Fundamentos de radiactividad

Medida de la radiación ionizante

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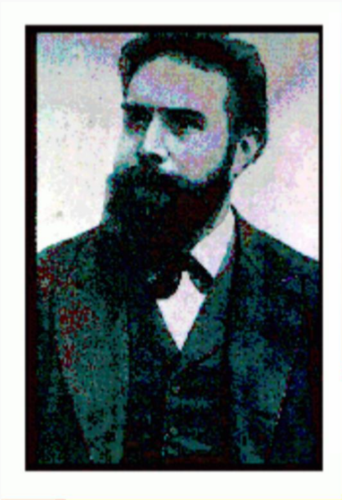
Once upon a time . . .



- X- rays
- Some materials emit radiation
- Wow ! we can penetrate our body

Once upon a time . . .

Once upon a time . . .

- Photographic plates can get dark in the presence of material called Uranium
- It must a property of the matter itself
- Such a material emits a type of radiation

Once upon a time . . .

MARIE SKLODOWSKA and PIERRE CURIE

Once upon a time . . .

A wonderful marriage

- Marie: a physicist and mathematician but . . . a Polish Woman
- Pierre: professor of Physics in Paris
- Studies on pitchblende

Once upon a time . . .

Their work with pitchblende

- They began separating elements and reducing sample's size
- They observe an increase on the intensity of emitted radiation
- They discovered **Polonium** in 1898

Once upon a time . . .

Their work with pitchblende

- After separation of Polonium . . . emitted radiation increases more and more
- It must be another element different from Uranium and different from Polonium. This element emits radiation too.

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  - Very poor materials and infraestructures to do the task
  - Laboratory: a simple shed
  - From pitchblende to radium: years and years of hard work

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  - Laboratory: a simple shed
  - From pitchblende to radium: years and years of hard work
  - 10^3kg pitchblende $\Longrightarrow$ few grams of radium

Once upon a time . . .

Milestones

- 1903: Nobel prize on Physics: Marie, Pierre and Becquerel (15000 $!!!)
- 1906: Pierre Curie passed away in a street accident in Paris on 19 April 1906 (*Crossing the busy Rue Dauphine in the rain at the Quai de Conti, he slipped and fell under a heavy horse-drawn cart. He died instantly when one of the wheels ran over his head, fracturing his skull (Wikipedia)*)
- 1911: Nobel prize on Chemistry: Marie Curie

Once upon a time . . .

Once upon a time ...

Other names to bear in mind

- Ernest Rutherford (1871 – 1937): concept of radioactive half-life; model of the atom
- Sir James Chadwick (1891 – 1974): the discovery of the neutron
- Frederick Soddy (1877 – 1956): radioactivity and nuclear reactions
- Friedrich Ernst Dorn (1848 – 1916): see later ...
- Rolf Maximilian Sievert (1896 – 1966): biological effects of radiation
- Max Karl Ernst Ludwig Planck (1858 – 1947): quantum theory

Once upon a time . . .

Credit

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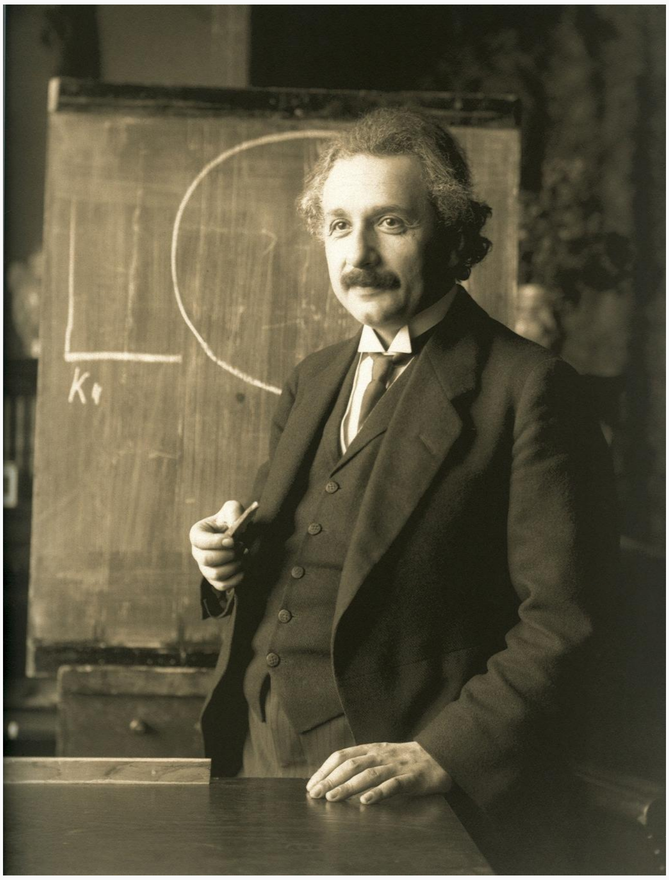

Credit

Learnings so far

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- Radioactivity: new phenomenon discovered at the end XIX century
- Curie: key name on the development of knowledge XX century
- The beggining of XX century gathered a fantastic pool of scientist as ever

Introduction

Radioactivity: fundamentals

Radioactivity: Doses

Radioactivity: Detection methods

Detection methods: radon

Detection methods: gamma spectrometry

Ionizing radiation

Radiation with enough energy to detach electrons from atoms or molecules, thus ionizing them

