Radiation and Life

"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".

Radiation and Life

Radiation is energy travelling through space. Sunshine is one of the most familiar forms of radiation. It delivers light, heat and suntans. We control its effect on us with sunglasses, shade, air conditioners, hats, clothes and sunscreen.

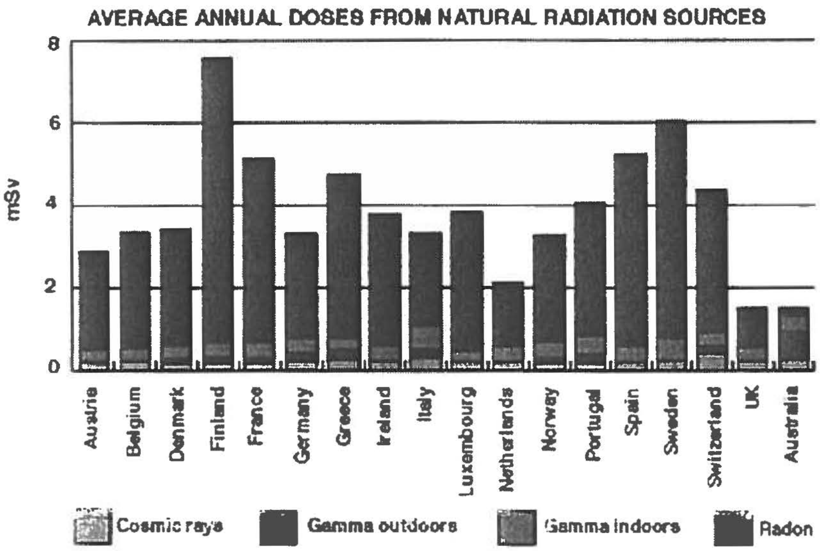
There would be no life on earth without lots of sunlight, but we have increasingly recognised that too much of it on our persons is not a good thing. In fact it may be dangerous, so we control our exposure to it.

Sunshine consists of radiation in a range of wavelengths from long-wave infra-red to shorter wavelength ultraviolet.

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.

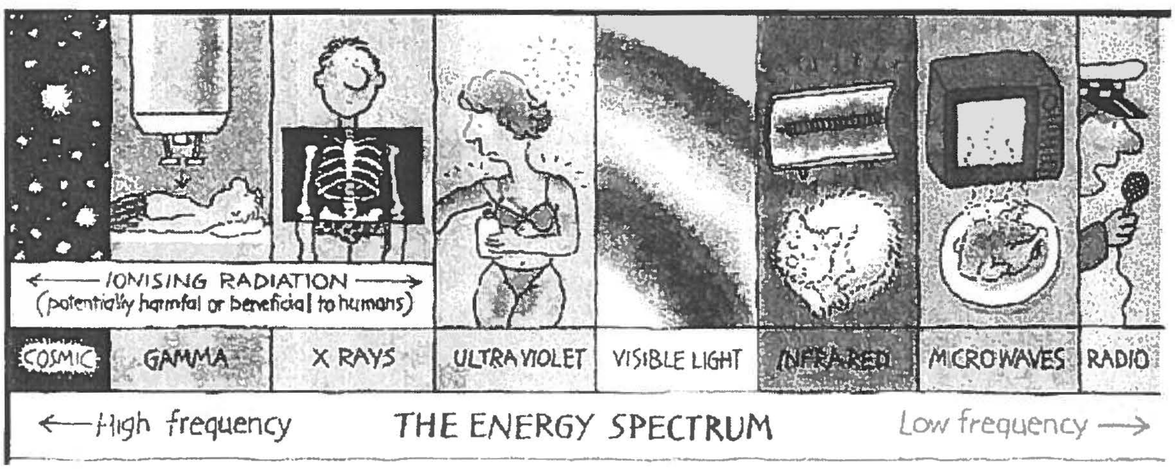
Living things have evolved in an environment which has significant levels of ionising radiation. Furthermore, many of us owe our lives and health to such radiation produced artificially. Medical and dental X-rays discern hidden problems. Other radiation is used to diagnose ailments and some people are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

Background radiation is that 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.



European data from NRPB, Australian from ARPANSA.

Radiation comes from atoms, the basic building blocks of matter.



THE UNSTABLE ATOM

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 eventually disintegrate into a totally new atom. These 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 to a more stable form. This is called 'radioactive decay'.

