Assessing potential exposures to people in the post-closure period of a waste disposal facility

I. General aspects

Gerhard Proehl

筑波大学
University of Tsukuba

Problem

- **Radioactive waste is generated world-wide during the application of nuclear techniques**
  - Energy production
  - Science and industry

- **Radioactive waste has to be disposed safely to ensure long-term isolation from the biosphere**

- **International Safety Standards require a comprehensive safety assessment** of facilities for disposal of radioactive waste
  - A key element of the safety assessment is the **assessment of potential exposures to people after closure** of the disposal facility
  - International Safety Standard recommend **dose criteria** for the exposures of people

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Problem (cont.)

- The safety assessment covers **time frames of several thousand years up to a million years**
  - Depending on the country and type of radioactive waste to be disposed

- Disposal facilities have a complex system of safety features
  - **Releases of radionuclides** from waste repositories to the biosphere in the post-closure period **may occur –** if at all **– only in the very far future**

- **Compliance with the radiological criteria has to be demonstrated today**
  - Assessments of potential exposures of people possibly living close to the disposal site have to be carried out
  - The consideration of long-time frames requires the consideration of changes in the environment

Relevant radionuclides for disposal of radioactive waste

Waste category	Radionuclide	Half-life (y)	Remark
Low-level waste	Cs-137	30.1	
	Sr-90	28.5	
Intermediate and high level waste	Cl-36	301 000	Potential high environmental mobility
	Ni-59	75 000	
	Se-79	65 000	Potential high environmental mobility
	Zr-93	1 530 000	
	Nb-94	20 300	
	Tc-99	213 000	Potential high environmental mobility
	Pd-107	6 500 000	
	Sn-126	100 000	
	I-129	15 700 000	Potential high environmental mobility
	Cs-135	2 300 000	
	U-238	4 500 000 000	
	- Th-230	77 000	Daughter nuclide of U-238
	- Ra-226	1 600	Daughter nuclide of U-238
	Am-243	7 380	
	- Pu-239	24 100	Daughter nuclide of Am-243
	- Pa-231	32 700	Daughter nuclide of Am-243
	Np-237	2 140 000	Potential high environmental mobility

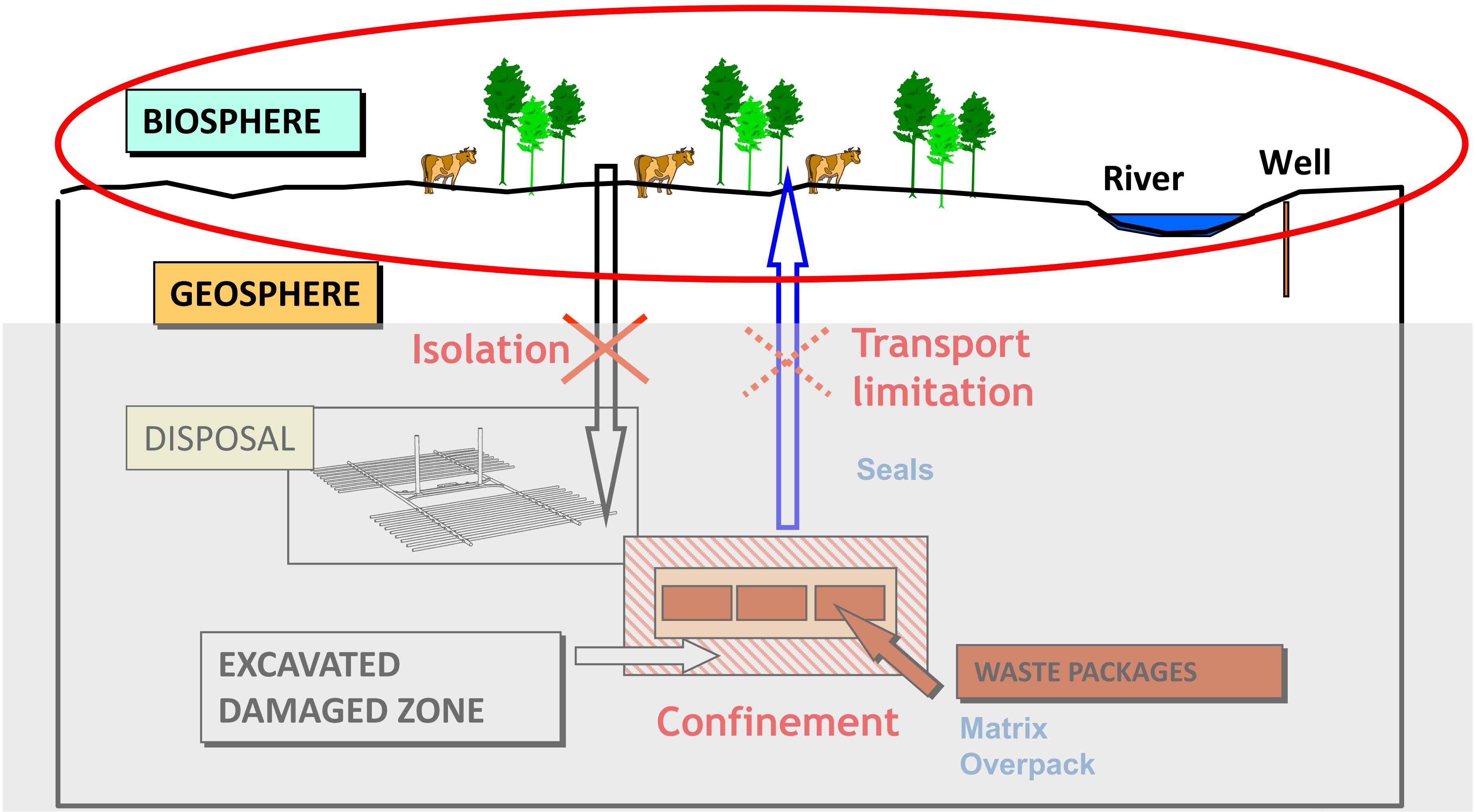
Time frames in safety assessments for disposal facilities

- **Disposal of low-level waste**
  - E.g. waste generated during the decontamination activities after nuclear accidents
  - Disposal in near-surface facilities
  - Required isolation time: **some 100 years**

- **Disposal of intermediate level waste**
  - Waste generated in nuclear facilities
  - Disposal in geological disposal at intermediate depth (around 100 m).
  - Required isolation time: **Some 1000 years**

- **Disposal of high-level waste**
  - Spent fuel from nuclear power plants
  - Waste from reprocessing of fuel elements
  - Disposal in deep geological formations at depths at around 500 m.
  - Required isolation time: **10000 years or more** (up to 1 million y), depending on the national regulations

