SAFETY ASSESSMENT CODES FOR THE NEAR-SURFACE DISPOSAL OF LOW AND INTERMEDIATE-LEVEL RADIOACTIVE WASTE WITH THE COMPARTMENT MODEL: SAGE AND VR-KHNP

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ABSTRACT

Based on the conceptual design of a near-surface disposal facility for Low- and Intermediate-level radioactive waste in Korea, safety assessment code called SAGE was developed and intensive efforts for program verification and validation has been made. With this regards, VR-KHNP which is recently developed based on multi-compartment model is benchmarked with SAGE. Through the comparison of radionuclide release rate at near- and far-filed, two computer codes show good agreement.

INTRODUCTION

According to national radioactive waste management policy, Korea Hydro & Nuclear Power Co. Ltd. (KHNP) will select a disposal site in agreement with the local community and operate a disposal facility for Low- and Intermediate-level radioactive waste (LILW) by 2008. Planned capacity of disposal facility will be 100,000 drums at the first stage and 800,000 drums finally. Disposal type will be decided depending upon the site conditions as either rock cavern type or near-surface engineered vault type.

In this regard, KHNP has conducted the conceptual design study of a near-surface disposal facility for LILW.[1] Along with and based on this conceptual design, safety assessment program called SAGE (Safety Assessment Groundwater Evaluation) [2] was developed through the joint collaboration of KHNP, Korea Atomic Energy Research Institute (KAERI) and Monitor Scientific LLC, USA. Preliminary safety assessment has also been conducted.[3-6] Intensive efforts for the program verification and validation was made for technical and interfacial functionality as many aspects of the code as practicable. [7]

Recently, KHNP conducted the collaborative work with Univ. of California, Berkeley (UCB) to develop the safety assessment code called VR-KHNP [8-9] (Virtual Repository for Korea Hydro & Nuclear Power) for Korean LILW disposal facility.

In this paper, a benchmarking problem is formulated and tested the multi- compartment model with both SAGE and VR-KHNP programs.

SAFETY ASSESSMENT CODES: SAGE AND VR-KHNP

SAGE was developed to describe post-closure radionuclide releases and potential radiological doses for LILW disposal in an engineered vault facility in Korea. The overall scheme of safety assessment models have been divided into three categories: Near field, Far field, and Biosphere models. The code has modular structure having the capability to treat input parameters either deterministically or probabilistically. The code has been written to easily interface with more detailed codes for specific parts of the safety assessment

The conceptual model is focused on the release of radionuclide from a gradually degrading engineered barrier system to an underlying unsaturated zone, and then to a saturated groundwater zone. The radionuclide transport equations are solved by spatially discretizing the system into a series of compartments. The near field of the disposal system includes waste form, packaging, and unsaturated zone. The Engineered Barrier System (EBS) and unsaturated zone can be further divided into a number of sub-compartments in SAGE program.

Mass transfer of radionuclide from one compartment to the other is by diffusion/dispersion and advection. The Waste-Form compartment represents the source of radionuclides released during the post-closure period of the waste facility. The release of radionuclides is caused by the failure of multi-layered cover system and water contact. The initiation of release is assumed to happen when water drips into the waste facility through failed cover system. The rate of infiltrating water through this compartment is treated as either linear or piecewise step function with time in order to simulate gradual degradation of the cover system. The EBS compartment receives advective release rates of radionuclides from the Waste-Form compartment and transfers radionuclides to the unsaturated zone compartments through the process of diffusion/dispersion and advection.

The biosphere compartments are assumed to be located at the end of the geosphere and to have a dilution effect on radionuclide concentrations transferred from the geosphere. The code calculates the rates of radionuclides released from the geosphere into the biosphere. The release rates then are converted to dose rates according to biosphere exposure pathways. The biosphere compartments represent well, soil, river, lake, and sea. The biosphere can be represented as a set of steady-state, radionuclide-specific dose conversion factors that are multiplied by the appropriate release rate from the far field for each pathway.

In all compartments, radionuclides are decayed either as a single-member chain or as multi-member chains. Parameter input is achieved through a user-friendly Graphical User Interface (GUI).

VR-KHNP is also based on the compartment model for radionuclide transport in a region of disposal facility including unsaturated and saturated zone. Comparison of these two programs with respect to key features is listed at Table I.

