Introduction to Radioactivity

Environmental Sampling techniques 2. (ktudminta2a17lm)

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What is Radioactivity?

- History
  - 1895. Wilhelm Conrad Röntgen discovers a type of electromagnetic radiation which he calls X-rays
  - 1896. Henri Becquerel discovers the principle of radioactive decay when he exposes photographic plates to uranium
  - 1897. Sir Joseph John Thomson first describes his discovery of the electron

What is Radioactivity?

- History
  - 1898. Marie and Pierre Curie announce discovery of two substances they call polonium and radium.
  - 1899. Ernest Rutherford classifies two types of radiation, alpha rays and beta rays.
  - Henri Becquerel discovers that radiation from uranium consists of charged particles and can be deflected by magnetic fields.

What is Radioactivity?

- Marie Curie coined the term radioactivity
- Radiation
- Activity

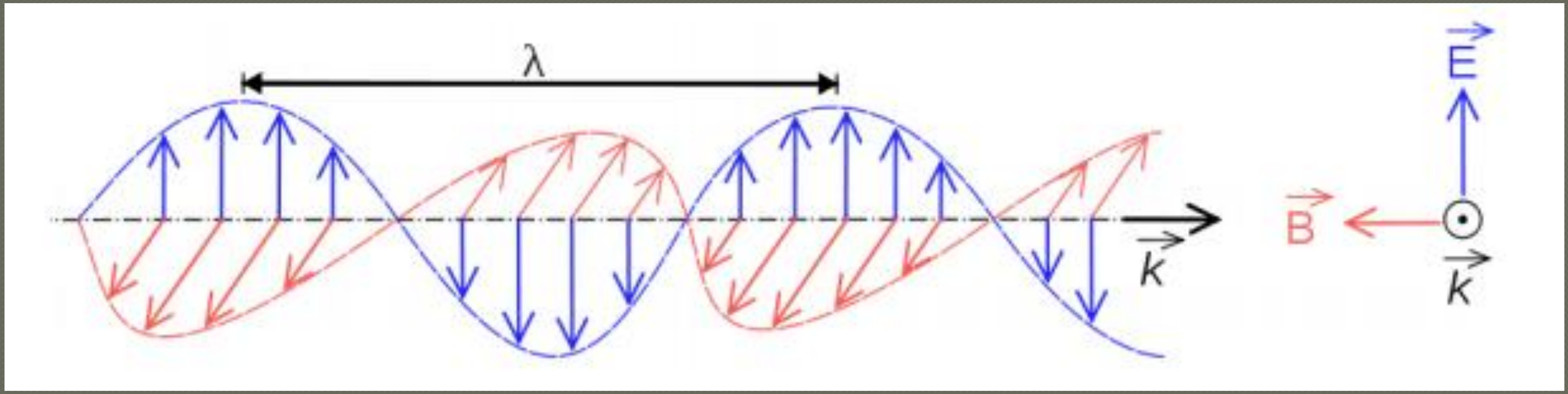
What is Radioactivity?

- Marie Curie coined the term radioactivity
- Radiation
  - Ionizing radiation
  - Non-ionizing radiation
- Activity

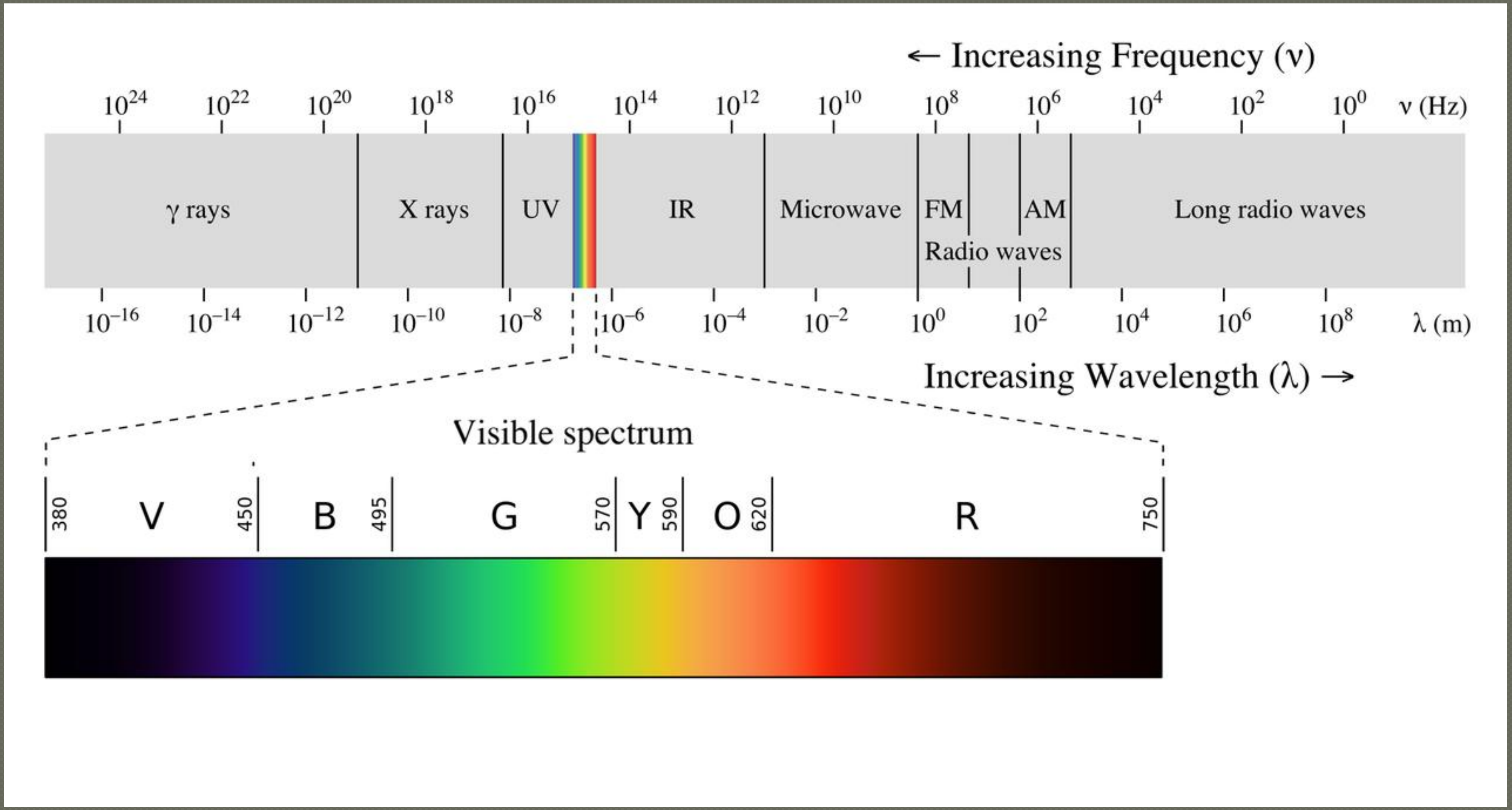
What is Radioactivity?

- Marie Curie coined the term radioactivity
- Radiation
  - Electromagnetic radiation
  - Particle radiation
  - Acoustic radiation
  - Gravitational radiation
- Activity