Biosphere in the post-closure period of a disposal facility



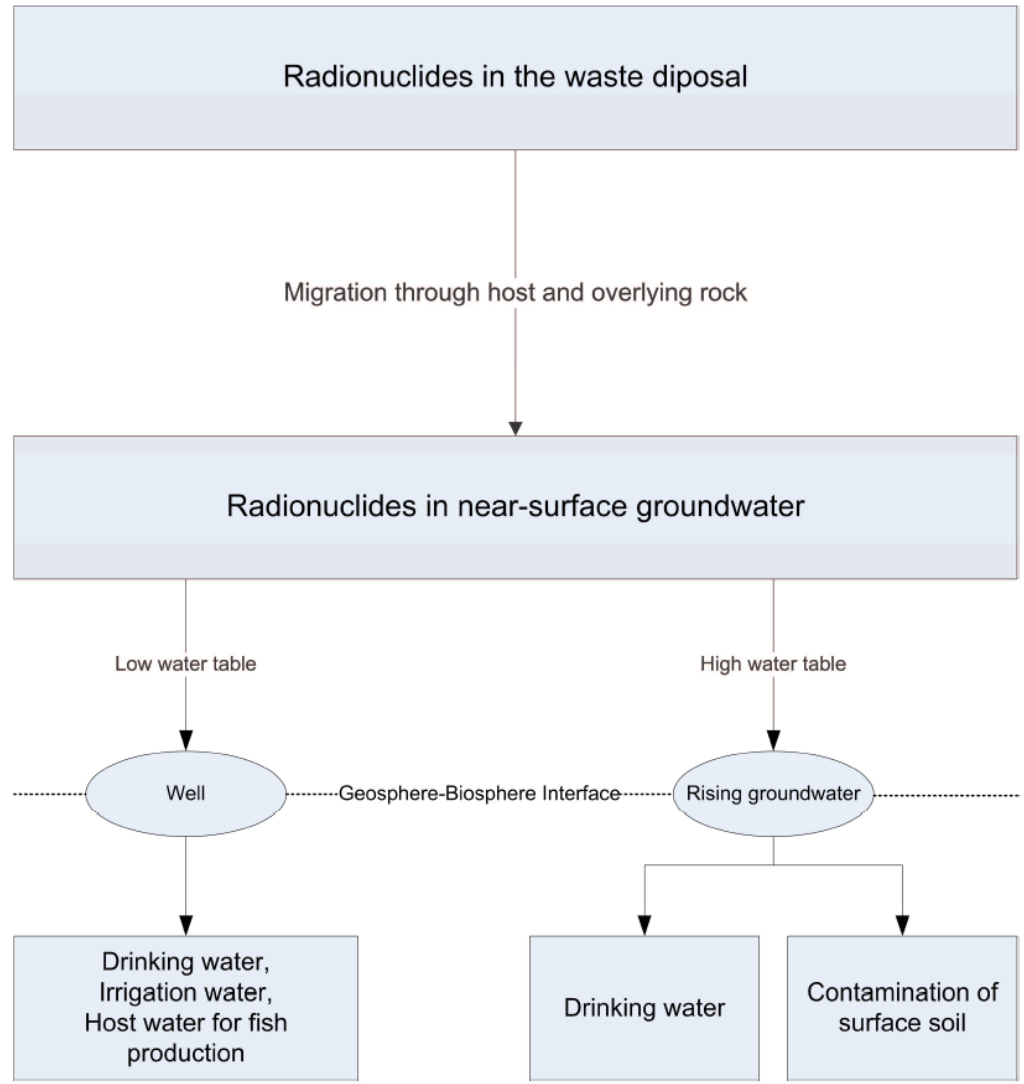
Radionuclides enter the biosphere

From the disposal area to the near-surface aquifer

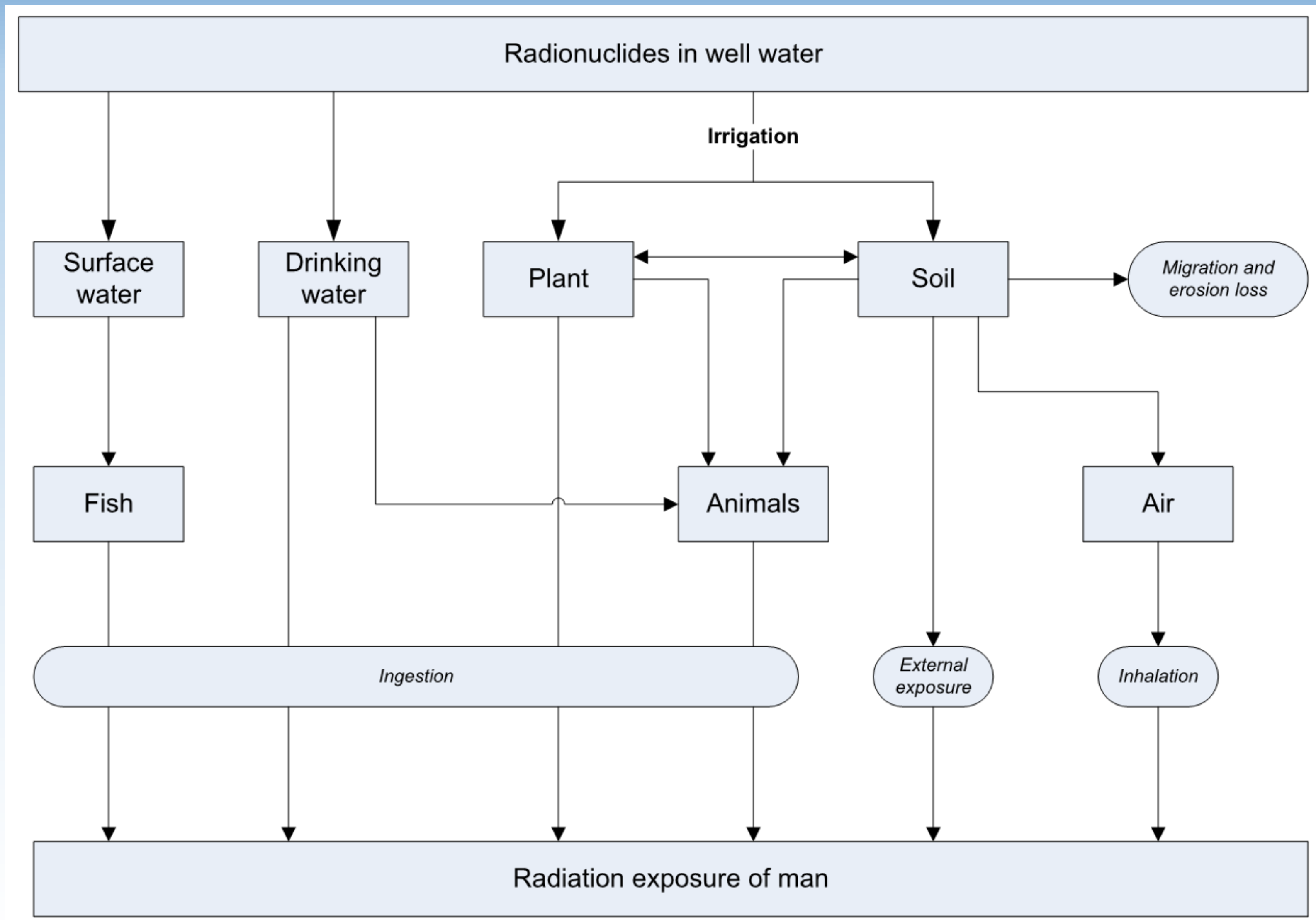
- Radionuclides are released from the disposal
- Radionuclides migrate through the overlying rock
- Radionuclide contaminate the near-surface aquifer

