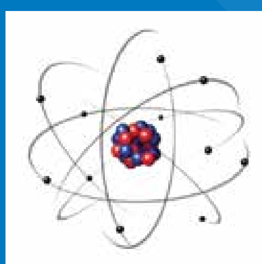
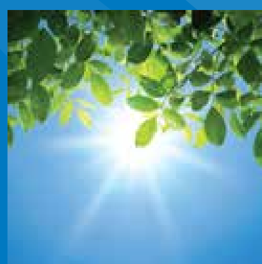
Canada's Nuclear Regulator

Introduction to Radiation

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Canada

Introduction to Radiation

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Introduction to Radiation

December 2012

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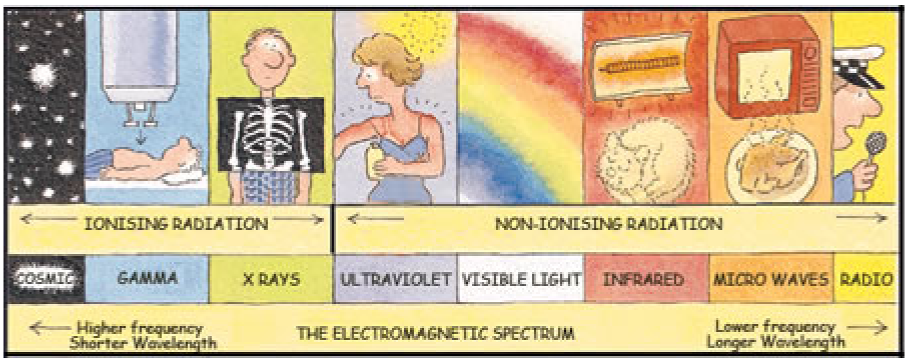
Introduction to Radiation

1. Overview

Radiation is energy in the form of waves or streams of particles. There are many kinds of radiation all around us. When people hear the word radiation, they often think of atomic energy, nuclear power and radioactivity, but radiation has many other forms. Sound and visible light are familiar forms of radiation; other types include ultraviolet radiation (that produces a suntan), infrared radiation (a form of heat energy), and radio and television signals. Figure 1 presents an overview of the electromagnetic spectrum; section 3 will go into greater detail on the different types of radiation.

Figure 1: The electromagnetic spectrum



Uncontrolled use of man-made radiation carries a potential risk to the health and safety of workers and the public. This is where the Canadian Nuclear Safety Commission (CNSC) comes in. The CNSC regulates the use of nuclear energy and materials to protect the health, safety and security of Canadians and the environment from the effects of radiation.

The purpose of this document is to provide clear and simple information about radiation: what it is, where it comes from and how it is used. It also presents information on radiation health effects, radiation doses and how the CNSC ensures the safety of the Canadian nuclear sector through its comprehensive regulatory framework and vigilant oversight.

2. Introduction to Radiation

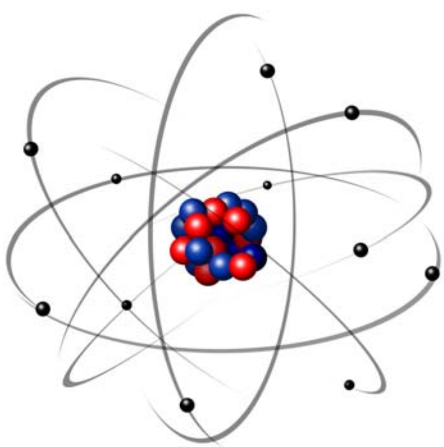
All life has evolved in an environment filled with radiation. The forces at work in radiation are revealed upon examining the structure of atoms. Atoms are a million times thinner than a single strand of human hair, and are composed of even smaller particles – some of which are electrically charged. Sections 2.1 to 2.3 discuss atoms in more detail, along with basic radiation-related principles.

2.1 Atoms: Where all matter begins

Atoms form the basic building blocks of all matter. In other words, all matter in the world begins with atoms – they are elements like oxygen, hydrogen, and carbon.

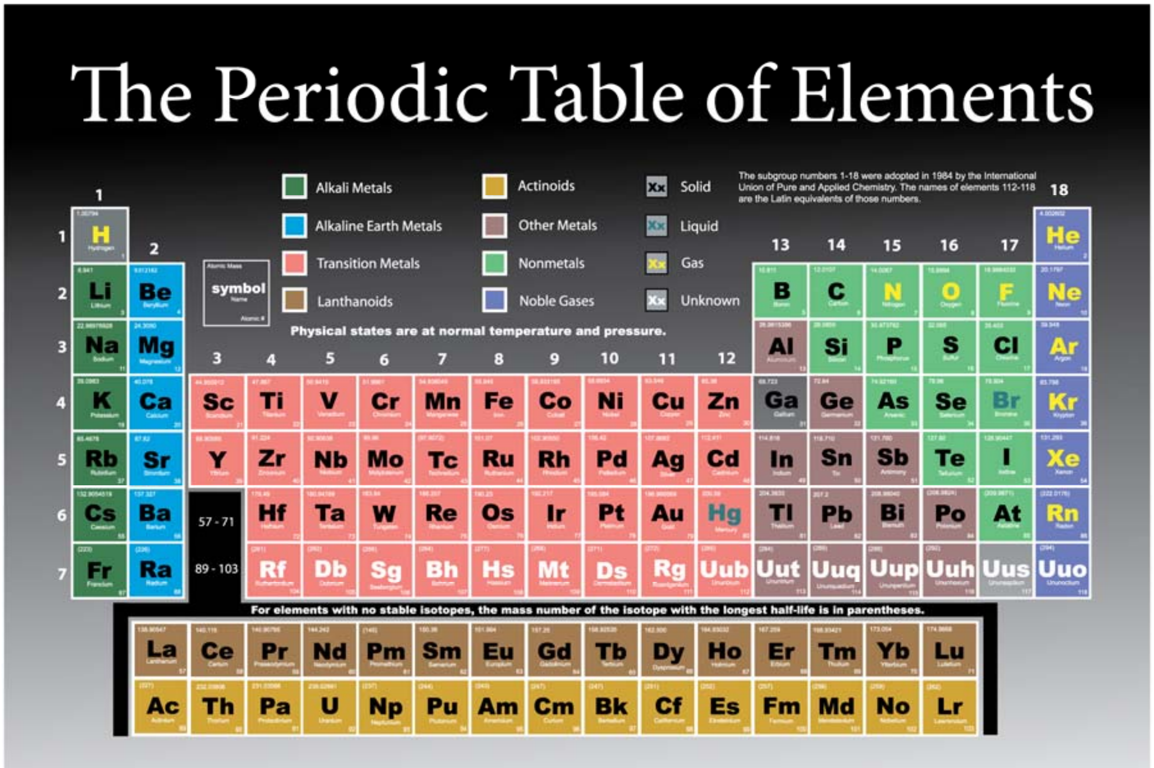
An atom consists of a nucleus – made up of protons and neutrons that are kept together by nuclear forces – and electrons that are in orbit around the nucleus (see Figure 2). The nucleus carries a positive charge; protons are positively charged, and neutrons do not carry a charge. The electrons, which carry a negative charge, move around the nucleus in clouds (or shells). The negative electrons are attracted to the positive nucleus because of the electrical force. This is how the atom stays together.

Figure 2: Model of an atom



Each element is distinguished by the number of protons in its nucleus. This number, which is unique to each element, is called the “atomic number”. For example, carbon has six protons; therefore, its atomic number is 6 on the periodic table (see Figure 3). In an atom of neutral charge, the atomic number is also equal to the number of electrons. An atom’s chemical properties are determined by the number of electrons, which is normally equal to the atomic number.

Figure 3: The periodic table of elements



Atoms from one or more elements combine to form molecules. A molecule of water, for example, is formed of two atoms of hydrogen bound to one atom of oxygen (H_2O).

A nuclide is a specific type of atom characterized by the number of protons and neutrons in its nucleus, which approximates the mass of the nuclide. The number that is sometimes given with the name of the nuclide is called its mass number (the total number of protons and neutrons in the nucleus). For example, a nuclide of carbon with 6 protons and 6 neutrons is called carbon-12.

2.2 Isotopes

An isotope is a variant of a particular chemical element. While all isotopes of a given element have the same number of protons, each isotope has a different number of neutrons.

For example, hydrogen has three isotopes (or variants):

- hydrogen-1 (contains one proton and no neutrons)
- hydrogen-2, which is called deuterium (contains one proton and one neutron)
- hydrogen-3, which is called tritium (contains one proton and two neutrons)

Another example is uranium-235, which has 92 protons and 143 neutrons, as opposed to uranium-238, which has 92 protons and 146 neutrons.

An isotope is stable when it has a balanced number of neutrons and protons. In general, when an isotope is small and stable, it contains close to an equal number of protons and neutrons. Isotopes that are larger and stable have slightly more neutrons than protons. Examples of stable nuclides include carbon-12 (six protons and six neutrons for a total mass of 12), phosphorus-30 (15 protons and 15 neutrons) and sodium-22 (11 protons and 11 neutrons).

2.3 Radioisotopes

Isotopes that are not stable and emit radiation are called radioisotopes. A radioisotope is an isotope of an element that undergoes spontaneous decay and emits radiation as it decays. During the decay process, it becomes less radioactive over time, eventually becoming stable.

Once an atom reaches a stable configuration, it no longer gives off radiation. For this reason, radioactive sources – or sources that spontaneously emit energy in the form of ionizing radiation as a result of the decay of an unstable atom – become weaker with time. As more and more of the source's unstable atoms become stable, less radiation is produced and the activity of the material decreases over time to zero.

The time it takes for a radioisotope to decay to half of its starting activity is called the radiological half-life, which is denoted by the symbol $t_{½}$. Each radioisotope has a unique half-life, and it can range from a fraction of a second to billions of years. For example, iodine-131 has an eight-day half-life, whereas plutonium-239 has a half-life of 24,000 years. A radioisotope with a short half-life is more radioactive than a radioisotope with a long half-life, and therefore will give off more radiation during a given time period.

There are three main types of radioactive decay:

- **Alpha decay:** Alpha decay occurs when the atom ejects a particle from the nucleus, which consists of two neutrons and two protons. When this happens, the atomic number decreases by 2 and the mass decreases by 4. Examples of alpha emitters include radium, radon, uranium and thorium.

