WHAT IS RADIOACTIVITY?

1.1 Design: ASN and IRSN Communications Departments - October 2021
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WHAT IS **RADIOACTIVITY?**

JOURNEY TO THE CENTRE **OF MATTER**

Our bodies are made up of a multitude of tiny bits: **atoms**.
They connect with one another to form molecules, which in turn form the basic structure of matter.

WHAT IS **AN ATOM MADE OF?**

An atom itself is made up of a nucleus and a surrounding cloud of electrons. These are the same electrons that run through our electrical wires.

There are 2 types of particles in the nucleus: **neutrons** and **protons.** The number of protons determines the chemical property of the atom. There can be more or fewer neutrons in the same element, thus forming different isotopes.

Some are radioactive. For example, carbon-12 with 6 neutrons is stable, while carbon-14 with 8 neutrons is unstable and radioactive.

WHAT ABOUT **MOLECULES?**

Atoms connect to one another to form molecules.

Molecules also connect with each other to form all kinds of structures, cells, objects, and living things.

UNSTABLE ATOMS

Most atoms are stable, i.e. they do not change over time.

Some are unstable and transform into other atoms, while emitting radiation: This is the phenomenon of **radioactivity.**

DEBATE

RADIOACTIVITY: IS IT A HUMAN INVENTION?

- **Radioactivity is a natural phenomenon that occurs everywhere and has existed since the Earth's origin. Radioactive elements are found in rocks, water, fruit, and even in our own bodies.**
- **The discovery of radioactivity led to inventions that produced artificial radioactive materials. Some of these are highly radioactive and could prove dangerous for current or future generations if they are not contained and controlled.**

In any case, knowing the origin of radioactivity allows us to better understand the phenomena.

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WHAT IS **RADIOACTIVITY?**

THREE TYPES **OF RADIATION**

Some atoms transform over time, emitting invisible radiation. Materials containing such atoms are said to be radioactive!

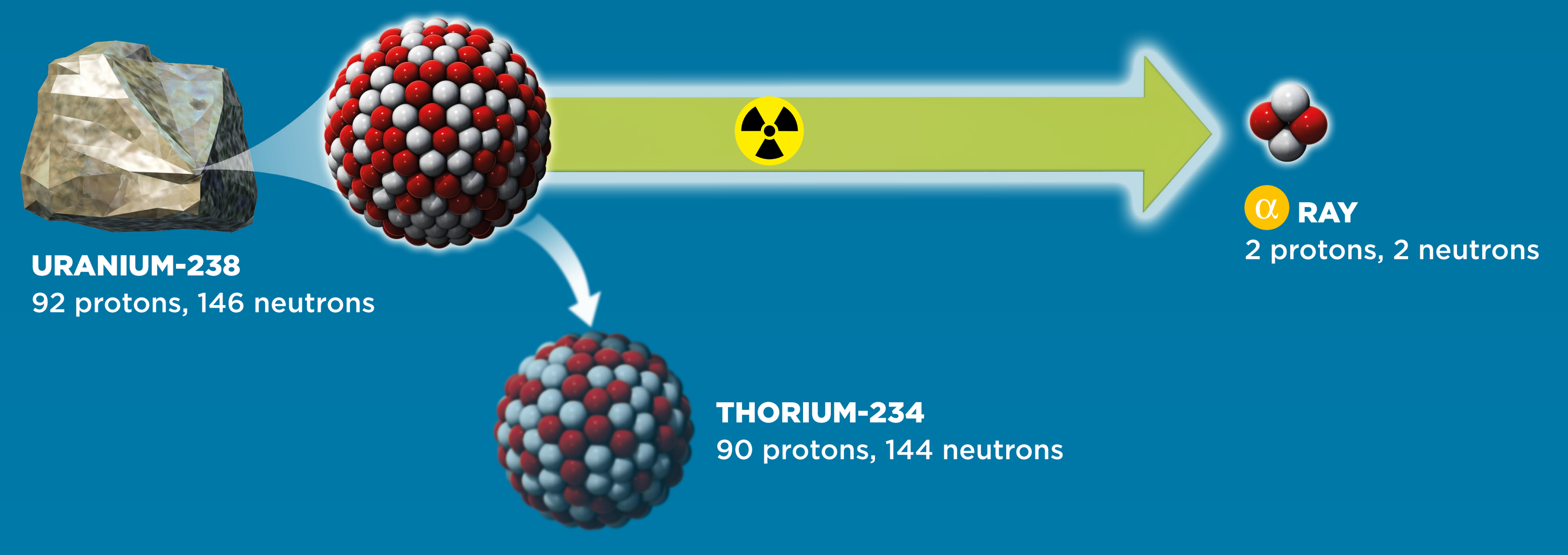
Scientifically, we say that an atom that is transformed by the process of radioactivity decays. It loses its integrity (disintegrates), releasing particles with varying degrees of energy.

Depending on its nature, an atom can emit three different types of radiation: **alpha, beta or gamma**.

ALPHA RADIATION α

Some heavy atoms are transformed by emitting a massive particle, made up of two protons and two neutrons; a helium nucleus known as an **alpha particle**.

