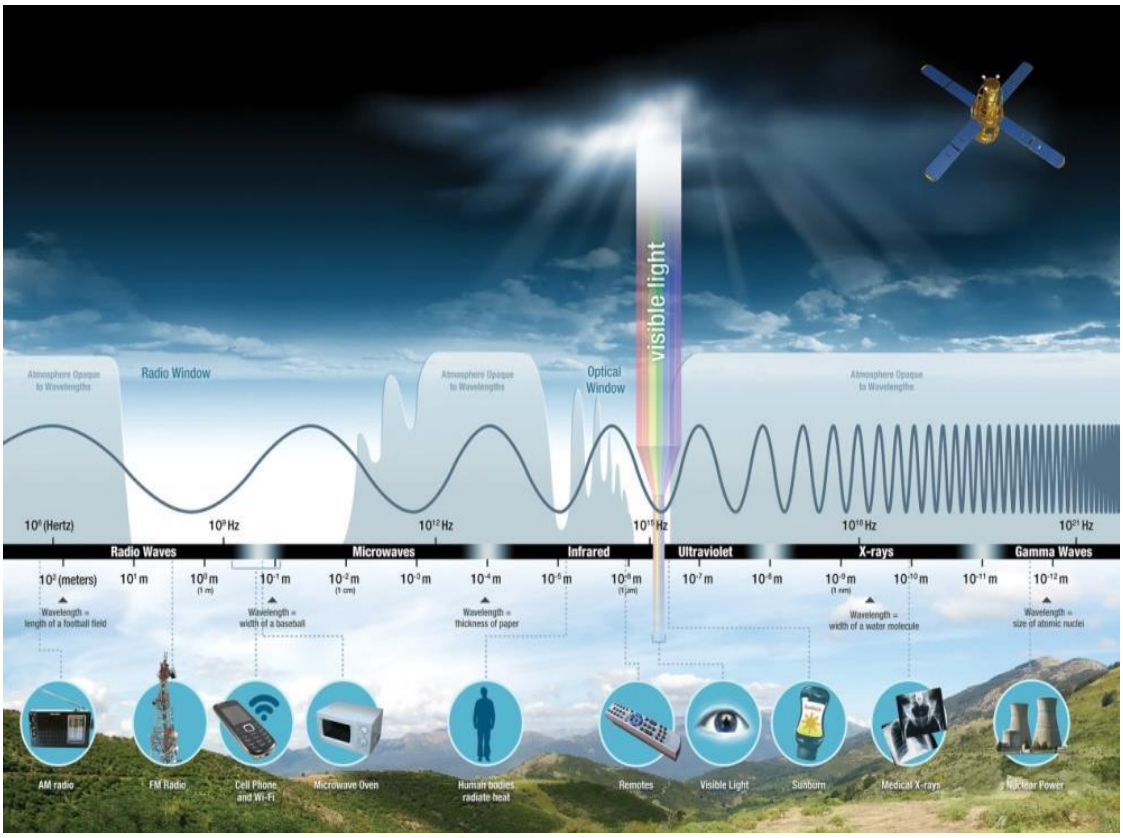
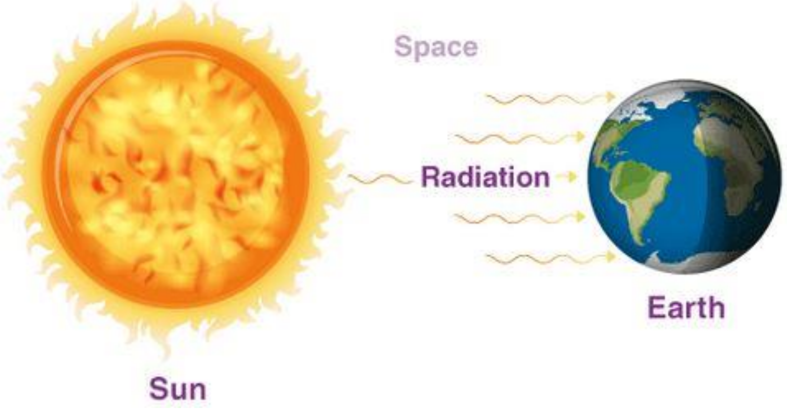
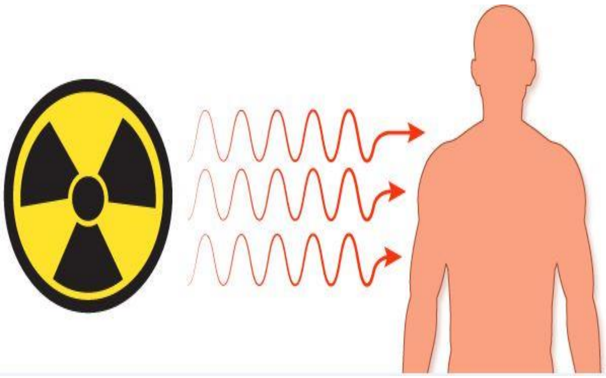




Radiation Energy



First Lecture (1)

First semester / Second year

By

By Assist. Lec. ASAL AHMED

Radiation Energy

Radiation: is energy moving in the form of waves or streams of particles, so it's the emission of energy as electromagnetic waves; since EM radiation is a form of energy.

Understanding radiation requires basic knowledge of atomic structure, energy, and how radiation may damage cells in the human body. Atoms are the basic building blocks of all matter; atoms consist of a nucleus containing protons and neutrons surrounded by electrons in orbitals around the nucleus. Some atoms are unstable and give off energy (i.e., decay) to become more stable. In this context, an unstable atom is *"radioactive,"* and the energy it releases is referred to as *"radiation"*.

Ionizing Radiation:

It is a special type of radiation that has enough energy to remove tightly bound electrons out of their orbits around atoms that interact with it, thus creating ions. The atom is called ionized. This process is called *"Ionization"*. The measure of the ionizing radiation released by a radioactive material is *"Radioactivity"*.

