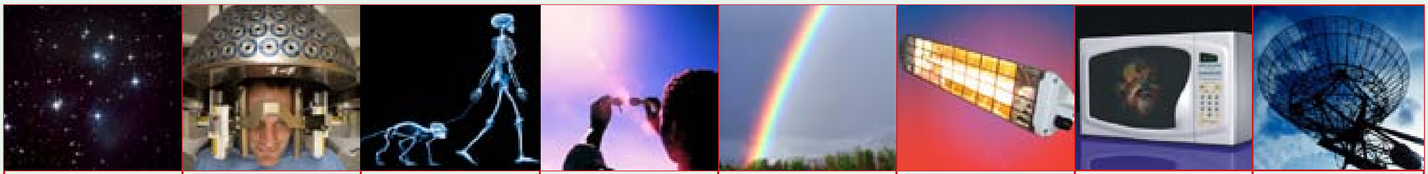
Radiation & Radioactivity

World Nuclear Association

"Life on earth has developed with an ever present background of radiation. It is not something new, invented by the wit of man: radiation has always been there."

Eric J Hall, Professor of Radiology, College of Physicians and Surgeons, Columbia University, New York, in his book Radiation and Life.



COSMIC	GAMMA	X RAYS	ULTRA VIOLET	VISIBLE LIGHT	INFRA RED	MICROWAVES	RADIO

← High Frequency THE ENERGY SPECTRUM Low Frequency →

Radiation is energy travelling through space. Sunshine is one of the most familiar forms of radiation. It delivers light, heat and suntans. We control our exposure to it with sunglasses, shade, hats, clothes and sunscreen.

There would be no life on Earth without lots of sunlight, but we have increasingly recognised that too much of it on our persons is not a good thing. Sunshine consists of radiation in a range of wavelengths from long-wave infra-red to short-wavelength ultraviolet, which creates the hazard. Beyond ultraviolet are higher energy kinds of radiation which are used in medicine and which we all get in low doses from space, from the air, and from the earth. Collectively we can refer to these kinds of radiation as **ionising radiation**. It can cause damage to matter, particularly living tissue. At high levels it is therefore dangerous, so it is necessary to control our exposure.

Living things have evolved in an environment which has significant levels of ionising radiation. Furthermore, many of us owe our lives and health to such radiation produced artificially. Medical and dental X-rays discern hidden problems. Other kinds of ionising radiation are used to diagnose ailments, and some people are treated with radiation to cure disease. We all benefit from a multitude of products and services made possible by the careful use of such radiation.

Background radiation is ionising radiation which is naturally and inevitably present in our environment. Levels of this can vary greatly. People living in granite areas or on mineralised sands receive more terrestrial radiation than others, while people living or working at high altitudes receive more cosmic radiation. A lot of our natural exposure is due to radon, a gas which seeps from the Earth's crust and is present in the air we breathe.

UNSTABLE ATOMS

Ionising radiation comes from atoms, the basic building blocks of matter. Each element exists in the form of atoms with several different sized nuclei, called isotopes.

Most atoms are stable; a carbon-12 atom for example remains a carbon-12 atom forever, and an oxygen-16 atom remains an oxygen-16 atom forever. But certain atoms change or disintegrate into totally new atoms. These kinds of atoms are said to be 'unstable' or 'radioactive'. An unstable atom has excess internal energy, with the result that the nucleus can undergo a spontaneous change towards a more stable form. This is called 'radioactive decay'.

Unstable isotopes (which are thus radioactive) are called radioisotopes. Some elements, eg uranium, have no stable isotopes.

ATOMIC DECAY

When an atom of a radioisotope decays, it gives off some of its excess energy as radiation in the form of gamma rays or fast-moving sub-atomic particles. If it decays with emission of an alpha or beta particle, it becomes a new element. One can describe the emissions as gamma, beta and alpha radiation. All the time, the atom is progressing in one or more steps towards a stable state where it is no longer radioactive.

Another source of nuclear radioactivity is when one form of a radioisotope changes into another form, or isomer, releasing a gamma ray in the process. The excited form is signified with an "m" (meta) beside its atomic number, eg technetium-99m (Tc-99m) decays to Tc-99. Gamma rays are often emitted with alpha or beta radiation also, as the nucleus decays to a less excited state.