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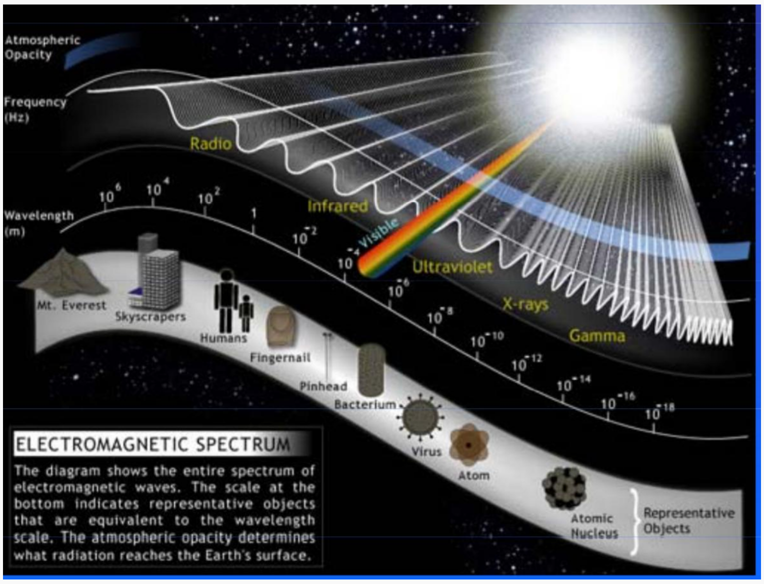

- Energies: keV and MeV
- Decay modes: alpha, beta and gamma

Numbers and names

Symbol	Definition	Fingerprint
Z (atomic number)	The atomic number of an atom is the number of protons it contains	ATOM
A (mass number; atomic mass number or nucleon number)	Total number of protons and neutrons (together known as nucleons) in an atomic nucleus	ISOTOPE

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radon: $^{222}_{86}Rn$; $^{220}_{86}Rn$; $^{219}_{86}Rn$

Decay modes

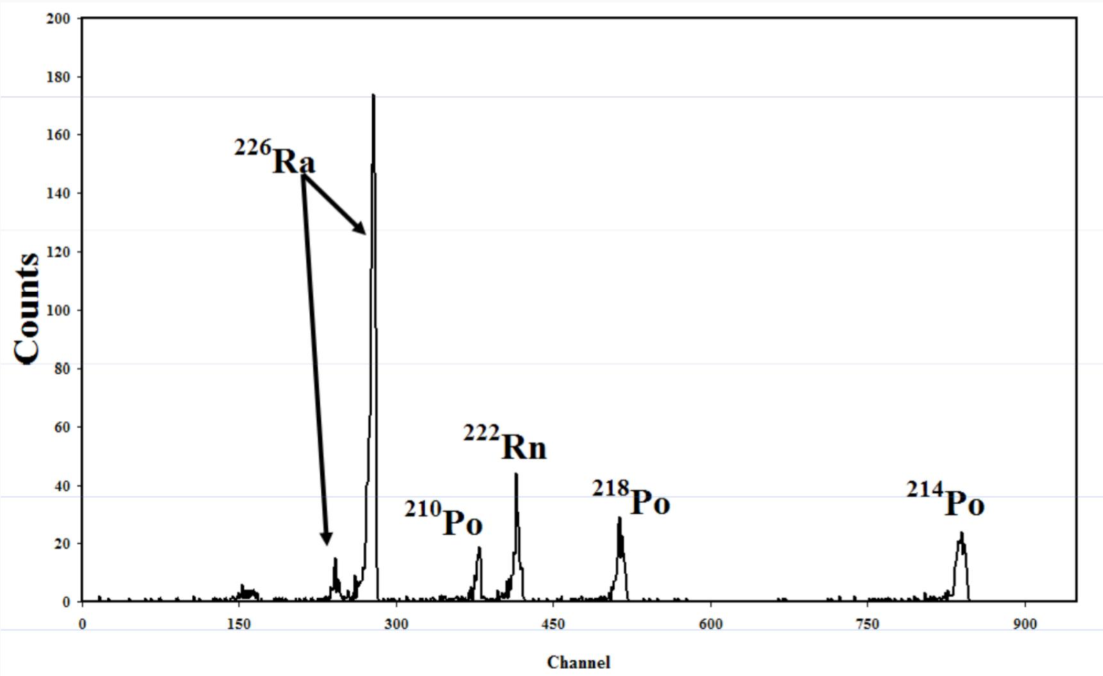
Alpha decay: Emission of an alpha particle ($^{4+}_{2}He$) by a nucleus

Characteristics of the alpha decay mode

- High enery (MeV)
- Heavy particles: they can be stopped in some cm
- Elements heavy nucleus
- Examples: $^{222}_{86}Rn$, $^{238}_{92}U$, $^{210}_{84}Po$