Each kind of atom is called an isotope, and unstable ones (which are thus radioactive) are called radioisotopes. Some elements, eg uranium, have no stable isotopes.

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 particles. If it decays with alpha or beta emission, it becomes a new element. All the time, the atom is progressing to 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" 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.

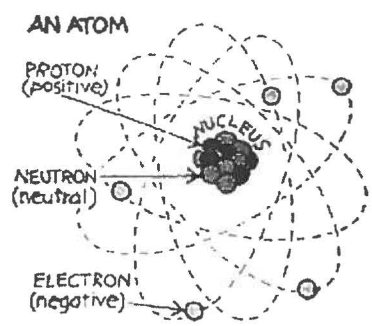
Apart from the normal measures of mass and volume, the amount of radioactive material is measured in **becquerels** (Bq), a measure which enables us to compare the typical radioactivity of some natural and other materials.

IONISING RADIATION

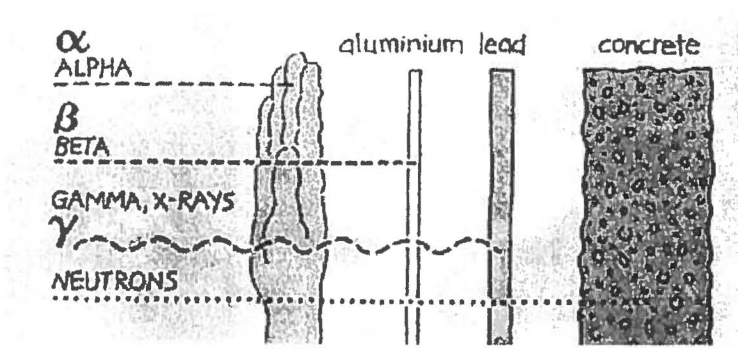
Here we are concerned mainly with ionising radiation from the atomic nucleus. It occurs in two forms - rays and particles, at the high frequency end of the energy spectrum.

Ionising radiation produces electrically-charged particles called ions in the materials it strikes. This process is called ionisation.

Ionising radiation has the ability to affect the large chemical molecules of which all living things are made and so cause changes which are biologically important.



There are several types of ionising radiation:



X-rays and gamma 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 do not come from the atomic nucleus. Unlike light, they both have great penetrating power and can pass through the human body. Thick barriers of concrete, lead or water are used as protection from them.

Alpha particles 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 they are taken into the body, for example by breathing or swallowing, alpha particles can affect the body's cells. Inside the body, because they give up their energy over a relatively short distance, alpha particles can inflict more biological damage than other radiations.

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

Cosmic radiations consist of a variety of very energetic particles including protons which bombard the earth from outer space. They are 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 ionising radiation does not cause the body to become radioactive.

Radioactivity of some natural and other materials

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

NB. Though the intrinsic radioactivity is the same, the radiation dose received by someone handling a kilogram of Canadian 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 below).

MEASURING AND MONITORING 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.

Ionising radiation is measured in the international units, the gray (Gy) and the sievert (Sv).

The amount of radiation, or 'dose', received by a person is measured in terms of the energy absorbed in the body tissue, and is expressed in **grays**.

Equal exposure to different types of radiation 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 in units called **sieverts**.

One sievert of radiation produces a constant biological effect regardless of the type of radiation.

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

HOW MUCH IONISING RADIATION IS DANGEROUS?

A scale of radiation levels

The following table gives an indication of the likely effects and implications of a range of radiation doses and dose rates to the whole body:

10,000 mSv (10 sieverts) in a short-term dose would cause immediate illness and subsequent death within a few weeks.

Between 2 and 10 sieverts in a short-term dose would cause severe radiation sickness with increasing liklihood that this would be fatal.

1,000 mSv (1 sievert) in a short term dose would probably cause (temporary) illness such as nausea and decreased white blood cell count, but not death. Above this, severity of illness increases with dose.

As a dose accumulated over some time, 1000 mSv would probably cause a fatal cancer many years later in 5 of every 100 persons exposed to it (ie. if the normal incidence of fatal cancer were 25%, this dose would increase it to 30%).

50 mSv/yr is, conservatively, the lowest dose rate where there is any evidence of cancer being caused. It is also the dose rate which arisies from natural background levels in several places. Above this, the probability of cancer occurrence (rather than the severity) increases with dose.

