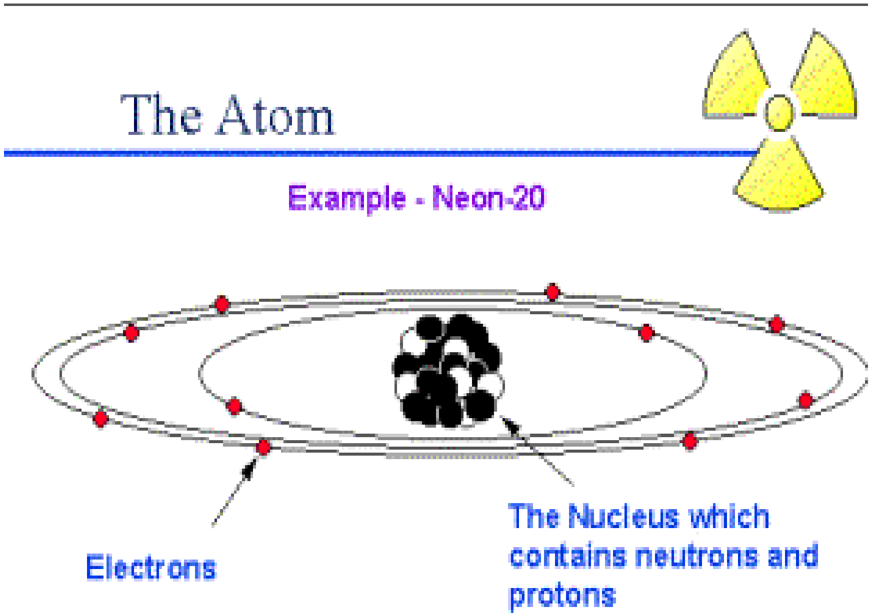
Module 1

Radiation Safety Fundamentals

Atomic Structure

Atoms are composed of a variety of subatomic particles. The three of interest to Health Physics are the electron, proton and neutron. In addition, the nucleus of the helium atom and photons (which are not really particles at all) are also of interest.

The two major intrinsic properties of these particles are their mass and their charge. The higher the charge and the more mass a particle contains, the more damage it can do.



Radioactivity

Radiation is the energy in the form of waves or particles sent out over distance. There are many types of radiation.

The emission of excess energy by unstable nuclei in order to achieve stability is the phenomenon of **radioactivity**. Radioactivity is a property of a substance but is independent of the atom's physical or chemical properties.

The process by which a nucleus spontaneously disintegrates (or is transformed) by one or more discrete energy steps until a stable state is reached is called **radioactive decay.**

During radioactive decay, an atom will emit subatomic particles (alpha and beta particles) and/or electromagnetic rays (x-rays and gamma rays).

