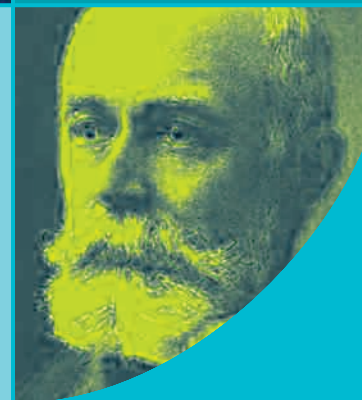


Learning more about radioactivity

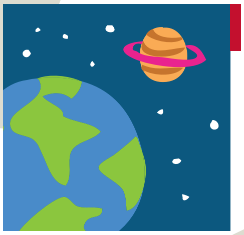
AREVA

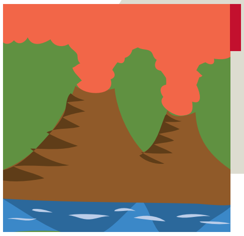
What is **radioactivity?**

Matter consists of tiny particles called “atoms”. The atoms themselves are made up of a nucleus around which electrons revolve. Some nuclei are stable and their lifetime infinite. Others are unstable, meaning that they change spontaneously while emitting one or more types of radiation. In that case, they are said to be radioactive. Polonium 210, for instance, spontaneously turns into stable lead 206. Some elements have both stable and unstable isotopes*. Carbon is a case in point: carbon 12, the most prevalent isotope, is stable, whereas carbon 14 is radioactive.

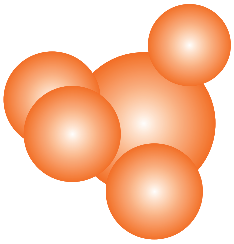
Other elements – 28 out of the 109 known today – occur only as radioactive isotopes. This is the case for uranium, plutonium and radium.

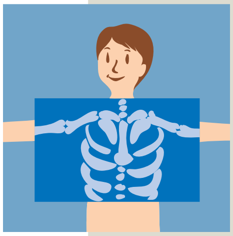
*The isotopes of an element have the same chemical properties but different atomic weights.





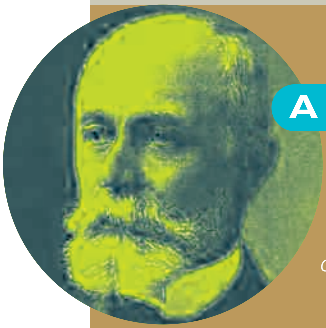
Where does **radioactivity come from?**





Radioactivity is an integral part of the universe. It is present everywhere, even without human intervention. The atmosphere and the earth’s crust contain radioactive elements. Some of the total radioactivity has been man-made since 1934, when the first radioactive nucleus was artificially created.

The radiation emitted by man-made radionuclides is identical to that of natural radionuclides.



A little history

Henri Becquerel *discovered radioactivity in 1896 while doing research on X-rays, which had just been discovered by Wilhelm Röntgen. In 1898, Pierre and Marie Curie discovered radium and proposed the word "radioactivity" to describe the phenomenon of radiation. In 1934, Irène and Frédéric Joliot-Curie produced man-made radioactivity.*

When the earth was formed five billion years ago, matter consisted of radioactive elements and stable elements. Since then, radioactivity has continually decreased as a large number of radioactive atoms have, for the most part, been transformed into stable elements.
Some continue to mutate, while others are still being formed. Natural radioactivity is present in living organisms as well. Organic tissues and bones contain essential life-sustaining elements which have radioactive isotopes, such as potassium 40 and carbon 14.

70% of the radioactivity to which humans are exposed is naturally occurring

Naturally occurring radioactivity has four sources:

COSMIC RAYS

from the sun and outer space.They vary with latitude and even more so with altitude. Exposure ranges from 0.5 mSv (millisievert) per person per year at sea level to 1.7 mSv per person per year at an elevation of 4000 m.

AMBIENT AIR

containing emanations of radon, a radioactive gas produced by the decay of uranium in the earth's crust. This gas and its by-products settle in the respiratory tract. The average "dose equivalent" in French homes is 1.3 mSv per person per year. This figure varies depending on the type of soil, building materials and ventilation.

TERRESTRIAL RADIATION

emitted by numerous radioactive elements in the earth's crust, such as uranium and thorium. They vary with the type of soil and thus from one region to another. Exposure ranges from 0.5 mSv per person per year on average in the Paris area to 1 mSv in Brittany and in the French Massif Central. This compares with 8 to 17.5 mSv in some regions of Brazil.