From the near-surface aquifer to the biosphere

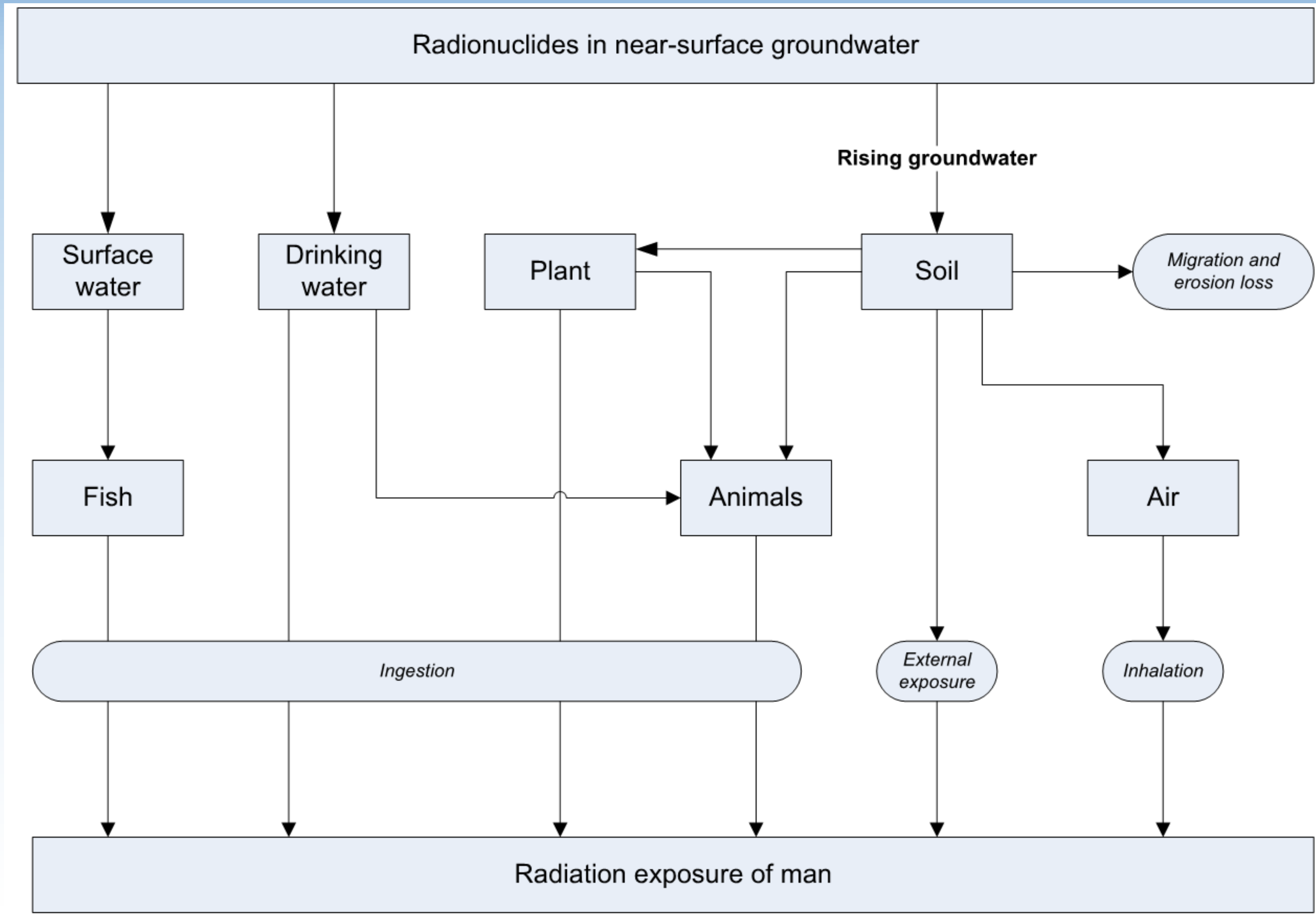
- Withdrawal of water via a well
- In case of high ground-water level, radionuclides may directly contaminate soils



