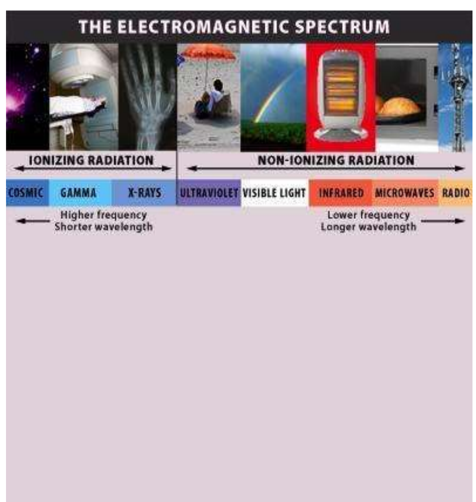
Principles of Radiation protection

Health physics is the science of measuring and controlling the exposure of people and the environment to radiation. The understanding of health physics begins with an understanding of the underlying fundamental physical characteristics of the radiation that is being measured; understanding the different types of radiation, how each type of radiation interacts with matter, and what effects they might have. Based on how radiation interacts with matter, measurements can be made to determine how much radiation an individual has been, is being, or may be exposed. This quantity is then compared with the applicable regulatory limits to determine if past operations have been, or proposed operations would be, in compliance with those regulations. In many instances, it is necessary to limit, control, or modify, how activities are conducted to remain in compliance.

Radiation Fundamentals

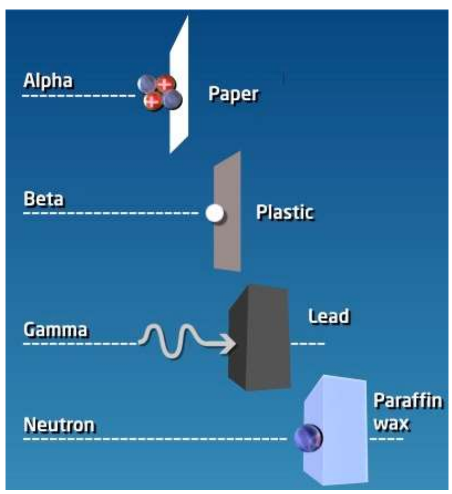
Radiation is the emission or propagation of energy through space. As such, it includes not only **alpha and beta particles, gamma and X-rays, and neutrons** but also visible light, radio waves, microwaves, infrared and ultraviolet light. The first five types of radiation are generally emitted during the process of nuclear decay or fission, events involving the nucleus of atoms with the exception of X-rays, and are what we usually mean when we refer to ionizing radiation. The last five are different in that they do not typically originate with nuclear events and they are considered non-ionizing radiations, i.e., they do not possess enough energy to knock an electron out of its orbit in an atom, ionizing the atom.



Radiation is therefore can be described by two categories

- **ionizing radiation, which includes alpha, beta, gamma, X-rays and neutrons; and**
- **non-ionizing radiation, which includes microwaves, infrared and ultraviolet radiation.**

The difference in energy dissipation mechanisms between charged and neutral particles causes them to create biological hazards by quite different mechanisms. The alpha and beta radiation emitted by fission products or other radioisotopes are charged particles. They are referred to as non penetrating radiation since they deposit their energy over a very short distance or range. Alpha or beta radiation will not penetrate the skin and can be stopped completely by a sheet of paper. Beta particles, which are electrons, are more penetrating than alpha particles, but can be stopped by, for example, a sheet of plastic or several sheets of paper. Therefore They (alpha and beta) are not significant hazard if the source is external to the body. They pose more serious problems if radioisotopes emitting them are inhaled or ingested. Then they can attack the lungs and digestive tract, and other organs as well, depending on the biochemical properties of the radioisotope. Radio strontium, for example, collects in the bone marrow and does its damage there, whereas for radioiodine the thyroid gland is the critical organ. In contrast, since neutral particles (neutrons and gamma rays) travel distances measured in centimeters between collisions in tissue, they are primarily a hazard from external sources. The damage neutral particles do is more uniformly distributed over the whole body, resulting from the ionization of water and other tissue molecules at the points where neutrons collide with nuclei or gamma rays with electrons. Gamma rays are much more penetrating than either alpha or beta particles. It takes dense materials such as concrete or lead to shield them. Neutrons are also very penetrating, but can be shielded by materials that contain lots of hydrogen atoms, like paraffin wax or water.