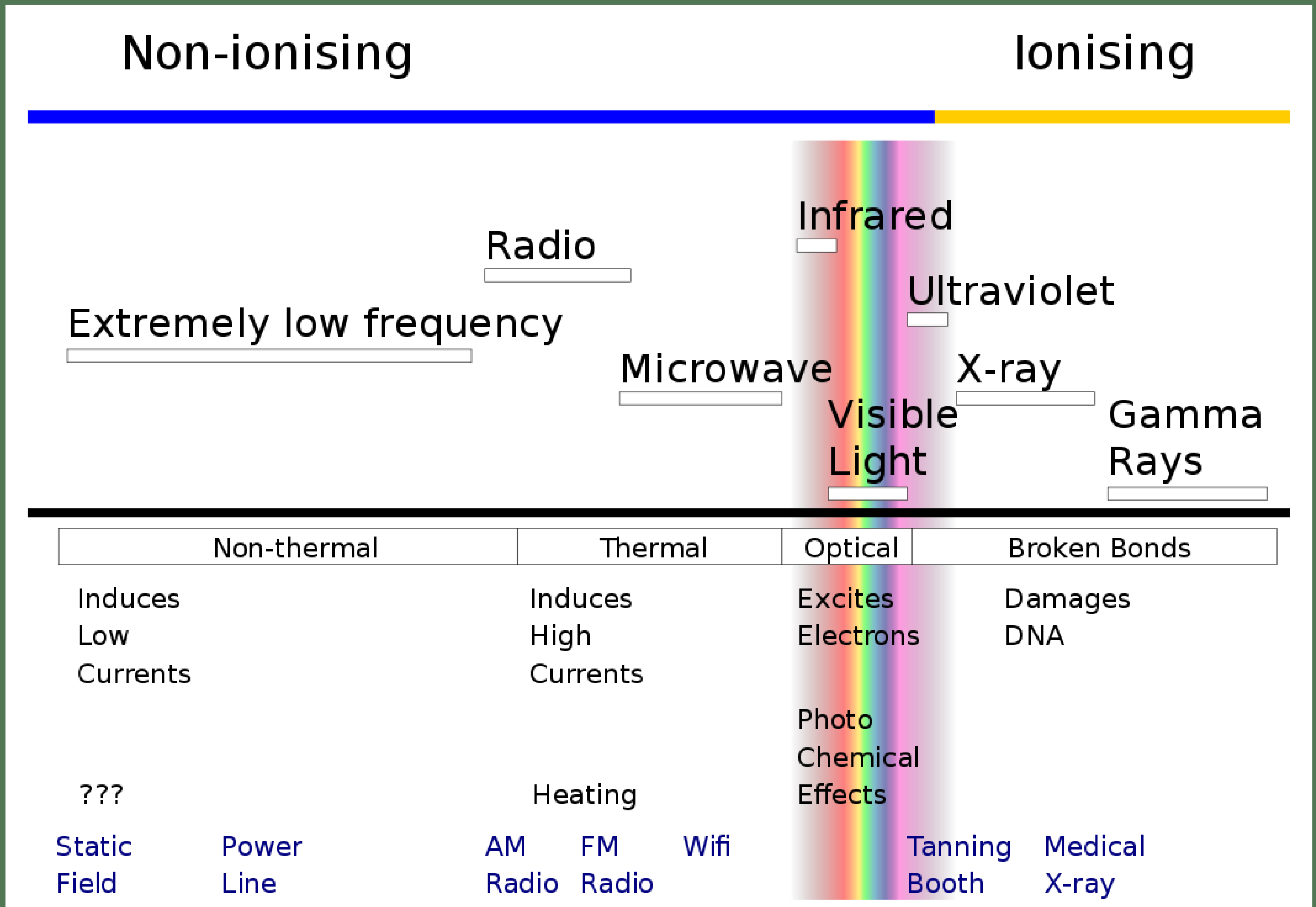
Electromagnetic Radiation



Electromagnetic Radiation



Electromagnetic Radiation



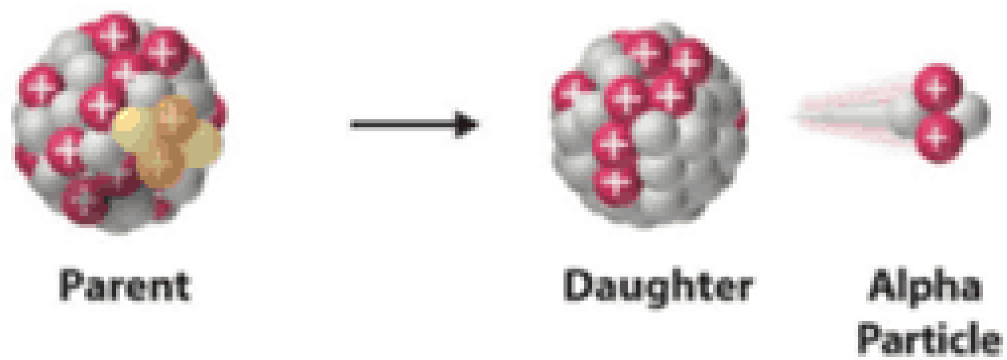
Particle Radiation

- Types of decays:

Particle Radiation

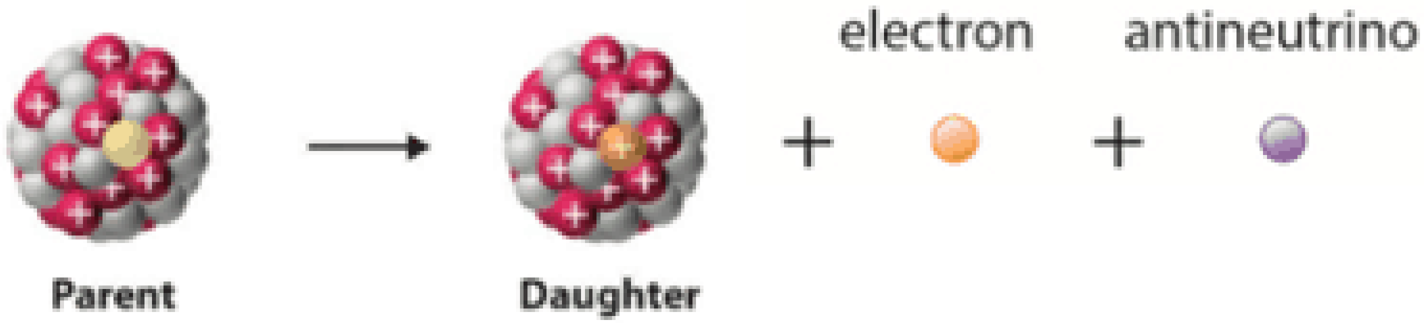
- Types of decays:
  - Alpha decay
  - Beta decay
  - Gamma decay
  - Neutron emission
  - Electron capture
  - Proton emission
  - Spontaneous fission
  - Cluster decay
  - Internal conversion

Alpha Decay



$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He + 4.78\ MeV$$

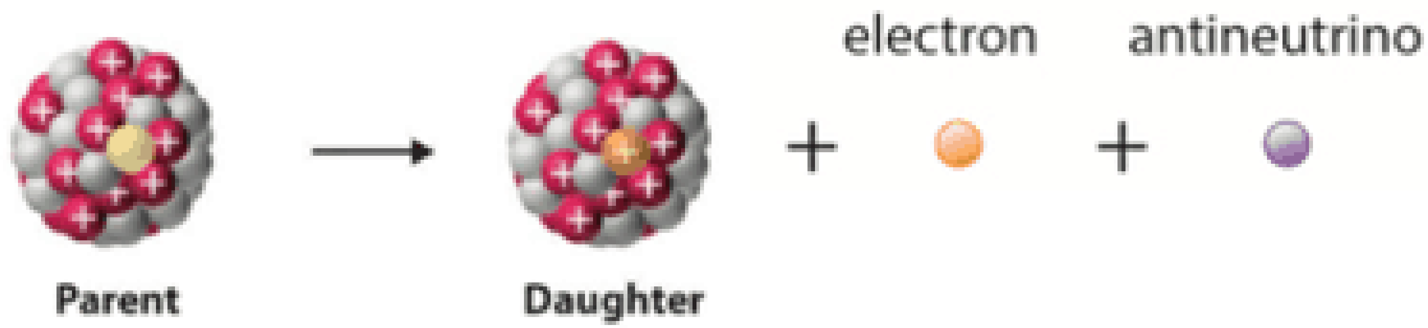
Beta Decay



Negative Beta Decay

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^{-} + \bar{\nu}_e$$

Beta Decay



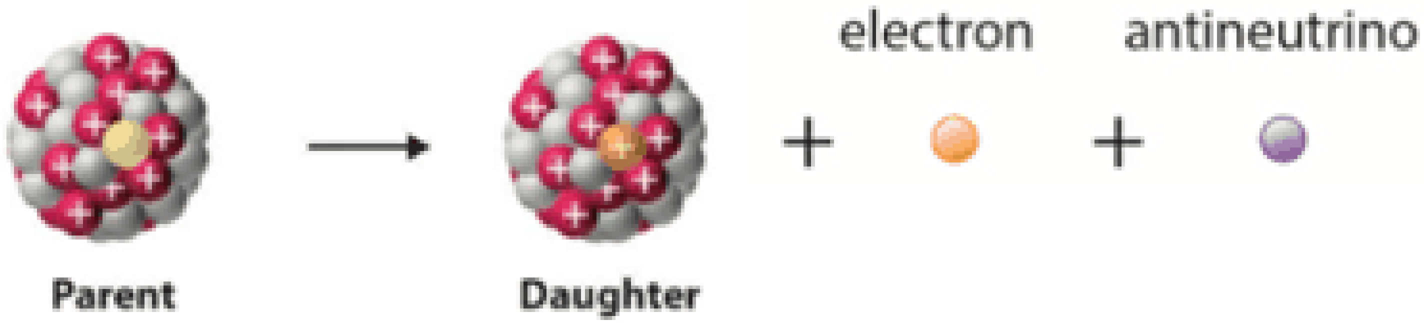
Negative Beta Decay

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^{-} + \bar{\nu}_e$$

Positive Beta Decay

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \beta^{+} + \nu_e$$

Beta Decay



Negative Beta Decay

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^{-} + \bar{\nu}_e $$

Positive Beta Decay

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \beta^{+} + \nu_e $$

Electron Capture

$$ {}^{A}_{Z}X + e^{-} \rightarrow {}^{A}_{Z-1}Y + \nu_e $$

Beta Decay

Negative Beta Decay

$$^{3}H \rightarrow {}^{3}He + e^{-} + \tilde{\nu}$$

Nucleus level

$$n \rightarrow p + e^{-} + \tilde{\nu}$$

Nucleon level

$$d \rightarrow u + e^{-} + \tilde{\nu}$$

Quark level

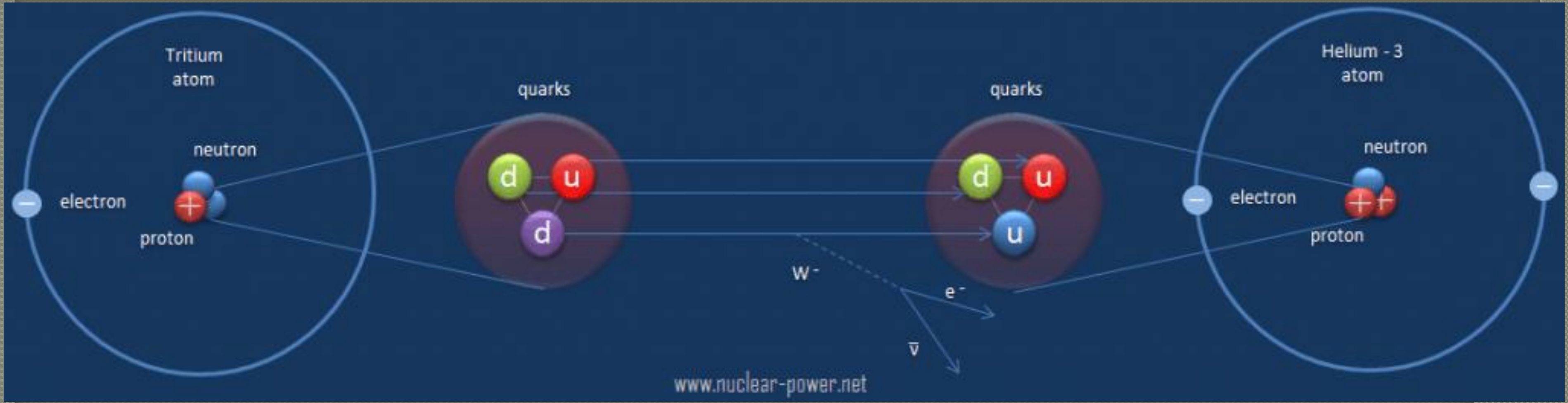
Beta Decay

Negative Beta Decay

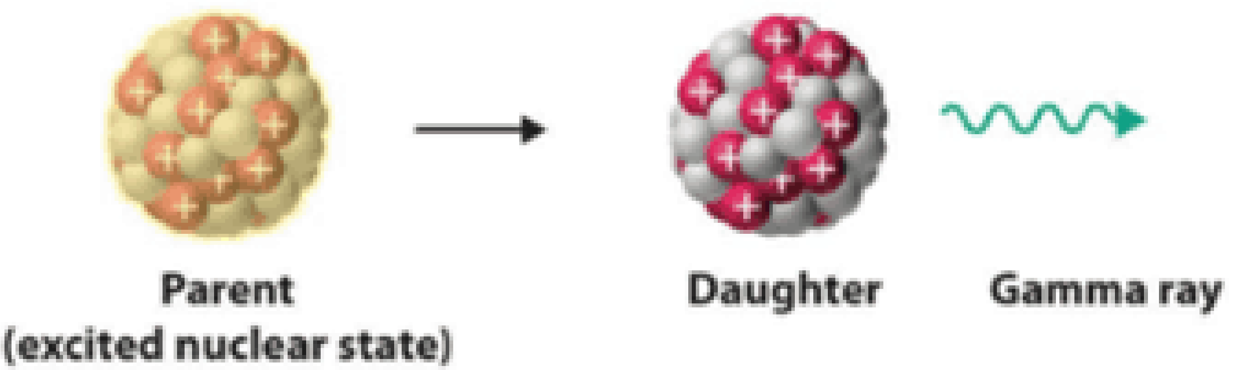
$${}^{3}H \rightarrow {}^{3}He + e^{-} + \tilde{\nu}$$ Nucleus level

$$n \rightarrow p + e^{-} + \tilde{\nu}$$ Nucleon level

$$d \rightarrow u + e^{-} + \tilde{\nu}$$ Quark level



Gamma Decay



$$^{234m}_{91}Pa \xrightarrow{t_{1/2}= 1.17\ min} {}^{234}_{91}Pa + {}^{0}_{0}\gamma$$