Pathways for withdrawal of water from a well



Pathways for rising ground water



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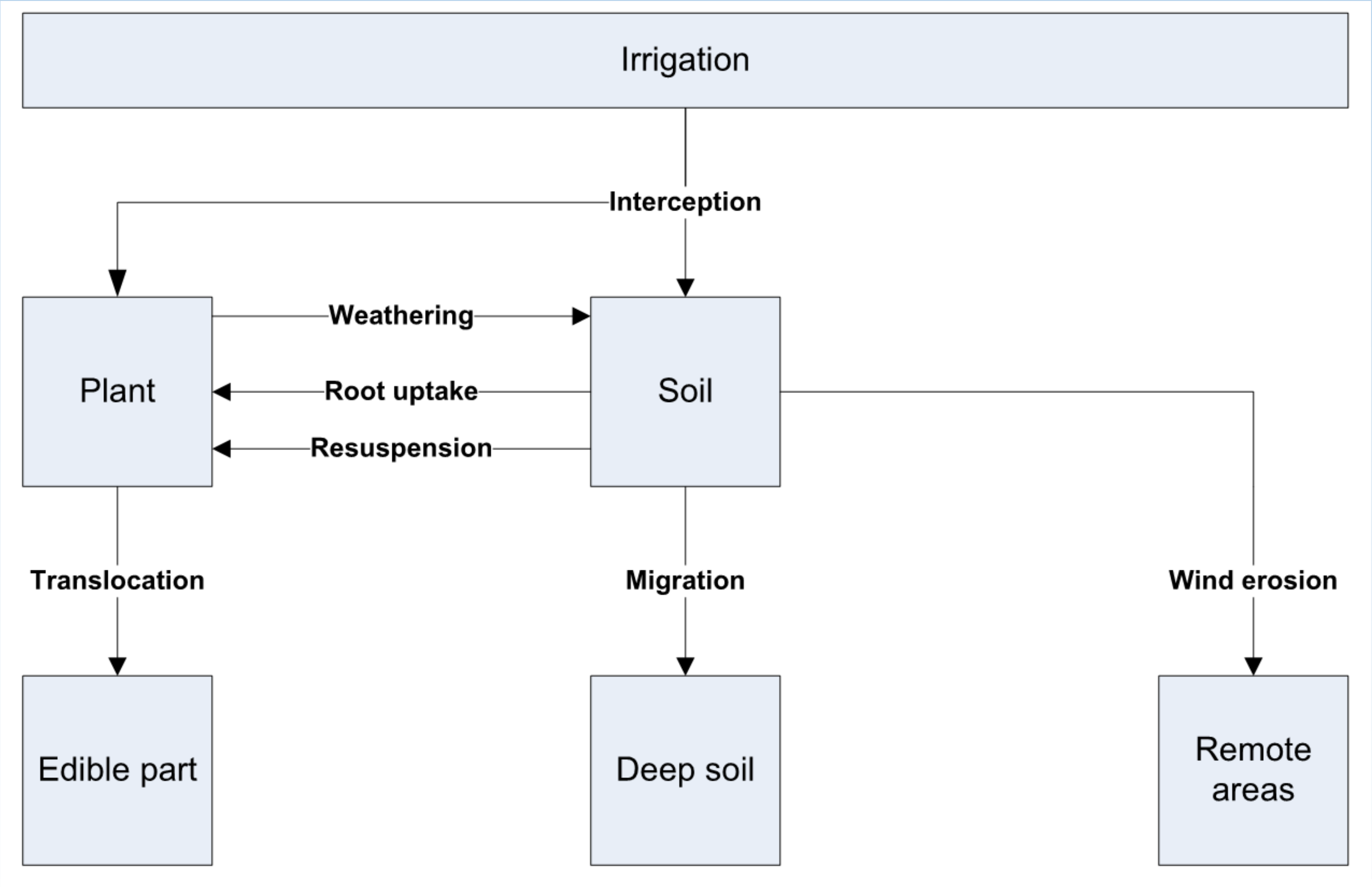
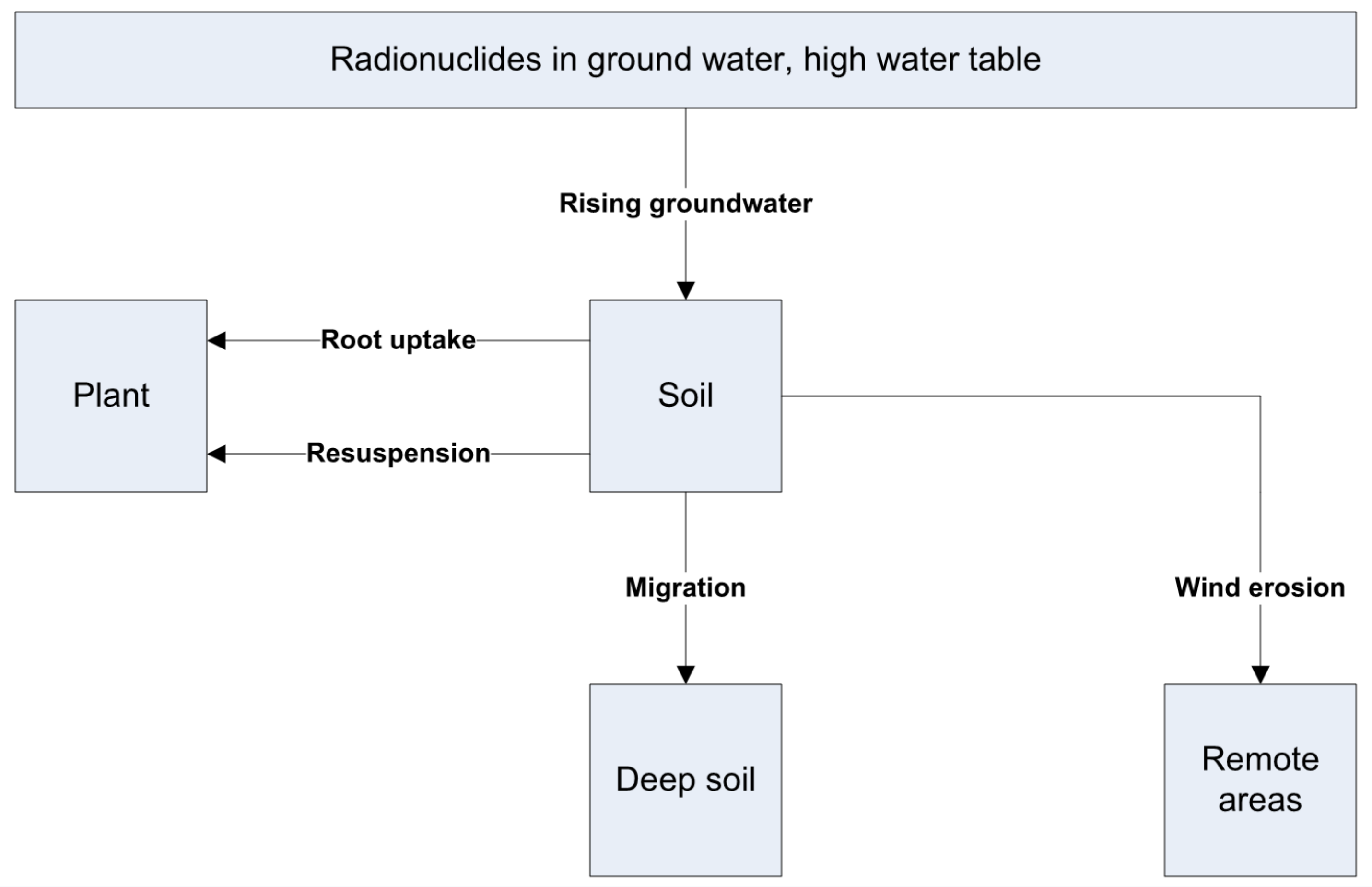
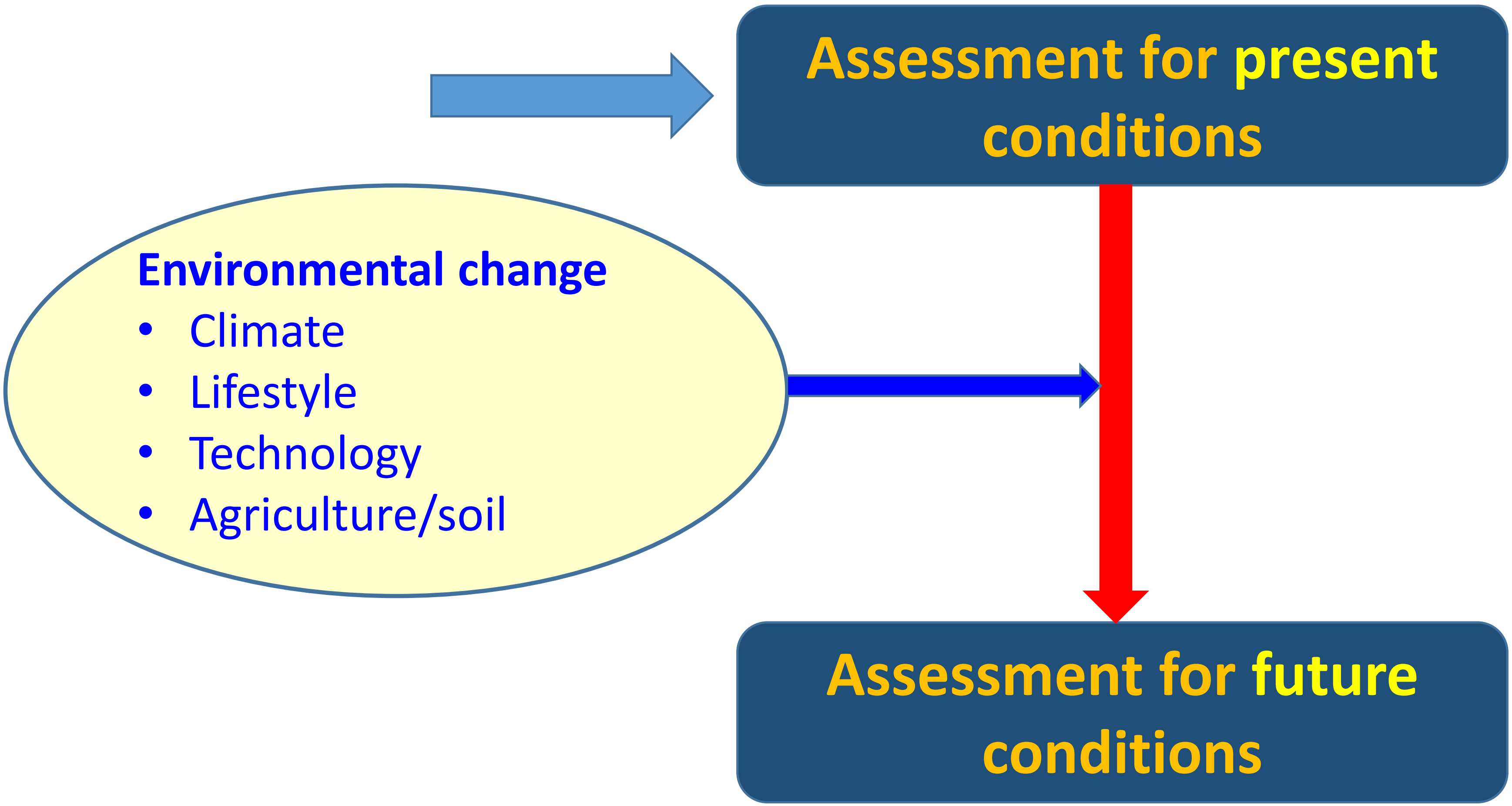
Plant model irrigation



Plant model for rising groundwater



From present to future conditions



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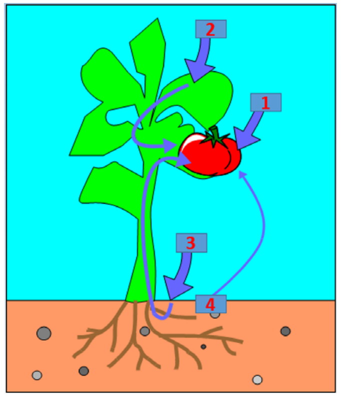
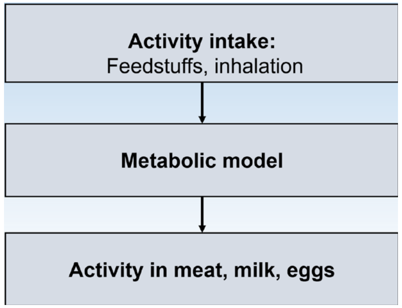
Processes causing radionuclide transfer in the environment

