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Safety assessment methodology for a German high-level waste repository in clay formations

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ABSTRACT

In the ANSICHT project that was jointly carried out by DBE TECHNOLOGY GmbH, BGR, and GRS gGmbH, two generic geological site models were used to develop a first draft of a methodology to demonstrate the safety of a high-level waste (HLW) repository in argillaceous formations in Germany, taking into account the regulatory requirements. The main results of the project are characterised by the developed repository concepts adapted to the geological conditions. The specific quantifications of the integrity criteria and their exemplary application with calculational proofs were used to demonstrate the integrity of the host rocks. The development of site-specific FEP (features, events, and processes) catalogues provided a complete system description for evaluation of the repository evolution. The developed work flow of the demonstration concept illustrated the complete sequence of the safety proof in a transparent way. It shows that various steps have to be performed, possibly iteratively, to provide a successful safety proof. The results form a useful tool in the pending search for a HLW repository site, especially when providing a basis for comparing safety analyses of different sites in Germany.

1. Introduction

With the restart of site selection for a high-level waste (HLW) repository in Germany, different types of host rocks, e.g. clay, are the focus. In Germany's neighbouring countries, such as France, Switzerland and Belgium, different clay formations are investigated as potential host rocks for a HLW repository. In France, the Callovo-Oxfordian clay is investigated (ANDRA, 2005), in Switzerland the so-called Opalinus Clay (Nagra, 2002) and in Belgium the Boom-clay formation (ONDRAF/NIRAS, 2001). Over the past years, the research activities in argillaceous rocks in Germany have been significantly intensified. Extensive participation in underground research laboratories in the Meuse-Haute Marne, France, and Mont-Terri, Switzerland, enabled Germany to build up the knowledge of the thermo-hydro-mechanical (THM) behaviors and the general sealing abilities of clay host rocks.

In the framework of the ANSICHT project, a safety assessment methodology for a HLW repository in clay formations in Germany was developed. This was done by a project team consisting of Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Federal Institute for Geosciences and Natural Resources (BGR) and DBE TECHNOLOGY GmbH. In the ANSICHT project, the idea was to use generic geological models to show typical clay formations and adjacent rock formations in Germany. Exemplarily, for different boundary geological conditions in Germany, two generic geological models, typical for potential clay sites in Northern and Southern Germany, were developed.

The project is important for the German scientific community in the field of the HLW disposal, and it is in line with the new site selection process in Germany, which at the first stage considers different host rocks equally eligible for the final disposal of HLW and spent fuel (SF) (StandAG, 2016).

2. Description of the safety and safety demonstration concept

The safety concept defines that barriers ensure the containment of the radionuclides in the waste repository to protect human and

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the environment from ionizing radiation and other harmful effects of heat-generating radioactive waste. In the "Safety Requirements Governing the Final Disposal of Heat-generating Radioactive Waste" (BMU, 2010), the safety concept for heat-generating waste repositories prescribes that the containment of the waste inside the containment providing rock zone (CRZ) has to be proven for a reference period of 1 million years. The CRZ ensures the retardation of radionuclides in combination with the geotechnical barriers. The assessment proofs of the repository are as follows:

(1) The integrity (containment abilities) of the CRZ is maintained over the whole assessment period of one million years and must not be disturbed either by internal or external processes (cf. Section 4.3).
(2) The integrity of the geotechnical barriers is maintained over the designated functional period. For the ANSICHT project, their minimum functional period has been defined as the transient phase of the THM processes in the repository system (cf. Section 4.4).
(3) The subcriticality of the waste to prevent nuclear accidents resulting from an inadvertent, self-sustaining nuclear chain reaction (not analysed in the ANSICHT project).
(4) The insignificance of a potential radiological exposure to the future population. According to the Safety Requirements, a simplified radiological assessment is allowed, in which the radionuclide fluxes outside the CRZ boundary are compared with a regulatory value. No transport in the geosphere outside the CRZ is considered in this case (cf. Section 4.5).

