Radioactivity and radiation exposure from natural sources

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What is radioactivity?

Radioactivity is the phenomenon of

- Disintegration of atomic nuclei and the simultaneous emission energetic radiation

Elements and isotopes

- Atom nuclei comprise of protons and neutrons
- An element is defined by the number of protons
  - The number of neutrons varies, therefore any element has different isotopes
  - Non-stable isotopes of an element are called **radio-isotopes**
  - Radioactive atoms are called **radionuclides**
- There are 118 elements
  - Only 80 elements have stable isotopes
  - In total, there are about 1000 radionuclides

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Characterisation of radionuclides

The decay of a radionuclide is specific

- **Radiation type**
  - Alpha-radiation: helium-nucleus (2 protons, 2 neutrons)
  - Beta-radiation: electrons
  - Gamma-radiation: electro-magnetic radiation
- **Energy of the radiation emitted**
  - Measured in units of electron-volt [eV, keV, or MeV]
  - The emission of alpha- and beta-radiation is usually accompanied by the emission gamma-radiation

Origin of radionuclides

- **Primordial** radionuclides exist since the creation of the Earth
- **Cosmogenic** radionuclides are generated due to interaction of cosmic radiation with atoms at high altitudes
- **Man-made** radionuclides are generated in nuclear installations as nuclear power plants, research reactors and accelerators

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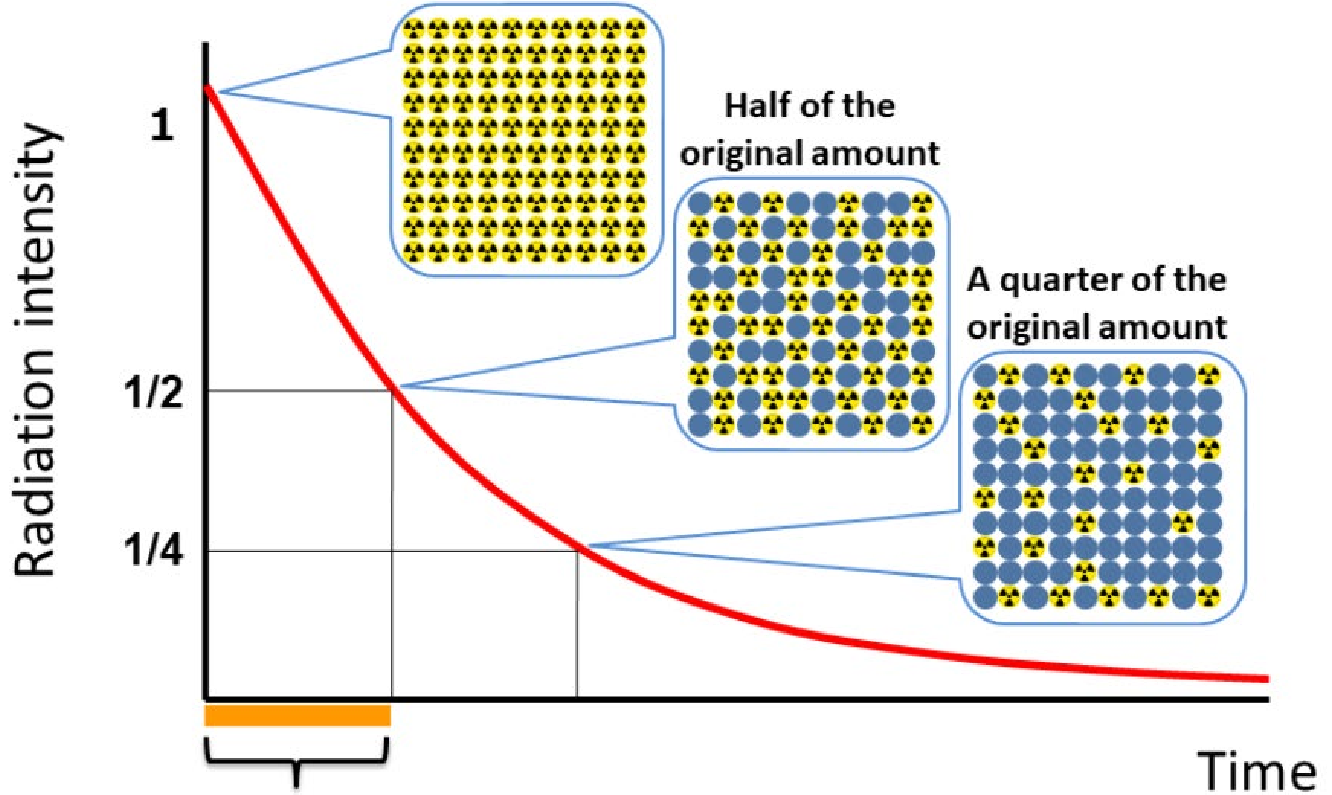
Every radionuclide is characterised by its physical half-life



