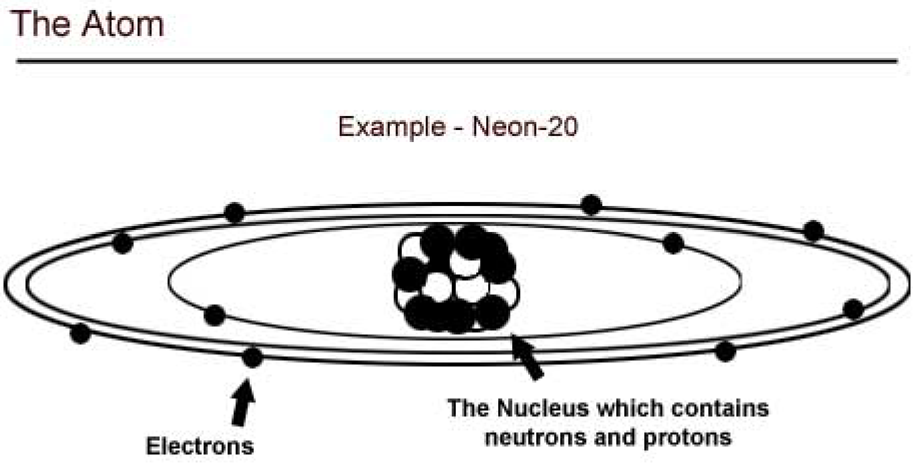
Radiation Properties

The Atom



The Bohr Model of the atom consists of a central nucleus composed of neutrons and protons surrounded by a number of orbital electrons equal to the number of protons.

Protons are positively charged, while **neutrons** have no charge. Each has a mass of about 1 atomic mass unit or amu. **Electrons** are negatively charged and have mass of 0.00055 amu.

The number of protons in a nucleus determines the element of the atom. For example, the number of protons in uranium is 92 while the number in neon is 10. The proton number is often referred to as Z.

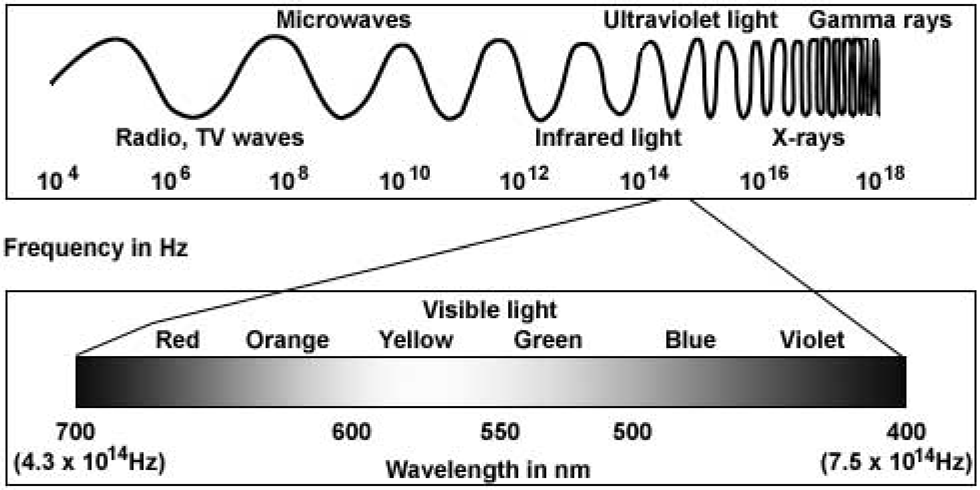
An element may have several isotopes. **An isotope** of an element is comprised of atoms containing the same number of protons as all other isotopes of that element, but each isotope has a different number of neutrons than other isotopes of that element. Isotopes may be expressed using the nomenclature Neon-20 or 2ONe10, where 20 represents the combined number of neutrons and protons in the atom (often referred to as the mass number A), and 10 represents the number of protons (the atomic number Z).

While many isotopes are stable, others are not. Unstable isotopes normally release energy by undergoing nuclear transformations (also called decay) through one of several radioactive processes described later in this module.

Elements are arranged in the periodic table with increasing Z. Radioisotopes are arranged by A and Z in the chart of the nuclides.

Radiation

Radiation is energy transmitted through space in the form of electromagnetic waves or energetic particles. Electromagnetic radiation, like light or radio waves, has no mass or charge. The following chart shows the electromagnetic spectrum.



