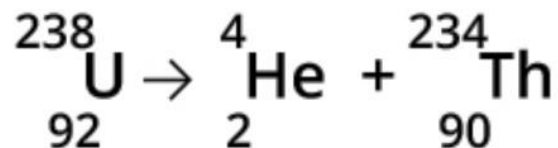
Types of Radiations

There are three common types of radiation and nuclear changes.

Alpha radiation (α):

Emission of an alpha particle from an atom's nucleus is called the alpha radiation.

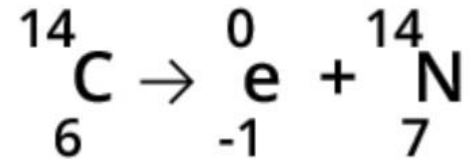
An alpha particle contains 2 protons and two neutrons and is similar to He (Hilium) Nucleus (${}^4_2\text{He}$). When an atom emits α particle the atom's atomic mass will decrease by four units (because two protons and two neutrons are lost) and the atomic number (z) will decrease by two units. The element is said to "transmute" into another element that is two z units smaller. e. g. Uranium decays into Thorium by emitting alpha particle.



In nuclear chemistry, element symbols are traditionally preceded by their atomic weight (upper left) and atomic number (lower left).

Beta radiation (β)

The transmutation of a neutron into a proton and an electron followed by the emission of the electron from the atom's nucleus. **When an atom emits β particle the atom's mass will not change since there is no change in the total of nuclear particles.** There will be **an increase in the atomic number by one** because of the transmutation of a neutron to an additional proton. e.g. Carbon -14 an isotope of Carbon into the element Nitrogen.



Gamma radiation (γ)

It is the emission of electromagnetic energy (Similar to light energy) from an atom's nucleus. **There will be no emission of particles during gamma radiation and gamma radiation does not itself cause the transmutation of atom.** It is often observed that γ - radiation during the transmutation of atoms to, α or β radioactive decay. e.g. X-rays emitted during the beta decay of Cobalt -60.

Stimulated Nuclear Reactions

While many elements undergo radioactive decay naturally, nuclear reactions can also be stimulated artificially. There are two such types of nuclear reactions:

Nuclear fission

Reactions in which an atom's nucleus splits into smaller parts, releasing a large amount of energy in the process. Most commonly this is done by "firing" a neutron at the nucleus of an atom.

