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Development of Biosphere Assessment Modeling Strategy for Deep Geological Disposal in Generic Site of the Korean Peninsula

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As part of the safety case development for generic disposal sites in Korea, it is necessary to develop generic assessment models using various geosphere–biosphere interfaces (GBIs) and potentially exposed groups (PEGs) that reflect the natural environmental characteristics and the lifestyles of people in Korea. In this study, a unique modeling strategy was developed to systematically construct and select Korean generic biosphere assessment models. The strategy includes three process steps (combination, screening, and experts' scoring) for the biosphere system conditions. First, various conditions, such as climate, topography, GBIs, and PEGs, were combined in the biosphere system. Second, the combined calculation cases were configured into interrelation matrices to screen out some calculation cases that were highly unlikely or less significant in terms of the exposure dose. Finally, the selected calculation cases were prioritized based on expert judgment by scoring the knowledge, probability, and importance. The results of this study can be implemented in the development of biosphere assessment models for Korean generic sites. It is believed that this systematic methodology for selecting the candidate calculation cases can contribute to increasing the confidence of future site-specific biosphere assessment models.

Keywords: Deep geological disposal, Biosphere assessment, Generic modeling strategy, Climate change & Landscape development, Biosphere system conditions

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1. Introduction

In the Republic of Korea (ROK), a national R&D project for the development of a system-level safety assessment methodology for deep geological disposal facility of spent nuclear fuel has been launched and is undergoing in various relevant fields. The ROK Nuclear Safety and Security Commission (NSSC) Notice No.2021-21, Article 8 requires that the safety of the deep geological disposal facility shall be demonstrated as the safety case for all stages such as site investigation, construction, operation, closure, and post-closure [1]. As a part of the safety case development, it is necessary to assess the individual dose or risk to a representative person in the biosphere of the candidate site for reasonably assuring the safety of the disposal facility. Risk assessment dealing with post-closure long-term safety of disposal facility must understand and characterize aspects of the environment and biosphere that can be critical to the dose and variable in the future. For dose or risk assessment modeling, it is required to develop a biosphere assessment methodology reflecting the domestic environmental characteristics and people's lifestyles and to secure the related data. The candidate disposal site has not yet been specified in the ROK, so the relevant necessary information is very limited. Thus, it is necessary to develop generic assessment models using various types of Geosphere-Biosphere Interfaces (GBIs) and Potentially Exposed Groups (PEGs) corresponding to domestic biosphere conditions based on historical records and preliminary prediction for climate change and land development before the actual siting and licensing of a disposal facility.

Long global joint studies have been done in the fields of biosphere characterizing and modeling for the biosphere assessment in parallel with near field and geosphere assessments. The International Atomic Energy Agency (IAEA) has developed a methodology for biosphere assessment of deep geological disposal facility - BIOMASS (BIOsphere Modelling and ASSessment) through international research projects such as BIOMASS and BIOMOVS-II (BIOspheric MOdel Validation Study-II) [2]. In 2018, European Commission has updated the BIOMASS methodology through the international joint research forum of BIOPROTA [3]. The BIOMASS methodology suggested the systematic assessment process consisted of setting down the assessment context, justification, and description of biosphere systems, consideration of PEGs, model development, and calculation. Some countries such as Sweden and Finland have implemented the BIOMASS methodology in support of license submission for the construction of their disposal facilities.

The Forsmark site [4] in Sweden and the Olkiluoto site [5] in Finland are representative cases of the site-specific assessments undertaken for licensing the disposal facility. Regulatory authorities of Sweden and Finland require a time frame of 1 million years to be reflected in the safety assessment of disposal facilities. It was expected that there would be significant changes in the external environmental conditions of disposal facilities during such a long-term assessment period. In particular, climate change would be the most significant external factor affecting the long-term safety of disposal facilities [6]. Therefore, Sweden and Finland have reconstructed and repeated Europe's latest glacial cycle to form a baseline glacial cycle and set up a climate change scenario. In addition, both countries introduced the concept of Biosphere Object for the development of assessment models that take into account changes in GBI and biosphere.

In Japan, disposal facility biosphere safety assessment was conducted on the base of generic sites because the disposal site has not been specified. They reviewed firstly the long-term scale change in radioactive waste disposal facilities in the H-12 Report in 1999 [7]. The H-17 Report in 2005 [8] specified the climate state based on the Köppen climate classification scheme regarding to modeling of distant future climate change. In the recent safety case project [9], the basic scenario assumed that the current environmental state would continue. In addition, the

