NUMO-TR-12-01

Collaboration on Strategies for the development of a Repository Program

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NUMO

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July 2012

Nuclear Waste Management Organization of Japan
（NUMO）

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1 Introduction

1.1 Background of this study

The Nuclear Waste Management Organization of Japan (NUMO, hereafter) has selected an open solicitation approach for the site selection process in Japan, both for the high-level waste repository (open call in 2002) and the TRU repository (open call in 2008). Such an approach, albeit flexible, poses a special challenge for NUMO's repository design team.

A detailed repository design must be tailored to the given geological and surface environment, not least to take advantage of the potential for optimization. The repository design must fulfill a broad range of requirements resulting, for example, from the long-term safety goals, engineering practicality and socio-economic issues. The special challenge for NUMO's design team is to be able to specify a number of different designs for sites in different geological and geographical settings and, moreover, to be able to finalize such designs within a very limited time period.

Regarding the Swiss radioactive waste disposal program, Nagra has built up a long experience through the investigation of a wide range of geological environments for both the HLW and L/ILW. As a consequence it was agreed to set up a collaborative study aimed at transferring relevant knowledge from the Swiss geological disposal program to the Japanese disposal program in first instance. Later in the project, where this was relevant for NUMO, also experience from other European implementers was drawn upon.

1.2 Overview of the collaborative study

The repository concept (RC) collaborative study was initiated in 2001, mainly as a technical knowledge transfer between the implementing organizations of Japan and Switzerland. The focus was on developing a methodology for tailoring repository concepts to a broad range of site environments. The outcome of the study between 2001 and 2003 is summarized in NUMO (2004).

The RC collaborative study was then continued and expanded to cover a wide range of topics from the strategic to the technical level. Every year joint team meetings have been organized in Switzerland and in Japan. These were supplemented by a number of working meetings also in Switzerland and Japan. The working meetings allowed the members of the NUMO-Nagra team to exchange, discuss, and further develop ideas and concepts applicable to the Japanese environment. The main meetings also discussed work performed by contractors and guided future developments.

The 2nd phase of the RC study was completed in FY 2007. The main results of this phase are discussed in Kurikami et al. (2009) and can be summarized as follows:

- Development of the roadmap for the preliminary investigation (PI) stage in Japan
- Identification of issues for the scenario development methodology of NUMO
- Discussion/suggestion for requirements management system of NUMO

In its 3rd phase, the RC collaborative study was expanded to develop the above topics from the strategic to the technical level. The 3rd phase covers FY 2008 to FY 2010.

The goal of this report is to summarize the main results of the study during the 3rd phase. For each of the fiscal years covered in this report, Appendix A shows the main topics investigated as part of the RC study collaborative study. From the list described in Appendix A, the outcomes of development and the International workshop on Requirement Management Systems have already been published (Suzuki et al., 2008: Suzuki et al., 2010a: Suzuki et al., 2010b: NUMO, 2011a). Also, the outcomes of the International workshop on scenario development methodology have already been published (Ebashi et al., 2010).

From the list of topics covered under the collaboration, in terms of the following points, the some topics are selected for this summary report and described in more detail.

- Exclusion of topics already published by some form
- Focus on technical and important topics in initial stage of NUMO’s about 100-years program

Chapter 2 summarizes the activities for the Detailed Investigation (DI) stage based on the boundary conditions and the DI objectives.

In Chapter 3 aspects of the management of uncertainties in safety assessment are discussed.

In Chapter 4 the definition and concept of demonstration in general are discussed.

Chapter 5 contains the conclusions of the collaborative study.

2 Provisional activities for the DI stage

2.1 Introduction

In this chapter a provisional DI activities is described. The DI activities was developed in a series of working meetings, discussed and finalized during the Joint Team Meetings. In FY'06 and FY'07, the NUMO-Nagra team developed a activities for the PI phase (Kurikami et al., 2009). In FY’08, this work was extended to the activities for the DI stage.

During the DI stage, NUMO will construct an Underground Investigation Facility (UIF) to the host rock. The NUMO-Nagra team has gone through the expected work processes during the DI stage and developed a provisional DI activities. The activities covers all major groups of activities expected during the DI stage, namely additional surface-based investigations, construction of the access, excavation of experimental tunnels and performing tests underground. This activities will contribute to the understanding of the type of activities that will need to take place in the DI stage in a comprehensive manner. It should be noted that the activities developed is site-generic and more detailed work will be required once the site conditions become more concrete. In addition, NUMO has showed the basic idea for DI stage in FY’11 (NUMO, 2011b), and then it is based on this activities.

2.2 Boundary conditions

Figure 2-1 shows NUMO's activities during the site investigation stages. The DI stage is when NUMO goes underground to conduct detailed investigations. It is also important to point out that NUMO, most probably, will have to purchase the surface land; this will be a major decision for NUMO.

The following (assumed) boundary conditions have been applied in this development:

Although there is no official duration, it is expected that the DI stage will take approximately 15 years

After the DI stage, NUMO will select a repository site and start to prepare the licensing

Field work will be carried out continuously even during licensing (but may not be called DI)

The activities that NUMO is required to complete in the DI stage are defined in Article 8 of the Final Disposal Act.

Final Disposal Act: Selection of a Site for Repository Construction

Article 8. The Organization shall, when it intends to select a site for repository construction, carry out in advance the detailed investigation in accordance with the final disposal plan and the approved implementation plan of the Organization with respect to the matters mentioned in the following items in the detailed investigation areas under Article 5, paragraph 2, item (iii), as stated in the said approved implementation plan:

(i) matters concerning the strength of rocks that make up a geological formation where the final disposal will be carried out (to be referred to in this article as the "subject geological formation") and the physical properties of the said subject geological formation in the said detailed investigation areas;

(ii) matters concerning hydrogen ion concentration in the said subject geological formation and other chemical properties of the said subject geological formation;

(iii) matters concerning the details of groundwater flows, if any, in the said subject geological formation; and

(iv) other matters specified in the Ordinance of the Ministry of Economy, Trade and Industry.

Subject to the provisions of the Ordinance of the Ministry of Economy, Trade and Industry, when the Organization has carried out the detailed investigation in accordance with the provisions of the preceding paragraph, it shall, based on the results of the detailed investigation, select a site for repository construction from among those detailed investigation areas with respect to which the said detailed investigation has been carried out and which are deemed to meet all of the following criteria:

(i) it is expected that underground engineered facilities in the said subject geological formation are unlikely to be exposed to unusual pressure, and in other respects, the physical properties of the said subject geological formation are expected to be suitable for the construction of a final disposal facility;

(ii) it is expected that underground engineered facilities in the said subject geological formation are unlikely to be exposed to unusual corrosive action, and in other respects, the chemical properties of the said subject geological formation are expected to be suitable for the construction of a final disposal facility;

(iii) it is expected that groundwater or groundwater flow in the said subject geological formation is unlikely to disturb the functions of underground engineered facilities; and

(iv) other matters specified in the Ordinance of the Ministry of Economy, Trade and Industry.

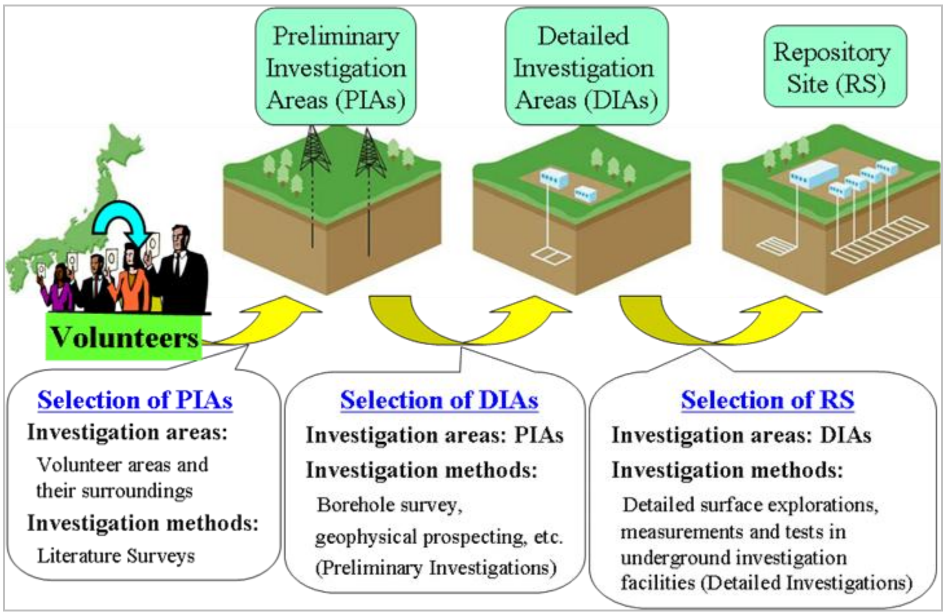


Figure 2.1 Site investigation stages for the HLW disposal program in Japan

2.3 General remarks

The legal requirements contain essential aspects that need to be addressed in a DI activities, but additional considerations are needed for its development, as described herein. A key challenge in the DI stage is the integration of excavation activities with the requirements of (most probably) building a safety case for a license application of this site. It is required to handle scientific work in harmony with ongoing excavation work without jeopardizing the objectives of the DI.

The site characterization during the DI is a continuation of the one performed in the PI stage, but expanded to include both surface-based and underground investigations. The underground construction itself, combined with mapping, represents an important component of the detailed characterization activities because any underground excavation is, at least temporarily, a major disturbance to the overall geological system, and a monitoring program is needed.

Another potential use of the underground space is to carry out specific tests. However, a detailed test program can be developed only after the repository site, the host rock and a repository concept have been determined. It is also necessary to consider what tests should be done in an underground facility at the site – and what could be done elsewhere.

A activities structure similar to the PI roadmap (Kurikami et al., 2009) is suggested for the DI stage. This structure includes the main processes, their interactions and the key decision points.

2.4 Objectives of DI activities

The activities are developed with the following objectives in mind:

- Confirm that the Detail Investigation Areas (DIA) fulfils all of the legal and NUMO requirements
- Provide sufficient input for preparing the licence application with its safety case for the repository – even if some complementary activities may be needed. The input for the licence application preparation would include for example confirming that the thickness and extent of the selected host rock are sufficient to accommodate the planned waste volumes and that the investigations provide sufficient input for the basic/detailed design of the repository.

2.5 DI activities

2.5.1 Overview

The proposed DI activities is shown in Figure 2.2. It is structured in a similar manner to the PI roadmap (Kurikami et al., 2009). It contains the main steps as well as the input required for each step and the products expected as an output.

Input from prevous step/stage	*Activities*	*Expected outcome*

Step 1: Activities before access construction

* SDM 1.0	1.1 Initial planning and characterisation of monitoring	* Completed surface based investigations
* Preliminary repository concept	1.2 Initial planning of testing in the host rock and elsewhere	* Preliminary plans for underground characterisation and monitoring
* Preliminary safety assessment	1.3 Complementary surface-based investigations	* Preliminary plans for underground testing
* Issues remaining from PI	1.4 Initiation of baseline monitoring	* Plans for tests in generic URLs
	1.5 Update SDM	* Baseline monitoring system on site
	1.6 Detailed design of access and surface facilities	* Updated SDM 2.0
		* Detailed design of access including time schedule

Step 2: Activities during construction of access

* Detailed design of the access	2.1 Construction of access tunnel or shaft to reach host formation	* Completed access and including characterisation and monitoring
* Plan for underground characterisation and monitoring	2.2 Characterisation of monitoring during access construction	* Installed and initiated underground monitoring
	2.3 Assessment of findings during access construction	* Monitoring data from the surface
* Assessment of activities in other URLs (Japan or overseas)	2.4 Revision of underground test and characterisation plan	* Updated SDM 3.0 in the access and testing volume
		* Updated test plan
		* Updated characterisation and monitoring plan

Step 3: Activities in the host rock formation

*Revised underground testing and characterisation plan	3.1 Construction of test (and potential characterisation) tunnels	*Completed test and characterisation tunnels
*Monitoring concept of the near-field	3.2 Continued characterisation and monitoring	*Completed characterisation activities
*Method statements for excavation of test and disposal tunnels	3.3 Implementation of tests	*Installed and initiated monitoring system
		*Results of tests and their interpretation

Step 4: Final evaluation and reporting of the DI stage

Updated SDM 4.0
Detailed repository design
Updated safety case

Figure 2.2 Outline of the provisional activities for the DI stage

2.5.2 Available information from the PI stage

The work carried out in the PI stage, e.g. as outlined in the "fundamental activities of the PI stage", provides crucial information for the planning and execution of the DI stage. This information includes:

SDM (Site Descriptive Model) version 1.0 (SDM 1.0 hereinafter): The SDM after completion of the PI stage should include the geometry of the host formation, the location of layout-determining features, and a statistical description of key host formation properties, groundwater composition, migration properties, rock engineering properties and dilution in aquifers/surface waters. It will also include a description of the evolution of the site conditions, e.g. uplift/erosion, ongoing and past geochemical processes, faulting, etc. and a quantification of key uncertainties related to PI targets.

A preliminary repository design: The design should be based on SDM 1.0 and should fulfil the specified requirements. The engineering feasibility with respect to the requirements should be assessed and issues/uncertainties requiring resolution should be identified.

A preliminary safety assessment: The safety assessment should be based on SDM 1.0 and the preliminary repository design. It should provide a list of safety arguments and outstanding issues.

Issues remaining from PI: An outline plan for resolving remaining issues, i.e. a general characterization, testing and technical development plan for the DI stage. Such a plan would include approaches for verification of assumptions made regarding rock conditions and engineering feasibility (to be executed during the DI stage), characterisation targets for the DI stage, required R&D topics for DI, remaining issues relating to long-term safety, engineering design and site understanding as identified when developing the preliminary safety case and an assessment whether further resolution of these issues is needed (input from the preliminary safety case).

