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A Study on the Application of Probability of Scenario for Risk Assessment of Deep Geological Repository for High-Level Radioactive Waste

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1. Introduction

According to the domestic notification [1], the main safety objective of risk assessment for deep geological repository for high-level radioactive waste is risk. In order to assessment the risk, a risk-based assessment methodology is required, and commercial nuclear power plants also calculate the risk through a systematic risk-based assessment methodology. However, in the case of deep geological repositories, a new risk assessment methodology that can reflect the characteristics of deep geological repositories, not the methodology used in commercial nuclear power plants, must be applied. According to previous studies related to the risk assessment methodology of deep geological repositories currently under development [2], it is judged necessary to discuss the 'plan to apply the probability of scenarios' as one of the many pending issues for methodology development. Based on this background, this paper presents an idea for applying the probability of scenario to be used in the risk assessment methodology of a deep geological repositories.

2. Risk assessment

2.1 Definition of risk

According to the domestic notification [1], the total risk caused by all scenarios related to the deep geological repository should not exceed $10^{-6}/\text{year}$, and at the same time, the effective dose caused by each scenario is 10mSv/year should not exceed. That is, the main safety objective consists of risk, and the secondary safety objective consists of dose. This risk-based assessment methodology must satisfy requirements such as satisfaction of risk triplet and presentation of assessment results corresponding to changes in time [3]. The total risk finally derived through the assessment is calculated by multiplying the probability of each scenario, the effective dose, and the dose conversion coefficient as shown in Equation (1), and the safety of the deep geological repository is proved by comparing the derived result with the safety objective.

$$\text{Total risk} = \gamma \sum P_i D_i \tag{1}$$

Where, γ is the risk coefficient(0.05/Sv), i is the exposure scenario, P is the probability of exposure scenario, D is the annual dose rate for representative

2.2 Risk profile ($\vec{R}$)

When interpreting the risk calculation formula in Equation (1), the risk calculation result appears to be derived as a scalar value, but in reality it would be appropriate to derive it in the form of a risk profile. In this paper, the total risk is expressed in the form of a risk profile and the probability of scenario is applied as a weight concept. Accordingly, the risk calculation formula in Equation (1) is expressed in the form of a risk profile as in Equation (2).

$$\vec{R} \approx \gamma \sum_{i=1}^{N} \sum_{j=1}^{m_i} P_i^j \vec{D}_i^j \tag{2}$$

Where, $\vec{R}$ is total risk profile, i is the scenario number, N is the total number of scenarios, j is the simulation condition number, m_i is the total number of simulation conditions in scenario i, P_i^j is the probability of a scenario when scenario i is condition j, $\vec{D}_i^j$ is the dose profile when scenario i is condition j

In equation (2), P_i^j corresponds to a scalar value, and $\vec{D}_i^j$ means the dose profile information derived according to the lapse of time after post-closure.

P_i^j depends on the type of scenario i, and in the case of an abnormal scenario, the distribution of the probability of an abnormal event occurring over time (e.g., divided into a discrete probability distribution or a continuous probability distribution, in the case of a discrete probability distribution, whether it occurs or, if it is a continuous probability distribution, the probability corresponding to each time period).

$\vec{D}_i^j$ means a simulated dose profile by reflecting the effect of an event every time a predetermined time step elapses. After denoting the identifier j for this simulation condition, $P_i^j \vec{D}_i^j$ is calculated by weighting the probability of scenario under that condition to the dose profile derived for each condition. $\vec{D}_i^j$ can be expressed as Equation (3) by reflecting the time variable.

$$\vec{D}_i^j = \left[D_i^j(t), D_i^j(t+\Delta t), \cdots, D_i^j(T)\right] \quad (3)$$

Where,$D_{i,}^j(t)$ *is the dose value corresponding to time t in simulation condition j of scenario i,,* Δt *is the time step,* T *is the total risk assessment period*

The element of $\vec{D}_i^j$ in Equation (3) is the dose value corresponding to the corresponding time, and $\vec{D}_i^j$ is formed by integrating it according to time.