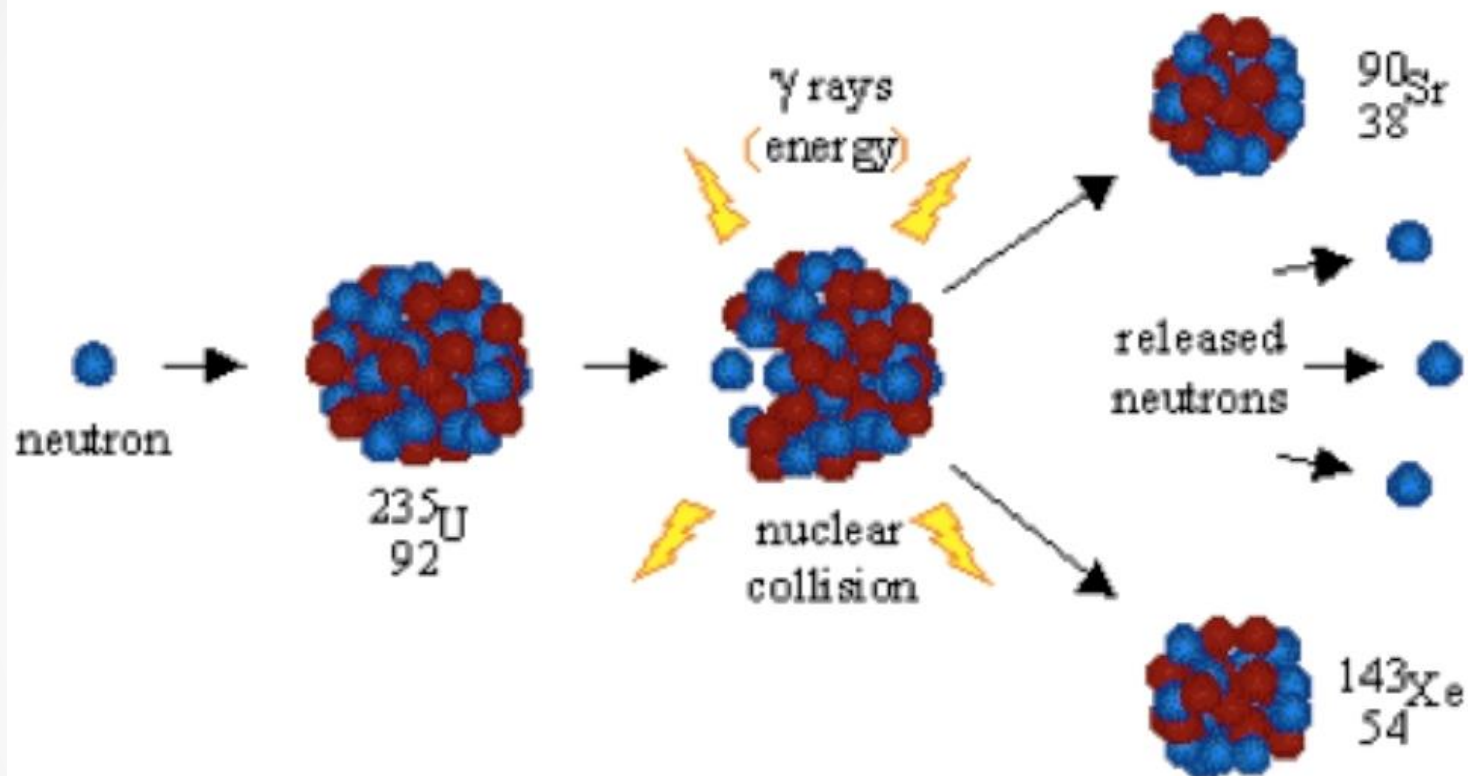
The energy of the neutron "bullet" causes the target element to split into two (or more) elements that are lighter than the parent atom.

During the fission of U235, three neutrons are released in addition to the two daughter atoms. If these released neutrons collide with nearby U235 nuclei, they can stimulate the fission of these atoms and start a self-sustaining nuclear chain reaction. This chain reaction is the basis of nuclear power. As uranium atoms continue to split, a significant amount of energy is released from the reaction. The heat released during this reaction is harvested and used to generate electrical energy.

Two Types of Nuclear Chain Reactions.

Concept simulation – Reactions controlled and uncontrolled nuclear chain reactions.

