Development of a methodology at European level for dose-assessment and estimate of amount of NORM waste disposable at landfills for conventional waste

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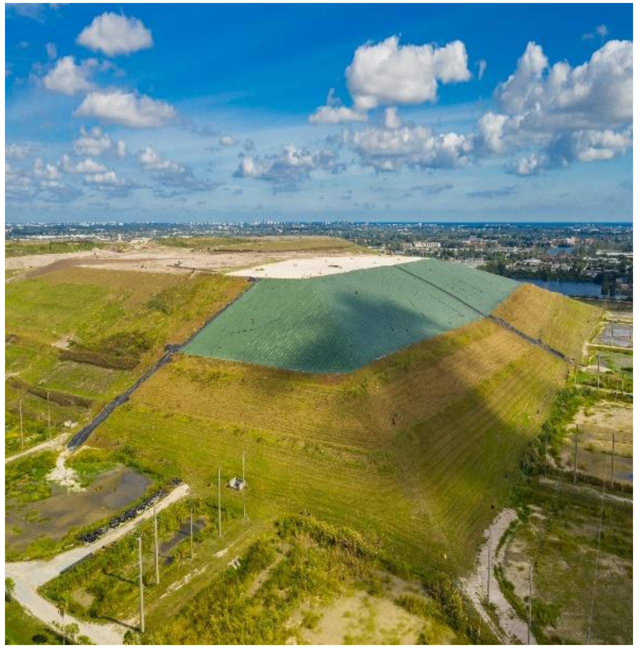
Introduction

- **COUNCIL DIRECTIVE 2013/59/EURATOM**: General clearance level is CL= 1 Bq g^{-1} for U-238 series and Th-232 series, 10 Bq g^{-1} for K-40 with a dose increment liable to be incurred by an individual of ≤ 1 mSv $year^{-1}$

- The aims set by the EURATOM Directive are achieved differently by each Member State. This is also the case for regulating final disposal of NORM residues at landfills

- A methodology to deal in practice with updated regulations can support the stakeholders involved in disposal of NORM and increases confidence in dealing with NORM



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Regulatory approaches for dealing with final disposal of residues

Germany	France	Italy	Norway
Radiation Protection Ordinance (2018)	**Public Health Code including Code for Workers and Code for Environment (2018)**	**Legislative Decree on ionising radiation nr°101 (2020)**	**Pollution Control Act (2011) Act on Radiation Protection and Use of Radiation (2000)**
For exempted NORM there exist special joint landfilling criteria If C above CL in landfills for non-hazardous/hazardous waste with the option of a case-by-case analysis	Up to C=20 Bq g^{-1} in landfills for inert/non-hazardous/hazardous waste, if C above CL provisions required for the protection of the environment If C> 20 Bq g^{-1} low level radioactive waste repository Four waste landfills authorized to receive NORM	If C is <= ½ of CL, NORM in landfill for non-hazardous/hazardous waste, if C close to CL value dose assessment required Not exempted NORM goes in dedicated NORM repository for hazardous waste	Exempted NORM goes into a landfill for non-hazardous/hazardous waste, if CL < C < 10 Bq g^{-1} dose-assessment required (also for non-human biota) Dedicated NORM waste repository for residues from oil/gas industry If C> 10 Bq g^{-1} low level waste repository

Management of NORM residues in the context of conventional waste disposal

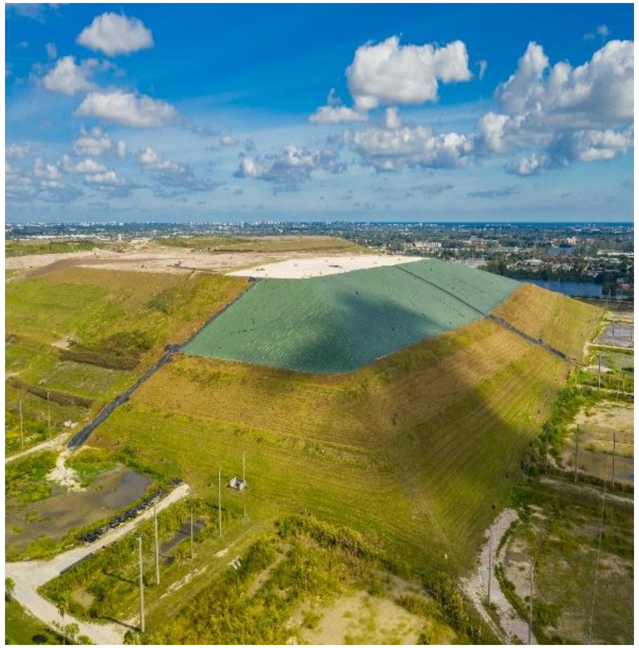
Goal of the present study is to estimate disposable mass of NORM residues for which dose criteria 1 mSv year^{-1} is fulfilled.

This requires

- A dose-assessment procedure for a relevant exposure situation and initial activity concentration 1 Bq g^{-1}
- Information about landfills, assumptions on situations and parameters involved (e.g. Mora et al. 2016; Anderson and Mobbs, 2010; RP122/2)

Results:

- Tabulated values per each NOR decay chain :
  - Maximal dose per unit activity concentration
  - Maximal activity concentration per 1 mSv year^{-1}
- Mathematical relation between admissible amount of residues (tonnes) and maximal activity concentration (Bq g^{-1})



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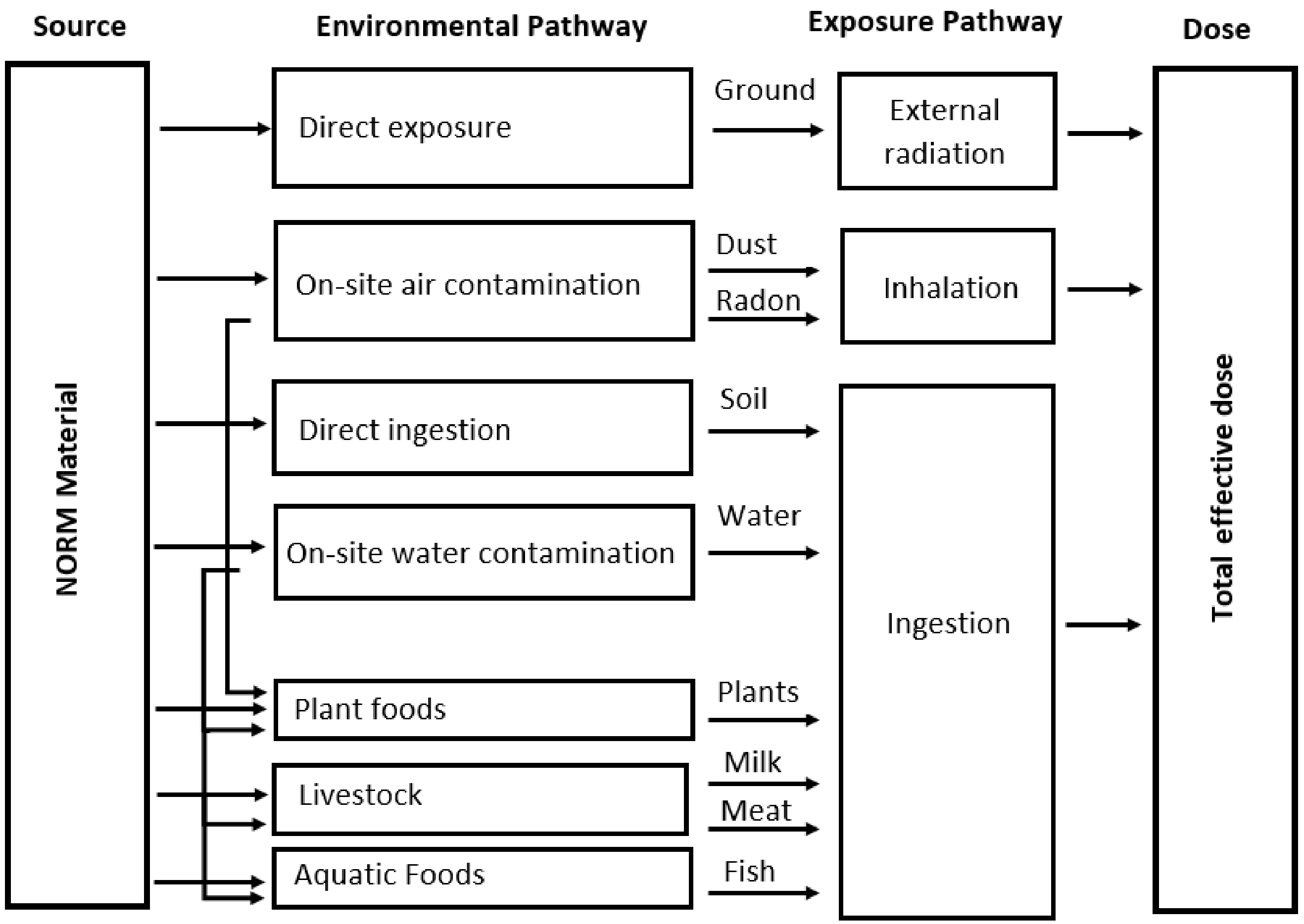
Dose-assessment

