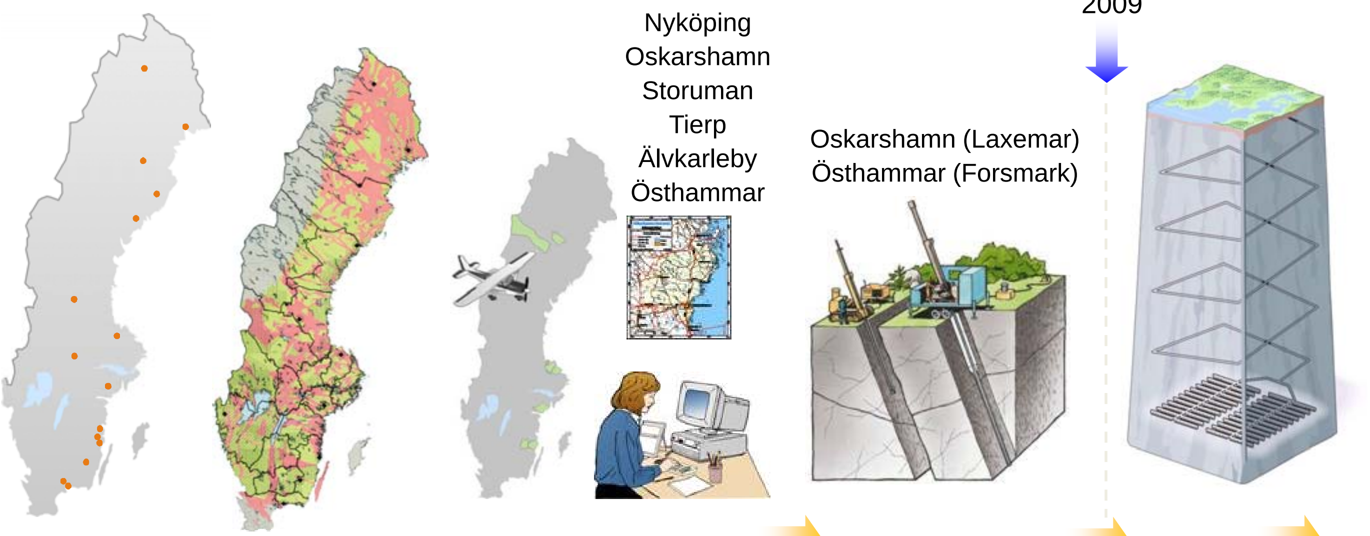
Need for PA in Site Selection

the Swedish Experience

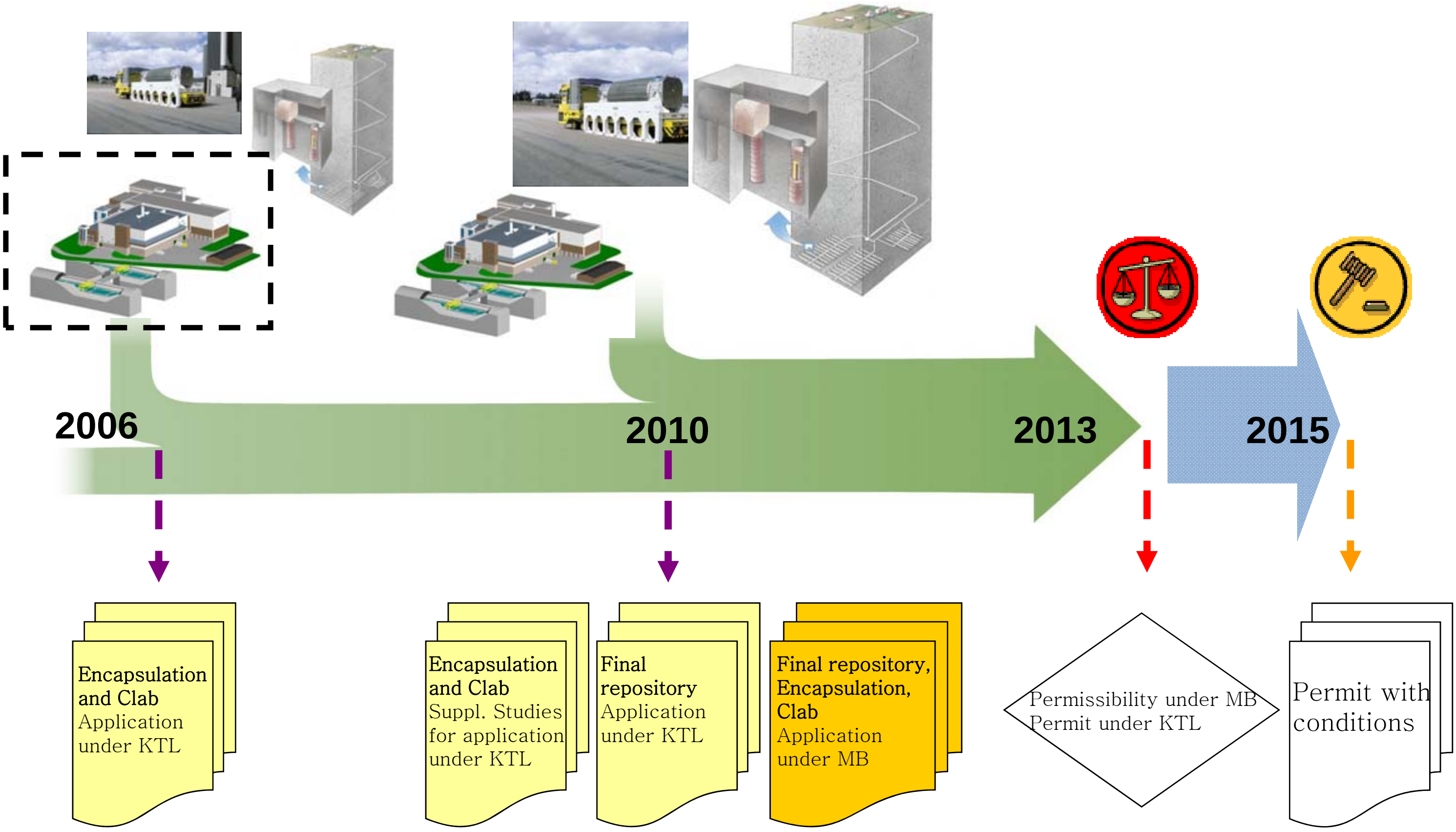
The road to a final repository for spent nuclear fuel

Accumulation of knowledge

Siting process



