Quantitative vs. Qualitative Performance Assessment of Closure

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Safety functions set for the closure system of the KBS-3 repository help to define the more detailed requirements set for the design and its overall performance. The maturity of these safety requirements and design define how different closure components and their performance are handled in the safety case. In Posiva's case, the safety case for OLA (operational license application) is being prepared before the final design of closure for the licensing documentation. For the licensing, there is a need to assess the long-term safety of the closure based on a well-defined design. However, in the case of closure, requirements and design development are greatly affected by the fact that the implementation of closure will happen decades after the licensing process, leading to a need to maintain flexibility in the design, so that it can be further developed during upcoming years. There are two ways of assessing performance (deterministic approach) of a given system, qualitatively and quantitatively. Qualitative understanding is needed to build conceptual models. This is essential in order to develop credible numerical models and thus have meaningful results from the modelling efforts. A qualitative assessment is also needed when there is no quantitative information or a model available or when requirements are such that detailed numerical modelling work cannot be called for (e.g. very long-term performance or qualitative requirements). In the safety case, the performance of the closure is discussed mainly in two reports, performance assessment and complementary considerations.

1 Introduction

Posiva is developing a new safety case for the KBS-3 repository at Olkiluoto, Finland, (Figure 1) to support the operation license application (OLA). At this stage, operational aspects are of growing importance in order to show practical feasibility of the repository construction and performance. Regarding closure, objectives of the safety case in this respect need to be set to reflect the fact that the actual implementation of the closure is decades away from the start of the operation. Nevertheless, at the time of granting operation license, the design and function of the closure needs to be assessed in detailed enough level, in order to:

- Present a reference solution that can be shown to be feasible to build,
- Have confidence on the performance of the closure design presented, so that its implications for overall long-term safety are understood and,
- Allow guidelines to further design development and optimisation of closure during the coming years.

1.1 Closure of a KBS-3 repository

The closure of the KBS-3 repository consists of the backfill and plugs in the underground openings that are located outside deposition tunnels (see Figure 1). Closure design in the previous safety case was generic and safety case was based on a reference solution (Figure 2), where backfilling material types and potential concrete based plugging was presented without providing details on composition and dimensions. The closure is part of the Engineered Barrier System, and thus has safety functions assigned to it.

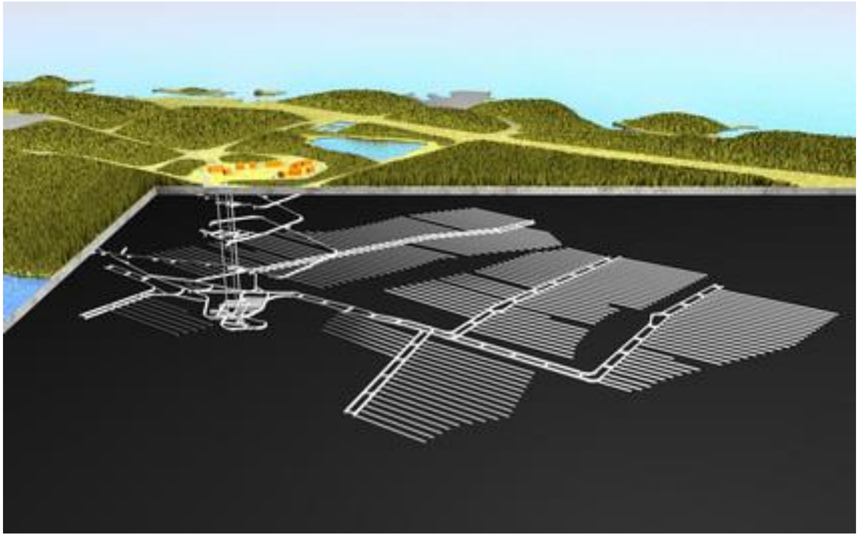

Figure 1. Schematic presentation showing the repository and its access routes (Posiva). Deposition tunnels are shown as parallel tunnels; all other tunnel volumes are part of the closure.

