An Introduction to Radiation

Believe it or not, you are surrounded by radiation! As you are sitting here reading this article, electromagnetic radiation from sunlight, electric lights, power cables in the walls, and the local radio station are coursing through your body.

Is radiation something to worry about? It all depends on how much you absorb, and in what forms.

There are two main types of radiation: **electromagnetic** radiation, and **particle** radiation. These are also called 'non-ionizing' and 'ionizing' radiation. Both forms carry energy, which means that if you accumulate too much over time, either in the tissues of your body, or in sensitive electronic equipment, they can potentially do damage.

Electromagnetic Radiation: This 'EM' radiation travels at the speed of light, and is defined by its wavelength or its frequency. EM radiation spans a wide wavelength range from gamma-rays and X-rays at the shortest, through ultraviolet and visible light, and to longer wavelengths in the infrared, and radio. The harmfulness of EM radiation depends on BOTH its intensity and its wavelength. A small amount of short-wavelength (UV-B) ultraviolet radiation can give you a nice tan, and allows your skin to form Vitamin-D. Too much can increase your risk for skin cancer. A small amount of radio radiation is enough for a car radio to pick up a distant station, but too much in a microwave oven will cook you in 60-seconds flat! EM radiation is produced by heated bodies, chemical reactions, nuclear reactions and a variety of man-made technologies such as medical imaging systems, radio transmitters, electrical power systems, cell phones, microwave ovens and computers.

Particle Radiation: This radiation consists of particles of matter traveling through space at high-speed. Usually these particles are atomic particles such as electrons, neutrons, alpha particles or even entire atomic nuclei such as helium. A small amount of particle radiation produced by, say, the radium dial of a watch, is enough to make it glow in the dark harmlessly, but too much can destroy the DNA in your cells and lead to mutations, cancer, and even death.

Particle radiation is usually produced by unstable atoms that are 'radioactive', or by many different astronomical systems in which matter can be accelerated to high speed such as supernova explosions, pulsars and solar flares. Man-made particle radiation can be produced in nuclear reactors, or under laboratory conditions at Fermi Lab, CERN or other accelerator labs.

There are three common types of particle radiation found on Earth, and produced by many radioactive substances. Each produces its own level of tissue damage.

Alpha-particles are given-off by radioactive atoms. They are nuclei containing two protons and two neutrons: essentially helium nuclei. They can be stopped by a sheet of paper and rendered harmless, however they can be trapped on dust particles and be inhaled, doing damage to lung tissue as they build up their concentration. Spacesuits can typically shield an astronaut from alpha-particles that occur in solar flares and cosmic rays.

Beta-particles (or Beta-rays) are also given off by radioactive atoms during the process of 'beta decay'. They consist of energetic electrons traveling at high-speed, and require several millimeters of aluminum to stop most of them. A spacesuit normally has a few millimeters of aluminum in its fabric, so astronauts are usually well-protected from beta-rays from solar flares and other sources.

Neutron particles are produced in nuclear reactions including fission and fusion. Because they carry no charge, they easily penetrate many substances. Large quantities of dense lead or cement are required to shield against neutron radiation. The walls of spacecraft provide adequate shielding from neutron particles. During EVAs, astronauts receive unavoidable radiation exposure to neutrons and other energetic particles such as cosmic rays.

To discuss radiation and human exposure to it, we have to use standard units to describe the amount present, and its accumulation in both human tissue, and in technological systems.

Scientists measure radiation doses and dose equivalent in terms of units called Rads and Rems (Grays and Seiverts are used in Europe).

Dose: This is a measure of the amount of total energy that is absorbed by matter over a period of time. This matter can be human tissue, or sensitive computer circuitry. The unit for dose is the Rad, which means 'Radiation Absorbed Dose'. One Rad is equal to 100 ergs of energy delivered to one gram of matter. The equivalent SI unit is the Gray (G). **One Gray equals 100 Rads.**

Dose Equivalent: This compares the amount of absorbed energy (Rads) to the amount of tissue damage it produces in a human. It is measured in units of the Rem, which means 'Roentgen Equivalent Man'. The equivalent SI unit is the Seivert (Sv**). One Seivert equals 100 Rems.**

