Svensk Kärnbränslehantering AB

Swedish Nuclear Fuel and Waste Management Company

Crystalline research programme in Sweden

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Svensk Kärnbränslehantering AB

Swedish Nuclear Fuel and Waste Management Company

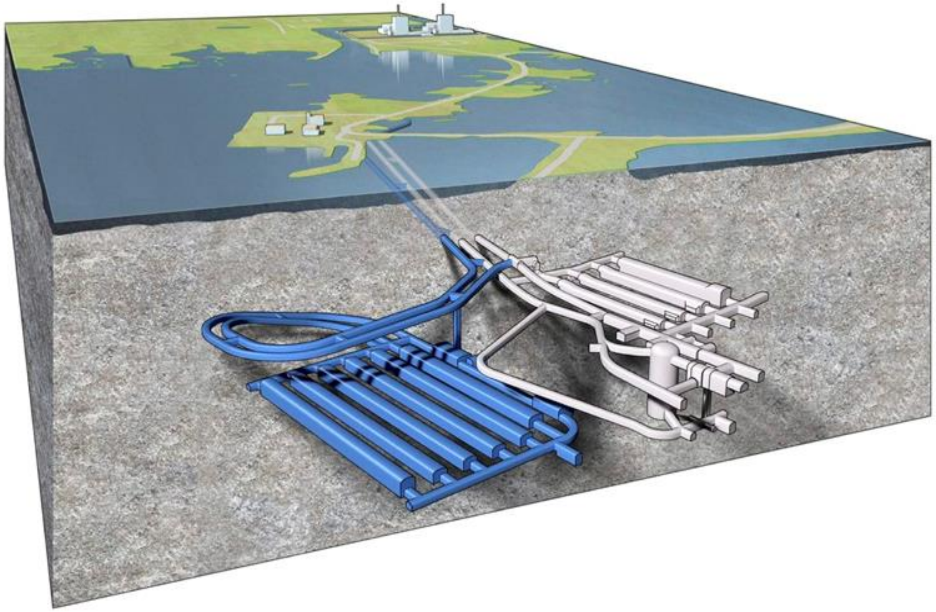
- SKB is responsible for handling and disposal of all Swedish nuclear waste.
- SKB is owned by the nuclear power companies in Sweden, in proportion to their share of nuclear power production; Vattenfall, E-ON and Fortum.

Over-all status of the Swedish nuclear waste disposal programme, (1/3)

- Application for a licence to construct **the spent fuel repository** was submitted in 2011
- The Swedish Radiation Safety Authority (SSM) and the Land&Environmental Court are expected to give their recommendations to the Government in 2017
- Decision by the Government in ?
- Planned start of construction in 2019
- Operation from 2030

Over-all status of the Swedish nuclear waste disposal programme, (2/3)

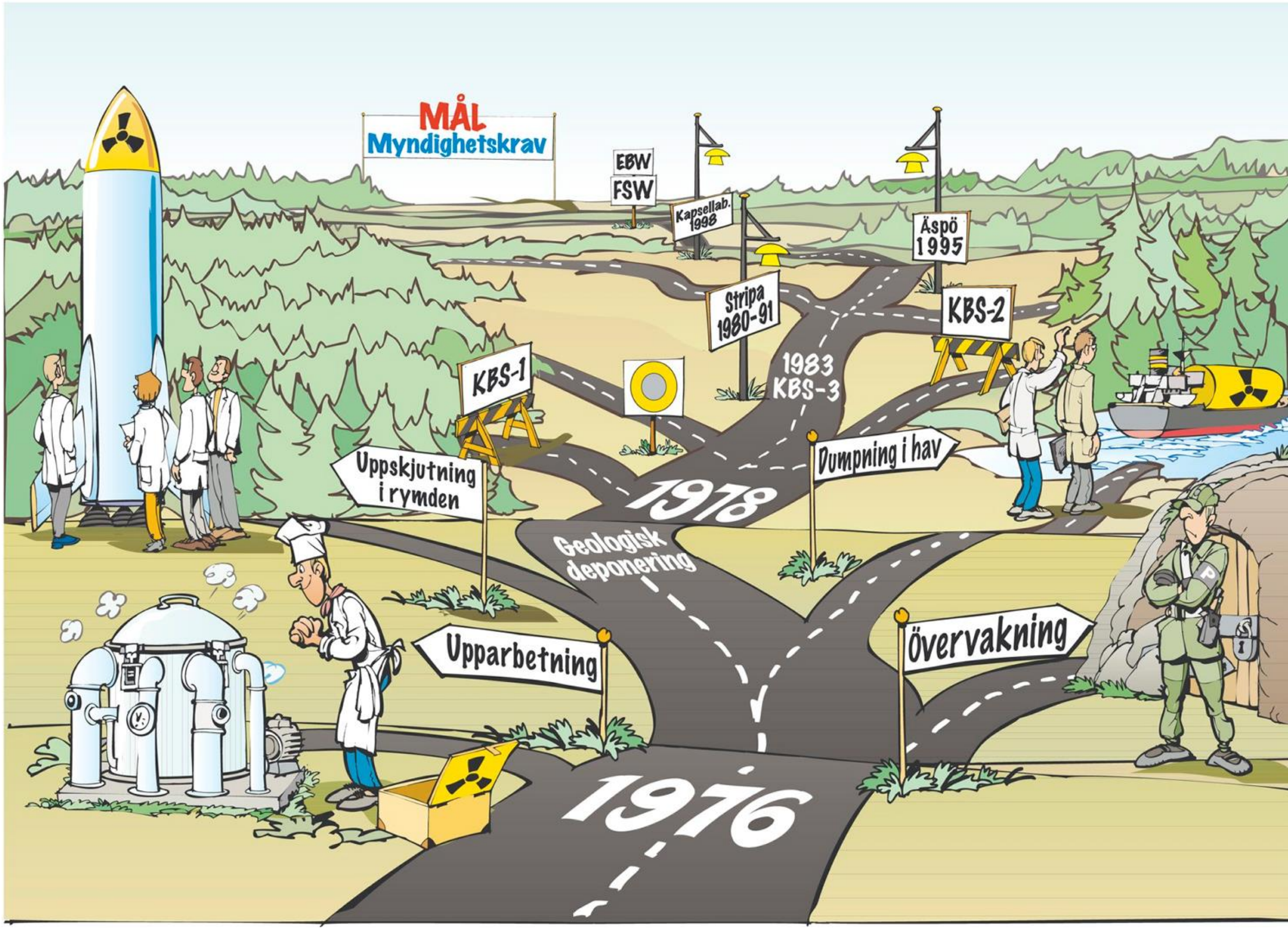
- Application for an extention of the repository for **low and intermediate level waste** (SFR) was submitted 17 December 2014. The new rock caverns are needed mainly for decomissioning waste.



Over-all status of the Swedish nuclear waste disposal programme, (3/3)

- A repository for **long-lived waste** (other than the spent fuel) is planned to be taken into operation around 2045

