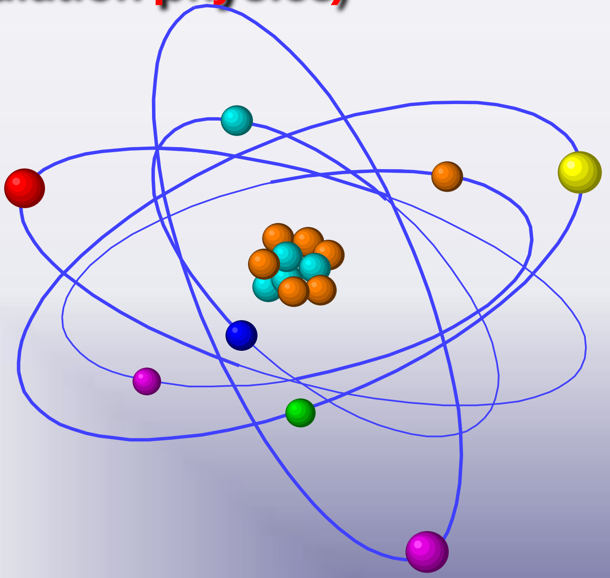
Chapter One

Radiation (Radiation physics)



Prof. Dr. Asaad H. Ismail
PhD Medical Physics
Salahaddin University-Erbil
E-mail: asaad.ismail@su.edu.krd

The Radiation

Basic concepts in ;

Radiation Physics
Radiation Biology
Radiation Epidemiology

We have three sections about the radiation in radiology.

1) The first presents the principles of physics related to ionizing radiation.

2) The second presents the biology necessary for understanding how radiation affects cells and the mechanisms of radiation injury and repair.

3) The third section describes the methods used to identify and measure the risks to persons who are exposed to radiation.

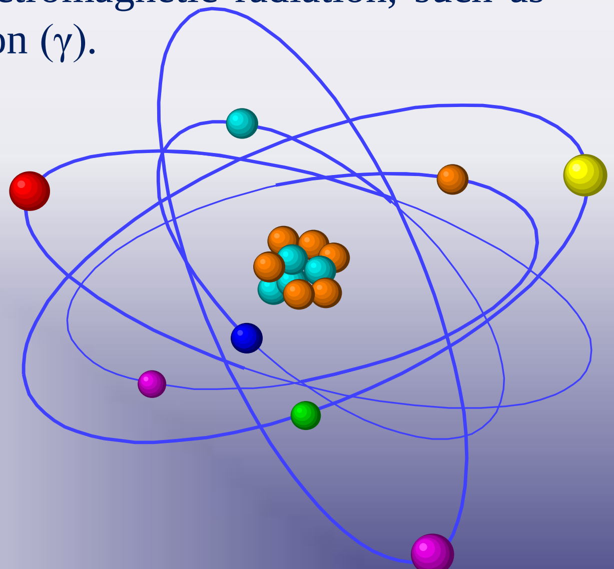
Basic concepts in Radiation Physics

Definition of Radiation

Observable matter is made up of discrete components known as atoms and molecules. Atoms are divisible into particles, such as electrons, protons, and neutrons. Other elementary particles are part of the fabric of nature, but they are more elusive and do not directly form stable atoms or molecules. When a particle or group of particles is accelerated, it can reach high energies and travel a large distance in a very short time. Radiation can be defined as any collection of elementary particles that have sufficient energy to interact with and transfer some of their energy to objects or materials that intercept their path.

So in physics, radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium. This includes: electromagnetic radiation, such as radio waves, microwaves, visible light, x-rays, and gamma radiation (γ).

Basically, Radiation is energy given off by matter in the form of rays or high-speed particles. All matter is composed of atoms. Atoms are made up of various parts; the nucleus contains minute particles called protons and neutrons, and the atom's outer shell contains other particles called electrons. The nucleus carries a positive electrical charge, while the electrons carry a negative electrical charge. These forces within the atom work toward a strong, stable balance by getting rid of excess atomic energy (radioactivity). In that process, unstable nuclei may emit a quantity of energy, and this spontaneous emission is what we call radiation.



Physical Forms of Radiation

As previously indicated, matter gives off energy (radiation) in two basic physical forms;

1) One form of radiation is pure energy with no weight. This form of radiation — known as **Electromagnetic Radiation** — is like vibrating or pulsating rays or "waves" of electrical and magnetic energy. Familiar types of electromagnetic radiation include sunlight (cosmic radiation), x-rays, radar, and radio waves.

2) The second form of radiation — known as **Particle Radiation** — is tiny fast-moving particles that have both energy and mass (weight). This less-familiar form of radiation includes alpha particles , beta particles , and neutrons , as explained by the process of Radioactive Decay and Nuclear Fission

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Radioactive Decay and Nuclear Fission (Form of emitting radiation)

Radioactive Decay;

As previously indicated, large unstable atoms become more stable by emitting radiation to get rid of excess atomic energy (radioactivity). This radiation can be emitted in the form of positively charged alpha particles, negatively charged beta particles, gamma rays. Through this process radioisotopes lose their radioactivity over time. This gradual loss of radioactivity is measured in half-lives. Essentially, a half-life of a radioactive material is the time it takes one-half of the atoms of a radioisotope to decay by emitting radiation. This time can range from fractions of a second (for radon-220) to millions of years (for thorium-232). When radioisotopes are used in medicine or industry, it is vital to know how rapidly they lose their radioactivity, in order to know the precise amount of radioisotope that is available for the medical procedure or industrial use.

Nuclear Fission

In some elements, the nucleus can split as a result of absorbing an additional neutron, through a process called nuclear fission. Such elements are called fissile materials. One particularly notable fissile material is uranium-235. This is the isotope that is used as fuel in commercial nuclear power plants.

When a nucleus fissions, it causes three important events that result in the release of energy. Specifically, these events are the release of radiation, release of neutrons (usually two or three), and formation of two new nuclei (fission products).

