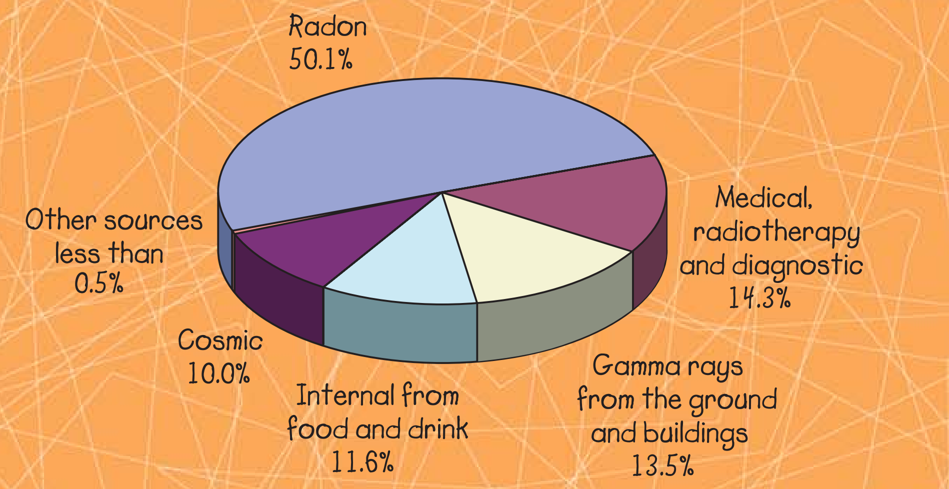
Ionising Radiation

The presence of natural background radiation is an inescapable fact of life. We are all exposed to it. We breathe small amounts of the radioactive gas 'radon'. The ground and buildings around us are slightly radioactive. Our bodies contain natural radioactivity from our food and drink, and cosmic rays fall on us all the time.

The subject of radiation receives a great deal of attention in our society partly because radiation is one cause, among many, of cancer. We cannot in general sense radiation and this no doubt adds to our anxiety. However radiation can also be used for our benefit, particularly in healthcare. Most of us are familiar with chest and dental X-rays, investigation of bone fractures or other diagnostic procedures.



Sources of radiation dose to the UK population. The total annual equivalent dose is 0.0026 Sv, but individual doses vary enormously.

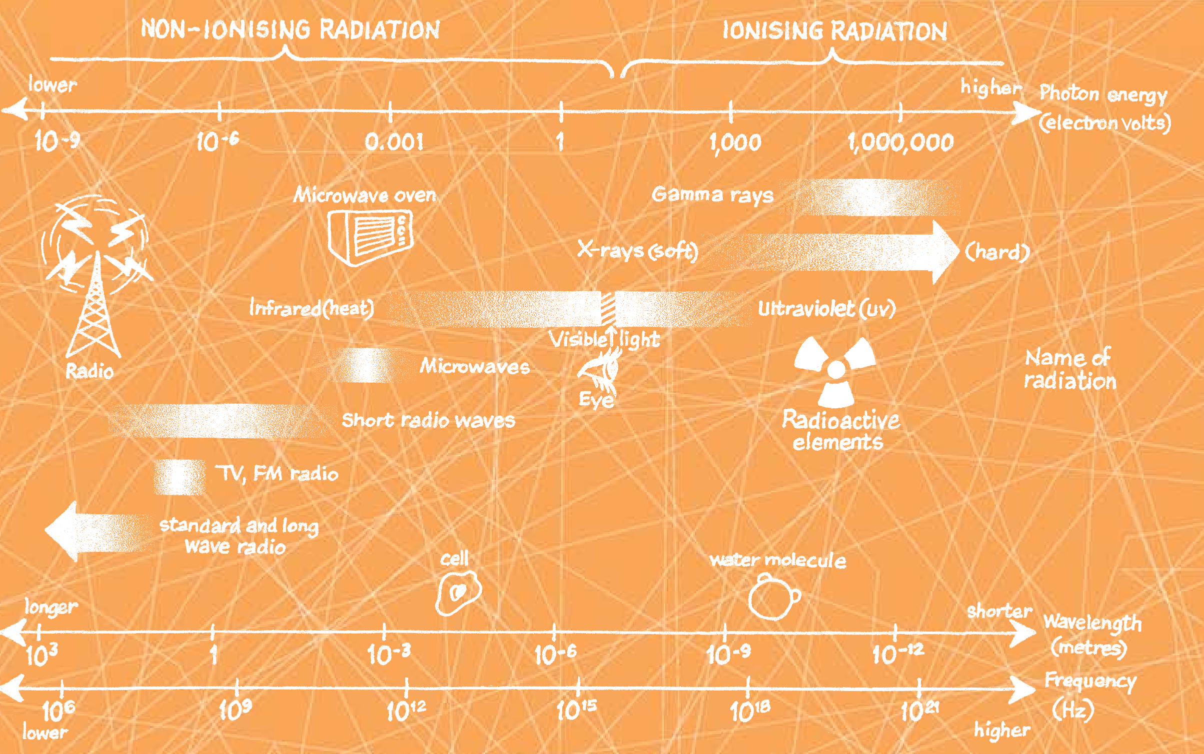
What is radiation?