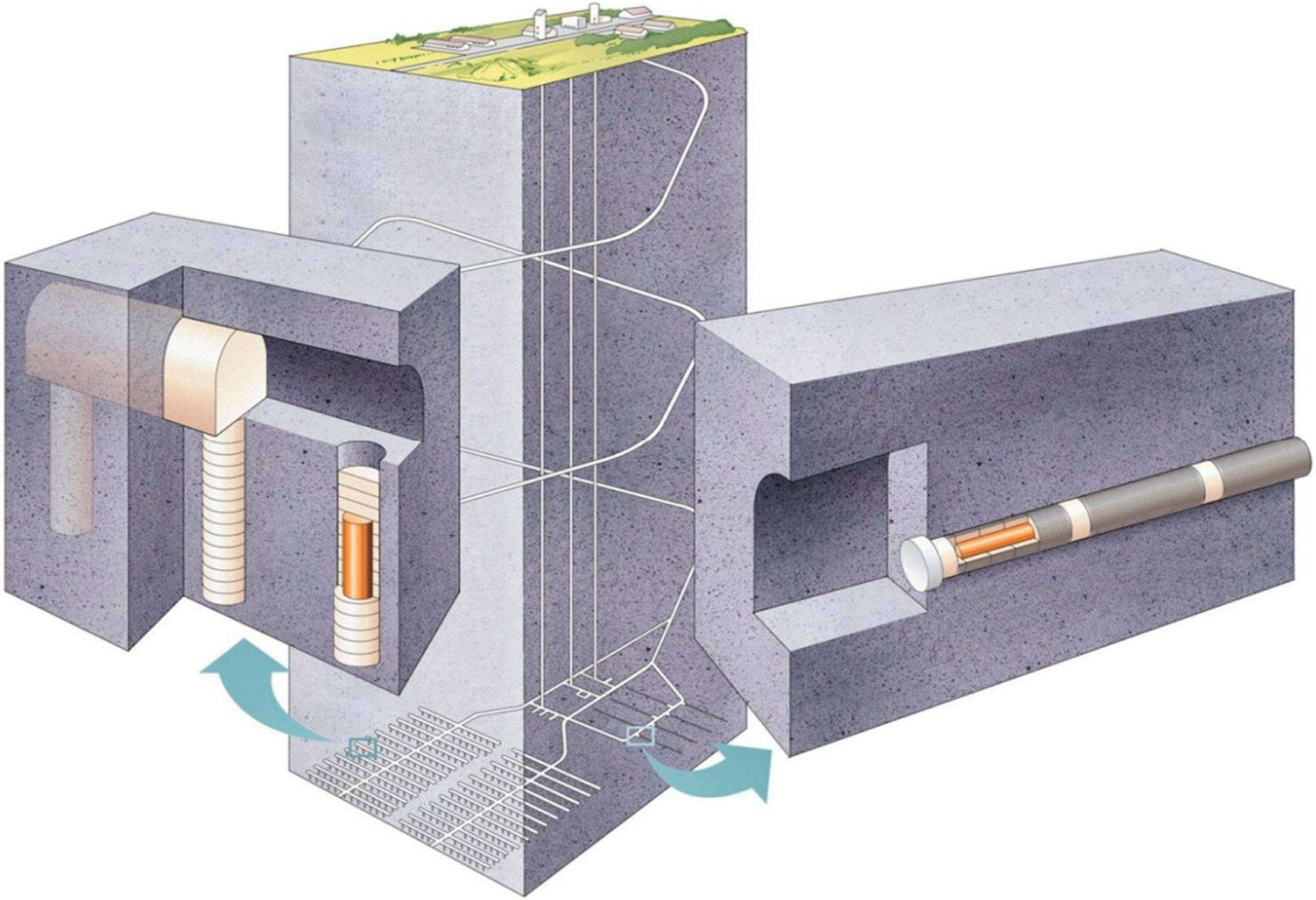
As time goes by…



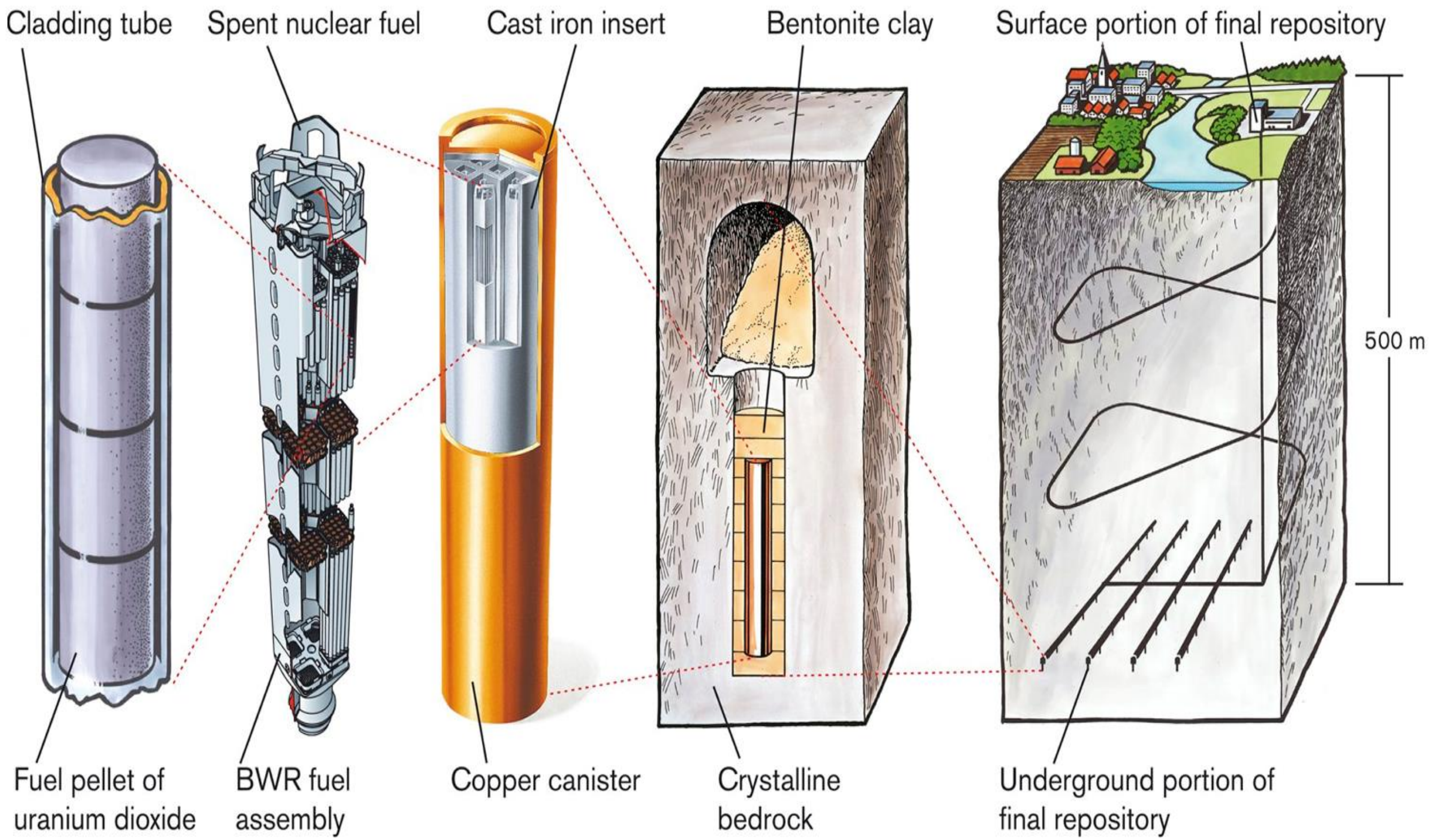
The geological map of Sweden indicate where suitable host rocks for the spent fuel repository could be found. These areas consist of homogeneous crystalline rock formed between one and two billoin years ago.

- Crystalline rock is the obvious alternative for deep geological disposal in Sweden.
- Mechanically stable
  - –Suitable for underground constructions

Illustration of two variants of the KBS-3 disposal concept. SKB has applied for licence to construct a repository for the left hand (vertical) variant



