Comparative Study on Monitoring Requirements and Guidelines of Site Investigation for Deep Geological Repositories

Jae Hee Ro, Moonjoo Gil, Hyong Chol Kim*
NSE Technology, 5F Convergence Technology Research Commercialization Center
218 Gajeong-ro, Yuseong-gu, Daejeon, 34129, Republic of Korea
**Corresponding author: hckim@nsetec.com*

***Keywords**: deep geological repository, site monitoring, site characterization, requirements, guidelines

1. Introduction

The disposal of high-level radioactive waste (HLW), primarily from spent fuels, is one of the urgent issues that countries operating nuclear power plants need to address. It is widely accepted in the scientific community that Deep Geological Repositories (DGRs) are a safe and effective solution for the permanent disposal of spent nuclear fuel and high-level radioactive waste.

Geological site characterization is essential for identifying suitable DGR sites, and monitoring plans should accompany this process. Recently, hydrogeochemical monitoring parameters for characterizing repository sites have been reviewed and identified for different stages, regions, and scales based on the experiences of DGR implementations [1].

Monitoring records are used to select suitable sites and are preserved as baseline data for repository facilities through the construction, operation, and long-term post-closure periods, subject to review and inspection under the independent regulatory framework. Therefore, site monitoring must be planned according to potential regulatory requirements.

In light of this, this study reviews the monitoring requirements and guidelines for site characterization of potential DGR sites, based on international standards and Korean domestic regulations. It also aims to highlight the essential characteristics of site monitoring requirements that should be considered during the preliminary site characterization stage, prior to site selection.

2. International Standards

Since the standards for HLW disposal facilities have been developed with a focus on the long-term safety of the repository, monitoring requirements and guidelines for site characterization of potential DGR sites are not found as independent requirements in international standards. Instead, they are stipulated as pre-operational requirements before the construction of the facility.

Multiple IAEA (International Atomic Energy Agency) standards can be consulted for monitoring requirements and guidelines regarding the siting or site characterization of DGRs, in terms of the hierarchical framework, the purpose of the facility, and the basis for monitoring functions.

2.1 Site Evaluation for Nuclear Installations, SSR-1 [2]

The requirements in the standard of SSR-1 apply to all nuclear installations, including storage facilities for spent fuel. Requirement 28 states that all natural and human-induced external hazards and site conditions relevant to the licensing and safe operation of the nuclear installation shall be monitored over the lifetime of the installation.

The monitoring plan shall include the parameters to be monitored, the type of data to be collected, the methodology for data collection (including the location and frequency of data collection), the necessary resolution and precision of any measurements, data backup requirements, as well as requirements for data processing and analysis.

Before the commissioning of the nuclear installation begins, the levels of background radioactivity in the atmosphere, hydrosphere, lithosphere, and biota in the region shall be measured to determine any additional radioactivity resulting from the operation of the installation.

2.2 Disposal of Radioactive Waste, SSR-5 [3]

The standard of SSR-5 specifies requirements specifically for disposal facilities, with site requirements included in SSR-1. One type of disposal facility considered in this standard is geological disposal, which can be constructed in vaults or silos in a specific geological formation and designed to receive high-level radioactive waste (HLW) including spent fuel.

Site characterization for a disposal facility is specified in Requirement 15. The focus of the site characterization must be on features, events, and processes related to the site that could impact safety and are addressed in the safety case and supporting safety assessment. This has to demonstrate that there is adequate geological, geomorphological or topographical stability, and features and processes that contribute to safety. Additionally, investigating natural background radiation and the radionuclide content in soil, groundwater, and other media may contribute to a better understanding of the site characteristics. This can also assist in evaluating radiological impacts on the environment by providing a reference for future comparisons.

Requirement 21 stipulates monitoring programs at a disposal facility. A monitoring program shall be carried

out prior to, during, and after the construction and operation of a disposal facility. Plans for monitoring, aimed at providing assurance of safety after closure, must be drawn up before the construction of a geological disposal facility to indicate possible monitoring strategies.

Requirement 25 requires that the management systems providing for quality assurance be applied to all safety-related activities, systems, and components. The management system must provide for the preparation and retention of documentary evidence to illustrate that the necessary quality of data has been achieved. This data is interpreted to include monitoring data.

2.3 Geological Disposal Facilities for Radioactive Waste, SSG-14 [4]

The safety guide of SSG-14 provides guidance and recommendations for the development and regulatory control of facilities for the geological disposal of radioactive waste, in order to meet the safety requirements of SSR-5.

Siting encompasses a range of activities from initial conceptual design and site selection through to the confirmation of the site for the construction of a disposal facility.

Regarding the site characterization requirement, this guide recognize four stages: (1) the conceptual and planning stage, (2) the area survey stage, (3) the site investigation stage, and (4) the stage of detailed site characterization leading to site confirmation for the construction of the disposal facility, as illustrated in Fig. 1.