Table I. Comparison of Key Features: SAGE and VR-KHNP

Items	SAGE	VR-KHNP
Infiltration rate in Unsaturated Zone	-step or linear function with time	-step function with time only
source term release mode	-instant dissolution or congruent release	-instant release only
precipitation	-considered with solubility limit	-not considered
molecular diffusion	-considered	-neglected
connection between Unsaturated zone and Saturated Zone	-logically connected -separate calculation of near- and far-field	-physically connected -simultaneous calculation of near- and far-field
result	-release rate at NFI and GBI -dose rate at biosphere	-release rate and concentration at all designed compartments
subprogram	-SAGE NF -SAGE FF -SAGE BIO	-VR-KHNP

BENCHMARKING PROBLEM

To compare these two codes, a benchmarking problem which can be described with the common features is defined. Designed compartment system for radionuclide transport is illustrated in Figure 1. The benchmarking calculations performed by VR-KHNP and SAGE use the same number of compartments and same physical properties such as porosity, sorption coefficients, etc.

Radionuclides dissolved instantaneously in the water are transported into the concrete region, into the unsaturated soil layers and then into the aquifer by advection. Effect of molecular diffusion is neglected. It is assumed that the degrading waste form is a porous material with pores partially filled with water and that the moisture content is steady and uniform throughout the waste compartment. Linear sorption equilibrium between the solid phase and the water phase is assumed everywhere.

Aquifer is divided into a series of compartments of identical dimensions. It is assumed that groundwater flows horizontally at a constant and uniform velocity in the aquifer. Radionuclides that have entered the aquifer are transported by advection. Table 2 and Table 3 summarized the input data for benchmarking problem.

Radionuclide fluxes at the interface between the unsaturated zone and the saturated zone are compared with the conditions of piecewise step infiltration rate, instant dissolution of radioactive waste and no molecular diffusion in the near-field media.

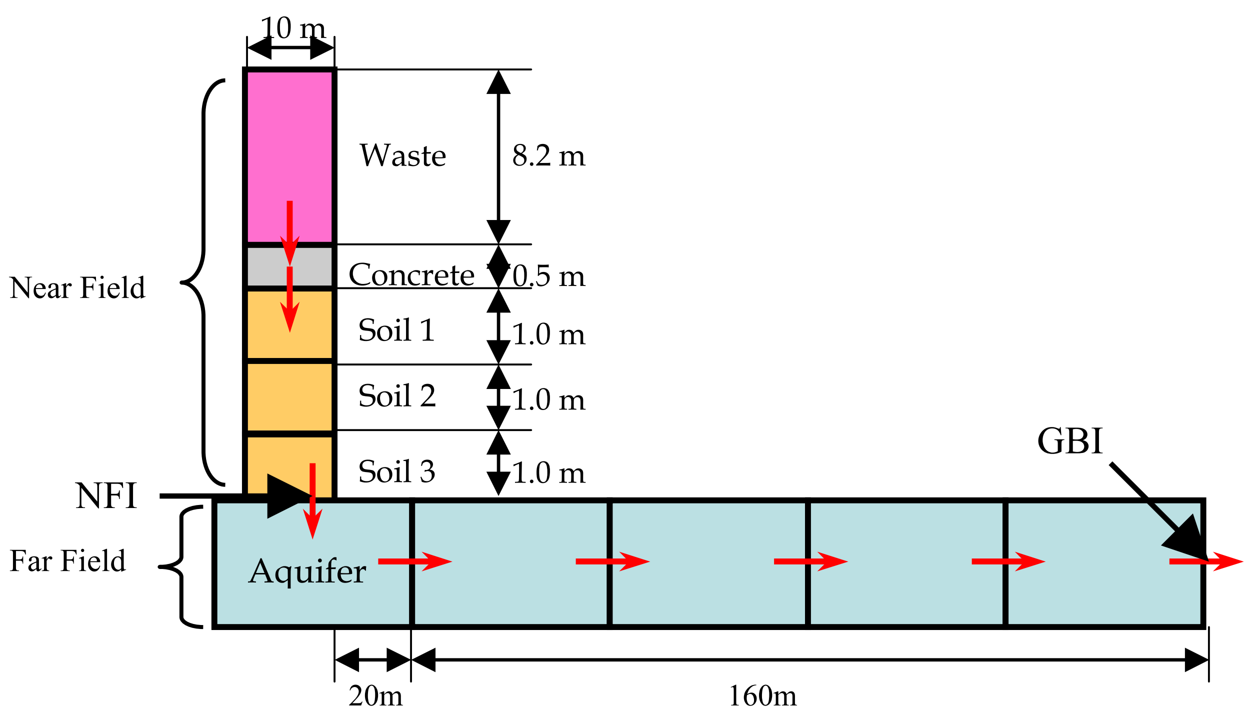

Fig. 1. Compartment model for benchmarking between SAGE and VR-KHNP

Table II. Input Data for Near-Field System of Benchmarking Problem

Unsaturated Zone	Porosity (-)	Saturation degree (-)	Density (kg/m^3)	Effective Diffusion Coeff. (m^2/s)
Waste	0.12	0.5	2840	1.7e-12
Concrete	0.12	0.5	2840	1.6e-12
Soil	0.30	0.7	2571	5.1e-14