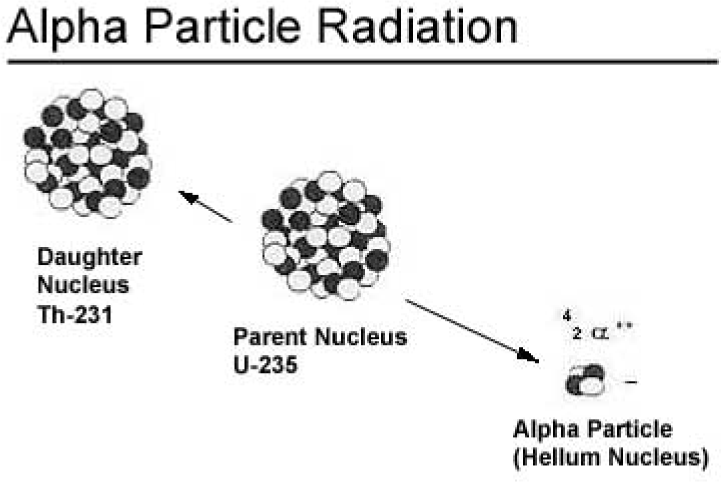
The training is concerned with radiation that has sufficient energy to remove electrons from atoms in materials through which the radiation passes. This process is called ionization, and the high frequency electromagnetic waves and energetic particles that can produce ionizations are called ionizing radiations. Examples of ionizing radiation include:

alpha particle radiation
beta particle radiation
neutrons
gamma rays
x-rays

Nonionizing radiations are not energetic enough to ionize atoms and interact with materials in ways that create different hazards than ionizing radiation. Examples of nonionizing radiation include:

microwaves
visible light
radio waves
TV waves
ultraviolet light

Alpha Particle Radiation

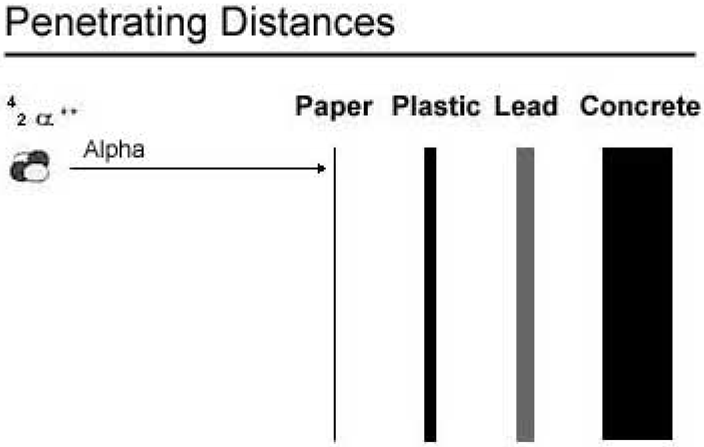


(diagram courtesy of the University of Michigan Student Chapter of the Health Physics Society)

An **alpha particle** consists of two neutrons and two protons ejected from the nucleus of an atom. The alpha particle is identical to the nucleus of a helium atom.

Examples of alpha emitters are radium, radon, thorium, and uranium.

Because alpha particles are charged and relatively heavy, they interact intensely with atoms in materials they encounter, giving up their energy over a very short range. In air, their travel distances are limited to no more than a few centimeters. As shown in the following illustration, alpha particles are easily shielded against and can be stopped by a single sheet of paper.

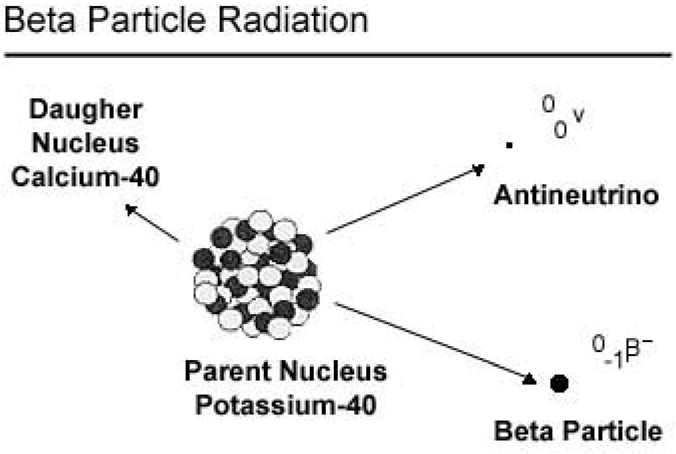


(diagram courtesy of the University of Michigan Student Chapter of the Health Physics Society)

Since alpha particles cannot penetrate the dead layer of the skin, they do not present a hazard from exposure external to the body.