Radioactivity

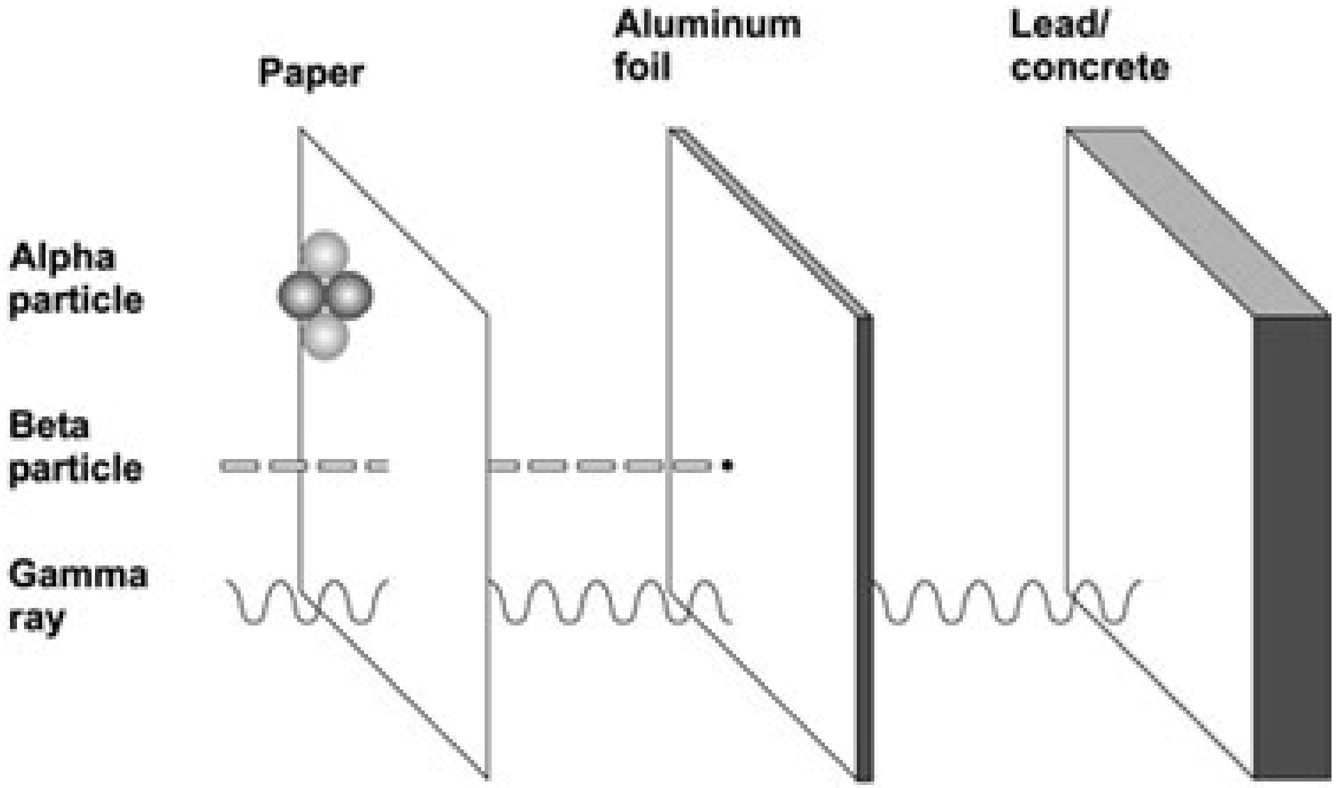
An atom is unstable as a result of an excess or a deficiency of neutrons in the nucleus.

Neutrons provide the force that keeps the positively charged protons from repelling each other and ripping the atom apart.

An atom with an insufficient number of neutrons or an excessive number of neutrons is more likely to decay radioactively.

In addition, when an atom reaches a certain size, the distance across the atom becomes great with respect to the range of the force that is trying to hold the atom together. This makes large elements more likely to give off protons or neutrons.

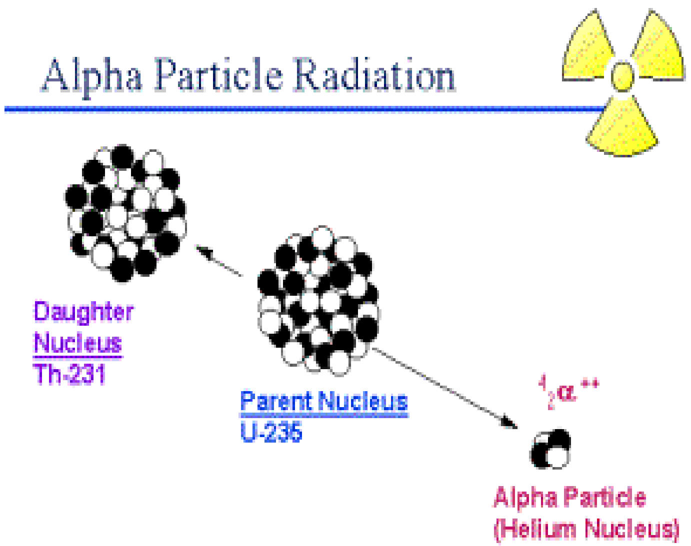
Types of Radiation



Source: www.ocrwm.doe.gov/factsheets/doeymp0403.shtml

Types of Radiation: Alpha

An alpha particle is composed of 2 neutrons and 2 protons (a helium atom without electrons) that has escaped from the nucleus of a heavy radioactive element. An alpha particle has a charge of +2.