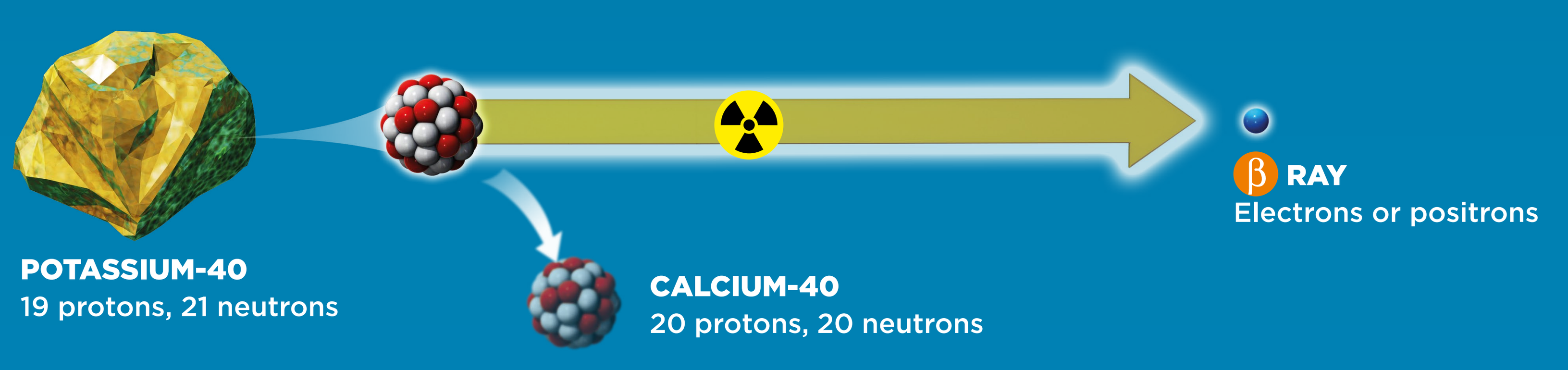
Because of their large size, alpha particles are not very penetrating and are stopped by a simple sheet of paper. On the other hand, they release a great deal of energy on impact.



BETA RADIATION β

In the nucleus of an atom, a neutron can change into a proton or, conversely, a proton can change into a neutron. This transformation is accompanied by the emission of an electrified particle called a **beta particle**.

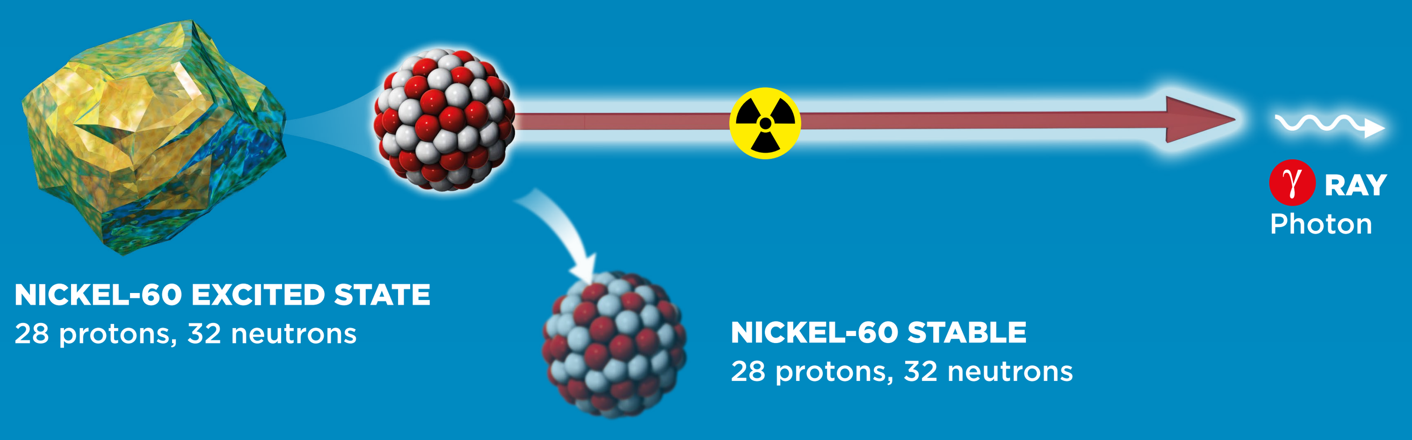
These electrified particles, electrons or positrons, can pass through paper but are stopped by aluminium foil. More penetrating than alpha particles, they also deposit their energy more gradually as they travel.



