Identification of NORM cases and existing regulatory context

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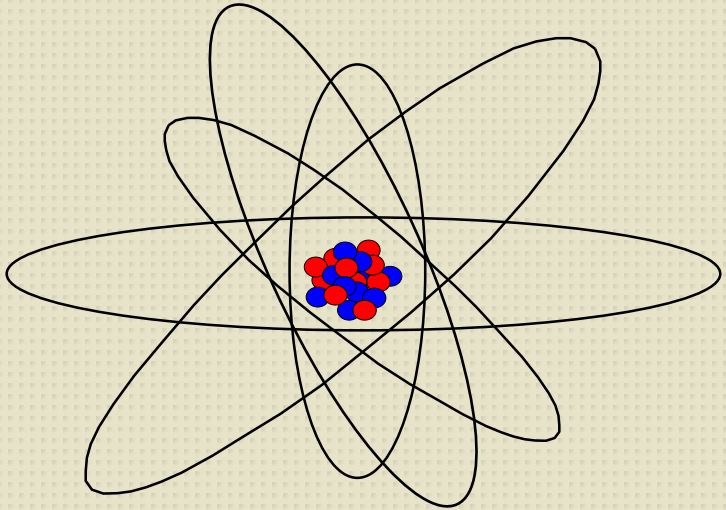
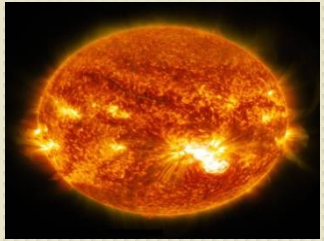
Despite being consistently portrayed in the media and popular culture, many people don’t really know what radioactivity as a phenomenon is all about.



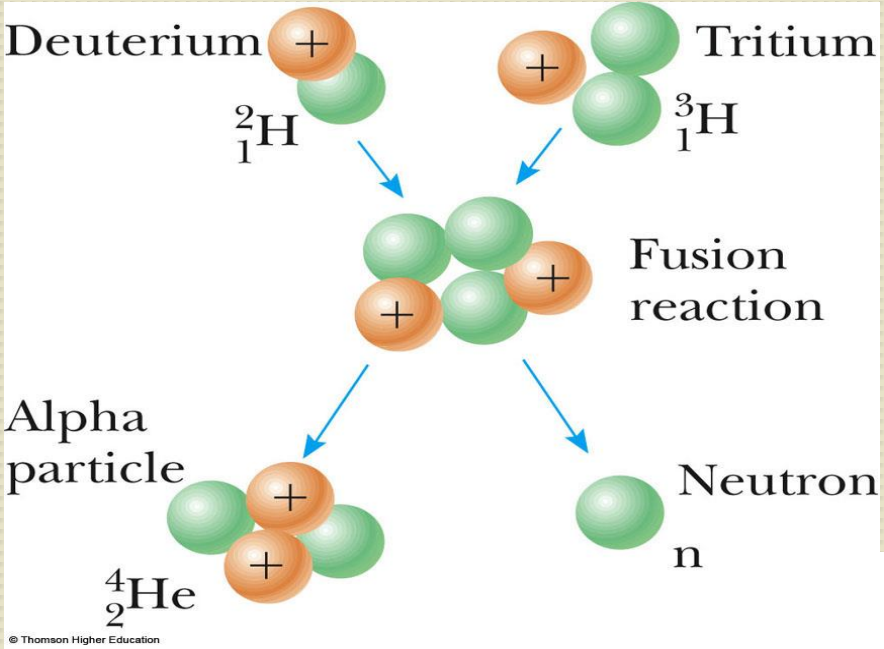
Lecture content:

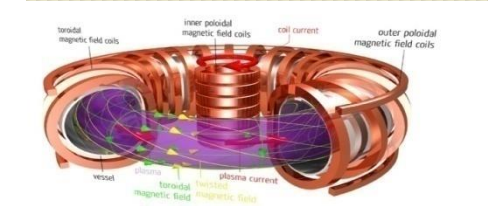
- Rudiments of radiation physics (types of decay and radiation, successive decay , decay series, equilibrium/ disequilibrium),
- Identification of processes leading to NORM creation,
- Exposure to humans/environment scenarios including building materials,
- Differences between NORM contaminated materials and contaminated materials with artificial radionuclides,
- Applied terminology and existing definitions,
- Development of existing regulation in historical context.

- Contrary to popular belief, the presence of radioactive materials is not only limited to high-tech chemical laboratories; rather, radioactivity is a part of the Earth and has existed since its birth. Radioactive materials are found naturally in the Earth's crust, rocks, soil, ocean water etc.
- Not only that, but radiation is also present in our buildings, walls and floors; even our own bodies play host to certain naturally-occurring radioactive elements. Suffice to say that one cannot EVER be in a "radioactivity-free environment".