Examples for Decays

$$^{14}_{6}C \rightarrow ^{14}_{7}N + e^{-} + \bar{\nu}_e$$

$$^{3}_{1}H \rightarrow ^{3}_{2}He + e^{-} + \bar{\nu}_e$$

$$^{23}_{12}Mg \rightarrow ^{23}_{11}Na + e^{+} + \nu_e$$

$$^{81}_{36}Kr + e^{-} \rightarrow ^{81}_{35}Br + \nu_e$$

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Positive Beta Decay

Electron Capture

$$^{81}_{36}Kr + e^{-} \rightarrow ^{81}_{35}Br + \nu_e$$

The Overview of the Decays

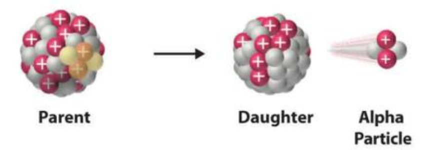
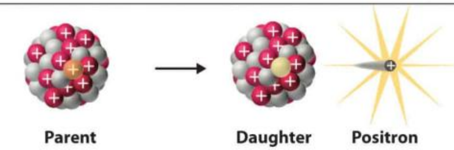
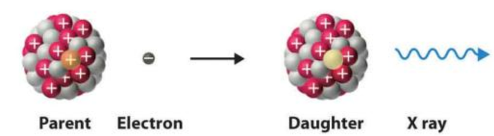
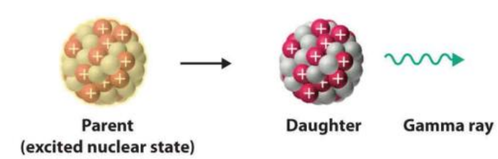
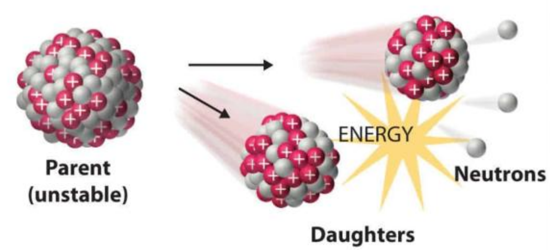
Decay Type	Radiation Emitted	Generic Equation	Model
Alpha decay	${}^{4}_{2}\alpha$	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}X' + {}^{4}_{2}\alpha$	
Beta decay	${}^{0}_{-1}\beta$	${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}X' + {}^{0}_{-1}\beta$	
Positron emission	${}^{0}_{+1}\beta$	${}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}X' + {}^{0}_{+1}\beta$	
Electron capture	X rays	${}^{A}_{Z}X + {}^{0}_{-1}e \longrightarrow {}^{A}_{Z-1}X' + \text{X ray}$	
Gamma emission	${}^{0}_{0}\gamma$	${}^{A}_{Z}X^{*} \xrightarrow{\text{Relaxation}} {}^{A}_{Z}X' + {}^{0}_{0}\gamma$	
Spontaneous fission	Neutrons	${}^{A+B+C}_{Z+Y}X \longrightarrow {}^{A}_{Z}X' + {}^{B}_{Y}X' + C\,{}^{1}_{0}n$	

Table of Nuclides - Segre chart

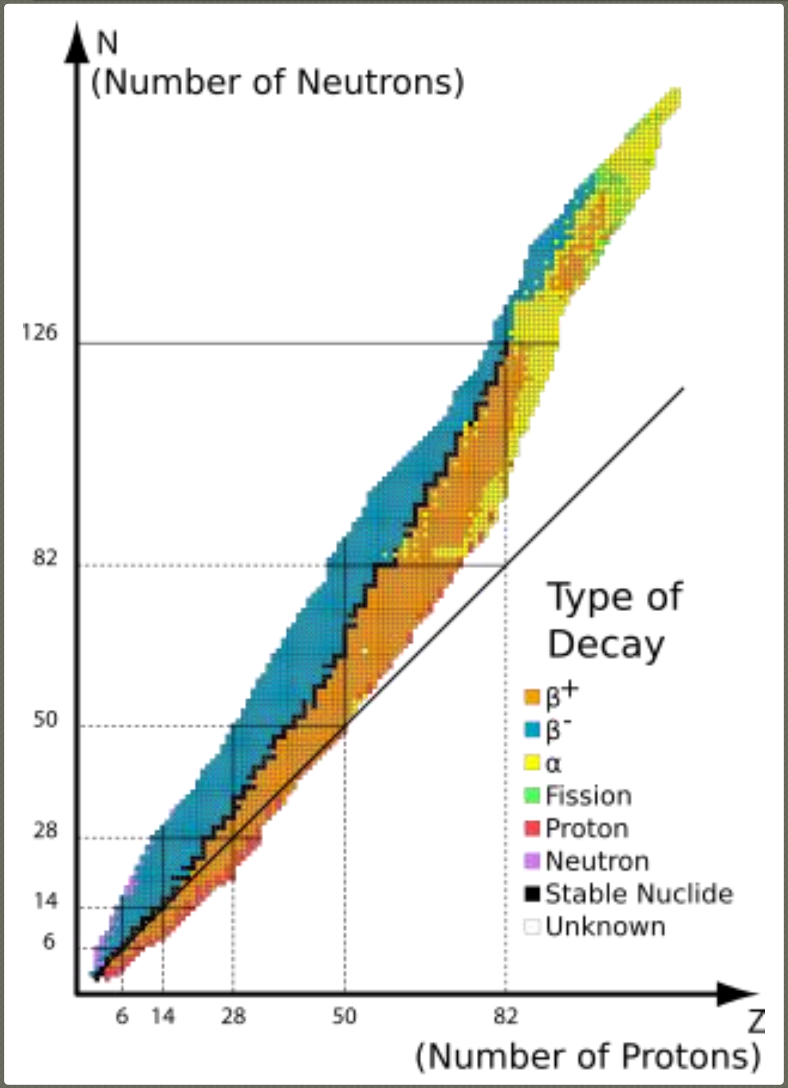
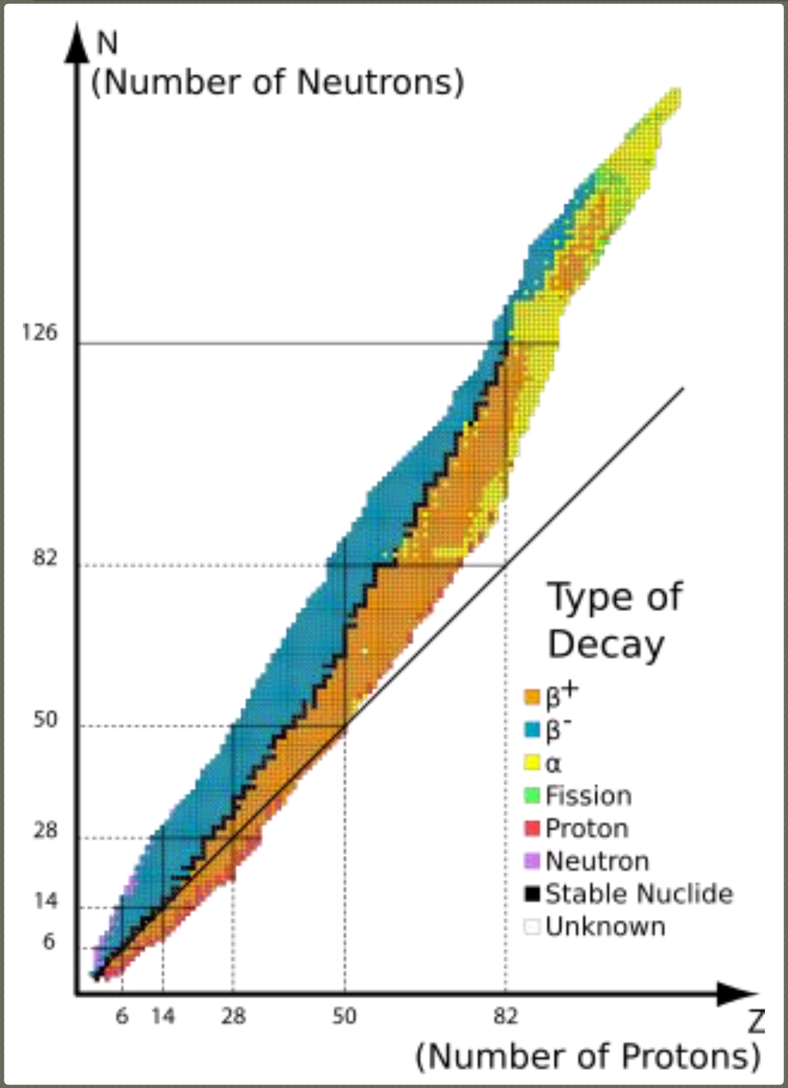
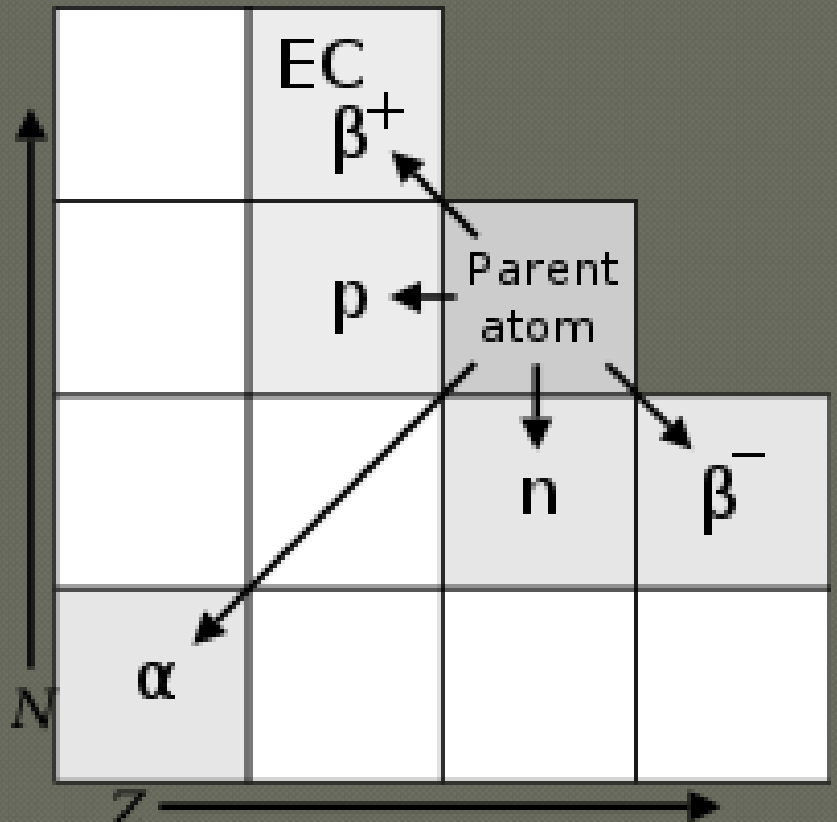


Table of Nuclides - Segre chart





What is radioactivity?

