SCENARIO DEVELOPMENT METHODOLOGY FOR PERFORMANCE ASSESSMENT OF NEAR-SURFACE LILW REPOSITORY BASED ON FEPS AND INTERACTION MATRIX APPROACH

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ABSTRACT

Systematic procedure of developing radionuclide release scenarios was established based on FEP list and Interaction Matrix for the near-surface LILW repository. The relevant FEPs were screened by experts' review in terms of domestic situation and combined into scenarios on the basis of Interaction Matrix analysis. A computer program named IMFEP_NS was developed to view and select project FEPs, to make its Interaction Matrix at user's disposal, and to visualize the interaction between FEPs and Interaction Matrix. The concept of approach to generate scenarios for entire domain is to divide the whole system domain into three sections: Near-field, Far-field, and Biosphere. Possible sub-scenarios were generated within each sectional sub-scenario set composed by assembling relevant FEPS and Interaction Matrix in advance, and then scenarios for entire system were built up with sub-scenarios of each section. As an application of established scenario generation approach, sixteen design scenarios and two alternative scenarios for near-surface repository were evaluated. Finally, a reference scenario and other noteworthy scenarios were selected through experts' scenario screening.

INTRODUCTION

The generation of scenarios and their associated justification methodology has become a very important aspect of confidence building for the post-closure safety assessment of radioactive waste repository. Although lots of scenarios were recognized from the past scenario development studies, it has been needed to establish a systematic framework and development procedure(1). To supplement this needs, the Rock Engineering System matrix method which utilizing Features, Events and Processes(FEP) and Interaction Matrix(IM) was examined and adopted(2,3). This study is focused on the development and application of a methodology, based on FEP and IM, to systematize the procedure for developing radionuclide release scenarios in a near-surface LILW repository in Korea.

FEPs database was set up and underwent experts' review to screen out those irrelevant to domestic situation in the first step of scenario development. And then, IM was created in connection with the qualified FEPs. A computer program named IMFEP_NS was developed for this purpose. It was possible to recognize and develop scenarios by combining FEPs on the basis of IM.

The procedure for moving from a comprehensive FEPs database to a set of justified scenarios are often poorly developed and documented. In this study, an approach to generating scenarios from those screened FEPs and IM was developed on the basis of divide-and-combine concept. It consists of two stages of procedure, firstly dividing the repository system domain into three sections from near-field to biosphere and developing sub-scenarios for each section in advance, and then combining sub-scenarios of each section to buildup the scenarios for entire system.

Scenario development methodology using the developed approach was applied for generating a complete set of scenarios to be used in the safety/performance assessment of near-surface disposal system in Korea. Scenario screening by expert judgment is also applied. After experts' review on these developed scenarios, reference scenarios expected to have relatively high probability were selected.

APPROACH TO SCENARIO DEVELOPMENT

Systematic procedure of developing radionuclide release scenarios was established based on FEP list and IM for the near-surface LILW repository. The relevant FEPs were screened by experts' review in terms of domestic situation and combined into scenarios on the basis of IM analysis. IMFEP_NS (Interaction Matrix and FEP Viewer for Scenario Development of Near Surface Repository) was developed to view and select project FEPs from an extensive FEP database, to make its IM at user's disposal, and to visualize the interaction between FEPs and IM. FEPs can be mapped to the all matrix components thought to have interaction by using this tool. Figure 1 illustrates a screen clip on FEP database viewer within the IMFEP_NS.

