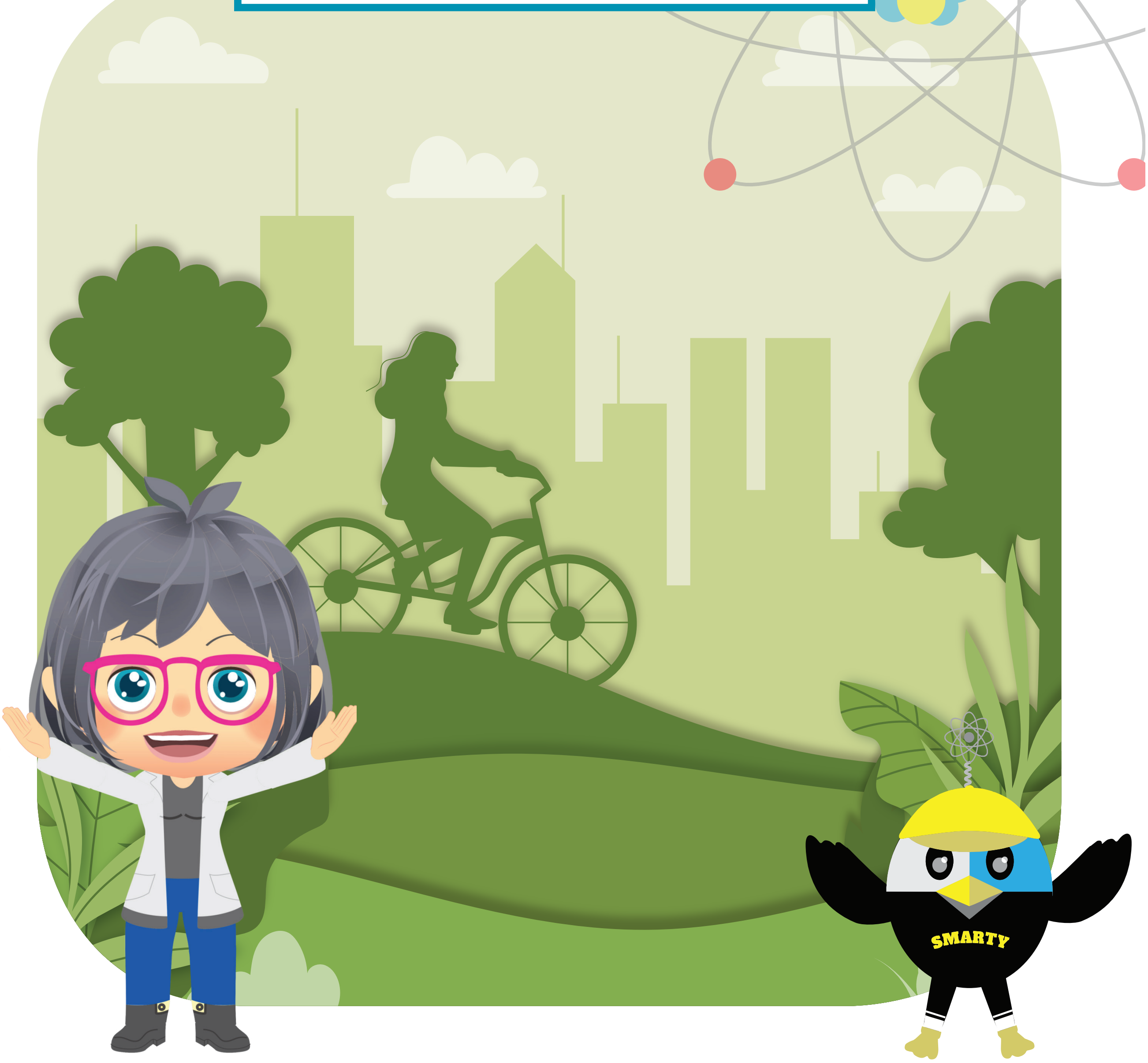
1 NUCLEAR 101

Radiation Around Us



Nuclear 101
Radiation Around Us

A Resource Material for Secondary Students and Science Teachers

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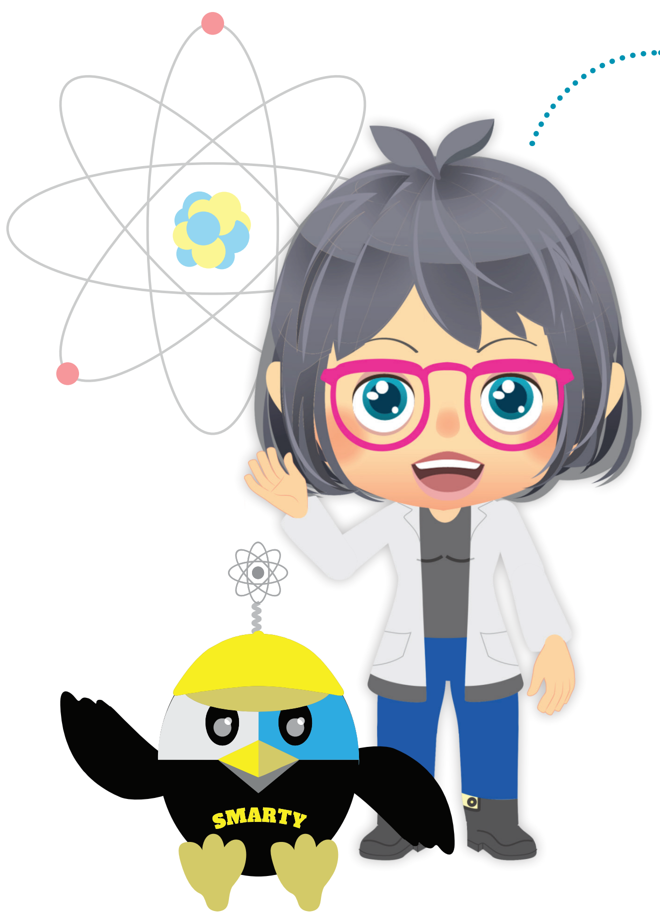


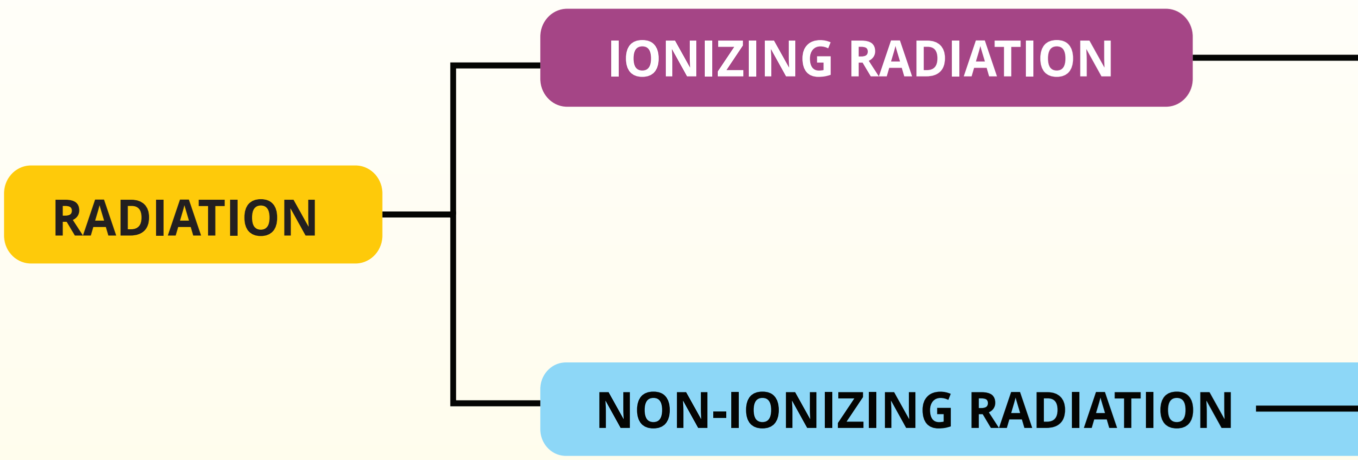
Hi there! I'm Radia! In this booklet, you will learn about:

1. *The structure of the atom and how to use this to identify where radiation comes from*
2. *The different types of radiation, how they are produced and their uses*
3. *Sources of background radiation and how to make a rough calculation of your annual radiation dose.*

WHAT IS RADIATION?

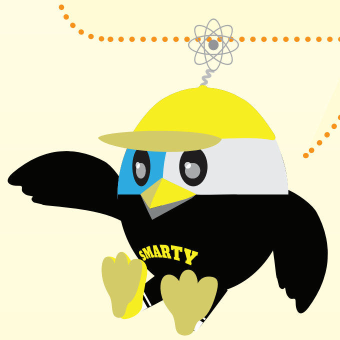
Radiation is energy that comes from a source and travels through space or vacuum at the speed of light. Most often, radiation transmit energy through electromagnetic waves. Other types of radiation however, transfer energy through particle beams. Depending on its energy, radiation can be classified as either ionizing or non-ionizing.

