Modelling of radionuclide migration in a generic deep geological repository in granitic host rock considering engineered and natural barrier interaction

Povilas Balčius [1], Dalia Grigaliūnienė [1]

1 Lithuanian Energy Institute, Nuclear Engineering Laboratory

Keywords: Deep geological repository, radionuclide migration, radionuclide sorption.

Introduction

Deep geological repositories (DGR) are considered as a standard end-point for long-lived low and intermediate level radioactive waste (RAW) management. An extensive safety assessment is important during the design and construction process of such installations. This helps to take into account the possible leaching of potentially dangerous substances into the environment surrounding the DGR. To perform such assessment, it is important to take into account interaction of engineered and natural barriers, their evolution and capability to retain radionuclides.

The aim of this work is to investigate radionuclide release from a generic DGR, and migration into the host rock, considering the changes in natural and engineered barrier properties due to their interaction.

Modelling approach

A model of pH changes in cement was done to analyze cement degradation was done in previous work [1]. A 1D case was selected: granitic water infiltration through the left boundary (**Fig. 1**) of the system over a time period of 1E+5 years was modelled. This data is then used for radionuclide migration and sorption evaluation models over the same period of time. pH change is linked to cement degradation stages. Degradation state of concrete has an impact on Kd in concrete. Water from concrete percolates into granite, changing the pH values and Kd [2, 3]. HYDRUS 1D [4] modelling software was used for calculation.

Using this data radionuclide sorption and transport modelling is performed. 4 cases were modelled in total:

Variant 1 (Var_1) – Constant Kd value as a base case was modelled;

Variant 2 (Var_2) – Same as Var_1 but with the 1 m thick EDZ around the cementitious barriers influencing radionuclide transportation;

Variant 3 (Var_3) –Kd change based on the change of pH in the system was modelled;

Variant 4 (Var_4) –Kd change and EDZ influence on radionuclide transport was modelled.

System description

A low and intermediate long-lived RAW disposal cell in granitic rock is considered with a potential EDZ (excavation damaged zone), see **Fig. 1**. The repository consists of a multilayer concrete barrier system: cementitious material backfill (1.1 m thick), functional concrete barriers (0.2 m thick) and the waste cell with cemented waste (7.4 m). The size in EDZ can vary from 0.3 m to 2.5 m depending on excavation technique [5]. The considered EDZ in this work is 1 m. The total length of the modelled domain is 30 m. The measurements of modelled domains and system scheme are provided in **Fig. 1**. Water flow through the system is modelled as a constant flux of 7.35E-6 m/y. of granitic pore water, that causes cement barrier degradation [6].

Kd values used in the models are provided in **Tables 1** and **2**. Differently sorbing radionuclides were modelled: I-129 (low-sorbing), Ni-59 (medium-sorbing) and Pu-239 (strong-sorbing).

Results and discussion

Modelling of concrete degradation in the considered system reached only stage 2 (equilibrium with portlandite) of degradation, see **Table 1**, having a negligible impact on sorption values in cementitious materials. In granite, percolating cement pore water causes significant pH and Kd value changes.

I-129 flux was only minorly impacted on differing models due to its very low sorption in cement-based materials and no sorption in granite. Only a slight change in I-129 flux outgoing from the modelled domain was observed, see **Fig. 2**.

A larger effect on Ni-59 fractional concentration profiles and flux can be observed. (**Fig. 3a**) . In Var_1 nickel migrates through 1 m of host rock at 4E+4 years, see **Fig. 3b.** When taking into account Kd changes (Var_3) nickel migrates slower (at 1 m depth in granite it appears 1.5E+4 years later). When taking into account the pH change induced Kd changes, the increased Kd of nickel lead to a slower migration. Modelling of the EDZ (Var_2 and Var_4) provided faster migration in the EDZ. Due to increased flow Ni-59 migrates up to 3 m deep into granite (**Fig. 3a**) at the end of the modelled time (1E5+ years).

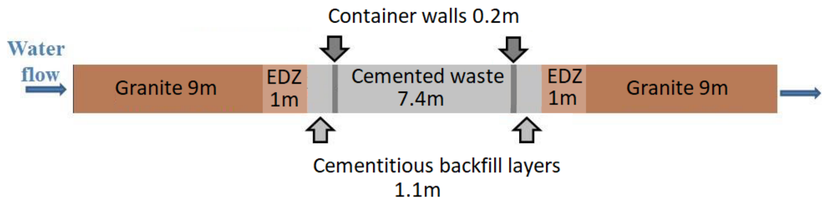


Fig.1 Schematic of the modelled system.