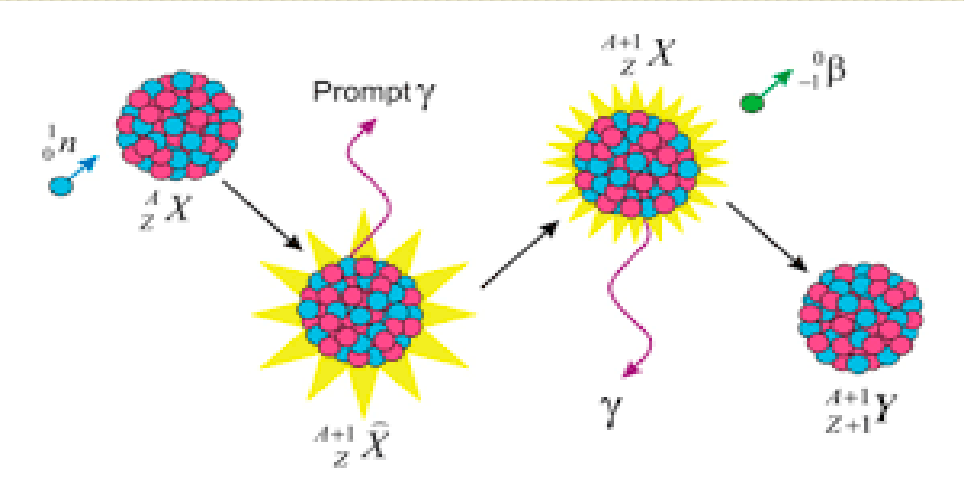


Nuclear Fusion

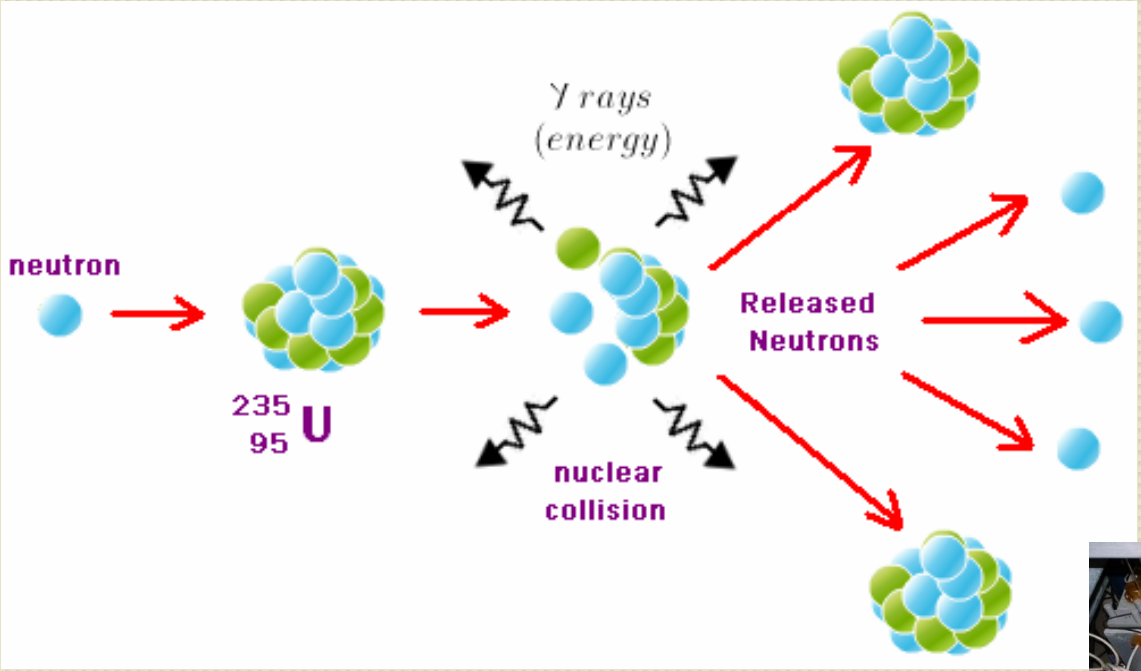




Neutron Activation



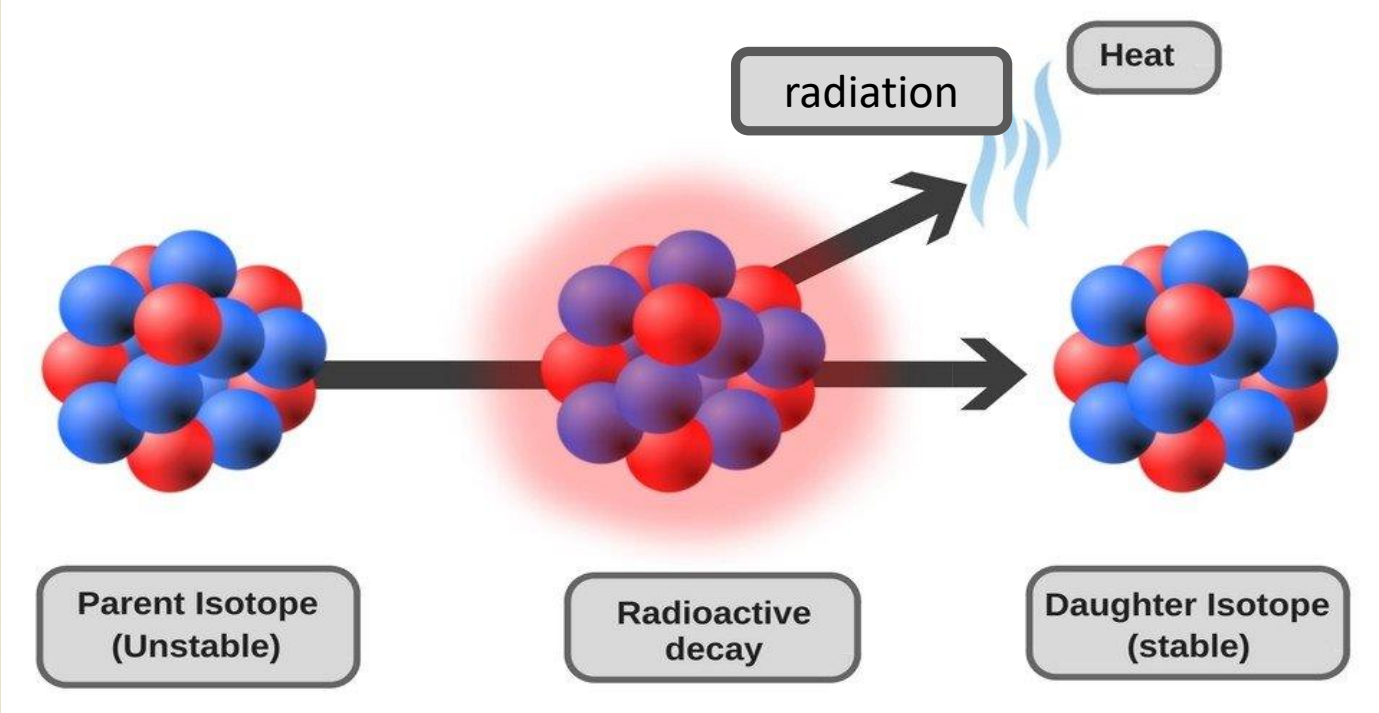
Nuclear Fission



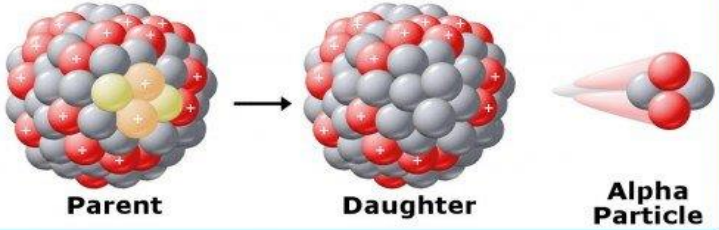
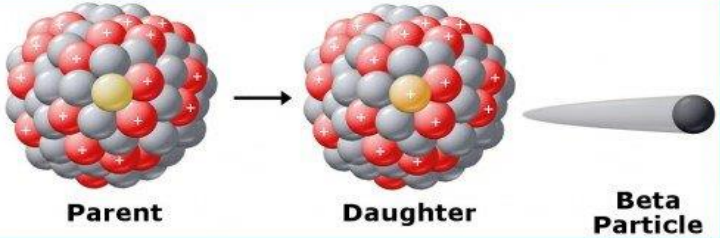
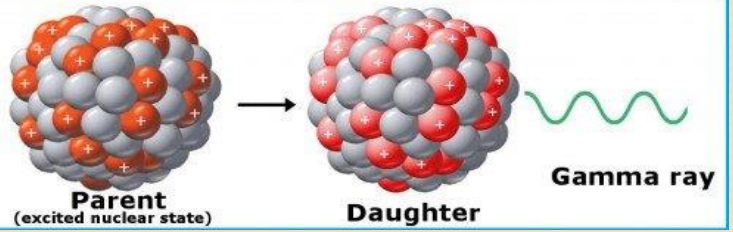
- However, there are certain atoms that either have too many or too few neutrons or protons in their nuclei. This results in an imbalance between the forces holding them together, which leads to an excess of internal energy. Such atoms are said to be **unstable or radioactive**.

- In a bid to attain stability, **these atoms throw off protons or neutrons to reduce their mass**, which are converted into energy (think Einstein's energy-mass equivalence) and emitted in the form of ionizing radiation (like alpha, beta and gamma radiation).

Radiaoctive decay



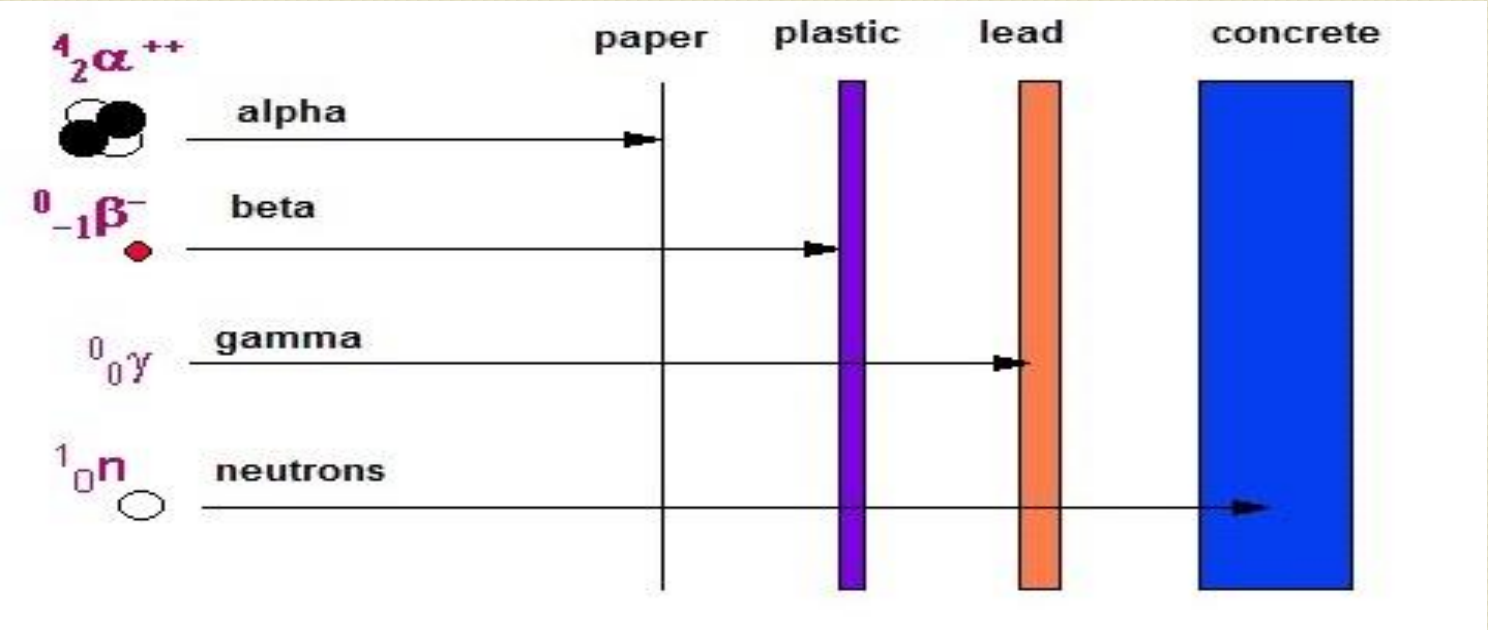
Types od radioactive decay

Decay Type	Generic Equation	Model
Alpha decay	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}X' + {}^{4}_{2}\alpha$	
Beta decay	${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}X' + {}^{0}_{-1}\beta$	
Gamma emmission	${}^{A}_{Z}X^{*} \xrightarrow{\text{Relaxation}} {}^{A}_{Z}X' + {}^{0}_{0}\gamma$	

