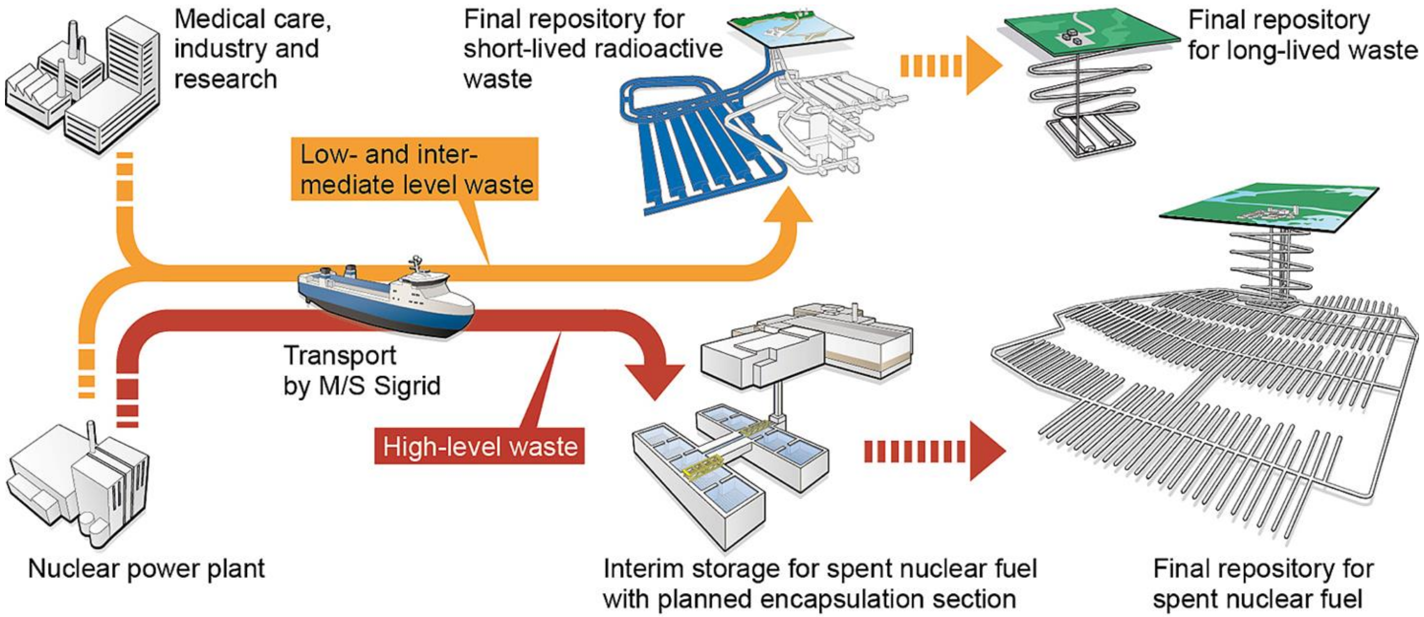
SCIENCE UNDERPINNING THE SAFETY CASE OF DEEP GEOLOGICAL REPOSITORIES

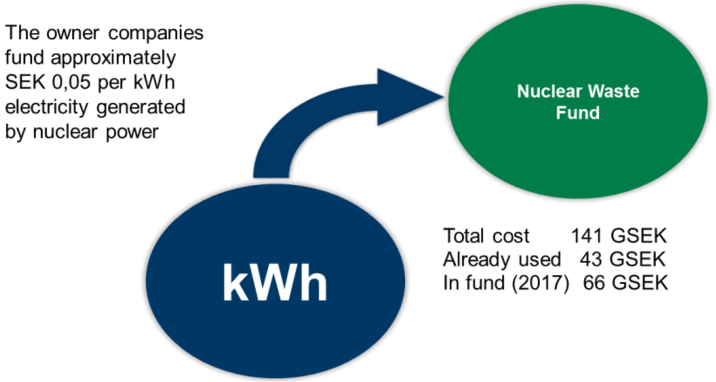
Challenges in the past and in the future and how to maintain knowledge and competence during operation

Johan Andersson

Management and disposal of radioactive waste and spent nuclear fuel in Sweden

- Based on current planning from NPP's:
- Reference scenario
  - 2 Plants already phased out
  - Phasing out the 4 oldest reactors
  - 60 years of operation for remaining 6 plants
- Spent nuclear fuel
  - In store about 6500 tonnes
  - To be produced about 5000 tonnes
  - Approximately 6 000 canisters
- LLW and ILW
  - From operation and decommissioning
  - Legacy waste
  - Approx 170 000 m^3 short-lived waste
  - Approx   16 000 m^3 long-lived waste
- Clear responsibility and sound financing





