Modelling soil and soil - plant transfer processes of radionuclides and toxic chemicals at long time scales for performance assessment of Radwaste disposal

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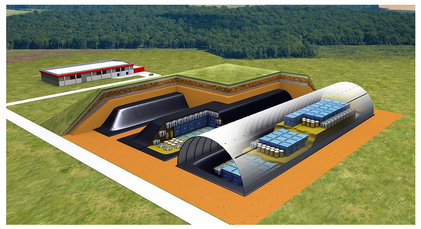
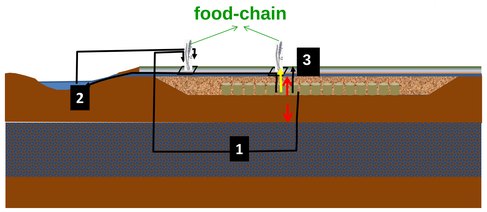
Problem statement:

Performance assessments for (near) surface nuclear waste disposal facilities require simulation of transfer processes from the waste canisters to a reference group living near-by. Such simulations need to be extended over several thousand years, restraining possibilities to represent short term system complexity and variability. Related modelling can be simplified as long as doses for radionuclides and risk factors for toxic chemicals are estimated larger compared to more realistic modelling approaches.



Of the 3 main entrance pathways to the human food chain: groundwater[1], river water[2], direct contamination via upward movement[3], the latter is quantified using a defined upward flux mixed continuously into a 2 m thick homogenised soil column (Aquabios model). For a more detailed evaluation of transfer within such a soil layer a multilayer transfer model (SAMM) has been developed.



The model (SAMM):

pore water concentration

depth, time

$$\frac{\partial C_{V\_eau}(z,t)}{\partial t} =$$

Marschner, 1995

advection/ infiltration	$Vi_z(z,t)\frac{\partial C_{V\_eau}(z,t)}{\partial z} + C_{V\_eau}(z,t)\frac{\partial Vi_z(z,t)}{\partial z}$	flow velocity: Infiltration/ capillary rise
upward movement	$-Vr_z(z,t)\frac{\partial C_{V\_eau}(z,t)}{\partial z} + C_{V\_eau}(z,t)\frac{\partial Vr_z(z,t)}{\partial z}$	
diffusion	$+D_a(z)\frac{\partial^2 C_{V\_eau}(z,t)}{\partial z^2} + \frac{\partial D_a(z)}{\partial z}\frac{\partial C_{V\_eau}(z,t)}{\partial z}$	apparent diffusion coefficient
decay / ingrowth (p = parent)	$-\lambda . C_{V\_eau}(z,t) + \lambda_p . \frac{[\theta + \rho_b . Kd_{sol\_p}]}{[\theta + \rho_b . Kd_{sol}]} C_{V\_eau\_p}(z,t)$	
root transfert	$-d_r(z).r.FT_{sp}\left(\frac{\theta}{\rho_b} + Kd_{sol}\right)C_{V\_eau}(z,t)$	water content, bulk density, solid/liq. distribution coefficient
root depth distribution, yield, soil/plant transfer factor		

Miquel, 2010; Miquel and Basso, 2010; Wheater et al. 2007

A numerical scheme for the resolution of the differential equations, based on a finite difference approach, (replacing differentials by differences using the Taylor-Young equation), is applied with calculations carried out in Matlab.

Soil - and U & Th transfer parameters

Matlab reads input parameters from an Excel sheet. We use a simple homogeneous 2 m soil column with 65% saturation, 50% porosity everywhere and grass root development only in the first 10 cm. The particle – solution distribution coefficient (Kd), the soil to plant transfer parameter (FTsp) and the decay constant (λ) need to be adapted for U-238 and Th-232:

Paramètres du sol				Paramètres du RN : r = 1			
Profondeur (m)	Degré de saturation (-)	Porosité du sol (-)	Distribution racinaire (%)	Kd (m^3/kg)	λ(/an)	FTsp (kgsec/kgfrais)	Do (m2/an)
0.1	0.65	0.5	100.0	6.00E-02	1.55E-10	0.00082	0.038
0.2	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
0.3	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
0.4	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
0.5	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
0.6	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
0.7	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
0.8	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
0.9	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
1	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
1.1	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
1.2	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
1.3	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
1.4	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
1.5	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
1.6	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
1.7	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
1.8	0.65	0.5		6.00E-02	1.55E-10	0.00082	0.038
1.9	0.65	0.5		6.00E-02	1.55E-10	0.00082	0
2	0.65	0.5		6.00E-02	1.55E-10	0.00082	0
Aquifère	1	0.5		6.00E-02			