Types and Sources of Radiation

Types of radiation : **Depending on how radiation affects matter , radiation can be either**

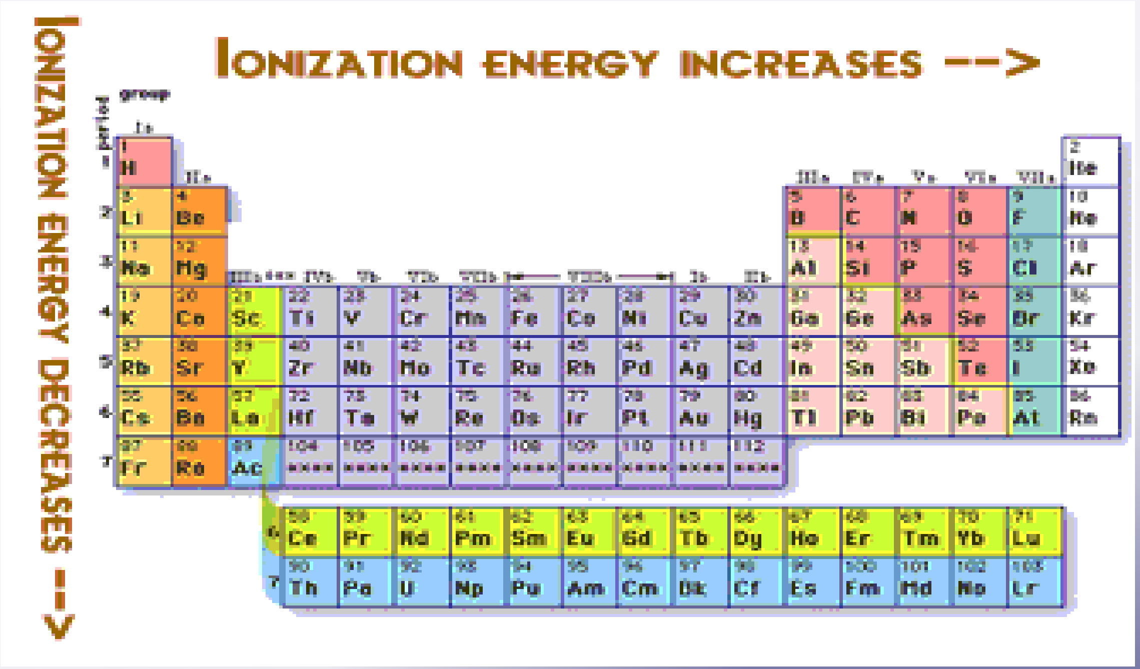
1) Ionizing Radiation

or

2) Non- Ionizing Radiation

1) Ionizing Radiation

What is the ionization? (Process in which an atom or molecule acquires a positive charge (by losing electrons) or negative charge (by gaining electrons)).

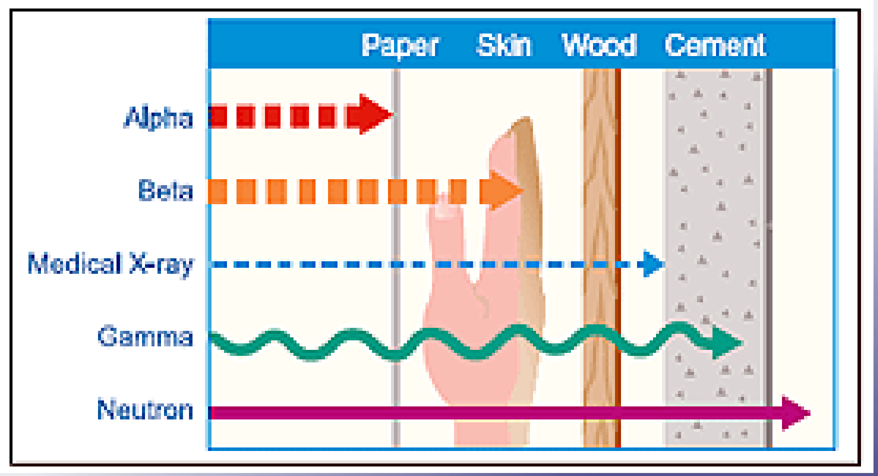


1) Ionizing Radiation

Ionizing radiation (such as x-rays and cosmic rays) is more energetic than non-ionizing radiation. Consequently, when ionizing radiation passes through material, it deposits enough energy to break molecular bonds and displace (or remove) electrons from atoms. This electron displacement creates two electrically charged particles (ions), which may cause changes in living cells of plants, animals, and people.
Ionizing radiation has a number of beneficial uses. For example, we use ionizing radiation in smoke detectors and to treat cancer or sterilize medical equipment. Nonetheless, ionizing radiation is potentially harmful if not used correctly.

Five major types of ionizing radiation:

1) Alpha Particles
2) Beta Particles
3) Gamma Rays
4) X-Rays
5) Neutrons



Alpha Particles

Alpha particles are charged particles, which are emitted from naturally occurring materials (such as uranium, thorium, and radium) and man-made elements (such as plutonium and americium). These alpha emitters are primarily used (in very small amounts) in items such as smoke detectors.

In general, alpha particles have a very limited ability to penetrate other materials. In other words, these particles of ionizing radiation can be blocked by a sheet of paper, skin, or even a few inches of air. Nonetheless, materials that emit alpha particles are potentially dangerous if they are inhaled or swallowed, but external exposure generally does not pose a danger.

Beta Particles

Beta particles, which are similiar to electrons, are emitted from naturally occurring materials (such as strontium-90). Such beta emitters are used in medical applications, such as treating eye disease.

In general, beta particles are lighter than alpha particles, and they generally have a greater ability to penetrate other materials. As a result, these particles can travel a few feet in the air, and can penetrate skin. Nonetheless, a thin sheet of metal or plastic or a block of wood can stop beta particles.

Gamma Rays and X-Rays

Gamma rays and x-rays consist of high-energy waves that can travel great distances at the speed of light and generally have a great ability to penetrate other materials. For that reason, gamma rays (such as from cobalt-60) are often used in medical applications to treat cancer and sterilize medical instruments. Similarly, x-rays are typically used to provide static images of body parts (such as teeth and bones), and are also used in industry to find defects in welds.