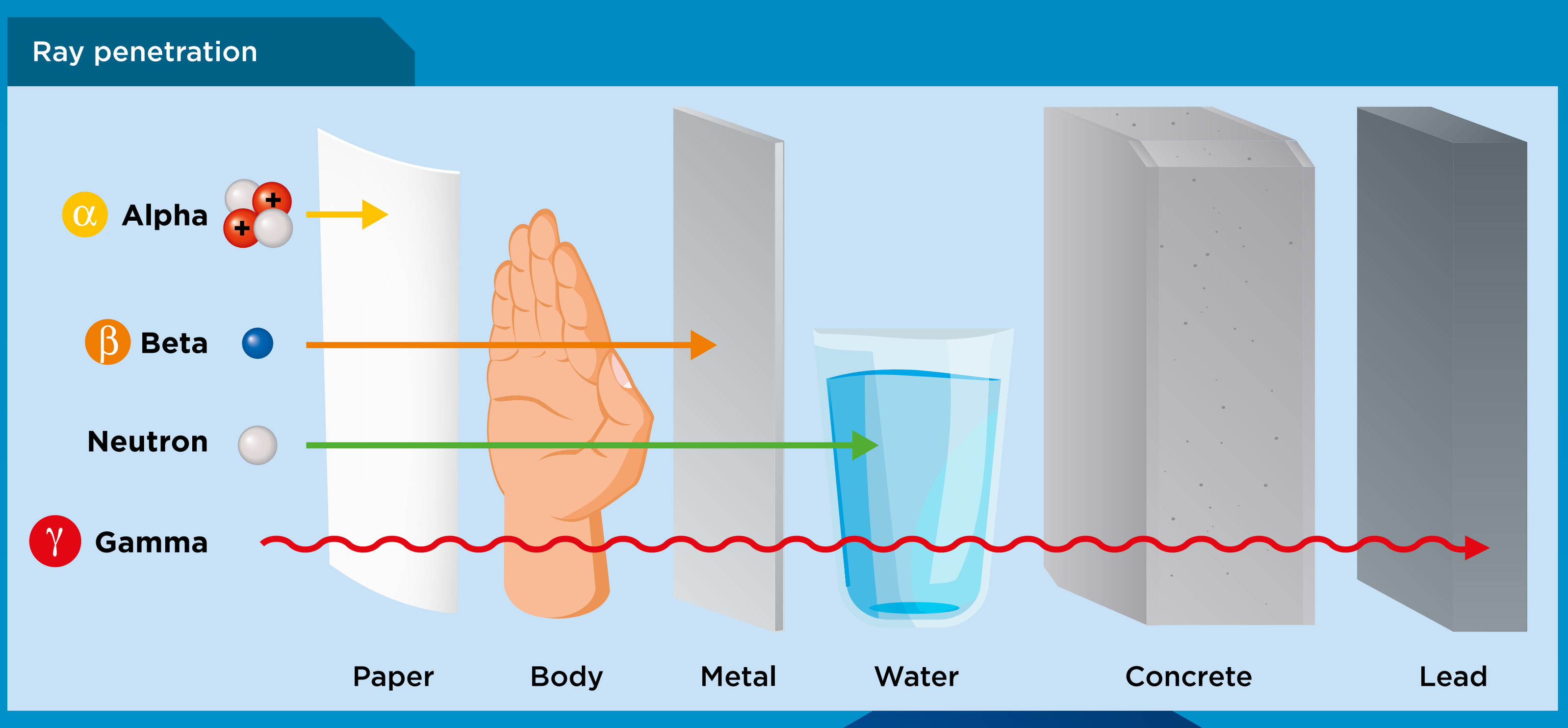
GAMMA RADIATION γ

After emitting an alpha or beta particle, some atoms become unstable. They then emit **gamma radiation** to stabilise. Gamma rays are not composed of material particles but of particles of light, or photons.

Gamma rays are highly penetrating and require several centimetres of lead or tens of centimetres of concrete to stop them. It is difficult to protect against gamma rays.



Ray penetration



Some materials are radioactive: they emit radiation with varying degrees of energy.

These types of radiation are all dangerous **and require appropriate means of protection**.

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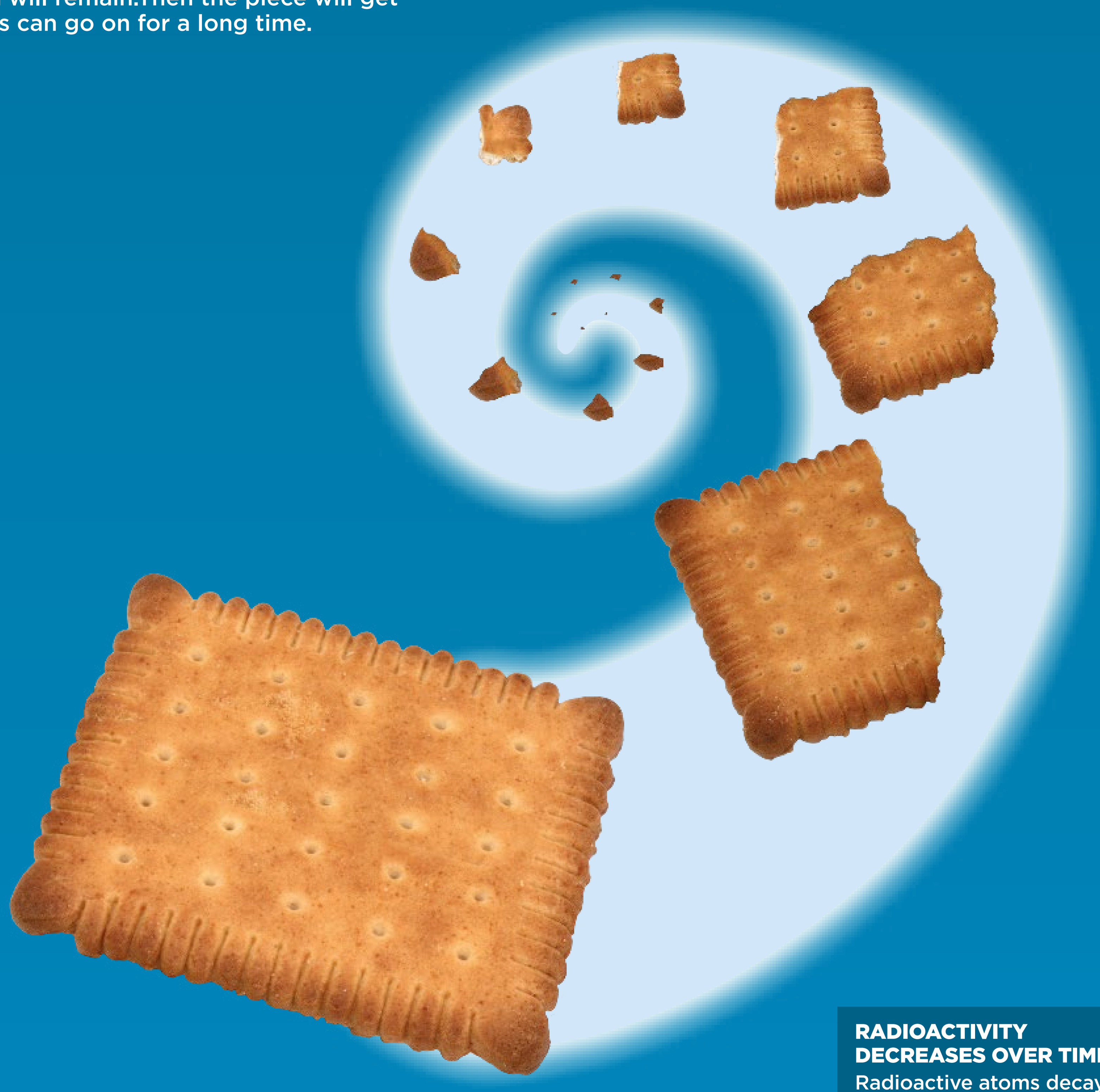
WHAT IS **RADIOACTIVITY?**