20 mSv/yr averaged over 5 years is the limit for nuclear industry employees and uranium or mineral sands miners, who are closely monitored.

10 mSv/yr is about the maximum actual dose rate received by any Australian uranium miner.

3-5 mSv/yr is the typical dose rate (above background) received by uranium miners in Australia and Canada.

3 mSv/yr (approx) is the normal background radiation from natural sources in North America, including an average of almost 2 mSv/yr from radon in air.

2 mSv/yr (approx) is the normal background radiation from natural sources, including an average of 0.7 mSv/yr from radon in air. (1.5 mSv/yr average in Australia is close to the minimum dose received by all humans on earth.)

0.3-0.6 mSv/yr is a typical range of dose rates from artificial sources of radiation, mostly medical.

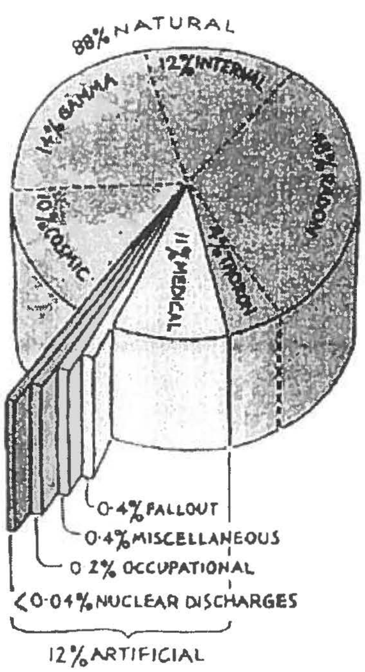
0.05 mSv/yr, a fraction of natural background radiation, is the design target for maximum radiation at the perimeter fence of a nuclear electricity generating station. In practice the actual dose is much less.

For low levels of radiation exposure the biological effects are so small they cannot be detected. Radiation protection standards assume however that the effect is directly proportional to the dose, even at low levels. According to this 'linear' theory of radiation effects, if the dose is halved the effect, or the risk of any effect, is halved.

Higher accumulated doses of radiation, while not immediately fatal, may produce a cancer which would only be observed several years after the radiation exposure.

The body has defence mechanisms against damage induced by radiation as well as by chemical carcinogens. However, typically the body has to deal only with a relatively tiny amount of damage at any one time, as opposed to having to deal with a very large amount at once, as was the case for the atomic bomb survivors in 1945. Some allowance has been made for this effect in setting occupational risk estimates, but the degree of protection for low-level radiation exposure may well be greater than these estimates cautiously allow.

Tens of thousands of people in each technically advanced country work in environments where they may be exposed to radiation above background levels. Accordingly they wear monitoring 'badges' while at work, and their exposure is carefully monitored.



BACKGROUND RADIATION

Naturally occurring background levels of radiation can typically range from 1.5 to 3.5 millisieverts a year and in some places can be much higher. 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 an annual dose rate which averages over 15 millisieverts per year from gamma, plus a similar amount from radon.

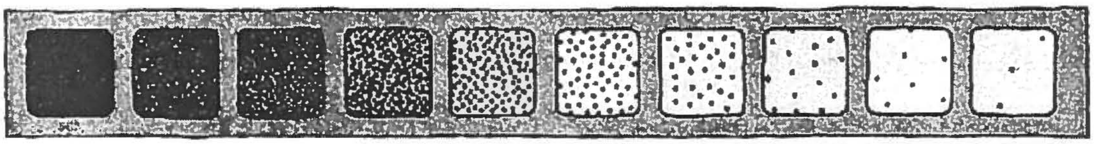
Comparable levels ocur in Brazil, Iran and Sudan, with average exposures up to 38 mSv/yr. Four places are known in India and Europe where natural background radiation gives dose rates of more than 50 mSv per year. No adverse health effects have been discerned from doses arising from these high natural 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 (left).

Natural radiation contributes about 88% of the annual dose to the population and medical procedures most of the remaining 12%. Natural and artificial radiations are not different in kind or effect.

Decay rate of radioactivity: After ten half lives, the level of radiation is reduced to one thousandth



URANIUM 238 (U238) RADIOACTIVE DECAY

type of radiation	nuclide	half-life
	uranium-238	4.47 billion years
α		
	thorium-234	24.1 days
β		
	protactinium-234m	1.17 minutes
β		
	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
α		
	lead-214	26.8 minutes
β		
	bismuth-214	19.7 minutes
β		
	polonium-214	0.000164 seconds
α		
	lead-210	22.3 years
β		
	bismuth-210	5.01 days
β		
	polonium-210	138.4 days
α		
	lead-206	stable

RADIOACTIVE DECAY

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.