However, due to the very large number of ionizations they produce in a very short distance, alpha emitters can present a serious hazard when they are in close proximity to cells and tissues such as the lung. Special precautions are taken to ensure that alpha emitters are not inhaled, ingested or injected.

Beta Particle Radiation

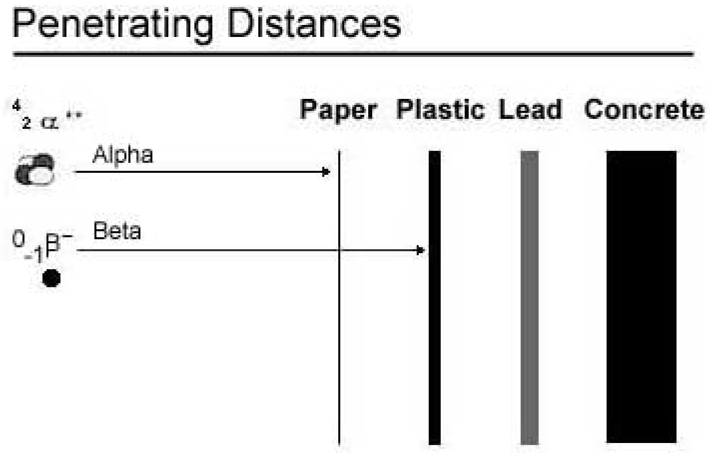


(diagram courtesy of the University of Michigan Student Chapter of the Health Physics Society)

A **beta particle** is an electron emitted from the nucleus of a radioactive atom.

Examples of beta emitters commonly used in biological research are: hydrogen-3 (tritium), carbon-14, phosphorus-32, phosphorus-33, and sulfur-35.

Beta particles are much less massive and less charged than alpha particles and interact less intensely with atoms in the materials they pass through, which dives them a longer range than alpha particles. Some energetic beta particles, such as those from P-32, will travel up to several meters in air or tens of mm into the skin, while low energy beta particles, such as those from H-3, are not capable of penetrating the dead layer of the skin. Thin layers of metal or plastic stop beta particles.



(diagram courtesy of the University of Michigan Student Chapter of the Health Physics Society)

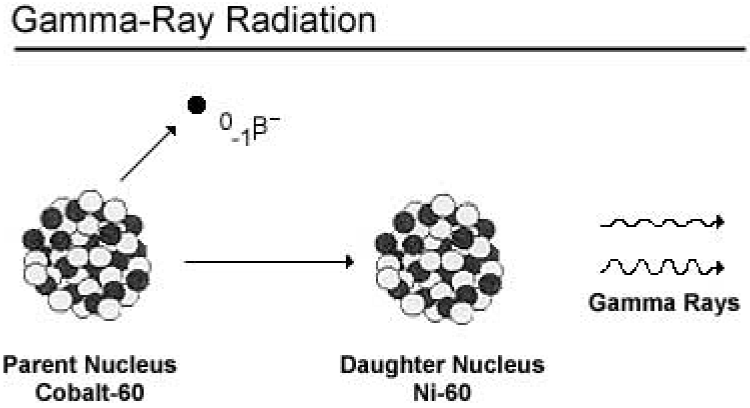
All beta emitters, depending on the amount present, can pose a hazard if inhaled, ingested or absorbed into the body. In addition, energetic beta emitters are capable of presenting an external radiation hazard, especially to the skin.

Bremsstrahlung

An important consideration in shielding beta particle radiation is the ability of beta particles to produce a secondary radiation called **bremsstrahlung.** Bremsstrahlung are x-rays produced when beta particles or other electrons decelerate while passing near the nuclei of atoms. The intensity of bremsstrahlung radiation is proportional to the energy of the beta particles and the atomic number of the material through which the betas are passing.

Consequently, bremsstrahlung radiation is generally not a concern for lower energy beta emitters such as carbon-14 and sulfur-35, but the higher energy betas from phosphorus-32 can produce significant bremsstrahlung, especially when passing through shielding materials such as lead. Lower atomic number materials such as Plexiglas are preferred shielding materials for high energy emitters such as phosphorus-32.