Important processes and features

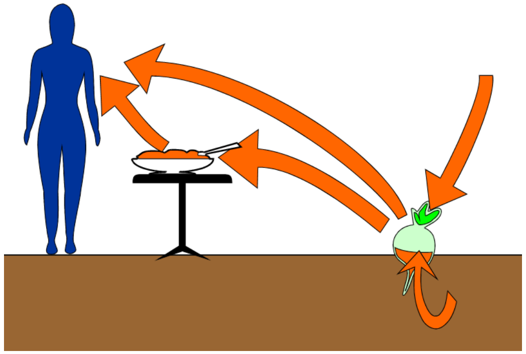
- **Irrigation**
  - Water demand of crops in different climates
- **Processes involved in the behaviour of radionuclides in plants**
  - Interception of radionuclides in irrigation water by crops
  - Weathering and loss from plants
  - Systemic transport of radionuclides in plants
  - Uptake of radionuclides by crops via the rots from soil
  - Migration in soil



- **Processes involved in the transfer of radionuclides to animal products**
  - Feed and water intake
  - Metabolism in the animal
  - Transfer to meat milk and eggs



- **Processing and culinary preparation**
- **Intake of food**
  - Demand for nutrients
  - Plant and animal food products



Contamination routes for plant products

A Short-term

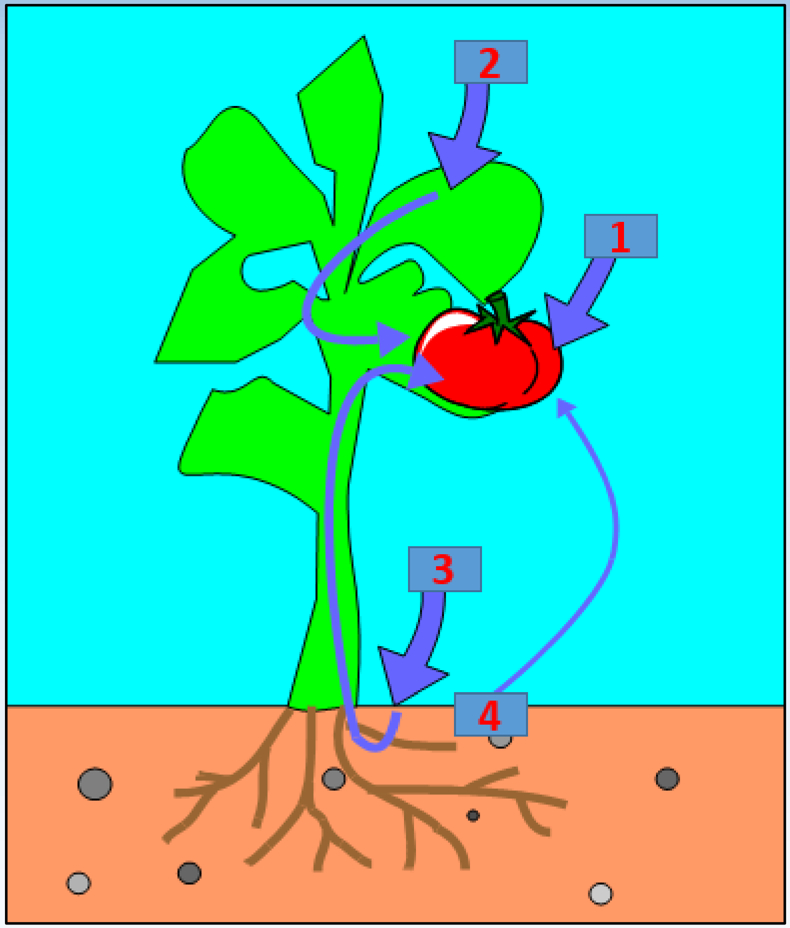
1 Direct deposition onto edible parts of plants

2 Deposition onto leaves
-> transport to the edible parts

B Long-term

3 Deposition on soil and uptake through the roots

4 Resuspension of dust and re-deposition on leaves and fruits



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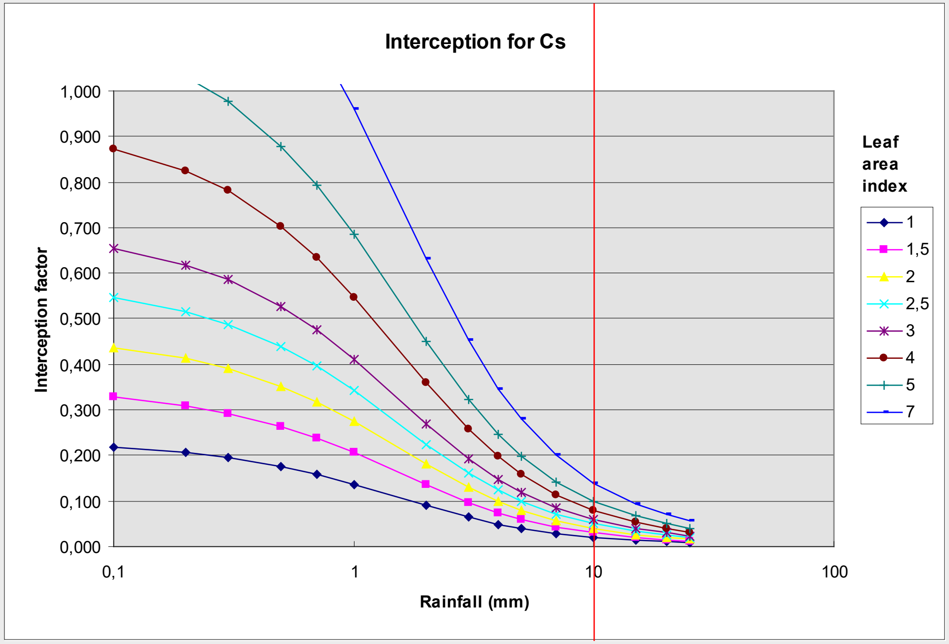
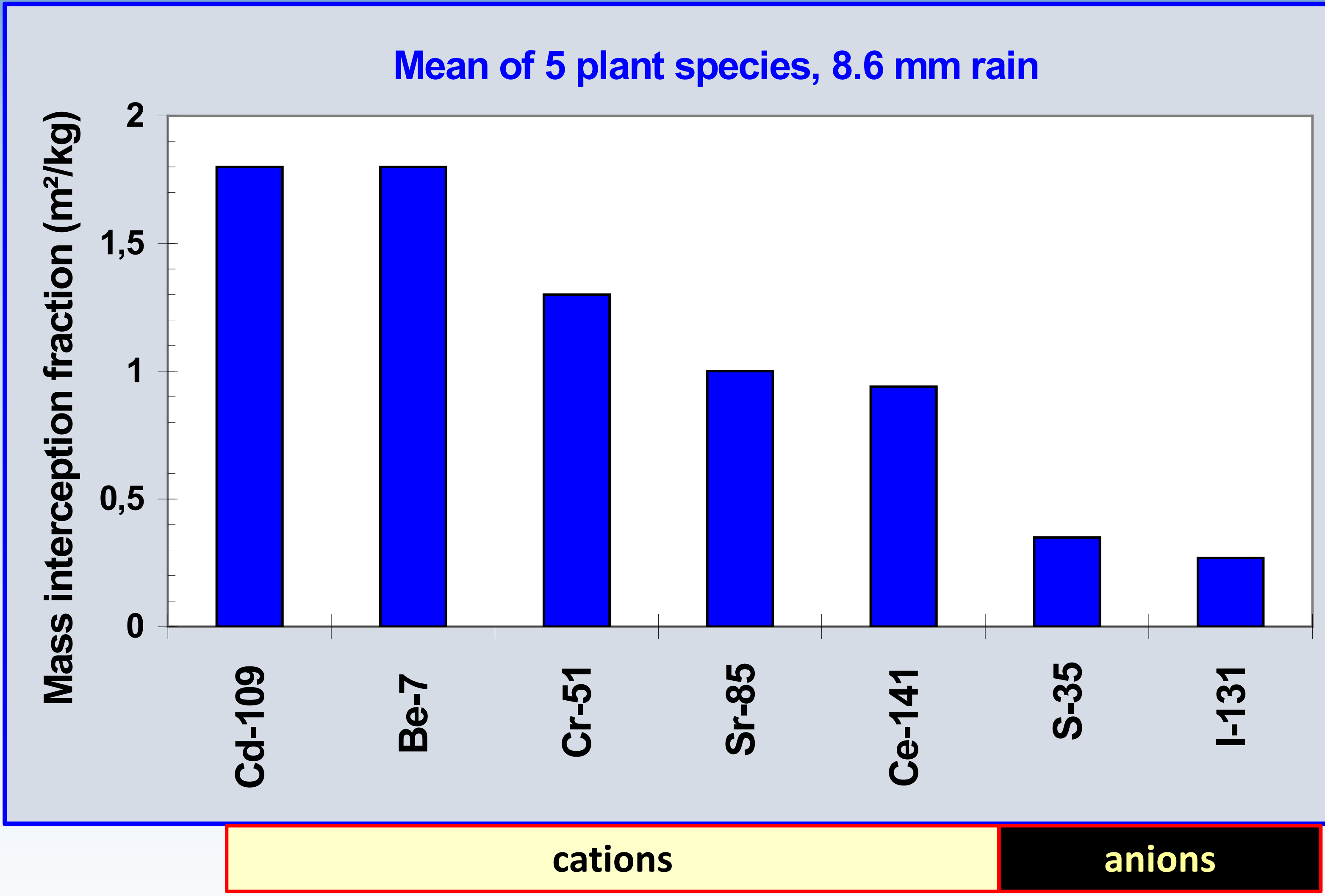
Interception of radionuclides dissolved in irrigation water