Radiation is the energy carried by either electromagnetic waves or moving particles. Electromagnetic waves can vary in energy and wavelength.

Quantum mechanics predicts that very short wavelength electromagnetic waves behave as uncharged particles, called photons. Therefore the distinction between waves and particles at short wavelengths as with X-ray and gamma rays is blurred.

Ions are atoms with too few or too many electrons. *Ionising radiation* is radiation that has enough energy to kick electrons out of atoms and therefore produce ions. X-rays and gamma rays are forms of *ionising radiation.*

THE ELECTROMAGNETIC SPECTRUM



Ionisation can start chemical processes for example in an X-ray photographic image. On the other hand radiation-induced chemical processes can in turn lead to biological effects such as the destruction of a cancer tumour.

Particles other than photons can also carry 'radiation' energy. Electrons, sometimes called beta particles, are small mass, negatively charged particles. Protons are larger mass positively charged particles. Neutrons have a similar mass to protons, but are uncharged. The particles described so far fit together to make atoms. Alpha particles are particularly stable groups of two protons and two neutrons. All types of atomic particles can carry energy.

Radiation sources

Radiation sources can be split into two main types: *naturally radioactive atoms* and artificial sources using accelerated and/or decelerated charged particles.

Some nuclei naturally break up, because they are unstable. The process is called radioactive decay. Radioactive nuclei can be produced artificially. When the constituents of nuclei rearrange themselves to release energy and become stable they normally produce gamma rays and other particles.

Charged particles experience a force when placed in an electric field. Therefore *charged particles can be accelerated to very high energy.*

The sudden *slowing down of charged particles produces X-rays* e.g. in an X-ray set. X-rays can also be produced when atoms rearrange themselves to release energy. These are called characteristic X-rays.

Molecules are groups of atoms e.g. water molecule H_2O

An atom consists of electrons and a nucleus e.g. for the oxygen there are 8 negatively charged electrons orbiting a positively charged nucleus

A nucleus consists of protons and neutrons e.g. for oxygen the nucleus contains 8 protons and 8 neutrons

Radiation quantities and units

Radiation is difficult to measure, we cannot detect it through any of our senses though we can measure it by indirect means. We can interpret the measurements we make in terms of the energy deposited by the radiation. The amount of energy deposited per unit mass in a material is called the 'absorbed dose'. The unit of absorbed dose is the *gray* (Gy), which is one joule per kilogram.

Ionising radiations differ in the way in which they interact with biological materials, so that equal absorbed doses do not always have equal biological effects. Equivalent dose is the absorbed dose multiplied by a factor that takes account of the relative effectiveness in causing biological harm. *The unit of equivalent dose is the sievert* (Sv), which is one joule per kilogram.

