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Development of Reference Scenarios Based on FEPs and Interaction Matrix for the Near-surface LILW Repository

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Abstract

Systematic procedure of developing radionuclide release scenarios was established based on FEP list and Interaction Matrix for near-surface LILW repository. FEPs were screened by experts' review in terms of domestic situation and combined into scenarios on the basis of Interaction Matrix analysis. Under the assumption of design scenario, The system domain was divided into three sections: Near-field, Far-field and Biosphere. Sub-scenarios for each section were developed, and then scenarios for entire system were built up with sub-scenarios of each section. Finally, sixteen design scenarios for near-surface repository were evaluated. A reference scenario and other noteworthy scenarios were selected through experts' scenario screening.

Key Words : FEP, interaction matrix, design scenario, reference scenario, LILW repository

1. Introduction

Although lots of scenarios were recognized from the past scenario development studies, it has been needed to establish a systematic framework and development procedure[1-5]. To supplement this needs, FEP (Features, Events and Processes) and Interaction Matrix were adopted to systematize the procedure for developing radionuclide release scenarios in near-surface LILW repository. 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, Interaction Matrix was created in connection with the qualified FEPs. It was possible to recognize and develop scenarios by combining FEPs on the basis of Interaction Matrix. 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. The system domain was divided into three sections: Near-field, Far-field and Biosphere. Sub-scenarios for each section were developed in advance. Scenarios for entire system could be generated by arraying sectional sub-scenarios from near-field to biosphere. After

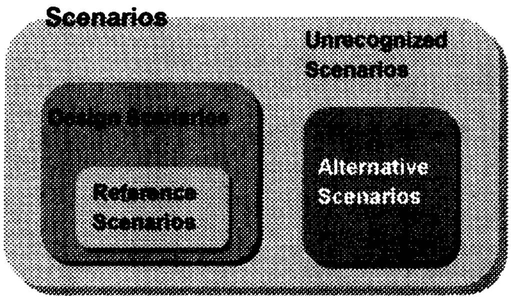

Fig. 1. Relation of Each Scenario Concept

experts' review on these developed scenarios, reference scenarios expected to have relatively high probability were selected.

2. Approach to Scenario Development

This study focused on the selection of reference scenarios among the developed design scenarios under the highest-level assumptions. Alternative scenarios will be studied by altering those assumptions. Figure 1 shows the relation of each scenario concept mentioned above.

To make design scenarios first, some highest-level assumptions were used such as 1) design and construction as planned, 2) no human intrusion, 3) no wide-range geological process like earthquake, 4) no climate change, 5) 300-year of total institutional control period (100-year of active institutional control period and 200-year of passive one), and 6) biosphere as present day[6]. 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, Interaction Matrix for the design scenario was evaluated as represented in Figure 2[6,7]. And then, FEPs were mapped to the all matrix components thought to have interaction by using FEP database which had