Time required for the amount of the radionuclides to reduce to half = (physical) half-life

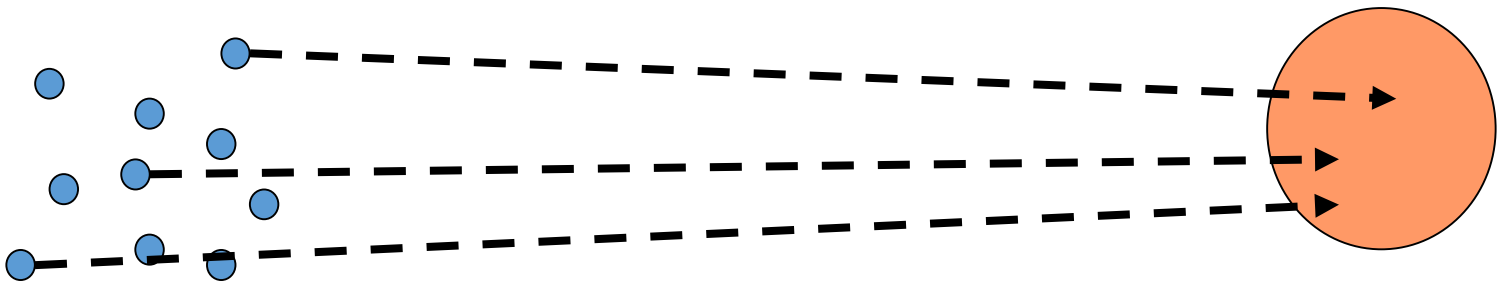
Half-lives vary from very small fractions of seconds to billions of years

Types of radiation and characteristics

- **Alpha radiation**
  - Relatively large particles: He-nucleus (2 protons. 2 neutrons)
  - Range in air: few cm
  - Range in water: Fraction of 1 mm
- **Beta radiation**
  - Small particles: electrons
  - Range in air: some 10 cm to some meters
  - Range in water: few mm
- **Gamma-radiation**
  - Electro-magnetic radiation
  - Range in air: some 100 m
  - Range in water: some 10 cm
- **X-rays**
  - Similar characteristics as gamma-radiation

Activity and radiation dose

Radionuclide | Radiation type (α, β, γ) | Tissue



Energy-emission | Energy transport | Energy absorption

Unit for activity

1 Bq

= 1 decay per second

Unit for dose

1 mSv

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Effects of ionizing radiation

- **Ionisation of atoms**
  - Formation of free radicals
- **Interaction of radicals with cells**
  - Damage of the cell nucleus
  - Damage of DNA
- **Possible effects**
  - Cell killing
  - Malignant degeneration => formation of a cancer cell
  - Mutations

$\Rightarrow$ Therefore we need radiation protection

Range of gamma-radiation and of x-rays

Thickness of a layer reducing the radiation by 50 %

Photon energy	Material			
	Air	Water	Concrete	Lead
20 keV		**8 mm**	**0.1 mm**	**0.005 mm**
50 keV		2 cm	2 mm	0.02 mm
100 keV	**37 m**	**4 cm**	**7 mm**	**0.1 mm**
200 keV		7 cm	2 cm	0.4 mm
500 keV	**66 m**	**8 cm**	**3.4 cm**	**4 mm**
1 MeV	90 m	10 cm	4.6 cm	9 mm
2 MeV	**130 m**	**14 cm**	**6.6 cm**	**1.3 cm**
5 MeV	210 m	23 cm	10 cm	1.4 cm

