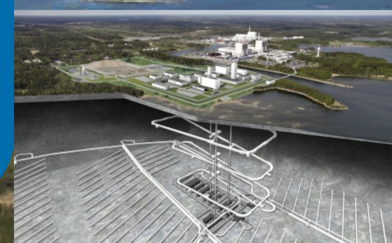
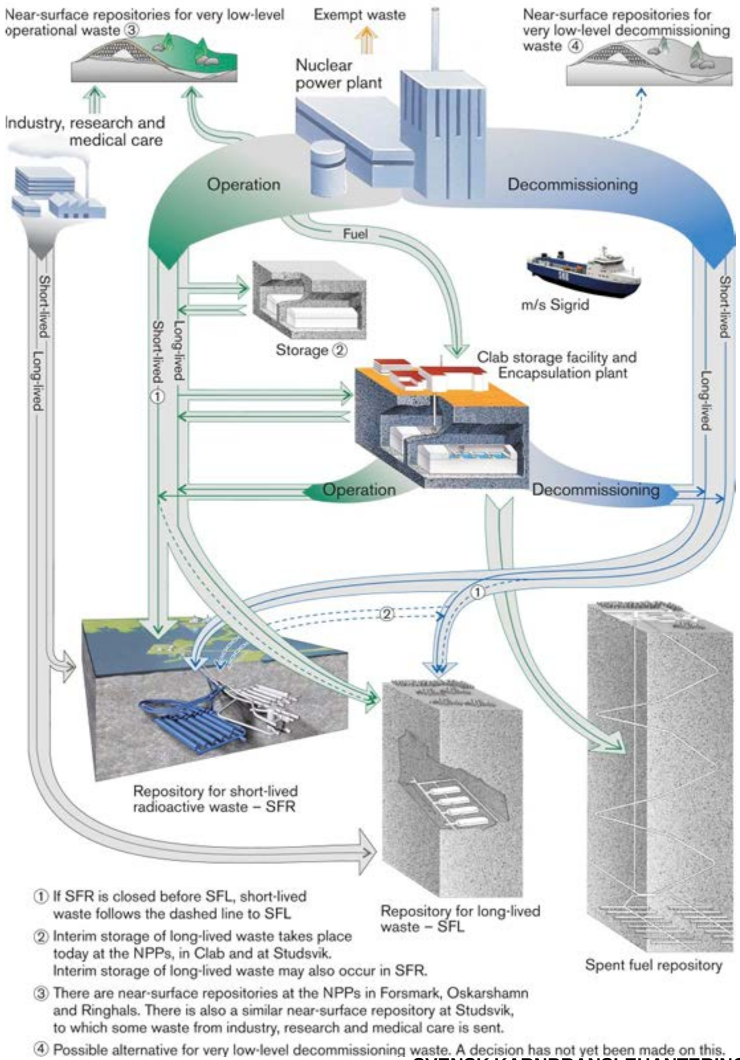
Industrialisation and optimisation of KBS3



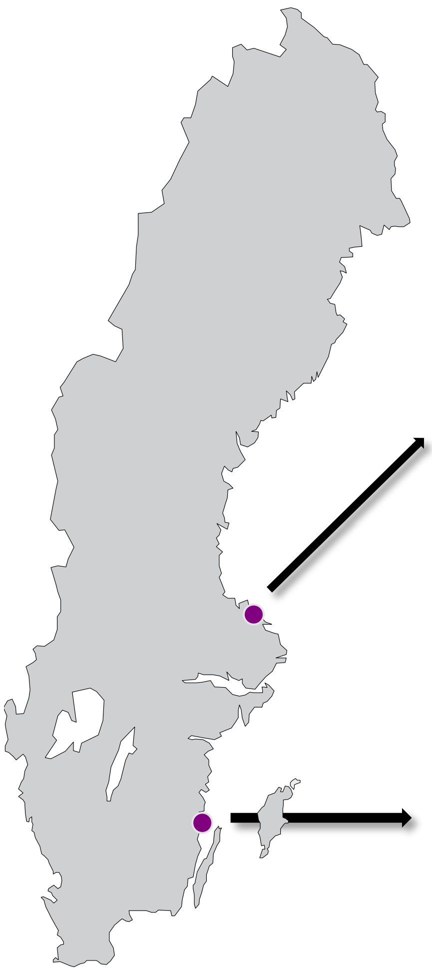
Management and disposal of radioactive waste and spent nuclear fuel in Sweden

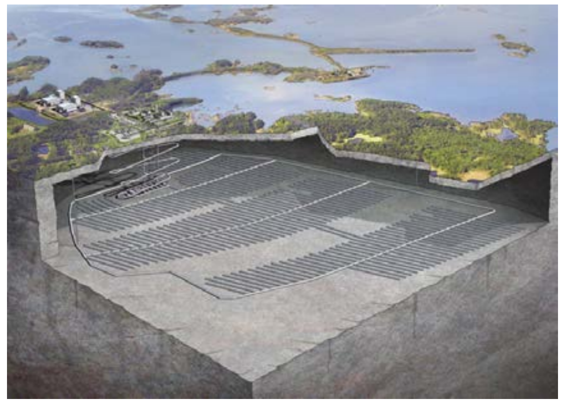
- Based on current planning from NPP's:
- Reference scenario
  - Phasing out the 4 oldest reactors
  - 60 years of operation for remaining plants
- Spent nuclear fuel
  - Approximately 12 000 tonnes HM
- LLW and ILW
  - From operation and decommissioning
  - Approx 170 000 m³ shortlived waste
  - Approx   16 000 m³ longlived waste