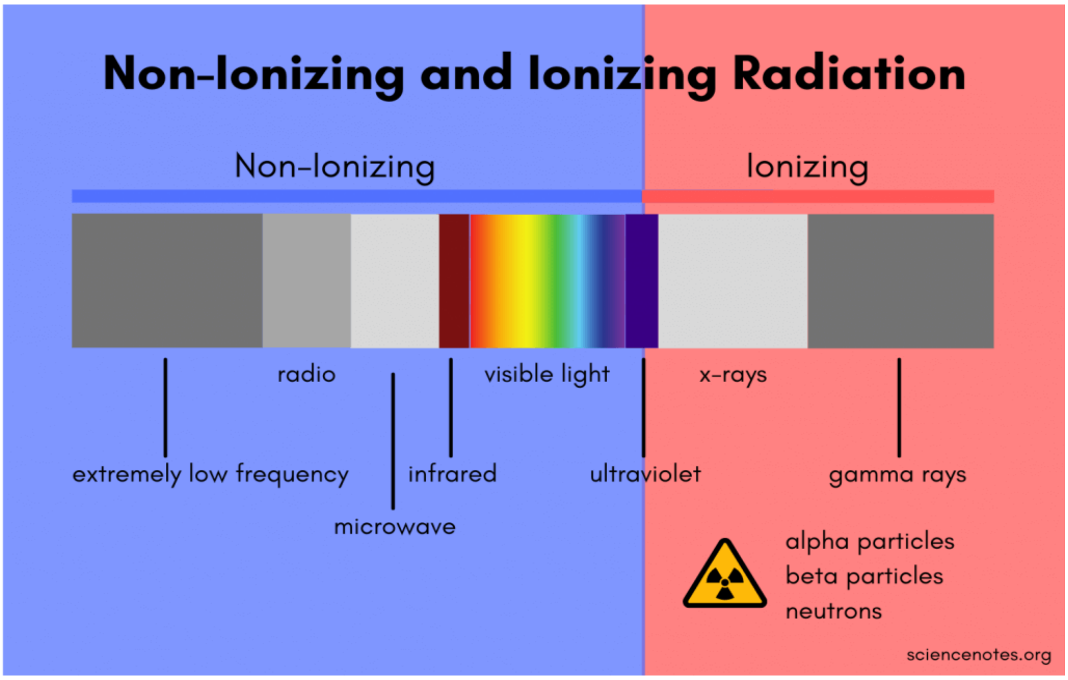


Figure (1): The Types of Non-Ionizing and Ionizing Radiation.

Types of Ionizing Radiation:

Alpha particles (α):

- ✓ It is a *helium nucleus*, and it's the least penetrating; some unstable atoms emit alpha particles.
- ✓ It is positively charged and made up of two *protons* and two *neutrons*, and it comes from the decay of the heaviest radioactive elements, such as Uranium, Radium and Polonium.
- ✓ Even very energetic alpha particles can be stopped by a sheet of paper; they are so heavy that they use up their energy over short distances and are unable to travel very far from the atom.

Beta particles (β-):

- ✓ It is fast-moving *electrons* with a negative electrical charge.
- ✓ It is emitted from an atom's nucleus during radioactive decay with more penetrating, but it can still be absorbed by a few millimeters of aluminum. However, in cases where high-energy beta particles are emitted, shielding must be accomplished with low-density materials, e.g., plastic, wood, water, or acrylic glass.
- ✓ They travel farther in the air than alpha particles but can be stopped by a layer of clothing or by a thin layer of a substance such as aluminum.

Neutron Radiation:

- ✓ Nuclear fission or nuclear fusion are the typical phenomena that cause the release of free neutrons, which then react with the nuclei of other atoms to form new nuclides,which, in turn, may trigger further neutron radiation. A common source of neutrons is the nuclear reactor, in which the splitting of a Uranium or Plutonium nucleus is accompanied by the emission of neutrons.
- ✓ Neutron radiation is not as readily absorbed as charged particle radiation, which makes this type the most penetrating. Neutrons are absorbed by the nuclei of atoms in a nuclear reaction. This most often creates a secondary radiation hazard as the absorbing nuclei transmute to the next heavier isotope, many of which are unstable.

Gamma Rays:

- ✓ It is a weightless packet of energy called a *photon*.
- ✓ Gamma Rays have the smallest wavelengths, so they have much higher energy than any others in the electromagnetic spectrum.
- ✓ Unlike alpha and beta, which have both energy and mass, Gamma Rays are pure energy.
- ✓ Gamma Rays are often emitted along with alpha or beta particles during radioactive decay and in nuclear explosions.

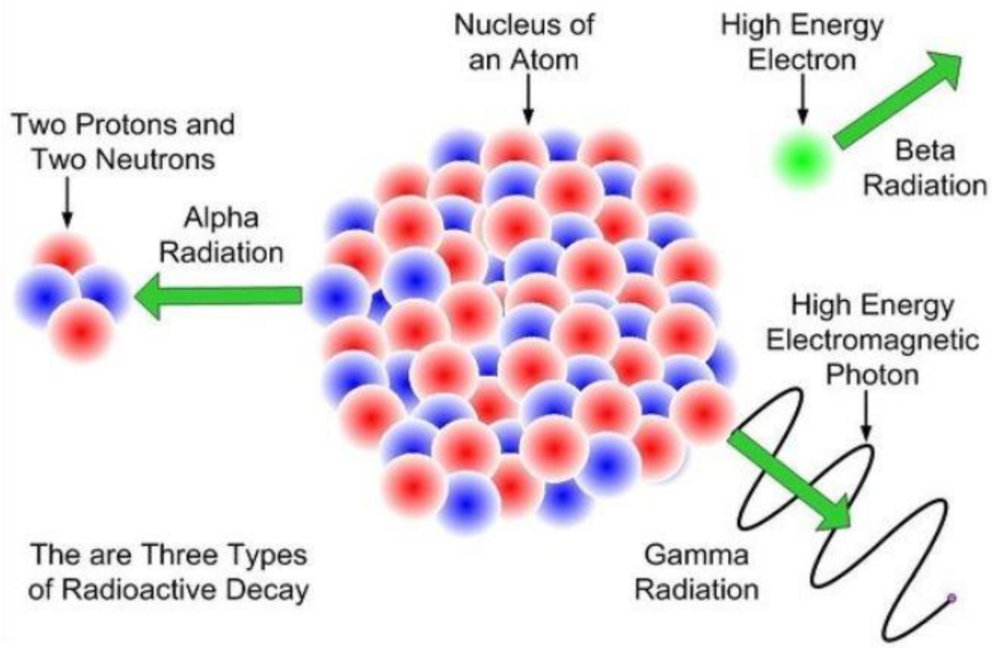


Figure (2): The Types of Radioactive Decay.