The KBS-3 concept´s (safety) barriers



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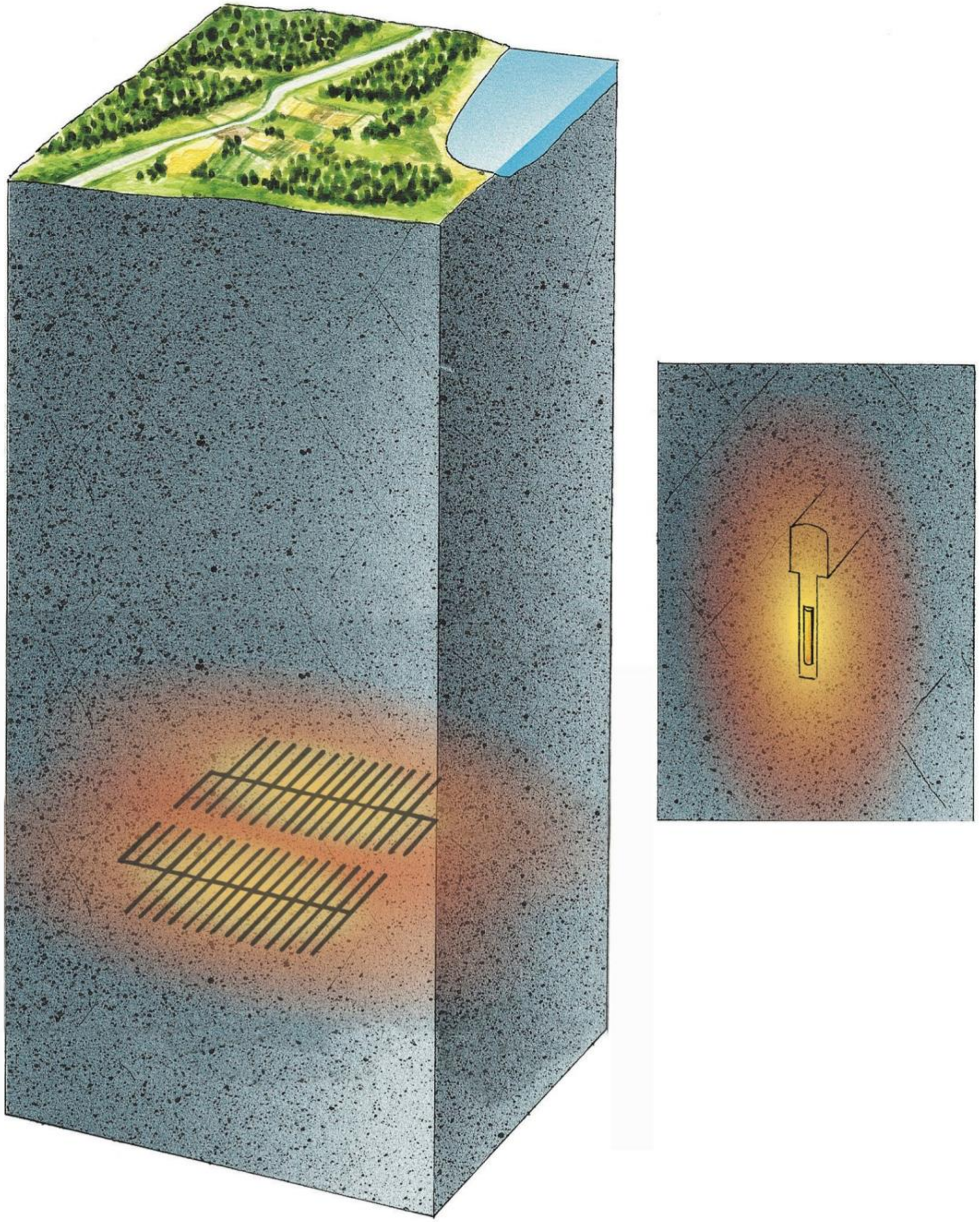
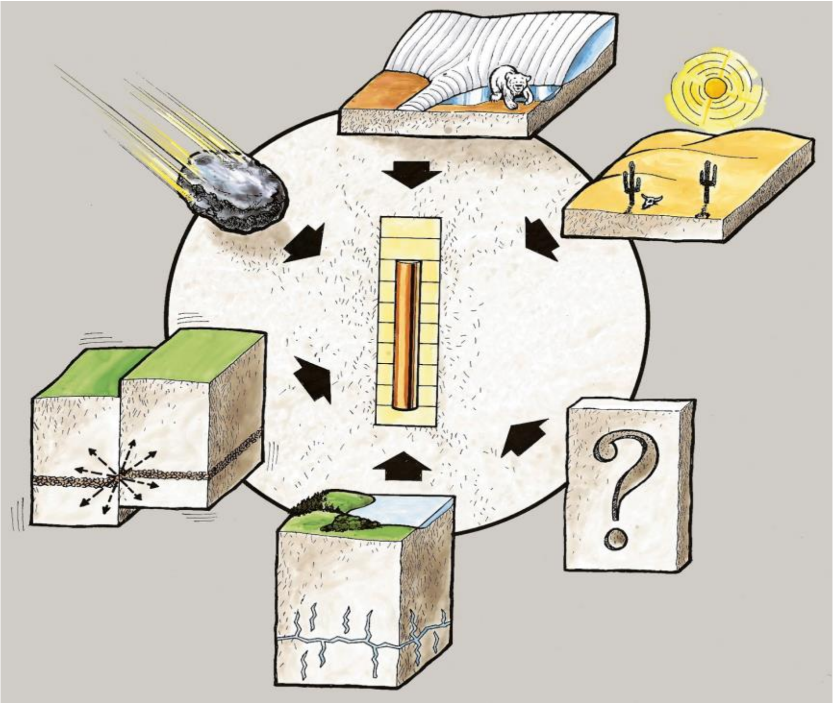
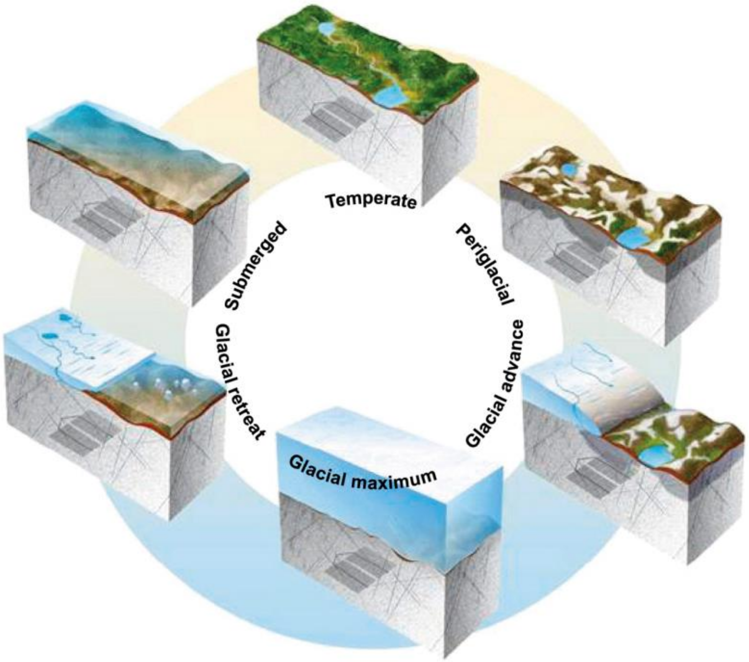
The sealed repository will cause an enhanced temperature during the first 1000 years, maximum < 100 degrees centigrade on the canister surface is reached after ten years.



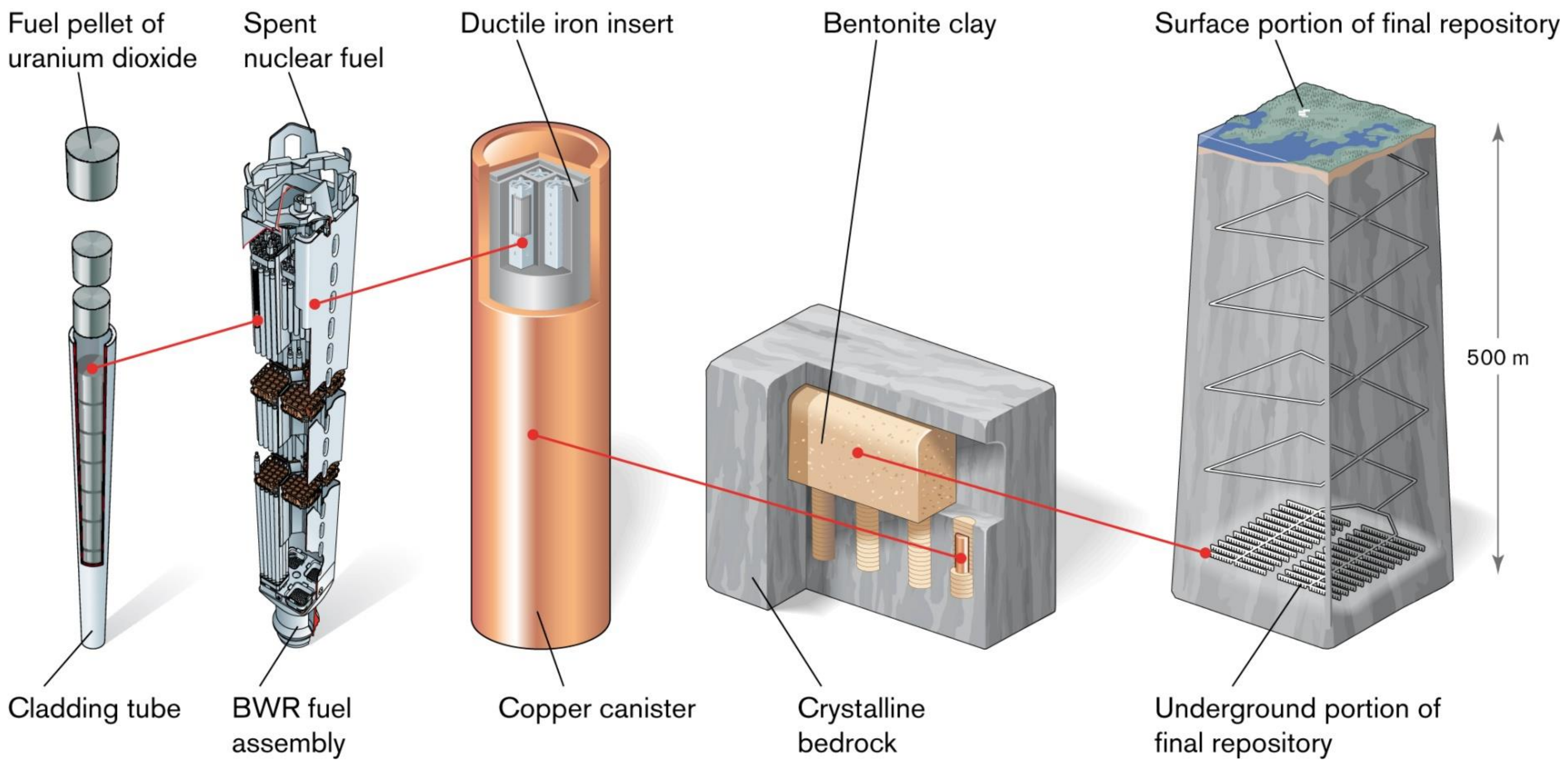
Scenarios for the assessment of the long-term safety of a spent fuel repository