Alpha particles are capable of causing more damage than any other form of radiation but are also far less penetrating than other forms of radiation. A piece of paper is an adequate alpha shield.

Alpha particles generally cannot penetrate the dead layer of skin we all have making alpha particles a concern for internal doses only.

A nucleus emitting an alpha particle decays to a new daughter element that is reduced in atomic number by 2 and reduced in mass number by 4.

Uranium and radium are examples of an alpha emitters.

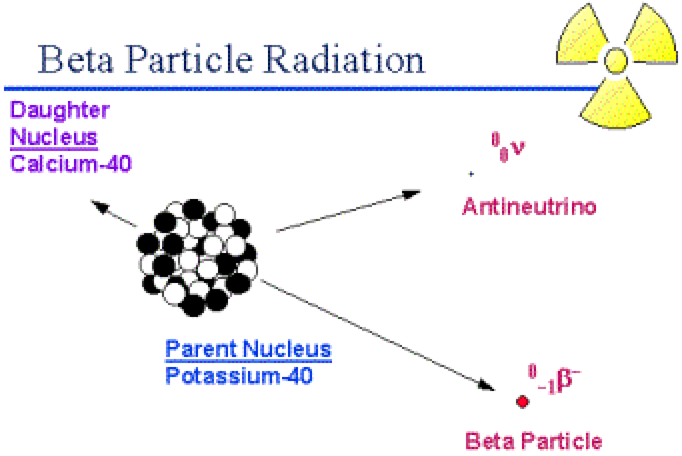
Types of Radiation: Beta

- Beta particles are fast moving particles emitted from the nucleus during radioactive decay.
- There are 2 modes of beta decay:
  - Beta minus (often referred to as beta decay) and
  - Beta positive (often referred to positron decay)
- Beta minus decay is more common than beta positive decay.

Types of Radiation: Beta

Beta Minus Decay:

- If a nuclide has an excess number of neutrons it will generally decay by beta minus emission.
- A neutron is changed into a proton resulting in the emission of a negatively charged beta particle that has the same mass as an electron.
- Beta particles originate in the nucleus. Ordinary electrons exists in orbits around the nucleus.
- Because the atom gains a proton, the atomic number increases by one. The mass number is unchanged.
- This type of decay changes an atom from one element to another element since an element is defined by the number of protons it contains.



Types of Radiation: Beta

Beta Positive Decay:

- If a nuclide has an excess number of protons it will generally decay by beta positive emission.
- A proton is changed into a neutron resulting in the emission of a positively charged beta particle that has the same mass as an electron.
- Because the atom losses a proton, the atomic number decreases by one. The mass number is unchanged.
- This type of decay also changes an atom from one element to another element.