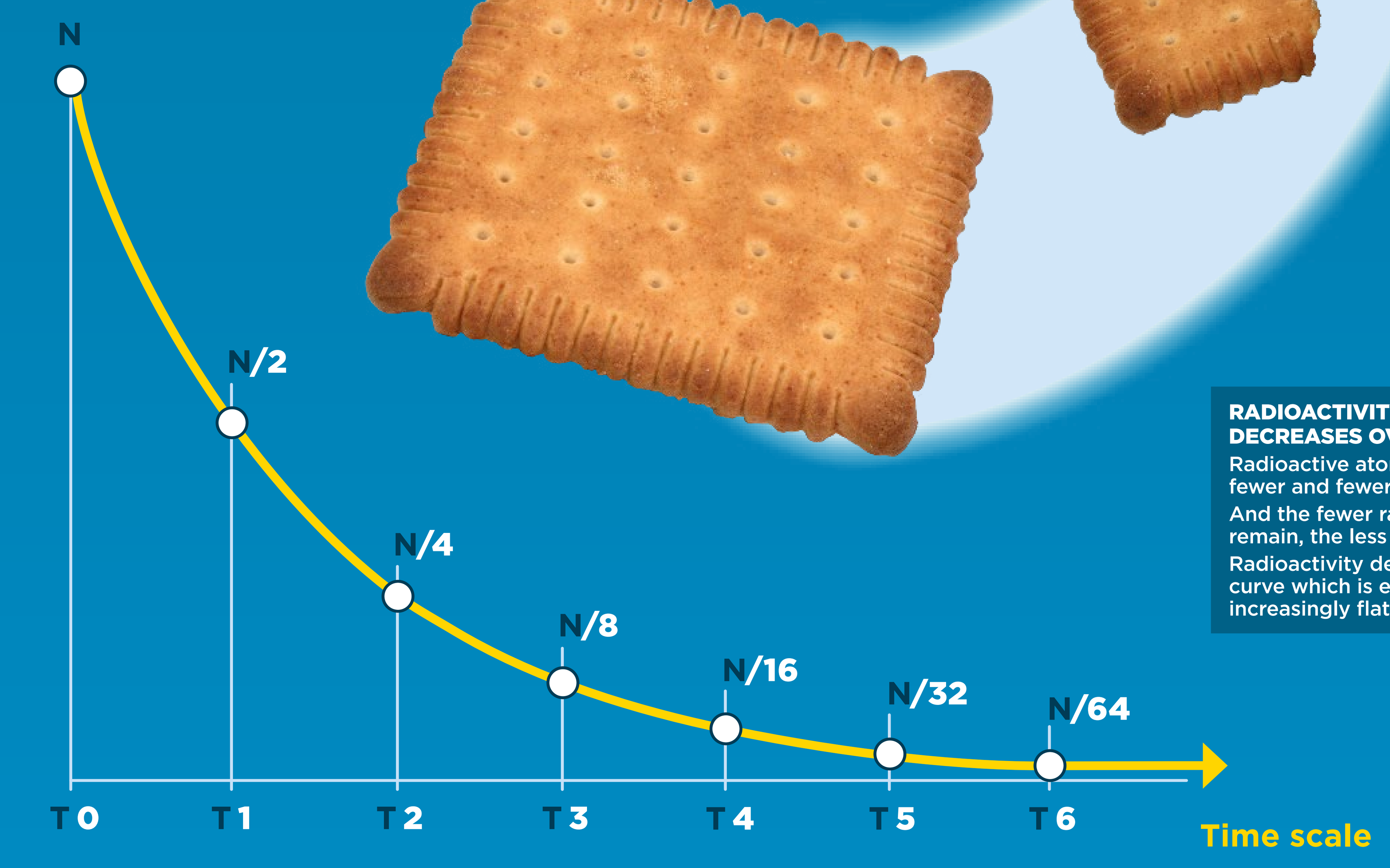
HOW LONG **DOES RADIOACTIVITY LAST?**

Radioactivity is not eternal. Radioactive materials lose particles over time, leaving only stable materials in the end. Does this happen quickly? To find out, we need to look at the concept of **half-life**.