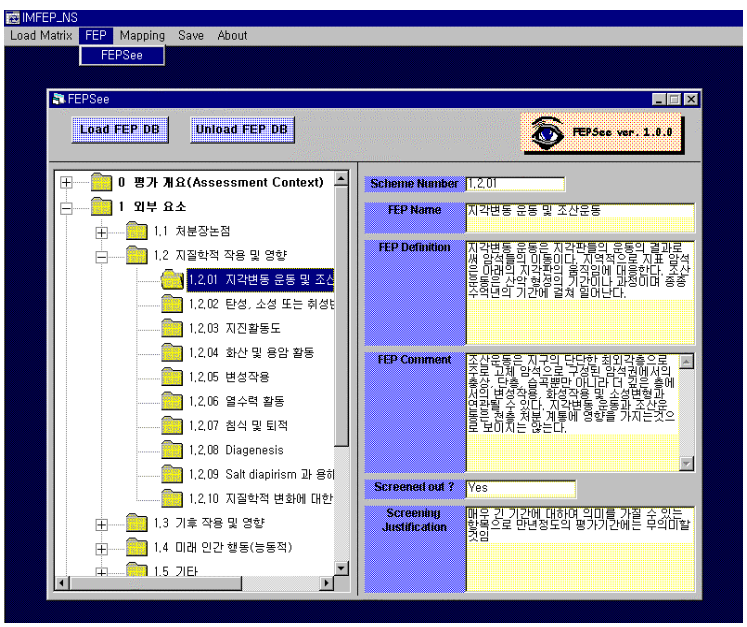

Fig. 1. An illustrative clip of IMFEP_NS

The concept of approach to developing scenarios from those screened FEPs and IM for entire domain is shown in Figure 2. The whole system domain was divided into three sections such as Near-field, Far-field, and Biosphere. Possible sub-scenarios were generated within each sectional sub-scenario set labeled their own numbers in advance. Each sectional sub-scenario was composed by assembling relevant FEPs along the directions shown in IM. A number of sub-scenarios could be generated in each section. Though 2^n scenarios are possible from combination of n FEPs theoretically, it is needed to identify a limited number of representative scenarios rather than comprehensively identify every possible scenario. The existing list of generic scenarios can serve as a guidance of what scenario to consider for a given geologic condition and disposal facility type. After it was done over three sections to pick out one sub-scenario from a sectional sub-scenario set, scenarios for the complete domain were created by combining these three sub-scenarios into one overall scenario. Applicable scenarios set could be established by iterating this work for all possible combinations.

To identify the more important scenarios, the ranking system based on expert judgment was introduced to the scenario screening. Importance of consequence, probability, and uncertainty were used as screening criteria for possible scenarios.

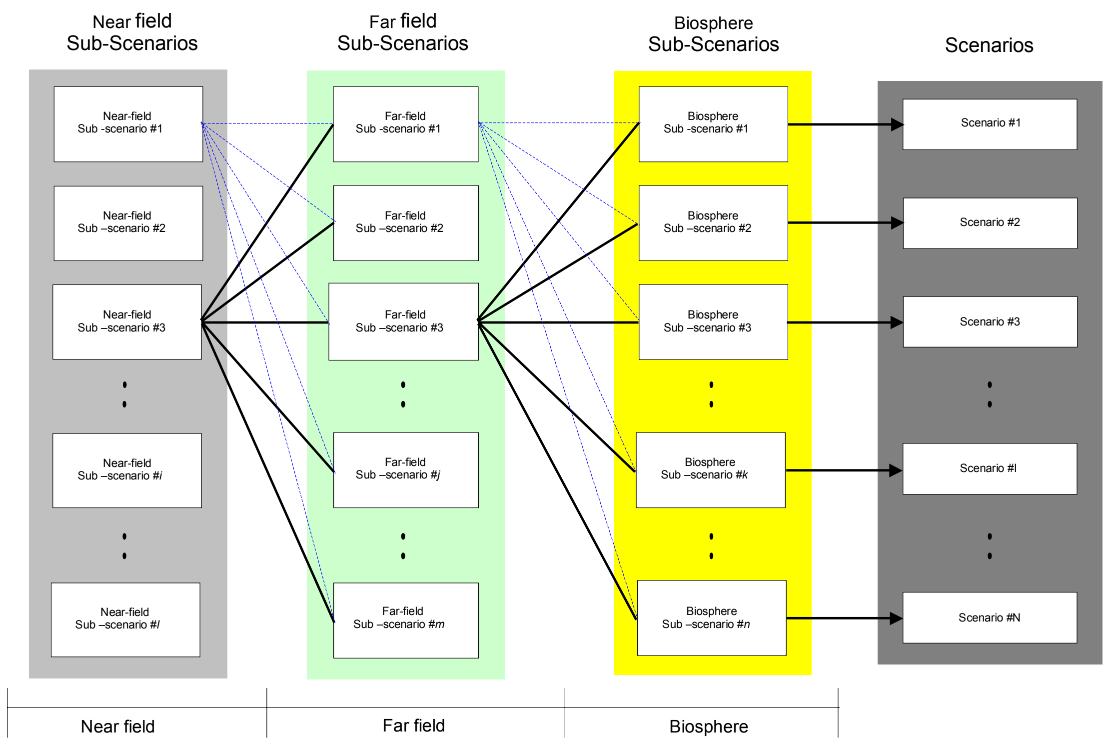

Fig. 2. Concept of approach to scenario development

APPLICATION OF SCENARIO DEVELOPMENT METHODOLOGY

Established scenario development methodology was applied to generate various design and alternative scenarios for performance assessment of a hypothetical engineered vault disposal facility in Korea.