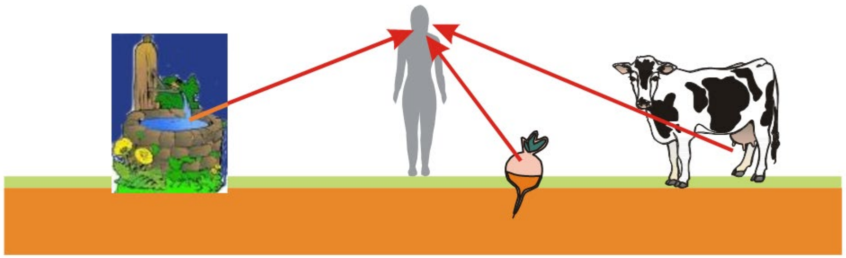
The relevant gamma-energy for Cs-137 is 662 keV.

Natural radionuclides in the body

Intake via food and drinking water

- Natural decay chains
- Primordial radionuclides (existing since Earth´s creation)
- Cosmogenic radionuclides (generated by cosmic radiation)

- **Most important radionuclide ^{40}K (potassium-40)**
  - Typical ^{40}K-concentration
    - Milk 50 Bq/kg
    - Meat 50 – 100 Bq/kg
    - Vegetables 30 – 150 Bq/kg
  - ^{40}K intake with food: 90 Bq per day
    - ^{40}K-activity in the body: 4.000 Bq per body
    - Effective dose from ^{40}K in foods: 0.15 mSv per year



- **Effective dose from all natural radionuclides in the body**
  - 0.3 mSv/a

Primordial radionuclides

Radionuclide	Half-life (years)	Radionuclide	Half-life (years)	Radionuclide	Half-life (years)
K-40	**1.3×10^{9}**	Cd-116	2.6×10^{19}	Sm-147	1.1×10^{11}
V-50	1.4×10^{17}	In-115	4.4×10^{14}	Sm-148	7.0×10^{15}
Ge-76	1.5×10^{21}	Te-123	1.2×10^{13}	Gd-152	1.1×10^{14}
Se-82	1.0×10^{20}	Te-128	7.2×10^{24}	Lu-176	2.6×10^{10}
Rb-87	4.8×10^{10}	Te-130	2.7×10^{21}	Hf-174	2.0×10^{15}
Zr-96	3.9×10^{19}	La-138	1.1×10^{11}	Ta-180	1.2×10^{10}
Mo-100	1.2×10^{19}	Nd-144	2.3×10^{15}	Re-187	5.0×10^{10}
Cd-113	9.0×10^{15}	Nd-150	1.7×10^{19}	Os-186	$2.0 \times\cdot 10^{15}$
				Pt-190	6.5×10^{11}