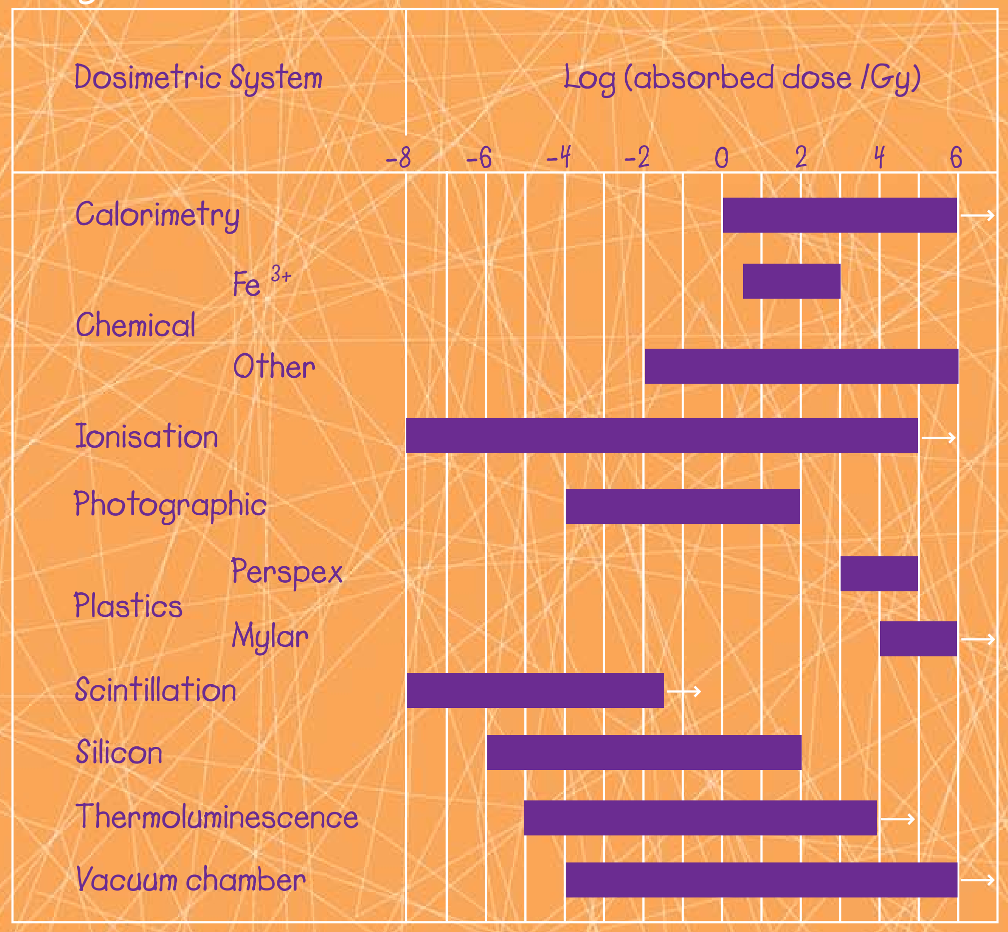
For beta, gamma and X-rays, 1 Gy is the same as 1 Sv, but neutrons and alpha rays are more damaging and, for these, 1 Gy is worth between 5 Sv and 20 Sv.

The unit of radioactivity is the *becquerel* (Bq), this is equal to one nuclear disintegration per second.

Radiation measuring instruments

There are a wide variety of instruments used to measure different types of radiation, different energy ranges and different accuracies. Here are a few examples. In radiography such as a chest X-ray, the variation of the penetrating power of X-rays in bone and tissue gives rise to an image. It is natural to use an ion chamber to measure ionising radiation. An ionisation chamber collects the charge normally from ions in a gas. Since most of the energy absorbed by radiation eventually appears as heat, it is possible to measure the temperature rise due to radiation directly. These devices are called calorimeters. The primary standard for absorbed dose is a device of this type.

