The ongoing Swiss site selection process: Current status, recent achievements and outlook, with special emphasis on the prominent role of safety

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Summary

The Swiss site selection process for geological repositories is a stepwise approach defined by the ‘Sectoral Plan for Deep Geological Repositories’ issued by the Federal Government in 2008. The narrowing down process began with the selection of broad geological siting regions (Stage 1).

The evaluation of the various potential regions was performed based on geological criteria related to safety and engineering feasibility explicitly defined in the Sectoral Plan. Stage 1 was completed in 2011 with the approval by the Federal Government of the three (for the HLW repository) and six (for the L/ILW repository) potential siting regions proposed by Nagra. All three siting regions for the disposal of HLW are also suitable for the disposal of L/ILW, as well as for implementing a so-called combined repository for both waste categories.

The narrowing-down process continued with Stage 2, the focus of which is the selection of at least two potential sites for each type of repository. Criteria addressing spatial planning and environmental aspects were also considered in Stage 2 for the siting of the surface facilities within each siting region. Nagra proposed that two out of the six potential siting regions defined in Stage 1 should be further investigated. Nagra's proposals were published in early 2015. In April 2017 the regulator (ENSI) published their review report. ENSI agreed to six out of seven proposals made by Nagra. However, ENSI stated that in their view, Nördlich Lägern (one of the siting regions identified in Stage 1 as being potentially suitable for both the HLW and the L/ILW repository or for a combined repository), which Nagra proposed to put into reserve, should also be further investigated in Stage 3 as the reasons provided by Nagra to put that region into reserve were not considered to be sufficiently justified by the currently available geological information. It is expected that the Federal Government will issue its decision after a broad consultation at the end of 2018.

Stage 3 has as a goal the selection of one site for each type of repository (or one site for a combined repository). For each repository a general licence application will be submitted which must be approved by the Federal Government, ratified by parliament, and is subject to a facultative national referendum. In contrast to Stages 1 and 2, a safety case is required for each repository as part of the general licence application.

In addition to giving an overview of the Swiss site selection process, this paper discusses the different roles of performance assessment and dose calculations and presents an example for supplementary ‘insight calculations’ not required by the Sectoral Plan but
performed by Nagra to have confidence in safety for the HLW and the L/ILW repository at the siting regions to be selected in Stage 3.

1. Current status, recent achievements and outlook

Introduction

The Swiss nuclear energy legislation requests that all types of radioactive wastes (L/ILW as well as HLW) must be disposed of in deep geological repositories (KEG 2003). The Swiss concept foresees two separate repositories (one for L/ILW and one for HLW), with different requirements on geology. In principle, a so-called combined repository for both waste categories is also an option if a siting region fulfils the requirements for both types of repository. According to the associated Nuclear Energy Ordinance (KEV 2004) the site selection process for geological repositories is a stepwise approach defined by the ‘Sectoral Plan for Deep Geological Repositories’, which was approved by the Swiss Federal Government in 2008 (SFOE 2008). The Sectoral Plan is a spatial planning instrument that clearly defines the selection criteria, the role of the various stakeholders in the three stages of the process and the input needed for decision making at the end of each stage.

The procedure is led by the Swiss Federal Office of Energy (SFOE), with Nagra being the implementer and the Swiss Federal Nuclear Safety Inspectorate (ENSI) the safety authority and involving several other committees and expert groups.

Starting with a "white map of Switzerland" (nothing is a priori excluded from site selection), the stepwise narrowing down process began with the selection of broad geological siting regions (Stage 1); following their approval, the process continued with the identification of siting areas for the surface facilities within each of the siting regions. This was followed by narrowing down to at least two potential siting regions for each type of repository (Stage 2); and, following the approval of those, one site for each type of repository will be selected (Stage 3). For each repository a general licence application will be submitted which must be approved by the Federal Government and ratified by parliament. The parliament’s decision is subject to a facultative national referendum.

Results of Stage 1

Stage 1 was completed in 2011 with the approval by the Federal Government of the three (for the HLW repository) and six (for the L/ILW repository) potential siting regions proposed by Nagra (Fig. 1). All three siting regions for the disposal of HLW are also suitable for the disposal of L/ILW, as well as for constructing a combined repository.

In the selected regions there are geological formations with favourable properties for construction, operation, closure and long-term safety of a deep geological repository according to the geological criteria related to safety and engineering feasibility defined in the Sectoral Plan (SFOE 2008).

Results of Stage 2

In Stage 2, the first goal was to identify siting areas for the surface facilities within each of the siting regions. The second goal was to narrow down the number of siting regions to at least two for each type of repository.

For the selection of siting areas for the surface facilities, Nagra developed 20 proposals; they were published in 2012 as a starting point for the discussions with the siting regions (Nagra 2011). The proposals were based on a conceptual design of the surface facilities and took into account the following primary objectives proposed by Nagra: (i) ensure safety and engineering feasibility of the surface facilities and of the access to the underground facilities of the geological repository; (ii) ensure compatibility
with spatial and environmental planning in order to minimise environmental impact; and (iii) ensure an optimal integration of the facilities into the region. The publishing of Nagra’s 20 proposals marked the start of an intense phase of interaction with the regions. By applying a different weighting on the criteria and indicators, the regions identified additional siting areas for the surface facilities, which they requested Nagra to evaluate. A total of 32 potential siting areas were considered. This process resulted in 7 siting areas designated by Nagra on the basis of the views expressed by the sting regions as input to Stage 2 (Fig. 2).