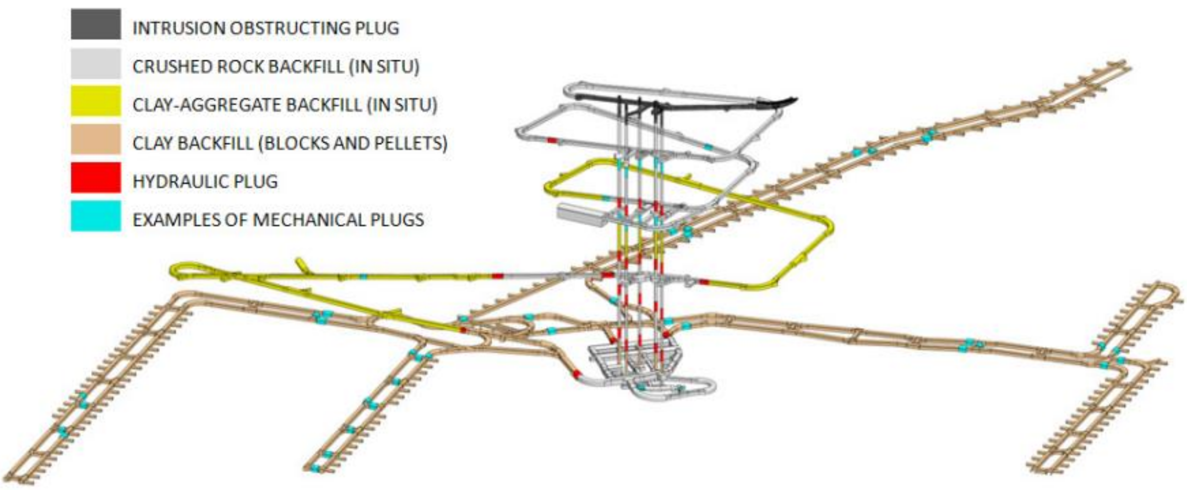

Figure 2. Materials in the reference design for the closure in the construction license application (Sievänen et al. 2012). The type and location of plugs at different depths is just illustrative.

1.2 Safety functions and performance

In case of closure, most of the safety functions aim at protecting the repository itself. Safety functions of the closure in Posiva's previous safety case (Posiva 2012) were defined as follows:

- Prevent the underground openings from compromising the long-term isolation of the repository from the surface environment and normal habitats for humans, plants and animals.
- Contribute to favourable and predictable geochemical and hydrogeological conditions for the other engineered barriers by preventing the formation of significant water conductive flow paths through the openings.
- Limit and retard inflow to and release of harmful substances from the repository.

Assessing performance of the repository system is guided by the requirements set for each engineered barrier component within the repository system. These long-term safety requirements, i.e. design basis (see Posiva 2012a), are based on the regulatory guidelines and a series of the iterations between long-term safety assessment and design work. Performance of a given component in the repository system is assessed with respect to the different performance requirements (performance targets).

While requirements for an individual closure component may be less stringent than those for near-field components, its functionality is assessed mainly as how closure supports the overall performance of the repository and how closure structures interact with other system components during the long-term evolution of the repository

2 Assessment of closure performance in Posiva's safety case

Posiva's safety case methodology consists of describing the design basis, the main features, events and processes affecting (or potentially affecting) the barrier system, describing the initial state and the main lines of evolution (referred to as "performance assessment") and assessing the consequence of uncertainties through scenarios to be analysed for their radiological consequences. In addition to quantitative performance assessment, qualitative complementary considerations about the evolution and performance of the barriers will be presented as well. The safety case will be presented in the form of a report portfolio reflecting the methodology above. The Design Basis report describes the chain of requirements:

Safety functions → performance targets → design requirements

Safety functions describe the roles of the barriers at high level. Performance targets refer to the performance of the barriers during the long-term evolution and design requirements describe the design features that should be fulfilled at the initial state (See Table 1 for closure).

Table 1. Performance targets and design requirements defined for closure in TURVA-2012 safety case (Posiva 2012a).

Performance targets for closure (Posiva 2012a):
Closure of the disposal facility includes backfill and plugs in access and central tunnels, shafts, miscellaneous excavations, and investigation holes. Different types of closure components may be used in different parts of the repository volumes. Closure shall complete the isolation of the spent fuel and support the safety function of the other barriers.
Unless otherwise stated, the closure materials and structures shall fulfill the performance targets listed below over hundreds of thousands of years in the expected repository conditions except for incidental deviations.

