The 13th **International Congress on Rock Mechanics**

ISRM CONGRESS 2015

Palais des congrès de Montréal, Québec, Canada **May 10 to 13, 2015**

ISRM

Imperial College London

4th International Underground Research Laboratory (URL) Workshop

“Contributions of Rock Mechanics to Radioactive Waste Disposal Evaluations”

John A Hudson

Emeritus Professor,

Dept. Earth Science and Engineering,

Imperial College London, UK

Organized by:

CIM ICM Canadian Institute of Mining, Metallurgy and Petroleum

In collaboration with:

ISRM

CARMA CANADIAN ROCK MECHANICS ASSOCIATION

ARMA american rock mechanics association

McGill

UNIVERSITY OF TORONTO

Queen's UNIVERSITY

1. Unlike other civil rock engineering projects, such as a metro tunnel or a mine, the repository provides a static disposal function. This means that the repository can be located in different rock masses and at different depths

2. Because of the isolation function, the design involves coupled geological-thermal-hydrological-mechanical-chemical-biological processes to a significantly greater degree than for other rock engineering projects.

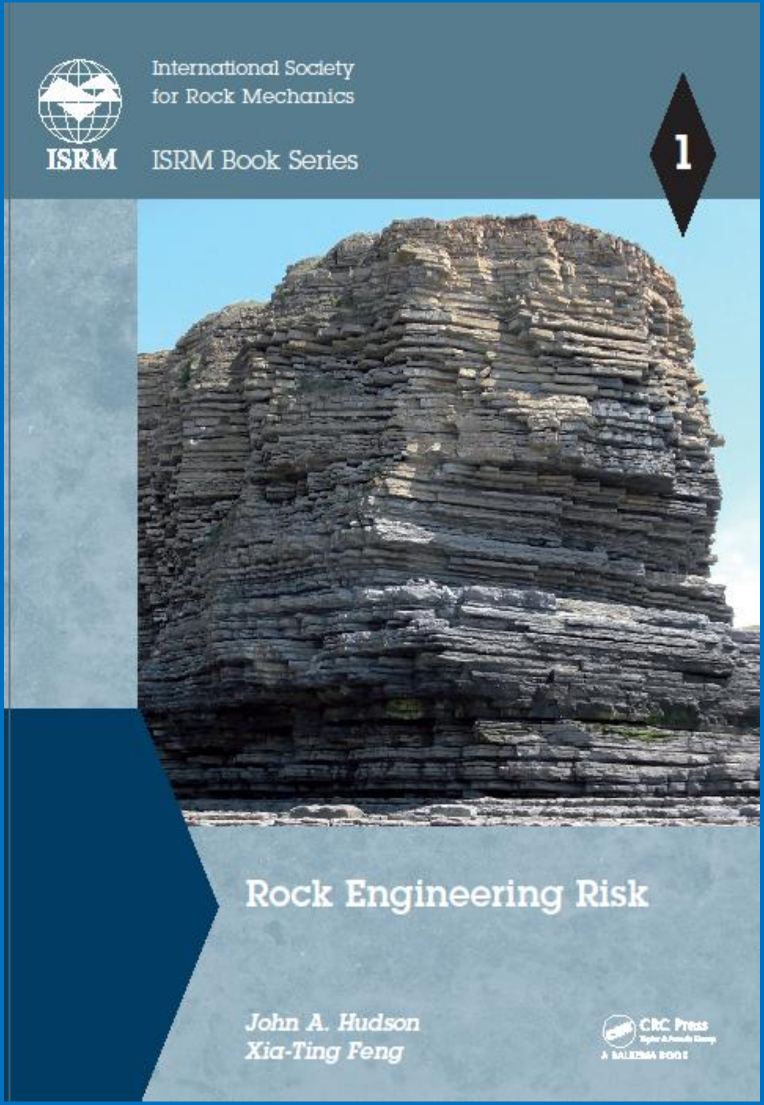
3. The regulators require that the design life of the repository is of the order of hundreds of thousands of years, compared to about 100 years for ‘conventional’ civil rock engineering projects.

4. There will be significant public involvement in the location and acceptability of a repository facility

5. Unacceptable quantities of radionuclides should not escape to the biosphere

HOW TO OVERCOME COMPLEXITY & RISK?

Overcoming Complexity and Risk


International Society
for Rock Mechanics
ISRM
ISRM Book Series
1

Rock Engineering Risk

John A. Hudson
Xia-Ting Feng

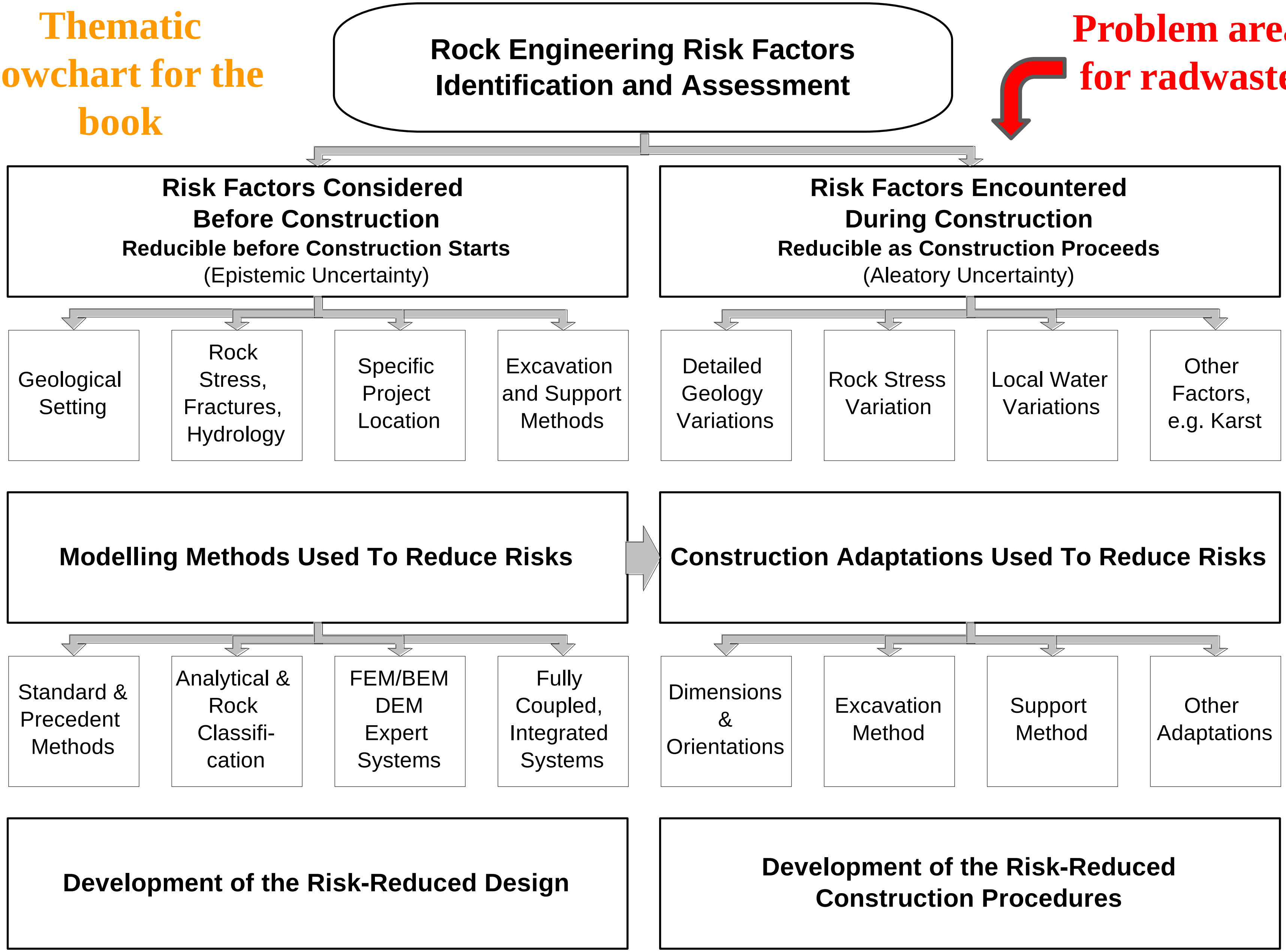
CRC Press
Taylor & Francis Group
A BALKEMA BOOK