Note that gammas and neutrons are different from alphas and betas, in that paper and plastic stop all of the alphas and betas, but lead, concrete or wax reduces the intensity of a beam of these radiations but may not stop all of the gammas and neutrons (**Recall neutron attenuation**).
These properties are important considerations when designing protection against exposure to radiation. This is discussed in detail in a later section.

Natural Sources of Radiation

Radioactive isotopes, shortened to "radioisotopes", appear naturally in nature. Some were created during the birth of our solar system, and some are being continuously created today. For example, tritium, an isotope of hydrogen composed of one proton and two neutrons, is generated by the interaction of cosmic rays and atoms in our atmosphere.

Radioisotopes like uranium and thorium were created during the formation of our solar system and have half-lives of billions of years, and so they still exist in our environment today. As these naturally occurring radioactive materials decay and change, some of them produce a radioactive gas called radon, which is present in small amounts in the air we breathe.

Ionizing radiation is a natural part of the world. We receive small amounts of radiation from uranium and other radioactive elements which are found everywhere in rocks and soil.

We also receive cosmic radiation from the sun and from deep space. Most of this radiation is stopped by the atmosphere, but some does get through. People who live at higher altitudes or who frequently travel by airplane are exposed to more cosmic radiation than those who do not.

All of us have very small amounts of naturally-occurring radioactive substances in our own bodies. We absorb these substances from the foods we eat and drink (e.g. K-40), and from the air we breathe.

The sum of all this natural radiation is called background radiation. It accounts for about 60% of the radiation which an average Canadian receives in a lifetime. The other 40% comes from artificial sources.

Artificial Sources of 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 are regulated by the CNSC. The CNSC also licenses the reactors and particle accelerators that produce isotopes destined for medical and industrial applications.

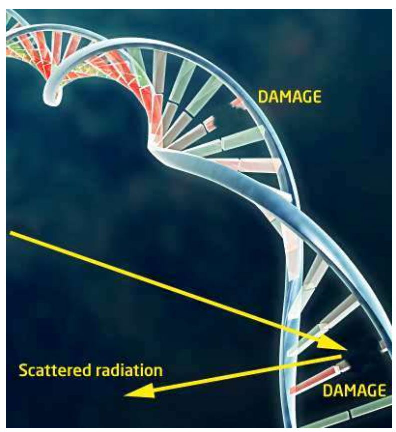
Industrial Sources: Radiation has a variety of industrial uses that include density gauges used to build roads and measure the flow of material through pipes in factories. It is also used for smoke detectors, some glow-in-the dark exit signs, and to estimate reserves in oil fields. Radiation is also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

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

Biological Effects of Radiation

Health effects are produced by exposure to radiation primarily through breakage of DNA molecules by the radiation. DNA is a long chain of amino acids whose pattern forms the blueprint for how cells live and function. When radiation breaks or damages the DNA of a living cell, three things can happen:

- **The DNA repairs itself properly**. In this case, the cell is repaired properly and it continues to function normally.
- **The DNA damage is so severe that the cell dies.** When the DNA or other critical parts of the cell receive a large dose of radiation, the cell may either die or be damaged beyond repair. If this happens to a large number of cells in tissue or organ, immediate radiation effects occur. These are called deterministic effects and the severity of the effects vary according to the intensity of the radiation. Effects can include burns, cataract, and death.
- **The cell incorrectly repairs itself and continues to live.** In this case, the DNA is damaged by radiation, and the cell incorrectly repairs itself. The cell may continue to function properly, or it may show changes in its function or ability to reproduce. As a result, cancer and hereditary effects may arise. These potential changes are not certain to occur and so we assign probabilities that harmful effects arise. Because of the probabilistic nature of these effects, they are called stochastic effects. The probability of a stochastic effect arising increases proportionally to the radiation dose received: the higher the dose, the higher the probability of occurrence.

