Complementary considerations in the safety case, support from natural analogues and natural systems

Anne Lehtinen

13th NAWG Workshop, May 13th-16th 2013, Nagoya

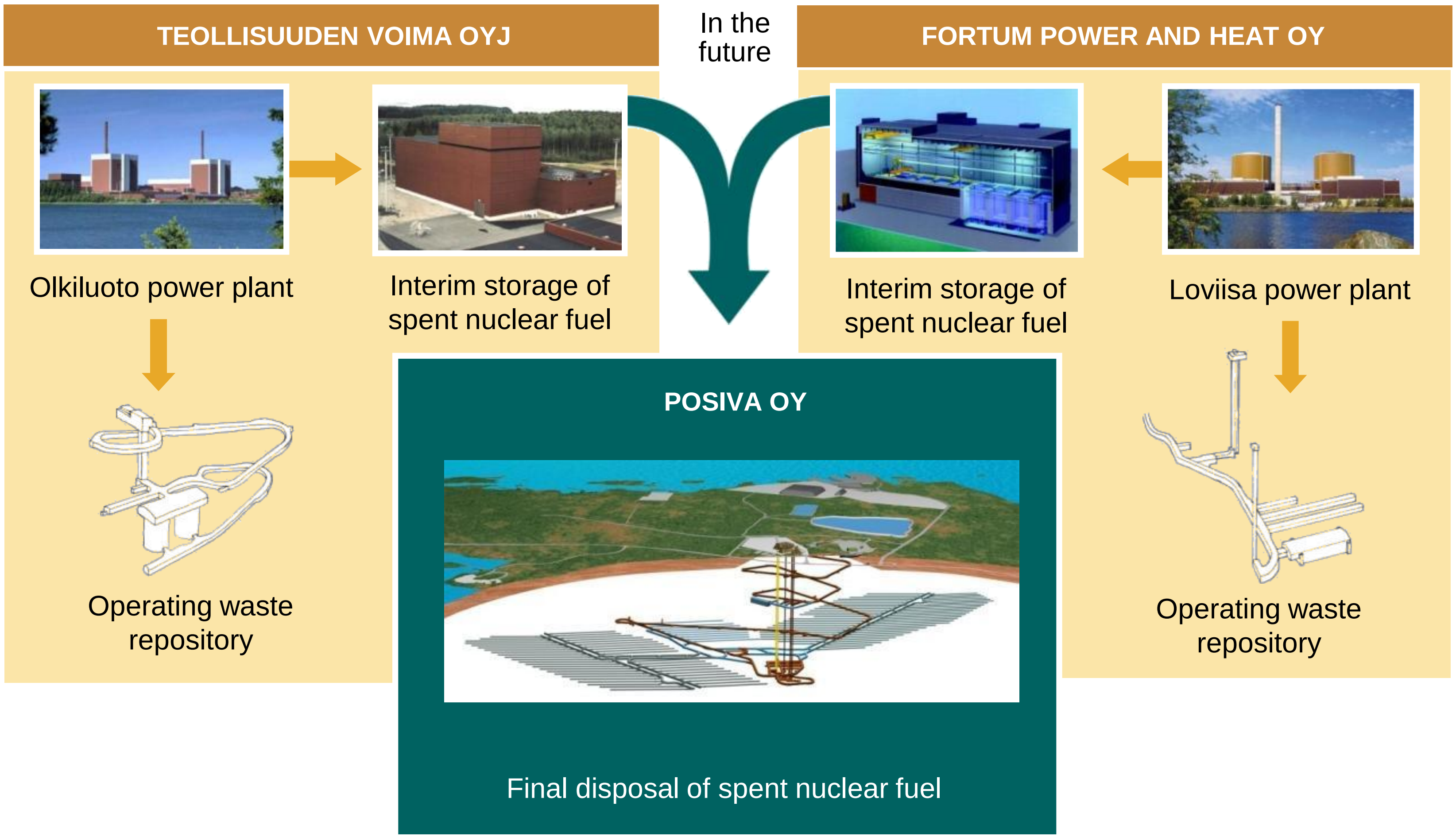
POSIVA

www.posiva.fi/en

Outline

- Introduction
- Background
- Regulatory requirements
- Scope of the complimentary considerations
- Introducing complementary considerations
- Summary