- Marie Curie coined the term radioactivity
- Radiation
- Activity
  - decay/ desintergration per second

The Basic Laws of Radioactive Decay

In a simple decay, if the number of decaying nucleus is N(t)

$$A = -\frac{dN}{dt}$$

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the solution of this differential equation

Exponential Decay Law

$$N(t) = N_0 e^{-\lambda t}$$

The Basic Laws of Radioactive Decay

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Decay constant λ

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Half-life time $T_{1/2}$

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Half-life time $T_{1/2}$

$$N_0 / 2 = N_0 \exp(-\lambda T_{1/2})$$

The Basic Laws of Radioactive Decay

Exponential Decay Law

$$N(t) = N_0 e^{-\lambda t}$$

Decay constant λ

Half-life time $T_{1/2}$

$$N_0 / 2 = N_0 \exp(-\lambda T_{1/2})$$

$$\lambda = \frac{\ln 2}{T_{1/2}}$$

The Basic Laws of Radioactive Decay

Half-life time

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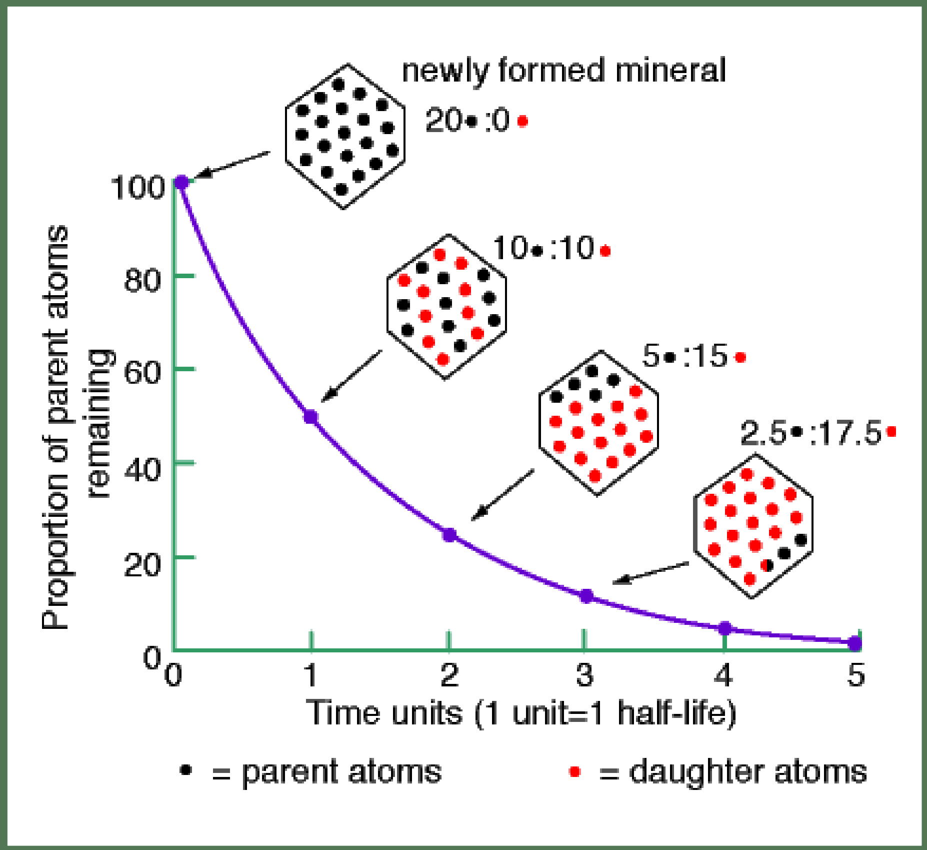

The Basic Laws of Radioactive Decay

Half-life time

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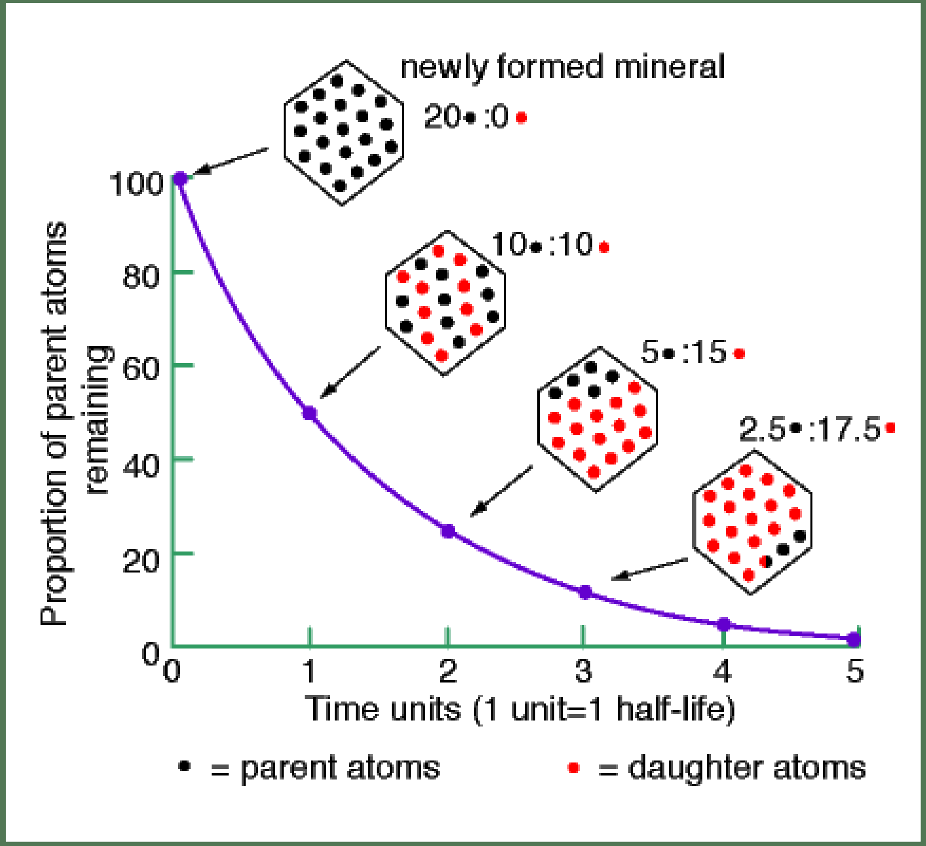

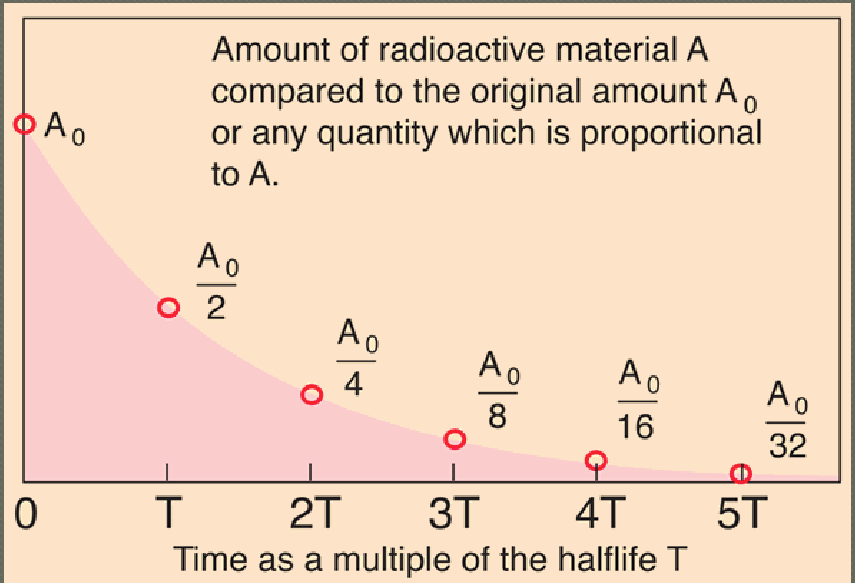

The Basic Laws of Radioactive Decay

Decay chain

if $\lambda_1 << \lambda_2 << \lambda_3 \ldots << \lambda_i$

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$$\frac{dN_1}{dt} = -\lambda_1 N_1$$

$$\frac{dN_2}{dt} = -\lambda_2 N_2 + \lambda_1 N_1$$

$$\frac{dN_3}{dt} = -\lambda_3 N_3 + \lambda_2 N_2$$

.

.