Licensing procedure



KTL = Nuclear Activities Act, MB = Environmental Code

SKB's site selection strategy

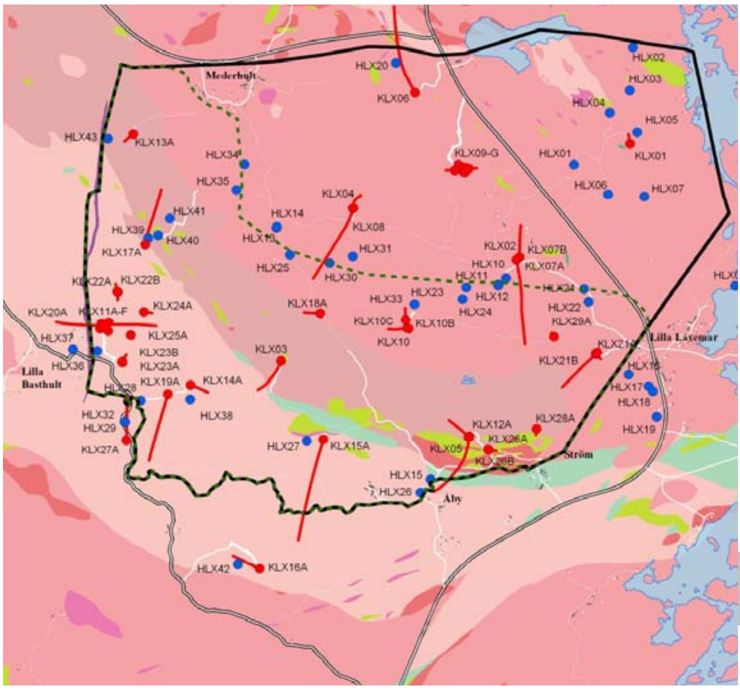
I. The site that offers the best prospects for achieving long-term safety in practice will be selected