- In RP a dose-assessment is carried out whenever compliance with dose limits is to be verified
- Radioecological models are necessary to carry out dose-assessments, e.g. **RESRAD-ONSITE**
- Conservative approach: calculated dose **shall overestimate** real dose
- Use of dose coefficients (DCFs) e.g. for external exposure new values from ICRP 144
- Segments of decay chains in secular equilibrium (e.g. Ra226+, Pb210+)



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Landfill structure / Implementation in RESRAD

- **COUNCIL DIRECTIVE 1999/31/EC (non-hazardous waste)**
- Permeability k_f depends on type of material (clay, sand, gravel, synthetic material, ..), thickness (Th) of each layer fullfills minimum criteria of Directive
- **Active landfill**: 100% performance of landfill layers, no final cover
- **Landfill after closure**: Performance of layers may deteriorate, final cover layers above waste considered all together in one unique layer (2 m)
- Landfill characteristics: 1 hectar area, Th=20 m, density of waste material = 1.5 g cm^{-3}

Recultivation layer	Th = 1 m, k_f = 315 m $year^{-1}$
Drainage layer	Th=0.3 m; k_f = 31545 m $year^{-1}$
Plastic sealing	Th=0.0025 m; k_f = 0.001 m $year^{-1}$
Mineral sealing	Th=0.5 m; k_f = 0.15 m $year^{-1}$
Gas drainage layer	Th =0.5 m
Waste	Th=20 m, k_f=10 m $year^{-1}$
Drainage layer	Th= 0.3 m; k_f = 31545 m $year^{-1}$
Mineral sealing	Th = 0.5 m; k_f = 0.15 m $year^{-1}$
Plastic sealing	Th= 0.0025 m; k_f = 0.001 m $year^{-1}$
Geological barrier	Th =1 m; k_f = 0.031 m $year^{-1}$
Aquifer	Th= 1 m; k_f = 100 m $year^{-1}$

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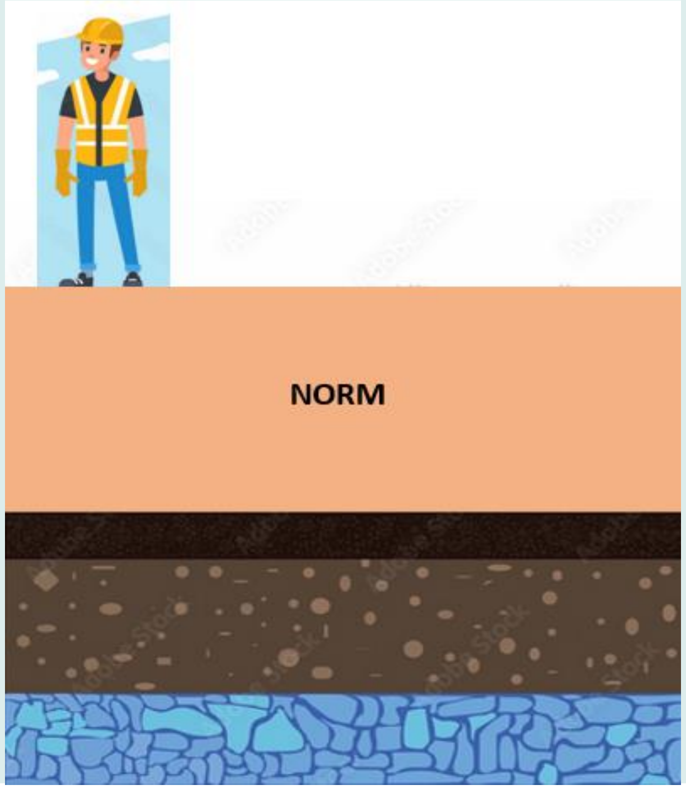
Short-term scenario

Landfill worker active landfill for 35 years	Main assumptions/parameters for modelling
	• 1800 working hours per year (always outdoor) • **External radiation** with no cover, no shielding of excavation cab • (Accidental) **soil ingestion** - ingested soil per year 7 g • **Inhalation of dust** - dust concentration 0.1 mg m^{-3}, breathed air in 1 year 1680 m^3 • No dilution of NORM residues with other waste, i.e. homogeneous distribution in landfill layer

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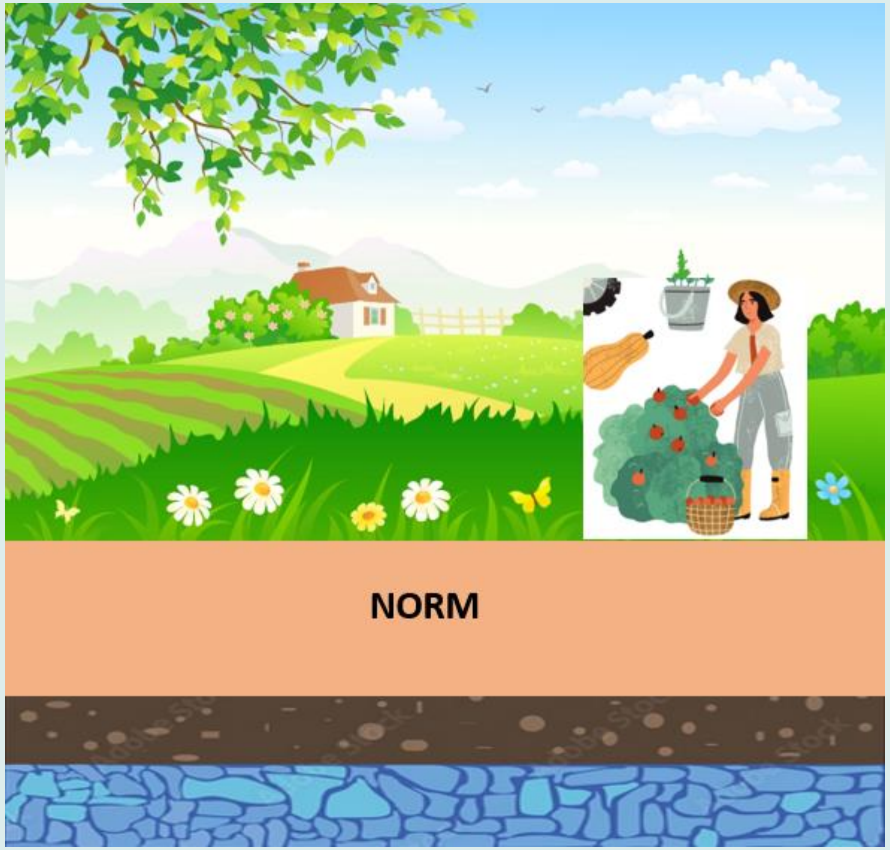
Long-term scenario

Members of the public living in 50% subsistence on top of landfill; up to 1000 years after closure	Main assumptions/parameters for modelling
	• Presence of final cover, residential building built on top, area for food production • **Processes of leaching, erosion by wind and by rain** • Member of the public spending 6 hours outside and rest of time inside • Food consumption rates to quantify dose from ingestion of contaminated products • Groundwater pathway (RESRAD/IAEA SRS 44) : Simple **mass balance model** which accounts for leaching, properties of soil layers (e.g. permeability, thickness, density) and radioactive decay. The mobility of each radionuclide in landfill/soil layers is accounted for via parameter K_d (L kg^{-1}). Radionuclide concentration in well-water is calculated directly from the diluted seepage.