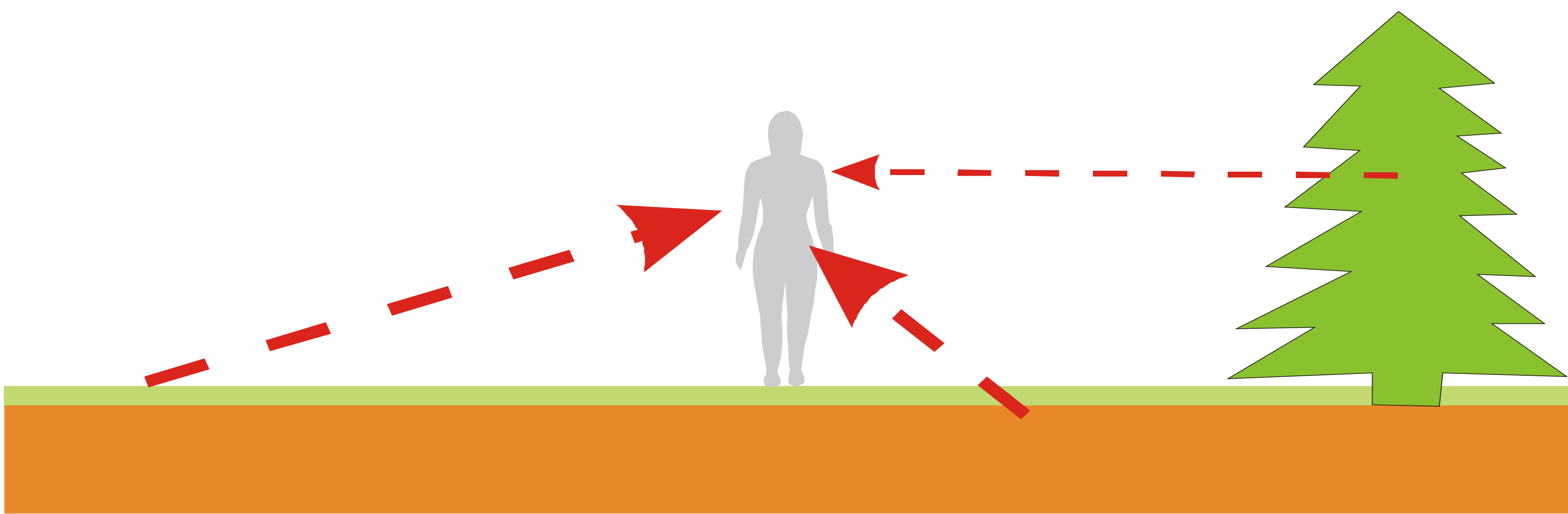
Cosmogenic radionuclides

Radionuclide	Half-life	Radionuclide	Half-life
Tritium (H-3)	12.3 y	Silizium-32 (Si-32)	101 y
Beryllium-7 (Be-7)	53.3 d	Phosphorus-32 (P-32)	14.3 d
Beryllium-10 (Be-10)	1.6×10^6 y	Argon-39 (Ar-39)	269 y
Carbon-14 (C-14)	5730 y	Krypton-81 (Kr-81)	2.1×10^5 y
Sodium-22 (Na-22)	2.6 y	Krypton-85 (Kr-85)	10.7 y

Natural exposure

Terrestrial exposure

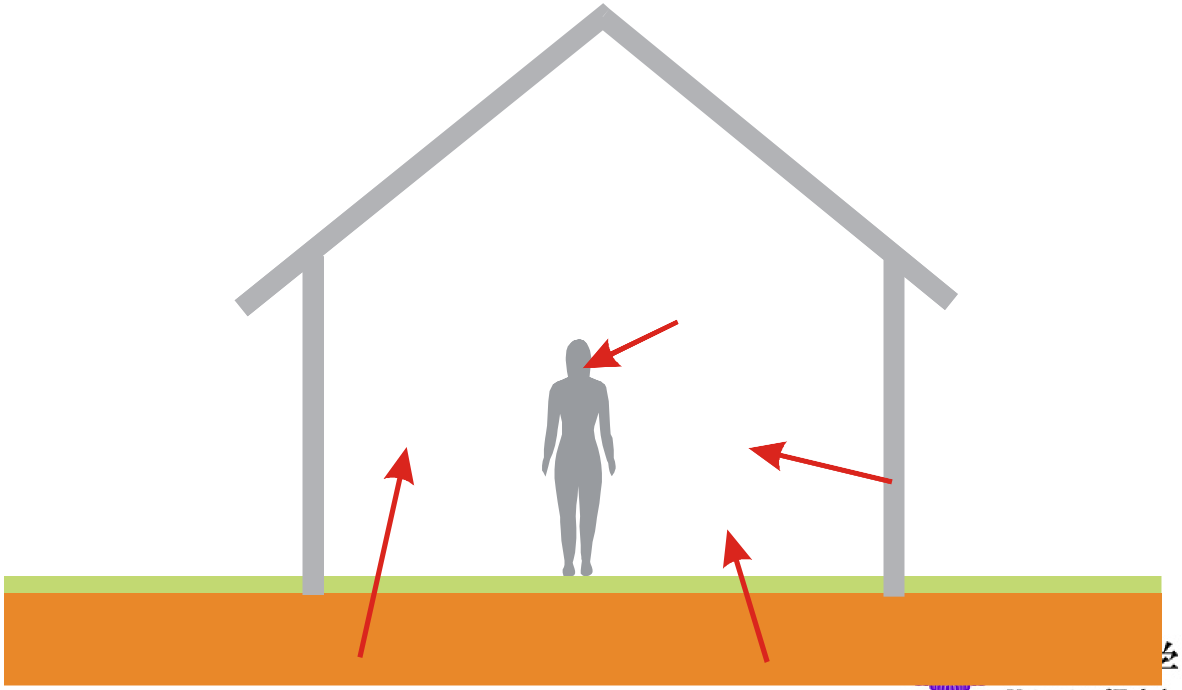
- Radionuclides in rocks, soil, construction material. plants …..
- **0.4 mSv per year**