- **Beta decay:** In basic beta decay, a neutron is turned into a proton and an electron is emitted from the nucleus. The atomic number increases by one, but the mass only decreases slightly. Examples of pure beta emitters include strontium-90, carbon-14, tritium and sulphur-35.

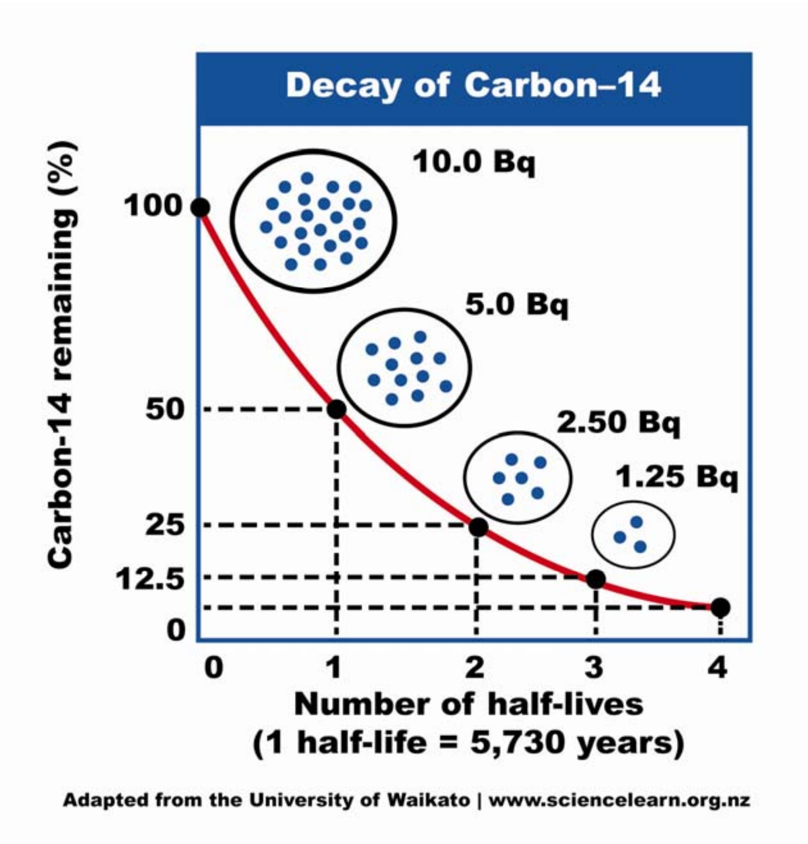
- **Gamma decay:** Gamma decay takes place when there is residual energy in the nucleus following alpha or beta decay, or after neutron capture (a type of nuclear reaction) in a nuclear reactor. The residual energy is released as a photon of gamma radiation. Gamma decay generally does not affect the mass or atomic number of a radioisotope. Examples of gamma emitters include iodine-131, cesium-137, cobalt-60, radium-226 and technetium-99m.

The number of nuclear disintegrations in a radioactive material per unit time is called the activity. The activity is used as a measure of the amount of a radionuclide, and it is measured in becquerels (Bq).
1 Bq = 1 disintegration per second.

If the original source of the radioactivity is known, it can be predicted how long it will take to decay to a given activity. The decay is exponential and the isotope must go through many half-lives to become non-radioactive. Figure 4 depicts the radioactive decay curve of carbon-14, which has a half-life of about 5,700 years.

Even after a radioisotope with a high activity has decayed for several half-lives, the level of remaining radioactivity is not necessarily safe. Measurements of a radioactive material's activity are always needed to estimate potential radiation doses.

Figure 4: Radioactive decay curve of carbon-14



3. Types and Sources of Radiation

Radiation is energy in the form of waves of particles. There are two forms of radiation – non-ionizing and ionizing – which will be discussed in sections 3.1 and 3.2, respectively.

3.1 Non-ionizing radiation

Non-ionizing radiation has less energy than ionizing radiation; it does not possess enough energy to produce ions. Examples of non-ionizing radiation are visible light, infrared, radio waves, microwaves, and sunlight.

Global positioning systems, cellular telephones, television stations, FM and AM radio, baby monitors, cordless phones, garage-door openers, and ham radios use 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 and are not considered to pose a health risk**.**

3.2 Ionizing radiation

Ionizing radiation is capable of knocking electrons out of their orbits around atoms, upsetting the electron/proton balance and giving the atom a positive charge. Electrically charged molecules and atoms are called ions. Ionizing radiation includes the radiation that comes from both natural and man-made radioactive materials.

There are several types of ionizing radiation:

Alpha radiation (α)
Alpha radiation consists of alpha particles that are made up of two protons and two neutrons each and that carry a double positive charge. Due to their relatively large mass and charge, they have an extremely limited ability to penetrate matter. Alpha radiation can be stopped by a piece of paper or the dead outer layer of the skin. Consequently, alpha radiation from nuclear substances outside the body does not present a radiation hazard. However, when alpha-radiation-emitting nuclear substances are taken into the body (for example, by breathing them in or by ingesting them), the energy of the alpha radiation is completely absorbed into bodily tissues. For this reason, alpha radiation is only an internal hazard. An example of a nuclear substance that undergoes alpha decay is radon-222, which decays to polonium-218.

Beta radiation (β)
Beta radiation consists of charged particles that are ejected from an atom's nucleus and that are physically identical to electrons. Beta particles generally have a negative charge, are very small and can penetrate more deeply than alpha particles. However, most beta radiation can be stopped by small amounts of shielding, such as sheets of plastic, glass or metal. When the source of radiation is outside the body, beta radiation with sufficient energy can penetrate the body's dead outer layer of skin and deposit its energy within active skin cells. However, beta radiation is very limited in its ability to penetrate to deeper tissues and organs in the body. Beta-radiation-emitting nuclear substances can also be hazardous if taken into the body. An example of a nuclear substance that undergoes beta emission is tritium (hydrogen-3), which decays to helium-3.

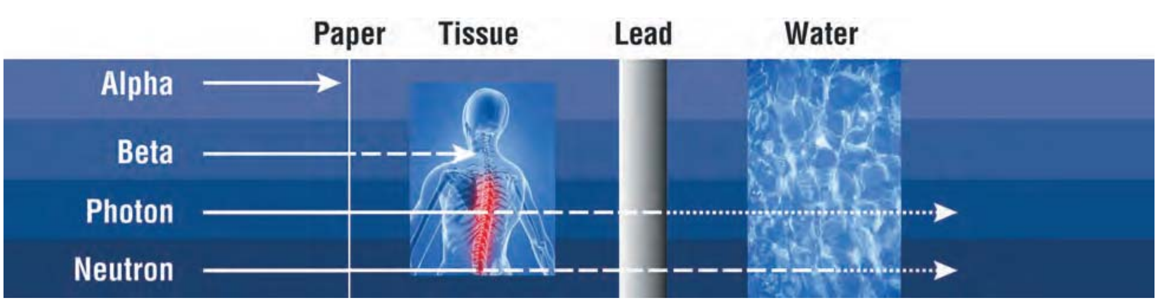
Photon radiation (gamma [γ] and X-ray)
Photon radiation is electromagnetic radiation. There are two types of photon radiation of interest for the purpose of this document: gamma (γ) and X-ray. Gamma radiation consists of photons that originate from within the nucleus, and X-ray radiation consists of photons that originate from outside the nucleus, and are typically lower in energy than gamma radiation.

Photon radiation can penetrate very deeply and sometimes can only be reduced in intensity by materials that are quite dense, such as lead or steel. In general, photon radiation can travel much greater distances than alpha or beta radiation, and it can penetrate bodily tissues and organs when the radiation source is outside the body. Photon radiation can also be hazardous if photon-emitting nuclear substances are taken into the body. An example of a nuclear substance that undergoes photon emission is cobalt-60, which decays to nickel-60.

Neutron radiation (n)
Apart from cosmic radiation, spontaneous fission is the only natural source of neutrons (n). A common source of neutrons is the nuclear reactor, in which the splitting of a uranium or plutonium nucleus is accompanied by the emission of neutrons. The neutrons emitted from one fission event can strike the nucleus of an adjacent atom and cause another fission event, inducing a chain reaction. The production of nuclear power is based upon this principle. All other sources of neutrons depend on reactions where a nucleus is bombarded with a certain type of radiation (such as photon radiation or alpha radiation), and where the resulting effect on the nucleus is the emission of a neutron. Neutrons are able to penetrate tissues and organs of the human body when the radiation source is outside the body. Neutrons can also be hazardous if neutron-emitting nuclear substances are deposited inside the body. Neutron radiation is best shielded or absorbed by materials that contain hydrogen atoms, such as paraffin wax and plastics. This is because neutrons and hydrogen atoms have similar atomic weights and readily undergo collisions between each other.

Figure 5 summarizes the types of radiation discussed in this document, from higher-energy ionizing radiation to lower-energy non-ionizing radiation. Each radiation source differs in its ability to penetrate various materials, such as paper, skin, lead and water.