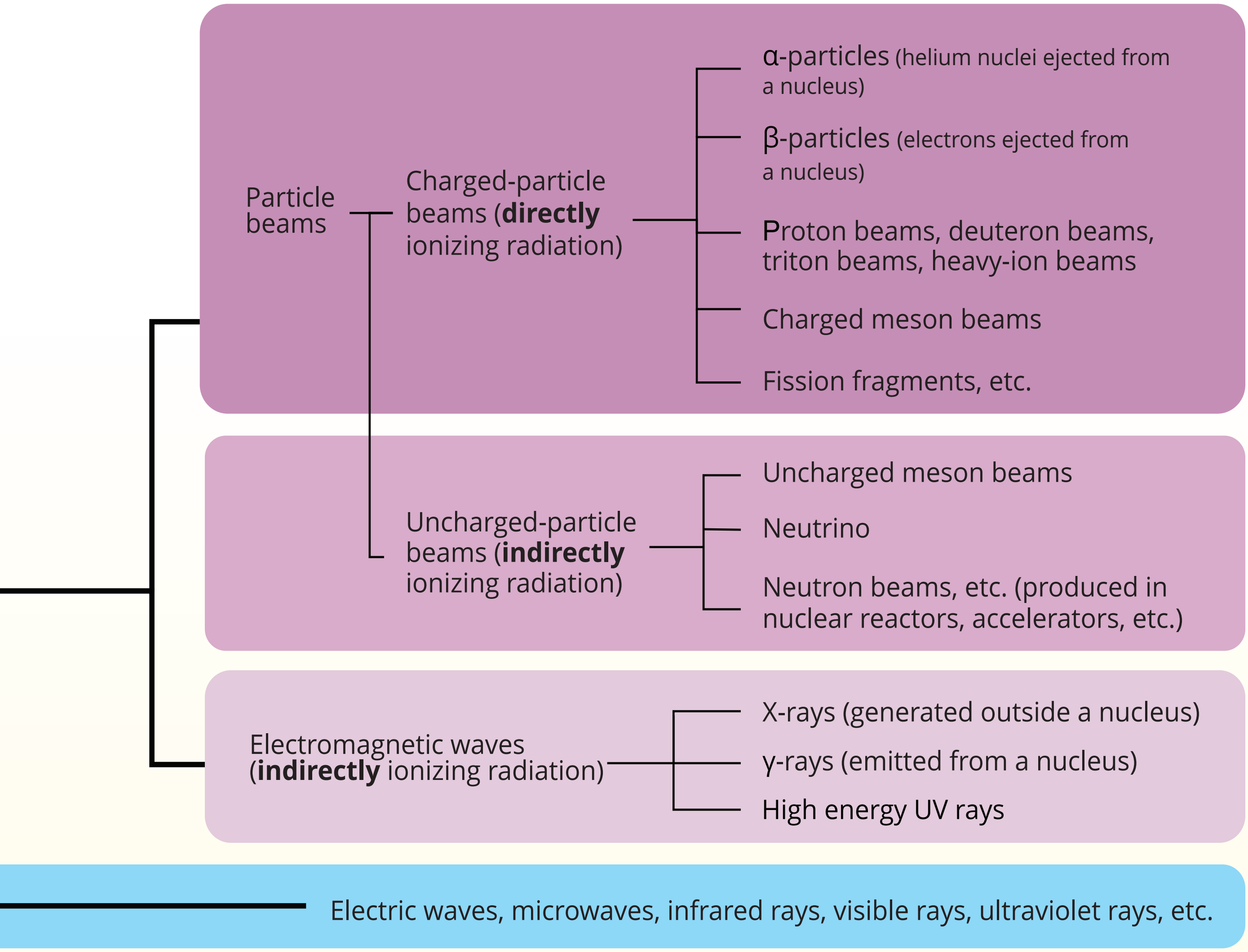
Types of Radiation



Ionizing radiation is radiation with enough* energy so that during an interaction with an atom, it can remove tightly bound electrons from the orbit of an atom, causing the atom to become charged or ionized. Alpha and beta particles are considered directly ionizing because they carry a charge and can interact directly with the electrons in the atom through coulombic forces. Neutrons, X-rays and gamma rays are indirectly ionizing because they are electrically neutral and therefore do not interact with the electrons in the atom through coulombic forces.

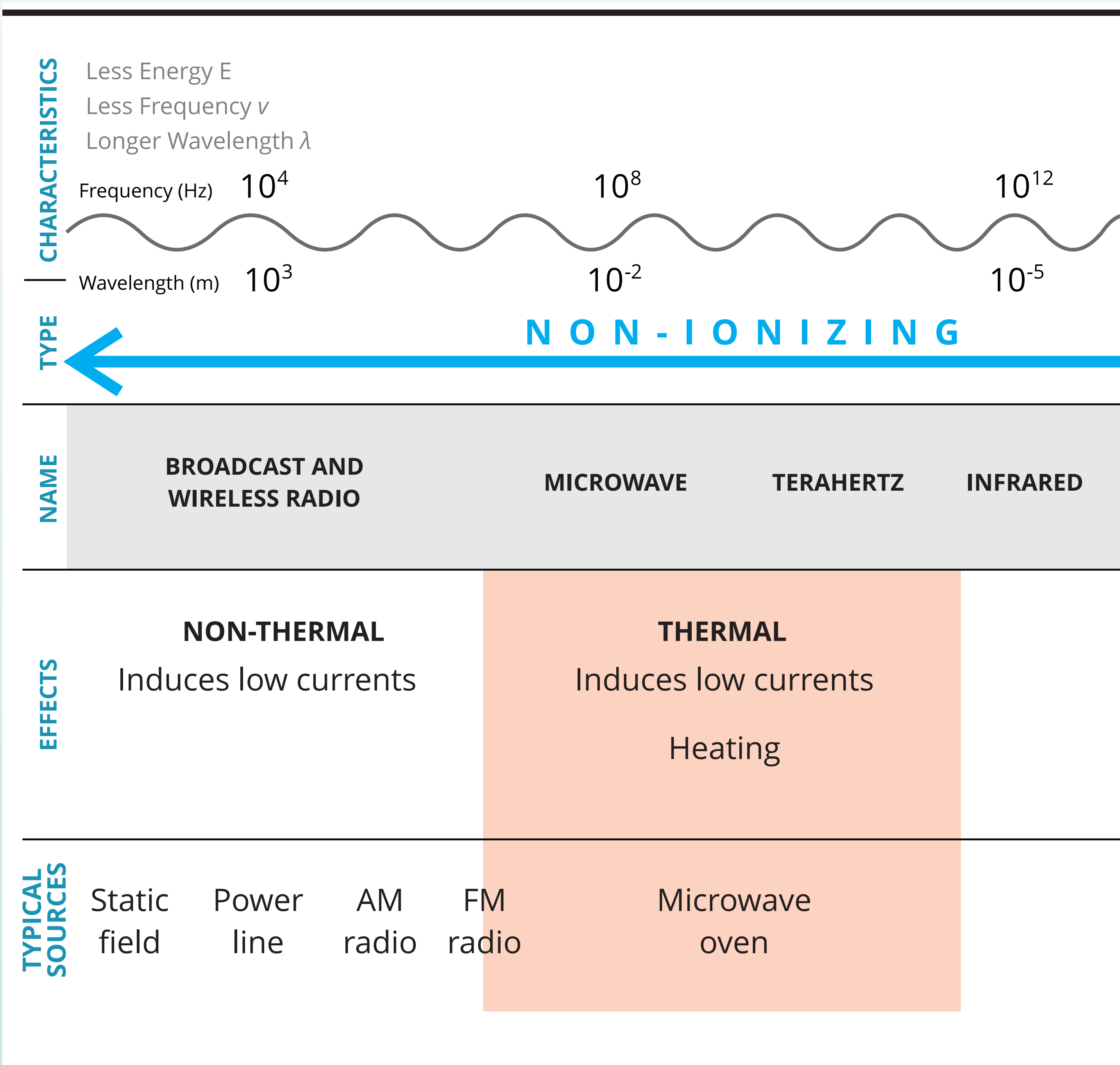
**How much is "enough"? Radiation of energy more than 13.6 electronvolt (eV) is ionizing!*



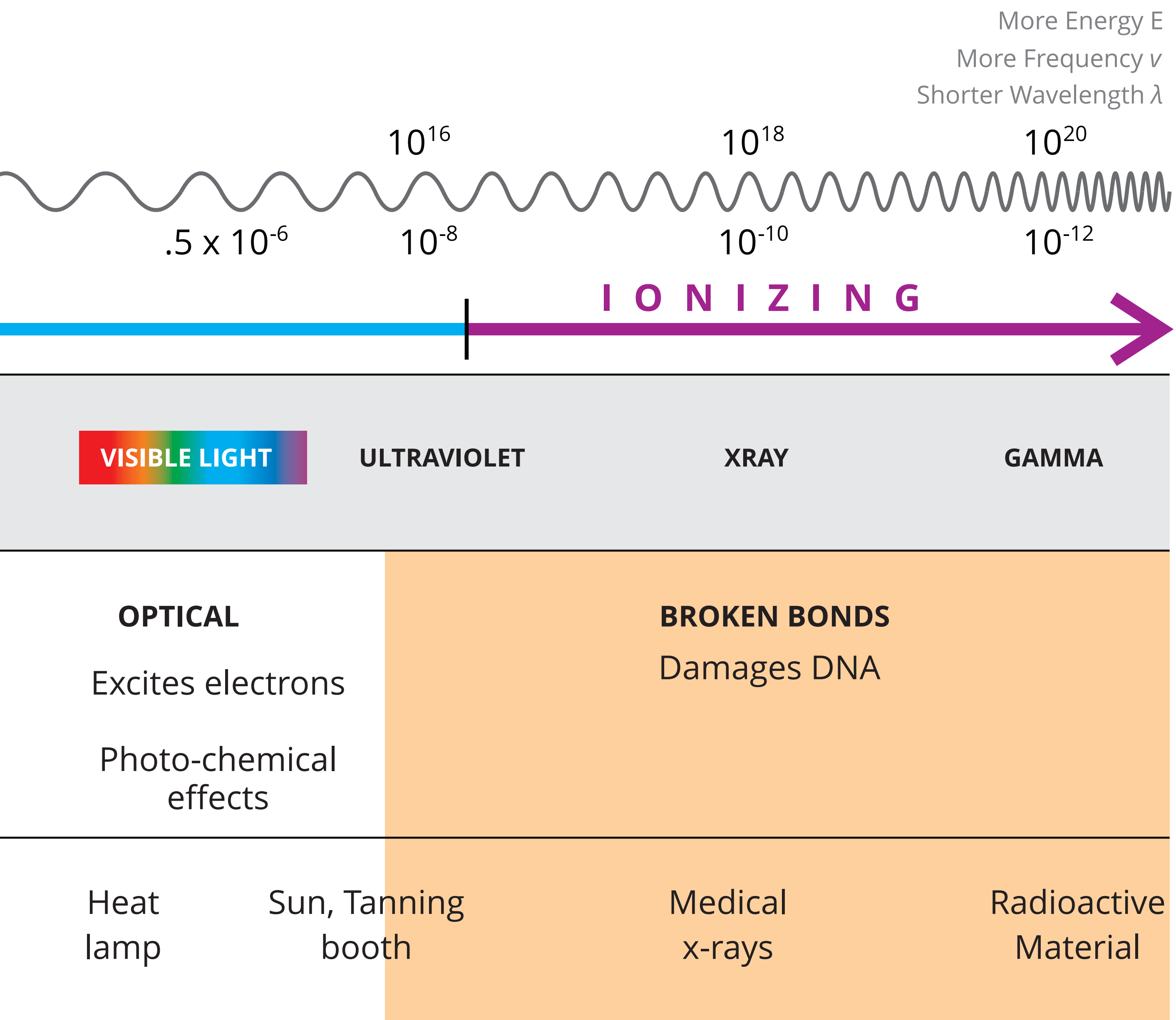


Non-ionizing radiation, on the other hand, have insufficient energy to cause ionization. When non-ionizing radiation interacts with matter, it can change either the rotational, vibrational or electronic valence configurations of molecules and atoms, which produces thermal effects. In other words, the energy imparted by non-ionizing radiation to the electron in the atom will generally cause the electron to be energized or "**excited**". However, the electron is still bound to the atom and will sooner or later return to its ground state emitting the excitation energy it initially absorbed in the form of electromagnetic waves. Generally, excitation creates heat.

