ENVIRONMENTAL IONIZING RADIATION

L. de Saint-Georges
Department of Radioprotection, CEN/SCK, Mol, Belgium.

Keywords: Ionizing radiation, radioactivity, health effects, radiation dose, radioactive waste, waste transport.

Contents

1. Introduction

Radiation is energy transfer. When radiation has sufficient energy to remove an orbital

UNESCO – EOLSS SAMPLE CHAPTERS

electron from its atom, an ionized atom is formed, and radiation with the capacity to do this is called ionizing radiation. Although the effects of radiation are on interactions at the atomic level, chemical changes that can impair the function of molecules can result from these atomic changes. Experimental evidence indicates that the key target of radiation is the DNA molecule, the molecule that contains genetic information. All the molecules in every cell of the body are potential targets for ionization, but the final effect of radiation will be dramatic only if the function impaired is a function that is critical for life.

Ionizing radiation has existed naturally in the environment since the earth's formation long before life appeared. Life has developed DNA repair mechanisms that have made evolution possible in such a radioactive world. In addition to the natural background ionizing radiation, some man-made ionizing radiation also contributes to the radiation sources to which people are exposed. Nobody can escape exposure to the natural background radiation that effects all life, and the positive or negative effects of this exposure are discussed below. Unlike natural background radiation, however, artificial radiation exposure can be regulated.

2. Radiation

2.1 Definition

Everything around us, visible or not, can be classified either as matter or energy. Matter is characterized by its mass, which is the quantity of matter. According to the mass-equivalence relationship proposed by Einstein, mass also represents the energy equivalence of that matter.
Energy can be best defined as the ability to do work, and there are many different types of energy: potential, kinetic, chemical, thermal, electrical, electromagnetic, and nuclear energy are the most familiar forms. Matter can be transformed into energy and energy can easily be transformed from one type to another. This is how the nuclear energy from a power plant starts as matter and is ultimately transformed into electrical energy, which can be further transformed into electromagnetic energy like the energy in a bulb that lights a room or in an X-ray radiographic device in a radiology facility.

Energy that is emitted and transferred is called radiation, and matter that intercepts radiation and absorbs part or all of it is said to be exposed or irradiated. The sun, for example, transfers all the energy that sustains life on earth through electromagnetic radiation.

The amount energy in any type of energy cited above may vary greatly as different types of energy have different work capacities. Electromagnetic radiation carries a very large range of different energies depending on the radiation frequency or the inverse of the radiation wavelength. We are most familiar with radiation with a wavelength of 10^{-6} to 10^{-7} m because these wavelengths constitute visible light. Longer wavelengths include microwaves and radio waves, whereas shorter wavelengths with higher energy levels include UV light, X-rays and gamma rays.

Just as an atom represents the smallest component of an element of matter, the smallest

UNESCO – EOLSS SAMPLE CHAPTERS

quantity of electromagnetic radiation is called a "photon". There are light photons, x-ray photons, gamma ray photons, and other types of photons as well, and these photons are characterized by their different energy.

2.2 Ionizing Radiation

A photon that can transfer enough energy to one electron to remove it from its atomic orbital will cause the ionization of an atom and the formation of an ion pair. To form an ion pair, the removed electron constitutes the negative ion, the anion, and the remaining atom is the positive ion or cation.

Radiation with sufficient energy to ionize matter is called ionizing radiation, and x-rays and gamma rays are the only known types of electromagnetic ionizing radiation. The only difference between x-rays and gamma rays lies is their origin. X-rays are emitted from the electron cloud of a stimulated atom, whereas gamma rays come from the nucleus of a radioactive atom. At the same energy level, however, there is no other way to differentiate one from the other, and the same applies for electron and beta particles. Beta particles are different from electrons due to their origin within the nucleus. In Figure 1, the electromagnetic spectrum is shown. The energy is directly proportional to the frequency and inversely proportional to the wavelength of the radiation.

Besides x-ray and gamma ray electromagnetic radiation, some particles with high kinetic energies (particles traveling at very high speeds) are also capable of inducing ionization. This includes alpha and beta particle radiation, which can cause ionization when emitted.