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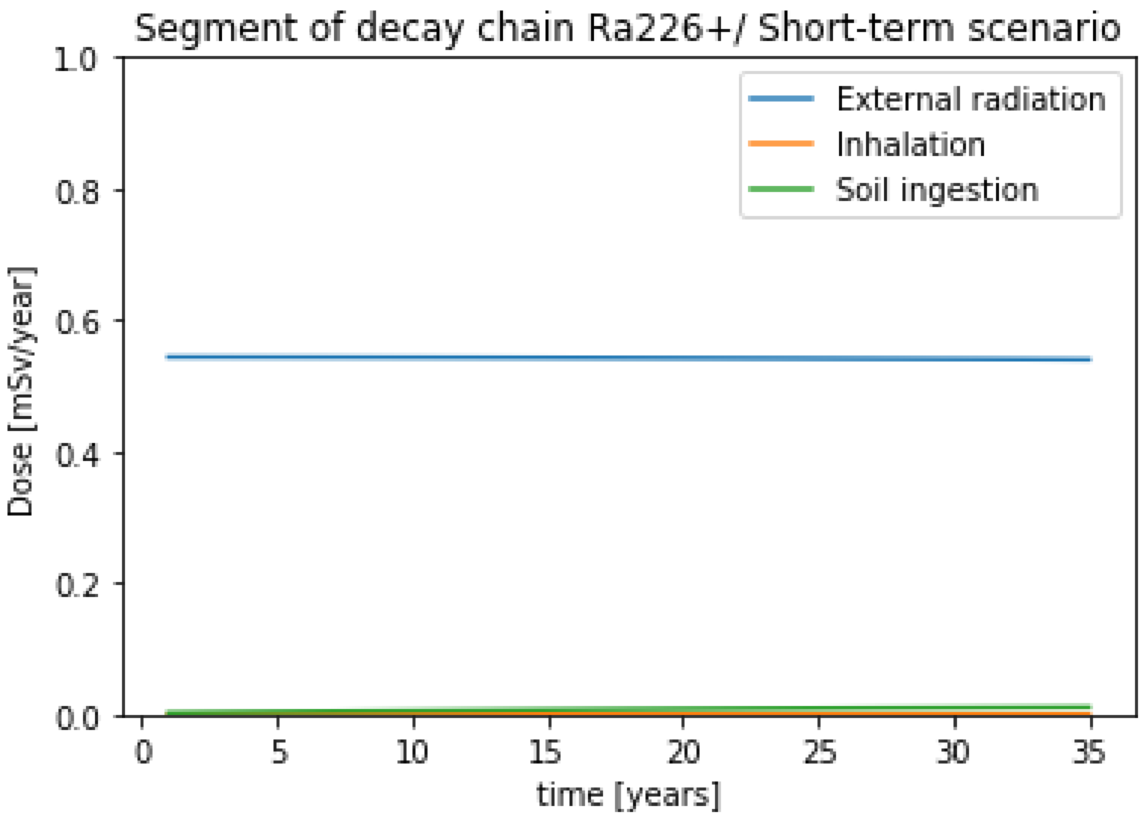
Short-term scenario - results

Worker at the (active) landfill:

- External radiation, inadvertent soil ingestion, inhalation
- Calculation time 35 years
- **External radiation** is dominant contribution



Tabulated values		
Segment of decay chain	**D_{max} (mSv/year) per unit concentration**	**C_{max} (Bq/g) based on dose limit 1 mSv/year**
U-238sec	0.60	1.7
Unat	0.03	35.0
Th-230	0.01	77.5
Ra-226+	0.55	1.8
Pb-210+	0.02	51.5
Po-210	0.004	245.2
U-235sec	0.20	5.0
U-235+	0.04	25.6
Pa-231	0.12	8.7
Ac-227+	0.14	9.6
Th-232sec	0.76	1.3
Th-232	0.74	1.4
Ra-228+	0.45	2.2
Th-228+	0.41	2.5
K-40	0.06	16.7

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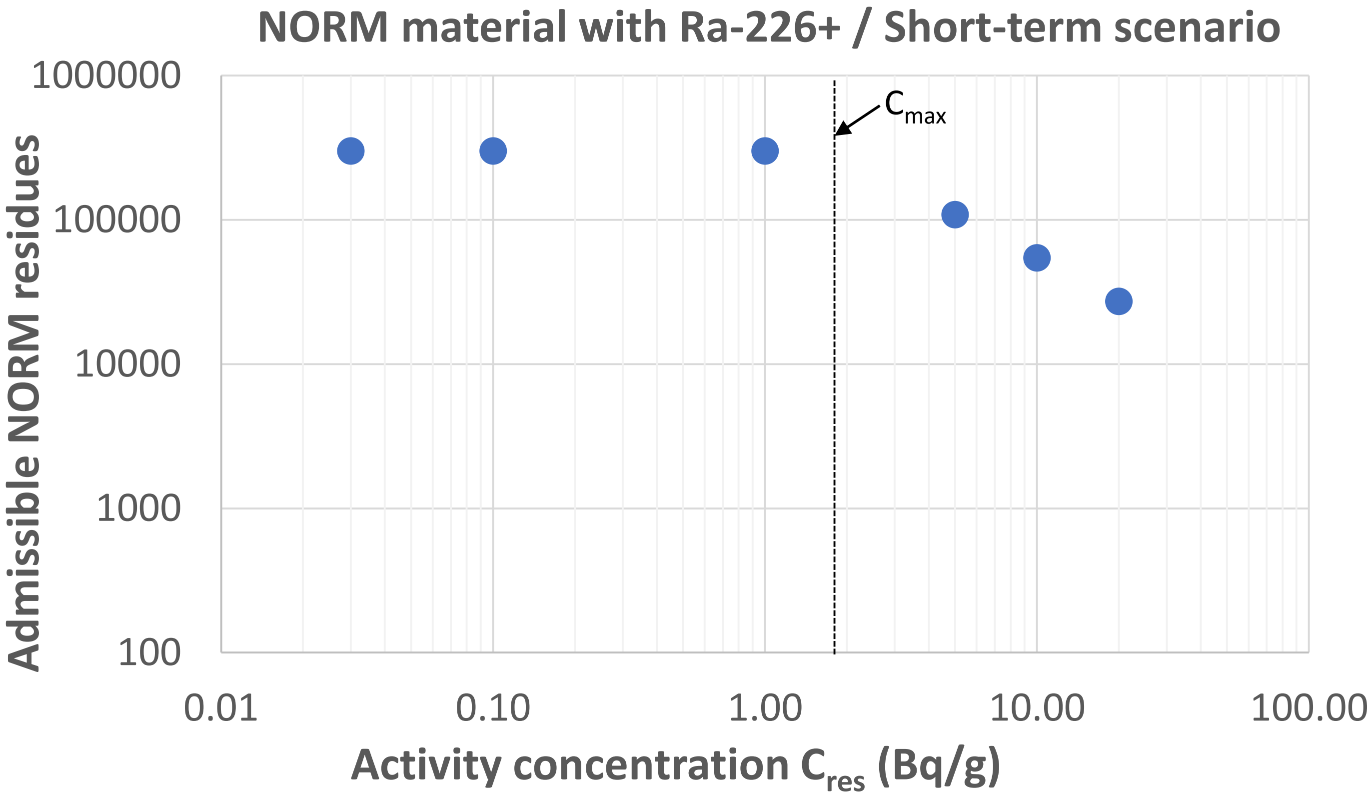
Admissible mass at landfill

- Considering short-term scenario, for one segment of decay chain, if $C_{res} > C_{max}$, disposable mass M is:

$$M(\text{tonnes}) = M_{\text{landfill}}(\text{tonnes}) \cdot \frac{C_{max}(\frac{Bq}{g})}{C_{res}(\frac{Bq}{g})}$$

- M_{landfill} is the total capacity of the landfill – depends on geometry of the site and density of residues (test case $3 \cdot 10^5$ tonnes)
- C_{max} is the activity concentration corresponding to the maximum dose for relevant scenario
- C_{res} is the activity concentration of the NORM residues



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Admissible mass considering multiple types of residues

- If different type of NORM residues to be disposed of i.e. different segments of decay series *i*= 1,..n, disposable mass M is:

$$\mathrm{M(tonnes)} = \mathrm{M_{landfill}(tonnes)} \frac{1}{\sum_{i=1}^{n} \frac{C_{res}(\frac{Bq}{g})}{C_{max}(\frac{Bq}{g})}}$$

- Example:

For a landfill with capacity of 300000 tonnes, if 2 segments of NORM residues (or 2 kinds of residues) are to be disposed of, e.g. Ra226+ with C_{res}= 5 Bq/g and Th-232 with C_{res}= 10 Bq/g, disposable mass is:

$$\mathrm{M} = 300000/(5/1.8 + 10/1.4) \backsimeq 30000 \text{ tonnes}$$

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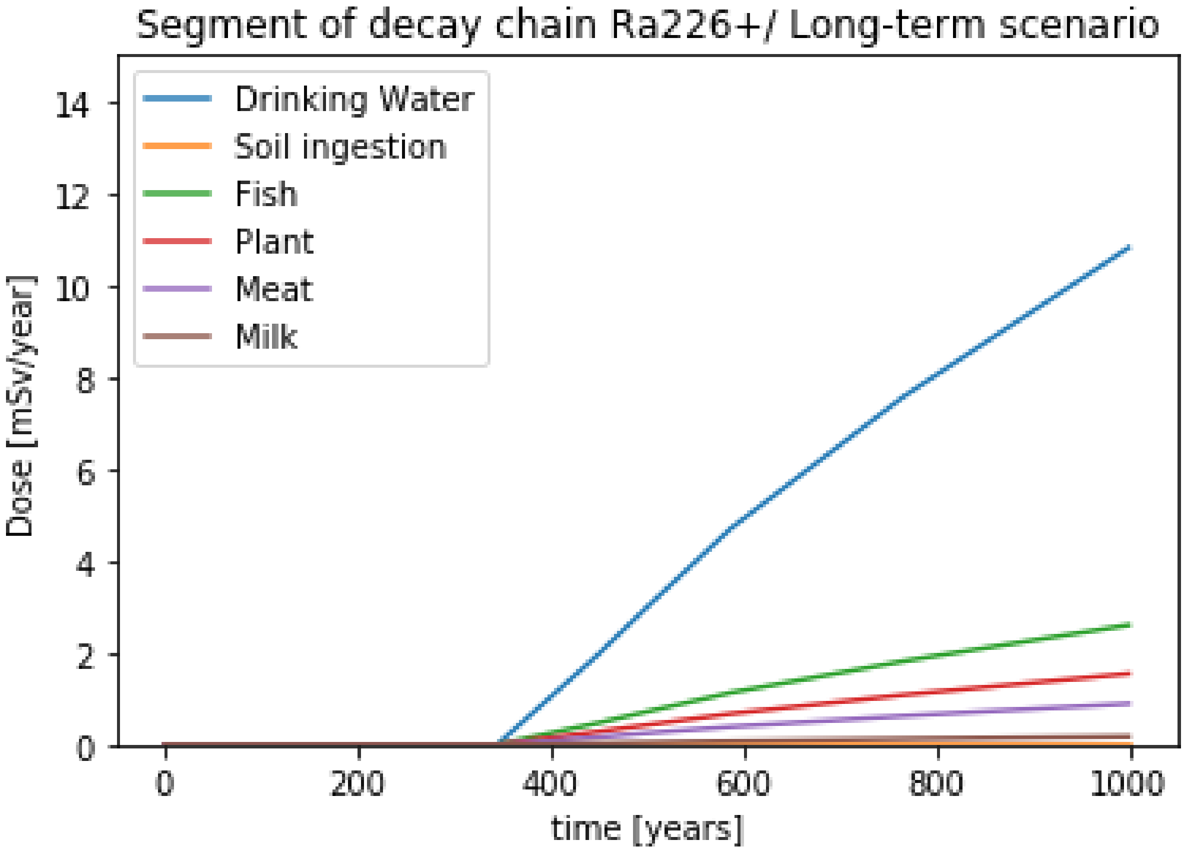
Long-term scenario - results

Member of the public living on top of landfill up to year 1000 after closure

- Calculation up to 1000 years, final cover present on landfill
- **Radon** builds up over time:

Relevant segments of decay chains	Radon indoor concentration (Bq m^{-3})	
	t=1 y	t=1000 y
U238sec	258	601
Th230	< 1	227
Ra226+	258	374

- **Groundwater pathway** dominates at later time



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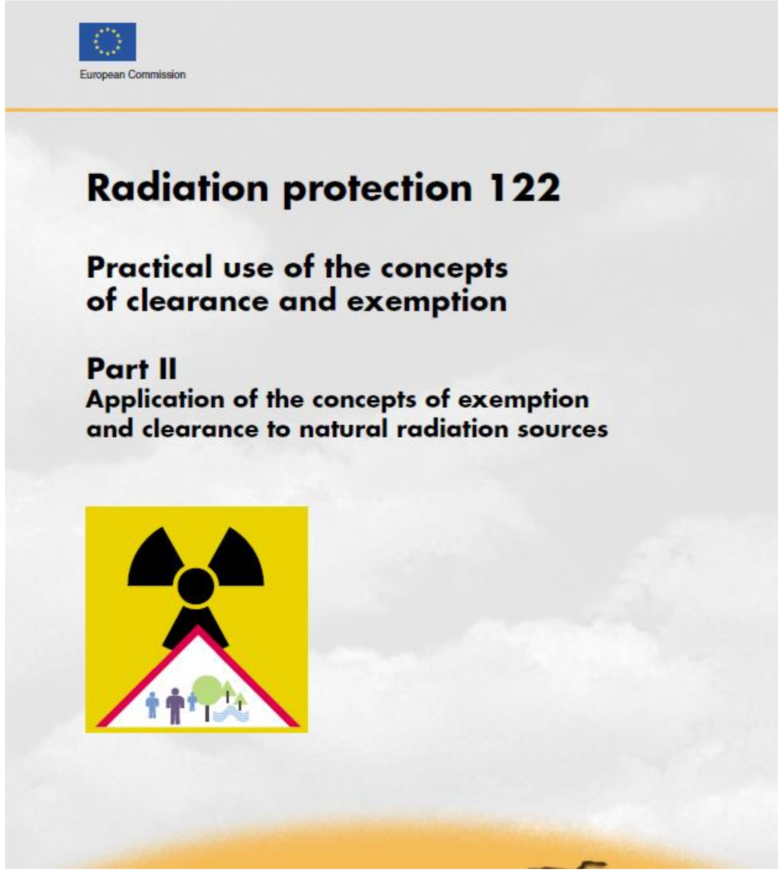
Comparison between RP122/2 and short-term scenario

- Radiation Protection 122 – Part 2 „Practical use of the concepts of clearance and exemption/ Application to natural radiation sources“ provides CLs based on scenario worker at landfill

- The C_{max} values obtained in the study can be compared to these of RP122/2

- By considering same dose criteria* and a shielding factor =2 for use of excavation cab, C_{max} obtained are within a factor 2-3 of the CLs from RP122/2

➔ Main differences are attributed to
  - Contribution of ingrowth/decay of progeny considered in the present work
  - Updated DCFs for external radiation



* dose criteria in RP122/2 is 0.373 mSv $year^{-1}$

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Conclusion

- A methodology was developed considering initial activity concentration 1 Bq g^{-1} for segments of NOR decay chains and dose limit 1 mSv $year^{-1}$ for **quantifying admissible mass at landfill**

- For dose-assessment the exposure of workers at the active landfill is considered (short-term scenario – focus on protection of workers)
  - If the long-term scenario were considered as limiting scenario, more restrictive values for admissible mass would be obtained

- RESRAD is suitable for this type of analysis BUT
  - Does not take into account drainage system and realistic containment options of a landfill
  - Other software may be suitable e.g. MicroShield, Excel Sheets, German Calculation Guide Mining

- Further work:
  - Assess level of conservatism of considered model: compare with HYDRUS and HELP code
  - Compare with RP122/2 more in detail
  - Apply methodology to specific situations (also in light of RadoNorm/NORM survey results) and decrease level of conservatism

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Thank you!