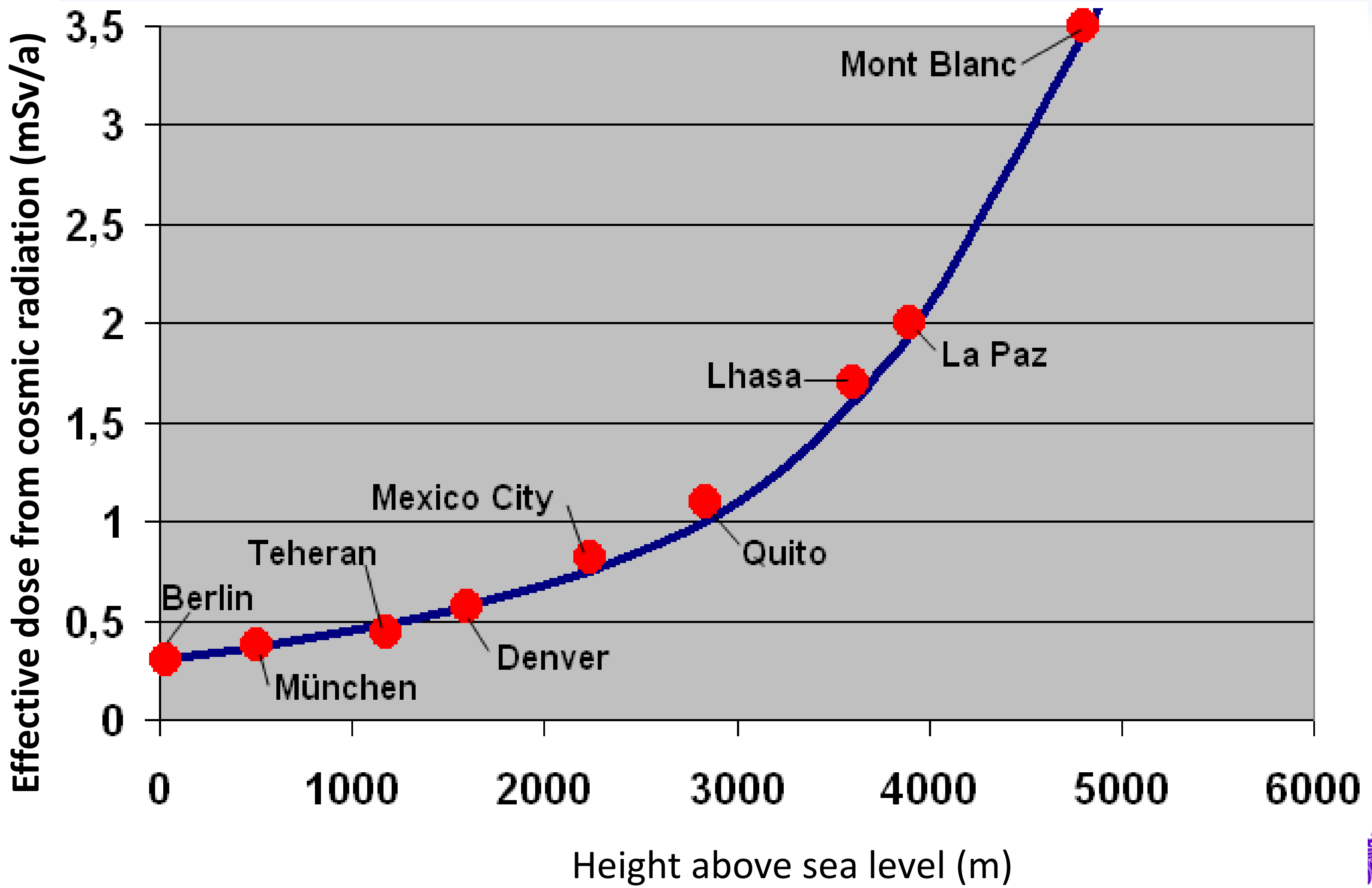
Natural exposure

Inhalation of radon

- Radioactive noble gas emanating from soil and construction materials
- Exposure varies widely
  - **1-10 mSv per year**



Natural exposure - cosmic radiation



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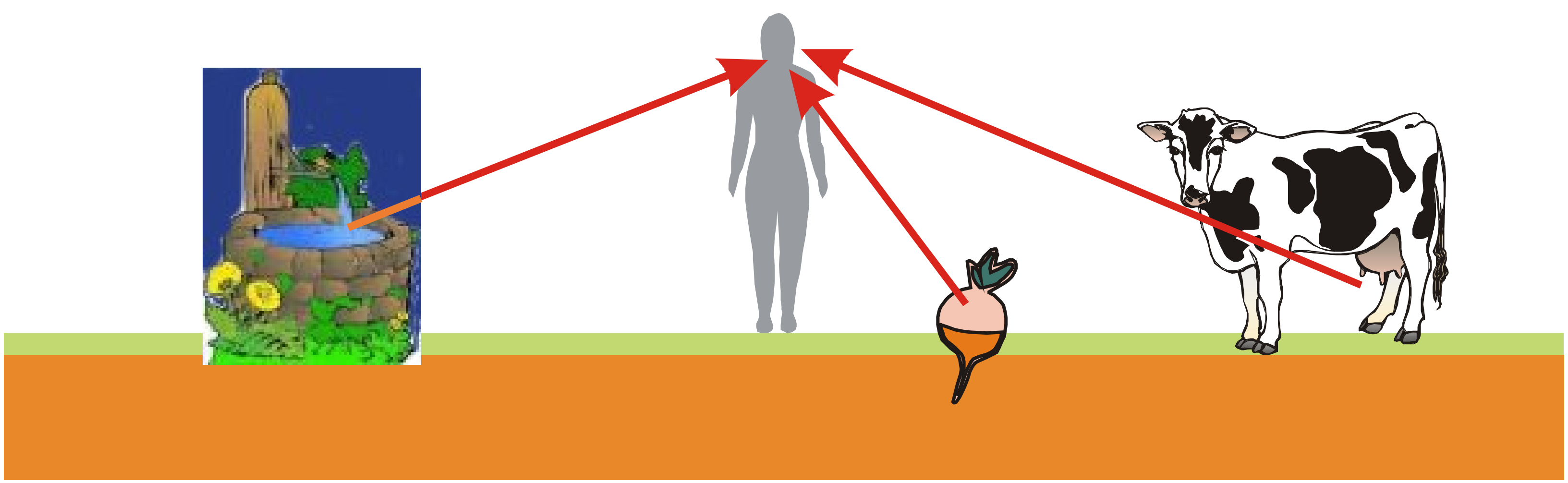
Natural exposure

Internal exposure

- Intake with food
- Most important: potassium-40 (K-40)
- Exposure: **0.3 mSv per year**



Natural radiation exposure (UNSCEAR 2008)

Source	Annual effective Dose (mSv/a)	
	Mean	Range
Ingestion	**0.3**	**0.2 - 1**
^{40}K	0,17	
U- und Th- decay chains	0,12	
Cosmogenic radionuclides	0,01	
Inhalation	**1.256**	**0.2 - 10**
U- Th–decay chain	0,006	
Radon (^{222}Rn/^{220}Rn and decay chains.)	1,25	
External exposure	**0.87**	**0.6 - 2**
Cosmic radiation (at sea level)	0,39	0,3 - 1
Natural radionuclides in soil	0,48	0,3 - 1
Total	**2.4**	**1 - 13**