Types of Radiation: Beta

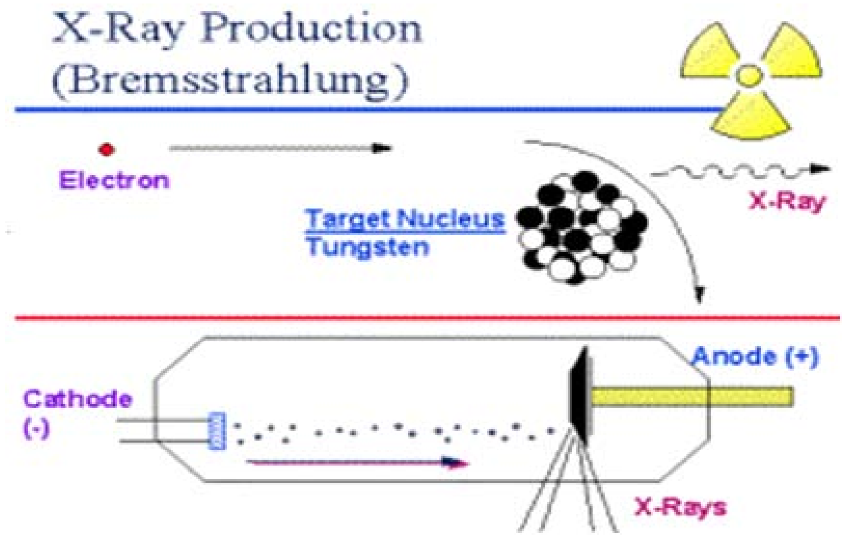
Beta radiation is weakly penetrating and usually constitutes a skin dose only. The lens of the eye and the skin are most susceptible.

The number of ionizations caused by beta radiation is proportional to the energy (velocity) of the beta radiation and to the mass of the atoms that it is passing through.

Higher-energy beta particles will cause more ionizations.
P-32, P-33, C-14, S-35 and H-3 are all examples of beta emitters.

Types of Radiation: X-ray Production

Bremsstrahlung is German for "braking radiation" and is caused by an electron passing near a heavy atom. The atom and electron interact electrostatically. The atom deflecting the electron gives off x-ray radiation as it changes course. A thin lead shield around a beta source will shield all beta radiation but will emit x-rays due to bremsstrahlung.



Beta particles that are passing by heavier atoms will cause more bremsstrahlung x-rays.

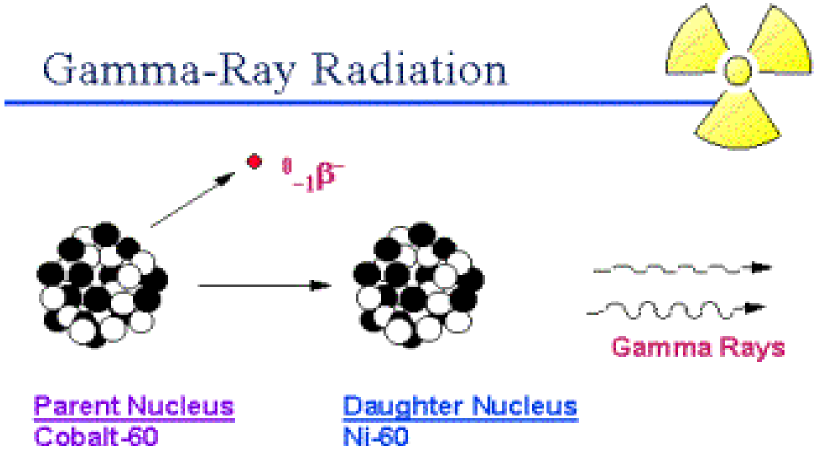
Types of Radiation: Electron Capture

- If a nuclide has an excess number of protons it can also decay by electron capture.
- In electron capture, the nucleus captures an electron from one of its orbital shells.
- The electron combines with a proton for form a neutron, followed by the emission of a neutrino.
- Electrons in higher energy levels move in to fill the vacancies left in the lower energy levels. The excess energy is given of as X-rays.
- Because the atom losses a proton, the atomic number decreases by one. The mass number is unchanged.
- This type of decay also changes an atom from one element to another element.

Types of Radiation: Gamma

A high-energy photon given off by an atom that has been excited by beta emission, neutron capture, electron capture or some other means is gamma radiation.

- Gamma rays have no mass and no charge.
- Gamma radiation does not involve the loss or gain of protons.



Gamma rays interact by either:

- direct collision with electrons, knocking them out of their orbits,
- production of an electron-positron pair, if it passes by a heavy nucleus, **or**
- by absorption and re-emission by an atom, usually in a different direction and at a different energy.