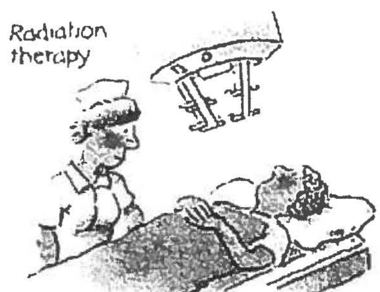
All uranium atoms are mildly radioactive. The following table for uranium-238 shows the various changes, the type of radiation given off at each step and the 'half-life' of each step that U-238 goes through in its change into stable, non-radioactive lead-206. The shorter-lived each kind of radioisotope, the more radiation it emits per unit mass.

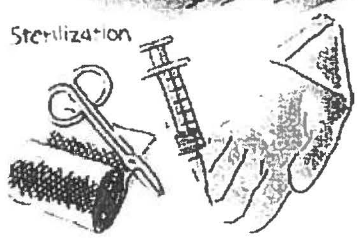
see also ANSTO paper on Radioactivity, Radioisotopes etc

THE HEALTH RISKS OF RADIATION

Many things potentially of great benefit to humanity have associated risks when used. Radiation falls into this category. However, radioactive materials should only be used where the benefits significantly outweigh the risks.

Ionising radiation is only one of hundreds of things that may cause serious health effects in humans. The degree of damage caused by radiation depends in turn on many factors - dose, dose rate, type of radiation, the part of the body exposed, age and health, for example.





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, leukemias ('cancer of the blood'), and genetic mutations (though not in humans) that affect future generations. But what are the chances of developing cancer from low doses of radiation? Any dose of radiation, no matter how small, is assumed to involve a possibility of risk to human health, but at doses below 50 millisieverts per year the risks are so small the effects are not measurable and may be negligible.

There is also a delay of many years between a person's exposure to a potential cause of cancer and the appearance of the disease. This makes it difficult to say with any certainty which of many possible agents were the cause of a particular cancer. Cigarette smoking, dietary factors and sunlight are among the most probable causes of cancer. But it is clear that radiation used improperly can increase health risks.

On the other hand, large doses of radiation directed at a tumour are used in radiation therapy to kill cancerous cells, while 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. See also The Peaceful Atom in this series.

PROTECTION FROM RADIATION

Because exposure to ionising radiation carries a risk, should we avoid it entirely? Even if we wanted to, this would be impossible. Radiation has always been present in the environment and in our bodies. We can however avoid undue exposure.

There is a range of simple, sensitive instruments capable of detecting minute amounts of radiation from natural and man-made sources. Radiation is very easily detected. In addition there are four ways in which we can protect ourselves:

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 almost eliminated by limiting exposure time.

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

Shielding: Barriers of lead, concrete or water give good protection from penetrating radiation such as gamma rays. 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 in the smallest possible space 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 of it.

Radiological protection

Most countries have their own systems of radiological protection which are often based on the recommendations of the International Commission on Radiological Protection (ICRP). The authority of the ICRP comes from the scientific standing of its members over more than fifty years and the merit of its recommendations.

The three key points of the ICRP's recommendations are:

- No practice shall be adopted unless its introduction produces a positive net benefit.
- All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account.
- The dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.

In each country, Radiation Protection Standards are based on ICRP recommendations for both Occupational and Public categories.

The ICRP recommends that the maximum permissible dose for occupational exposure should be 20 millisieverts per year averaged over five years (ie 100 millisieverts) with a maximum of 50 millisieverts 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.

In Australia, radiation protection regulations are set by States and Territories, as well as by the Environment Protection (Nuclear Codes) Act 1978. Three Codes of Practice have been developed by a Joint Commonwealth - States Consultative Committee to cover:

- Radiation Protection in the Mining and Milling of Radioactive Ores.
- The Safe Transport of Radioactive Substances.
- Management of Radioactive Waste from the Mining and Milling of Radioactive Ores.

Further information on the subject, together with links to overseas sources, can be found in the UIC/UI briefing paper on Radiation and the Nuclear Fuel Cycle.

For further information **Search this site** or Return to Index (UIC home page).

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