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$$\frac{dN_i}{dt} = -\lambda_i N_i + \lambda_{i-1} N_{i-1}$$

The Basic Laws of Radioactive Decay

Decay chain

if $\lambda_1 << \lambda_2 << \lambda_3 \ldots << \lambda_i$

$$\frac{dN_1}{dt} = \frac{dN_2}{dt} = \frac{dN_3}{dt} = \ldots = \frac{dN_i}{dt} = \ldots = 0$$

$$\frac{dN_1}{dt} = -\lambda_1 N_1$$

$$\frac{dN_2}{dt} = -\lambda_2 N_2 + \lambda_1 N_1$$

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The Basic Laws of Radioactive Decay

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$$\frac{dN_1}{dt} = \frac{dN_2}{dt} = \frac{dN_3}{dt} = \ldots = \frac{dN_i}{dt} = \ldots = 0$$

$$\lambda_1 N_1 = \lambda_2 N_2 = \lambda_3 N_3 = \ldots = \lambda_i N_i = \ldots = activity$$

The Basic Laws of Radioactive Decay

Decay chain

if $\lambda_1 << \lambda_2 << \lambda_3 \; ... << \lambda_i$

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$$\frac{dN_2}{dt} = -\lambda_2 N_2 + \lambda_1 N_1$$

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$$\frac{dN_i}{dt} = -\lambda_i N_i + \lambda_{i-1} N_{i-1}$$

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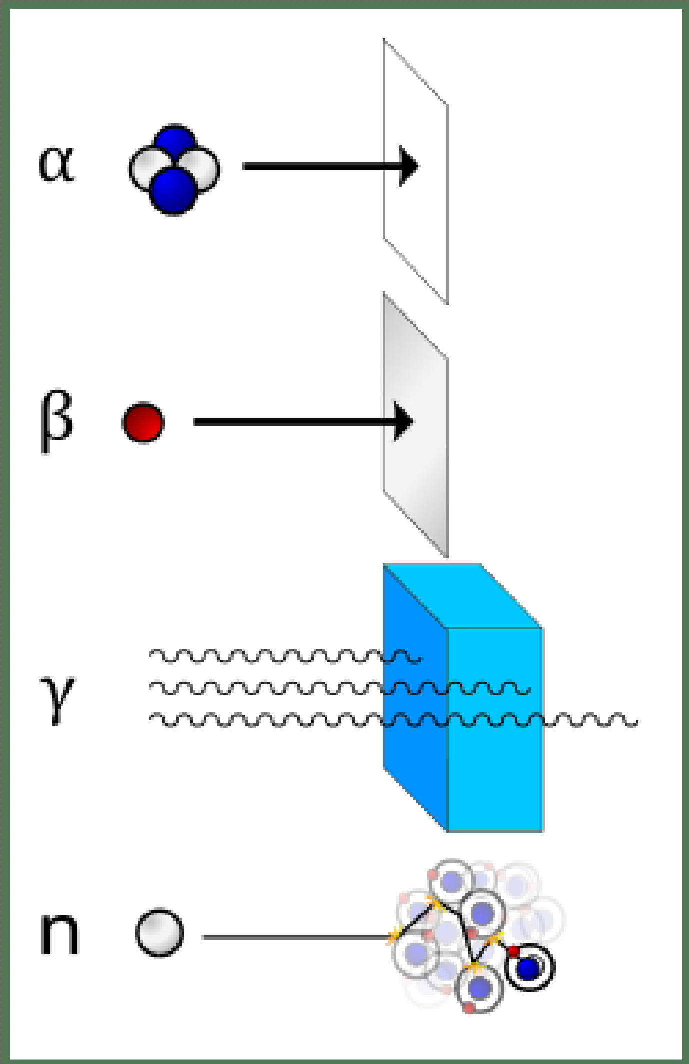
$$\lambda_1 N_1 = \lambda_2 N_2 = \lambda_3 N_3 = ... = \lambda_i N_i = ... = activity$$

Secular equilibrium

Particle Radiation - Shielding



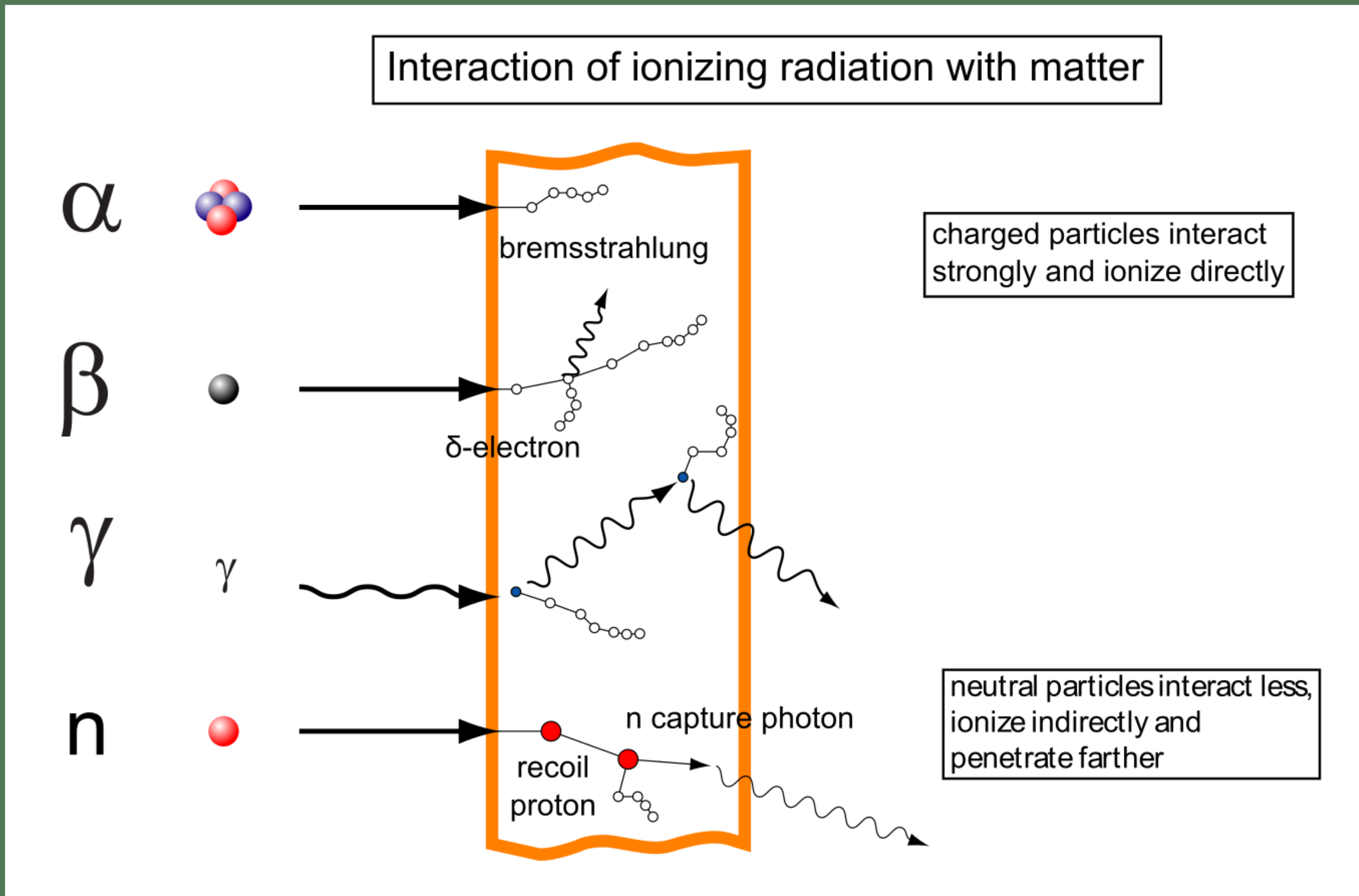
sheet of paper

Al shielding

very thick layer of lead

light elements (hydrogen)

Interaction with Matter



Radiation Protection - Principles

Radiation Protection - Principles

- Stochastic vs Deterministic effects
- Justification
- Limitation
- ALARA
- Time
- Distance
- Shielding

Radiation Protection - Principles

- Stochastic vs Deterministic effects
- Justification: no unnecessary use of radiation is permitted, which means that the advantages must outweigh the disadvantages
- Limitation: each individual must be protected against risks that are too great, through the application of individual radiation dose limits
- ALARA - *"As Low As Reasonably Achievable"*
- Time: Reducing the time of an exposure reduces the effective dose proportionally
- Distance: Increasing distance reduces dose due to the inverse square law
- Shielding: absorbing the energy of the radiation

Grouping by Origin

- Primordial Radionuclides
- Secondary Radionuclides
- Cosmogenic Radionuclides
- Artifical Radionuclides

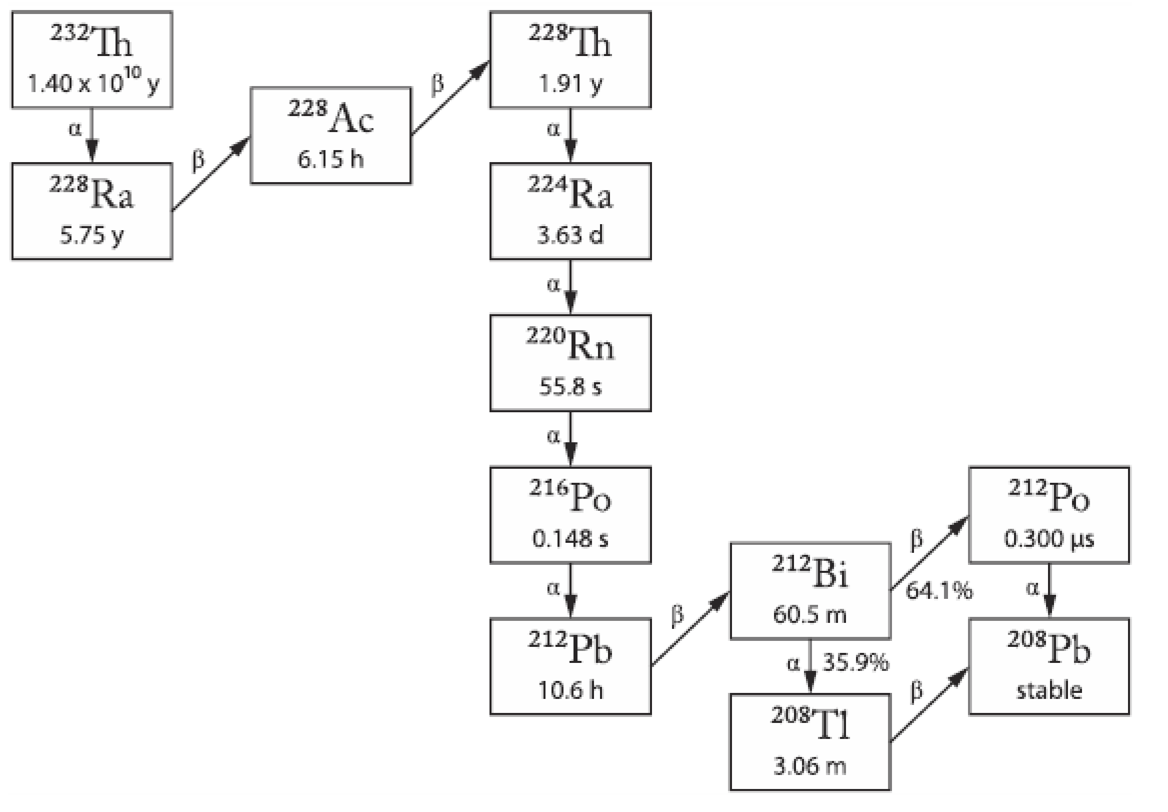
Grouping by Origin

- **Primordial Radionuclides** are produced in stellar nucleosynthesis and supernova explosions, their half-lives are so long (>100 million years)

- **Secondary Radionuclides** derived from the decay of primordial radionuclides

- **Cosmogenic Radionuclides** are continually being formed in the atmosphere due to cosmic rays.