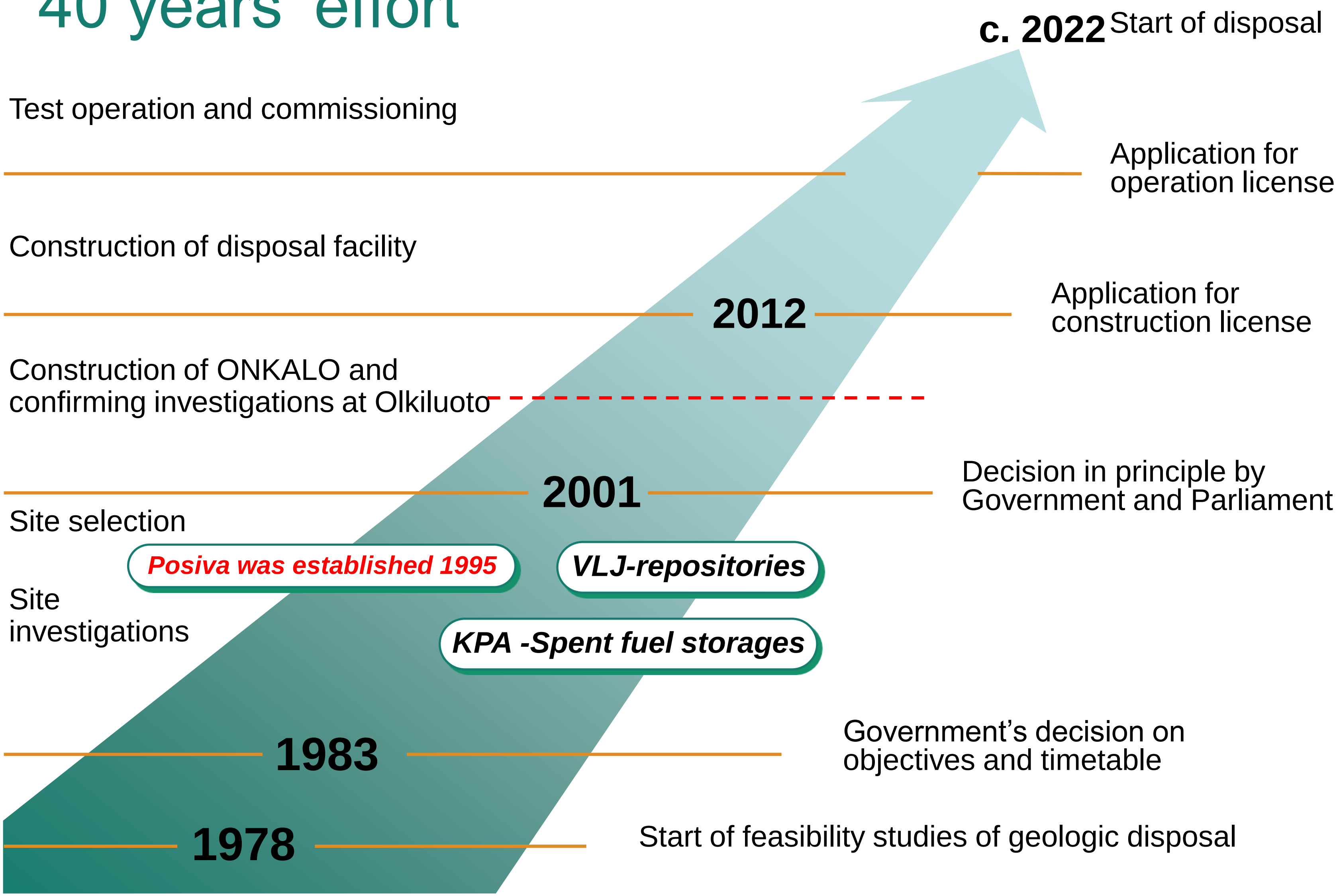
Posiva´s goal: The safe disposal of spent nuclear fuel



Posiva Oy

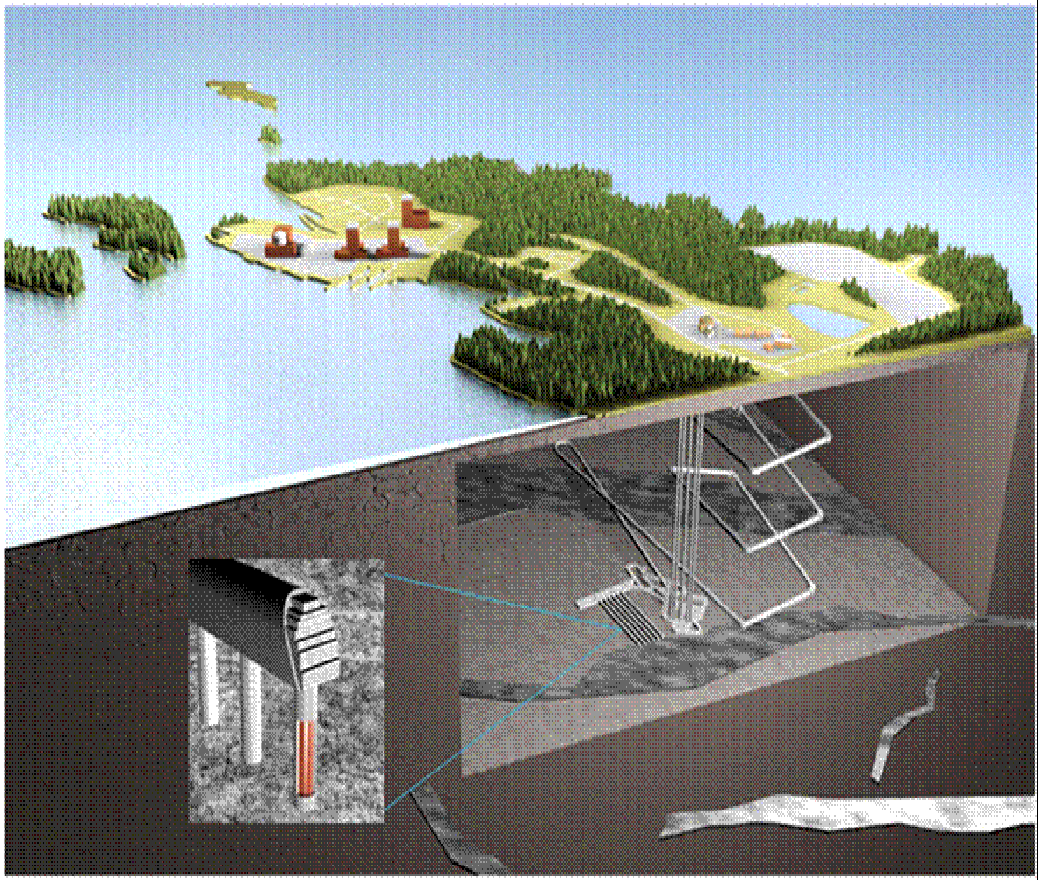
- Company established in 1995
  - Ownership: Teollisuuden Voima Oyj (TVO) 60 %,
Fortum Power and Heat Oy 40 %
- Mission: Final disposal of spent nuclear fuel of the owners and other tasks of expertise within nuclear waste management
- Gradual change from a R&D company to an implementing organisation
  - Organisation adjusted according to changing demands
- Steadily developing staff
  - Own staff about 100 persons coupled with extensive use of contractors
  - Total employment effect of the final disposal over 300 persons
- Turnover
  - Accrued in 2012: EUR 67 million
  - Estimated for 2013: EUR 73 million

40 years' effort



Multibarrier principle of geological disposal

- The flow rate of the groundwater in bedrock is minor and slow.
- The groundwater found deep in the bedrock contains no oxygen and has no impact on copper.
- The backfill material expands and prevents any water movement around the container.
- The host rock of the final repository almost completely prevents water movement, which means that all the material will virtually stay in their place in the bedrock.



Regulatory requirements for complementary considerations

Regulatory Guides on nuclear safety: (YVL) D.5 Section A09 (draft)

- The importance to safety of **such scenarios that cannot** reasonably **be assessed by** means of quantitative **safety analyses**, **shall be examined by** means of **complementary considerations**.
- They may include e.g. analyses by **simplified methods**, comparisons with **natural analogues** or observations of the **geological history of the disposal site**.

Regulatory requirements for complementary considerations continues

Regulatory Guides on nuclear safety (YVL) D.5 Section A09 (draft)

- The **significance** of such considerations **grows as the assessment period increases**, and safety evaluations extending **beyond time horizon of one million years** can mainly be based on the complementary considerations.

- Complementary considerations shall also be applied parallel to the actual safety assessment in **order to enhance the confidence in results of the analysis** or certain part of it.