The electromagnetic spectrum



The electromagnetic spectrum shows the different types of ionizing and non-ionizing radiation and the differences in their energy, frequency and wavelength. Note that ***alpha*** *and* ***beta*** *radiation are not listed in the spectrum. Why is this so?*

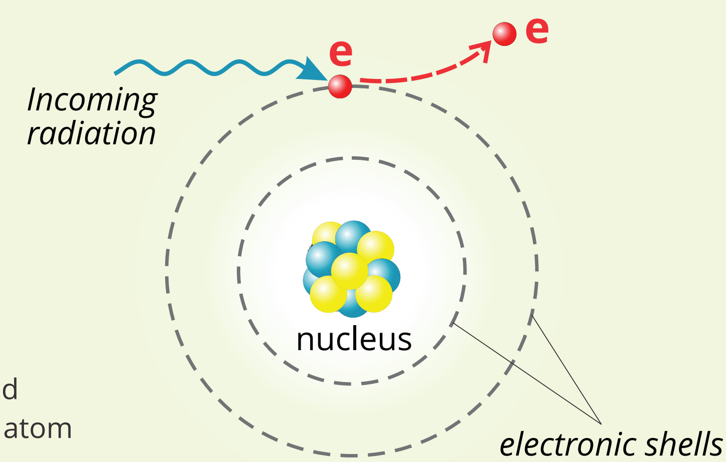


Ionization vs. Excitation

Ionization *is a process which results to the removal of an electron from an atom leaving the atom with a net positive charge.*

Excitation *is the transfer of a bound electron to a more energic state. The electron is still bound to the atom and will sooner or later return (de-excitation) to its ground state.*

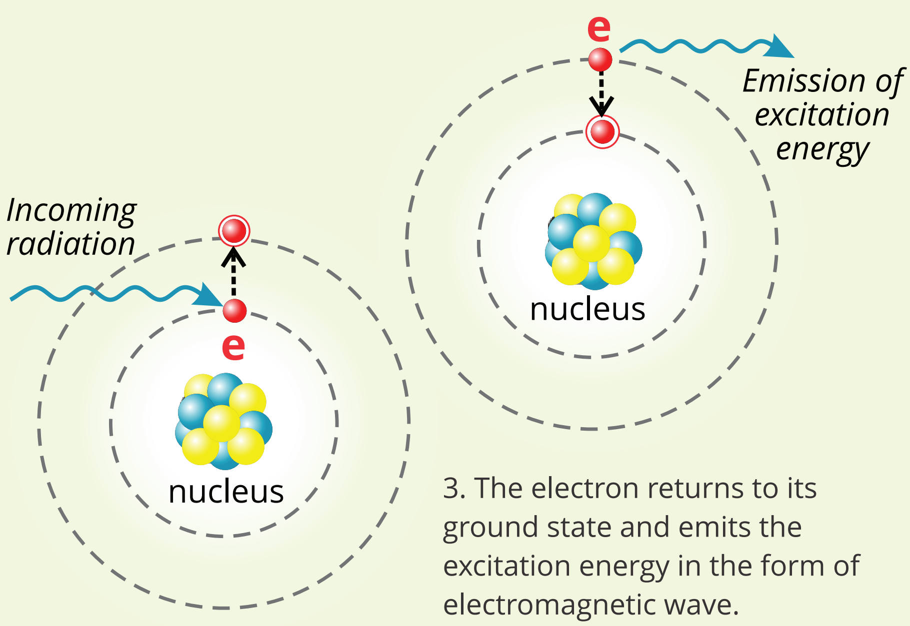
Ionization



What happens?

1. Orbital electron is ejected
2. An ion pair is created – the ejected electron and the positively charged atom

Excitation

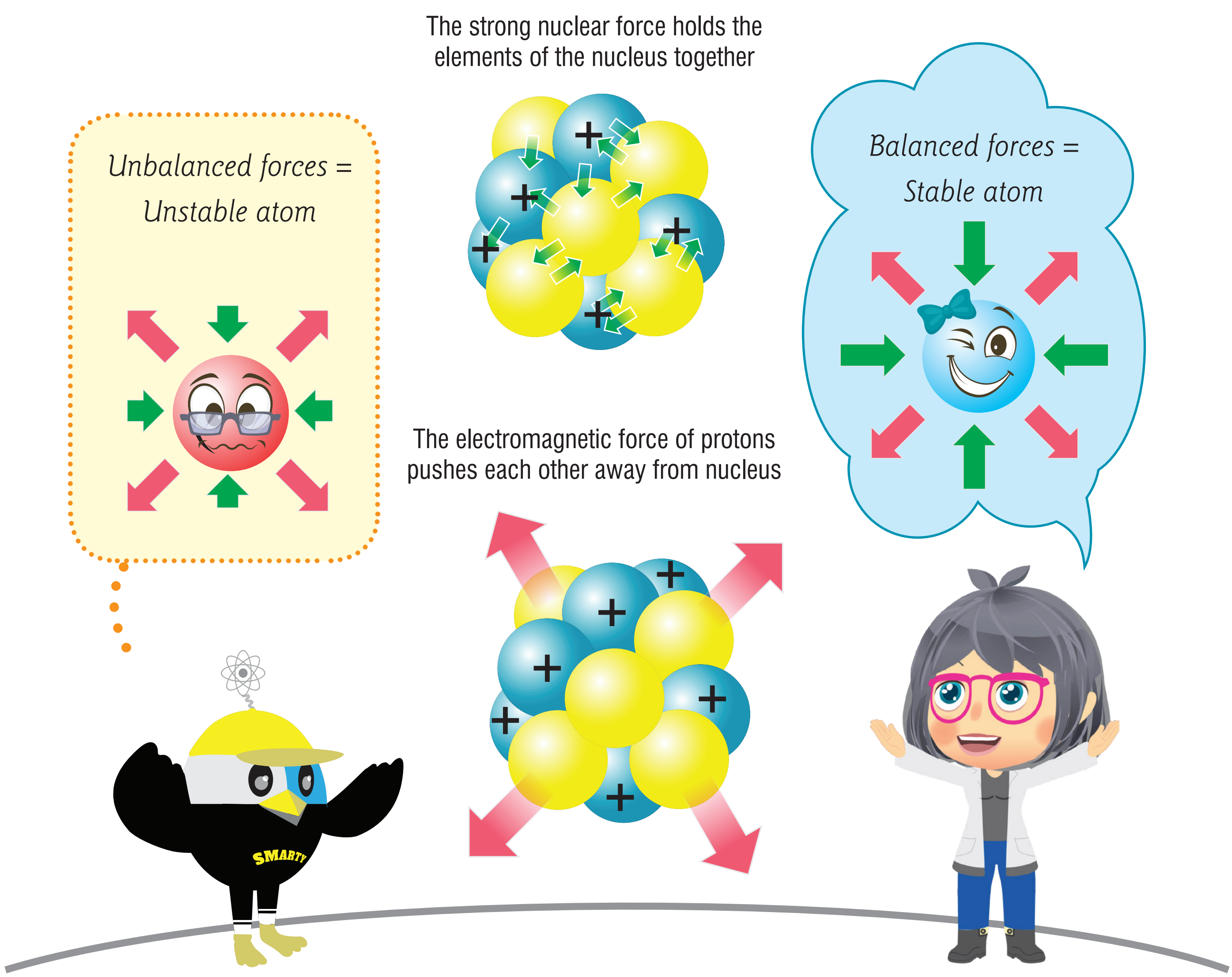


What happens?

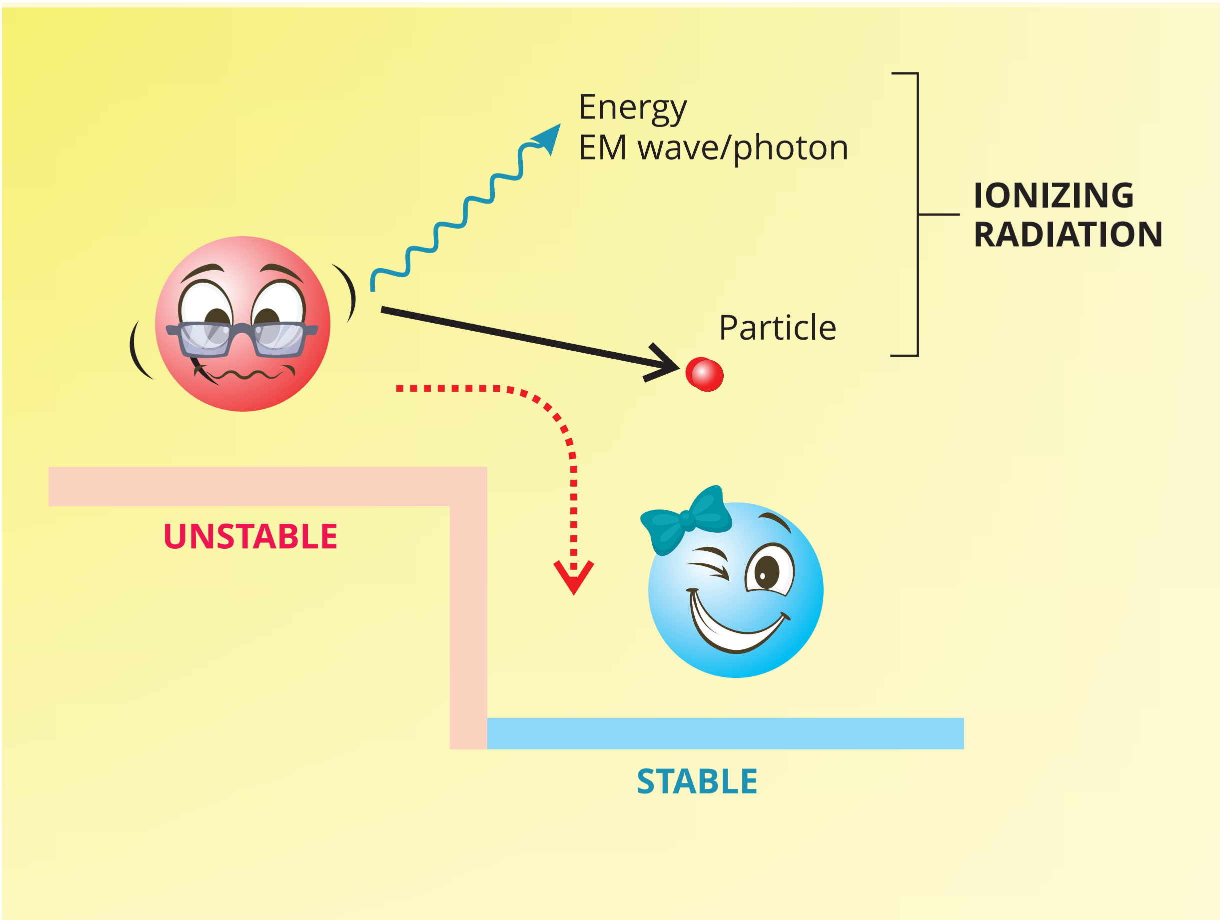
1. Energy is transferred by the incoming radiation to the electron.
2. Energy is not enough to eject the electron. The electron is “excited” to a higher energy level.
3. The electron returns to its ground state and emits the excitation energy in the form of electromagnetic wave.

