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Long-Term Impact on Humans from a Repository for Radioactive Waste: Experimentally Verified Radioecological Biosphere Model

Joint Project TRAVARIS: **Tra**nsfer of long-lived radionuclides from the **va**dose zone to the **r**h**i**zo**s**phere and their uptake by plants, taking microbiological processes into account

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Federal Ministry of Research, Technology and Space

Agenda

1 About the project TRAVARIS

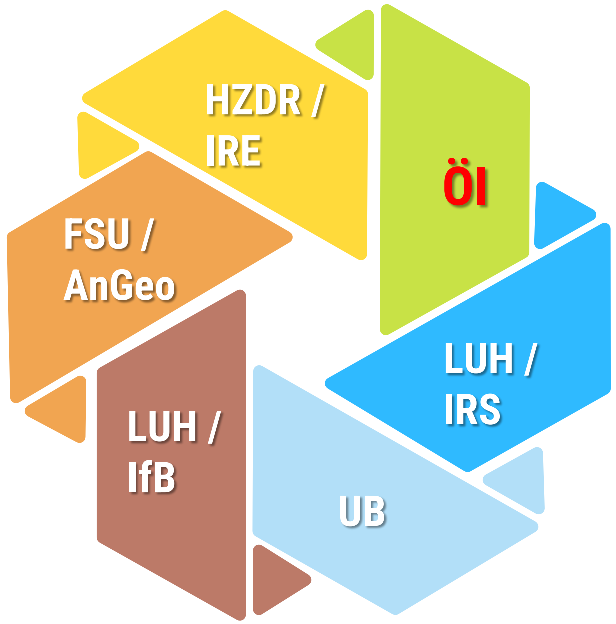
2 Development of radioecological biosphere model

3 Model parts

4 Preliminary results

Overall concept

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA | HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF | Universität Bremen | Öko-Institut e.V. Institut für angewandte Ökologie Institute for Applied Ecology | Leibniz Universität Hannover



Radionuclides
I, Se, Tc, Am, Pu, U, Np, Eu

Experiments on water and radionuclide transport in the soil and uptake mechanisms of radionuclides in plants interlinked with the model development.

Experiments

- Subproject A (FSU-AnGeo): Water level fluctuations, influence of variable hydraulic conditions on the distribution of radionuclides in soil
- Subproject B1 (LUH-IRS): Water level fluctuations, microbial diversity, interaction of radionuclides and root exudates, uptake in plants
- Subproject B2 (LUH-IfB): Plant transporters for the uptake of radionuclides from the soil into plants
- Subproject C (HZDR-IRE): Soil microbiology in the presence of root exudates and radionuclides, uptake mechanisms in plants

Modelling

- **Subproject D (ÖI): Radioecological biosphere modelling with representation of uncertainties in dose estimation (AISM)**
- Subproject E (UB-IUP): Geochemical modelling of micro- and mesoscale systems (PHREEQC)

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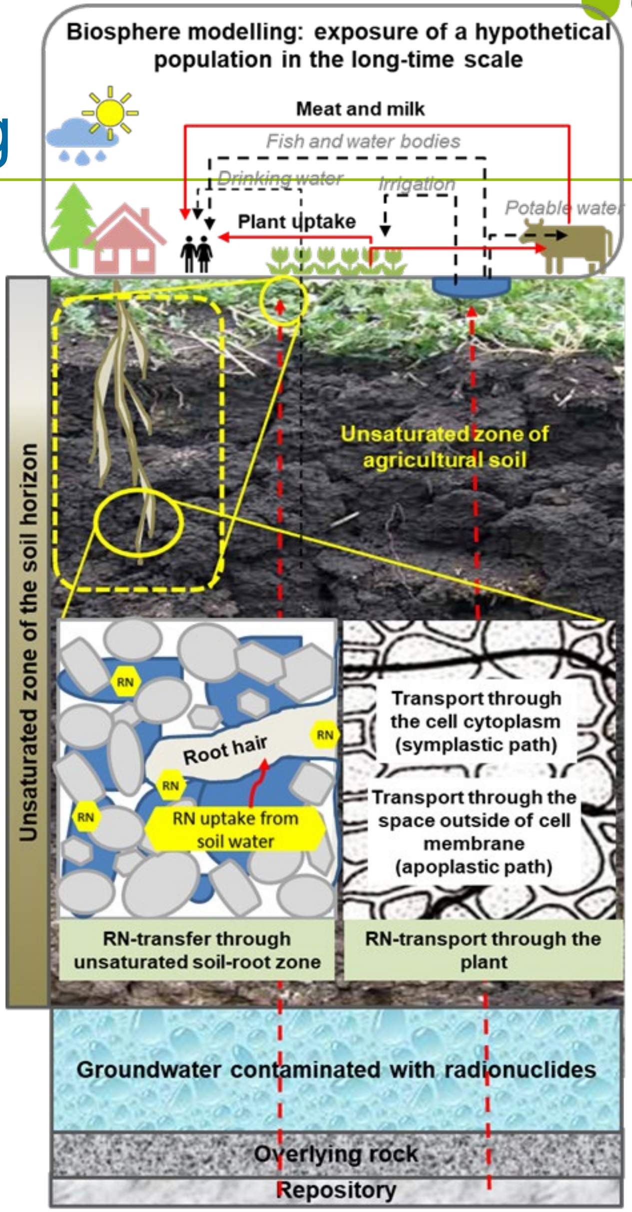
Radioecological biosphere model
Software AFRY Intelligent Scenario Modelling

Macroscale: Dose calculation, statistical analysis of uncertainties in exposure determination with Monte Carlo simulations.

Mesoscale: Radionuclide transport in soil due to water table fluctuations and evapotranspiration as f(e.g. C_{org}, clay/illite, pH).

Microscale: Radionuclide behaviour in the root zone and in plant compartments, implementing transfer factors, consideration of transporters and root exudates.



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Radioecological biosphere model: model parts

- **Model part "soil transport":** describes water level fluctuations in the pore space under the influence of evapotranspiration along several soil horizons and the associated interaction of the radionuclides in the pedosphere
- **Model part "plant":** takes into account the microscale accumulation processes of radionuclides in the root area and the distribution in plant compartments
- **Model part "dose estimation"** over long periods of time due to water intake, plant consumption…
- Considering several scales from micro to macro

Experiments

Agreement with project partners on the experimental design and procedure for the experiments: linkage with the process description and relevant parameter in the biosphere model

Model PHREEQC

Delivering basis for look up table describing dependencies of radionuclide sorption on pH-Value or organics