Final repositories for spent nuclear fuel are approaching implementation

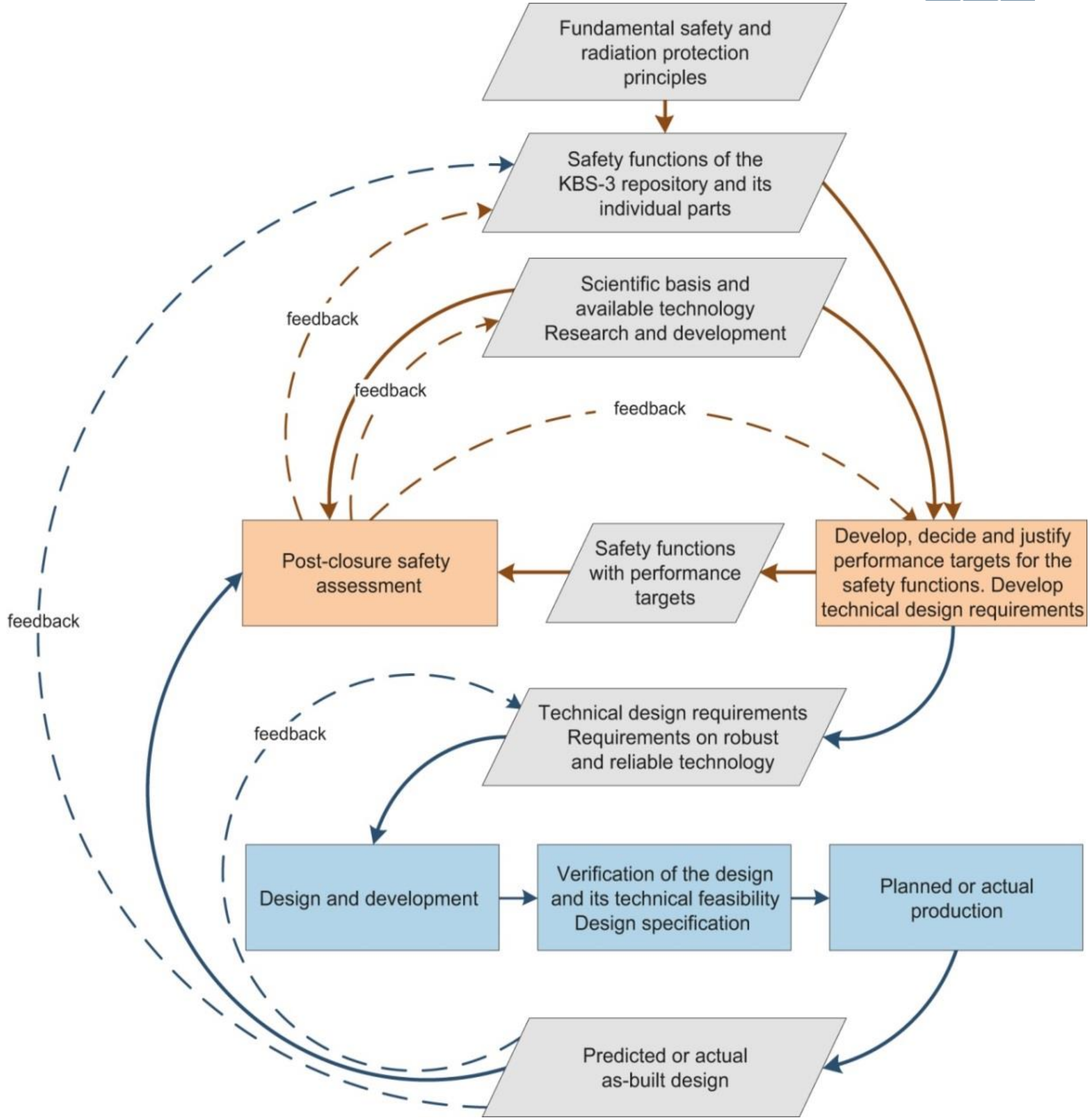
- In 2011, SKB applied for a permit to build a KBS-3 type final repository for spent nuclear fuel at the Forsmark site.
  - Examined by the Swedish Radiation Safety Authority (SSM) under the Act on Nuclear Activities and by a Swedish Land and Environmental Court under the Environmental Code
  - In March 2019 SKB submitted supplementary material
  - The matter now rests with the Government. Construction of the repository may start around 2023 and operation may start early 2030, provided the Government grants a decision during 2020.
- In Finland, a KBS-3 type repository for the spent fuel has obtained a construction license in 2015. Provided licenses are approved operation may start around 2024.
- Prerequisite for these advancements
  - it has been shown that the repository can be constructed and operated in practice in such a way that safety can be assured both during operation and over very long time scales.
  - Rests on decades of structured and objective driven research and development including both theoretical assessments and practical test in the laboratory and in full scale. T
  - A dedication to bring the repository programme to a conclusion with a structured siting strategy, sufficient and long term funding, and a clear strategy for research and development

Research strategy - objectives

- Research is one of the pillars in SKB’s programme since its start in the 1970s.
  - Secure safe management and final disposal of nuclear waste by ensuring access to the knowledge that is needed in order to assess a site, design, licence, construct and operate existing and planned facilities.
- Research should:
  - provide sufficient knowledge of post-closure safety and make sure that safety can be assessed for SKB’s existing and planned facilities also in the future,
  - provide sufficient information for the continued technology development and planning that is needed in order to obtain efficient and optimised solutions that at the same time provide safety both during operation and after closure of SKB’s final repository.

Strategy - Iterative development

- Designs are evaluated in safety assessments that provide feedback to (siting factors) technology development, design and requirements
  - Each decision step requires an assessment of post-closure safety to judge whether the knowledge base concerning post-closure safety is sufficient to proceed to the next step.
- Steps in the past
  - KBS-3 in 1983 – design concept established
  - SR-97 (1997) – siting factors
  - SR-Can (2006) – detailed design requirements
  - SR-Site (2011) – basis for license application
- Coming steps
  - PSAR - supported by updated requirements and more detailed designs, to be submitted to SSM as a basis for obtaining a license to start underground excavation.
  - Updated to a safety analysis report (SAR) that will form the basis for the construction and operation of the repository.

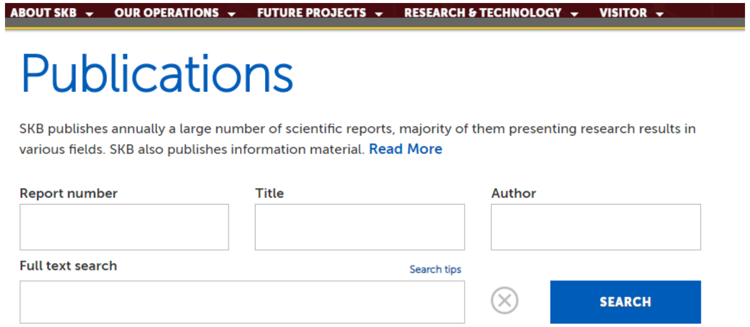


Research strategy – in house competence

- Need sufficient in-house competence to
  - assimilate the knowledge that is present in the community of importance for management and final disposal of nuclear waste, and
  - be a skilled research client.
- Core of the in house competence has been to maintain a coherent group of professionals
  - with knowledge of the methodology for the assessment of post-closure safety
  - with both wide and deep interdisciplinary insight on how the different processes that affect repository safety interact.
- By conducting its own research, SKB has ensured this maintenance of competence
  - Need also input from a very wide range of scientific and technical disciplines

Research strategy – openness

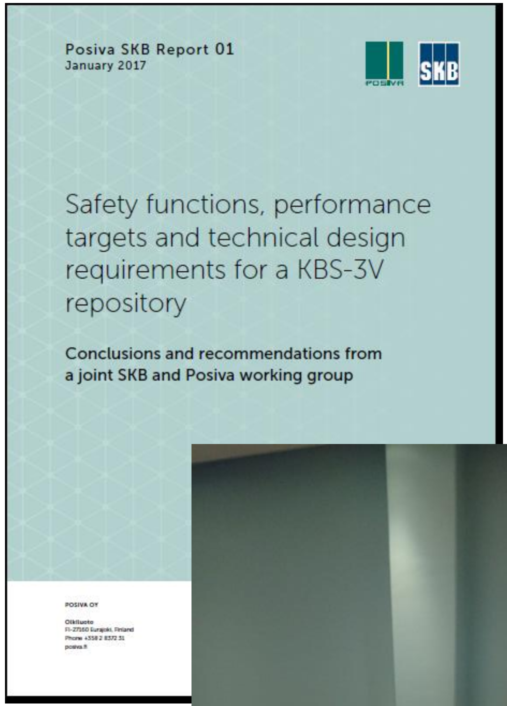
- All research should be publicly available
- A strive to publish results in open peer reviewed journals.
- In communicating with the public through media, open seminars or other events
  - let the internal experts be the main spokespersons
  - foster a frank and open discussion.
- Openness and an strive to demonstrate that there is nothing to hide
  - judged a basis for developing confidence with the public, the research community and authorities.

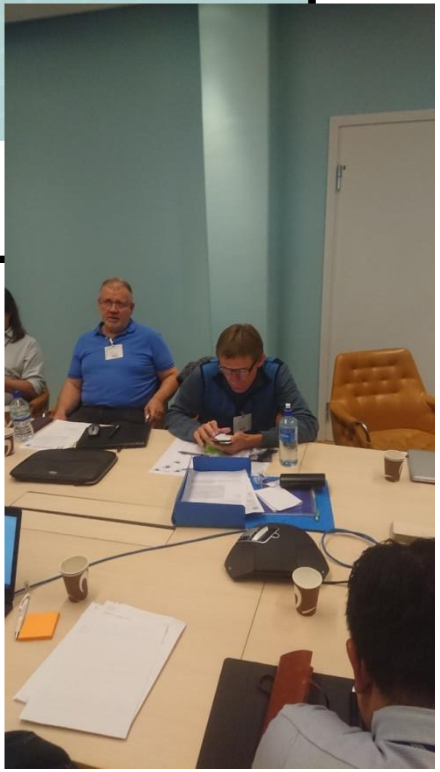


www.skb.se

Research strategy – international cooperation

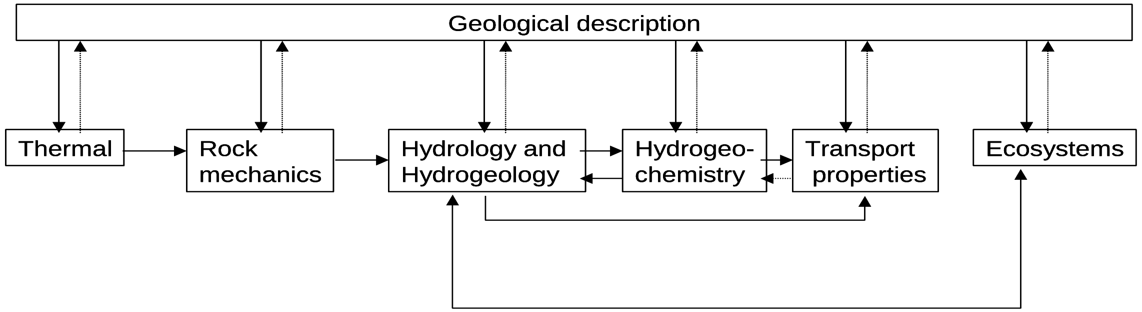
- In building up and maintaining competence international cooperation has been essential.
  - Direct cooperation with sister organisations
  - using experts trained in other programmes
  - Participation in the work of International organisations like the IAEA, OECD/NEA and the European Commission.
- Direct cooperation with sister organisations
  - E.g between SKB in Sweden and Posiva in Finland or NWMO in Canada,
  - Allows for sharing resources and ensuring that the expertise involved reaches critical mass.
- IAEA , NEA and EU
  - provide platforms for interaction with peers from sister organisations and
  - also allowed interaction with regulators from other countries.
  - Over the years these interactions have strongly advanced the understanding on how to conduct a repository development programme and how to carry out safety assessments.
  - Direct funding of research projects by the European Commission not primarily important in relation to other funding but, *it has allowed networking on a detailed level directly with a broad range of researchers and other experts*.

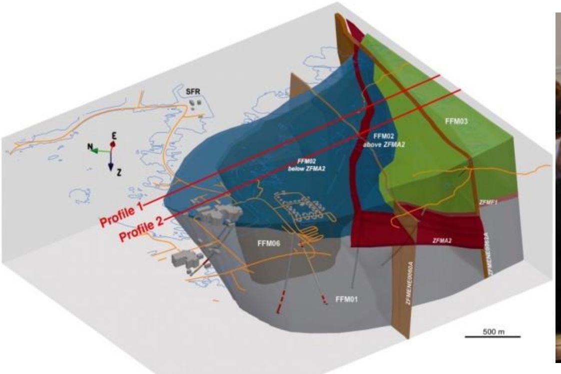


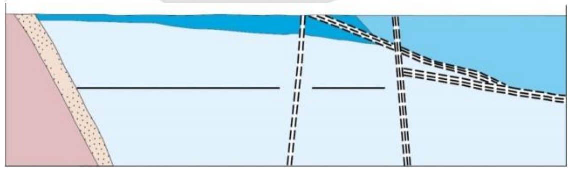


Knowledge management tools – site descriptive modelling

- Introduced in 2001 when surface based investigation started
  - to be used both as input to the safety assessment and to the engineering design work
  - Entails transfer of the information from quality-assured databases produced by the site investigations to discipline-specific descriptions applicable to various subdivisions of the system made up of surfaces and volumes.
- Included in the SDM work is
  - Control of primary data
  - Disciplinary and interdisciplinary integrated modelling providing basic geometrical descriptions and parameterisations of the bedrock and the surface system.
  - Evaluation of uncertainties in values of parameters describing the material properties and states of the studied system and the realism in the subdivision of the studied system
- Development and updating an SDM forces interaction
  - between experts from different geoscientific disciplines
  - between experts and designing engineers and safety assessment teams.

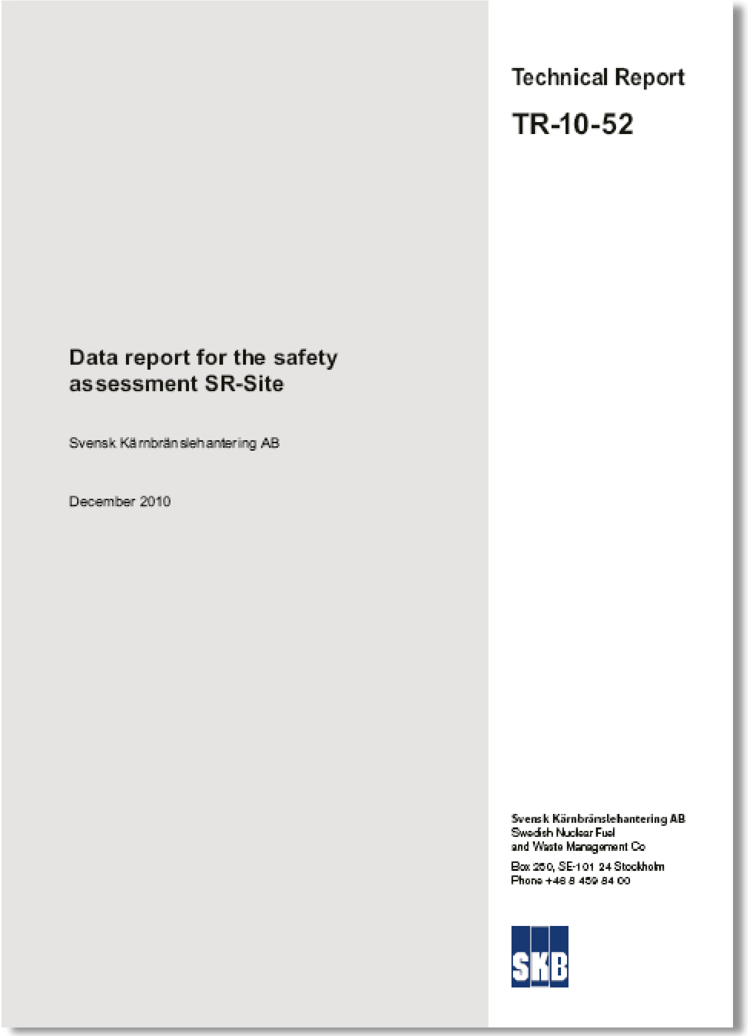






Knowledge management tools – data qualification

- Safety assessment and design work involves several different teams using data on e.g. fundamental processes, site characteristics and design solution
  - These data originate from various sources of different quality.
  - Different teams may need data on the same aspects and phenomena.
- When SKB updated the safety assessment methodologies was realised that
  - it is necessary to ensure that different teams use the same data for describing the same things and
  - that the quality of the data are assessed as well as their uncertainties
  - Strict procedures for data and uncertainty qualification were introduced by the concept of data reports


Technical Report

TR-10-52

Data report for the safety assessment SR-Site

Svensk Kärnbränslehantering AB

December 2010

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
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Knowledge management tools – peer review

- Both internal and external peer review are essential quality assurance tools.
- SKB has developed and applies strict protocols for these reviews.
  - Review plans are established defining the review criteria and the qualification of the reviewer.
  - A review is conducted using standardized protocols where the reviewer both makes an overall assessment against the review criteria stated in the review plan and provides detailed comments.
  - In completing the reviewed document the reviewee needs to respond to every such comment in writing.
- May have been regarded as tedious in the beginning- now seen as essential and a safeguard against the many mistakes that otherwise would have been made

Project KBP3007 - Review statement for "SKB – Impact of the earthquake induced displacements on the canister steel lid, SKBdoc 1522977"

☒ **Factual review**

☐ **Quality review**

Document to be reviewed *(Filled in by referee)*

Title	Document ID	Version
Review statement for "SKB – Impact of the earthquake induced displacements on the canister steel lid	SKBdoc 1522977	0.2

Review plan *(Filled in by referee)*

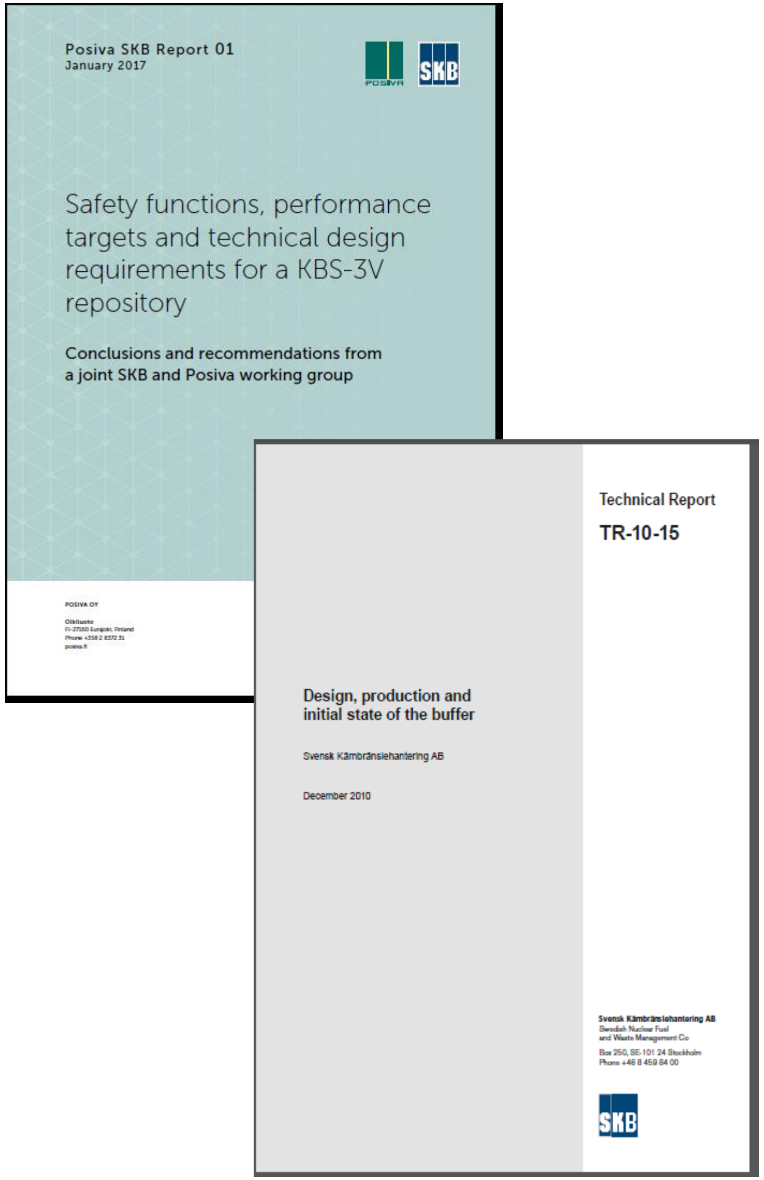
Title	Document ID	Version
Project KBP3007 – Review plan for factual review of "SKB – Impact of the earthquake induced displacements on the canister steel lid, SKBdoc 1522977"	SKBdoc 1524144	2.0

Referee *(Filled in by referee)*

Name, Company name/ University	Position and competence *(Short description of the referee's position, competence and experience with importance for the review.*

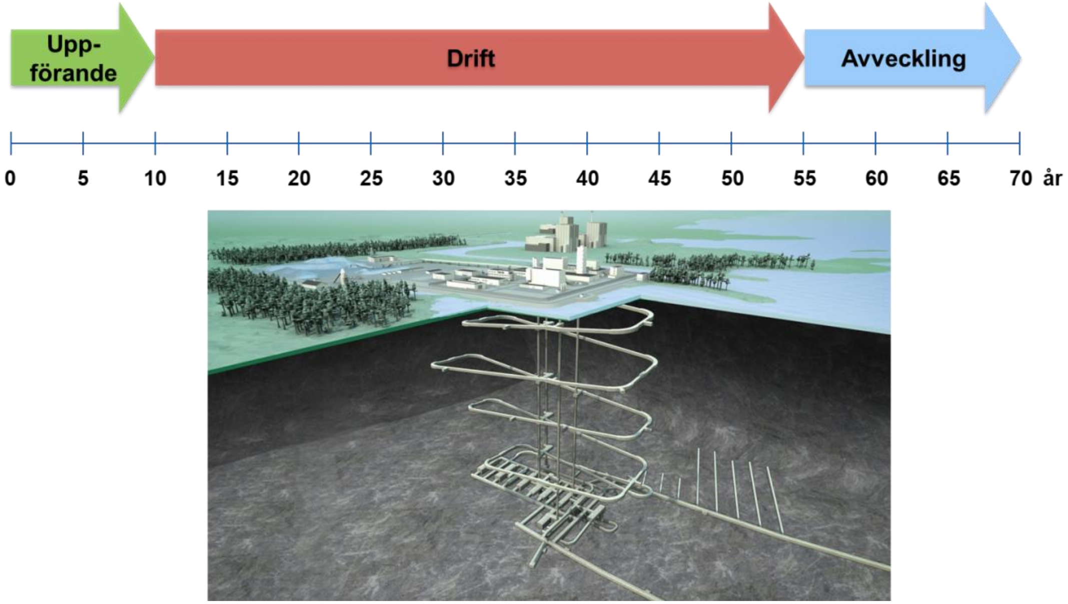
Knowledge management tools – Requirements and quality control of production and installation

- Confidence in the post-closure safety assessment rests upon
  - understanding of the THMCB processes determining the evolution of the repository
  - a demonstration that the installed engineered barriers and the underground construction work conforms to stated technical design requirements.
- For the latter a Quality Control programme is being developed.
  - Implies possibilities to find potential manufacturing or installation errors or other deviations in material, equipment and handling.
  - Before and during waste emplacement, quality control provides the main source for ensuring that the as-built stage complies with stated design requirements.
- Well-defined technical design requirements needed
  - Formulation of design requirements is not trivial.
  - From the Safety Assessment perspective they should be sufficient to yield a safe repository.
  - From the designers perspective they need to be possible to implement and verify.
- Stepwise development
  - An initial set of design requirements were specified in SKB's license application
  - Together with Posiva, SKB has presented revised technical design requirements



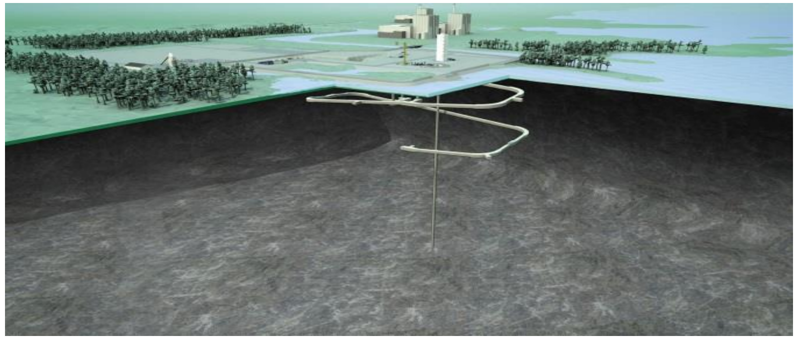
Future challenges - Safety case needs to be up to date during the entire operational time

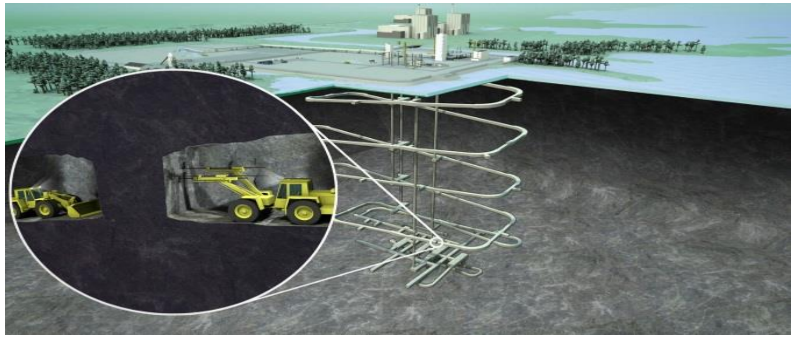
- Need to be able to make safety assessments does not disappear with the construction license.
    - Need to assess how the engineered barriers and the natural processes in the rock and on the ground surface interact and evolve in time.
- Research and new findings regarding the long term properties will continue,
    - driven by SKB,
    - within other implementing organisations
    - the scientific community at large.
- There has to be a readiness to assess the safety implications of such new findings.
- According to the regulations, the SAR should be constantly kept up-to-date and with a periodic overall evaluation.

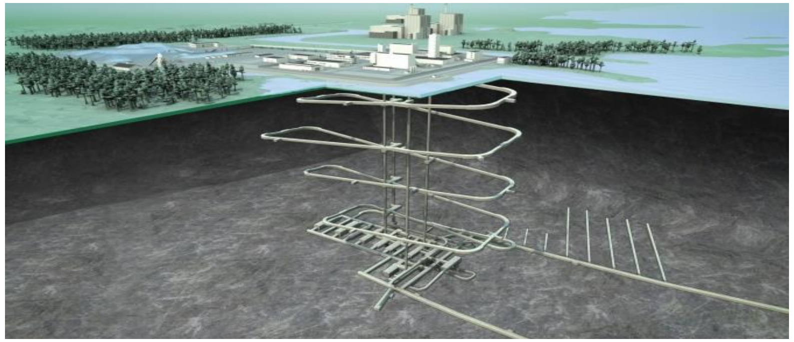


Developing the Safety Case for the KBS-3 repository when approaching construction and operation

- While licensing process proceeds
  - Assessments and analyses to prepare the Preliminary Safety Assessment Report (PSAR) needed in an application for a permit to start the construction of the repository are underway.
  - Initial planning on the updated Safety Assessment Report (SAR) needed in an application for a permit to start emplacement.
- New aspects to consider in these safety cases

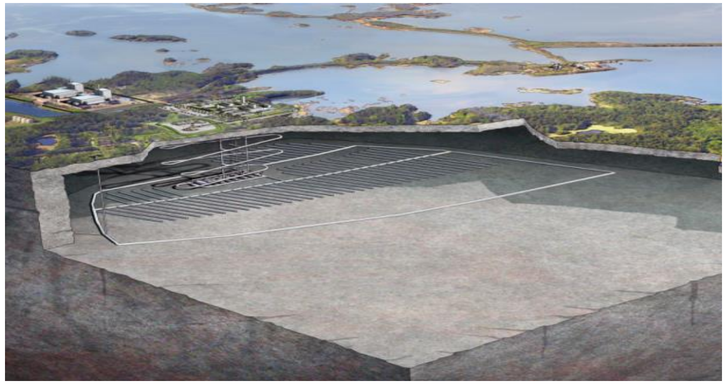


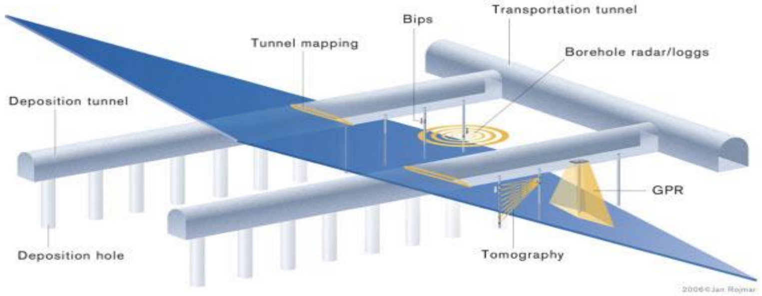


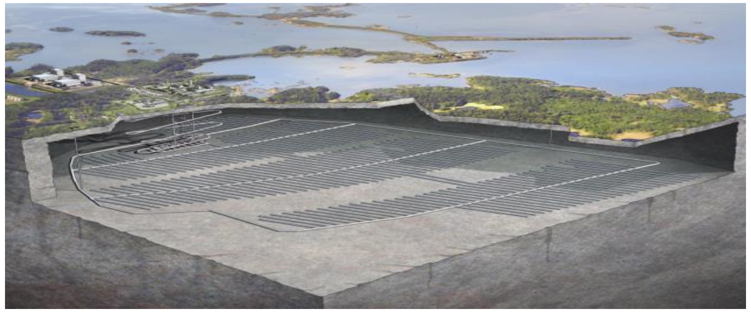


Access to detailed data from the underground

- Volumes of the host rock that are hard to characterize from the surface will be accessible to mapping and (short) borehole investigation from the underground galleries being excavated.
- Provides input both for
  - confirmation that the host rock has the expected (and suitable) properties
  - high resolution data allowing for local adaptation of the repository like specifying the exact location of deposition tunnels and deposition holes
- Parts of the repository ~~will~~ already have been constructed, and characterized, other parts are yet to be excavated.
  - “As-built” will be revealed gradually







SKB

Relation between operational safety and post-closure safety

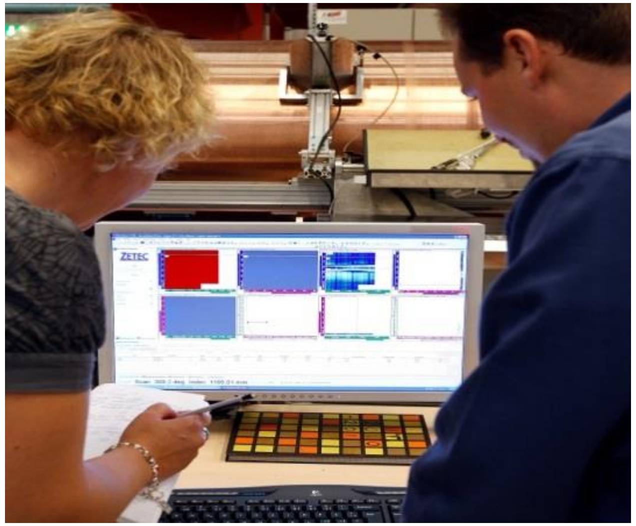
- Conflicts between operational safety, workers’ protection and post-closure safety could be a reason to update designs such that these conflicts are resolved.
- Actions during operation should not only consider impacts on operational safety, but also how these actions might affect post-closure safety.