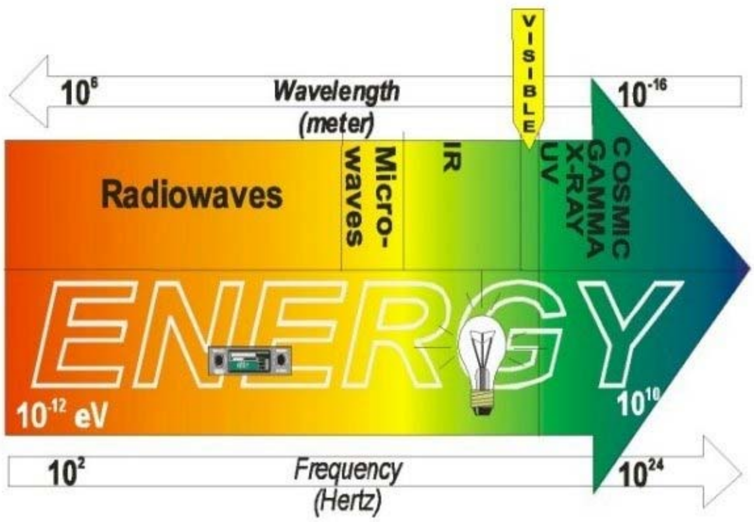

Figure 1. The Electromagnetic Spectrum

2.3 Units

Radiation is a transfer of energy, and the importance of irradiation is due to the energy that is transferred. The unit of energy that is absorbed, *the absorbed dose*, is the "Gray" (Gy). A dose of 1 Gy corresponds to a transfer of 1 joule of energy per Kg^{-1} of irradiated matter. The Gray is a very important unit, but unfortunately is not sufficient to account for all the phenomena that must be considered in radiology. The different radiation types (x-ray, alpha radiation, etc) do not distribute energy the same way in their target, and the consequences to exposing living tissues to radiation can therefore vary greatly. For example, if the same amount of energy is deposited in the same tissue, alpha radiation will result in more severe damage that gamma radiation. This is called different linear energy transfer (LET), and low LET radiation causes few ionizations, while high LET radiation causes many ionizations along it path. As the LET increases, the ability to produce biologic damage also increases. This effect is quantitatively described by the RBE (Relative Biological Effectiveness), which uses the following equation to measure the effectiveness of different types of radiation at inducing a particular biological effect:

$$\text{RBE} = \frac{\text{Dose of standard radiation necessary to produce a given effect}}{\text{Dose of test radiation necessary to produce the same effect}}$$

In utilizing RBE, the effectiveness of a given type of experimental radiation dose is determined and then compared to the dose of a 250 kilovolt x-ray dose (reference radiation dose) necessary to obtain the same effect.

To account for these differences in energy transfer, another unit, the "sievert" (Sv), was introduced. The sievert is calculated by multiplying the Gray by a weighting factor (W), which is characteristic of the radiation type. The equation is1Sv = W x 1 Gy, and the W values have been estimated for the different types of radiation. A dose expressed in sieverts always has the same detrimental exposure effects regardless of how the dose has been delivered.

Because of their different metabolic activities, the different organs of a living being do not have the same radio-sensitivity, and it follows that the same dose will not present the same risk to different exposed tissues. The **effective dose** is the dose equivalent corrected by a risk coefficient characteristic of the organ being considered, and the effective dose is also expressed in sieverts. The effective dose expressed in sieverts is a very important measurement that covers all exposure modes, applies to all types of ionizing radiation and is valid for whole or partial body exposure.

Some other units are also used for particular purposes. After intake of a radioactive element, the **committed dose** will indicate the dose received by an organ or a tissue until total decay of the radionuclide occurs. If the radionuclide (see *natural radiation sources*) has a very long decay that exceeds life expectancy, an arbitrary estimated life expectancy of 50 years for an adult and 70 years for a child is considered. The **committed equivalent dose** concerns a particular tissue, and the **committed effective dose** concerns the whole body. The **collective dose, collective equivalent dose** or **collective effective dose** are the total dose received by a population. This can be calculated by finding the sum of individual exposures or by finding the product of the number of irradiated individuals and the average individual irradiation dose.

Ionizing radiation also creates electric charges in the air. The measure of the electric

UNESCO – EOLSS SAMPLE CHAPTERS

charge per unit mass of air, **Coulomb/kg (C/Kg)**, is a direct measure of the *exposure intensity* from a radiation source.

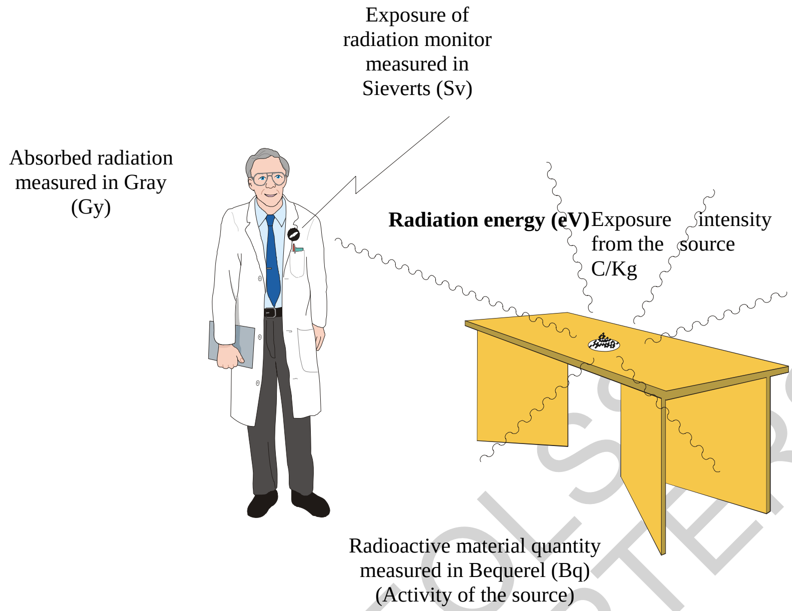

Figure 2. Radiological units of the International system (SI)

The **bequerel (Bq)** is a very small unit that represents the **quantity of matter** that undergoes one disintegration per second, so it expresses the activity of a radiation source. It is not affected by the nature of the disintegration, and it does not provide any information on the type or the energy of the ray emitted by a radioactive material. The human body has an activity of about 8000 Bq.

The energy carried by electromagnetic radiation is measured in **electron volts (eV).** One eV corresponds to the energy of an electron that is accelerated by an electric potential of one volt. The measured energy levels are very high, so it is better to express them in kilo electron volts (KeV, which is 1000 eV) or Mega electron volts (MeV, which is 10^6 eV).

Today, the scientific community has largely adopted the International System (SI) of units and the gray, sievert, bequerel and coulomb.Kg^{-1} now replace the rad, rem, curie and roentgen. However, because these units are still found in relevant literature, it is worth knowing the conversion equations with the SI units (Table 1).

Former units	SI units	Conversion
Roentgen (R)	C Kg^{-1}	1R = 2.58 x 10^{-4} C Kg^{-1}
Rad	Gray (Gy)	1 Rad = 10^{-2} Gray
Rem	Sievert (Sv)	1 Rem = 10^{-2} Sv
Curie (Ci)	Bequerel (Bq)	1 Ci = 3.7 x 10^{10} Bq

Table 1. Units Relevant to Radiation Sources and Conversions

UNESCO – EOLSS SAMPLE CHAPTERS

3. Sources of Ionizing Radiation

We are living in a world in which radiation, including ionizing radiation, is and has always been omnipresent. Radiation is part of our natural environment, and it is only very recently, since about 100 years ago, that other sources of man-made radiation were progressively developed and added to the natural background radiation.

For an individual, all radiation sources, both natural and man-made, contribute to a total average annual radiation dose of about 2 mSv (see *natural radiation sources)*. About 88% of this total comes from natural sources, and of the 12% left, the largest part, 11%, is due to medical exposure. All other sources contribute about 1% of individual radiation exposure altogether.

However, these values are averages and need to be adjusted according to individual lifestyle and residence location. For example, healthy people who are not undergoing medical care that involves the use of ionizing radiation will receive 99% of their annual dose from the natural sources. People living in the mountains or traveling frequently on jet airplanes cruising at high altitudes are exposed to more cosmic radiation than others.

Data obtained from radiotherapy facilities indicates that high radiation doses contribute significantly to the average annual radiation exposure of the population, but in medical cases the benefit that the patient gets from radiation exposure always exceeds the possible radiation risk to which he will be exposed by the treatment.

3.1 Natural Radiation Sources

Of the 103 different known atoms, 91 are present in the natural environment. Some of these exist in different isotopic forms that differ only by the neutron content of their nuclei, and about 300 natural nuclides exist. Of these 300 nuclides, 70 are unstable. They emit gamma rays and subatomic particles like alpha and beta particles, neutrons and other rare nuclear fragments.

When nuclides emit ionizing radiation, they are called radionuclides, and the naturally occurring radionuclides are also called the primordial radionuclides. Some primordial radionuclides have become undetectable due to their constant decay. This constant decay can occur when the decay of a particular existing primordial radionuclide exceeds the life of the earth itself, or when the nuclide is constantly recreated as a by-product of the decay of other nuclides.

Radionuclides have a limited lifetime, and their radioactivity naturally decreases exponentially with time (Figure 2). For convenience, the radioactive decay of a radionuclide is described by its half-life, also known as its period, which is the time required for a 50% decrease in its radioactivity.

