Swedish Nuclear Fuel and Waste Management Company

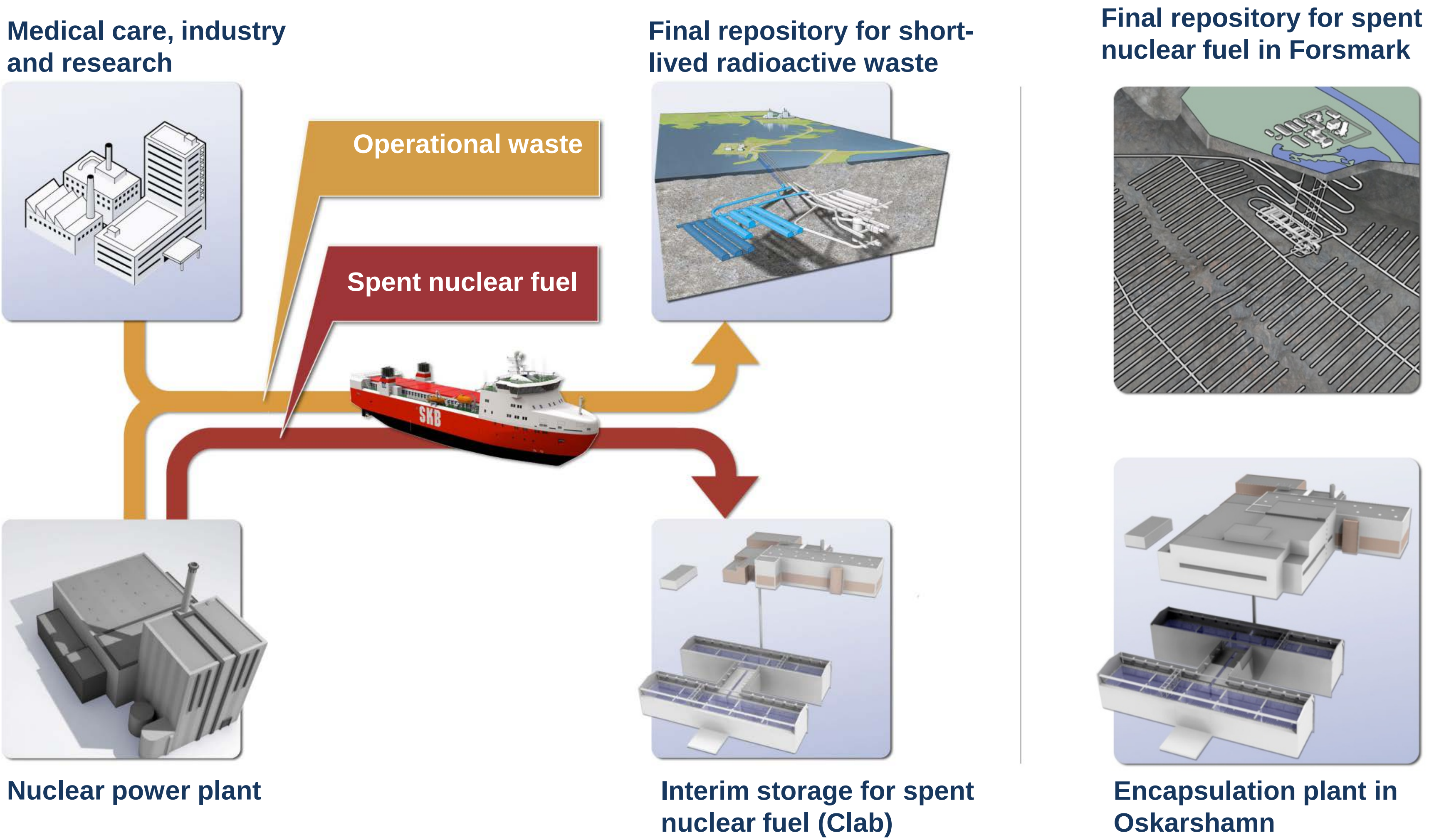
Svensk Kärnbränslehantering AB

Development of the repository for spent nuclear fuel in Sweden. Need for continued technology development and large scale experiments

Johan Andersson, SKB

Presentation to JAEA February 2013

SKB’s system



Medical care, industry and research
Operational waste
Spent nuclear fuel
SKB
Final repository for short-lived radioactive waste
Final repository for spent nuclear fuel in Forsmark
Nuclear power plant
Interim storage for spent nuclear fuel (Clab)
Encapsulation plant in Oskarshamn

Clear responsibility and financing

SKB's owners:

VATTENFALL

FORSMARKS KRAFTGRUPP

e·on

okg - ett företag i E.ON koncernen

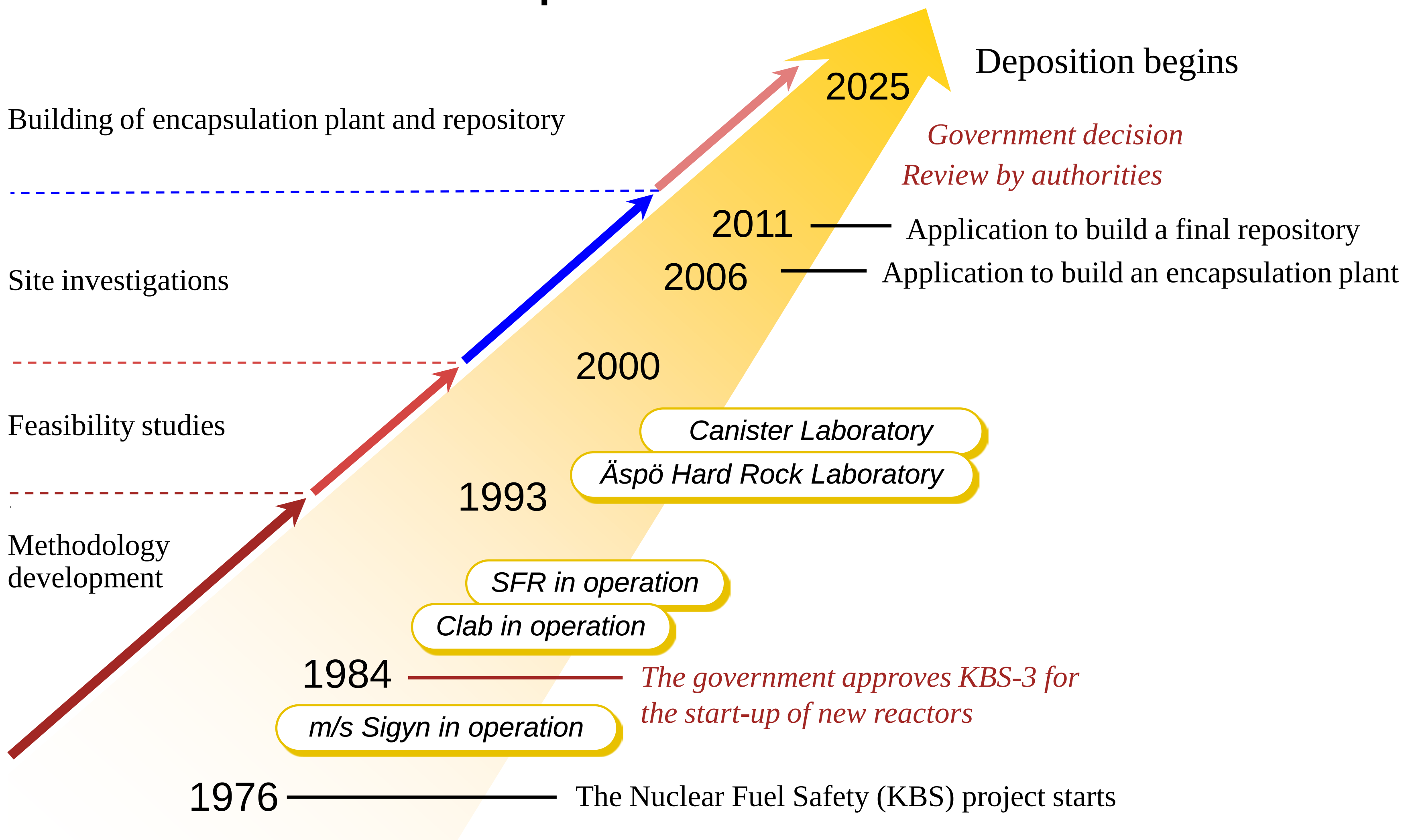
Financing:

About 0.022 SEK per kWh of nuclear electricity

Around 46.3 billion SEK in 2011

SKB

40 Years of Development



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Authorities and legislation

The Government

The Swedish Radiation Safety Authority

The Swedish National Council for Nuclear Waste

The Land and Environmental Court

The municipalities

Financing Act

Nuclear Activities Act

The Swedish Environmental Code

Radiation Protection Act

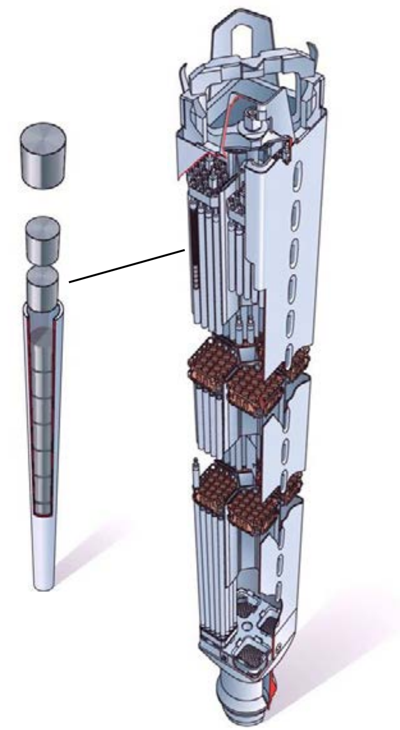
The Planning and Building Act

Different kind of waste – different solutions

Operational and decommissioning waste

Low- and intermediate level

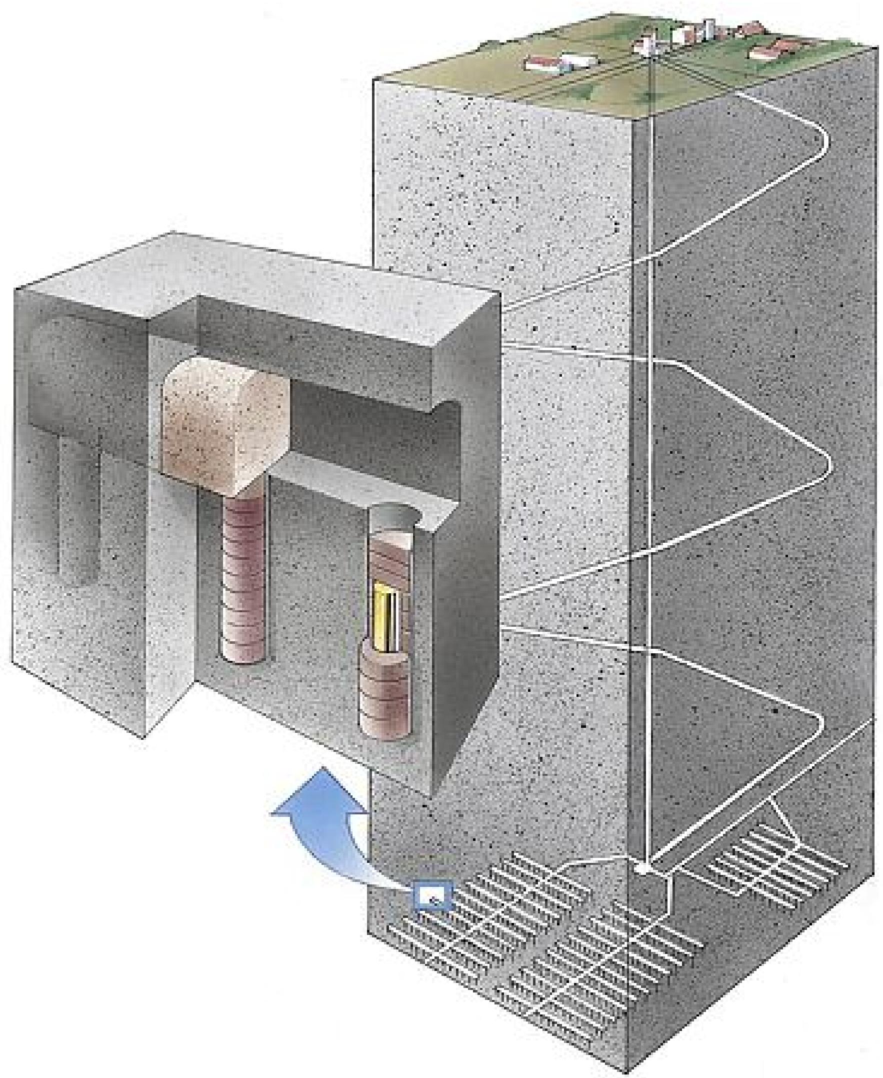
Spent nuclear fuel



Long-term

SKB

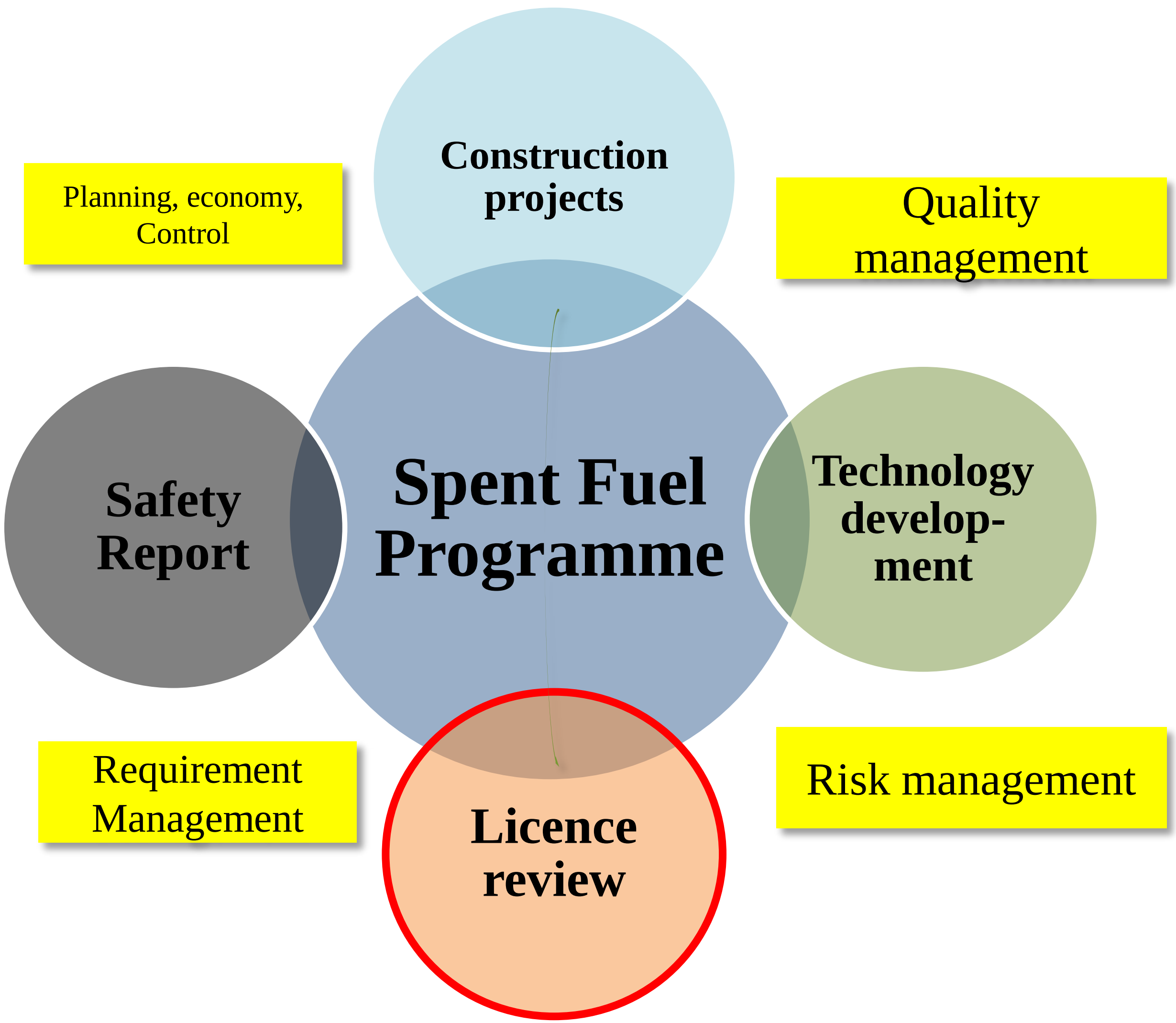
KBS-3: SKB's method for depositing spent nuclear fuel

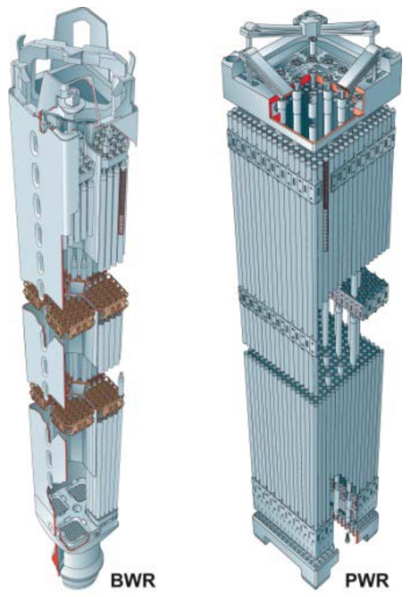


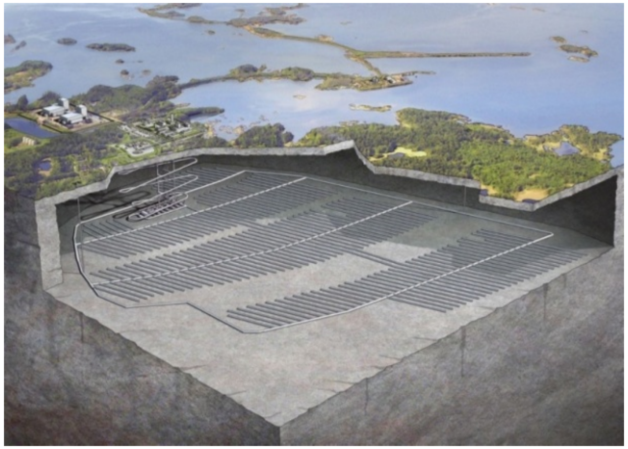
Licence applications nuclear fuel repository