Apart from the normal measures of mass and volume, the amount of radioactive material is given in becquerel (Bq), a measure which enables us to compare the typical radioactivity of some natural and other materials. A becquerel is one atomic decay per second[1].

MEASURING RADIOACTIVITY

The becquerel (symbol Bq) is the unit of radioactivity. One Bq is defined as the activity of a quantity of radioactive material in which one nucleus decays per second. The becquerel is named for Henri Becquerel, who shared a Nobel Prize with Pierre and Marie Curie for their work in discovering radioactivity.

As there are many atoms in any substance the decay of one nucleus per second represents a very low level of radioactivity. For more radioactive substances or for much larger quantities multipliers are used. A thousand becquerels is a kilobecquerel (KBq), a million becquerels is a megabecquerel (MBq), a million million Becquerels is a Terabecquerel (TBq).

Radioactivity of some natural and other materials

1 adult human (100 Bq/kg)	7000 Bq
1 kg of coffee	1000 Bq
1 kg superphosphate fertiliser	5000 Bq
The air in a 100 square metre Australian home (radon)	3000 Bq
1 household smoke detector (with americium)	30 000 Bq
Radioisotope for medical diagnosis	70 MBq
Radioisotope source for medical therapy	100 000 000 MBq
1 kg 50-year old vitrified high-level nuclear waste	10 000 000 MBq
1 luminous EXIT sign (1970s)	1 000 000 MBq
1 kg uranium	25 MBq
1 kg uranium ore (Canadian, 15%U)	25 MBq
1 kg uranium ore (Australian, 0.3%U)	500 000 Bq
1 kg low-level radioactive waste	1 MBq
1 kg of coal ash	2000 Bq
1 kg of granite	1000 Bq

NB. Though the intrinsic radioactivity of the actual uranium is the same, the radiation dose received by someone handling a kilogram of high-grade uranium ore will be much greater than for the same exposure to a kilogram of separated uranium, since the ore contains a number of short-lived decay products (see section on Radioactive Decay).

[1] A former unit of (radio)activity is the Curie – 1 Bq is 27 x 10^{-12} curies.

Ionising Radiation

Here we are concerned mainly with ionising radiation from the atomic nucleus. It occurs in two forms, rays and particles, at the high frequency end of the energy spectrum.

Ionising radiation produces electrically-charged particles called ions in the materials it strikes. This process is called ionisation. In the large chemical molecules of which all living things are made the changes caused may be biologically important. There are several types of ionising radiation:

ALPHA PARTICLES consist of two protons and two neutrons, in the form of atomic nuclei. They thus have a positive electrical charge and are emitted from naturally occurring heavy elements such as uranium and radium, as well as from some man-made elements. Because of their relatively large size, alpha particles collide readily with matter and lose their energy quickly. They therefore have little penetrating power and can be stopped by the first layer of skin or a sheet of paper.

However, if alpha sources are taken into the body, for example by breathing or swallowing radioactive dust, alpha particles can affect the body's cells. Because they give up their energy over a relatively short distance, alpha particles inside the body can inflict more severe biological damage than other types of radiation.

Uranium 238 (U238) Radioactive Decay

type of radiation	nuclide	half-life
α	uranium-238	4.47 billion years
β	thorium-234	24.1 days
β	protactinium -234m	1.17 minutes
α	uranium-234	245000 years
α	thorium-230	8000 years
α	radium-226	1600 years
α	radon-222	3.823 days
α	polonium-218	3.05 minutes
β	lead-214	26.8 minutes
β	bismuth-214	19.7 minutes
α	polonium-214	0.000164 seconds
β	lead-210	22.3 years
β	bismuth-210	5.01 days
α	polonium-210	138.4 days
	lead-206	stable

MEASURING IONISING RADIATION - GRAYS AND SIEVERTS

The human senses cannot detect radiation or discern whether a material is radioactive. However, a variety of instruments can detect and measure radiation reliably and accurately. The amount of ionising radiation, or 'dose', received by a person is measured in terms of the energy absorbed in the body tissue, and is expressed in **gray**. One gray (Gy) is one joule deposited per kilogram of mass.