Safety-related restrictions on underground access: Such restrictions would be based on the selected repository concept and could relate to location of access, groundwater control, chemicals that could be used, etc.

2.5.3 Step 1: Activities before access construction

The following activities are foreseen the construction of the access tunnel or shafts.

- Step 1.1 Initial planning of characterisation and monitoring during DI
- Step 1.2 Initial planning of testing in the host rock and elsewhere

- Step 1.3 Complementary surface-based investigations (additional borehole & geophysical surveys)
- Step 1.4 Initiation of baseline monitoring
- Step 1.5 Update SDM 2.0
- Step 1.6 Detailed design of access

These are further outlined in the following sections.

Step 1.1 Initial planning of characterization and monitoring during DI

While planning of the DI already starts as part of the DIA selection (i.e. at the PI stage), a more detailed, although still preliminary, planning of the characterisation and monitoring during DI is needed once the DIA selection is made.

Issues to be considered:

The following items should be considered in the characterization and monitoring planning:

- Key remaining issues from PI
- Need for complementary surface-based investigations. It is very likely that complementary surface-based investigations (boreholes and geophysical surveys) will be needed in the DI stage. The main objective of these investigations would be to support the detailed repository design in rock volumes not directly reached by the underground excavations carried out in the DI stage. This also means that the scope and intensity of these investigations will depend on the DI objectives, the type of host rock and the understanding of the host rock
- What characterisation is needed for the detailed design of the access volume?
- Need for characterisation during access construction (relevance depends on the importance of understanding the overlying formations).
- Assessments whether remaining issues require specific characterisation or specific tests in situ in the host formation
- Assessment of needs/objectives of monitoring the impact of construction (mechanical, hydraulic, chemical)
- Need for extended surface-based characterisation - will the deep access sufficiently cover the footprint of the repository? (Depends on DIA objectives).
- Should there be a characterisation loop around the first repository panels (depends on DIA objectives).

It should also be noted that the list of issues assumes that the objective of the DIA stage is not only to show that the DIA fulfils the legal requirements, but also that the DIA should lead to detailed design of the repository.

Required input

The following input is required for the planning:

- Feedback from design and safety assessment
- Safety-related restrictions on underground access (location of access, groundwater control, chemicals, e.g. low-pH grout, etc.)

Outcome

The expected outcome of the planning is:

- A programme for the complementary surface-based investigations
- Preliminary plans for underground characterization and monitoring

Step 1.2: Initial planning of testing in the host rock and elsewhere

In addition to the initial planning of characterisation and monitoring during DI, there is also a need for initial planning of testing in the host rock and elsewhere, even if such tests would typically only start when the excavation has reached the host rock at relevant depths. It should also be realised that the initial test plan might be substantially revised based on the findings made during the underground excavation.

Issues to be considered

The following issues should be considered in the initial test planning:

- Key remaining issues from PI
- Assessment whether remaining issues requires specific tests in the host formation (e.g. interaction between EBS and rock, demonstration of construction technologies, demonstration of operating technologies (transportation and emplacement), demonstration of closure technologies (plug, backfill, borehole sealing, etc.))
- Is it necessary to perform the test at the site – or could it be done at another URL?
- Will the test provide results in time for the completion of the DI stage?
- Are there tests that could help guide the implications of the concept of "performance confirmation monitoring", e.g. THMC processes, metal corrosion.

Required input

The following input is required:

- Feedback from design and safety assessment
- Initial planning of characterisation and monitoring during DI (Step 1.1 above)
- Safety-related restrictions on underground access (location of access, groundwater control, chemicals, e.g. low pH grout, etc.).
- Assessment of on-going and planned tests at URLs in Japan and abroad.

Outcome

The following outcome is expected:

- Preliminary plans for underground testing, with justification
- Plans for trial-and-error type testing in generic URLs that may or may not be confirmed later at the DI site.

Step 1.3: Complementary surface-based investigations

Step 1.3 involves the actual performance of the surface-based investigations. However, it should be noted that these investigations do not necessarily end once underground excavation starts. There may be good reasons to continue with some surface-based investigations during later steps.

Issues to be considered

The basic issue to be considered is the timing and logistics of the investigations, i.e. when are the results needed. It should be noted that surface-based investigations do not necessarily end once underground excavation starts. There may be good reasons to continue with some surface-based investigations during later steps. The following should be considered:

- Information needs for the detailed design of the access (e.g. pilot hole in the proposed shaft). These investigations clearly need to be completed and evaluated in time for the detailed design of the access
- Additional boreholes needed for baseline monitoring purposes – these boreholes also need to be completed and instrumented prior to the start of the excavation
- Investigations aimed at more detailed coverage of the potential repository volume. These investigations can probably be conducted in parallel with access construction.

Required input

Performance of the complementary surface-based investigations requires the programme for the complementary surface-based investigations developed in Step 1.1.

Outcome

The outcome of this step is the completed investigations with their results.

Step 1.4: Initiation of baseline monitoring

If not earlier, baseline monitoring needs to be initiated prior to the potential disturbances caused by the excavation activities. To a large extent, the monitoring would be a continuation of the monitoring (potentially) initiated during the later stages of the PI stage.

Issues to be considered

The following issues should be considered:

- Monitoring should be seen as part of the characterisation programme – not as a separate activity!
- Some of the monitoring should have been initiated in the PI stage
- Additional borehole drilling might be required if the boreholes already drilled for site investigation are not sufficient for baseline monitoring (see Step 1.3).

Required input

The following input is required:

- Preliminary plans for underground characterisation and monitoring (see Step 1.1)
- Existing monitoring programme from the PI stage
- Specification and location of existing boreholes that could be used for monitoring in the DIA
- Requirements for baseline conditions from safety assessment and repository design perspectives.

Outcome

The outcome is the baseline monitoring system on site.

Step 1.5: Update SDM 1.0 to SDM 2.0

The information obtained from the characterisation work prior to excavation should be evaluated and assembled in an updated SDM 2.0.

Issues to be considered

The basic issue to be considered is how to update the SDM such that it can be used as input for the detailed design of the underground access. This means that it will focus on rock formations along the access and may be less ambitious regarding other formations, even if they are eventually very important for the safety case and the detailed design of the entire repository. Furthermore, the description in the access formations might have a much higher geometric resolution compared to the SDMs developed during the PI stage.

Required input

The following input is required:

- SDM 1.0 from the PI
- Findings from additional characterisation (see Step 1.4) and monitoring (see Step 1.5) before the start of the detailed design work.

Outcome

The basic outcome of this step is the updated SDM 2.0, with the focus on the details of the volume in the vicinity of the underground excavation access.

Step 1.6: Detailed design of access and surface facilities

The final step prior to excavation is the detailed design of the access and the surface facilities.

Issues to be considered

There are several issues to be considered in the detailed design of the access, including:

- Detailed design of the surface facilities for DI (e.g. facilities for tunnel/shaft construction, excavation muck storage, water treatment facility, pipeline for groundwater discharge)
- Estimation of required land area for DI activities and purchase of the land
- Developing the preliminary design into a detailed design that can be readily applied by the constructor
- Ensuring proper integration between the excavation work and the characterization activities. This has proved to be a real challenge based on the experience of e.g. SKB at the Äspö HRL, AECL at their URL and Posiva at ONKALO. There is an inevitable conflict between, on the one side, the constructor who usually has a considerable incentive to complete the access as quickly as possible and, on the other side, recognising that the underground excavations are made for a very specific purpose – and not only for completing the underground facilities. Careful attention to contractual agreements and incentives is needed
- Restrictions related to long-term safety (e.g. formations that must not be penetrated, materials that might not be acceptable, and long-term safety requirements on the access such as the EDZ)
- Type of access (e.g. ramp or shaft or both).

Required input

The following input is required for the detailed design of the access:

- Detailed scale SDM for the access volume (see Step 1.5)
- Detailed engineering requirements (to be identified based on the updated SDM)
- Requirements/restrictions regarding long-term safety (to be identified based on the updated SDM)
- Preliminary plans for underground characterisation and monitoring during access construction (see Step 1.1)
- How will the access be used for repository construction or operation at a later stage? This might affect the decision between a ramp or a shaft and also what kind of restrictions might apply.

Outcome

The following outcome is expected from the detailed design:

- Detailed design of the access, integrated with a plan for underground characterisation and monitoring
- Detail time schedule for access excavation.

2.5.4 Step 2: Activities during construction of the access

The following activities are foreseen during access construction:

- Step 2.1: Construction of an access tunnel or shaft to reach the host formation
- Step 2.2: Characterisation and monitoring during access construction
- Step 2.3: Assessment of findings during access construction – update of SDM 2.0, consideration of whether safety case and critical issues in safety case have been addressed
- Step 2.4: Revision of the underground characterisation and test plan.

  (Decision to proceed with the DIA).

These are further outlined in the following sections.

Step 2.1: Construction of an access tunnel or shaft to reach the host formation

Based on the detailed design developed in Step 1.6, construction should proceed, while still meeting the expectations of characterisation and monitoring.

Issues to be considered

The following issues should be considered during the access construction:

- Constructing the access and implementing the characterisation and monitoring plan
- Handling "surprises". There will be surprises, e.g. the construction will encounter formations or conditions that were not fully anticipated in SDM 2.0. Such situations should not be regarded as catastrophic, but instead be anticipated and measures prepared for handling them, e.g. by applying the "observational method"
- Meeting the construction schedule without jeopardising the objectives of the DI in general and the underground characterisation and monitoring plan in particular (see previous comments in Step 1.6).

Required input

The basic input required for this step is the detailed design developed in Step 1.6.

Outcome

The basic outcome of this step is the completed access and the characterisation and monitoring associated with this.

Step 2.2: Characterization and monitoring during access construction

It is highly likely that rock characterisation and monitoring will be a crucial activity during access construction.

Issues to be considered

The following issues should be considered for the characterisation and monitoring during access construction:

- Carrying out the characterisation and monitoring plan without unduly disturbing the excavation work
- Being able to adjust the plan based on new findings and surprises
- Monitoring of the potential perturbations in the geosphere caused by the underground construction.

Required input

The basic input required is the plan for the underground characterisation and monitoring (see Step 1.3).

Outcome

The outcome of this step is:

- Completed characterisation activities
- Installed and initiated underground monitoring
- Monitoring data from the surface.

Step 2.3 Assessment of findings during access construction

The findings during access construction need to be evaluated and assessed, not only in terms of an updated SDM, but potentially also in terms of an updated repository design and updated safety assessment.

Issues to be considered

The following issues should be considered for this step:

- Is there a need for a detailed SDM in the local host volume for potential test tunnels?
- Consideration of whether the safety case and critical issues in the safety case require revision
- Assessment of disturbances caused by the excavation (e.g. estimation of macroscopic hydraulic properties of the rock formations using the water inflow rate along the access, assessment of buffering of infiltrating groundwater)

- Are the disturbances affected by local phenomena (such as "skin" or grouting) – or do they tell something about the site?

Required input

The basic input required for this step is the results of characterisation and monitoring during access construction (see Step 2.2).

Outcome

The outcome of this step is:

- Update of the SDM 3.0 in the access and testing volume
- Updated needs for underground tests - are there remaining uncertainties regarding the site conditions that are highly relevant for safety or design?

Step 2.4: Revision of the underground test and characterization plan

The findings from the access construction characterisation and from other activities are likely to suggest that the preliminary underground test plan (Step 1.2) needs to be updated and revised.

Issues to be considered

Issues to be considered in the test plan revision include:

- Are there continuing characterisation and monitoring needs?
- Should there be specific characterisation tunnels around the first disposal panels and what investigations should be carried out?
- Can remaining uncertainties in the site conditions that are highly relevant for safety or design (see Step 2.3) be resolved by underground tests?
- Are there other needs for underground tests from a safety or engineering point of view?
- Is there a special need for demonstration in addition to the purely technical needs?
- Will the relevant tests, i.e. the ones that meet needs, produce results in time for the completion of the DI stage?
- Are tests really needed in the host formation? What can be achieved by testing in other URLs?
- Advantage of parallel tests underground and at the surface for comparison purposes
- Will tests provide results in time for the completion of the DI stage?

Required input

The basic input required is:

- Results of Step 2.3
- Other needs for underground tests

- Assessment of activities in other URLs (in Japan or elsewhere).

Outcome

The basic outcome of this step is:

- Updated test plan
- Updated characterisation and monitoring plan.

Examples of tests on the actual rock conditions

Example of issues related to testing the actual rock conditions that could be important for resolving by underground tests include:

- Mechanical stability (rock stress and rock mechanical responses), detailed migration paths in the near-field
- Geochemical processes.

Examples of geosphere tests that would serve such needs include:

- Mechanical tests (e.g. mechanical and thermal property tests on rock samples, initial stress measurements)
- Hydraulic tests in boreholes (pressure, conductivity, fracture contribution to groundwater flow, gas permeability, gas breakthrough pressure)
- Geochemical investigations (redox conditions/buffering capacity, high-pH buffering capacity, groundwater history, groundwater dating)
- EDZ measurements (hydraulic properties, depth, etc.)
- Geophysical tests to detect features in the host rock (identification of detection limit – distance, size, and feature).

Examples of EBS tests

Examples of issues related to the EBS to be considered when planning EBS tests include:

- Aspects of EBS design that would be good to test in situ
- THM processes in the EBS and its interaction with the host rock.

However, it must be noted that many of these tests could be done at other URLs and the tests may take too long to complete during the DI stage (depends on the objectives of the DI stage, see Section 2.4). This means that NUMO needs to think about critical EBS tests that could be conducted at other URLs already during the LS and PI stages. EBS tests carried out at the

DIA stage would typically be confined to confirming the applicability of results obtained from more elaborate and time-consuming tests carried out previously.

Examples of EBS tests include:

- Demonstration test of EBS transportation and emplacement in the host rock (operational test), if possible with a prototype remote handling system to check engineering practicality and cycle time, etc.
- Designing and testing the measures taken against potential operational hazards, e.g. derailing, canister drop, rock fall, flooding, fire, recovery of emplaced EBS, etc.
- EBS behaviour test: buffer saturation test, THM coupling test, canister corrosion test, gas generation and migration test, material interaction study (e.g. bentonite-cement).

Examples of other tests

There will also be other tests to consider, notably focusing on demonstration and repository operations. Examples of issues to be considered include:

- Testing aspects of the repository components (e.g. drilling deposition holes, backfilling, plugs, borehole sealing, etc.)
- Demonstration of the practicalities of repository operation
- Needs from public relation.

Examples of other tests include:

- Sealing technologies (e.g. grouting, temporary plug, borehole sealing)
- Repository closure technologies (backfilling, permanent plug, feasibility of long-term monitoring concept and technologies).

2.5.5 Step 3: Activities in the host formation

At least the following activities are foreseen when the access has reached the host formation:

- Step 3.1: Construction of test and (potential) characterisation tunnels
- Step 3.2: Continued characterisation and monitoring
- Step 3.3: Implementation tests

These are further outlined in the following sections.

Step 3.1: Construction of test tunnels and (potential) characterization tunnels

Clearly, test tunnels and potential characterisation tunnels need to be excavated according to plan. Furthermore, the excavation experience itself also provides important input for the detailed design of the repository.

Issues to be considered

The following issues should be considered:

- Ensuring that the test and characterisation tunnels are constructed to meet test objectives
- Testing logistics
- Considering the potential use of the test and characterisation tunnels for future near-field monitoring
- Testing excavation methods for disposal tunnels
- Feasibility of an exploration tunnel around the repository area
- Worker safety (ventilation, fire, etc.).

Required input

The following input is required for this step:

- Revised underground testing and characterisation plan (see Step 2.4)
- Monitoring concept for the near-field
- Method statements for excavation of test tunnels and actual disposal tunnels.

Outcome

The main outcome of this step is:

- Completed test and characterisation tunnels
- Experience gained from the excavation.

Step 3.2: Continued characterization and monitoring

Characterisation and monitoring continue. Depending on the plans, characterisation may be carried out using boreholes drilled from underground, potentially complemented by a characterisation loop around the first repository panels. One possibility is to excavate exploratory tunnels around the planned disposal area. This allows direct confirmation of the host formation, e.g. extent, location and impact of features, etc.

Issues to be considered

The following issues should be considered:

- Carrying out the characterisation and monitoring plan in the host rock and elsewhere without unduly disturbing the excavation work
- Being able to adjust the plan based on new findings and surprises

- Monitoring of EDZ development or a mine-by test with the progress of excavation of the test tunnel
- In the event that an exploratory tunnel is constructed around the planned disposal area, the time schedule must be well planned as the excavation may take quite a long time considering the interaction with investigation work, e.g. mapping of tunnel surface, potential tests for characterising features.

Required input

The basic input required is the revised underground testing and characterisation plan (see Step 2.4)

Outcome

The outcome of this step is the completed characterisation activities and the installed and initiated monitoring system.

Step 3.3: Implementation of the tests

Implementation of the tests is likely to involve several issues, but at this early stage of planning only a few can be listed.

Issues to be considered

The basic issue to be considered is carrying out the tests according to plan.

Required input

The main input required is the revised underground testing plan (see Step 2.4) and the completed test tunnels (see Step 3.1).

Outcome

The outcome is the results of the tests.

2.5.6 Step 4: Final evaluation and reporting of the DI stage

While evaluation and reporting are needed throughout the DI stage, it is also important to envisage the activities needed for the final evaluation and reporting. The following steps are envisaged:

- Step 4.1 Updated SDM 4.0
- Step 4.2 Detailed repository design
- Step 4.3 Updated safety case

These are further outlined in the following sections.

Step 4.1: Updated SDM 4.0

All the findings on the rock characteristics and monitored changes during the DI stage need to be evaluated and documented in an updated SDM 4.0.

Issues to be considered

At least the following issues need to be considered:

- Addressing targets and issues in previous plans
- Ensuring fulfilment of engineering and performance assessment needs.

Required input

The following input would be required:

- Findings from characterisation, monitoring and construction experience
- Findings from tests.

Outcome

The outcome of the step would be

- An updated SDM – with the focus on the detailed data on the rock formations
- Assessment of confidence over the entire footprint – is there a need for more surface-based investigations prior to the licence application?

Step 4.2: Detailed repository design

If the DI stage includes detailed repository design, this design needs to be developed.

Issues to be considered

Issues to be considered in the detailed repository design include:

- Revising the repository design based on the results of the tests performed (including transportation/emplacement of the EBS)
- How will the repository be designed (including layout), considering all safety-related restrictions and the desired repository capacity (including potential for TRU waste).

Required input

At least the following input is required:

- Updated SDM 4.0
- Construction experience from the DI
- Findings from activities during DI stage.

Outcome

The outcome should include:

- A detailed repository design building on the most recent SDM 4.0 and findings from the tests

- A suggested approach for constructing the repository in accordance with the detailed design.

Step 4.3: Updated safety case

Since the DI stage should lead to the licence application, the safety case needs to be updated with the findings from the DI stage.

Issues to be considered

The following issues should be considered:

- Conclusions to be drawn from the various tests carried out during DI
- Are there any findings during DI that would dramatically change the safety case?
- Feedback to the repository construction stage.

Required input

The following input is required:

- Updated SDM 4.0 (see Step 4.1)
- Detailed repository design (see Step 4.2)
- Findings from activities during DI stage.
- Any relevant scientific and technical information available at this stage (e.g. lab tests, generic URL, natural analogues, domestic and overseas safety assessment studies).

Outcome

The outcome of this step should include:

- Updated safety case based on findings from the DI stage
- List of issues and further investigations (if any) that need to be completed prior to the licence application
- Feedback to the repository construction stage.

2.6 Outlook

This activities provides a framework for the activities that will need to be implemented in the DI stage. It describes the basic activities and the required feedback between activities needed during the DI stage as they can be defined and anticipated in this early stage of the programme.

As the programme matures, the repository concept will be selected and insight will be gained into the potential host rock and sites that will become DI areas, the type of activities will become more concrete and the effort needed to conduct them can then be specified.

However, the structures that will need to be in place before the start of the DI stage, in order to conduct the activities will need to be well though off in advance. This would require to:

- Further specify the objectives and scope of the DI stage
- Further elaborate on the iteration and feedback between site characterization, underground excavation experience, detailed underground design and safety assessment.

3 Uncertainty management in the safety case

3.1 Introduction

There are multiple uncertainties in describing the evolution and performance of a geological repository. For example, the evolution of a repository over the time frame of interest in a safety case generally involves a large number of coupled and sometimes complex phenomena, some of which are incompletely understood or characterized. Uncertainties may affect the initial state of the system (e.g. uncertainties regarding the presence of fabrication defects). They may also affect the rates of processes and the timing of events in the course of the repository evolution. Additionally, there may be uncertainty in whether or not a process or event will actually occur, and/or the extent of its impact on evolution and performance.

Uncertainties may be aleatory or epistemic in nature. Aleatory uncertainties are those that cannot be reduced by more accurate measurements, and are associated with features, events or processes that show natural variability. Uncertainties may also be epistemic, i.e. associated with ignorance or lack of knowledge, and may in principle be reduced e.g. by performing observations or measurements. According to OECD/NEA (2004a):

"Overall, the distinction between aleatory and epistemic uncertainties is not always clear, and both can be treated mathematically in the same way."

The overall strategy for the management of uncertainties can be summarized in four words: **identify**, **avoid**, **reduce** and **assess**. According to Posiva (2008):

"Identification and communication of uncertainties are usually an essential part of all the reports related to the development of the safety case. The development of the disposal system is based on the idea of robustness, which means avoiding concepts and components the behaviour of which would be difficult to understand and predict. The stepwise implementation process of the repository allows the reduction of uncertainties by means of continuous RTD efforts. However, some uncertainties will always remain and have to be assessed in terms of their relevance to the final conclusions on safety."

This strategy is applied iteratively through the various stages of a repository programme, and provides guidance to site characterisation, concept development and scientific research in support of the safety case.

The cyclical nature of uncertainty management is depicted in Figure 3.1, the elements of which are used to structure the present chapter. Uncertainties with potential safety relevance must first be identified. The identification of uncertainties is dealt with in Section 3.2. They must then be described or quantified to the extent necessary to assess their impacts. The description and quantification of uncertainties is covered in Section 3.3. Assessment of impact is discussed in Section 3.4. Those that are shown to have impacts that could compromise repository safety must be:

- Reduced, e.g. by developing a better understanding of uncertain processes
- Mitigated by making the repository concept less sensitive to particular uncertainties, e.g. by the conservative dimensioning of some repository barriers; or
- Avoided, e.g. by the use of well understood materials that are less subject than others to uncertain processes.

Avoidance, reduction and mitigation of uncertainties are discussed further in Section 3.5.

The final aim of the strategy is the identification and characterisation of a site and development of a concept for which adequate levels of safety can be shown in spite of any residual uncertainties.

The descriptions in Sections 3.2 to 3.5 are not intended to be comprehensive. All programmes follow a similar overall strategy for uncertainty management, but the approaches adopted differ in detail, and Sections 3.2 to 3.5 simply provide a few examples of recent developments, some of which are still under active development.

Finally, Section 3.6 provides ideas for future work resulting from the NUMO-Nagra collaboration.

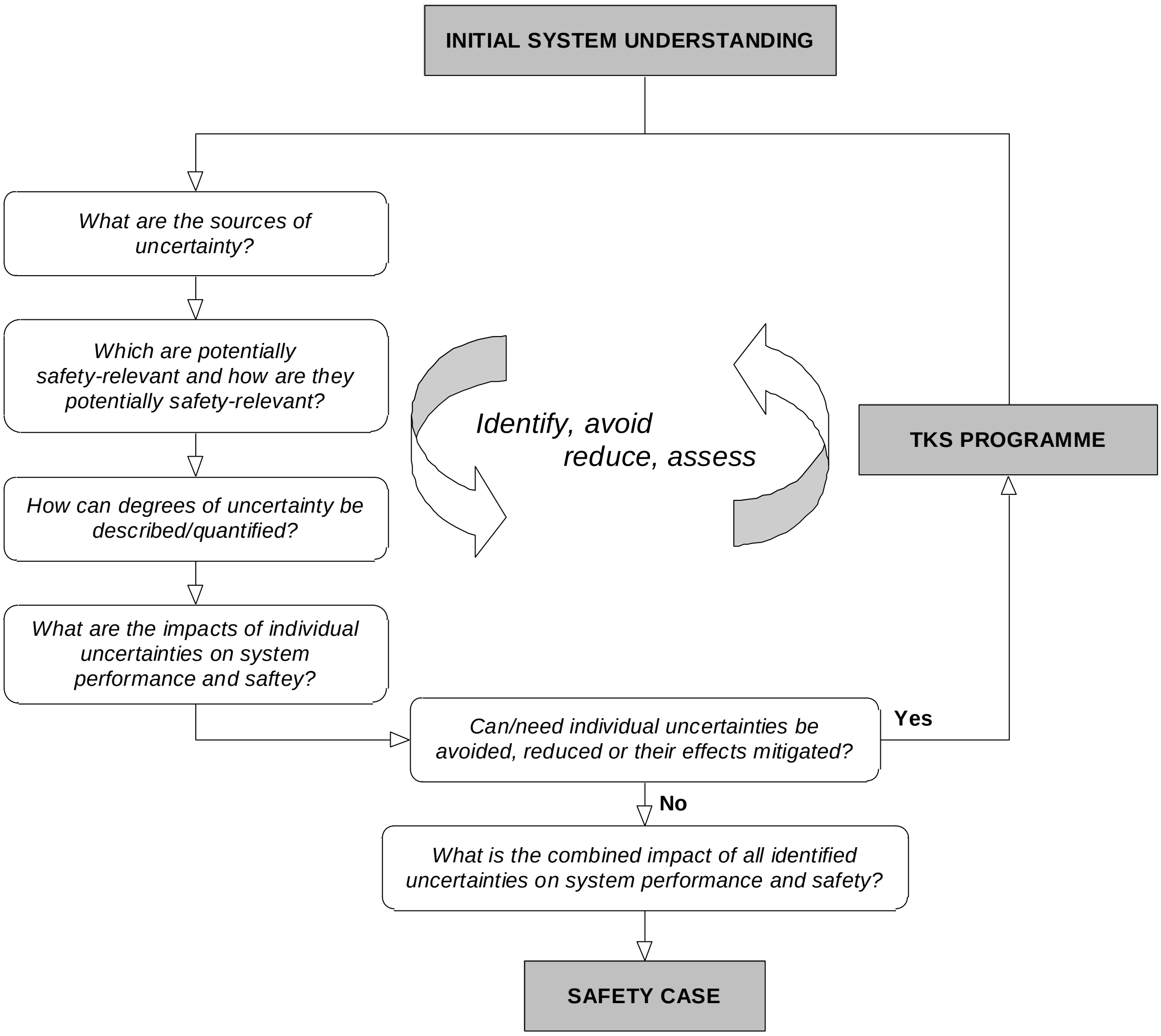


Figure 3.1 The cyclical strategy for identification, avoidance, reduction and assessment of uncertainties (adapted from Figure 6-9 of Posiva 2008)

3.2 Identification of safety-relevant uncertainties

For organizing a safety assessment, it is often convenient to categorize the uncertainties that affect the evaluation of safety indicators such as dose as "scenario", "model" or "parameter". It should be noted, however, that the distinctions between these classes is not always well defined. For example, according to Nagra (2002):

"It is recognized that there is an overlap between the different categories of uncertainty and allocation to a particular category is an operational matter that may involve a subjective decision."

As discussed in the previous chapter, scenarios are often defined in terms of the broad evolution of the main safety functions provided by a repository over time. The scenario uncertainties are those that lead to significantly different possibilities for the evolutions of the safety functions. Systematic methods for the identification of such uncertainties are being developed in several national programmes.

SKB has developed a methodology based on the concepts of safety functions and their associated indicators and criteria, defined as follows and based on SKB (2006a):

Overall safety functions of the repository are containment and retardation

These are differentiated into a number of **lower-level safety functions** for the main repository components

Safety function indicators are measurable or calculable property of the repository component associated with each (lower-level) function

Safety function indicator criteria are defined such that, if a safety function indicator fulfils a criterion, then the corresponding safety functions in is upheld.

As an example, safety functions, indicators and criteria for the buffer identified in the SKB SR-Can safety assessment are shown in Figure 3.2.

The use of these concepts in the identification of safety-relevant uncertainties is illustrated in Figure 3.3, which considers the process of buffer erosion due to the penetration of low ionic strength groundwater to repository depth. This process could occur, for example, in association with glacial advance or retreat above the repository. If erosion occurs, it will affect buffer density and in turn the buffer swelling pressure which, as shown in Figure 3.4, is a safety function indicator associated with the buffer safety functions of limit advective transport. If these safety functions are lost the supply of corroding sulphide will increase substantially, which in turn enhances canister corrosion to an extent that the integrity of the canister (another safety function) may be lost. Loss of buffer density will also affect elimination of microbes and preventing canister sinking. The degree of erosion that might occur over time is, however, subject to numerous uncertainties, which must be taken into account when evaluating with model calculations whether the criteria for these safety function indicators are upheld.

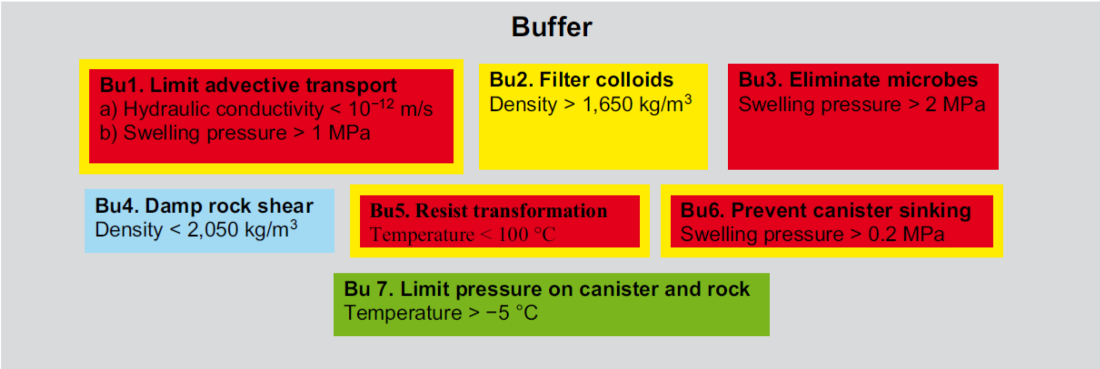


Figure 3.2 Safety functions (bold), safety function indicators and safety function indicator criteria for the KBS-3V buffer (SKB, 2006a)

The colour coding shows how the functions contribute to the canister safety functions - corrosion barrier (red), withstand isostatic load (green), withstand shear load (blue) - or to retardation (yellow). Many functions contribute to both the canister corrosion barrier function and retardation (red box with yellow board) (after Figure 9-2 of SKB 2006a)

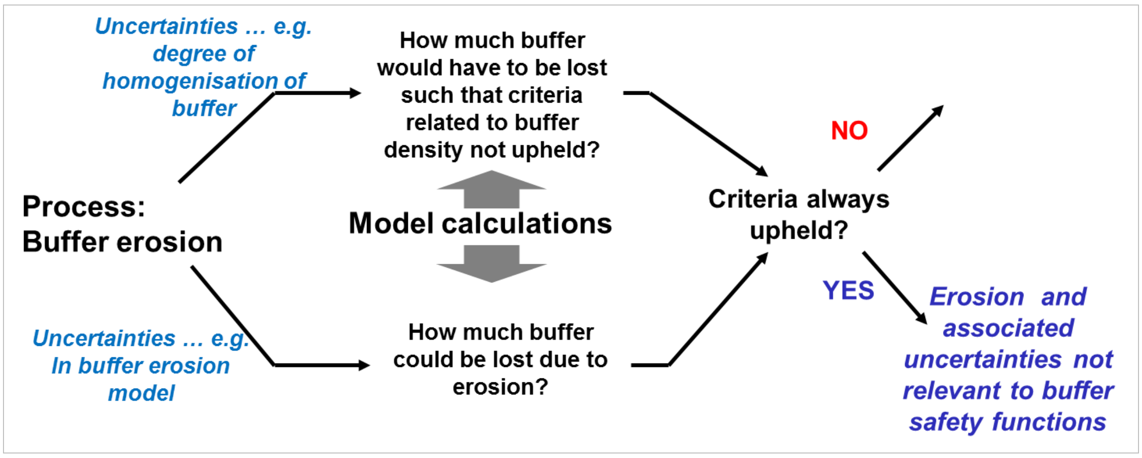


Figure 3.3 Use of safety functions, indicators and criteria for the evaluation of the safety-relevance of the process of buffer erosion and its associated uncertainties

In the case of buffer erosion, there are two more specific questions to be addressed by model calculations in order to answer the more general question of whether relevant criteria are upheld:

1) How much buffer could be lost due to erosion?

2) How much buffer would have to be lost such that the criteria on maximum hydraulic conductivity and minimum swelling pressure would no longer be upheld?

A buffer erosion model has been developed in order to address the first of these questions (Neretnieks et al., 2009). This is subject to numerous uncertainties in both the understanding of the erosion process itself, and in the parameters to be assigned to the model. The same is true of the calculations of buffer homogenisation following mass loss that are performed in order to answer the second of the questions (Åkesson et al., 2010).

Based on the model calculations, and taking all these uncertainties into account, the question of whether the density-related safety function indicator criteria are always upheld is considered. If, in spite of the uncertainties, the answer is confidently judged to be yes, then the buffer erosion process need not be considered further in the safety assessment. If this judgement cannot be made with confidence, then the possibility of the loss of one or more buffer safety functions must be considered as alternative buffer scenarios in the safety assessment.

The planning of model calculations to support judgements as to whether or not safety function indicator criteria are upheld is iterative, as illustrated in Figure 3.4.

Process	Premises for calculations	Sub-process	Safety-function indicator	End-point
Copper corrosion	Buffer/backfill safety functions fulfilled, RSC applied, …	Corrosion by sulphide	Copper thickness > 0	Number of canisters potentially failing
		Corrosion by oxygen		
	Advective conditions in buffer ….	Corrosion by sulphide	*iteration*	
		Corrosion by oxygen		>0?
Buffer erosion	Proper emplacement, GW chemistry evolves as expected, ….	Chemical erosion while dilute groundwater present	Buffer hydraulic conductivity < 10^{-12} m s^{-1}	Number of deposition holes developing advective conditions

Figure 3.4 Illustration of iterative nature of the planning of model calculations to support judgments as to whether or not safety function indicator criteria are upheld

For example, calculations of the corrosion lifetime of the KBS-3 copper canisters (i.e. calculations of whether, and for how long, the safety function indicator that the copper thickness > 0 over the entire canister surface is upheld) will be based on certain calculation premises, e.g. that the repository buffer and backfill perform their respective safety functions, implying that diffusion is the dominant transport process in the repository near field, that the deposition hole positions are chosen according to appropriate rock suitability criteria (RSC), etc. However, calculation of buffer erosion of the type described above may indicate that these premises are not necessarily fulfilled at all canister positions for all relevant times and, for example, copper corrosion in conjunction with advective conditions in the buffer may need to be considered in some deposition holes. A general scheme for iterative planning of such calculations is illustrated in Figure 3.5.

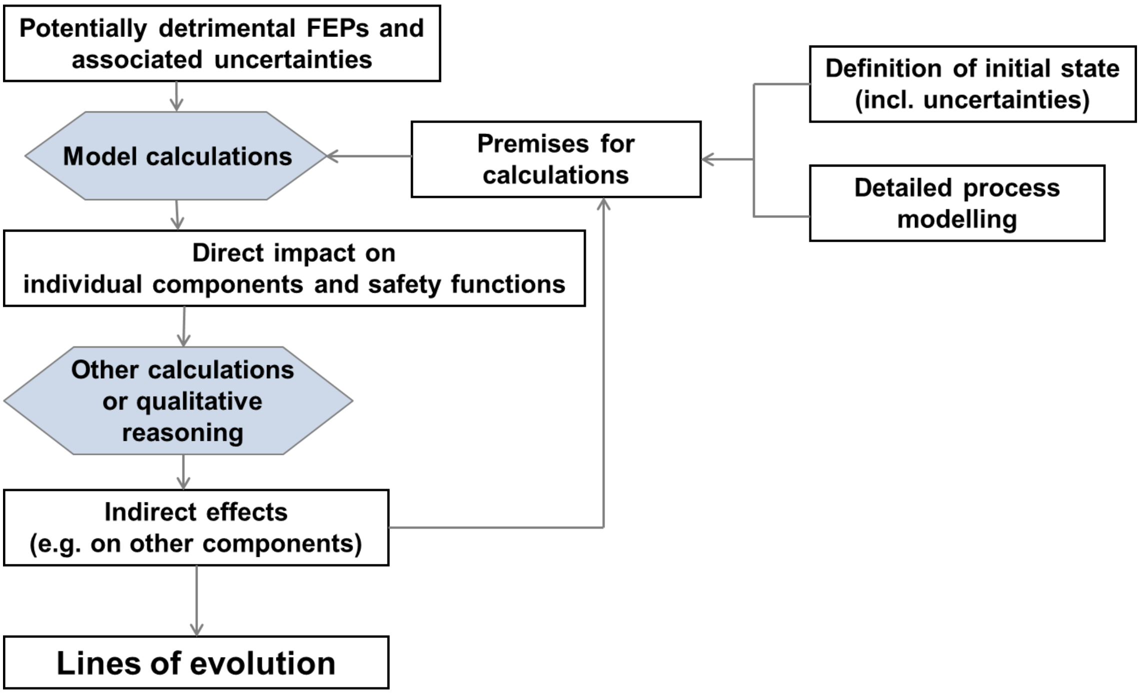


Figure 3.5 General scheme for the iterative planning of model calculations

ONDRAF/NIRAS has developed a different, though related, methodology based on the concept of a hierarchy of safety statements. As shown in Figure 3.6, the statements at a higher level are very general and concern aspects of the safety concept whereas lower level statements concern detailed aspects related to the phenomenological understanding of the system. The lower statements are directly supported by the evidence from the scientific understanding of the site and repository concept. The statements are developed in a top-down manner, with lower-level statements being those that need to be substantiated in order to substantiate, or at least increase confidence in, the higher-level statements.

The uncertainty analysis systematically examines perturbing phenomena and associated uncertainties potentially affecting the validity of each of the lowest-level safety statements, and the propagation of these uncertainties from one statement to another. Any uncertainty that calls into question the validity of lowest-level statements may also call into question the higher-level statements that the low-level statements underpin. In this way, uncertainties may propagate through the hierarchy of statements, from the bottom-up. Any uncertainty propagating as far as safety statements representative of the safety functions of the disposal system gives rise, potentially, to altered evolution scenarios and is thus categorised as a scenario uncertainty. (Smith et al, 2009).

The assessment basis provides evidence that the safety functions will be fulfilled as described by the safety concept

- Indeed, the disposal system and its geological coverage isolate the wastes for as long as required in such a way as to minimise the probability and consequences of human intrusion and humans actions and to protect the wastes and system components against internal and external geodynamic events and processes (I)
    - Indeed, ...
- and the supercontainer of vitrified high-level waste and spent fuel provides complete containment of the radionuclides and other contaminants at least through the thermal phase (C)
    - Indeed, ...
- and the disposal system delays and attenuates releases of radionuclides and other contaminants to the environment for as long as required (R)
    - Indeed, the release of radionuclides and other contaminants from the waste forms is spread in time (R1)
        - Indeed, ...
    - and the properties of the disposal system limit the water flow, ensuring a diffusion-dominated transport (R2)
        - Indeed, the characteristics of the host formation ensure a diffusion-dominated transport which is not jeopardised by the disturbances related to waste emplacement
            - Indeed, the host formation has a fine homogeneous pore structure and a low hydraulic conductivity
                - which is true because the host formation has a fine homogeneous pore structure
                - and because the host formation has a low hydraulic conductivity
            - and the hydraulic gradient over the host formation is low
            - and the diffusion-dominated transport is not jeopardised by waste emplacement
                - which is true because ...
        - and the transport through the engineered barrier system is diffusion dominated
    - and the disposal system limits the migration of radionuclides and other contaminants (R3)
        - Indeed, ...

Figure 3.6 Examples from the ONDRAF/NIRAS hierarchy of safety statements (after Table 1 of Smith et al. 2009)

The propagation of uncertainties from lower-level safety statements towards higher-level statements is illustrated in Figure 3.7, for the example of uncertainties associated with the impact of climate change on the Boom Clay host rock. Subject experts are asked whether, for example, cracks in the Boom Clay could develop as a result of permafrost penetration. If the answer is yes, the hierarchy of statements is examined to assess whether this could conceivably affect the validity of the highest-level statements concerning the Boom Clay safety functions (i.e. compromise the safety function of the Boom cay of limiting water flow and ensuring diffusion-dominated transport).

It should be noted that, though not yet attempted, the concept of safety function indicator criteria could be incorporated in the ONDRAF/NIRAS methodology, i.e. criteria could possibly be developed that, if upheld, would imply that a given statement can be considered substantiated.

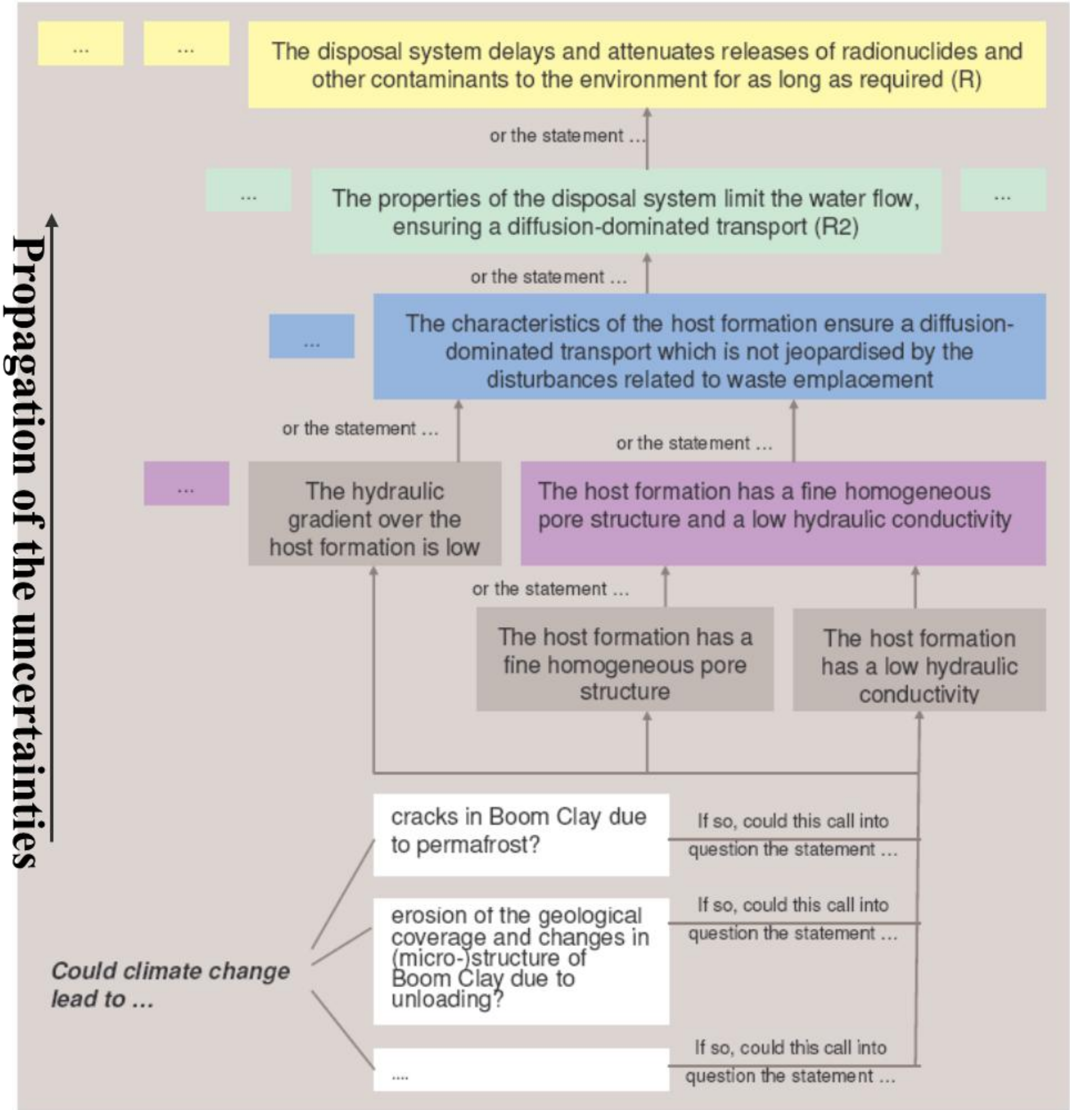


Figure 3.7 Example of the propagation of uncertainties related to a change of climate through a hierarchy of safety statements (after Figure 10 of Smith et al. 2009)

Uncertainties that do not propagate to the highest-level statements may nevertheless affect how specific processes are modelled in a given scenario, and the values assigned to model parameters. These are, respectively, the model and parameter uncertainties. In general, the identification of model and parameter uncertainties relies heavily on the use of expert judgement by subject specialists.

To identify model uncertainties, it can be helpful to list systematically all the assumptions that underlie a particular model, and then to consider whether these assumptions are fully justified, or whether alternative assumptions need to be considered. An example of such a listing is given in Table 3.1 for the case of matrix diffusion.

Table 3.1 Example of a listing of assumptions related to the modeling of matrix diffusion, and identification of possible alternative assumptions

Reference assumption	Possible alternatives	Treatment in assessment
Matrix diffusion occurs only within a limited volume of rock adjacent to the bedrock fractures	All the pore space between fractures is accessible to matrix diffusion.	Reference assumption and alternative considered
Diffusion is well described by Fick's law	-	Reference assumption only
Diffusion properties of some RNs affected by anion exclusion	-	Reference assumption only

In the case of parameter uncertainties, to focus discussion with experts and to reduce the possibility of important uncertainties being overlooked, it can be helpful to identify "checklists" of the important causes of such uncertainties. For example, ONDRAF/NIRAS have identified as important sources of uncertainty in the parameter values used in its assessment models (Section 2.2.4 of Smith et al., 2009):

- The applicability of the phenomenological data obtained from observations or laboratory experiments over relatively short intervals of space over the larger spatial scales of interest in safety assessment.
- The applicability of the phenomenological data representative of the host formation in one location in another location or a larger zone. Transferability considers up scaled data as its starting point, which increases the uncertainty and thus broadens the parameter ranges.
- The impact on the phenomenological data obtained today of phenomena occurring over time that may affect the disposal system, such as phenomena triggered from within the disposal system (for example, the effect of the thermal phase on clay properties) or external events (for example, human intrusion or climate changes). The analysis of the impact of evolving conditions on phenomenological data uses as a starting point data that have undergone an up scaling and/or a transferability process, and further increases the uncertainty, thus broadening the parameter ranges. This analysis requires the knowledge of the evolution of the system components, of its geological coverage and of the biosphere.

There are, however, other sources of parameter uncertainty that should not be overlooked, such as measurement errors and incomplete datasets.

3.3 Description and quantification of uncertainties

Depending on whether the safety assessment adopts a probabilistic or deterministic approach (or a combination of both, see Section 3.4), parameter uncertainties may be quantified in terms of probability density functions or in terms of discrete alternative values. Scenario and model uncertainties will typically be described in terms of the "degree of belief" in the various alternative scenarios or models that have been identified.

In general, the quantification of uncertainties in terms of numerical probabilities is only attempted in the case of parameter uncertainties. Scenario and model uncertainties are often described in terms of a qualitative judgement as to whether a given alternative is, for example, likely, unlikely, very unlikely, etc. In some cases, however, (e.g. in the U.S. programmes) model and scenario uncertainties have been represented in terms of additional parameters, to which probabilities have been attached.

Figure 3.8, from Nagra's Project Opalinus Clay illustrates some of the probability density functions (PDFs) commonly used to quantify parameter uncertainties. Where possible, support for parameter values and PDFs is sought from a wide range of sources, including laboratory and field experiments and observations from nature, in order to ensure that the range of parameter uncertainty is reliably bounded. In order to test the robustness of the system with respect to parameter uncertainty, "what if?" parameter values that lie outside the range of possibilities supported by observations and experiments and for which it is thus meaningless to make a statement about their probability of occurrence may also be considered in safety assessment.

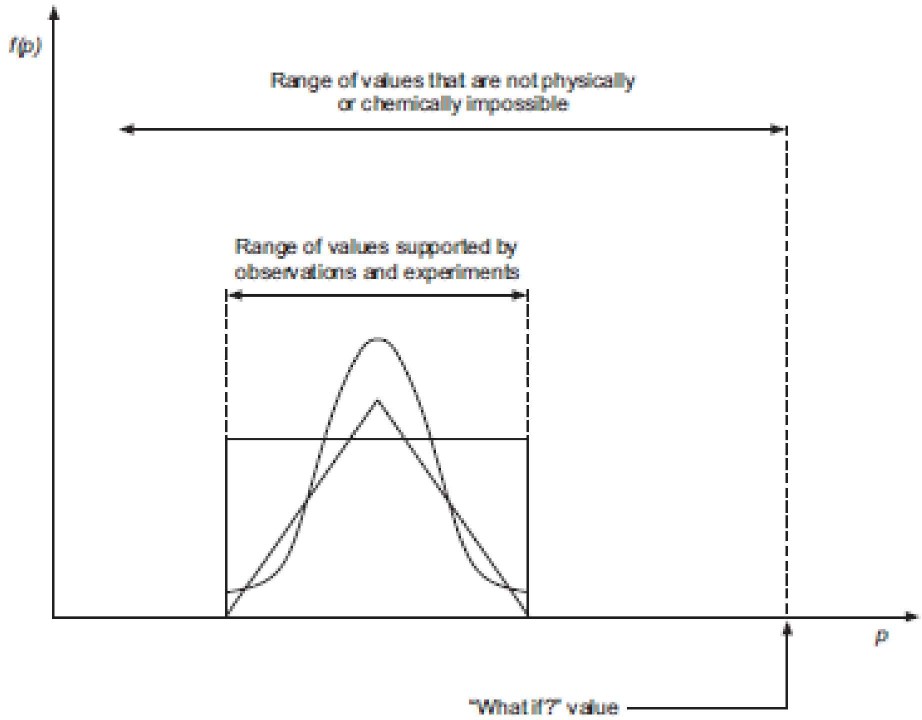


Figure 3.8 Examples of probability density functions and a more speculative "what-if?" value (after Figure A1.2 of Nagra (2002))

Discrete alternative parameter values may be described using terms such as "best estimate", "optimistic" or "pessimistic". Alternative, ranges may be defined, within which all parameter values are considered equally probable. This is, for example, the approach currently being considered by ONDRAF/NIRAS (Smith et al., 2009). The uncertainty treatment of ONDRAF/NIRAS includes a non-parametric protocol to quantify the uncertainties of a parameter on the basis of the expert knowledge. Uncertainty ranges are defined, within which all parameter values are considered equally probable. Following this protocol, ONDRAF/NIRAS ask their subject experts to specify two ranges for parameter values, taking into account the various sources of parameter uncertainty described in Section 3.2. These ranges, also illustrated in Figure 3.9, are:

- The *source range* is the range of values outside of which the parameter value is very unlikely to lie, considering current knowledge
- The *expert range* is the range of values within which experts expect the parameter value to lie.

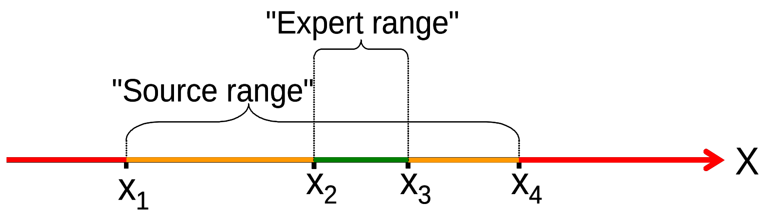


Figure 3.9 Ranges of parameter uncertainty (adapted from Smith et al 2009)

These ranges can be linked to subjective, common-language terms such as "expected", "not really expected" or "not expected", which can facilitate the communication of their meaning. Furthermore, concepts such as "imprecision", "vagueness", "incompleteness" and "conflicting evidence" can be taken into account in defining the source range, which are not readily describable using probabilities. Despite the qualitative character of this elicitation process, the ranges estimated by experts have to be justified by multiple lines of evidence. Currently ONDRAF/NIRAS uses expert and source ranges in safety calculation cases in order to perform sensitivity analysis and identify critical issues. It gives guidance to prioritize the RD&D program. Expert ranges are used in the framework of the reference scenario while source ranges would give an indication of the robustness of the system.

It is important when describing parameter uncertainties to consider how uncertainty in one parameter is linked to, or correlated with, uncertainties in others. For example, uncertainties in the sorption coefficients of each radionuclide species cannot, in general be described independently. In particular, they are all affected by uncertainties in groundwater chemistry, and so, for example, a high sorption coefficient or one species will tend to be correlated with high sorption coefficients of other, chemically similar species. As a further example, high values of near-field flow, which for example can strongly affect radionuclide release across the near-field/geosphere interface, will tend to be accompanied by low values of the overall transport resistance of the host rock, especially since it is often the rock immediately around the engineered barriers that main contribution to this transport resistance.

3.4 Assessing the impacts of uncertainties

Safety assessments treat uncertainties primarily by defining and analysing a wide range of assessment cases – i.e. specific model realisations of different possibilities or illustrations of how a system might evolve and perform. The cases, which may be analysed deterministically, probabilistically or by some combination of these approaches, each address the impact of some particular uncertainty or combination of uncertainties. Categorisation of uncertainties can provide a basis for organising such cases.

In a deterministic approach, parameter values for each case are individually specified. In a probabilistic approach, parameter values sampled randomly from probability density functions (PDFs). Probabilistic calculations explore the full extent of a defined parameter space. Deterministic calculations explore just a few locations in parameter space.

In general, alternative models and alternative scenarios are not integrated within the set of probabilistic calculations (although, as noted earlier, this can be done by representing model and scenario uncertainties in terms of additional parameters, to which probabilities are attached). Rather, discrete sets of calculations are calculated for each alternative scenario and, within each scenario, for each alternative subsystem model.

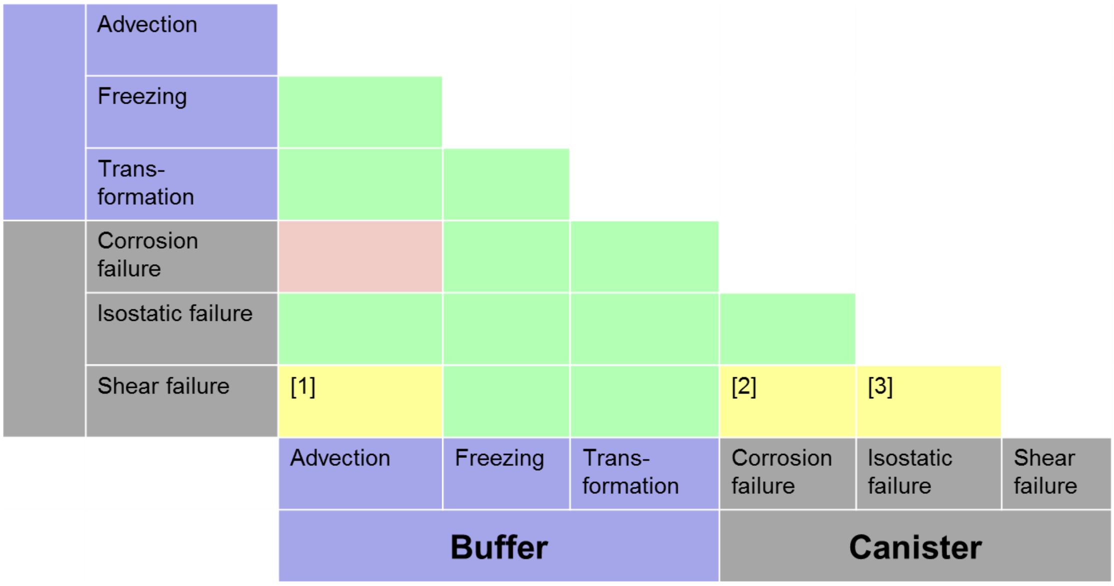
Correlations, discussed above in the context of describing and quantifying uncertainties, need to be taken into account when defining the defining deterministic calculation cases, or when sampling probabilistically from PDFs. Similarly, when defining the models and scenarios to be analysed, possible combinations of alternative model assumptions and alternative scenarios need to be considered, taking into account the likelihood of occurrence of such combinations. As an example, Table 3.2 shows some alternative scenarios for buffer and canister evolution considered in the SR-Can safety assessment. Based on an extensive analysis of current understanding of relevant processes, the scenarios were classified as "likely", "less likely" or "residual", where only those classified as "likely" or "less likely" were considered to have any appreciable probability of occurrence, and so needed to be taken into account in evaluating compliance with Swedish regulatory risk targets.

Table 3.2 Buffer and canister scenarios considered in the SR-Can safety assessment, indicating which are judged to be residual (adapted from SKB (2006a))

Only those indicated by an asterisk are judged to have an appreciable probability of occurrence

	Scenario	Description	Assessment of likelihood
Buffer	Advection	Advection use to loss of buffer mass and increase of hydraulic conductivity	*
	Freezing	Due to change to colder climate	Residual
	Trans-formation	Mineralogical changes	Residual
Canister	Corrosion failure	Due to aggressive species, such of oxygen or sulphide	*
	Isostatic failure	Due e.g. to additional loading during glaciation	Residual
	Shear failure	Due to movement on intersecting fractures	*

The residual scenarios were considered individually as hypothetical "what-if?" situations. However, because of the hypothetical nature of individual residual scenarios combinations of residual scenarios were not considered (green combinations in Figure 3.10). Other possible binary combinations of scenarios were, however, systematically considered. Three were eliminated from inclusion from the risk assessment (yellow combinations in Figure 3.10), for reasons summarized in the notes in Figure 3.10. Only one combination remained to be included in the risk assessment, namely erosion of the buffer leading to advective conditions around one or more canisters, combined with corrosion failure of these canisters (the red combination in Figure 3.10).



[1]	Eroded buffer less likely to give rise to shear collapse
[2]	Copper corrosion does not affect shear collapse (insert is load bearing)
[3]	Stability of rock fractures increases during periods of high isostatic load

Figure 3.10 Binary combinations of buffer and canister scenarios considered in the SR-Can safety assessment
(simplified version of Table 12-5 of SKB (2006a))

This issue of risk dilution needs to be considered when performing probabilistic calculations to assess compliance with mean dose or risk targets. Risk dilution denotes the situation where a higher degree of uncertainty in input parameters, i.e. a broader input distribution, leads to a lower mean value of an output quantity, e.g. mean dose or risk. As noted in SKB (2006a):

"A seemingly paradoxical situation arises where less knowledge implies a safer repository if the mean value to a highly exposed individual at a certain point in time is used as the safety indicator. Less knowledge will spread the dose over more individuals and over longer times."

The issue in an inevitable consequence of mean dose or risk targets and cannot therefore be avoided if compliance with such targets is required by regulations. However, it is important to acknowledge and discuss the issue in the documentation of the safety assessment and safety case.

Not all uncertainties are treated by developing specific calculation cases or probabilistic realisations to illustrate their impacts. Some are treated using model assumptions or simplifications that are conservative, meaning that they tend to over-estimate evaluated doses or risks. Parameter values can also be selected conservatively or pessimistically[1]. Such an approach is necessary, for example, if there is no adequate model or dataset to evaluate the impact of a particular process, but simply omitting the process is confidently expected to lead to conservative results. The conservative or pessimistic treatment of at least some uncertainties is also acceptable within a safety case given that regulatory safety criteria generally refer to dose or risk limits, the demonstration of compliance with which requires only bounding estimates of these safety indicators.

Identifying what is a conservative assumption or approach is not, however, always straightforward - what is conservative with respect to one process may not be conservative with respect to another competing process. Furthermore, a purely conservative approach does not give a basis for deciding which uncertainties are the most important in terms of performance. Neither does it allow different design, operational or siting variants to be compared. Identification of critical uncertainties and open siting or design issues is necessary, particularly at early programme stages, in order to guide the strategy for addressing them during future stages (Section 3.5). Excessive conservatism or pessimism may also make it impossible to satisfy relevant regulatory criteria. The use of conservative and pessimistic assumptions for the treatment of uncertainties thus tends focus on those uncertainties for which the effort in reducing them by further research and technical development is not deemed to justify the likely gains in calculated performance - the lack of a suitable model or dataset often reflects the fact that a process is not easily amenable to reliable scientific investigation.

There may, however, be some conservatively omitted processes for which there are judged to be good prospects for more realistic modelling (and gains in calculated performance) at later stages of the programme. These are termed "reserve FEPs" in, for example, Swiss safety assessments, and their existence can provide a qualitative safety argument complementing calculated doses or risks.

3.5 Avoidance, reduction and mitigation of remaining uncertainties

A key role of the safety case, which includes an assessment of the impact of uncertainties, is to provide guidance to the programme of research and technical development, including site selection and characterisation. In particular, it will indicate which, if any, uncertainties have the potential to weaken the safety case, and thus need to be avoided, reduced or their effects

[1] The term "pessimistic" is sometimes used (e.g. in Nagra 2002) to refer to values that, within the range of possibilities according to current scientific understanding, give rise to the highest consequences. The term "conservative" refers to values that are outside that range (e.g. assigning zero sorption to migrating species that are known to sorb to some extent, even though the degree of sorption may be uncertain).

mitigated. This role has been recognised by the OECD/NEA in the Safety Case Brochure published in 2004 (OECD/NEA 2004b):

"The synthesis should ... consider the limitations of currently available evidence, arguments and analyses .... This includes the strategy by which any open questions and uncertainties with the potential to undermine safety will be addressed and managed."

"At the earliest stages of a programme, there may be many such open questions and uncertainties, and the safety case should make clear the view of the developer that there are good prospects for dealing with these in the course of future stages, e.g. by site characterisation and optimizatioin of system design, and set out the strategy by which this will be achieved."

The feedback from the safety case to research and technical development is recognised in the programme descriptions and illustrative flowcharts produced by implementing organizations. Figure 3.11 is an example from the Finnish programme.

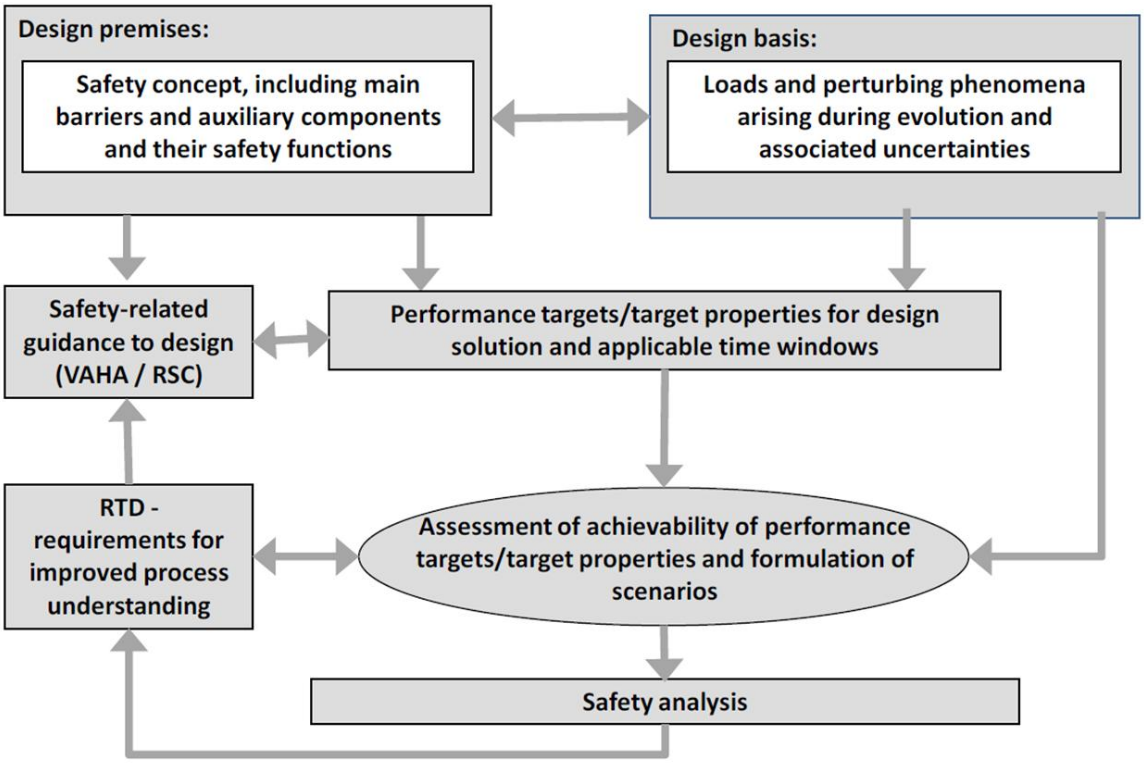


Figure 3.11 The coupling between Research and Technical Development (RTD) work, planning, performance targets/target properties and safety analysis (after Figure 6-1 of Posiva (2009)).

The figure shows that the feedback occurs not only in the form of results of safety analysis (e.g. calculations of dose for a range of calculation cases illustrating the impact of different scenario, model and parameter uncertainties), but also at the stage of subsystem performance evaluation and scenario formulation, when the assessment of the achievability of performance targets (for the EBS) or target properties (for the rock), these being similar to the safety function indicator criteria used in the Swedish programme. In particular, undertaking this assessment is likely to highlight any deficiencies or uncertainties in the models and parameter values used to evaluate whether criteria are upheld, such as the model of buffer erosion cited in Section 3.2.

The safety case also provides an important platform for discussion with the regulator regarding those uncertainties that the regulator considers to be important to address, e.g. prior to the granting of a licence. In some countries, including Sweden, Finland and the U.S., the regulator and its advisory groups, based in part on their review of safety assessments as well as the implementer's research plans, compiles a Tracking Issue List (TIL). Such lists identify issues that, in the regulators view, remain unresolved, as well as others that can be considered closed once certain conditions have been fulfilled. Resolved issues may also be retained in the list so as to maintain a complete and open record of the issue resolution process.

3.6 Issues to be considered in the future

As a framework for the application of assessment models, the scenario development tools could, however, be further refined and extended to deal with model and parameter uncertainties, and hence the development of a range of calculation cases for safety assessment. More specifically, the approach to identify uncertainties as well as if and how they affect the safety functions needs further development. As part of scenario development, it has been proposed to identify:

- The safety functions of the disposal system, e.g. containment of radionuclides by the over pack
- Processes that influence these safety functions, e.g. corrosion of carbon steel
- Environmental conditions that affect the occurrence or rate of such processes, e.g. temperature
- Factors that affect these environmental conditions, e.g. heat generation by the waste, or the thermal conductivities of repository materials.

The above are likely to be identified in a top-down fashion, starting with the safety functions, as shown on the left-hand side of Figure 3.12.

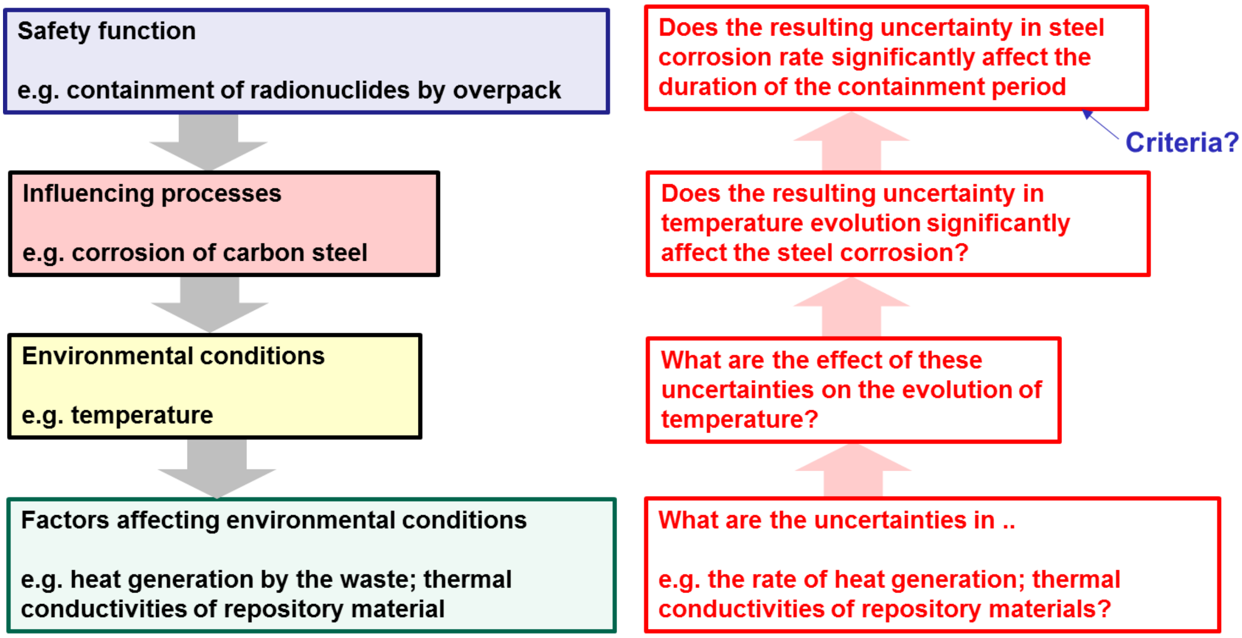


Figure 3.12 Top-down identification of processes, conditions and factors affecting controlling the safety functions, and the bottom-up propagation of uncertainties

A logical way to identify uncertainties with the potential to affect the safety functions could be to begin with factors that affect the environmental conditions, and consider first the uncertainties in these, e.g. in the rate of heat generation by the waste, or the magnitudes of the thermal conductivities of repository materials. Next, the implication of these uncertainties for uncertainties in the environmental conditions – the evolution of temperature in this example – could be considered. Then, the implications of uncertain environmental conditions for uncertainties in processes affecting the safety functions could be considered – the rate of steel corrosion in this example. Finally, the implication of uncertainties in processes – the rate of steel corrosion in this example – on the evolution of the safety functions could be assessed. A new scenario could arise, for example, if the uncertainty in steel corrosion rate is such that over pack failure during the repository thermal phase is judged to be a possibility. Criteria could be developed specifying, for example, how rapid a processes such as steel corrosion would need to be in order to generate a new scenario, such as over pack failure during the thermal phase.

This top-down/bottom up approach has clear similarities to the ONDRAF/NIRAS approach summarized in Section 3.2, and builds on the approach already partly developed by NUMO (NUMO, 2011b). Care must, however be taken to ensure that no significant sources of uncertainty are overlooked. In particular, uncertainties in the initial state (e.g. possibility of initial defects in the overpack) must be captured, and this is likely to require further development of the approach outlined above.

4 Definition and concept of Demonstration

4.1 Definition of demonstration

The issue of demonstration in radioactive waste management is practically as old as the radioactive waste management programmes themselves. The first demonstration experiments were initiated in the late seventies, few examples being: the Climax mine experiment (1978 – 1983) by the US DOE in Nevada, USA, which focussed on demonstrating the capability to handle and package spent fuel and to emplace it in storage holes about 400 meters below the surface in crystalline rock; the G-Tunnel experiment (1979–1990) also by USDOE in Nevada; the Stripa mine (1976–1992) in Sweden, which evolved to become the first multinational cooperation experiment on issues of geological disposal demonstration.

A discussion on the definition and role of demonstration in radioactive waste management was initiated by OECD/NEA in the beginning of the 80s resulting in a report summarising the conclusions and state-of-the-art at that time (OECD/NEA, 1983). It was recognised from the beginning that whereas the definition of demonstration in "research" is clear and well understood, in "applied science", part of which is the management of radioactive waste and the geological disposal, demonstration should be understood in a broader text. In research demonstration is defined as the verification by experiment of one or a set of assumptions. Although research is one of the key components in applied science, the definition of demonstration also incorporates attributes such as:

- Scientific and engineering considerations
- Engineering competence
- Quality of construction
- Skill of operators.

Hence, demonstration here includes the commonly used notion for the scientific part and expands to include, what we will refer to in the rest of this chapter as, "know-how". In the case of radioactive waste disposal, an organization can demonstrate "know-how" by showing that:

- It has the tools and methods to characterise the site, to design and build the repository
- It has the necessary database and knowledge to evaluate the repository system and ensure that it will meet the required performance
- It has the organizational structures and the capabilities to implement the process of developing and realising a geological repository.

In the above definition the reader should note that, "tools and methods" is used here in a broad sense and it includes the testing equipment, the testing and interpretation methods, the numerical tools, the machinery and manufacturing processes etc. Also the term "database" is used in a broad sense and it includes the data (from quality assured laboratory tests and field investigations), the methodology to develop a quality assured assessment basis (conceptualisation of processes, treatment of events and features, formulation of scenarios and assessment cases, treatment of uncertainty) etc.
A more difficult aspect of demonstration in geologic disposal results from the consideration of time scales, which extend to periods of hundreds of thousands of years. The OECD/NEA treatment introduces and clearly differentiates between:

Direct demonstration, which refers to aspects that can be demonstrated within the short time scale, and

Indirect demonstration, which refers to aspects that correspond to much longer time scales.

Long-term safety of the geological repository system, i.e. demonstration that the repository system (engineered and geologic barriers) will meet the required performance criteria, belongs to the second category of demonstration. The demonstration of geological disposal of radioactive waste, according to the OECD/NEA (1983) definition includes then two steps:

Direct demonstration, which aims at proving (showing) that the system could be:

- Built
- Operated and
- Closed safely and
- At acceptable costs, using available technology and engineering experience.

Indirect demonstration, which requires to make a convincing evaluation of the system's performance and long term safety on the basis of predictive analyses confirmed by a body of available data and evidence.

Although the first type of demonstration is amenable to "proof", the second type is not, because of the time-scales involved. Thus, for the second it can be said paraphrasing OECD/NEA (1983) that: "As usual in similar situations, it will be the role of competent national authorities to critically examine the scientific and technical evidence provided for the long term safety and reliability of high level waste disposal concepts. They will have to satisfy themselves that the nature and extent of this evidence (what is now referred to as the Safety Case) show a sufficiently deep understanding of the problems involved and that the proposed solutions can meet long term safety objectives."

In 2001, a working group under the auspices of the OECD/NEA Radioactive Waste Management Committee examined the definition of demonstration with respect to activities being performed at underground research laboratories or facilities (OECD/NEA, 2001). It proposed the following definition:

Demonstration is the illustration, at full scale and under real and/or simulated repository conditions, of the feasibility of the repository design and of the behaviour and performance of various (or all) of the components of the repository.

For a radioactive waste management programme to be at the stage of considering its own demonstration activities at underground laboratories, normally the implicit assumption is that it has made advances in the development of the repository system considered as well as the potential geological barriers. Thus, the definition above can be too restrictive for the earlier stages of the repository development programme, a focus which was beyond the scope of the OECD/NEA (2001) report. The definition neither considers the differentiation between direct and implicit demonstration nor the demonstration activities that precede the stage of development of underground testing or characterisation facilities.

In the late 90s the notion of demonstration was given a much more prominent position and became one of the additional components in the research and development activities of the various programmes, which are now referred to as RD&D plans. However no specific definition of demonstration has been adopted in those RD&D plans, rather the common implication that demonstration activities predominantly focus on "engineering" demonstration, part of the direct demonstration activities mentioned above. An examination of the specific activities however, shows that they correspond to a much broader range than this "traditional" engineering demonstration and also include research aspects.

Nagra in its recent RD&D report (Nagra, 2009) discusses the concept of demonstration as follows: "The concept of demonstration exists at several levels in the context of repository development. The first could be described as demonstration of the feasibility of **key technological elements**. An example in Nagra's RD&D programme involves studies of emplacement of pelletized bentonite at large-scale, which have been pursued at Mont Terri and elsewhere. The next level involves demonstration that **full-scale components can be manufactured** e.g. the SKB copper canister (SKB, 2006b). The final level involves demonstration of **integrated operations at full-scale** (e.g. the requirement that Nagra demonstrate canister retrievability prior to receiving the nuclear operation licence for the repository)." A comparison with the OECD/NEA definition would place this discussion of the concept of demonstration to the "direct demonstration" defined in the early 80s. Indirect demonstration would be performed through the Safety Case, as is the current practice in all other programmes.

SKB introduced the term demonstration in its RD&D programme with the RD&D report in 1992 (SKB, 1992). The term was dedicated to the "demonstration deposition". In the next 3-yr RD&D report, demonstration was focused on experiments at the Äspö underground laboratory (SKB, 1995). In the most recent RD&D report (SKB, 2010), the role of demonstration as the site license application is being finalised, is reflected upon as follows:

" By means of demonstrations at our laboratories, we have shown on a full scale that we can manage the different steps from fabricating and depositing canisters to closing and sealing tunnels. We believe the time has now come to proceed to the next stage in the Nuclear Fuel Programme and, after a due licensing process, commence the actual construction of the facilities in the KBS-3 system.

The remaining development work requires extensive technical resources. SKB's own laboratories − the Äspö HRL, the Canister Laboratory and the Bentonite Laboratory – are built and equipped for full-scale tests, demonstrations and dress rehearsals. Other facilities, such as Posiva's Onkalo facility in Finland and our underground facilities and laboratories in Europe, will also be valuable for our development work.

We are now at a point where we are about to start putting the results of many years of research, development and demonstration to practical use in industrial processes in new facilities."

Although the proposed repository site is located at Forsmark, SKB's policy is that research, technology development, long-term experiments and demonstration will primarily be based at the Äspö HRL, at least until start of operation in mid 2020s. The focus of the activities at Forsmark will be on underground construction, detailed investigations, update of the SDM etc. The programme for the detailed investigations will also include activities of a more research character but directly related to the specific conditions at the Forsmark site, for example:

- Size and orientation of rock stress and rock mechanics issues related to high rock stresses
- Thermally induced spalling in deposition holes – although SKB will primarily follow the POSE-project conducted by Posiva in ONKALO
- Groundwater chemistry with focus on sulphide content and degree of oxidation of fracture minerals
- Biosphere studies.

Reflecting on the experience from SKB, one can recognise that although full-scale testing (corresponding to the more "standard" use of the term demonstration) is a necessary component of technology development:

- Full-scale testing is never "only" about demonstration, i.e., there is valuable scientific or engineering knowledge that can be gained and provide feedback to the designs and/or the long-term safety assessment
- Early Full-scale tests are needed to advance technology development to meet challenges in implementation, i.e., whereas a specific design may appear advantageous on paper or at small scale, its implementation as an industrial process is not trivial and could have safety implications which would require further developments – ones that can only be realised with a full-scale demonstration not be as straightforward
- While early solutions may later be revised – lessons learned from "old concepts" are still essential
- Demonstrating, by use of the full-scale tests, is essential for showing stakeholders how the system will look like and that it can be achieved, and such early demonstrations may be essential for the acceptance of the repository development programme
- Full-scale tests and a demonstration facility is needed also after site is selected

In seeking a succinct definition that would reflect the current understanding on "demonstration" it is proposed here to combine elements of the definitions of demonstration in the two OECD/NEA documents, and modify them according to the implementation of demonstration in the RD&D plans of other programmes. The resulting definition is shown in the box below and it is the one that will be used throughout the remaining of this chapter.

Demonstration encompasses all activities that increase confidence in the safety and feasibility of a proposed repository system. It includes those activities that:

i) Directly illustrate under real and/or simulated repository conditions, the feasibility of the repository design and of the behaviour and performance of the various components of the repository, as well as, the know-how to characterise, built, operate and close safely the repository → collectively referred to as **direct demonstration**, and

ii) Aim at a convincing evaluation of the system's performance and its long term safety on the basis of an assessment of its future evolution confirmed by a body of available data and evidence → collectively referred to as **indirect demonstration**.

4.2 Demonstration concept

In developing NUMO's demonstration concept the basic approach was to elaborate and consolidate in a systematic manner the activities that NUMO should perform according to the definition in Section 7.1, considering at the same time the boundary conditions and the history of the radioactive waste disposal programme in Japan.

NUMO was established as the implementer and entrusted with the realisation of geological repositories for specified waste (HLW and later TRU) in Japan in 2000. Up to that point the radioactive waste programme had been managed and driven by JAEA (formerly PNC and JNC). Thus, NUMO was fortunate in being able to utilise the momentum that already existed without starting from "scratch". The main emphasis however up to that point was on generic aspects of geological disposal and on the "demonstration" of its feasibility in Japan, with main emphasis on scientific and applied research aspects. NUMO had to initiate thus additional activities that focussed on expanding the know-how to the implementation, as opposed to the research, aspects of the geological disposal.