In the period 2011-2015, the Design Methodology Commission of the ISRM has been studying the subject of risk in connection with rock engineering projects—which has led to the book “Rock Engineering Risk”

The subject of Chapter 5 is “Radioactive Waste Disposal: Overcoming Complexity and Risk”

Thematic flowchart for the book

Problem area for radwaste



Rock Engineering Risk Factors Identification and Assessment

Risk Factors Considered Before Construction
Reducible before Construction Starts
(Epistemic Uncertainty)

- Geological Setting
- Rock Stress, Fractures, Hydrology
- Specific Project Location
- Excavation and Support Methods

Risk Factors Encountered During Construction
Reducible as Construction Proceeds
(Aleatory Uncertainty)

- Detailed Geology Variations
- Rock Stress Variation
- Local Water Variations
- Other Factors, e.g. Karst

Modelling Methods Used To Reduce Risks

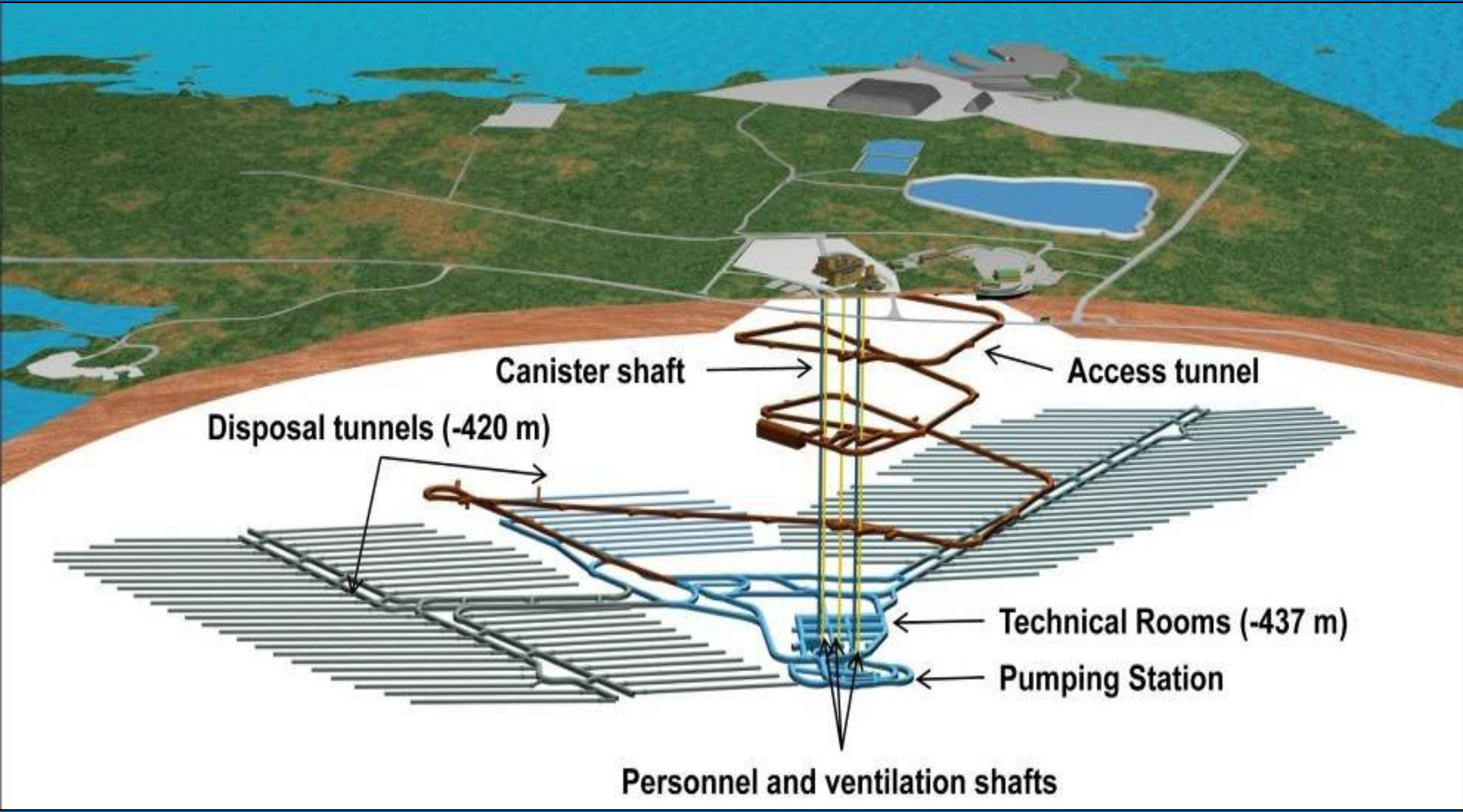
- Standard & Precedent Methods
- Analytical & Rock Classification
- FEM/BEM DEM Expert Systems
- Fully Coupled, Integrated Systems