2.3 Probability of scenario (P_i^j) & Dose profile ($\vec{D}_i^j$)

The probability of scenario means the probability that the scenario will occur with time as a variable, and the value derived for each scenario type that requires risk assessment is applied. To this end, it is necessary to determine in advance the probability of scenario according to the time distribution.

First, the normal scenario refers to a scenario in which the functional loss of engineered barriers and natural barriers in a deep geological repository proceeds as expected by the designer and finally, radionuclides leak into the biosphere. Based on this concept, it can be seen that the normal scenario has a 100% probability that the impact will be manifested immediately after the deep geological repository is closed.

Abnormal scenarios include initial container defect scenarios, seismic scenarios, and human intrusion scenarios. In the case of an abnormal scenario, the probability and timing of occurrence of the scenario must be determined through reasonable logic or assumptions. In this paper, a random assumed value was applied to be used for the case study in Chapter 3.

The initial container defect scenario refers to the case where some containers used in deep geological repository have undetected defects from the manufacturing stage. In this case, since it is highly likely to have an effect immediately after the deep geological repository is closed, this time can be selected as the time of occurrence, and it can be assumed that it will occur with a 100% probability.

A typical human intrusion scenario is a case where humans unintentionally drill a well into the location and depth of a deep geological repository. In fact, when human intrusion occurs, the radiation effect caused by it is very large, so the human intrusion scenario applies the dose as a reference level. In this paper, we are interested in the utilization process rather than the actual result, and it is assumed that human intrusion occurs once in 100 years and once in 1000 years after the deep geological repository is closed, and engineering barriers cannot be breached.

A seismic scenario is a case where an earthquake of a certain magnitude or more causes deformation of the deep geological repository and an increase in cracks in the rock through which groundwater can flow. The earthquake occurrence probability is not a discrete probability distribution as in the previous case It corresponds to a continuous probability distribution.

If information on the frequency of earthquake is available, the probability of earthquake for each section of time after closure can be calculated using an exponential distribution. This can be expressed as Equation (4).

$$P_{seismic}^{t,t+\Delta t} = F_t(\lambda, t+\Delta t) - F_t(\lambda, t) \quad (4)$$

Where, $P_{t,t+\Delta t}^{seismic}$ *is the probability of an earthquake occurring between year* t *and* $t+\Delta t$, $F_t(\lambda, t)$ *is the cumulative distribution function at time t of an exponential distribution following the earthquake frequency* λ

In the normal scenario and the initial container defect scenario, it is assumed that the impact of the event occurs immediately after the deep geological repository is closed. Therefore, it is only necessary to derive the dose profile under the condition of being affected by the event immediately after the closure without redundant calculation of the dose profile according to the change in time step.

In the case of the human intrusion scenario, it is assumed that an event occurs once every 100 years and once every 1000 years, which can be seen as an event occurring in 100 years with a 50% probability and a remaining 50% probability in 1000 years. In this case, $P_i^j \vec{D}_i^j$ is derived by weighting the probability of scenario to the dose profile derived by simulating the case of human invasion in the 100th year and the case in which the human invasion occurred in the 1000th year, respectively.

If the probability of scenario is a continuous probability distribution, such as a seismic scenario, the analyst selects an appropriate Δt and divides the period from $t = 0$ to $t = T$, that is, the conformance evaluation period, to determine m_i in Equation (2). can After that, as in the case of the human intrusion scenario, the case where an earthquake occurs at each time step is simulated, and the corresponding earthquake occurrence probability is weighted to derive $P_i^j \vec{D}_i^j$. A conceptual diagram for this is presented in Figure 1.

3. Case study

The focus of this paper is the application of probability of scenario, and it is assumed that the dose value affected by the phenomenology of each event is determined as an arbitrary value through an appropriate calculation process.

In this chapter, we assume random example exposure scenarios applicable to the method presented in Chapter 2.