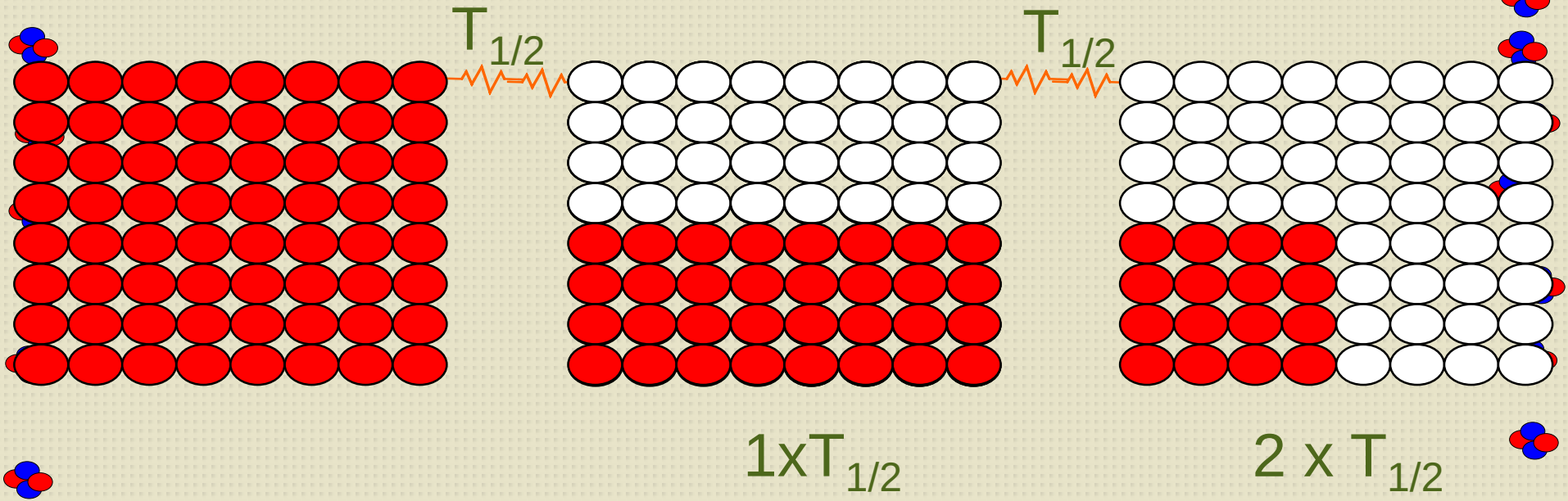
Types od radioactive decay

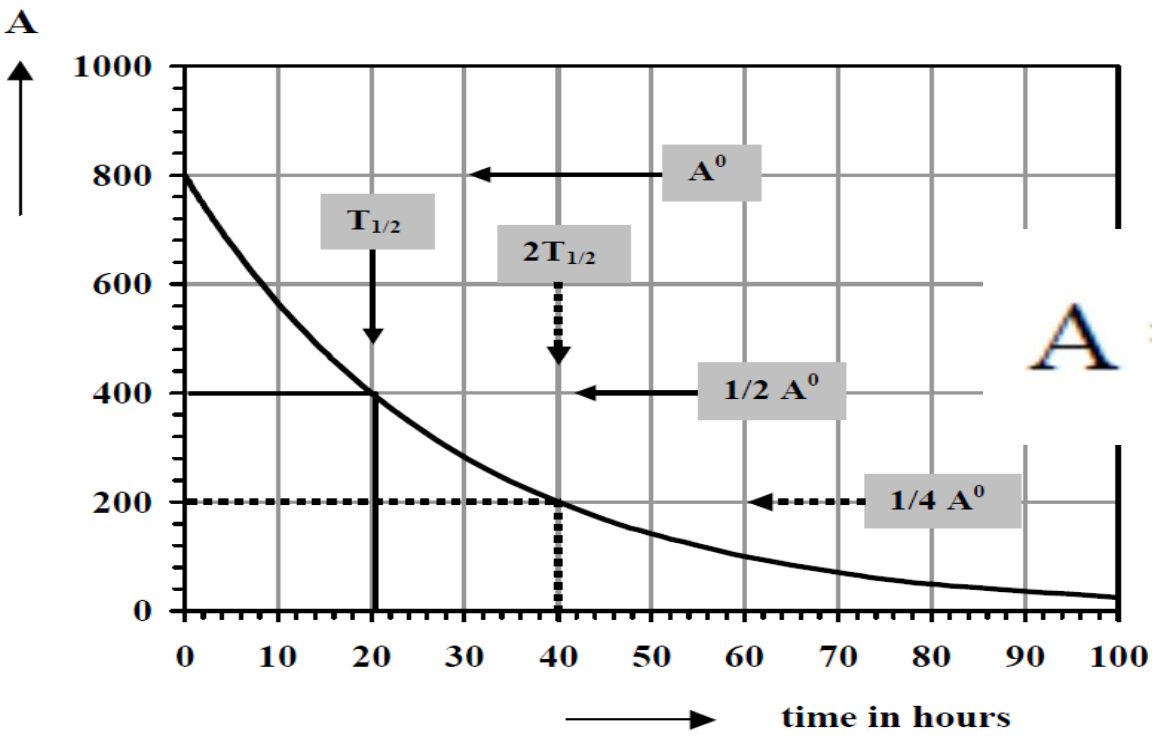
- Except for gamma decay or internal conversion from a nuclear excited state, the decay is a **nuclear transmutation** resulting in a daughter containing a different number of protons or neutrons (or both). When the number of protons (Z) changes, an atom of **a different chemical element is created**, when (A) mass number is changed **a new isotope is created**

Types of radiation



Half-life ($T_{1/2}$)





$$A = A^0 e^{-\lambda t}$$

The rate of radioactive decay. After each subsequent half-life of 20 hours the number of radioactive nuclei and the original radioactivity of 800 units are divided into half.

Half-life, decay constant and activity

$$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{T_{1/2}}$$

$$A_{spec} = \lambda N$$

Radioactivity in environment

Natural radiation background - usually is not considered to be harmful

but .....

selective accumulation of radionuclides in some industrial processes occurs ... causing significant contamination of human environment.

NORM Naturally Occurring Radioactive Materials

TENORM Technologically Enhanced Naturally Occurring Radioactive Materials

Definitions

- The definition of NORM (Naturally Occurring Radioactive Materials - that is usually used for description all cases of natural radioactivity occurrence) is provided by the IAEA [2007] as "***Radioactive material containing no significant amounts of radionuclides other than naturally occurring radionuclides***" where the exact definition of '*significant amounts*' would be a regulatory decision.
- This definition does not give any suggestion concerning a possible derived exposure scenario whether to humans or to environment, however the remark is included that "*material in which the activity concentrations of the naturally occurring radionuclides have been changed by a process is included in naturally occurring radioactive material*".

IAEA Safety Glossary (version 2.0):

Definitions

- The approach presented by the US EPA (U.S. Environmental Protection Agency) and referred to as TENORM (that means Technologically Enhanced Naturally Occurring Radioactive Material) that is defined as, "*naturally occurring radioactive materials that have been concentrated or exposed to the accessible environment as a result of human activities such as manufacturing, mineral extraction, or water processing*" provide a clue as to where high concentrations of natural radioactivity are expected.
- Contrary to the IAEA definition, the US EPA defines NORM as "*materials which may contain any of the primordial existing from the beginning of time, naturally occurring radionuclides or radioactive elements as they occur in nature, such as radium, uranium, thorium, potassium and their radioactive decay products that are undisturbed as a result of human activities.*" It is not clearly declared, but this definition suggests that NORM, is not subject to authority control based on the exclusion rules recommended by the IAEA [IAEA, 2004].

In practice **NORM** implies:

- materials with **elevated concentrations of natural radionuclides**, significantly above the average level of background radiation, albeit not related to or caused by any type of either chemical or physical processes resulting from human activity. It has to be noted that NORM in this meaning is treated as a component of the natural background radiation and usually is considered as an unamenable source of radiation; hence, it is excluded from radiation protection.

- However, when such materials, even if they are not being altered in anyway, are present or moved to the human's natural or work environment – i.e. **is *exposed to the accessible environment*** - due to industrial activity, they immediately became subject to radiation protection. It is clear that this definition limits the exposure scenarios that are subject to regulation to excavation, transport and storage of, usually, raw materials, where additional radiation risk is just caused by the presence of NORM with no regard to its final form i.e., bulk, fume/dust or effluents.