Following the identification of the siting areas for the surface facilities within each of the siting regions, Nagra had to narrow down the number of siting regions to at least two for each repository type. This was done based on the guidance set forth by authorities for Stage 2 and according to a methodology developed for this purpose by Nagra (Nagra 2014a), taking into account the outcome of Stage 1. As result of applying this methodology, Nagra proposed that two out of the six potential siting regions defined in Stage 1 should be further investigated, with Opalinus Clay as host rock for both types of repository. Nagra’s proposals were published in early 2015 (Nagra 2014a and references therein). In April 2017 the regulator (ENSI) published their review report (ENSI 2017). ENSI agreed to six out of seven proposals made by Nagra. However, ENSI stated that in their view, Nördlich Lägern (one of the siting regions identified in Stage 1 as being potentially suitable for both the HLW and the L/ILW repository or for a combined repository), which Nagra proposed to put into reserve, should also be further investigated in Stage 3 as the reasons provided by Nagra to put that region into reserve were not considered to be sufficiently justified by the currently available geological information. Thus, there will likely be three siting regions as a basis for Stage 3 (Fig. 2). It is expected that the Federal Government will issue its decision after a broad consultation at the end of 2018.

**Figure 1:** The selected siting regions (Cantons are given in brackets) and the respective host rocks

**Figure 2:** The three siting regions at the end of Stage 2 (decision by the Federal Government expected at the end of 2018)
Outlook on Stage 3 and beyond

Stage 3 has as a goal the selection of one site for each type of repository (or one site for a combined repository). In Stage 3, the remaining sitting regions will be investigated in depth with a view to site selection and preparation of an application for general licences. 3D seismic campaigns took place in the three sitting regions under consideration (Fig. 2) between October 2015 and February 2017. Later in the process, drilling of deep (800 – 1’300 m) boreholes will also take place (expected to start in 2019). General licence applications will be submitted for the L/ILW and the HLW (or a combined) repository around 2024. The decision by the Federal Government on general licences is not expected before 2027. It will be followed by a debate in Parliament and an optional referendum at the national level.

After the construction and operation of facilities for underground geological investigations, applications for a construction licence and ultimately for an operating licence for each repository will follow, both of which will be granted by the relevant Federal Department. According to the current schedule, the L/ILW repository should be operational around 2050 and the HLW repository around 2060.

2. The role of safety in the Swiss site selection process

Introduction

According to the Sectoral Plan for Deep Geological Repositories, the focus of the site selection process is on safety-based criteria, with land use and socio-economic aspects playing a secondary role (SFOE 2008). More specifically, the Sectoral Plan lists 13 geological criteria for site evaluation from the viewpoint of safety and engineering feasibility, grouped into four criteria groups. For the application of the criteria, Nagra has further defined for each criterion corresponding indicators and, for each indicator, the minimum (indispensable) requirements that have to be met as well as, in many cases, more stringent ones, which if they were met would have a further favourable impact on long-term safety and engineering feasibility (Nagra 2008). An overview of the safety-based stepwise narrowing-down methodology (including the role of dose calculations) developed by Nagra for Stages 1 and 2 and its application is given in Zuidema and Vomvoris (2017) and is not discussed further in the present paper. Instead, some more general thoughts on the role of safety (and safety analysis) in site selection are discussed.
Safety and the role of safety analysis

Safety is provided by a well-chosen system; i.e. a well-selected site with ‘good’ geology (host rock with favourable properties, large enough blocks of host rock with the required properties and a setting ensuring long-term stability) and suitable engineered barriers taking the properties of the waste into account and complementing the geological barrier. One key role of safety analysis is to provide input to the design concept through a balanced safety concept and to make the quality of the chosen system visible. More specifically, the quality of the system is assessed by looking both at the phenomena contributing to safety as well as at those with the potential to undermine safety in order to identify measures to further improve the system and finally to confirm the quality of the system in an iterative, stepwise refinement process.

Next, the broad steps involved in a typical safety analysis used to compile a safety case according to the authors’ current understanding based on, e.g., NEA (2013) and on previous and on-going work at Nagra are briefly discussed. These steps will be further refined in the course of preparing the safety case(s) for the general licence application.

The ‘starting point’ are the requirements, which are documented in a Requirements Management System. These include principles (safety principles, principles related to land use and the environment, principles related to the economic use of resources) as well as boundary conditions and constraints (waste to be disposed of, available geology (host rock, size of host rock ‘blocks’ with required properties, stability), legal & regulatory requirements, etc.). Next, a description of the system that meets the requirements is provided (the ‘system concept’), followed by a description of how the system provides safety (the ‘safety concept’). The safety concept is based on information from field studies (e.g. isotope profiles, see, e.g., Wersin et al. 2018 and references therein) and is illustrated by safety analysis, including so-called ‘insight calculations’. The ‘safety functions’ play an important role in the safety concept: They are key functions provided by the system that ensure that the safety principles are met and that the system provides the required safety.