Radiation dose can be very accurately measured and defined. It is just the amount of energy delivered to a sample of matter. Equivalent dose, however, is much more complicated. This term has to do with the amount of **damage** that a given amount of energy does to a tissue sample or an electronic component. Each kind of radiation, for the same exposure level, produces a different amount of damage. Mathematically, this is represented by the equation:

Dose Equivalent (in Rem) = Dose (in Rads) x Q

Different forms of radiation produce different levels of tissue damage. EM radiation, such as x-rays and gamma-rays, produce 'one unit' of tissue damage, so for this kind of radiation Q = 1, and so 1 Rad = 1 Rem. This is also the case for beta radiation, which has the same Q value. For alpha particles, Q = 15-20, and for neutrons, Q = 10. That means that a dose of 1 Rad of radiation (which equals 1000 ergs delivered to 1 gram of matter) produces a dosage of 10 Rem for Q = 10.

Radiation also has different effects depending on how much you absorb over different amounts of time. Let's consider two extreme examples where your entire body is 'irradiated': A big dose over a short time, and a small dose over a long time.

Strong and Brief! In cancer therapy, small parts of your body are irradiated to kill cancerous cells. This works because radiation transports energy into cellular tissue where it is absorbed, and cancerous cells are very sensitive to heat compared to normal cells. Although patients sometimes report nausea and loss of hair, the benefits in destroying cancerous cells (the survival of the patient) far outweighs the collateral effects, which are usually temporary. Typical dosages are about 200 Rads over a few square centimeters, or even 5,000 Rads over a single tumor area! For whole-body dosages, the effects are far worse as the table below shows!

50 - 100 Rads	No significant illness
100 - 200 Rads	Nausia, vomiting. 10% fatal in 30 days.
200 - 300 Rads	Vomiting. 35% fatal in 30 days.
300 - 400 Rads	Vomiting, diarrhea. 50% fatal in 30 days.
400 - 500 Rads	Hair loss, fever, hemorrhaging in 3wks.
500 - 600 Rads	Internal bleeding. 60% die in 30 days.
600 -1,000 Rads	Intestinal damage. 100% lethal in 14 days.
5,000 Rads	Delerium, Coma: 100% fatal in 7 days.
8,000 Rads	Coma in seconds. Death in an hour.
10,000 Rads	Instant death.

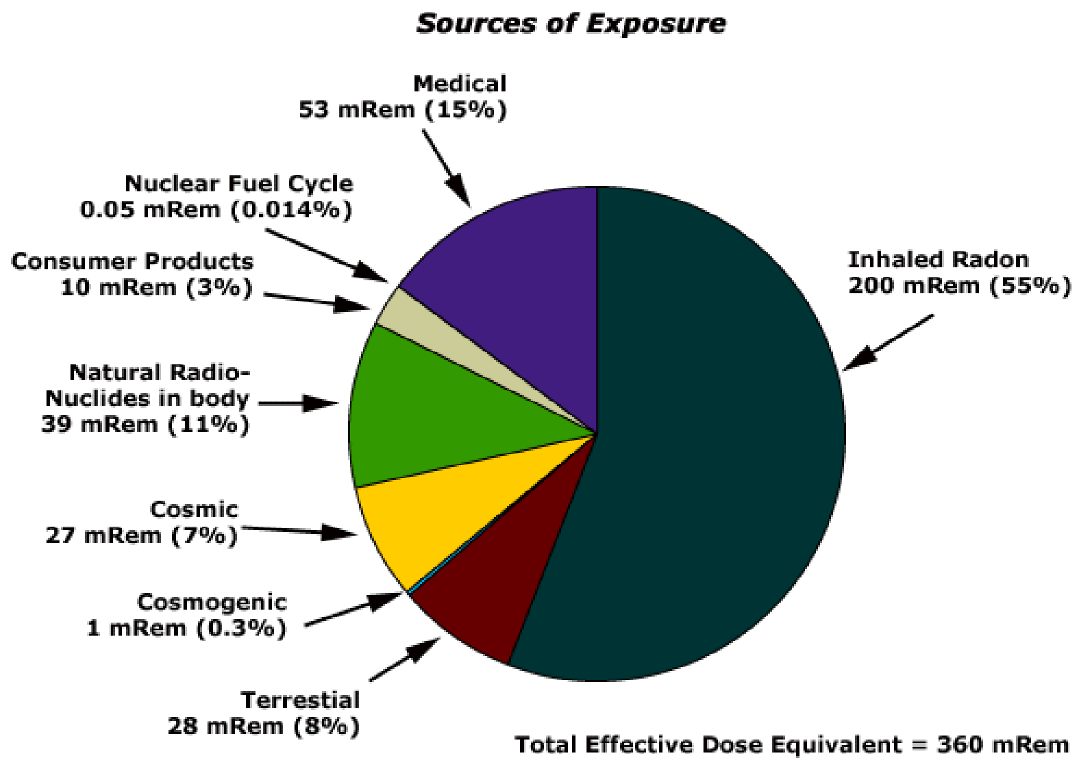
Weak and Long! On the ground, you receive about 0.4 Rads each year (e.g. 400 milliRem/yr for Q=1) from: natural backround radiation; radiation from all forms of medical testing; what you eat; and where you live. Over the course of your lifetime, say 80 years, this adds up to **80 x 0.4 = 32 Rads** of radiation. By far, the biggest contribution comes from radioactive radon gas in your home, which can amount to as much as 0.1 Rem/year, and yields a lifetime exposure of 8 Rads. Some portion of this radiation exposure invariably contributes to the average cancer risk that each and every one of