Gamma Ray Radiation



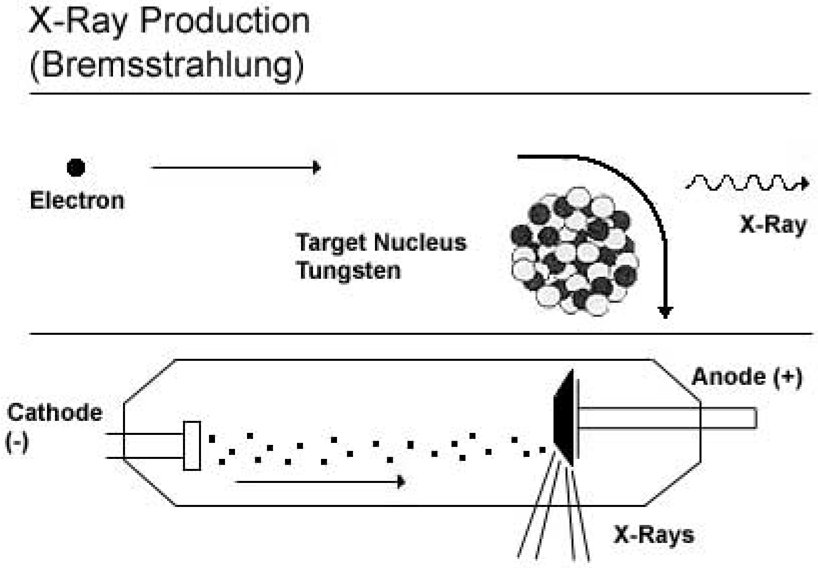
(diagram courtesy of the University of Michigan Student Chapter of the Health Physics Society)

A **gamma ray** is a packet (or photon) of electromagnetic radiation emitted from the nucleus during radioactive decay and occasionally accompanying the emission of an alpha or beta particle. Gamma rays are identical in nature to other electromagnetic radiations such as light or microwaves but are of much higher energy.

Examples of gamma emitters are cobalt-60, zinc-65, cesium-137, and radium-226.

Like all forms of electromagnetic radiation, gamma rays have no mass or charge and interact less intensively with matter than ionizing particles. Because gamma radiation loses energy slowly, gamma rays are able to travel significant distances. Depending upon their initial energy, gamma rays can travel tens or hundreds of meters in air.

X-Ray Radiation



(diagram courtesy of the University of Michigan Student Chapter of the Health Physics Society)

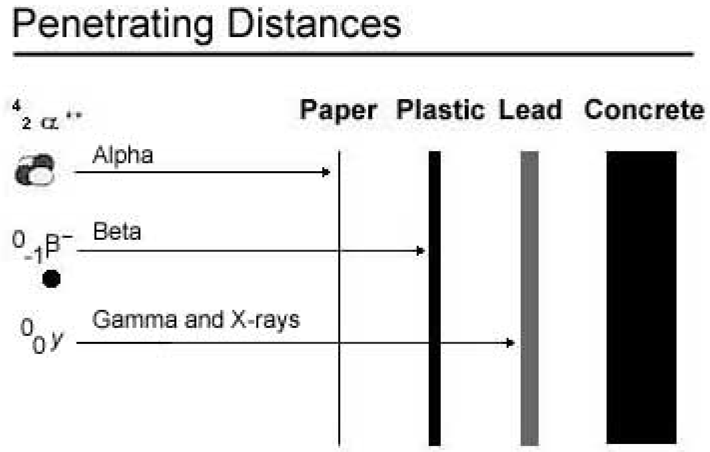
Like a gamma ray, an **x-ray** is a packet (or photon) of electromagnetic radiation emitted from an atom except that the x-ray is not emitted from the nucleus. X-rays are produced as a result of changes in the positions of the electrons orbiting the nucleus, as the electrons shift to different energy levels.

Examples of x-ray emitting radioisotopes are iodine-125 and iodine-131.

X-rays can be produced during the process of radioactive decay or as bremsstrahlung radiation. Bremsstrahlung radiation are x-rays produced when high-energy electrons strike a target made of a heavy metal, such as tungsten or copper. As electrons collide with this material, some have their paths deflected by the nucleus of the metal atoms. This deflection results in the production of x-rays as the electrons lose energy. This is the process by which an x-ray machine produces x-rays.