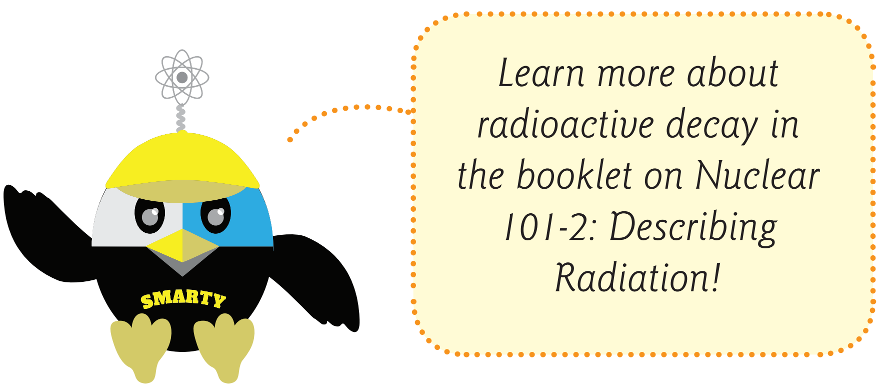
WHERE DOES IONIZING RADIATION COME FROM?

Except for x-rays, all other types of ionizing radiation originate from the **nucleus** of the atom. The nucleus of the atom is made up of protons and neutrons, also called collectively as **nucleons**. Nucleons are held together by the strong nuclear force which balances the repulsive electrical force between the protons. When these forces are not balanced, as in the case when there are too many neutrons in the nucleus or too little, the nucleus becomes **unstable** or **radioactive**.



An unstable nucleus will attempt to reach stability by ejecting nucleons, as well as other particles, or by releasing energy in other forms such as a photon. The process by which an unstable nucleus loses energy by radiation is called **radioactive decay**. The decay of the unstable nucleus will continue until the forces in the nucleus are balanced.

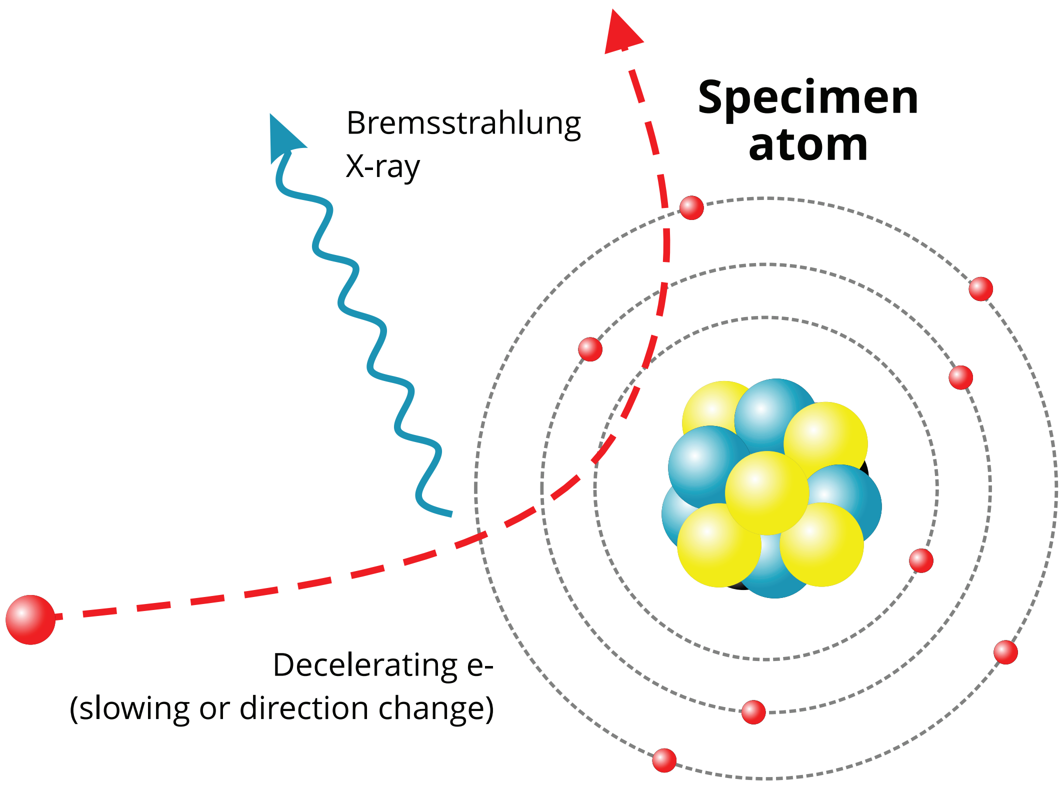




How X-rays are produced

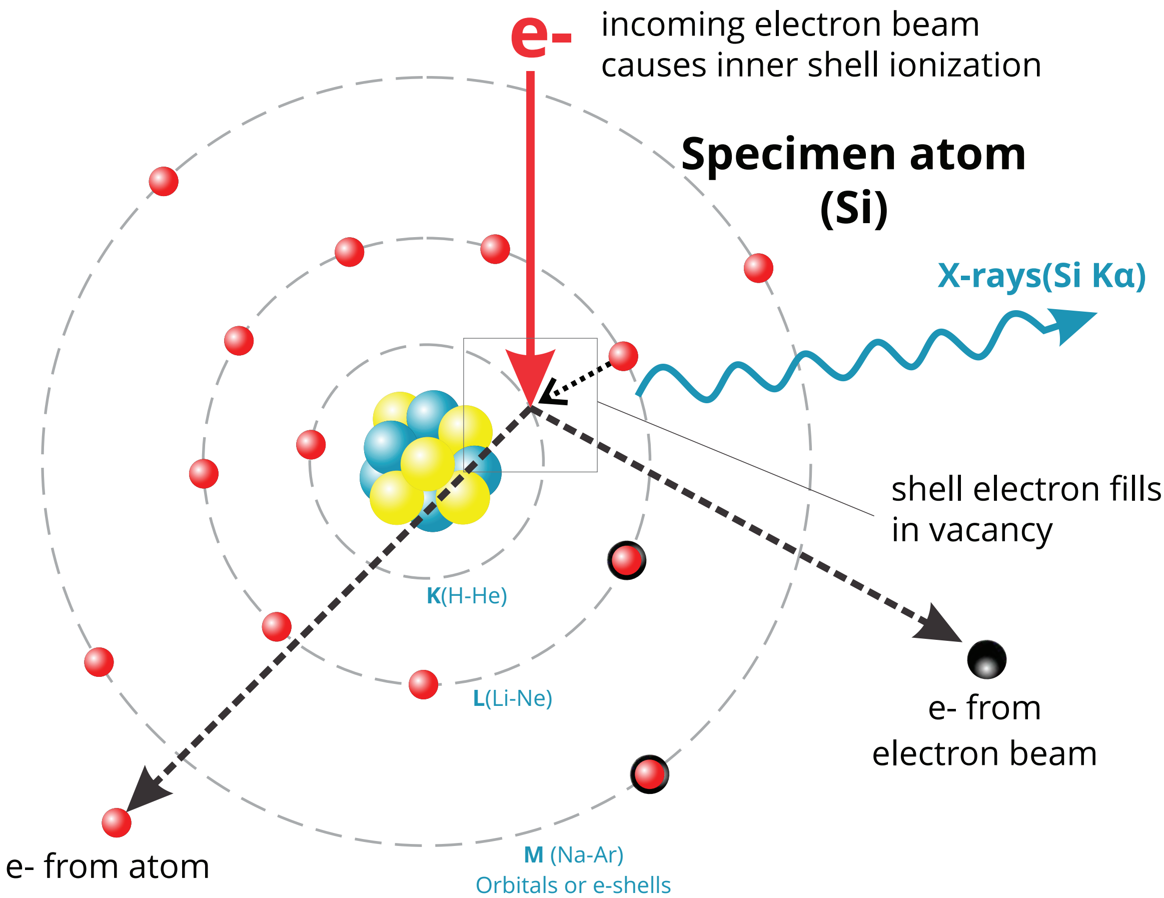
X-rays are similar to gamma rays however the main difference is the way they are produced. X-rays are **produced by electrons external to the nucleus**. X-rays originate from the electron cloud of the atom. Two types of X-rays are produced when an electron beam interacts with the atoms in a sample material – (1) Bremsstrahlung X-rays (also known as "breaking" radiation) and (2) characteristic X-rays.

A. Bremsstrahlung X-ray Production



Bremsstrahlung X-rays are produced when a free electron is slowed down by the electric field surrounding the nuclei of the target atoms. The free electron loses energy as it slows down and change direction. This "lost" energy is converted to X-rays. Most X-rays generated in X-ray tubes in medical examinations are Bremsstrahlung X-rays. The generation of X-rays stops when the X-ray tube is switched off.