Medical Diagnostic Radiation (Q=1 for EM):

0.002 Rems	Dental x-ray
0.010 Rems	Diagnostic chest X-ray
0.065 Rems	Pelvis/Hip x-ray
0.150 Rems	Barium enema for colonoscopy
0.300 Rems	Mammogram
0.440 Rems	Bone scan
2 to 10 Rems	CT scan of whole body

So, the medical impact of radiation depends on the intensity of the dose, whether your whole body or just a few cells are involved, and how long your exposure will be at a given dosage. This makes the calculation of radiation effects a complicated process. 280 Rads all at once is fatal for 35% of people after 30 days, but the same exposure over a 70-year lifespan is only 4 Rads each year, which is easily survivable and harmless.

Just remember that some exposure to radiation is simply part of the price we pay for living on the surface of Earth and eating a well-balanced diet. In fact, because radiation leads to mutations, and mutations lead to evolution, it is entirely reasonable to say that, without radiation, the evolution of organic life on this planet would have taken a very different, and much slower, path!



This figure shows the various kinds of radiation sources that contribute to your annual dosage. Some of these sources you can do nothing about. For example, '**Natural Radionuclides in Body**' refers to the radioactive elements out of which your bones and tissues are constructed. '**Nuclear Fuel Cycle**' refers to atmospheric forms of radioactivity that are there because of nuclear power plants. Other forms can be reduced or increased depending on where you choose to live, or your personal situation. For example, '**Medical**' refers to annual dental x-rays or nuclear imaging. If you have cancer and undergoing radiotherapy, you may be exposed to much more radiation than someone else. '**Cosmic**' refers to sources of radiation in the form of cosmic rays that come from the sun or from space. The atmosphere shields us from most of these, but if you live at higher elevations or are a frequent airline passenger, this exposure can be higher. **'Terrestrial'** refers to sources of radiation in soils or rocks. The clay in some areas contains higher concentrations of radioisotopes than in other locations, also if you are living near large deposits of granite, there may be higher quantities of uranium or other radioactive ores embedded in the rock. **'Consumer Products'** can include food. Bananas are rich in potassium, but also contain slight quantities of the radioactive isotope of potassium. By far, the biggest contribution comes from **Radon Gas** that can be trapped in your basement, and is a major source of lung cancer. This is why you should keep your basement properly ventilated, and periodically checked for radon!

Radioactive Contamination vs Radiation Exposure

Radioactive contamination is any material that gives off radiation (energy in the form of alpha particles, beta particles, or gamma rays) in a location where it is not desired. For example, in the aftermath of the Japan Earthquake of March 10, 2011, stored spent fuel rods of the Fukushima nuclear plant became part of a fire. The radioactive material contained in the rods was released to the environment through ash and smoke. The ash is considered to be radioactive contamination and any object or place that it lands on is considered to be contaminated. In contrast, properly stored spent fuel rods are **not** considered to be contamination because the radioactive material is contained in the desired location and unable to spread.