The glacial cycle



The KBS-3 concept



Primary safety function: Complete containment

Secondary safety function: Retardation

The safety assessment Methodology in eleven steps has been developed over a ten year period

Reference design | **Site description** | **R&D results** | **Results of earlier assessments** | **FEP databases**

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1 Processing of features, events and processes (FEPs) (ch 3)
Initial state | Internal processes | External factors

2a Description of site initial state (ch 4)

2b Description of engineered barrier system (EBS) initial state (ch 5)

2c Description of repository layout (ch 5)
– with site adaptations

3 Description of external conditions (ch 6)
– Climate and climate related issues
– Future Human Actions

4 Compilation of Process reports (ch 7) with handling prescriptions, including models

5 Definition of safety functions and function indicators (ch 8) Define
– safety functions of the system,
– measurable/calculable safety function indicators and
– safety function indicator criteria

6 Compilation of input data (ch 9)

7 Definition and analyses of reference evolution (ch 10)
Study repository evolution for
– repetition of most recent 120,000 year glacial cycle and
– variants assuming global warming due to increased greenhouse effect

8 Selection of scenarios (ch 11) based on
– results of reference evolution
– FEP analyses
– safety functions

9 Analyses of selected scenarios with respect to
– containment (ch 12)
– retardation (ch 13)

10 Additional analyses (ch 14)
– scenarios related to future human actions
– optimisation and best available technique (BAT)
– relevance of excluded FEPs
– time beyond one million years
– natural analogues

11 Conclusions (ch 15)
– compliance with regulatory requirements
– feedback to design, R&D, site investigation

7.Definition and analysis of a reference evolution

- Reference evolution = reasonable future development of the repository
- Defined as repetition of last 120,000 year glacial cycle + 7 additional repetitions to cover one million years
- Model reconstruction of development of permafrost, glaciers etc
- Comprehensive modeling of THMC-processes in rock, buffer, canister
- Focus on containment, no modeling of radionuclide transport
- Provides understanding of repository development for a wide variety of conditions
- Safety over time evaluated through developing status of safety functions
- Reference evolution an important basis for scenario selection

General outcome of the analysis of the reference evolution

- The outcome of the analysis of the reference evolution implies that
  - The vast majority of the 6,000 deposition positions will experience favorable mechanical , hydrogeological and chemical conditions throughout the one million year assessment period.
  - As a consequence, the vast majority of the 6,000 canisters are expected to maintain their containment capacity throughout the assessment period
- However, canister failures cannot be entirely ruled out due to
  - Enhanced corrosion in deposition positions where advective conditions prevail after buffer loss due to erosion
  - Earthquake induced secondary shear movements in fractures intersecting deposition holes
  - Both are low probability phenomena

Compliance – SSM's risk criterion

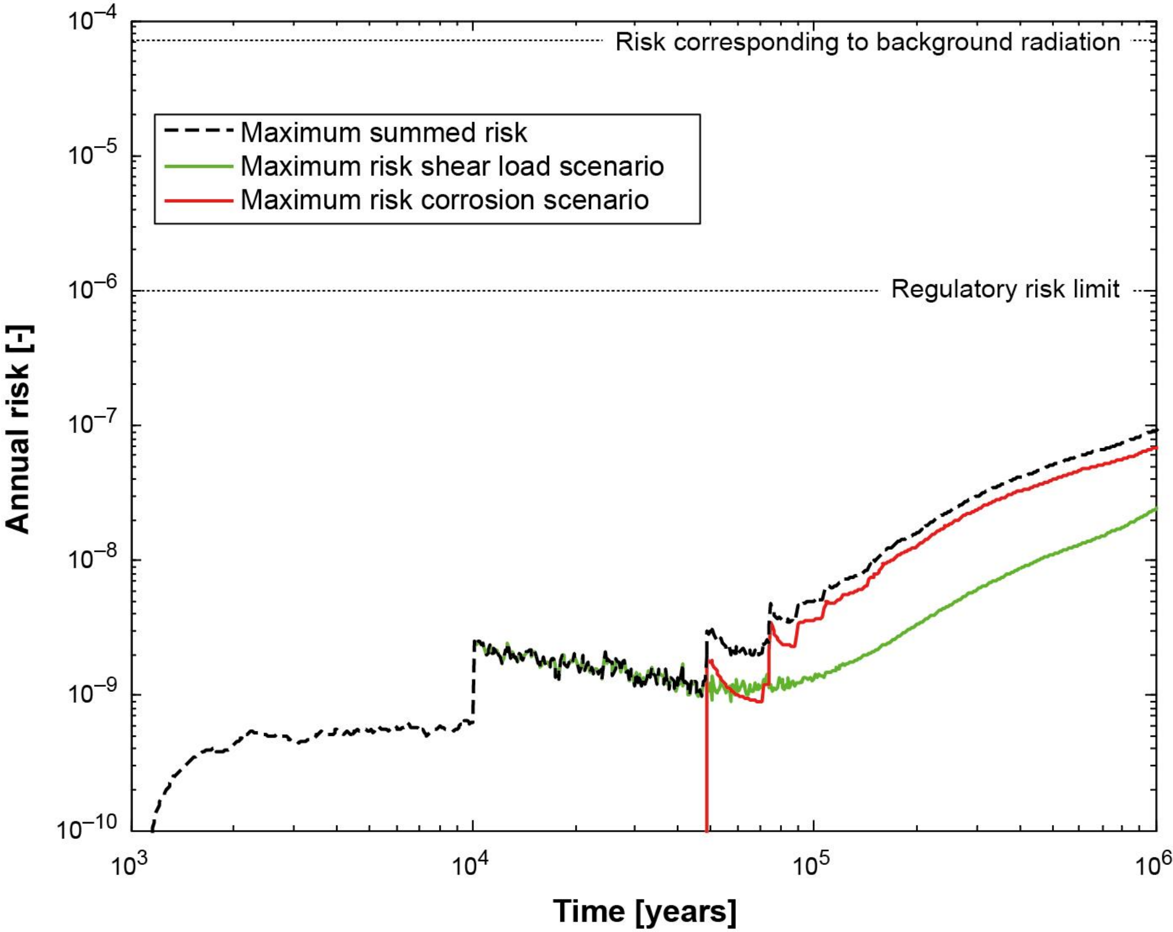
- Penetrating canister failures cannot be ruled out due to
  - Enhanced corrosion by sulfide after erosion of the buffer when exposed to low salinity groundwaters. Canister failures require combination of high groundwater flow and high sulfide concentrations. Mean number of failed canisters less than one out of 6,000 at one million years.
  - Large earthquakes in the vicinity of the repository. May occur only in large fracture zones where no canisters are deposited. Failures may occur due to secondary movements in fractures intersecting deposition holes. Mean number of failed canisters less than 1/10 out of 6,000 at one million years.
- A number of other safety functions of the repository have been demonstrated to be maintained throughout the assessment period (conclusions from scenario analyses).

Risk curves for the two contributing scenarios

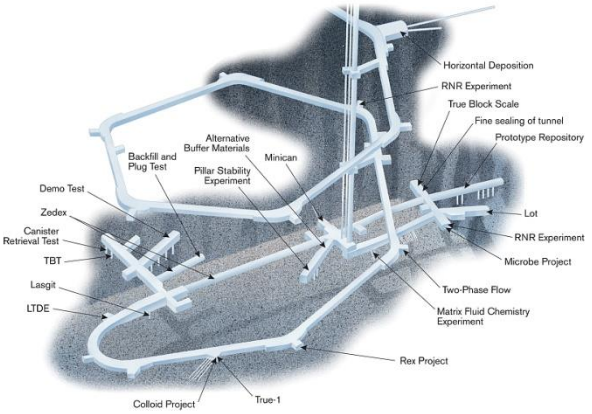
- **Central conclusion:**

A KBS-3 repository that fulfils long-term safety requirements can be built at the Forsmark site

  - The calculated risk for a final repository at Forsmark is below the regulatory risk criterion with a margin, even in a million year time perspective.



Important facilities for SKB´s R&D work



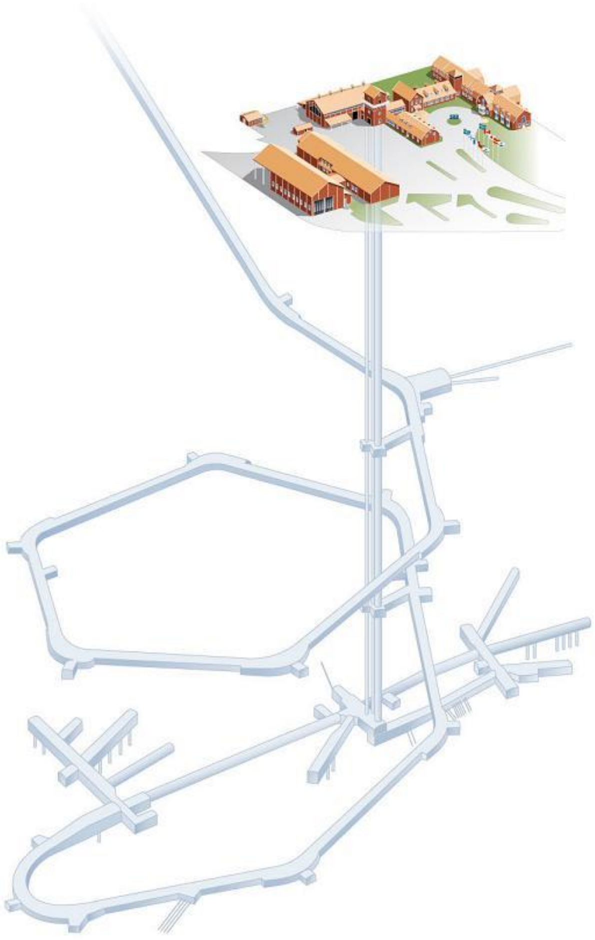
Äspö Hard Rock Laboratory,
in operation since 1996

Canister Laboratory,
in operation since 1998

Bentonite Laboratory,
in operation since 2007

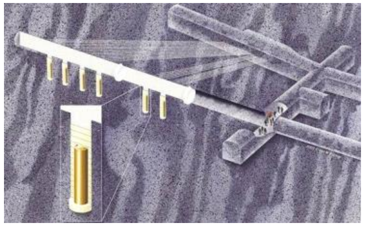
The role of the Äspö Hard Rock Laboratory

- ✓ Develop and demonstrate methods for construction and operation of the final repository.
- ✓ Test alternative technology that can improve and simplify the design of the final repository without compromising its high quality and safety.
- ✓ Increase the scientific understanding of the safety margins and provide realistic data for safety assessments of the long-term safety of the repository system.
- ✓ Provide experience and train personnel for various tasks in the final repository.
- ✓ Provide information to the general public on technology and methods that are being developed for the final repository.



Äspö Hard Rock Laboratory

Phases of realization



Preconstruction phase, 1986 – 1990

- Regional geological investigations
- Surface and borehole investigations
- Predictions based on the site investigations

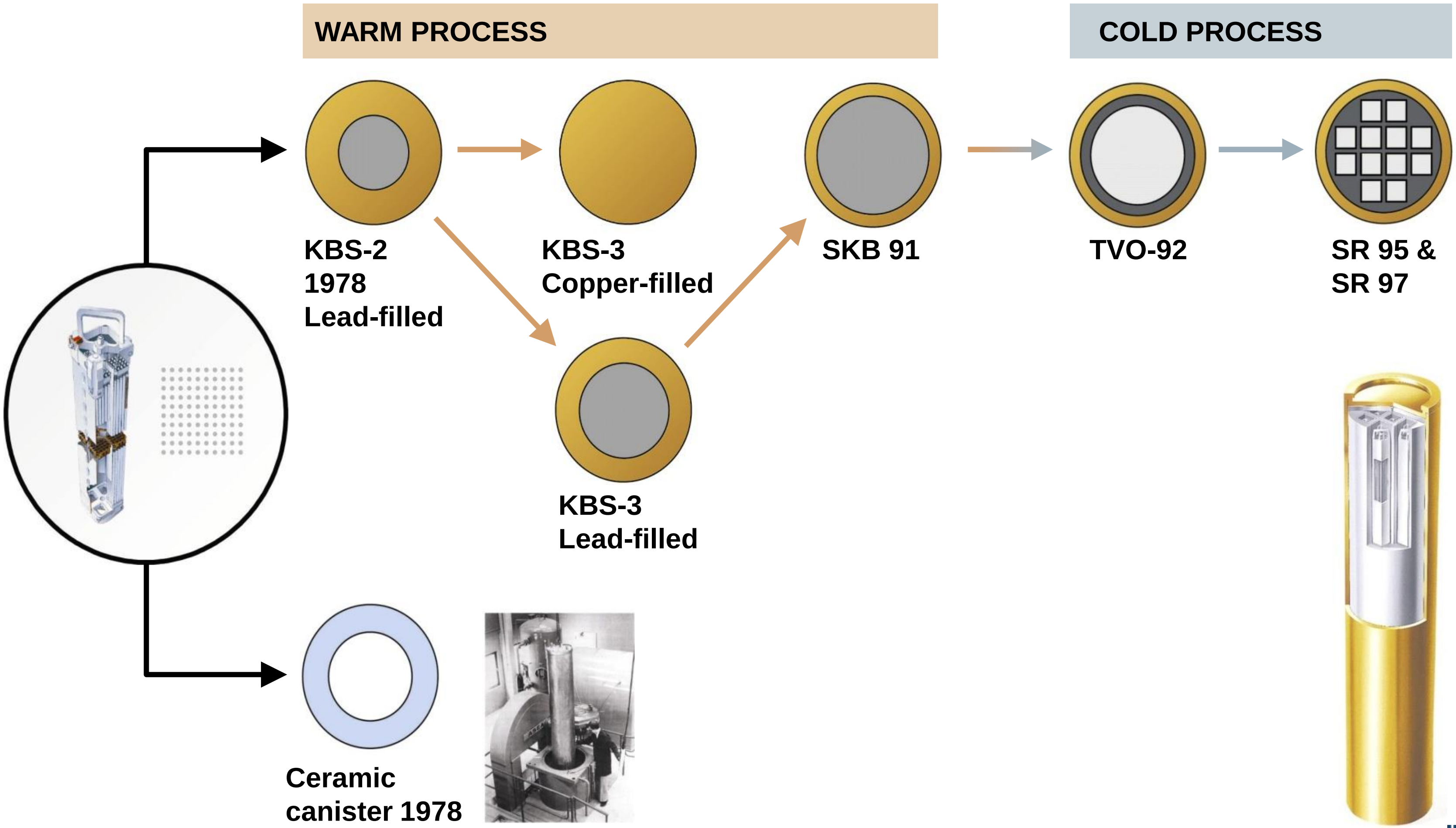
Construction phase, 1990 – 1995

- Detailed characterisation of the rock
- Modelling of groundwater flow
- Evaluation of predictions from the preconstruction phase

Operating phase, 1995 – 2025

- Test models describing the barrier function of the rock
- Demonstrate technology and function of the repository system
- Refinement of detailed characterisation technology

Canister development



SKB:s research and development programme is stipulated by the law

R&D programme – 86

- **Presentation of plans for an underground research laboratory, the Äspö Hard Rock** Laboratory

R&D programme – 89

- Comparison between the KBS-3 method and one called WP-Cave
- **Plans for a new long-term safety assessment, SKB 91**

RD&D programme - 92

- Start of planning the repository for spent nuclear fuel
- Start of locating the repository

RD&D programme- 95

- Encapsulation project
- Deep repository project
- **Scheme for reporting of safety assessments, SR -97**

SR -97 safety assessment

- Using field date from three different sites ➔
- All three would meet the safety criteria put up by the regulator

RD&D programme - 98

Presented :

- Outcome of locating studies and criteria for site selection
- System analysis

SKB -91 safety assessment

- Varying geological conditions ➔ Reliance on engineered barriers

R&D 1986

R&D 1989

RD&D 1992

RD&D 1995

RD&D 1998

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SKB:s research and development programme cont.