Equal exposure to different types of radiation expressed as gray do not however necessarily produce equal biological effects. One gray of alpha radiation, for example, will have a greater effect than one gray of beta radiation. When we talk about radiation effects, we therefore express the radiation as effective dose, in a unit called the **sievert (Sv)**.

Regardless of the type of radiation, one sievert (Sv) of radiation produces the same biological effect.

Smaller quantities are expressed in 'millisievert' (one thousandth) or 'microsievert' (one millionth) of a sievert. We will use the most common unit, millisievert (mSv), here.

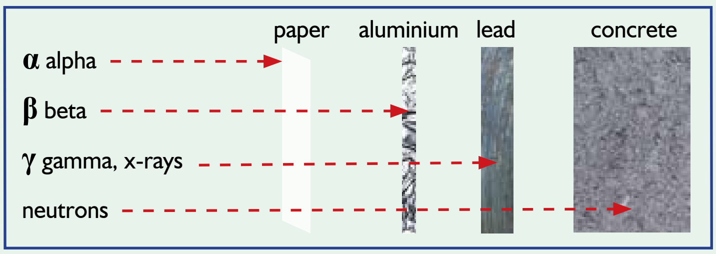
BETA PARTICLES are fast-moving electrons ejected from the nuclei of many kinds of atoms. These particles are much smaller than alpha particles and can penetrate up to 1 to 2 centimetres of water or human flesh. They can be stopped by a sheet of aluminium a few millimetres thick.

GAMMA RAYS, AND X-RAYS like light, represent energy transmitted in a wave without the movement of material, just as heat and light from a fire or the sun travels through space. X-rays and gamma rays are virtually identical except that X-rays are generally produced artificially rather than coming from the atomic nucleus. But unlike light, these rays have great penetrating power and can pass through the human body. Mass in the form of concrete, lead or water are used to shield us from them.

COSMIC RADIATION consists of very energetic particles, mostly protons, which bombard the earth from outer space. It is more intense at higher altitudes than at sea level where the earth's atmosphere is most dense and gives the greatest protection.

NEUTRONS are particles which are also very penetrating. On Earth they mostly come from the splitting, or fissioning, of certain atoms inside a nuclear reactor. Water and concrete are the most commonly used shields against neutron radiation from the core of the nuclear reactor.

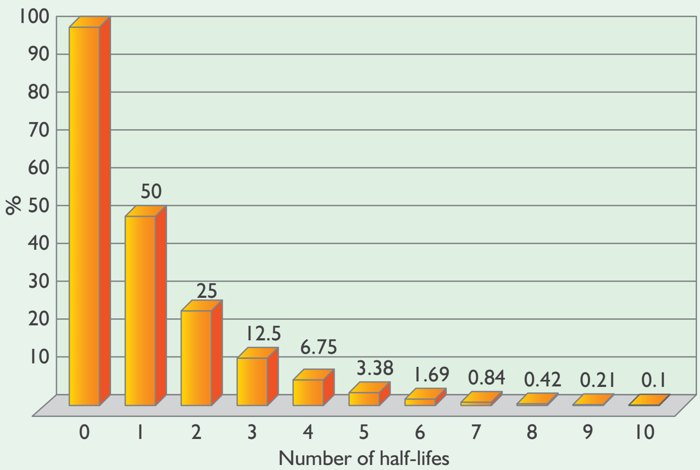
It is important to understand that alpha, beta, gamma and X-radiation does not cause the body or any other material to become radioactive. However, most materials in their natural state (including body tissue) contain measurable amounts of radioactivity.



HALF-LIFE

Atoms in a radioactive substance decay in a random fashion but at a characteristic rate. The length of time this takes, the number of steps required and the kinds of radiation released at each step are well known.

The half-life is the time taken for half of the atoms of a radioactive substance to decay. Half-lives can range from less than a millionth of a second to millions of years depending on the element concerned. After one half-life the level of radioactivity of a substance is halved, after two half-lives it is reduced to one quarter, after three half-lives to one-eighth and so on.