Decay modes

Example of alpha spectrum



Decay modes

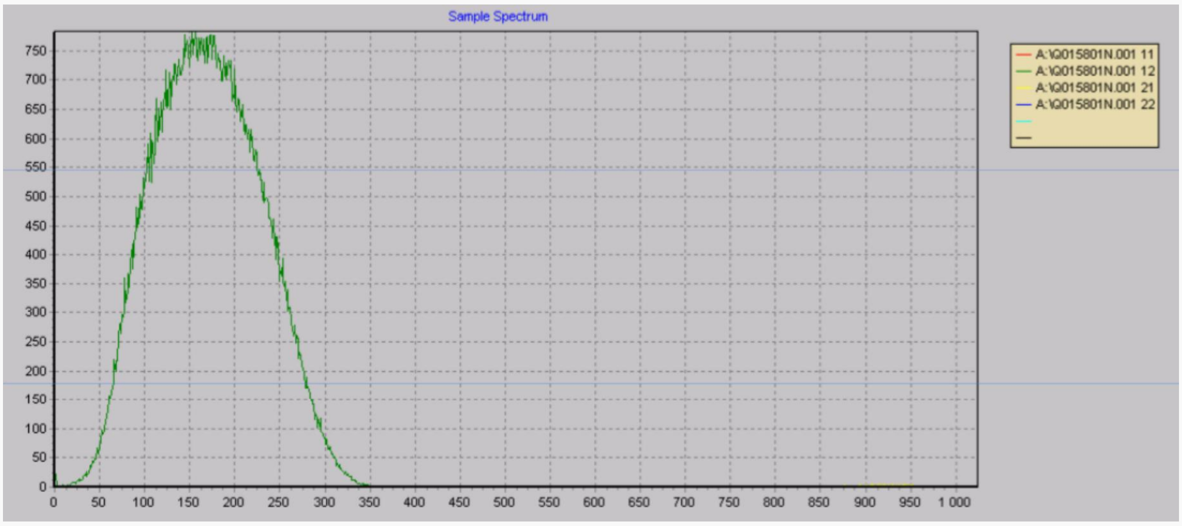
Beta decay: Emission of beta particle (positive or negative) by a nucleus. Also electron capture by a nucleus.

Characteristics of the beta decay mode

- Less energy than alpha emission
- Longer distance before stopping
- Continuous spectrum of energy
- Examples: ${}^{3}_{1}\mathrm{H}$, ${}^{90}_{38}\mathrm{Sr}$

Decay modes

Example of beta spectrum



Decay modes

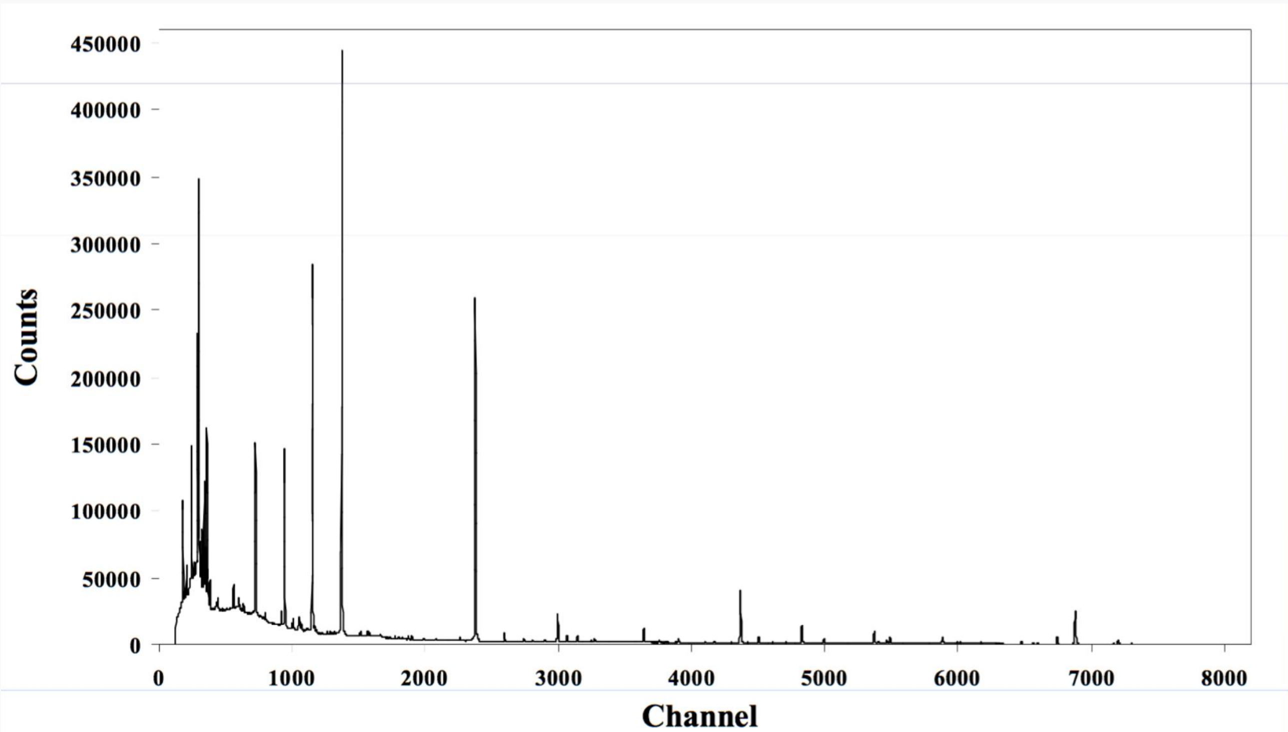
Gamma decay: Photon's emission by a nucleus when reaching steady state of energy.

