Sensitivity Analysis of Simulating Radionuclide Decay Transport of Low-level Radioactive Waste in Nearshore Environment

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Abstract

Tunnel disposal at nearshore environment is one of potential final disposal sites proposed for the low-level waste in Taiwan. The proposed tunnel disposal facilities were located roughly 800 m away from the shoreline and 50 m below sea levels. Geosphere parameters, sea levels, and infiltration rates are critical to radionuclide decay transports in far-field environments. A radionuclide decay chain of 4N+2, including Pu-238 → U-234 → Th-230 → Ra-226, was simulated by the 3-D HYDROFEOCHE5.6 numerical model for sensitivity analysis of far-field radionuclide decay transport for 100,000 years with steady flow and transient transport. Hydraulic conductivities, diffusion coefficients, and dispersivities were selected for sensitivity analysis of geosphere parameters. With 10 times higher of hydraulic conductivities than reference values, the Pu-238 concentrations are higher and peak concentration appear earlier at shorelines. However, the Ra-226 concentrations simulated with 10 times higher/lower hydraulic conductivities are all lower than those with reference values at shorelines. Higher hydraulic conductivities will favor migration of mother radionuclides of Pu-238, U-234, and Th-230 before decaying to Ra-226 at shorelines, while 10 times lower of hydraulic conductivities will hinder migrations of all radionuclides considered in this study. Sensitivities of diffusion coefficients on radionuclide decay transport are not significant in this study. Cases with 10 times higher/lower dispersivities than reference values deliver higher/lower concentrations for all radionuclides at shorelines. Considering radionuclide decay transport in association with changes of geosphere parameters are much more complicated than single species simulations. Changes of sea levels and infiltration rates are designed to investigate changes boundary conditions on radionuclide decay transport through changes of fields. Reliable site investigations are crucial to reliabilities of far-field radionuclide transport simulations.

1. Introduction

Nuclear power generation is one of Taiwan's major power resources, second only to thermal power generation. Although relatively less greenhouse gases emitted by nuclear power generations, the resulting radioactive wastes produced great environmental concerns and debates in safety of waste managements. Geological waste repositories have been constructed to isolate radioactive wastes from the environments in many countries. After regional surveys and preliminary site investigations, the

Ministry of Economic Affairs officially announced two potential sites, One in Daren Township located in southeast Taiwan and another in Wuciou Township located in an offshore island of Kinmen, selected for the final disposal of low-level radioactive waste in Taiwan (2012). Confidences and acceptances of waste final disposal in designed repositories require demonstrations of long-term safety with numerical simulations. The lack of knowledge and other uncertainties in the calculation conditions may create various uncertainties due to scenario uncertainty, system uncertainty, model uncertainty, parameter uncertainty, and spatial variations in parameters (SKB, 2014). In this study, we mainly focus on geosphere parameters of the Daren site by performing sensitivity analysis to investigate influences of geosphere parameter uncertainties on radionuclide decay transports in far-field geosphere. Waste repository of the Daren case was designed with multiple engineering barriers of tunnel disposal in stable formations isolated from human inhabitants. Sensitives of geosphere parameters, sea levels, and infiltration rates on far-field radionuclide decay transport are simulated for 100,000 years by a special version of a 3-D HYDROGEOCHEM5.5 (Yeh et al., 2009) A radionuclide decay chain of 4N+2 series, including Pu-238 → U-234 → Th-230 → Ra-226, is considered with simulations of steady flow and transient decay transport. The evaluation of parameter sensitivities is an important part of the safety assessment to identify individual parameters with a strong influence on radionuclides migrations and support the need of detailed site investigations.