Closure shall complete the isolation of the spent nuclear fuel by reducing the likelihood of unintentional human intrusion through the closed volumes.
Closure shall restore the favourable, natural conditions of the bedrock as well as possible.
Closure shall prevent the formation of preferential flow paths and transport routes between the ground surface and deposition tunnels/deposition holes.
Closure shall not endanger the favourable conditions for the other parts of the EBS and the host rock.
Design requirements (Posiva 2012a):
The ground surface of the disposal area shall be landscaped to resemble its natural surroundings.
Structures and materials that considerably obstruct unintentional intrusion shall be utilized in the closure of the uppermost parts of the facility and investigation holes extending to the ground surface.
Structures and materials of the closure components shall be selected in such a way that the isolation functions of closure can be provided despite possible loadings related to glacial cycles, such as permafrost or changing groundwater chemical conditions.
Rock materials shall be used increasingly as backfill when moving from the disposal depth up to the ground surface due to the increasing risk of clay erosion.
Closure as a whole shall be so designed that the hydraulic connections from the disposal depth to the surface environment through the closed tunnels, shafts, and investigation holes are not better than through existing natural fractures and fracture zones.
Sections in the underground openings intersected by highly transmissive zones such as the HZ20 structure shall be hydraulically isolated from other facility sections.
The closure as a whole shall be so designed that short-cuts from the deposition tunnels/deposition holes to existing significant groundwater flowpaths are prevented.
The closure components shall keep the backfill and plugs of the deposition tunnels in place.
The amount of chemical species harmful for canister/buffer/deposition tunnel backfill/host rock in closure components shall be limited.

2.1 Description of the Initial State

The ‘Initial state report’ will describe the features of the closure design that are essential for the safety case. Initial state of the closure is the state after emplacement when direct control over a specific part of it ceases and only limited information can be made available on the subsequent development of conditions in that part of the system.

Operational aspects are seen as of growing importance and are taken into account in a more systematic way in the next safety case through failure mode and effect analysis (FMEA) (see e.g. Stamatis 2003 for a general description). The potential deviations caused during operation should be identified and assessed for their implication on long-term safety. FMEA process analyses the implementation process of the repository project and focuses on such events during the production process that could be left unnoticed and thus lead to deviations at initial state. These deviations essentially describe the situations where the as-built state of the repository goes beyond the design and its tolerances. FMEA is applied to all the components of the repository system, in order to map potential operational failure modes that could lead to deviations from the planned initial state.

FMEA is carried out for closure at level of detail consistent with the development of the design. In this work, knowledge based on the deposition tunnel backfill and deposition tunnel plug can be greatly utilised. The FMEA process will identify a set of potential deviations that will be used as source of information when formulating the scenarios for the repository system evolution. The deviation analysis is a qualitative analysis, for which, in some cases, quantitative information can also be provided in the form of probabilities.

2.2 Conceptual understanding and geological time scales

Qualitative analysis and understanding of the processes that potentially affect the repository system is of essence in building conceptual models. This is also the case with respect to closure. Features, Events and Processes (FEPs) screened for a site-specific safety case need to be elaborated during the assessment work (see e.g. Posiva 2014). In case of closure, in this regard, the most important issues are related to degradation of the materials and structures used in closure. How do different materials degrade, what can be leached out of the system, how the leachates migrate and change the groundwater chemistry, and do these processes affect the long-term performance of the repository. Conceptual models are needed as a basis for quantitative assessment methods (see Section 3.2).

Closer to the surface, the long-term performance of the closure becomes more complex, in the sense of accounting for the changes in the surrounding rock and the variability in closure materials, and because external processes, such as freezing and thawing, glaciations, erosion etc. have more likely impact during the assessment time frame. On the other hand, the requirements can be less stringent closer to the surface in the sense that a localised loss of closure performance does not necessarily affect the repository at depth. In this context, a more qualitative assessment and the use of geological and anthropogenic analogues becomes more relevant and a more qualitative assessment can be seen as sufficient.

Considering the long-term evolution of closure during and beyond the next glacial cycle, geological evidence, i.e. natural analogues, is the only way to observe safety-relevant processes in the relevant time scales.

2.3 Processes affecting the near field

The main safety function of the closure is to support the performance of the repository system. Thus, many processes occurring locally or only in the upper parts of the closure system do not necessarily have any effect on the overall performance of the repository. Some processes, however, can have some effects on the near-field performance if they are related to interactions between closure materials and near-field components (backfill, buffer and canister) or if they affect the radionuclide transport in the system.

One example of these is cement degradation and formation of a high pH plume that can react with the backfill and bentonite buffer (e.g. REF). A quantitative assessment is needed for processes that have the potential to perturb the performance of the barriers system, i.e. rock, backfill, buffer and canister. It is also of use for developing the design specifications, by providing information on the amounts of potentially harmful substances that can be allowed in the repository closure.

The interaction between the deposition tunnel backfill and plug and the closure in the central tunnels can be studied through the PA analyses. This analysis can give feedback to the design of the closure central tunnel backfill.

2.4 The performance assessment of closure

How performance targets are then met during the repository evolution is assessed in the performance assessment report along with the formulation of scenarios to be analysed to assess the impact of uncertainties. In the TURVA-2012 safety case, submitted in support for the construction license application, closure performance was assessed quantitatively in relation to its effects on the hydrogeological evolution of the geosphere as well as with respect of the long-term effects of the cement degradation on clay-based materials (i.e. alkaline plume from cement leachates reacting with bentonite) (Posiva 2013a).

The approach for assessing the closure performance will be updated from the TURVA-2012 safety case including assessments of quantitative and qualitative nature. Updating discussion and new modelling reflect the updates in the initial state of the repository system.

The modelling of the hydrogeological evolution of the Olkiluoto site forms a major part of the performance assessment work. It provides information of the flow routes within the system than can be used also in material transport assessment for closure (e.g. alkaline plume), it also provides means of estimating transport paths for the radionuclide release calculations. To assess closure's significance/uncertainties in the overall system performance, closure needs to be included in the models. This is done by using different hydraulic conductivities for the closure sections at different depths within the models. This has been included already in the TURVA-2012 analysis, and in the modelling updates a similar approach will be included.

2.5 Complementary considerations

The Complementary Considerations report will support the performance assessment. Processes related to closure were also discussed in qualitative level in Complementary Considerations (Posiva 2012b) reports. While central tunnel backfilling will be quite similar to that of deposition tunnels and the geological context is also relatively similar, especially in the upper parts of the repository materials and processes can be discussed in more qualitative way. The processes included in CC especially in relation with depth consider behaviour of plugs low-pH and OPC, behaviour of mixed crushed rock/clay materials, behaviour of rock based backfills etc. All these are discussed in relation to their installation depth and hence, considering effects of groundwater composition changes at relevant depth range, the expected extent of external processes (e.g. permafrost). Also erosion is included in discussion of closure's very long-term evolution (100 000 to beyond 1 Ma).

3 Summary

Providing a complete enough assessment for closure in Posiva's next safety case requires careful balancing between a sufficient level of detail for the design and the necessary information to assess whether the performance targets are met during the repository evolution. Both quantitative and qualitative assessments are needed to cover the essential parts of the safety case that involves closure:

- Assessing the performance of the closure also in relation to depth and related requirements
- Understanding of the behaviour of the closure during the whole 1Ma time frame and beyond
- Understanding the extent of closure near-field interaction and its long term implications
- Understanding of the general significance of the closure on the overall repository performance

The safety case methodology will present the information and assessment results in the context of performance assessment and complementary considerations. These two reports will describe the essential knowledge and assessment results. To some extent, it can be said that quantitative analyses are mostly provided within the performance assessment and qualitative analyses in complementary considerations. A report, Initial state, is planned to describe the design as installed and related potential deviations. Requirements for the closure will be described in the design basis report. Following the methodology presented in this paper, the assessment of the closure performance in the safety case will provide the level of detail needed for the operational license application as well as important feedback for future optimisations of the closure design.

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