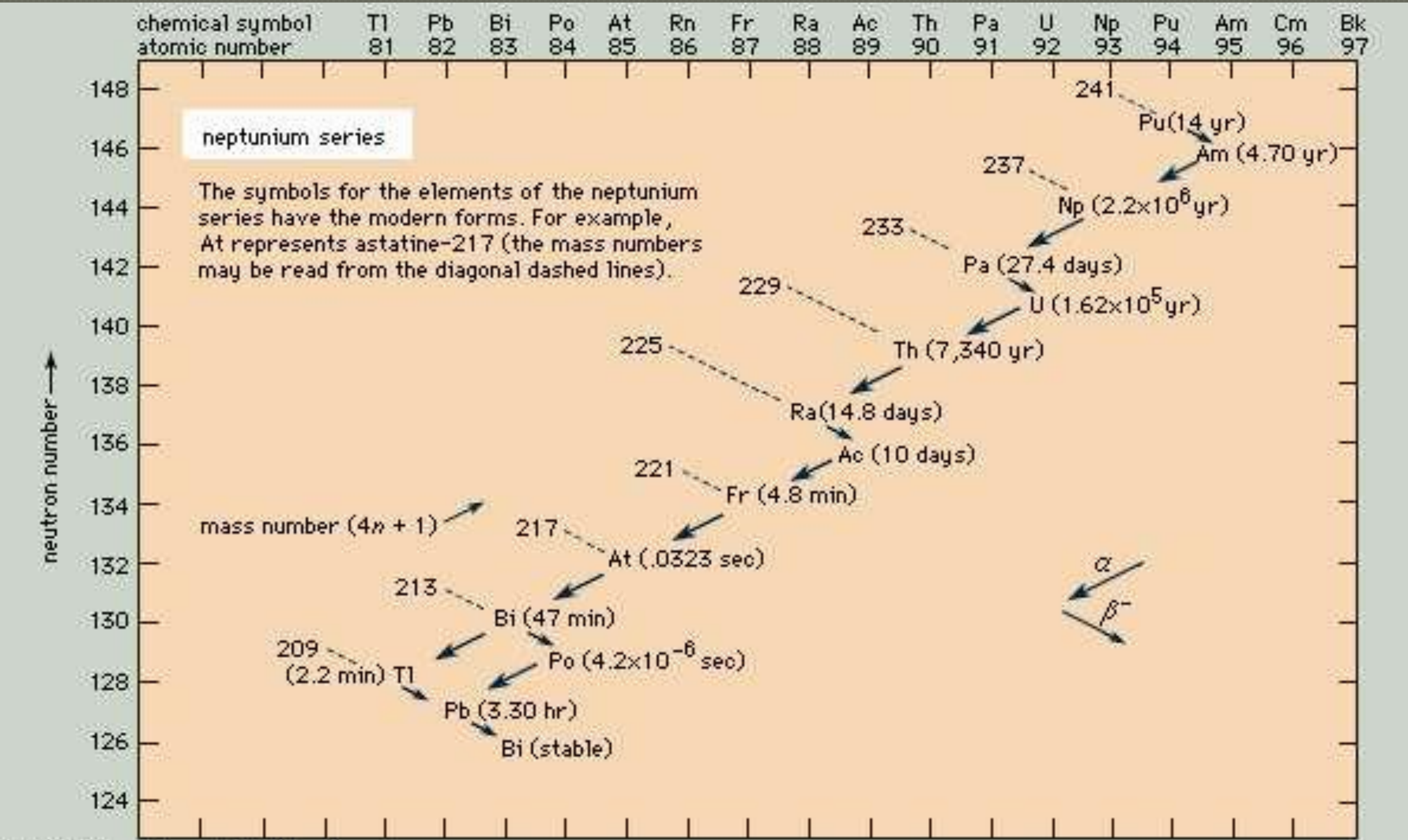
Decay series (4n)



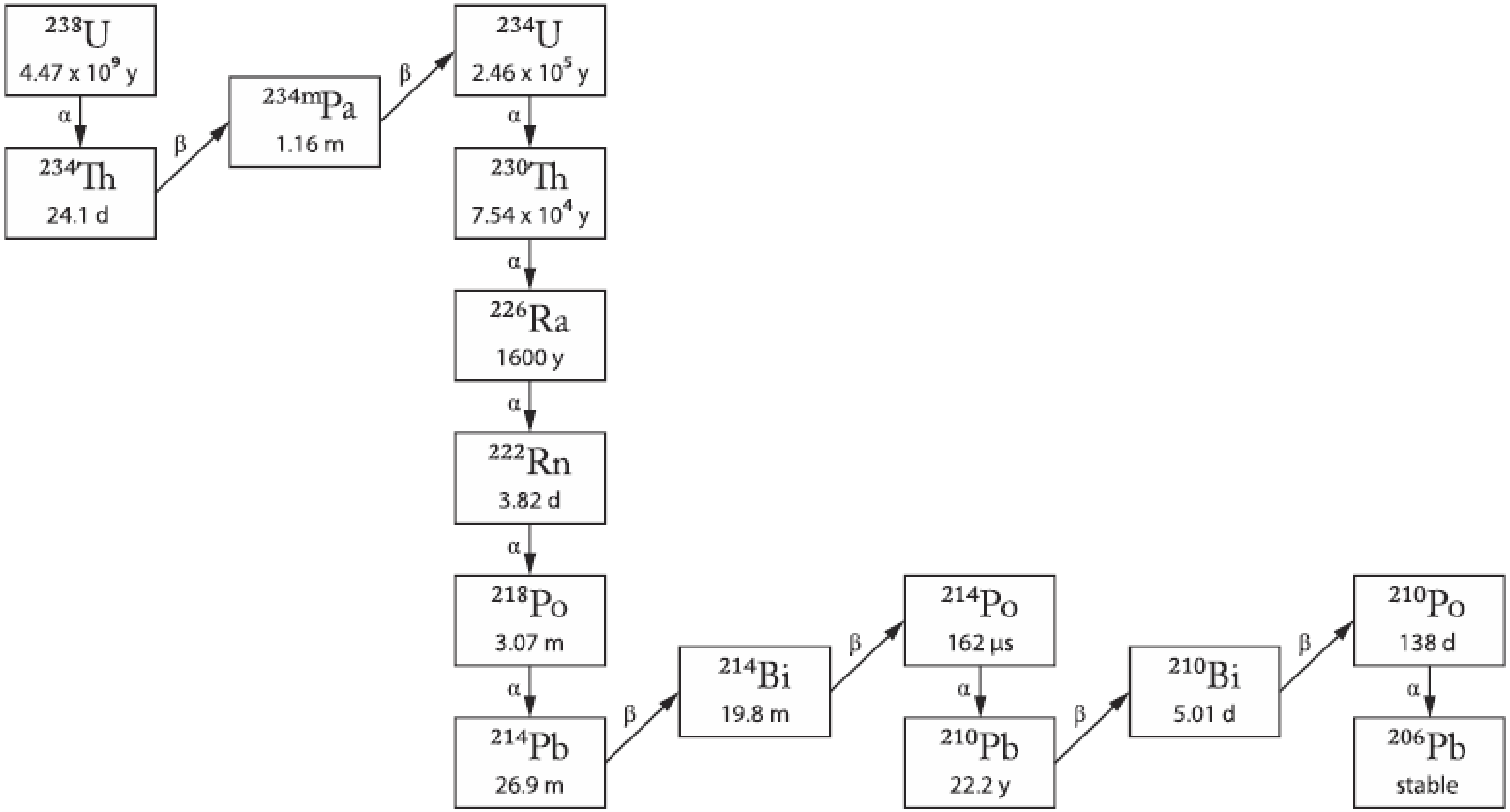
Thorium decay series.

IAEA (2013)

Decay series (4n+1)



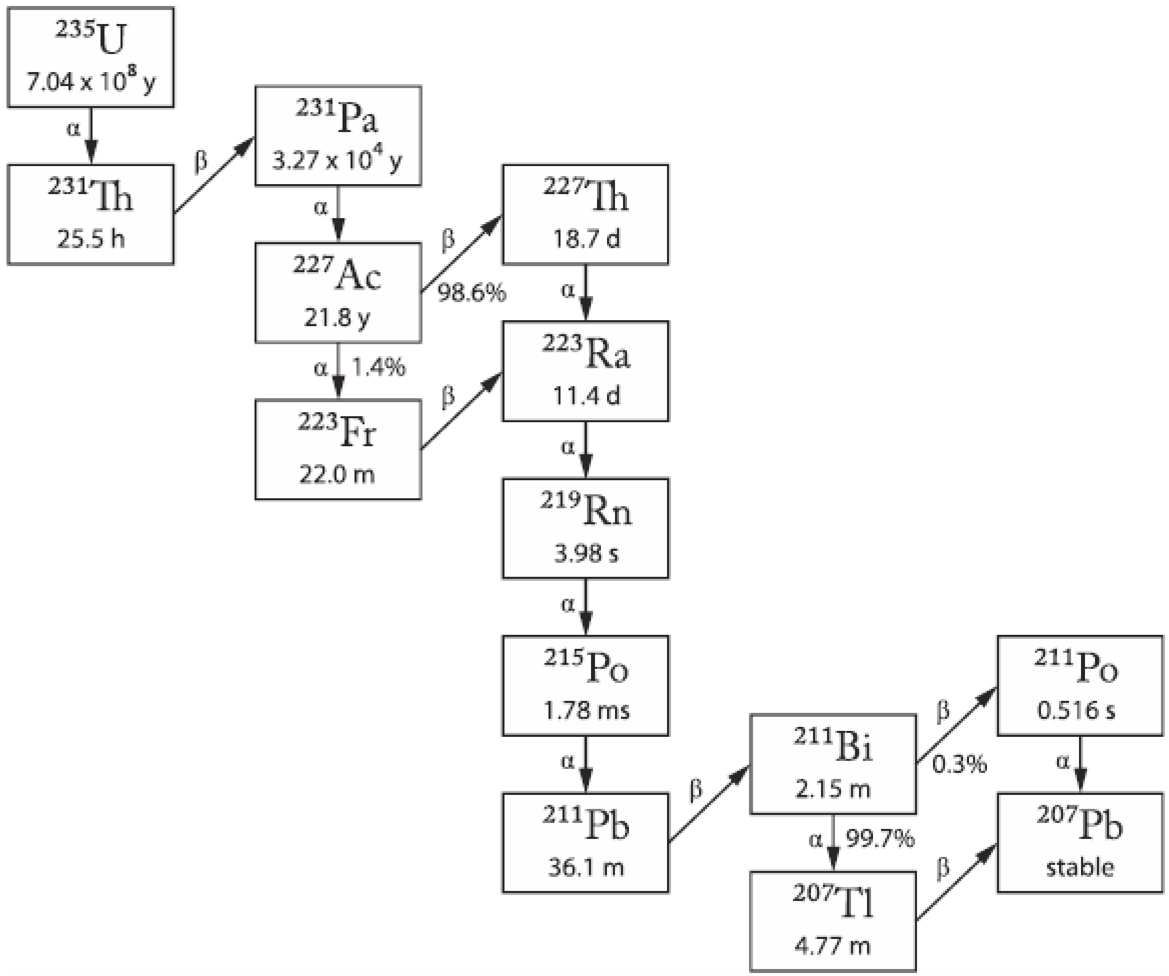
Decay series (4n+2)