The KBS-3 system in Sweden

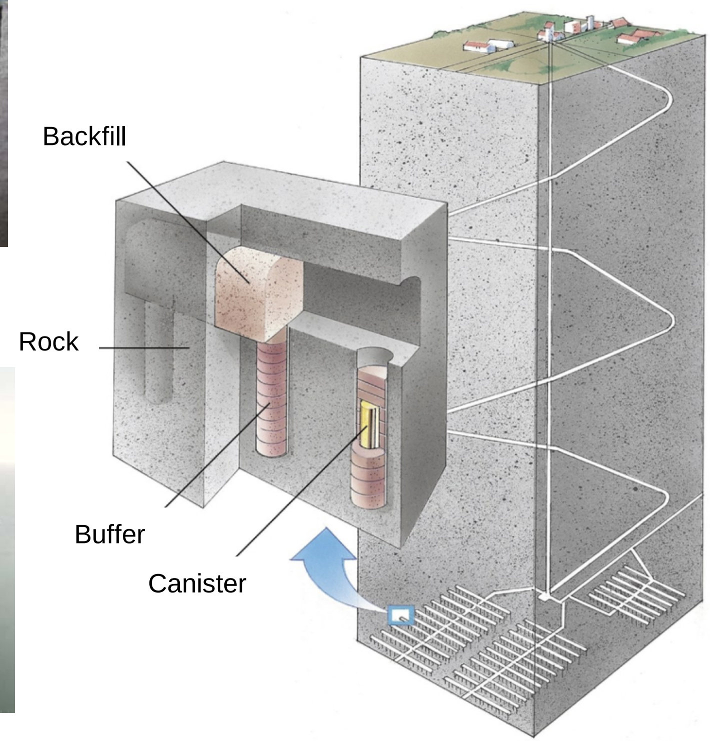
Application submitted in 2011





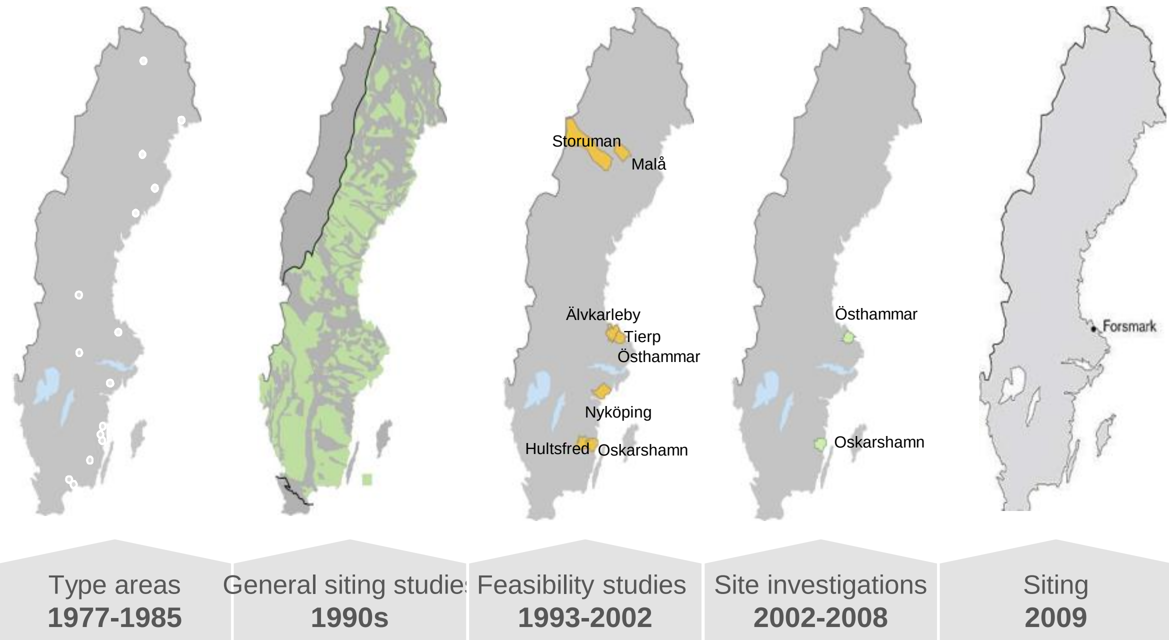
Spent Fuel Repository at Forsmark

Encapsulation plant (Clink) in Oskarshamn



Site selection and license application

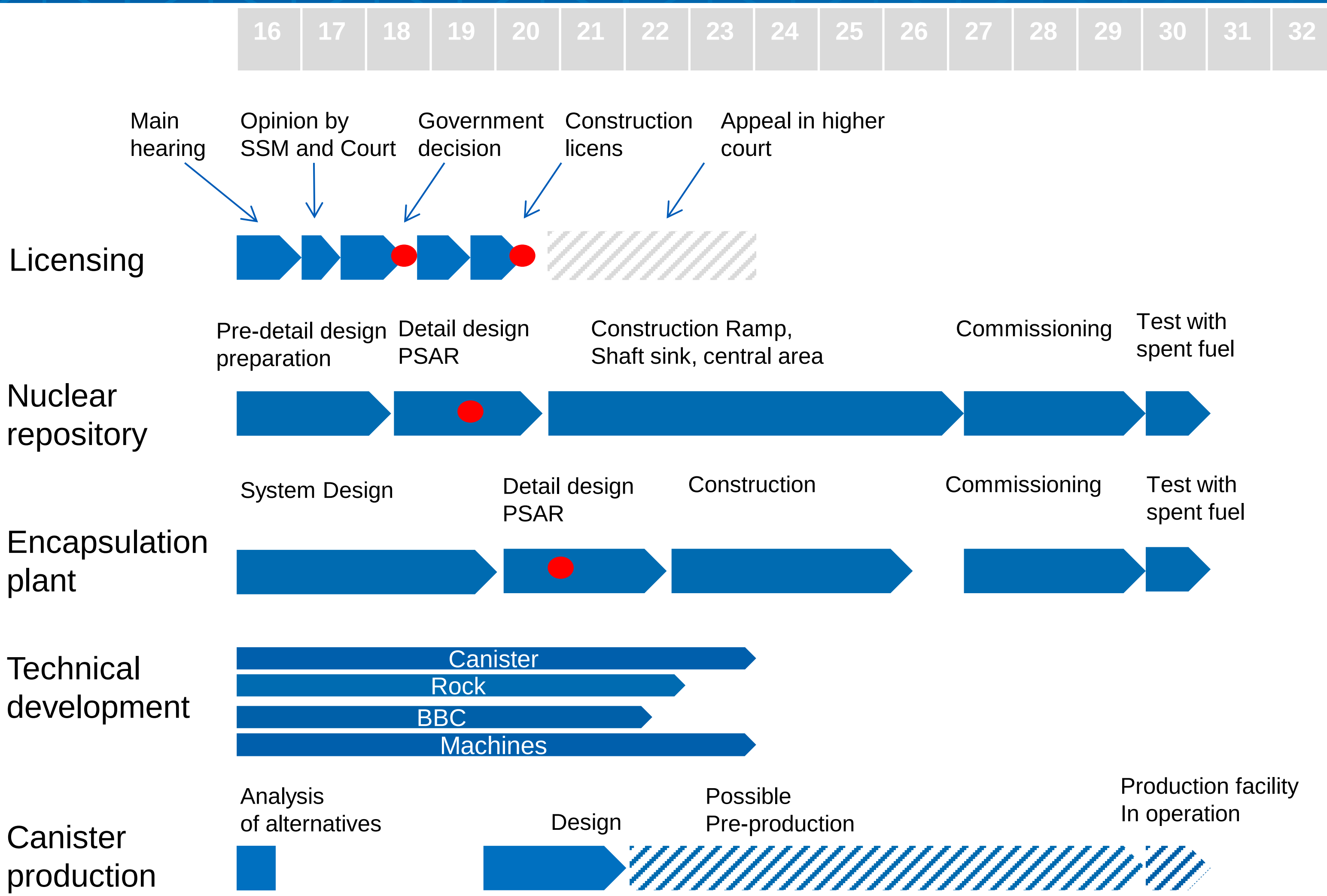
- In 2009 SKB selected Forsmark
  - The rock in Forsmark provides good prerequisites for long-term safe disposal
  - The surface facility can be built within the existing industrial area
- License application 2011
  - Construct and operate a facility for encapsulation of spent nuclear fuel (Clink)
  - Construct and operate a facility for final disposal of spent nuclear fuel (The Spent Fuel Repository)
  - Two legislations (Environmental Code) (Act on Nuclear Activities)
  - Reviewing is ongoing – main hearing late 2016
  - Local veto
  - Swedish Government makes final decisions



Status October 2016

- Environmental Court prepared for Main hearing
  - Probably early 2017
- Statement by Swedish Radiation Safety Authority (SSM)
  - The Swedish Radiation Safety Authority has assessed that the Swedish Nuclear Fuel and Waste Management Company (SKB) has the potential to comply with the Authority’s nuclear safety and radiation protection requirements for the final disposal of spent nuclear fuel. Consequently, the Authority recommends in its statement of findings to the land and environmental court that the repository system should be deemed a permissible activity according to the Swedish Environmental Code.
  - *For future authorization steps, SKB will need to carry out further development of its safety analysis report to demonstrate the repository’s radiological long-term safety*