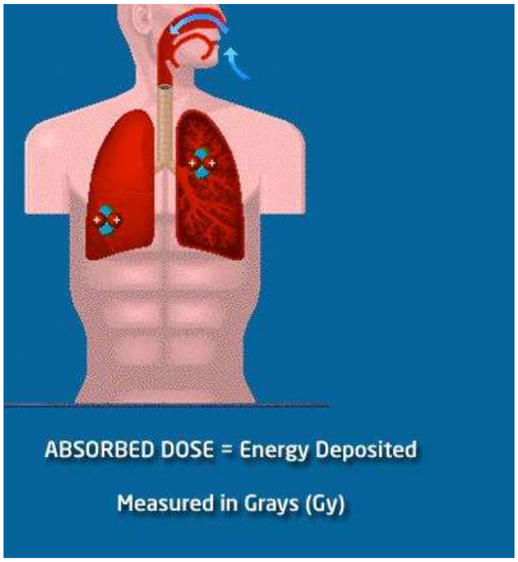


Radiation Doses

As described in the previous section, radiation damages the DNA of living cells. The result of that damage depends greatly on the intensity of the radiation. Therefore, we need a systematic way of evaluating the effects of radiation on the human body. This systematic way uses the concept of a dose. When ionizing radiation penetrates the human body, it deposits energy. This energy absorbed from exposure to radiation is called a dose. Radiation dose quantities are described in three ways: absorbed, equivalent, and effective.

- **Absorbed Dose**

The amount of energy deposited in the substance (for example human tissue) per unit mass is called the **absorbed dose**. The absorbed dose is measured in a unit called the Gray (Gy). 1 Gy=1J/kg

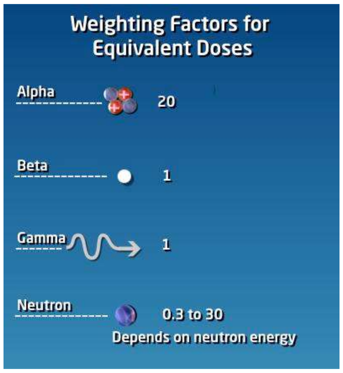


Equivalent Dose

The actual biological effect of an absorbed dose is different for different types of radiation and also depends on the tissue or organ being irradiated. For example, one Gray of alpha radiation is more harmful to tissue than one Gray of beta radiation, and bone marrow is much more susceptible to radiation damage than muscle or nerve tissue. Therefore, we need to take account of these two aspects:

- The differing biological effectiveness which depends on the type of radiation; and
- The differing sensitivity to radiation of organs and tissues.

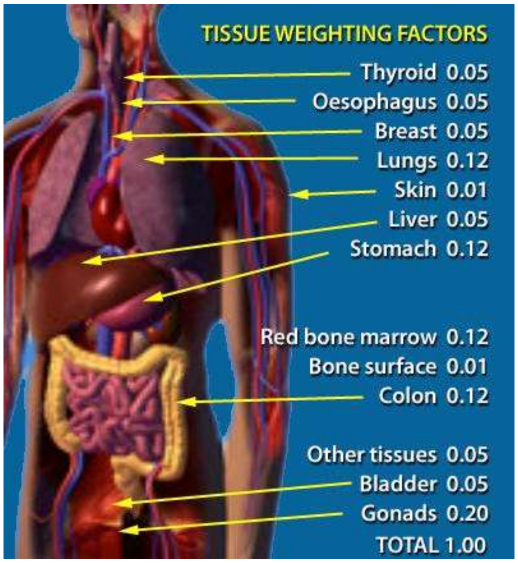
To account for the differing biological effectiveness, a **radiation weighting factor** is used to tag different types of radiation with different biological effectiveness for causing harm. This weighted absorbed quantity of energy is called the **equivalent dose** and is expressed in a unit called the Sievert (Sv). This means that one Sievert of alpha radiation will have the same equivalent health effect as one Sievert of beta radiation.



To take account of the differing sensitivity of different organs to radiation, we define a new unit by multiplying the equivalent dose by a factor which depends on the tissue being exposed to the

radiation, called the **tissue weighting factor**. The result is called the **effective dose**, and is also expressed in Sieverts.
The effective dose, therefore, takes account of:

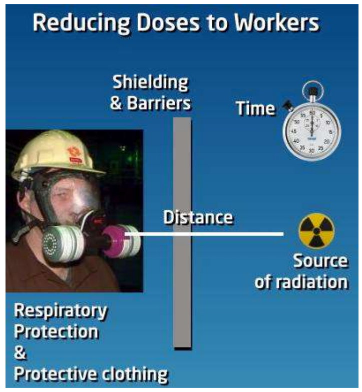
- The energy deposited in the body by the radiation;
- The type of radiation; and
- In which tissue or organ the radiation energy is deposited.