In practice **TENORM** implies:

any material, product, residue or waste, in which the activity concentration of natural radionuclides has been altered (increased) as a result of technological processes involving either physical processing or chemical reactions to levels significantly above the natural background radiation. It does not matter if the enhancement is intentional or not.

NORM vs. TENORM

(with no regard to abbreviations used by either IAEA or EPA)

- The term **NORM** should be used only when **elevated concentration of natural radionuclides**, significantly above the average background, **is the primordial property** of material of concern.
- NORM is taken into account in the radiation control **only in cases when appearing in the natural or work environment due to human activity,** otherwise they are treated as natural background component.
- **TENORM** is used towards any substance in which concentrations of natural radionuclides have been **enhanced as a result of technological processes.** It doesn't matter if the enhancement is intentional or not.
- **It's possible to create TENORM in processes where no NORM have been used as input materials!**

NORM & TENORM

- Raw materials
- Products, by-products
- Waste and residues

Raw materials (NORM)

- More than 400 minerals occurring in Earth crust are classified as radioactive,
- Some of them are source of valuable elements necessary in the modern economy,
- The most commonly used are:
  - Uranium containing minerals used in nuclear fuel cycle,
  - Rare Earth Oxides (REOs),
  - Phosphorite, (phosphate rock),
  - Potassium salt;
  - Thorium bearing minerals;
  - Ores of non uranium metals e.g. tin, niobium, copper, nickel.

Products

- Due their properties radioactive elements sometimes are used with no regards to their radioactivity:
    - Thorium in optical glass, welding rods, gas mantles,
    - Depleted uranium for shielding, ballast and ammunition.
- Some radioactive minerals are directly used for production:
    - Refractories and abrasive materials,
    - Glaze and ceramics,
    - Fertilisers.
- and also some NORM residues are directly used for production building and construction materials

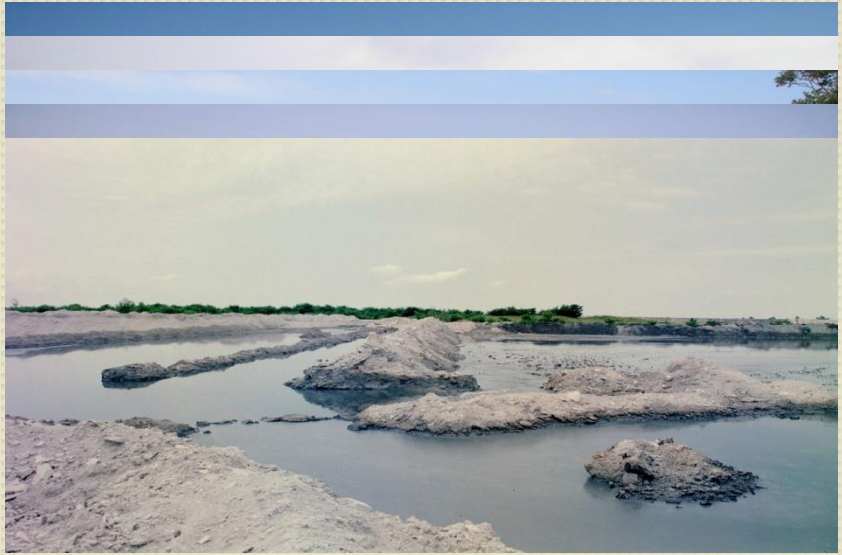
NORM type waste

- Waste rocks from mining exploitation and raw materials cleaning or enrichment, together with possible contamination resulting from radionuclides leaching;
- Brines, released from oil and gas rigs or hard coal mines;
- Residues from Rare Earth Oxides (REOs) fractionation;
- Radon and its progeny in caves, underground mines, in tunneling and in natural gas;
- Dust from of air cleaning systems;
- Residues from uranium minnig and milling (a part of nuclear fuel cycle).

TENORM type waste created by mass reduction processes

- Waste from fossil fuel combustion (i.e. CCP – coal combustion products);
- Waste materials from chemical processing (mainly production of phosphoric acid and titanium dioxide pigment);
- Slag from metallurgical industry (iron ore processing and steel production);
- Waste products from non-ferrous ore processing – mainly tin, copper, zirconium and niobium;
- Tailings from rare earth metals industry;
- Deposits in underground galleries and settling ponds, scales in the dewatering systems in wells and underground mining industry;
- Solid waste from water treatment plants and geothermal energy use.

(TE) NORM waste looks like …..



source geometry, location and possible dispersion models: typical NORM repositories have the appearance of common waste dumps and tend to have more in common with industrial waste than with spent nuclear fuel cycle or dispensable radioactive sources;

total amount: NORM residues are usually bulk materials, e.g. phosphogypsum, slag, sediments, sometimes water;

ambient conditions: residues are usually in direct contact with environment, it means that they are exposed to meteorological conditions (water and wind erosion) and unlimited access by biota;

Frequently they are associated with other pollutants as heavy metals, sulphates, hydrocarbons.

Features of environmental impact of NORM residues:

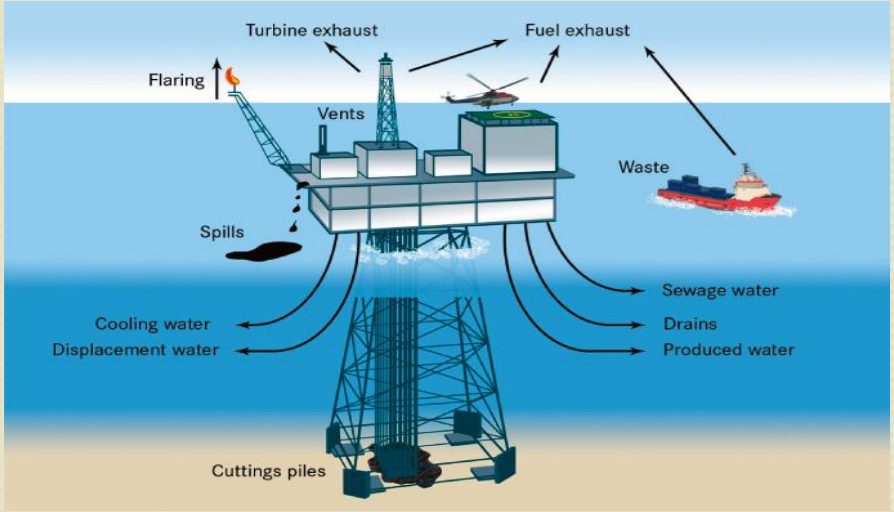
exposure scenario: a waste heap

- **Looks like radioactive waste repository …**
- **Exposure pathways:**

- ~~Direct exposure~~
- Migration: Dust resuspension
- Rainwater seepage
- Ground water contamination
- Total contaminated area is not to big
- Exposed ecosytem ?
- Endagered species?

Features of environmental impact of NORM residues:

exposure scenario: water discharged to sea



- **Point source discharging contaminated water**

- **Exposure pathways:**

- ~~Direct exposure~~
- Direct migration into pelagic fish, zooplankton, phytoplankton
- Precipitation and accumulation in bottoms
- Migration benthic organism
- Entering food chain
- Exposure to marine ecosystem,

Features of environmental impact of NORM residues:

exposure scenario: water discharged into inland water

- **Point source discharging contaminated water :**

- **Exposure pathways:**

- ~~Direct exposure~~
- Direct migration into pelagic fish, zooplancton, phytoplancton
- Precipitaiton and accumulation in bottoms
- Migration into benthic organism
- Entering food chain