RADIOACTIVITY IS NIBBLED AWAY

Radioactive materials become less and less radioactive over time. It's a bit like deciding to nibble on a biscuit every day, biting into half of what's left. After a day, the biscuit will be half its size. In three days, only one eighth will remain.Then the piece will get smaller and smaller, but this can go on for a long time.





RADIOACTIVITY DECREASES OVER TIME

Radioactive atoms decay: there are fewer and fewer of them.

And the fewer radioactive atoms that remain, the less intense the radioactivity.

Radioactivity decreases according to a curve which is exponential, becoming increasingly flat over time.

THE HALF-LIFE

Physicists refer to the **half-life** of radioactive material as the time by which half of the original atoms have decayed.

The half-life gives a good indication of how **quickly a radioactive material disappears**.

In the case above, scientists would say that the biscuit has a half-life of one day: it is half its size after one day.

EXAMPLES

TECHNETIUM-99m
Half-life: 6 hours.
It has a very short half-life. It is used to make medical diagnoses. It is quickly eliminated.

POTASSIUM-40
Half-life: 1.35 billion years.
Contained in the soil, it is also present in food and the human body.

URANIUM-238
Half-life: 4.5 billion years.
Like that contained in granite rock, its half-life is equivalent to the age of the Earth.
The Earth contains half as much uranium-238 as it did at its origin.

It will take 300 years for the quantity of caesium-137 released during the Fukushima accident to be **divided by a thousand**.

The same reduction was obtained after 80 days for radioactive iodine-131, which disappeared in a few months.

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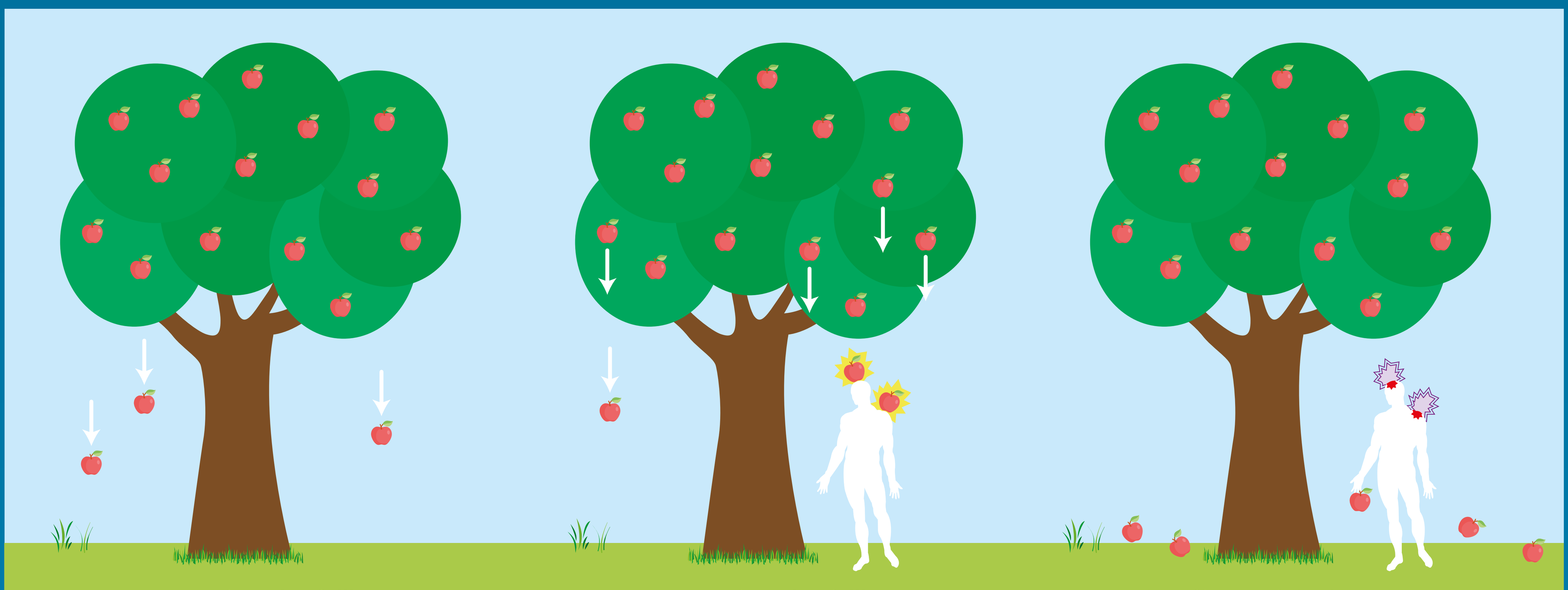
WHAT IS **RADIOACTIVITY?**

UNITS OF MEASUREMENT OF RADIOACTIVITY

Some materials are radioactive: they emit radiation with varying degrees of energy.