Table 1 Kd dependence on pH in concrete

pH		>12.5	12.5	12.5-12.5	<10.5
Concrete degradation stage		Stage 1	Stage 2	Stage 3	Stage 4
Kd(l/kg)	Ni	40	40	40-4	4
	I	3	3	3-0.3	0.3
	Pu	5000	5000	5000-1000	1000

Table 2 Kd dependence on pH in granite [3 ,4]

Granite pH	pH	~8.5	>10
Kd(l/kg)	Ni	0.001	0.004
	I	0	0
	Pu	5000	5

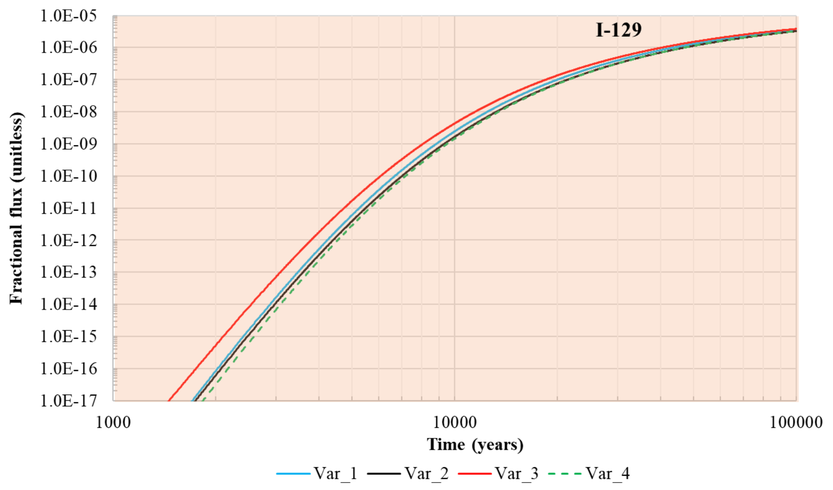
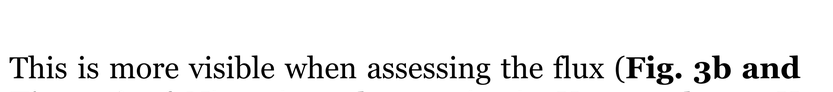


Fig. 2 I-129 flux in the granitic host rock (1 m from cement backfill)



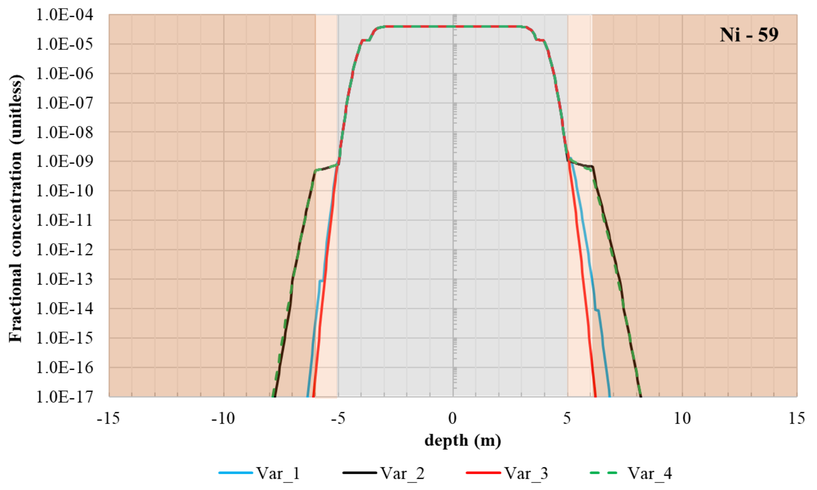


Fig. 3a Ni-59 radionuclide concentration profile t=1E+5 years

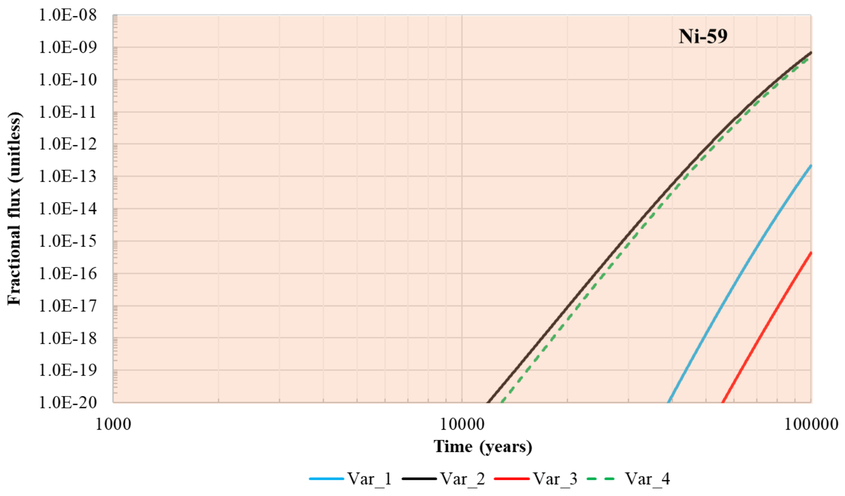


Fig. 3b Ni-59 flux in granitic host rock (1 m from cement backfill)