2. Methodology

The digital elevation model delineated around the Daren waste repository was shown in the top left of Fig. 1 (left) and discretized with 5970 nodes and 4749 hexahedral elements. The disposal tunnel having a dimension of 1200 m in length, 800 m in width, and 20 m in height, roughly 800 m away from the shoreline and 50 m below current sea levels, was considered as an internal source of releasing radionuclides. A radionuclide decay chain of 4N+2 series, including Pu-238 → U-234 → Th-230 → Ra-226, was simulated with initial concentrations of unity for Pu-238 and zero for the three daughter radionuclides. Flow and transport parameters given for the reference case were listed in Table 1. Four observation points at different surface locations as show in Fig. 1 (right) were selected to compare the release of radionuclides in terms of peak concentration values and peak concentration times.

The 3-D HYDROFEOCHE5.5 (Yeh et al., 2009) is a three-dimensional finite element numerical model capable to simulate coupled fluid flow, thermal transport, and hydrogeochemical transport through variable saturated subsurface. A special version of HYDROGEOCHEM5.5, namely HYDROGEOCHEM5.6, with improved capability of handling decay chains was used in this study for simulations of steady flow and transient decay transport for 100,000 years. Sensitivities of geosphere parameters were examined with simulation settings as the following,

1. Changing hydraulic conductivities with values of 10 times (or 0.1 times) to the reference values
2. Changing diffusion coefficients with values of 10 times (or 0.1 times) to the reference values
3. Changing longitudinal and lateral dispersivities with values of 10 times (or 0.1 times) to the reference values

The second part of sensitivity test involves combinations of changes in infiltration rates, sea levels, and hydraulic conductivities as shown in Table 2. The infiltration rate in the reference case was set as 3% of annual rainfalls. We increased the infiltration arte to 10% of annual rainfall as the case of elevated seepages due to changes in precipitation or landuse. Following the studies by the Sinotech Engineering Consultants, LTD (2013), gradually decreased of sea levels to 66 m below current position was considered. Therefore, there are 12 simulation cases (i.e., 2 infiltration rates, 2 sea levels, and 3 hydraulic conductivities) examined in this study as listed in Table 2.

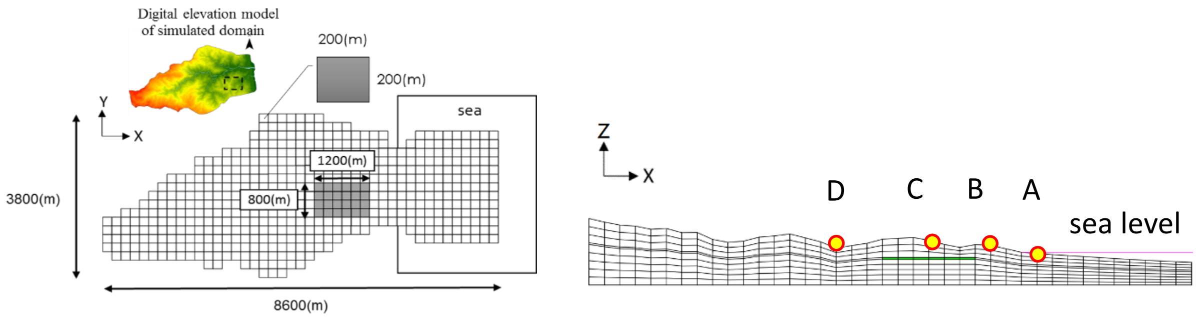

Figure 1 Elements and scales of far-field simulations in plan view (left) and selected observation points in vertical view (right)

Table 1 Parameters given in the reference case

	Simulation setting			
Vertical layer	9	Height		25~85(m)
Horizontal layer	529	Length & width		200(m)*200(m)
Total nodes	5970	Total elements		4749
Flow parameters		layer1	layer2	layer3
	$k_x = k_y$	$3*10^{-2}$ (m/day)	$3*10^{-3}$ (m/day)	$3*10^{-5}$ (m/day)
	k_z	$8.9*10^{-2}$ (m/day)	$8.9*10^{-3}$ (m/day)	$3*10^{-5}$ (m/day)
	Porosity	0.08	Infiltration rate	0.0003(m/day)
Transport parameters	Longitudinal dispersivity		800(m)	
	Lateral dispersivity		200(m)	
	Diffusion coefficient		10^{-4}(m^2/day)	