All uranium atoms are mildly radioactive and decay through a number of steps on the way to becoming stable lead. Each step has a half-life, and a characteristic type of radiation. The shorter-lived each kind of radioisotope in the decay series, the more radiation it emits per unit mass. Much of the natural radioactivity in rocks and soil comes from the decay of uranium-238 (U-238) and its daughter products.

What are health risks from Ionising Radiation?

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It has been known for many years that large doses of ionising radiation, very much larger than background levels, can cause a measurable increase in cancers and leukemias ('cancer of the blood') after some years delay. It must also be assumed, because of experiments on plants and animals, that ionising radiation can also cause genetic mutations that affect future generations, although there has been no evidence of radiation-induced mutation in humans. At very high levels, radiation can cause sickness and death within weeks of exposure.

The degree of damage caused by radiation depends on many factors – dose, dose rate, type of radiation, the part of the body exposed, age and health, for example. Embryos including the human fetus are particularly sensitive to radiation damage.

But what are the chances of developing cancer from low doses of radiation? The prevailing assumption is that any dose of radiation, no matter how small, involves a possibility of risk to human health. However there is no scientific evidence of risk at doses below about 50 millisievert in a short time or about 100 millisievert per year. Dose rates greater than 50 mSv/yr arise from natural background levels in several parts of the world but do not cause any discernible harm to local populations. At lower doses and dose rates, up to at least 10 millisievert per year, the evidence suggests that beneficial effects are as likely as adverse ones.

Above about 100 mSv, the probability of cancer (rather than the severity of illness) increases with dose. The estimated risk of fatal cancer is 5 of every 100 persons exposed to a short-term dose of 1000 mSv (ie. if the normal incidence of fatal cancer were 25%, this dose would increase it to 30%).If doses greater than 1000 mSv occur over a long period they are less likely to have early health effects but they create a definite risk that cancer will develop many years later.

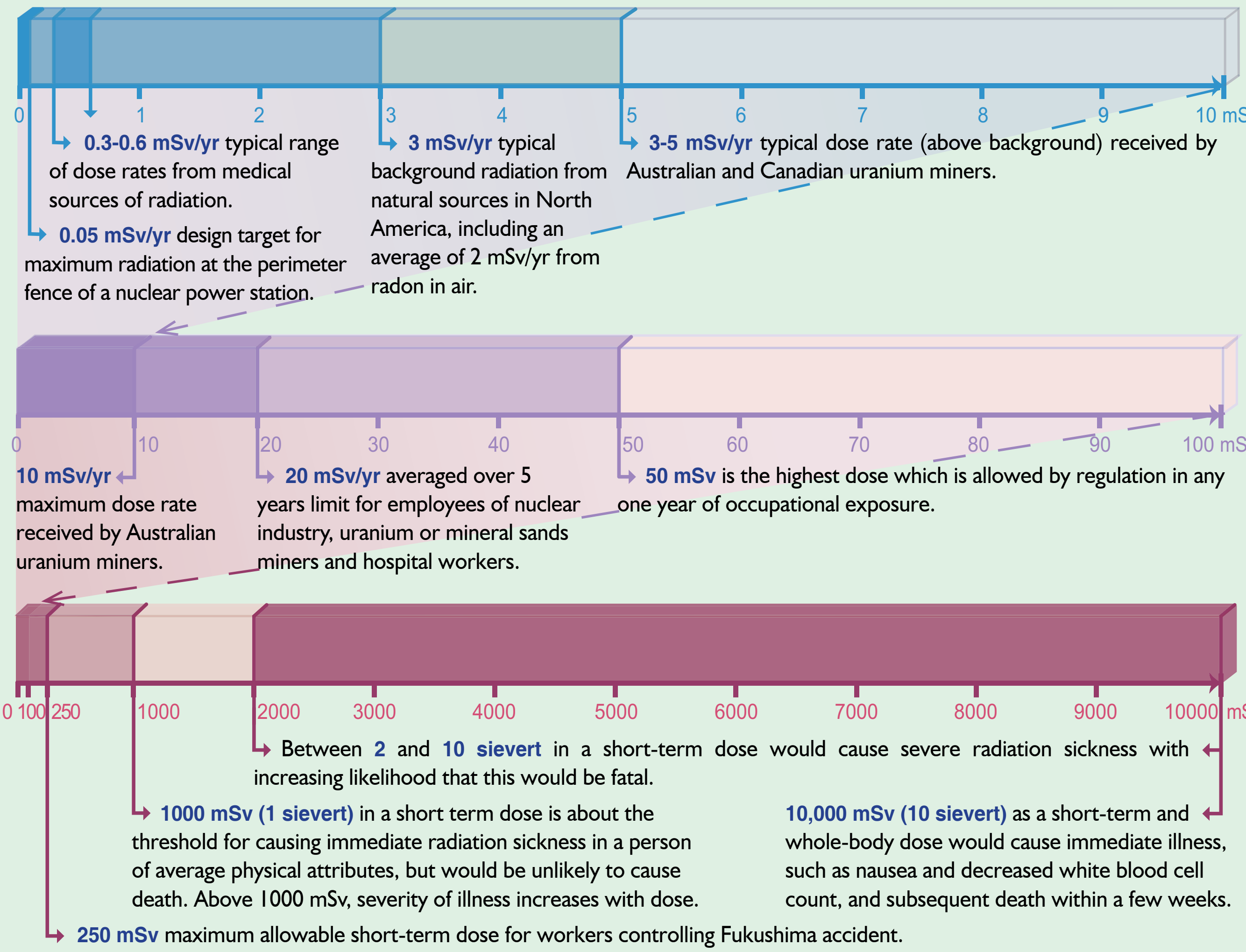
Higher accumulated doses of radiation might produce a cancer which would only be observed several – up to twenty – years after the radiation exposure. This delay makes it impossible to say with any certainty which of many possible agents were the cause of a particular cancer. In western countries, about a quarter of people die from cancers, with smoking, dietary factors, genetic factors and strong sunlight being among the main causes. Radiation is a weak carcinogen, but undue exposure could certainly increase health risks.