RD&D programme - 04

- Fullscale tests at the Äspö- and at the enkapsulation labs

RD&D programme -01

- Focus on research issues related to technical development and long- term safety assessment

RD&D programme -07

- Measures needed to apply for the license to construct the repository for spent nuclear fuel

RD&D programme-10

- Focus on issues for low- and intermediate level waste disposal

RD&D 2001

RD&D 2004

RD&D 2007

RD&D 2010

SR–Can

- Preliminary long-term safety assessment of a repository for spent nuclear fuel located in Forsmark and Laxemar

SR–Site

- Safety assessment of the final repository for spent nuclear fuel in Forsmark
- Part of the licence application

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Research, development and siting

Technology implementation, licensing and building of encapsulation plant and repository

2029 Deposition begins

2015

m/s Sigrid in operation

Application to build a final repository and an encapsulation plant

Site investigations, Technology development

2010

Site selection Forsmark

2005

Bentonite Laboratory

Feasibility studies and development of scientific basis

2000

Canister Laboratory

1995

Äspö Hard Rock Laboratory

Methodology development

1990

SFR in operation

1985

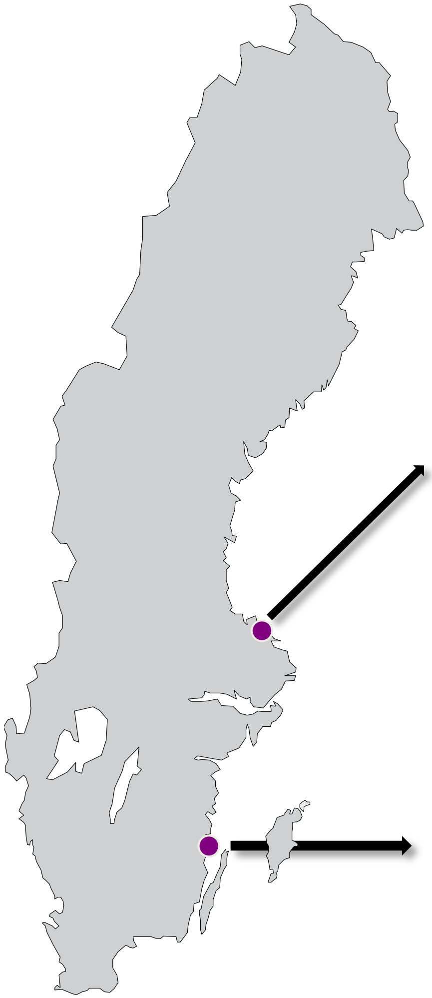
Clab in operation

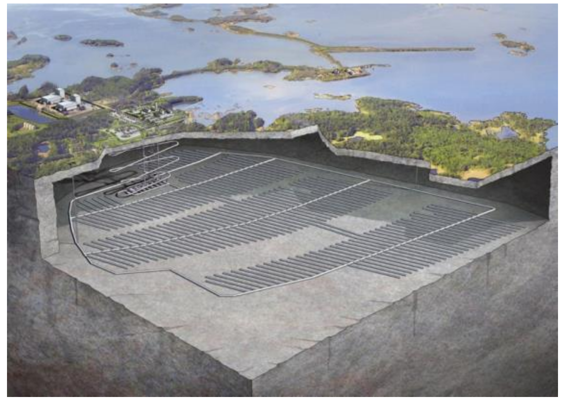
1976

m/s Sigyn in operation

RD&D programme reviewed and approved every three years

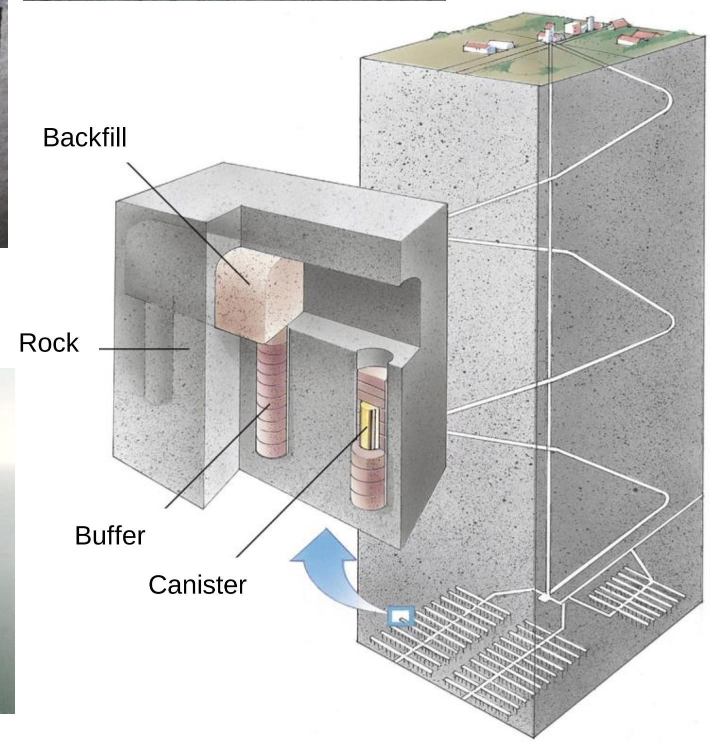
The KBS-3 system





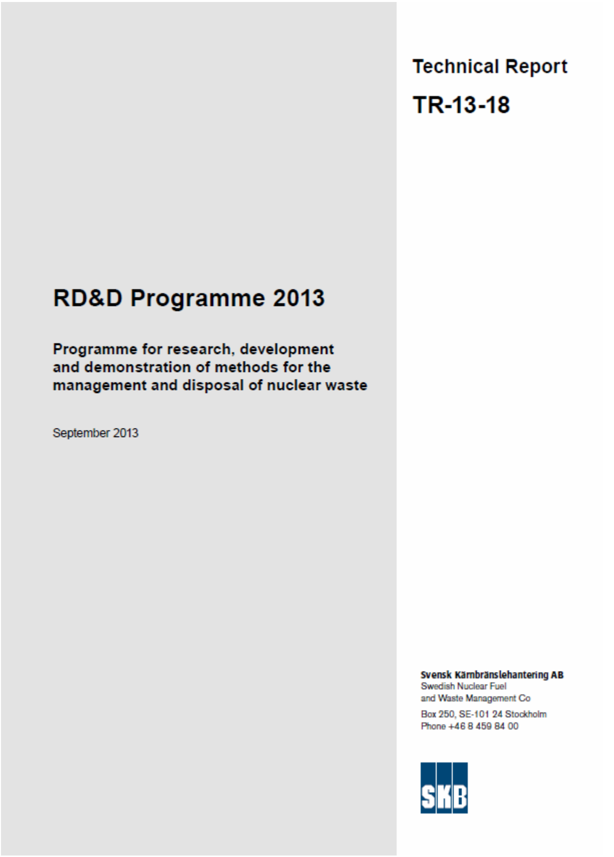
Spent Fuel Repository at Forsmark

Encapsulation plant (Clink) in Oskarshamn



Research, Development and Demonstration Programme 2013

- Requirements according to the Nuclear Act
  - License holders for nuclear reactors should every 3rd year submit a programme for research and development and other measures necessary for decommissioning of nuclear facilities and final disposal of nuclear waste.
  - The programme should provide an overview of all measures that may be necessary and specify in more detail the measures that are intended to be implemented within at least six years.
  - The programme shall be submitted to SSM by the end of September every third year.
- Has been in effect since 1986.