FOOD AND DRINK

contain radioactive elements. Once ingested, these elements settle in the tissues and bones. The human body contains an average of 4,500 Bq (Becquerel) of potassium 40 and 3,700 Bq of carbon 14, for example. Internal irradiation amounts to an average of 0.2 per person per year.

There are many uses for ionizing radiation

MEDICAL IRRADIATION

is the greatest source of exposure owing to the development of radiation therapy, nuclear medicine and thermal cures (some mineral waters are rich in radium and thorium). In the most industrialized countries, each person receives an annual dose equivalent of 1.8 mSv. The world average is 0.6 mSv per person per year.

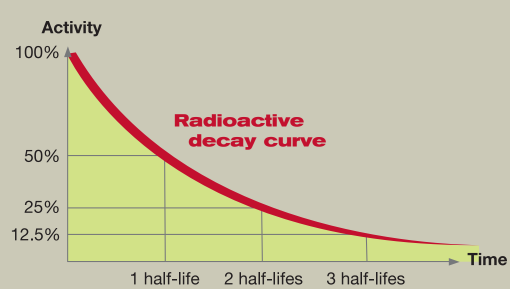
TECHNICAL AND INDUSTRIAL USES

are also a source of radioactivity. Mining industries, fallout from weapons testing or, on a more daily basis, exposure to radiation emitted by television sets and computer screens result in a dose equivalent of 0.1 mSv per person per year. The entire nuclear power generation industry contributes less than 0.01 mSv per person per year.

30% of the radioactivity to which humans are exposed comes from applications of ionizing radiation

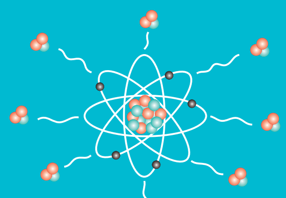
What is a radioactive half-life?

The number of nuclei transformed in a sample in one second determines its disintegration rate. This rate decreases over time based on a radioactive decay curve. The curve is used to define the radioactive half-life of an element, which corresponds to the time in which the activity of the sample has decreased by half.

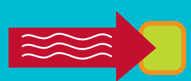


Typical radioactive half-lives	
uranium 238	4,47 million years
uranium 235	704 million years
carbon 14	5730 years
radium 226	1600 years
cesium 137	30,2 years
cobalt 60	5,27 years
phosphorus 30	2,55 minutes
helium 6	0,82 second

MESURING RADIOACTIVITY



Becquerel (Bq)
Number of disintegrations per second



Gray (Gy)
Amount of energy received by the object irradiated

Sievert (Sv)
Effects of radiation on the organism (expressed in "dose equivalent")

Radioactivity is a measurable phenomenon. There are three international units of measure. Each one uses different types of data

- **The disintegration** rate is measured in **becquerel (Bq)**. This is the number of disintegrations of radioactive nuclei occurring in a sample every second. For instance, about 9,000 atoms disintegrate every second in the body of a person weighing 70 kg. That person's activity is therefore 9,000 Bq. The former unit was the curie, which equaled 37 billion becquerel.

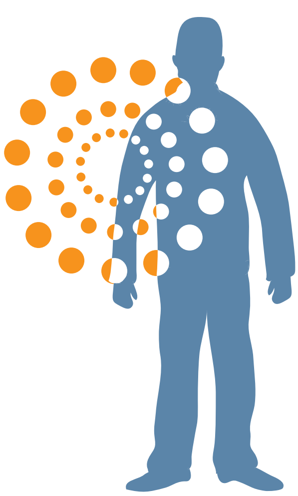
- **The amount of radiation absorbed** by an organism or object exposed to radiation is measured in **gray (Gy)**. This is a measurement of energy representing 1 joule per kilogram of matter. For example, in the French Massif Central region, an object or a body absorbs 200 billionths of a gray every hour.

The gray superseded the rad (1/100th of a gray) in 1986.

- **The biological effects of radiation on the exposed organism** are measured in **sievert (Sv)**. This is a radiation protection unit. It is expressed in "dose equivalent" and takes into account the characteristics of the radiation and of the organ irradiated. The sievert superseded the rem (1/100th of a Sv) in 1986. The millisievert (mSv), or thousandth of a sievert, is frequently used. Worldwide, the average annual "dose equivalent" from natural radiation is around 2.4 mSv per person.