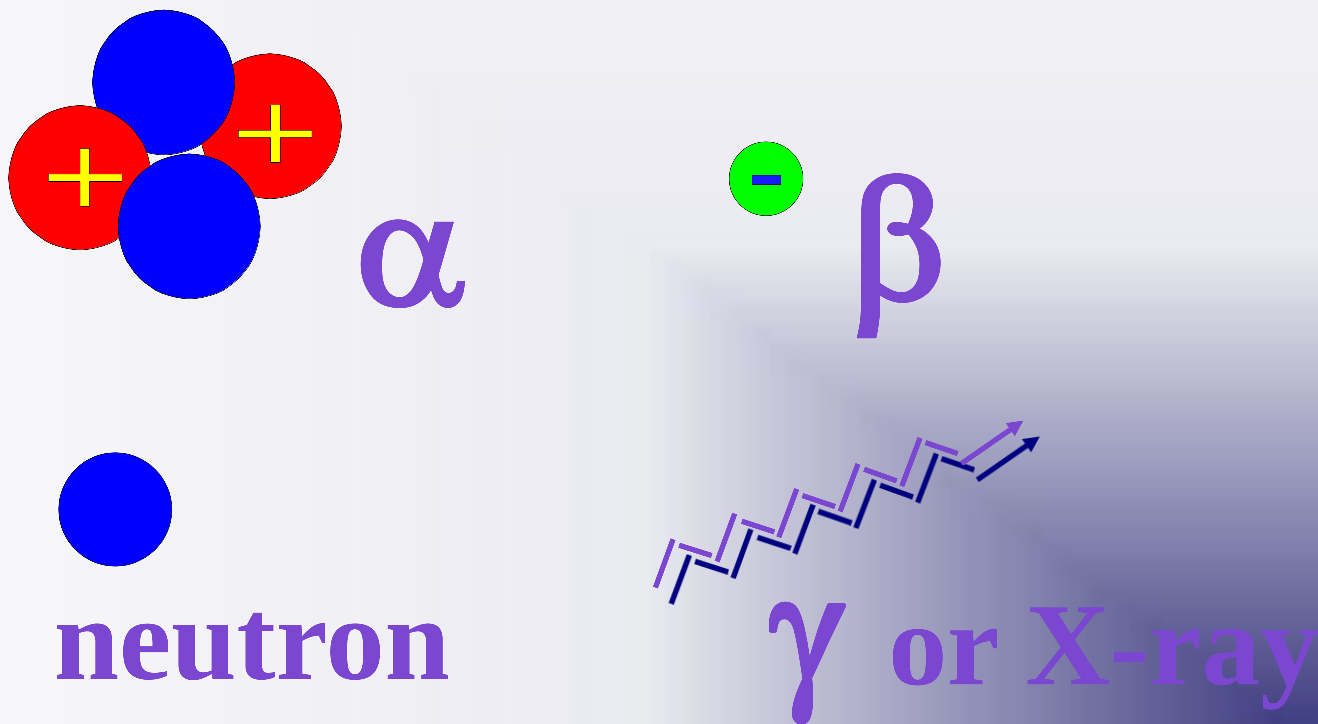
Despite their ability to penetrate other materials, in general, neither gamma rays nor x-rays have the ability to make anything radioactive. Several feet of concrete or a few inches of dense material (such as lead) are able to block these types of radiation.

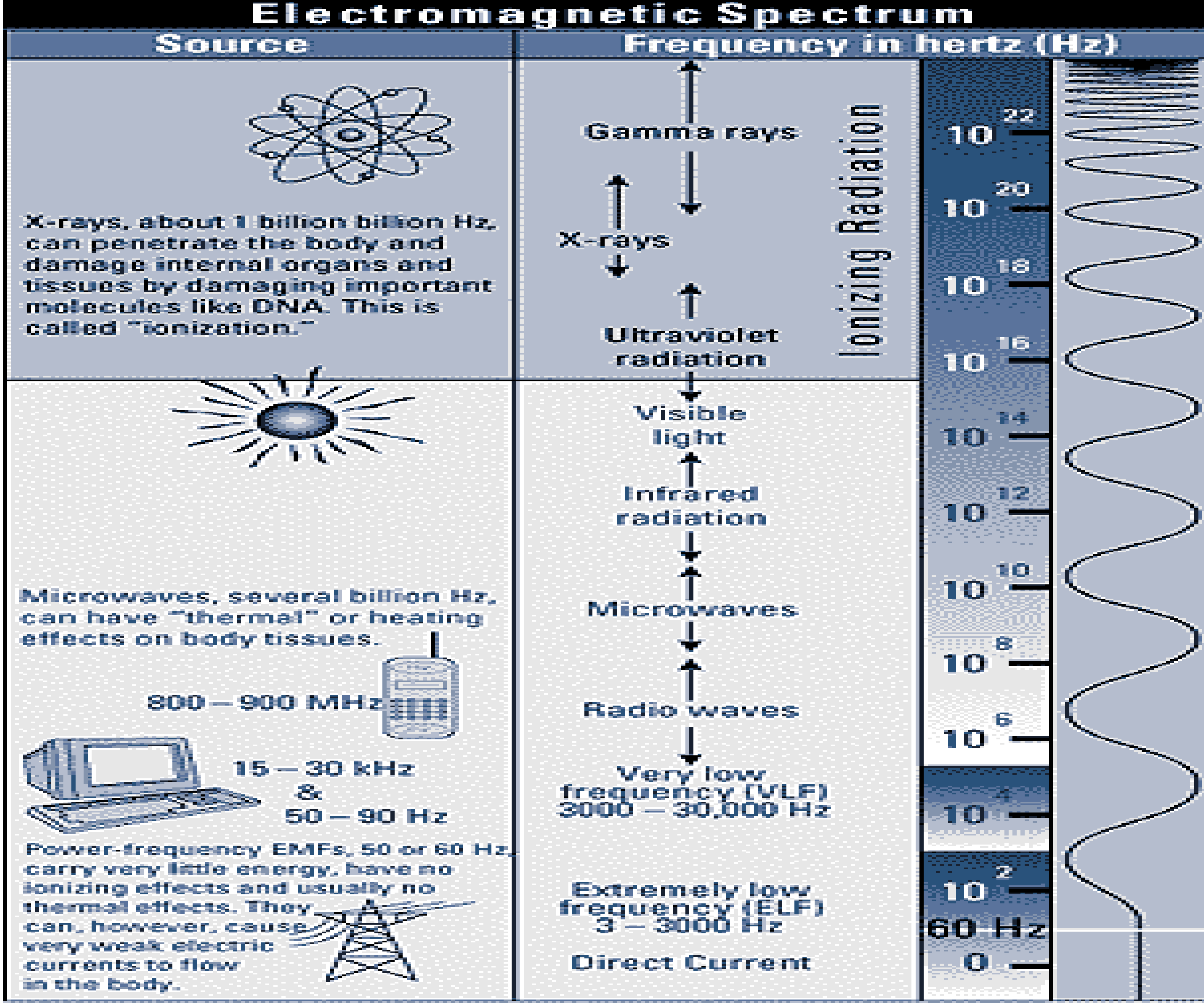
Neutrons

Neutrons are high-speed nuclear particles that have an exceptional ability to penetrate other materials. Of the five types of ionizing radiation discussed here, neutrons are the only one that can make objects radioactive. This process, called neutron activation, produces many of the radioactive sources that are used in medical, academic, and industrial applications (including oil exploration).

Because of their exceptional ability to penetrate other materials, neutrons can travel great distances in air and require very thick hydrogen-containing materials (such as concrete or water) to block them. Fortunately, however, neutron radiation primarily occurs inside a nuclear reactor, where many feet of water provide effective shielding.