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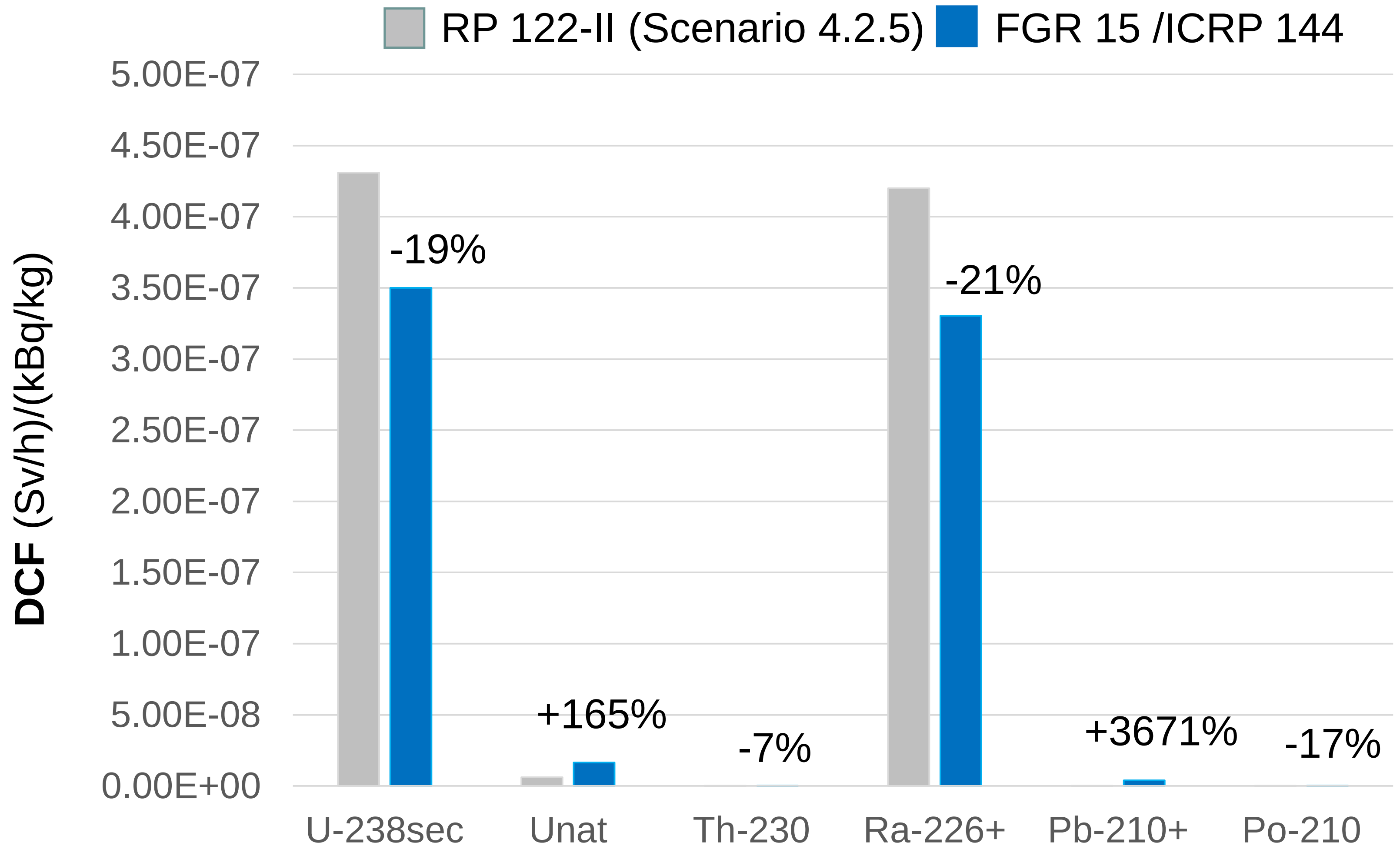
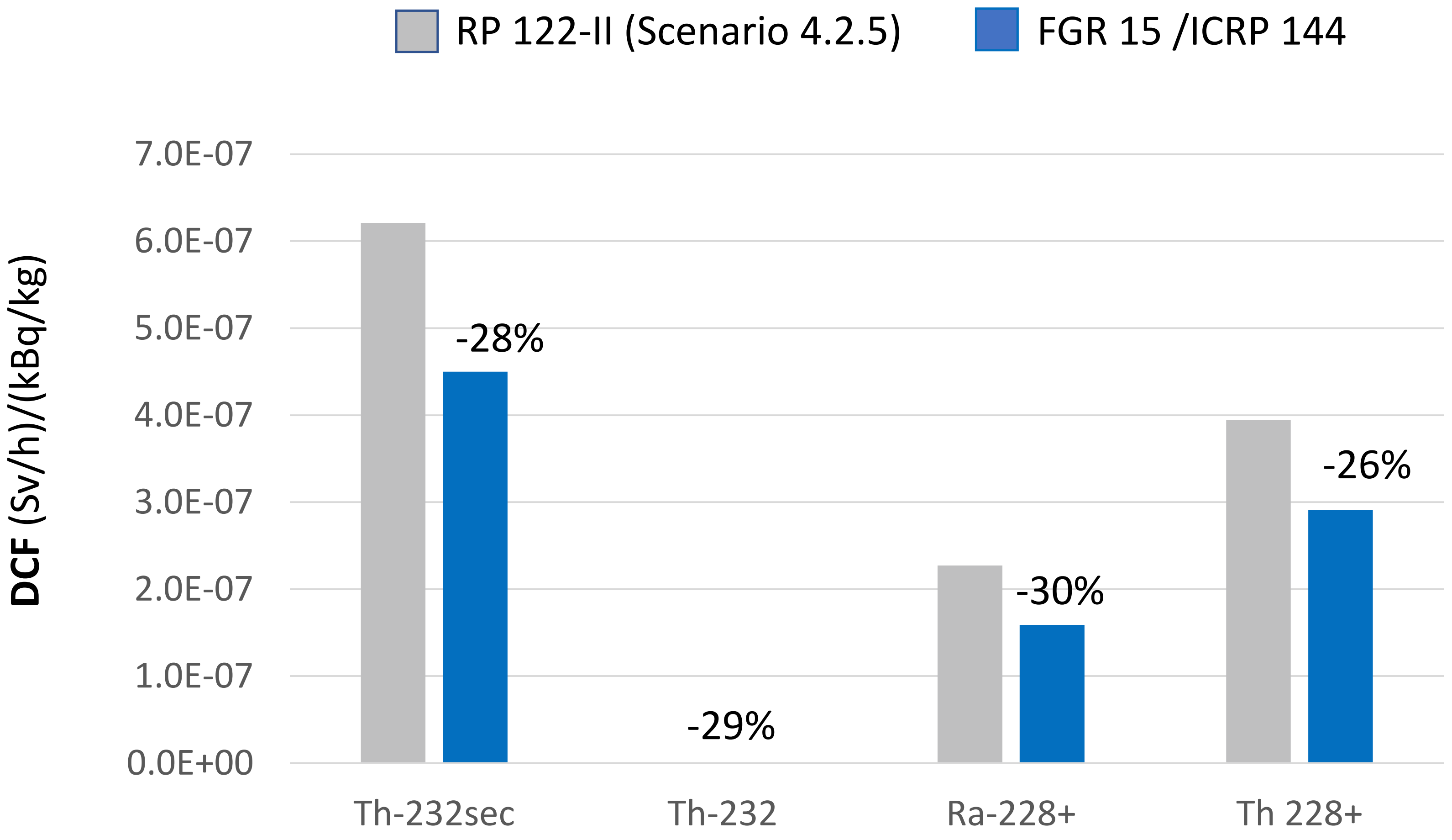
DCF external radiation – RP 122 *versus* ICRP 144 (1)



U-238 series

Chain segment	RP-122-II	FGR 15/ICRP-144
U-238sec	4.3E-07	3.5E-07
Unat	6.2E-09	1.7E-08
Th-230	3.9E-11	3.6E-11
Ra-226+	4.2E-07	3.3E-07
Pb-210+	1.1E-10	4.0E-09
Po-210	2.1E-12	1.7E-12

DCF external radiation – RP 122 *versus* ICRP 144 (3)



Th-232 series

Chain segment	**RP-122-II**	**FGR 15/ICRP-144**
Th-232sec	6.2E-07	4.5E-07
Th-232	2.2E-11	1.6E-11
Ra-228+	2.3E-07	1.6E-07
Th 228+	3.9E-07	2.9E-07

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Short-term scenario – results – Th232

Worker at the (active) landfill:

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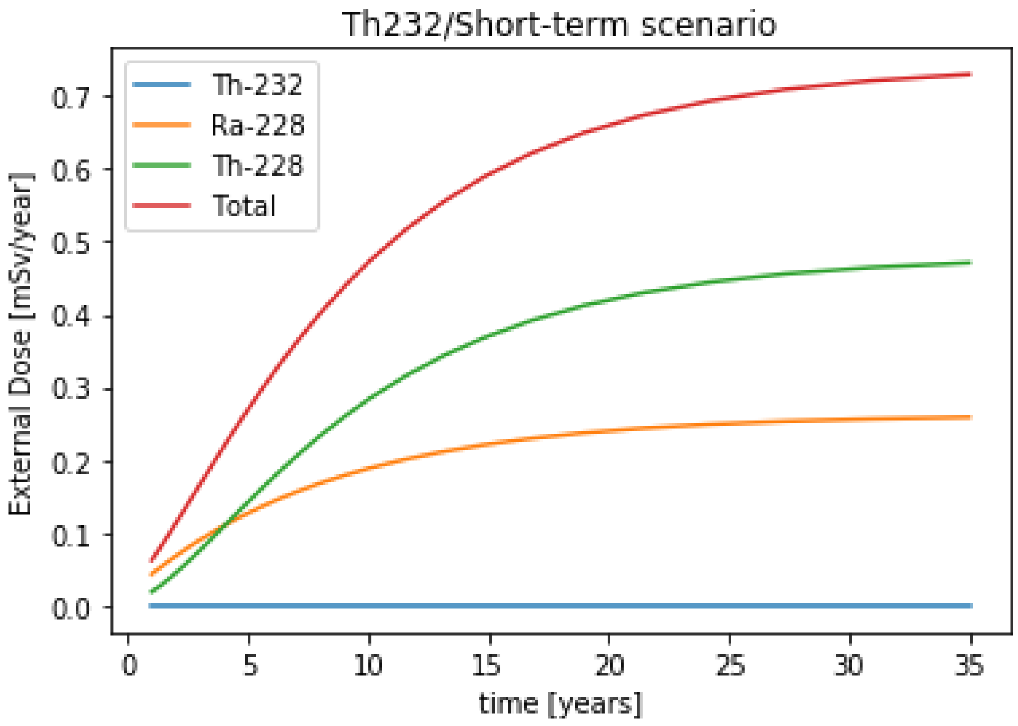
- Calculation time 35 years
- **External radiation** is dominant contribution