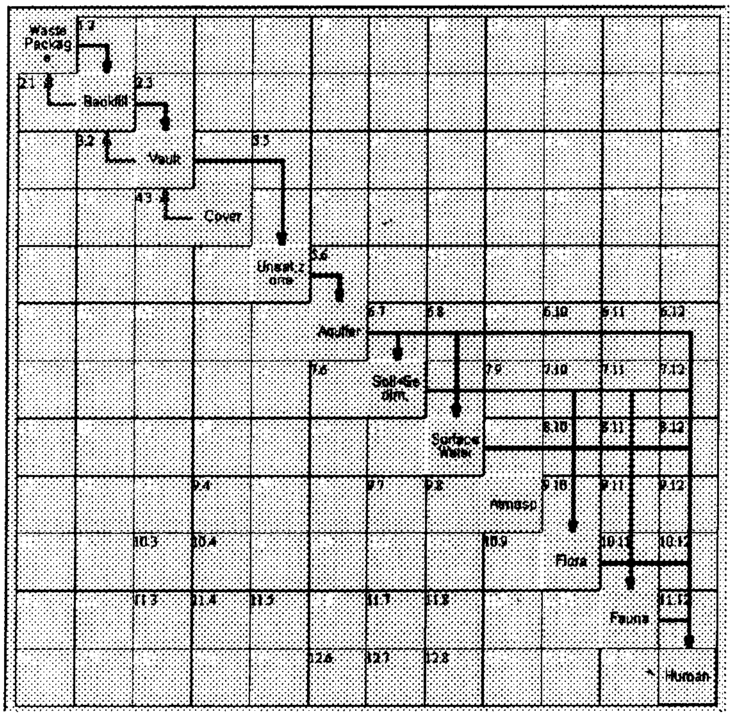

Figure 2. Interaction Matrix for Release of Liquid Phase Radionuclides

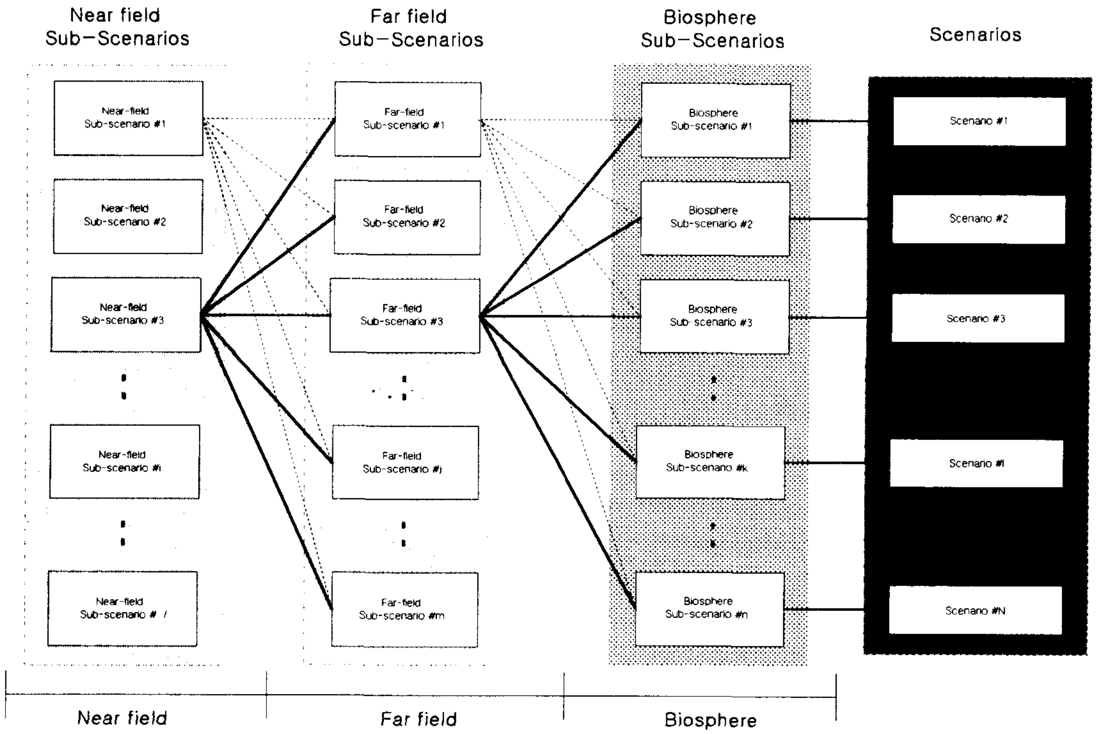

Figure 3. Concept of Approach to Scenario Development

been prepared through experts' review in terms of domestic conditions.

The concept of approach to developing scenarios for entire domain is shown in Figure 3. 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 Interaction Matrix, Figure 2. Therefore, after it was done over three sections to pick out one sub-scenario from a sectional sub-scenario set, design scenarios for the complete domain were created by combining these three sub-scenarios into one overall scenario[7]. Design scenarios set could be established by iterating this work for all possible combinations.

2.1 Near-field Sub-scenario Set

Waste package, backfill, vault and cover were included in near-field. Near-field sub-scenarios were developed under the highest-level assumptions. Sub-scenarios correspond to alternative scenario will be considered in future study. The near-field sub-scenarios are generated as follows.