II. If no decisive difference is found between the sites in terms of their prospects for achieving long-term safety, we select the site that is judged to be the most favourable for accomplishing the final repository project from other aspects

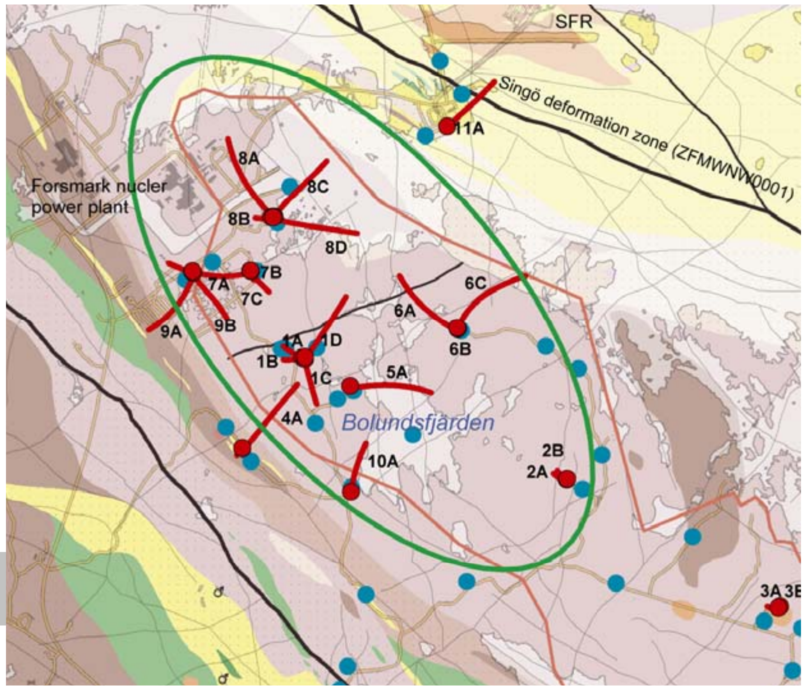
Our sites

Comprehensive investigations have been completed and evaluated at both sites

Laxemar



Forsmark



SKB's siting factors

Safety related site characteristics
- Bedrock composition and structure
- Future climate
- Rock mechanical conditions
- Groundwater flow
- Groundwater composition
- Retardation
- Biosphere conditions
- Overall site understanding

Technology for execution
- Flexibility
- Technical risks
- Technology development needs
- Functionality, operational aspects
- Synergies
- Costs

Societal resources
- Suppliers, human resources
- Public and private services
- Communications

Health and environment
- Occupational health and radiation protection
- Natural environment
- Cultural environment
- Residential environment
- Management of natural resources

Safety assessments (1/2)

- Long-term safety is evaluated by means of safety assessments
- SKB has made a series of safety assessments
- Early and important milestone: KBS-3 report in 1983
  - Basis for application for operational permit for F3 and O3
- The most recent assessment, SR-Can, was published in 2006
  - Main purpose to give the regulatory authorities an opportunity to review the safety assessment methodology, and to make a preliminary evaluation of the safety of a repository in Forsmark and Laxemar
  - Based on site data from initial investigations in Forsmark and Laxemar

Safety assessments (2/2)

- SR-Can was reviewed by SKI and SSI, supported by three international expert panels
- Main message in review report: "Safety assessment methodology is largely acceptable and complies with regulations"
- We therefore have a developed method for evaluating long-term safety
  - The method has now been used to compare the sites
- SR-Can demonstrated clear differences in Forsmark's favour
  - But it was unclear how representative the initial data were, especially for Laxemar

Comparative analysis of safety related site characteristics

- Objectives
  - Present analyses of primary importance for site suitability with respect to long term safety.
  - Assess whether conclusions on differences in suitability between the sites can be drawn or not based on this set of analyses.
  - Assess potential differences in suitability with respect to long term safety for the two sites.
- Limitation in scope
  - Not a formal assessment whether a final repository at the investigated sites fulfils regulations. Such an assessment will be made in SR-site, for the selected site only.
- Size
  - 100-120 pages
- Status
  - First, internal, version produced in June 2009, as a basis for the site select
  - This version is internal to SKB and will NOT be published.
  - Final version will be produced in coordination with SR-Site and will be externally published in connection to SKB's submittal of license applications in 2010..