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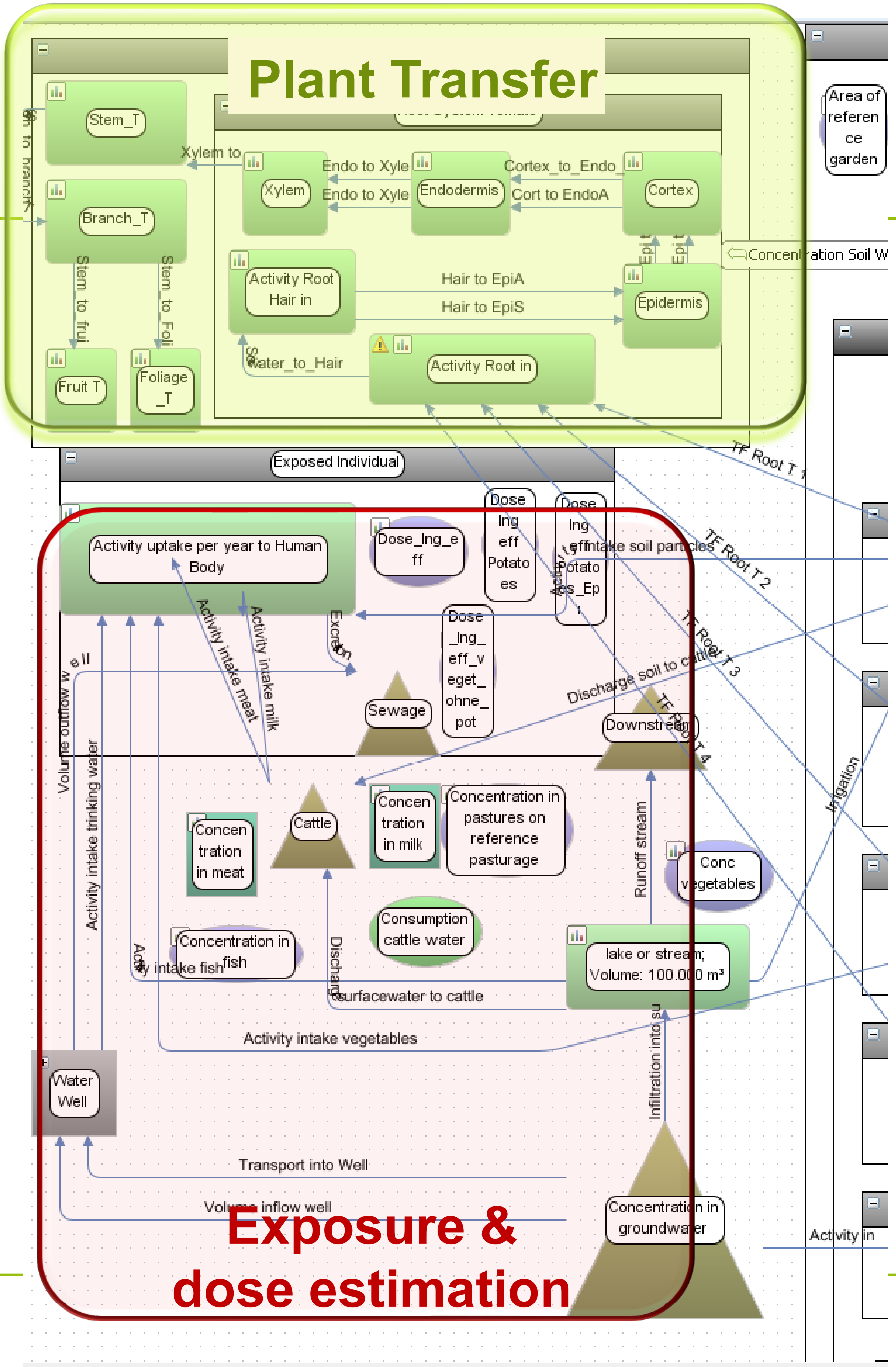

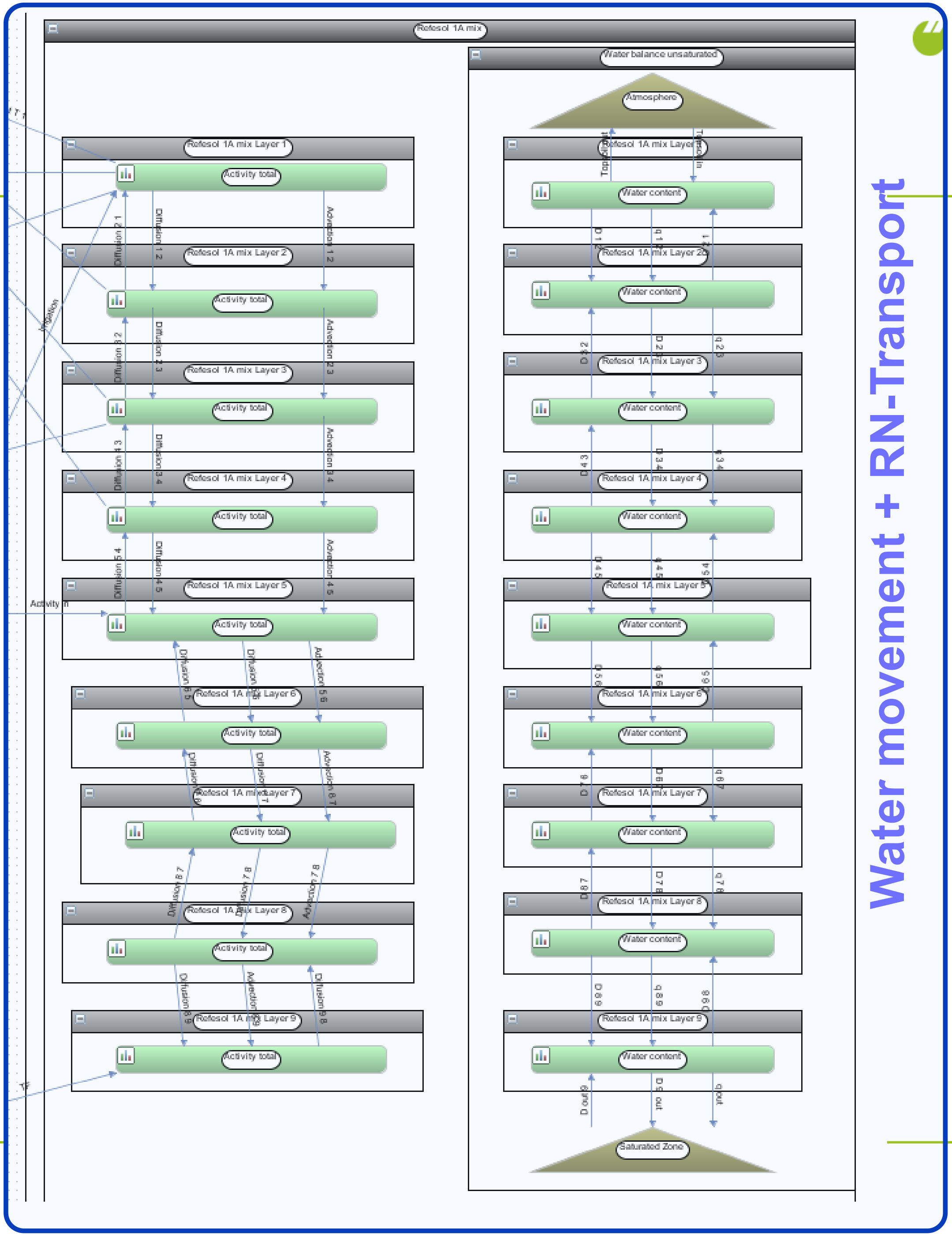

Input from project partners: process understanding, parameter values

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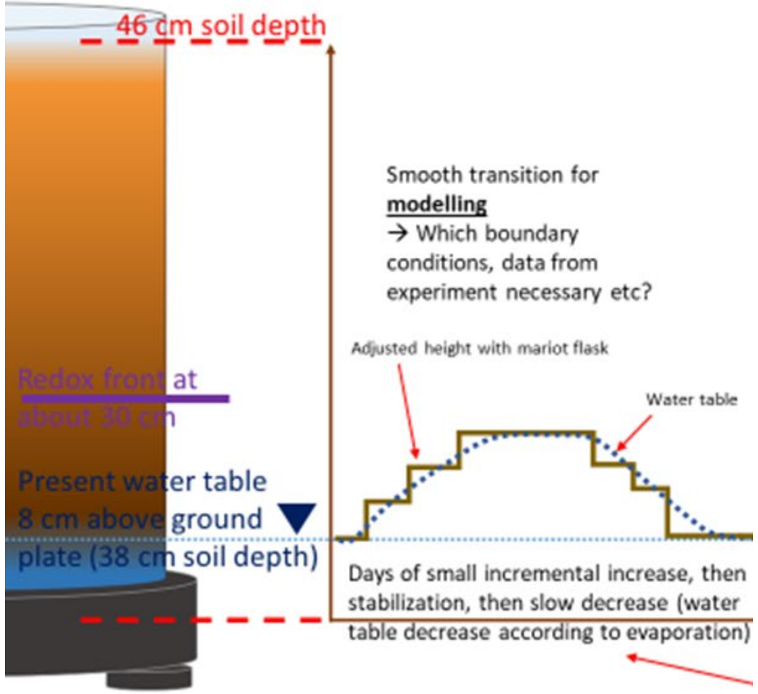
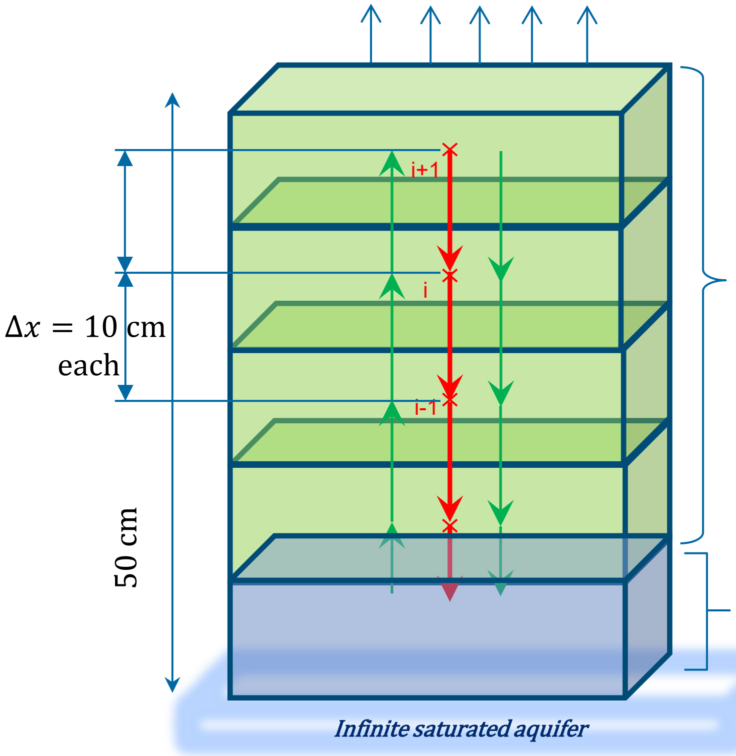
Water movement and radionuclide transport under water level fluctuations: finite volume method