Protection Against Occupational Exposure

There are approximately 40,000 people who work in the Canadian nuclear industry. Many more work in jobs where they are exposed to radiation (e.g. X-ray technicians). These people are called Nuclear Energy Workers (NEW). To reduce occupational radiation exposures from sources external to the body, and to prevent radioactive substances from entering the body, the following factors are taken into account:

- **time**: the time a worker is exposed to radiation is controlled;
- **distance**: the further from a source of radiation a worker is, the lower the resultant dose;
- **shielding**: appropriate materials to shield radiation are placed between the worker and the source of radiation. For example, plastic goggles can be worn to shield the eyes from beta radiation, concrete or lead walls can be used to shield gamma radiation, while paraffin wax blocks or water can be used to shield neutrons;
- **barriers**: nuclear facilities use barriers to prevent workers from coming too close to sources of radiation;
- **respiratory protection**: if the source of radiation is airborne, then masks are used to prevent inhalation of the radioactive particles;
- **protective clothing**: plastic suits can be used to protect against radioactive contamination.



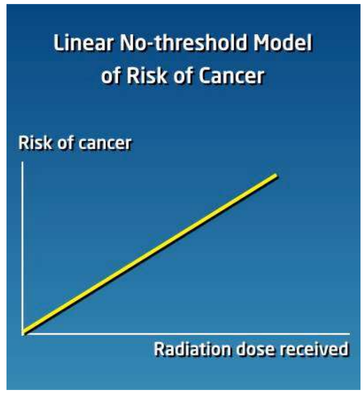
As Low As Reasonably Achievable (ALARA) principle

One of the most important aspects of radiation protection requirements is the concept of ALARA which requires that the license holder shall use, to the extent practicable, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA)." Implementation of ALARA is quite subjective due to the differences in possible interpretation of what is "reasonable" or "achievable." When applying the ALARA philosophy, one should consider:

- The state of available technology: what can we do?
- Economic costs vs. benefits: is it worth doing?
- Socioeconomic/societal considerations: what are the down sides in terms of expense and impact upon the public or large populations?

The Dose limits

The dose limits for workers and the public are set by the government (in Canada, the Canadian Nuclear Safety Commission). This is done by following the recommendations of the International Commission on Radiological Protection, which comprises some of the world's leading scientists and other professionals in the field of radiation protection, and by using many of the standards and guides of the International Atomic Energy Agency.
The Linear No-Threshold model (LNT) is a risk model used internationally by most health agencies and nuclear regulators to set dose limits for workers and members of the public. The LNT conservatively assumes there is a direct relationship between radiation exposure and cancer rates. In other words, the more exposure, the greater the likelihood of developing cancer.



The Radiation Protection Regulations prescribe limits on the amount of radiation the public and nuclear energy workers can receive.

The dose limit for the general public is 1 mSv per year from regulated activities.

For people whose work exposes them to levels of ionizing radiation which would give rise to a dose above that of the general public, the regulated dose limit is set below the lower boundary of what is considered unacceptable exposure. For example, the dose limit for pregnant workers is 4 mSv from the time the pregnancy is declared to the end of term. For nuclear energy workers, the effective dose limits are 50 mSv per year and 100 mSv over 5 years. These limits reduce the probability of causing stochastic effects such as cancer. The equivalent dose limits for hands and feet (500 mSv/year), skin (500 mSv/year), and eyes (150 mSv/year) if respected, will eliminate deterministic (immediate) effects, such as radiation burns or cataracts.

Dose Limits in Canada

Nuclear Energy Worker (NEW)	50 mSv / yr AND 100 mSv / 5 yrs
Pregnant NEW *	4 mSv
Public	1 mSv / yr

* For the balance of the pregnancy.

Doses in Perspective

The image below shows radiation doses in perspective:

• health effects caused by radiation (shown with red background);

• dose limits (green background); and

average doses from X-rays, air travel and background radiation (blue background).

Note that the dose limits are very conservative: the dose limit for the general public is smaller than the dose we all receive from background radiation each year.