Modularization Approach on Source-term Simulation of Deep Geological Disposal Repository for Spent Nuclear Fuel

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1. Introduction

The release of radionuclides is a critical process in the safety assessment of a deep geological repository (DGR) for spent nuclear fuel (SNF) [1]. The Korea Atomic Energy Research Institute (KAERI) has developed a numerical model called the APro (Adaptive Process-based total system performance assessment framework) to simulate transport of radionuclides in the DGR. In this study, we describe the source-term module of the APro framework to evaluate the long-term release of radionuclides in the DGR system. The modeling approach and representative results are presented in this paper.

2. Methods

2.1 Modeling Approach

To simulate the radionuclides release, the prediction of several parameters is critical. These parameters are the radionuclides inventory bounded within the UO_2 matrix of SNF, the radionuclides concentration in the gap, the degradation rate of the UO_2 matrix, the instantaneous release fraction (IRF), and the corrosion rate of a disposal canister. Among them, the most uncertain and complex part is the prediction of the degradation rate of the UO_2 and the corrosion rate of the disposal canister because complex chemical and electrochemical reactions in a radiologically altered condition should be considered. For this reason, several modeling approaches have been suggested to elucidate the corrosion of the disposal canister and the degradation of the UO_2 matrix [3; 4; 5; 6].

In the APro framework, the different modeling approaches are modularized so that potential users can select estimation method of the source-term calculation for their own purposes. Three options are available for the corrosion of the disposal canister: default module, alternative module #1 and #2. Likewise, three options are available for the degradation of the UO_2 matrix: default module, alternative module #1 and #2. Details of these options are described in next sections.

2.2 Module for Corrosion of Cu Disposal Canister

In the default module, user defines the lifetime of the canister. In the alternative module #1, the corrosion rate is estimated by transport limited model. The alternative module #2, on the other hand, calculates the corrosion rate based on mixed-potential modeling approach.

2.3 Module for Degradation of the UO_2 Matrix

In the default module, user defines the constant degradation rate of the UO_2 matrix. In the alternative module #1, the degradation rate is estimated by solubility limited model. The alternative module #2, on the other hand, calculates the degradation rate based on mixed-potential modeling approach.

2.4 Input Parameters

Fig. 1 shows the model domain for the source-term simulation in the APro framework based on the KRS^+ design [2]. In this domain, transport of chemical species is coupled with the source-term process. The hydraulic parameters and initial concentration for the transport process summarized in Table I and II. The initial inventory of radionuclides is summarized in Table III.

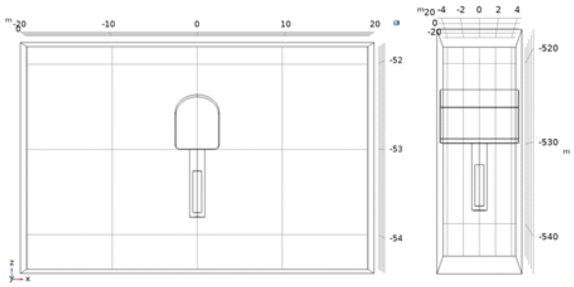

Fig 1. The APro domain for the source-term simulation

Table I. Input data for hydraulic parameters

Parameters	Domain Components		
	Bentonite	Backfill	Host Rock
Porosity	0.40	0.40	0.0116
Intrinsic permeability	$2.32{\cdot}10^{-20}$ m^2	$2.32{\cdot}10^{-20}$ m^2	10^{-18} m^2
Hydraulic head gradient	1% (x-axis)		

Table II. Initial concentration for the corrosion simulation

Chemicals	Initial concentration [mM]			Diffusion coefficient [m^2/s]
	Bentonite	Backfill	Host Rock	
O_2	0.1	0.1	10^{-6}	10^{-9}
HS-	0.1	0.1	0.1	
Cl^-	0.01	0.01	10^{-3}	

Table III. Radionuclides inventory [7]