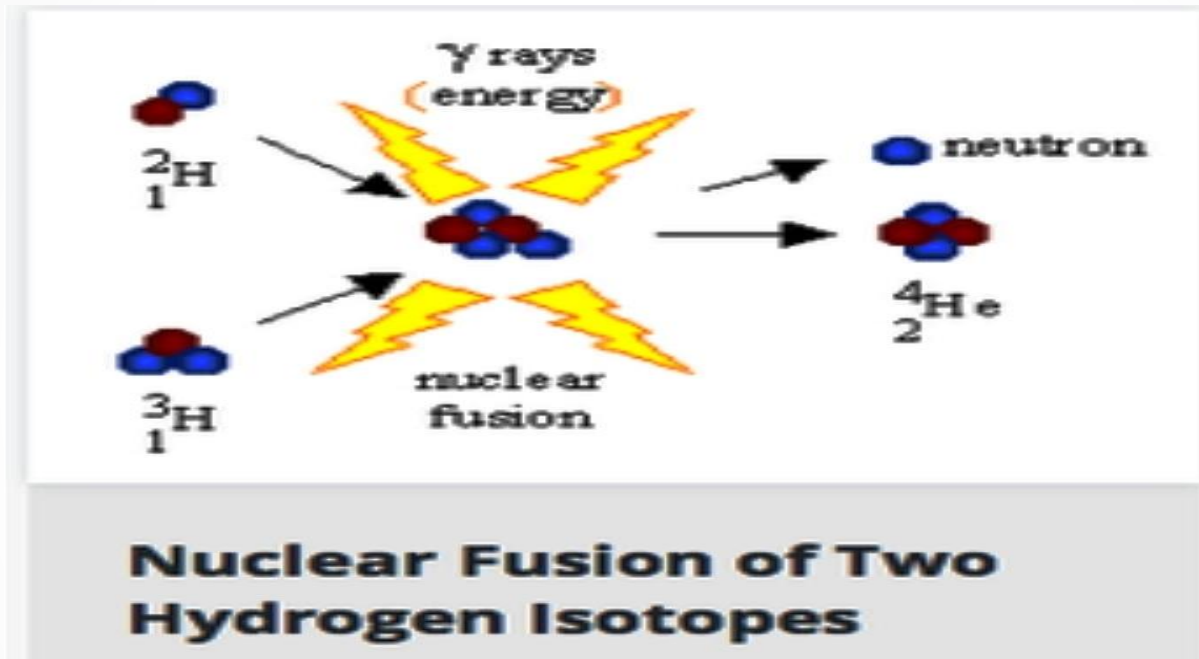




The Fission Reaction of Uranium-235

Nuclear fusion

Reactions in which two or more elements "fuse" together to form one larger element, during the process energy is being released. A good example is the fusion of two "heavy" isotopes of hydrogen (deuterium: ${}^2_1\text{H}$ and tritium: ${}^3_1\text{H}$) into the element helium.



Fusion reactions release tremendous amounts of energy and are commonly referred to as thermonuclear reactions. Although many people think of the sun as a large fireball, the sun (and all stars) is actually enormous fusion reactors. Stars are primarily gigantic balls of hydrogen gas under tremendous pressure due to gravitational forces. Hydrogen molecules are fused into helium and heavier elements inside of stars, releasing energy that we receive as light and heat.

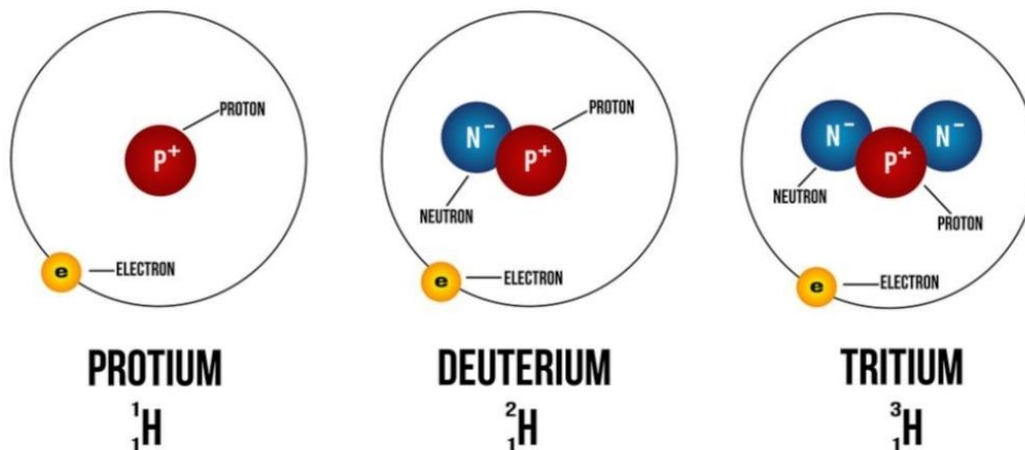
Isotopes

Definition: Isotopes may be defined as the atoms of the same element that have an equal number of protons but different numbers of neutrons. Their atomic numbers are the same but their mass numbers are different.

Such atoms have practically same structure of their electrons shells and belong to the same chemical element of the periodic system. Consequent to the development of mass spectroscopy, it became possible to discover isotopes among the naturally occurring compounds of non radio active elements. Further with the development of nuclear physics it has become possible to obtain different isotopes for different elements artificially.