Characteristics of the gamma decay mode

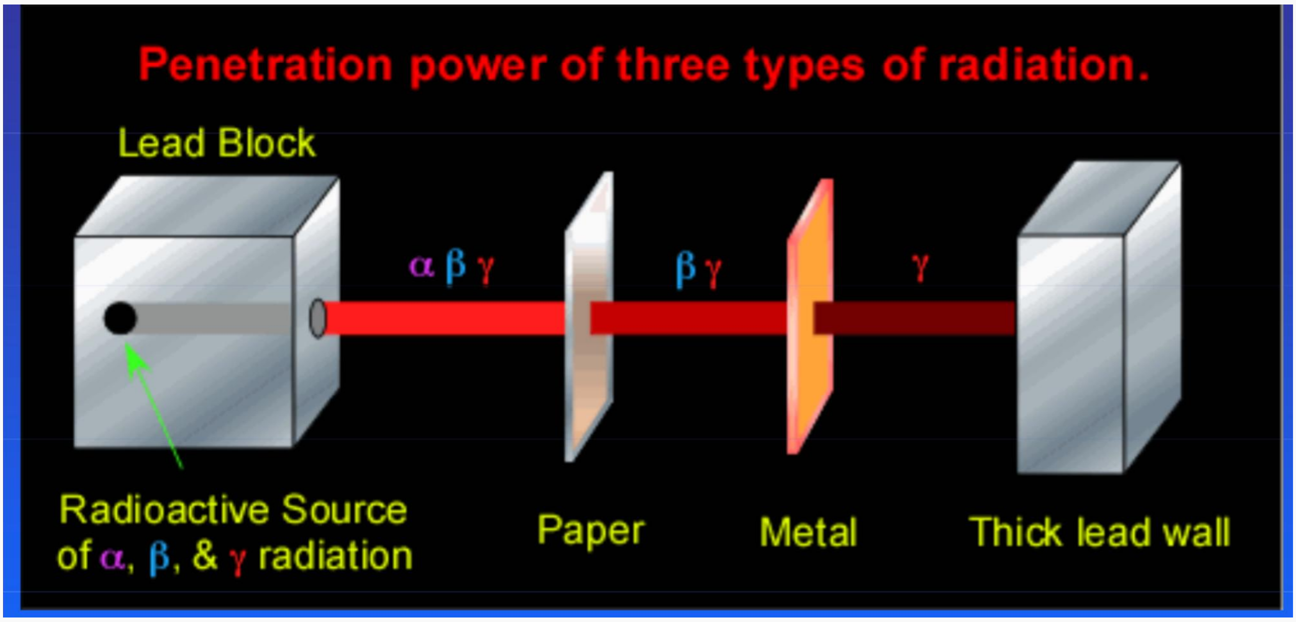
- Photons with different energies
- X Rays
- Gamma Rays (with different energies)
- Gamma rays = Nucleus
- X Rays = Atomic crust
- Examples: $^{99}_{43}$Tc, $^{60}_{27}$Co

Decay modes

Example of gamma spectrum



Penetration power



Definitions

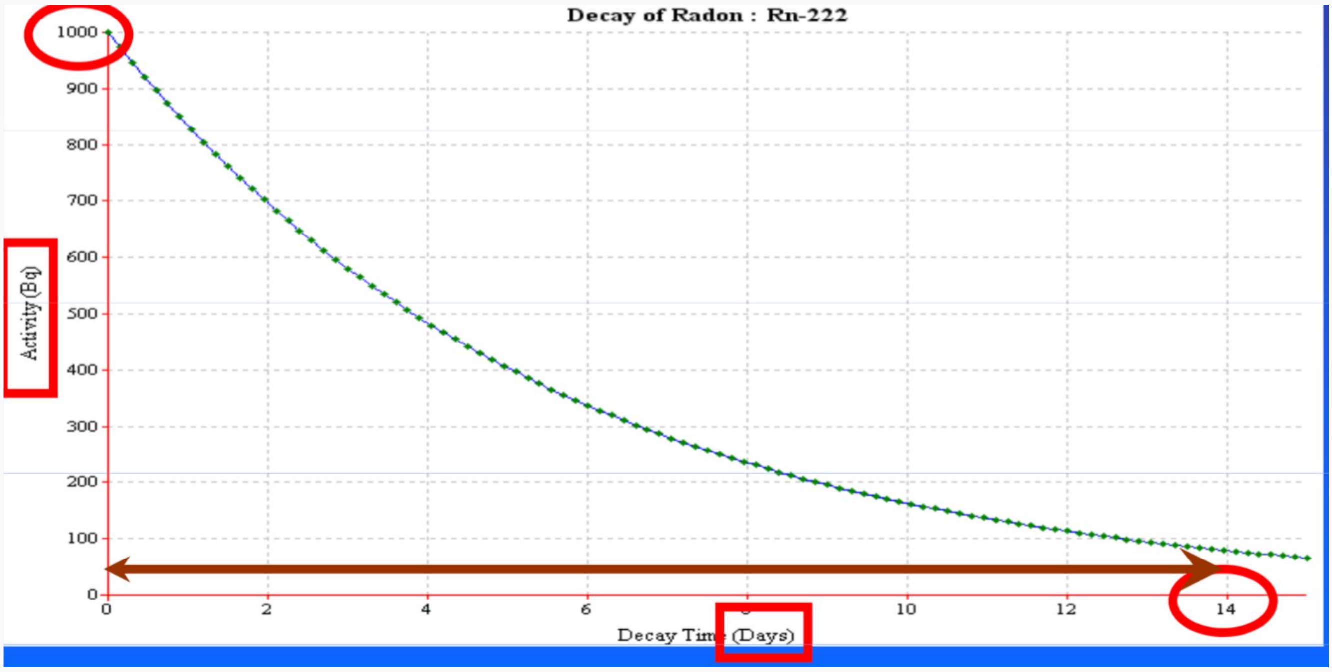
- Activity (A): Number of disintegrations per second
- Half life ($T_{1/2}$): Neccesary time for an isotope to decrease its nucleus by half (s)
- Decay constant (λ): Probability of disintegration by time (s^{-1})
- Decay chain: chained series of transformations (4 Natural decay chains)