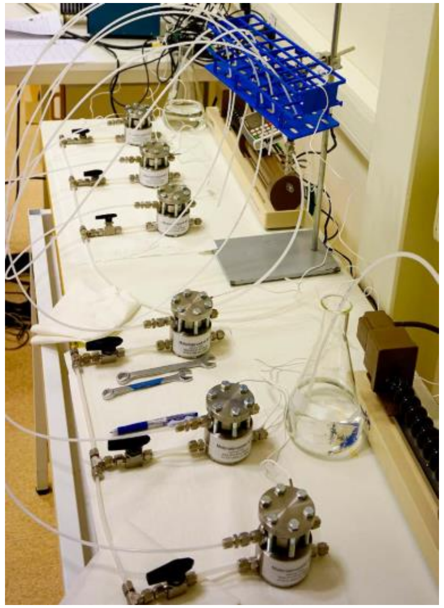
Monitoring

- Monitoring changes due to disturbances from excavation and operation both
  - characterization aspects and
  - provides additional input to the confidence in the safety case.
- Monitoring results can essentially never relate to direct safety impacts,
  - But a management structure should be in place to handle situations when monitoring results deviate from expectations
- A monitoring program to be implemented at the start of construction is now being developed
  - Measurements in most of the boreholes drilled during site investigations as well as in boreholes drilled from the underground
  - Long term tests at different scales building on experiences gained at Äspö HRL and from other URL:s

Future challenges - Proven quality control as an essential part of the safety case

- Ensure TDRs technically achievable and possible to verify at the latest at the time of final installation, deposition or backfilling.
  - Ongoing and future technology developments focus on these aspects.
- Concern
  - processes, methods, equipment and personnel for fabrication and installation, testing and inspection.
- Important to establish:
  - principles for safety and quality classification,
  - what is to be quality-managed and quality-controlled, and
  - when quality management and control are to be performed and by whom in terms of first, second and third parties.



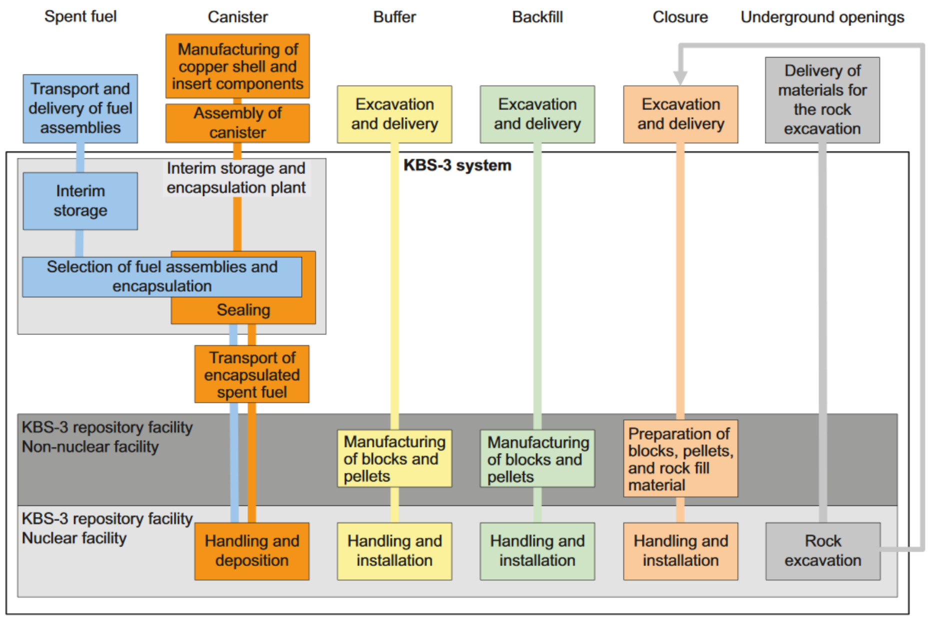


Future challenges - Implementation

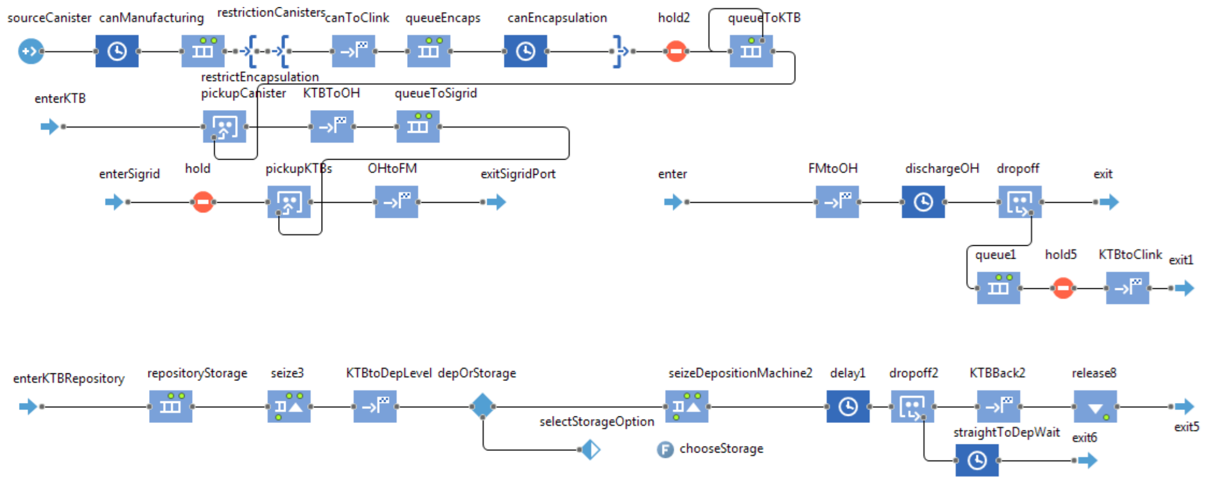
- Technology development and need for detailed investigations
  - SKB has established a technically feasible reference design and layout
  - Detailed designs adapted to an industrialized process designed to fulfilling specific requirements on quality, cost and efficiency need still be developed.
  - Layout needs to be adapted to the local conditions found when constructing the repository at depth.
- Should result in at least the same level of safety as the current reference design
- To be implemented in production system
  - Encapsulation facility, Clink
  - Final repository
  - External production facilities

e.g. Logistics studies

- Map the different flows of material etc
    - Spent fuel flow
    - EBS material flow
        - Focus on storage levels, flow and AGV amounts
    - Deposition sequence
        - Modelled for both dry and wet deposition hole scenarios
        - Both general planning tunnel lengths and detail level planning tunnel lengths can be applied to the model
    - Rock work together with detailed investigations

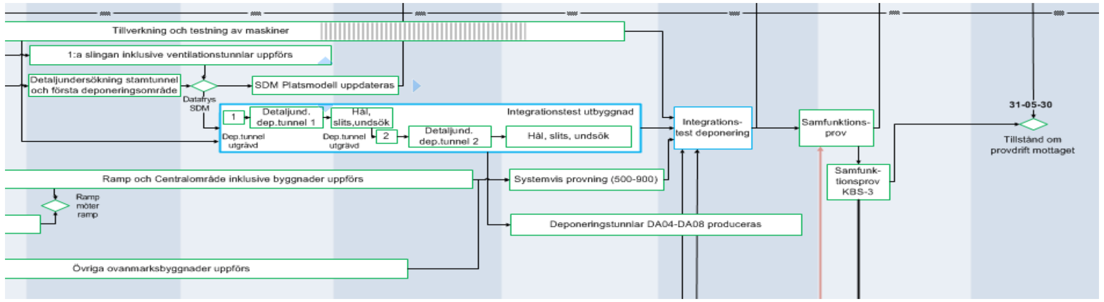


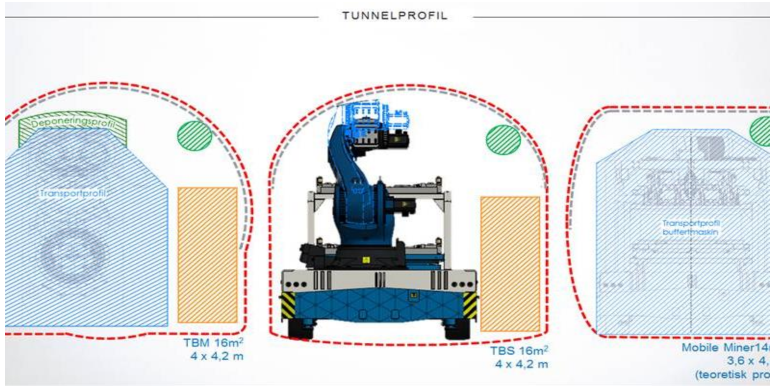
- Among issues studied
    - Identification of plausible bottlenecks
    - Need of storage in KTB logistics and operations
    - Utilization levels of machinery, buffer production, resources and Sigrid
    - Impact of uncertainties

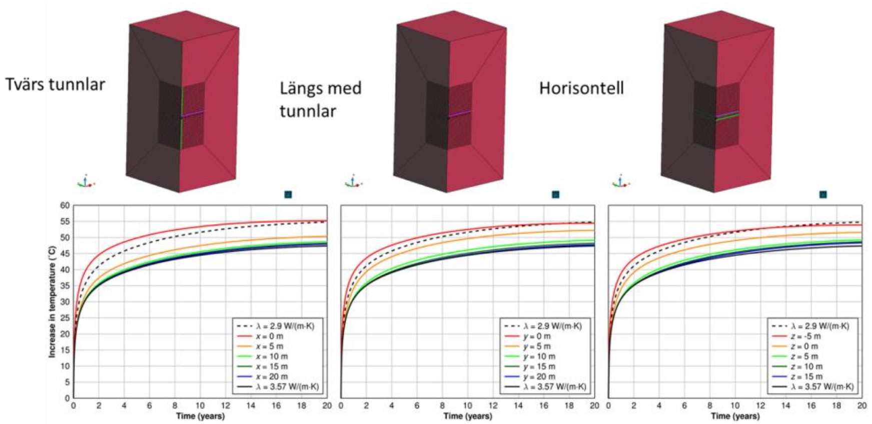


Future challenges - Optimisation

- Systematic and organized approach to provide the necessary functions in a project at the lowest cost without sacrificing functionality.
- Examples
  - Ventilation solution
  - Faster time to operation Excavation logistics of the first deposit area needs to be rearranged
  - Decrease deposition tunnel area
  - Shorter distance between deposition holes (thermal optimization)
  - Bentonite handling
  - Canister manufacturing and procurement process
- Need
  - an overall system understanding
  - focus on where the great costs are both in investment and operation







Future challenges - Knowledge management and in-house competence needed

- Research and development will need to continue also after a license to construct a repository is granted.
    - A need to apply, maintain and develop the knowledge management tools already established.
    - Workable procedures for information handling and QA already developed and successfully applied but wealth of information and pressure to act quickly will increase when construction and operation starts.
    - Practical application of tools for requirements management and quality control of production and installation.
    - Will also be used by even larger groups of experts.
- A core competence on post closure safety assessment including at least on overall understanding on how the repository components evolve over time needed for each WMO
    - Evaluation of the knowledge base both with regard to processes and input data in the assessment.
- Safety assessments are thus fundamental for the prioritisations of the research programme.
    - *It may be more difficult to attract a new generation of researchers and to justify funding the R&D when the fundamental issues are less acute.*

Role of international cooperation to meet future challenges

- Even more important on developing, sharing and managing the knowledge needed.
- Guidelines and other recommendations issued by the international agencies
  - not only important for developing programmes
  - also serve as a fundamental memory in more developed programmes when the experts ones being authoring such guides now have retired or soon will retire.
- Essential for sharing competences where the national contexts is too small, especially on issues essentially only of interest to the nuclear waste community.
- Training
- Participation in international work may also be an inspiration and reason to carry on for internal staff, as well as researches at universities, to consider the work sufficiently interesting

Conclusions

- SKB is closing the back end of the fuel cycle
    - Research and development would need to continue, although with a new focus.
    - Need to apply, maintain and develop the knowledge management tools already established.
- International cooperation will be even more important on developing, sharing and managing the knowledge needed