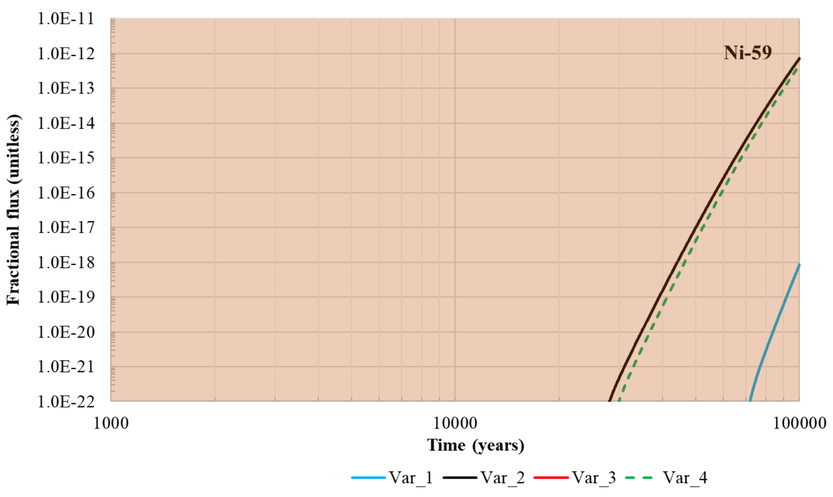


Fig. 3c Ni-59 flux into granitic host rock (2 m from cement backfill)

This is more visible when assessing the flux (**Fig. 3b and Fig. 3c**) of Ni-59 into the granite in Var_1, where pH induced Kd change was not taken into account, as Ni-59 appears at the measurement point 1.5E+4 years earlier than in Var_3. The modelling of the EDZ (Var_2 and Var_4) leads to a faster migration of nickel into intact granitic host rock (**Fig. 3c**). However, the Kd change due to increased pH had a minor effect on nuclide migration when compared to Var_1 and Var_3.

Good sorption of Pu-239 in cementitious materials, allowed it to remain in the modelled cementitious barrier (**Fig. 4**). Pu-239 results showed that it never leached outside cementitious barriers.

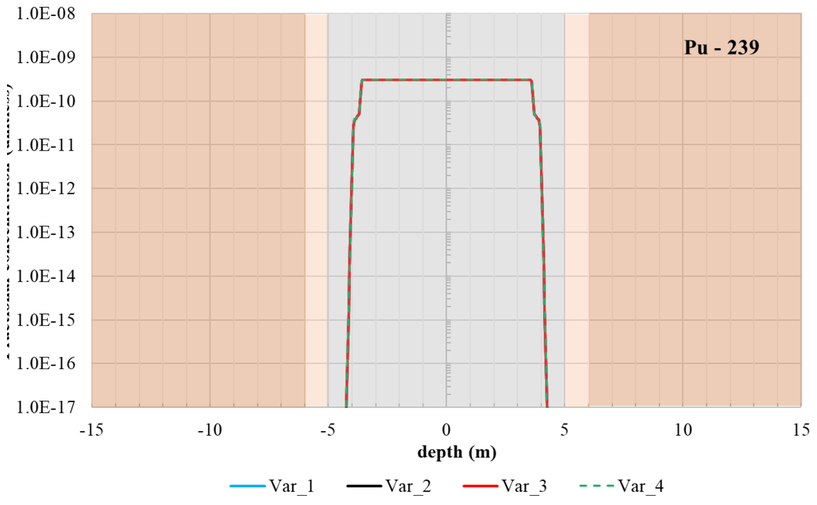


Fig. 4 Pu-239 concentration profile t=1E+5 years

Conclusions

For the cases of I-129 and Pu-239, radionuclide migration changed insignificantly when taking into account Kd changes and EDZ.

For medium-sorbed radionuclides such as Ni-59, the results showed that selecting of modelling approach had noticeable impact on the results of modelling radionuclide behavior.

Contact information:

Povilas Balčius

Junior associate researcher

Lithuanian Energy Institute, Breslaujos st. 3,

LT-44403, Kaunas

povilas.balcius@lei.lt

+370 62643066

1. *D. Grigaliūnienė, P. Balčius, D. Jacques, P. Poškas. Assessment of parameter evolution in a radioactive intermediate level waste disposal cell in granitic host rock applying reactive transport abstracted models. Environmental Earth Sciences, 2024, Vol. 83: 575. https://doi.org/10.1007/s12665-024-11885-8.*
2. *Safety assessment methodologies for near surface disposal facilities: results of a co-ordinated research project. Volume 1 Review and enhancement of safety assessment approaches and tools. Vienna: IAEA, 2004. ISBN 9201040040*
3. *Quantification of rock matrix Kd data and uncertainties for SR-PSU. SKB Report R-13-38. James Crawford. ISSN 1402-3091.*
4. *J. Šimůnek, M. Šejna, H. Saito, M. Sakai, and M. Th. van Genuchten. The HYDRUS-1D Software Package for Simulating the One-Dimensional Movement of Water, Heat, and Multiple Solutes in Variably-Saturated Media. July 2018.*
5. *Kwang-Il Kim et.al. Effect of excavation damaged zone on the long-term coupled thermo-hydro-mechanical behaviors of deep geological repositories in granitic rock masses. https://doi.org/10.1016/j.ijrmms.2025.106353*
6. *D. Jacques et al. Modelling chemical degradation of concrete during leaching with rain and soil water types. Cement and Concrete Research. https://doi.org/10.1016/j.cemconres.2010.02.008.*