Types or Products of Ionizing Radiation

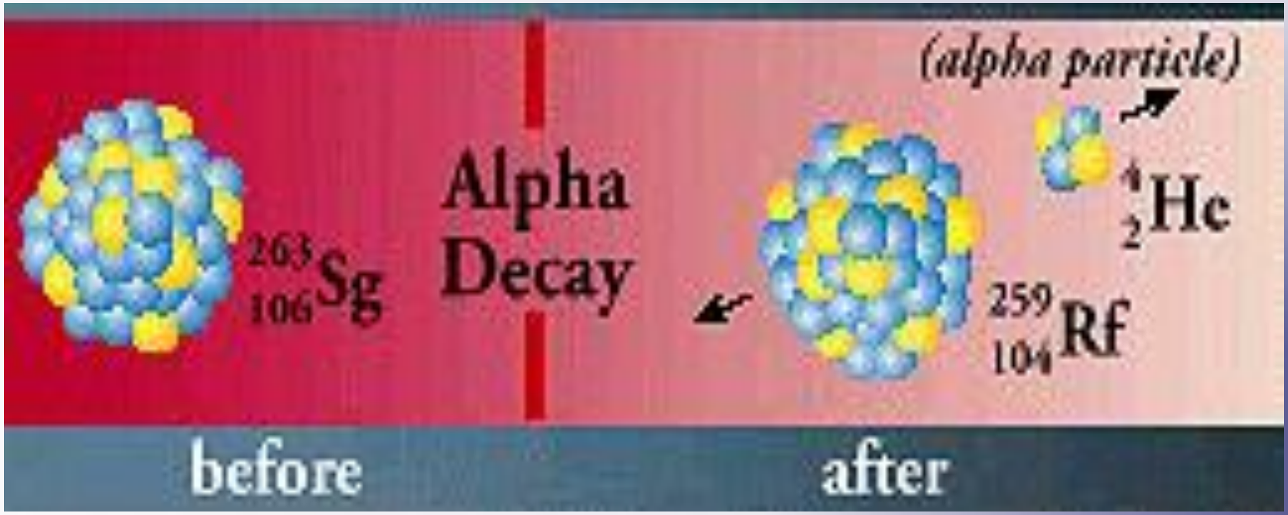



Electromagnetic Spectrum
Source
Frequency in hertz (Hz)
X-rays, about 1 billion billion Hz, can penetrate the body and damage internal organs and tissues by damaging important molecules like DNA. This is called "ionization."
Gamma rays
X-rays
Ultraviolet radiation
Ionizing Radiation
Visible light
Infrared radiation
Microwaves
Radio waves
Very low frequency (VLF) 3000 – 30,000 Hz
Extremely low frequency (ELF) 3 – 3000 Hz
Direct Current
Microwaves, several billion Hz, can have "thermal" or heating effects on body tissues.
800 – 900 MHz
15 – 30 kHz & 50 – 90 Hz
Power-frequency EMFs, 50 or 60 Hz, carry very little energy, have no ionizing effects and usually no thermal effects. They can, however, cause very weak electric currents to flow in the body.
10^22
10^20
10^18
10^16
10^14
10^12
10^10
10^8
10^6
10^4
10^2
60 Hz
0

Types and Characteristics of Ionizing Radiation

Alpha Particles

Alpha Particles: 2 neutrons and 2 protons / They travel short distances, have large mass / Only a hazard when inhaled



Alpha Particles *(or Alpha Radiation)*:

Helium nucleus (2 neutrons and 2 protons);

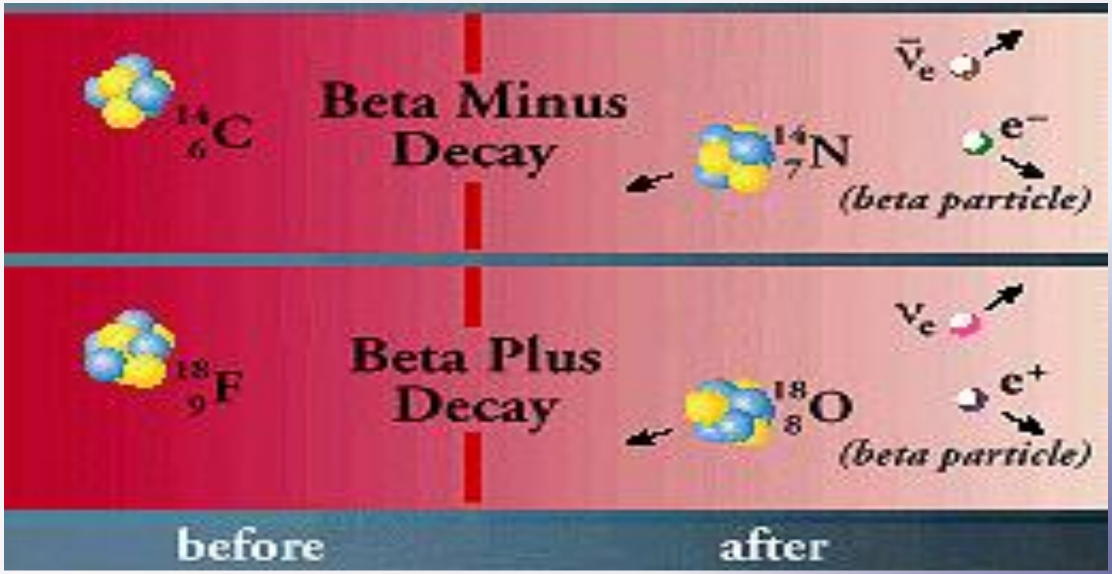
+2 charge; heavy (4 AMU).

Typical Energy = 4-8 MeV;

Limited range (<10cm in air; 60µm in tissue); High LET (**QF=20**) causing **heavy damage** (4K-9K ion pairs/µm in tissue). **Easily shielded** (e.g., paper, skin) so an **internal radiation** hazard. Eventually lose too much energy to ionize.