Units

- Becquerel (Bq) : unit of activity in the International System of Units: 1Bq = 1 DPS (disintegration / second)
- Curie(Ci):Old unit of activity: $1\text{Ci}=3.7 \cdot 10^{10}$ Bq
- Concentration : Bq/kg, Bq/l, Bq/m3
- Sievert (Sv) : Unit for equivalent dose
- Working Level Month (WLM): Occupational exposure (1 WLM is approximately equivalent to an exposure of 150 Bq m^{-3} in a year)

Exponential's decay law

$$A = A_0 e^{-\lambda \cdot t}$$



Half-lives

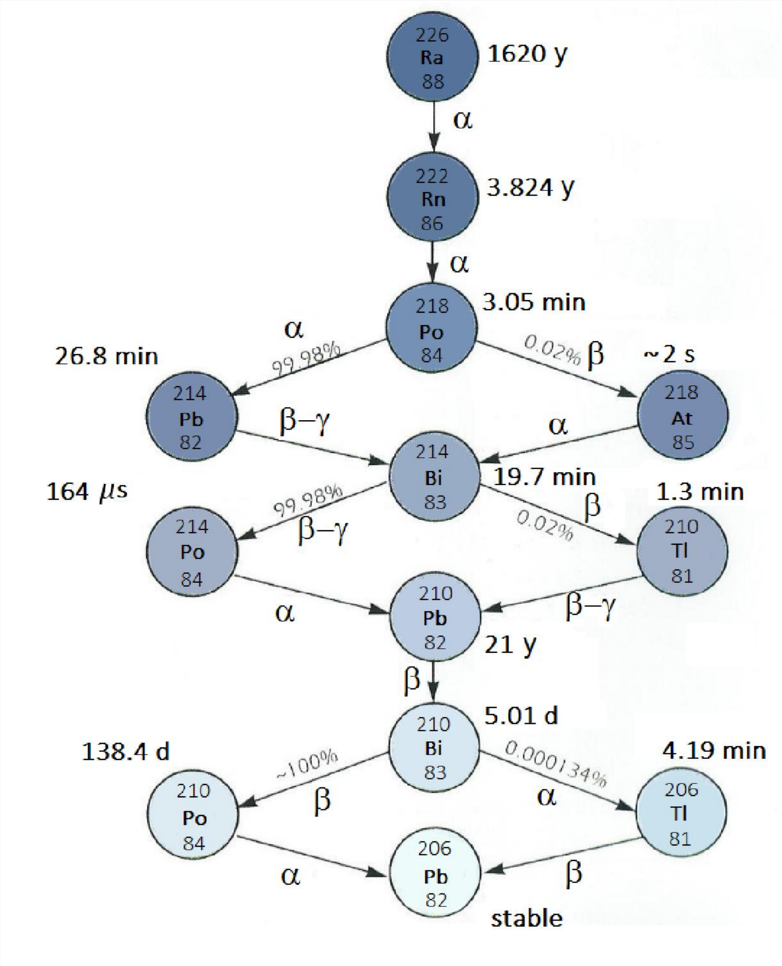
Isotope	Half life
^{238}U	$4.5 \cdot 10^9$ y
^{14}C	5730 y
^{3}H	12.4 y
^{131}I	8.03 d
^{222}Rn	3.8 d
^{99}Tc	6 h
^{219}Rn	3.96 s

Natural decay series

Series	Start	Half life (y)	Final product
Thorium	^{232}Th	$1.41 \cdot 10^{10}$	^{208}Pb
Neptunium	^{237}Np	$2.14 \cdot 10^{6}$	^{209}Pb
Uranium	^{238}U	$4.51 \cdot 10^{9}$	^{206}Pb
Actinium	^{235}U	$7.18 \cdot 10^{8}$	^{207}Pb