Performance assessment is then used to provide the arguments that the system will work as assumed. This includes an analysis of repository-induced effects such as the role of the excavation-damaged zone around access tunnels and emplacement rooms, of the backfill and seals of underground structures, of thermal effects, of gas generation and of chemical interactions as well as an analysis of the impact of the geological evolution (incl. changes in climate). Performance assessment typically starts with a phenomenological analysis of the system, followed by a quantitative analysis of specific aspects, e.g. by using process models. It is important to involve representatives of the scientific community (‘science’) from an early stage such that they are ‘part of the team’ and fully support the process and its results. Specifically, the authors found it valuable to involve ‘science’ when developing the phenomenological analysis of the system and discussing specific process models. Another important aspect is to ensure that a broad enough spectrum of analysis cases is analysed to adequately capture all reasonably conceivable uncertainties. Also from this point of view, an early involvement of ‘science’ is essential.

Once the arguments are put together that the performance of the system for the expected evolution as well as all credible deviations is captured by the spectrum of assessment cases, the ‘classical’ dose calculations are still an important part of a safety case because it has to be shown that calculated doses, for each future evolution classified as likely, the release of radionuclides may not lead to an individual dose or risk exceeding the relevant protection criteria (ENSI 2009).

The ‘final’ steps involve the compilation of further arguments (e.g. the use of natural analogues) and the synthesis into a safety case. It has to be pointed out that although this description of the broad steps involved in a typical safety analysis may give the
impression of a ‘sequential’ procedure, in reality this is a highly iterative, often ‘non-linear’ process.

The system considered in Stage 3

Fig. 3 schematically shows the system (i.e. the engineered and geological barriers) considered in Stage 3. The disposal canisters are placed in disposal tunnels and are completely surrounded by bentonite buffer. The tunnels are placed in the approximately 100 m thick Opalinus Clay host rock with its confining units above and below. The modelling of measured natural isotope profiles shows that diffusion is the main transport mechanism in Opalinus Clay and its confining units (see, e.g., P. Wersin et al. 2018 and references therein). In such a system typical dose curves for a HLW repository show the excellent properties of Opalinus Clay. With an effective migration distance of 50 m, the calculated dose curves show releases only for longer-lived non-sorbing or very weakly sorbing isotopes, all other isotopes are not released for times up to 10 Mio. years. This is also the case for the assumption of a poorly performing near field - also then only long lived non-sorbing nuclides can escape (Zuidema and Schneider 2017).

Figure 3: The system (engineered and geological barriers) considered in Stage 3 (spent fuel)

Insight models

There are many different types of insight models (see, e.g., Nagra 2002, Ch. 9). Fig. 4a shows an example of a simple insight calculation, performed for the system shown in Fig. 3 (host rock with confining units, see Nagra (2014b)). The figure shows the diffusive transport time (see Nagra 2002, Ch. 9, for a definition) in relation to half-life plotted against half-life for a number of ‘typical’ nuclides. The horizontal line separates regions with transport times greater than (upper part) and less than (lower part) 30 times the half-life. The diagonal line separates regions with transport times greater than (right-hand side) and less than (left-hand side) $10^6$ years. This was chosen to capture most of the release integrated over time. Thus, we expect to see the nuclides in the white (non-shaded) region in ‘full’ dose calculations for the period of 1 Mio years. This is confirmed by Fig. 4b, which shows ‘full’ dose calculations for the same system.

Figure 4: Example of a simple insight model (a, left) and the corresponding ‘full’ dose
calculations (b, right)

Conclusions

The Swiss site selection process is well established; with a broad involvement of all stakeholders, with roles and responsibilities as well as information flow clearly defined. It is well on the way, with two of the three stages (almost) completed, and the third stage well prepared. The overriding principle 'first priority to safety' has found to be crucial for a wide acceptance of the process. At the end of Stage 2, Opalinus Clay has been designated as host rock for both the HLW and L/ILW repository. Safety analysis (involving a number of well-defined steps) is used to illustrate the quality of the system. In this so-called 'insight calculations' using 'insight models' may be helpful. In many cases even rather simple insight models can capture the broad system behaviour quite well (e.g. transport time / half-life vs. dose curves). Performance assessment is a vital part of safety analysis to provide the arguments that the performance of the system is captured by the calculations performed (expected evolution, credible deviations) and taking into account all reasonably conceivable uncertainties by analysing a broad enough spectrum of analysis cases. The safety analyses performed so far have shown that in Switzerland the repository system with Opalinus Clay as host rock and its confining units has many advantages:

- Opalinus Clay and its confining units is a powerful barrier to radionuclide migration (diffusion-dominated system),
- the system shows relative insensitivity of total system performance to uncertainties in near-field performance,
- the self-sealing capacity of Opalinus Clay ensures that the permeability of natural or construction-induced disturbances are low, and
- the system provides long-term geological stability in the siting region(s) considered.
References