Discussion on water table fluctuations (IRS, FSU, UB, ÖI)

→ goal: modelling of hydrological changes in soil substrate and investigation of associated RN mobilization

Concept/scheme of implementation as basis for discussion:





Water content form of Richards-Equation:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left(D(\theta)\,\frac{\partial\theta}{\partial x}\right) - K(\theta)\frac{\partial\theta}{\partial x} - w$$

$$q^D_{i\to i\pm1} = \Theta_i\,(0,5\,[\overline{D_i(\theta) + D_{i\pm1}(\theta)}])/(\Delta x)^2$$

$$q^A_{i\to i\pm1} = K_s\,\left(\frac{\theta_i - \theta_f}{\theta_s - \theta_f}\right)/\Delta x$$

- Advective flow due to gravity (red)
/
- diffusive flow due to capillarity (green)

-Radionuclides move with water

Initial condition $\theta(t=0)=\theta_s$

Source picture water level fluctuation: TRAVARIS project meeting; Presentation M. Böhm / Institute of Geosciences at Friedrich Schiller University Jena

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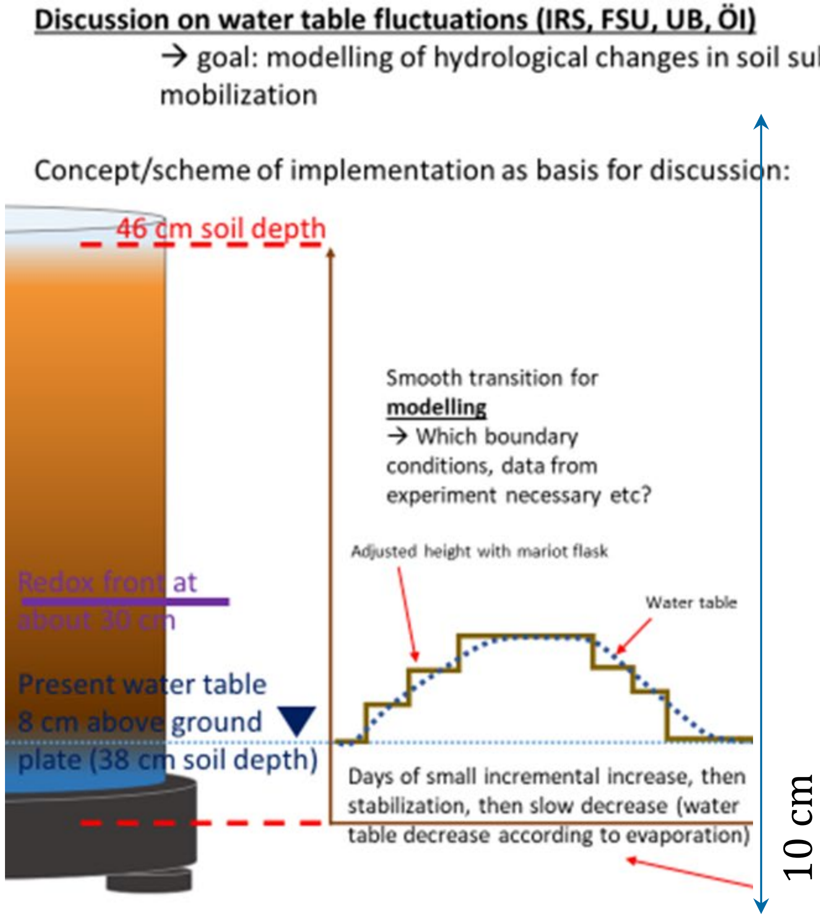
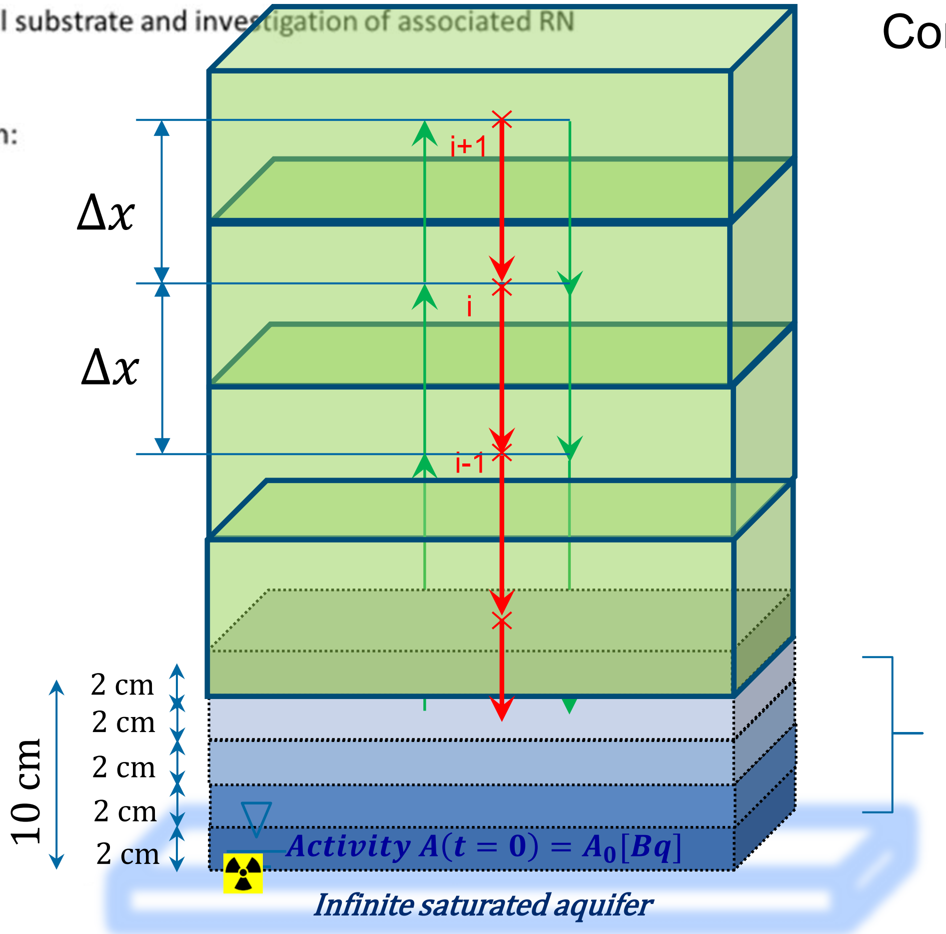
Water movement and radionuclide transport under water level fluctuations: finite volume method