Construction Adaptations Used To Reduce Risks

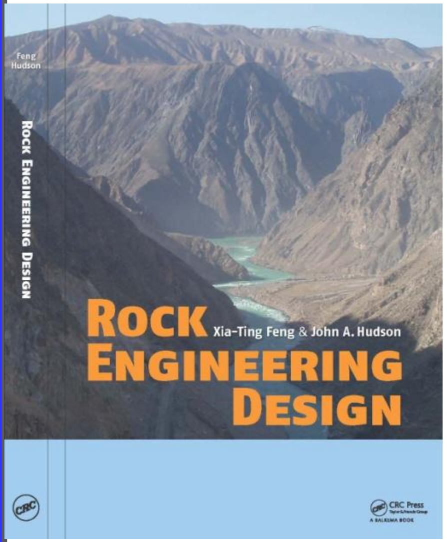
- Dimensions & Orientations
- Excavation Method
- Support Method
- Other Adaptations

Development of the Risk-Reduced Design

Development of the Risk-Reduced Construction Procedures



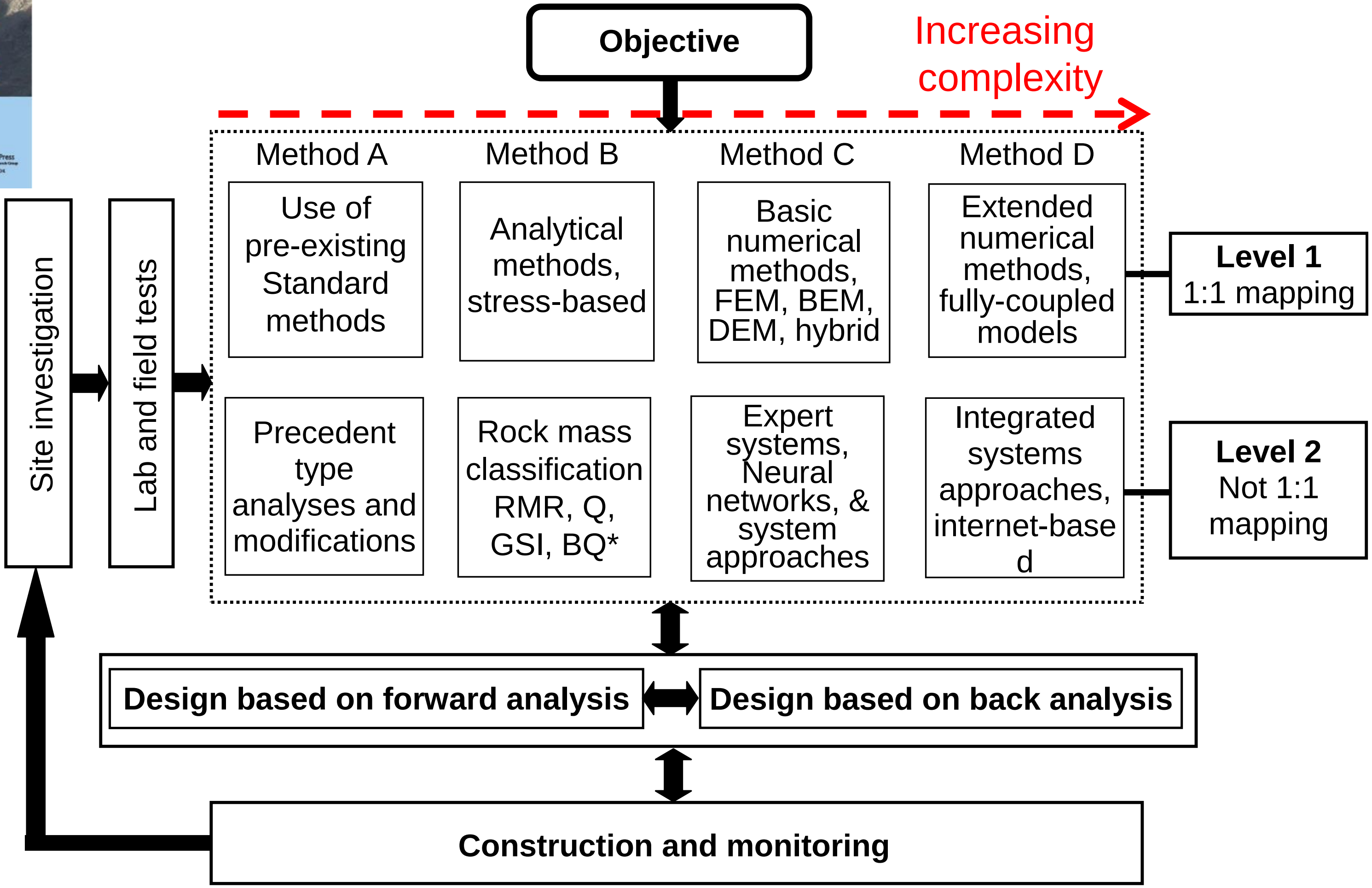
Schematic of a radioactive waste repository layout (from Posiva, Finland)



2011

Thematic flowchart for the book:

Methods for rock mechanics modelling and geo-engineering design analyses



Objective

Increasing complexity

Site investigation

Lab and field tests

Method A	Method B	Method C	Method D
Use of pre-existing Standard methods	Analytical methods, stress-based	Basic numerical methods, FEM, BEM, DEM, hybrid	Extended numerical methods, fully-coupled models
Precedent type analyses and modifications	Rock mass classification RMR, Q, GSI, BQ*	Expert systems, Neural networks, & system approaches	Integrated systems approaches, internet-based