The body has defence mechanisms against damage induced by radiation as well as by chemical and other carcinogens. These can be stimulated by low levels of exposure, or overwhelmed by very high levels.

On the other hand, large doses of radiation directed specifically at a tumour are used in radiation therapy to kill cancerous cells, and thereby often save lives (usually in conjunction with chemotherapy or surgery). Much larger doses are used to kill harmful bacteria in food, and to sterilise bandages and other medical equipment. Radiation has become a valuable tool in our modern world.

RADIATION LEVELS AND THEIR EFFECTS

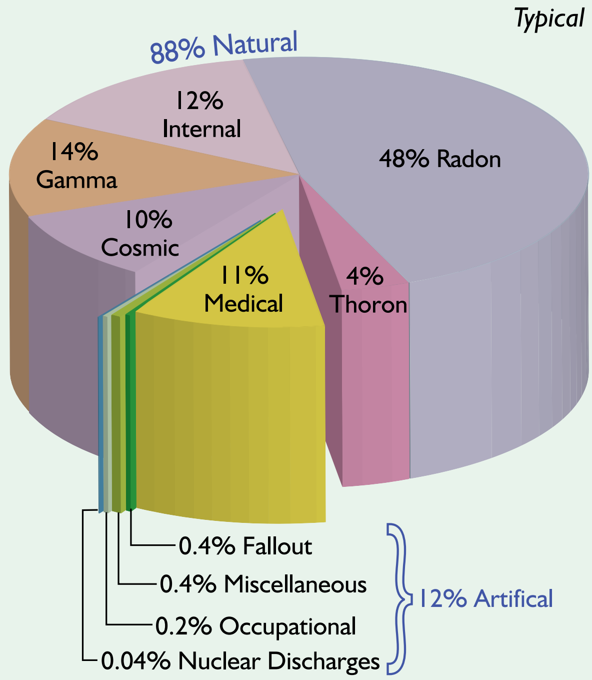
– an indication of the likely effects of a range of whole-body radiation doses and dose rates to individuals:



Background Radiation

Naturally-occurring background radiation is the main source of exposure for most people. Levels typically range from about 1.5 to 3.5 millisievert per year but can be more than 50 mSv/yr. The highest known level of background radiation affecting a substantial population is in Kerala and Madras States in India where some 140,000 people receive doses which average over 15 millisievert per year from gamma radiation in addition to a similar dose from radon. Comparable levels occur in Brazil and Sudan, with average exposures up to about 40 mSv/yr to many people.