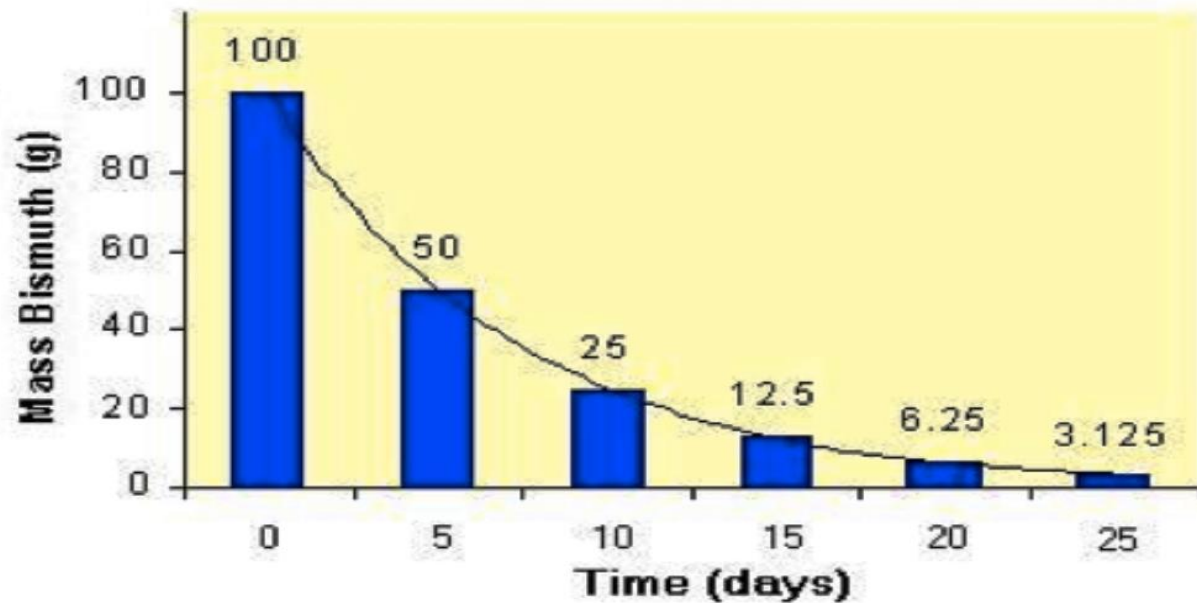
Example: Hydrogen has three isotopes, Chlorine contains two major isotopes: Chlorine-35 and chlorine -37

THE THREE ISOTOPES OF HYDROGEN



Nature of isotopes

The composition of Isotopes of naturally occurring elements is markedly constant.



Radioactive Decay of Bismuth-210 ($T_{1/2} = 5$ days)

Half-Life

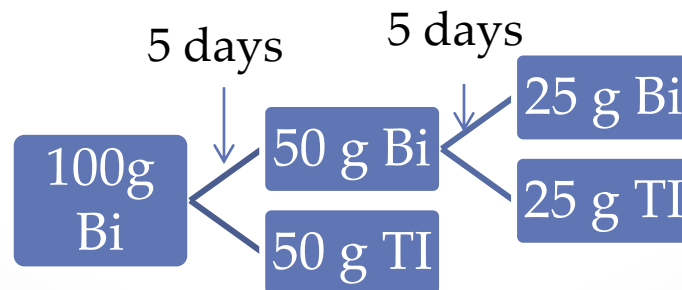
Definition:

Radioactive material will lose its radio activity by emitting the radiation into the atmosphere. Consequently the ability to emit radiation by a given radioactive material progressively gets reduced. The time taken for half of the radionuclide's atoms to decay is commonly referred as half life ($T_{1/2}$).

This property is related to decay constant. The radioactivity of any radionuclide is based on its half-life. A radio nuclide is said to be highly radioactive if the half life is short while a radionuclide having longer half-life is considered to radioactively weak. There is wide variation in **half-life of known radionuclides which ranges from 10¹⁹ years to 10⁻²³ seconds.**

Example,

The radioactive element bismuth (^{210}Bi) can undergo alpha decay to form the element thallium (^{206}Tl) with a reaction half-life equal to five days.



The reaction proceeds in halves, with half of whatever is left of the radioactive element decaying every half-life period.