Like gamma rays, x-rays are typically shielded using **very dense materials** such as lead or other dense metals.

X-rays particularly can present a hazard from exposures to the body.



(diagram courtesy of the University of Michigan Student Chapter of the Health Physics Society)

Gamma radiation is typically shielded using **very dense materials** (the denser the material, the more chance that a gamma ray will interact with atoms in the material) such as lead or other dense metals.

Gamma radiation particularly can present a hazard from exposures external to the body.

Measures of Radioactivity

Activity: The quantity of radioactive material present at a given time:

-- Curie (Ci): 3.7×10^{10} disintegration per second (dps)

or

-- Becquerel (Bq): 1 dps

Quantity

The **quantity** of radioactive material present is generally measured in terms of **activity** rather than mass, where activity is a measurement of the number of radioactive disintegrations or transformations an amount of material undergoes in a given period of time. Activity is related to mass, however, because the greater the mass of radioactive material, the more atoms are present to undergo radioactive decay.

The two most common units of activity are the **Curie** or the **Becquerel** (in the SI system).

1 Curie (Ci) = 3.7×10^{10} disintegrations per minute (dpm)

1 Becquerel (Bq) = 1 disintegration per second (dps)

Obviously, 1 Curie is a large amount of activity, while 1 Becquerel is a small amount. In the typical Princeton University laboratory, millicurie (or kilo and MegaBecquerel) amounts of radioactive material are used.

1 millicurie = 2.2×10^{9} disintegrations per minute (dpm) = 3.7×10^{7} Bq = MBq

1 microcurie = 2.2×10^{6} dpm = 3.7×10^{4} Bq = 37 kBq

Intensity

For the purposes of radiation protection, it is not always useful to describe the potential hazard of a radioactive material in terms of its activity. For instance, 1 millicurie of tritium a centimeter from the body poses a much different hazard than 1 millicurie of phosphorus-32 a centimeter from the body.

Consequently, it is often preferable to measure radiation by describing the effect of that radiation on the materials through which it passes. The three main quantities, which describe radiation field intensity, are shown in the following table:

Quantity	Unit	What is measured	Amount
Exposure	Roentgen (R) Coulombs/kg	Amount of charge produced in 1 kg of air by x- or gamma rays	1 R = 2.58 x 10-4 Cb/kg
Absorbed Dose	Rad Gray (Gy)	Amount of energy absorbed in 1 gram of matter from radiation	1 rad = 100 ergs*/gram 1 Gy = 100 rad
Dose Equivalent	Rem Sievert (Sv)	Absorbed dose modified by the ability of the radiation to cause biological damage	rem = rad x Quality Factor 1 Sv = 100 rem

* An erg is a unit of work

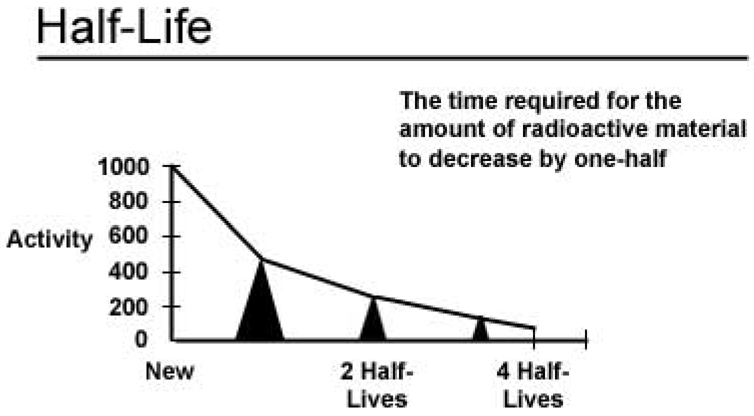
Coulombs/kilogram, the Gray, and the Sievert are the SI units for these quantities.

Radioactive Decay

The atomic structure for certain isotopes of elements is naturally unstable. **Radioactivity** is the natural and spontaneous process by which the unstable atoms of an isotope of an element transform or decay to a different state and emit or radiate excess energy in the form of particles or waves. These emissions are energetic enough to ionize atoms and are called ionizing radiation. Depending on how the nucleus loses this excess energy, either a lower energy atom of the same form results or a completely different nucleus and atom is formed.