Photons (gamma radiation) interact very weakly with matter and are best shielded by dense material such as lead. Gamma rays cause a whole-body dose because they penetrate through the entire body.

Types of Radiation: Gamma vs. X-rays

Gamma rays versus X-rays:

Gamma rays and x-rays pose the same kind of hazard and both are electromagnetic radiation, the difference is their origin.

- Gamma rays are originate from the nucleus of an atom.

- X-rays are originate from the electron shells of an atom.

Types of Radiation: Neutron Particle

Neutrons are neutrally charged and relatively massive, weighing in at one atomic mass unit (amu).

Being electrically neutral, the neutron only interacts by direct collision. But being massive, the neutron can collide numerous times, creating many ion pairs while slowing down.

Neutrons may be moving either very quickly (fast neutrons) or relatively slowly (thermal neutrons).

Neutrons interact best with hydrogen-containing material such as water, plastic, or body tissue. Therefore, the best shield for neutron radiation is hydrogenous material. Materials such as boron and water have a propensity for absorbing neutrons making them good shielding.

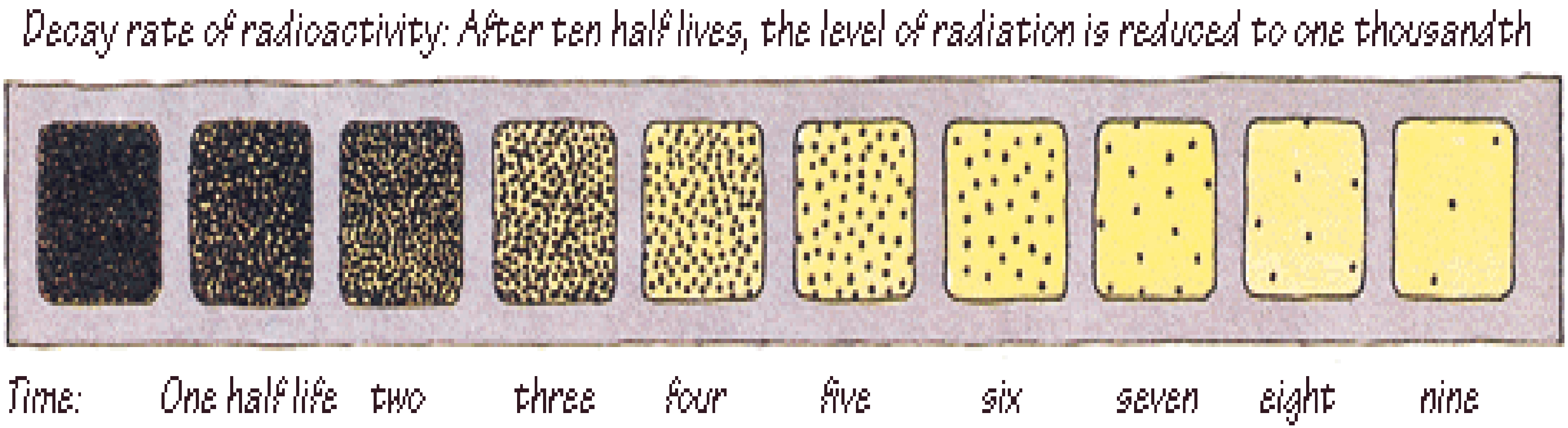
Summary of Types of Radiation and Properties

Type	Mass	Charge	Penetrating Ability	QF	Shielding
Alpha	4	+2	very low	20	skin, paper
Beta	0.0003	± 1	low	1	clothing, plastic
Gamma	0	0	high	1	lead, water
Neutron	1	0	high	3-10	water, plastic

“**QF**” refers to what is know at the **quality factor**. The quality factor is analogous to the amount of damage that the radiation can cause in the body. Different sources will give different values for the quality factors associated with neutron and alpha radiation. The ones shown in this table are typical values.