The fraction of parent material that remains after radioactive decay can be calculated using the equation:

$$\text{Fraction remaining} = 1/2^n$$

where n = number of half-lives elapsed

The amount of a radioactive material that remains after a given number of half-lives is therefore:

$$\text{Amount remaining} = \text{Original amount} * \text{Fraction remaining}$$

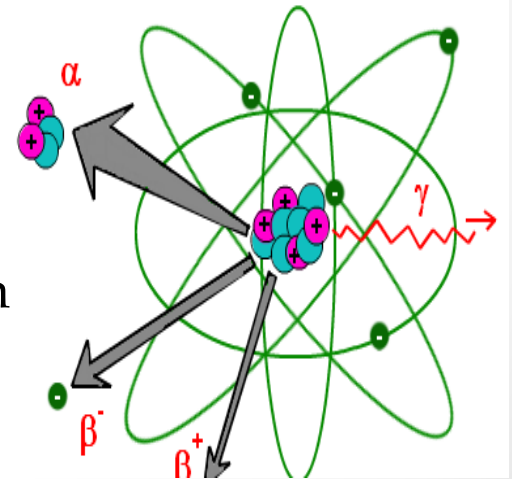
The decay reaction and $T_{1/2}$ of a substance are specific to the isotope of the element undergoing radioactive decay.

For example,

- Bi210 can undergo decay to Tl206 with a $T_{1/2}$ of five days.
- Bi215, by comparison, undergoes decay to Po215 with a $T_{1/2}$ of 7.6 minutes,
- Bi208 undergoes yet another mode of radioactive decay (called electron capture) with a $T_{1/2}$ of 368,000 years!

What is radionuclides?

- A radionuclide/radioisotope/radioactive isotope is an atom that has excess nuclear energy, making it unstable
- Spontaneously emits radiation—which includes the emission of energetic α particles, β particles, and γ particles—is considered radioactive
- Radioactivity, is the process by which a nucleus of an unstable atom loses energy by emitting particles of ionizing radiation





Sources of nucleotides



Naturally occurring radionuclides	Artificial radionuclides
☐ Naturally present in the environment	☐ Radiation from man-made activities
☐ Exposed to radiation from radionuclides on a daily basis	☐ Medical diagnostic intervention
☐ Radiation comes from space (cosmic rays)	☐ Industries that concentrate natural radionuclides
☐ Naturally-occurring radioactive materials found in the soil, water and air	☐ Civil or military nuclear operations
	☐ Burning of coal and oil
	Mixture of radionuclides generated inside the reactor from a nuclear power plant