Comparative analysis of safety related site characteristics

- 1 Introduction
- 2 Achieving the initial state
- 3 Sensitivity to climate evolution
- 4 Changes in fracturing - Thermally induced spalling
- 5 Hydrogeology and transport conditions
- 6 Chemical conditions and their evolution
- 7 Earthquakes
- 8 Mineral resources
- 9 Retardation
- 10 The biosphere
- 11 Expected results of risk calculation
- 12 Confidence in the site descriptive models
- 13 Conclusions

Safety-related site characteristics

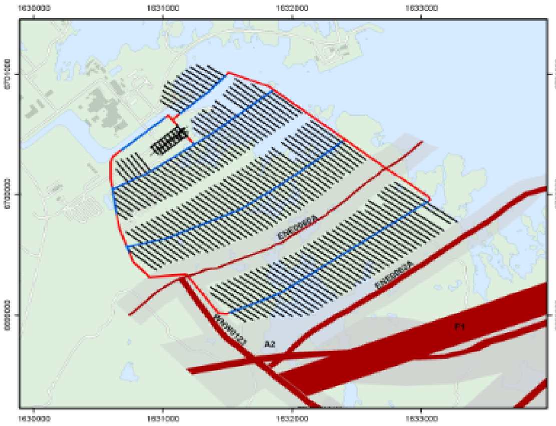
The repository is adapted to the rock conditions

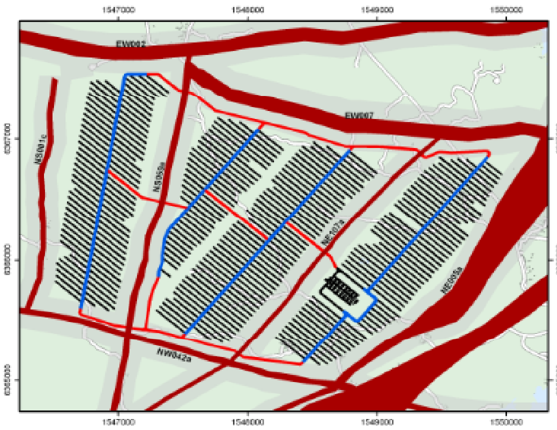
Point of departure for safety evaluation

- Respect distance to deformation zones
- Thermal conductivity
- Long fractures

After adaptation there is little or no difference for the following factors

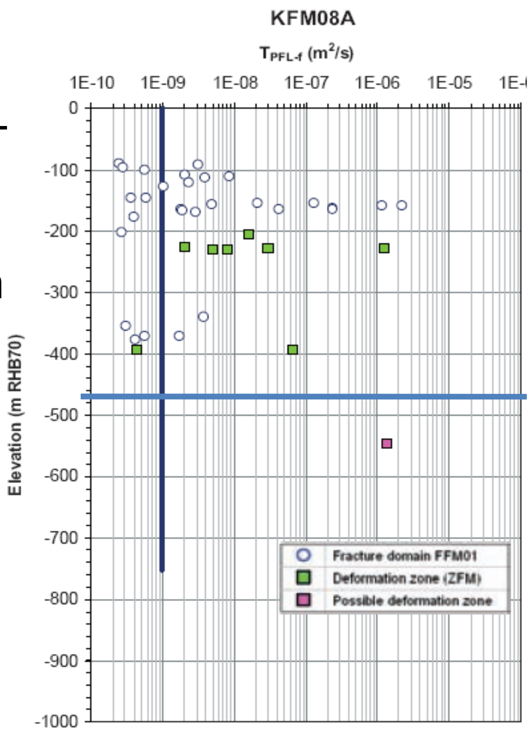
- Earthquakes
- Biosphere conditions
- Site understanding