The half-life of a radioactive substance can vary from a fraction of a second to several million years. For example, the half-life of natural uranium (U^{238}, which has a period of 4.5 billion years), helped in determining the birth date of the Earth.

UNESCO – EOLSS
SAMPLE CHAPTERS

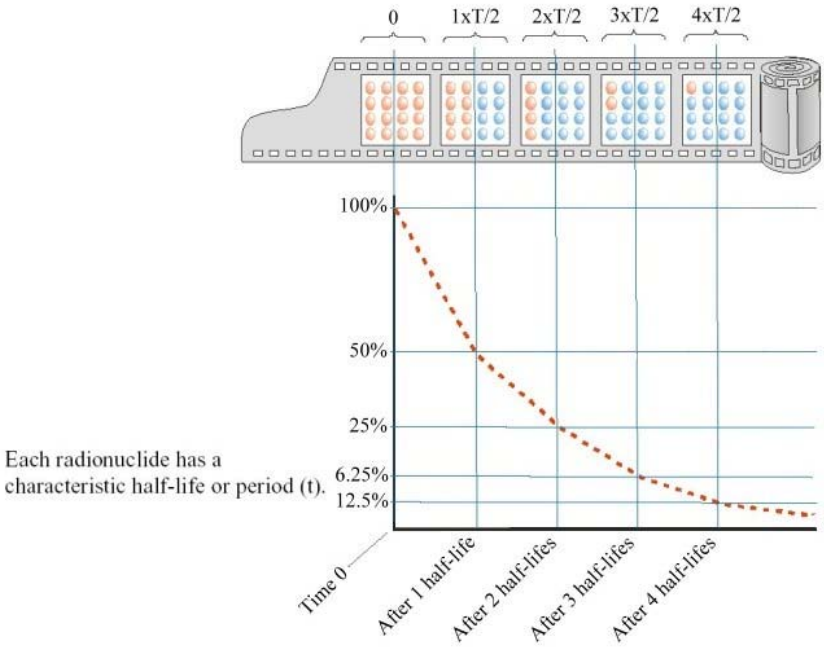

Figure 3. The number of radioactive atoms that exist over the course of time creates an exponential decay curve.

Natural radiation exposure comes from cosmic radiation, from the atmosphere, from our diet, from the soil and even from building materials. Everybody is exposed to natural radiation, which for most people constitutes the highest contribution to their annual dose. For some, natural radiation even constitutes all of their annual radiation exposure.

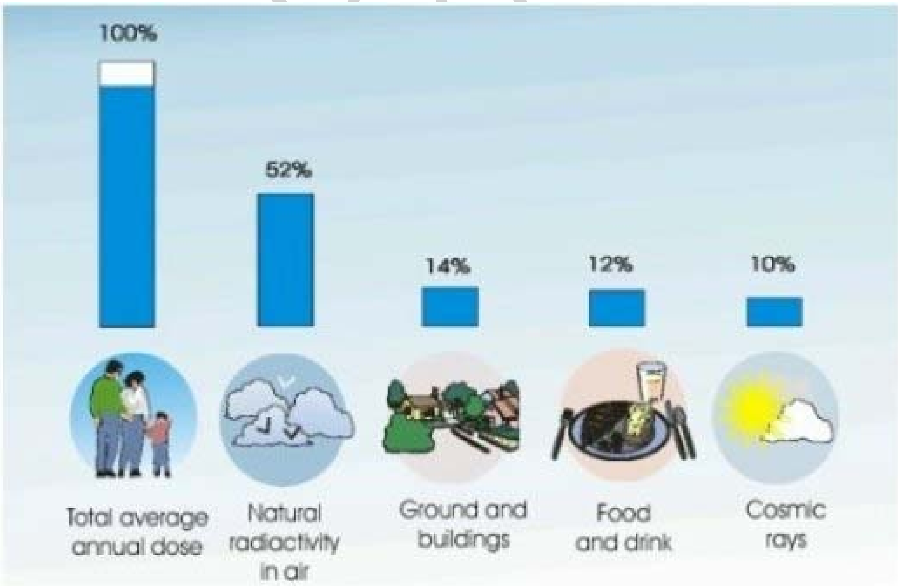

Figure 4. Partition of the average exposure to natural sources of radiation. The total natural source exposure represents circa 88% of the total annual dose

The average worldwide exposure, determined by finding the sum of the exposure from the various natural sources, is estimated to be 2.2 mSv.