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K-40	0.06	16.7

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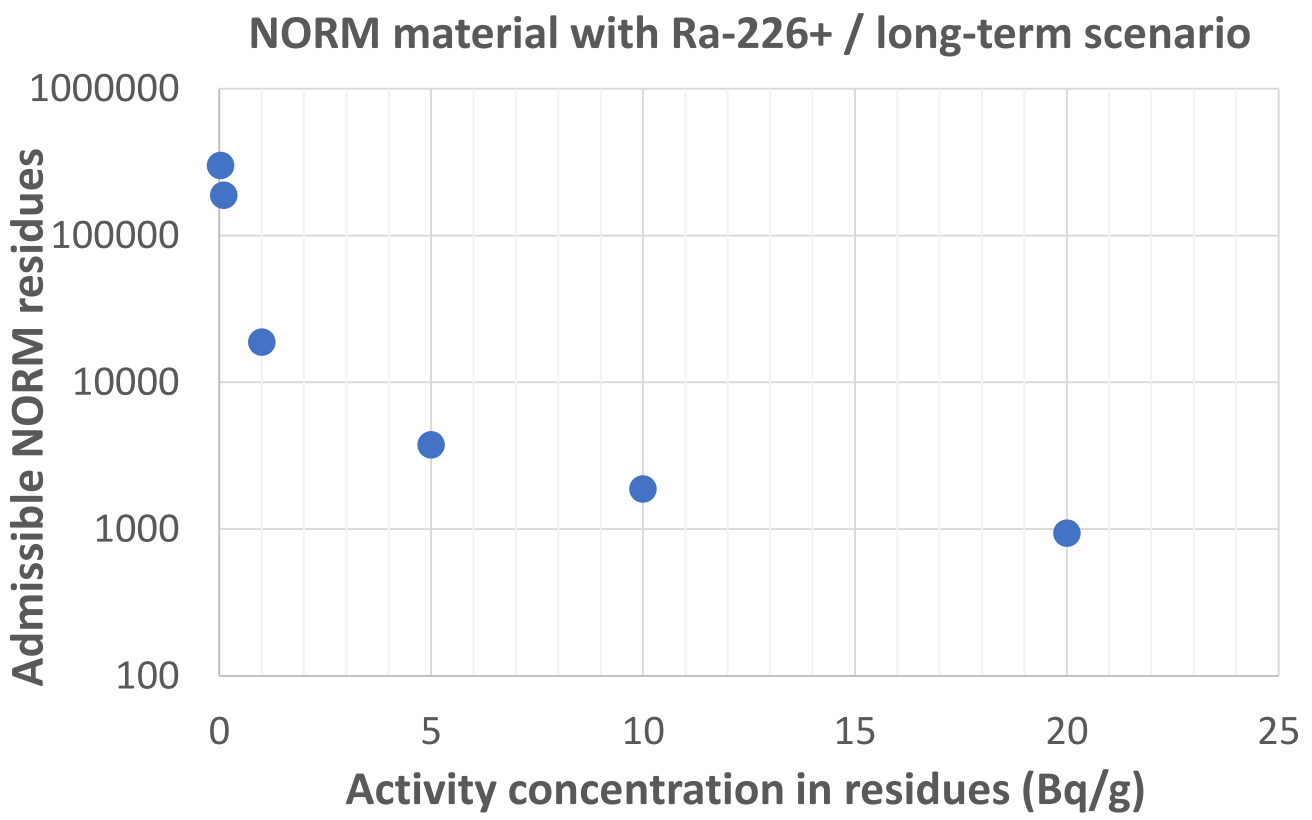
Admissible mass at landfill – Long-term scenario

If limiting scenario for admissible mass were the long-term scenario:



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Comparison between RP122/2 and short-term scenario

- A factor 2 for shielding of an excavation cab is considered
- Soil ingestion parameter decreased and dust concentration increased compared to RESRAD calculation to match RP122/2

Segment of decay chain	C_{max}** (Bq/g)	CL (Bq/g) RP122/2 Disposal	C_{max}/CL
U-238sec	1.2	0.68	1.8
Unat	19.5	9.60	2.0
Th-230	46.9	17.00	2.8
Ra-226+	1.4	0.87	1.6
Pb-210+	35.7	22.00	1.6
Po-210	134.9	13.00	10.4
U-235sec	3.3	1.00	3.3
U-235+	16.9	7.40	2.3
Pa-231	1.9	6.00	0.3
Ac 227+	4.7	1.40	3.3
Th-232sec	1.0	0.49	2.0
Th-232	1.0	11.00	0.1
Ra-228+	1.7	1.50	1.1
Th 228+	1.8	0.78	2.4
K-40	12.4	9.90	1.3

** Dose criteria in RP122/2 is 0.373 mSv year^{-1}

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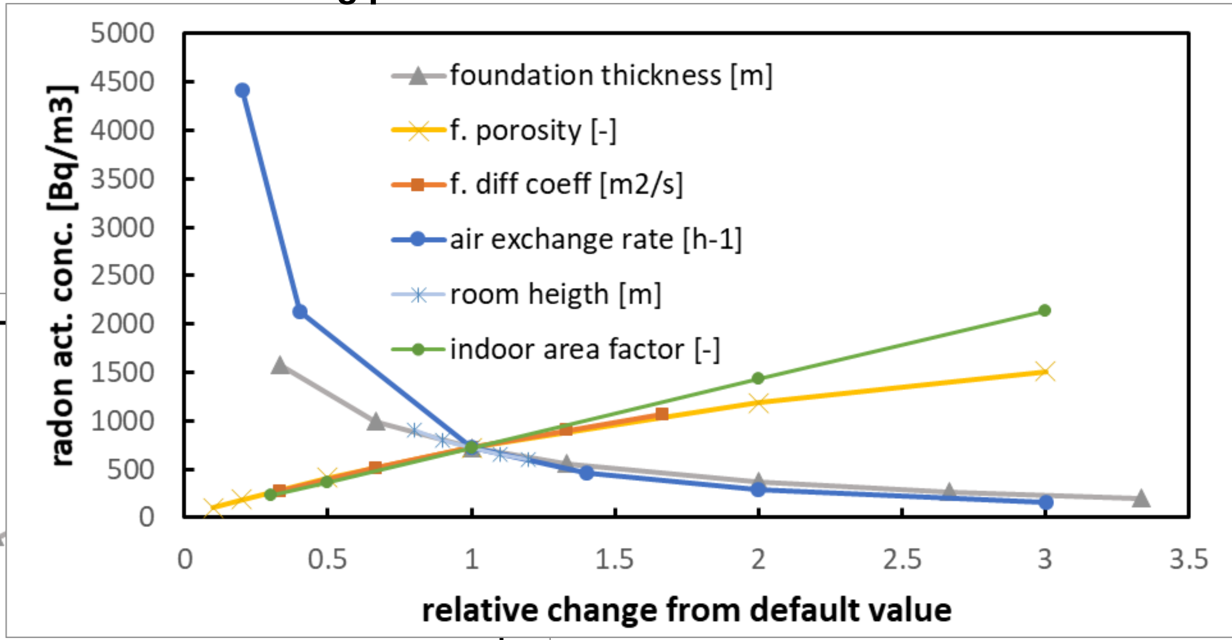
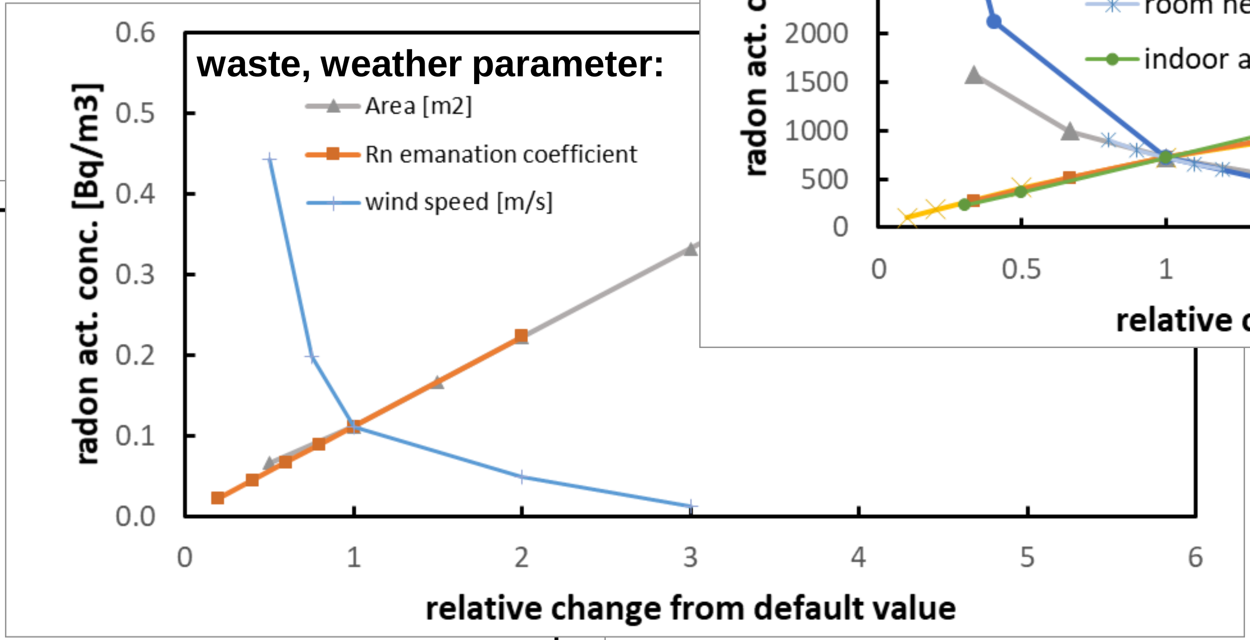
General radon sensitivity analysis