Time schedule KBS3 Sweden

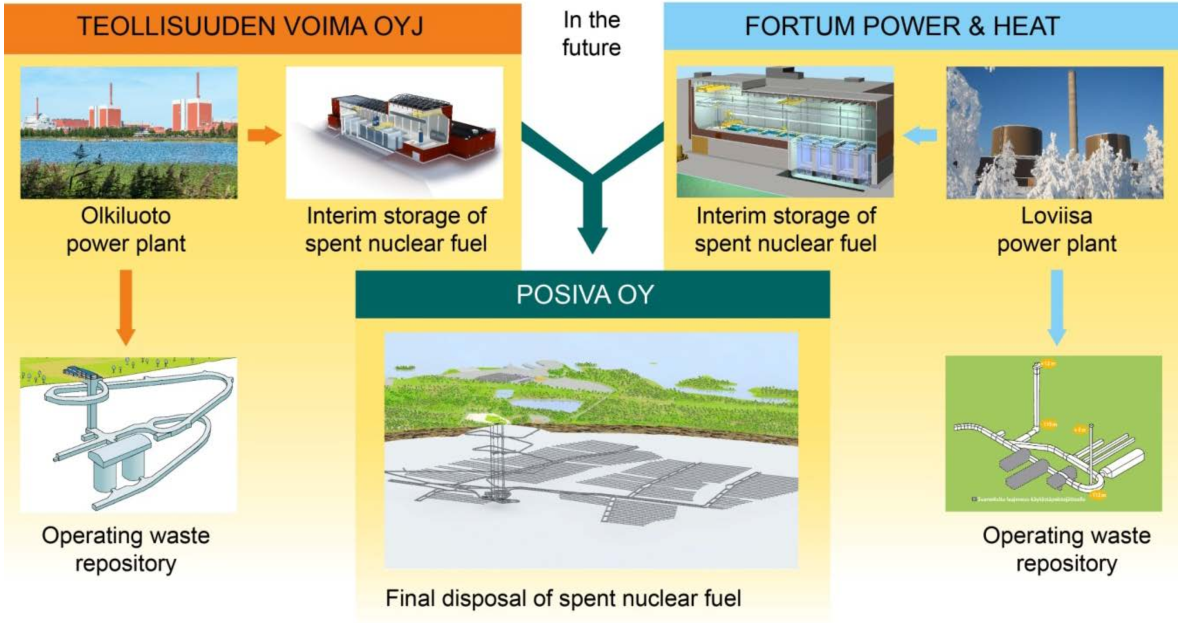


Overall objectives in the SKB RDD plan for KBS-3

- Before the start of construction of the Spent Fuel Repository and the encapsulation portion of the Clink
  - Preliminary Safety Report, PSAR, SR-Site, will be updated with some of the material presented in the supplement to the application under the Nuclear Activities Act and the updates in the initial state as ongoing technology development lead to.
  - The goal of technology development is to ensure that the technology needed to begin construction of the Spent Fuel Repository and the encapsulation portion of Clink, is available before the start of construction.
  - Detailed design phase will essentially have been passed for all barrier systems, except for the parts that require in situ tests. For the Spent Fuel Repository this first regards characterization methods and techniques for the construction of the repository access.
- Construction start deposition area
  - At the start of construction of the deposition area of the Spent Fuel Repository the design requirements for this must be established and therefore also the design and installation methods for the buffer, backfill and plugs need to be finished as well as methods for the host rock characterization and methodology for excavation of deposition tunnels. Control methods to be applied shall be verified.
- Before the trial operation
  - Integration testing and commissioning tests need to need to be conducted in the nuclear fuel repository and be reported in the updated Safety Analysis Report (SAR). These tests will serve as verification of the operations including both further construction and disposal, as a means to ensure that both safety during operation and post-closure safety are maintained. These tests are performed at a late stage with the equipment and with the involvement of the personnel who will operate the facility as a final check that the operation can be carried out as intended
- Before the routine operation of the KBS-3 system
  - An updated safety analysis report, SAR, considering the experience of trial operation is needed. The repository system operation will then evolve into a management phase with recurrent overall assessments of safety and radiation protection every ten years.

Management and disposal spent nuclear fuel by Posiva

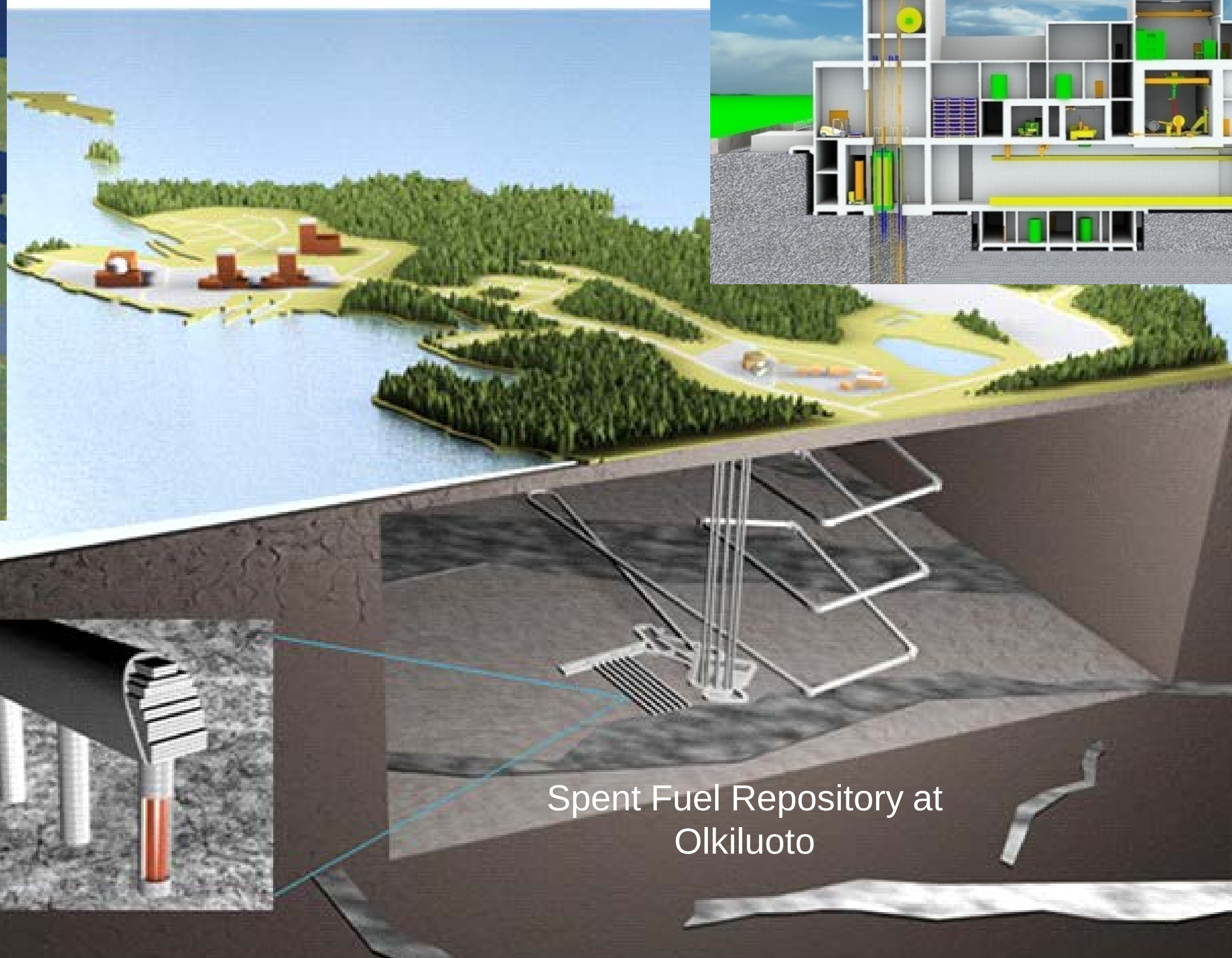
- Posiva's responsibility is the disposal of SF of their owners
- Reference scenario
  - 50 -60 years of operation for the four NPP's in operation in Olkiluoto and Lovisa
  - 60 years of operation for new-built reactor in Olkiluoto



- Spent nuclear fuel
  - The construction license applied for 6 500 tU
- Operators responsibility:
  - Storage of SF and management and disposal of LLW and ILW