X-Rays:

- ✓ It is similar to Gamma ray in that they are *photons* of pure energy.
- ✓ X-Rays and Gamma Rays have the same basic properties but come from different parts of the atom. X-Rays are emitted from processes outside the nucleus, but Gamma Rays originate inside the nucleus.
- ✓ It generally has lower energy and, therefore, is less penetrating than Gamma Rays but has higher energy than ultraviolet waves.

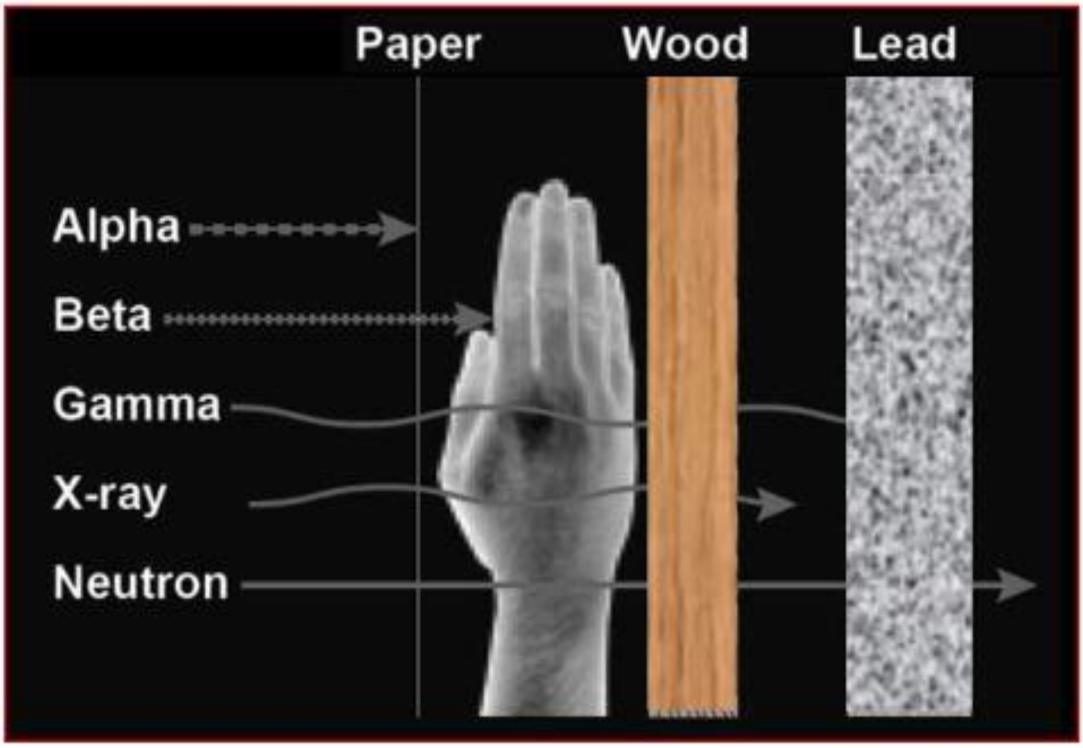


Figure (3): The penetration abilities of different types of ionizing radiation.

What is the health effect of exposure to alpha, beta, gamma, and neutron radiation?

1. **Alpha particles (α):** depend greatly on how a person is exposed. Alpha particles lack the energy to penetrate even the outer layer of skin, so exposure to the outside of the body is not a major concern. Inside the body, however, they can be very harmful. If alpha emitters are inhaled, swallowed, or get into the body through a cut, they can damage sensitive living tissue. The way these large, heavy particles cause damage makes them more dangerous than other types of radiation. The ionizations they cause are very close together—they can release all their energy in a few cells. This results in more severe damage to cells and DNA.
2. **Beta particles (β-):** Some beta particles are capable of penetrating the skin and causing damage such as skin burns. However, as with alpha-emitters, beta-emitters are most hazardous when they are inhaled or swallowed.
3. **Neutron Radiation:** They are able to penetrate the tissues and organs of the human body when the radiation source is outside the body. Also, it can be hazardous if neutron-emitting nuclear substances are deposited inside the body. It's best shielded or absorbed by materials that contain hydrogen atoms, such as paraffin wax and plastics. (This is because neutrons and hydrogen atoms have similar atomic weights and readily undergo collisions with each other.)

4. **Gamma Rays:** This radiation hazard for the entire body it can easily penetrate barriers, such as skin and clothing, which can stop alpha and beta particles. It has so much penetrating power that several inches of a dense material like lead or even a few feet of concrete may be required to stop them. It can pass completely through the human body easily; as it passes through, it can cause ionizations that damage tissue and DNA or kill living cells, a fact that medicine uses to its advantage, using gamma-rays to kill cancerous cells.