Convection-Dispersion-Equation

$$\frac{\partial c_n}{\partial t} = \frac{\partial q}{R_n}\frac{\partial c_n}{\partial x}(I) + \frac{\partial}{\partial x}\left(\frac{D_{eff,n}}{R_n}\frac{\partial c_n}{\partial x}\right)(II) - \lambda_n c_n (III)$$

$$\frac{\Delta A_i}{\Delta t} = \frac{\sum q}{R\Delta x}(A_{i-1} - A_i)$$

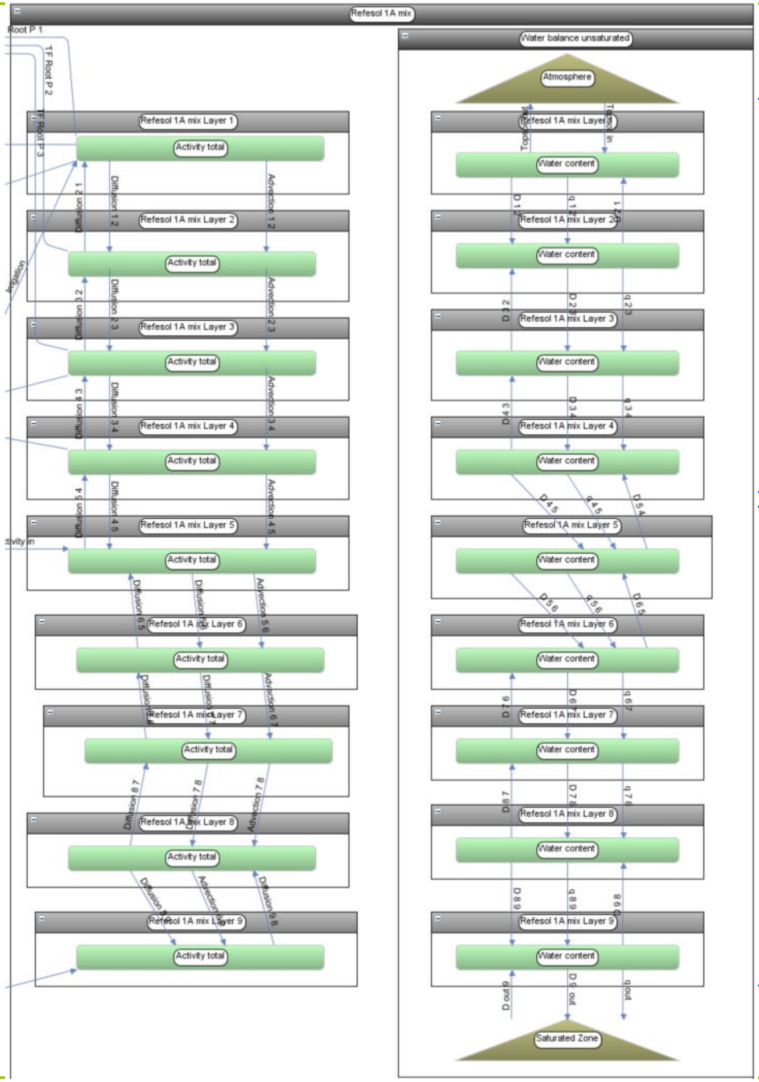
$$\frac{\Delta A_i}{\Delta t} = \frac{D_{eff}}{R(\Delta x)^2}(A_{i+1} - 2A_i + A_{i-1})$$

Subsystem water fluctuation with $\Delta xf = 2\text{cm}$

Source picture water level fluctuation: TRAVARIS project meeting; Presentation M. Böhm / Institute of Geosciences at Friedrich Schiller University Jena

Water and radionuclide transport under water level fluctuations

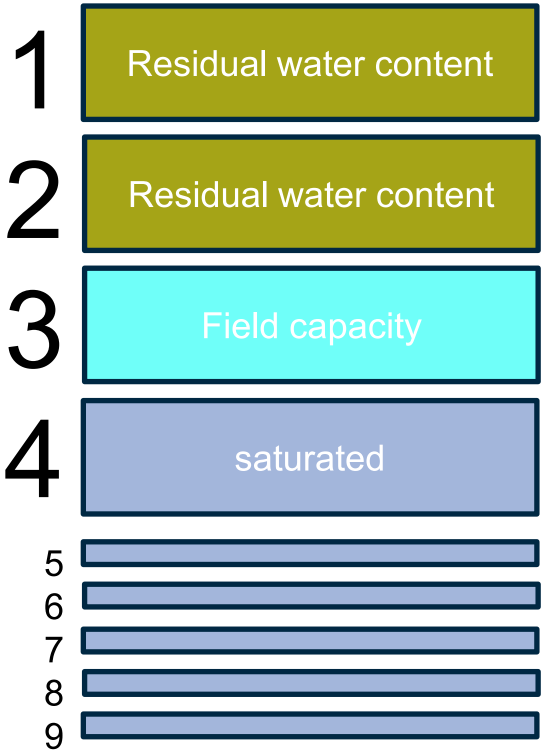
1
2
3
4
5
6
7
8
9

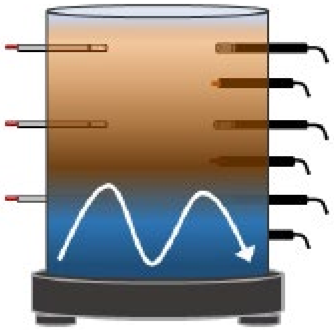


4 x 10 cm layers

5 x 2 cm layers

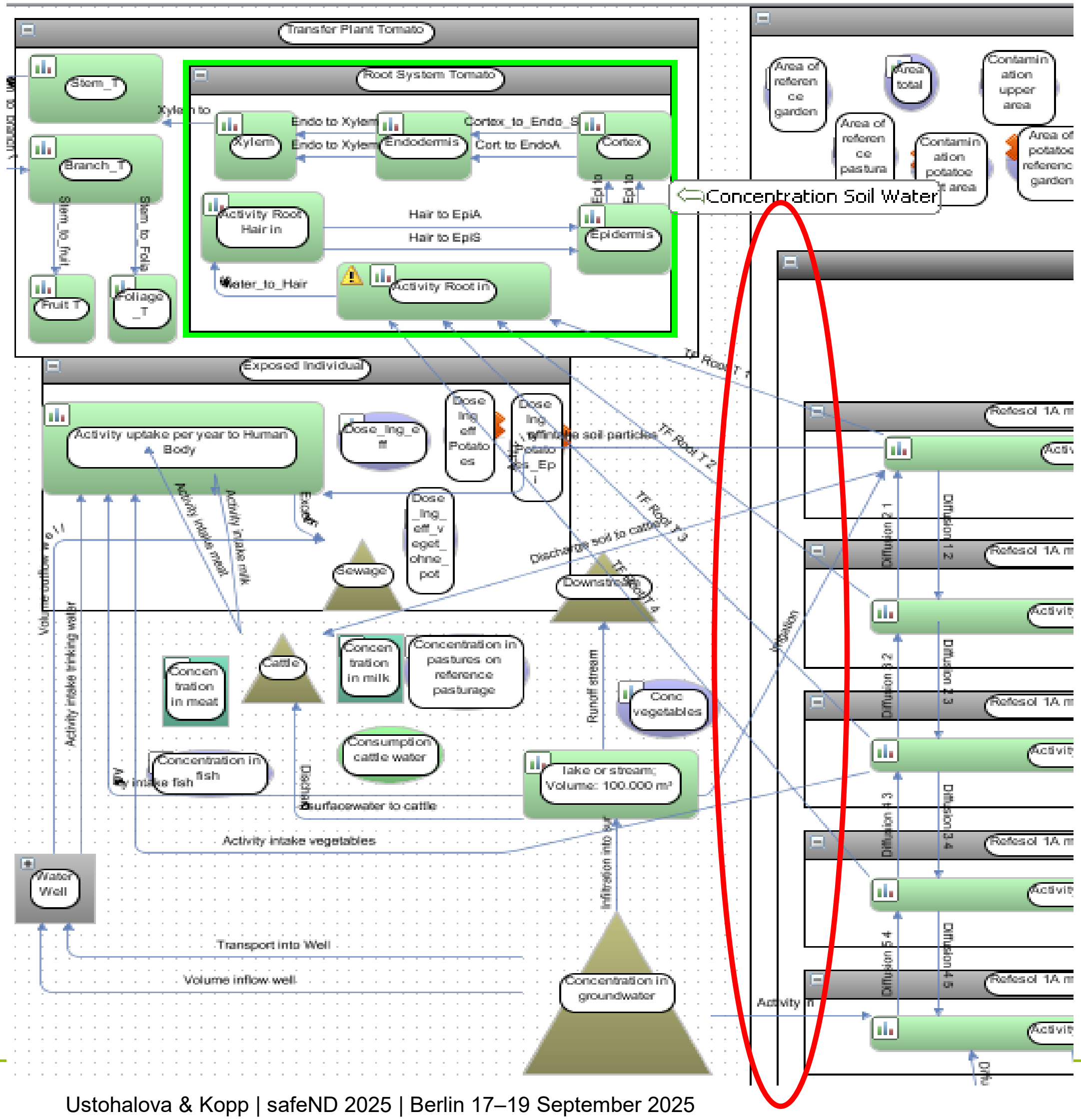
Colours indicate initial conditions for water content :