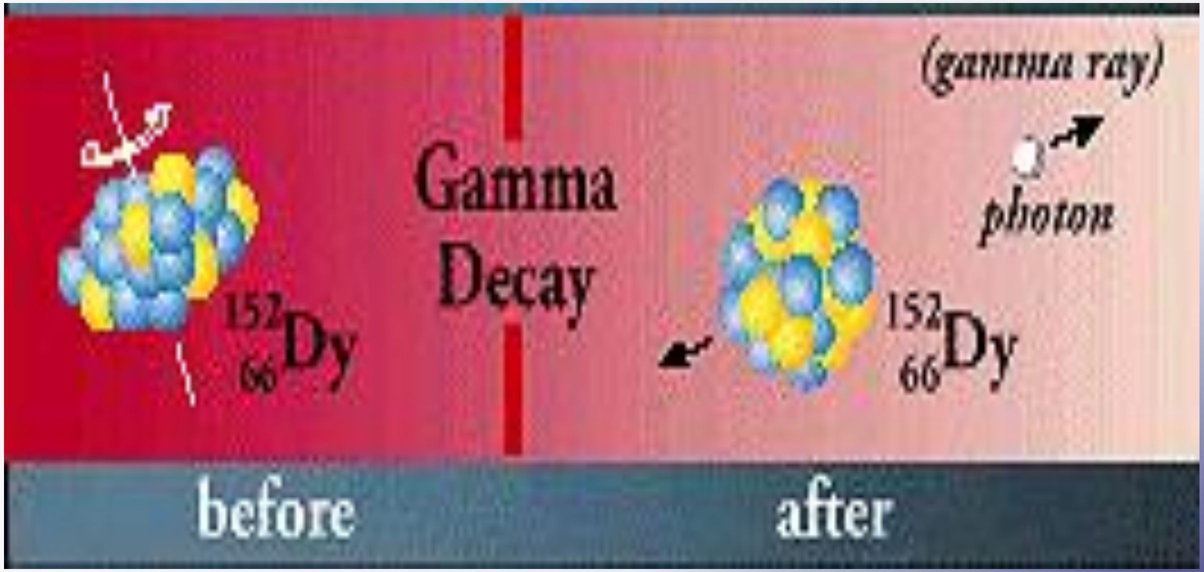
Beta Particles

Beta Particles: Electrons or positrons having small mass and variable energy. Electrons form when a neutron transforms into a proton and an electron or:



Gamma Rays

Gamma Rays (or photons): Result when the nucleus releases energy, usually after an alpha, beta or positron transition



Beta Particles: High speed **electron ejected from nucleus**;

-1 charge, light 0.00055 AMU;

Typical Energy = several KeV to 5 MeV;

Range approx. 12'/MeV in air, a few mm in tissue;

Low LET (**QF=1**) causing **light damage** (6-8 ion pairs/μm in tissue).

Primarily an internal hazard, but high beta can be an external hazard to skin. In addition, the high speed electrons may lose energy in the form of X-rays when they quickly decelerate upon striking a heavy material. This is called **Bremsstralung** (or Breaking) **Radiation.**

Aluminum and other light (<14) materials are used for shielding.

X-Rays: Occur whenever an inner shell orbital electron is removed and rearrangement of the atomic electrons results with the release of the elements characteristic X-Ray energy

X- Ray *and* ***Gamma Rays***

X-rays are photons (Electromagnetic radiations) emitted **from electron orbits**. **Gamma rays** are photons emitted **from the nucleus**, often as part of radioactive decay. Gamma rays typically have higher energy (Mev's) than X-rays (KeV's), but both are unlimited.

Neutrons: Have the same mass as protons (approximately) but are uncharged

2) Non- Ionizing Radiation

People use and are exposed to non-ionizing radiation sources every day. This form of radiation does not carry enough energy to ionize atoms or molecules.

Microwave ovens, global positioning systems, cellular telephones, television stations, FM and AM radio, baby monitors, cordless phones, garage-door openers, and ham radios all make use of non-ionizing radiation. Other forms include the earth's magnetic field, as well as magnetic field exposure from proximity to transmission lines, household wiring and electric appliances. These are defined as extremely low-frequency (ELF) waves.

((Excitation potential is the energy required to jump from one energy level to other while ionization potential is the energy required to remove an electron from an atom)).

Calculation:

Excitation Potential:

When an electron jumps from ground state (n=1) to another (n=2) energy level the corresponding energy is called 1st excitation potential.

When an electron jumps from ground state (n=1) to another (n=3) energy level the corresponding energy is called 2nd excitation potential.

1st excitation potential = $\text{Energy}_{(n=2\ \text{level})} - \text{Energy}_{(n=1\ \text{level})} = -3.4\ \text{ev} - (-13.6\ \text{ev}) = 10.2\ \text{ev}$

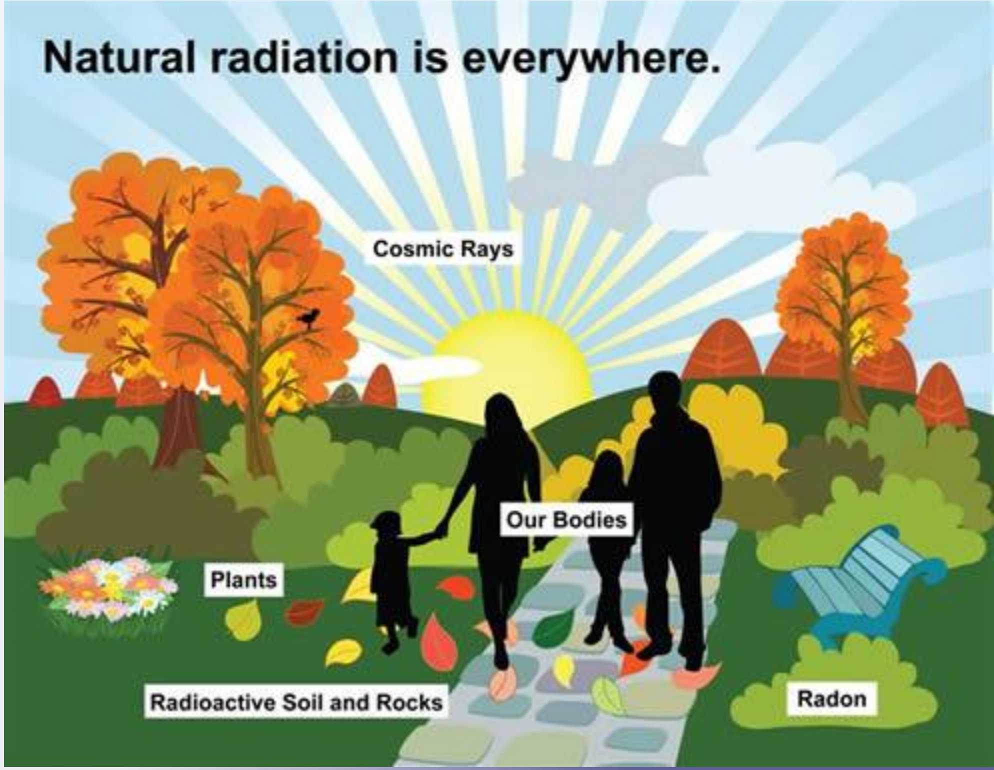
2nd excitation potential = $\text{Energy}_{(n=3\ \text{level})} - \text{Energy}_{(n=1\ \text{level})} = -1.5\ \text{ev} - (-13.6\ \text{ev}) = 12.1\ \text{ev}$

Sources of Radiation (Ionizing Radiation)

n general there are two types of the sources of radiation

1) Natural background radiation

People are constantly exposed to small amounts of ionizing radiation from the environment as they carry out their normal daily activities; this is known as natural background radiation.



Radiation has always been present and is all around us. Life has evolved in a world containing significant levels of ionizing radiation. Our bodies are adapted to it. The following section outlines sources of natural background radiation.