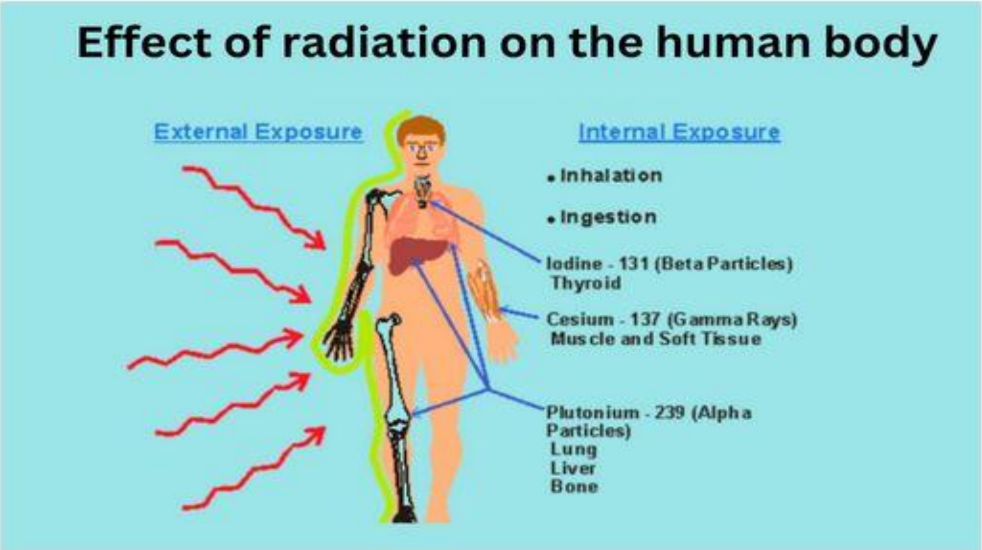


Figure (4): The effect of radiation on the human's body.

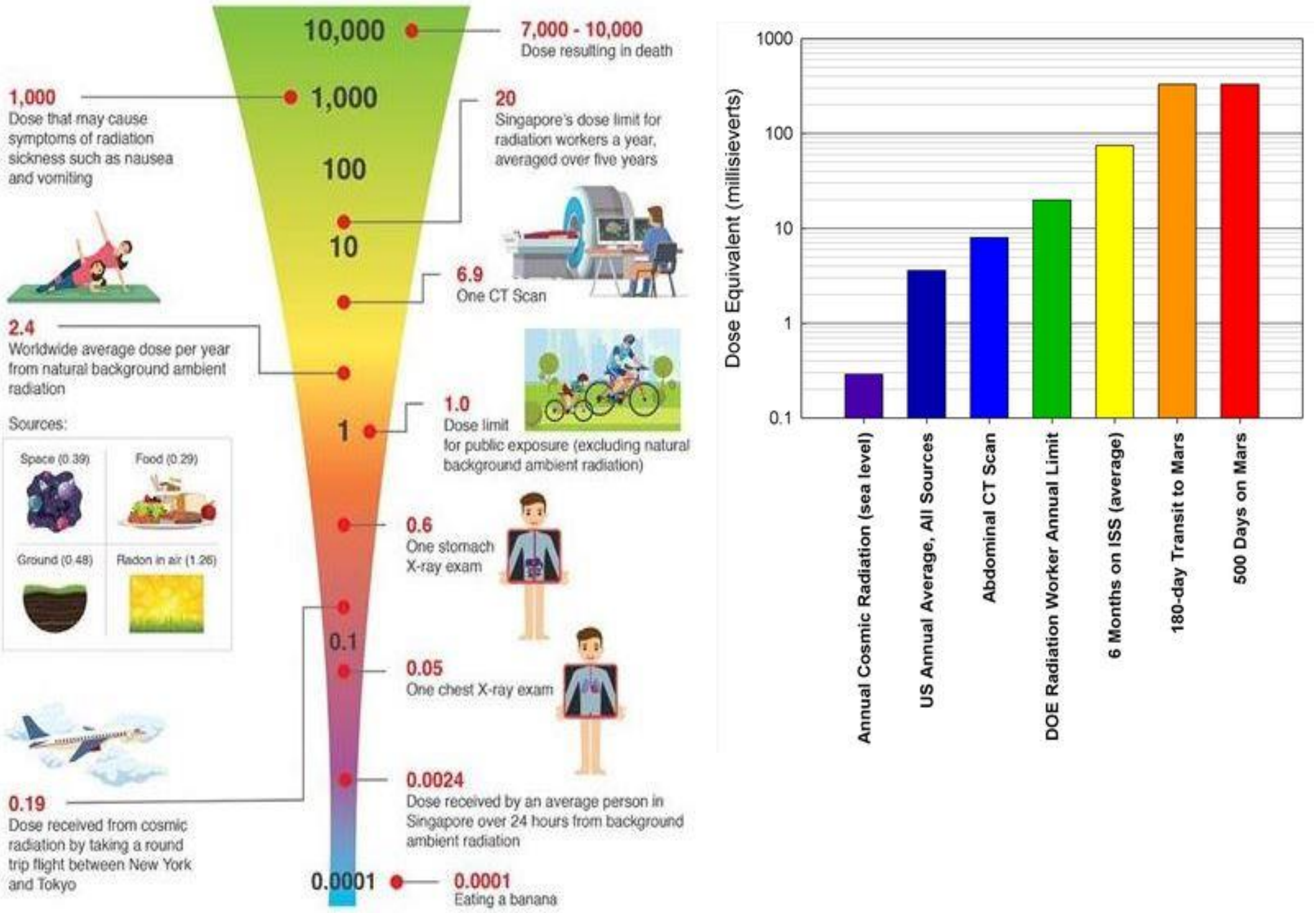
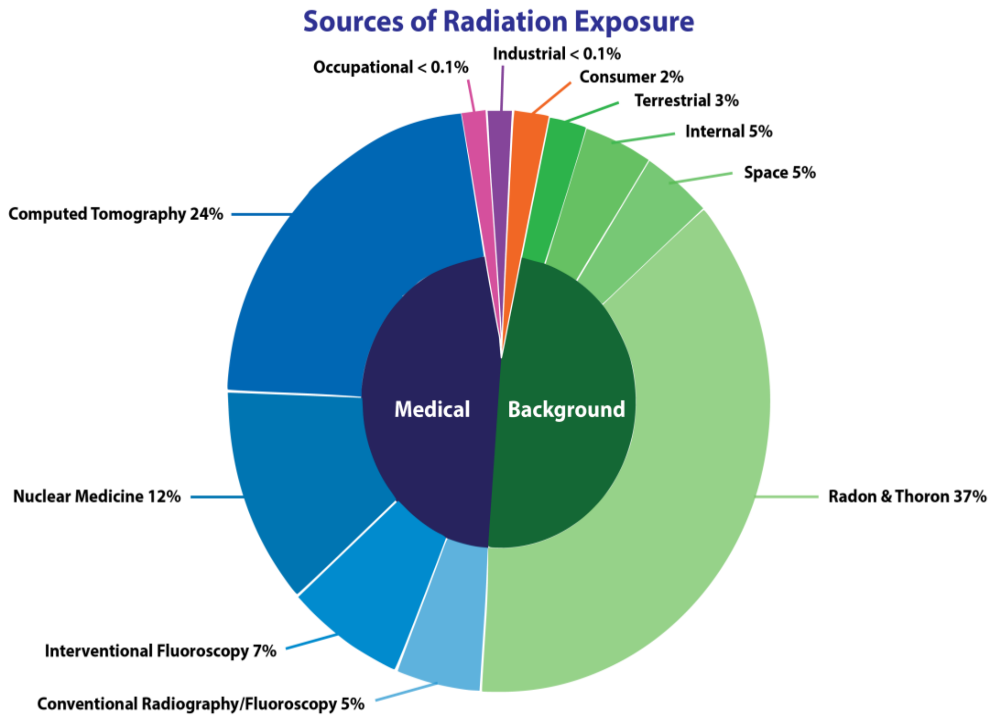
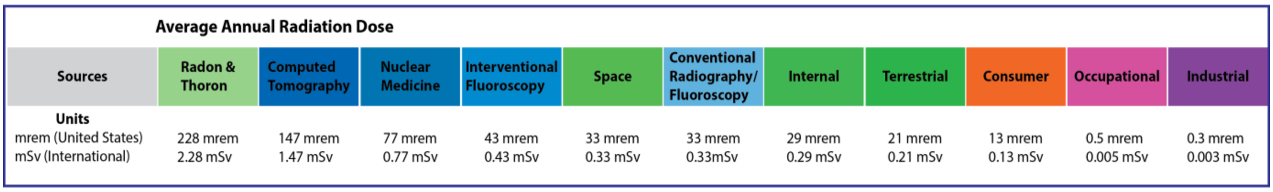