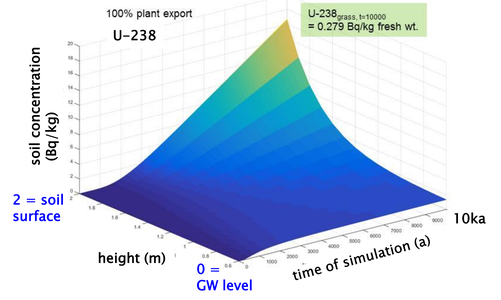
5.4 4.9e-11 2.7e-5

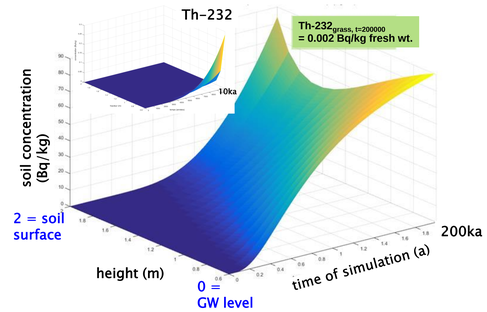
Groundwater contamination and hydrology:

When simulating upward transfer we define an advective flux of 1 Bq.m^{-2}.an^{-1} from the groundwater, contaminated at 20 Bq.m^3 with either U-238 or Th-232 in this example, into the soil. Downward flow of water is avoided by considering precipitation not to percolate through the column. The upward flux – not physically fully justified – can be seen as a capillary rise. Diffusion losses are prevented by applying a diffusion coefficient (D_0) of 0 in the compartments in contact with the ground water.

Result:

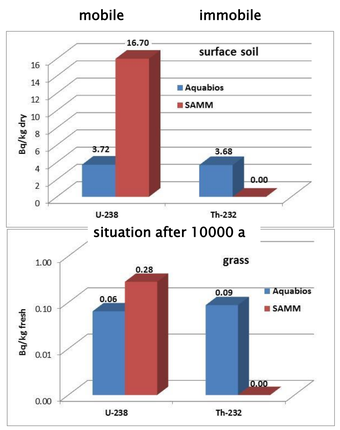
U, considered relatively mobile (Kd =0.06m^3.kg^{-1}) can move up the soil column to reach the root zone, from where transfer into grass (assumed cut and exported out of the system each year) is possible. Th, much less mobile (Kd =5.4m^3.kg^{-1}) does not reach the surface after 10ka, but only after a much longer simulation period.

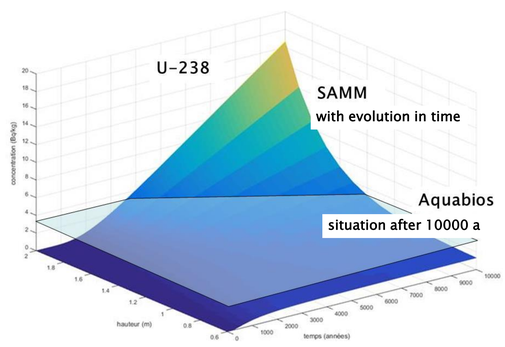




Comparison with fully homogenised soil model (Aquabios):

For mobile radionuclides (U-238) a finer model approach (SAMM) leads to higher surface soil and plant concentrations in comparison to the fully homogenised approach. The homogenised approach can thus not be considered conservative. But the factor 4.5 (case of U-238) remains below the general uncertainty level of one order of magnitude characteristic for long-term dose assessments. Immobile radionuclides tend to remain in the lower part of the soil profile; the homogenised model thus strongly overestimates the actual impact.





Conclusions:

- **A refined approach for modelling soil upward transport indicates the degree of conservatism (immobile radionuclides) as well as the degree of underestimation (mobile radionuclides).**
- **The refined approach allows going beyond the use of generic transfer parameter values with the application of measured depth dependent data (Kd, root uptake and distribution; data available but not shown here).**
- **It allows also to quantify the likelihood of the pessimistic hydraulic scenario that permits advective upward movement even in a temperate climate.**
- **In spite of the very long simulation periods the more detailed multilayer approach helps remaining somewhat closer to physical reality.**
- **Uranium also needs to be considered as a toxic chemical; the model approach for non radioactive toxic chemicals is identical to the one shown above (with the decay constant λ = 0).**

Marschner, H., 1995. Mineral nutrition of higher plants. Academic Press, London, 889 p
Miquel, S., 2010. Adaptation du modèle sol multicouche pour les applications FAVL-Radifère du Programme Scientifique; Rapport final. Rapport N°: F.RP.FSTR.10.0006.A, Société de Calcul Mathématique, S.A., Paris.
Miquel, S.et Basso, M., 2010. Considération d'une fluctuation du niveau de la nappe dans le modèle sol multicouche : Applications au Programme Scientifique FAVL-Radifère; Rapport final. Rapport N°: F.RP.FSTR.10.0017.A, Société de Calcul Mathématique, S.A., Paris.
Wheater, H.S., Bell, J.N.B., Butler, A.P., Jackson, B.M., Ciciani, L., Ashworth, D.et Shaw, G., 2007. Biosphere implications of deep disposal of nuclear waste - The upwards migration of radionuclides in vegetated soils. Imperial College Press, London.

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