Uranium decay series.

IAEA (2013)

Decay series (4n+3)



Actinium decay series.

IAEA (2013)

Radon

Table 1. Radionuclides and their activity concentration range in the free atmosphere near ground level (United Nations, 1982; Bundesminister für Umwelt, Naturschutz und Reaktorsicherheit, 1984; Porstendörfer *et al.*, 1990)

Radionuclide	Half-time		Activity concentration ($mBq\ m^{-3}$)
Natural	^{3}H	12.3 a	≈20
	^{14}C	5736 a	≈40
	^{7}Be	53.6 d	1–7
	RnD*	164 μs–26.8 min	1000–50,000
	^{210}Pb	22.3 a	0.2–1
	^{210}Po	138.4 d	0.03–0.3
	^{212}Pb	10.6 h	20–1000
	^{212}Bi	60.6 min	10–700
Artificial	^{131}I	8.04 d	<0.0001 (16,000†)
	^{137}Cs	30.1 a	0.0005–0.005 (4000†)
	^{106}Ru	386.2 d	0.0001–0.002 (2000†)

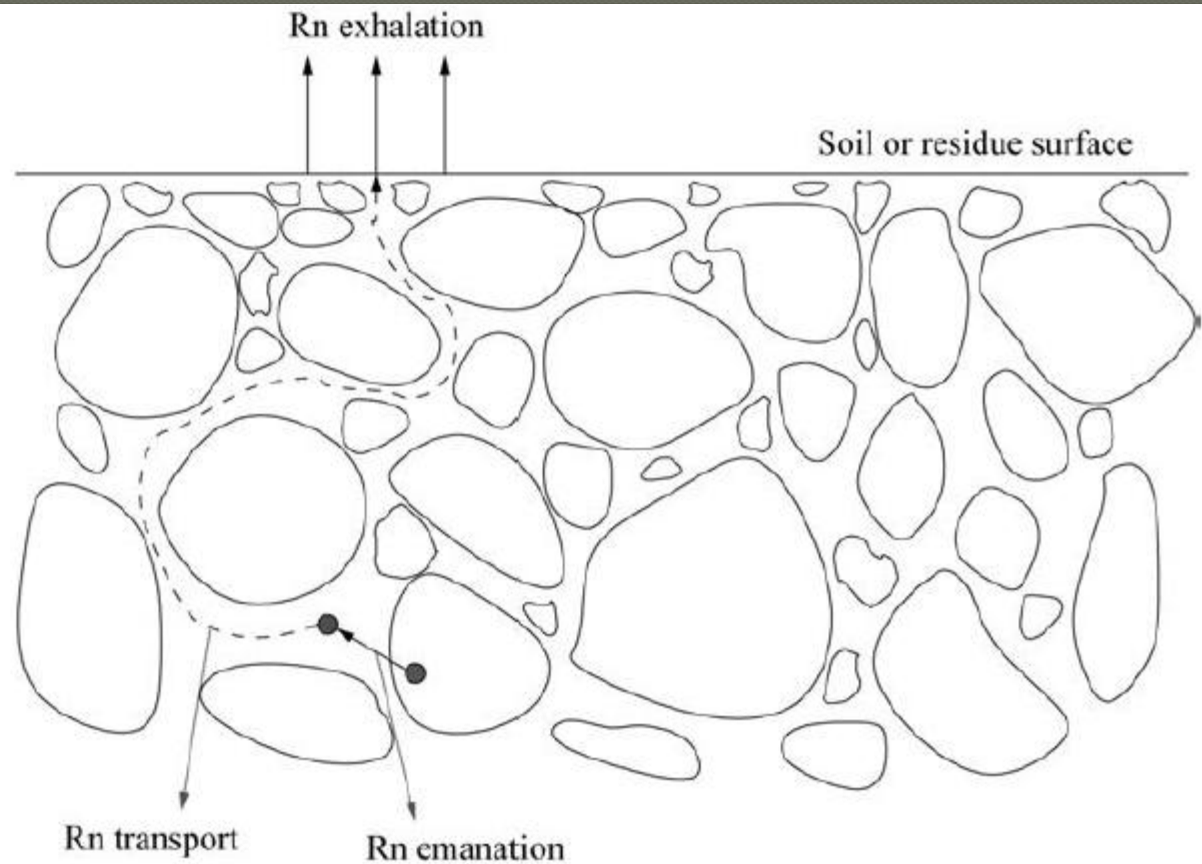
* Short-lived radon daughters: ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po.
† After the nuclear accident in Chernobyl the highest value in Göttingen, 2–3 May 1986.

J. Porstendörfer (1994)

Radon isotopes

Isotope sign	Name	First member of decay series	Mother element	Half-life time
^{222}Rn	Radon	^{238}U	^{226}Ra	3.8 d
^{220}Rn	Toron	^{232}Th	^{224}Ra	55 s
^{219}Rn	Aktinon	^{235}U	^{223}Ra	4 s

Radon



Processes leading to radon release to the atmosphere.

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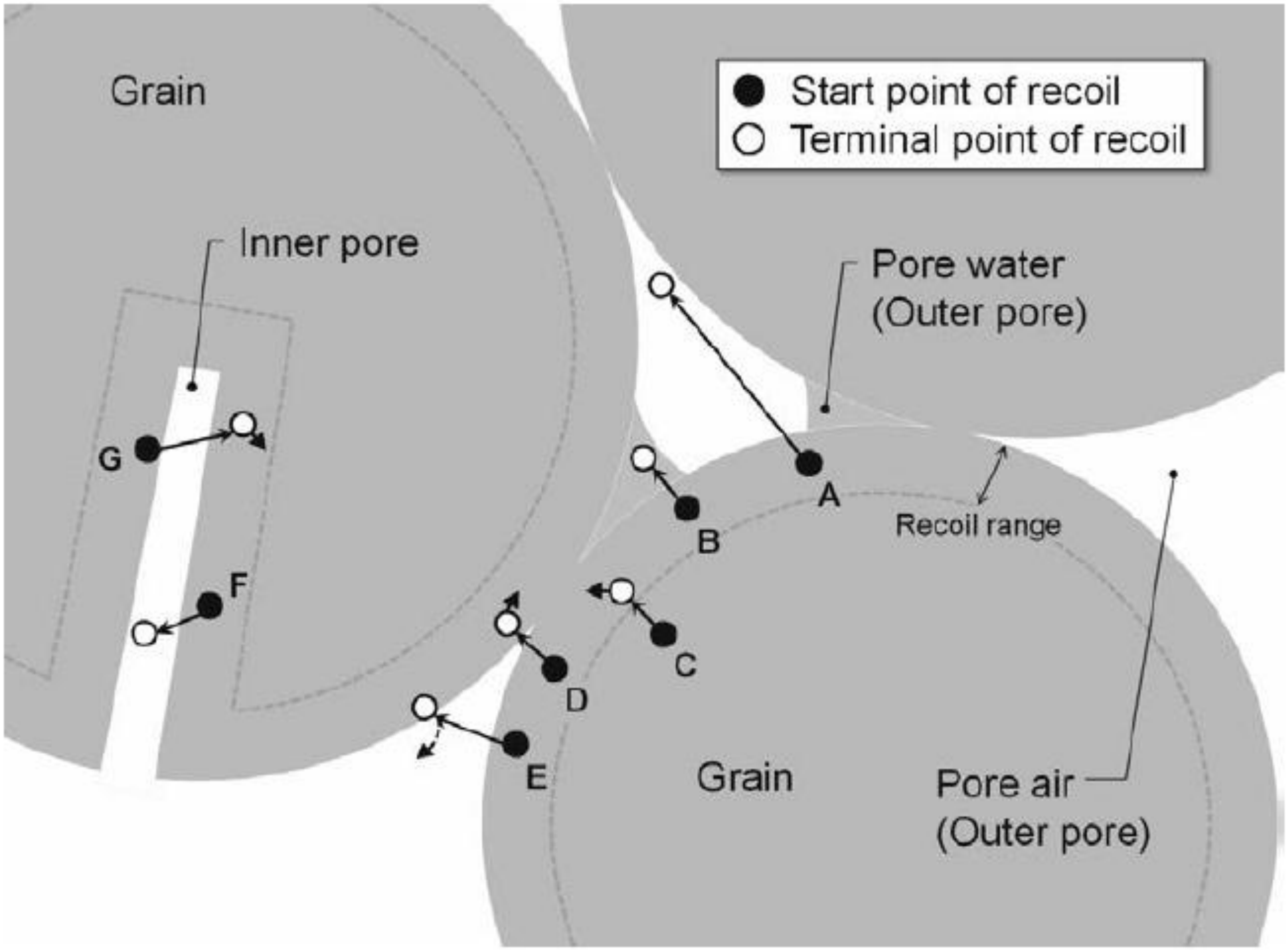
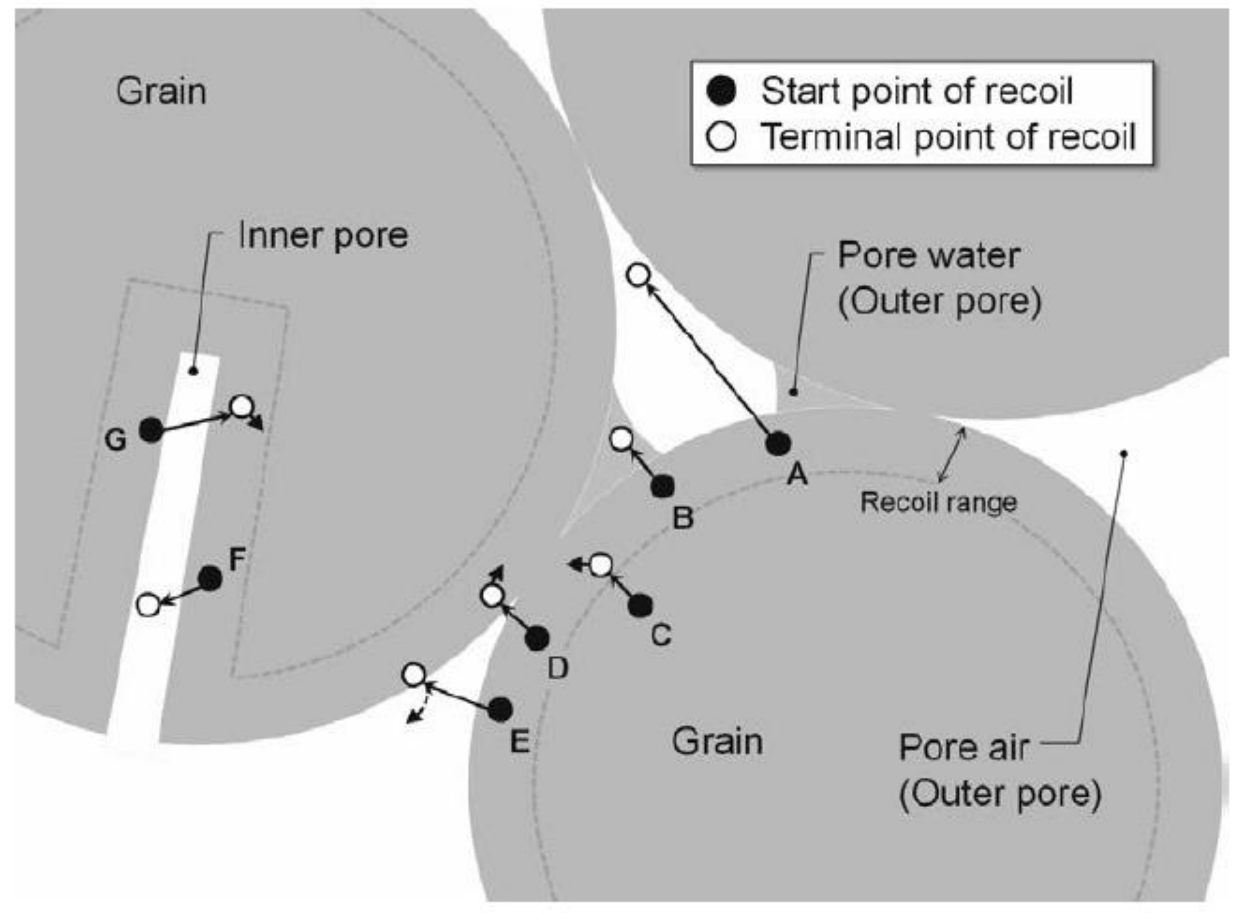
Radon