The KBS-3 system in Finland

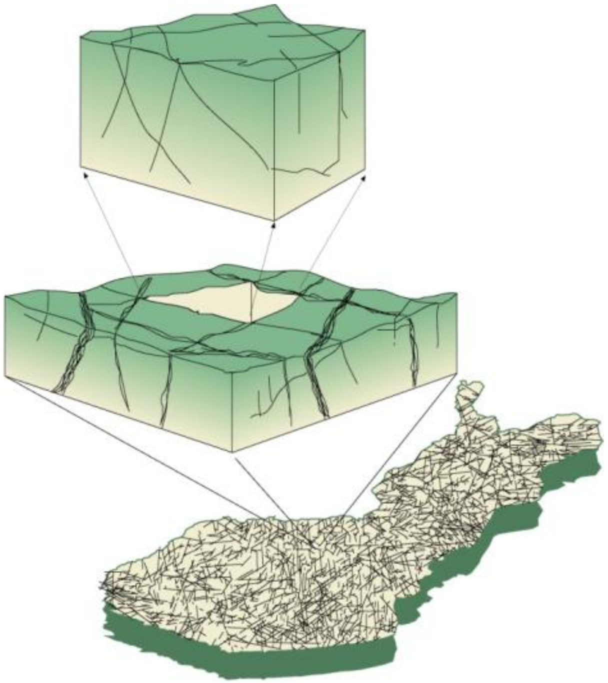
License granted in 2015



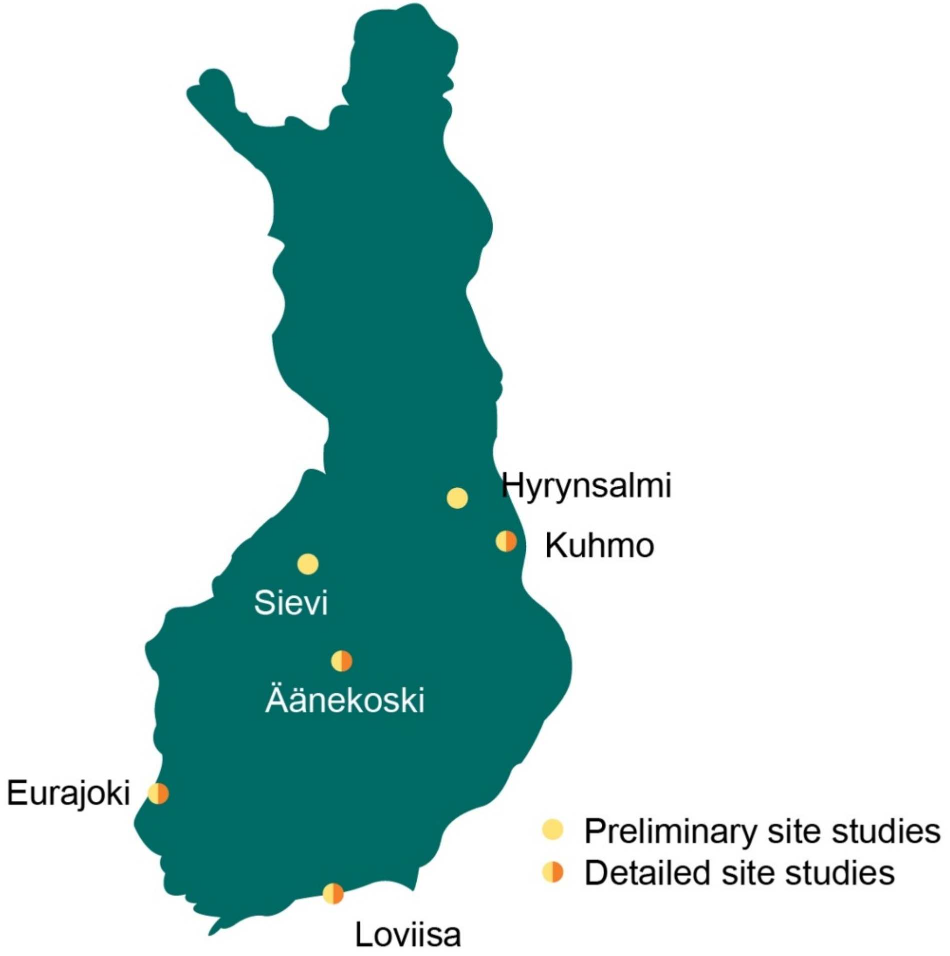
Posiva's site selection research programme 1983 - 2000

Site Identification

1983 - 1985



More than 100 candidate sites were identified



Posiva's licencing process

- In 1999, the disposal site was selected in conjunction with the application for Decision-in-Principle of geological final disposal
- The Decision-in-Principle was ratified by the parliament in 2000 and by the Finnish Government in 2001
- To confirm the suitability of the site, construction of an underground rock characterisation facility ONKALO was started in 2004. The excavation of ONKALO is soon completed.
- In 2012 Posiva submitted a construction licence application for the spent nuclear fuel facility to the MEE
- The detailed technical documentation incl. the safety case was reviewed by STUK during 2013-2014, based on which STUK gave a statement and safety assesment for the MEE in February 2015 stating that final disposal facility can be built to be safe

THE CONSTRUCTION LICENCE!

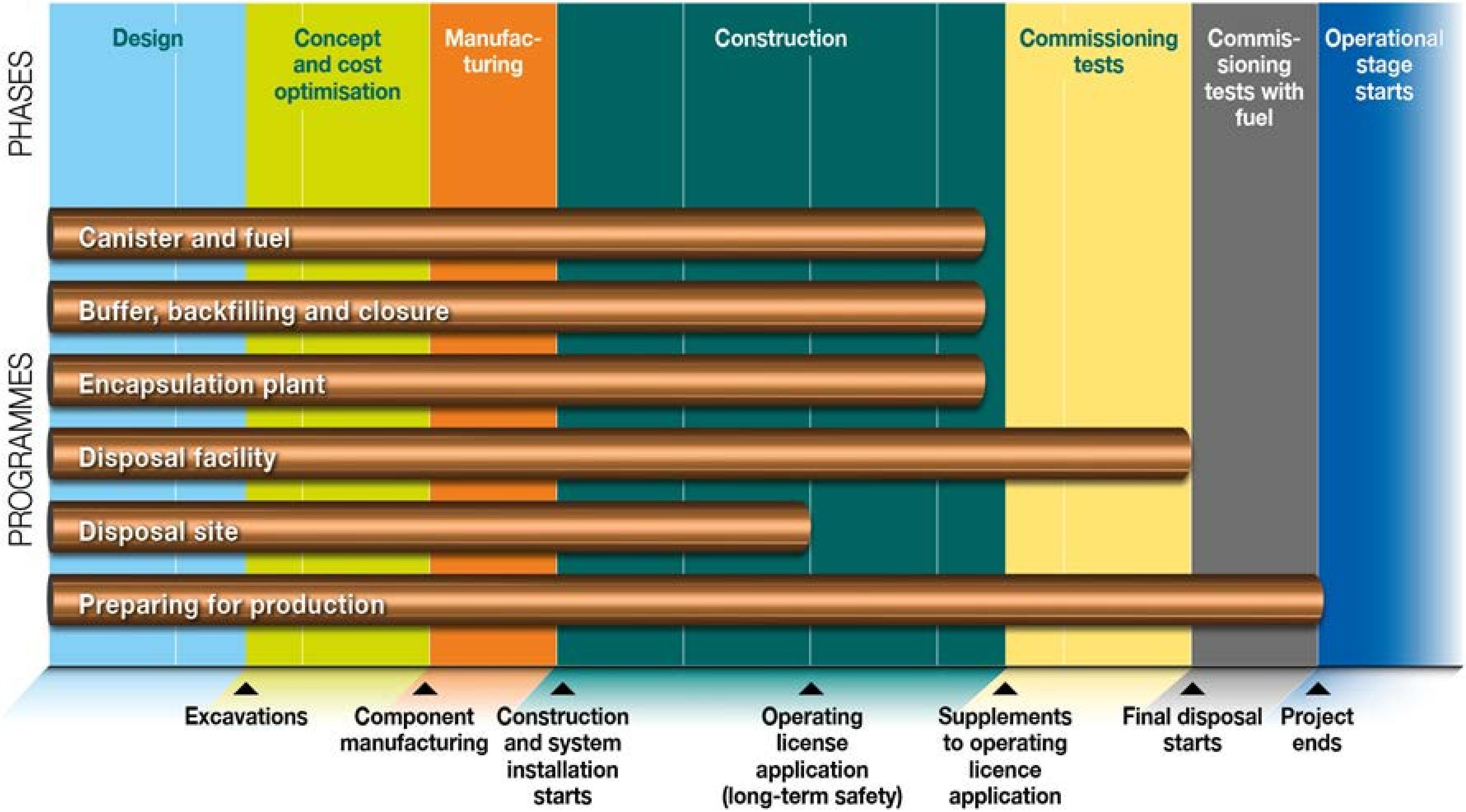
NEWS RELEASE
12 November 2015 at 1.40pm

POSIVA IS GRANTED CONSTRUCTION LICENCE FOR FINAL DISPOSAL FACILITY OF SPENT NUCLEAR FUEL

The Finnish Government has today granted a licence to Posiva for the construction of a final disposal facility for spent nuclear fuel. After an extensive and multidisciplinary research and development work Posiva can now proceed to construction of the final disposal facility in Olkiluoto according to the concept it has developed. The final disposal of the spent fuel generated in the Olkiluoto and Loviisa nuclear power plants into the Finnish bedrock is planned to start in the early 2020's.

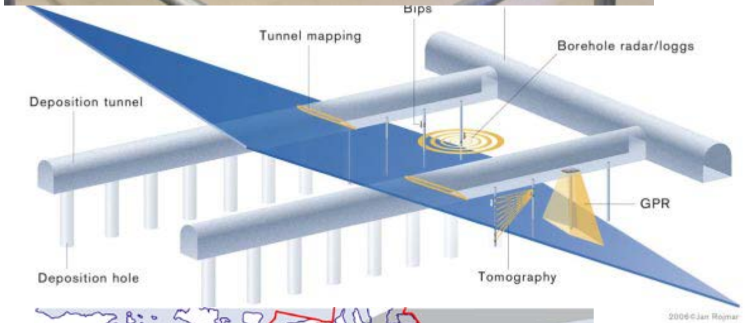
STUK

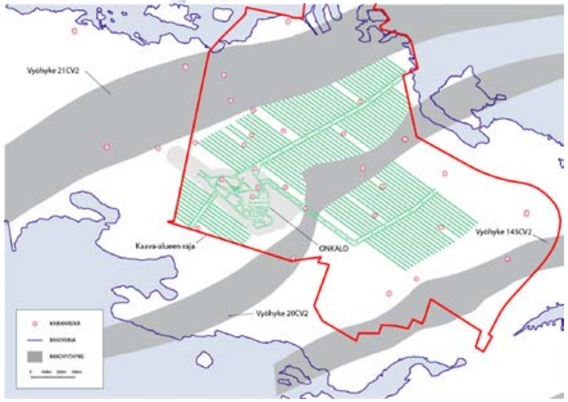
Posivas time schedule



Need for further development

- Technology development and need for detailed investigations
  - SKB and Posiva have established technically feasible reference designs and layouts
  - 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
  - Final repository
  - External production facilities





Overall objectives in the Posiva's RDD plan for KBS-3

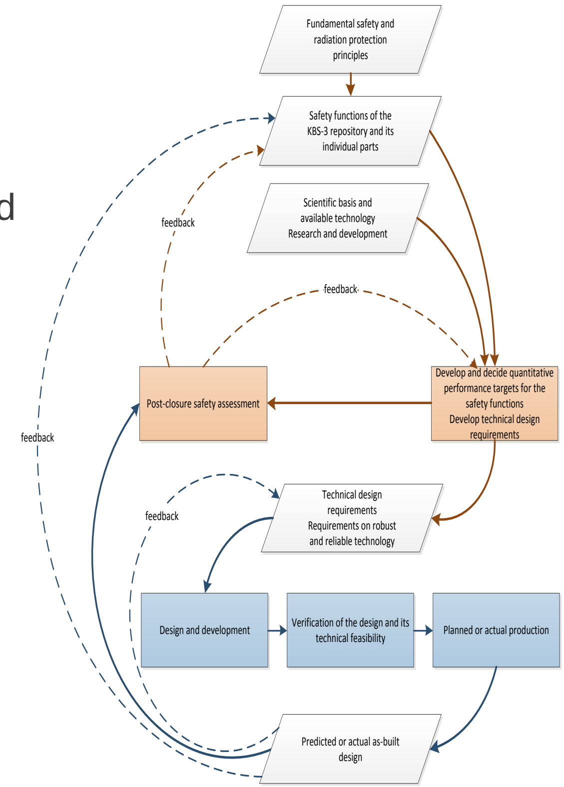
- Before submitting the operation licence
  - The remaining open R&D issues will be closed
  - The safety case TURVA-2012 will be updated. TURVA-2020 project has been launched and work is on-going
  - Detailed design of the EBS and the host rock addressed to meet the requirements
- Construction start
  - The detailed design of the encapsulation plant and the final disposal facility is on-going
- Before the trial operation
  - Full-scale in-Situ system test FISST and commissioning tests need to be conducted in the nuclear facilities and be reported in the FSAR. These tests will serve as verification of the operations to ensure that both safety during operation and post-closure safety are maintained. These tests are performed with the equipment and with the involvement of the personnel who will operate the facility as a final check that the operation can be carried out as intended
- Before the routine operation of the KBS-3 system
  - Disposal operations in one deposition tunnel will be performed with the spent fuel in the canisters

Design Requirements in license application

- Initial set of design requirements is specified in the SKB and Posiva license applications, respectively.
- Design requirements (design premises)
  - Requirements which the KBS-3 facilities with their barriers must satisfy in order to ensure safety both during operation and after closure, e.g.
  - what mechanical loads the barriers must be able to withstand
  - limitations concerning the composition and properties of the barrier materials
  - acceptable deviations in the dimensions of the barriers
  - acceptance criteria for the various underground openings.

Formulation of requirements not trivial

- Safety Assessment perspective
  - Requirements should be sufficient to lead to safe repository
  - Assessment usually studies one or a few specific designs
  - Would generally not say if there are other designs that may also lead to safety.
- Designers perspective
  - Requirements needs to be possible to implement and verify
  - Easy to formulate rules that would lead to safety, but are impossible to implement and verify
- *Iteration and "negotiations" between safety assessment and design work needed*
- *SSM*
  - SSM believes that SKB's methodology regarding design *requirements are appropriate for this stage of SKB's program*
  - *SSM considers that SKB for a possible application for a construction would need to update the design requirements based on the results of the safety assessment SR-Site and on SSMs findings in its review*



Harmonizing and evolving the requirements

- Structure
  - *Fuel, Canister, Buffer, Backfill, Closure, Host rock and underground openings*
  - *Design, purpose and function in the KBS-3 repository*
  - *Safety functions and performance targets*
  - *Technical design requirements*
- Reporting
  - Title: *Safety functions, performance targets and technical design requirements of a KBS-3V repository*
  - Publish jointly with Posiva's Design Basis report (to clarify relation) and ensure consistency with KUPP/VAHA report
  - Potentially first report in a common SKB/Posiva report series
- Time schedule
  - Formal review completed
  - Approved report – During 2016

Safety functions, performance targets and technical design requirements for a KBS-3V repository

Conclusions and recommendations from a joint SKB and Posiva working group

Factual review version 2016-05-16

Content

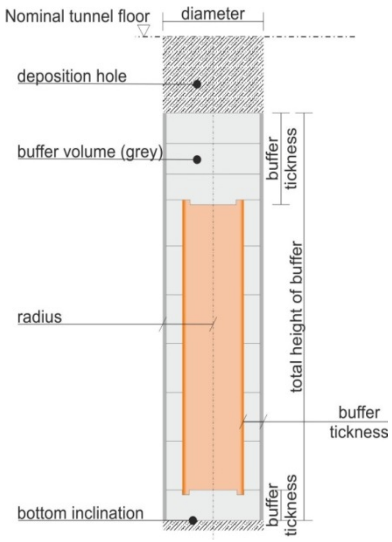
POSIVA

SKB

Example: Buffer requirements

- Old formulations
  - Posiva:*The buffer shall be so designed that it will mitigate the mechanical impact of the postulated rock shear displacements on the canister to the level that the canister integrity is preserved*
  - SKB: *Initially deposited buffer mass should be such that it corresponds to a saturated buffer density in the volume initially filled with buffer that is: less than 2,050 kg/m^3 to prevent too high shear impact on canister and higher than 1,950 kg/m^3 to ensure a swelling pressure of 2MPa*
- Assessment:
  - Posiva's requirement too general. SKB's requirement only valid for MX-80. Neither requirement can be tested in practice

characteristic	**technical design requirement**	**related safety function(s)**
material specific relation dry density – swelling pressure	The minimum dry density yielding a swelling pressure >3 MPa, determined in specific laboratory test.	limit microbial activity keep the canister in position ensure diffusive transport
	The maximum dry density yielding a swelling pressure < 10 MPa, determined in specific laboratory test.	limit pressure on the canister
material specific relation dry density – hydraulic conductivity	The dry density yielding a hydraulic conductivity < 10^{-12} m/s, determined in specific laboratory test.	ensure diffusive transport
material specific relation dry density – shear strength	The dry density yielding an unconfined compressive strength at failure < 4 MPa at a deformation rate of 0.8%/min when determined for fully Ca-exchanged material specimens in a specific test.	mitigate rock shear

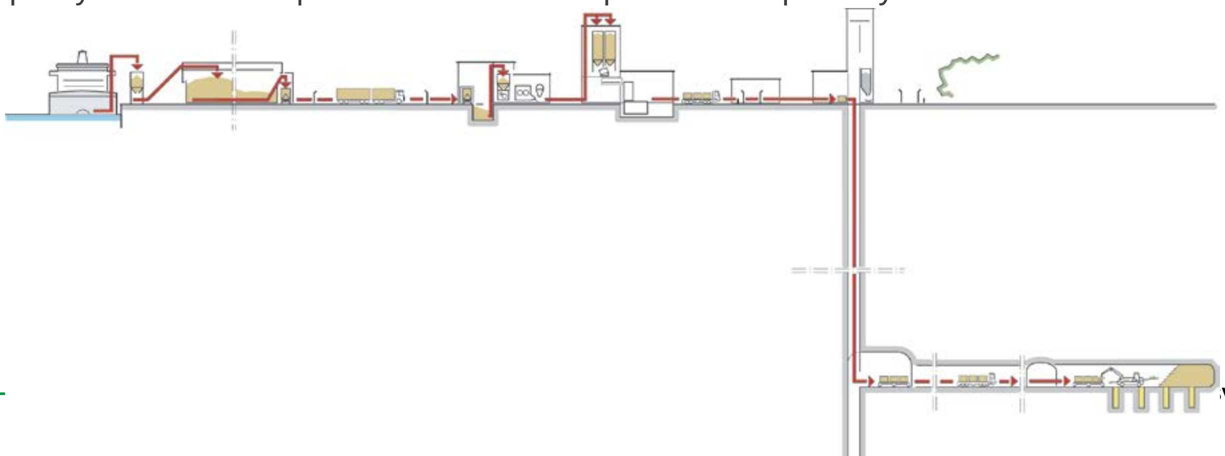


POSIVA

SKB

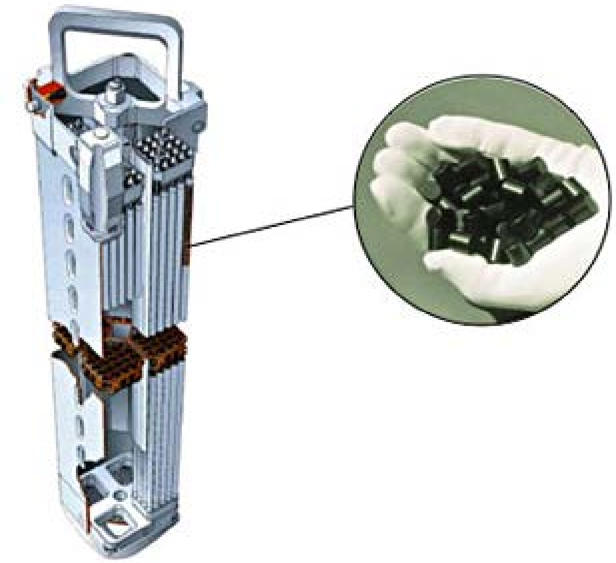
Quality management and control

- Assurance that the requirements made on the facilities during operation and after closure of the Spent Fuel Repository are satisfied.
  - described in general terms in the license applications
  - will also progress
- A number of important activities in this process are to establish:
  - principles for safety and quality classification.
  - what is to be quality-managed and -controlled, when quality management and control are to be performed and by whom in terms of first, second and third parties.
  - qualify processes, methods, equipment and personnel for fabrication and installation, testing and inspection.
  - Procedures to be applied in production to ensure the repository satisfies quality requirements.
- Establishing and qualifying all aspects of the quality control system is a considerable undertaking
  - many of the quality needs and requirements will be unique for the repository



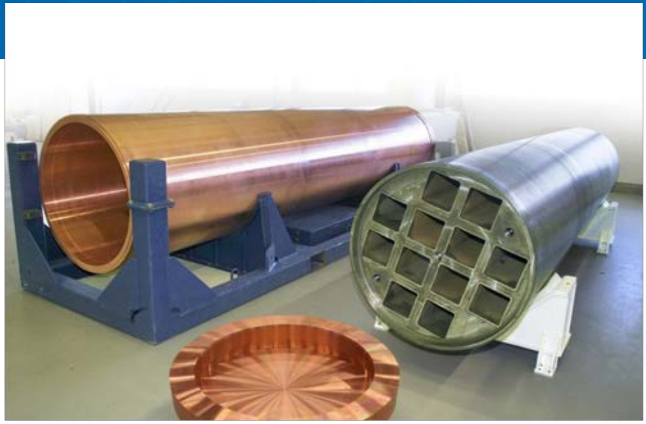
Spent fuel key issues 2016 - 2019

- Fuel information and data bases
- Residual power and other fuel measurement
- Treatment of damaged fuel.
- Criticality
- Ageing – impact on future handling
- Fuel chemistry including fuel dissolution

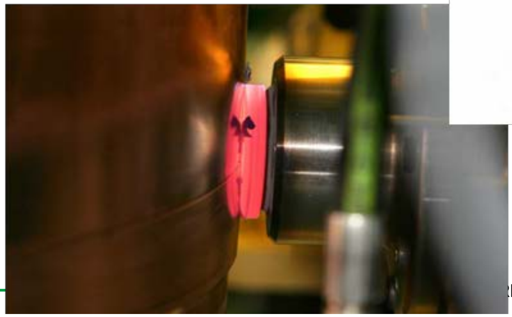


Canister – key R&D issues 2016-2019

- Post closure safety
  - Corrosion (sulphides, SSC,…)
  - Copper creep – understanding the process and function of P.
- Technology development
  - Canister design should be verified in conformity with requirements, manufacturing methods verified, testing and control processes should be developed and prerequisites from qualification clarified.
    - Copper components and welding
    - Insert design, manufacturing and qualification
    - Revised approach to NDT
- Basis for canister production system and canister assembly facility
  - Technology and methods for production should be developed and shown to work in industrial scale

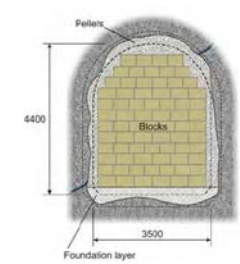


$$2\,Cu + HS^{-} + H^{+} \rightarrow Cu_2S + H_2$$



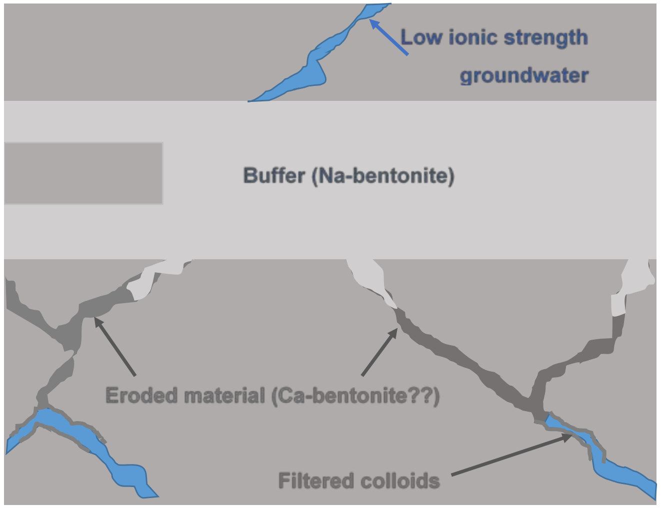
Buffer, backfill, closure key R&D issues 2016-2019

- Post closure safety
  - Buffer erosion
  - Sulphide production (well underway in ISP)
  - Homogenisation process
- For SKB, technology development needed in time for PSAR
  - Basis for updated production reports for BBC, based on updated technical design requirements.
  - Product and process mapping done. Preliminary quality plans written. Need for qualification clarified
- Technology development for detailed design of production facility (*and to be part of the reporting to SSM in 2019*)
  - Material Procurement Specification established (including material studies)
  - Decision on pressing methodology
  - Bentonite block manufacturing methods that works in industrial scale
  - Control methods that work in industrial scale
  - Control programmes for materials and production established.



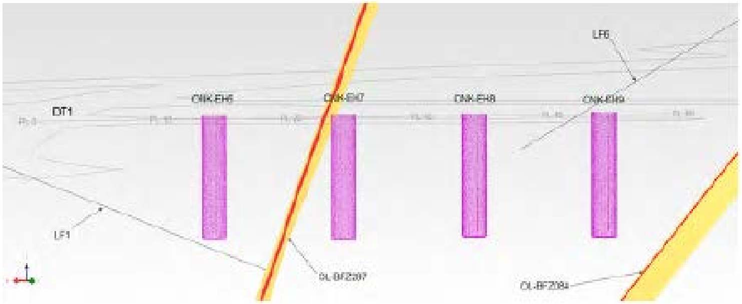
Posiva's buffer, backfill, closure key R&D issues 2016-2019

- Post closure safety, same remaining issues as SKB has
  - Buffer erosion
  - Sulphide production (well underway in ISP)
  - Homogenisation process
- Posiva has frozen the B&B designs for the safety case for the OLA
  - Construction plans incl. quality plans and control methods compiled
- Posiva is evaluating the feasibilities of production methods and means of production
  - Own facility, outsourced or joint production with SKB
  - Industrial scale production tested when producing B&B components for the FISST
  - Qualifications of the B&B production methods planned for 2019