Technical Report
TR-13-18

RD&D Programme 2013

Programme for research, development and demonstration of methods for the management and disposal of nuclear waste

September 2013

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Swedish Nuclear Fuel and Waste Management Co
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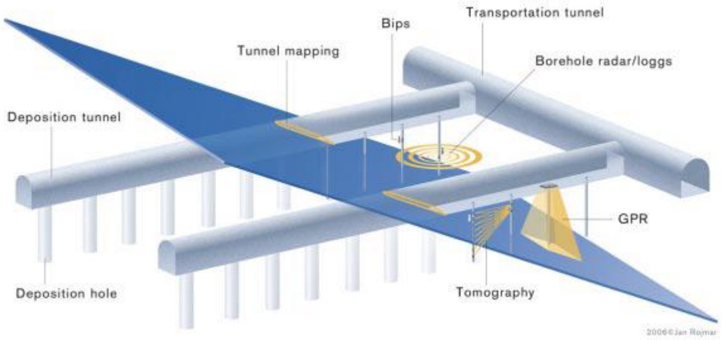
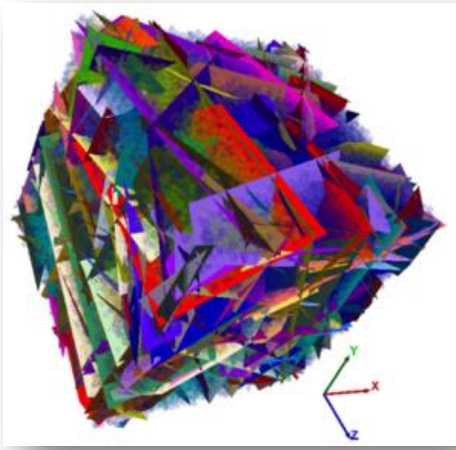
Technology development

- Technology development and need for detailed investigations
  - SKB has established a technically feasible reference design and layout
  - Detailed designs adapted to an industrialised 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



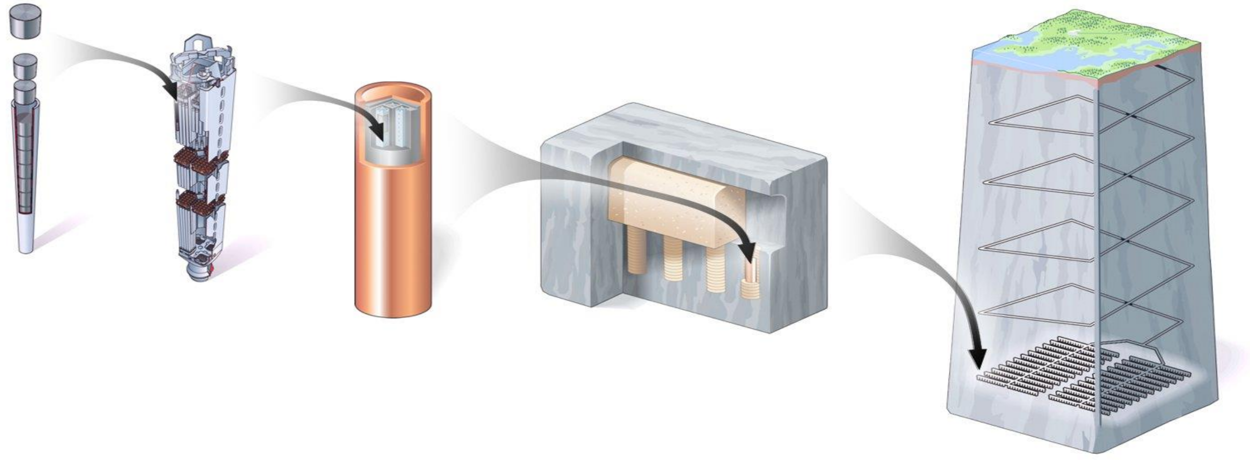
Research for assessment of long-term safety

- Main objectives in the current phase (for KBS-3)
  - find solutions to identified problems that affect safety or that reduce uncertainty in the assessment of long-term safety,
    - Focus on factors that contribute to risk, further clarify assumptions in the assessment
  - follow scientific progress, and
  - maintain and develop the competence necessary to carry out assessment of long-term safety.



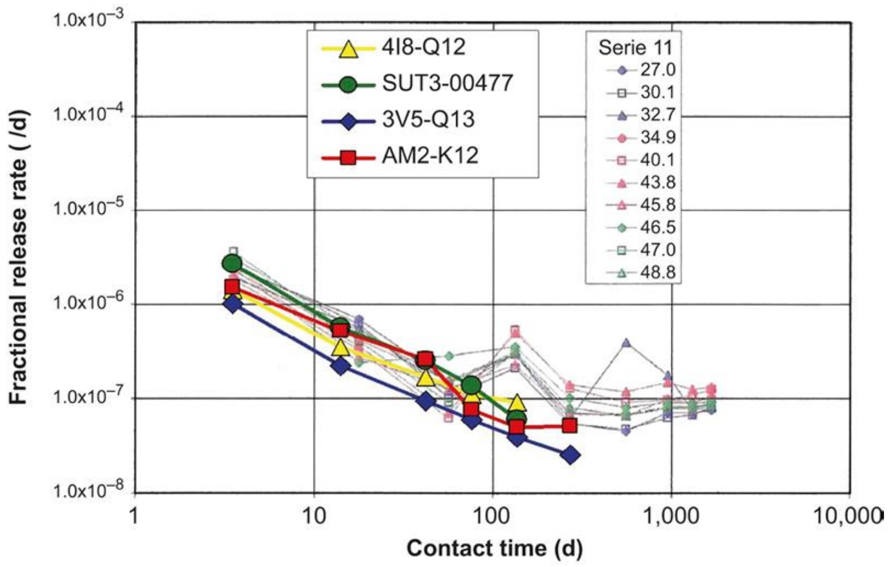
Research issues in focus

- Copper corrosion
- Buffer erosion
- Canister – Design and properties
  - E.g. mechanical properties of nodular cast iron
- Climate evolution scenarios
  - Bounding scenarios, e.g. maximum ice thickness



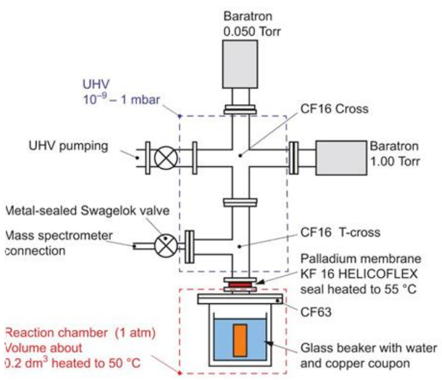
Spent fuel

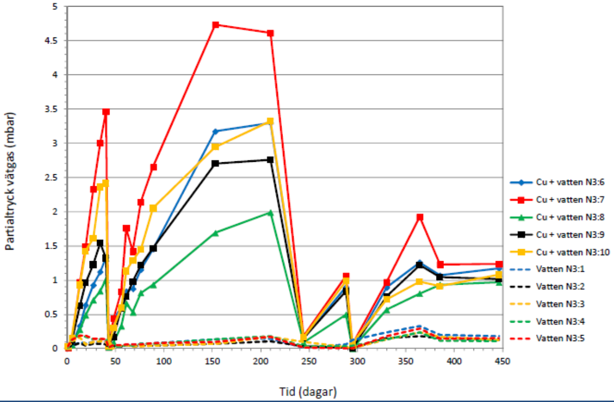
- Containment – As long as the canister is intact → no release of radionuclides
- Spent fuel dissolution is a central research area
  - Data for fuel dissolution under repository-like conditions
  - Shed light on the mechanisms of the different processes that contribute to fuel dissolution
  - Properties of high-burnup fuels
  - Properties for new types of fuel



Canister

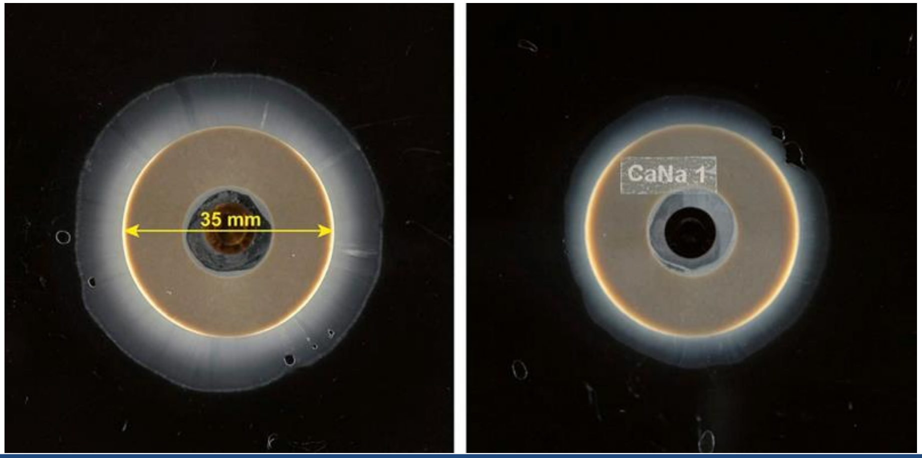
- Two scenarios that contribute to risk
- Mechanical loads
  - What is the maximum acceptable isostatic load?
  - What is the resilence to shear loads (future earth quakes)?
  - Creep properties of copper
- Copper corrosion
  - Copper corrosion in water with no dissolved oxygen
  - Sulphide corrosion
  - Stress corrosion cracking