Figure (6): Shows the comparison of radiation doses.

NOW, what are the Sources of Ionizing Radiation?

Natural Sources, and ***Human-made Sources:*** Figure (5) Shows all sources of radiation exposure.





Average Annual Radiation Dose

Sources	Radon & Thoron	Computed Tomography	Nuclear Medicine	Interventional Fluoroscopy	Space	Conventional Radiography/ Fluoroscopy	Internal	Terrestrial	Consumer	Occupational	Industrial
Units mrem (United States) mSv (International)	228 mrem 2.28 mSv	147 mrem 1.47 mSv	77 mrem 0.77 mSv	43 mrem 0.43 mSv	33 mrem 0.33 mSv	33 mrem 0.33mSv	29 mrem 0.29 mSv	21 mrem 0.21 mSv	13 mrem 0.13 mSv	0.5 mrem 0.005 mSv	0.3 mrem 0.003 mSv

(Source: National Council on Radiation Protection & Measurements, Report No. 160)

Figure (5): Shows the sources of radiation exposure.

Today, the most common sources of human exposure to radiation are:

I. Natural radiation comes from many naturally occurring radioactive materials found in soil, water, air, and the body. Every day, people inhale and ingest forms of radiation from air, food, and water. Exposure to radiation can result from natural sources (e.g. radon in homes), planned (medical, occupational), or accidental situations. **Exposure may be external (with or without contamination of skin, hair, or clothes), internal (inhalation, ingestion, or via a contaminated wound), or a combination of both.**

II. Exposure to radiation comes from human-made sources ranging from nuclear power generation to medical uses and devices. Ray machines and Radiopharmaceuticals are used for diagnostics or radiotherapy. **Today, the most common sources of ionizing radiation are medical devices, including X-Ray machines and Computed Tomography (CT) scanners.**

Quastion: How can we produce X-Ray and where can we use them?

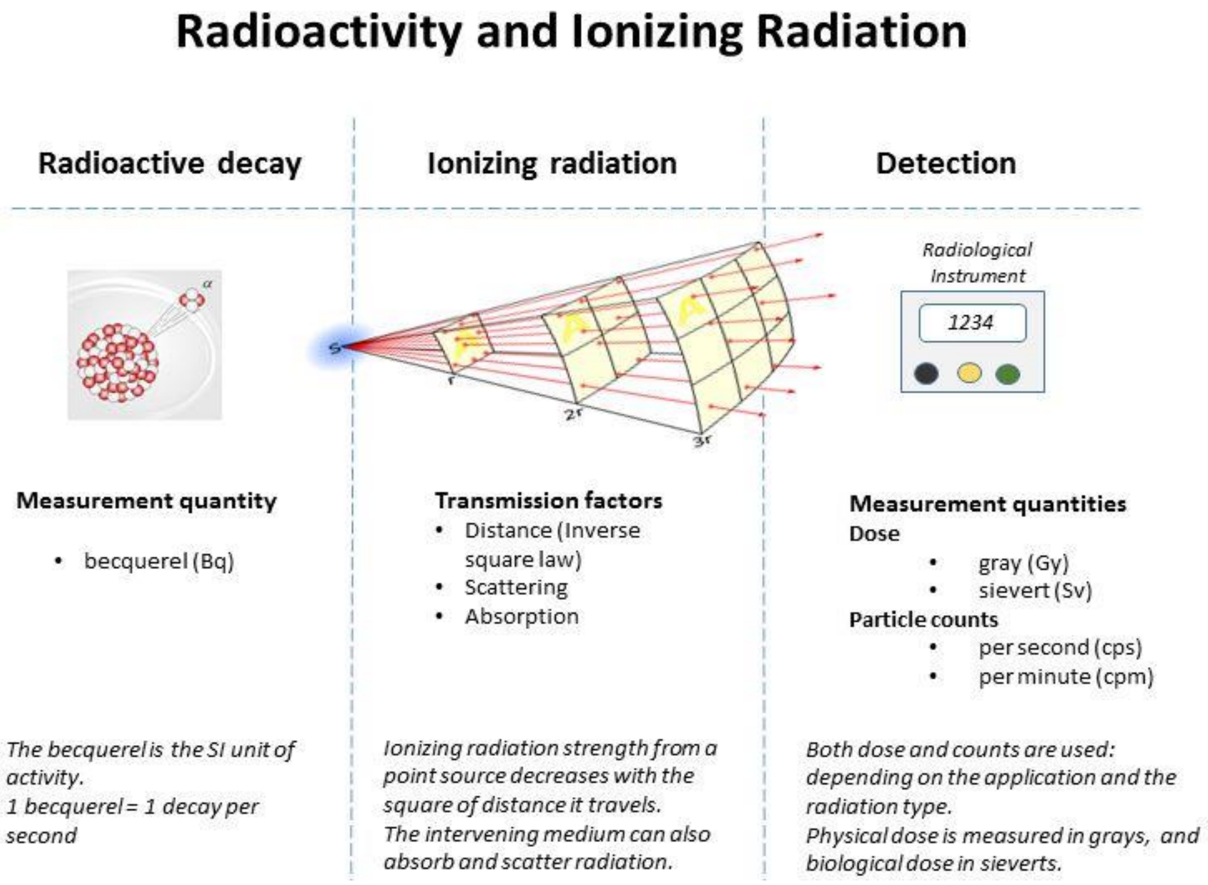
Answer: X-Rays can be produced naturally or artificially by machines using electricity. Literally thousands of X-Ray machines are used daily in medicine. Computed Tomography (CT) scanners use special X-Ray equipment to make detailed images of bones and soft tissue in the body. X-Rays are also used in industry for inspections and process controls.