The effects of **radioactivity on the body**

The effects of radiation on the body vary greatly depending on the dose received, the exposure time and mode, and the type of radionuclide involved. The pathways are external irradiation or contamination. When the body is in the path of radiation, the person is irradiated. If the person touches, breathes or swallows a radioactive substance, he or she is contaminated.



The ionization phenomenon

Alpha, beta, gamma and X radiation disrupts the structure of living matter. Atoms located in their path can lose one or more electrons. These atoms then transform into electrically charged "ions", which will in turn disrupt the structure of the molecules or cells of which they are constituents. This is why radioactive radiation is said to be "ionizing". The ionization phenomenon is the main mechanism by which radioactivity acts on matter. Radioactivity is detected and measured by highly accurate instruments (Geiger counters, ionization chambers, scintillators) and devices (photographic films) that function using radiation's properties. Natural radioactivity has no detectable impact nor apparent health effects. The organism incorporates it like a natural component of the biological process.

The health effects of radiation

Knowledge on the effects of radioactivity is derived from analysis of actual cases of persons exposed to irradiation by accident or for medical reasons; from epidemiological studies on highly exposed populations, such as survivors of Hiroshima and Nagasaki; and from experimental studies. These studies enabled the development of a risk scale linked to radiation exposure.

- Early effects of ionizing radiation.

Detectable only in the event of exposure to high doses of radiation above a given threshold (0.2 sievert), these effects vary according to the dose received, ranging from a temporary modification of the blood count without any clinical signs (around 0.3 sievert) to a lethal dose beyond therapy (above 15 sieverts).

- Delayed effects of ionizing radiation.

Radiation acts on DNA molecules in particular and may result in delayed pathological effects such as cancer, leukemia or genetic alterations. These effects are random; in other words, they do not appear systematically. It is usually considered that the probability of their appearance is proportional to the radiation dose received: the lower the dose, the lower the probability of cancer. With that as a basis, radiation protection authorities have, for precautionary reasons, set very low limits for exposure to artificial radioactivity: 1 millisievert per year for the public and 20 millisieverts per year for nuclear workers. These limits are 1,000 and 50 times lower respectively than doses that cause the first detectable signs of an early pathology.

Protecting against radioactivity

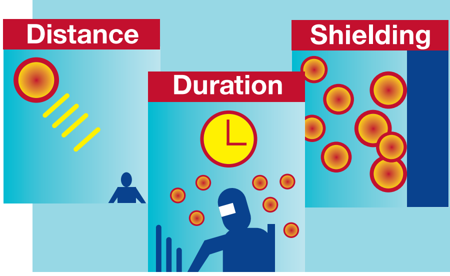
One can protect against radiation and contamination from radioactive sources by observing stringent rules.

Three types of protection can be used

The distance between the organism and the radioactive source is a fundamental safety measure. A controlled area is established around exposed sites and all handling is done remotely.

The duration of radiation exposure is controlled in exposed areas. The harmfulness of the radiation depends on the dose received, which increases with exposure time.

Adequately thick lead, metal or concrete **shielding** stops radiation. A few meters of water also provide effective protection. Workers wear totally encapsulated protection suits to avoid the risk of contamination by unsealed radioactive sources.



Stringent regulations

The purpose of radiation protection is to prevent the exposure of any person to excessive doses of radioactivity.

Dose limits have deliberately been set at very low rates, making them "safety limits" more than "danger limits". They apply to the public as well as to nuclear professionals at hospitals, nuclear power plants and elsewhere. Output doses are systematically monitored and measured. Individual dosimeters are used to determine the dose received by each individual working in a hazardous environment. Radioactivity levels in the environment are measured around facilities in which radioactive products are handled, and doses to the public are assessed.

International scientific bodies such as the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Radiation (UNSCEAR), and national governmental agencies issue recommendations and ensure strict enforcement of regulations and compliance with protection standards. In France, this role is filled by the department of nuclear safety and radiation protection (DGSNR, Direction générale de la sûreté nucléaire et de la radio-protection), which reports to the Ministries of Industry, of the Environment and of Health.

Nuclear facility safety

In France and in most countries of the world, nuclear facilities are designed based on the risks they involve and built with a concern for maximum safety. Nuclear power stations in particular have a series of three containment barriers: the metallic fuel cladding, the steel vessel housing the reactor core and its cooling system, and the concrete containment vessel surrounding the core designed to contain radioactive products.

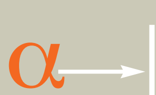
The Chernobyl power plant lacked a containment building. At the Three Mile Island plant in the United States, on the other hand, the partial meltdown of the core in 1978 and substantial contamination inside the containment building had no detrimental impacts outside the site.