(1) Normal Evolution - NSS1

Rainfall infiltrates through cover, and dissolves the radionuclides in the degraded waste packages. The dissolved radionuclides are released along groundwater flow. Major transport mechanisms are diffusion, advection and so on.

(2) Colloid Transport - NSS2

Released radionuclides from degraded waste package turn into pseudo-colloid because they may be adsorbed to natural colloid that exists in groundwater or to colloid created in backfill. Radionuclide transport is occurred by keeping colloid phase[8].

(3) Gas Generation - NSS3

Chemical reaction of infiltrated water with waste package or degradation of organic materials by microbe may generate gas in the near-field. Generated gas may enlarge or create pores within engineered barriers[8].

2.2 Far-field Sub-scenario Set

Unsaturated zone and aquifer among the diagonal elements in Interaction Matrix were included in Far-field. The far-field sub-scenarios are generated as follows.

(1) Fracture Flow - FSS1

In case LILW repository is located above crystalline rock, radionuclides dissolved in groundwater will migrate from near-field to biosphere through fracture networks.

(2) Porous Flow - FSS2

In case LILW repository is located above sedimentary rock where fractures are not as well developed as crystalline rock, radionuclides dissolved in groundwater will migrate through pores.

(3) Colloid Transport - FSS3

Pseudo-colloids generated in near-field may migrate faster and reach biosphere earlier than radionuclides dissolved in groundwater do[8].

(4) Undetected Features - FSS4

Geologically undetected features such as fault during site investigation may affect the groundwater to move unexpectedly.

2.3 Biosphere Sub-scenario Set

Soil and sediment, surface water, atmosphere, flora, fauna and human among diagonal elements in Interaction Matrix were included in biosphere. Sub-scenarios in this section were developed by focusing on the exposure pathways. The biosphere sub-scenarios are generated as follows.

(1) Water Resource - BSS1

This corresponds to direct extraction of water resource from aquifer by human. 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.

(2) Discharge to Surface Water Body - BSS2

Groundwater in aquifer is released into surface water body (e.g., ocean, lake, river and stream) along normal groundwater flow. Exposure will occur to human when surface water body is used by mankind directly or transferred through food chains including fauna and flora.

(3) Soil and Sediment - BSS3

Groundwater in aquifer may be released into soil and sediment by capillarity and osmosis along normal groundwater flow. Exposure will occur to human when contaminated soil and sediment are used by mankind directly or transferred through food chains including fauna and flora.

3. 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

Table 1. Criteria for Scenario Screening[6]

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 2. 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

cases dealt with, BSS-2 and BSS-3 were put together as one sub-scenario. In addition, two assumptions were taken into account. Firstly, NSS-2 could be connected with only FSS-3 and FSS-4 among far-field sub-scenarios. Secondly, it was not permitted to combine FSS-3 with NSS-1 or NSS-3. Consequently, 16 design scenarios were pre-selected in advance of experts' review.

Table 3. Descriptions of Reference and Other Notable Scenarios

Scenarios	Composition	Description
Reference scenario	$NSS1+\begin{Bmatrix} FSS1 \\ or \\ FSS2 \end{Bmatrix}+\begin{Bmatrix} BSS1 \\ BSS2 \\ BSS3 \end{Bmatrix}$	**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	$NSS2 + FSS3 + \begin{Bmatrix} BSS1 \\ BSS2 \\ BSS3 \end{Bmatrix}$	**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.
	$NSS3 + FSS1 + \begin{Bmatrix} BSS1 \\ BSS2 \\ BSS3 \end{Bmatrix}$	**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.

Criteria for scenario screening are represented in Table 1. Seven experts checked off the one of the 12 position in Table 1 for 16 design scenarios. Criteria for scenario screening as shown in Table 1 were used. The score within parentheses of Table 1 was valued for each experts' checks for each design scenario. Table 2 shows summarized results in terms of assigned scores and their sum based on experts' choices. 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.

4. Conclusions

In this study, a systematic procedure based on FEP list and Interaction Matrix for scenario development was established and applied to developing reference scenario practically. Reference scenario, the final objective of this work, 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 will be applicable to other alternative scenarios such as human intrusion scenario, climate change scenario and so on.

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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