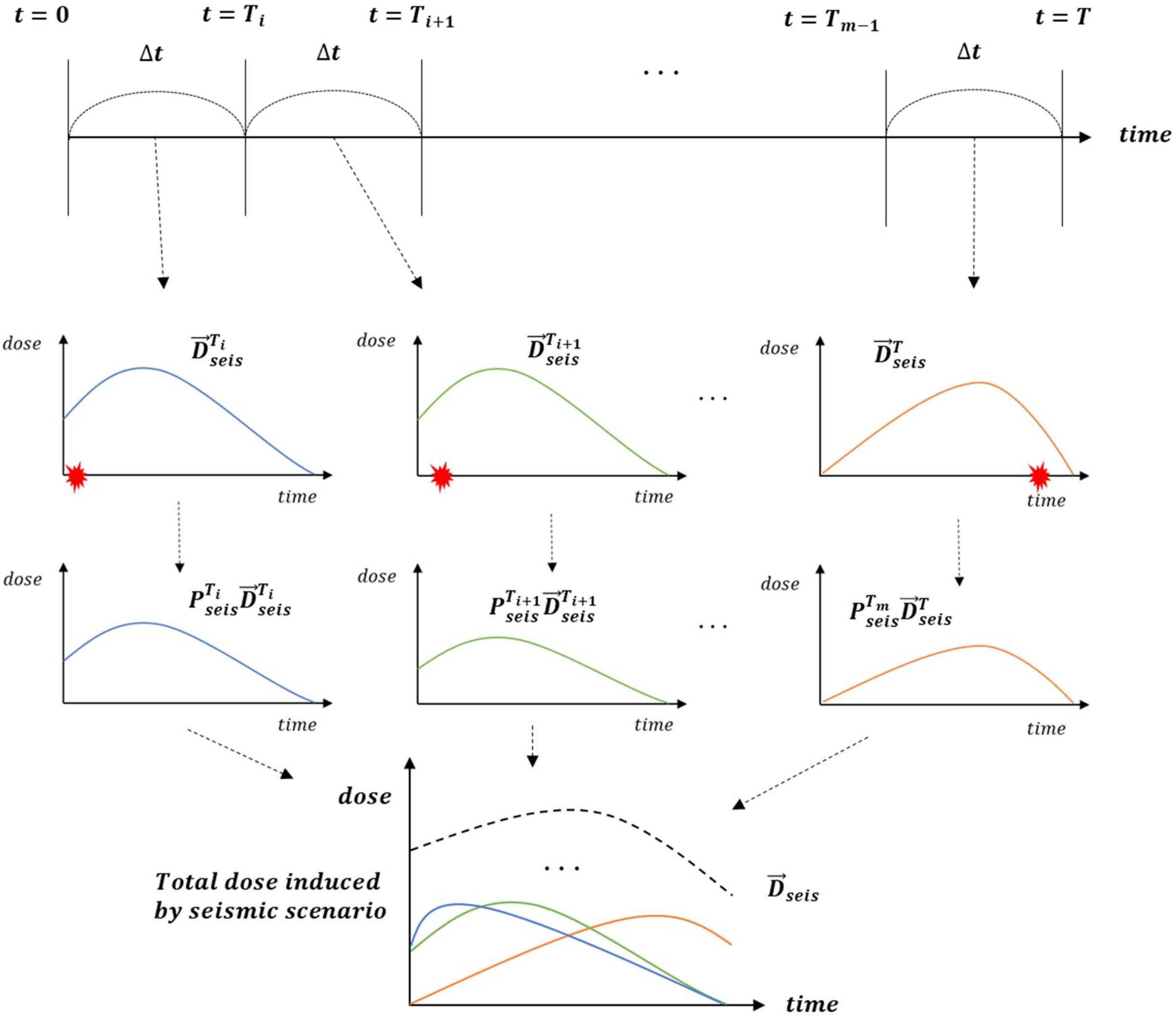

Fig. 1. Conceptual diagram of risk profile derivation of seismic scenario

3.1 Scenario type and number, assessment period

The case study is set to have an assessment period of 10,000 years, and the types of scenarios are normal scenario ($i = 1$), initial container defect scenario ($i = 2$), human intrusion scenario ($i = 3$), and seismic scenario ($i = 4$). , assuming a total of four.