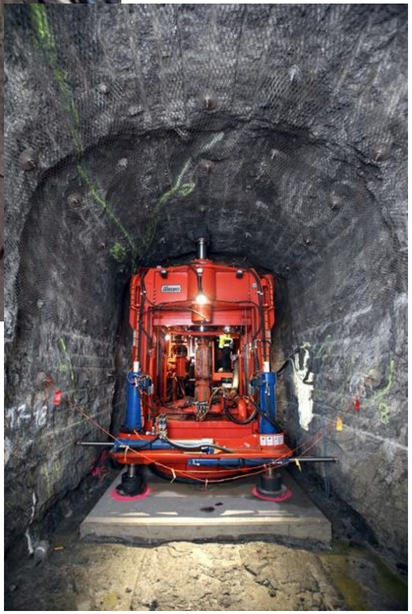
Rock and underground openings – R&D issues 2016-2019

- Detailed investigations etc.
  - Input to the *Operational programme for detailed investigations of the access*
    - Final methods and modelling approaches
    - Means of verification of site (and depth) suitability
  - Strategies and modelling as a basis for the *Preliminary operational detailed characterisation programme of the deposition areas*
    - Finalization of RSC characterisation and acceptance together with Posiva.
    - Hydraulic criteria for accepting deposition holes
    - Efficient and accepted models describing the fracture system (DFN-work)
    - Ensuring a reasonable assessment of impact of future earthquakes (still an issue with STUK and SSM)
- Optimise construction of 3V deposition tunnels
  - Tunnel excavation (smooth floors, potential for mechanical excavation)
  - Production of deposition holes
  - Grouting and grouting materials
  - Reinforcement without concrete



Rock and underground openings – Posiva's R&D issues 2016-2019

- The remaining open R&D issues consist of confirmation studies and demonstrations for
  - Improving the understanding of the prosesses at the site
  - Updating the site description models based on the information gathered from the Olkiluoto monitoring programme and on the results of the on-going site related projects
  - Updating the requirements and design specifications of the host rock
  - Standardizing the control measures of the Excavation damaged Zone (EDZ)
  - Addressing the reliability of the rock classification system (RSC) during the construction of the deposition tunnel for the commissioning test
- Optimise construction of 3V deposition tunnels
  - Tunnel excavation (smooth floors, potential for mechanical excavation)
  - Production of deposition holes
  - Grouting and grouting materials
  - Reinforcement without concrete



Addressing the feasibility of the construction methods – Posiva’s demonstration tunnel and plug slot

Demonstration disposal tunnel

Slot for the tunnel end plug

Posiva's Rock suitability assessment RSC

Repository stage

- investigations
- modeling
- rock suitability
- design
- construction

Panel stage

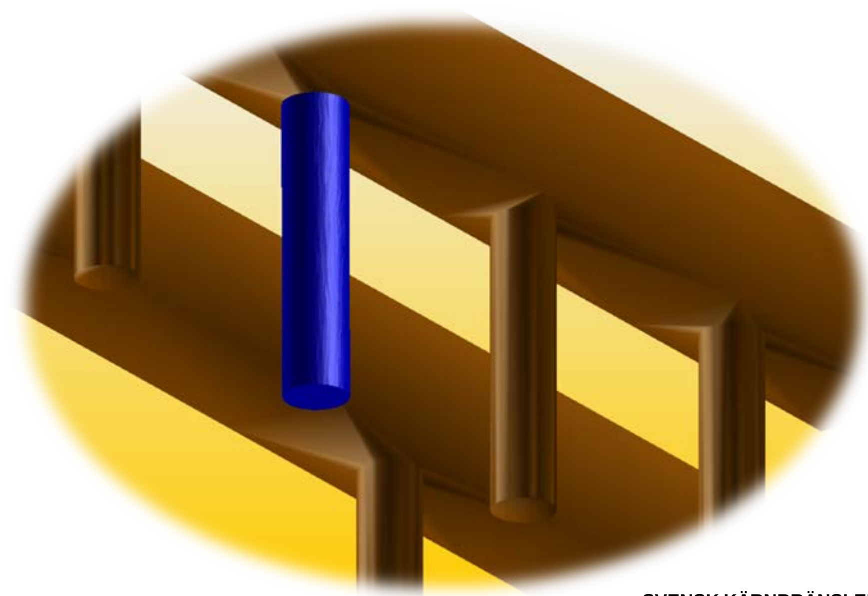
- investigations
- modeling
- rock suitability
- design
- construction

Tunnel stage

- investigations
- modeling
- rock suitability
- design
- construction

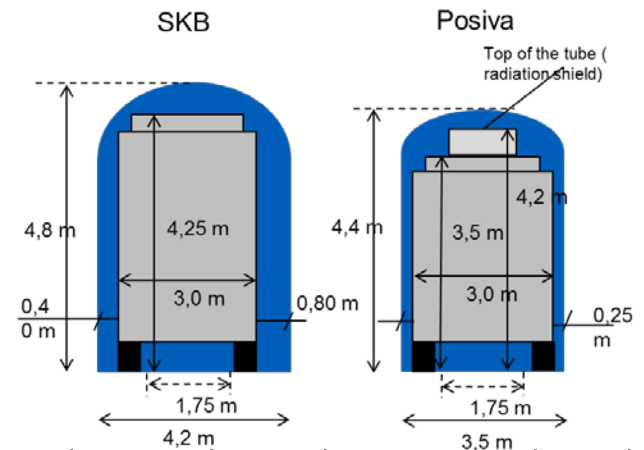
Hole stage

- investigations
- modeling
- rock suitability
- design
- construction



Machine and system development

- Most machines will be standard equipment.
  - Procurement and integration part of the “facility projects”
- Some special machines needed
  - EBS installation and drilling of deposition holes
- Prototypes exists – but further development needed
  - Capacity
  - Degree of automation..
  - Quality control
  - Optimization (requirement on open spaces, smoothness of floors, ventilation needs,..)
  - Maintenance needs

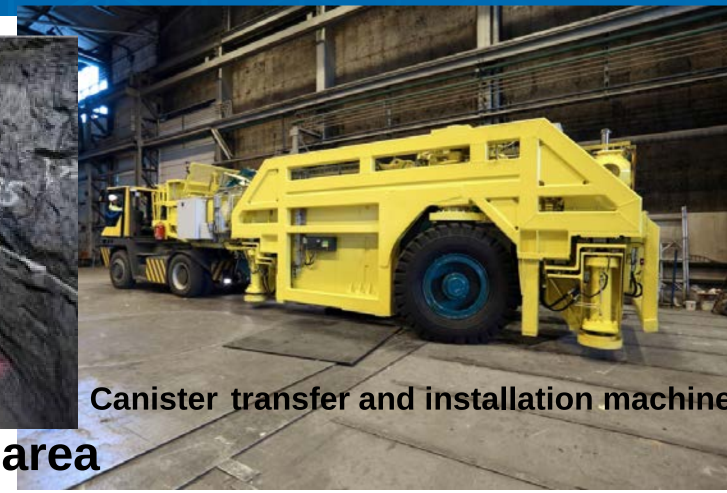


Tunnel cross sections to a large extent are the result of machine requirements. Reducing cross section saves need for backfill, but may imply more complicated machines