Radiation Measurement Units:

Properties Considered When Ionizing Radiation Measured:

Ionizing radiation is measured in terms of:

- The strength or radioactivity of the radiation source.
- The energy of the radiation.
- The level of radiation in the environment.
- The radiation dose, or the amount of radiation energy absorbed by the human body, is the most important.



Measurement quantity

- becquerel (Bq)

The becquerel is the SI unit of activity.
1 becquerel = 1 decay per second

Transmission factors

- Distance (Inverse square law)
- Scattering
- Absorption

Ionizing radiation strength from a point source decreases with the square of distance it travels.
The intervening medium can also absorb and scatter radiation.

Measurement quantities

Dose

- gray (Gy)
- sievert (Sv)

Particle counts

- per second (cps)
- per minute (cpm)

Both dose and counts are used: depending on the application and the radiation type.
Physical dose is measured in grays, and biological dose in sieverts.

Figure (7): Radiologic Measurements and units.

1. Roentgen (R):

Roentgen is the unit of dose exposure or intensity of electromagnetic radiation. It is equal to the radiation intensity that will create 2.08×10^9 ion pairs in a cubic centimeter of air that is:

$$\mathbf{1\ R = 2.08 \times 10^{9}\ ion\ pairs/cm^{3}.}$$

The official definition, however, is in terms of electric charge per unit mass of air:

$$\mathbf{1\ R = 2.58 \times 10^{-4}\ C/kg.}$$

The charge refers to the electrons liberated by ionization. The output of X-Ray machines is specified in roentgens, or sometimes millroentgens (mR). The roentgen applies only to X-Rays and Gamma Rays and their interactions with air.

2. Rad:

Rad is used to measure the amount of radiation absorbed by an object or person, which reflects the amount of energy that radioactive sources deposit in materials through which they pass. It is used for any type of ionizing radiation for any exposed matter. An absorbed dose of 1 rad means that 1 gram of material absorbed 100 ergs of energy (a small but measurable amount) as a result of exposure to radiation.

1 Rad = 100 ergs/g

Where the erg (joule) is a unit of energy and the gram is a unit of mass. The related international system unit is the gray (Gy), where 1 Gy is equivalent to 100 rad.

1 Gy = 100 Rad, so 1 Rad = 10^{-2} Gy.

3. Rem:

Rem is the traditional unit of dose equivalent (DE) or occupational exposure; it's used to express the quantity of radiation received by radiation workers. Some types of radiation produce more damage than X-Rays. This is particularly important to people working near nuclear reactors or particle accelerators.

4. Curie:

Curie (Ci) is the original unit used to express the decay rate of a sample of radioactive material. It is equal to that quantity of radioactive material, not the radiation emitted by the material in which the number of atoms decaying per second is equal to 37 billion 3.7×10^{10}. In other words, one Curie is that quantity of material in which $3.7\text{x}10^{10}$ atoms disintegrate every second. Becquerel (Bq), or Curie, is a measure of the rate, not energy, of radiation emission from a source.

5. Electron Volt:

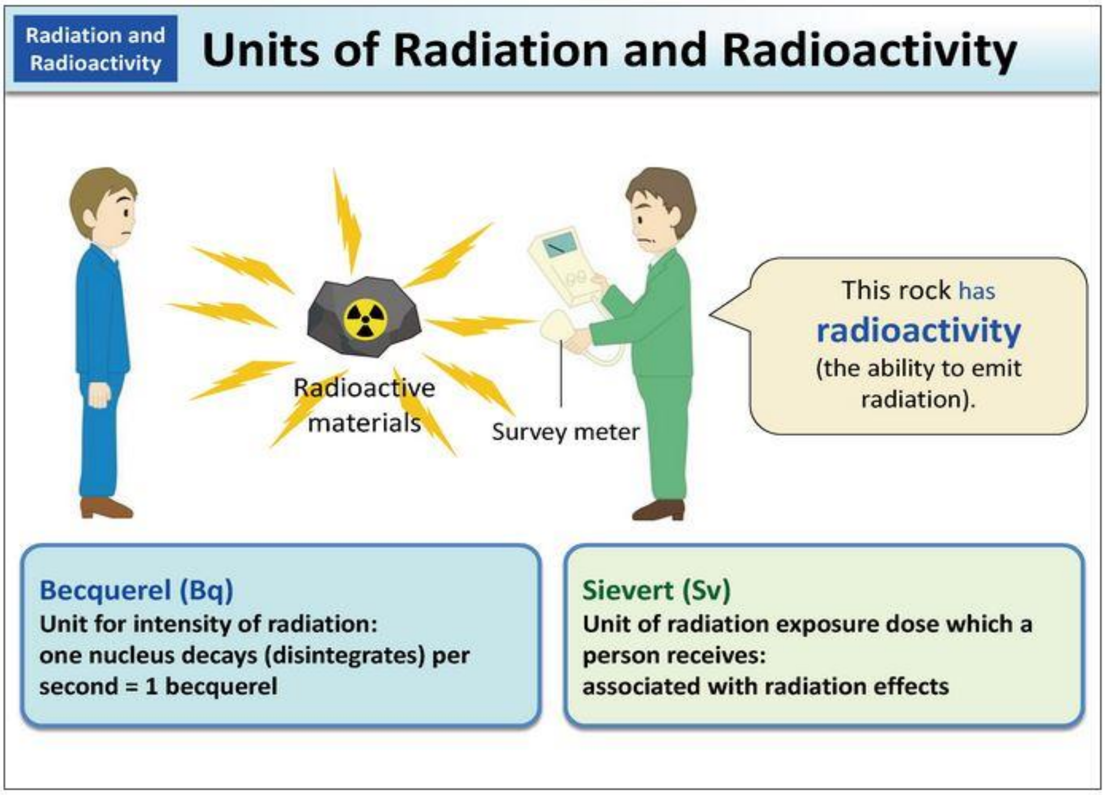
Electron Volt is the amount of energy produced by the charge of a single electron moving across an electric potential difference of one volt. The unit of energy is the joule, which means a particle with charge has energy after passing through the potential. Therefore, one electron volt is equal to a joule. The energy is measured in eV or KeV. Most X-Rays used in diagnostic radiology have energy up to 150 KeV, whereas those in radiotherapy are measured in MeV.