Level 1
1:1 mapping

Level 2
Not 1:1 mapping

Design based on forward analysis

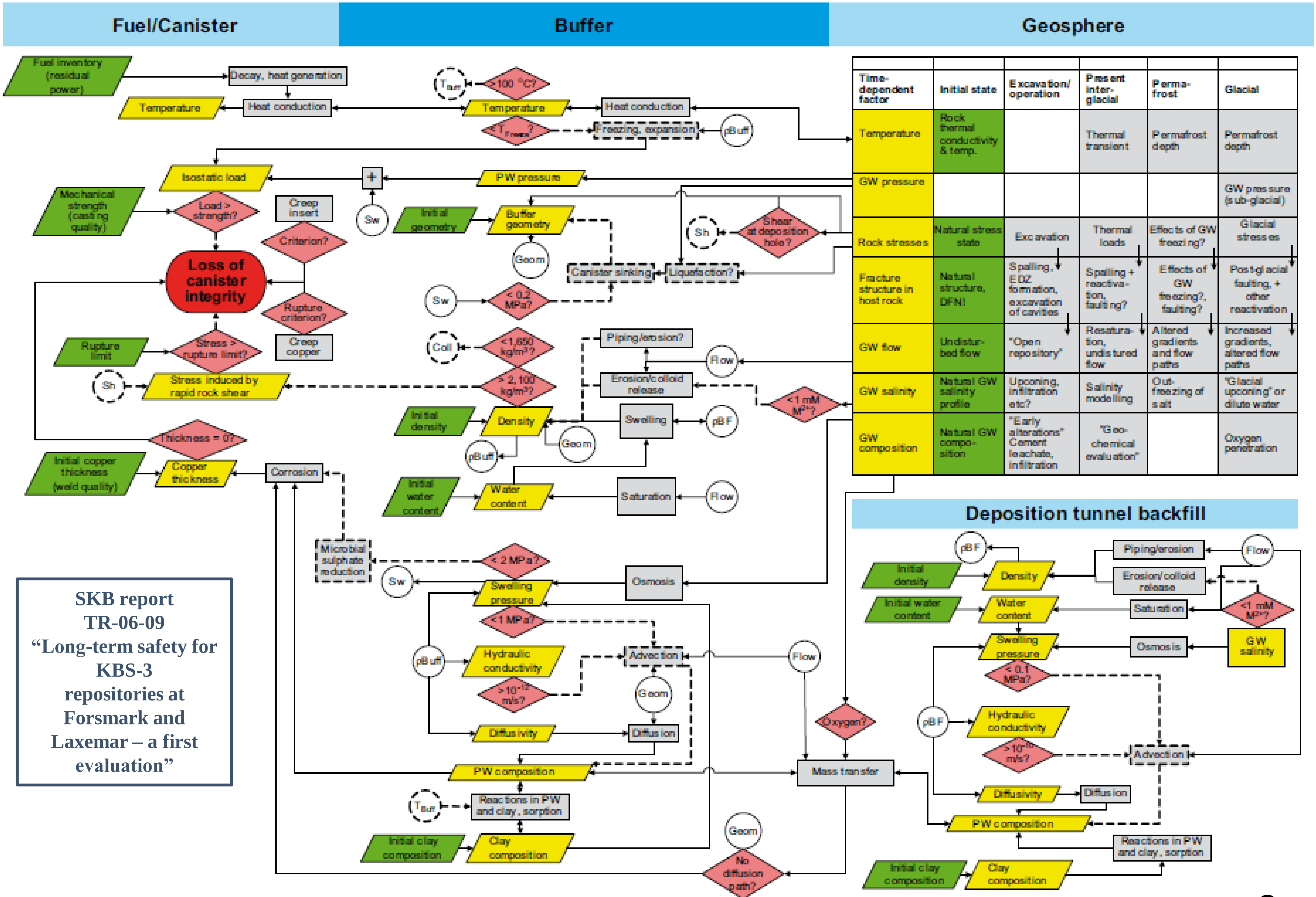
Design based on back analysis

Construction and monitoring

The main factors

1. Geology – what is the potential host rock and how might its history and characteristics affect the repository design?
2. Rock Mechanics – what are the rock mechanics characteristics, e.g. rock stress, intact rock, fractures, large shear zones?
3. Hydrogeology – what is the hydrogeology setting, e.g. groundwater table, hydraulic heads, type of flow (water-bearing fractures and/or rock matrix), fracture geometry?
4. Hydrogeochemistry – origin of groundwater, residence time for groundwater, hydrogeochemical stability
5. Evolution of the site during repository construction, and after the waste is emplaced – both internal effects (heat produced by the waste) and external effects (geological changes)

But what are all the detailed factors?



Time-dependent factor	Initial state	Excavation/ operation	Present inter-glacial	Perma-frost	Glacial
Temperature	Rock thermal conductivity & temp.		Thermal transient	Permafrost depth	Permafrost depth
GW pressure					GW pressure (sub-glacial)
Rock stresses	Natural stress state	Excavation	Thermal loads	Effects of GW freezing?	Glacial stresses
Fracture structure in host rock	Natural structure, DFN!	Spalling, EDZ formation, excavation of cavities	Spalling + reactiva-tion, faulting?	Effects of GW freezing?, faulting?	Post-glacial faulting, + other reactivation
GW flow	Undistur-bed flow	"Open repository"	Resatura-tion, undistured flow	Altered gradients and flow paths	Increased gradients, altered flow paths
GW salinity	Natural GW salinity profile	Upconing, infiltration etc?	Salinity modelling	Out-freezing of salt	"Glacial upconing" or dilute water
GW composition	Natural GW compo-sition	"Early alterations" Cement leachate, infiltration	"Geo-chemical evaluation"		Oxygen penetration

SKB report
TR-06-09
"Long-term safety for
KBS-3
repositories at
Forsmark and
Laxemar – a first
evaluation"

Figure 7-3. The SR-Can FEP chart. Colour coding: Initial state factors, Variables, Processes, Safety function indicators. Solid lines: Influences that always occur. Dashed lines: Influences if there is safety function indicator violation. Circles: Interrupted influence lines (to increase readability).

SKB report TR-06-09 “Long-term safety for KBS-3 repositories at Forsmark and Laxemar – a first evaluation”