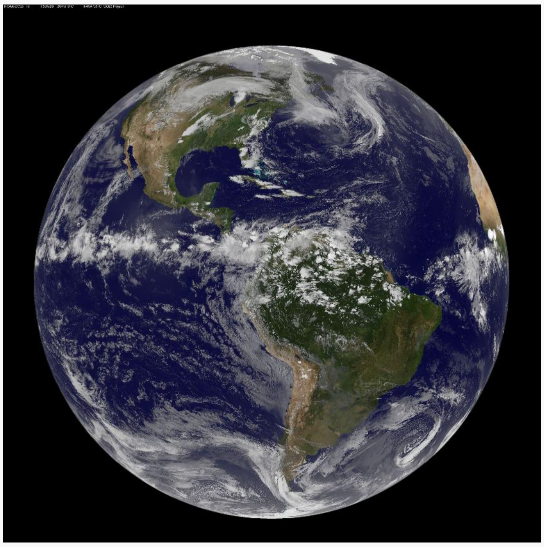
Earth's age: $4.65 \cdot 10^9$

Natural decay series Uranium



Natural radioactivity

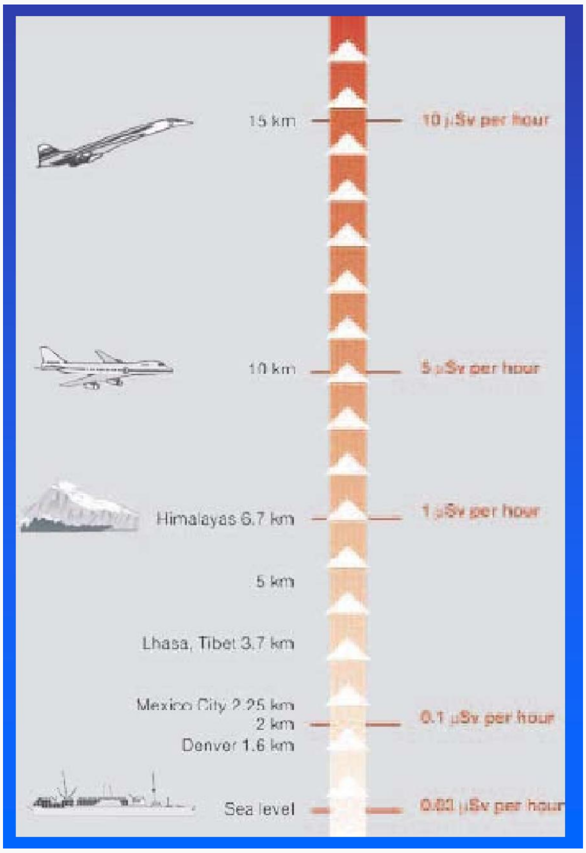
- Since the Earth Earth's birth
- Every second values are lower and lower : Exponential decay In our bodies
- ^{40}K In the rocks, air, water, food, clothes, EVERYWHERE
- More than 50 % of dose is NATURAL RADIATION



Credit: NASA Goddard Space Flight Center

Natural radioactivity

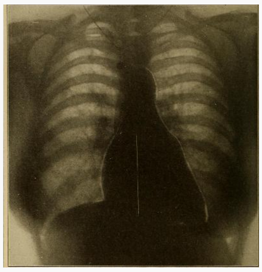
COSMIC RADIATION



Credit: Radiation, people and the environment (IAEA, February 2004)

Artificial radioactivity

- Radioactive isotopes can be created
- Fission and fusion = Energy AND/OR destruction
- X-ray detectors
- Medical applications
- Industrial applications



Credit: Xiquinho Silva

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- 4 Natural decay series

Exposure (X)

Definition: is a measure of the ionization of air due to ionizing radiation from photons, that is, gamma rays and X-rays. It is defined to be the electric charge freed by the radiation divided by the mass of the air.
Units: coulomb per kilogram, however the roentgen is commonly used internationally in the nuclear industry (1R $\sim$ 3876 C kg^{-1})

Exposure rate constant

The gamma ray field can be characterized by the exposure rate

$$X = \frac{\Gamma \cdot A}{r^2}$$

- X: exposure rate (R h^{-1})
- Γ: exposure rate constant
- A: activity
- r: distance

Exposure rate constants for various radionuclides

Radionuclide	Exposure rate constant ($R\ cm^2\ h^{-1}\ mCi^{-1}$)
^{60} Co	12.838
^{99}Mo	1.03
^{99m}Tc	0.720
^{137}Cs	3.400
^{226}Ra	8.25

Absorbed dose (D)

Definition: the mean energy imparted to matter per unit mass by ionizing radiation
Units: joules per kilogram (gray, Gy)

1 Gy = 1 J kg^{-1}
1 Gy = 100 rad
1 rad = 0.01 Gy = 10 mGy

Exposure and absorbed dose

$$D = f \cdot X$$

f: conversion coefficient depending on medium

The absorbed energy in a quantity of air exposed to 1 C kg^{-1} of X Rays is 0.869 Gy $f(\text{air}) = 0.869$

Conversion coefficients (*Credit: IAEA*)

Photon energy (keV)	f water	f bone	f muscle
10	0.91	3.5	0.93
100	0.95	1.5	0.95

Equivalent dose (H)

Definition: is the absorbed dose multiplied by a dimensionless radiation weighting factor, wR which expresses the biological effectiveness of a given type of radiation

Units: the SI unit of equivalent dose is called the sievert (Sv). The old unit was the "rem"

1 Sv = 100 rem

Radiation weighting factor wR

- For most of the radiation used in medicine (X Rays, γ, e^-) wR is = 1, so the absorbed dose and the equivalent dose are numerically equal
- exceptions
  - alpha particles (wR = 20)
  - neutrons (wR = 5 - 20)

Activity and equivalent dose

$$\dot{H} = \frac{K \cdot A}{r^2}$$

- $\dot{H}$: equivalent dose rate (mSv h^{-1})
- A: activity (Bq)
- r: distance
- K: factor

Effective dose (E)

Definition: Radiation exposure of the different organs and tissues in the body results in different probabilities of harm and different severity. The combination of probability and severity of harm is called "detriment". o reflect the combined detriment from stochastic effects due to the equivalent doses in all the organs and tissues of the body, the equivalent dose in each organ and tissue is multiplied by a tissue weighting factor, WT, and the results are summed over the whole body to give the effective dose E

Units: Sievert (Sv)