- On March 16 2011, SKB applied for licences
  - to construct and operate a facility for encapsulation of spent nuclear fuel in the municipality of Oskarshamn
  - to construct and operate a KBS-3 repository for final disposal of spent nuclear fuel at the Forsmark site in the municipality of Östhammar
- The safety assessment SR-Site is a key component in the safety case for the final repository

The Nuclear Fuel Programme







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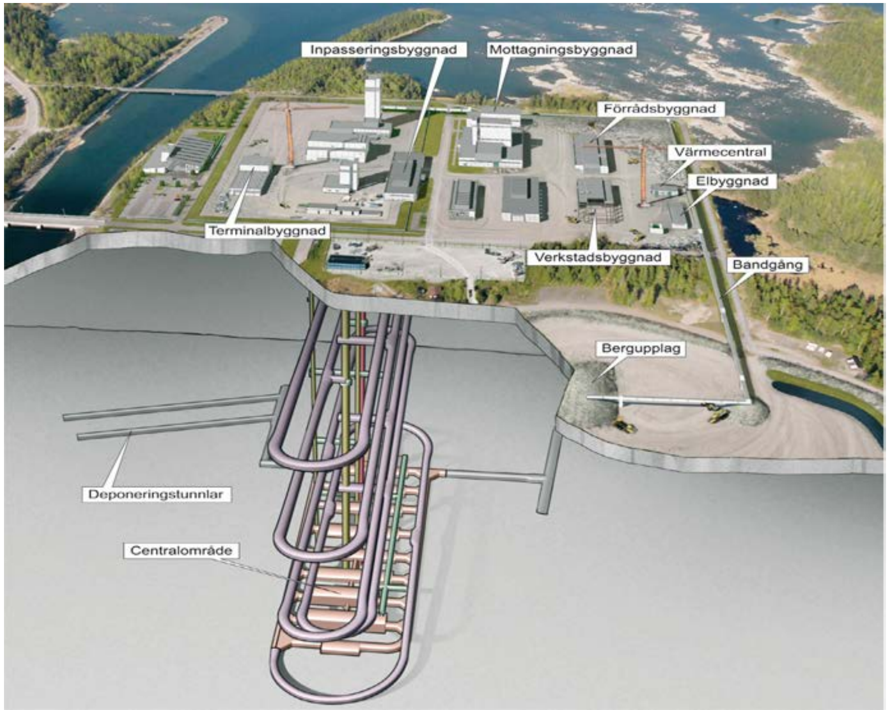
KBS-3 system - facilities