B. Characteristic X-ray Production

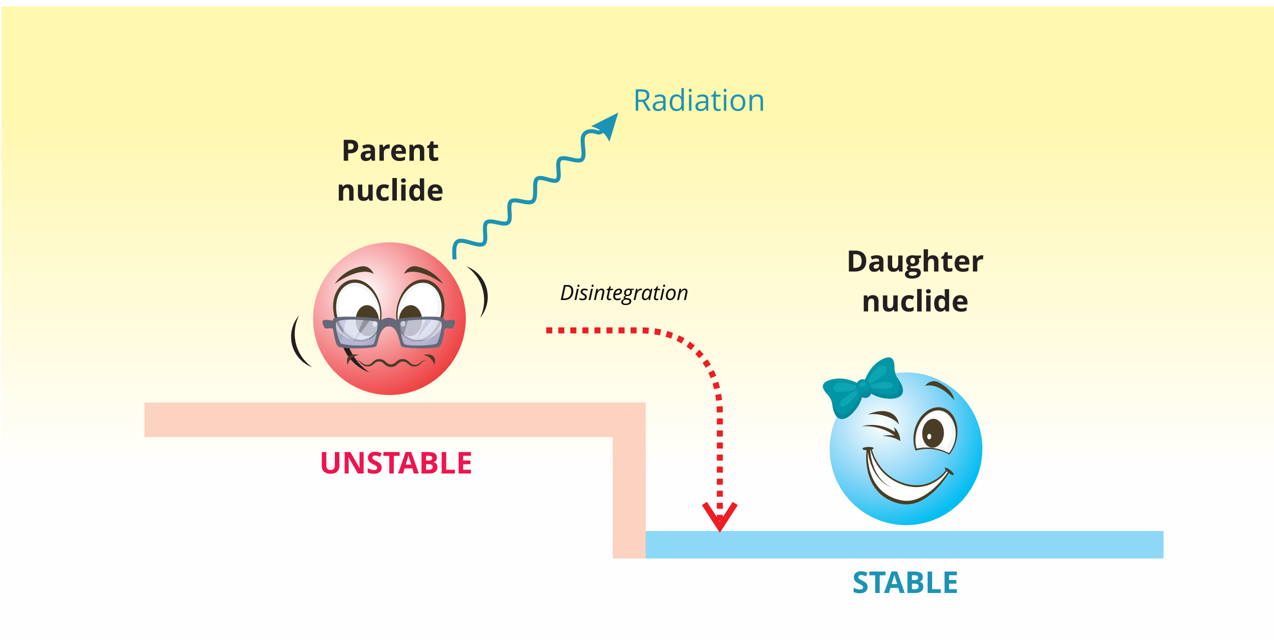


Characteristic X-rays are produced by the transition of electrons between electron shells. Electron shells correspond to a stable set of energy levels occupied by electrons in an electron cloud. The shell closest to the nucleus is known as the K shell, followed outwards by the L, M, N, O, P and Q shells. The further from the nucleus the shell is, the lower its ionization energy. The electrons in each shell and subshell have specific ionization energies, and these are different for every element. For instance, the ionization energy of the K shell in a silicon (Si) atom is about 1.84 kiloelectronvolt (keV) while the ionization energy of the K shell in a platinum (Pt) atom is about 78.4 keV. Hence, characteristic X-rays are useful in identifying the elements present in a sample material.

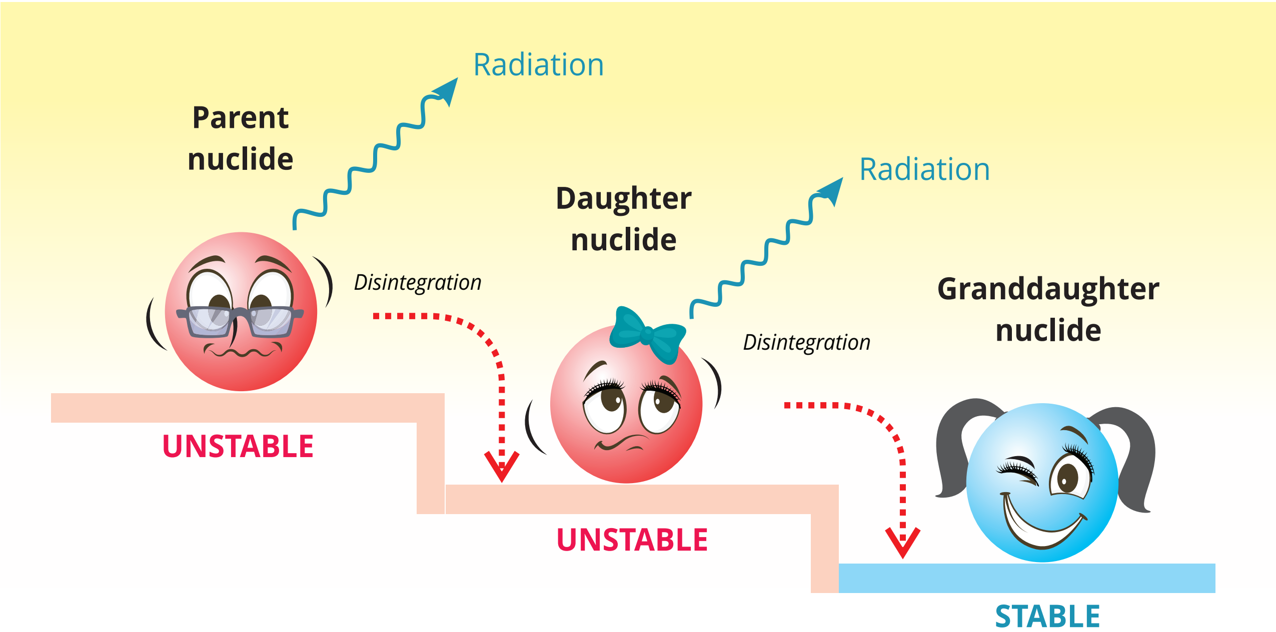
The production of characteristic X-rays is a two-stage process. First, the incoming electron beam removes an electron from one of the inner shells of the atom so that the atom is ionized and in an unstable state. Then, the atom regains stability as an electron from an outer shell fills the vacancy in the inner shell, emitting an X-ray photon in the process.

WHAT HAPPENS TO AN ATOM AFTER IT RELEASES RADIATION?

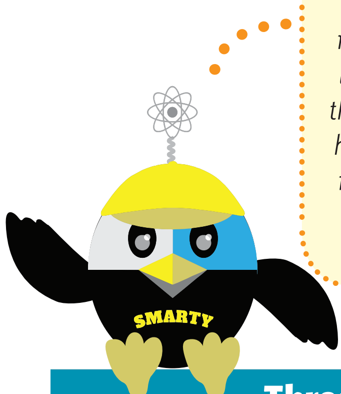
As the unstable nucleus emits radiation in the form of a wave or a particle, the radioactive atom transforms to a different nuclide and continues to do so until the forces in the nucleus are balanced. For instance, tritium, a radioactive isotope of hydrogen, will emit a beta particle and transform into helium, in order to become stable. The phenomenon wherein a radionuclide transforms into a different nuclide after emitting radiation is called **disintegration**. A nuclide before disintegration is called a parent nuclide. After disintegration the resulting nuclide is called a daughter nuclide.



A nuclide before disintegration is called a parent nuclide.
After disintegration, it is now called a daughter nuclide.



A nuclide whose daughter nuclide is energetically unstable repeats disintegration until becoming energetically stable.



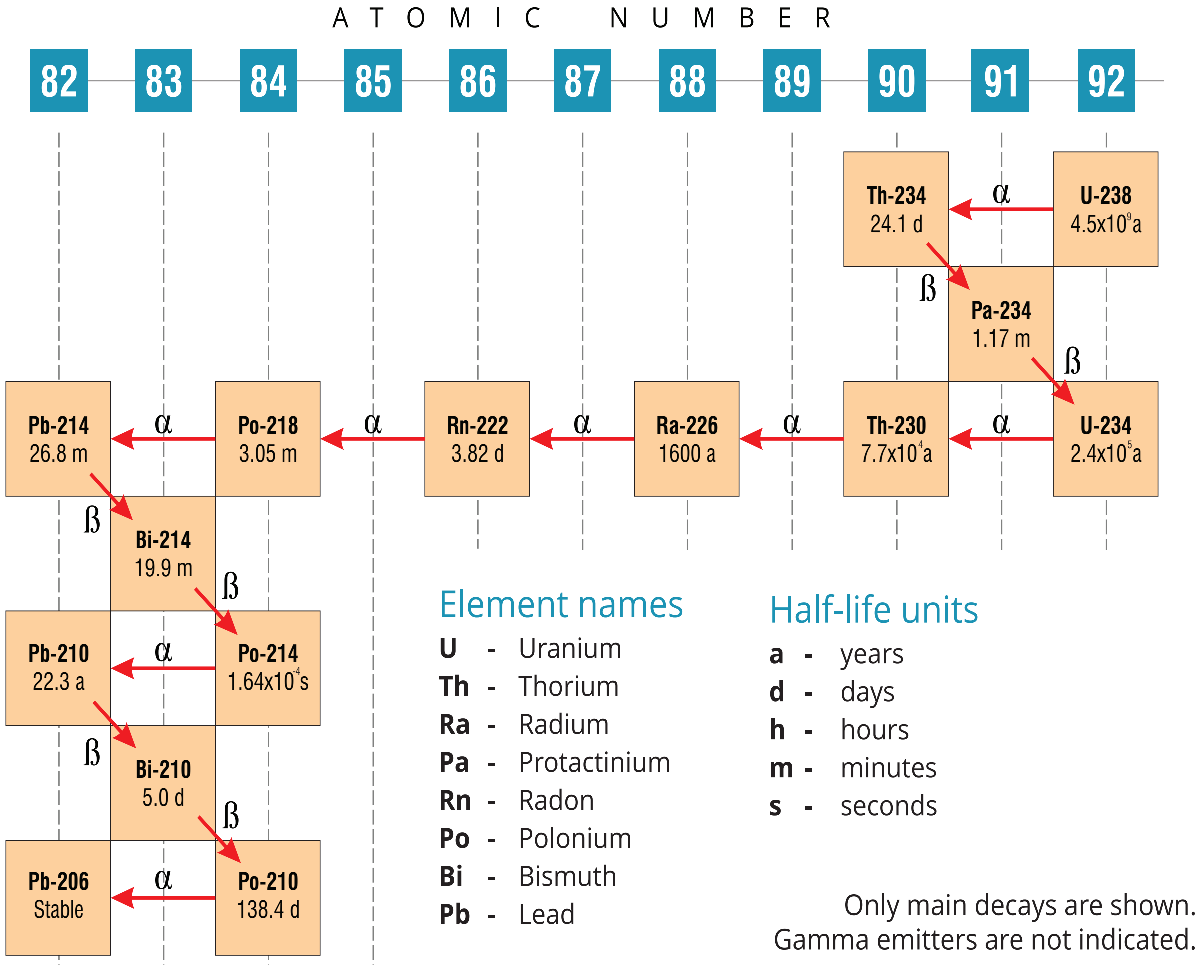
*A **nuclide** is a term used to refer to any particular atom characterized by the number of protons and neutrons. Radionuclides are nuclides that are radioactive. Different nuclides of the same element are called isotopes. There are more than 3000 nuclides identified in the Nuclide Chart! The names of isotopes and nuclides are specified by the name of the particular element, followed by a hyphen and the mass number (e.g., helium-3, carbon-12, carbon-13, iodine-131 and uranium-238). In symbolic form, the mass number is denoted as a superscripted prefix to the chemical symbol (e.g., 3He, 12C, 13C, 131I and 238U). Another symbolic notation used is the chemical symbol followed by a hyphen and the mass number.*

Three Nuclides of the Hydrogen Isotopes

Protium	*Deuterium*	*Tritium*
Hydrogen -1	Hydrogen-2	Hydrogen-3
^{1}H or H-1	**^{2}H or H-2**	**^{3}H or H-3**
1 proton	1 proton 1 neutron	1 proton 2 neutron

Decay Series of Uranium

Uranium-238 undergoes several nuclear transformations or disintegrations before becoming lead-206, a stable nuclide.