3.2 Cosmic Rays

Radiation doses from *cosmic rays* increase with altitude and latitude (towards the poles). A cosmic ray is a flux of a particle traveling through space with very high speed. The magnetic terrestrial field around the earth forms a magnetic shield that helps, to a certain extent, to protect the earth from cosmic rays. Due to the penetrating power of cosmic rays, however, little can be done to reduce the amount that reaches Earth's surface.

3.3 Atmospheric Exposure

The air we breathe contains many natural radionuclides that disintegrate in our lungs daily, giving off alpha or beta particles and some gamma rays. Radon and thoron gas, for example, which are products of uranium and thorium decay, are dispersed in the air. Their concentration in the atmosphere, though very low, varies greatly depending on the local geology of a particular location, and in poorly ventilated buildings the concentration can increase. Radon exposure is the main natural source of human irradiation.

3.4 Food and Drinks

Food and drinks that humans ingest are slightly radioactive because of the trace presence of potassium-40, which is the major source of internal irradiation by food. Potassium-40 is present in the soil, and it becomes part of the food chain when it is dissolved in water and incorporated by plants. All the natural radionuclides are also present in seawater and are concentrated by marine organisms. There are few possibilities to reduce exposure to natural radioactivity through one's diet, but the dose received from the diet is very small and presents no health risk.

3.5 Ground and Building Materials

Nobody can escape exposure to the gamma rays emitted by the radioactive materials present in the ground. Building materials that are extracted from the ground are radioactive, so people are irradiated indoors as well as outdoors by radiation called telluric radiation. In some circumstances, enhanced exposure to natural radiation sources can occur. This is especially true for workers in industries involved in mineral processing.

-
-
-

TO ACCESS ALL THE **22 PAGES** OF THIS CHAPTER,
Visit: http://www.eolss.net/Eolss-sampleAllChapter.aspx

UNESCO – EOLSS SAMPLE CHAPTERS

Bibliography

Health effects of exposure to low levels of ionizing Radiation. National Research Council, BEIR V, National Academy Press, Washington D.C. 1990, 421 pp. [This book release a follow up on the health effect associated with radiation exposure]

IARC Monographs on the evaluation of carcinogenic risks to humans. Volume 75, ionizing radiation, part 1: x- and gamma- radiation, and neutrons. World Health Organization, International Agency for Research on Cancer, 2000, 491 pp. [One of the most comprehensive references on the evaluation to carcinogenic risk associated to ionizing radiation exposure]

ICRP Publication 60, 1990. Recommendations of the International Commission on Radiological Protection, Pergamon Press, 1991. [This book is intended to be a help to regulatory and advisory agencies, at national and international levels, by providing guidance on the fundamental principles on which appropriate radiological protection can be based]

Ionizing Radiation, Effects of low doses. ONDRAF/NIRAS Brussels 1998 –228 pp. [This work reviews the basic physical, biological and epidemiological aspects of radiation exposure and protection]

Radiation Protection, Safeguarding Europe's Citizens – EUR 18760. Office for official publications of the European communities, 1999 – 56 pp. [Booklet with very concise and accessible informations on Radiation Protection]

Radiation and You, P. Saunders, 1990. Office for Official Publications of the European Communities, Luxembourg. 24 pp. [Booklet with very concise and accessible information on Radiation Protection]

UNSCEAR, Sources and effects of ionizing radiation, 1993 Report. [One of the most complete reference about the sources and the effect of ionizing radiation]

Annex A: Exposures from natural sources of radiation

Annex B: Exposures from man-made sources of radiation

Annex C: Medical radiation exposure

Annex D: Occupational radiation exposure

Annex E: Mechanisms of Radiation oncogenesis

Annex F: Influence of dose and dose rate on stochastic effects on radiation

Biographical Sketch

Louis de Saint-Georges obtained a PhD in Biology at the University of Louvain (UCL), Belgium, were he was a teaching assistant. His first research activity at the Laboratory of Embryology and Comparative Anatomy was on morphogenesis, cell-to-cell interactions in the first developmental stage of the amphibian embryo. As head of the electron microscopy laboratory of the radiobiology department at the Nuclear Energy study Center (CEN/SCK) his research efforts have been on radiation-induced pneumonitis and murine radiation-induced leukemias. From 1988 to 1990, he was a research associate at the Radiobiology Department of the University of Utah, USA. As a senior scientist in the radioprotection department of the CEN/SCK, his current research activity concerns radiosensitivity of the organism in development with special emphasis on the developing brain. Particular attention is paid to radiation-induced apoptotic response to low level doses of ionizing radiation.

UNESCO – EOLSS SAMPLE CHAPTERS