Features of environmental impact of NORM residues:

exposure scenario: stack emission

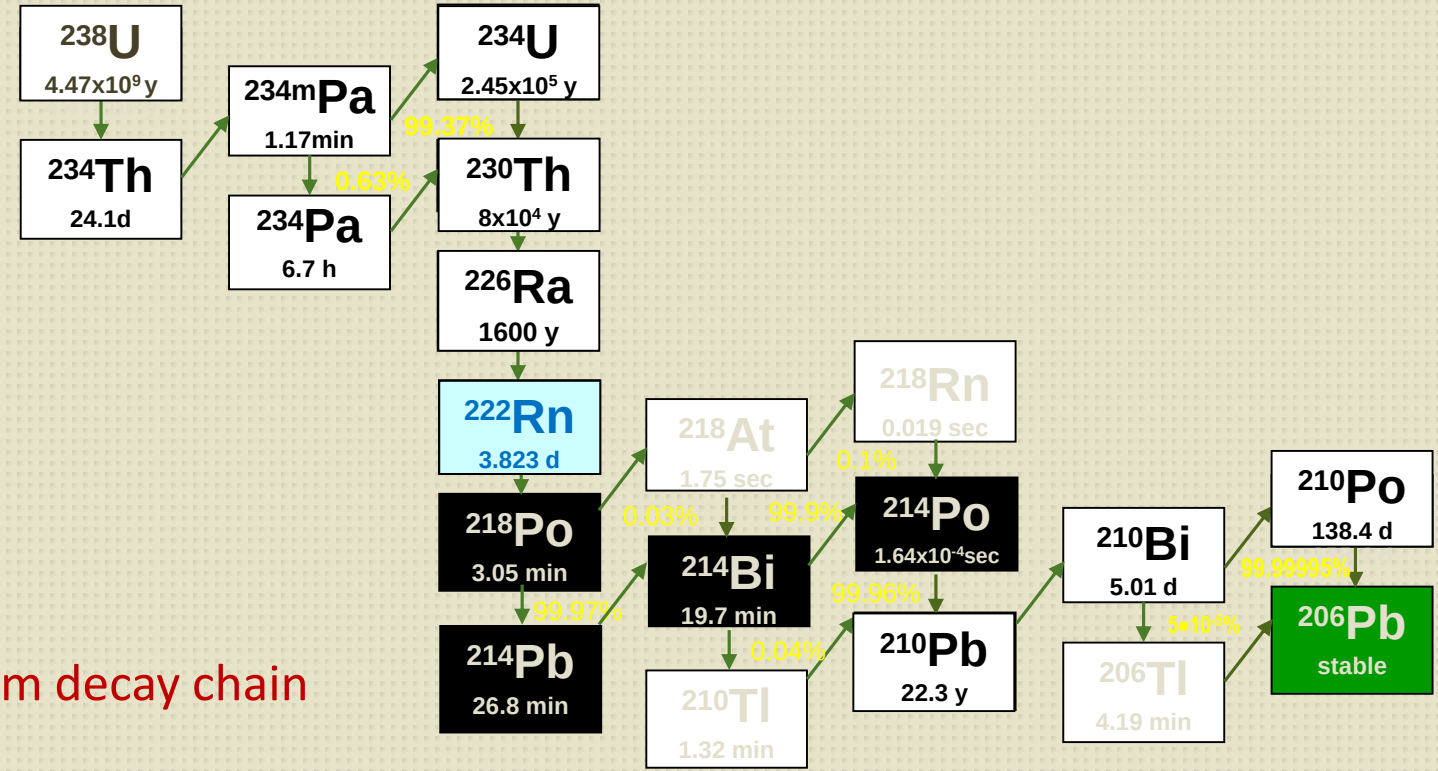
Volatile radionuclides ^{210}Pb , ^{210}Po

- **Point source discharging (effect similar to fallout but area are smaler)**

- **Exposure pathways:**

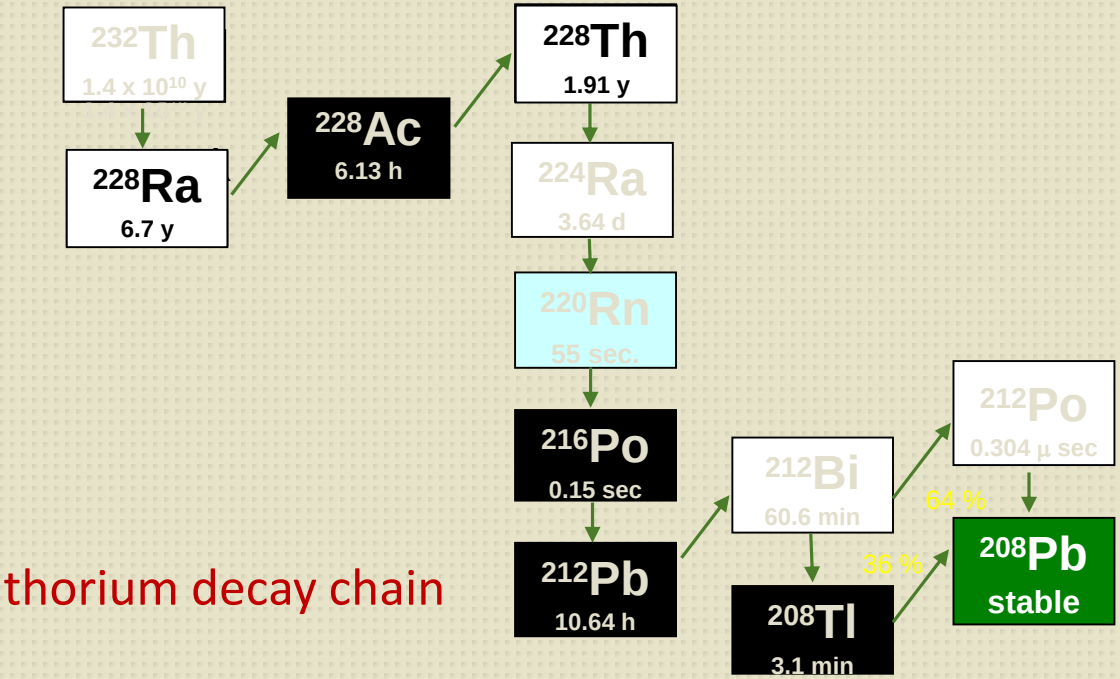
❑direct exposure to external radiation
❑migration to biota (interception)
❑inhalation
❑contamination of food chain

Radionuclides of concern

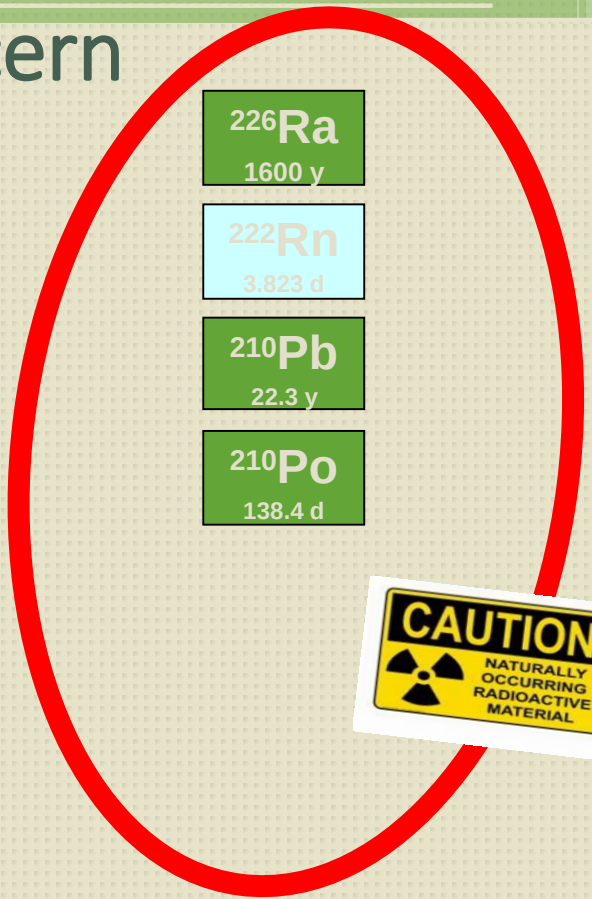


uranium decay chain

Radionuclides of concern



thorium decay chain

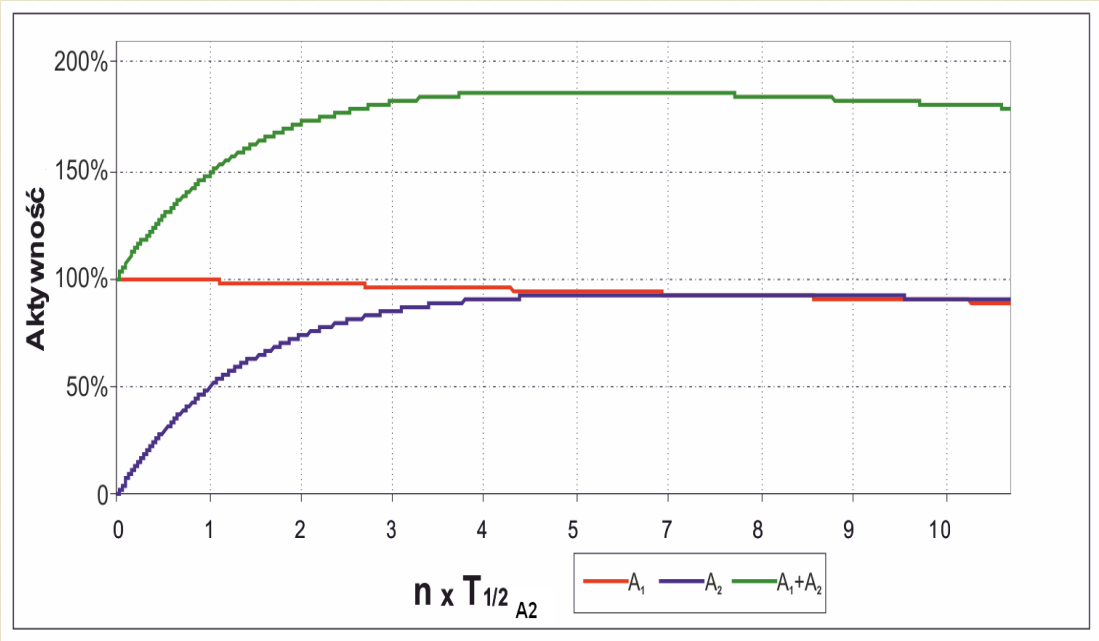


Successive decay (1) -**secular equilibrium**

The half-life of the parent radionuclide (A_1) is significantly longer than its decay product (A_2):

$$T_{1/2}\ A_1 >>> T_{1/2}\ A_2$$

the activity of this decay product increases during the time equal to approximately five periods product (A_2) and then activity of A_2 ≈ activity of A_1. The activity of A_1+A_2 decrease according to $T_{1/2}$ of A_1