To limit the number of all possible scenarios under control, the highest-level assumptions were introduced to categorize the created scenarios into design scenario in this study. Here the term of 'design scenario' represents the scenario which could be expected the system to evolve assuming the design functions as planned. After experts' review on these design scenarios developed, reference scenarios expected to have relatively high probability were selected. Altering those assumptions developed alternative scenarios. Figure 3 shows the relation of each scenario concept mentioned above.

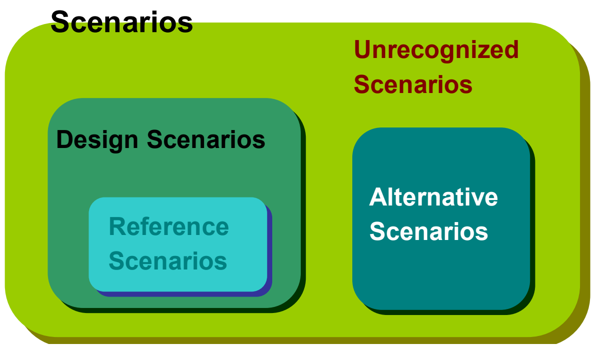

Fig. 3. Relation of each scenario concept.

To make design scenarios first, some highest-level assumptions were used such as i) design and construction as planned, ii) no human intrusion, iii) no wide-range geological process like earthquake, iv) no climate change, v) 300-year of total institutional control period (100-year of active institutional control period and 200-year of passive one), and vi) biosphere as present day(4). Considering these assumptions, radionuclides release scenarios based on natural flow of groundwater were developed. In order to show the process of liquid phase radionuclides along groundwater from waste to biosphere, IM for the design scenario was evaluated as represented in Figure 4. And then, FEPs were mapped to the all matrix components thought to have interaction by using FEP database which had been prepared through experts' review in terms of domestic conditions(5). Each sectional sub-scenario set based on the screened FEPs and IM was prepared as a next step.

Near-field, Far-field, and Biosphere Sub-scenario set

Waste package, backfill, vault and cover were included in near-field. Three near-field sub-scenarios, Normal Evolution(NSS1), Colloid Transport(NSS2), and Gas Generation(NSS3), are generated under the highest-level assumptions. Unsaturated zone and aquifer among the diagonal elements in IM were included in far-field. The far-field sub-scenarios are generated as Fracture Flow(FSS1), Porous Flow(FSS2), Colloid Transport(FSS3), and Geologically Undetected Features(FSS4) such as fault during site investigation may affect the groundwater to move unexpectedly. Soil and sediment, surface water, atmosphere, flora, fauna and human among diagonal elements in IM were included in biosphere. Sub-scenarios in this section were developed by focusing on the exposure pathways. The biosphere sub-scenarios generated are Water Resource(BSS1), Discharge to Surface Water Body(BSS2), and Soil and Sediment(BSS3).