Nuclides	Inventory [mol/canister]	IRF [%]
^{238}U	6.63e3	-
^{234}U	2.27	-
^{230}Th	2.49e-4	-
^{226}Ra	5.09e-8	-
^{222}Rn	3.33e-13	-
^{14}C	8.69e-1	11.0
^{99}Tc	2.17e1	0.2
^{137}Cs	8.88	4.3
^{135}Cs	8.61	4.3
^{129}I	3.39	4.3

3. Results

Fig. 2 shows the change in the corrosion depth of Cu disposal canister depending on the estimation methods: alternative #1 vs #2. The change in radionuclides inventory bounded within the UO_2 matrix without the release is shown in Fig. 3. The source-term simulation results with the lifetime of canister of 1,000 simulation years is presented in Fig. 4: the degradation rate of the UO_2 matrix is assumed to be 10^{-6} fraction/yr. The difference in the results between the UO_2 degradation estimation methods is shown in Fig. 5.

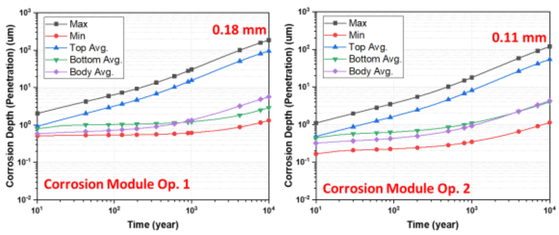

Fig. 2. Change in the corrosion depth of Cu canister: corrosion alternative module #1 vs #2

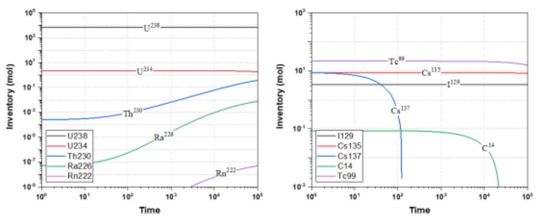

Fig 3. Inventory bounded within the UO_2 matrix (no release)

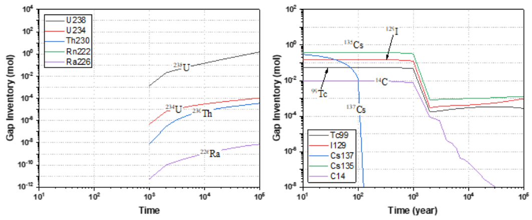

Fig. 4. Change in gap concentration of radionuclides (canister failure at 1,000 years simulation time)

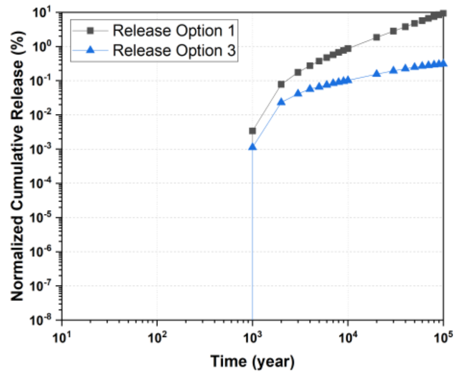

Fig. 5. Cumulative release fraction: default module vs alternative module #2.

4. Conclusions

In this paper, the simulation results of the source-term model of the APro framework are presented. Through the modularization approach, the processes of the radionuclides release from the failed disposal canister were successfully evaluated. The developed numerical modules can be coupled with transport of chemicals in EBS and near field host rock.

Depending on the estimation methods of the numerical modules, the lifetimes of the canister and the UO_2 matrix were slightly different. This is because that the alternative modules incorporate kinetic reactions elucidating the source-term processes, while the default modules simplify the processes with justified and conservative assumptions. From the results, we conclude that default modules are more appropriate for the assessment of normal scenario where safety functions of the DGR system are not disturbed. In case of other scenarios where the safety functions are disturbed, the alternative modules will be required.

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