Table 2 Lists of combined sensitivity tests with changes of infiltration rates, sea level, and hydraulic conductivities

Case	1	2	3	4	5	6	7	8	9	10	11	12
Infiltration rates	3%	3%	3%	10%	10%	10%	3%	3%	3%	10%	10%	10%
Sea levels change	×	×	×	×	×	×	○	○	○	○	○	○
Hydraulic Conductivities (times)	0.1	1	10	0.1	1	10	0.1	1	10	0.1	1	10

3. Results and Discussions

Figure 2 presents comparisons of relative concentrations at surface Point A with different hydraulic conductivities. Concentrations and peak arrival times of Pu-238, U-234, Th-230 with 10 times hydraulic conductivities are higher and faster, respectively, than those at Point A of the reference case. However, concentrations of Ra-226 with 10 times hydraulic conductivities are smaller than those at Pont A of the reference case due to fast migration of mother radionuclides. Differences in concentrations as changes in hydraulic conductivities observed at Points B, C, and D, are more significant than those observed at Point A due to those locations are close to repository tunnel. As well, effects of changes in hydraulic conductivities on peak arrival times at Points B, C, and D are less significant than those observed at Point A. Effects of changes in diffusion coefficients are insignificant in all cases and observation points as the example depicted for Point A in Fig. 3. Figure 4 presents Comparisons of relative concentrations at surface Point A with different dispersivities. Concentrations and peak arrival times of all radionuclides with 10 times dispersivities are higher and faster, respectively, than those at Point A of the reference case.

The second part of sensitivity simulations involves combinations of changes in infiltration rates, sea level, and hydraulic conductivities. Figure 5 presents comparisons of relative concentrations of Pu-238 simulated with 12 cases observed at surface Point A. At Point A, changes in hydraulic conductivities have the most significant effects on concentrations and peak arrival time of Pu-238 among both factors of changes in infiltration rates and sea levels in this study. Although changes in infiltration rates to 10% of annual precipitations may increase seepage rates favoring radionuclide migrations, the increased infiltrated water, on the other hand, may dilute radionuclide concentrations as well. Changes in sea levels lower than current positions cause the surface Point A became drier than the reference case, which may hinder radionuclide migration due to less saturated conditions.

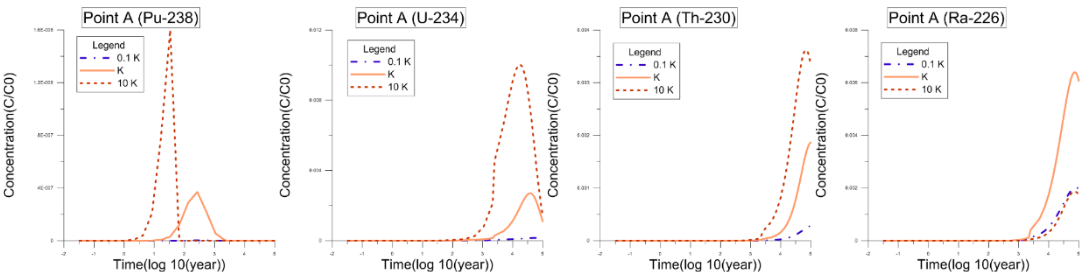

Figure 2 Comparisons of relative concentrations at surface Point A with different hydraulic conductivities

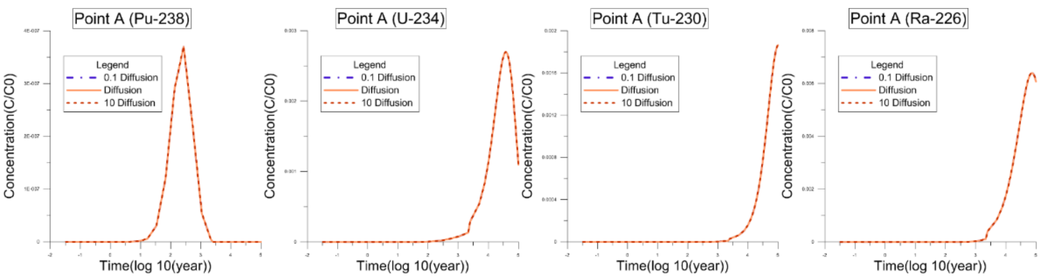

Figure 3 Comparisons of relative concentrations at surface Point A with different diffusion coefficients