The volunteer approach adopted in Japan requires the maximum degree of flexibility from NUMO with respect to the specific disposal concept to be evaluated, which has to be tailored to the yet unknown geologic formation(s) and geographic conditions of the volunteers. NUMO has been using as starting concepts those developed in the H-12 report, but has also examined alternative concepts. This situation makes it a lot more challenging to narrow down the scope of long-term large/full-scale demonstration experiments.

Considering these boundary conditions, a four track demonstration concept canvassing the whole spectrum of demonstration activities was proposed during the NUMO-Nagra collaboration. The four tracks proposed are shown in Figure 4.1 and are:

- Demonstration of know-how
- Illustration of repository system components
- Demonstration of the engineering systems and engineering processes
- Demonstration of the long-term safety assessment.

A definition of each of these tracks and a description of the different areas each one covers is given below.

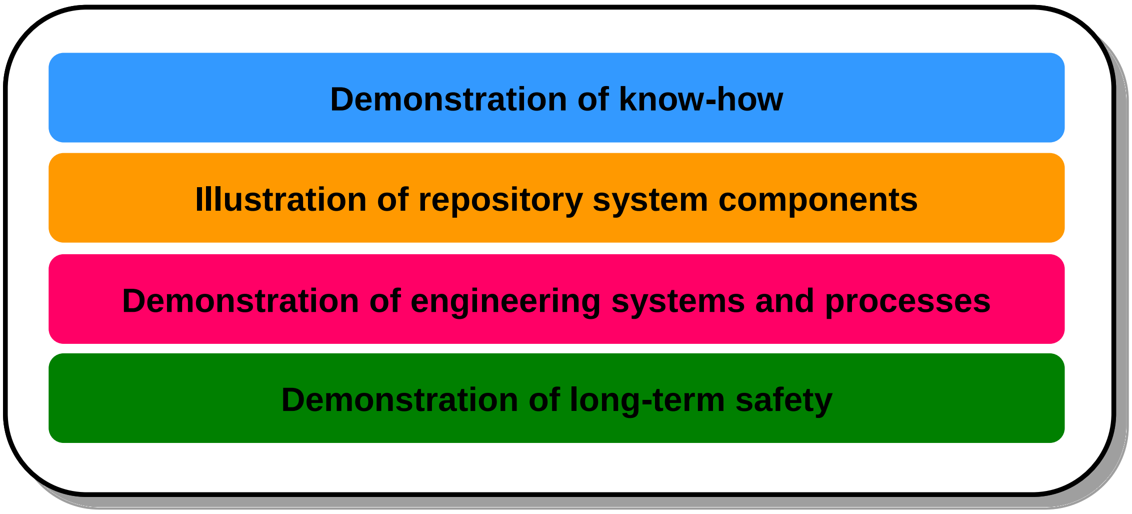


Figure 4.1 A possible demonstration concept for NUMO consisting of four parallel tracks

Track 1: Demonstration of know-how

Demonstration of know-how is broadly defined and it includes all activities that show that NUMO is in the position to:

- Characterise a site, for example,
- Develop and execute an investigation plan
- Manage field activities ensuring that high-quality results are obtained
- Evaluate the results from different disciplines and develop a consistent model (conceptual and eventually numerical) for the site, as a basis for engineering design and performance assessment, etc.

Tailor existing, or develop new, repository concepts appropriate for a specific volunteer site, for example has the,

- Engineering capabilities to assess concepts with respect to their feasibility, their operational and long-term safety, and their life-cycle costs
- Capabilities to manage the development of new concepts, if required
- Capabilities to plan and integrate the transportation of the considered wastes to the specific site, etc.

Assess the long-term performance of proposed repository concepts, for example:

- Has the methodology to develop the scenarios for the possible repository evolutions in a site (including evolution of the wastes, the engineered barriers, the geosphere etc.)
- Have the "tools" and methods to evaluate the different scenarios for their compliance with the regulatory stipulations (long-term radiological safety, environmental impact etc.)
- Has the methodologies and knowledge to develop site-specific Safety Case, etc.

Manage effectively and efficiently the whole process of step-wise repository development, for example:

- Has the internal organizational structure and related quality-assured process
- Has the appropriate trained staff and, in addition, access to external qualified resources, as they may be needed
- Have the mechanisms to ensure transparency of decision taking, continuity of knowledge and know-how throughout the whole programme, etc.

It should be noted that the list of examples above is exemplary and not exhaustive.

Track 2: Illustration of repository system components

System components is used herein to describe different parts of the repository concept, for example, over pack and other engineered barriers like bentonite buffer, or also, more broadly, equipment that will be used in the repository operations, such as emplacement of the over pack and the engineered barriers, retrievability etc. The term chosen for this track is illustration, instead of demonstration, to differentiate between the engineering demonstrations that are included under Track 3 and will most probably be part of the requirements to obtain an operation license.

Because the time of the repository operation is several decades away it is expected that further improvements in technology or engineering will occur and will be considered, even if one has a specific disposal concept as a reference. In fact it is one of the advantages of the stepwise implementation that within a repository programme one has indeed the possibility to further improve the designs chosen. Therefore at an early stage, such as the one that NUMO is in right now, it would not make sense to strive for a demonstration of the actual system that will be used in the (intermediate) future. Nevertheless, lessons can be learned by initiating experiments on, or technological developments of system components that will be integrated in the further development of the system components. For these illustration experiments, the actual details of the components, for example geometry, need not be a strict representation of the final design, rather they need to capture the main characteristics that one would like to test and show.

Numerous examples of such experiments and projects exist, for example:

- The in-situ part of FEBEX (Full-scale Engineered Barrier Experiment), from which valuable lessons were obtained for the buffer emplacement process and which led to the study of other emplacement processes such as pelletized buffer, or the "mock-up" part of FEBEX, which has been providing valuable data on up scaling THM processes since 1997
- The GMT (Gas Migration Test), which provided feedback both on the engineering design (sand/bentonite emplacement in the annulus around disposal cell of silo-type) but also on testing and up scaling models for the description of gas migration through such systems
- The range of all the experiments initiated within the ESDRED project (ESDRED, 2009), such as the emplacement machines for Andra's concept, or the large scale test of bentonite behaviour at the surface facilities at Mol, etc.

A lot of these illustration experiments can be performed in a surface facility, in particular those that represent components of the repository at a 1:1 scale, even if this is done with artificial materials or with first "prototypes" machines.

Track 3: Demonstration of engineering systems and process

Under this track, the demonstration activities are very similar to the ones expected under the "standard" definition of demonstration. The demonstration is direct, it involves almost exclusively designs considered in the reference case and which are part of the Safety Case. The geometric scale, the host rock and the related environmental conditions, and the engineering processes (for example material flow, emplacement rate etc.) are an image of the anticipated operations. This is also true for the surface-related operations, such as transportation, encapsulation (if applicable), bentonite block manufacturing (if applicable) etc. The main purpose of this type of demonstration is to obtain a licensing application to proceed with this particular disposal concept and disposal process.

Track 4: Demonstration of long-term safety

A separate track is dedicated to the demonstration of long-term safety to draw special attention because, as discussed in Section 4.1, this is an indirect demonstration. As such, it can only be achieved through the preparation of a "convincing evaluation of the system's performance and long term safety on the basis of predictive analyses confirmed by a body of available data and evidence". The decision of whether the demonstration of long-term safety has been achieved will be finally made by the national authorities, which have to critically examine the scientific and technical evidence provided. Although they may also request support, in terms of review, from international bodies, at the end they will have to satisfy themselves that the nature and extent of this evidence (what is now referred to as the Safety Case) show that the proposed solutions can meet the long-term safety objectives. It is of outmost importance that during the repository development period up to licensing, the authorities have also build-up and accumulated the required know-how and they are considered the established competent independent body that can make this important decision.

There are many similarities between Track 4 and Track 1, because at the end the development of the Safety Case for the demonstration of long-term safety requires convincingly showing that you have the know-how and the data to do so. Under this track, NUMO has to demonstrate that it has the capability:

To obtain the necessary data, for example,

- Specific site data
- Laboratory data (either from the literature, after evaluating their quality, or through the initiation of additional necessary experiments).

The list above is not exhaustive but is intended to assist in defining what has to be done to demonstrate long-term safety. An important element here is the step-wise iterative approach followed, which also implies that there will be more than one Safety Case, or more than one versions of a Safety Case, as the repository development progress. As a result, demonstration of long-term safety is a process that will extend through all the stages of the repository culminating with the one that will enable the final step of the programme, namely the repository closure.

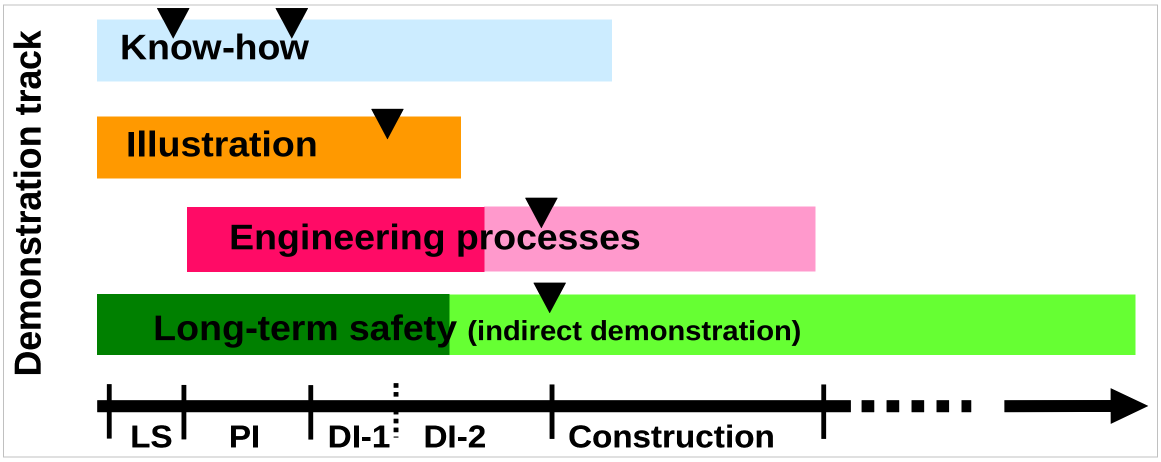


Figure 4.2 Timing of the demonstration activities according to NUMO's stepwise repository development approach (A darker shade indicates a higher intensity of activities)

The timing and intensity of demonstration activities along the four tracks proposed above vary according to the major stages in the repository development. Figure 4.2 shows schematically that, activities for:

Track 1 can start (and already have started) before the literature survey stage and will continue with the same intensity until the choice of the DI area(s). After the selection of the location of an on-site UIF demonstration of know-how will continue but with a much lower intensity, mainly focussing on new methods or techniques specific to the repository concept.

Track 2 can also start before the literature survey stage. The intensity of the corresponding activities should reach its "highest" during the PI stage, the expectation being that these activities will facilitate communication with the various stakeholders as the process of "narrowing-down" to the DI areas takes place. With the construction of NUMO's UIF, or if the possibility to perform such activities in other generic testing facilities in Japan arises, there will also be a shift of the nature of these activities from Track 2 to Track 3.

Track 3 should start after sites have been identified and preliminary site-specific repository concepts can be developed. The activities are expected to intensify before applying for the repository construction license and to continue, at a reduced intensity, during the construction and operation in case modifications of engineering system components or engineering processes that have been already licensed by the authorities are considered, and they should be demonstrated in advance.

Track 4 can start (and already have started) before the literature survey stage and their intensity will be quite high during the DI Stage – in the first part of the DI stage to support the selection of the site(s) for underground construction and in the second part to support the license application. They will continue throughout the repository operation, albeit with much lower intensity, and short-duration peaks for supporting the "confirmation" milestones expected in the programme or for the closure application.

5 Overall conclusions

Based on Nagra's experience through investigation of a wide range of geological environments for both the HLW and L/ILW, the repository concept (RC) collaborative study was initiated in 2001. Its initial aim was mainly organising a technical knowledge transfer between the implementing organizations of Japan and Switzerland. The focus was on developing a methodology for tailoring repository concepts to a broad range of geological and geographical environments. Over the years the project evolved, a broad range of issues has been studied, and also experiences from other European implementers were included where these were found useful for NUMO.

This report summarizes three of the specific areas studied and advances made through this collaboration in the period FY 2008 to FY 2010, namely:

- Development of NUMO's DIA activities
- Uncertainty management in safety case
- Demonstration concept.

The project allowed the development of a multi-year continuous platform for a compact, efficient and quick information exchange. As such the collaboration could be seen by NUMO as a portal to European implementer developments, which could be interpreted in the light of NUMO's needs based on the fact that through the years a detailed mutual understanding of each other's programs developed.

Developments in some areas will continue to keep abreast of the best available technology at the international level, but instruments and technologies will also be tailored for application within the Japanese environment. Especially, based on the DI activities described in this report, it is necessary to embody the planning and activities in practical manner, in response to the specific site characterization.

Acknowledgements

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Appendix A: Main topics studied between FY2008 and FY 2010

FY 2008

- Review of NUMO's fundamental activities in the PI stage (Action Plan)
- Provisional activities for the DI stage
- Assessment of the potential for reducing the I-129 releases from a TRU repository
- Concept for repository closure
- Scenario analysis work frame: review and suggested future activities
- R&D work for the radioactive waste disposal programme
- Case studies of design changes
- Nagra's technical information management system.

FY 2009

- International workshop between implementers on scenario development methodology
- International workshop for stakeholders on Requirement Management Systems
- Review of the NUMO 2009 report.

FY 2010

- Kick-off meeting of the International review of the NUMO 2010 report and review of the roadmaps
- Treatment of uncertainties in the safety case
- Overview of R&D programmes of implementing organizations
- Role of demonstration in an implementer’s program
- Summary report on RC collaboration (draft).