Figure 5: Penetration abilities of different types of ionizing radiation

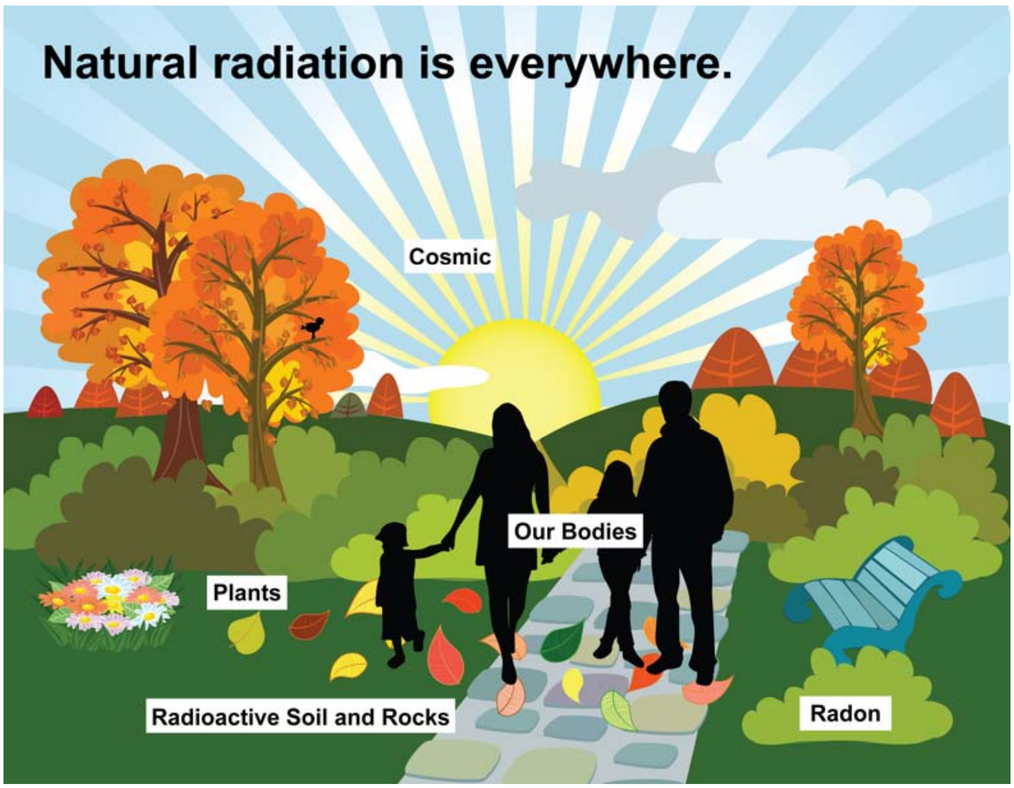


3.3 Natural sources of ionizing radiation

Radiation has always been present and is all around us in many forms (see Figure 6). Life has evolved in a world with significant levels of ionizing radiation, and our bodies have adapted to it.

Many radioisotopes are naturally occurring, and originated during the formation of the solar system and through the interaction of cosmic rays with molecules in the atmosphere. Tritium is an example of a radioisotope formed by cosmic rays' interaction with atmospheric molecules. Some radioisotopes (such as uranium and thorium) that were formed when our solar system was created have half-lives of billions of years, and are still present in our environment. Background radiation is the ionizing radiation constantly present in the natural environment.

Figure 6: Sources of natural radiation



The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) identifies four major sources of public exposure to natural radiation:

- Cosmic radiation
- Terrestrial radiation
- Inhalation
- Ingestion

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.

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 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 decay of 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. For more information on radon, read the CNSC's *Radon and Health* document (INFO-0813) at nuclearsafety.gc.ca or visit Health Canada's Web site (hc-sc.gc.ca) to learn more about the means to control it in your home.

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 and are commonly found in many foods, such as Brazil nuts. Table 1 identifies the amount of radioactivity from potassium-40 contained in about 500 grams of different food products.

Table 1: Potassium-40 content of certain foods

Food	Activity in Bq per 500 grams
Red meat	56
White potato	63
Carrot	63
Banana	65
Lima beans	86
Brazil nuts[1]	103

Source: Brodsky, 1978.
[1]Brazil nuts also naturally contain radium-226 (between 19 and 130 Bq per 500 grams).

Several radioactive isotopes also occur naturally in the human body (see Table 2).

Table 2: Radioactive isotopes found in the human body (70 kg adult)

Isotopes	Amount of radioactivity in Bq
Carbon-14	3,700 [a]
Polonium-210	40 [b,d]
Potassium-40	4,000 [b]
Radium-266	1.1 [b]
Thorium	0.21 [b]
Tritium	23 [c]
Uranium	2.3 [a, b, d]

a ICRP, 1975
b Eisenbud and Gesell, 1997
c UNSCEAR, 2000
d ICRP, 1980

3.4 Artificial (man-made) sources of ionizing radiation

People are also exposed to man-made radiation from medical treatments and activities involving radioactive material. Radioisotopes are produced as a by-product of the operation of nuclear reactors, and by radioisotope generators like cyclotrons. Many man-made radioisotopes are used in the fields of nuclear medicine, biochemistry, the manufacturing industry and agriculture. The following are the most common sources:

- **Medical sources:** Radiation has many uses in medicine. The best-known application is in X-ray machines, which use radiation to find broken bones or to diagnose diseases. 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. A gamma camera (see Figure 7) is one piece of medical equipment commonly used in diagnosis .The CNSC regulates these applications of nuclear medicine, as well as related equipment. It also licenses reactors and particle accelerators that produce isotopes destined for medical and industrial applications.

Figure 7: A gamma camera used in nuclear medicine, for diagnosing illnesses

- **Industrial sources:** Radiation has various industrial uses, which range from nuclear gauges (see Figure 8) used in the building of roads to density gauges that measure the flow of material through pipes in factories. Radioactive materials are also used in smoke detectors and some glow-in-the dark exit signs, as well as to estimate reserves in oil fields. Other applications include sterilization, which is performed using large, heavily shielded irradiators. Industrial activities are licensed by the CNSC.

Figure 8: A portable nuclear gauge

- **Nuclear fuel cycle:** Nuclear power plants (NPPs) use uranium to produce a chain reaction that produces steam, which in turn drives turbines to produce electricity. As part of their normal activities, NPPs release small quantities of radioactive material in a controlled manner to the surrounding environment. These releases are regulated to ensure doses to the public are well below regulatory limits. Uranium mines (see Figure 9), fuel fabrication plants and radioactive waste facilities are also licensed so the radioactivity they release (that can contribute to public dose) can be controlled by the CNSC.

Figure 9: McClean Lake Uranium Mine (Saskatchewan)

- **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. People and the environment receive smaller and smaller doses from the fallout every year.

3.5 Striking a balance

Normally, there is little 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 – such as radon gas in the home – may be unacceptably high and need to be reduced.

The ionizing radiation that comes from man-made sources and activities is controlled more carefully. In these settings, a balance is struck between radiation's societal benefits and the risks it poses to people, health and the environment. Dose limits are set 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). There must also be a net benefit to support the use of radiation. For example, smoke detectors are permitted to use radioactive isotopes because smoke detectors save lives. Similarly, nuclear power plants provide us with electricity, while posing minimal risks that are carefully controlled.

4. Health Effects of Radiation Exposure

The word "safe" means different things to different people. For many, the idea of being safe is the absence of risk or harm. However, the reality is that almost everything we do presents a certain level of risk.

For example, speed limits on roads are set to maximize safety. Nevertheless, accidents occur even when drivers obey the speed limit. Despite this risk, we still drive.

Similar informed decisions are made when radiation is used. Radiation exposure carries a health risk. Understanding the risks helps the CNSC and other regulatory bodies establish dose limits and regulations that keep exposure at an acceptable or tolerable risk level, where it is unlikely to cause harm.

One significant advantage of radiation is that more is known about its associated health risks than about any other chemical or otherwise toxic agent. Since the early 20th century, radiation effects have been studied in depth, in both the laboratory and among human populations.

4.1 Epidemiological evidence

Studies on survivors of the atomic bombings of the cities of Hiroshima and Nagasaki in 1945 indicate that the principal long-term effect of radiation exposure is an increase in the frequency of cancer and leukemia.

Similar results have been found in these groups:

- people who have been exposed to radiation through medical treatments or diagnostic procedures
- early uranium mine workers
- workers who manufactured atomic weapons
- people exposed to radiation as a result of the Chernobyl nuclear accident
- people exposed to radon gas in their homes

Studies have shown that radiation will increase the frequency of some cancers that already occur naturally (or spontaneously), and that this increase is proportionate to the radiation dose; that is, the greater the dose, the greater the risk of cancer. These are referred to as stochastic effects (see section 4.3). However, studies to date have not shown that people chronically exposed to radiation at doses lower than about 100 millisieverts (mSv)[1] per year will experience an increase in cancer or other diseases.

The following hypotheses attempt to explain why we cannot see radiation effects at doses of less than 100 mSv per year:

- One possible explanation is a dose threshold below which no cancers are caused; for example, radium has a threshold of 10 Sv for bone cancer.
- Another hypothesis is that the incidence of cancer caused by low radiation doses is so low that it cannot be distinguished from natural (or spontaneous) occurrences of the same cancer. This hypothesis is supported by studies of the National Academy of Biological Effects of Ionizing Radiation (BEIR), the French Academy of Sciences and the International Commission on Radiation Protection (ICRP).

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[1] The sievert (Sv) is the unit used to express "equivalent dose" and "effective dose". It is equal to 1 joule/kilogram. The millisievert (mSv) is 1/1000 of a sievert

Scientists continue to try to detect the effects of low-dose radiation to support either of these potential explanations. In the meantime, the CNSC and other regulatory bodies take a cautious approach and assume that all radiation exposure carries some risk.

Most people who showed health effects in studies were exposed to relatively high doses (greater than 100 mSv) delivered over a very short period of time. This is known as “acute” exposure. Normally, workers and members of the public exposed to radiation from the nuclear industry receive much lower doses over a considerably longer period of time (years as opposed to seconds). This is known as “chronic” exposure. Acute radiation exposure is estimated to be about 1.5 to 2 times more likely to produce health effects than chronic exposure.

4.2 Cancer risk assessment

The ICRP has calculated the probability of fatal cancer by relying primarily on the assessment of radiation effects by scientific bodies such as UNSCEAR and BEIR. It then determined what it calls the overall “detriment” of radiation exposure. This includes:

- the probability of fatal cancer
- the probability of non-fatal cancer
- the probability of severe hereditary effects
- the length of life lost if the harm occurs

Using all these risks, the ICRP calculated an overall detriment of 0.042 (4.2%) per sievert for adult workers and 0.057 (5.7%) per sievert for the overall population (ICRP 103). The risk for the overall population is slightly higher than that of workers due to differences in certain variables, such as sex and age ranges, that were taken into account.