TYPES OF RADIATION

Radionuclides emit radiation during the process of nuclear decay. There are very different types of radiation, which are classified according to their power to penetrate matter.

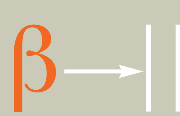
Alpha rays (α) are low penetration radiation.

They are produced when a positively charged helium nucleus (2 protons and 2 neutrons) is expelled. Their range in the air varies from 2.5 cm to 8.5 cm. They can be stopped by a sheet of paper or the outer layer of the skin.



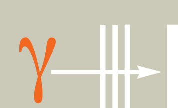
Beta rays (β) penetrate further.

They are produced when an electron is expelled. Their range in the air is a few meters. They can cross through the surface layer of the skin. They can be stopped by a sheet of aluminum foil or a glass pane.



Gamma rays (γ) penetrate deeply.

They are produced when a photon is expelled. They are electromagnetic rays, like light or X-rays. They travel at the speed of light. Very thick, dense materials, such as concrete or lead, are required to stop them.



The uses of radioactivity

In the medical field

Radiodiagnosis is used to explore the human body and to diagnose certain diseases. The concept involves injecting specific radionuclides into the organism and monitoring their path and behavior. This enables an accurate determination of organ morphology and reveal anatomic and functional anomalies.

Nuclear medicine calls on a large number of techniques related to the properties of radioactivity. Radioisotope scanning provides computer displays of information collected by highly sophisticated detectors such as gamma-cameras. Nuclear magnetic resonance spectroscopy or camera examination of positron emissions shows complex organ functional processes by monitoring how radionuclides injected into the patient are metabolized.

Radiation therapy uses the energy from ionizing radiation to destroy cancer cells. The radiation can be applied externally through external beam irradiation (cobalt 60 “bombardment”) or internally through endobrachytherapy (by means of needles positioned close to the tumor). In France, 30,000 cancers are cured every year with radiation therapy.

In industry

Power generation
Currently, 17% of the world’s electricity is generated by nuclear power stations. In France, almost 80% of the electricity is of nuclear origin.

Industrial radiography
is used to X-ray metallic parts and to check welds. Gamma radiography of this type is widely used in metallurgy and in aeronautics.

Radioisotope gauges
measure the intensity of radiation at the source and at the destination. They are used to gauge liquid levels (to monitor the filling of a reservoir or a pit) and to check the thickness, density or homogeneity of a material.

Ionization detectors
are used to detect the presence of various gases in the atmosphere. They have multiple uses, including fire detectors and firedamp concentration detectors in mines.

Industrial irradiation
allows development of more resistant and lighter materials. It has many uses in medicine and industry, including lighter prostheses and stronger electric cables.

Industrial tracers
are used to detect liquid or gas leakage in underground or inaccessible pipes by taking advantage of the ability to detect radionuclides in an extremely precise manner. They also enable the study of underground flows of water and potential pollutants and of sand and mud transfers during the design of ports and estuaries.

In the food industry

The ionization of food products
such as potatoes, onions and strawberries by gamma rays, electron beams or X-rays improves their preservation by stopping germination and destroying parasites and micro-organisms. This technique does not make the product radioactive or alter its nutritional quality, and is commonly used in many countries, including France.

Crops can be improved
with "radiomutagenesis". Exposing plants such as wheat, barley and rice to gamma rays causes some of their genes to mutate. Mutant strains are selected based on their resistance to disease or bad weather, or their suitability for poor soil.

Irradiating processes have been developed to sterilize certain types of male insects, such as the tsetse fly, to protect humans and crops. The population of insect pests is gradually declining as a result through radiosterilization, without the use of insecticides.

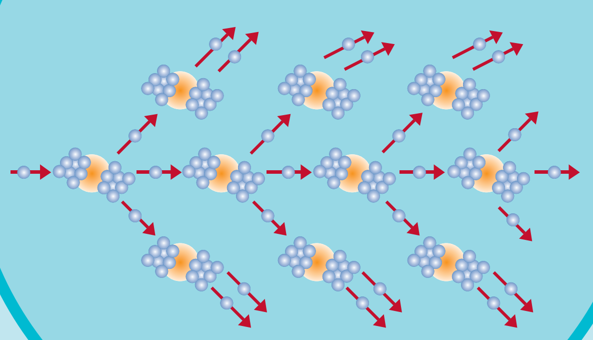
In the cultural world

Carbon 14 dating
in archeology is a practical application of the law of radioactive decay. This property makes it possible to determine when the radionuclide was incorporated into the sample to be dated. Carbon 14, thorium 232 and potassium 40 are all used to date fossils, bones and minerals ranging in age from 5,000 to 1 billion years.