For a radioactive waste repository in clay formations, the containment of the radionuclides inside the CRZ is achieved by:

(1) limiting the advective transport by choosing a host rock with low permeability and restoring the low permeability in excavation damaged zones (EDZs);
(2) limiting the diffusive transport, i.e. choosing a host rock with high sorption capacity and low pore water diffusion.

Additional objectives of the repository design were defined to limit thermal, gas-generating and microbial processes as well as to guarantee canister retrieval for 500 years according to the Safety Requirements.

The concept for a safety case developed for the post-closure phase can be divided into the two-level fundamental modules and system analysis. Fig. 1 gives an overview of these two levels and the interrelations of the individual modules of the safety and safety demonstration concept (Jobmann et al., 2016).

2.1. Fundamentals

The concept is based on the Safety Requirements (BMU, 2010) from which the first level module of safety strategy is derived. In addition to the objectives, the safety strategy involves general conceptual specifications and technical measures that are further developed and described in detail in the subjacent modules.

One of the first fundamental modules concerns the quantification of the integrity criteria. The Safety Requirements define the integrity criteria qualitatively. To demonstrate the integrity of the CRZ, it is necessary to quantify these criteria in such a way that a numerical demonstration is possible within the scope of the safety demonstration concept. The quantification of the integrity criteria requires adequate knowledge about the thermal (T), mechanical (M), hydraulic (H), chemical/mineralogical (C), and biological (B) properties of the host rock formation. During this process step, knowledge gaps may be significant that have to be abridged within the scope for further studies. Based on these quantified criteria, numerical simulations of the repository evolution can be carried out for development of future scenarios.

The two modules mentioned above, concerning the safety strategy and the quantification of the integrity criteria, are not specific to a site. All other modules described below are site-specific. The basic module of safety strategy is the geological site description, which comprehensively describes the initial (current) state of the site, especially its structural geology and the (hydro-) geological conditions. In addition to an analysis of the initial state, a long-term geoscientific forecast for future evolution of the site region has to be carried out for the whole reference period. The forecast serves as an important input for the description of the geological processes.

Directly connected with the geological site description is the development of a 3D (three-dimensional) model of the geological situation in the area under investigation. This is carried out on the basis of the module modeling and data compilation. The result is called repository site model that contains all important geological formations and structures to reflect especially the (hydro-) geological conditions in the area under investigation. The model refers to the host rock formation where the repository is located. The repository site model is generated in such a way that – after a further abstraction – it serves as a basis for calculations to prove the integrity of the CRZ, for radiological safety demonstration. Such calculations require numerical model parameters derived from the knowledge about the properties of the geological units. Therefore, the generation of a geoscientific data basis is required. Firstly, all available details related to the geological units are compiled and documented. Then, all units identified in the 3D model can be assigned with adequate parameters. This step gives indications about the quality of the available data and allows the identification of knowledge gaps that have to be filled with the scope of future site explorations.

Based on the repository site model, the emplacement concept and the repository design are developed as the fundamental technical module, which takes into account the extent, thickness, depth, and properties of the host rock formation. They contain a description of the emplacement selected (borehole emplacement or drift emplacement) and the container characteristics based on the waste inventory. They also contain general information for support constructions needed in drifts and shafts. The safety strategy and the integrity criteria give an important guidance to the repository design.

Based on the geological, especially the hydrogeological, settings as well as the emplacement concept and site-specific repository design, a backfilling and sealing concept is developed in the second technical module. This concept describes the measures to backfill and seal the underground excavations in such a way that only minor radionuclide release is to be expected even via the drift and shaft system.

2.2. System analysis

The first step of the system analysis is to comprehensively describe the system. This is done with a site-specific FEP (features, events, and processes) catalogue that compiles all processes considered in the description and development of the repository site model, including an estimation of their occurrence probabilities. All data relevant for the safety analysis are included in the FEP catalogue. The catalogue thus contains a complete system description. Based on the FEP catalogue, a scenario development is carried out to derive the descriptions of probable and less probable repository evolutions.

According to the Safety Requirements, the following steps have to be carried out for probable repository evolutions. The integrity proof of the geotechnical barriers is obtained using a methodology