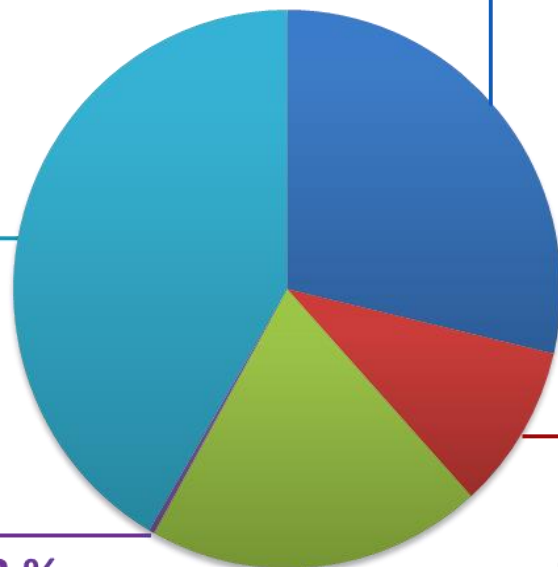
Radionuclides



41.6 %
Radon



0.3 %
Other



28.7 %
Cosmic (12.9%) and
terrestrial (15,8%)
radiations

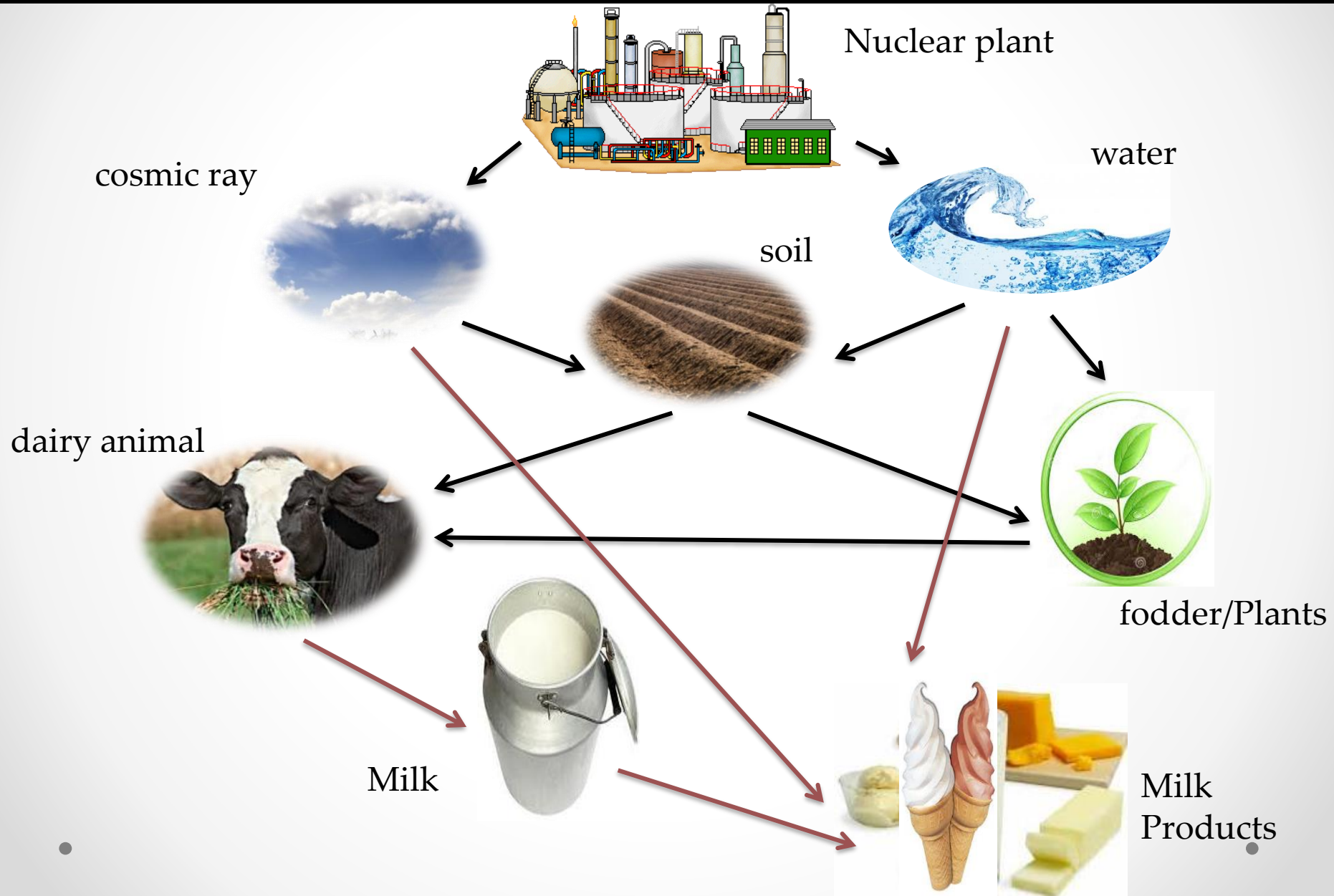


9.6 %
Ingestion of
radionuclides naturally
present in foodstuffs

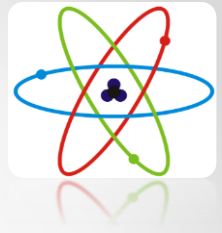
19.8 %
Medical



Pathways of radionuclides into milk



Contamination



- Milk is likely to be contaminated by radioactive iodine and caesium
- Contamination occur by inhalation of radionuclides or ingestion of radionuclides in drinking water and contaminated feed by animal
- Contamination of milk will be greatest when cows are grazing during the fallout period
- Degree of harm to human health depends on the type of radionuclides and the length of time people are exposed to it

Natural nucleotides present in milk

Radionuclides	Activity(Bq/l)	Mean(Bq/l)
^{40}K	40-60	50
^{87}Rb	0.5-3.5	2
^{14}C	14-16	15
^3H	0.1-1.0	0.5

Bq (Becquerel) is the S.I unit of radio activity

Codex limit for milk

Radio active isotope	Level(Bq/Kg)
^{238}Pu , ^{239}Pu , ^{240}Pu	10
Sr^{90} , Ru^{106} , I^{129} , I^{131}	100
Sr^{89} , Ru^{103} , Cs^{134} , Ce^{144} , Cs^{137}	1000
H^3 , C^{14}	10000