To measure radioactivity accurately, **3 complementary units of measurement** are used: becquerel, gray and siervert.

LET'S COMPARE A RADIOACTIVE SOURCE TO AN APPLE TREE



The number of apples falling from the tree is measured in **becquerel (Bq)**.

The dose of apples falling on the head of the person under the tree is measured in **gray (Gy)**.

The effects of the impact of fruit on the person's body are measured in **sievert (Sv)**.

ACTIVITY OF A SOURCE

The number of becquerels corresponds to the number of times per second the source emits radiation.
The greater the number, the greater the activity of the source.

The Geiger counter is used to measure radioactivity and each disintegration recorded is converted into sound.

THE DOSE RECEIVED

The gray is used to measure the energy resulting from the amount of radiation received.
This is known as the dose received.

The dosimeter is designed to measure the radioactive dose or dose equivalent received by a person exposed to radioactive radiation.

THE EFFECTIVE DOSE

The sievert measures dangerousness. When it comes specifically to the human body, the effects of different types of radiation vary according to the organs or tissues affected. Some are more sensitive than others.

The dose received by an organ is the result of a calculation that takes various factors into account. For example, radiation weighting factors are applied depending on the organs affected.

WEIGHTING ACCORDING TO ORGANS AFFECTED BY DOSE RECEIVED

- Breast 0.12
- Colon 0.12
- Lung 0.12
- Stomach 0.12
- Heart 0.12
- Pancreas 0.12
- Small intestine 0.12
- Cervix 0.12
- Muscles 0.12
- Bone marrow 0.12
- Prostate 0.12
- Gonad 0.08
- Bladder 0.04
- Liver 0.04
- Thyroid 0.04
- Brain 0.01
- Skin 0.01

Key figures

- **0.03 mSv:** a flight from Paris to New York, dose due to natural cosmic rays in the upper atmosphere.
- **0.7 mSv:** a chest X-ray.
- **3 mSv:** one year's exposure to natural radioactivity in France.
- **10 mSv:** a CT scan.
- **100 mSv:** value above which an increase in the risk of cancer has been measured.
- **Above 1 Sv (1000 mSv)** received in a short period of time, radiation can cause disorders and malfunctions, and even death in the short or medium term.

ESTIMATE THE DOSE RECEIVED

Estimate your dose for your next flight by scanning the following QR Code or visiting http://www.sievert-system.org/

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WHAT IS **RADIOACTIVITY?**

WE ARE ALL **EXPOSED**

We are all constantly exposed to **small doses** of radioactivity, whether of natural or artificial origin.

NATURAL RADIOACTIVITY OR **ARTIFICIAL** RADIOACTIVITY ?

Radiation comes from the cosmos, the Earth, the air we breathe and the food we eat. Every day we ingest radioactive atoms that are naturally present in our environment.

Nuclear facilities also generate airborne emissions and waste. In hospital, doctors also use equipment that emits radiation, such as X-ray and scanner machines, to treat patients.

Two types of exposure need to be taken into account: artificial exposure and natural exposure.

VARIABLE LEVELS OF EXPOSURE

Our exposure varies according to our lifestyle, where we live and the frequency of medical examinations (X-rays and scans). This leads to a very different annual dose from one person to another.

FOR EXAMPLE

Someone who skis a lot (altitude), eats a lot of bananas (naturally radioactive potassium), lives in Brittany (naturally radioactive granite) or has a lot of medical check-ups or air travel will be much more exposed than someone who lives in the Paris region, rarely visits hospitals and rarely stays at altitude.

ESTIMATE YOUR ANNUAL EXPOSURE

Estimate your annual exposure by scanning the following QR Code or visiting https://expop.irsn.fr/