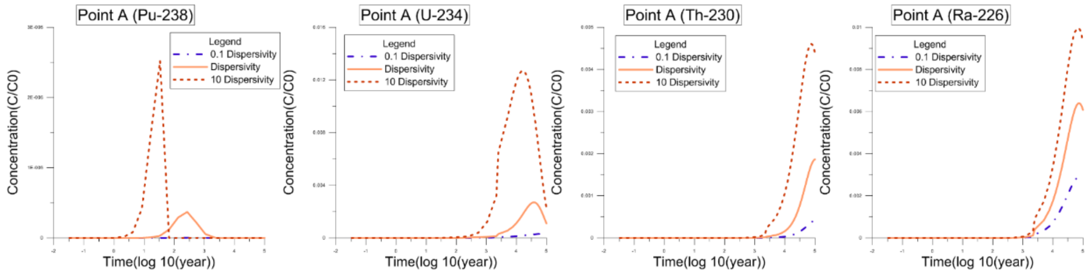

Figure 4 Comparisons of relative concentrations at surface Point A with different dispersivities

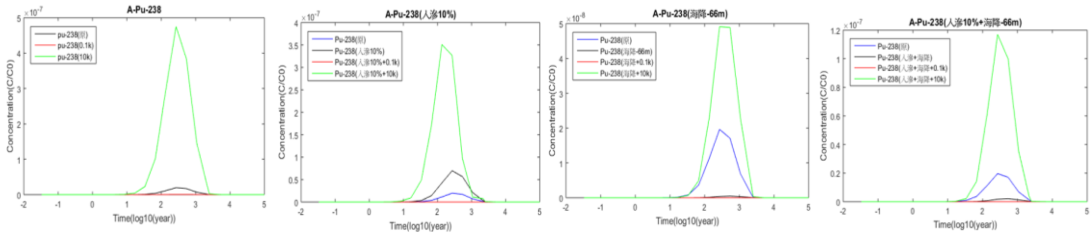

Figure 5 Comparisons of relative concentrations of Pu-238 simulated with 12 cases observed at surface Point A

4. Conclusion

This study performs numerical simulations to investigate sensitivities of geosphere parameters, including hydraulic conductivities, diffusion coefficients, and dispersivities, on far-field radionuclide decay transports of the potential low-level disposal site in Taiwan. Among three geosphere parameters examined, hydraulic conductivities are the most important parameters affecting radionuclide decay transport in views of changes in peak concentrations and peak arrival times. However, increased in hydraulic conductivities may have opposite effects on daughter radionuclide than those on mother radionuclide due to fast migrations of mother radionuclides reaching outside of domain. We further designed 12 simulation cases with combinations of changes in infiltration rates, sea levels, and hydraulic conductivities. Among three variables examined in the 12 simulation cases, changes in hydraulic conductivities have the most significant effects on radionuclide decay transports than those of considering changes in infiltration rates and sea levels. Increases in infiltration rates may dilute radionuclide concentrations. Decreases in sea levels may cause surface points of observations became drier than those in the reference sea levels, which may hinder migrations of radionuclides. The evaluation of uncertainties is an important part of every safety assessment. Uncertainties should be discussed and examined in depth through sensitivity simulations of selecting calculation cases. This study only stands as a very preliminary step on sensitivity analysis of radionuclide decay transport in one of potential low-level repository in Taiwan. Further investments including site investigations and modelling practices are crucial to the confidence and acceptance of our final disposal site.

5. References

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