Production system for canisters

Encapsulation Plant

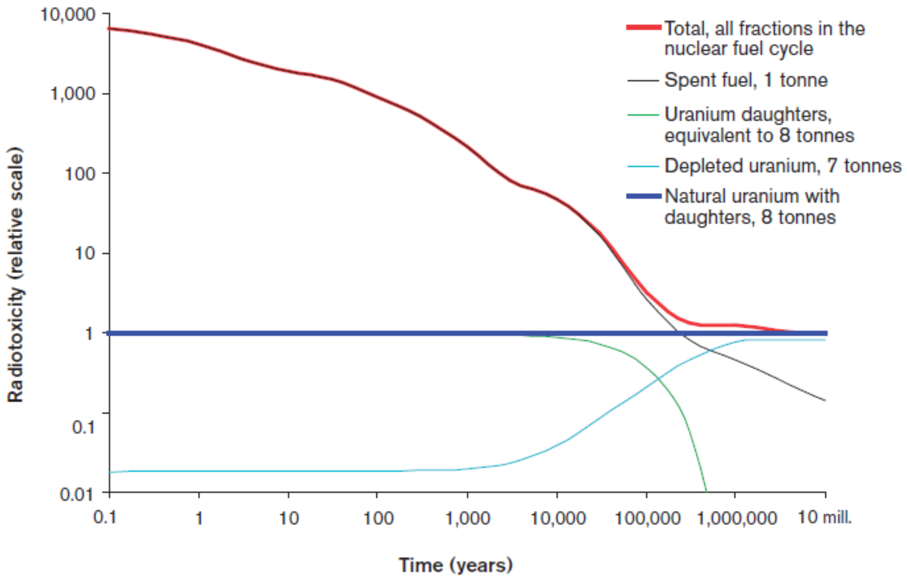


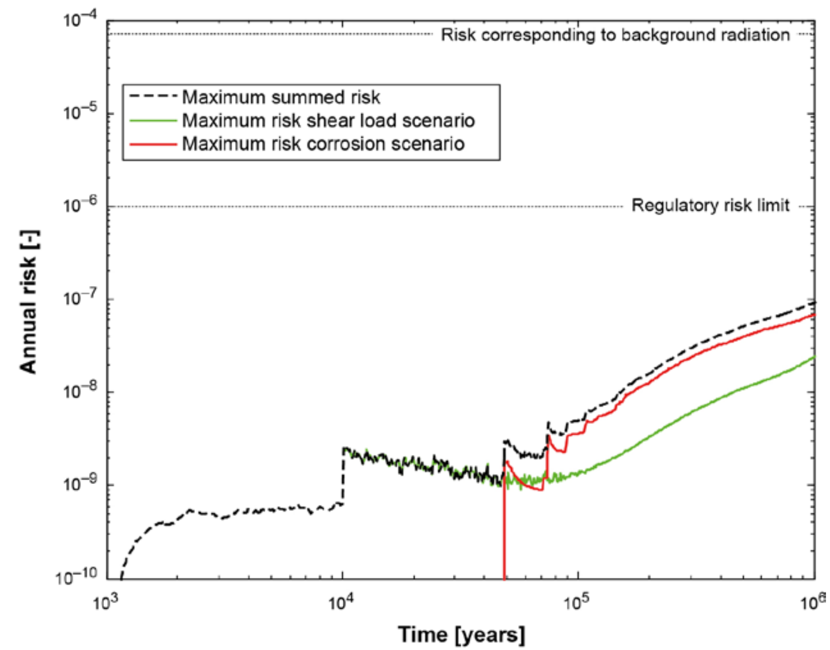
Nuclear Fuel Repository

SKB

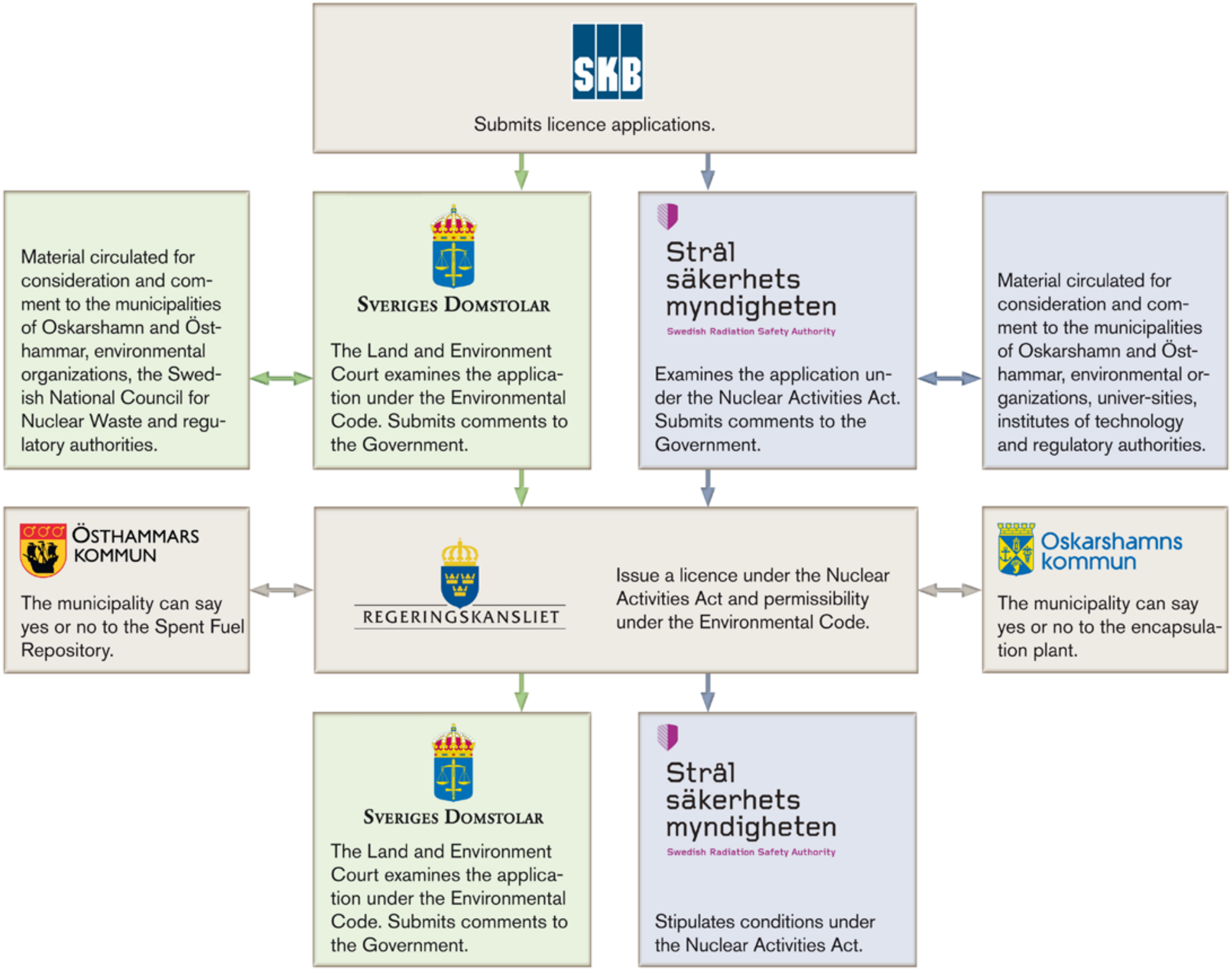
Safety Assessment – SR-Site

- Investigate whether the repository as designed and adapted to the Forsmark site will be safe
- Forms an essential part of SKB's license application
  - KBS-3 repository concept
  - The Forsmark site
  - All spent nuclear fuel forecasted to arise in Sweden's nuclear energy program
- Future evolution the next 10^6 years
  - "*annual risk … (must) not exceed 10^{-6} for a representative individua*l" (SSMFS 2008:37)
  - After 100,000 yrs, radiotoxicity comparable with that of the natural uranium ore once used to produce the fuel
- 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.

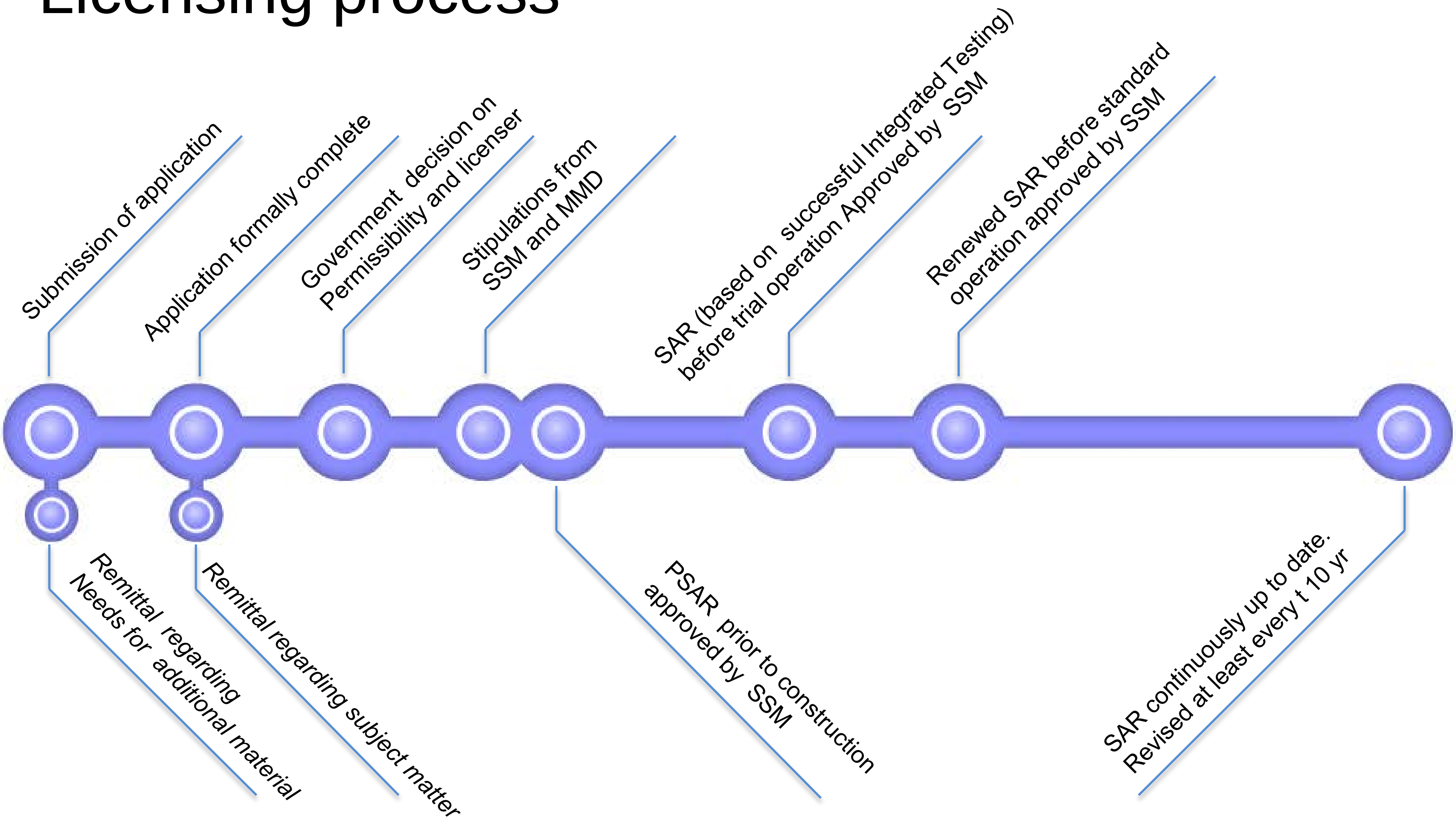




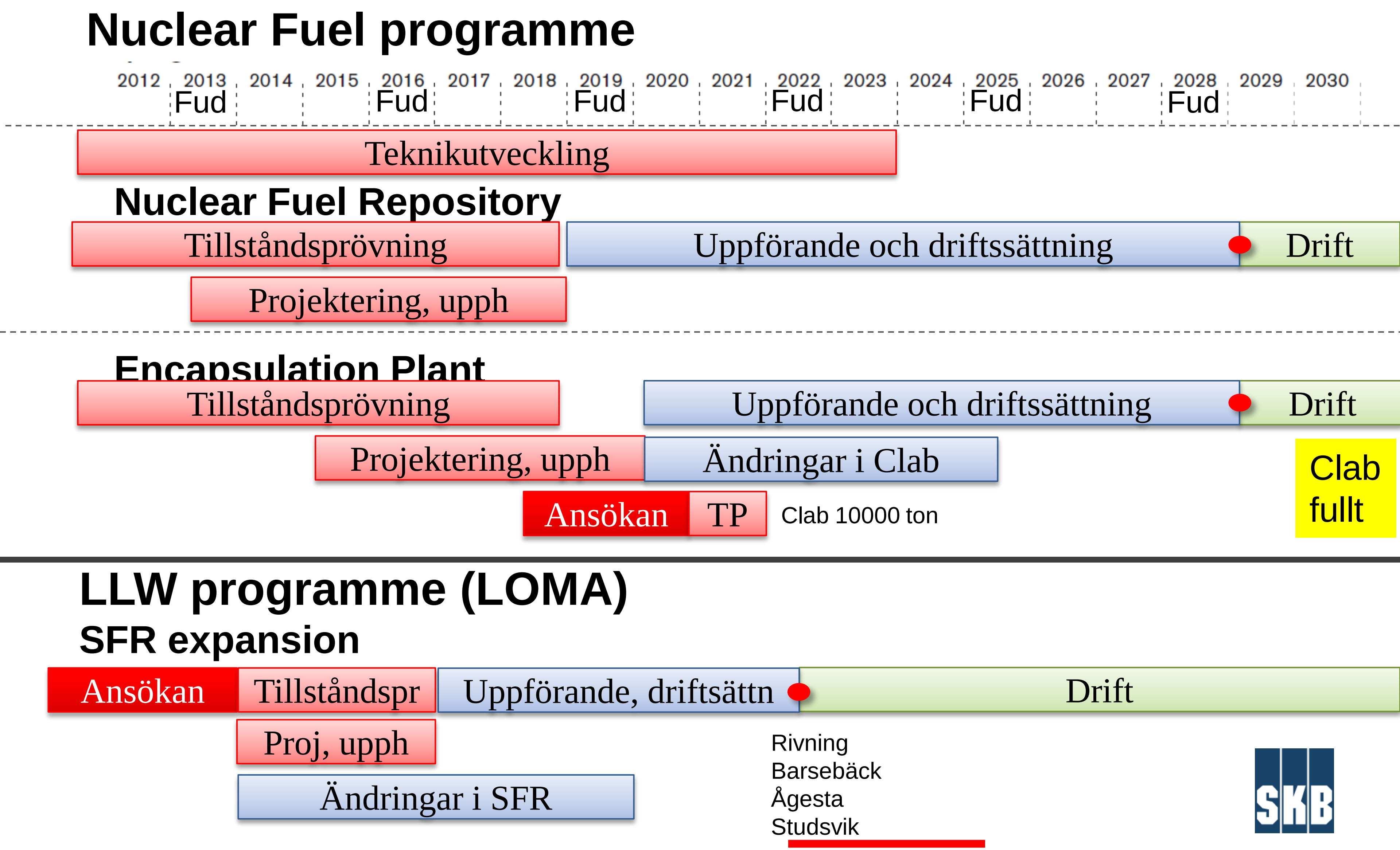
Licensing process



Licensing process

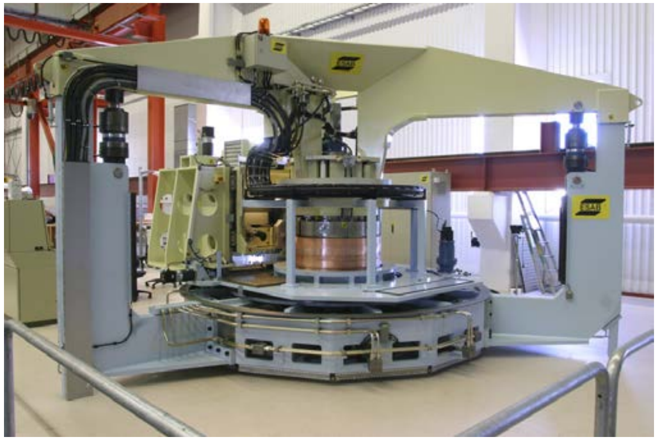


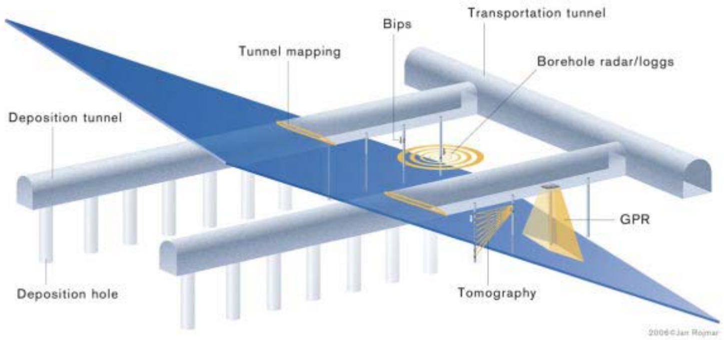
SKB time schedule – construction start by 2019



Preparing for implementation

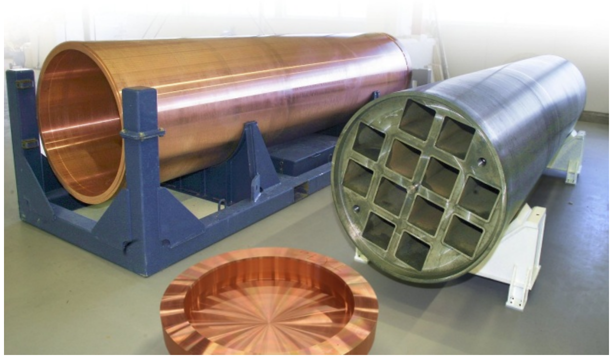
- Technology development and need for detailed investigations
  - SKB has established a technically feasible reference design and layout
  - Detailed designs adapted to an industrialised process designed to fulfilling specific requirements on quality, cost and efficiency need still be developed.
  - 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
- Basic R&D
  - Generalresearch on processes of importance for safety should continue

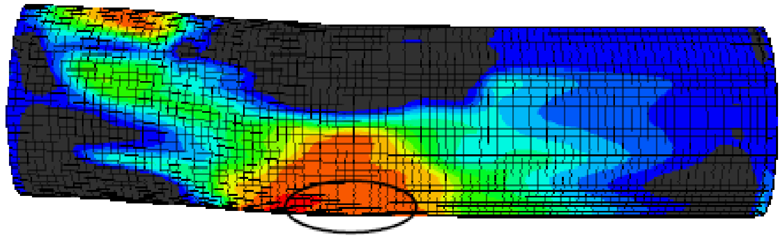




Design premises – long term safety

- Design must be such that it results in a safe repository
- Design premises (TR-09-22) based on previous safety assessment (SR-Can)
  - loads the barriers must withstand
  - restrictions on the composition of barrier materials or acceptance criteria for the various underground excavations
- Example – handle shear load
  - Canister: Should remain intact after a 5 cm shear movement at 1 m/s for buffer material properties of a 2,050 kg/m^3
  - Buffer: Maximum buffer density<2050 kg/m^3: Avoid large fractures in deposition holes
  - Rock: Deposition holes are not allowed to be placed closer than 100 m to deformation zones with trace length longer than 3 km. Avoid large fractures in deposition holes
- Revised design premises envisaged as the basis for the preliminary safety analysis report that SKB must submit and receive approval before the start of construction





Technology Development Plan – Nuclear Fuel

- SKBdoc id 1325700
- Objective:
  - Clarify and justify the technology needed in order to operate the repository (completed technology development), when it needs to be done and the resources required.
- Aim
  - Common holistic view and understanding of what is needed to reach the target operating facility
  - Contribute to the overall planning when the various development efforts need to be initiated in relation to the program plan for nuclear fuel program with regard to the time and resources technology development needs.
  - Provide feedback to the program plan and the assumptions underpinning it.
  - Combine the strategic planning, with the more short-term work planning.
  - Provide evidence and arguments in the upcoming VP-work and in the longer-term strategic planning of SKB's efforts.
  - Be a tool for long-term resource planning (including staffing plans for Technollogy Development Department)
  - Provide input to the RD & D program
  - Provide a basis for cost estimates

Structure

1. **Inledning**
   – Bakgrund, Mål och syfte
2. **Generella förutsättningar för teknikutveckling**
   – System: Produkter och processer, Ansvarsförhållanden
   – Projektstyrmodellen Leveransstyrmodellen, Teknikutvecklingsmodellen
   – Var bör teknikutveckling genomföras**?**
3. **Konstruktionsförutsättningar och andra krav**
4. **Övergripande milstolpar för teknikutveckling**
5. **Linjevisa kapitel Bränsle, Kapsel, BBC, Berg, Tekniska system**
   – Inledning
   – Produkter och processer
   – Milstolpar
   – Nuläge
   – Strategier och aktiviteter för att nå uppsatta milstolpar
   – Kopplingar och beroenden
   – Utmaningar

10. **Resursbehov**
11. **Tidsplan**
12. **Risker**
13. **Slutsatser**

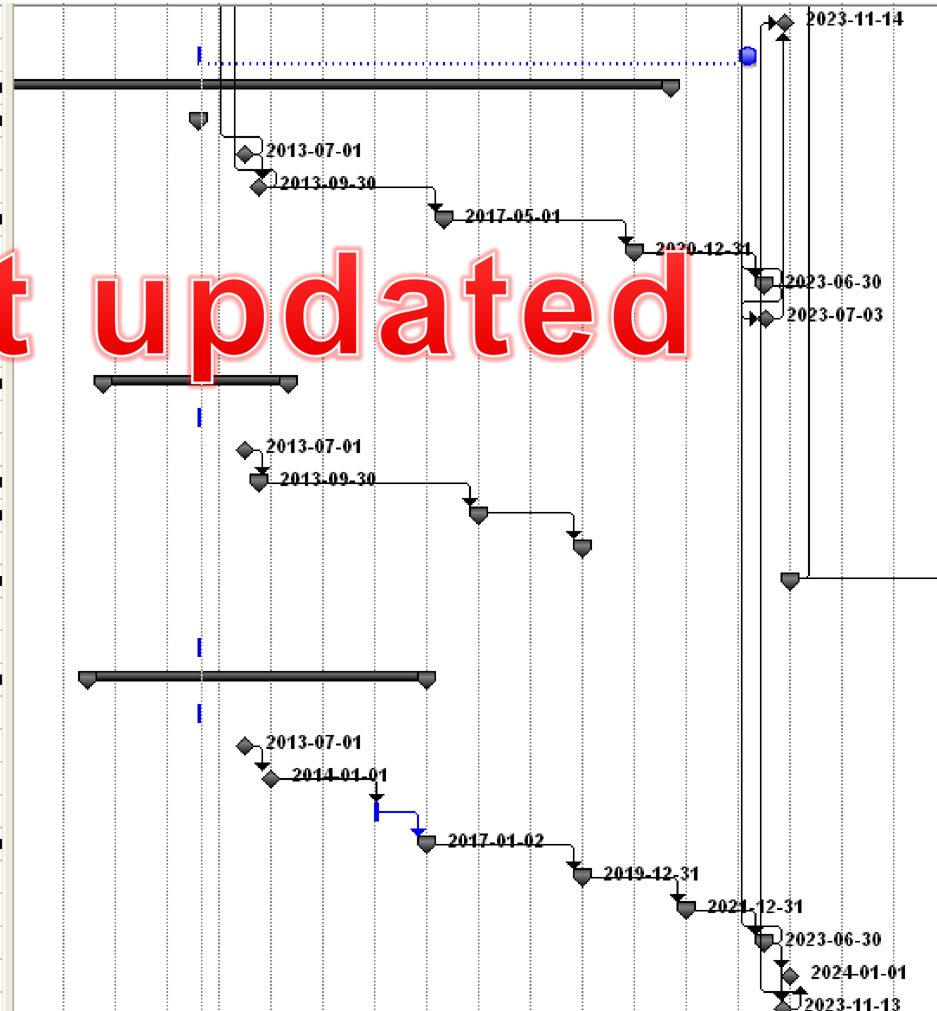
- ***Introduction***
  – *Background, Objectives and purpose*
- ***General preconditions for technology development***
  – *System: Products and processes Responsibilities*
  – *Project Control Model Supply Control Model, Technology Model*
  – *Where should technology be implemented?*
- ***Design premises and other requirements***
- ***Overall milestones for technology development***
- ***For each production line (Fuel, Canister, BBC, Rock, Technical systems***
  – *Introduction*
  – *Products and processes*
  – *milestones*
  – *Situation*
  – *Strategies and activities to achieve set milestones*
  – *Linkages and dependencies*
  – *challenges*
- ***Resource needs***
- ***Timetable***
- ***Risks***
- ***Conclusions***