Ranges of absorbed dose



In order to characterise a radioactive material, two pieces of information are needed: the activity and the way in which the nuclei decay. The latter information depends solely on the particular radioactive nuclei present. The activity of radioactive material, however, is a measurement that needs to be made in each individual case.

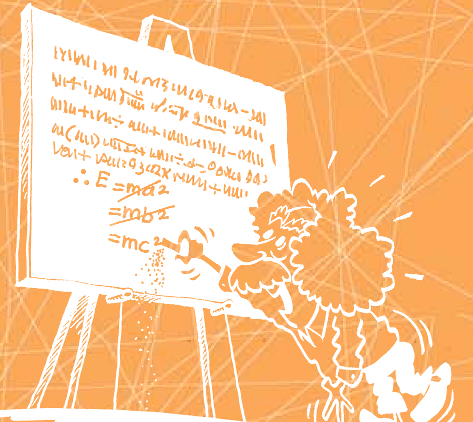
Radiation scale

	Equivalent Dose (Sv)
Dose required to sterilise medical products	25 000
Typical total radiotherapy dose to cancer tumour	60
50% survival probability, whole body dose	4
Legal worker dose limit (whole body)	0.02
Average annual dose from all sources in Cornwall	0.008
Average annual dose from natural radiation	0.002
Typical chest X-ray dose	0.00002
Average dose from a flight from UK to Spain	0.00001

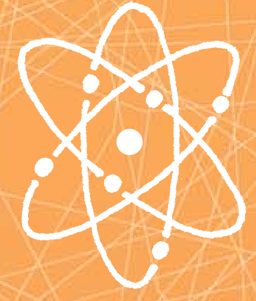
A brief history of radiation

1895
Röntgen discovered X-rays as the cause of fluorescence

1898
Marie and Pierre Curie discover the radioactive elements radium and polonium



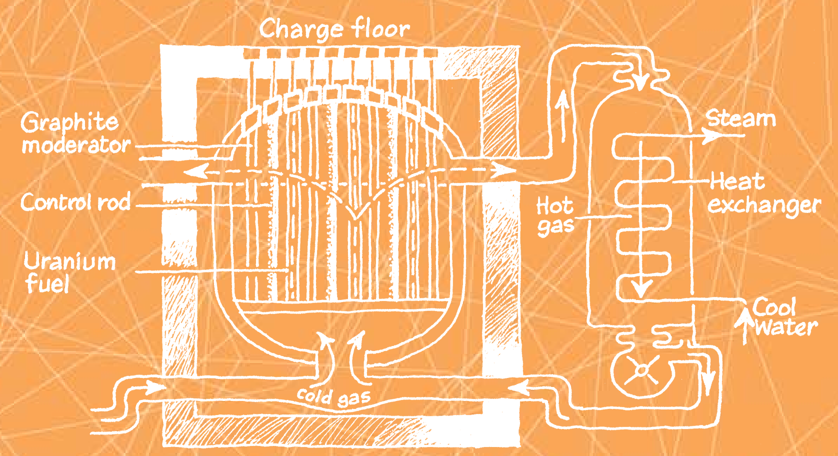
1905
Einstein discovered the mass energy relation $E=mc^2$



Atom

1913
Bohr suggested the idea of a nuclear atom

1910-1926
Balloon experiments in upper atmosphere confirm the presence of cosmic radiation



NUCLEAR REACTOR PRINCIPLE

1942
Fermi achieved the first self-sustaining chain reaction and thereby initiated the controlled release of nuclear energy in nuclear reactors

1979
Nobel Prize awarded to Hounsfield and Cormack following invention of CT scanner

If you have a measurement-related scientific question contact us on: telephone 020 8943 6880
e-mail: enquiry@npl.co.uk or visit our website that has lots of measurement-related information at: www.npl.co.uk

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