Picture lysimeter: TRAVARIS project meeting; Presentation M. Böhm / Institute of Geosciences at Friedrich Schiller University Jena

AfryISM model structure – model parts plant and dose estimation

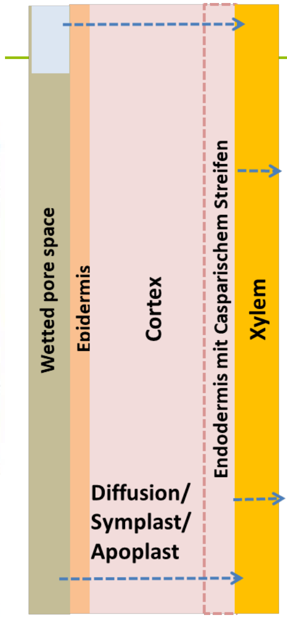


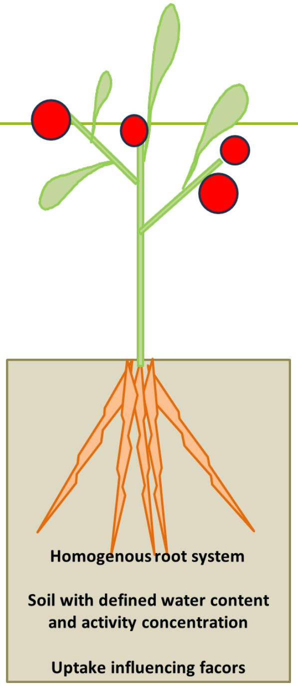
- Model structure of the plant
- Radionuclide uptake from several soil layers by considering the water content and radionuclide concentration
- Dose calculation according to German AVV* based on the resulting contamination of edible parts

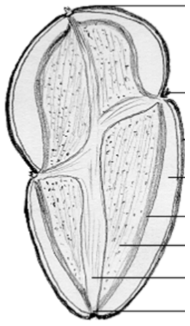
*General administrative regulation for determining the exposure of individuals in the population

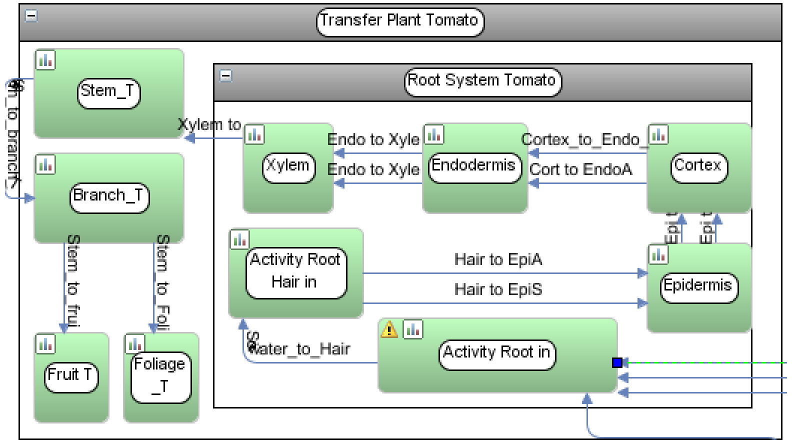
Model part Plant

- Plant type and radionuclide
- Root system/form and root depth, root area
  - Tomato - root depth 0,6 – 1,2m
  - Potato tuber - depth 0,2 – 0,5m
- Vegetation period/growth phase and radionuclide uptake
  - 1. implementing transfer factors (RN like Tc-99 dependence on the growth phase)
  - 2. influencing factors on the root/tuber exchange with the soil: soil properties (pH, P …..) and root exudates or transponters









Picture Rhizobox: TRAVARIS project meeting; Presentation of Institute of Radioecology and Radiation Protection at Leibniz University Hanover

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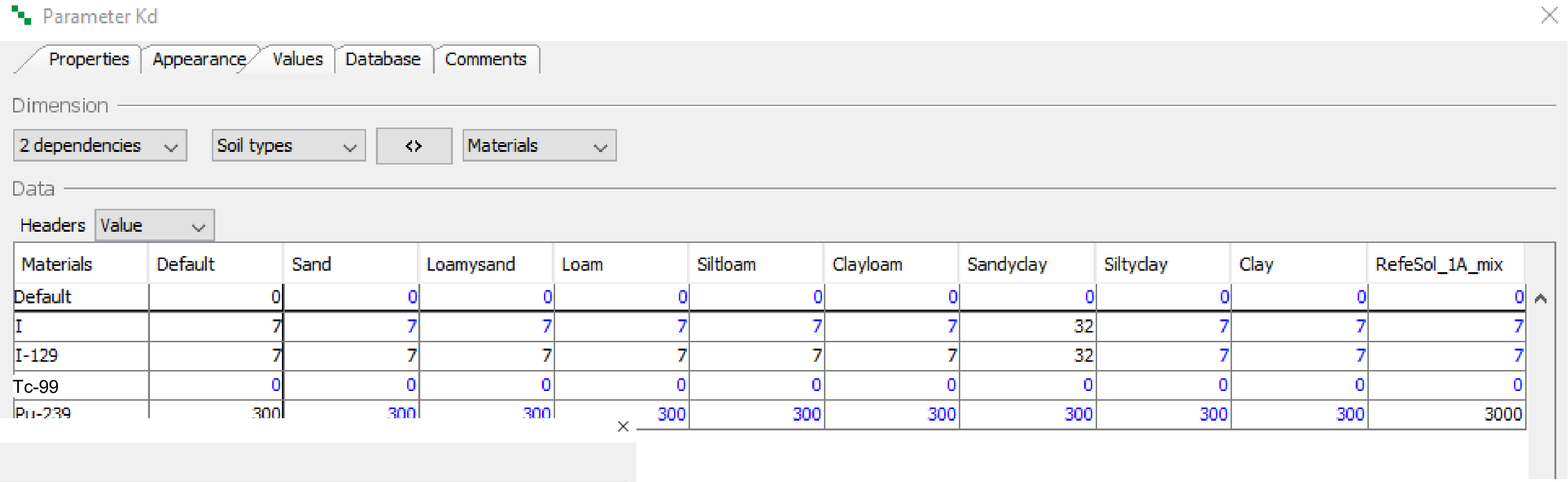
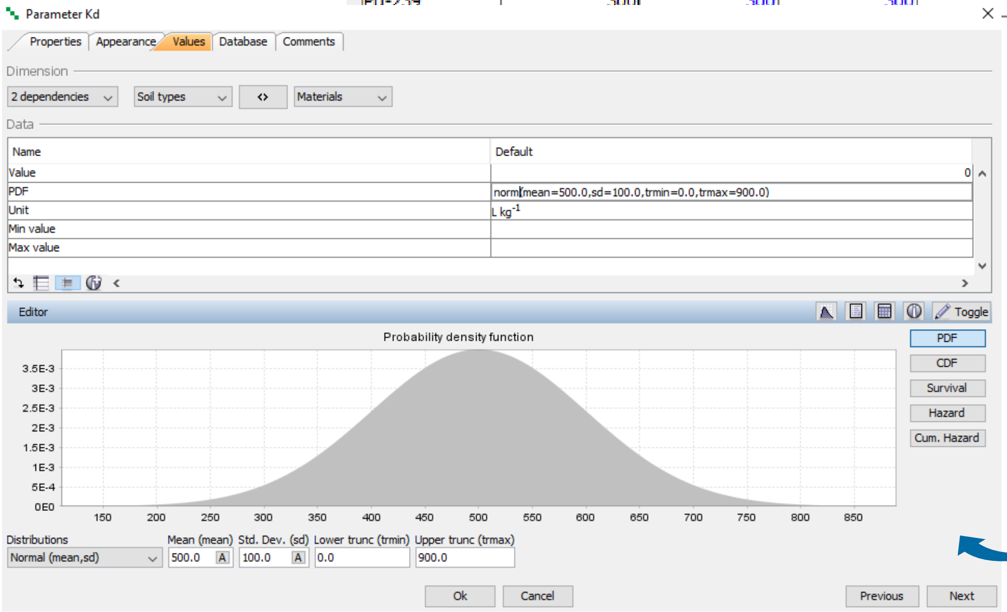
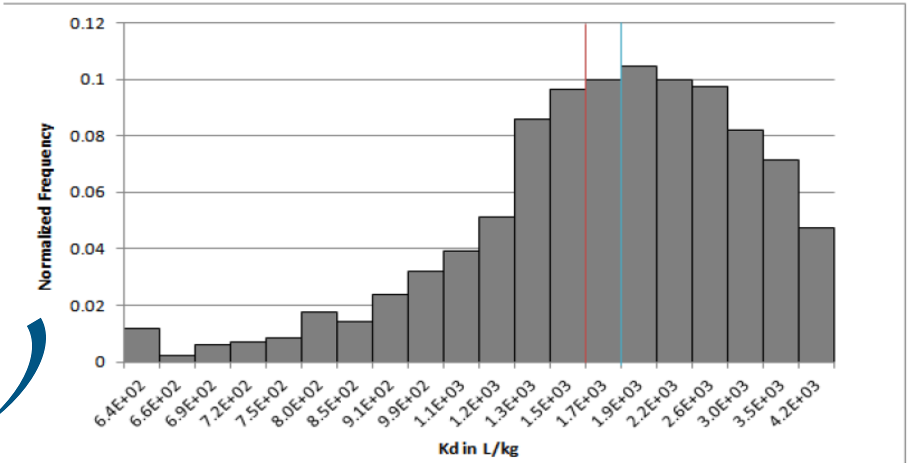
Deterministic / probabilistic simulation: Example of implementation of Kd-value variability