A given radioactive isotope decays through a specific transformation or set of transformations. The type of emissions, along with the energy of the emissions, that result from the radioactive decay are unique to that isotope. For instance, an atom of phosphorus-32 decays to an atom of non-radioactive sulfur-32, accompanied by the emission of a beta particle with an energy up to 1.71 million electron-volts.

Half-Life



Background Radiation & Other Sources of Exposure

Natural Background Radiation

We are all exposed to ionizing radiation from natural sources at all times. This radiation is called natural background radiation, and its main sources are the following.

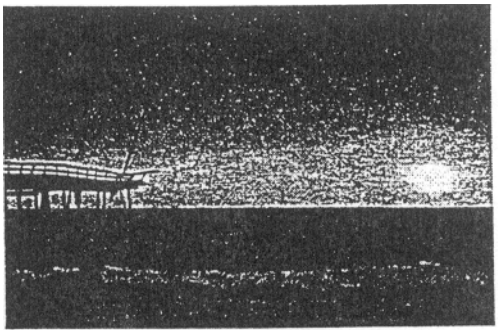
- radioactive substances in the earth's crust
- emanation of radioactive gas from the earth;
- cosmic rays from outer space which bombard the earth;
- trace amounts of radioactivity in the body

Radioactivity in the Earth

When the earth was formed four billion years ago, it contained many radioactive isotopes. Since then, all the shorter-lived isotopes have decayed. Only those isotopes with very long half lives (100 million years or more) remain, along with the isotopes formed from the decay of the long-lived isotopes.

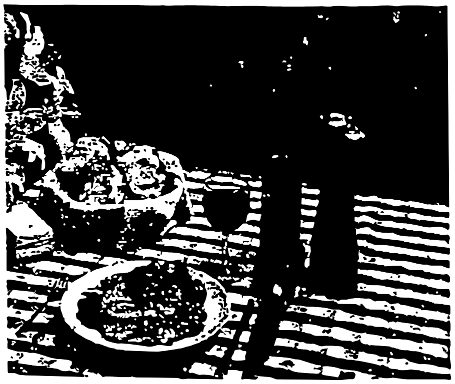
Theses naturally occurring isotopes include uranium and thorium and their decay products, such as radon. The presence of these radionuclides in the ground leads to both external gamma ray exposure and internal exposure from radon and its progeny.

Cosmic Radiation



Cosmic rays are extremely energetic particles, primarily protons, which originate in the sun, other stars and from violent cataclysms in the far reaches of space. Cosmic ray particles interact with the upper atmosphere of the earth and produce showers of lower energy particles. Many of these lower energy particles are absorbed by the earth's atmosphere. At sea level, cosmic radiation is composed mainly of muons, with some gamma-rays, neutrons, and electrons.

Because the earth's atmosphere acts as a shield, the exposure of an individual to cosmic rays is greater at higher elevations than at sea level. For example, the annual dose from cosmic radiation in Denver is 50 millirem while the annual dose at sea level is 26 millirem.



Small traces of many naturally occurring radioactive materials are present in the human body. These come mainly from naturally radioactive isotopes present in the food we eat and in the air we breathe.

These isotopes include tritium (H-3), carbon-14 (C-14), and potassium-40 (K-40).

Radiation Doses to the U.S. Population

Radiation Source	Average Annual Whole Body Dose (millirem/year)
Natural: Cosmic	29
Terrestrial	29
Radon	200
Internal (K-40, C-14, etc.)	40
Manmade: Diagnostic x-ray	39
Nuclear Medicine	14
Consumer Products	11
All others (fallout, air travel, occupational, etc.)	2
Average Annual Total	**360 millirem/year**

Tobacco (if you smoke, add ~250 millirem)

Average doses from some common activities

Activity	**Typical Dose**
Smoking	280 millirem/year
Using radioactive materials in a Ohio University 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

Biological Effects of Ionizing Radiation

Mechanisms of Damage

Injury to living tissue results from the transfer of energy to atoms and molecules in the cellular structure. Ionizing radiation causes atoms and molecules to become ionized or excited. These excitations and ionizations can:

- Produce free radicals
- Break chemical bonds
- Produce new chemical bonds and cross-linkage between macromolecules
- Damage molecules that regulate vital cell processes (e.g. DNA, RNA, proteins).

The cell can repair certain levels of cell damage. At low doses, such as that received every day from background radiation, cellular damage is rapidly repaired.

At higher levels, cell death results. At extremely high doses, cells cannot be replaced quickly enough, and tissues fail to function.