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WHAT IS **RADIOACTIVITY?**

RADIOACTIVITY **IN FOOD**

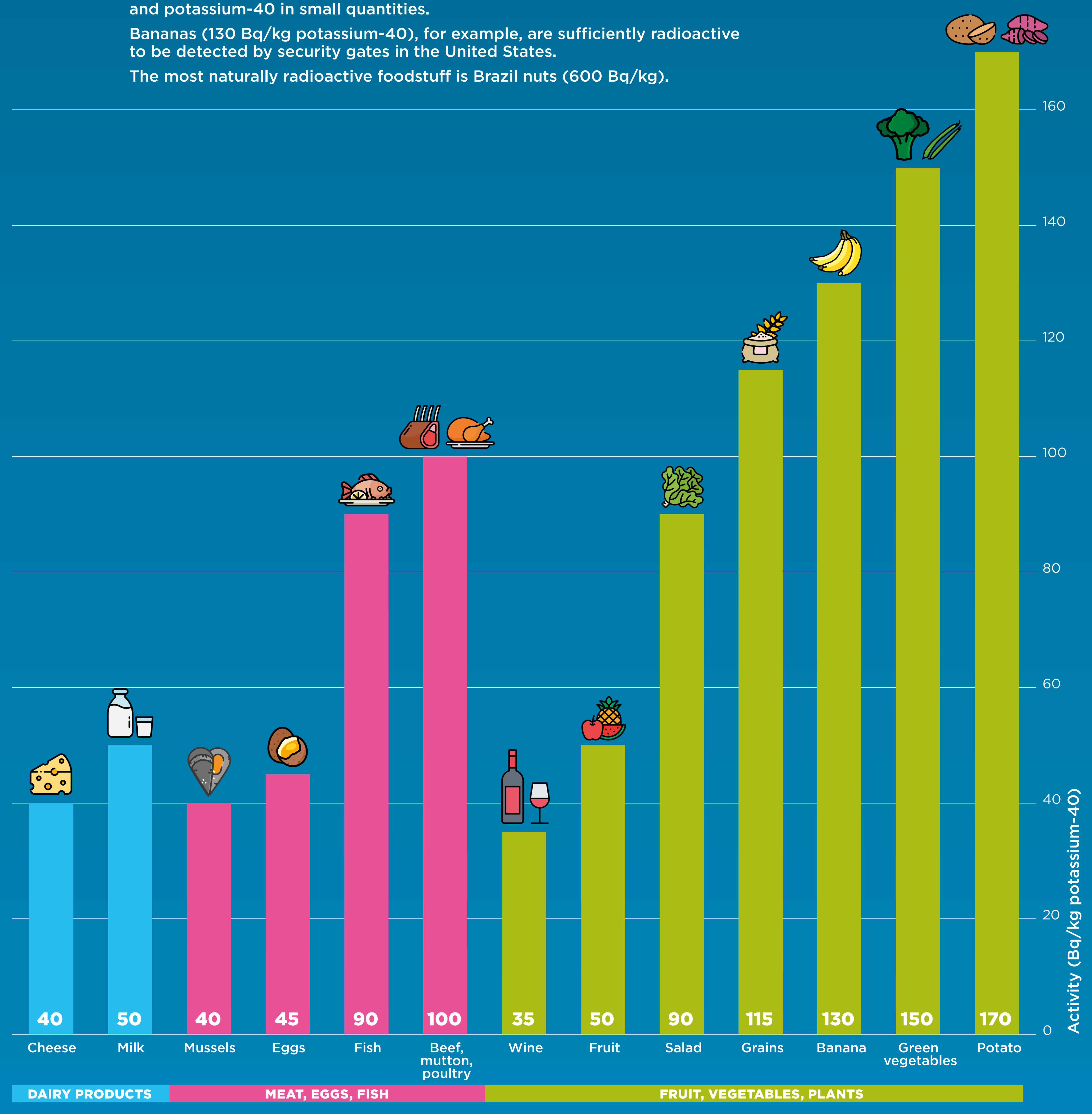
The food we eat is naturally radioactive.

NATURALLY RADIOACTIVE SUBSTANCES

All our food is somewhat radioactive, containing elements such as carbon-14 and potassium-40 in small quantities.

Bananas (130 Bq/kg potassium-40), for example, are sufficiently radioactive to be detected by security gates in the United States.

The most naturally radioactive foodstuff is Brazil nuts (600 Bq/kg).



PRECISELY MEASURE THE DOSE RECEIVED NATURALLY

Depending on its nature, a radioactive element will bind to one organ or another. The body does not store all these elements; it evacuates the quantity it does not need or eliminates it little by little.

For example, only a limited quantity of potassium-40 is fixed by the body, the rest is eliminated. Half of the carbon-14 is eliminated in 40 days. On the other hand, the body can store polonium-210 (very prevalent in fish and crustaceans) without limit. **0.55 mSv/year** is the average dose ingested in France.

A table can be used to convert the quantity of becquerels of a radioelement ingested into millisieverts, depending on the person's age. For example, in crustaceans, there is naturally 18 Bq/kg of polonium-210 and 10 Bq/kg in small fish.
Let's imagine that you ingested 100 Bq of polonium-210 by eating a lot of fish or crustaceans (about 10 kg):
- an adult will receive a dose of $1.2 \times 10^{-6} \times 10^2 = 0.12\ 10^{-3}$ sieverts, i.e. 0.12 mSv;
- a 5-year-old child will receive a dose of $4.4 \times 10^{-6} \times 10^2 = 0.44\ 10^{-3}$ sieverts, i.e. 0.44 mSv.

Radioelement	Age				
	1 year	5 years	10 years	15 years	Adult
Potassium-40	$4.2\ 10^{-8}$	$2.1\ 10^{-8}$	$1.3\ 10^{-8}$	$7.6\ 10^{-9}$	$6.2\ 10^{-9}$
Carbon-14	$1.6\ 10^{-9}$	$9.9\ 10^{-10}$	$8.0\ 10^{-10}$	$5.7\ 10^{-10}$	$5.8\ 10^{-10}$
Polonium-210	$2.6\ 10^{-5}$	$4.4\ 10^{-6}$	$2.6\ 10^{-6}$	$1.6\ 10^{-6}$	$1.2\ 10^{-6}$

Brazil nuts are naturally the most **radioactive food**.

It is made up of **three hundred sextillion atoms** (300,000,000,000,000,000,000,000).

Every minute, around twenty of these atoms emit radiation.

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WHAT IS **RADIOACTIVITY?**

MAKING **RADIOACTIVITY**

**At the end of the 19th century, humans discovered the natural phenomenon of radioactivity.
This enabled the creation of other radioactive elements and their use in many fields:
This is artificial radioactivity.**

THE BEGINNINGS OF ARTIFICIAL RADIOACTIVITY

In the early part of 1934, Irène and Frédéric Joliot-Curie announced in a note to the Académie des Sciences (French Academy of Sciences) that they had made a radioactive atom that did not exist in nature.