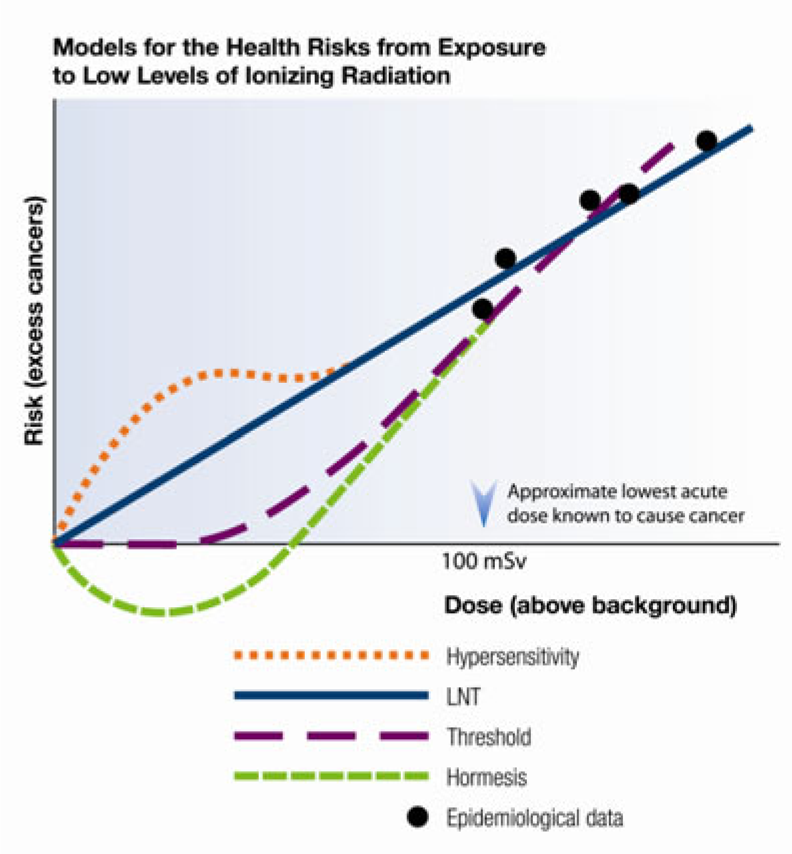
In considering where to set dose limits, the CNSC has largely adopted the ICRP’s recommendations. Dose limits are set at a level below which the risk is regarded as acceptable. However, as a prudent measure, it is assumed that every exposure to radiation, even if under the dose limit, carries some risk; therefore, regulations require to reduce all doses to levels that are ALARA. ALARA is not a dose limit, but a practice that aims to keep dose levels as far as possible below the regulatory limit – which, in Canada, is set at 1 mSv per year for the public. In fact, the total radiation dose attributable to the nuclear industry represents only a tiny fraction of that dose; i.e. in the range of 12–18 microsieverts (µSv)[2], which is thousands of times lower than the limit.

[2] Because doses to workers and the public are so low, most reporting and dose measurements use the terms millisievert (mSv) and microsievert (µSv) which are 1/1000 and 1/1,000,000 of a sievert, respectively. These smaller units of the sievert are more convenient to use in occupational and public settings.

The linear non-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.

Several other risk models exist (see Figure 10), each with advantages and disadvantages. They differ depending on the basis of their assumptions and whether they take uncertainty into account. The CNSC uses the LNT model in its approach to radiation protection and in setting appropriate regulations.

Figure 10: Models to estimate the health risks from exposure to low levels of ionizing radiation



4.3 How radiation affects cells

Radiation affects our health primarily through breakage of deoxyribonucleic acid (DNA) molecules. DNA is a long chain of amino acids whose pattern forms the blueprint on how a cell lives and functions, and radiation is able to break that chain. When it does, three things can happen:

1. **The DNA is repaired properly:**
   In this case, the cell is repaired properly and it continues to function normally. DNA breakage occurs normally every second of the day, and cells have a natural ability to repair that damage.

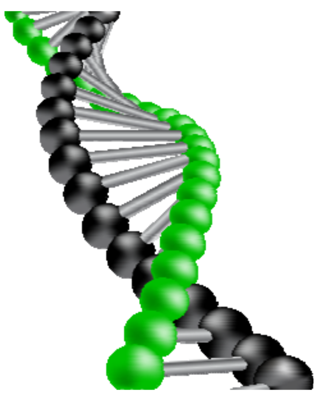
2. **The DNA damage is so severe that the cell dies (deterministic effects):**
   When the DNA or other critical parts of a cell receive a large dose of radiation, the cell may die or be damaged beyond repair. If this happens to a large number of cells in a tissue or organ, early radiation effects may occur. These early effects are called "deterministic effects" and their severity varies according to the radiation dose received. They can include burns, cataracts and, in extreme cases, death.

The first evidence of deterministic effects became apparent with early experimenters and users of radiation. They suffered severe skin and hand damage due to excessive radiation exposure. More recently, such effects were observed during the 1986 Chernobyl nuclear plant accident where more than 130 workers and firefighters received high radiation doses (800 to 16,000 mSv) and suffered severe radiation sickness. Two of the people exposed died within days of exposure, and close to 30 more workers and firefighters died within the first three months.

The CNSC and other international regulators have put measures in place – including stringent dose limits and databases to track radioactive sources – to mitigate the chances of the public or workers receiving radiation doses high enough to cause deterministic effects. The CNSC also has strict regulations on how nuclear substances and devices must be handled in Canada.

3. **The cell incorrectly repairs itself, but it continues to live (stochastic effects):**
In some cases, part of the DNA in the cell (see Figure 11) may be damaged by radiation and may not properly repair itself. The cell may continue to live and even reproduce itself. However, during that process, errors that have not been repaired in the DNA chain will also be present in the cell descendents and may disrupt these cells' functioning. This type of detrimental effect has a probability that is proportionate to the dose, and is called a "stochastic effect." With stochastic effects, the likelihood of effects increases as the dose increases. However, the timing of the effects or their severity does not depend on the dose.

Figure 11: A strand of DNA



DNA damage happens continuously in the human body. People experience about 15,000 DNA damage events that do not result in cell death, every second of every day. After a cell is damaged, its structure can change due to improper repair; this alteration could have no further effect, or it could result in effects, such as cancer and hereditary effects, which show up later in life.

If the DNA of sperm or egg cells is damaged, genetic damage occurs. This damage can result in a harmful characteristic that can be passed on from one generation to the next. Animal studies, such as those conducted on fruit flies by Hermann J. Muller in 1926, showed that radiation will cause genetic mutations. However, to date, genetic effects caused by radiation have not been observed in humans. This includes studies involving some 30,000 children of survivors of the atomic bombings of the Japanese cities of Hiroshima and Nagasaki, in 1945 (BEIR VII).

Table 3 summarizes the potential health effects associated with given radiation doses. Dose limits have also been included to illustrate how they protect workers and the public.

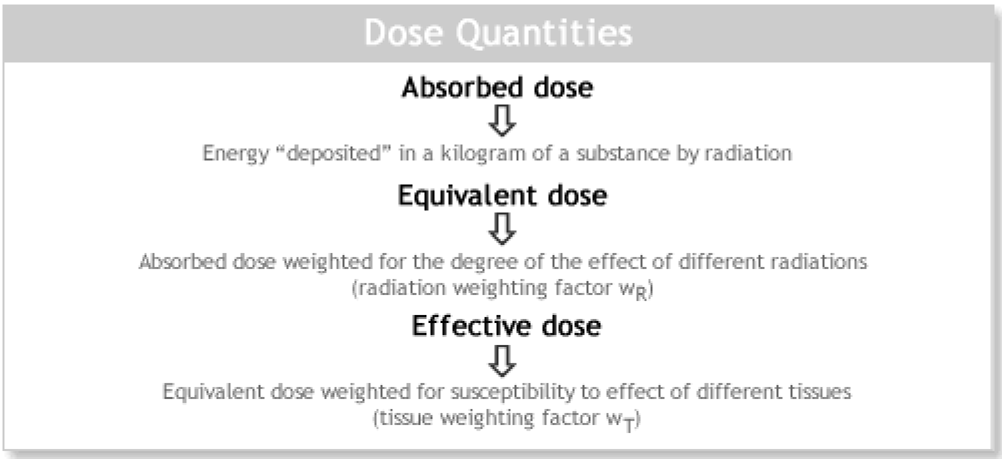
Table 3: Radiation doses, dose limits and potential health effects

Dose	Limit or Health Effect
More than 5,000 mSv	Dose that may lead to death when received all at once
1,000 mSv	Dose that may cause symptoms of radiation sickness (symptoms include tiredness and nausea) if received within 24 hours
100 mSv	Lowest acute dose known to cause cancer
30–100 mSv	Radiation dose from a full-body computed axial tomography (CAT) scan
50 mSv	Annual radiation dose limit for nuclear energy workers
1.8 mSv	Average annual Canadian natural background dose
1 mSv	Annual public radiation dose limit in Canada
0.1–0.12 mSv	Dose from lung X-ray
0.01 mSv	Dose from dental X-ray
0.01 mSv	Average annual dose due to air travel

5. Radiation Doses

For the purpose of radiation protection, dose quantities are expressed in three ways: absorbed, equivalent, and effective. Sections 5.1 to 5.3 describe these types of doses, respectively. Figure 12 presents an overview of the relationship between effective, equivalent and absorbed doses.

Figure 12: Relationship between effective, equivalent and absorbed doses



Section 5.4 presents typical radiation doses that could be expected in various scenarios, and section 5.5 discusses dose limits set by the CNSC.

5.1 Absorbed dose

When ionizing radiation penetrates the human body or an object, it deposits energy. The energy absorbed from exposure to radiation is called an absorbed dose. The absorbed dose is measured in a unit called the gray (Gy). A dose of one gray is equivalent to a unit of energy (joule) deposited in a kilogram of a substance.

