Nuclear test plutonium and radioceasium dispersion in lakes ecosystems: experimental data and novel modelling approach

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Problem

Commonly, migration of the technogenic radionuclides from water into soil and bottom sediments in the natural environment is described by one-stage models. The main drawback of such models is related to the fact that the radionuclide diffusion coefficient in sediments decreases with time.

However, analyses of radionuclide vertical profiles in carbonate bottom sediments as well as results of laboratory experiments show that the process proceeds in two temporal stages. The first fast migration stage is governed by the light ion transfer. The resulting vertical profile of the radionuclide activity concentration in sediments is exponentially decreasing with depth. The second migration stage is slow. It involves the main significant processes: bioturbation, sedimentation as well as the first order kinetic reactions and radioactive decay.

In the case of accidental appearance of radionuclides in water systems the one-phase model cannot be properly employed to predict the long-term consequences of radionuclide migration into zones where they are mostly accumulated - bottom sediments and soil solid phase. Application of the correct model of radionuclide behavior in the radioactive waste storage environment and in water saturated soils is of great concern as well.

Solution

The two-phase mathematical model of the radionuclide vertical migration in the water saturated solids (bottom sediments and soil). There is considered process of slow sorption and description of the radionuclide mobile fraction by solid particles.

Transport of the radionuclide in the two-phase environment is described by 1-D advection-diffusion equations, separately for the liquid volumetric activity c and flux [-c] and solid phase specific activity c and flux [-c].

\[
\frac{\partial (\theta c)}{\partial t} - \nabla \cdot (\theta \mathbf{v}) = \nabla \cdot ( \alpha \nabla c - \rho c) = - \frac{\partial \rho c}{\partial t} + \nabla \cdot ( \alpha \mathbf{v} )
\]

Stage (I)

Advection-dispersion, degradation and non-equilibrium exchange between phases during the stage (I) together with the boundary conditions and zero initial conditions belongs to the boundary value problem (BVP) solution.

\[
f(c) = -D c + y c
\]

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\]

\[
\frac{\partial (\rho c)}{\partial t} - \mathbf{v} \cdot \nabla \rho c = - \frac{\partial \rho c}{\partial t} + \mathbf{v} \cdot \nabla ( \mathbf{v} ) c + \rho c
\]

Stage (II)

Profile of the contamination distribution, obtained from the stage (I), is used as an initial conditions for calculating the solution of the two phases concentration distributions in the stage (II).

Boundary conditions for the stage (II):

\[
\left\{ \begin{array}{l}
\frac{\partial c}{\partial t} + \mathbf{v} \cdot \nabla c = - \frac{\partial \alpha c}{\partial t} + \mathbf{v} \cdot \nabla ( \alpha ) c, \\
\alpha (s,t) = f(s) = f_1(s, \exp(\alpha_1 s)), \\
\alpha (s,t) = f(s) = f_2(s, \exp(\alpha_2 s)). 
\end{array} \right. 
\]

Initial conditions for the stage (II):

\[
\left\{ \begin{array}{l}
\alpha (s,0) = f(s) = f_1(s, \exp(\alpha_1 s)), \\
\alpha (s,0) = f(s) = f_2(s, \exp(\alpha_2 s)). 
\end{array} \right. 
\]

Conclusions

The two stage and two phase (liquid and solid) radionuclide migration in the water-sediments ecosystem model is suitable for better prediction of the long-term consequences of radionuclide accumulation and transport after the accidental contamination of lake water.

References: