Integration Of Demonstrator Activities In Performance Assessment: Analysis Of Processes And Indicators

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As part of the European project DOPAS, NRG investigated how demonstrator monitoring activities can be coupled more closely to the performance assessment of a radioactive waste disposal, and developed and tested a methodology that allows the integration of demonstrator's results into the safety case. NRG aimed to develop a strategy for the integration of monitoring results by identifying indicators that are directly or indirectly measurable, and allow assessing the complete system behaviour.

SKB's concept of *safety function indicators* was a good starting point for identifying indicators, but in case related criteria are not met, these indicators provide insufficient information to substantiate the consequences for the long-term safety. A second principal limitation was the operation time: relevant processes, as resaturation of swelling clay, are rather slow and exceed the operational life time of the DOPAS demonstrators. This hampers the practical determination of parameters.

The tested *travel-time based indicator* was judged useful, allowing addressing processes upstream and downstream of the barrier independently. *Performance indicators related to safety functions* were found useful in quantifying the contribution of EBS-component to the long term safety. The principal parameter identified as relevant for plugs and seals is the *hydraulic conductivity* and is either related to clay swelling pressure and density, or to salt compaction and backfill pressure. Diffusion related processes are of less relevance because for most concepts and host rocks, diffusion cannot be avoided. Identification of monitorable parameters relevant for PA should therefore focus on hydraulic aspects, related to e.g. permeability, pressure, porosity, compaction, and convergence.

1 Introduction

Plugs and seals as part of the engineered barrier system (EBS) have essential roles in the design of radioactive waste disposal facilities, with the design basis and related criteria and requirements extensively reviewed in [DOPAS, 2014 & 2015]. Performance and safety assessments were identified as important step in the iterative process for developing the design basis [DOPAS, 2014]. NRG investigated how demonstrator monitoring activities can be coupled more closely to performance assessment (PA) calculations as part of the safety case, and developed, tested and discussed options to allow the integration of the results of technical demonstrators in a PA [DOPAS, 2016]. Presently the results of PA calculations are communicated in a safety case by so-called '*Safety and Performance Indicators'* [e.g. Becker *et al.*, 2009]. The definition of suitable indicators allows the analysis, understanding and communication of the outcomes of PA calculations. They can have a relevant role in supporting system understanding and providing evidence for safety, and thus are expected to contribute to the overall objective of confidence building. *Monitoring* of relevant processes *in-situ*, either in experimental or demonstrator systems, performed on real scale in URLs or in disposal facilities, can provide valuable evidence for safety.

2 Objectives

The objective of NRG's contribution to WP5 of the DOPAS project was to investigate how demonstrator monitoring activities can be coupled more closely to the outcomes of PA calculations, and develop and test approaches that allow the integration of technical demonstrator's results into a safety case. Presently the results of PA calculations are communicated in a safety case by s*afety* and *performance indicators*. NRG aimed to investigate a strategy for integration of monitoring results by identifying meaningful indicators that have two characteristics:

- the indicator is directly or indirectly measurable in demonstrators, and
- the indicator allows assessing the complete system behaviour.

3 Work procedures

For the preparation of the report, the five demonstrators that form the core of the DOPAS project where studied: *DOMPLU* (SKB), *ELSA* (GRS & DBE Technology), *FSS* (Andra), *EPSP* (SURAO), and *POPLU* (Posiva). The work was divided into five parts:

- Development and description of the overall methodology and extensions needed to include demonstrators in existing methodologies.
- Identification of (new) indicators.
- Qualification of the potential weight (or relevance) of the indicator on the (seal) performance status by discussing its potential impact on the overall safety.
- Establishment of a generic demonstrator case, and development and application of a suitable PA model representation to derive potential evolutions of the selected indicators in time.
- Analysis of the results of the actual demonstrator's projects performed in DOPAS.

The first parts of the work were performed on a generic level, observing that SKB's concept of safety function indicators and criteria [SKB, 2006] provides a good starting point. The generic demonstrator case study was based on the *ELSA* shaft sealing concept for a disposal in rock salt.

4 Results

Based on the lessons learned, a stepwise approach was proposed to identify suitable indicators and evaluate their monitorability:

1) Analyse the general properties of the disposal concept, related safety functions, FEPs, and scenarios, and - if available - existing indicators and criteria related to the barrier.
2) Establish key features and processes, and the system-specific underlying processes and parameters.
3) Evaluate potential indicators and the related parameters.
4) Estimate the relative contributions of diffusive and advective processes to the overall mass transport of radionuclides and deduce the relevance of the barrier of interest for the overall safety by relevance based indicators.
5) Investigate the technical feasibility to monitor the parameters of interest.

Based on this stepwise approach, a PA representation of a demonstrator test case was developed, based on the *ELSA* shaft seal concept for a disposal concept in rock salt [Rübel *et al*., 2016], and several indicators were evaluated. The PA model developed by GRS as part of the DOPAS project assesses the performance of the *ELSA* shaft sealing by calculating the amount of brine inflow, through the different shaft layers into the model repository. In the GRS simulation, properties of the shaft and repository (e.g. porosity, permeability) were assumed constant. NRG adopted the following assumptions for the demonstrator case:

- The shaft was modelled as a single porous medium with averaged properties.
- A layer of brine with constant properties on top of the shaft models the flooding scenario; as a result brine percolates through the shaft into the repository (1).
- The infrastructure area of the repository is modelled as a single segment containing salt grit backfill and converges as result of the overburden's pressure (2). The convergence rate in dry (initially) and wet (after start of the brine inflow) conditions is simulated by process models describing the compaction behaviour of salt grit [Schröder *et al*., 2009b].
- As soon as the volume of the brine inside the infrastructure area of the repository equals the pore volume of the compacting repository, the inflow of brine stops and is subsequently reversed (3) due to the ongoing compaction of the repository volume. This effect was not taken into account in the GRS simulations.

Figure 4-1 depicts the segment model structure for the ELSA shaft sealing concept (GRS, left) and the generic demonstrator case (NRG, right). The main difference between GRS's model and NRG's demonstrator case relates to the assumptions made for the backfill of the infrastructure area of the repository: in the GRS model the infrastructure volume is backfilled with non-compacting gravel, whereas in NRG's demonstrator case compacting salt grit is assumed as backfill. Assuming a compactible salt grit backfill enables the repository volume to converge and squeezing out of trapped brine and, if present, any dissolved radionuclides.

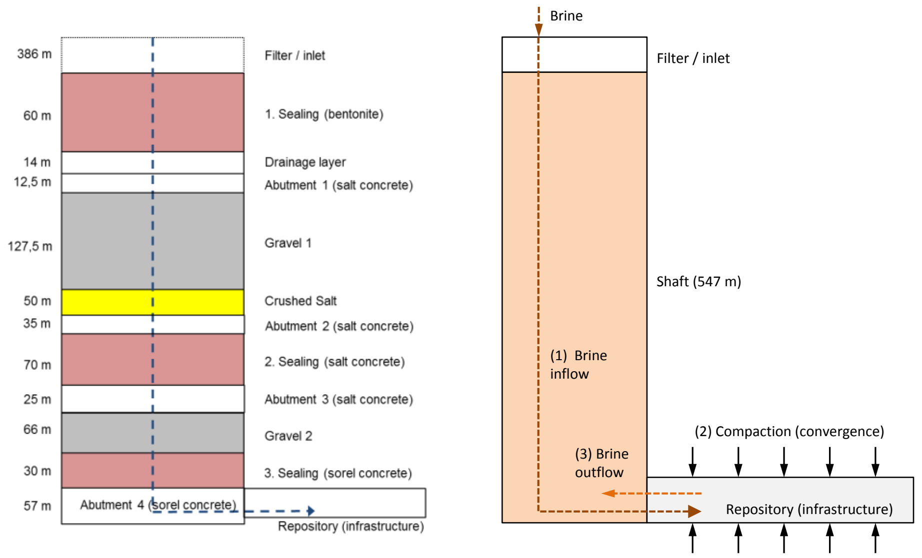

Figure 4-1: Set-up of NRG's generic demonstrator case (right) based on GRS's PA model (left)

The overall system behaviour of the modelled repository is shown in Figure 4-2. By imposing a constant initial convergence rate ($1 \cdot 10^{-4}$/a), the repository pore volume decreases in time. Starting from 700 years, brine percolates slowly into the repository, until full saturation is reached at approximately 41'000 years. From that time on, brine present inside the repository is squeezed out due to the ongoing convergence of the repository. The outflow of brine is restricted in the time interval to 58'000 years due to the hydraulic resistance of the vertical shaft. As a result of the ongoing convergence of the repository, the salt grit backfill will be compacted as time progresses. Consequently the porosity and the permeability of the backfill decrease. At a certain point in time (here: about 80'000 a) the repository' effective pressure equals the backfill stress, and the ongoing convergence rate is slowed down significantly, as is the outflow of brine.

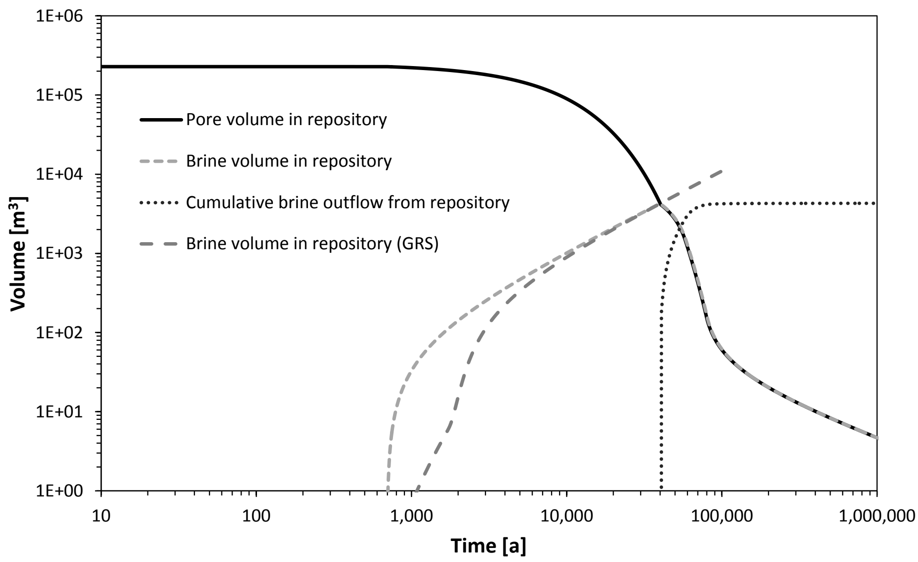

Figure 4-2: Evolution of repository and brine volumes

Combining the system behaviour described above with a travel-time based indicator [Schröder *et al.*, 2009a] provides insight about the breakthrough of radionuclides into the repository. In the present generic demonstrator case the following assumptions were applied:

- Three different initial convergence rates for the repository pore were considered.
- For the safety indicator *radiotoxicity flux to the geosphere*, a reference value of 0.1 Sv/a at the exit of the repository was assumed [Becker *et al.*, 2009].
- Given the long time period until the outflow of brine starts (several ten thousands of years), it was conservatively assumed that all brine from the disposal is directly entering the geosphere.
- Conservatively, a perfect mixing of the brine in the infrastructure area was assumed.

The travel time indicator can be calculated by dividing the reference value by the outflow of brine from the repository, and is depicted in Figure 4-3 for three different initial convergence rates.

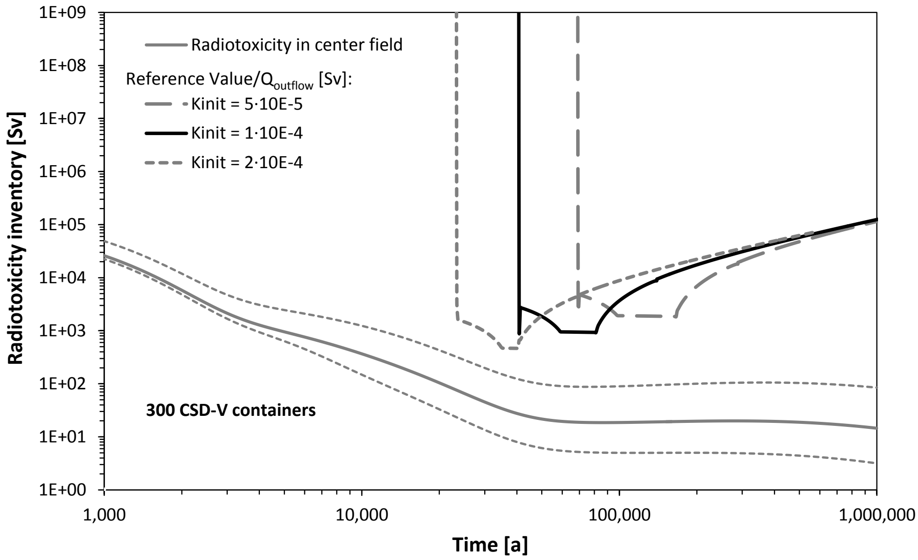

Figure 4-3: Evolution of indicator and radiotoxicity in repository for three initial convergence rates k and an inventory of 300 CSD-V containers

These curves in Figure 4-3 represent the maximum concentration of radiotoxicity that can be present in the repository without exceeding the given reference value, and can be compared with the evolution of the total radiotoxicity in that compartment (best fit: grey solid curve; uncertainty range: dotted curves). These curves are based on an assessment of a borehole from the generic Dutch disposal concept in rock salt [Schröder *et al.*, 2009b], with a salt grit sealing plug compacting as result of convergence. The inventory consists of 300 containers with high-level waste (HLW). A flooding scenario of the borehole combined with an immediate failure of all canisters was assumed. The figure shows that even for the very conservative and unlikely scenario assumptions and for all assumed repository convergence rates the radiotoxicity in the repository remains below the indicator value at all times, i.e. the plug performs sufficiently well.

5 Discussions

The following observations apply to the results of the generic demonstrator case study:

- The presence of brine is crucial in relation to the long-term safety of the repository and can be easily measured, e.g. by electrical conductivity. However, currently no mature technology is available to monitor over such long timescales.
- The presence of brine at various locations inside the shaft can in principle be detected in time frames shorter than several hundred years. If brine would be detected inside the shaft this information may help to analyse in detail the consequences of repository flooding.
- A parameter that is relatively straightforward to measure and that provides relevant information about the development of the repository system, including the shaft, is the pressure: the pressure inside the shaft can provide information about the convergence of (parts of) the shaft, and therefore the further reduction of the permeability and resistance to brine intrusion.

In general shows the *ELSA* shaft sealing case study that the applied travel-time based indicator is a useful tool, because it allows addressing processes upstream and downstream of the barrier independently. The indicator provides system understanding that can be used to identify measurable parameters which can be linked to long term safety indicators. However, it also shows that it needs (apart from understanding of the initial condition during operation) a detailed system understanding in order to extrapolate the operational conditions over long time frames. The approach illustrated for the barrier systems in rock salt is expected to be applicable in other (non-salt) systems as well.

6 Conclusions

SKB's concept of *safety function indicators* [SKB, 2006], including quantitative *criteria*, provides a good starting point for identifying indicators, but these indicators do not provide information on the safety in case criteria are not met. This makes it difficult to substantiate the consequences for the long-term safety. Nevertheless, the identification of safety functions for repository components is of vital importance for the development of a monitoring programme. Another limitation noted for the DOPAS demonstrators was their relatively short *operation time*: relevant processes, e.g. the resaturation of swelling clay, are rather slow and full resaturation of the barrier often exceeds the operational life time of the demonstrator. The slow evolution of the identified processes may hamper the practical determination of parameters regarded relevant for these processes: monitoring of processes may provide significant evidence for a safe evolution only over time intervals that cannot be realized due to technical limitations.

The tested *travel-time based indicator* was judged useful, because it allows addressing processes upstream and downstream of the barrier independently. Different assumptions and scenarios can be coupled, and can directly be related to relevant parameters. The *safety function indicators* and *performance indicators related to safety functions* are useful in identifying monitorable indicators, either because they may underpin statements on safety, or allow quantifying the contribution of each safety function or EBS-(sub)component to the long-term safety.

The principal parameter identified as relevant for the long-term safety is the *hydraulic conductivity*. The hydraulic conductivity can be related to the plug's sealing element or the buffer and backfill in the disposal cell. In case of swelling clay material, the related processes are the swelling pressure and density of the clay, and in case of salt grit the related processes are the salt compaction and backfill pressure. Other relevant key processes are the pressure gradient over the barrier, sorption, and solubility of radionuclides, with the latter two usually determined in independent batch experiments. Diffusion related processes are of less relevance, because for most concepts and host rocks, diffusion cannot be avoided. Identification of monitorable parameters relevant for PA should therefore focus on hydraulic aspects, related to e.g. permeability, pressure, porosity, compaction, and convergence. For disposal systems in rock salt, the presence of brine is an important monitorable parameter. Because most of the related parameters cannot be monitored either in demonstrators nor *in-situ*, they must be determined through indirect measurements or laboratory experiments. The derivation of these parameters involves process assumptions as a rule.

7 Acknowledgements

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