Fraction of activity retained by crops (interception) …

- … decreases with amount of irrigation water
- … increases with the development of crops
- … highest during the peak season



Interception depends on the chemical form (Hoffman et al., 1995)



(mass interception fraction = interception fraction normalized to the biomass)

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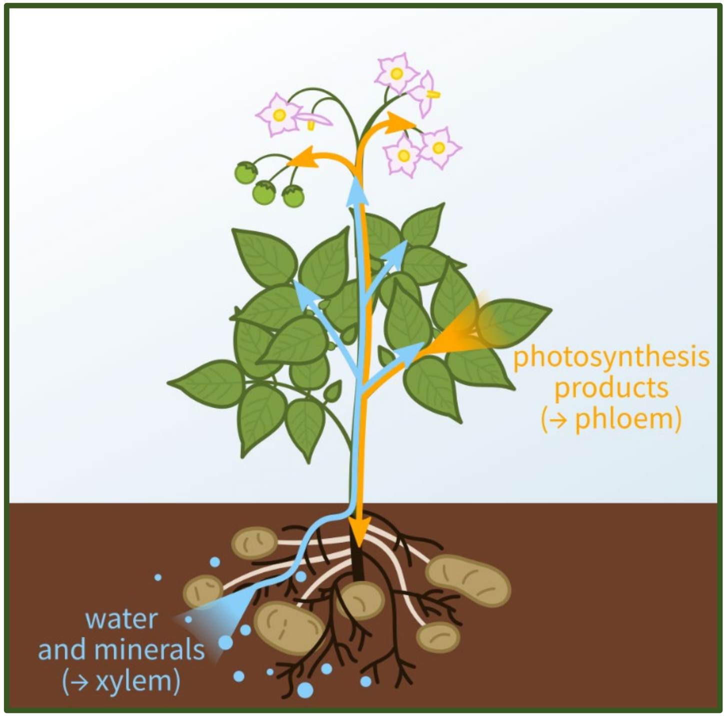
Translocation



Active transport of elements in plants

- Defines the amount of activity transported from leaves to edible parts

Depends on

- Element
  - Mobile elements (xylem + phloem)
  - Immobile elements (only phloem)
- Stage of development

- Pronounced seasonality
- Foliar uptake may exceed root uptake by orders of magnitude

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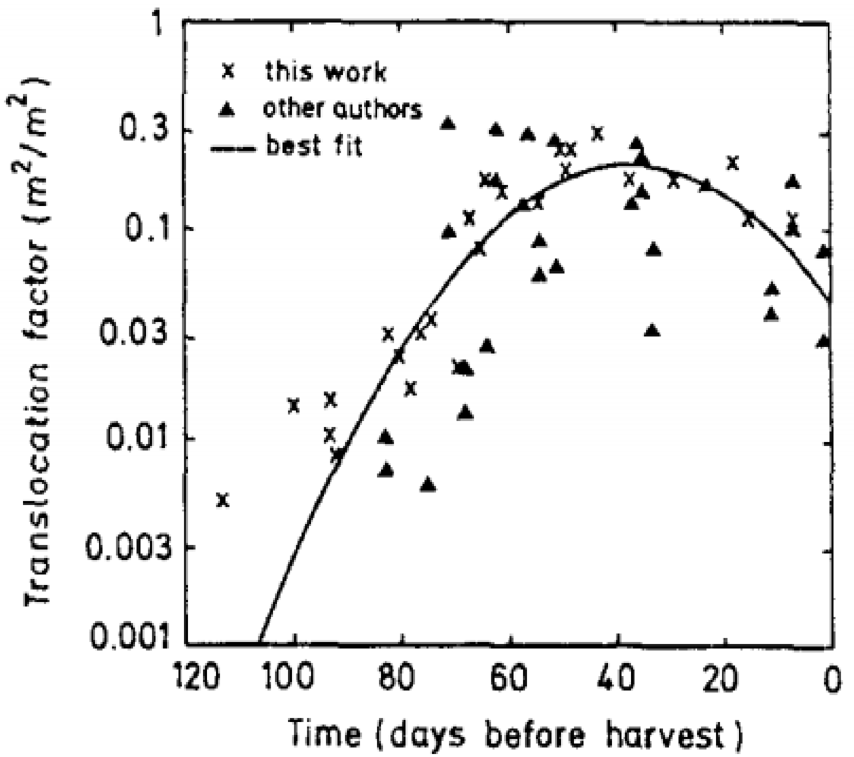
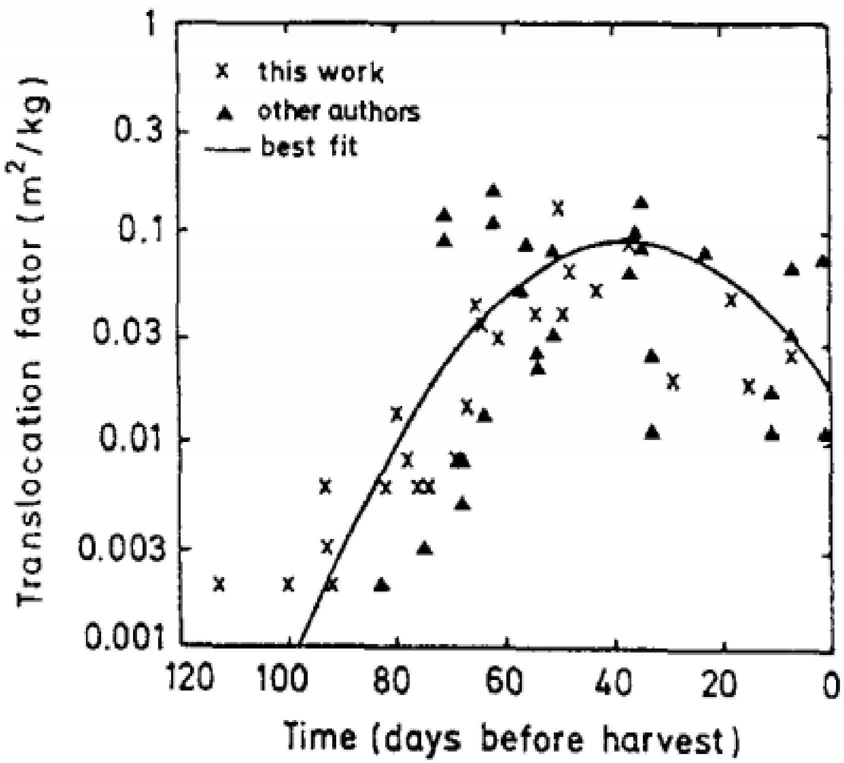
Translocation factors for wheat and barley