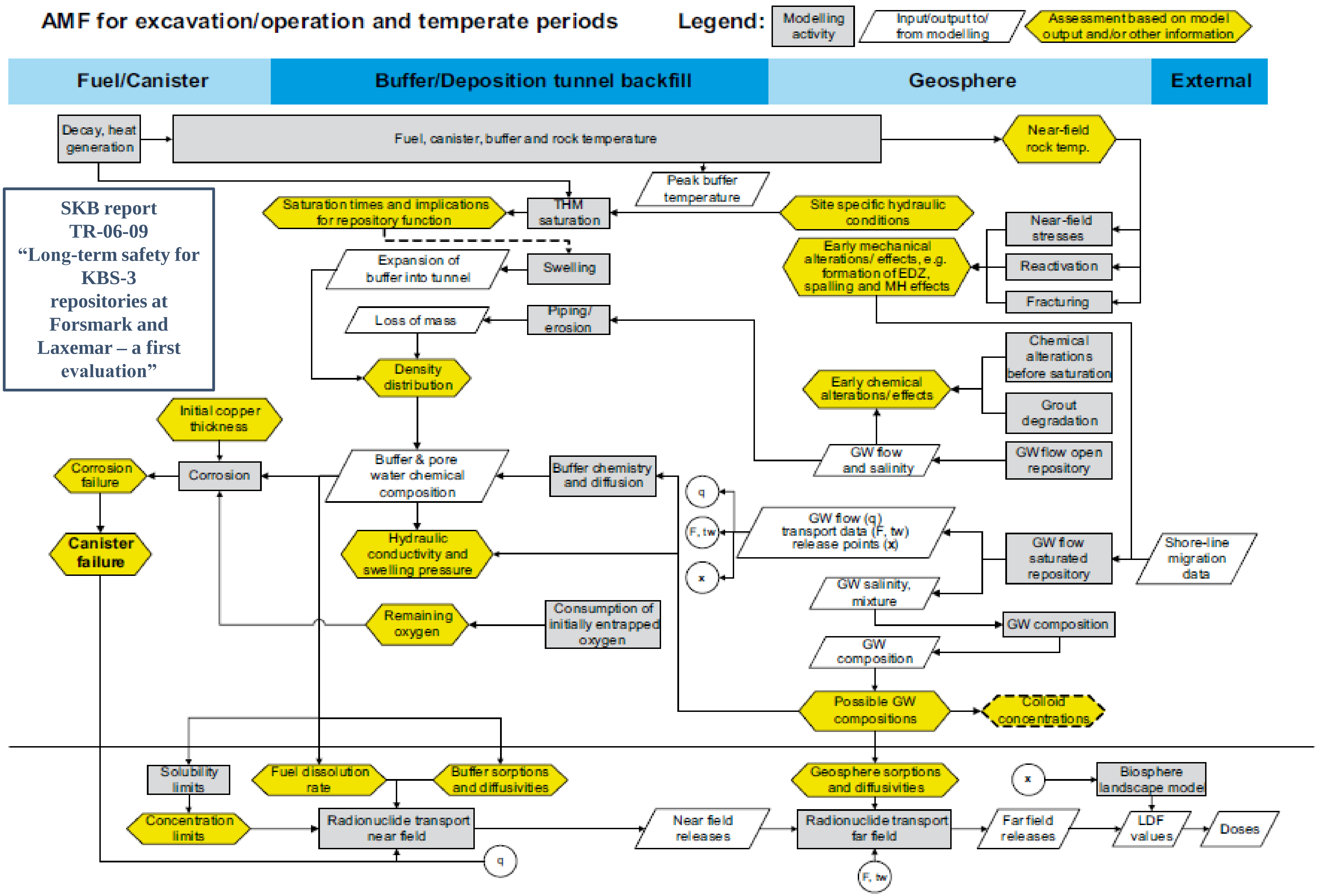
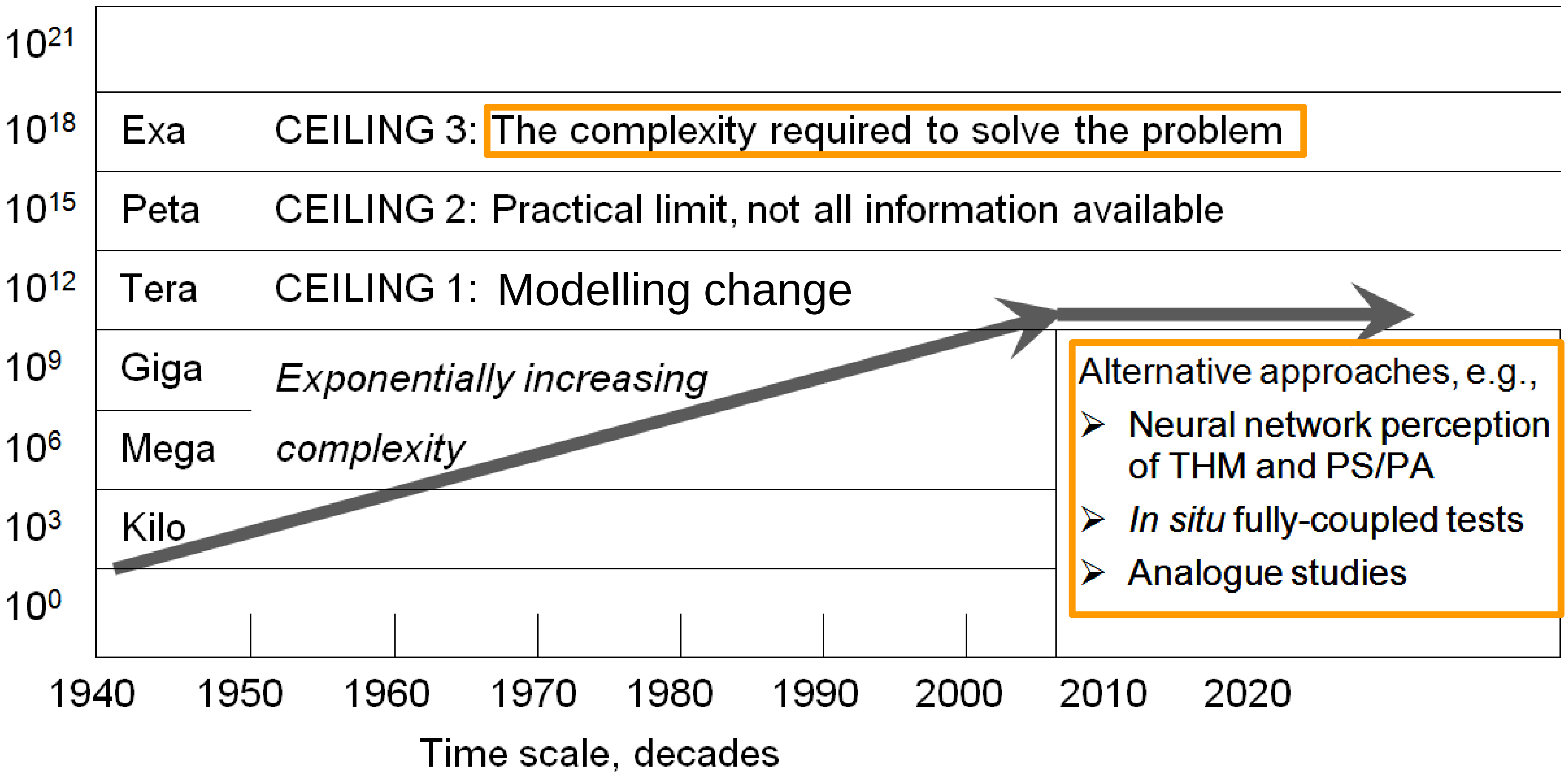


Figure 6-3. The assessment model flow chart for the excavation/operation period and the initial temperate period after closure. See main text for further explanations.

Problem 1: Complexity

y-axis is complexity of THM codes and numerical calculations
(in units of information, bits/bytes)



CEILING 3: The complexity required to solve the problem

CEILING 2: Practical limit, not all information available

CEILING 1: Modelling change

Alternative approaches, e.g.,

- Neural network perception of THM and PS/PA
- *In situ* fully-coupled tests
- Analogue studies

Problem 2: No Precedent Practice

(in terms of confirmation of repository function)

The required very long design life may require consideration of the effect of, not one, but several future ice ages with the associated effects on the groundwater, the rock stress and the fractures—depending on the site location.

Because of the long design life resulting from the half-lives of the radioactive materials,
a repository cannot be designed by precedent practice
because optimal site selection criteria have not been established from engineering experience—nor can they be if the design life has to be hundreds of thousands of years.