Table (1): Shows the special quantities of radiologic science and their-associated special units.

Quantity	***Customary unit***		***SI unit***	
	Name	***Symbol***	***Name***	***Symbol***
Exposure	Roentgen	R	Coulomb per kilogram	C/Kg
Absorbed dose	Rad	Rad	Gray	Gy
Equivalent Dose	Rem	Rem	Sievert	Sv
Radioactivity	Curie	Ci	Becquerel	Bq

****Note****: Because diagnostic radiology is concerned primarily with X-Rays, for our purposes, may consider other types of ionizing radiation; this generalization is not true.

1 R equal to 1 rad equal to 1 rem



Becquerel (Bq)
Unit for intensity of radiation: one nucleus decays (disintegrates) per second = 1 becquerel

Sievert (Sv)
Unit of radiation exposure dose which a person receives: associated with radiation effects

Figure (8): Units of Radiation and Radioactivity.

Activity:

Activity is the term used for radioactivity. It's the rate of decay it means the number of atoms that decay per unit time, in equation form, this is:

$$\text{Activity} = \frac{\text{number of disintegration}}{\text{time taken}} \quad , \; A = \frac{N}{t}$$

Where time is in seconds (s) and activity is measured in Becquerels (Bq). The number of disintegrations has no units. The number of disintegrations cannot be determined easily in practical work, but the count of radioactive particles detected by the Geiger-Muller Counter.

Exposure:

As of 2007, ***"medical radiation exposure"*** was defined by the International Commission on Radiological Protection as exposure incurred by people as part of their own medical or dental diagnosis or treatment; by persons, other than those occupationally exposed.

Absorbed Dose:

When ionizing radiation penetrates the human body or an object, it deposits energy. The fundamental units do not take into account the amount of damage done to matter (especially living tissue) by ionizing radiation. This is more closely related to the amount of energy deposited than the charge. The energy absorbed from exposure to radiation is called the ***"absorbed dose".*** It is measured in gray (Gy). J/kg, which represents the amount of radiation required to deposit 1 joule of energy in 1 kilogram of any kind of matter.

Kerma:

Kerma is a measure of energy transferred from radiation to matter and is an acronym for kinetic energy; it's related to the absorbed dose but not the same, and it's also measured by gray. It is the amount of energy that is transferred from photons to electrons per unit mass at a certain position. Absorbed dose, on the other hand, measures the energy deposited in a unit mass at a certain position. At radiological energies, the transfer and deposition of energy are equal. However, at higher energies, a photon may interact with tissue in one position and create an electron that possesses enough energy to deposit energy at a location away from the interaction point.

Equivalent Dose:

When radiation is absorbed, a biological effect may be observed. Equal doses of different types or energies cause different amounts of damage to living tissue. For example, 1 Gy of alpha radiation causes about 20 times as much damage as 1 Gy of X-Rays and is more harmful to a given tissue than 1 Gy of beta radiation. So, **the equivalent dose was defined to give an approximate measure of the biological effect of radiation.** To obtain the equivalent dose, the absorbed dose is multiplied by a specified radiation weighting factor (W_R), which is different for each type of radiation. It provides a single unit that accounts for the degree of harm that different types of radiation would cause to the same tissue. The weighted absorbed dose is called the ***"equivalent dose".*** It is calculated by:

$$\mathbf{H_T = \sum W_R \,.\, D_{T,R}}$$

Where H_T : is the equivalent dose in Sieverts (Sv), $D_{T,R}$ is the absorbed dose in grays (Gy) in tissue by radiation type R and W_R is the radiation weighting factor.

Effective Dose:

Different tissues and organs have different radiation sensitivities, as shown in figure (9).