- Cosmic radiation
- Terrestrial radiation
- Inhalation
- Ingestion

Natural background radiation

Exposure from cosmic radiation

The earth's outer atmosphere is continually bombarded by cosmic radiation. Usually, cosmic radiation consists of fast moving particles that exist in space and originate from a variety of sources, including the sun and other celestial events in the universe. Cosmic rays are mostly protons but can be other particles or wave energy. Some ionizing radiation will penetrate the earth's atmosphere and become absorbed by humans, which results in natural radiation exposure.

The doses due to natural sources of radiation vary depending on location and habits. Regions at higher altitudes receive more cosmic radiation.

Exposure from terrestrial radiation

The composition of the earth's crust is a major source of natural radiation. The main contributors are natural deposits of uranium, potassium and thorium which, in the process of natural decay, will release small amounts of ionizing radiation. Uranium and thorium are “ubiquitous”, meaning they are found essentially everywhere. Traces of these minerals are also found in building materials so exposure to natural radiation can occur from indoors as well as outdoors.

Exposure through inhalation

Most of the variation in exposure to natural radiation results from inhalation of radioactive gases that are produced by radioactive minerals found in soil and bedrock. Radon is an odourless and colourless radioactive gas that is produced by the decay of uranium. Thoron is a radioactive gas produced by the thorium. Radon and thoron levels vary considerably by location depending on the composition of soil and bedrock. Once released into the air, these gases will normally dilute to harmless levels in the atmosphere but sometimes they become trapped and accumulate inside buildings and are inhaled by occupants. Radon gas poses a health risk not only to uranium miners, but also to homeowners if it is left to collect in the home. On average, it is the largest source of natural radiation exposure.

Exposure through ingestion

Trace amounts of radioactive minerals are naturally found in the contents of food and drinking water. For instance, vegetables are typically cultivated in soil and ground water which contains radioactive minerals. Once ingested, these minerals result in internal exposure to natural radiation.

Naturally occurring radioactive isotopes, such as potassium-40 and carbon-14, have the same chemical and biological properties as their non-radioactive isotopes. These radioactive and non-radioactive elements are used in building and maintaining our bodies. Natural radioisotopes continually expose us to radiation. The table below identifies the amount of radioactivity from potassium-40 contained in about 500 grams of different food products. A becquerel is a unit of radioactivity, equal to one transformation (decay) per second.

2) Artificial sources of radiation (Man made radiation)

Atmospheric testing: The atmospheric testing of atomic weapons from the end of the Second World War until as late as 1980 released radioactive material, called fallout, into the air. As the fallout settled to the ground, it was incorporated into the environment. Much of the fallout had short half-lives and no longer exists, but some continues to decay to this day. People and the environment receive smaller and smaller doses from the fallout every year.

Medical sources: Radiation has many uses in medicine. The most well known use is X-ray machines, which use radiation to find broken bones and diagnose disease. X-ray machines are regulated by Health Canada and provincial authorities. Another example is nuclear medicine, which uses radioactive isotopes to diagnose and treat diseases such as cancer. These applications of nuclear medicine, as well as the related equipment, are regulated by the CNSC. The CNSC also licenses those reactors and particle accelerators that produce isotopes destined for medical and industrial applications.


Gamma Camera

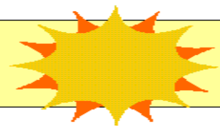
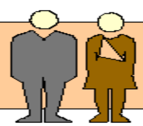
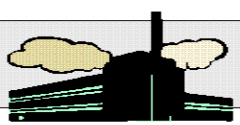
Industrial sources: Radiation has a variety of industrial uses that range from nuclear gauges used to build roads to density gauges that measure the flow of material through pipes in factories. It is also used for smoke detectors, some glow-in-the dark exit signs, and to estimate reserves in oil fields. Radiation is also used for sterilization which is done by using large, heavily shielded irradiators.

Nuclear Gauge

Nuclear Fuel Cycle: Nuclear power plants (NPPs) use uranium to drive a chain reaction that produces steam, which in turn drives turbines to produce electricity. As part of their normal activities, NPPs release regulated levels of radioactive material which can expose people to low doses of radiation. Similarly, uranium mines, fuel fabrication plants and radioactive waste facilities release some radioactivity that contributes to the dose of the public.

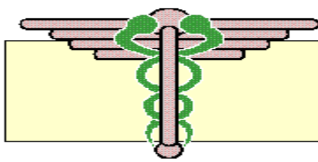
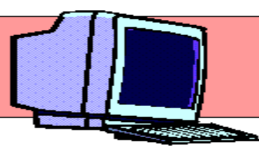
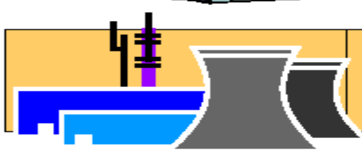
Uranium mine – McClean Lake, SK

Radiation from Natural Sources

	Source	mrem/year
	Cosmic rays	28
	The earth	26
	Radon	200
	The human body	25
	Building materials	4

Transparency 4-1

Radiation from Manmade Sources

	Source	mrem/year
	Medical	90
	Fallout	5
	Consumer products	1
	Nuclear power	0.3

Striking a balance of the ionizing radiation

Normally, there is little that we can do to change or reduce ionizing radiation that comes from natural sources like the sun, soil or rocks. This kind of exposure, while never entirely free of risk, is generally quite low. However, in some cases, natural sources of radioactivity may be unacceptably high and need to be reduced, such as radon gas in the home. The ionizing radiation that comes from man-made sources and activities is controlled more carefully. In these settings, a balance is struck between the benefits that the radiation provides to society and the risks it imposes on people and the environment. Dose limits are set in order to restrict radiation exposures to both workers and members of the public. In addition, licensees are required to keep all radiation doses as low as reasonably achievable (ALARA), social and economic factors being taken into account. Also, there has to be a net benefit to the use of radiation. For example, smoke detectors are permitted to use radioactive isotopes because smoke detectors save lives.