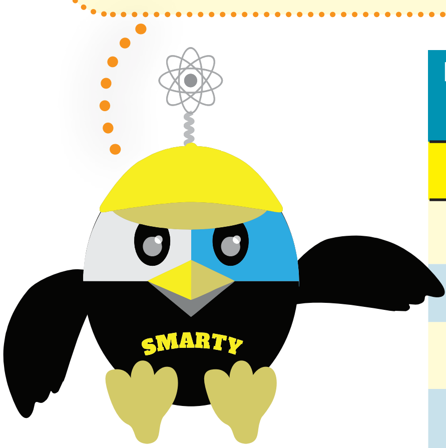
The series of transformations that a radioactive atom goes through to reach stability and the type of radiation produced is characteristic of the radioactive atom. The transformation stages form a **decay series**. Scientists use a tool known as the **nuclide chart** to identify the decay series of a particular nuclide. The nuclide chart also shows all the known isotopes of different elements. It organizes isotopes along the X-axis (horizontal) by their number of neutrons and along the Y-axis (vertical) by their number of protons.

Radiation Symbol

Ionizing Radiation Warning Symbol

Radioactive materials are materials whose atoms are unstable and thereby emit ionizing radiation. Traditionally, the three cornered trefoil symbol is used to label radioactive materials. In 2007, the International Atomic Energy Agency (IAEA) and the International Organization for Standardization (ISO) introduced a new ionizing radiation warning symbol to supplement the traditional international symbol for radiation.

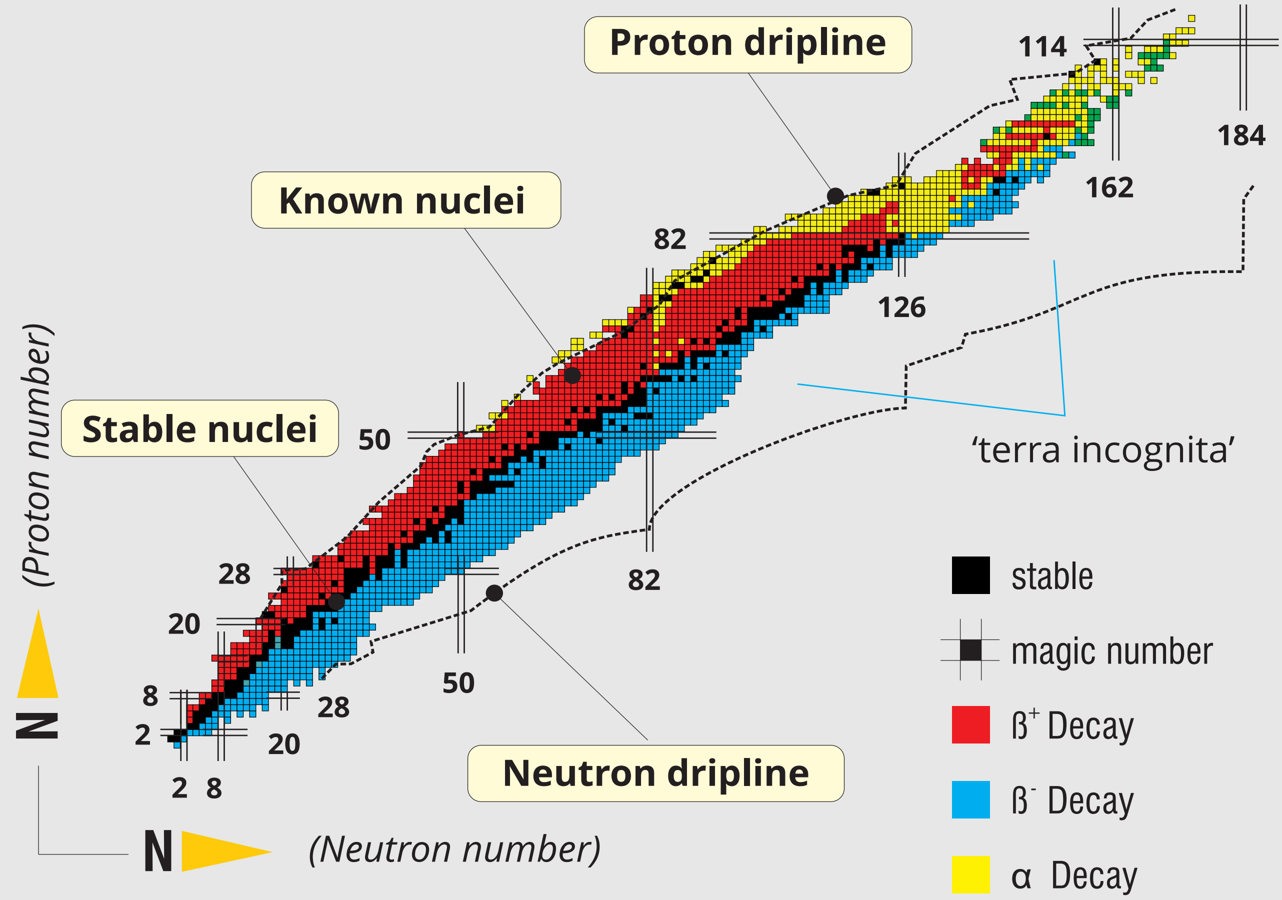
How to tell if a nuclide is stable or unstable? There are two main factors that determine nuclear stability – (1) the neutron/proton ratio, and; (2) the total number of nucleons. Generally, nuclides with neutron/proton ratio that is equal to 1 are stable. Heavy atoms, like those whose proton number is greater than 83 are unstable. The number of protons and neutrons that generate stable atoms are called "magic numbers". Nuclides that have these numbers occurring in either the proton or neutron are stable.



Distribution of Stable and Unstable Isotopes based on Neutron and Proton Numbers

PROTON NUMBER (z)	NEUTRON NUMBER	NO. OF STABLE ISOTOPES
EVEN	EVEN	163
EVEN	ODD	53
ODD	EVEN	50
ODD	ODD	4

The Nuclide Chart



"Dripline" is defined as the boundary beyond which no bound nucleus can exist.

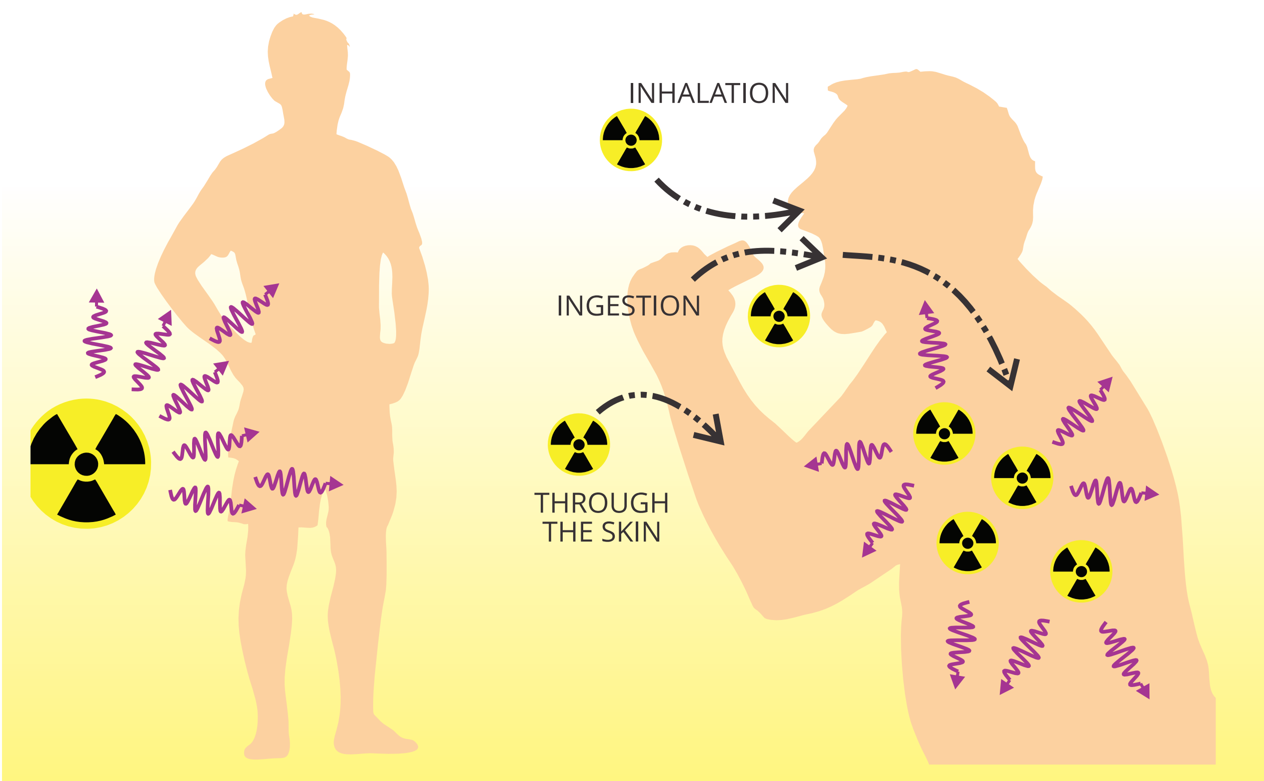
Try the interactive nuclide chart here:
https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html

HOW ARE WE EXPOSED TO IONIZING RADIATION?