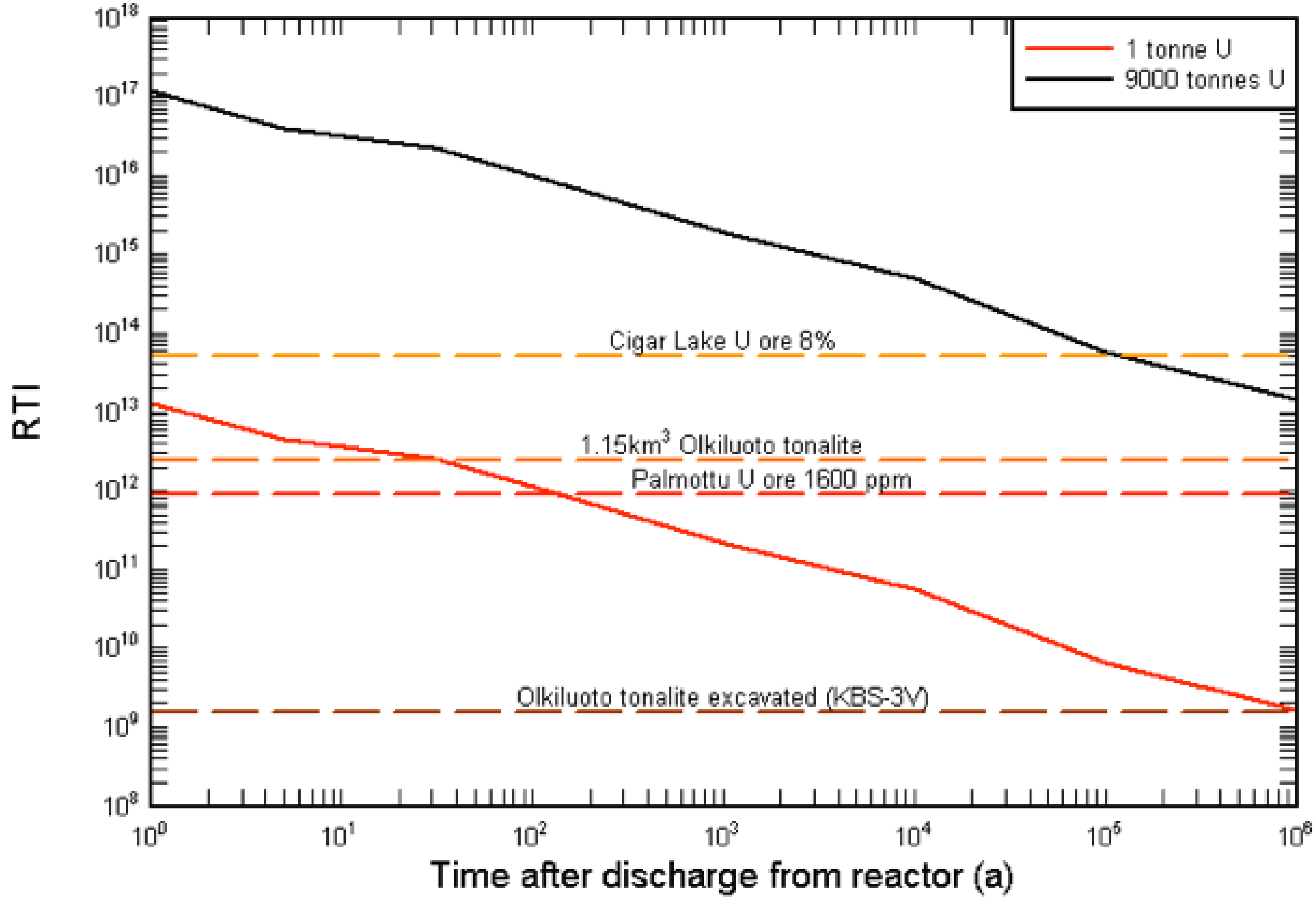
Complementary considerations is an approach taken to:

- address diverse and less quantifiable types of evidence and arguments made to enhance confidence in the outcome of the safety assessment.
- demonstrate repository safety at times greater than a few thousand of years, which is not possible using alone the indicators of safety dose or risk.
- Complementary considerations have been described (NEA 2004, 2009) as evaluations, evidence and qualitative supporting arguments that lie outside the scope of the other reports of the quantitative safety assessment.

Arguments and evidence may include:

- the use of complementary indicators
  - To complement the quantitative estimates of doses, in the period beyond a few thousand years *complementary safety indicators* have been proposed by the IAEA, 2003 using fluxes and concentrations of naturally-occurring radionuclides.
- and alternative indicators
  - such as “crossover times” could be useful in illustrating safety (IAEA, 2003)

A crossover time is the point in time in the future at which either the activity/radiotoxicity of the radionuclides remaining in the engineered barriers or released to the geosphere decrease due to radioactive decay below the corresponding values for relevant natural materials such as the original uranium ore or the excavated host rock.



Radiotoxicity index of 1 tonne and 9000 tonnes of Finnish spent nuclear fuel

Safety Case Portfolio reports

Green boxes: Safety Case main reports
Blue boxes: Safety Case supporting reports

Report	Description
Synthesis	Description of the overall methodology of analysis, bringing together all the lines of arguments for safety, and the statement of confidence and the evaluation of compliance with long-term safety constraints
Site Description	Understanding of the present state and past evolution of the host rock
Biosphere Description	Understanding of the present state and evolution of the surface environment
Design Basis	Performance targets and target properties for the repository system
Production Lines	Design, production and initial state of the EBS and the underground openings
Description of the Disposal System	Summary of the initial state of the repository system and present state of the surface environment
Features, Events and Processes	General description of features, events and processes affecting the disposal system
Performance Assessment	Analysis of the performance of the repository system and evaluation of the fulfillment of performance targets and target properties
Formulation of Radionuclide Release Scenarios	Description of climate evolution and definition of release scenarios
Models and Data for the Repository System	Models and data used in the performance assessment and in the analysis of the radionuclide release scenarios
Biosphere Data Basis	Data used in the biosphere assessment and summary of models
Biosphere Assessment: Modelling reports	Description of the models and detailed modelling of surface environment
Assessment of Radionuclide Release Scenarios for the Repository System; Biosphere Assessment	Analysis of releases and calculation of doses and activity fluxes.
Complementary Considerations	Supporting evidence incl. natural and anthropogenic analogues

Natural and archaeological analogues provide general support for the safety case

- Examples of the conditions in which the long-term stability (geological timescales) of the materials to be used in the engineered barrier system (EBS) is achievable.
- Allow comparisons with the conditions in the selected disposal site.
- Increase confidence in extrapolating results from laboratory and field experiments to the repository context.
- Contribute to understand the extent and consequences of the events and processes that may act during the long-term evolution of the disposal system

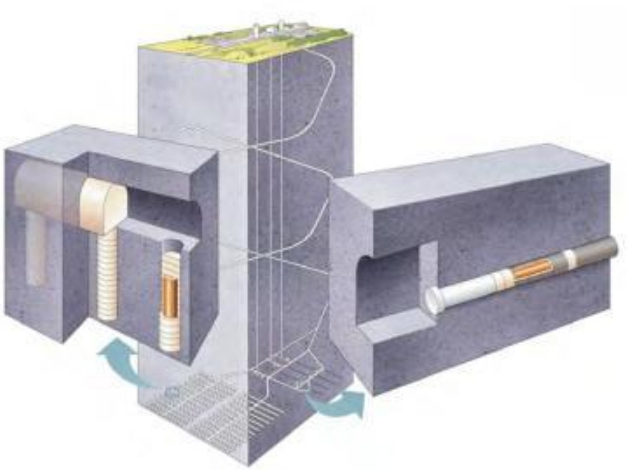
Complimentary Consideration report

- Neall, F (ed.)., Alexander, R., Laine, H., Marcos, N., Hjerpe, T., Smith, G. and Vuorio, M. 2013. Safety case for the disposal of spent nuclear fuel at Olkiluoto - Complementary Considerations 2012. Eurajoki, Finland: Posiva Oy. POSIVA 2012-11. ISBN 978-951-652-192-6.

- www.posiva.fi/en/databank/posiva_reports

Complimentary considerations report as a part of the Safety Case

- Focus on presenting support for:
  - Geological disposal concept
  - KBS-3 method
  - Suitability of geological disposal at Olkiluoto site
- Provide background data for complementary indicators to be utilised in the safety assessment



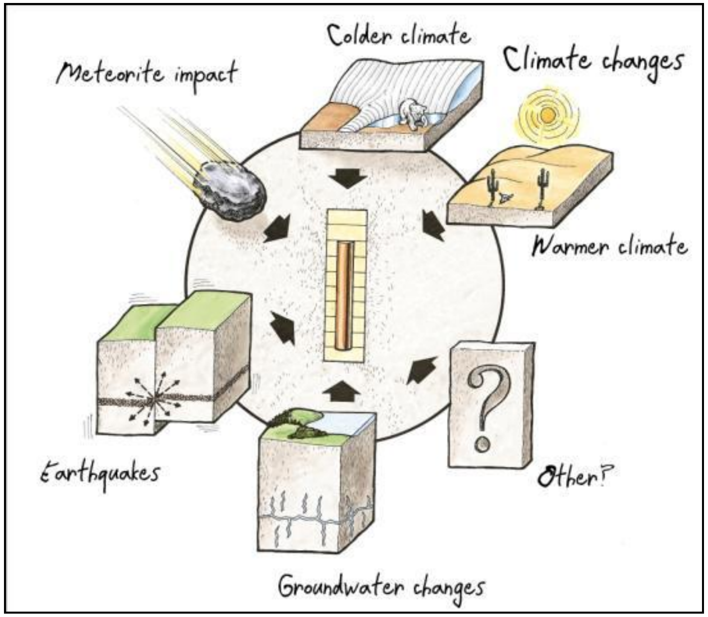
Complementary considerations -content in general includes:

- Geological disposal as a waste management option
- The KBS-3V design and safety concept
- The disposal system for spent nuclear fuel from Olkiluoto and Loviisa power plants
- Evidence for the stability of the host rock conditions
- Evidence for the suitability of the repository design and materials
- Evidence for limited rates of radionuclide migration in the repository system
- Analogues for potential future conditions in the surface environment
- Disposal of spent nuclear fuel in the context of other sources of radioactivity
- The evolution of the repository system beyond a million years in the future