Non-ionizing Radiation Sources

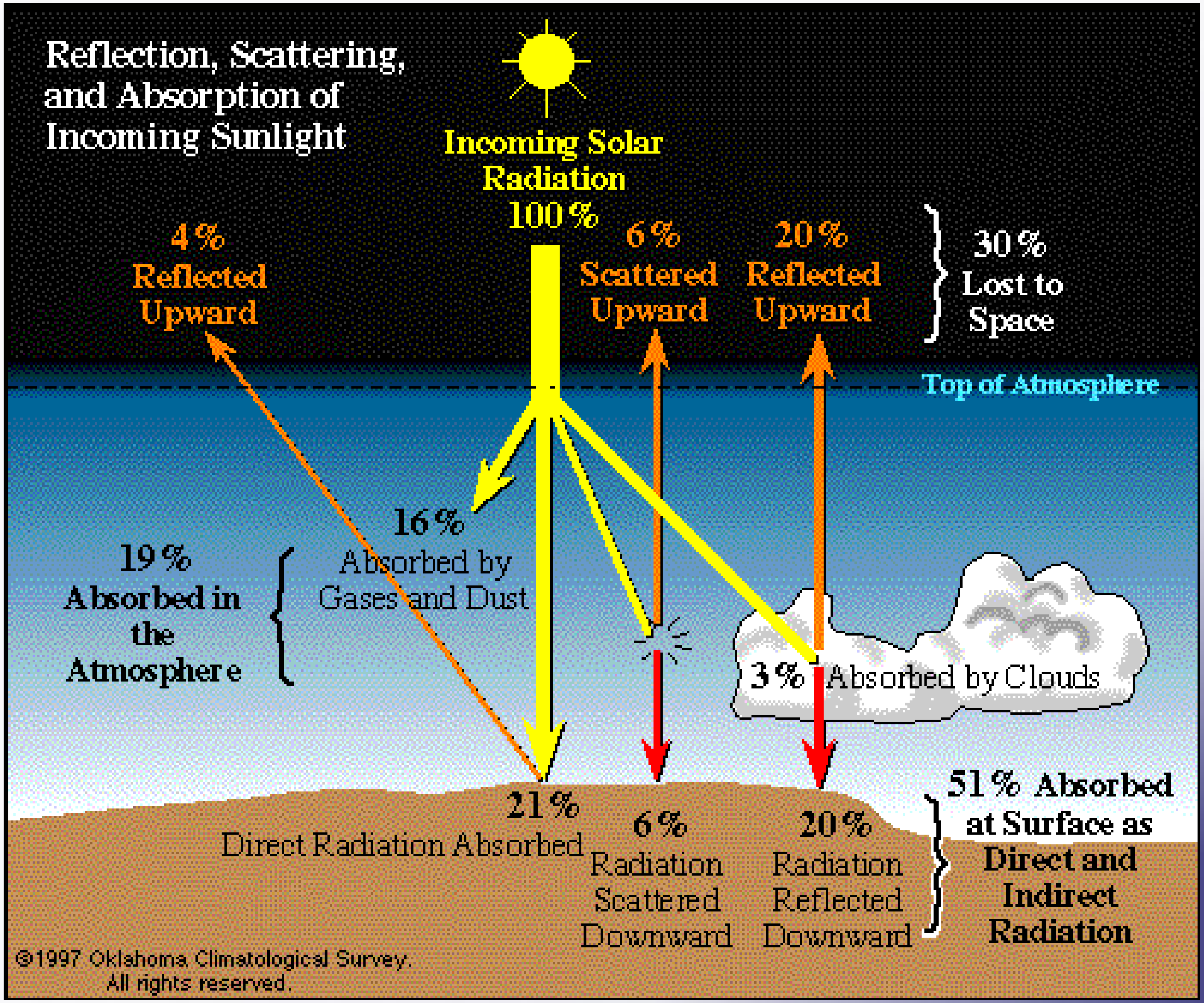
- Visible light
- Microwaves
- Radios
- Video Display Terminals
- Power lines
- Radiofrequency Diathermy (Physical Therapy)
- Lasers

Effects

- **Radiofrequency Ranges (10 kHz to 300 GHz)**
  - **Effects only possible at ten times the permissible exposure limit**
  - **Heating of the body (thermal effect)**
  - **Cataracts**
  - **Some studies show effects of teratoginicity and carcinogenicity.**

Other Manmade Sources of Non-Ionizing Radiation

Path of incoming solar radiation



RADIATION CONTROLS

Basic Control Methods for External Radiation

- Decrease Time
- Increase Distance
- Increase Shielding

NOTE: 1 rad (Roentgen absorbed dose) = absorption of 100 ergs of energy from **any radiation** in 1 gram of **any material**; 1 **Gray** (Gy) = 100 rads = 1 Joule/kg; Exposure to 1 Roentgen approximates 0.9 rad in air.

Radiation Measurements and Units

(Quantification of radiation)

Radiation can be described and measured in many ways. For purposes of radiobiology and radiation protection, the concept of absorbed dose, D, is most commonly used. It does not measure each particle but describes the energy deposited in a specified region. Absorbed dose is the energy absorbed in a volume of material divided by the mass of the material. It is the result of the physical interactions of the ionizing radiation within the volume of material. An absorbed dose can be delivered by any type or combination of types of radiation in any type of material.

The units of absorbed dose are the gray (Gy) in the SI and the rad in the traditional system often still used in the United States; 1 Gy is equivalent to 100 rad. The **centigray (cGy) is a unit of convenience often used in cancer therapy that is equivalent to 1 rad.**

Dose rate refers to the distribution of dose as a function of time. It can be expressed as Gy per second (Gy s^{-1}), per minute (Gy min^{-1}), per hour (Gy h^{-1}), and per year (Gy y^{-1}). A protracted dose is one received over a long period of time. A given dose delivered within 1 h often will have different consequences than the same total dose delivered over a period of one year. In some cases, if the dose rate is constant for long periods, it is referred to as continuous exposure to radiation. A dose rate can change with time; radiation could occur in the form of random pulses or vary periodically.

Dose fractionation (deviated) describes the case in which a dose is delivered in segments or fractions over a specified period. For example, in radiation therapy for cancer, a total dose of 50 Gy might be delivered at a high dose rate of 2 Gy min^{-1} for only 1 minute per day over a period of 25 days (5 weeks, excluding weekends).

Equivalent Dose

The concept of absorbed dose, D, was created to estimate biologic effects of ionizing radiation. Scientists hoped that absorbed dose could serve as a universal predictor of biologic effects and corresponding risks to humans from exposure to ionizing radiation. However, it was soon discovered that similar doses of radiation from different particles produced different amounts of biologic damage. In some cases, up to 1 Gy of gamma rays is needed to produce the same effect as 0.1 Gy of alpha particles. That was observed for many biologic systems and was ultimately referred to as relative biological effectiveness (RBE).

RBE is related to the density or rate of ionization produced by a particle as it passes through matter. Linear energy transfer, LET, is a measure of the rate of energy loss and therefore ionization along the track of a particle. Alpha particles have short tracks, but create large amounts of ionization along the track and are referred to as high LET radiation. Electrons and beta particles are sparsely ionizing and are referred to as low LET radiation. X rays and gamma rays create electrons when they interact in materials and are also considered to be low LET radiation. To a first approximation, **RBE increases with LET**.