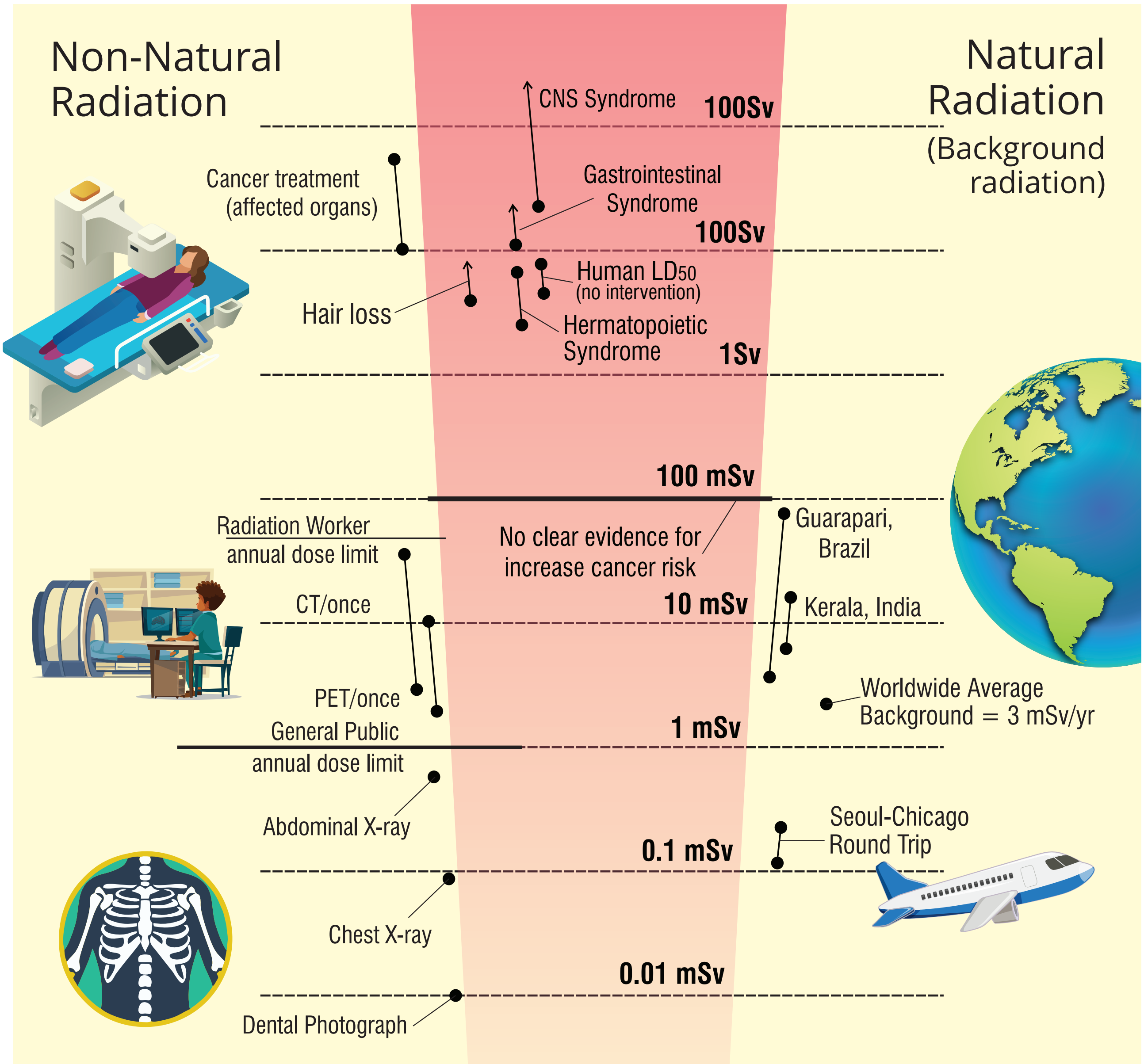
The human body is equally exposed to ionizing radiation internally or externally. **Internal exposure** happens when radioactive materials are being taken inside the body such as ingestion together with food or inhalation. **External exposure** refers to receiving radiation that comes from radioactive materials that are outside the body. These radioactive materials may exist on the ground, suspended in the air or on the surface of the body.

Exposure to ionizing radiation comes from **natural sources** and/or **artificial sources** of radiation. All the natural sources of radiation such as those from outer space and from the ground constitute what we call background radiation. Most of the artificial or man-made sources of ionizing radiation comes from medical X-rays.

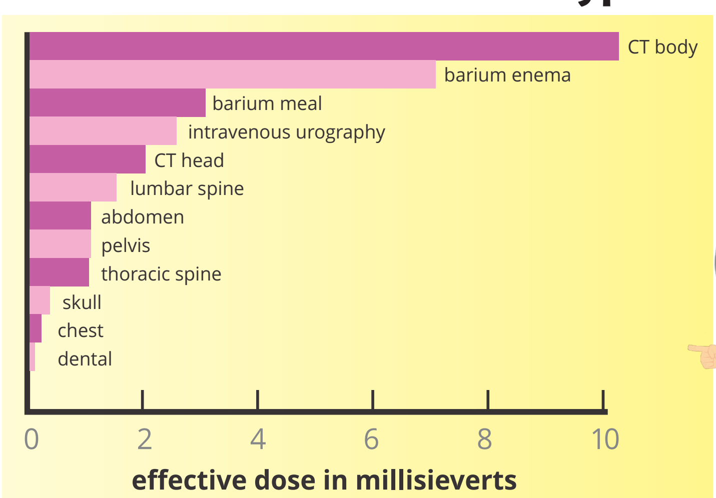
External vs. Internal Exposures



Artificial vs Natural Sources of Radiation

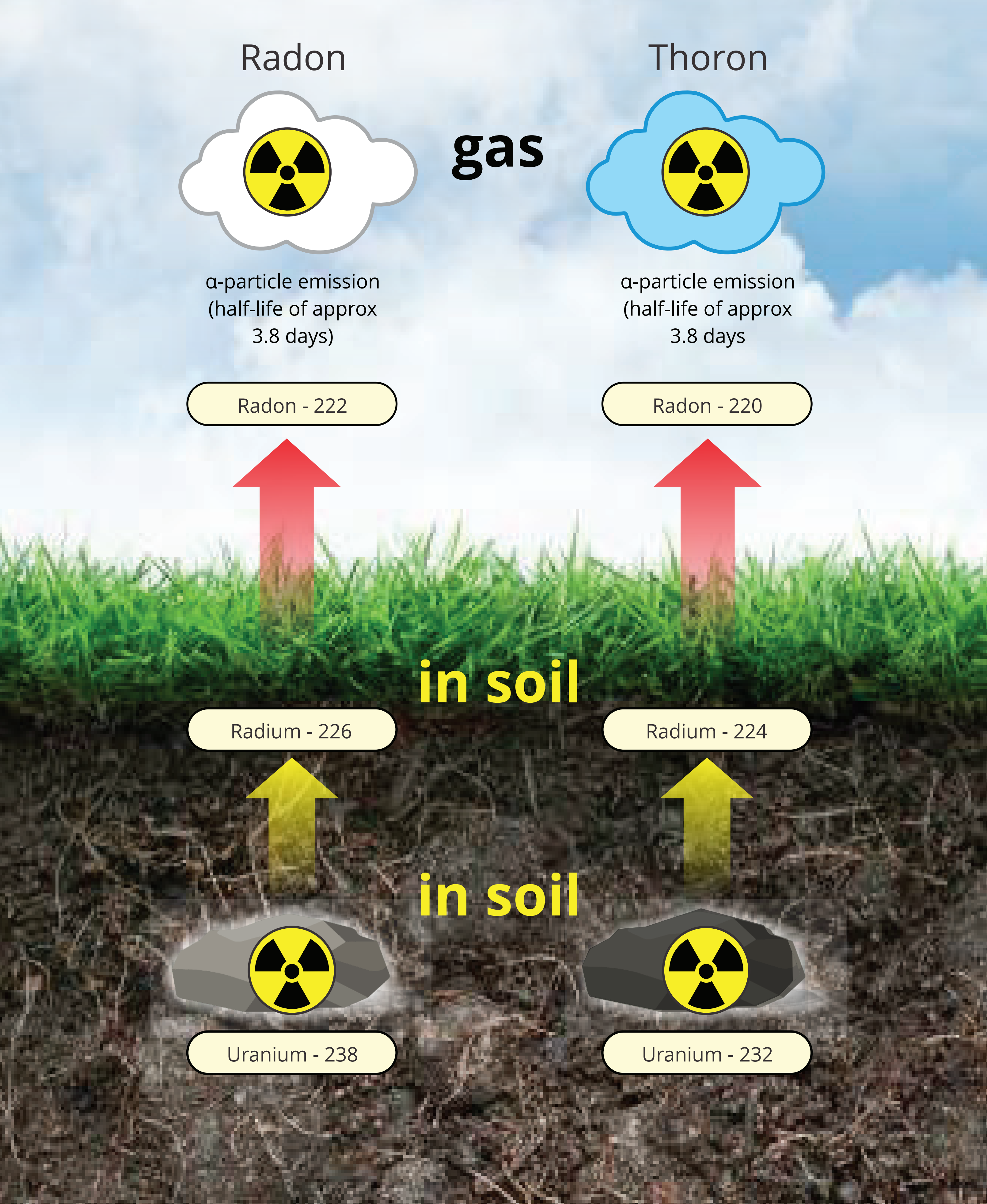


Effective dose of various medical x-ray procedures



*What is a millisievert (mSv)? **Sievert (Sv)** is the standard unit used to describe radiation effective dose or equivalent dose – the measure of the associated effect due to an amount of energy from radiation that is absorbed by matter. 1 mSv is equal to 0.001 Sv.*

Generation of Radon Gas from Solid Uranium



WHERE DOES BACKGROUND RADIATION COME FROM?

There are naturally occurring sources of radiation around. Collectively, these natural sources constitute what we call as background radiation. There is no single origin of background radiation. There are however, four sources that are significant:

1. Cosmic radiation

Cosmic radiation is radiation that originates from space. The sun is a major source of cosmic radiation. The Earth's magnetosphere acts a giant magnetic shield which prevents most of the cosmic radiation from ever reaching the surface of the Earth. However, it provides less protection for those who are at higher altitudes. Airline flights for instance, increases exposure to cosmic radiation.

2. Rocks and Buildings

Rocks and some buildings contain natural radioactive substances. Bricks, mortar, concrete and tiles all contain small amounts of naturally occurring uranium and thorium. But the amount of radiation is so low it has no effect on your health.

3. Radon

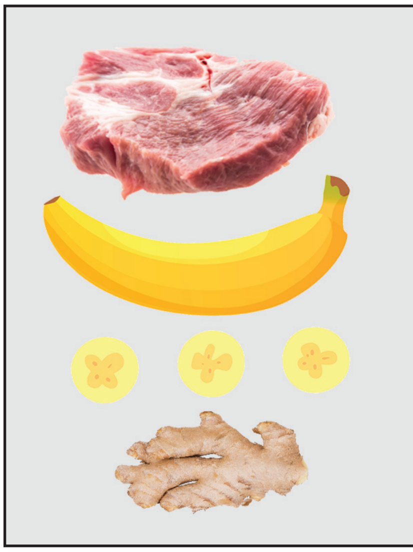
Radon is found in the Earth's atmosphere. It is a gaseous radioactive material that is produced though the decay of a radium ore present in the Earth's rocky layers. Because radon diffuses into the air from the ground, building materials, basements, etc., people inhale radon in their lives on a daily basis. Radon and its daughter nuclides are the largest contributor of natural radiation exposure.