Schematic diagram of radon emanation [23].

IAEA (2013)

Radon



Schematic diagram of radon emanation [23].

Recoil ranges depending on media:

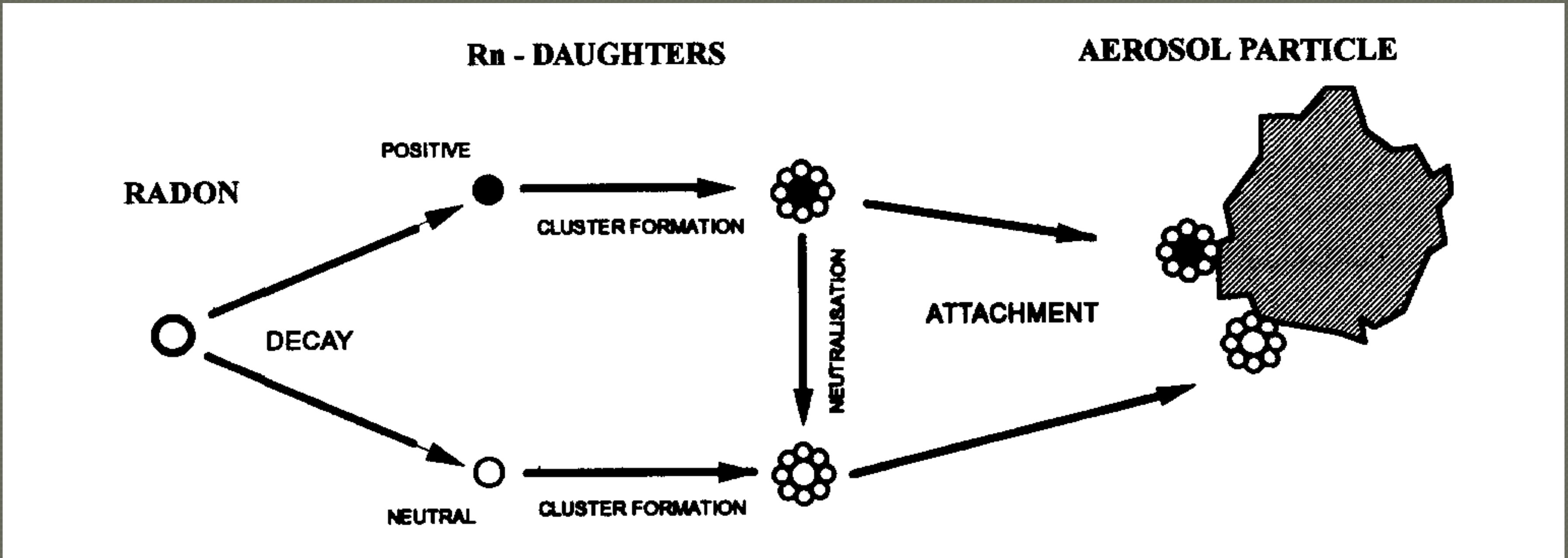
•solid 20-70 nm

•air ~60μm

•liquid100 nm

IAEA (2013)

Radon



J. Porstendörfer (1994)

Radon

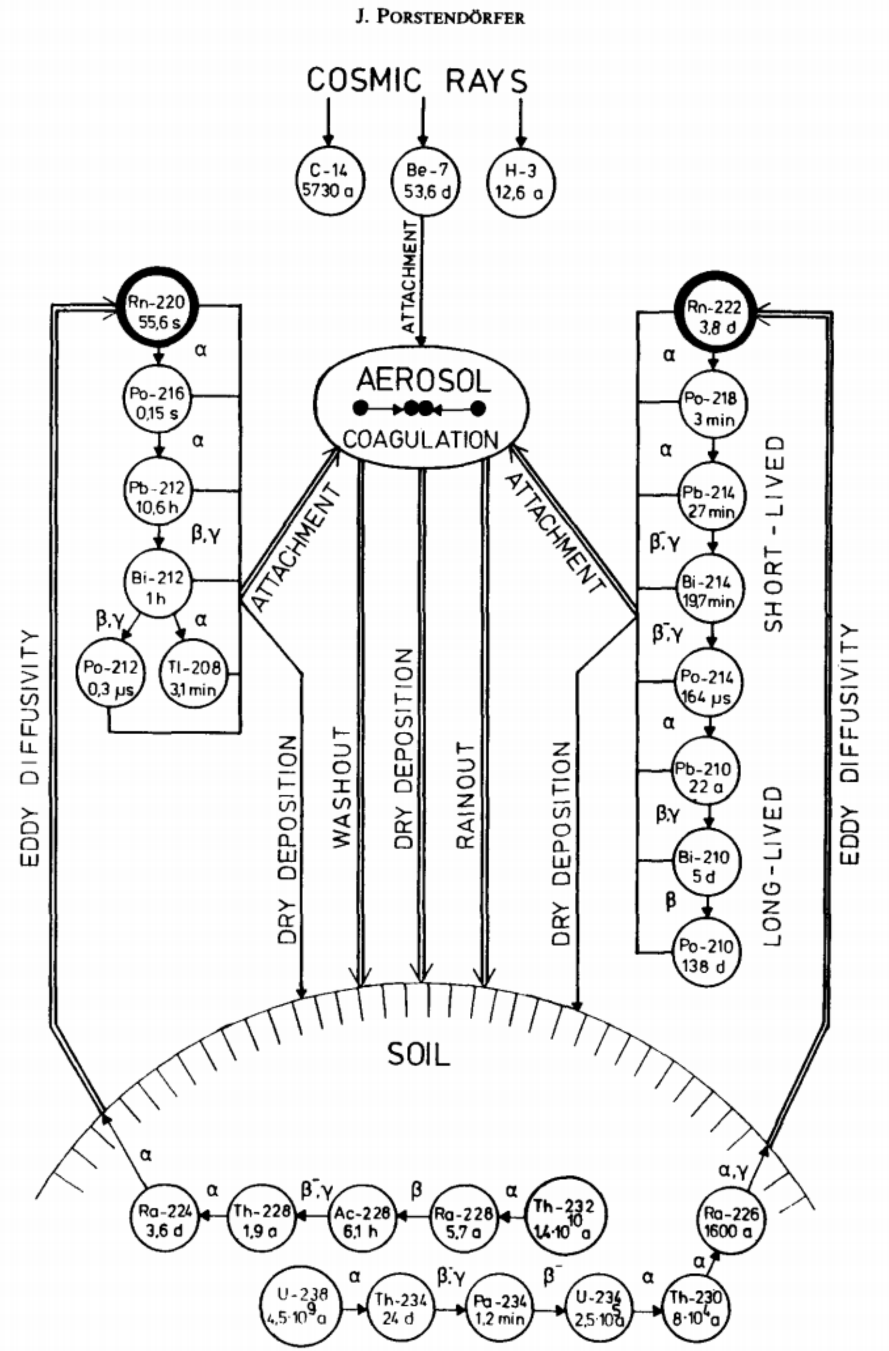


Fig. 1. Radon, thoron, and their decay products in the open atmosphere.

J. Porstendörfer (1994)

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