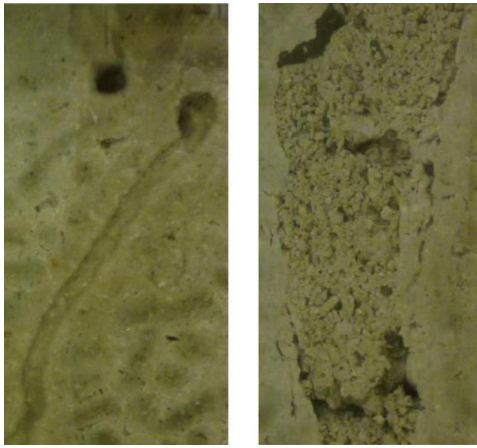




Buffer and backfill

- In the spent fuel repository the canister is embedded in a protective buffer of bentonite clay
  - Should limit the ground water flow to the canister
  - If the containment of the canister is broken the buffer should retard transport of radionuclides to the rock
- Research mainly on buffer erosion – studies of under what conditions the buffer is stable
- Developing a program for characterization of different bentonites



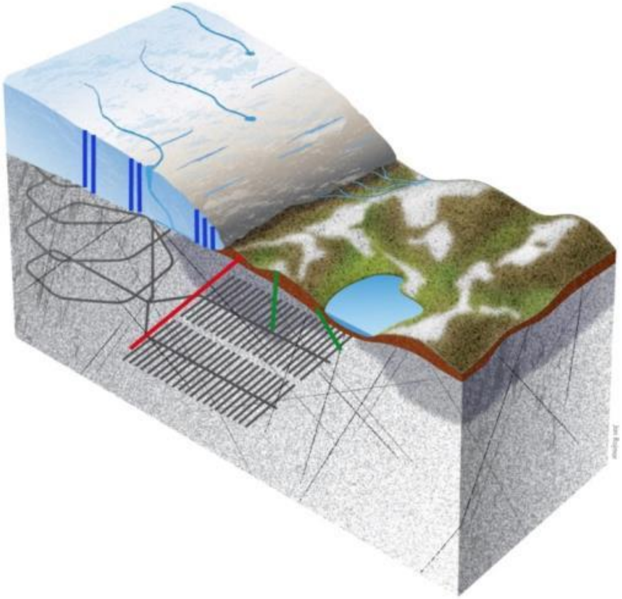


Climate evolution

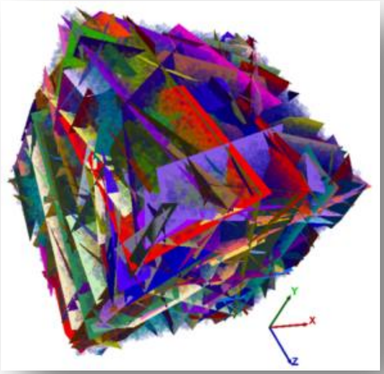
- Glaciations and permafrost affect:
  - Sea level
  - Ground water flow
  - Ground water chemistry
  - Rock stress in the crust
  - Biosphere at the surface
- Focus
  - Possible climate evolutions – identification and description
  - Limiting cases for climate scenarios to cover uncertainties
    - maximum thickness of a glacier?

Greenland Analogue Project – GAP

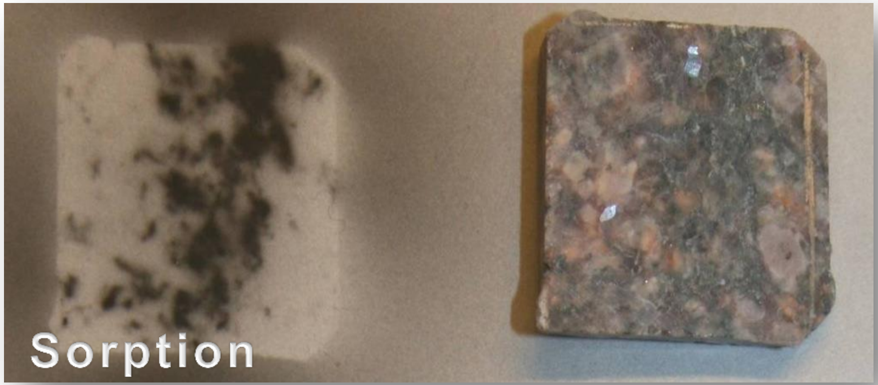
- Main focus:
  - groundwater flow and groundwater chemistry beneath a glacier
- Project started in 2009
- Now in final phase – data compilation and reporting
- Valuable knowledge obtained on hydrogeology, hydrochemistry and surface ecosystems



The geosphere (1)



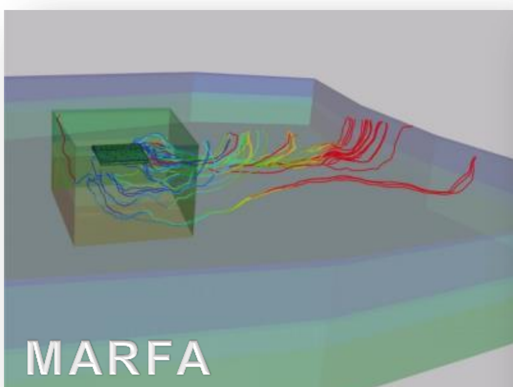
- **Fracturing and fracture propagation**
  - Stress induced spalling – controlling factors and remedial measures
- **Earth quakes**
  - Further development of numerical modeling of earth quakes
  - Studies of active faults in Sweden
  - Integrated analysis of Sweden's earth quake database
- **Hydrogeology**
  - Modeling of groundwater flow under glacial and permafrost conditions
  - Code development and maintenance
- **Geochemistry and microbial processe**s
  - Reactions between groundwater and rock
  - Experimental studies of ion exchange processes
  - Microbial processes in the presence of hydrogen, methane and sulphide, biofilms on fracture surfaces

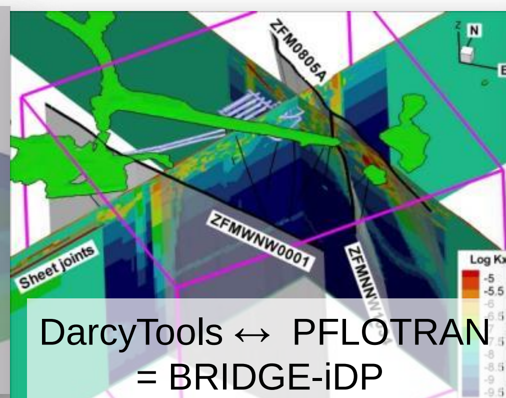


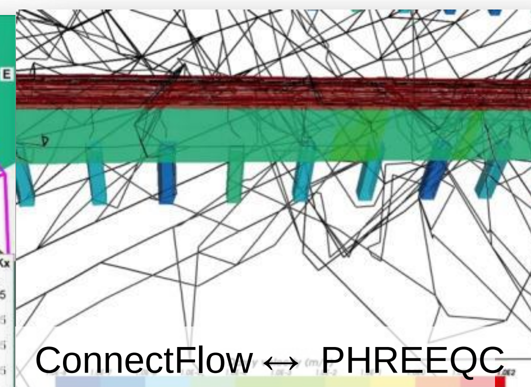
- **Radionuclide transport**
  - Improvement of the K_d concept – hydrochemical conditions in fractures

Geosphere (2)

- Integrated modeling
  - Discrete Fracture Network (DFN) modeling – geology, rock-mechanics, hydrogeology
  - Thermo-hydro-mechanical evolution
  - Hydrogeochemical and hydrogeologic modeling
  - Radionuclide transport – integration of codes for hydrogeology, geochemistry including sorption effects







Concluding remarks

- Main conceptual issues resolved
- Substantial technology development and demonstration efforts required before the KBS-3-system can be operated as an industrial enterprise (will be done in cooperation with Posiva)
- The KBS-3-system has been shown to provide safe final disposal for spent fuel at Forsmark and Olkiluoto
- Still some open issues remain to further strengthen the scientific basis on processes that contribute to risk
  - Reduce uncertainties
  - Additional data needs (host rock, engineered barrier properties)
- Maintain competence for future assessments

Full scale underground testing

- Commissioning tests of the entire KBS-3 system
  - Required input to operational license applications
  - quality control – products and organization
- Integration test before commissioning test are needed
  - ensure that the equipment and technological systems work together as intended would be needed
  - followed by modifications of the system (tools; procedures; organization).

SKB

Thank you for your attention!