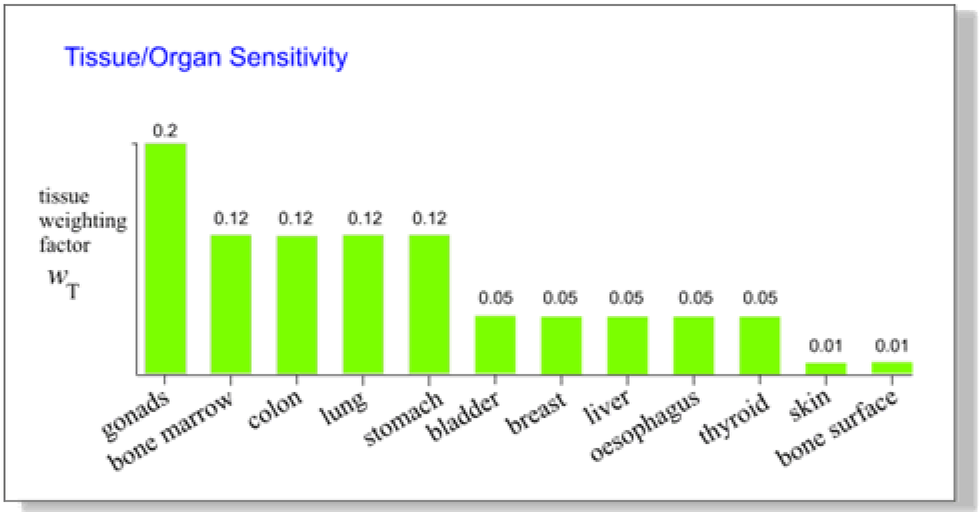
5.2 Equivalent dose

When radiation is absorbed in living matter, a biological effect may be observed. However, equal absorbed doses will not necessarily produce equal biological effects. The effect depends on the type of radiation (e.g., alpha, beta or gamma). For example, 1 Gy of alpha radiation is more harmful to a given tissue than 1 Gy of beta radiation. To obtain the equivalent dose, the absorbed dose is multiplied by a specified radiation weighting factor (w_R). A radiation weighting factor (w_R) is used to equate different types of radiation with different biological effectiveness. The equivalent dose is expressed in a measure called the sievert (Sv). This means that 1 Sv of alpha radiation will have the same biological effect as 1 Sv of beta radiation. In other words, the equivalent dose provides a single unit that accounts for the degree of harm that different types of radiation would cause to the same tissue.

5.3 Effective dose

Different tissues and organs have different radiation sensitivities (see Figure 13). For example, bone marrow is much more radiosensitive than muscle or nerve tissue. To obtain an indication of how exposure can affect overall health, the equivalent dose is multiplied by a tissue weighting factor (w_T) related to the risk for a particular tissue or organ. This multiplication provides the effective dose absorbed by the body. The unit used for effective dose is also the sievert.

Figure 13: Tissue weighting factors



Source: *Radiation Protection Regulations*.

For example, if someone's stomach and bladder are exposed separately to radiation, and the equivalent doses to the organs are 100 and 70 mSv respectively, the effective dose is: (100 mSv x 0.12) + (70 x 0.05) = 15.5 mSv. The risk of harmful effects from this radiation would be equal to a 15.5 mSv dose delivered uniformly throughout the whole body.

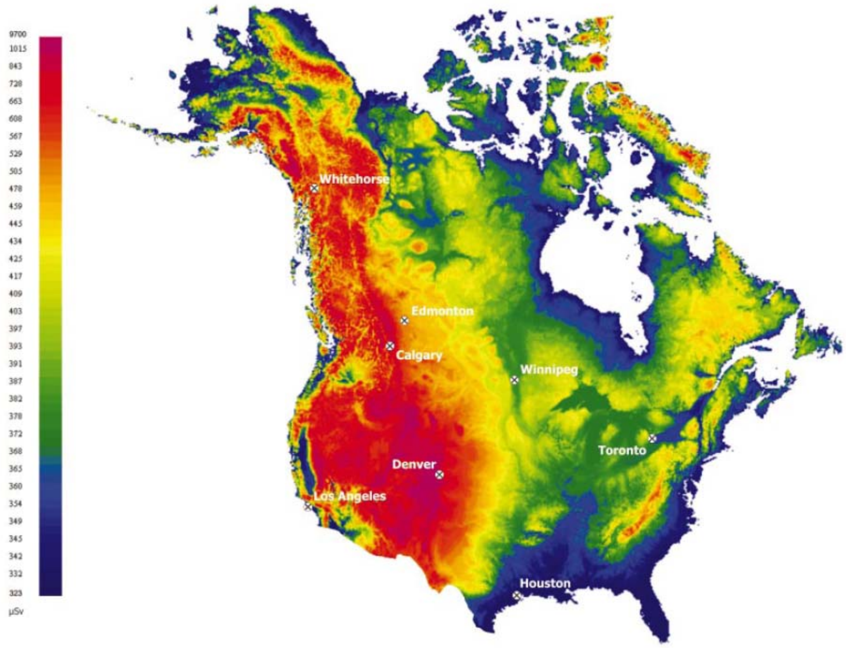
5.4 Typical radiation doses

5.4.1 Natural radiation

The total worldwide average effective dose from natural radiation is approximately 2.4 mSv per year; in Canada, the average effective dose is 1.8 mSv (see Table 4 and Figure 15). As discussed in section 3, dose can depend on the source of radiation:

- Cosmic radiation: Regions at higher altitudes receive more cosmic radiation. According to a recent study by Health Canada, the annual effective dose of radiation from cosmic rays in Vancouver, British Columbia, which is at sea level, is about 0.30 mSv. This compares to the top of Mount Lorne, Yukon, where at 2,000 m, a person would receive an annual dose of about 0.84 mSv. Flying in an airplane increases exposure to cosmic radiation, resulting in a further average dose of 0.01 mSv per Canadian per year. Figure 14 shows how levels of cosmic radiation vary with elevations above sea level and longitude and latitude.

Figure 14: Annual outdoor effective dose from cosmic radiation for North America (in microsieverts)



Source: Gratsky et al., 2004

- **Terrestrial radiation:** There are also natural sources of radiation in the ground, and some regions receive more terrestrial radiation from soils that contain greater quantities of uranium. The average effective dose from the radiation emitted from the soil (and the construction materials that come from the ground) is approximately 0.5 mSv per year. However, this dose varies depending on location and geology, with doses reaching as high as 260 mSv in Northern Iran or 90 mSv in Nigeria. In Canada, the estimated highest annual dose is approximately 2.3 mSv, as measured in the Northwest Territories.

- **Inhalation:** The earth's crust produces radon gas, which is present in the air we breathe. Radon has four decay products that will irradiate the lungs if inhaled. The worldwide average annual effective dose of radon radiation is approximately 1.3 mSv. A recent Health Canada survey on radon in homes reported that the radon levels in 93% of Canadian homes are below the current Canadian guideline of 200 Bq/m³.

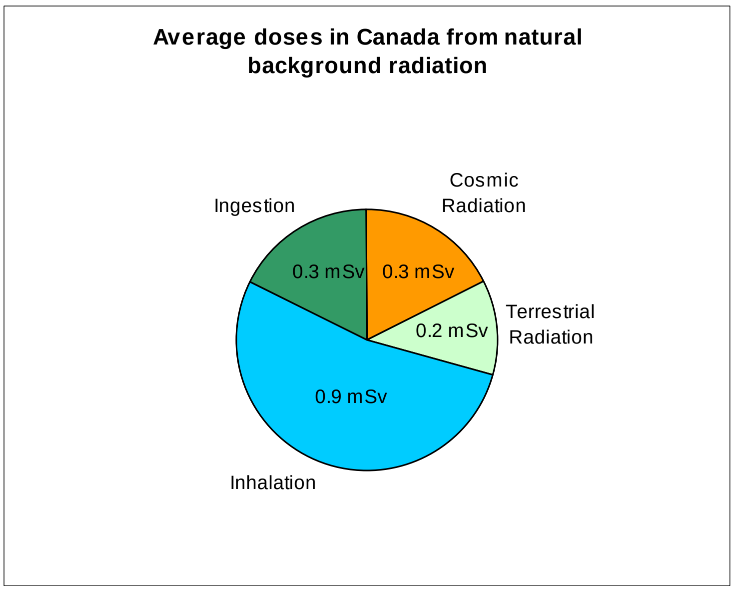
- **Ingestion:** Natural radiation from many sources enters our bodies through the food we eat, the air we breathe and the water we drink. Potassium-40 is the main source of internal irradiation (aside from radon decay). The average effective dose from these sources is approximately 0.3 mSv a year.

Table 4: Average effective dose in select Canadian cities compared to worldwide average

Radiation source	Worldwide average[1] (mSv)	Canada[2] (mSv)	Toronto[2] (mSv)	Winnipeg[2] (mSv)
Cosmic	0.4	0.3	0.3	0.4
Internal	0.3	0.3	0.3	0.3
Inhalation	1.3	0.9	0.8	3.2
External	0.5	0.2	0.2	0.2
Total	2.4	1.8	1.6	4.0

[1] UNSCEAR, 2010.
[2] Grasty and LaMarre, 2004.

Figure 15: Doses from natural background radiation in Canada



5.4.2 Man-made sources

Man-made sources of radiation (from commercial and industrial activities) account for approximately 0.2 µSv of our annual radiation exposure. X-rays and other diagnostic and therapeutic medical procedures (see Table 5) account for approximately 1.2 mSv a year (UNSCEAR 2000). Consumer products like tobacco and smoke detectors account for another 0.1 mSv of our exposure to radiation each year.

Table 5: Typical equivalent doses from various radiological examinations

Study type	Relevant organ	Dose (mSv)
Dental X-ray[1]	Brain	0.01
Chest X-ray[1]	Lung	0.1
Screening mammography[2]	Breast	3.0
Adult abdominal CT[2]	Stomach	10.0
Neonatal abdominal CT[2]	Stomach	20.0

[1]National Council on Radiation Protection and Measurements (NCRP) 2009
[2]Brenner and Hall, 2007

Overall, natural radiation accounts for approximately 60% of our annual radiation dose, with medical procedures accounting for the remaining 40%.

There is no difference between the effects caused by natural or man-made radiation.

5.5 Dose Limits

The CNSC sets dose limits for Canadian workers and the public. It does this by following the recommendations of the ICRP, which comprises some of the world's leading scientists and other professionals in the field of radiation protection, and also uses many of the standards and guides of the International Atomic Energy Agency (IAEA).

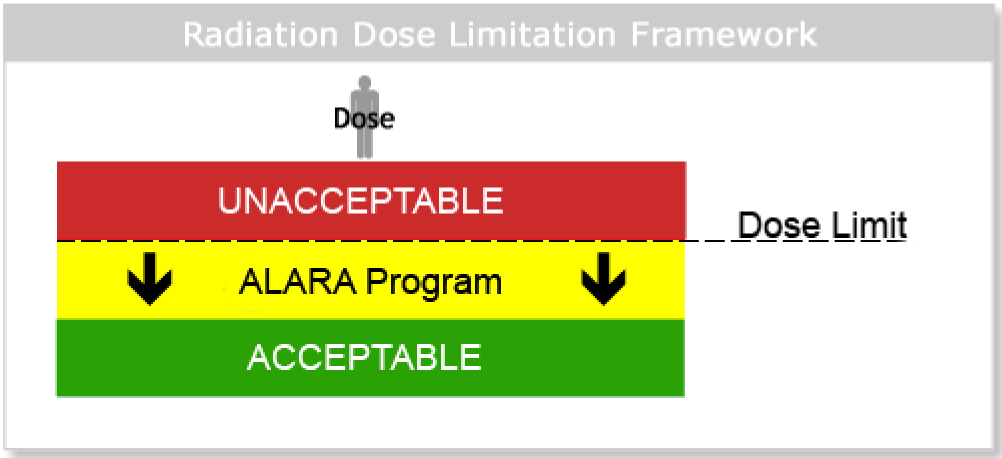
In Canada, the regulations, standards and practices to protect people and workers from radiation that are not regulated by the CNSC are implemented by Health Canada, Human Resources and Skills Development Canada, the Department of National Defence, and provincial/territorial governments.