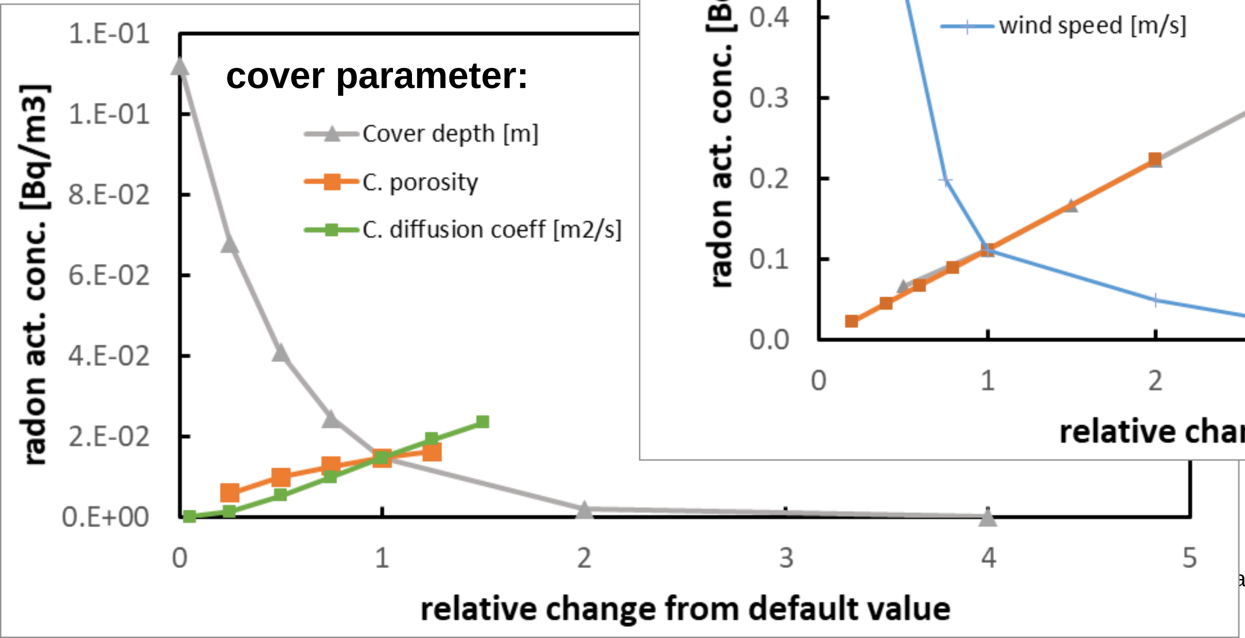
- Inhalation of 222Rn and its daughters is one major path for exposure (mainly indoor) in long-term scenario
- But 222Rn in free atmosphere and room air is sensitive to many waste/cover/weather/building parameters

→ Sensitivity analysis

building parameter:







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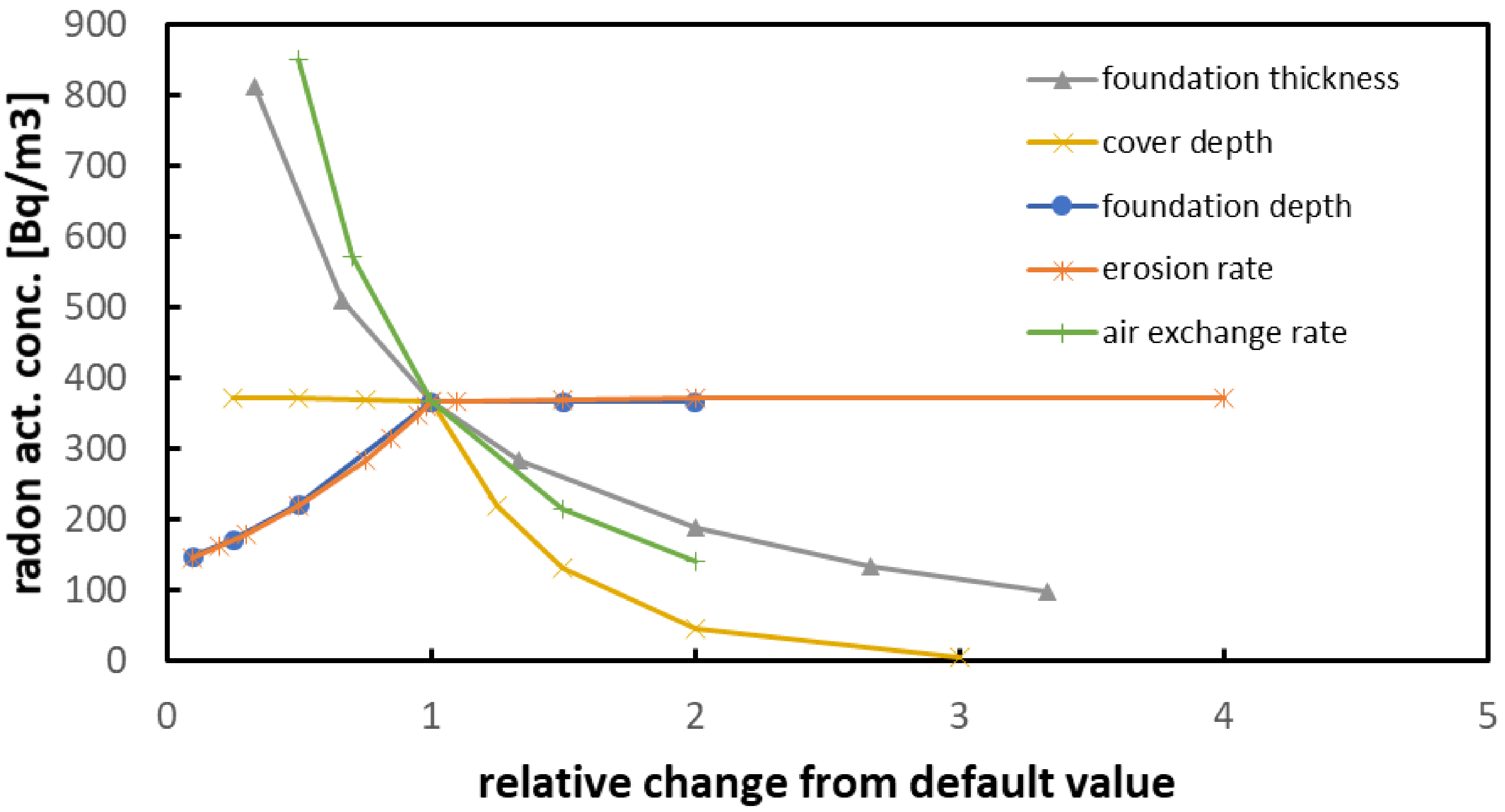
Radon sensitivity anaylsis for long-term scenario

- With respect to erosion and possible foundation depth: thicker covers may be needed
- Avoidance of basement level and need for thicker foundations

Sensitivity of indoor 222Rn activity concentration after 1000 years:



Default values:
Foundation thickness: 0.15 m
Cover depth: 2 m
Foundation depth: 1 m
Erosion rate: 0.001 m/a
Air exchange rate: 0.5 h^{-1}

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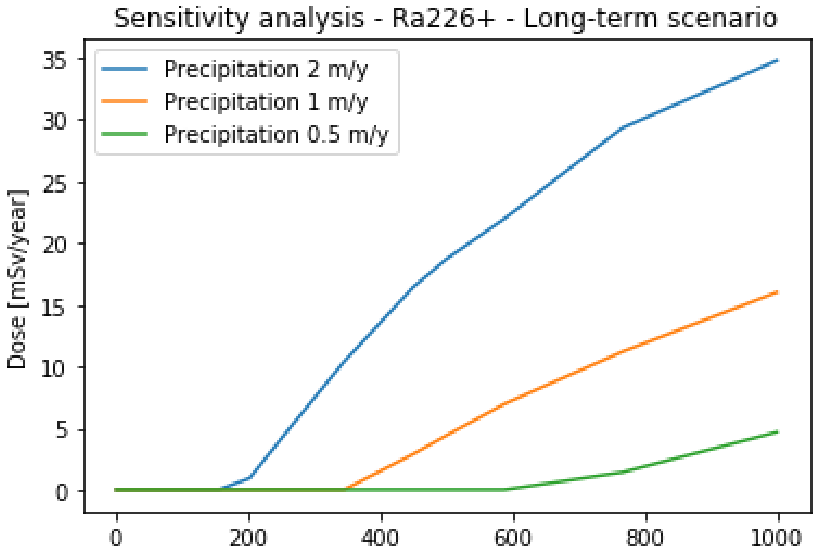
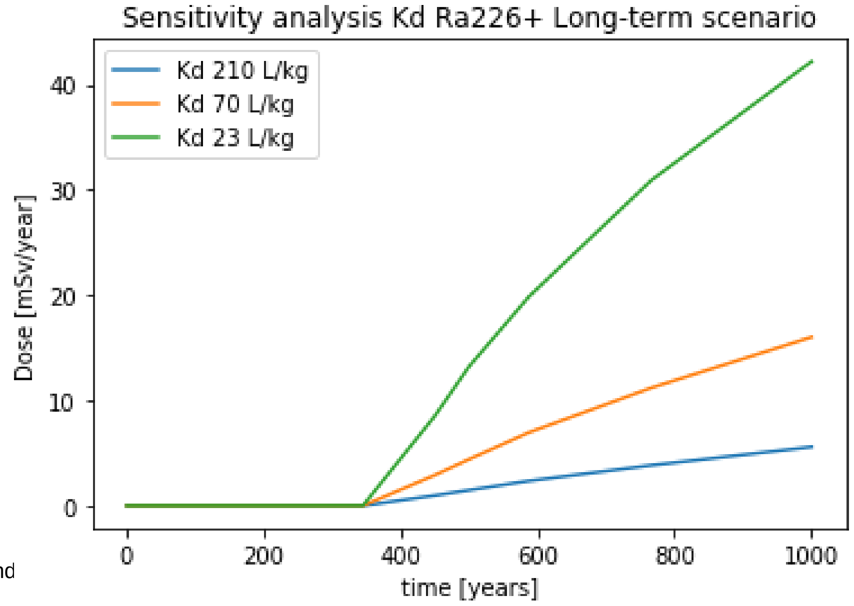
Sensitivity analysis on model parameters (1)

- For short-term scenario:
  - time spent outdoor plays dominant role for dose estimate, presence of cover/shielding of worker will reduce external radiation
- For long-term scenario:
  - The most impacting 'geometrical' parameter that affect model output is thickness of cover depth
  - The most impacting 'hydrological' parameters are the precipitation and evapotranspiration
- For generic dose-assessment a conservative value of distribution coefficient K_d (L/kg) with respect to the limiting scenario has to be considered





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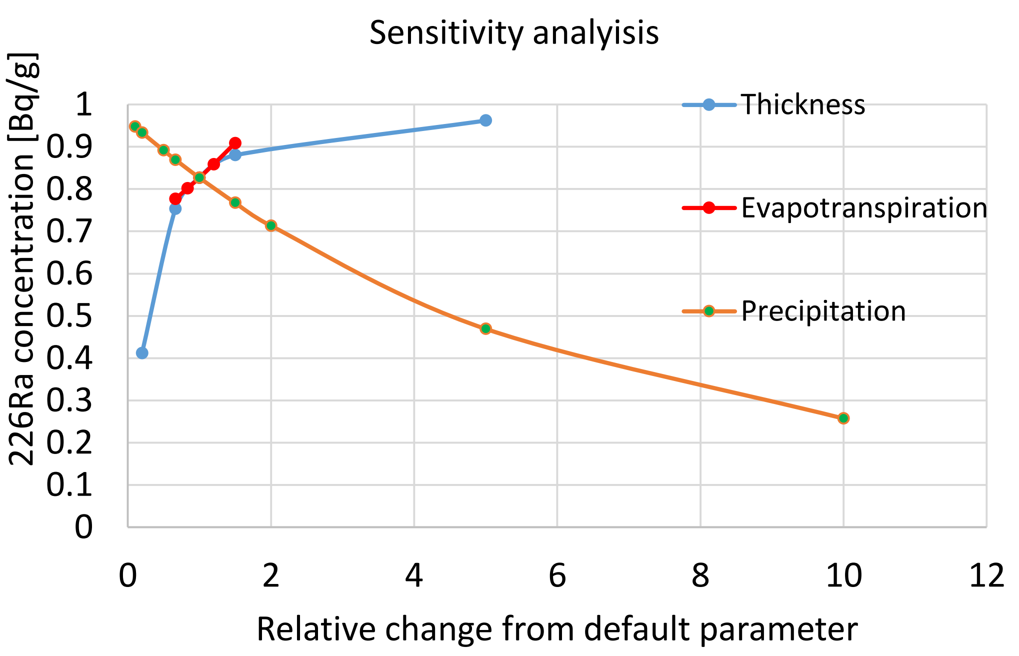
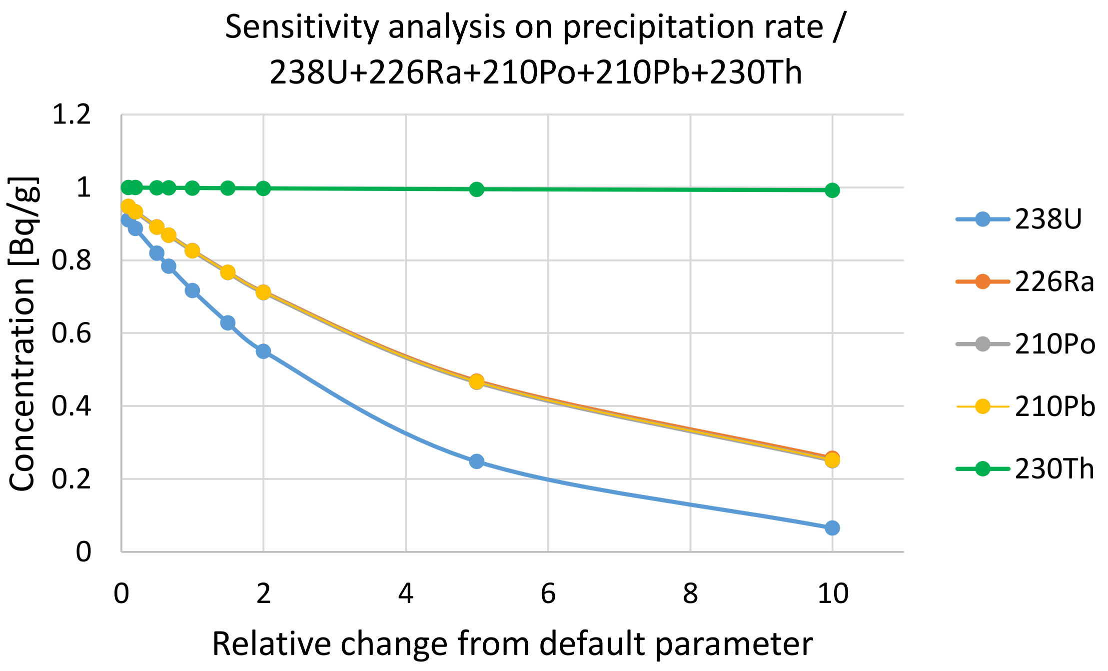
Sensitivity analysis on model parameters (2)

The most impacting "geometrical" parameters to activity concentration at t=1000 years are the thickness and density of waste layer, in the case of hydrological parameters the precipitation and evapotranspiration influence most the concentration in waste layer.





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