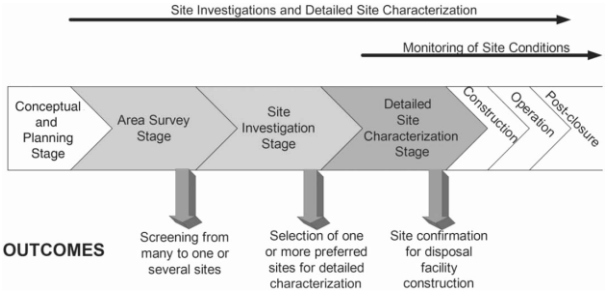

Fig. 1. Stages in the siting process [4].

Site characterization is an activity undertaken in order to understand the natural features, events and processes at a site along the timeline and to describe adequately their spatial and temporal extent and variability. Site characterization will comprise data acquisition (i.e. mensuration, sampling and monitoring) and the interpretation of that data to generate information and knowledge.

Site characterization will essentially begin at the earliest stage of the investigation of a site and is expected to become more intensive as the facility development program progresses through to confirmation of the site and commencement of construction. It is noted that, as indicated in Fig. 1, monitoring of site conditions is initiated generally in the last stage of detailed site characterization.

The site characterization program should identify the site conditions to be monitored in the pre-construction, construction and operational phases and should establish the required level of detail of measurement to ensure a suitable baseline record of the natural systems of the site against which the results of future site monitoring can be compared to determine any changes brought about by the construction and operation of the facility.

Baseline monitoring information typically include hydraulic pressure measurements, chemical constituents of groundwater and surface waters, surface water flows and natural background radioactivity. The sampling timescale interval should be selected to provide sufficient resolution to allow early notification of any significant changes in site conditions.

The site characterization program should include a management system for ensuring the quality and long-term usability of data, as well as their availability. The management system should take into account that site characterization data include spatially distributed information and time series data and that such information is necessary to support the establishment of a baseline for future monitoring.

Site characterization should continue as long as is necessary, including into the operational period, to provide the basic data for a specific understanding of the disposal area, to contribute further to an adequate baseline for future monitoring, and to contribute to the confirmation of assumptions made in earlier safety assessments.

The monitoring program should be defined prior to construction and should be included as part of the safety case. A baseline survey of the site, including the characteristics of the host rock, should be conducted before commencing construction activities.

The monitoring program should be subject to audit and independent verification by the regulatory body or other recognized organizations.

Appendix I of this guide specifically addresses site investigation and characterization guide, and data needs on hydrogeology and geochemistry.

2.4 Monitoring and Surveillance of Radioactive Waste Disposal Facilities, SSG-31 [5]

The safety guide of SSG-31 provides recommendations, particularly regarding the role of monitoring in the context of developing a disposal facility. Its scope includes geological disposal facilities.

The guide covers monitoring and surveillance during the pre-operational, operational, closure, and post-closure periods. The pre-operational period includes concept definition, site evaluation (selection, verification, and confirmation), safety assessment, and design studies. During this period, monitoring and testing programs needed to establish baseline conditions should be implemented.

The general objective of monitoring programs during the pre-operational period is to establish a baseline of pre-existing contaminant levels, enabling the evaluation of the waste disposal system's impact and identifying parameters indicative of performance in the post-closure period.

Site characterization programs conducted in the pre-operational period typically establish the natural characteristics of features, events, and processes occurring in the environment of the disposal facility, such as water table fluctuations and long-term facility performance. The baseline should be developed to identify trends and discern the facility's evolving impact over time.

In practice, monitoring will rely on on-site or remote instrumentation, visual inspections, sampling and analysis of samples, and data analysis and interpretation.

A disposal facility is monitored for different purposes throughout its lifetime. Monitoring for site characterization during the pre-operational period is conducted to establish a baseline and create a database of information on the surrounding environment.

To establish the baseline, certain monitoring activities are expected to begin as early as possible, before the perturbations caused by the disposal facility's construction and operation accumulate. In practice, the monitoring program will begin at the site investigation stage.

The characteristics of primary interest in the context of establishing baseline information are:

- The groundwater flow field in the host rock and in the surrounding geological environment.
- Geochemical characteristics of groundwater.
- Mineralogy of the host rock that makes up part of the disposal facility.
- Geomechanical properties of the host rock that contributes to the stability of the disposal facility structure.
- Transport and retention properties of the host rock.
- Characterization of discontinuities in the host rock.
- Background levels of natural radioactivity in groundwater, surface waters, air, soils and sediments, and animal and plant life.
- Meteorological conditions and climatic conditions.
- Hydrology of surface water systems, including drainage patterns and infiltration rates.
- Ecology of natural habitats and ecosystems.

The monitoring and surveillance program for a waste disposal facility should be capable of providing data in support of decisions that will be made over the entire lifetime of the facility. The management system established should be such as to maintain continuity of data collection, continuity of data management, and adaptability to new approaches for the collection and interpretation of data.