Left: Total activity in grain [Bq/m^2] per Total activity deposited on the plant [Bq/m^2]

Right: Activity concentration in grain [Bq/kg] per Total activity deposited on the plant [Bq/m^2]

Voigt, G, Proehl, G, and Mueller, H. Experiments on the seasonality of the cesium translocation in cereals, potatoes and vegetables. 1991. Web. doi:10.1007/BF01210514

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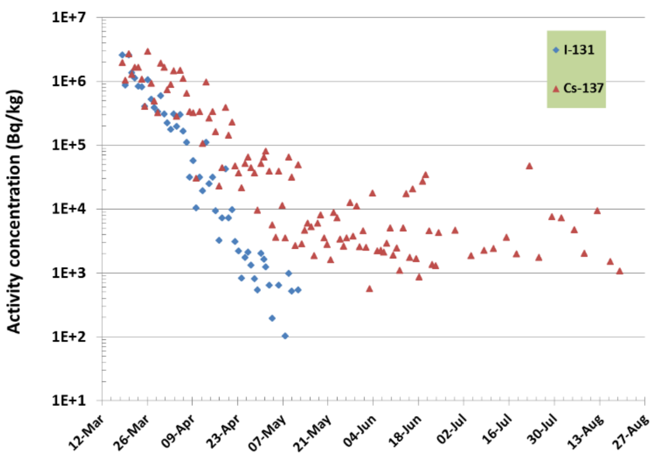
Loss of radionuclides from plants due to weathering



- ***Post-deposition activity loss from plants***
  - Rainfall, fog, foliar abrasion
  - Including the decrease of activity concentration due to increase in biomass (growth dilution)
- ***Influencing factors***
  - Time after deposition
    - Loss rate declines with time after deposition
  - Age of plants
    - Higher for young plants
  - Rainfall, fog

Cs-137 and I-131 activity in vegetables after single deposition event

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Radionuclide uptake from soil

***Long-term source of plant contamination*, depending on**

- **Soil characteristics**
  - Sorption capacity (Sand, loam and clay content, Organic matter)
  - pH value
  - Redox potential (esp. iodine, plutonium)
  - Concentration of antagonists
    - Cs vs K, Sr vs Ca
    - Use of fertilizer
- **Chemical form of the deposit**
  - Soluble vs inert particles
- **Time since the contamination**
  - Progressing sorption, fixation and incorporation processes

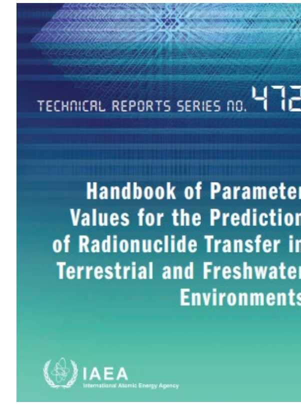
Quantification of the uptake of radionuclides from soil

Transfer factor soil-plant TF

$$TF = Activity_{(plant)} / Activity_{(soil)}$$

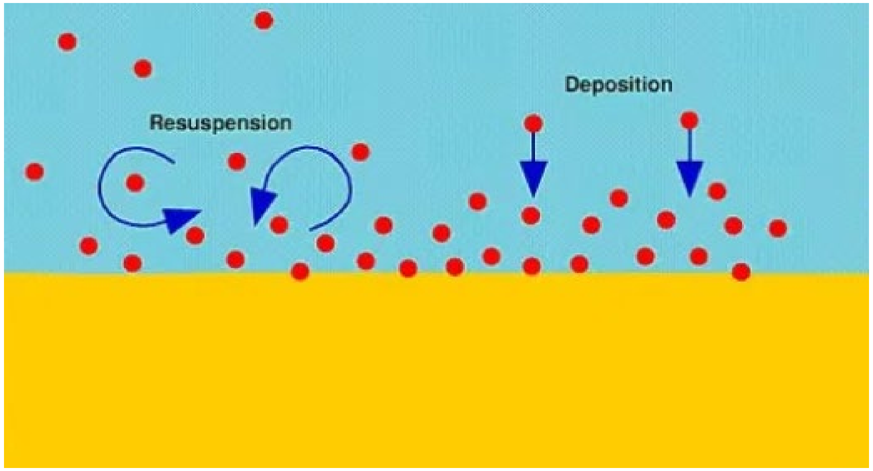
[Bq/kg fresh per Bq/kg dry]

Typical values for transfer factors soil-plant



- **Strontium:**
  - **0.1 - 1**
- **Caesium**
  - Well managed soils: 0.001 – 0.1
  - Organic, acid soils: 0.1-10
- **Technetium:**
  - 0.1 – 10
- **Iodine:**
  - 0.001 - 1
- **Plutonium, americium :**
  - 0.00001 – 0.001
- **Pronounced variability, also on the same site**

Resuspension of soil



- **Defines the flux of radionuclides from soil to atmosphere**
- **Depends on**
  – Soil texture and humidity
  – Vegetation cover
  – Wind speed
- **Areas particularly affected by resuspension**
  – Arid regions
  – In temperate climates, resuspension during storms may cause a relevant activity loss from soil

Erosion:

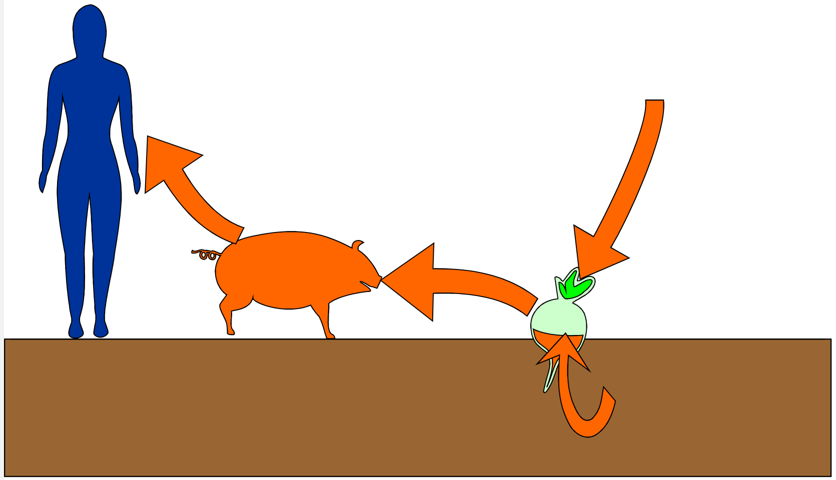
Degradation of soil due to removal of soil material by wind and water

- **Erosion by water**
  - Kinetic energy of rain destroys soil aggregates
  - Soil will be transported downhill
- **Factors increasing water erosion**
  - Precipitation and contribution of heavy rain showers
  - Slope
  - High fraction of sand and silt
  - Low content of clay and organic matter
  - Poor vegetation
- **Relevance**
  - Up to 200 t/(ha*a) (=> 1 cm soil)