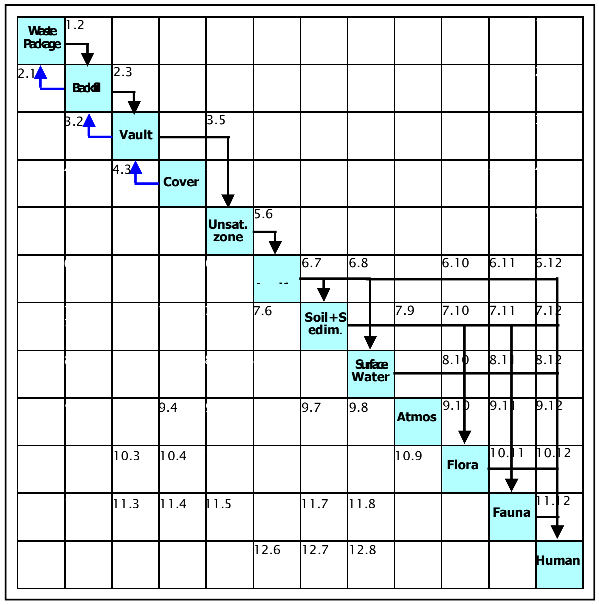

Fig. 4. Interaction Matrix for release of liquid phase radionuclides

Reference Scenario for Near-Surface LILW Repository

The number of design scenarios developed by assembling sub-scenarios is 36(=3x4x3) theoretically. However, to reduce the number of cases dealt with, BSS2 and BSS3 were put together as one sub-scenario. In addition, two assumptions were taken into account. Firstly, NSS2 could be connected with only FSS3 and FSS4 among far-field sub-scenarios. Secondly, it was not permitted to combine FSS3 with NSS1 or NSS3. Consequently, 16 design scenarios were pre-selected in advance of experts' review. Criteria for scenario screening are represented in Table I. Seven experts checked off the one of the 12 position in Table I for 16 design scenarios. Criteria for scenario screening as shown in Table I were used. The score within parentheses of Table I was valued for each experts' checks for each design scenario. Table II shows summarized results in terms of assigned scores and their sum based on experts' choices.

Table I. Criteria for scenario screening[4]

Importance of consequence	Probability	Knowledge		
		Certain	Uncertain	None
Important	High	Consider (6)	Investigate (5)	Investigate (4)
	Low	Investigate (3)	Investigate (2)	Investigate (1)
Not important	High	Screen out (0)	Check (0)	Check (0)
	Low	Screen out (0)	Screen out (0)	Check (0)

Table II. Summarized results based on experts' review

Design Scenarios		Experts							
		A	B	C	D	E	F	G	Sum
1-1	(= NSS1+FSS1+BSS1)	6	6	5	5	5	5	3	**35**
1-2	(= NSS1+FSS1+BSS2 and BSS3)	6	6	2	5	0	0	6	**25**
1-3	(= NSS1+FSS2+BSS1)	6	6	6	6	0	6	2	**32**
1-4	(= NSS1+FSS2+BSS2 and BSS3)	6	6	6	6	0	0	3	**27**
1-5	(= NSS1+FSS4+BSS1)	5	2	4	0	1	0	3	15
1-6	(= NSS1+FSS4+BSS2 and BSS3)	5	2	4	0	1	0	6	18
2-1	(= NSS2+FSS3+BSS1)	5	2	5	5	2	5	2	**26**
2-2	(= NSS2+FSS3+BSS2 and BSS3)	5	2	5	4	2	0	5	**23**
2-3	(= NSS2+FSS4+BSS1)	2	2	1	0	1	0	2	8
2-4	(= NSS2+FSS4+BSS2 and BSS3)	2	0	0	0	1	0	5	8
3-1	(= NSS3+FSS1+BSS1)	3	2	4	5	0	5	3	**22**
3-2	(= NSS3+FSS1+BSS2 and BSS3)	3	2	5	4	0	0	6	**20**
3-3	(= NSS3+FSS2+BSS1)	2	2	5	0	0	0	1	10
3-4	(= NSS3+FSS2+BSS2 and BSS3)	2	2	5	0	0	0	4	13
3-5	(= NSS3+FSS4+BSS1)	2	0	0	0	0	0	1	3
3-6	(= NSS3+FSS4+BSS2 and BSS3)	2	0	0	0	0	0	0	2

From these, it should be noted that design scenarios 1-1, 1-2, 1-3, and 1-4 were considered as more meaningful ones. Design scenarios 1-1 and 1-2 could be treated as one scenario, representing the characteristics of fracture flow migration if all biosphere sub-scenarios were considered at once. Also, 1-3 and 1-4 could be put together into one scenario in terms of porous flow migration. As a result, these design scenarios were selected as a reference scenario. The difference between these scenarios is only the migration mechanism in far-field, fracture or porous flow. Consequently, it would be possible to accept more inclusive scenario as a reference one because site-specific data are not available yet.

Finally, the description of reference scenario is represented in Table 3. Other scenarios to which might be paid attention are also described in Table 3 though they would not be selected as reference scenario.