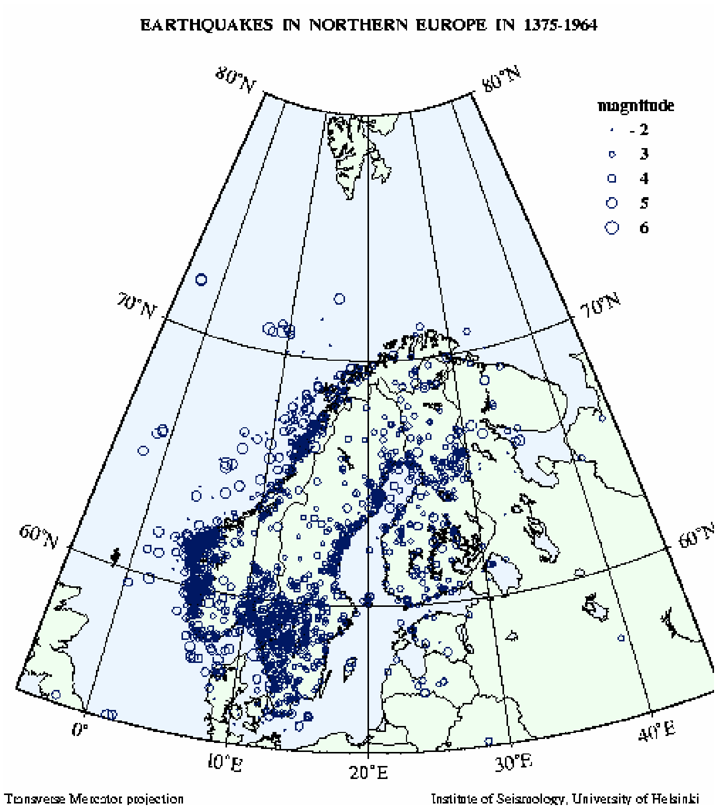
Evidence for the stability of the host rock conditions

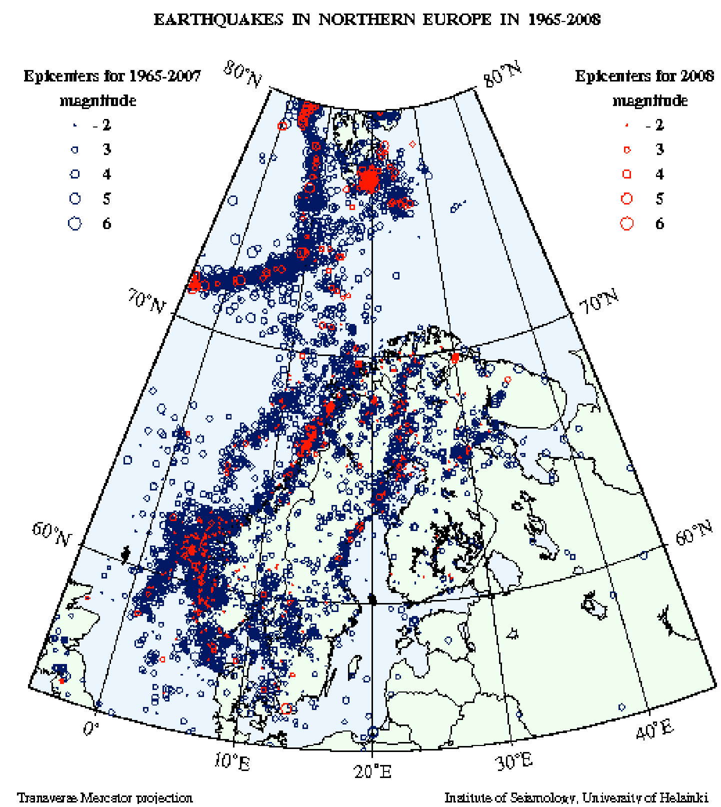
- Overall site understanding and the predictability of the site behavior in the future
  - Mechanical stability of underground spaces
    - low / intermediate repositories in Olkiluoto and Loviisa
  - Climate-change –driven processes
    - permafrost: past (recent modelling exercises, Pimenoff et al. 2011) /future (recent modelling excercice first colder period after 50 kyr→ probably no permafrost due to atmospheric CO_2 , within 120 kyr more likely)
    - dilute water intrusion; The current knowledge of the Olkiluoto site suggests that oxidizing groundwater never reached repository depth in the past and thus it is unlikely that this will happen in the future.

      GAP project
  - Impact of earthquakes
  - Erosion
  - Meteorite impact



Impact of earthquakes





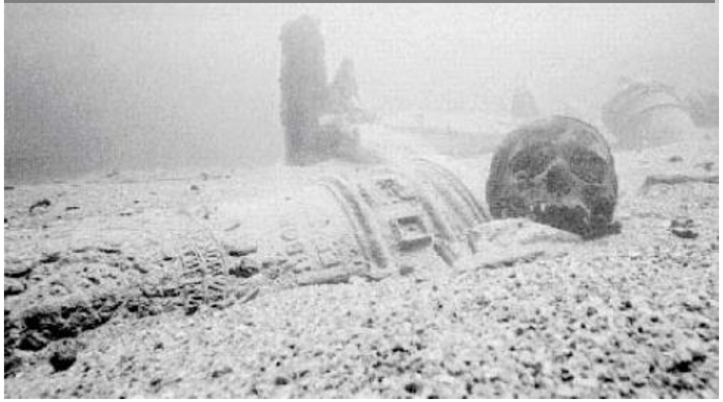
Earthquakes recorded in Northern Europe from 1375 to 1964 (left) and Earthquakes monitored in Northern Europe 1965−2008 (right) (University of Helsinki). Reason for earthquakes in Finland is land uplifting (recovery from the last glaciation)

