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Development of a Multi-Scale Hydrogeological Monitoring Framework for Long-Term Safety Assessment of Deep Geological Disposal of High-Level Radioactive Waste

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1. Introduction

Deep geological disposal of high-level radioactive waste (HLW) is founded on a multi-barrier concept in which the hydrogeological stability of the host rock critically governs groundwater flow and radionuclide transport (SKB, 2010; IAEA, 2011; POSIVA, 2013). Because long-term safety assessment extends to geological timescales, systematic hydrogeological monitoring is essential to define boundary conditions, quantify flow characteristics, and reduce predictive uncertainty. Monitoring data provide key inputs for site descriptive and numerical models, enabling iterative validation between observed behavior and model simulations. To ensure robust safety case development in Korea, this study proposes a structured monitoring framework that integrates meteorological, hydrogeological, and surface water factors within a multi-scale (national and site-scale) strategy based on analysis of domestic and international practices.

2. Key Monitoring Factors

Monitoring factors are categorized into three groups: meteorological, hydrogeological, and surface water hydrological factors.

2.1. Meteorological Factors

Meteorological variables define upper boundary conditions of groundwater systems. Precipitation controls recharge, and temperature governs evapotranspiration and seasonal hydrogeological responses. barometric pressure affects groundwater level interpretation. Long-term datasets are necessary for water balance analysis and climate scenario evaluation. High-resolution rainfall intensity data are particularly important for identifying rapid hydraulic responses in fractured rock.

2.2 Hydrogeological Factors

Hydrogeological parameters directly influence radionuclide transport behavior. Groundwater level and hydraulic head determine flow gradients and directions, while hydraulic conductivity and transmissivity characterize fracture permeability. At site scale, multi-level packer systems enable interval-specific head monitoring in fractured zones. Repeated hydraulic testing and tracer experiments provide estimates of permeability evolution, flow velocity, and connectivity, including evaluation of excavation damaged zones (EDZ).

2.3 Surface water Hydrological Factors

Surface water monitoring supports identification of recharge and discharge boundaries. River stage and discharge data allow evaluation of groundwater-surface water interaction and baseflow contributions. In coastal areas, sea level monitoring is required to assess density-driven flow and potential saline intrusion.

3. Multi-Scale Monitoring Strategy

A multi-scale approach integrating national-scale and site-scale monitoring is essential.

National-scale monitoring provides long-term climatic and hydrological baseline data. In Korea, extensive river, groundwater, and meteorological networks operate in real time. Similar nationwide systems exist in Sweden, Finland, Switzerland, and Canada. These datasets define regional boundary conditions and enable trend analysis under climate variability.

Site-scale monitoring focuses on high resolution characterization of the disposal host rock. Dense observation networks, multi-depth head measurements, repeated hydraulic testing, and tracer tests are required to quantify fracture connectivity and flow pathways. High temporal resolution monitoring (e.g., 5~10 minute intervals) is critical for capturing short-term hydraulic responses. Monitoring must follow an adaptive framework, where discrepancies between model predictions and observed data trigger re-evaluation and refinement.

4. Conclusions

This study presents a structured multi-scale hydrogeological monitoring framework to support the long-term safety assessment of deep geological disposal of high-level radioactive waste. Hydrogeological monitoring is identified as a fundamental component of the safety case because it directly contributes to model validation and uncertainty reduction over geological timescales. The monitoring system must systematically encompass meteorological forcing, groundwater flow characteristics, and surface-water interactions in order to capture the full hydrological cycle governing radionuclide transport. A clear distinction between national-scale and site-scale monitoring is essential: national-scale monitoring provides long-term climatic and hydrological boundary conditions and supports trend analysis, whereas site-scale monitoring focuses on high-resolution characterization of fracture-specific flow behavior, hydraulic properties, and excavation-induced changes such as EDZ effects. Integrating these scales within an adaptive, model-informed monitoring strategy enhances confidence in predicting long-term disposal performance and establishes a scientifically defensible basis for future HLW disposal programs in Korea.

REFERENCES

[1] SKB, Programme for the final repository for spent nuclear fuel (TR-10-01), Svensk Kärnbränslehantering AB, 2010.
[2] IAEA, Geological disposal facilities for radioactive waste (Specific Safety Requirements No. SSR-5), International Atomic Energy Agency, 2011.
[3] POSIVA, Posiva’s safety case for the disposal of spent nuclear fuel at Olkiluoto – Synthesis 2012 (Posiva Report 2012-12), Posiva Oy, 2013.