Rules for and regulation of radiation protection of humans must be related to the risks associated with exposure to ionizing radiation. RBE makes it impossible to base a system of regulations on absorbed dose alone. It was necessary to include the type of radiation in a consistent manner that reflected changes in the biology as well as the physics. For this reason, the concept of equivalent dose was established for purposes of radiation protection. Equivalent dose (H_T) in a tissue or organ, T, is the product of absorbed dose averaged within a tissue (D_T) and a radiation weighting factor (w_R), and thus $H_T = D_T \times w_R$.

The radiation weighting factor is used to adjust the absorbed dose to reflect the RBE for radiation of type R. It is thus related to LET. Alpha particles have
a w_R of 20. Beta particles, x rays and gamma rays have a w_R of 1.0. Equivalent dose is described in sievert (Sv) or rem.

Effective Dose

Some tissues and organs are more sensitive to radiation than others. When the entire body is irradiated uniformly, all organs receive a dose and contribute to the total risk of a health effect, such as cancer. In some cases, particularly with internal emitters, only one or two organs receive a dose, and the other organs are not at risk. When one needs to know the combined risk for such a case, it is necessary to include a factor that is related to the risk to each of the exposed organs. The equivalent dose, H_T, in each tissue, T, is multiplied by a tissue-weighting factor, w_T. The effective dose, E, is then the sum of $H_T w_T$ for all exposed tissues. Effective dose is a risk averaged dose that serves as a measure of risk including adjustments for both the type of radiation, w_R, and the tissues exposed, w_T. Effective dose is expressed in sievert (Sv) when the absorbed dose is measured in Gy, or in rem when the dose is measured in rads; 1 Sv = 100 rem.

The International Commission on Radiological Protection (ICRP, 1991) has made recommendations for values of w_T on the basis of the occurrence of cancer and hereditary (jenetic) effects observed in exposed populations.

TABLE 3.1 Currently Recommended Tissue Weighting Factors, w_T [a]

Tissue	w_T
Gonads	0.20
Bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surfaces	0.01
Remainder[a]	0.05
Total	1.00

[a] w_T for the remainder is divided equally between adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus, and uterus.

TABLE 3.3 Effective Dose Received from Diagnostic Examinations of Specific Organs and Tissues

the contribution from inhalation and deposition of radioactivity in the lung that originates from radon gas. *Medical* represents the contribution from diagnostic medical examinations. *Other* represents the contribution from man-made sources of ionizing radiation, such as the nuclear-power industry and consumer products (for example, smoke detectors, CRT monitors, porcelain, and tobacco).

Examination	mSv
Arms and legs	0.10
Chest	0.08
Pelvis	0.44
Upper gastrointestinal tract	2.40
Mouth (Dental)	0.03
Breast (mammography)	0.40
Head and body (CT)	1.11

Exposure Limits (accepted levels)

- Whole body limit = 1.25 rem/qtr or **5 rem (50 mSv) per year.**
- Hands and feet limit = 18.75 rem/qtr.
- Skin of whole body limit = 7.5 rem/qtr.
- Total **life accumulation = 5 x (N-18) rem where N = age**. Can have 3 rem/qtr if total life accumulation not exceeded.
- Note: New recommendations reduce the 5 rem to 2 rem.

External/Internal Exposure Limits for Occupationally Exposed Individuals

Annual Dose Limits

	Adult (>18 yrs)	Minor (< 18 yrs)
Whole body*	5000 mrem/yr	500 mrem/yr
Lens of eye	15000 mrem/yr	1500 mrem/yr
Extremities	50000 mrem/yr	5000 mrem/yr
Skin	50000 mrem/yr	5000 mrem/yr
Organ	50000 mrem/yr	5000 mrem/yr

Community Emergency Radiation

Hazardous Waste Sites:

Radiation above background (0.01-0.02 m rem/hr) signifies possible presence which must be monitored. Radiation above 2 m rem/hr indicates potential hazard. Evacuate site until controlled.

Human Annual Exposure

Activity	Typical Dose
Smoking	280 millirem/year
Radioactive materials use in a UM lab	**<10 millirem/year**
Dental x-ray	10 millirem per x-ray
Chest x-ray	8 millirem per x-ray
Drinking water	5 millirem/year
Cross country round trip by air	5 millirem per trip
Coal Burning power plant	0.165 millirem/year

ACUTE DOSE(RAD) EFFECT

0-25	No observable effect.
25-50	Minor temporary blood changes.
50-100	Possible nausea and vomiting and reduced WBC.
150-300	Increased severity of above and diarrhea, malaise, loss of appetite.
300-500	Increased severity of above and hemorrhaging, depilation. Death may occur
> 500	**Symptoms appear immediately, then death has to occur.**

Quantifying Exposure and Dose

Exposure: Roentgen

1 Roentgen (R) = amount of **X or gamma** radiation that produces ionization resulting in 1 electrostatic unit (esu) of charge in 1 cm^3 of dry **air** at STP. Instruments often measure exposure rate in mR/hr.

Absorbed Dose: rad

1 rad (Roentgen absorbed dose) = absorption of 100 ergs of energy from **any radiation** in 1 gram of **any material**; 1 **Gray** (Gy) = 100 rads = 1 Joule/kg; Exposure to 1 Roentgen approximates 0.9 rad in air.

Dose (in rads) = 0.869(f)(Roentgens) where the f-factor is the ratio of mass energy-absorption coefficient of medium, such as bone, compared to air.

Biologically Equivalent Dose: **rem**

Rem (Roentgen equivalent man) = dose in rads x QF, where QF = quality factor. 1 **Sievert** (Sv) = 100 rems.

Exposure Limits

Regulatory Agencies: OSHA, personnel exposures (29 CFR 1910.96, 1910.120); Nuclear Regulatory Commission, (10 CFR 19, 20, and 71); Dept of Transportation, (49 CFR). Most advocate **ALARA -** As Low As Reasonably Achievable.

OSHA Limits: Whole body limit = 1.25 rem/qtr or **5 rem (50 mSv) per year** (approx. 2.5 mrems/hr for all work hours). Hands and feet limit = 18.75 rem/qtr. Skin of whole body limit = 7.5 rem/qtr. Total **life accumulation = 5 x (N-18) rem where N = age**. Can have 3 rem/qtr if total life accumulation not exceeded. Restricted areas at 200 mrem/hr. Posting at 200 and 100 mrem/hr. Note: New recommendations reduce the 5 rem to 2 rem.

Working Level Month(WLM): Unit of exposure to Radon progeny in uranium mines. 1 **Working Level Month (WLM)** = exposure to 1 Working Level (1.3 x 10^5 MeV of alpha energy) for one month; roughly 100 pC/l.

Hazardous Waste Sites: Radiation above background (0.01-0.02 mrem/hr) signifies possible presence which must be monitored. Radiation above 2 mrem/hr indicates potential hazard. Evacuate site until controlled.