Effecitve dose (E)

$$E = \sum T \cdot WT \cdot H_T$$

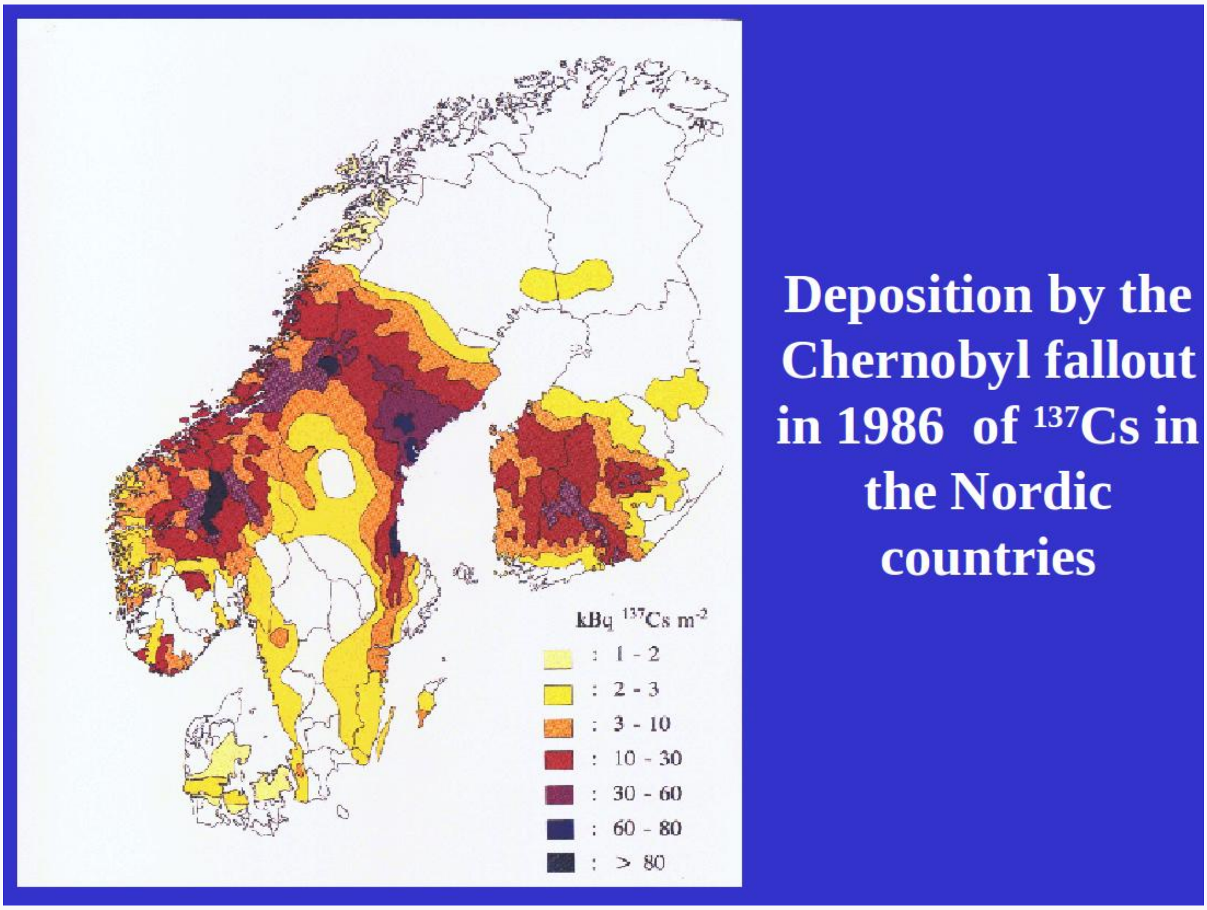
- E: Effective dose
- WT: weighting factor for organ or tissue T
- H_T: equivalent dose in organ or tissue T

Tissue weighting factors, wT

Conversion coefficients (*Credit: IAEA*)

Organ/Tissue	*WT*
Bone marrow	0.12
Bone surface	0.01
Brain	0.01
Breast	0.12
Colon	0.12
Gonads	0.08
Liver	0.05
Lung	0.12
Skin	0.01
Stomach	0.12
Thyroid	0.04

