Saf. Nucl. Waste Disposal, 2, 133–134, 2023
https://doi.org/10.5194/sand-2-133-2023
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Safety of Nuclear Waste Disposal
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Mitigating uncertainty in the site selection process for a German deep geological repository through a risk-based and multi-criteria decision-making approach

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Received: 13 April 2023 – Revised: 24 May 2023 – Accepted: 26 May 2023 – Published: 6 September 2023

Abstract. The site selection for final disposal of high-level radioactive waste is a complex process that requires careful considerations. In Germany, the site selection procedure for a deep geological repository occurs in multiple phases. Step one phase one involves the identification of 90 subareas of interest. In step two phase one, sub-regions are selected for surface exploration. Consequently, several dilemmas arise, such as the necessity to screen through a considerable number of subareas with large surfaces to select sub-regions that are most adequate for further investigation. The associated subsurface uncertainty and the high exploration and operational costs create an additional challenge when planning such a campaign.

To address these challenges, we propose a method of sub-region prioritization that combines favourability indexes developed using host-rock and subarea-specific criteria with the probability of success and risk of failure estimates. This method considers not only geological factors but also the heterogeneous nature of subsurface data quality and quantity. This heterogeneity leads to uncertainties that may overshadow the advantages of specific sub-regions at the expense of others. The method focusses only on the geological barriers of the repository system: the containment providing the rock zone, the surrounding host rock, and the overburden. The geological barriers are dealt with as a multi-component, multi-physics system. For each component, a risk matrix is generated; consequently, a risk estimation and a classification are made. To estimate the risk of failure in selecting an adequate sub-region prior to exploration, we propose the following formula based on Aven and Krohn (2014), which is defined as follows:

$$\text{Risk} = \text{likelihood} \times \text{consequence} \times \text{knowledge}.$$

This formula evaluates risk based on three factors: the probability of a specific event occurring that may jeopardize the integrity of the geological barriers (likelihood), the potential impact of that event (consequence), and the level of understanding or uncertainty associated with that event (knowledge), which can influence the overall risk assessment.

The method involves the identification and evaluation of subsurface risk factors using the multiple-criteria decision-making approach and the development of a risk matrix. The risk matrix is based on expert judgement and existing data to quantify the relative importance of each risk factor.

The method is evaluated by applying it to one of the subareas designated by the German federal company for radioactive waste disposal for methodological developments. The developed approach provides a valuable tool for enabling stakeholders to consider a wide range of factors, including the level of uncertainty and lack of knowledge associated with subsurface risk factors, and make informed decisions during the site selection process.

Published by Copernicus Publications on behalf of the Federal Office for the Safety of Nuclear Waste Management (BASE).

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