Posiva's prototype machinery designed, manufactured and tested

Buffer installation machine

in ONKALO demo area



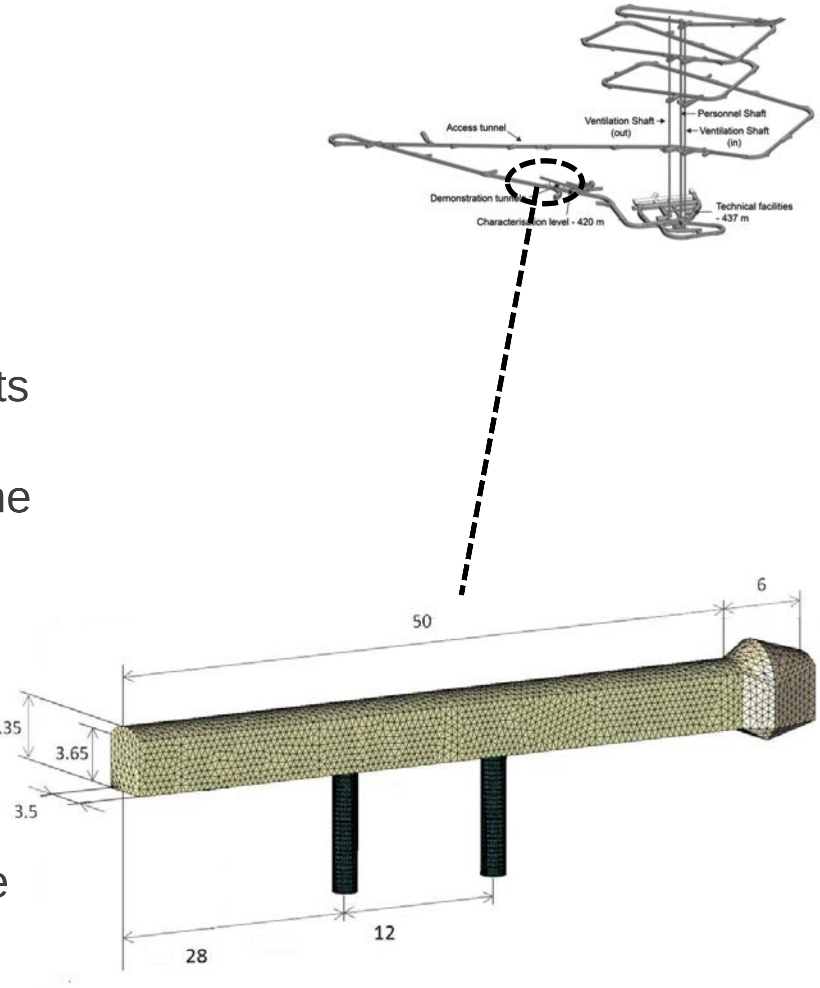
Canister transfer and installation machine

in test facilities

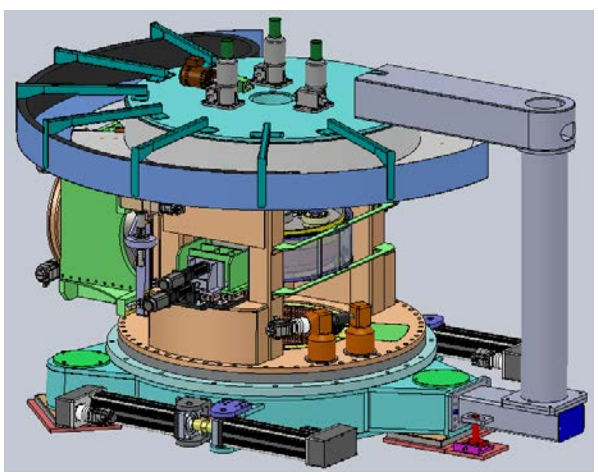
Backfill installation machine

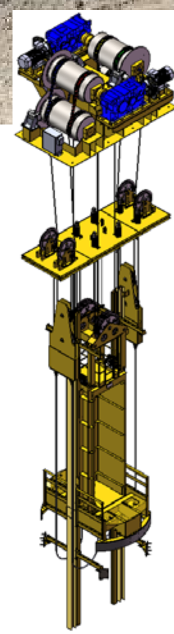
Posiva's FISST
Full scale in situ system test

- Planning on-going, installation planned in 2018
- Includes all engineered barriers
  - Canister, Buffer, Backfill and Plug
- Objectives of the test
  - Validate initial state of KBS-3V concept and its early phase evolution
  - Validate of the theoretical means to predict the evolution of the system
    - Clay swelling process, heat conductivity etc.
    - Scaling results from lab scale to full scale
  - Demonstrate the integrated installation of the EBS components
  - Confirm the operation costs during manufacturing, installation/construction of the components



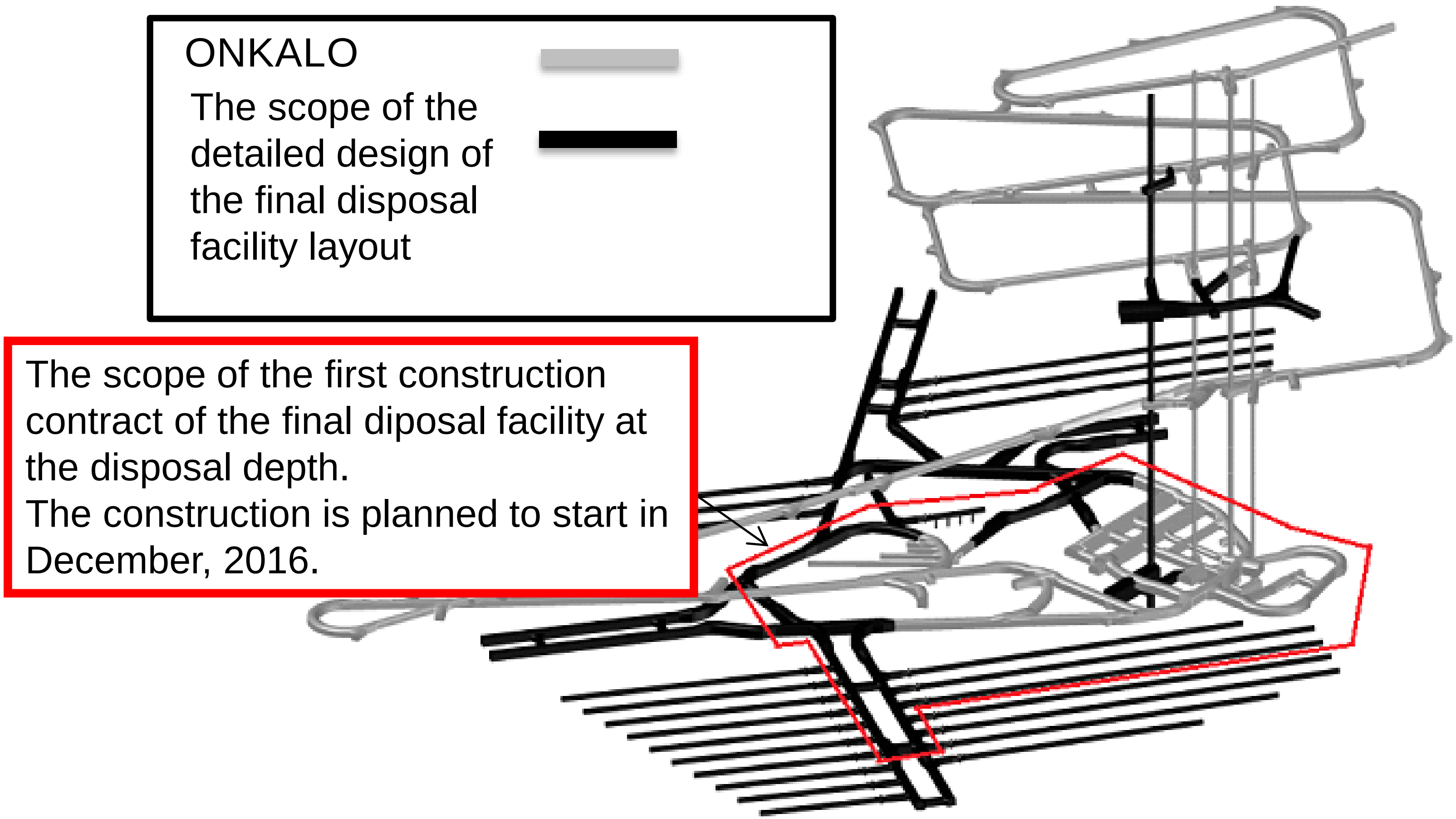
Posiva's Encapsulation plant project





- Detailed design of the systems on-going
  - Welding station
  - Canister lift
  - Docking stations
- Several safety classified system descriptions (7/21) sent to STUK for approval
- Suppliers for the three main equipment under evaluation

Posiva's Final Disposal Facility project:
Finishing ONKALO and moving into the construction of the final disposal facility



The scope of the Final Disposal Facility project includes the remaining volumes of ONKALO and the first construction contract of the final disposal facility

Nuclear waste repositories can only be developed in a staged iterative fashion

- Early stages, e.g. prior to site selection,
  - develop concepts that have the potential to result in a safe repository.
- During a siting process
  - need to show how a suitable design can be adapted to the available siting environments and potential host rocks
  - provide guidance for the characterization of the specific sites to be explored.
- When applying for a construction license
  - Need to demonstrate that the designs adapted to the site will lead to safety and that the design can be realized in practice.
- After the license
  - detailed designs adapted to an industrialized process designed to fulfilling specific requirements on quality, cost and efficiency
  - repository layout may need to be adapted to the local conditions found when constructing the repository at depth.
- During operation
  - Repositories typically will operate over several decades, further optimization of the design and operational procedures can be envisaged.