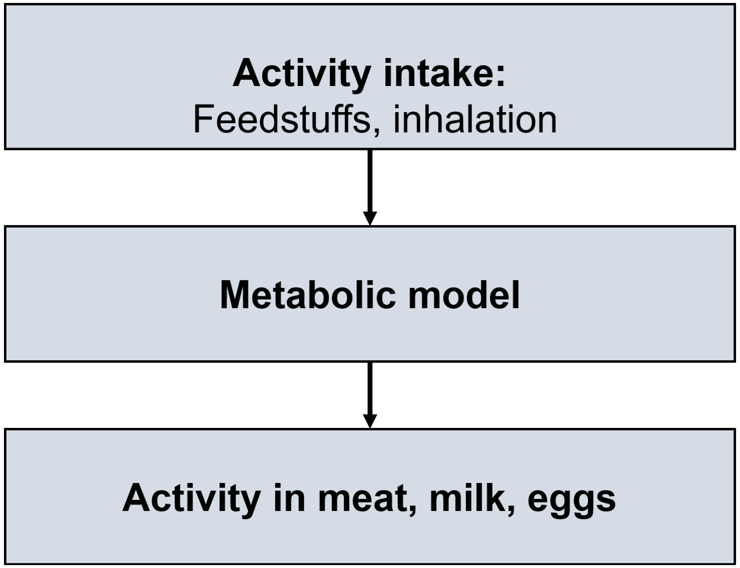
Erosion by water

- Rain splash affects the soil surface
- Creeks in a sloping field

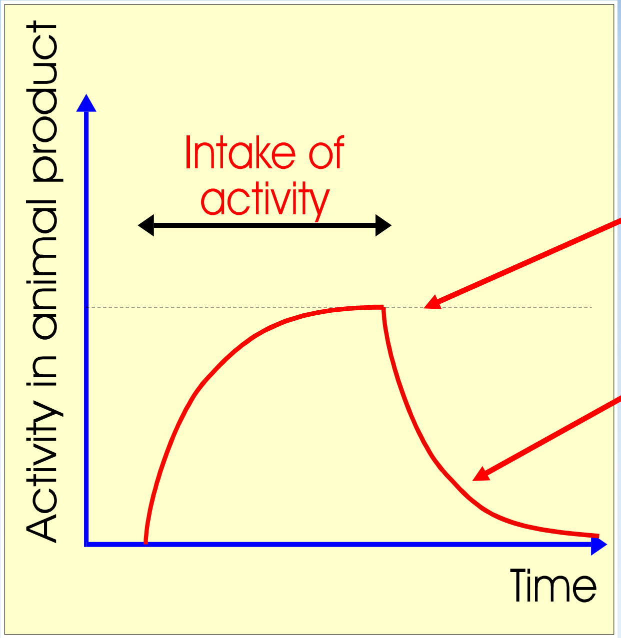
Transfer to animal products



- Use of contaminated feedstuffs
- Transfer to meat, milk, eggs



Simple model for the time-dependence of the activity in animal products



Quantification

- Transfer factor (steady state conditions)
- Biological half-lives

TF $_{\text{feed-(meat/milk/eggs)}}$ [d/kg]=

= Activity$_{\text{(meat/milk/eggs)}}$ [Bq/kg] / Daily activity$_{\text{(animal)}}$ [Bq/d]

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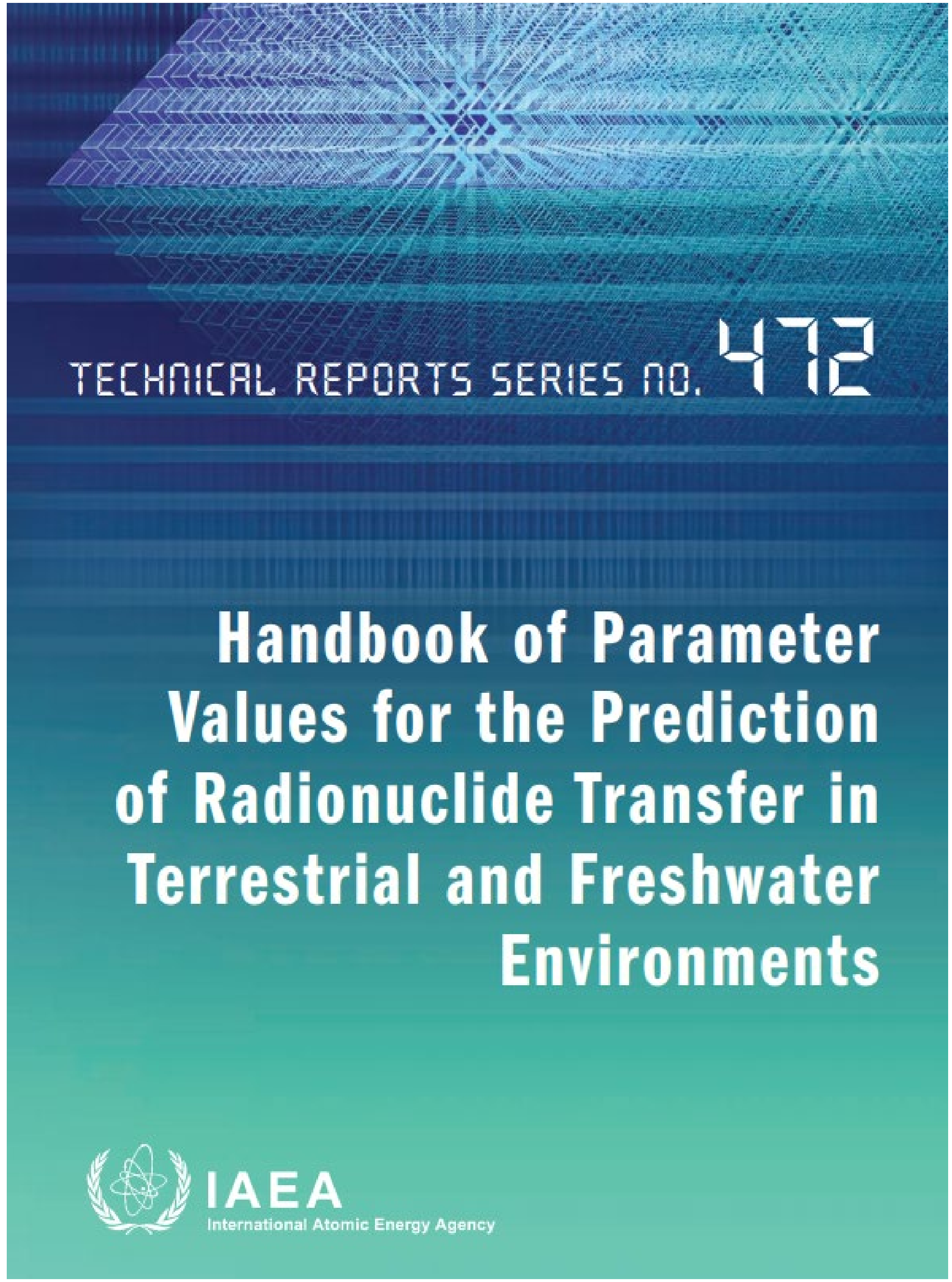
For more information:

Compilation of parameters for environmental transfer



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SUMMARY

- **Licensing of facilities for disposal of radioactive waste requires a safety assessment**
  - The assessment of radiation doses to people in the post-closure period is a key element of the safety assessment
- **Long time frames have to be considered**
  - Several 100 years for low level waste
  - Several 1000 years for intermediate level waste
  - 10000 and more for high level waste
- **Radionuclides enter the biosphere**
  - Abstraction of water from a well
  - Rising groundwater in case of high water tables
- **Safety assessment has to include all relevant pathways**
  - Intake of food and drinking water
  - Inhalation of resuspended soil
  - External exposure
- **Safety assessment has to consider all processes leading to an exposure of people**
  - Irrigation
  - Uptake of radionuclides from soil
  - Radionuclide sorption and migration in soil
  - Transfer to animal products
  - Erosion and resuspension