Table III. Input Data for Radionuclide Transport System of Benchmarking Problem

Nuclides	Decay Constant (1/yr)	Inventory (Bq)	Distribution Coefficient (m^3/kg)			
			Waste	Concrete	Unsaturated Soils	Aquifer[1]
H-3	5.59e-02	2.67e+13	0	0	0	0
C-14	1.21e-04	1.68e+13	2.50e+00	2.50e+00	5.00e-03	1.00e-02
Co-60	1.32e-01	1.73e+14	2.00e-02	2.00e-02	1.50e-02	1.00e+00
Ni-59	9.19e-06	3.64e+12	2.00e-02	2.00e-02	4.00e-01	1.00e+00
Ni-63	7.22e-03	9.51e+13	2.00e-02	2.00e-02	4.00e-01	1.00e+00
Sr-90	2.38e-02	1.39e+12	2.50e-03	2.50e-03	1.50e-02	2.00e-02
Nb-94	3.41e-05	1.00e+11	5.00e-01	5.00e-01	0	1.00e+00
Tc-99	3.25e-06	4.07e+10	5.00e-01	5.00e-01	1.00e-04	1.00e+02
I-129	4.41e-08	1.25e+10	6.00e-04	6.00e-04	1.00e-03	5.00e-03
Cs-137	2.31e-02	6.09e+13	2.50e-04	2.50e-04	3.00e-01	1.00e-01
U-238[2]	1.55e-10	4.75e+10	2.00e+00	2.00e+00	0	1.00e+02

[1] Density of aquifer is 3333 (kg/m^3) and porosity of aquifer is 0.25 (-).

[2] Radioactive decay chains are considered for U-238.

Radionuclide transport at aquifer compartment uses the darcy velocity of groundwater as 10 m/yr and longitudinal dispersivity as 20 m. Radioactive decay chain is considered for U-238 (U-238→U-234→Th-230→Ra-226→Pb-210→Po-210).

To consider the degradation of cover system of near-surface facility and the resultant increase of infiltration of surface water into waste matrix, time step increases at 100 yr (3.5e-4 →3.5e-2 m/yr) and 500 yr (3.5e-2 →3.5e-1 m/yr) are applied in the benchmarking problem

RESULTS OF BENCHMARKING PROBLEM

Figure 2 shows the benchmarking results both from SAGE and from VR-KHNP program. In Figure 2, black-dot profiles indicate the results from VR-KHNP and white-dot profiles indicate those from SAGE program.

Radionuclide release rates at near- and far-field of compartment model described in Figure 1 show good agreement. Near field release rate of Ni-59 from VR-KHNP shows slightly higher value than that from SAGE after 10,000 yrs.

Figure 3 shows the results of benchmarking problem for U-238 decay chain described in Table 3. Radionuclide release rates at near field of transport system show good agreement for mother and daughter nuclides in U-238 decay chain.