Management processes are necessary to establish the quality of data. The qualification of data should constitute a set of procedures that permit traceability and transparency of the data and their interpretation.

3. Domestic Regulations and Guidelines

3.1 General Standard for Deep Geological Disposal Facilities for High-Level Radioactive Waste [6]

In Korea, the 'General Standard for Deep Geological Disposal Facilities for High-Level Radioactive Waste' [6] stipulates detailed technical standards as delegated by the 'Enforcement Decree of the Nuclear Safety Act' and the 'Regulations on Technical Standards for Radiation Safety Management.' This standard applies as general technical requirements to ensure the safety of high-level radioactive waste disposal at each phase of the entire process, including basic research, site investigation, design, construction, operation, closure, and post-closure management of deep geological disposal facilities for high-level radioactive waste.

The standard provides declarative provisions regarding the site of the deep geological disposal facility and the geological stability of the site. Article 9 requires that the site should be a location where the natural environment and socio-cultural characteristics - such as the area's climatic conditions, surface conditions, distribution of surface and groundwater, and ecological features - do not affect the safe operation of the disposal facility.

Article 29 requires that the Safety Analysis Report describe the site characteristics, including the socio-cultural features of the region, climate, hydrology, geology, seismology, geotechnics, rock mechanics, geochemistry, natural resources, and ecosystems. It should also detail the site safety evaluation and the site monitoring plans before, during, and after the facility's operation and closure.

3.2 Draft Notification for Guidelines on Preparing Site Characteristic Reports [7]

Recently, the Korea Institute of Nuclear Safety (KINS) developed the ‘Draft Notification for Guidelines on Preparing Site Characteristic Reports’ and the ‘Draft Guidelines for Quality Assurance of Site Characteristic Investigations’ [7]. During the development process of these requirements and guidelines, regulatory requirements of the United States, Finland, Sweden, and Switzerland were reviewed as prior reference cases.

The detailed guidelines in the Draft Notification specify that the site characteristic report must describe the baseline information necessary to understand the characteristics of the disposal facility site. The site characteristics should include geography and population, facilities with the potential to cause human-induced disasters, climatic characteristics, surface water and marine characteristics, geological characteristics,

hydrogeological characteristics, hydrogeochemical characteristics, rock mechanics and thermal characteristics, contaminant migration characteristics, and other environmental characteristics such as human activities, ecosystems, and climate change.

The guideline stipulates that the details of site monitoring and investigation must be described for site characteristic investigation and assessment items, design, and site characteristics for long-term safety at each stage: pre-construction, construction and operation, and post-closure.

The detailed guidelines for preparing the site characteristic report stipulate that contents related to site monitoring and investigation should be presented to reduce the uncertainties of the site characteristic models.

The guideline also requires that the site characterization report be based on objective data obtained according to an approved quality assurance system.

4. Concluding Remarks

International and domestic site monitoring requirements and guidelines are generally stipulated on the premise that DGRs will be constructed at the site.

There are no independent requirements solely for site evaluation and monitoring without considering disposal facility construction. Therefore, for the monitoring of site investigations before determining a DGR site, it is necessary to selectively apply the suitable monitoring requirements specified for the pre-construction stage of deep geological disposal facilities.

The Korean domestic requirements and draft guidelines for site characterization have been developed with reference to foreign precedents. The monitoring scope and parameters are comprehensive and generally similar to international requirements and guidelines, but with more definite and extensive provisions. However, international standards provide more explanatory details regarding the background and rationale of site monitoring requirements and guidelines. Therefore, referring to these details when applying domestic standards can enhance the overall technical understanding of the requirements and guidelines.

Site characterization assessments are conducted repeatedly from the pre-construction to post-closure stages and serve as essential components of the Safety Case. For example, in relation to radioactivity, investigations into natural radiation backgrounds and radioactive nuclide content can be included, primarily to establish baselines for future comparisons. Therefore, it is recommended that site characterization assessments incorporate monitoring parameters that are useful for baseline establishment during the site evaluation stage.

Prior to construction, the monitoring program should focus on establishing a baseline for the site [5]. However, it is noteworthy that the domestic draft notification specifically requires that site monitoring should be planned to reduce the uncertainties of the site characteristic models.

The disposal facility monitoring program needs to ensure data continuity and traceability, as well as the adaptability of data collection and interpretation, so that it can provide data to support decisions throughout the facility's entire lifespan.

ACKNOWLEDGEMENTS

This work was conducted under the project titled ‘Development of monitoring and operational technique for site characterization factors in national/site scale’ (RS-2024-00419806), which is part of the main project titled ‘Development of long-term environmental change prediction technology for high-level radioactive waste disposal sites’ (RS-2024-00419276), supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry and Energy (MOTIE) of the Republic of Korea.

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