DECOVALEX-2015

D2015 Tasks

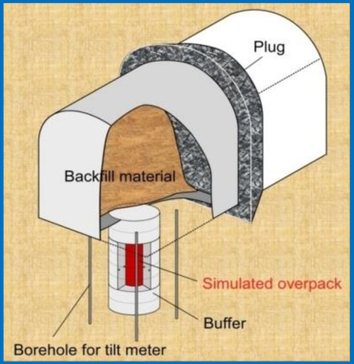
Task A: The Sealex *In Situ* Experiment, Tournemire Site, France

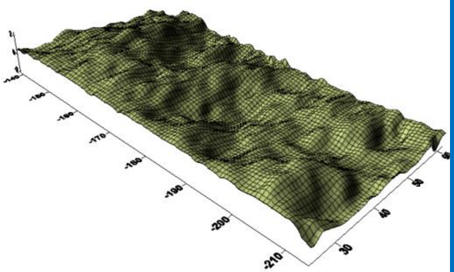
Task B1: HE-E Heater Test, Mont Terri, Switzerland

Task B2: EBS Experiment, Horonobe, Japan

Task C1: THMC of single rock fractures

Task C2: Bedrichov Tunnel, Czech Republic





The current DECOVALEX2015 project consists of an international consortium of ten Funding Organisations, comprising for this 2012-2015 phase,

China, Czech Republic, France, Germany,
Japan, Korea, Switzerland, UK, USA (x2),

which support Research Teams.

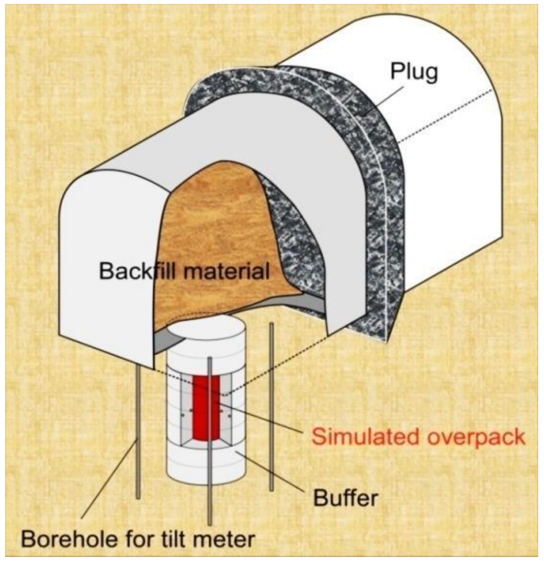
Participants at a Workshop meeting on Jeju Island in South Korea

Problem 3: Validation of Computer Models: DECOVALEX Project

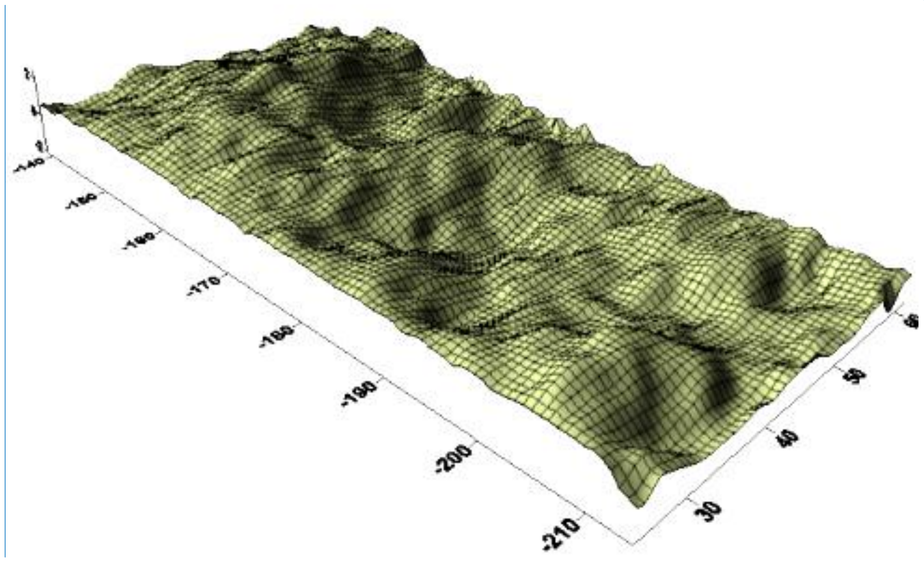
Tournemire site, France

Mont Terri, Switzerland

Bedrichov, Czech Republi

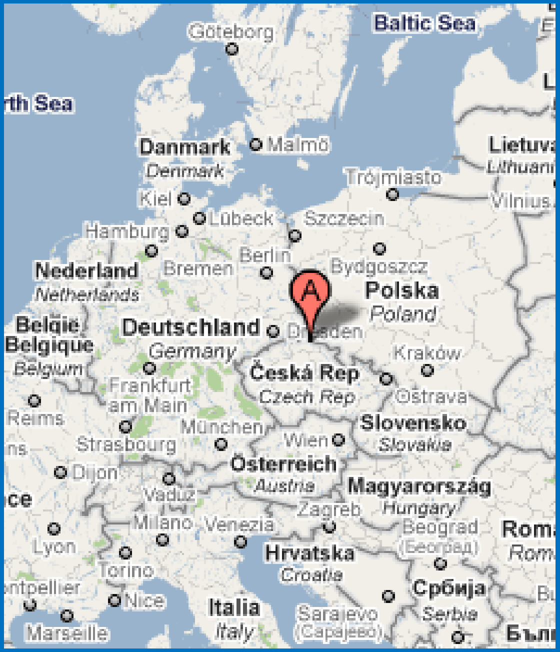


Horonobe, Japan



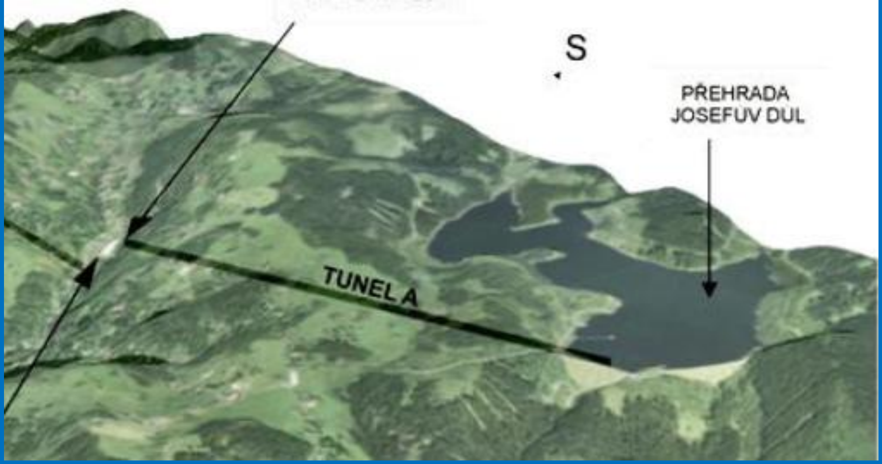
Lab Testing of water flow over quartz fracture