In addition, the Federal Provincial Territorial Radiation Protection Committee (FPTRPC) develops guidelines for ionizing and non-ionizing radiation and works to harmonize radiation protection regulations across Canada. Co-chaired by the CNSC, Health Canada and the provinces, the FPTRPC provides a national forum for radiation protection issues.

For people who operate or work with nuclear energy, the regulated dose limit is set below the lower boundary of what is considered unacceptable exposure. For example, effective dose limits for nuclear energy workers are 50 mSv per year and 100 mSv over 5 years. Radiation exposures below an acute dose of approximately 100 mSv have not been shown to increase the risk of health effects such as cancer.

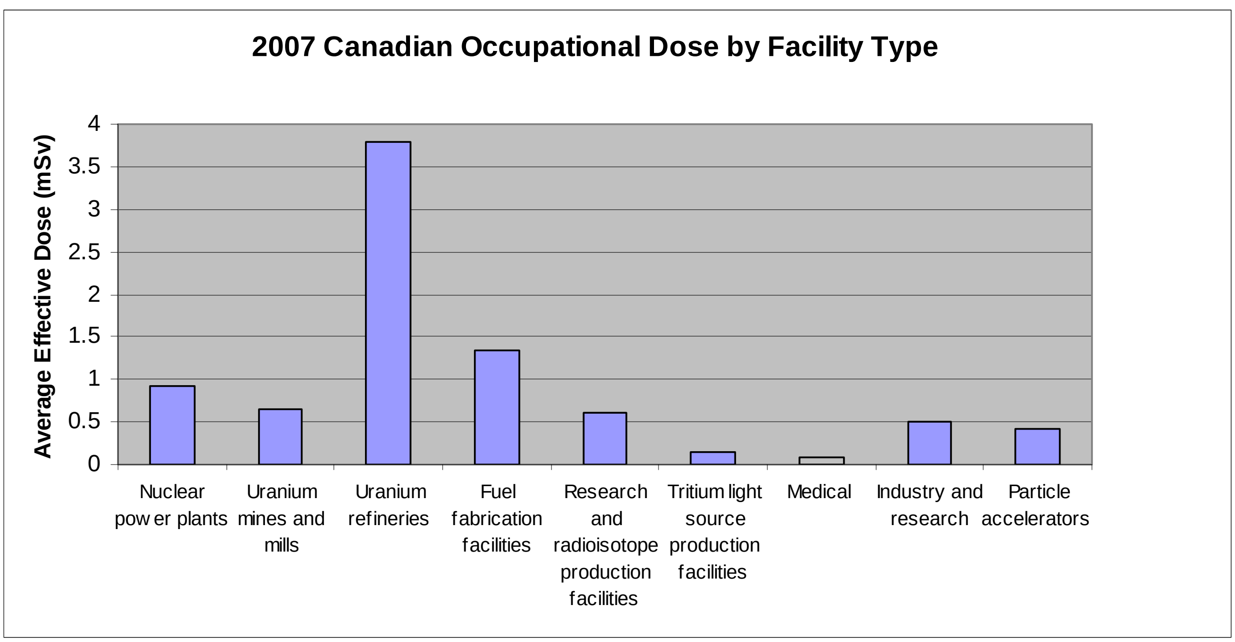
In addition, licensees must ensure that all doses are ALARA (see Figure 16).

Figure 16: Radiation dose limitation framework



Regular reporting and monitoring demonstrate that the average annual doses to workers at major Canadian nuclear facilities are approximately 1–2 mSv per year (see Figure 17)

Figure 17: Canadian occupational dose by facility type for 2007



*Data may include exposure from X-rays.
Source: National Dose Registry (Health Canada); based on most recently published data.

In Canada, the effective dose limit for the public is 1 mSv in one calendar year. Regular reporting and monitoring demonstrate that the annual effective dose to the public (from CNSC-licensed activities) ranges from 0.001 to 0.092 mSv per year. Table 6 lists the maximum annual dose to members of the public, as a result of airborne and waterborne emissions from various CNSC licensed facilities, by year. Doses as a result of airborne and waterborne emissions were not added together for Atomic Energy of Canada Limited (AECL) Chalk River Laboratories because these doses were for different representative exposed individuals from different populations.

Table 6: Maximum effective annual doses to members of the public by year, from airborne and waterborne emissions

Facility	**Maximum annual dose (mSv) to members of the public by year, from airborne and waterborne emissions**				
	2006	**2007**	**2008**	**2009**	**2010**
Nuclear generating stations					
Point Lepreau	0.0006	0.0007	0.0018	0.0004	0.0002
Gentilly-2	0.0007	0.0009	0.0006	0.0012	0.0010
Darlington	0.0011	0.0014	0.0013	0.0007	0.0006
Pickering	0.0028	0.0026	0.0041	0.0018	0.0010
Bruce	0.0025	0.0021	0.0027	0.0044	0.0029
AECL Chalk River Laboratories (airborne)	0.081	0.073	0.092	0.045	0.032
AECL Chalk River Laboratories (waterborne)*	0.027	0.014	0.013	0.0011	0.0004

Source: Licensee reports and environmental monitoring data, as submitted to the CNSC.

6. Regulating Radiation

The Canadian Nuclear Safety Commission (CNSC) regulates the use of nuclear energy and materials to protect the health, safety and security of Canadians and the environment; and to implement Canada's international commitments on the peaceful use of nuclear energy. The CNSC's mandate also includes disseminating objective scientific, technical and regulatory information to the public.

As Canada's nuclear regulator, the CNSC oversees all nuclear facilities and nuclear-related activities and applications. These include nuclear power plants, uranium mines and mills, processing and research facilities, radioactive waste and waste management facilities, and nuclear substances and radiation devices used in the medical and industrial sectors.

The CNSC has a strong licensing and compliance system to ensure that anyone using, possessing or storing nuclear substances and radiation devices does so in accordance with a licence and has implemented appropriate safety and security provisions. Over the years, these regulatory requirements have been strengthened as a result of increased knowledge about the effects of radiation.

6.1 Protecting Canadians

All nuclear facilities and activities in Canada are governed by the *Nuclear Safety and Control Act* (NSCA), which came into force in May 2000, replacing the former *Atomic Energy Control Act*. The NSCA and its Regulations are designed to protect the public, people who work in the nuclear sector, and our environment. The CNSC's role is to make sure the NSCA and its Regulations are followed.

The CNSC works with provincial and territorial regulatory bodies with respect to environmental and radiation protection. Many other federal bodies also play a role in protecting Canadians; the CNSC collaborates with Natural Resources Canada, Environment Canada, Health Canada, Fisheries and Oceans Canada, Transport Canada, National Defence and the Canadian Forces, and Foreign Affairs and International Trade Canada to regulate Canadian nuclear facilities and activities.

Canada's nuclear safety standards are benchmarked against international standards. To do this, the CNSC relies on the work of the International Atomic Energy Agency (IAEA) and other organizations such as the International Commission on Radiological Protection (ICRP), Health Canada and Environment Canada. Canadian scientists also participate on the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

With the cooperation of its member states, the IAEA publishes several international standards, including standards for nuclear non-proliferation. The CNSC's standards and best practices in this area respect those of the IAEA.

In the area of nuclear non-proliferation, the CNSC works on behalf of the Government of Canada to implement two policy objectives: to assure Canadians and the international community that our country's nuclear exports do not contribute to the development of nuclear weapons or nuclear explosive devices; and to promote a more effective and comprehensive international nuclear non-proliferation regime.

6.2 Protecting workers

The CNSC regulates Canadian nuclear facilities and their activities, with the goal of protecting the safety and health of workers. Nuclear facilities include power plants, uranium mines and mills, fuel fabrication facilities and those that perform processing and research. Regulated activities include security, dosimetry, packaging and transport of nuclear substances, and the import and export of nuclear substances.

An estimated 40,000 people work in Canada's nuclear industry, and many more work in jobs that expose them to radiation every day. There are two ways that Canadian workers are exposed to radiation: they work with sources of man-made radiation (for example, in the nuclear industry, health care, research institutions or manufacturing), or they are exposed to elevated levels of natural radiation (for example, in mining, air crews and construction).

The Canadian *Radiation Protection Regulations* set limits on the amount of radiation to which the public and nuclear energy workers (NEWs) can be exposed. These restrictions are referred to as "dose limits" (see section 5.5) and are set below the threshold that would be expected to result in adverse health effects. The Regulations also require licensees to implement radiation protection programs that limit workers' exposure to ionizing radiation below the dose limits and to a level that is as low as reasonably achievable, social and economic factors being taken into account (see Figure 17).

Nuclear facilities in Canada must have qualified personnel to carry out operations that comply with the NSCA and its Regulations. The CNSC also verifies that radiation protection personnel are capable of performing the duties specified in their licences.

Monitoring doses

All CNSC licensees are required to determine the radiation doses received by their workers in the course of their job-related duties. In addition, if effective doses are expected to exceed 5 mSv in one year, licensees are required to use licensed dosimetry services.

2011 Nuclear Accident in Fukushima

On March 11, 2011, a magnitude 9.0 earthquake, followed by a devastating tsunami, struck Japan. It left an estimated 25,000 people dead or missing, about half a million homes destroyed or damaged, and 560 square kilometres inundated.

The combined impact of the earthquake and tsunami on the Fukushima Daiichi nuclear power plant caused one of the world's worst-ever nuclear accidents. In the hours and days that followed, three of the plant's six reactors overheated and suffered damage. Workers battled extraordinary conditions to prevent or delay radioactive releases over the surrounding region and into the sea. It is a tribute to their efforts that releases were delayed sufficiently to enable the nearby population to be evacuated despite widespread damage to the local infrastructure.