Medical radiation exposure

Main source:
Diagnostic applying x-rays and computer tomography

Examples:	**mSv pro per image**
• Tooth	up to 0.01
• Extremities	0.01 bis 0.1
• Abdomen	0.5 bis 1.0
• Lumbar spine (in 2 levels)	0.8 bis 1.8
• Head – CT	2 bis 4
• Spine – CT	2 bis 11
• Abdomen – CT	10 bis 25

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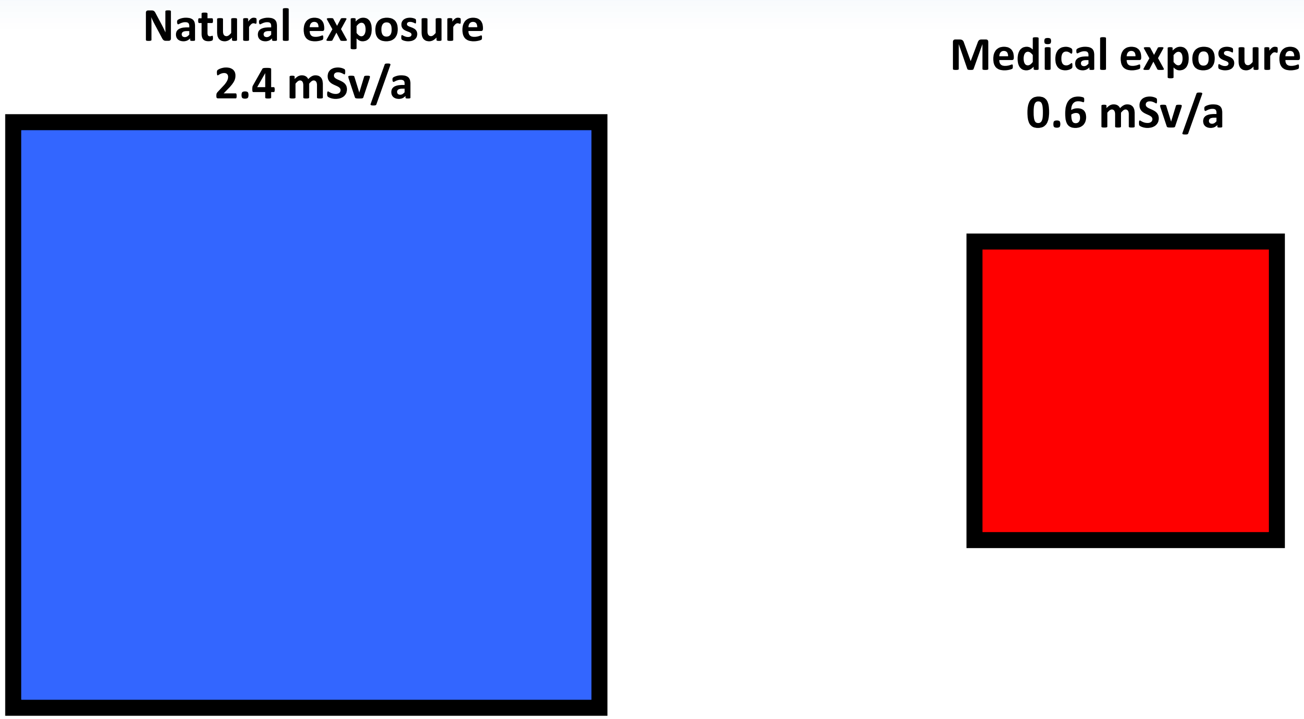
Medical exposure (global average)



UNSCEAR 2008

United Nations Scientific Committee on the Effects of Atomic Radiation

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Summary

Natural exposure varies widely

- Global average
  - Annual dose 2.4 mSv/a
  - Life-time dose (80 a): ≈ 200 mSv
- Global range:
  - Annual dose 1-13 mSv/a
  - Life-time dose: ≈ 80 - 1000 mSv

The level of natural exposure and its variation

- One (but not the only one) yardstick to evaluate the relevance of exposures from other sources

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