Anytime that radioactive material is not in a sealed radioactive source container and might be spread onto other objects, radioactive contamination is a possibility. A person near the Fukushima Nuclear plant in Japan could become externally contaminated if contaminated ash falls on their clothing or skin. A contaminated person will be exposed to the radiation (energy in the form of alpha particles, beta particles, or gamma rays) emitted by the radioactive materials in the ash until the ash is removed. Decontamination methods include proper disposal of the clothing and washing of the skin. Internal contamination is also a possibility if the contaminated ash is breathed in or swallowed. Risk of internal contamination can be reduced by wearing a mask or placing a wet towel over the nose and mouth preventing the entry of the ash into the body. Detection of contamination is usually accomplished by passing the wand of a radiation detector close to and over the surface areas that are suspect.

Radiation exposure on the other hand, is not spread and doesn't get "in" or "on" people. People become exposed to radiation when alpha particles, beta particles, or gamma rays hit their body and deposit energy in their body. That energy may or may not go on to cause biological harm. A person becomes exposed to radiation as the radiation eminates from a nearby radioactive source. Exposure to radiation can be minimized by reducing the time spent near the source of radiation, by getting further away from that source or by placing sufficient shielding between the person and the source. The source could be radioactive contamination that is on them, or near them, or it could come from a nearby stored and secure source of radiation.

For example, in the aftermath of the Japan Earthquake of March 10, 2011, workers working near the spent fuel storage areas of the Fukushima nuclear plants were normally exposed to very low levels of radiation that were deemed acceptable. Then damage resulting from the earthquake and Tsunami caused water covering the spent fuel to be lost. That water helped to shield the spent fuel and keep the radiation exposures to workers low. With the water missing, exposure rates increased, and workers had to evacuate those areas in order to decrease the time spent near the radiation source, and increase the distance from the radiation source, thereby reducing their exposure. Exposure levels are measured with hand held meters that measure ambient radiation levels, and with TLD's (thermoluminescent dosimeters) that are worn by people working near radiation sources to monitor their exposure rates and ensure that they are below acceptable standards.

Misconception 1: A person exposed to radiation will become radioactive.

This is **false**. A person becomes 'radioactive' because dust particles containing various radioisotopes or alpha particles land on the persons skin or garments. Once a person has been decontaminated by clothes removal and dermal scrubbing, all of the particulate radioactivity sources are eliminated, and the individual is no longer contaminated.

Misconception 2: People will 'glow in the dark' when contaminated.

This is **false**. There is no physical mechanism involving the emission of visible light that could ever cause a contaminated person to shine visibly. There are no radioisotopes likely to be trapped on dust grains and delivered to bodily surfaces that emit visible-light. There are however 'gamma emitters' that emit gamma rays, and 'beta emitters' that emit electrons, but these are invisible to humans. They can, however, be detected by standard dosimetry techniques, and removed through decontamination.

Misconception 3 – Radiation is always harmful.

This is **false**. It depends on how it is used. For diagnostic medicine or treating cancers, it is obviously beneficial compared to not using it at all. At high levels, however, it invariably leads to an increase in cancers in the exposed human population, which is obviously bad. At low levels, the ability of radiation to alter genetic information and cause mutations may actually be one of the 'driving forces' behind the evolution of life on Earth. As with all other natural phenomena, from ultraviolet rays used in sun tanning, to atomic disintegration used in nuclear fission reactors, radiation and radioactivity can be safely used provided that the proper steps are taken. You do not take a sports car out for a drive at 130 mph without knowing how to drive. Similarly, you do not use radioactivity without properly understanding its impacts.

Misconception 4 - A microSeivert is the same as a microSeivert per hour.

This is **false**. They are as different as 'mile' and 'speed' or 'gallons' versus 'gallons/hour'. It is common for newspaper articles to drop the 'per hour' when reporting radiation exposure. A microSeivert is the total dose you have accumulated, while a microSeivert per hour is the 'speed' with which you have absorbed the radiation.