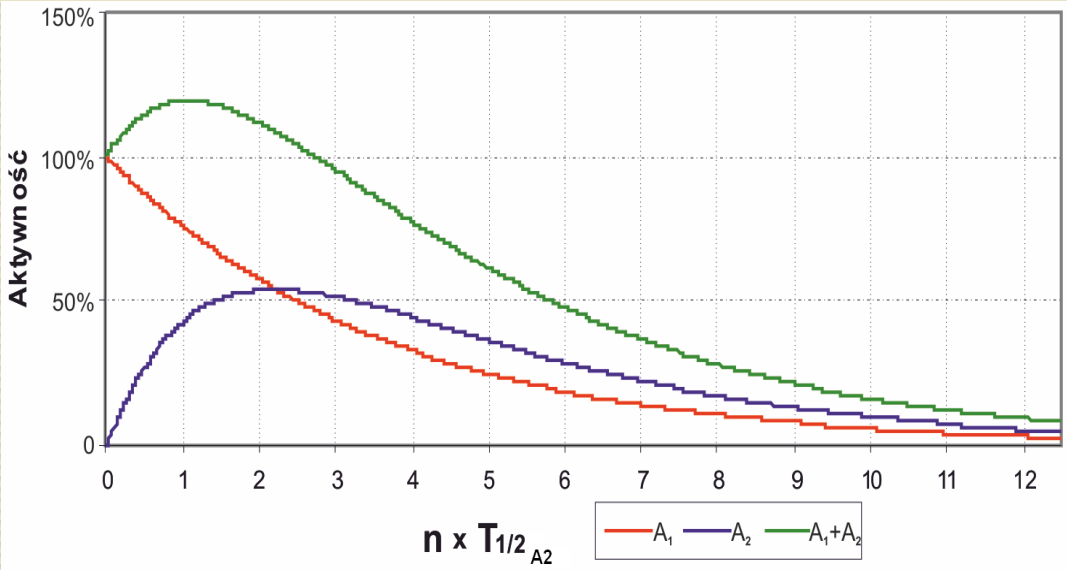


Successive decay (2): transient equilibrium

In the case when the half-life of the parent nuclide (A_1) is only slightly longer than the half-life of the decay product (A_2):

$$T_{1/2}\ A_1 > T_{1/2}\ A_2$$

the activity of the decay product (A_2) increases for a period equal to about twice its half-life and then activity of A_1+ A_2 decrease according to the half-life of the parent radionuclide (A_1) .

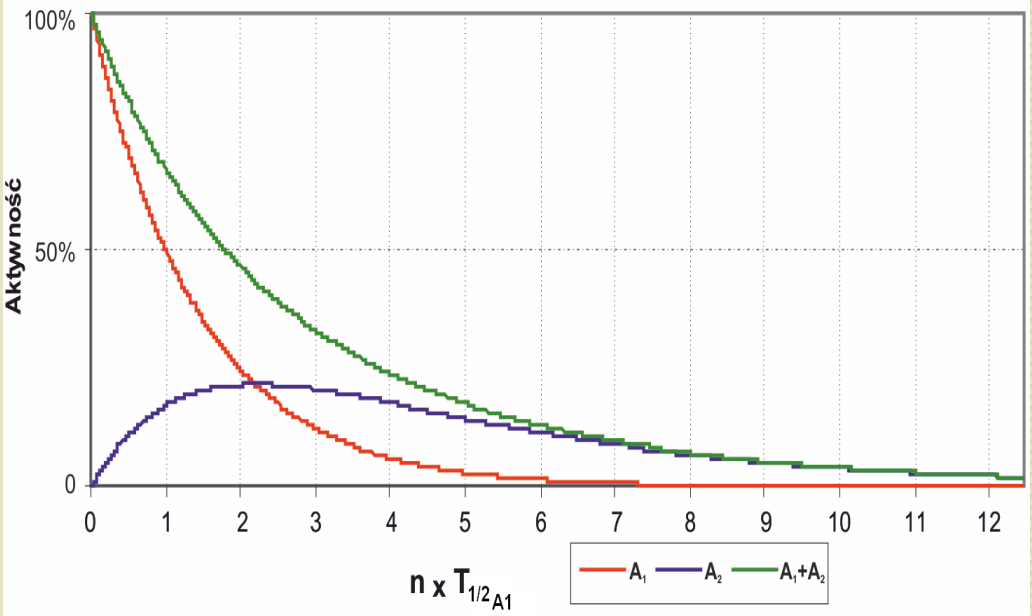


Successive decay (3): no equilibrium

In the third case, when the half-life of the parent nuclide (A_1) is shorter than the half-life of the daughter nuclide (A_2):

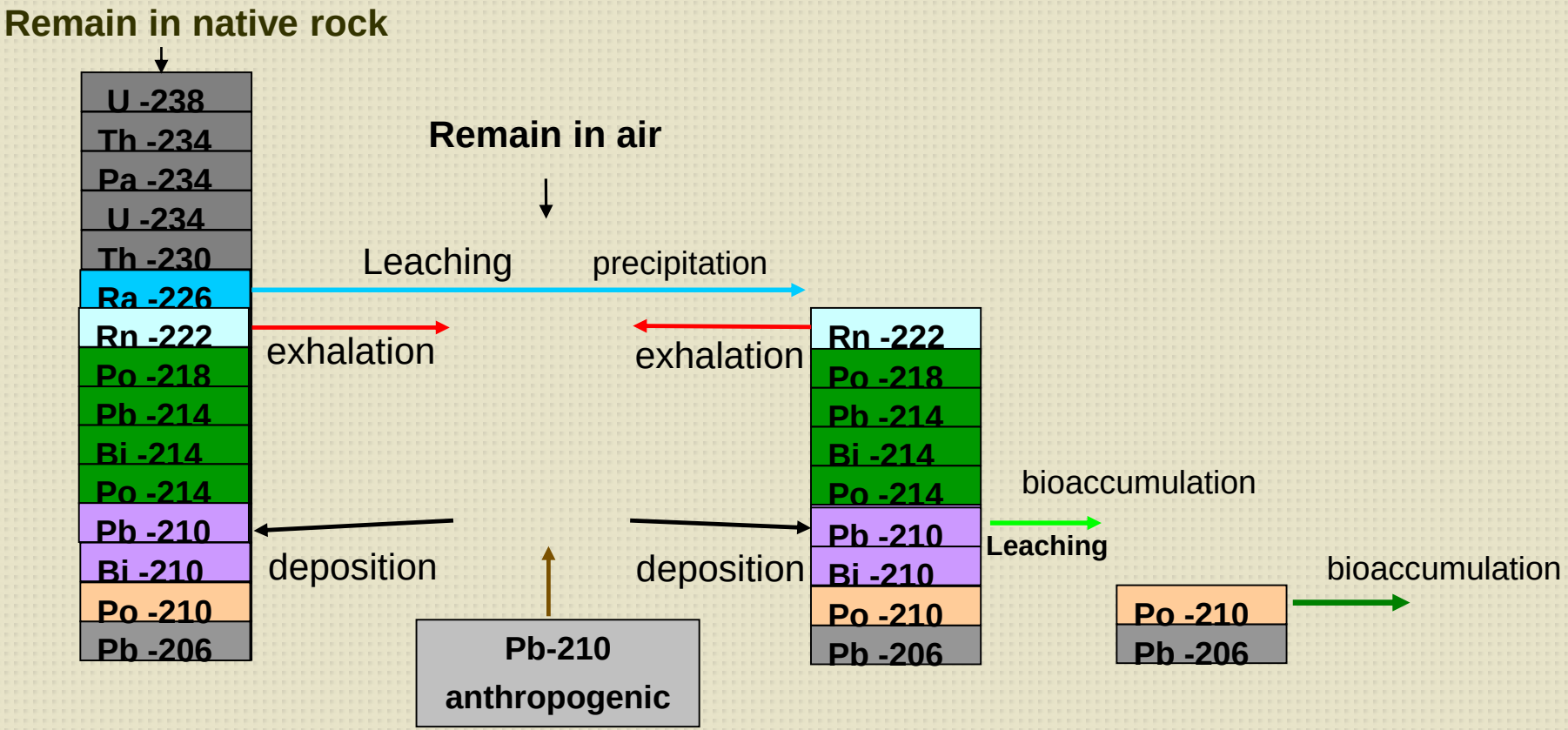
$$T_{1/2}\ A_1 < T_{1/2}\ A_2$$

the situation is similar as in case before, however, the activity of A_1+A_2 decreases according to (A_2) half-life.