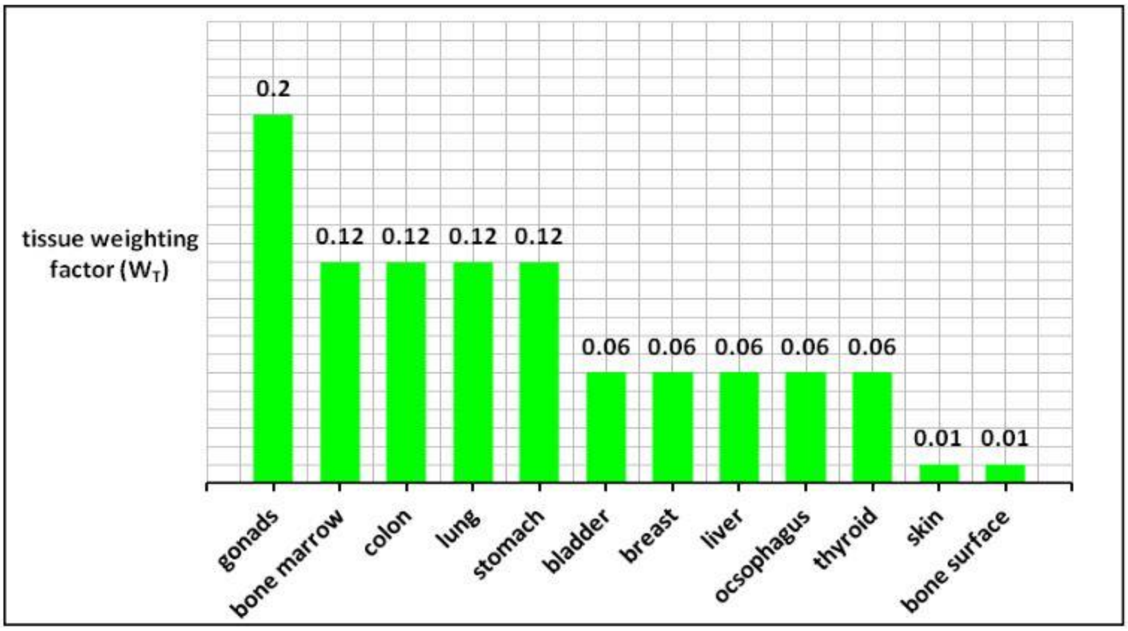


Figure (9): Tissue weighting factors.

An effective dose is not a real physical quantity but a "manufactured" quantity invented by the International Commission on Radiological Protection. For example, bone marrow is much more radiosensitive than muscle or nerve tissue. To obtain an indication of how exposure can affect overall health, the equivalent dose is multiplied by "risk weighting factors" (W_T), which give each organ's relative radiosensitivity to developing cancer; it's related to the risk for a particular tissue or organ. This multiplication provides the **"effective dose"** absorbed by the body; it's measured by sievert. Thus, the effective dose, E, is defined as:

$$\mathbf{E = \sum W_T} \cdot \boldsymbol{H_T}$$

Where W_T is tissue weighting factor, H_T is equivalent dose to tissue T.

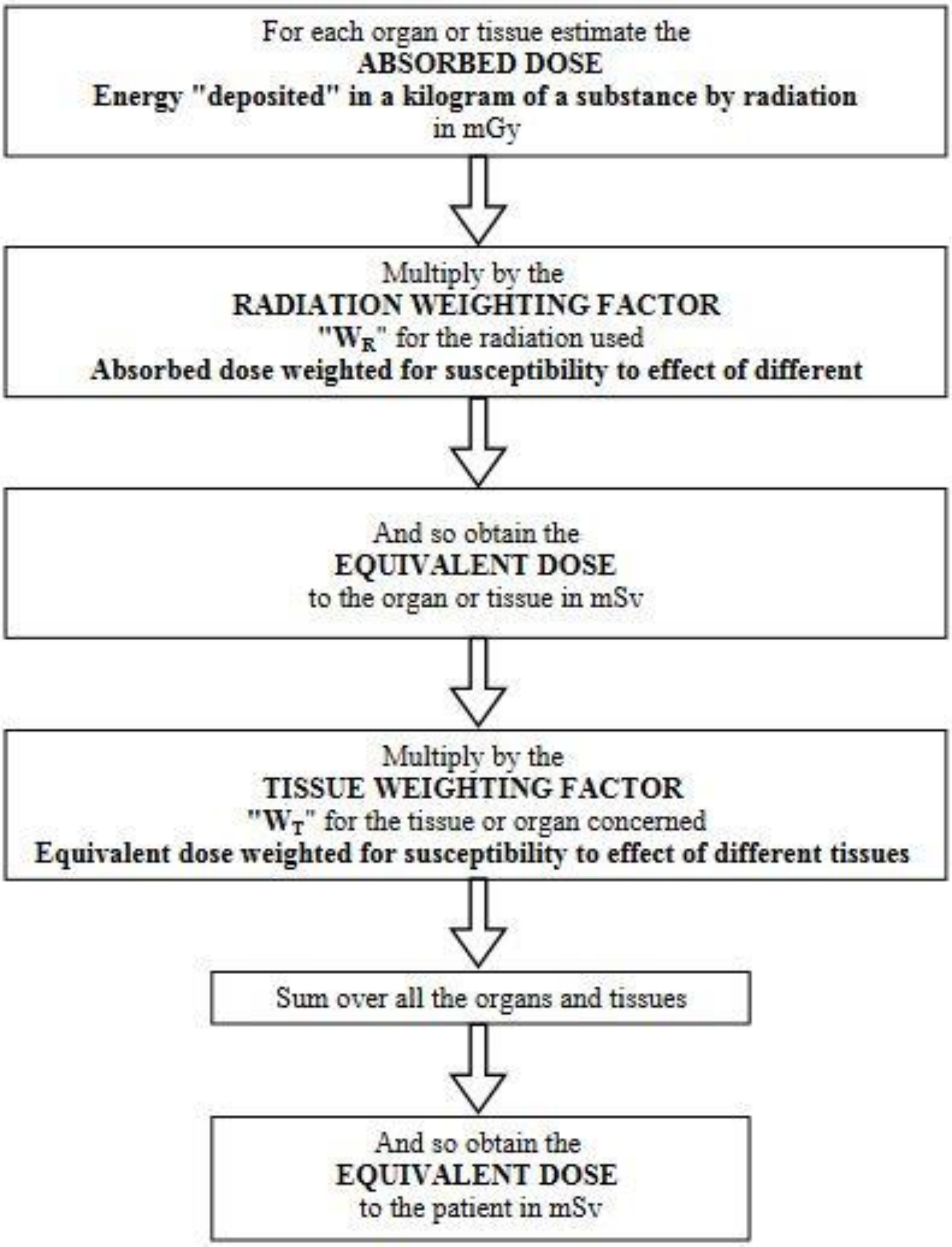


Figure (10): The relationship between Effective, Equivalent and Absorbed doses.