Codex limit for infant foods

Radio active isotope	Level(Bq/Kg)
^{238}Pu , ^{239}Pu , ^{240}Pu	1
Sr^{90} , Ru^{106} , I^{129} , I^{131}	100
Sr^{89} , Ru^{103} , Cs^{134} , Ce^{144} , Cs^{137}	1000
H^3 , C^{14}	10000

Max Permissible limit of nucleotide in milk and milk products

Food	^{137}Cs (Bq/l)	^{90}Sr (Bq/l)
Milk	30	10
Milk powder	330	110
Butter	40	15
Butter oil	40	15

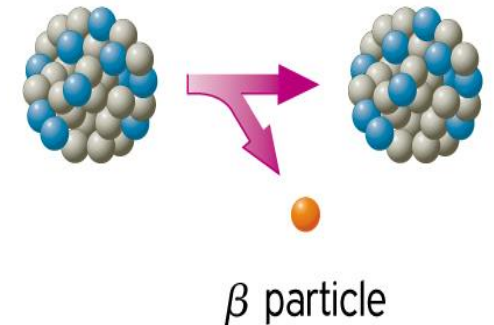
Health Effect

- Radiation can impair the functioning of tissues and/or organs
- Produce acute effects such as skin redness, hair loss, radiation burns
- Acute radiation syndrome. the dose threshold for acute radiation syndrome is about 1 Sv (1000 mSv)
- Potentially hazardous radionuclides in milk are:
 Sr^{90} , Sr^{89} , I^{131} , I^{133} , Cs^{134} , Ba^{140} and K^{40}
- Higher dose in short period – patient may die
- Other risks - Cancer, mutation, foetal abnormality
- Cancer types and target organs depend on the radionuclides



Radioactive iodine (I^{131})

- Rapid transfer to milk from contaminated feed
- Accumulation in the thyroid gland
- Short half-life (8 days)
- Increase the risk of thyroid cancer
- β - emitter
- Cause mutation and death in cells
- Potassium iodide pills can decrease the activity of radioactive iodine



Radioactive caesium (Cs^{134} and Cs^{137})

- Radioactive caesium can stay in the environment for many years and could continue to present a long term problem for food

Cs^{134} : Half-life- 2 years, Beta emitter

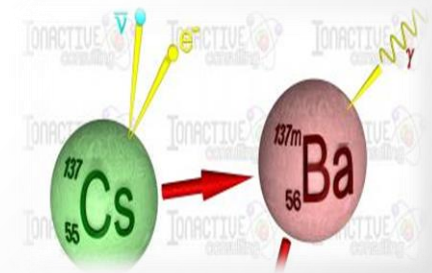
Cs^{137} :

Long half life- 30 years

Distributed uniformly throughout the body's soft tissues

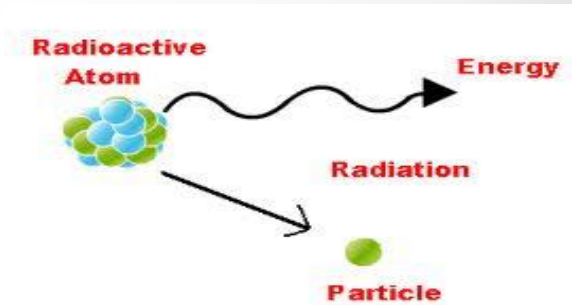
Results in an increased risk of cancer.

Gamma and beta emitter



Radioactive Strontium – Sr^{90}

- ☸ Deposited in bones and bone marrow
- ☸ Only 1% remaining in blood and soft tissues
- ☸ Bone seeker - exhibits biochemical behaviour similar to calcium
- ☸ β - emitter
- ☸ Half life - 28.8 years
- ☸ Cause bone cancer, cancer of nearby tissues, and leukemia
- ☸ Strontium has an affinity to the calcium sensing receptor of parathyroid cells - primary hyperparathyroidism



Radioactive Potassium- K^{40}

- ✦ Very long half-life of 1.248×10^9 years
- ✦ More hazardous due to higher energy of radiation
- ✦ Present at higher levels
- ✦ Emits beta and gamma ray