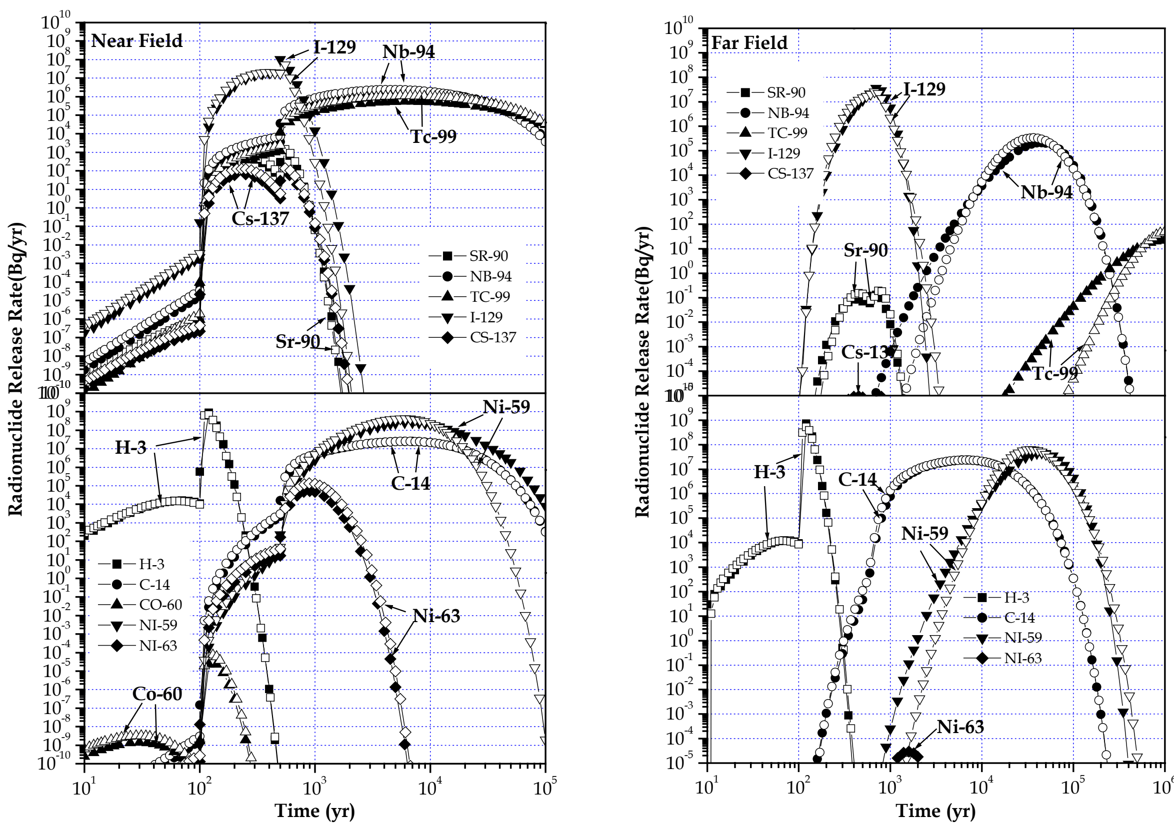

Fig. 2. Benchmarking results between SAGE and VR-KHNP: Near- and far-field (black-dot profiles indicate the results from VR-KHNP and white-dot profiles indicate those from SAGE)

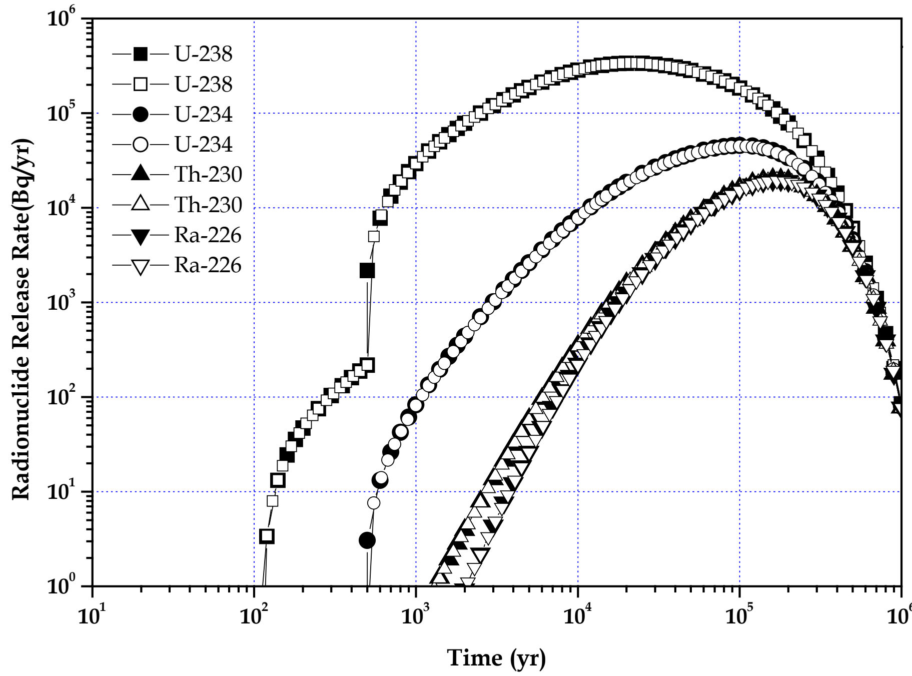

Fig. 3. Benchmarking results between SAGE and VR-KHNP: Decay chain at near-field (black-dot profiles indicate the results from VR-KHNP and white-dot profiles indicate those from SAGE)

CONCLUSIONS

Based on the conceptual design of a near-surface disposal facility for LILW in Korea, safety assessment code called SAGE was developed and intensive efforts for program verification and validation has been made. With this regards, VR-KHNP which is recently developed based on multi-compartment model is benchmarked with SAGE to test the performance of safety assessment codes.

Simple benchmarking problem for near-surface disposal of radioactive waste is constructed within the common features of these computer codes. Through the comparison of radionuclide release rates at near- and far-filed, two computer codes show good agreement.

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