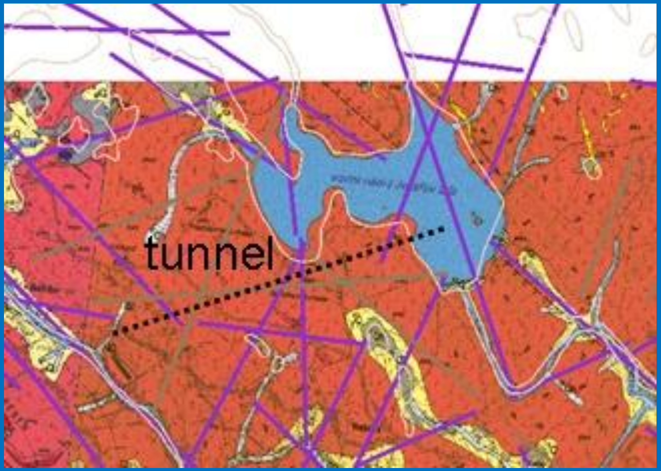
Task C2: Bedrichov Tunnel, Czech Republic



Research Topics include

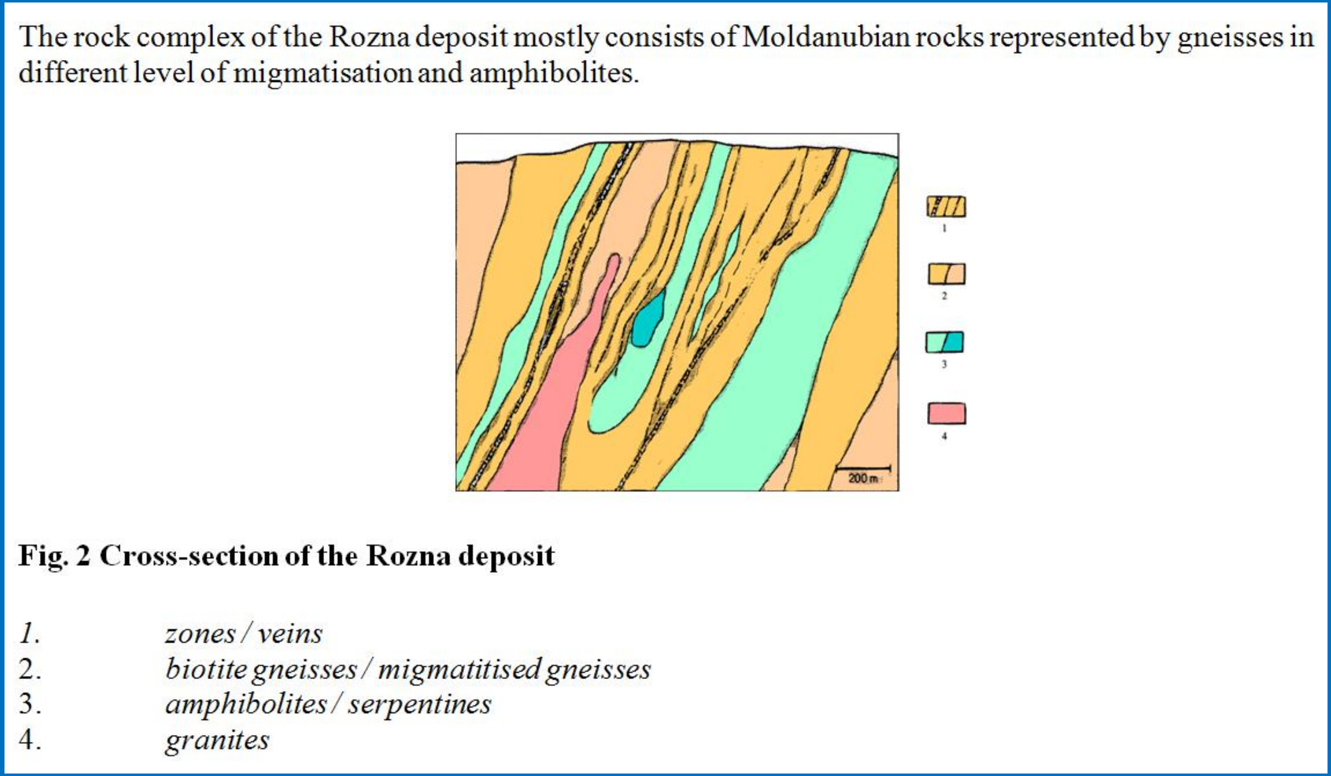
- Water flow in massif/ inflow to the tunnel
- Natural tracer transport surface-tunnel (water age)
- Water chemical composition (rock minerals dissolution)





SÚRAO | SPRÁVA ÚLOŽIŠŤ RADIOAKTIVNÍCH ODPADŮ

New projects benefit from existing projects



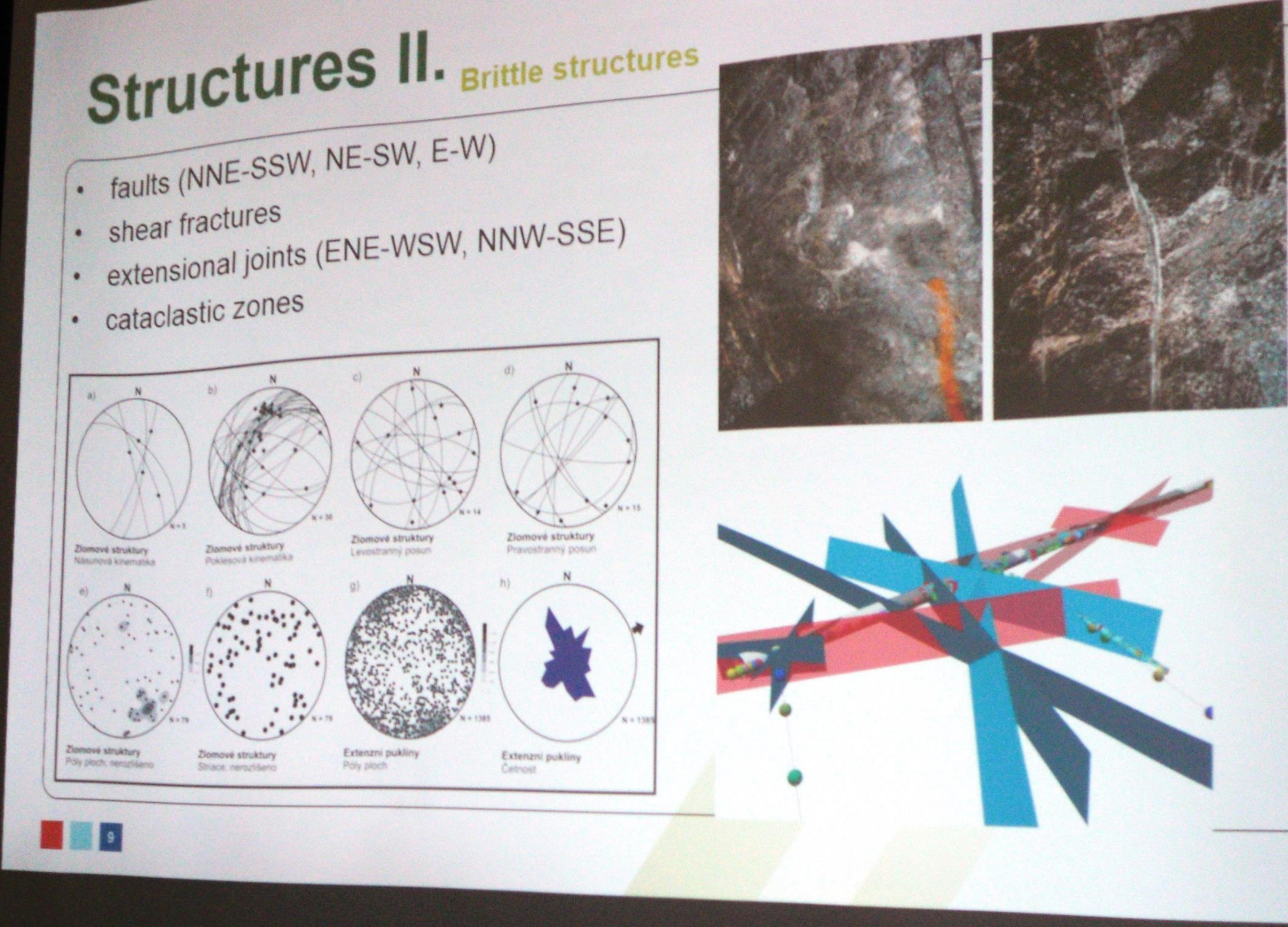
The rock complex of the Rozna deposit mostly consists of Moldanubian rocks represented by gneisses in different level of migmatisation and amphibolites.