Materials	Default	Sand	Loamysand	Loam	Siltloam	Clayloam	Sandyclay	Siltyclay	Clay	RefeSol_1A_mix
Default	0	0	0	0	0	0	0	0	0	0
I	7	7	7	7	7	7	32	7	7	7
I-129	7	7	7	7	7	7	32	7	7	7
Tc-99	0	0	0	0	0	0	0	0	0	0
Pu-239	300	300	300	300	300	300	300	300	300	3000





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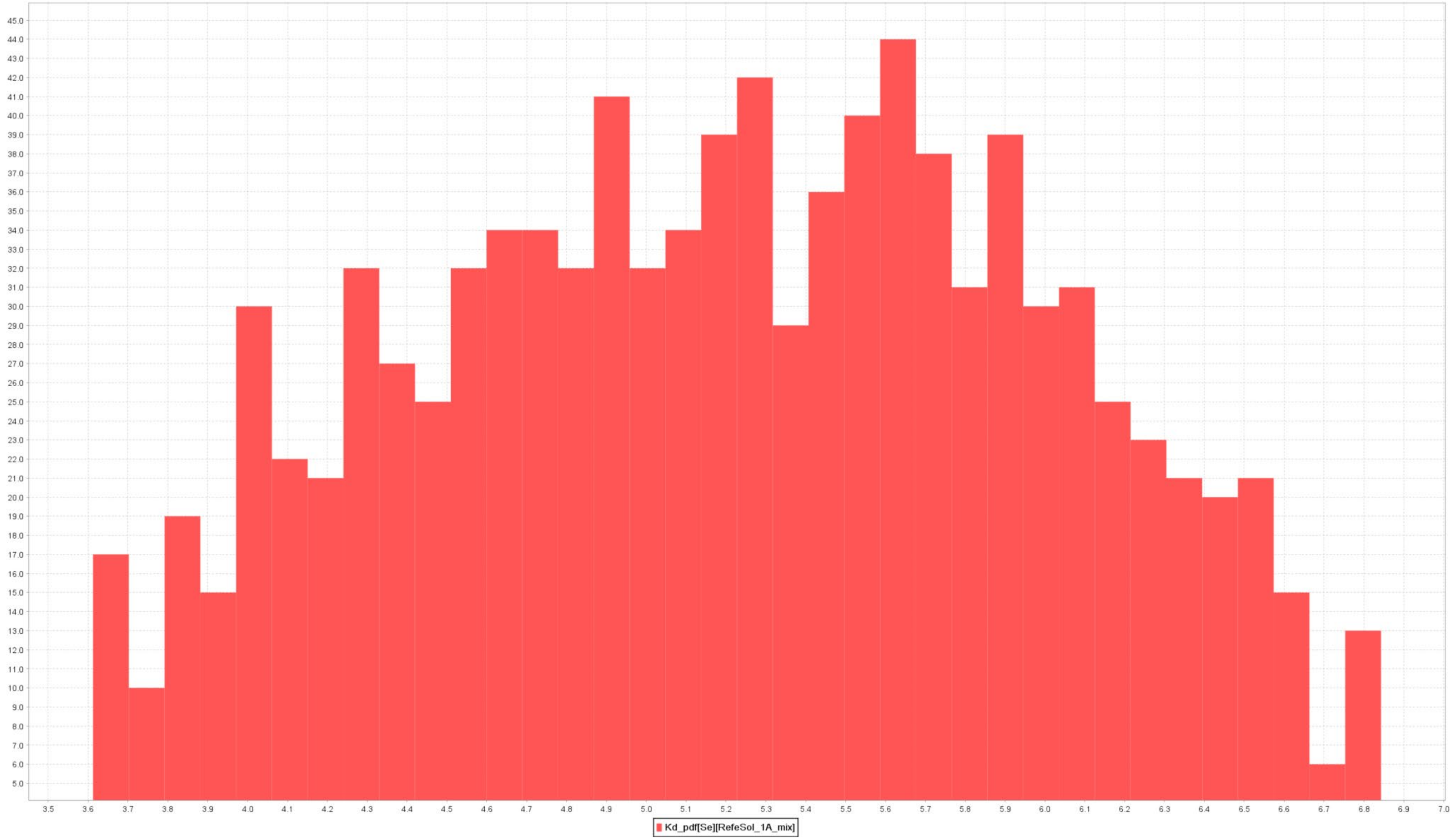
Example of K_d distribution for Selenium