Half-Life

All radioactive isotopes undergo radioactive decay at a characteristic rate. The rate at which one half of the original radioactive atoms decay is called the **half-life**. The half-life is unique for all radioactive elements and if precisely determined, is sufficient to identify a radionuclide.

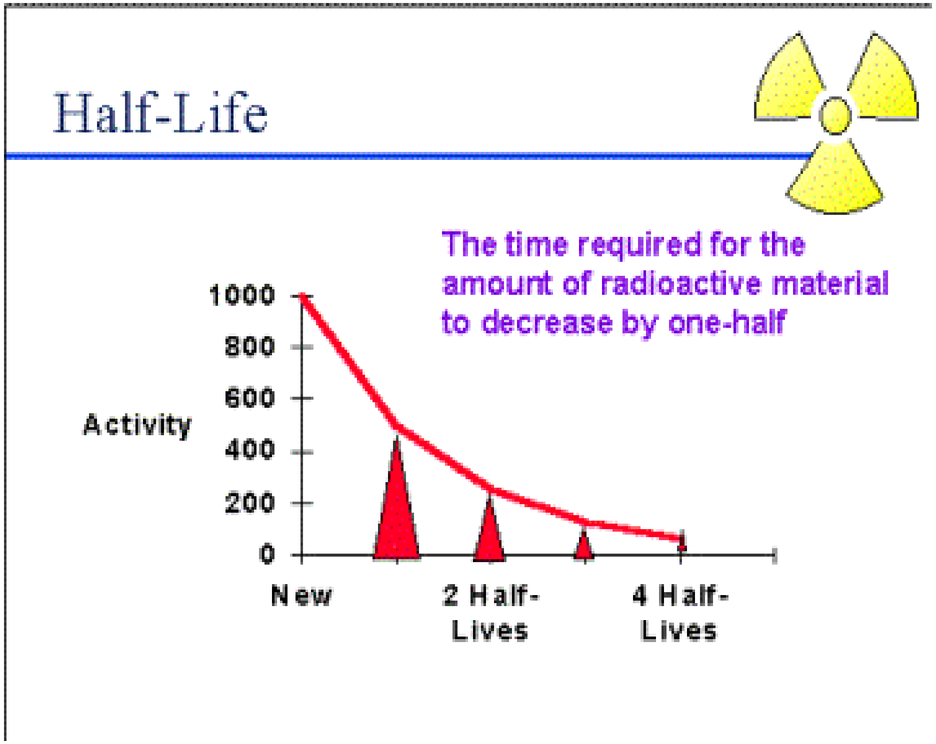


Half-Life

$$A_t = A_0e^{-\lambda t}$$

In this equation, A_t and A_o are the amounts of radioactivity present originally and at any subsequent time, t. The decay constant, λ, is the fraction of atoms that will decay in any given time period and is calculated by dividing the natural logarithm of 2 (equal to about 0.693) by the half-life of the isotope, $\lambda = \ln(2)/t1/2$.

The accompanying figure shows graphically how radioactivity decreases over time.



Biological Effects of Ionizing Radiation

Cellular Effects of Exposure to Ionizing Radiation

The first impact of radiation is on individual cells by causing:

- Ionizations of atoms within the cell
- Free radical formation within the cell
- Hydrogen peroxide poisoning of the cell
- Breakage of DNA strands

Cellular Effects of Exposure to Ionizing Radiation

Ionizing radiation will cause ionizations within the cell due to the primary and secondary effects of the radiation. Ionization of water can lead to the formation of H+ and OH- free radicals within the cell that will attack proteins within the cell that can then recombine to form hydrogen peroxide(H_2O_2) that poisons the cell.

Free radicals or the direct radiation can interact with the DNA strands in the nucleus of the cell to cause damage to the information stored. Under normal circumstances this damage can be repaired properly but, on occasion, it is either improperly repaired or not repaired at all leading to errors when the cell reproduces.