Fig. 2 Cross-section of the Rozna deposit

1. *zones / veins*
2. *biotite gneisses / migmatitised gneisses*
3. *amphibolites / serpentines*
4. *granites*

DECOVALEX Visit to the Bukov Uranium Mine in the Czech Republic, April 2015

New DECOVALEX Chairman for the 2015-2019 phase
Jens Birkholzer of LBNL



Structures II. Brittle structures

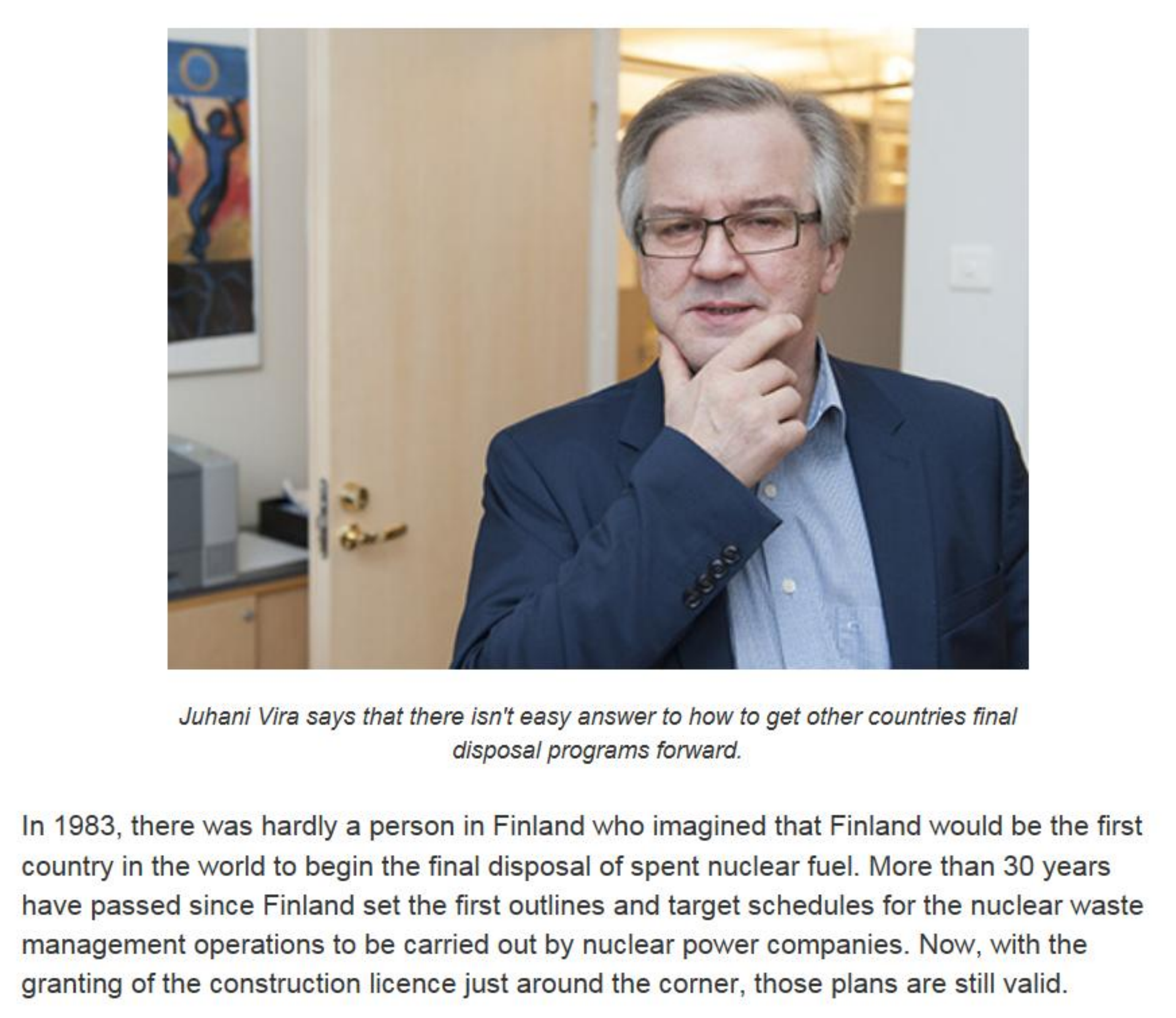
- faults (NNE-SSW, NE-SW, E-W)
- shear fractures
- extensional joints (ENE-WSW, NNW-SSE)
- cataclastic zones


3
4
3,6-4,4
S-4
5
5
6
6
4,4-6,4
7
7
8
8
S-4
6,4-8,4
9
9
10
10
8,4-10,1
10,1-11
11
11
12


ZAKÁZÁN


155

From Posiva Website in Finland



Juhani Vira says that there isn't easy answer to how to get other countries final disposal programs forward.

In 1983, there was hardly a person in Finland who imagined that Finland would be the first country in the world to begin the final disposal of spent nuclear fuel. More than 30 years have passed since Finland set the first outlines and target schedules for the nuclear waste management operations to be carried out by nuclear power companies. Now, with the granting of the construction licence just around the corner, those plans are still valid.

The End