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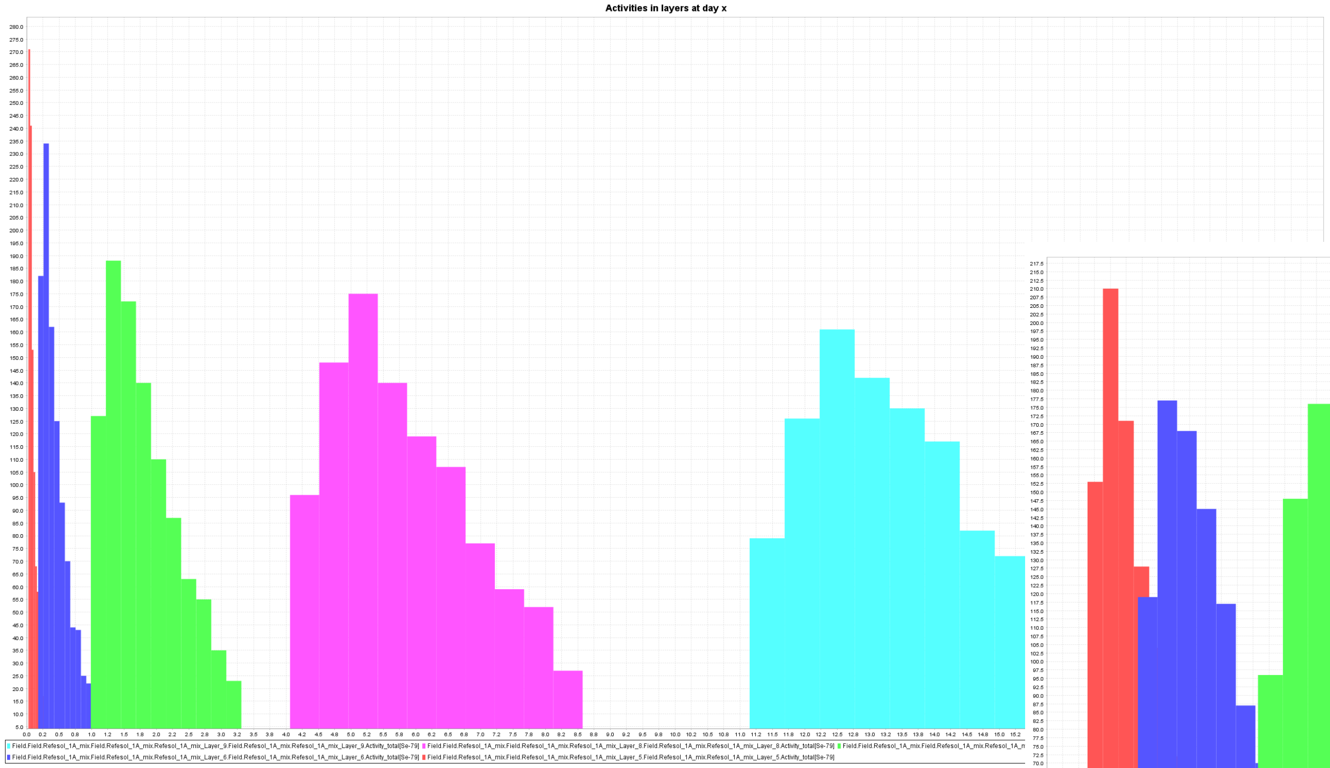
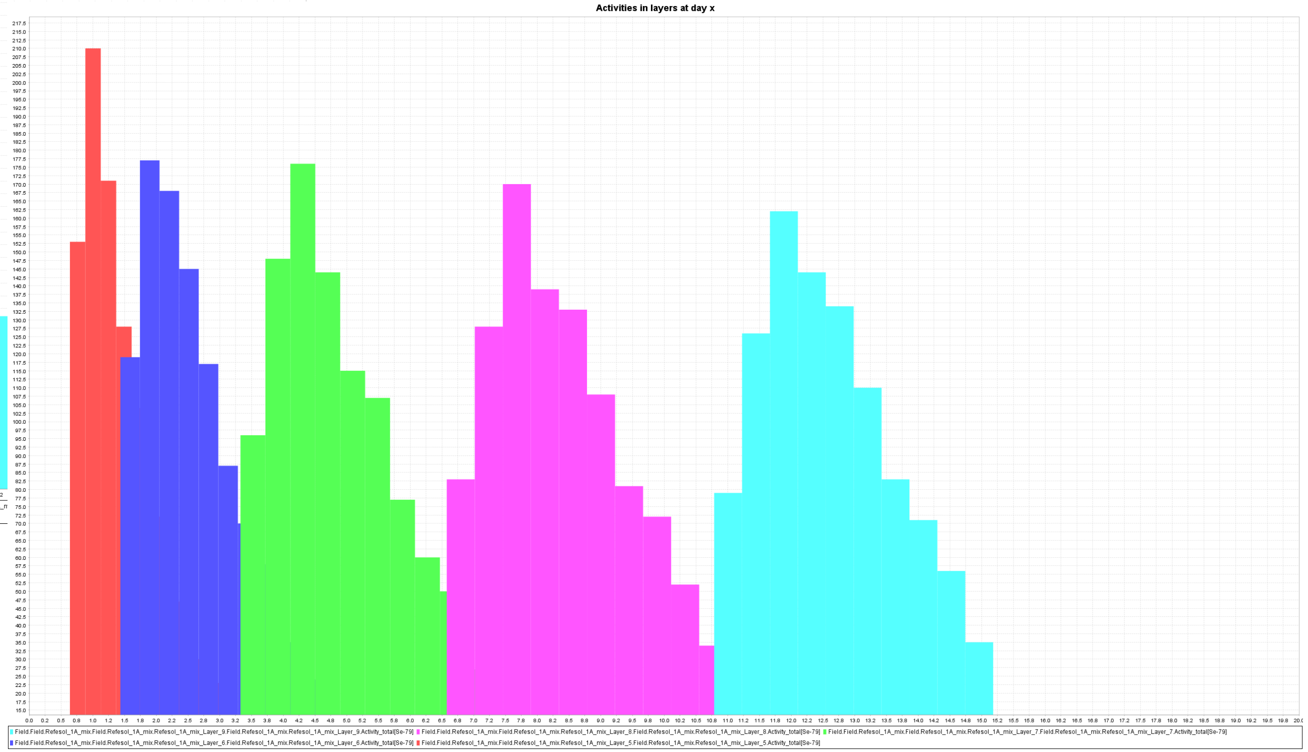
Frequency of Activities in layers at day 50 and 300





layer 5
layer 6
layer 7
layer 8
layer 9

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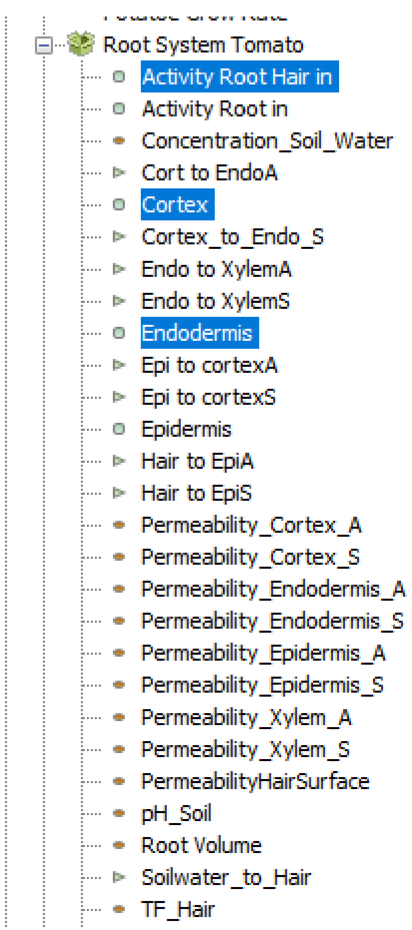
Uptake in the root system

Parameter		Dependencies				Data	References	Export info	
Name	Unit	Elements	Plant_spezies	Plant_Component	Soil_Texture	Value	Reference	Tags	ID
TF		I	potatoes	Root	Refesol_1Amix	16,69	IRS		Field.TF
TF		Tc	potatoes	Root	Refesol_1Amix	4,253	IRS		Field.TF
TF		Am	potatoes	Root	Refesol_1Amix	9,317	IRS		Field.TF
TF		Pu	potatoes	Root	Refesol_1Amix	6,14	IRS		Field.TF
TF		I	potatoes	EdibleP	Refesol_1Amix	0,267	IRS		Field.TF
TF		Tc	potatoes	EdibleP	Refesol_1Amix	0,418	IRS		Field.TF
TF		Am	potatoes	EdibleP	Refesol_1Amix	0,083	IRS		Field.TF
TF		Pu	potatoes	EdibleP	Refesol_1Amix	0,007	IRS		Field.TF

$$\frac{dc_{root,i,n}}{dt} = TF_{root,soil,n} * c_{Soil,i,n} - Tf_{Hair} * c_{Root,n,i}$$