By bombarding a sheet of aluminium with a source of alpha rays, they observed the appearance of an unknown element. This element turned out to be **an isotope of phosphorus, phosphorus-30.**

"I irradiate this target with alpha rays from my polonium source; you can hear the Geiger counter clicking [...] I remove the source: the clicking should stop... but the noise continues..."

Frédéric Joliot-Curie

THE APPLICATIONS OF ARTIFICIAL RADIOACTIVITY

Radioactive elements such as uranium and potassium have been naturally present in our environment since the beginning of the universe, because they are long-lived.

The other shorter-lived elements, which were also present at the origin of the universe, have since disappeared. However, we now know how to manufacture these elements and create others, more or less ephemeral, for energy, military, medical and scientific needs.

INDUSTRY


NUCLEAR POWER


RESEARCH


MEDICINE


MILITARY

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RADIOACTIVITY: A BRIEF HISTORY

Since its discovery at the end of the 19th century, **radioactivity** has been used in a **variety of fields** (research, medical, military, nuclear power, industry) and the associated risks have been managed.

TIMELINE OF RADIOACTIVITY

12 to 15 March 2011
Fukushima nuclear accident (Japan)

2006
Creation of the French Nuclear Safety Authority (ASN) and enactment of the law on nuclear transparency and safety (TSN law)

2001
Creation of the Institut de Radioprotection et de Sûreté Nucléaire (IRSN - Institute for radiation protection and nuclear safety) from the merger of OPRI and IPSN

1996
Last French nuclear test in French Polynesia and launch of the Laser Megajoule programme to simulate the operation of nuclear weapons

26 April 1986
Chernobyl nuclear accident (Ukraine)

28 March 1979
Three Mile Island nuclear accident (United States)

1976
Creation of the Institute for Nuclear Protection and Safety (IPSN) within the CEA

1973
Start of mass deployment of nuclear power in France (Messmer plan)

1973
Creation of the Service central de sûreté des installations nucléaires (SCSIN - central department for the safety of nuclear installations) attached to the Ministry of Industry, which became the Autorité de sûreté nucléaire (ASN - French Nuclear Safety Authority) in 2006

1972
Invention of the medical scanner by Godfrey N. Hounsfield

1 July 1968
Entry into force of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)

16 September 1962
Start-up of *Chinon A1*, EDF's first nuclear reactor

13 February 1960
Gerboise bleue, France's first nuclear explosion in the Sahara

1957
Windscale accident (United Kingdom), first major nuclear accident

1957
Creation of the Service central de protection contre les rayonnements ionisants (SCPRI - central department for the protection against ionising radiation), which became the Office de protection contre les rayonnements ionisants (OPRI - office for the protection against ionising radiation) in 1994

25 March 1957
Signature of the Treaty establishing the European Atomic Energy Community (EURATOM), which today remains one of the three fundamental treaties of the European Union

29 July 1957
Creation of the International Nuclear Energy Agency (IAEA) to promote the safe, secure and peaceful use of nuclear technologies, in particular by combating proliferation

1955
Creation of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)

20 January 1955
First sea trip by the *Nautilus*, the first nuclear submarine

26 June 1954
Commissioning of the Obninsk reactor (USSR), the world's first electricity-generating reactor, which operated until 29 April 2002

6 December 1953
Speech by President Eisenhower to the UN General Assembly *"Atoms for Peace,"* proposing the use of nuclear technologies for non-military purposes

20 December 1951
First nuclear power generation by the *BR1 reactor* in the United States

15 December 1948
Divergence of ZOE, the first French reactor

16 July 1945
Trinity, the first nuclear explosion in history in New Mexico (United States)

6 August 1945
Hiroshima explosion

9 August 1945
Nagasaki explosion

18 October 1945
Creation of the French Atomic Energy Commission (CEA), whose mission is to provide France with nuclear energy and nuclear weapons

2 December 1942
First divergence of a nuclear reactor, *Chicago Pile 1*, designed by Enrico Fermi

9 October 1941
Franklin D. Roosevelt approves the launch of the Manhattan Project, which will lead to the development of nuclear weapons and the creation of the "nuclear cycle"

1 May 1939
Frédéric Joliot-Curie filed three secret patents: two on reactor operation and one on the possibility of a "nuclear explosive"

1938
Hahn, Strassman and Meitner discover nuclear fission

1934
Discovery of artificial radioactivity by Irène and Frédéric Joliot-Curie

1932
Discovery of the neutron by James Chadwick (predicted in 1920 by Ernest Rutherford)

1928
Development of the Geiger-Müller counter

1928
On the initiative of Rolf Sievert, who gave his name to the unit measuring received dose, the "International Committee for Radiological Protection" was set up, later to become the International Commission on Radiological Protection (ICRP)

1914
Introduction of the "Petites Curies", vehicles that Marie Curie equipped with X-ray units to care for the wounded in the field during the First World War

1901
First results from the use of radium to treat disease

1900
First observation of the physiological effects of ionising radiation (inflammation of the skin after exposure)

21 December 1898
Discovery of radium by Marie and Pierre Curie

2 March 1896
Discovery of radioactivity by Henri Becquerel

July 1896
First radiation treatment carried out in Lyon by Dr Victor Despeignes to treat a stomach tumour

22 December 1895
First X-ray by Wilhelm Röntgen, who discovered X-rays

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