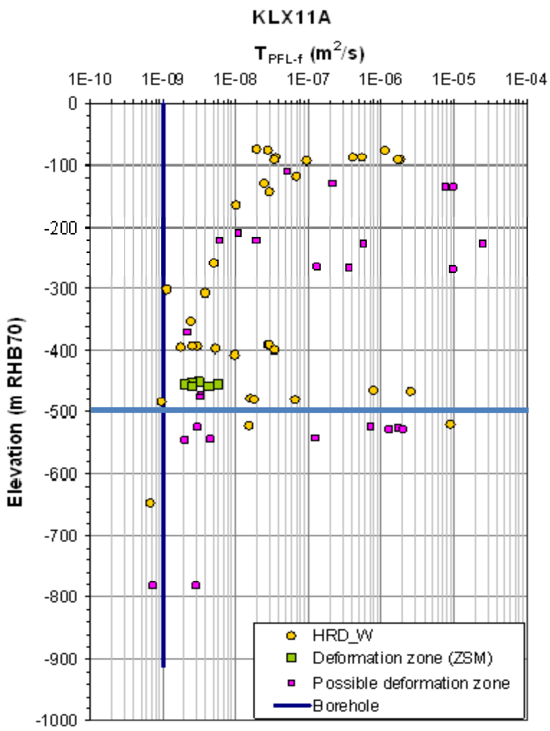




Safety-related site characteristics Groundwater flow

- Far fewer water-conducting fractures at repository depth in Forsmark
- Lower ground-water flows in Forsmark – on average about 100 times lower





Safety-related site characteristics Groundwater flow

- Far fewer water-conducting fractures in Forsmark
- Operating period
  - Water saturation of buffer and backfill takes long time in Forsmark
- Closed repository – temperate period
  - "Equivalent flow" around deposition hole on average 100 times lower in Forsmark
  - "Transport resistance" (F factor) on average 10 times higher in Forsmark
- Closed repository – glacial period
  - The groundwater flows can temporarily increase considerably, but the difference between the sites persists
  - The favourable composition (salinity) of the groundwater is less affected in Forsmark

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Safety-related site characteristics Groundwater chemistry

- Groundwater salinity (Na, Ca) affects the durability of the buffer
  - More favourable for Forsmark up to the next glaciation and maybe even under glacial conditions
- Possible infiltration of oxygen-containing groundwater under glacial conditions – affects the durability of the canister
  - More favourable in Forsmark due to lower groundwater flows
- Sulphide – affects the durability of the canister
  - Small differences between the sites

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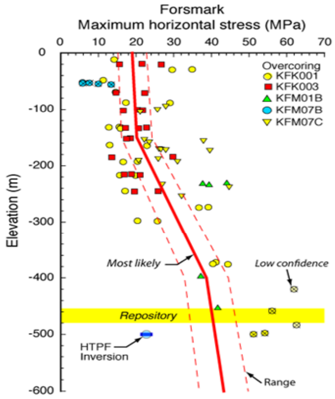
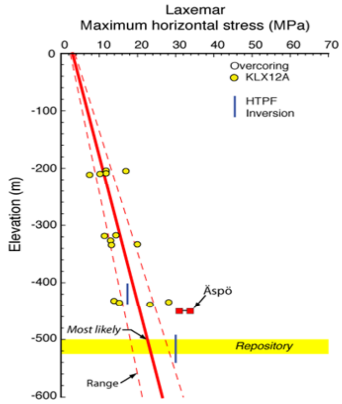
Safety-related site characteristics Rock mechanical conditions

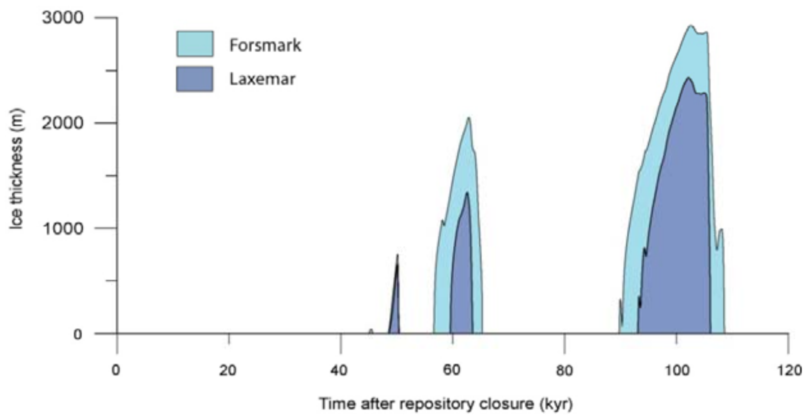
- Risk of thermal spalling
  - Higher rock stresses in Forsmark increase the risk of thermal spalling in deposition holes, i.e. fracturing when the heat is transmitted from the canister to the rock
  - Causes deterioration in barrier properties near the hole, but the low groundwater flow in Forsmark more than compensates for this disadvantage





Safety-related site characteristics Climatic conditions

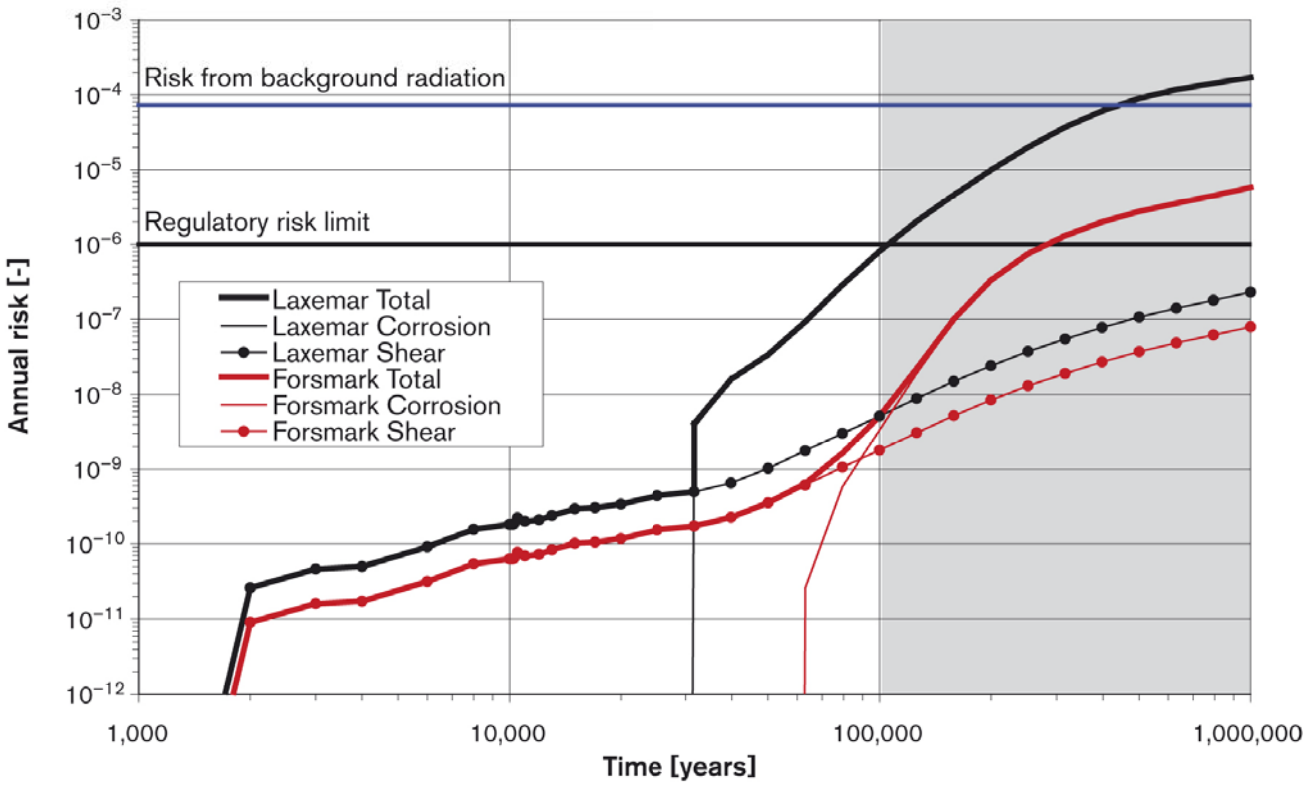
- Warmer climate does not affect the differences between the sites
- Permafrost reaches deeper in Forsmark due to the higher thermal conductivity of the rock
  - Judged not to damage buffer or backfill
- Longer period with ice sheet or under water in Forsmark



Safety-related site characteristics
Safety evaluation

- We have made a forecast of the outcome of the safety assessment based on the results of SR-Can and updates in input data since SR-Can
  - The safety assessment will be presented as part of the application
- Two scenarios contributed to the calculated risk in SR-Can:
  - Canister failure due to earthquake
  - Canister failure due to accelerated sulphide corrosion after the buffer has been eroded away
- Today buffer erosion – and thereby the risk-dominating sulphide corrosion scenario – is judged to remain and is handled in the same way as in SR-Can

Risk curves from SR-Can



Safety-related site characteristics
Expected results of risk calculations

- Earthquakes
  - No essential differences between the sites
  - The risk is judged to be equal to or lower than calculated in SR-Can
- Erosion/corrosion scenario
  - The risk that dilute groundwater during glaciation will damage the buffer is lower in Forsmark
  - If the buffer erodes, a few canisters could be damaged in Forsmark after a very long time. Many more canisters could be damaged in Laxemar due to the higher flows
- Much better prospects for achieving a safe final repository in Forsmark

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SKB's siting factors

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Technology for execution
- Flexibility
- Technical risks
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- Functionality, operational aspects
- Synergies
- Costs

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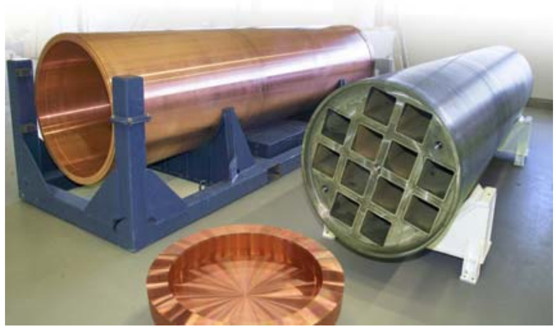
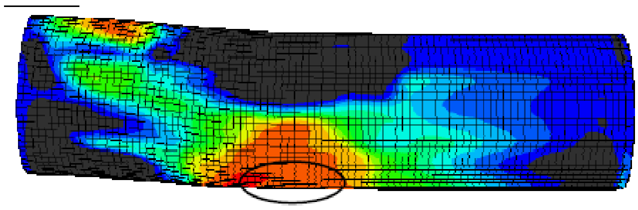
Design Premises – based on input from PA

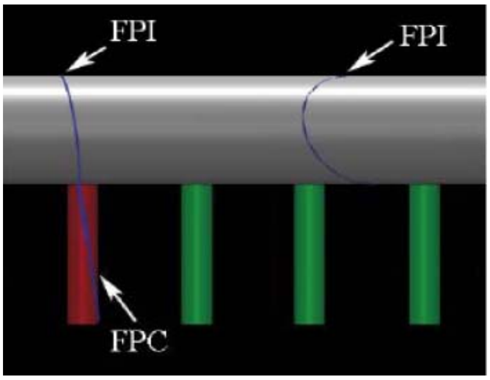
- Provide requirements from a long term safety aspect
  – to form the basis for the development of the reference design of the repository
  – to justify that design
- Design premises typically concern
  – specification on what mechanical loads the barriers must withstand
  – restrictions on the composition of barrier materials or acceptance criteria for the various underground excavations
- The justification for these design premises is derived from SKB's most recent safety assessment SR-Can (SKB 2006a) complemented by a few additional analyses.

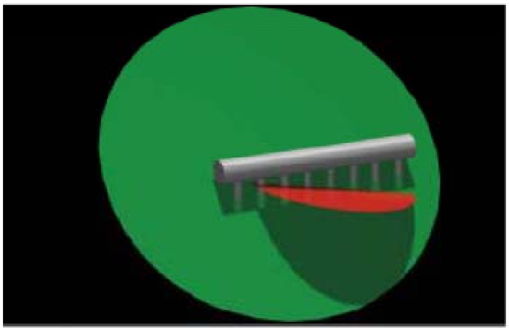




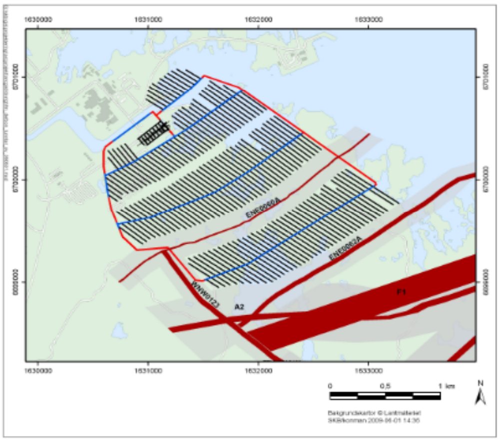
Design Premises – Underground excavation

- Respect distances to large deformation zones
- Deposition hole acceptance criteria (fractures, inflow, geometry)
- Thermal conditions (T<100 C)
- Allowed materials (e.g. only low pH concrete)
- …





Technology for execution
Flexibility – space



Forsmark

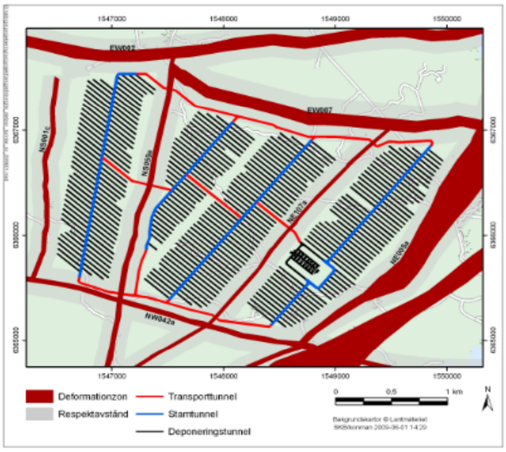
Room for 6,000 canisters if the loss rate of canister positions is less than 23%

Expansion options:
1) thermal optimization
2) repository in two levels
3) expand towards southeast

Laxemar

Room for 6,000 canisters if the loss rate is less than 25%

Expansion options:
1) thermal optimization
2) repository in two levels
3) expand towards west and south



Technology for execution
Loss of deposition positions

Forsmark

- Water not a problem
- Uncertainties in rock stresses
  - Can cause spalling in deposition holes
  - Loss of less than 500 positions
- Uncertainties concerning frequency of long fractures
  - Could at worst entail a loss rate of 10-25%
  - Reasonable to assume that the actual loss rate will be much lower

Laxemar

- High frequency of water-conducting fractures
  - Extensive grouting need
  - Loss of at least 3,000 positions
- Rock stresses not a problem
- Uncertainties concerning frequency of long fractures
  - Could at worst entail a loss rate of 10-25%
  - Reasonable to assume that the actual loss rate will be much lower

Technology for execution
Efficiency

- Forsmark entails a much lower risk of loss of deposition positions compared with Laxemar
- Higher thermal conductivity in Forsmark means a 30% smaller repository is needed
- Rock construction in Laxemar is impaired by large water inflows
- Laxemar requires extensive development of grouting methodology and backfilling technique
- In Forsmark there may be a need for additional rock support in tunnels, but this is not deemed to entail any appreciable difficulties
- Forsmark offers lower costs and more robust premises for planning and execution

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Summary – Safety and execution

- The rock in Forsmark provides much better conditions for a long-term safe repository and facilitates execution of the project
  - The rock is homogeneous and has few water-conducting fractures at repository depth
  - High thermal conductivity permits a compact repository
- Execution in Forsmark is more robust – manageable risks
  - Less need for grouting, simpler backfilling
  - Smaller repository – lower costs
  - High rock stresses judged to be manageable
  - High permeability in near-surface rock (<100 m)
  - Sensitive natural environment requires adaption

Summary – Could the assessment change?

- Continued research on bentonite erosion may show that we have been too pessimistic in our assessment of long-term safety
  - The difference between the sites may be greatly reduced and the radiological risk may be lower on both sites
- Possibilities for improved prospects for Laxemar
  - Development of grouting method and backfilling technique
  - Significantly increased repository depth (>700 m), but
    - Requires more investigations
    - Larger underground area needed due to higher temperature
    - Higher technical risks

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Role of PA - conclusions

- Key role of detailed safety functions
  - Risk curves themselves not appropriate for site selection – but assessment of Safety Function's is a useful means of breaking down the long term safety issues
- Feasiblity in Design and Construction also essential siting factors – strongly related to PA
  - , i.e. the main issue is how to meet design premises based on long term safety demands
- Envirnomental and sociatal factors important – but could not be decisive
- Remarks on MAA
  - Concept of multiple siting factors relevant
  - But, most siting factors dependent on each other
  - importance more on/off than gradual.
  - Using MAA points for decision making may be misleading

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Final repository for spent nuclear fuel at Forsmark