SKB

Milestones - related to nuclear fuel programme milestones

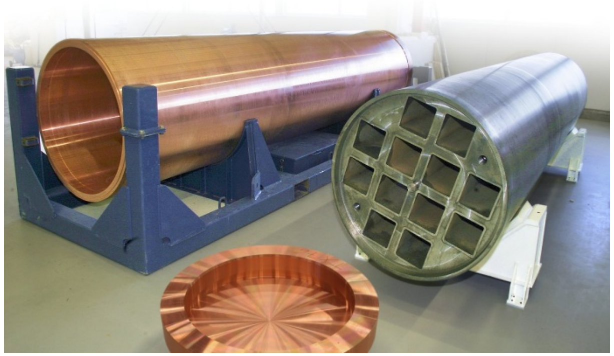
Times not updated

Underlag till SAR klara	ti 23-11-14
BBC	må 12-08-06
⊞ Pågående projekt, BBC	ti 08-01-01
⊞ Planerade projekt, BBC	må 12-08-06
Underlag till komplettering av ansökan framtagna, BBC	må 13-07-01
Underlag till PSAR och Suus framtagna, BBC	må 13-09-30
⊞ Underlag till detaljprojektering produktionsbyggnad klart	må 17-05-01
⊞ Deponeringssekvensen f[illegible] i[illegible]efattar även deponering av kapsel med tillhöra	to 20-12-31
⊞ Underlag till samfunktionspr[illegible]ning [illegible]po[illegible]rt, B[illegible]	fr [illegible]-30
Underlag till SAR framtagna, [illegible]C	m[illegible]3-07[illegible]3
KAPSEL	må [illegible]-06
⊞ Pågående projekt, Kapsel	må 10-10-04
Planerade projekt, Kapsel	må 12-08-06
Underlag till komplettering av ansökan framtagna, Kapsel	må 13-07-01
⊞ Underlag till PSAR och Suus framtagna, Kapsel	må 13-09-30
⊞ Underlag till detaljprojektering Kapselfabrik	må 18-01-01
⊞ Teknikutveckling innan provtillverkning	on 20-01-01
⊞ Teknikutveckling inför samfunktionsprovning - deponering klart	må 24-01-01
Underlag till SAR framtagna, Kapsel	on 27-06-30
BERG	må 12-08-06
⊞ Pågående projekt, Berg	to 10-06-17
Planerade projekt, Berg	må 12-08-06
Underlag till komplettering av ansökan framtagna, Berg	må 13-07-01
Underlag till PSAR och Suus framtagna, Berg	on 14-01-01
Underlag till detaljprojektering av tillfarter klart	fr 16-01-01
⊞ Byggstart	må 17-01-02
⊞ Passage av nivån under toppförslutning (-370 m)	ti 19-12-31
⊞ Metoder och delprocesser fungerande för Forsmarksförhållanden framtagna	fr 21-12-31
⊞ Underlag till samfunktionsprovning utbyggnad klart, Berg	fr 23-06-30
Fortsatt utbyggnad av provdrifts/deponeringsområdet	må 24-01-01
Underlag till SAR framtagna, Berg	må 23-11-13



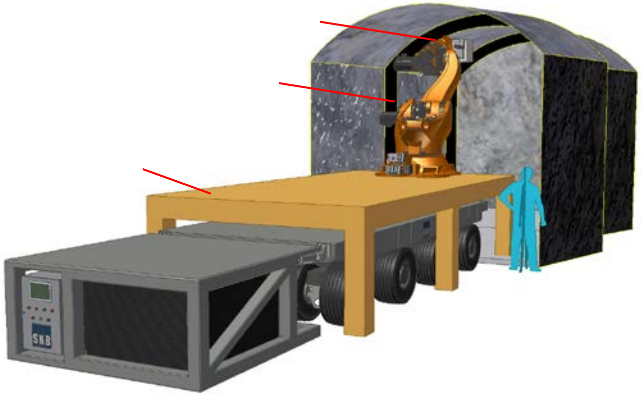
Canister development – critical milestones

- Basis for PSAR
  - Design phase should largely be completed
  - Canister reference design will be verified against requirements
  - Manufacturing should be verified
  - Control Processes should be clarified.
- Basis for detailed Design of Canister Factory
  - Technology and production practices must be developed and operate an industrial scale.
- Start commissioning tests deposition and backfilling
  - Prior to commissioning tests the qualification process need to be completed.
- Basis for SAR
  - Before operating an operating license for the nuclear fuel repository, a complete safety report SAR, needs to be submitted. The documentation to be produced includes besides updating the PSAR documentation quality systems, implemented control systems, management systems, etc..



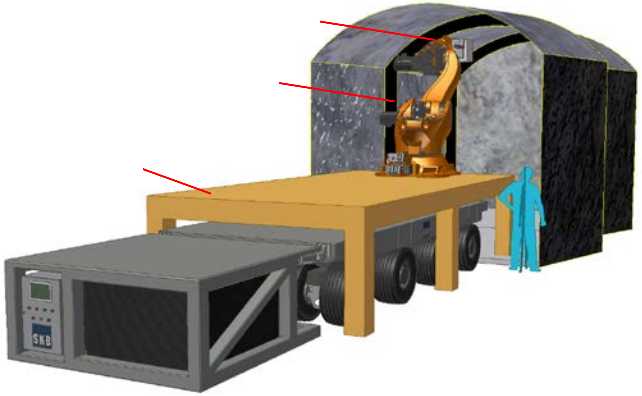
BBC development – critical milestones 1(2)

- Basis for PSAR
  - System design will in most cases be completed
  - Basis for updating production reports for buffer, backfill and closure including product and process mapping and development of quality plans
- Basis for detailed design of bentonite production facility
  - Detailed design of the production of buffer and backfill is to be completed.
  - Specifications of materials need to be established
  - Decisions on pressing technology for buffer blocks
  - Manufacturing methods that work on an industrial scale
  - Control methods that work on industrial scale.
  - Control programs for materials and production need to be established



BBC development – critical milestones 2(2)

- Detailed Design of Deposition system Completed
  - Installation and verification for buffer and backfill must be detailed designed and verified.
  - Verify that the installation of buffer and backfill work as intended within the required timeframes, tests need to be conducted in full scale in underground conditions.
  - Verification of the buffer and backfill blocks from the production plant and related transportation meets the requirements
  - Equipment will be procured and installed in production building.
- Before commissioning tests deposition and backfilling
  - Equipment must be installed in the production building. Operating instructions must be developed, qualification of equipment made
- Basis for SAR
  - Before operating an operating license for the nuclear fuel repository, a complete safety report SAR, needs to be submitted. The documentation to be produced includes besides updating the PSAR documentation quality systems, implemented control systems, management systems, etc...



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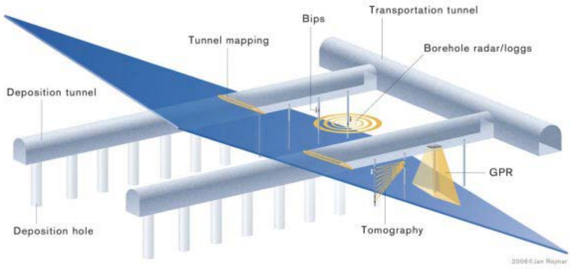
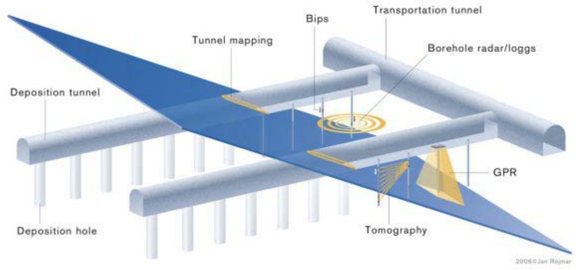
Rock development – critical milestones 1(2)

- Basis for PSAR
  - descriptions of requirements, methodology, execution and result verification (authentication) for all the rock work in the repository., rock work in the deposition area, choice of deposition tunnels and holes, and how the results of the rock work and selection will be verified against the design criteria.
  - Need to give a clear enough picture of the work and the end result, but the development of detail can continue until the detailed design of the deposition area starts.
- Basis for detailed design of access
  - observational method in the detailed design to be implemented and that the detailed characterization program for ramp and shafts implemented
- Passing the bottom level of the top seal (-370m)
  - It must be verified that excavation methods, monitoring and control, methods for rock reinforcement and grouting meets the requirements relating to the level below the top seal.



Rock development – critical milestones 2(2)

- Testing Area - Methods and sub-processes functioning for underground excavation for Forsmark conditions developed
  - Verification of site model / site understanding
  - Test that the developed criteria for the selection and qualification of deposition hole works in practice.
  - Drill deposition holes and test production of bevel in Forsmark rock
  - Excavation methods including reinforcement and grouting set
  - Flat tunnel floor for Forsmark conditions
- Before commissioning tests on excavation of deposition area
  - Methods and sub-processes for underground excavation established. In addition to this, you need the following to be completed:
  - Test deposition tunnel with deposition holes drilled to specification finished.
  - Organization and decision processes set.
- Basis for SAR
  - A description of the entire underground construction process of qualification of canister positions and own organization. This description should be updated based on the results from verifying tests

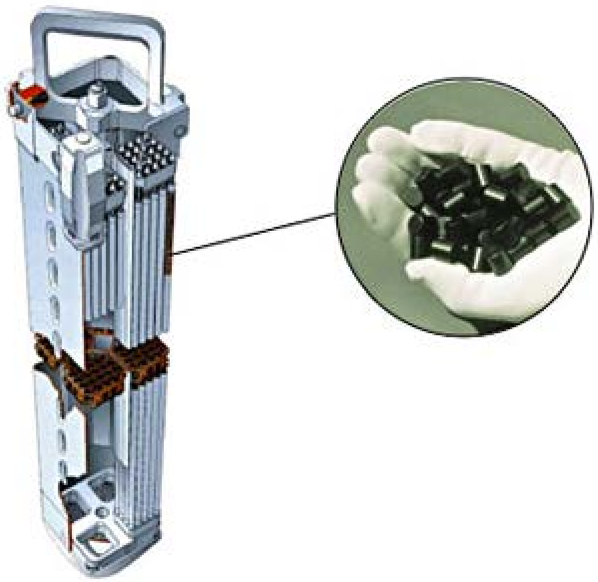


Technical system – (Machines)

- Basis for PSAR
  - basis for updating the production reports and existing system descriptions
- Basis for detailed design of bentonite production faciltiy
  - The equipment needed in the production building consists almost entirely of standard machines. "Concepts and Definitions" still need to be conducted to provide data to the specifications and equipment selection.
- Deposition sequence established
  - Prototype equipment is available and can be used at planned full-scale tests of the buffer and backfill.
  - Design and development of equipment for the handling and transport of the canister, buffer and backfill must be completed.
  - Prototypes of special machines need to have been developed and tested.
  - The control programme must be developed and equipment for the control of buffer and backfill installation.
- Before commissioning tests on excavation of deposition area
  - Equipment needed for excavation of the deposition area needs to be in place and must have completed integration testing.
- Before commissioning tests deposition and backfilling
  - The deposition system will be deployed at the commissioning tests which means that the technical systems for the handling and transport of canister, buffer and backfill must be in place and with completed integration testing.

The spent fuel

- Basis for PSAR
  - Issues brought up in SSM's review of license application
- Basis for detailed Design of Clink
  - System design of methods for fuel identification and residual heat measurement completed
- Start commissioning tests of Clink and transportation system
  - Prior to these tests equipment should be purchased, installed and tested.
  - The qualification process need to be completed.
- Basis for SAR
  - Before operating an operating license for the nuclear fuel repository, a complete safety report SAR, needs to be submitted. The documentation to be produced includes besides updating the PSAR documentation quality systems, implemented control systems, management systems, etc..



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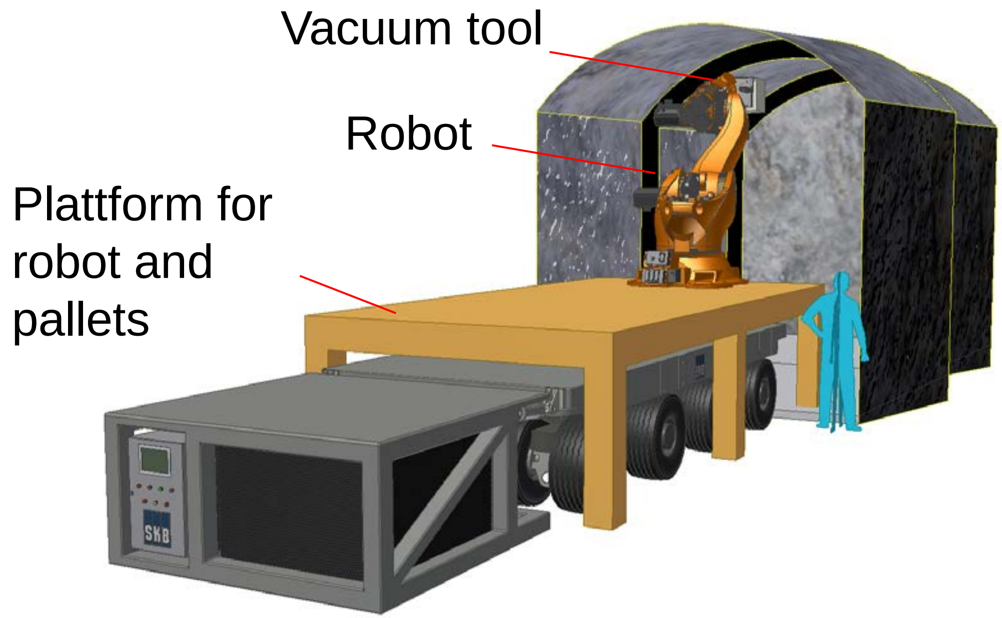
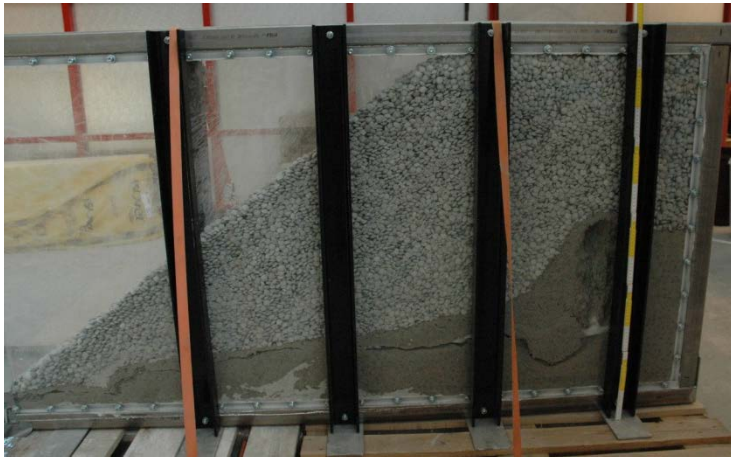
Large Scale Demonstration Experiments

Deposition tunnel backfilling

- DP1 Design
- DP2 Pellet optimization
- DP3 Block production and industrialization
- DP4 Installation
- (DP 5)
- DP6 Technique for water handling during backfilling