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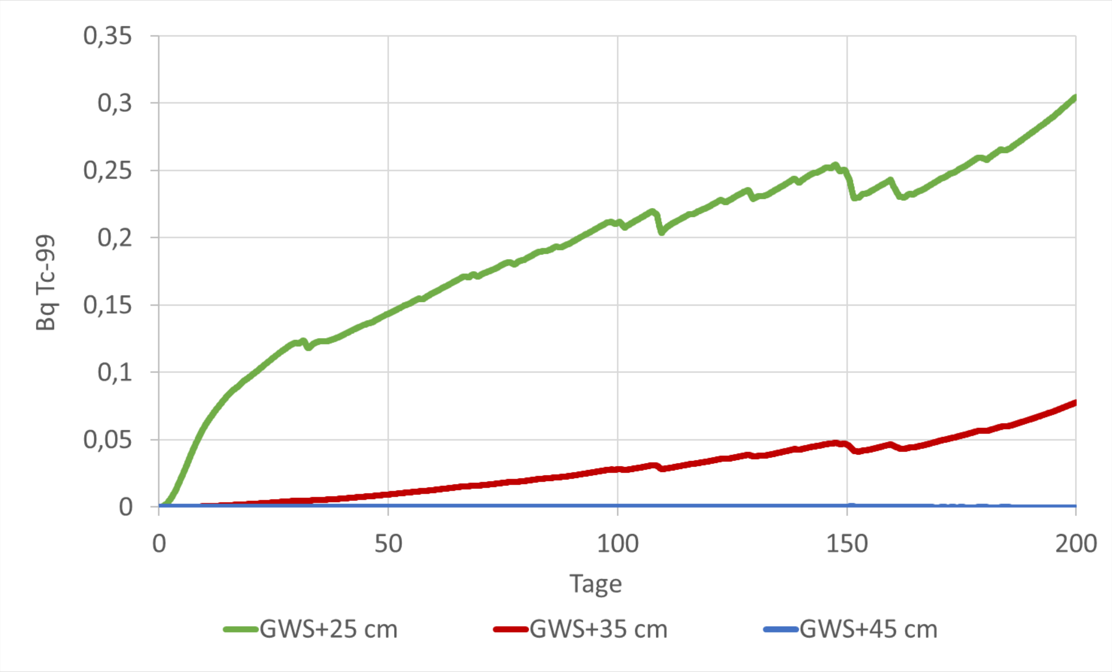
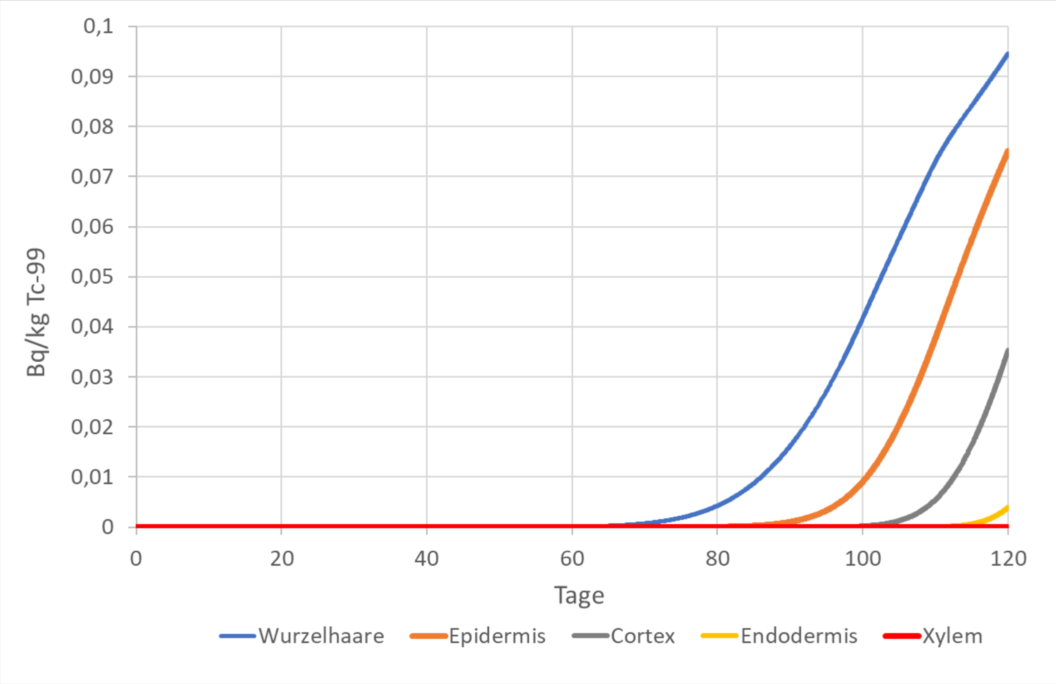
Uptake in the root system

Reduction in Tc-99 activity in the three soil layers above the GWL as a result of Tc-99 uptake by potato roots in the layers GWL+25 cm, GWL+35 cm, and GWL+45



Development of Tc-99 activity concentrations in the cell layers of the potato root until harvest (layer GWL+15 cm)



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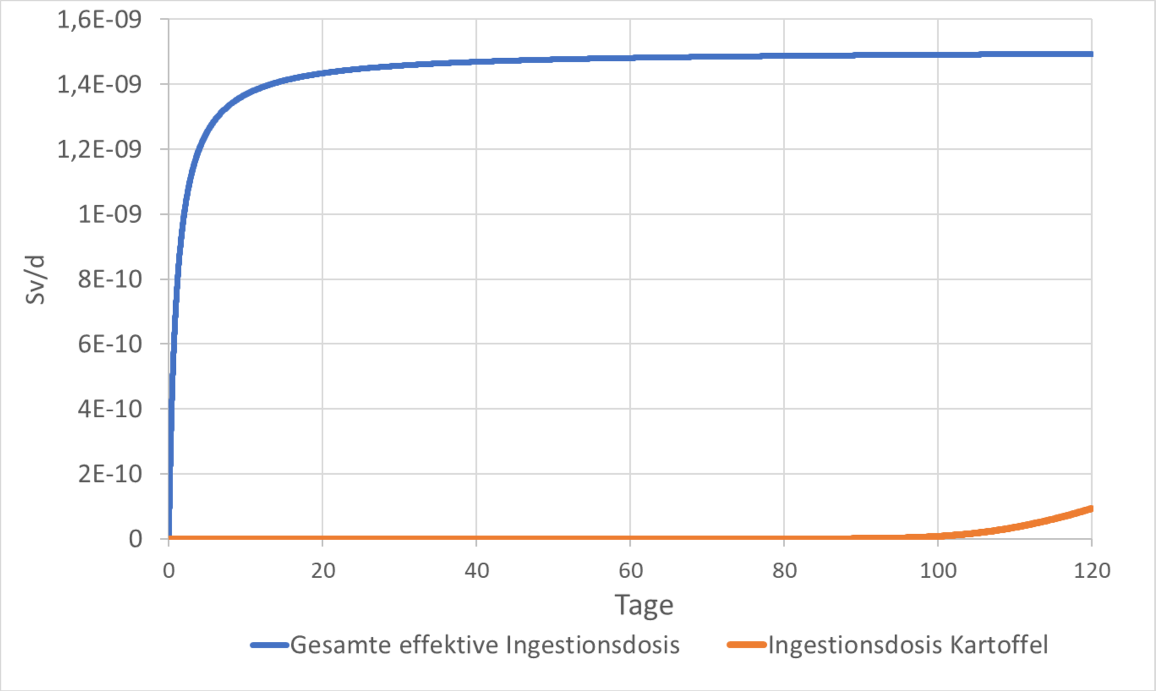
Dose estimation

- Hypothetical dose for Tc-99 for the most unfavourable age group <1 year compared to the total effective dose through ingestion



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Thank you for your attention!

Do you have any questions?

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