Heritage preservation
can use gamma ray irradiation processes to eliminate insects, fungi and bacteria responsible for often-irreversible deterioration.
The mummy of Ramses II benefited from just such a process in 1976.
The materials of an item to be restored can also be strengthened by impregnation with a resin hardened by exposure to radionuclides.

Chain reaction

Multiplication of fissions generates large amounts of energy.



Examples of **irradiation levels**

(expressed in mSv/person/year)

Average irradiation from nuclear power stations in France	0,01 mSv
Radiation from a Paris - New York flight	0,02 mSv
Radiation from a chest X-ray	0,3 mSv
Radiation from natural radioactivity in France	1 à 2 mSv
Total irradiation (natural + man-made) of the French population	2 à 3 mSv
Total natural irradiation of the world population	2,4 mSv

Exemples of **natural radioactivity**

Rain water:
0.3 to 1 Bq per liter

Mineral water:
up to 6 Bq per liter

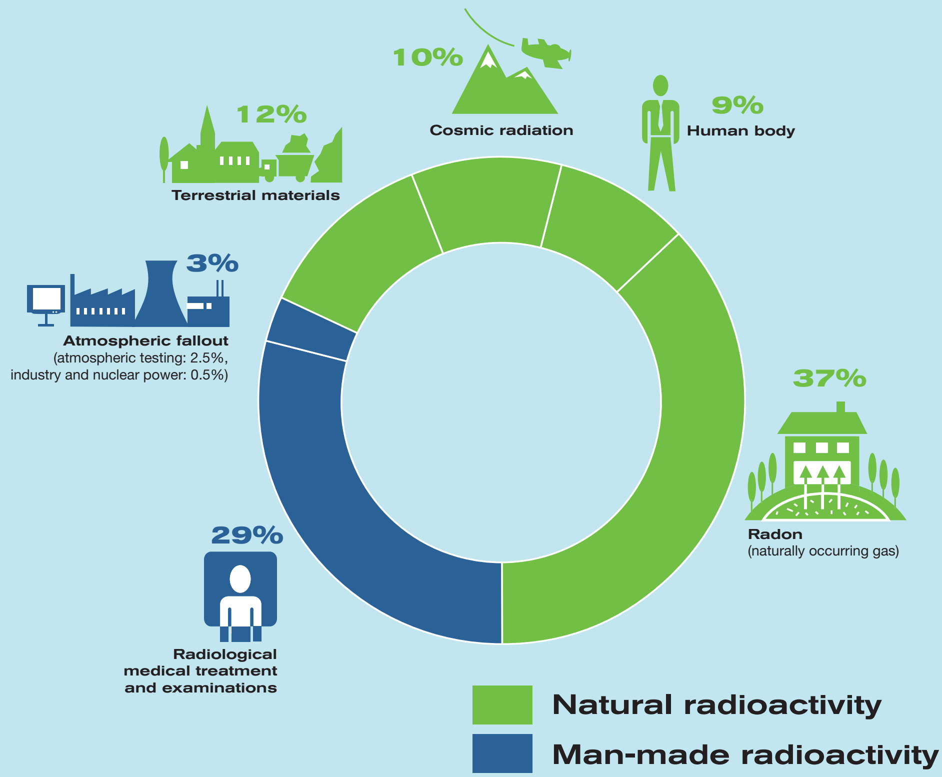
Sea water:
10 to 13 Bq per liter

Milk:
50 to 80 Bq per liter

Human body:
about 130 Bq per kilo

1 gram of Radium:
37 billion Bq

Distribution in France of **various sources of exposure**



To learn more

Les Rayonnements nucléaires by Pierre Radvanyi. Collection Que-sais-je ? Presses Universitaires de France.

L'Énergie by Jean-Louis Bobin. Collection Dominos, Flammarion.

Radiologie et radioprotection by Maurice Tubiana. Collection Que-sais-je ? Presses Universitaires de France.

La Radioactivité et ses applications by Maurice Tubiana and Robert Dautray. Collection Que-sais-je ? Presses Universitaires de France.

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Sustainable development is a core component of the group's industrial strategy. Its 75,000 employees work every day to make AREVA a responsible industrial player that is helping to supply ever cleaner, safer and more economical energy to the greatest number of people.

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