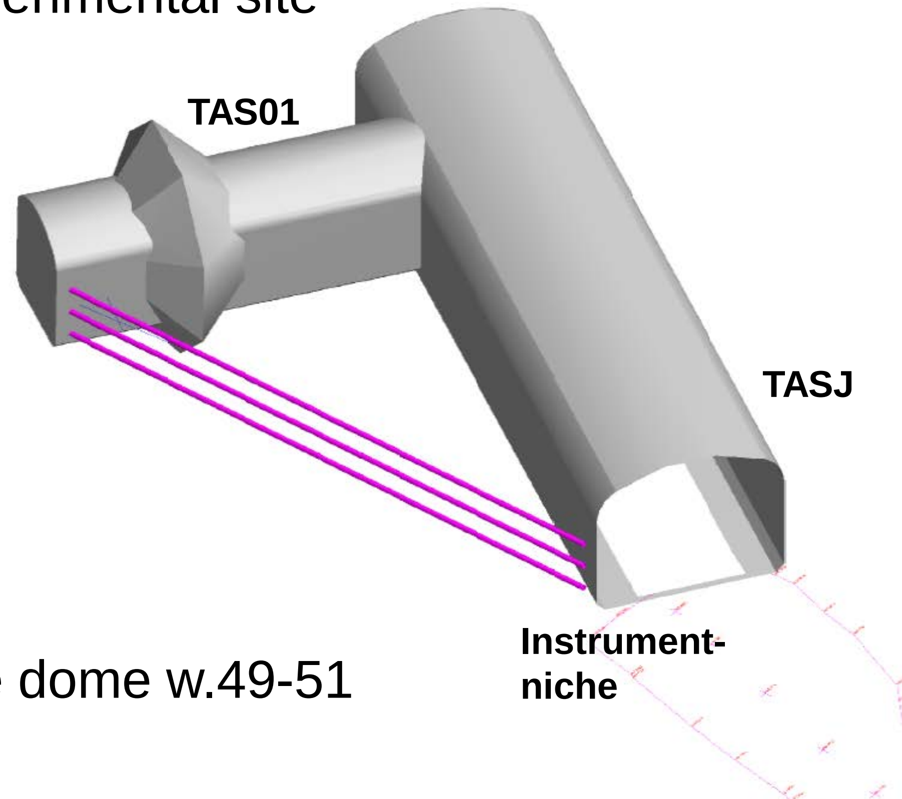


Backfilling – full scale experiment

- Why underground?
  - Show that methods work under
  - actual geometry (confined space, installations,…
  - environment (moisture, inflows..)
- Issues
  - Control of experimental variables?
  - Risk of failures with premature tests
  - PR issues

Plug development (KBP1004), status Oct. 2012

- Design of the full scale test is completed
- Completed laboratory tests on clay, filter-materials and concrete
- Scale model test is running at Clay Technology
- Pre-casting of low pH concrete (B200) at Äspö
- Investigations for a feasible experimental site
- Three boreholes (each 21 m) from a new instrument-niche
- Concrete casting at tunnel face
- Drilling of boreholes for the octagonal slot
- Wire-sawing is ongoing
- Installations w.44-48
- Formwork and concreting of the dome w.49-51



Plugg development

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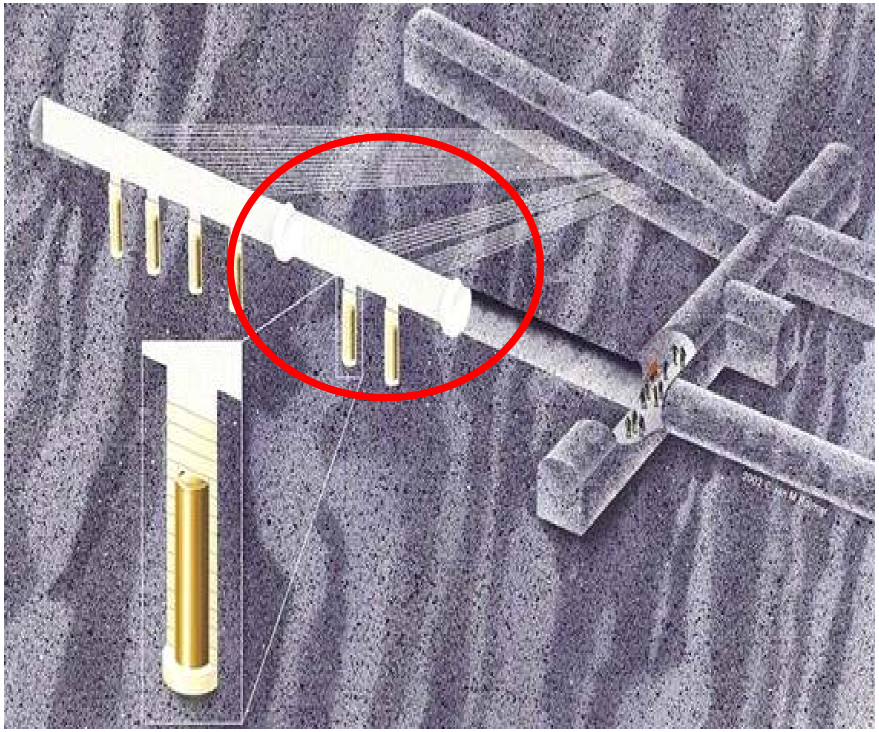
Prototype Repository at Äspö HRL

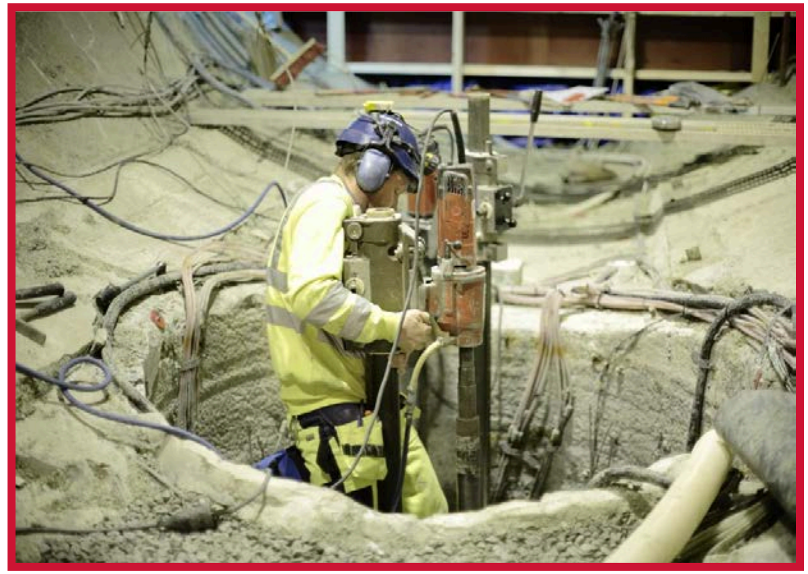


- The inner section was installed 2001
- The outer section was installed 2003
- The retrieval of the outer section started during 2011

Prototype repository

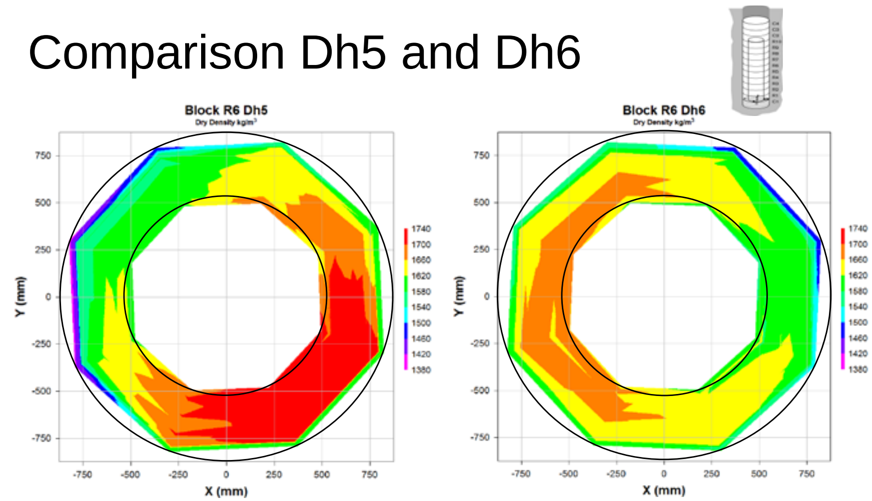
- Excavation of the backfill
  - The backfill has been removed (about 900 tons)
  - About 1100 determinations of water content and density on samples have been made
  - Preliminary analyses indicate that the backfill is fully saturated
  - No evidences of erosion and piping of the filling
- Canister retrieval
  - Possible to handle the limited space at the retrieval of the canister

Water content and density of the buffer



- Large vertical deformations of the buffer
- A consolidation of the pellets
- A swelling of the outer part of the blocks
- The initial inner gap has disappeared
- The water uptake was not axisymmetric

Comparison Dh5 and Dh6



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Copper corrosion – prototype repository

- The copper electrodes in Dh 5 have been retrieved
  - The copper electrodes will examined
  - The bentonite around the electrodes will be analyzed
  - The redox potential will be examined
- *A sample of copper and bentonite have been taken in Dh 5 at the top of the canister*
  - *The copper piece will be examined*
  - *The bentonite will be examined (microbiologic tests, content of copper, Mössbauer-analyzes)*
- Copper samples will be taken from canister in Dh 6
  - The copper samples will be examined

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Need for full scale integrated installation tests?

- Are the procedures for barrier production and canister emplacement practical?
  - Testing tools, equipment, logistics or organisation
  - But, we will not have complete organisation and equipment
  - Still very much to learn
- Verifying that design premises can be met in practice
  - Several requirements not trivial to verify
  - Distribution of buffer density, EDZ, tightness of plugs…
- ”Validating” evolution from state at installation to “saturation”?
  - Show whether the system is behaving as expected, or used to verify that the processes of importance is not neglected.
  - However
    - But often allow only a limited ability to vary or control the boundary conditions
    - Very limited time frames – (saturation may take 100 years or more)
    - Results can be dominated by processes linked to an initial disturbance of the system is of limited importance for the system in the long term
  - *Still: Consider what we can learn from the tests that anyway need to be done*

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Concluding remarks

- Concept and technology development, safety assessment and site characterization an iterative process
- 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