If this damage occurs slowly, then it can be repaired as it happens. In the case of a large acute dose the damage may be extensive enough and in a short enough time frame to be irreversible, resulting in the death of the cell.

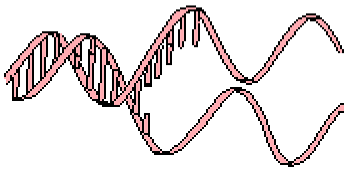
Biological Effects of Ionizing Radiation

Genetic Effects of Exposure to Ionizing Radiation

- Damage to ova in ovaries
- Damage to sperm-forming cells
- Damage to ova or sperm
- Mutations of genetic material in ova or sperm

Biological Effects of Ionizing Radiation

Genetic Effects



Under a high enough radiation dose, mutations can occur as the radiation causes changes in the DNA, usually in the ova since sperm are relatively short-lived.

Studies indicate that the increased mutation rate due to most radiation doses is statistically insignificant. Most mutations that occur, whether due to the normal mutation rate or radiation-induced, are either stillborn or spontaneously aborted (miscarried).

Biological Effects of Ionizing Radiation

Gross Effects on the Organism

Increased cancer risk of about 2 cancers per 10,000 person-REM of exposure*.

Increased cancer death rate of about 1 fatality per 10,000 person-REM of exposure*.

Cataracts from cumulative exposures of several hundred REM over years.

Life expectancy changes: ~2 ½ days per REM (low dose) ~10 days per REM (high dose) radiation burns (skin erythema) from acute doses of a few hundred rem.

* Assuming that the linear no-threshold model is accurate, otherwise the risk is lower.

* REM measures the effects of radiation on the human body. The concept is similar to measuring temperature by degrees.

Biological Effects of Ionizing Radiation

Gross Effects on the Organism

The USEPA conversion factor for converting millirem of exposure to excess lifetime fatal cancer risk are 3.9 * 10-7/mrem for beta-gamma and 3.2 * 10-6/mrem for alpha radiation. This comes out to about 4 fatal cancers per 10,000 person-REM for exposure to beta-gamma radiation and 32 fatal cancers per 10,000 person-rem for exposure to alpha radiation.

The increased cancer risk and the life expectancy changes are far lower than the expected cancer and mortality risks that are encountered daily by smokers, residents of urban areas, drivers, construction workers and numerous others.

Biological Effects of Ionizing Radiation

Radiation Sickness

A large acute dose of radiation can result in radiation sickness. The different organs in the body respond differently to radiation and to radiation doses. Blood-forming organs and the digestive system being the most sensitive; extremities and the brain being least sensitive.

Radiation sickness, in general, consists of vomiting, fatigue, and nausea in varying degrees with hair loss and skin burns in severe cases.

- 0-50 REM no obvious effects, blood chemistry changes.
- 100 REM minor radiation sickness in about 10% of the cases.
- 150 REM minor radiation sickness in about 25% of the cases.
- 200 REM radiation sickness in about 50% of the cases.
- 300 REM radiation sickness in all exposed, about 20% death rate within one month.
- 450 REM about 50% death rate without medical treatment.
- 500 REM radiation sickness within 4 hrs, over 50% death rate.
- 1000 REM radiation sickness within 1-2 hrs., 100% death rate.

Biological Effects of Ionizing Radiation

The yearly legal dose limit is 5 REM for occupational workers and 0.1 REM for non-occupationally exposed personnel. The exposure limit for pregnant workers is 500 mREM over the entire pregnancy and 50 mREM in any month after the pregnancy is declared. This is much lower than any dose shown previously.

It should be noted that there is a difference between exposure to high levels of radiation in a short period of time (**acute exposure**) and long-term exposure to low levels of radiation (**chronic exposure**). Generally, chronic exposure is less damaging that acute exposure because the body has a chance to repair damage as is occurs rather than being overwhelmed. It is akin to throwing small pebbles at someone over a long period of time as opposed to dropping a boulder on them.