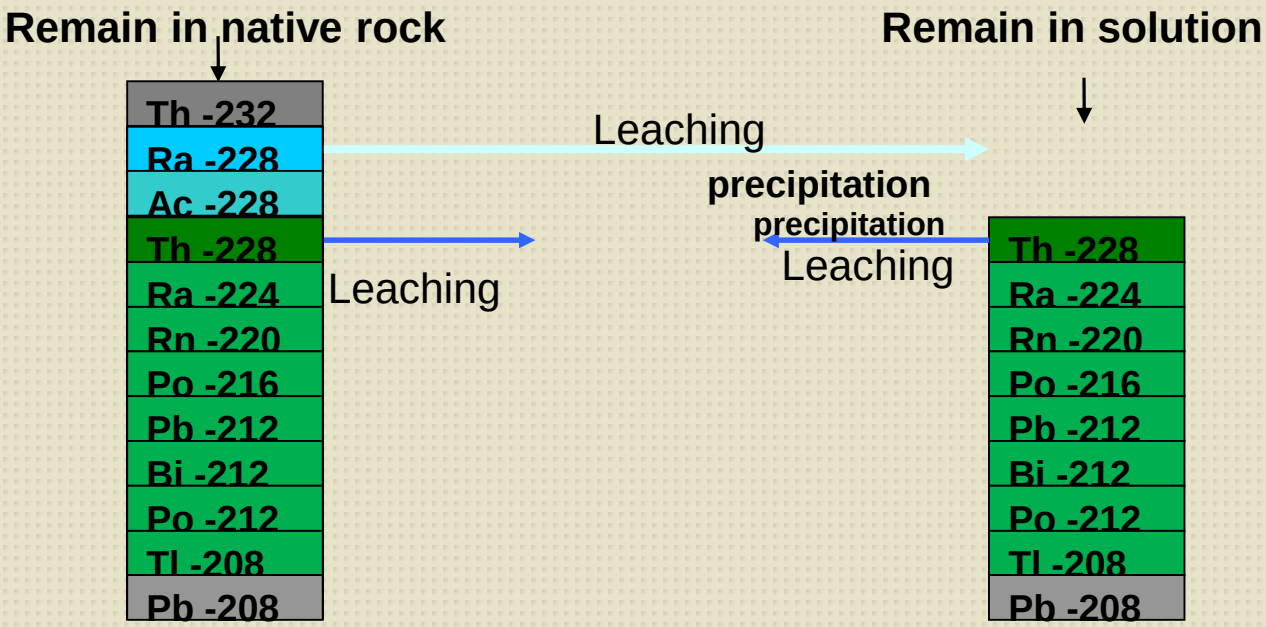
Radionuclides fractionation

^{238}U decay chain



Radionuclides fractionation

^{232}Th decay chain

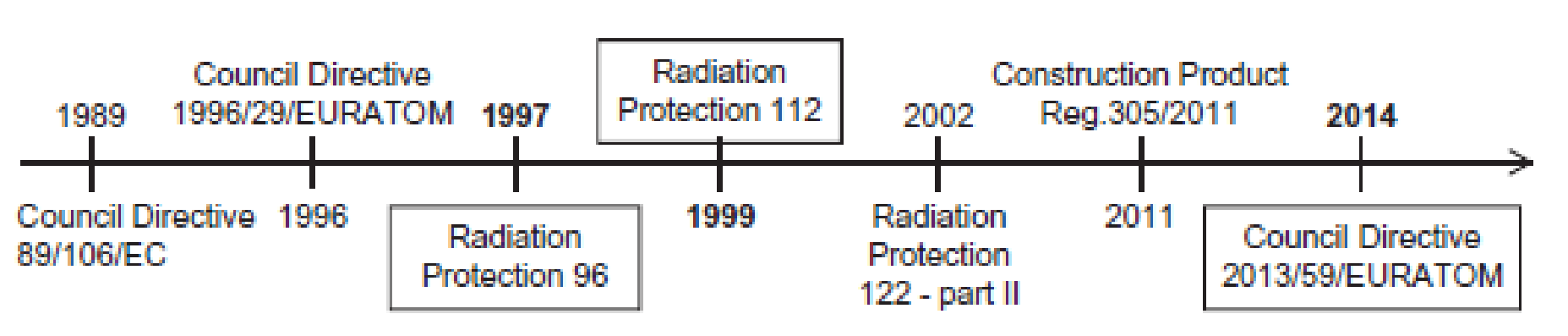


Radioactivity vs chemical toxicity

Radionuclide	Specific activity	The mass of daughter radionuclide being in secular equilibrium with 1 gram of ^{226}Ra
	Bq/g	g
^{238}U	1.24×10^{4}	2.96×10^{6}
^{226}Ra	3.66×10^{10}	1.00
^{222}Rn	5.69×10^{15}	6.43×10^{-6}
^{218}Po	1.03×10^{19}	3.55×10^{-9}
^{214}Pb	1.20×10^{18}	3.04×10^{-8}
^{214}Bi	1.63×10^{18}	2.24×10^{-8}
^{214}Po	1.21×10^{22}	3.03×10^{-12}
^{210}Pb	2.84×10^{12}	1.29×10^{-2}
^{210}Bi	4.59×10^{15}	7.97×10^{-6}
^{210}Po	1.66×10^{14}	2.20×10^{-4}

[i] Theoretical Division of the Los Alamos National Laboratory (http://t2.lanl.gov/data/nuclides/map8.html) Accessed March 10, 2011 r.

European legislation evolution



Source: Naturally Occurring Radioactive Materials in Construction. Edited by W.Schroeyers. Elsivier Ltd. 2017

COUNCIL DIRECTIVE 2013/59/EURATOM of 5 December 2013

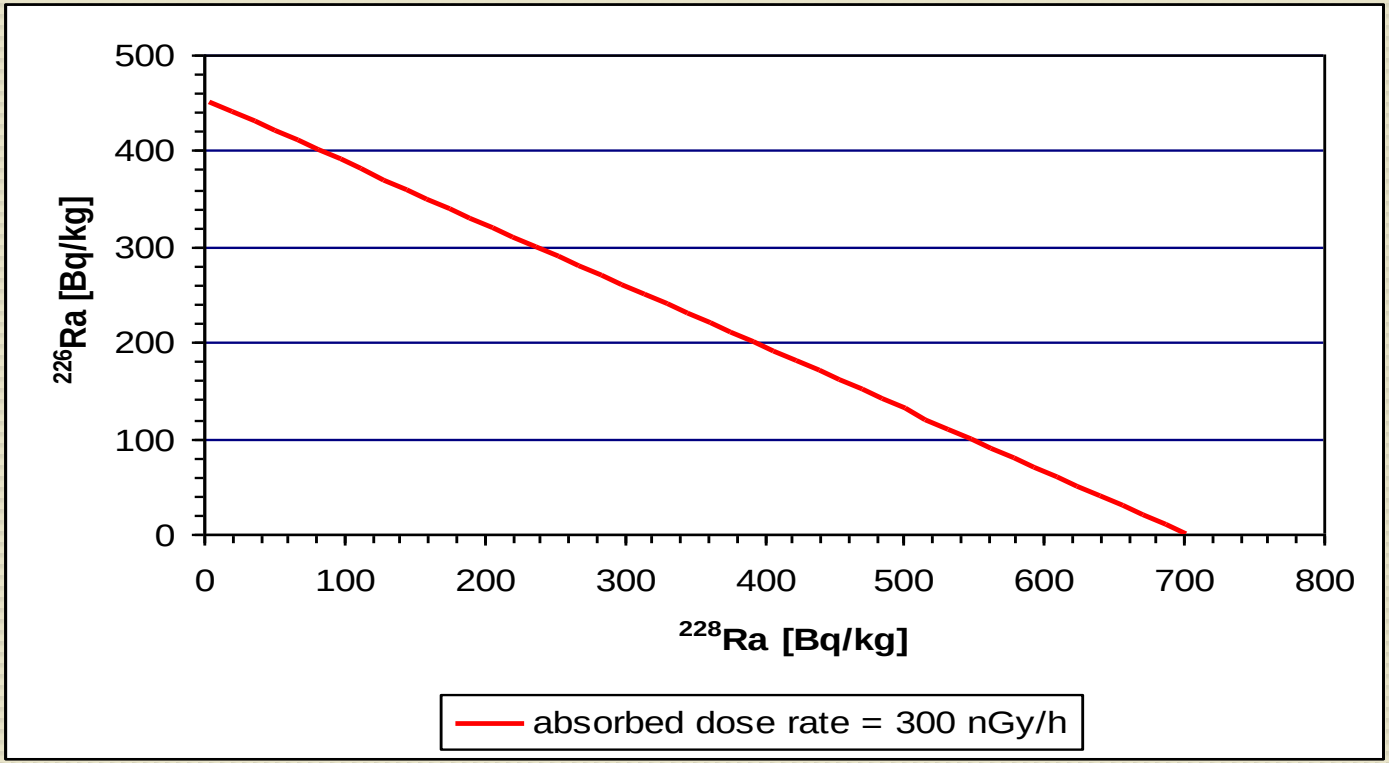
laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation

- Clearance levels for solid materials

Radionuclide	Activity concentration (kBq kg^{-1})
Natural radionuclides from the ^{238}U series	1
Natural radionuclides from the ^{232}Th series	1
^{40}K	10

- Clearance and exemption level for any activity : **1 mSv/year**

Absorbed dose rate 1 meter above infinite source with homogeneously distributed radium isotopes



EU BSS: *Article 30*

Release from regulatory control

3. Member States shall ensure that for the clearance of materials containing naturally-occurring radionuclides, where **these result from authorized practices <u>in which natural radionuclides are processed for their radioactive, fissile or fertile properties</u>**, the clearance levels comply with the **<u>dose criteria</u> for clearance of materials containing artificial radionuclides**.

(10 µSv instead of 1 mSv for „normal" NORM !,
Activity concetration limits for individual radionuclides)

Uranium mining and milling in frame of nuclear fuel cycle is not considered as NORM

EU BSS: *Article 25*

Notification

3. Notwithstanding the exemption criteria laid down in Article 26, in situations identified by Member States where there is concern that ***a practice identified in accordance with Article 23*** may lead to the presence of **naturally-occurring radionuclides in water liable to affect the quality of drinking water supplies or affect any other exposure pathways,** so as to be of concern from a radiation protection point of view, the competent authority may require that the practice be subject to notification.

EU BSS: *Article 65*

Operational protection of members of the public

In addition, these discharge authorizations shall take into account, where appropriate, the results **of a generic screening assessment** based on internationally recognised scientific guidance, where such an assessment has been required by the Member State, **to demonstrate that environmental criteria for long-term human health protection are met.**

EU BSS: **Building materials classification**

$$I = \frac{C_{Ra-226}}{300} + \frac{C_{Th-232}}{200} + \frac{C_{K-40}}{3000}$$

where C_{Ra-226} , C_{Th-232} and C_{K-40} are the activity concentrations in Bq/kg of the corresponding radionuclides in the building material.

EU BSS: Article 30

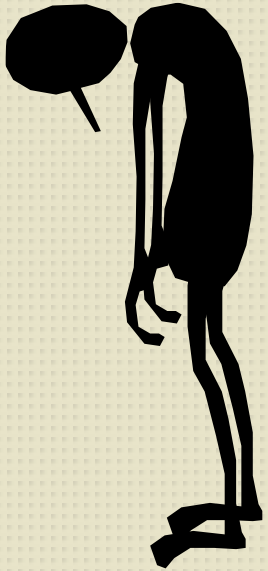
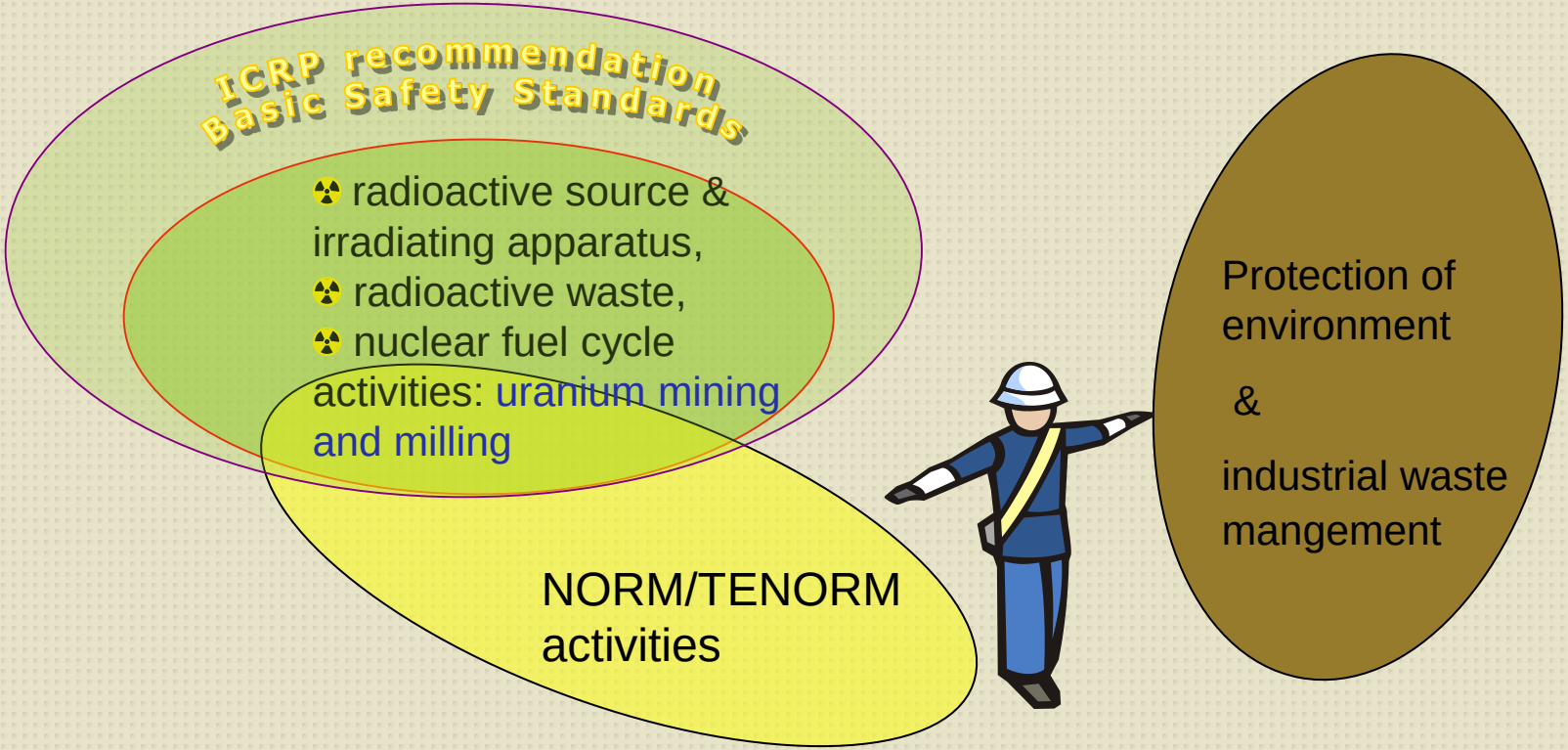
Release from regulatory control

- 1. Member States shall ensure that the **disposal, recycling or reuse** of radioactive materials arising from any authorised practice is subject to authorisation.
- …..
- 4. Member States **shall not permit the deliberate dilution of radioactive materials for the purpose of them being released from regulatory control**. ***The mixing of materials that takes place in normal operations where radioactivity is not a consideration is not subject to this prohibition***. The Competent Authority may authorise, in specific circumstances, the mixing of radioactive and non-radioactive materials for the purposes of re-use or recycling.

Conclusion

Despite of the strong declaration in the introduction, the EU BSS:

1. **Sets unclear criteria for NORM residues exemption and clearance (the general criterion is not valid in some specific situation as building materials or liquid effluents)**
2. **Still differentiates the risk originating from natural sources of radiation from the artificial ones (even different approach is recommended towards natural sources of radiation varying in origin – e.g. nuclear fuel process and others …)**
3. **Still lefts NORM residues in the gap between regulation dealing with radioactive and non radioactive waste**
4. **Does not precise a clear requirements concerning protection of environment**



Existing regulations overlap