Evidence for the suitability of the repository design and materials

- Spent nuclear fuel stability
  - spent nuclear fuel dissolution, evidence for conditions favoring low dissolution rates, low likelihood of criticality
- Canister materials stability
  - archaeological analogues (e.g. The Kronan Cannon), geological analogues, iron analogues
- Buffer and backfill analogues
  - thermal and chemical alteration, mechanical deformation, hydraulic barrier functions, freezing and thawing, chemical erosion
- Impact of cement materials
  - cement analogues, cement-bentonite interaction, cement-host rock interaction, carbonation
- Silica sol analogues

Canister material stability

- Copper archaeological analogues
  - The Kronan Cannon, boat sink in 1676 and few cannon were recovered in 1980s. (corrosion rate 0.15µm/a, low due to marine clay, montmorillonite)



- Copper geological analogues
  - In sedimentary rock: Keweenaw Peninsula, lake Superior region, Michican, US; South Devon, UK.
  - In basaltic lavas: Dalane, Norway
  - In granitic rocks: Hyrkkölä and Askola, Finland

Buffer and backfill material analogues

including:

- For the extent of thermal alteration
  - Indication of local cementation (high temperatures implied)
- For their hydraulic barrier function
  - Dunnarobb Sequoia forest, Italy: The massive trees were preserved by a sudden flood of lacustrine clay (courtesy Chris Weiss).

Buffer and backfill material analogues continues

including:

- For freezing and thawing
  - The Wyoming bentonites (one product is MX-80) located near the border of the Laurentide Ice sheet and as such, the area was subject to permafrost periods during the last ice age and also during previous ice ages.
- For chemical erosion (indirect)
  - A thin layer of soil at the top of bentonite is enough to “buffer” dilute water and prevent chemical erosion.
  - In repository conditions, there is a barrier of about 400 m of rock between the soil and the bentonite and backfill in the EBS, which would buffer any dilute rain or glacial water long before reaching repository depth.

Evidence for limited rates of radionuclide migration in the repository system

- In natural systems a number of chemical retardation mechanisms have been identified:
  - Adsorption
  - Ion-exchange (and isotope exchange)
  - Precipitation and co-precipitation
  - Mineralisation
- Examples of radionuclide retention in buffer and backfill materials
  - Clay halo around U ore, Cigar Lake, Canada
  - Koongarra, Australia
  - Fracture smectite at Hyrkkölä, Finland

Analogues for potential future conditions in the surface environment

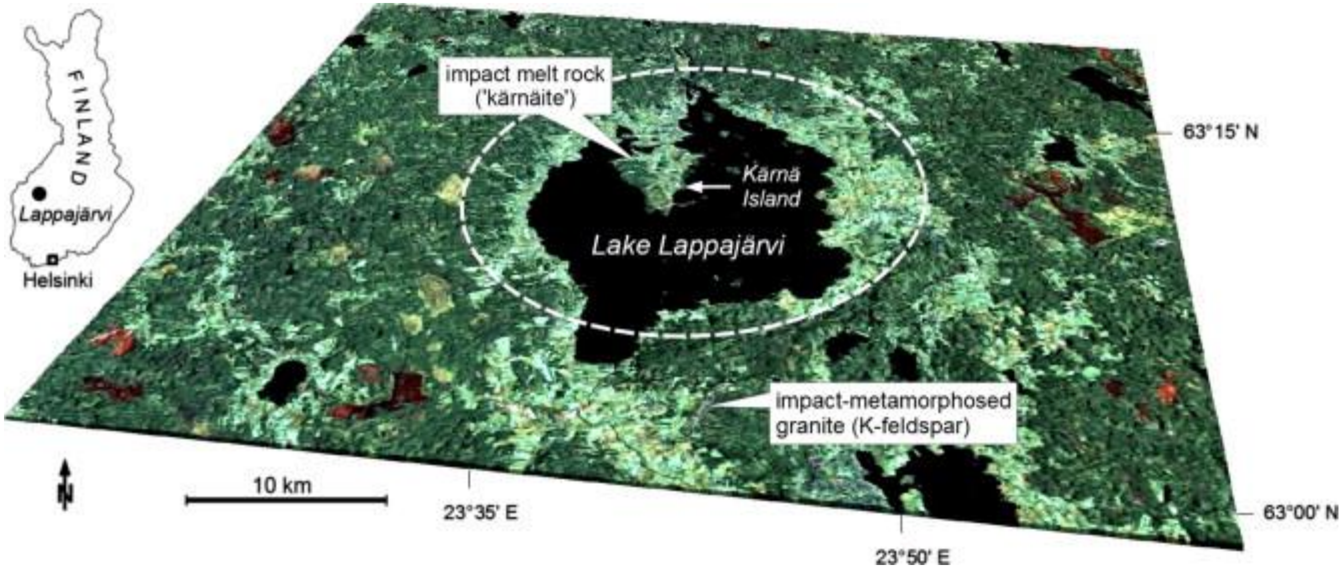
- Lakes and mires

Disposal of spent nuclear fuel in the context of other sources of radioactivity

- Complementary indicators
- Natural radionuclide concentrations and fluxes within the geosphere and to the biosphere
- Radionuclides relating to industrial activity