Examples of doses due to artificial radionuclides



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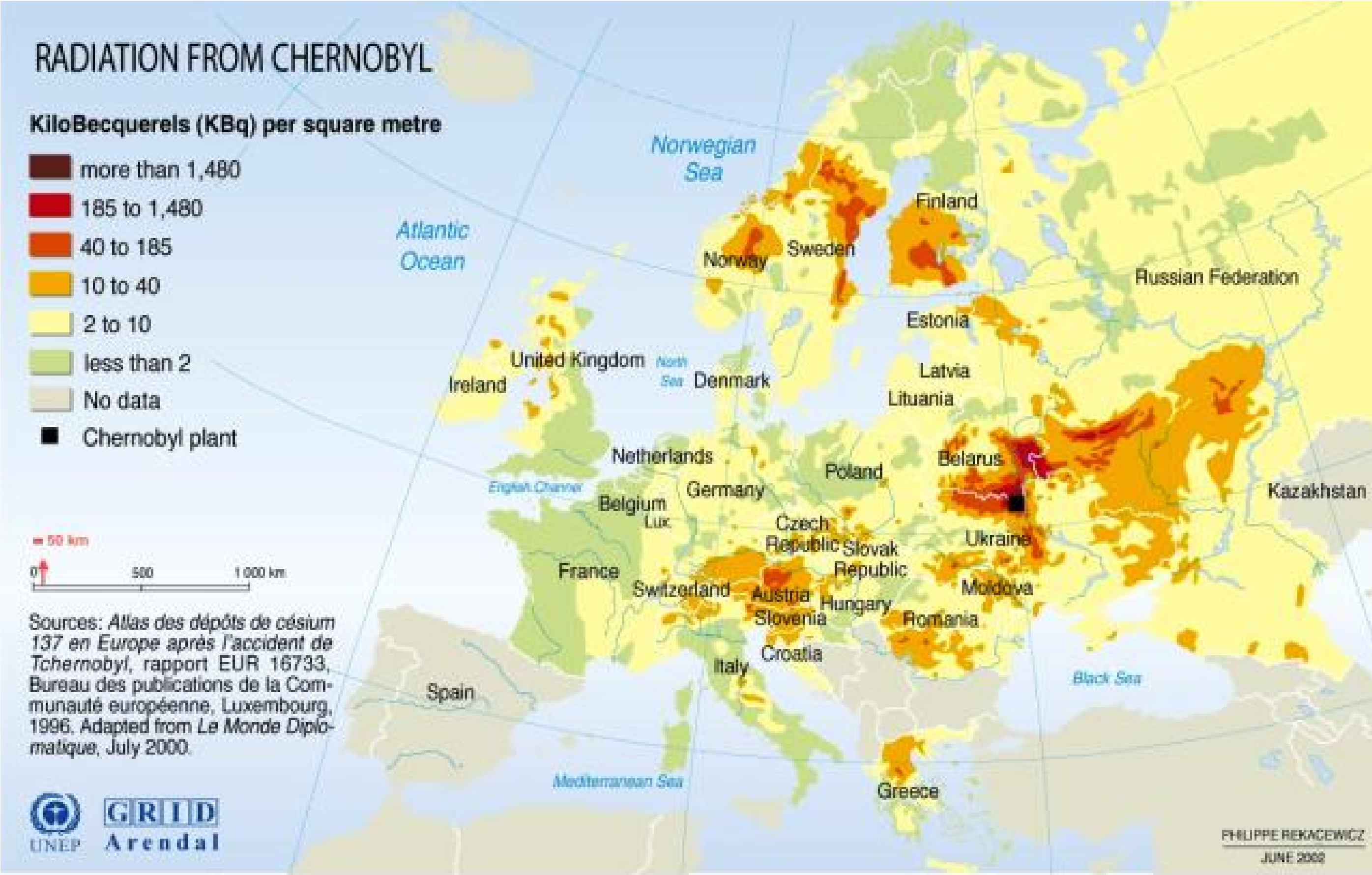
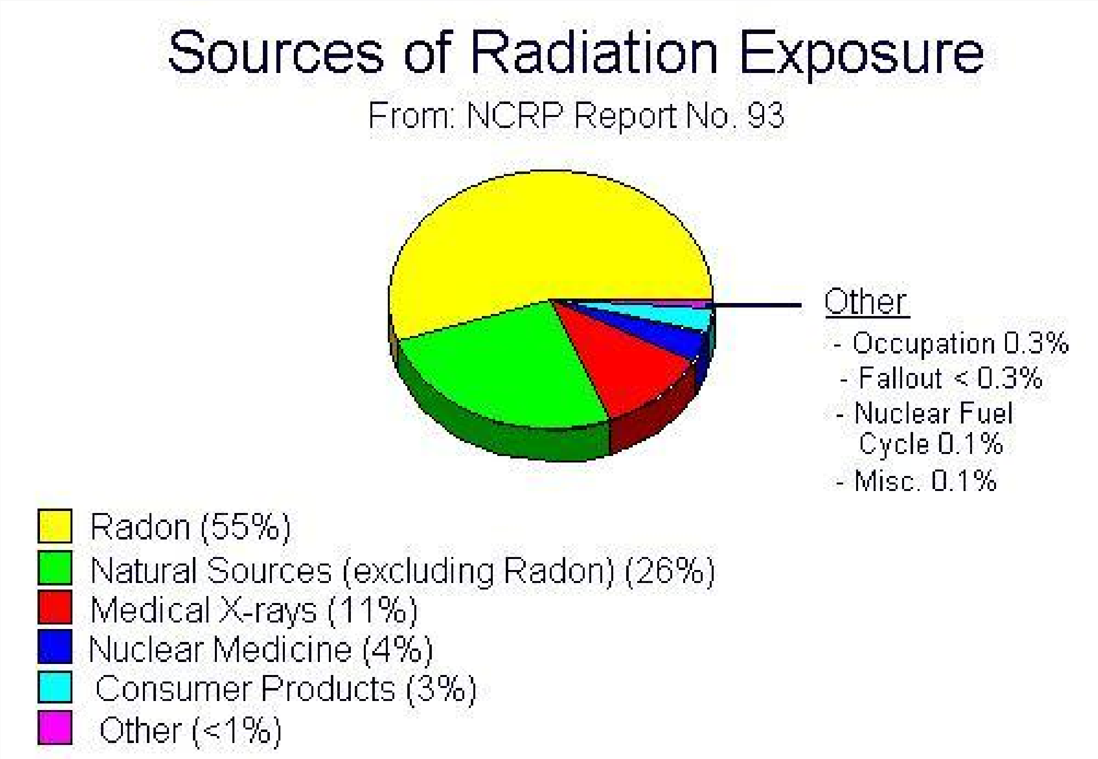


Sources: UNEP/GRID-Arendal, European Environment Agency; *AMAP Assessment Report : Arctic Pollution Issues*, Arctic Monitoring and Assessment Programme (AMAP), 1998, Oslo; European Monitoring and Evaluation Programme (EMEP); Co-operative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe, 1999. Adapted from *Le Monde Diplomatique, July 2000.*

Examples of doses due to natural radionuclides



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