Alternative Scenarios for Near-Surface LILW Repository

By altering one of highest-level assumptions, i.e. inadvertent human intrusion into the disposal facility is assumed to occur at time after loss of institutional control of 300 years, human intrusion scenarios are developed from the same procedure as in the design scenario development. In this study, five kinds of scenarios as potential intruder events are identified.

These scenarios are results from the combination of one near-field sub-scenario(NSSHI1) representing degraded radioactive waste itself with five biosphere sub-scenarios - Drilling(BSSHI1), Construction of Road(BSSHI2), Hosing & Gardening(BSSHI3), Post-drilling(BSSHI4), and Post-excavation(BSSHI5)-, respectively. There is no far-field sub-scenario in this case.

As for poor design/performance scenario, four near-field sub-scenarios are identified, i.e., failure of backfill, fracture formation in the concrete vault structure, failure of closure cover, and failure of drainage system. These sub-scenarios could be combined with the same far-field and biosphere sub-scenarios as in the design scenario.

Table III. Descriptions of reference and other notable scenarios

Scenarios	Composition	Description
Reference scenario	NSS1+ {FSS1 or FSS2} + {BSS1 BSS2 BSS3}	**Normal Evolution :** Rainfall infiltrates through cover, and dissolve the radionuclides in the degraded waste packages. The dissolved radionuclides are released along groundwater flow. Major transport mechanisms are diffusion, advection and so on. In case LILW repository is located in crystalline rock[or sedimentary rock in where fractures are not as well developed as crystalline rock], radionuclides dissolved in groundwater will migrate from near-field to biosphere through fracture networks[or pores]. Exposure will occur when mankind drills a well to get water for the purpose of drinking or other uses since the groundwater in aquifer is contaminated. And also, Groundwater in aquifer may be released into surface water body (e.g., Ocean, lake, river and stream)[or/and soil and sediment by capillarity and osmosis] along normal groundwater flow. Exposure will occur to human when surface water body[or/and contaminated soil and sediment] is used by mankind directly or transferred through food chains including fauna and flora.
Other notable scenarios	NSS2 + FSS3 + {BSS1 BSS2 BSS3}	**Colloid Transport :** Released radionuclides from degraded waste package turn into pseudo-colloid because they may be adsorbed to natural colloid that exist in groundwater or to colloid created in backfill. Radionuclide transport occurs keeping colloid phase. Pseudo-colloids generated in near-field may migrate fast and reach biosphere earlier than radionuclides dissolved in groundwater do. And also, Groundwater in aquifer may be released into surface water body (e.g., Ocean, lake, river and stream)[or/and soil and sediment by capillarity and osmosis] along normal groundwater flow. Exposure will occur to human when surface water body[or/and contaminated soil and sediment] is used by mankind directly or transferred through food chains including fauna and flora.
	NSS3 + FSS1 + {BSS1 BSS2 BSS3}	**Gas Generation :** Chemical reaction of infiltrated water with waste package or degradation of organics by microbe may generate gas in the near-field. Generated gas may enlarge or create pores within engineered barriers. In case LILW repository is located in crystalline rock, radionuclides dissolved in groundwater will migrate from near-field to biosphere through fracture networks. And also, Groundwater in aquifer may be released into surface water body (e.g., Ocean, lake, river and stream)[or/and soil and sediment by capillarity and osmosis] along normal groundwater flow. Exposure will occur to human when surface water body[or/and contaminated soil and sediment] is used by mankind directly or transferred through food chains including fauna and flora.

CONCLUSION

In this study, a systematic procedure based on FEP list and IM for scenario development was established and applied to developing reference scenario practically. Reference scenario was evaluated not by scenario developer's arbitrary decision but by related experts' choice. Reference scenario selected by experts' review among all suggested scenarios in this work will be reliable and able to show the clear-cut basis of selection. The advantage of this procedure is extensible feature in developing scenarios with all possible considerations by adding sub-scenarios into each section. Although a few sub-scenarios were used in this work, other various sub-scenarios within each section of system domain may be added properly. If site-specific information is available, other probable scenarios will be generated by applying this procedure to scenario development. In addition, this procedure was also applied to develop alternative scenarios by considering future human actions and repository design/performance issues.

Addition of other possible sub-scenarios into each sectional sub-scenario set will assure more prudent scenario selection in future. And, by virtue of this systematic scenario development procedure, confidence building for the post-closure safety assessment of near-surface LILW repository will be provided.

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