The evolution of the repository system beyond a million years in the future

- Evolution of the engineered barriers
- Evolution of the site
  - (as an example: Lappajärvi impact crater from 73 Ma ago



(Schmieder & Jourdan, 2013)

Sum up the support for the robustness of the KBS-3 method

Copper canister

- although there is no ‘perfect’ analogue, there is strong evidence from a range of natural occurrences of native copper for very low corrosion rates of Cu for millions of years under the groundwater and redox conditions similar to, or less favorable than, those at Olkiluoto;
- archaeological artefacts, while representing much more variable and often more severe conditions, suggest low localized copper corrosion rates that are not likely to be significant in determining canister longevity compared with general corrosion.

Sum up the support for the robustness of the KBS-3 method

Bentonite

- On the basis of observations from natural systems, there is good evidence to indicate that temperature-induced changes occur in bentonite at temperatures above about 150−200 °C, but that significant changes are also dependent on a supply of potassium, which will be limited in the buffer
- Bentonite interaction with cement leachate seems to be the only potential detrimental consideration (can be avoided by design or substituted with silica sol, replaced with low pH cement)
- There are several excellent illustrations of the long-term performance of bentonite as a hydraulic barrier in preserving wood and human cadavers, which also suggest that microbial activity was significantly reduced

Sum up the suitability of geological disposal at the Olkiluoto site

- geological stability of the site
- physical isolation due to depth, which minimizes the risks of future perturbations (e.g. due to glaciation) and human intrusion
- mechanical protection of the EBS
- favorable geochemical conditions and sufficiently low groundwater flow rates

Sum up the suitability of geological disposal at the Olkiluoto site

- crystalline rock has been investigated as a potential repository (including L/ILW repositories) host rock in various countries, including Argentina, Canada, China, France, Japan, Norway, Sweden, Switzerland, the UK and the USA
- L/ILW repositories already exist in this rock type in Norway (Himdalen), Sweden (Forsmark) and Finland (Loviisa and Olkiluoto)
- coastal sites such as Olkiluoto have also been assessed in Japan, Korea, Sweden and the UK and two coastal repositories are already in place – Gyeongju in Korea and Rokkasho in Japan.

Thank you for your attention!

References

- IAEA 2003a. The long term storage of radioactive waste: safety and sustainability: A position paper of international experts. Vienna, Austria: International Atomic Energy Agency. IAEA-LTS/RW.
- Marcos , N. 2002. Lessons from nature. The behavior of technical and natural barriers in the geological disposal of spent nuclear fuel. Espoo, Finland: Finnish academy of technology. Acta Polytechnica Scandinavia, Civil Engineering and Building Construction Series. No. 124.
- NEA 2004a. Post-closure safety cases for geological repositories. Nature and Purpose. Paris, France: OECD/Nuclear Energy Agency (NEA): NEA Report 3679. 56 p.
- NEA 2009a. Considering timescales in the post-closure safety of geological disposal of radioactive waste. Paris, France: OECD/Nuclear Energy Agency (NEA). NEA Report No. 6424.
- Pimenoff, N., Venäläinen, A., Järvinen, H. 2011.Climate scenarios for Olkiluoto on a time-scale of 120,000 years. Eurajoki, Finland: Posiva Oy. Posiva 2011-04.
- Posiva 2003. Nuclear waste management of the Olkiluoto and Loviisa power plants: Programme for research, development and technical design for 2004–2006. Olkiluoto, Finland: Posiva Oy. TKS-2003. 288 p.
- Posiva Oy, 2013. Safety case for the disposal of spent nuclear fuel at Olkiluoto - Complementary Considerations 2012. Eurajoki, Finland: Posiva report 2012-11. Posiva Oy. 272 p.
- Posiva Oy, 2013. Safety case for the disposal of spent nuclear fuel at Olkiluoto - Assessment of Radionuclide Release Scenarios for the Repository System 2012 2012. Eurajoki, Finland: Posiva report 2012-09. Posiva Oy.
- Schmieder, M., Jourdan, F. 2013. The Lappajärvi impact structure (Finland): Age, duration of crater cooling, and implications for early life. Geochimica et Cosmochimica Acta, Volume 112, Pages 321-339.