Radiographs of pork meat, banana (cut vertically and horizontally), and ginger
https://www.env.go.jp/en/chemi/rhm/basic-info/1st/02-05-13.html

Radiation from Foods

- Mostly β-particles from potassium-40
- The natural abundance ratio of potassium-40* is 0.012%
- Potassium-40 has a half-life of 1.26 x 109 years

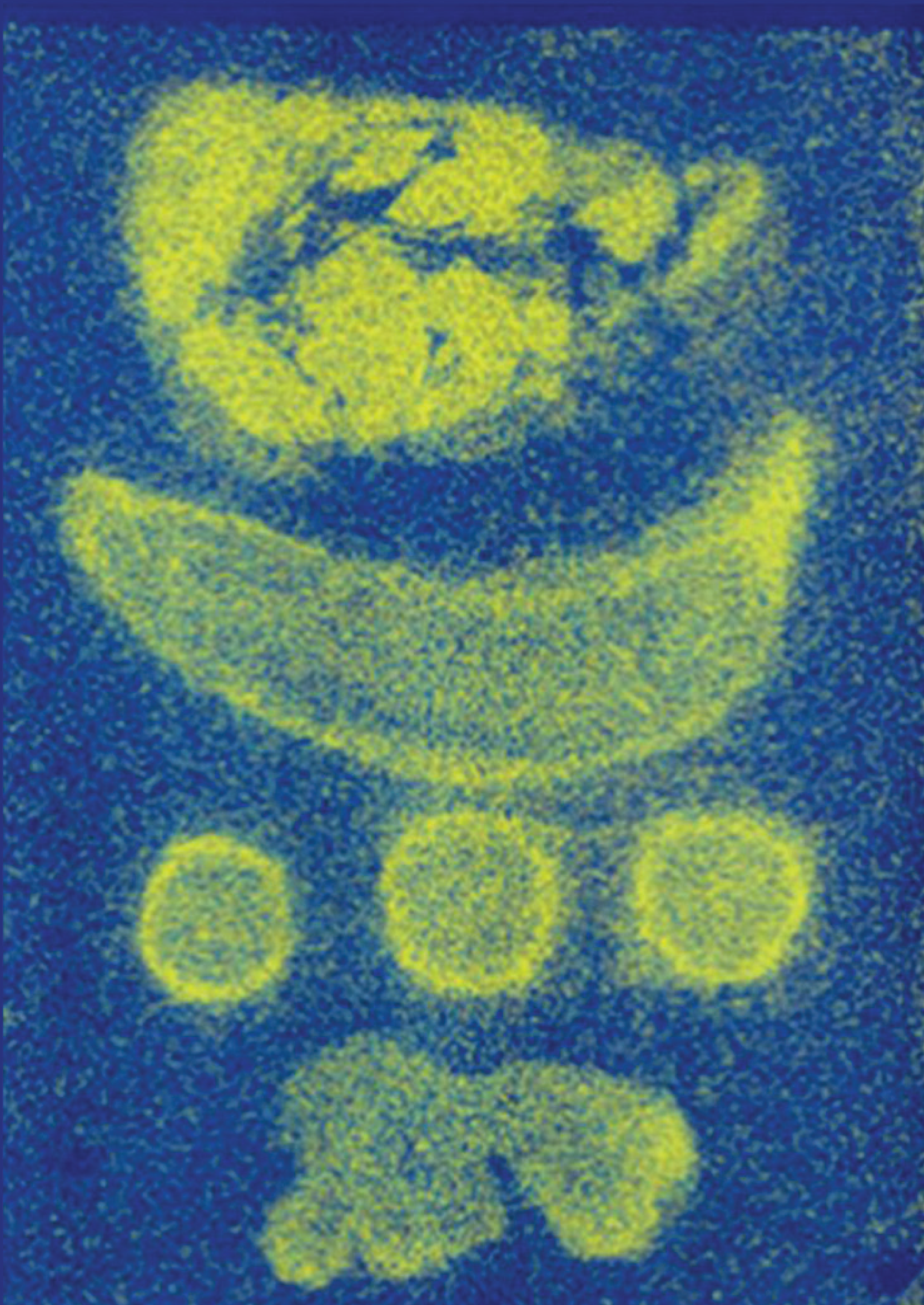
*Percentage of potassium-40 relative to the total amount of potassium found in nature



The image on the opposite page was obtained by placing pieces of pork meat, banana and ginger on an imaging plate and exposing for 25 days while shielding external radiation. The protein part of the pork meat, the peel of the banana, and the buds of the ginger contain relatively large amounts of potassium. It can be seen that the fat portion of the pork meat contains little potassium.

4. Food and Drinks

Naturally-occurring radionuclides such as potassium, carbon, radium and their decay products are found in some foods and drinks. Levels of natural radionuclides in food and drinking water are generally very low and safe for human consumption. For instance, because, 0.012% of potassium in nature is radioactive, most food like banana, broccoli, sweet potato, orange, spinach, etc. contain traces of radioactive potassium. But there is no need to avoid them, as you would need to eat 10 million bananas every year before you get even a mild radiation illness.

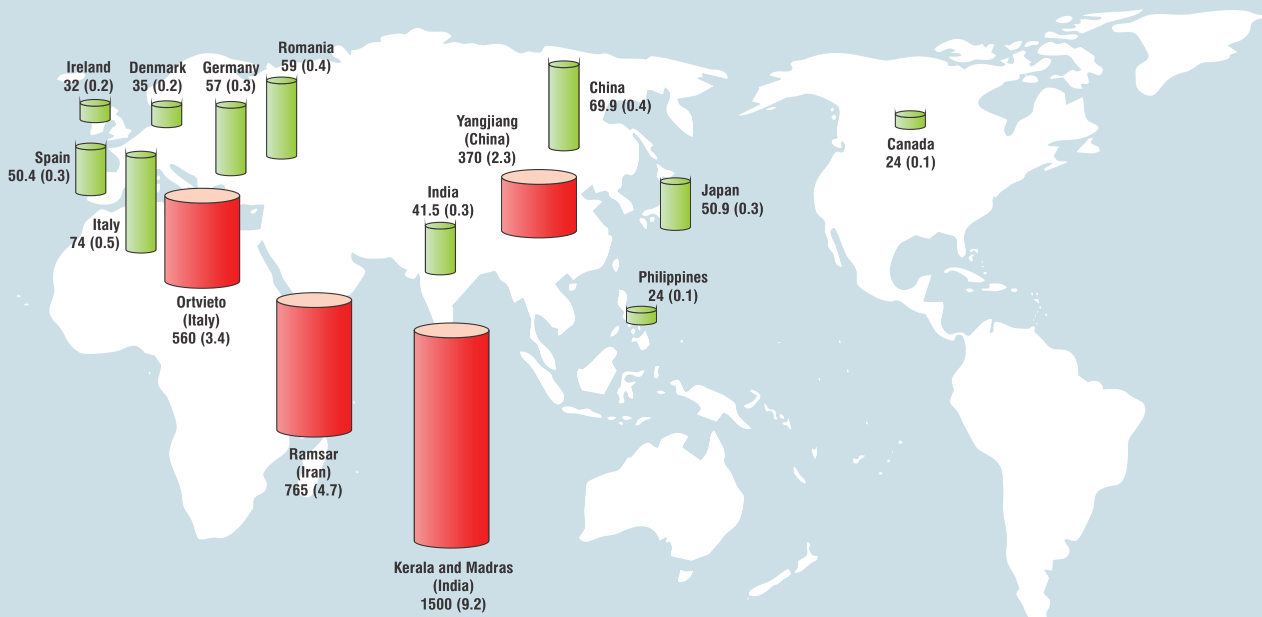


Ambient Radiation Dose Per Year in the World

Different regions around the world have different amounts of background radiation. The high levels of natural radiation in some areas are due to the fact that soil there is rich in naturally occurring radioactive materials such as radium, thorium and uranium. According to the United Nations Scientific Committee on the Effects of Atomic Radiation report of 2008, the Philippines has an ambient dose of 24 nanogray/hour. This is equal to an effective dose of 0.1 millisievert/year.

Ground Radiation (World)

Nanograys/h (mSv/y)
0.7 Sv/gray is used in conversion to effective doses



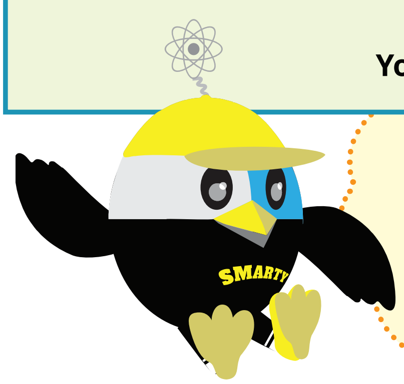
Sources: Prepared based on the 2008 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report; and "Environmental Radiation in Daily Life (2011)," Nuclear Safety Research Association

Source: https://www.env.go.jp/en/chemi/rhm/basic-info/1st/02-05-05.html.
Numbers in parenthesis is in the unit mSv/y.

HOW MUCH IONIZING RADIATION ARE WE EXPOSED TO IN A YEAR?

Curious as to how much ionizing radiation you are exposed to in a year? Provide the information needed below to calculate your annual radiation dose.

1	**Cosmic Radiation** How high do you live above sea level? At ground level the average dose is 0.25 mSv/y.	
	Ground Level	**0.25 mSv**
	Add 0.001mSv/y for each 30m that you live above sea level. Your height above sea level: ________ m x 0.001 →	
	Add 0.004mSv for every hour that you have travelled by airplane in the past 12 months. Hours travelled by airplane: ______ h x 0.004 →	
2	**Food & Drink**	
	A healthy, balanced diet will approximately produce 0.24 mSv/y	
3	**Radon**	
	Indoor radon concentration levels in the Philippines leads to an estimated annual average effective dose of 0.4 mSv. It is impossible to give a more accurate level without measurement. Wherever you live though, this will amount to at least half of your total dose.	
4	**Rocks & Buildings**	
	Add 0.35 mSv/y for a brick or stone house, 0.3 mSv/year for a concrete building or 0.14 mSv/y for a wooden construction.	
5	**Medical X-rays**	
	How many times have you had an X-ray in the last year? A typical chest X-ray accounts to about 0.1 mSv. Check the graph in page 17 to estimate your dose.	
6	**Power Stations**	
	Add 0.005 mSv if you live less than 1.6 km from a nuclear power station	
	Add 0.0004 mSv if you live less than 1.6 km from a coal-fired power station	
	Add 0.0002 mSv if you live between 1.6 and 8 km from a coal-fired power station	
7	**Miscellaneous Sources**	
	Add 0.01mSv/y	
	Now, add up all the figures in the boxes. **Your total annual dose of ionizing radiation is:**	



How radioactive are you? Try this online app to estimate your annual dose and compare results.

http://howradioactiveami.com

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