Geophysical Research Abstracts
Vol. 14, EGU2012-7196, 2012
EGU General Assembly 2012

Estimation of aquifer radionuclide concentrations by postprocessing of conservative tracer model results

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Radionuclide concentrations in aquifers represent an important indicator in estimating the impact of a planned surface disposal for low and medium level short-lived radioactive waste in Belgium, developed by the Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS), who also coordinates and leads the corresponding research.

Estimating aquifer concentrations for individual radionuclides represents a computational challenge because (a) different retardation values are applied to different hydrogeologic units and (b) sequential decay reactions with radionuclides of various sorption characteristics cause long computational times until a steady-state is reached.

The presented work proposes a methodology reducing substantially the computational effort by postprocessing the results of a prior non-reactive tracer simulation. These advective transport results represent the steady-state concentration – source flux ratio and the break-through time at each modelling cell. These two variables are further used to estimate the individual radionuclide concentrations by (a) scaling the steady-state concentrations to the source fluxes of individual radionuclides; (b) applying the radioactive decay and ingrowth in a decay chain; (c) scaling the travel time by the retardation factor and (d) applying linear sorption. While all steps except (b) require solving simple linear equations, applying ingrowth of individual radionuclides in decay chains requires solving the differential Bateman equation. This equation needs to be solved once for a unit radionuclide activity at all arrival times found in the numerical grid. The ratios between the parent nuclide activity and the progeny activities are then used in the postprocessing.

Results are presented for discrete points and examples of radioactive plume maps are given. These results compare well to the results achieved using a full numerical simulation including the respective chemical reaction processes.

Although the proposed method represents a fast way to estimate the radionuclide concentrations without performing timely challenging simulations, its applicability has some limits. The radionuclide source needs to be assumed constant during the period of achieving a steady-state in the model. Otherwise, the source variability of individual radionuclides needs to be modelled using a numerical simulation. However, such a situation only occurs in cases of source variability in a period until steady-state is reached and such a simulation takes a relatively short time.

The proposed method enables an effective estimation of individual radionuclide concentrations in the frame of performance assessment of a radioactive waste disposal. Reducing the calculation time to a minimum enables performing sensitivity and uncertainty analyses, testing alternative models, etc. thus enhancing the overall quality of the modelling analysis.