As the accident unfolded, the evacuation zone was expanded and people in a wider area were asked to shelter indoors. Widespread radiation monitoring and control of food production and distribution were implemented. Going forward, this monitoring and control of food and water supplies will need to be maintained, perhaps for many years.

The nuclear event prompted many countries to evaluate the safety of their nuclear infrastructure. The Canadian Nuclear Safety Commission launched a review of all major nuclear facilities in Canada. Led by a multidisciplinary CNSC task force, the review confirmed Canadian facilities' ability to withstand and respond to credible external events, such as earthquakes. A four-year action plan is underway to strengthen defences and further minimize risk, including improvements to existing *Radiation Protection Regulations* to integrate new requirements for emergency situations.

The CNSC grants licences to dosimetry services that ensure accurate and precise dose measurements. Dosimetry service licensees are obligated to regularly file information with the National Dose Registry (NDR). The NDR, operated by Health Canada's Radiation Protection Bureau, includes radiation dose records from all commercial dosimetry processors, nuclear power generating facilities, Atomic Energy of Canada Limited (AECL), and uranium mines. The registry also includes dose records from X-ray users such as dentists, radiologists and chiropractors, as well as radon progeny exposures from some mines that are not licensed by the CNSC.

7. Summary

Radiation has always been present and is all around us. Life has evolved in a world containing significant levels of ionizing radiation. We are also exposed to man-made radiation from sources such as medical treatments and activities involving radioactive material.

The health effects of radiation are well understood. Since the early 20th century, radiation's effects have been studied in depth, in both the laboratory and among human populations. Because of the known health risks of radiation, it must be carefully used and strictly controlled. A balance must be struck between radiation's societal benefits and the risks that radiation poses to people, health and the environment.

The CNSC regulates the use of nuclear energy and materials to protect the health, safety and security of Canadians and the environment; and to implement Canada's international commitments on the peaceful use of nuclear energy. It also sets dose limits to prevent workers and the public from excessive radiation exposure.

Understanding radiation risks helps the CNSC and other regulatory bodies set dose limits and regulations that limit exposure to safe levels. Licensees are required to keep all radiation doses at levels that are ALARA. Environmental radiation monitoring programs are carried out near nuclear power stations and at other nuclear facilities across Canada to protect people and the environment from the potential effects of radiation.

Government and industry programs routinely measure levels of radioactivity in the air, drinking water, surface water, soil and food. With this data, the CNSC can verify that standards are being met, evaluate the effectiveness of controls, and determine environmental trends.

For more than 65 years, Canada has enjoyed an internationally recognized track record for nuclear safety. The CNSC is proud to have contributed to that safety record by providing strong regulatory oversight. Canadians can be assured that the CNSC will remain vigilant in overseeing Canada's nuclear industry, so that health and safety are never compromised.

Glossary

absorbed dose: The amount of energy absorbed by irradiated matter per unit mass. This reflects the amount of energy deposited by ionizing radiation as it passes through a medium (such as air, water or living tissue) Unit: gray. Symbol: Gy.

activity: The number of nuclear disintegrations in a radioactive material per unit time. Used as a measure of the amount of a radionuclide present. Unit: becquerel. Symbol: Bq. 1 Bq = 1 disintegration per second.

acute dose: Exposure received within a short period of time (hours or days). The term "acute" refers only to the duration of exposure and does not imply anything about a dose's magnitude.

ALARA (as low as reasonably achievable): An optimization principle in radiation protection used to keep individual, workplace and public doses as low as reasonably achievable, social and economic factors being taken into account. ALARA is not a dose limit; it is a practice that aims to keep dose levels low.

alpha particle: A positively charged particle consisting of two protons and two neutrons that is emitted by the nuclei of some radioactive elements as they decay. An alpha particle is relatively large and may be stopped by skin or a sheet of paper. An alpha particle is identical to a helium nucleus.

amino acids: The building blocks of proteins. They are organic molecules containing both an amino group (NH_2) and a carboxyl group (COOH).

artificial radiation: Radiation created by human activities and that adds to naturally occurring background radiation.

atom: Unit of matter consisting of a single nucleus surrounded by a number of electrons (equal to the number of protons in the nucleus). The atom is the smallest portion of an element that can combine chemically with other atoms. All atoms other than hydrogen-1 also have neutrons in the nucleus.

atomic mass: The mass of an isotope of an element expressed in atomic mass units, which are defined as 1/12 the mass of an atom of carbon-12. An atomic mass of 1 is equivalent to about 1.66×10^{-27}kg.

atomic number: The number of protons in the nucleus of an atom. Symbol: Z.

becquerel: The SI unit of activity of a radioactive substance. The becquerel supersedes the non-SI unit of the curie (Ci). Symbol: Bq. 1 Bq is equal to one nuclear disintegration (decay) per second; 1 Bq = 27 pCi (2.7×10^{-11} Ci) and 1 Ci = 3.7×10^{10} Bq. (see "SI")

beta particle: An electron (negatively charged particle) or a positron (positively charged particle) that is emitted by the nuclei of some radioactive elements as they decay. A beta particle is relatively small and may be stopped by a sheet of aluminum or plastic a few millimetres thick.

bioassay (radiological): Any procedure used to determine the nature, activity, location or retention of radionuclides in the body by direct measurement *(in vivo)* or by analysis of material excreted or otherwise removed from the body *(in vitro).*

cancer: A large group of diseases caused by an uncontrolled division of abnormal cells.

cataract: A condition that occurs when the normally clear lens inside the eye becomes cloudy or dark and causes blurred vision that is not correctable by ordinary glasses. The most important factor in cataract formation is increasing age, but there are additional factors, including smoking, diabetes and excessive exposure to sunlight and radiation.

cell: The smallest structural and functional unit of all known living organisms

chain reaction: See nuclear chain reaction.

chronic dose: Exposure persisting over time (months or years). The term "chronic" relates only to the duration of exposure, and does not imply anything about a dose's magnitude.

cosmic rays: A source of natural background radiation that originates in outer space. These rays are composed of penetrating ionizing radiation (both particulate and electromagnetic) and can have energies of more than 10^{20} eV. The Earth's magnetic field deflects charged cosmic rays towards the poles.

decay (radioactive): The transformation of a radioactive nuclide into a different nuclide (or nuclides) by the spontaneous emission of radiation such as alpha, beta, or gamma rays, or by electron capture. The end product is a less energetic, more stable nucleus. Each decay process has a definite half-life.

deterministic effects: Changes in cells and tissues that are certain to occur after an acute dose of radiation (above a threshold value of at least 1000 mSv), below which the radiation effect is not detected. The severity of health effects – such as skin reddening, burns, and hair loss – increases with the radiation dose received.

deoxyribonucleic acid (DNA): The molecular compound in the nucleus of a cell that forms the blueprint for the structure and function of the cell.

deuterium: An isotope of hydrogen with one proton and one neutron in its nucleus.

dose: A general term used to refer to the amount of energy absorbed by tissue from ionizing radiation. Absorbed dose is measured in grays (Gy), where 1 gray is equal to 1 joule per kilogram. See also absorbed dose, equivalent dose and effective dose.

dose limits: Limits on effective and equivalent dose, prescribed by the *Radiation Protection Regulations*. These limits are in place to minimize the risk of adverse health effects caused by radiation exposure associated with CNSC-licensed activities.

dosimeter: A portable device for measuring doses of ionizing radiation. A dosimeter is normally worn or carried by an individual.

dosimetry: A scientific subspecialty in radiation protection and medical physics that focuses on measuring, estimating, calculating and recording the internal and external doses from ionizing radiation.

effective dose: A measure of dose designed to reflect the amount of radiation detriment. It is obtained by multiplying the equivalent dose to each tissue or organ by an appropriate tissue weighting factor and summing the products. Unit: sievert (Sv).

electron capture: A radioactive decay process in which an orbital electron is captured by the nucleus and merges with it. After the process, the mass number is unchanged, but the atomic number is decreased by one because a proton has been converted to a neutron.

electromagnetic radiation: A traveling wave motion resulting from changing electric and magnetic fields. The spectrum of familiar electromagnetic radiation includes the range of: X-rays (and gamma rays) of short wavelength and high energy; ultraviolet, visible, and infrared light; and radar and radio waves of relatively long wavelength and low energy. High-energy electromagnetic radiation may behave as particles (photons), according to quantum mechanics.

electron: A stable elementary particle with a negative electric charge of 1.6×10^{-19} coulombs and a mass of 9.1×10^{-31} kg.

element: a chemical substance consisting of one specific type of atom distinguished by its atomic number (the number of protons in the nucleus). Atoms of one element may have a different number of neutrons.

emissions: Nuclear substances and materials released to the environment (for example, as a liquid or gas) from CNSC-licensed activities.

energy: A physical quantity that describes the amount of work that can be performed by a given force, where mass-energy is conserved. Different forms of energy include kinetic, potential, thermal, gravitational, sound, light, elastic, nuclear and electromagnetic.

epidemiology: The study of the distribution and determinants of diseases in human populations. It serves as the foundation for public health and preventive medicine and is based on observations, rather than on experiments.

equivalent dose: A measure of the dose to a tissue or organ designed to reflect the amount of harm caused to the tissue or organ. It is obtained by multiplying the absorbed dose by a radiation weighting factor, to allow for how different types of radiation have different levels of biological effectiveness in causing harm to tissue. Unit: sievert (Sv).

electron-volt (eV): A unit of energy equal to approximately 1.6×10^{-19} joules.

fission: See nuclear fission.

gamma rays: Penetrating electromagnetic radiation emitted by an atomic nucleus during radioactive decay; a high-energy, short wavelength form of ionizing radiation.

gray (Gy): The SI unit of absorbed dose. Unit: 1 joule/kilogram, but has restricted use.

half-life (radiological): The time required for a given radionuclide's activity to decrease by half through radioactive decay. Symbol $t_{1/2}$. Atoms with shorter half-lives are more radioactive than those with longer half-lives.

heavy water: Water containing an elevated concentration of molecules with deuterium (heavy hydrogen) atoms. Heavy water is used as a moderator in some reactors because it slows down neutrons effectively and also has a low probability of absorbing neutrons.

***in vitro*:** A term used to describe an experiment performed outside of a living organism, in a controlled environment, such as in a test tube or Petri dish. Latin for "*within the glass*".

***in vivo*:** A term used to describe an experiment using a whole, living organism as opposed to a partial or dead organism, or an *in vitro* controlled environment. Latin for "*within the living*".

ion: An atom, molecule or fragment of a molecule that has acquired an electrical charge through the loss or capture of electrons.

ionizing radiation: A form of radiation that is capable of adding or removing electrons as it passes through matter (such as air, water, or living tissue). Examples are alpha particles, gamma rays, X-rays and neutrons.

isotopes: Two or more forms of a given element with identical atomic numbers (the same number of protons in their nuclei) and very similar chemical properties, but different atomic masses (different numbers of neutrons in their nuclei) and distinct physical properties. For example, uranium has 16 different isotopes, denoted by U-234, U-235, U-236, U-238, etc.

leukemia: Cancer of the white blood cells (leukocytes).

licensed dosimetry service: A company or institution that has a CNSC licence to measure radiation doses to workers.

light water: Ordinary water composed of molecules with two hydrogen atoms and one oxygen atom (H_20). Distinct from heavy water, which is composed of molecules of one hydrogen atom, one deterium atom (symbol D) and one oxygen atom (HDO).

linear non-threshold model (LNT): A dose-response model based on the assumption that, in the low dose range, radiation doses greater than zero will increase the risk of excess cancer and/or heritable disease in a simple proportionate manner.

man-made radiation: See artificial radiation.

mass: See atomic mass.

mass number: The number of neutrons and protons in the nucleus of an atom.

microsievert: One one-millionth (1/1,000,000) of a sievert (see sievert). Symbol: µSv.

millisievert: One one-thousandth (1/1000) of a sievert (see sievert). Symbol: mSv.

moderator: A material, such as ordinary water or heavy water, which is used in a reactor to slow down high-velocity neutrons, thus increasing the likelihood of fission.

molecule: A group of atoms chemically bonded to each other.

mutation: A chemical change in the DNA in the nucleus of a cell. Mutations in sperm or egg cells or their precursors may lead to inherited effects in children or later generations. Mutations in somatic cells (non-reproductive cells) may lead to effects such as cancer.

natural background radiation: A constant source of radiation present in the environment and emitted from a variety of sources. These sources include ambient air (radon), terrestrial sources (radioactive elements in the soil), cosmic rays, and internal sources (food and drink). The total worldwide average effective dose from natural radiation is approximately 2.4 mSv per year (UNSCEAR 2008).

neutron: An uncharged elementary particle found in the nucleus of an atom (with the exception of hydrogen), with a mass similar to that of a proton, of about 1.67×10^{-27} kg.

neutron capture: A type of nuclear reaction in which an atom's nucleus absorbs a free neutron and they merge to form a heavier nucleus. Neutrons can react with a nucleus in several ways, each ending with a different product.

neutron radiation: Radiation that occurs when neutrons are ejected from the nucleus by nuclear fission (i.e., splitting the atom) and other processes. Neutron radiation is absorbed by materials with a high concentration of hydrogen atoms, such as paraffin wax and plastics.

non-ionizing radiation: Radiation with lower energy than ionizing radiation; i.e., it does not possess enough energy to produce ions. Examples are visible light, infrared, and radio waves.

nuclear chain reaction: An example of nuclear fission, where a neutron being ejected from one fissioned atom will cause another atom to fission, ejecting more neutrons.

nuclear fission: The splitting of a heavy nucleus into two (or, rarely, more than two) parts with comparable masses; usually accompanied by the emission of neutrons and gamma radiation.

nuclear energy worker (NEW): A person who is required, in the course of his or her business or occupation in connection with a nuclear substance or nuclear facility, to perform duties in such circumstances that there is a reasonable probability of receiving a radiation dose that is greater than the CNSC's prescribed limit for the general public (1 mSv/year).

nuclear non-proliferation: Efforts to prevent the development of nuclear weapons or other nuclear explosive devices. The CNSC is responsible for implementing Canada's nuclear non-proliferation policy, which has two broad, long-standing objectives:

1. to assure Canadians and the international community that Canada's nuclear exports do not contribute to the developments of nuclear weapons or other nuclear explosive devices
2. to promote a more effective and comprehensive international nuclear non-proliferation regime

nuclear reactor: A device in which a nuclear fission chain reaction occurs under controlled conditions in a self-sustaining chain reaction, in order to generate energy or produce useful radiation.

nuclear substances: Isotopes that emit radiation.

nucleus (of an atom): The positively charged central portion of an atom that contains protons and neutrons. The total number of protons and neutrons is called the mass number.

nuclide: A general term that refers to all known isotopes, both stable and unstable.

optimization: The process of determining what level of protection and safety makes exposures and the probability and magnitude of potential exposures, as low as reasonably achievable (ALARA), with economic and social factors being taken into account, as recommended by the International Commission on Radiological Protection.

photon: A quantum (smallest possible amount) of energy emitted in the form of electromagnetic radiation.

positron: An elementary particle with a positive electric charge of 1.6×10^{-19} coulombs and a mass of 9.1×10^{-31} kg (i.e. similar to an electron, but positively charged).

positron emission: A type of radioactive decay in which a proton is converted to a neutron, and it releases a positron. In those instances where the neutron-to-proton ratio is too low and alpha emission is not energetically possible, the nucleus may, under certain conditions, attain stability by emitting a positron.

proton: A stable elementary particle found in the nucleus of an atom with a positive electric charge of 1.6 x 10^{-19} coulombs and a mass of 1.67 x 10^{-27} kg.

radiation: Energy travelling in the form of waves or particles. The term radiation, as used in this document, implies ionizing radiation, unless otherwise specified.

radiation device: As defined in the *Nuclear Substances and Radiation Devices Regulations*: (*a*) a device that contains more than the exemption quantity of a nuclear substance and that enables the nuclear substance to be used for its radiation properties; and (*b*) a device that contains a radium luminous compound.

radiation sickness: The complex of symptoms characterizing the disease known as radiation injury, resulting from excessive exposure of the whole body (or a large par of it) to ionizing radiation. The earliest of these symptoms are nausea, fatigue, vomiting, and diarrhea, which may be followed by loss of hair, hemorrhage, inflammation of the mouth and throat, and general loss of energy.

radiation weighting factor: A factor by which the absorbed dose in a tissue or organ is multiplied to reflect the relative biological effectiveness of the radiation in inducing stochastic effects at low doses, the result being the equivalent dose.

radioactive: Exhibiting radioactivity; spontaneously emitting energy in the form of ionizing radiation (such as alpha and beta particles, neutrons or gamma rays) as a result of the decay of an unstable atom.

radioisotope: An isotope of an element that undergoes spontaneous decay and emits radiation.

radionuclide: A radioactive nuclide.

radiosensitive: A qualitative term to differentiate cells, tissues, and organs that are more susceptible to radiation damage than others.

radon: A chemical element with symbol Rn and atomic number 86. Radon is a colorless, odorless, tasteless, naturally occurring, radioactive noble gas that is formed from the decay of radium. It is one of the heaviest substances that remains a gas under normal conditions and is a health hazard.

radon decay products: A term used to refer collectively to the immediate products of the radon decay chain. They include polonium-218, lead-214, bismuth-214, and polonium-214, and have an average combined half-life of about 30 minutes. Also called radon progeny and radon daughters.

relative biological effectiveness: A relative measure of the effectiveness of different radiation types at inducing a specified health effect. It is expressed as the inverse ratio of the absorbed doses of two different radiation types that would produce the same biological end point.

SI: The international system of units, abbreviated SI from French: *Système international d'unités.*

sievert: The SI unit of “equivalent dose” and “effective dose”. It is equal to 1 joule/kilogram. It replaces the older radiation unit of the rem. Multiples of the sievert (Symbol Sv) used in practice include the millisievert (mSv; 1/1000 of 1 Sv) and the microsievert (μSv; 1/1,000,000 of 1 Sv).

stochastic effects: A term used to group radiation-induced health effects (such as cancer or inheritable diseases) that have a statistical risk. For these diseases, the probability of their occurrence increases proportionally with the radiation dose received: the higher the dose, the higher the probability of occurrence. The severity of the effect is not proportional to the dose.

tissue weighting factor: The factor by which equivalent dose is weighted for the purpose of determining effective dose. The tissue weighting factor for an organ or tissue represents the relative contribution of that organ or tissue to the total detriment due to effects resulting from uniform irradiation of the whole body.

tritiated water: Tritiated water (HTO) is a water molecule where one or both of the hydrogen molecules has been replaced by a tritium atom.

tritium: A radioactive isotope of hydrogen with two neutrons and one proton in its nucleus. Tritium decays by emitting an electron (beta radiation) and has a half-life of 12.3 years. Tritium occurs both naturally and as a by-product in nuclear reactors.

X-ray: Ionizing electromagnetic radiation emitted by an atom when it has been bombarded with electrons. X-rays differ from gamma rays in that they are emitted from the orbiting electrons, not the nucleus and are typically lower in energy than gamma radiation. X-rays are produced mainly by artificial means, rather than from radioactive substances, and are used mainly for medical purposes.

Acronyms and Units

AECL: Atomic Energy of Canada Limited
ALARA: as low as reasonably achievable
BEIR: National Academy of Biological Effects of Ionizing Radiation
Bq: becquerel
CAT: computed axial tomography
CNSC: Canadian Nuclear Safety Commission
DNA: deoxyribonucleic acid
ELF: extremely low frequency
FPTRPC: Federal Provincial Territorial Radiation Protection Committee
Gy: gray
H_2O: chemical symbol for water, also seen as HOH
HTO: chemical symbol for tritiated water
IAEA: International Atomic Energy Agency
ICRP: International Commission on Radiological Protection
ICRU: International Commission on Radiation Units and Measurements
J: joule
LNT: linear non-threshold
mSv: millisievert
NCRP: National Council on Radiation Protection and Measurements
NDR: National Dose Registry
NEW: nuclear energy worker
NPP: nuclear power plant
NSCA: *Nuclear Safety and Control Act*
Sv: sievert
$t_{½}$: Symbol for half-life of a radionuclide
UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation
w_R: radiation weighting factor
w_T: tissue weighting factor
μSv: microsievert
UV: ultraviolet

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