Several places are known in Iran, India and Europe where natural background radiation gives an annual dose of more than 50 mSv and up to 260 mSv (at Ramsar in Iran). Lifetime doses from natural radiation range up to several thousand millisievert. However, there is no evidence of increased cancers or other health problems arising from these high natural levels.



MAN-MADE RADIATION

Ionising radiation is also generated in a range of medical, commercial and industrial activities. The most familiar and, in national terms, the largest of these sources of exposure is medical X-rays. A typical breakdown between natural background and artificial sources of radiation is shown in the pie chart. Natural radiation contributes about 88% of the annual dose to the population and medical procedures most of the remaining 12%. Natural and most artificial radiations are not different in kind or effect.

PROTECTION FROM RADIATION

Because exposure to high levels of ionising radiation carries a risk, should we attempt to avoid it entirely? Even if we wanted to, this would be impossible. Radiation has always been present in the environment and in our bodies. However, we can and should minimise unnecessary exposure to significant levels of man-made radiation. Radiation is very easily detected. There is a range of simple, sensitive instruments capable of detecting minute amounts of radiation from natural and man-made sources. There are four ways in which people are protected from identified radiation sources:

Limiting time: For people who are exposed to radiation (in addition to natural background radiation) through their work, the dose is reduced and the risk of illness essentially eliminated by limiting exposure time.

Distance: In the same way that heat from a fire is less the further away you are, the intensity of radiation decreases with distance from its source.

Shielding: Barriers of lead, concrete or water give good protection from penetrating radiation such as gamma rays. Highly radioactive materials are therefore often stored or handled under water, or by remote control in rooms constructed of thick concrete or lined with lead.

Containment: Radioactive materials are confined and kept out of the environment. Radioactive isotopes for medical use, for example, are dispensed in closed handling facilities, while nuclear reactors operate within closed systems with multiple barriers which keep the radioactive materials contained. Rooms have a reduced air pressure so that any leaks occur into the room and not out from the room.

STANDARDS AND REGULATION

Radiation protection standards are based on the conservative assumption that the risk is directly proportional to the dose, even at the lowest levels, though there is no evidence of risk at low levels. This assumption, called the 'linear no-threshold (LNT) hypothesis', is recommended for radiation protection purposes only, such as setting allowable levels of radiation exposure of individuals. It cannot properly be used for predicting the consequences of an actual exposure to low levels of radiation. For example, it suggests that, if the dose is halved from a high level where effects have been observed, there will be half the effect, and so on. This could be very misleading if applied to a large group of people exposed to trivial levels of radiation and could lead to inappropriate actions to avert the doses.

Much of the evidence which has led to today's standards derives from the atomic bomb survivors in 1945, who were exposed to high doses incurred in a very short time. In setting occupational risk estimates, some allowance has been made for the body's ability to repair damage from small exposures, but for low-level radiation exposure the degree of protection may be unduly conservative.

In any country, radiation protection standards are set by government authorities, generally in line with recommendations by the International Commission on Radiological Protection (ICRP), and coupled with the requirement to keep exposure as low as reasonably achievable - taking into account social and economic factors.

The authority of the ICRP comes from the scientific standing of its members and the merit of its recommendations. The three key points of the ICRP's recommendations are:

Justification: No practice should be adopted unless its introduction produces a positive net benefit.

Optimisation: All exposures should be kept as low as reasonably achievable, economic and social factors being taken into account.

Limitation: The exposure of individuals should not exceed the limits recommended for the appropriate circumstances.

National radiation protection standards are framed for both Occupational and Public exposure categories.

The ICRP recommends that the maximum permissible dose for occupational exposure should be 20 millisievert per year averaged over five years (ie 100 millisievert in 5 years) with a maximum of 50 millisievert in any one year. For public exposure, 1 millisievert per year averaged over five years is the limit. In both categories, the figures are over and above background levels, and exclude medical exposure.