3.2 Probability of event by time of scenario

It is assumed that the normal event and the initial container defect event occur immediately after the closure of the deep geological repository, and the human intrusion event occurs once every 100 years and once every 1000 years. It is assumed that earthquakes with a magnitude of 8 or higher occur with a frequency of $3.5 * 10^{-4}$ from related paper[4]. Also, since it is a continuous probability distribution, a time step must be determined, which is assumed to be one year. Using this information, the probability of an earthquake occurring per year and the total number of simulation conditions, m_i, can be determined through Equation (4).

3.3 The dose profile of each scenario

The effect of the event that triggers each scenario will be reflected in the simulation, and the dose profile is derived as a result of the calculation.

The number of dose profiles for each scenario is equal to the number of m_i, and normal events and initial container defect events are not simulated several times according to the time step to calculate the dose profile (different meaning from simulating several times under the same conditions). In the case of human invasion, the dose profile is derived by simulating the conditions affected by human invasion at the 100th year and the conditions affected by human acupuncture at the 1000th year. In the case of an earthquake event, since the simulation is performed every year, there will be 10,000 dose profiles marked with various colors in Figure 1.

Table 1. Summary of case study results

Term	Normal	Initial container defect	Human intrusion	Seismic
i	1	2	3	4
m_i	1	1	2	10000/1=10000
P_i^j	P_1^1	P_2^1	$[P_3^1, P_3^2]$	$[P_4^1, \cdots, P_4^{10000}]$
$\vec{D}_i^j$	$\vec{D}_1^1$	$\vec{D}_2^1$	$[\vec{D}_3^1, \vec{D}_3^2]$	$[\vec{D}_4^1, \cdots, \vec{D}_4^{10000}]$
$\sum_{j=1}^{m_i} P_i^j \vec{D}_i^j$	$P_1^1 \vec{D}_1^1$	$P_2^1 \vec{D}_2^1$	$P_3^1 \vec{D}_3^1 + P_3^2 \vec{D}_3^2$	$P_4^1 \vec{D}_4^1 + \cdots + P_4^{10000} \vec{D}_4^{10000}$
$\sum_{i=1}^{N} \sum_{j=1}^{m_i} P_i^j \vec{D}_i^j$	$P_1^1 \vec{D}_1^1 + P_2^1 \vec{D}_2^1 + \left(P_3^1 \vec{D}_3^1 + P_3^2 \vec{D}_3^2\right) + (P_4^1 \vec{D}_4^1 + \cdots + P_4^{10000} \vec{D}_4^{10000})$			
Risk profile	$\gamma\{P_1^1 \vec{D}_1^1 + P_2^1 \vec{D}_2^1 + \left(P_3^1 \vec{D}_3^1 + P_3^2 \vec{D}_3^2\right) + (P_4^1 \vec{D}_4^1 + \cdots + P_4^{10000} \vec{D}_4^{10000})\}$			

3.4 Derivation of final risk profile and comparison of target value

The results calculated in Sections 3.2 and 3.3 are weighted for each scenario, and the sum of all values is multiplied by the risk coefficient to derive the final risk profile of the deep geological repository. This result is used to compare whether there is a section that exceeds the safety objective.

If each step described above is expressed in a formula, it is shown in Table 1. If actual data exists, a risk profile can be derived using actual data.

4. Conclusions

In order to calculate and assess risk, which is main safety objective in deep geological repository for high-level radioactive waste, it is necessary to develop a risk-based assessment methodology, and this paper presents study results on how to apply probability of scenario, known as one of the parts of the risk assessment methodology.

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