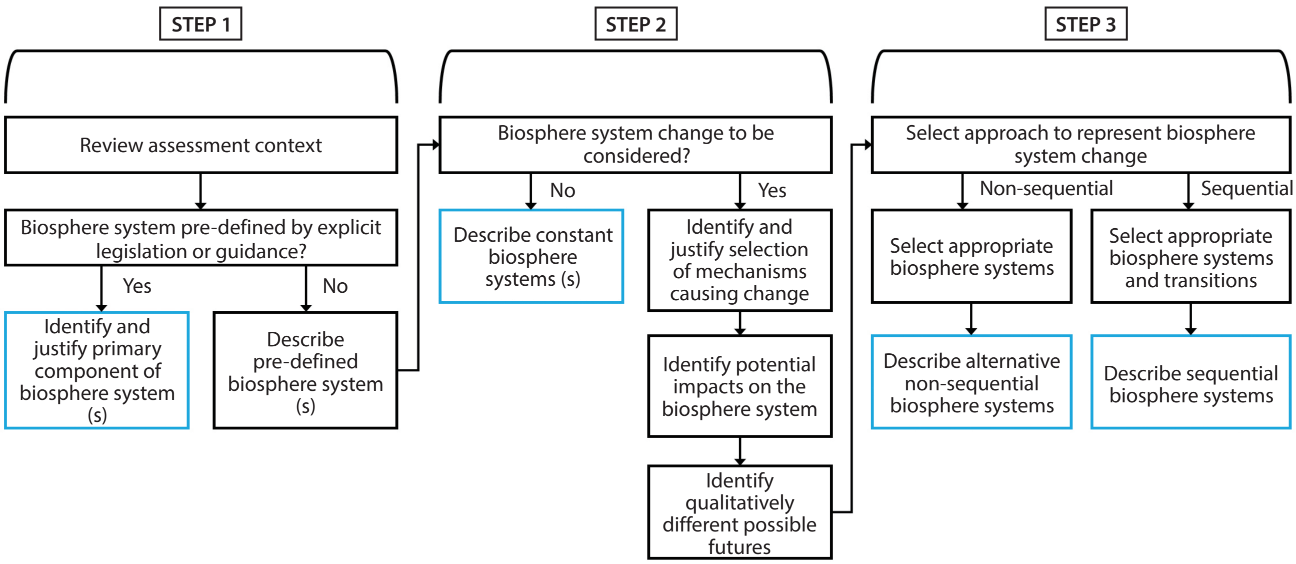


Fig. 1. Decision tree for use in the identification and justification of biosphere systems [2].

variation scenarios considering the change in landscape, climate, and GBI were evaluated and compared with the basic scenario.

In this study, after analyzing the experience of leading countries such as Sweden, Finland, and Japan on setting environmental conditions when evaluating the biosphere of spent nuclear fuel disposal facilities, a strategy to establish a biosphere assessment model with applying to domestic environmental conditions of ROK was presented. In chapter 2, the IAEA BIOMASS methodology and biosphere assessment models applied in the leading countries were reviewed. In chapter 3, an overall strategy to treat biosphere conditions and to select calculation cases for the biosphere assessment systematically was proposed. In chapter 4, the environmental conditions such as climate, topography, GBIs, and PEGs corresponding to the ROK generic site to be applied in the biosphere model and the interrelation between those environmental conditions were presented and a preliminary selection of the biosphere conditions and their combinations were described. In addition, the selected calculation cases were ranked based on the importance, likelihood, and knowledge status of each case from experts' judgment.

2. Foreign Cases Review on Biosphere System Condition Setting Down

2.1 BIOMASS Methodology

The stages for developing a conceptual biosphere assessment model for radioactive waste disposal facilities are from the assessment context to PEGs in the BIOMASS methodology process. The assessment context is the first stage in the development of the biosphere assessment model and the assessment context consists of eight elements such as assessment purpose, calculational endpoints, and site context [2]. Identification and justification of the biosphere system is the second stage and changes in the site context, climate, landscape, and human activity are considered. In the third stage of the biosphere system description, qualitative and quantitative information are provided. In the final stage, PEGs are identified through an understanding of exposure pathways and the correlation between exposure pathways and human activities, which is the biosphere assessment target.

The time frame of the biosphere assessment model spans millions of years, which inevitably brings various uncertainties in the modeling of future site context and human activities. Therefore, it is very important to consider and define long-term changes in the biosphere conditions for the development of the biosphere assessment model. In particular, the modeling of variation in future human activities, surface environmental conditions (climate and landscape), and exposure pathways are critical from the viewpoint of biosphere condition change. Based on these contexts, the BIOMASS suggests a procedure (decision tree) to consider and decide biosphere system conditions through the following three steps, as shown in Fig. 1.

- Step 1: The assessment context is reviewed to see whether it pre-defines the biosphere systems to be considered. If this is not the case then the components of the biosphere systems are identified and justified using information from the assessment context.
- Step 2: A decision is made based on the assessment context as to whether biosphere change is to be considered. If change is to be considered then the mechanisms causing change and the associated potential impacts on the system are identified. If change is to be not considered then refer to the present biosphere and description of the normal states biosphere system.
- Step 3: If change is to be considered in Step 2 then consider how to treat the change biosphere system. In the case of treating system change non-sequential, select several relevant biosphere systems and description them. Whereas, in the case of treating system change sequentially, the time-dependent change to the biosphere system is described.

2.2 Biosphere System Condition in Leading Countries' Biosphere Models

Biosphere models of Sweden and Finland refer to the Weicheslian, the last glacial cycle in Northern Europe to define the climate condition. Weicheslian consists of temperate, periglacial, and glacial [3]. Temperate is a similar

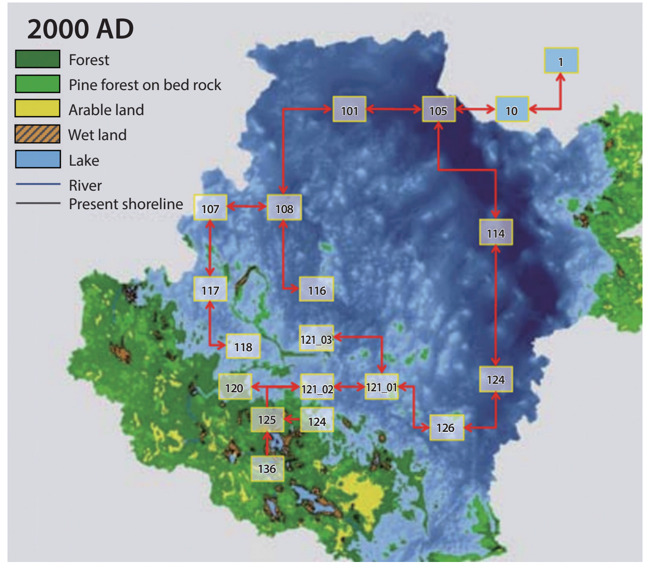


Fig. 2. Biosphere object in Forsmark site [6].

state to the present climate. Periglacial is a state similar to the tundra that is not affected by glacial directly but by the edges of glacial areas. In addition, it was considered a submerged facilities period due to the rise of sea water level affected by deglaciation.

In Sweden, climate change scenarios included a reasonable continuation of identified climate conditions. Two base scenarios were established by future climate change cases that reference the glacial cycle and consider global warming, respectively. In addition, alternative scenarios were considered that are expected to affect the disposal facilities' safety, that is, extended global warming, extended ice sheet duration, and severe permafrost. In contrast, Finland has decided that climate uncertainty can be sufficiently considered by only the transition of CO_2 concentration and the effect of insolation. Thus, Finland has applied the global warming case as the base scenario. In addition, they considered the extended global warming case as an alternative climate change scenario [5].

Sweden and Finland have applied a concept of biosphere objects to set up the landscape, GBIs, and PEGs [5, 6]. Biosphere objects are defined as the most affected area by potential radionuclide release through groundwater

Table 1. Landscape state in Forsmark site [6]

State	Description
Sea	The biosphere is a sea basin. During this period, the object has only an aquatic biosphere.
Transitional	The sea bay is isolated and transforms into a lake or a stream (aquatic) surrounded by a wetland (terrestrial) or directly into a wetland.
Lake	The surrounding wetland expands into the lake, and aquatic sediments are gradually covered by a layer of peat.
Terrestrial	The biosphere object has reached a mature state and no further natural succession occurs. For the majority of discharge areas, the end stage is a wetland that is drained by a small stream.

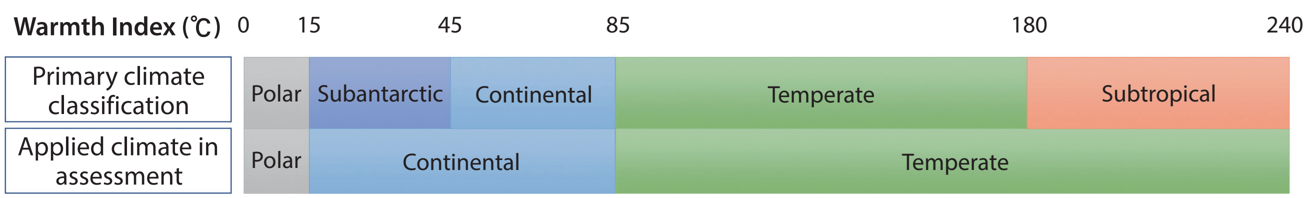


Fig. 3. Climate classification in Japan biosphere assessment case [9].

or surface water in the glacial cycle. Sweden and Finland identified potential radionuclide release points using groundwater flow modeling from a repository to a surface for identifying biosphere objects [10]. The biosphere objects configured in Sweden are shown in Fig. 2. Most biosphere objects continue to change in the temperate period, and they feature four main states as shown in Table 1. Furthermore, potential radionuclide release points are associated with current and long-term possible landscape features like lakes, sea basins, and wetlands.

The biosphere can change in type and scale by long-term changes in the natural environment or landscape features. Therefore, Sweden and Finland have developed models that include both the terrestrial and aquatic biosphere to facilitate modelling of the long-term landscape change. PEGs were assumed to be residents who always stay in the contaminated area and are supplied with all food and drinking water there. In addition, a representative person was selected in the most exposed group, according to each climate and landscape condition.

Japan has combined overall landscape and climate classification to define site environmental conditions for base and variant scenarios and applied warmth index calculated by summing the average temperature of the months with a monthly average temperature of 5°C or higher. Among five primary climate conditions based on the warmth index, similar conditions that would not be expected to differentiate significantly the biosphere evaluation results were integrated [9]. Thus, climate conditions in Japan were classified into three cases as shown in Fig. 3.

In the case of landscape classification [9], the overall topography of Japan was considered. It was classified as mountain, hill, and plain by topographic relief. In addition, the landscape classification is combined with climate classification to set up calculation cases. Then, they expected polar climate conditions would occur only in some mountains. Thus, seven climate-landscape combinations were set up excluding hill-polar and plain-polar, as shown in Table 3. Japan has judged that a deep geological disposal facility is unsuitable within the range of 15 km centered on the Quaternary volcano. Except for this area, the average elevation is about 100 m, corresponding to the lowland plain. Nowadays, most area in Japan is a temperate climate. In addition, considering the long-term climate change, the area that could be covered by glaciers is expected to be limited

Table 2. Landscape-Climate combine in Japan biosphere system condition [9]

Climate / Landscape	Polar	Subantarctic	Continental	Temperate	Subtropical
		Continental		Temperate	
Mountain	1	2		3	
Hill	-	4		5	
Plain	-	6		7	

Table 3. Summary of biosphere system conditions set in Sweden, Finland, and Japan

Category	Sweden	Finland	Japan
Climate	Temperate-Periglacial-Glacial-Submerged		Temperate-Continental-Polar (Non-glacial)
Topography	Continuous transition of sea, lake, wetland, and arable land	Continuous transition of various biosphere types using on/off function in biosphere object modules	Non transition of mountain, hill, and plain
GBIs	Identifying potentially radionuclide release point based on groundwater flow modeling	Identifying potentially radionuclide release point based on simple biosphere modeling and groundwater flow modeling	- Liver and sea (Base scenario) - Deep well (Variant scenario)
PEGs	Representative person in biosphere object that calculated most exposed		- Farming group - Marine water fishing group - Freshwater fishing group

to only some regions. Therefore, they considered combination number 7 in Table 2 as the base scenario condition.

GBIs in Japan were expected to change according to biosphere conditions such as climate change, uplift, and erosion in a long-term assessment timescale. Thus, aquifer, river, coastal water, and sea sediment were set as GBIs according to overall groundwater flow and landscape. In the case of the base scenario, it was reasonable to set river and sea water as GBIs because the base scenario is corresponding to the low land plain. In addition, based on the fact that about 20% of the catchment area is groundwater, they included a deep well as GBI in a variant scenario. PEGs were expected to be the farming group, the freshwater fishing group, and the marine fishing group according to GBIs. In the case of GBI of coastal water, the freshwater fisher group was excluded based on the nuclide transport process.

The summary of biosphere system conditions set in Sweden, Finland, and Japan is shown in Table 3.

3. Development Strategy of Korean Biosphere Assessment Model

3.1 Strategy to Select Biosphere Assessment Model

In the BIOMASS methodology [2], it is recommended that define whether the biosphere system changes need to be considered or not based on the assessment context and relevant legislation or guidance. Since the future radionuclide releases and related radiological impacts as a result of climate change and landscape development would be significantly different from those of present-day, the biosphere system changes consistent with the reasonable and possible future conditions should be considered in the safety assessment of deep geological disposal facility. Changes in the biosphere over time were considered in Sweden [4, 6] and Finland [5] where construction licenses for the geological disposal

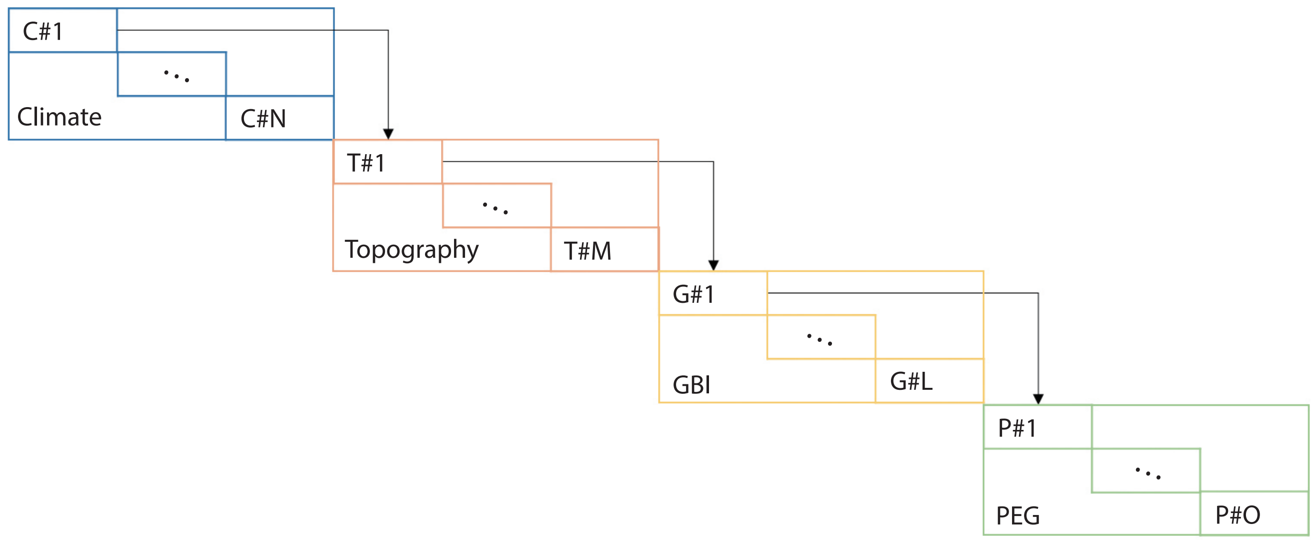


Fig. 4. Method for configuration of biosphere conditions.

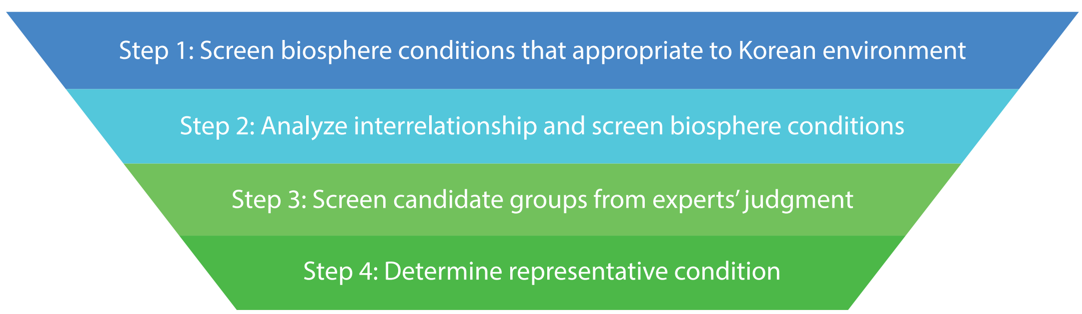
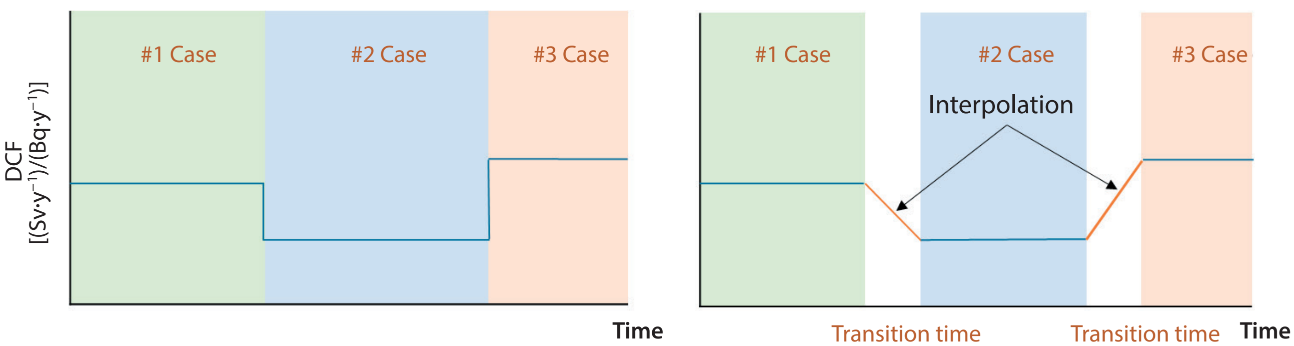


Fig. 5. Screening procedure of biosphere system conditions to construct Korean biosphere assessment model.

facility were obtained, so it would be necessary to take into account the biosphere system changes for the Korean disposal facility also. However, since the candidate disposal site has not been yet specified in Korea, there are limitations to the information on the disposal site. Thus, in advance of the site selection, it is necessary to develop generic biosphere models to be applied to various conditions of climate and landscape, etc. which are suitable for the domestic environmental conditions. The generic biosphere assessment model of the hypothetical site should represent the generic domestic environmental characteristics so that the site-specific assessment could be conducted by modifying some parts of the generic model when the candidate sites are specified.

Biosphere components of the assessment model for the hypothetical site should be determined based on the biosphere conditions, for instance, climate, topography, GBI, and PEG. In the safety assessment for the deep geological disposal facility, since its timeframe is usually up to millions of years, it is impossible to predict the status of the future biosphere. Therefore, the biosphere system should be constructed conservatively so that exposure doses of PEG are maximized according to the conditions of the biosphere. For this reason, a strategy was established to combine the biosphere components by arranging and linking the various conditions in climate, topography, GBI, and PEG, as shown in Fig. 4. In Fig. 4, arrows mean an example case of



(a) Step-wise

(b) Interpolation of transition time

Fig. 6. Examples of DCF changes over time.

1-1-1-1, and N, M, L, and O mean the number of conditions in climate, topography, GBI, and PEG, respectively. The biosphere conditions of the generic site are a wide variety, so hundreds of calculation cases that follow N×M×L×O could be generated. Thus, it is necessary to select realistic candidates among them.

In this study, to screen the appropriate conditions in a systematic way, the procedure shown in Fig. 5 was established. In step 1, the conditions in the climate, topography, GBI, and PEG that are not appropriate to the generic site were excluded. Also, based on human activities in the distant future, PEGs which are expected to be low exposure doses were excluded. In step 2, combinations that would be impossible or highly unlikely were excluded through the analysis of the interrelationship between the biosphere conditions. In step 3, the calculation cases screened in step 2 were scored from an experts' point of view and prioritized.

3.2 Strategy to Treat Biosphere System Evolution

Climate changes and landscape development could occur in various ways during the long timeframe of millions of years. In the BIOMASS methodology [2], it is suggested that the biosphere assessment should be conducted based on the description and determination that biosphere system changes are either sequential or non-sequential. In Sweden [4, 6] and Finland [5], the biosphere system evolution was expressed based on the predictions of climate change and landscape development of the specific site selected. However, it is difficult to predict climate change and landscape development in the case of Korea that the disposal site has not been specified. Therefore, in this study, a Korean-unique modeling strategy was established that the biosphere changes over time are treated discretely but arranged in sequential order with referring to the case study in Japan [7, 8, 9].

The exposure doses could be varied depending on the biosphere types that would be changed in the future, therefore, it is necessary to model the various biosphere systems according to the specific time in the future conditions. When the biosphere system models are changed by applying climate change and landscape development as a certain event, the Dose Conversion Factor (DCF) would be expressed step-wise as shown in Fig. 6(a). In this case, there is a limitation in the insurance of mass balance, and non-realistic and abrupt changes in radionuclide concentration over time make it difficult to treat the mass balance numerically. Therefore, in order to address these problems, in this study, the periods in which climate change and landscape development would occur are treated as transition periods and are connected to the adjacent biosphere cases with interpolation as shown in Fig. 6(b).

This strategy enables the evaluation of time-dependent exposure dose by combining and connecting the evaluation results for each calculation case when the configuration of the climate change and landscape development is determined. This strategy could play an important role in the selection of a Korean deep geological disposal site by enabling the realistic assessment for various requirements.

4. Estimation of Korean Biosphere System Conditions

4.1 Composition of Biosphere System Conditions for Korean Generic Site

4.1.1 Climate

The global climate can be classified by using the Köppen climate classification method into tropical, dry, temperate, continental, and polar climates [11]. While the Korean current climate can be classified as a temperate climate, the future climate can change because the earth has experienced a repeated glacial cycle in which in the greatest ice age, 30% of the earth surface was covered with ice and when it was warm the climate was similar to current. Hence, the long-term future climate can be variant. In the case of Sweden and Finland, temperate, periglacial, and glacial climates were considered as climate variations through the climate change analysis. In addition, the submerged condition of post-glacial was added due to the landscape development caused by ice sheets at the disposal site. Hence, it was required to consider the glacial and submerged conditions in the climate change for the two countries.

In the case of Japan which is adjacent to Korea, the disposal site was assumed not to be covered by glaciers, based on the historic record of nationwide Paleolithic evidence between 20,000 and 30,000 years ago, when was the last ice age. Hence, the climate was classified into polar, cool, and temperate. In the Korean Peninsula, there is no sign of glaciers except for the Kaema plateau in North Korea, so the Korean disposal site would not be covered by glaciers even in the far future similar to the case of Japan. The dry climate can also be excluded since Korea has sufficient precipitation at present and the continuous existence of trees was confirmed in the paleoclimate literature. The tropical climate means that the monthly mean temperature is over 18°C throughout the year and the mean temperature of the coldest month in Korea for 50 years since 1973 was −10.6 to −2.5°C [12] and considering Japan's prediction that the average annual temperature will rise by up to 2–3°C, no tropical climate is expected in the far future. Therefore, the Korean climate condition in the far future could be classified into temperate, continental, and polar climates.

Table 4. Average value of altitude, slope, and LER of classified topography of Korean Peninsula [13]

	Mountain	Hill	Plain
Altitude (m)	794	188	47
Slope (°)	24.4	19	7
LER (m)	1,009	694	399

4.1.2 Topography

In the case of Sweden and Finland, the topography of the specific site licensed for the disposal facility construction was used for biosphere assessment. In the case of Japan, mountains, hills, and plains were considered for the biosphere evaluation without a specific topography for the disposal site. The topography of the Korean Peninsula can be classified by cluster analysis using altitude, slope, and local elevation range (LER) [13]. Table 4 shows the average value of altitude, slope, and LER of the classified topography of the Korean Peninsula. The Korean Peninsula consists of 49% of mountains, 32% of hills, and 19% of plains. Considering the future landscape development and no specification of the disposal site, it is necessary to evaluate all topographies since the disposal site can change to any topography.

4.1.3 GBI and PEG

In the case of Sweden and Finland, particle tracking simulations were performed to find possible GBIs at the

Table 5. Human activities and exposure groups related to potential radiation exposure

Human activity	Exposure group
All activities, activity near contamination source, processing	All
Mining, quarrying	Miner
Drinking, bathing, swimming, cooking, in/outdoor activity	Resident, tourist
Animal husbandry, eating terrestrial animal products	Livestock raiser, hunter
Eating aquatic products	Freshwater fisher, marine fisher
Soil disturbance activity, gardening, eating plant products	Farmer, forestry worker, gatherer

Table 6. Composition for evaluation of biosphere system conditions in Korea

Climate	Topography	GBI	PEG
Temperate, continental, and polar	Plain, hill, and mountain	Surface water, marine water, and well	Farming, freshwater fishing, marine water fishing, hunting, and gathering

disposal site. According to the selected GBIs and future biosphere changes, the groups that potentially experience the largest exposure doses were selected for biosphere assessment and called as PEGs. In the case of Japan, the entire area except for the range of 15 km centered on the Quaternary volcano can be appropriate for deep geological disposal. Since the average altitudes of those areas were about 100 m, a lowland plain can be the candidate site. Also, GBI was judged to be likely to be located downstream of the disposal facility following the groundwater flow system. Thus, rivers located in the lowland plains and coastal waters were selected as GBIs for the basic scenario. In addition, the deep well was selected as a GBI in the variant scenarios due to the possible use of contaminated well since about 20% of the water source was groundwater [14].

In the case of Korea where the candidate site has not been specified yet, the area within about 20 km from the coast could be considered as the preliminary candidate site for the deep geological disposal considering the domestic transportation of spent nuclear fuel [15]. The preliminary candidate sites include surface water (river, reservoir, lake), and sea. Groundwater used for drinking and agriculture was considered in this study. Also, uncommon and local phenomena such as marine water backflow from the west coast to inland toward the Han River due to the difference in seawater tidal were not considered. Thus, it is necessary to select surface water, marine water, and well as GBIs. The exposure groups are summarized in Table 5 based on human activities that lead to potential radiation exposure presented in IAEA BIOMASS [2].

Since the disposal site has not been specified and it is impossible to predict the human lifestyles in the vicinity of the disposal sites for the timeframe of up to millions of years, all of the presented groups in Table 5 would be able to be assumed to be PEGs. As recommended by ICRP-101 [16], combinations of activities with two or more significantly different exposure pathways were excluded (e.g., both agricultural and fishing). In the case of the miner group, radiation exposures are mainly due to inhalation, accidental ingestion, skin absorption, and external exposure during the activities of mining minerals contaminated from the aquifer. This case can be excluded from the PEGs because the exposure dose will be lower than the ones resulting from activities directly affected from daily diets such as

Table 7. Excluded biosphere conditions based on climates

Climate	Topography			GBI			PEG				
	Plain	Hill	Mountain	Surface water	Marine water	Well	Farming	Freshwater fishing	Marine water fishing	Hunting	Gathering
Temperate										X	X
Continental										X	X
Polar	X	X									

farming or fishing. The resident group can also be excluded because this group is included in most other exposure groups. In the case of a tourist group, the time spent at the target site would be limited and consequently, the exposure dose would be lower than those of other groups such as the farming group, hence this group can be excluded from PEGs. The livestock raiser group was integrated into the farming group assuming that the farming group could raise livestock along with the agricultural activity. The forestry group can be excluded because that activity is not directly affected by food, similar to the miner group.

Accordingly, the climates, topographies, GBIs, and PEGs of Korea selected for detailed analysis in the following section of this chapter are presented in Table 6.

4.2 Screening of Biosphere System Conditions Using Interrelation Analysis

There could be very unlikely or impossible combination cases depending on the biosphere system conditions used in the combination. For example, if GBI is set to be marine water, radionuclides are restricted from moving to surface water, hence it is not appropriate to select freshwater fisher as PEG. In this section, these very unlikely calculation cases were screened out by analyzing the interrelationships between these biosphere system conditions.

4.2.1 Interrelations between Climate vs Topography, GBI, PEG

In the interrelation between climate and topography, the current climate of Korea is mostly temperate and some mountainous regions are continental. Even if the ice age arrives in the distant future, it is expected that only some mountainous regions could change to the polar climate, which is similar to the combination of Japan in Table 2. Hence, it can be assumed that the polar climate is possible only in the mountainous region. In the interrelation between climate and GBI, GBIs are expected to be unrestricted for certain climates. In the interrelation between climate and PEG, in the case of the temperate and continental climates, the farming group that cultivates crops is expected to be exposed more than the hunting and gathering groups, thus hunting and gathering groups could be excluded. The biome in the polar climate is expected to be similar to that of the current tundra. In this environment, it is difficult to select groups with more exposure compared to hunting and gathering groups because food production through agriculture is limited. Hence, it is necessary to consider all of farming, fishing, hunting, and gathering groups in the case of polar climate. Table 7 shows the results of the screening-out of biosphere conditions based on the climates.

4.2.2 Interrelations between Topography vs GBI and PEG

It is not appropriate for the sea to exist in the mountainous topography. And in mountainous topographies, aquifers due to rainwater are formed near the surface and it is not realistic to drill a deep well in the aquifer connected to the disposal site. Hence, the marine water and the well were excluded from GBIs in the case of mountainous topography.

Table 8. Excluded biosphere conditions based on topographies

Topography	GBI			PEG				
	Surface water	Marine water	Well	Farming	Freshwater fishing	Marine water fishing	Hunting	Gathering
Plain								
Hill								
Mountain		X	X			X		

Table 9. Excluded biosphere condition based on GBIs

GBI	PEG				
	Farming	Freshwater fishing	Marine water fishing	Hunting	Gathering
Surface water			X		
Marine water	X	X		X	X
Well		X	X	X	X

Thus, marine water fishing can be excluded from the PEGs. Table 8 shows excluded biosphere conditions based on the topographies.

4.2.3 Interrelations between GBI vs PEG

In the case of GBI of surface water, even if radionuclides are transported to sea through a river, the concentration of radionuclides will be greatly diluted. Hence, the marine fishing group is expected to be exposed less than the freshwater fishing group. In the case of GBI of marine water, contaminated water is not used for hunting, freshwater fishing, farming, and gathering activities. In the case of a well, hunting, marine fishing, and gathering activities can be excluded from PEG because the well does not affect these activities. Also, in the case of PEG of freshwater fishing, since only a very small portion (1.8%) of total groundwater is used for freshwater fishing in Korea, this case was screened out. Table 9 shows the excluded biosphere conditions based on the GBIs.

4.2.4 Interrelation Matrix for Biosphere Conditions

Based on the interrelation analyzed in Section 4.2, the total interrelation matrix between each condition in the biosphere system components was developed as shown in Fig. 7. When creating calculation cases for biosphere system assessment using this matrix, each condition in the climate, topography, GBI, and PEG are combined one by one between different components. The case with the 'X' symbol, such as the combination of temperate and hunting, is an excluded calculation case.

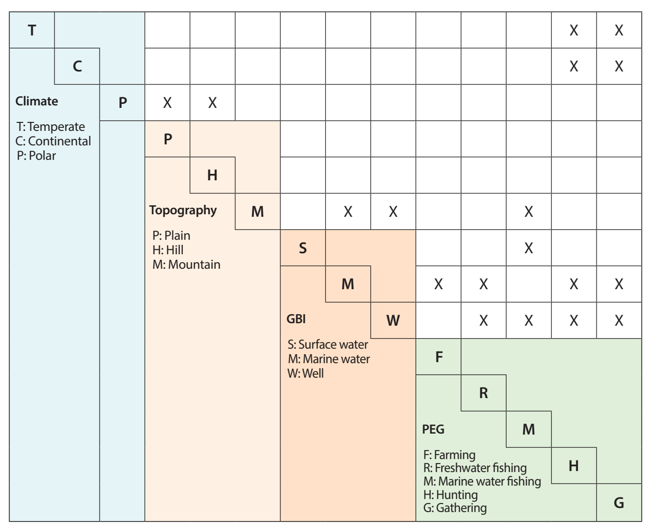


Fig. 7. Interrelation matrix for combination of biosphere system conditions.

Table 10. Scoring criteria to select priority

Importance of consequence	Occurrence probability	Knowledge level (Score)		
		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 11. Descriptions of calculation cases

Calculation cases	Biosphere descriptions
TPWF	Plain with temperate climate. GBI of a shallow well. PEG using water from shallow well for intaking and farming.
TPMM	Plain with temperate climate. GBI of marine water. PEG fishing in marine.
TMSR	Mountain with temperate climate. GBI of surface water. PEG intaking surface water and fishing in surface water.
TPSR	Plain with temperate climate. GBI of surface water. PEG intaking surface water and fishing in surface water.
TPSF	Plain with temperate climate. GBI of surface water. PEG using surface water for intaking and farming.
TMSF	Mountain with temperate climate. GBI of surface water. PEG using surface water for intaking and farming.
THWF	Hill with temperate climate. GBI of a deep well. PEG using water from a deep well for intaking and farming.
THMM	Hill with temperate climate. GBI of marine water. PEG fishing in marine water.
THSR	Hill with temperate climate. GBI of surface water. PEG intaking surface water and fishing in surface water.
THSF	Hill with temperate climate. GBI is surface water. PEG using surface water for intaking and farming.
CPWF	Plain with continental climate. GBI of a shallow well. PEG using water from shallow well for intaking and farming.
CPMM	Plain with continental climate. GBI of marine water. PEG fishing in marine water.
CPSR	Plain with continental climate. GBI of surface water. PEG intaking surface water and fishing in surface water.
CPSF	Pain with continental climate. GBI of surface water. PEG using surface water for intaking and farming.
CMSF	Mountain with continental climate. GBI of surface water. PEG using surface water for intaking and farming.
CMSR	Mountain with continental climate. GBI of surface water. PEG intaking surface water and fishing in surface water.
CHWF	Hill with continental climate. GBI of a deep well. PEG using water from deep well for intaking and farming.
CHMM	Hill with continental climate. GBI of marine water. PEG fishing in marine water.
CHSR	Hill with continental climate. GBI of surface water. PEG intaking surface water and fish in surface water.
CHSF	Hill with continental climate. GBI of surface water. PEG using surface water for intaking and farming.
PMSH	Mountain with polar climate. GBI of surface water. PEG hunting animals contaminated by surface water.
PMSG	Mountain with polar climate. GBI of surface water. PEG gathering plants contaminated by surface water.
PMSF	Mountain with polar climate. GBI of surface water. PEG using surface water for intaking and farming.
PMSR	Mountain with polar climate. GBI of surface water. PEG intaking surface water and fishing in surface water.

Table 12. Calculation case scores based on experts' evaluations (Organized in order of scores)

Calculation case	Experts					
	A	B	C	D	E	Sum
TPSF	6	6	6	6	6	30
TPMM	5	6	5	6	6	28
TPWF	6	5	5	6	6	28
TPSR	6	6	6	3	6	27
THMM	6	5	3	6	6	26
CPSF	5	5	6	5	5	26
CPMM	3	6	5	5	6	25
CPWF	5	3	5	5	6	24
CPSR	5	6	6	2	4	23
THWF	6	2	2	6	6	22
THSF	3	5	3	6	4	21
CHWF	5	2	2	5	6	20
CHMM	3	5	3	5	4	20
CHSF	3	5	3	2	4	17
TMSR	3	3	2	4	4	16
THSR	3	2	3	3	3	14
TMSF	3	2	2	3	3	13
CHSR	3	2	3	2	3	13
PMSG	4	5	1	1	2	13
CMSF	3	2	2	2	3	12
CMSR	2	2	2	2	3	11
PMSH	4	2	1	1	2	10
PMSF	3	2	1	1	1	8
PMSR	2	1	1	1	3	8

4.3 Priority Selection of Candidates Considering Expert Judgments

The number of calculation cases for biosphere assessment in Korea evaluated in Section 4.1 is 135 (3[Climate] 3[Topography] 3[GBI] 5[PEG], Table 6), and could be reduced to 24 cases through interrelation analysis of each combination as described in Section 4.2. To prioritize these 24 calculation cases and select more significant cases among them, the scoring criteria based on the importance, probability, and knowledge level for each calculation case as presented in IAEA ISAM [17] was made as shown in Table 10. The numbers in parentheses in Table 10 mean scores used in the experts' evaluation. Table 11 is the description for 24 calculation cases and Table 12 shows the summarized results from five (5) experts' scoring. For illustrative purposes, the expert panel was composed of researchers who have studied the biosphere assessment methodology.

All the experts gave the highest score to the case of TPSF, hence this case was evaluated as the most realistic basic calculation case, farming using contaminated surface water in a plain with a temperate climate. All the cases with plain in temperate climate were scored from the 1st to the 4th ranking. Hence, these cases would be high-priority cases. Among the cases with a continental climate, cases with plain have a high ranking. All three calculation cases with the polar climate ranked low.

The mean scores of all the cases with temperate, continental, and polar climates were 23, 19.1, and 9.8, respectively, that is, cases with temperate scored highest and cases with polar scored lowest. This is due to the following reasons: (1) Knowledge of the current climate is higher than others, (2) Topography of the polar climate is limited to the mountainous site, and (3) The possibility of a mountain to be selected as the disposal site is low. In addition, according to the Japan case, it was analyzed that exposure doses tend to decrease in continental and polar climates compared to temperate climates.

The mean scores of all the cases with plain, hill, and mountain as topographies were 26.4, 19.1, and 11.1, respectively, that is, the cases with a topography of plain ranked highest. This priority could attribute to the topography of the Korean preliminary candidate disposal site could be a plain near the coast. The mean scores of the cases with all GBIs and exposure groups excluding mountain topography were 24.8 for [marine water]-[fishing], 23.5 for [well]-[farming], 23.5 for [surface water]-[farming] and 19.3 for [surface water]-[fishing]. The surface water-fishing case scored the lowest, and the others scored similar values. Although cases with well GBI were expected to be ranked lower than cases with other GBIs in advance of the experts' evaluation, experts gave fairly high scores, hence the well GBI cases must be considered as important calculation cases. In addition, it would be required to collect and analyze the relevant data to build up generic biosphere assessment models based on the priorities obtained from this study.

5. Conclusions

It is necessary to develop generic biosphere system assessment models suitable to the Korean domestic environmental conditions before candidate disposal sites are specified for deep geological disposal of spent nuclear fuel. In order to develop the Korean generic biosphere assessment models, a biosphere assessment modeling strategy considering long-term climate change and landscape development in the Korean Peninsula was established through review and reference to the biosphere assessment methodologies of international cooperative researches. Biosphere models applied in the leading countries of Finland and Sweden and approach methodology in Japan are reviewed. In this study, a unique strategy composed of three (3) process steps of combination, screening, and experts' scoring on the biosphere system conditions was developed in order to construct the Korean generic biosphere assessment models. Firstly, various conditions in the biosphere system components of climate, topography, GBI, and PEG were combined each other. Secondly, the combined calculation cases were configured into the interrelation matrices to screen out some calculation cases very unlikely or less significant in aspects of exposure dose. And finally, the selected calculation cases were prioritized based on the expert's judgment through scoring on the knowledge and importance, etc. In addition, the biosphere evolution over a long-term period was expressed discretely but sequentially with a strategy of introducing transition periods between chronologically adjacent biosphere systems with different climates and landscapes. The results, in this study, would be implemented in the development of biosphere assessment models for the Korean generic site and it is expected that this systematic methodology to select the candidate calculation cases could contribute to building up the confidence of site-specific biosphere assessment models to be developed in the future.

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