Underground Research Laboratories: Purposes, Evolution of Objectives, and Brief History*

A Presentation to

US Nuclear Waste Technical Review Board

April 24, 2019

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*Derived from IAEA, 2019 presentation

Presentation Overview

1. Role and objectives of Underground Research Facilities (URFs)
2. Evolution of URF objectives during a repository-development program
3. History of URFs and their changing role
4. Short tour of some landmark URFs

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Part 1: The Role and Objectives of URFs

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Definitions and Meanings

- URL: underground research laboratory
  - '*laboratory*' implies the main emphasis is on experimental work to explore fundamental processes in the rock-water system
- URF: underground research facility
  - '*research*' implies that the facility is for <u>applied</u> research, supporting the Safety Case
- RCF: rock characterization facility
  - the main purpose is to characterize the properties of the host rock for input to design and Safety Case
- **URF: underground rock facility**
  - **more generic: a facility for research, characterization and demonstration of excavation and emplacement of engineered barrier system (EBS)**
  - **this is more in tune with the current international status of geological disposal**

Today, the emphasis is on characterizing the host rock for design and Safety Case iterations, along with testing and demonstrating constructability/ feasibility aspects of the EBS and closure systems. **The era of fundamental experiment and research is long past.**

Source: IAEA (2019)

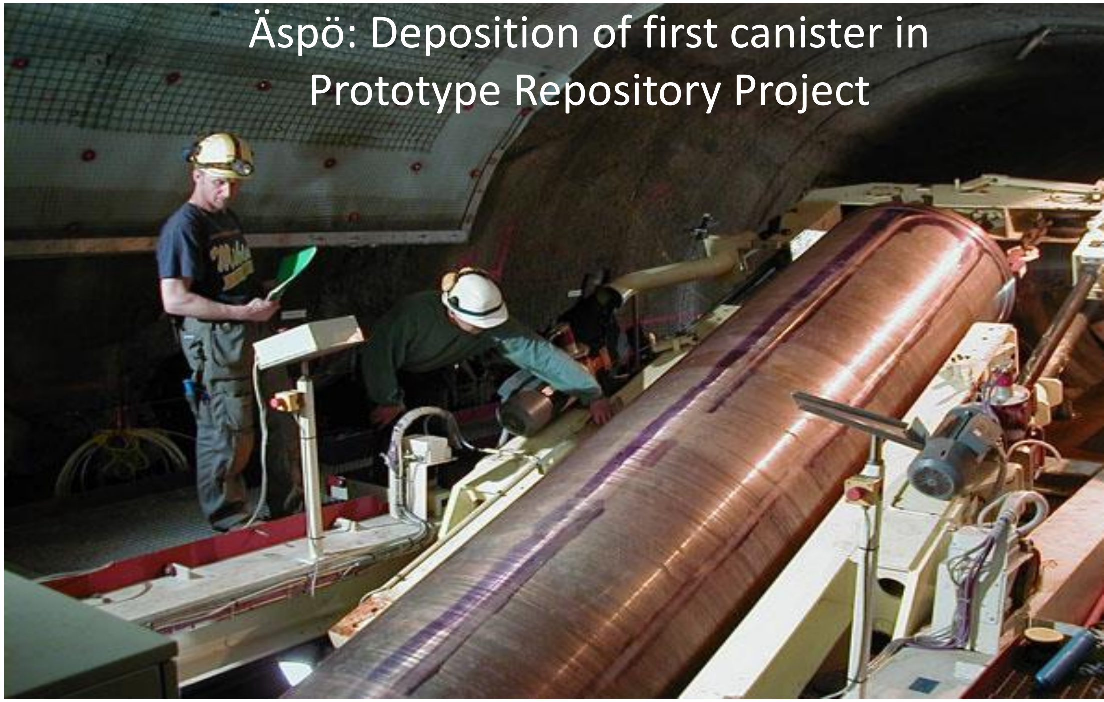
Value of an Underground Rock Facility (URF)

1. Provides training and underground working experience for engineers and technicians
2. Is essential for verifying and improving on surface-based geological information on rock and groundwater properties by direct observations at disposal depth: these are key to the Safety Case (*in situ* characterization)
3. Tests characterization methods that will be used routinely throughout operations to make detailed decisions of rock suitability as each disposal tunnel, vault of disposal hole is constructed
4. Permits development and testing of specialized rock excavation and waste package emplacement machinery
5. Permits full-scale demonstration of waste, EBS and seal emplacement
6. Allows realistic, *in situ* demonstration and testing of aspects of the Safety Case and operations to stakeholders
7. Allows, if desired, a *pilot disposal* to take place and be monitored from an early stage of the disposal program

Source: IAEA (2019)

Public Demonstration Capability of URFs

- Most people, including technical experts, are not familiar with the underground
- Demonstrate the methods of geological disposal
- **In earliest stages**: show stakeholders what deep rock is like and show how science is being used to aid design and assess safety
- **From middle stage onwards**: developed concepts can be shown at increasing scale (both spatial and temporal) for the purpose of *"performance confirmation"*



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When Does a URF Play a Role in the Disposal Program?

1. Training
2. *In situ* characterization
3. Test characterization methods used in operations
4. Develop and test specialized rock machinery
5. Full-scale demonstration
6. *In situ* demonstration to stakeholders
7. Pilot disposal facility

1. After rock type is selected
2. After site selection
3. After site selection
4. After site selection
5. Close to construction license
6. Close to construction license
7. After operating license

Source: IAEA (2019)

Generic or Site-specific URF?

- Generic URF
  - training in underground activities
  - developing and testing specialized excavation methods (e.g. deposition holes in hard rock)
  - developing and testing waste and EBS handling machinery
  - testing sealing systems
- Site-specific URF, as part of the repository
  - underground characterization and demonstration work
  - … and **all of the activities on the next slide**...

As all of the work done in a generic URF can be done in a site-specific URF, which will in any case be an essential facility, is it worth investing in a generic URF?

Source: IAEA (2019)

Typical URF Activities at a Repository Site

- Assessment and testing of sampling and monitoring techniques
- Characterizing properties of host rock and groundwater system
- Characterizing thermal-hydrological-mechanical-chemical (THMC) impacts of construction and excavation on host rock
- Characterizing *in situ* behavior of engineered barrier system components
- Characterizing interactions between disposal system components
- Investigating sealing of tunnels, shafts and boreholes
- Demonstrating and optimizing construction approaches and methods
- Testing approaches to qualifying suitable rock volumes for waste emplacement
- Testing and demonstrating methods of waste package handling and emplacement
- Providing pilot waste emplacement region for long-term monitoring
- Testing and demonstrating methods of routine repository operation
- Testing and demonstrating seal systems prior to repository closure

Part 2: Evolution of URF Objectives During a Repository Development Program

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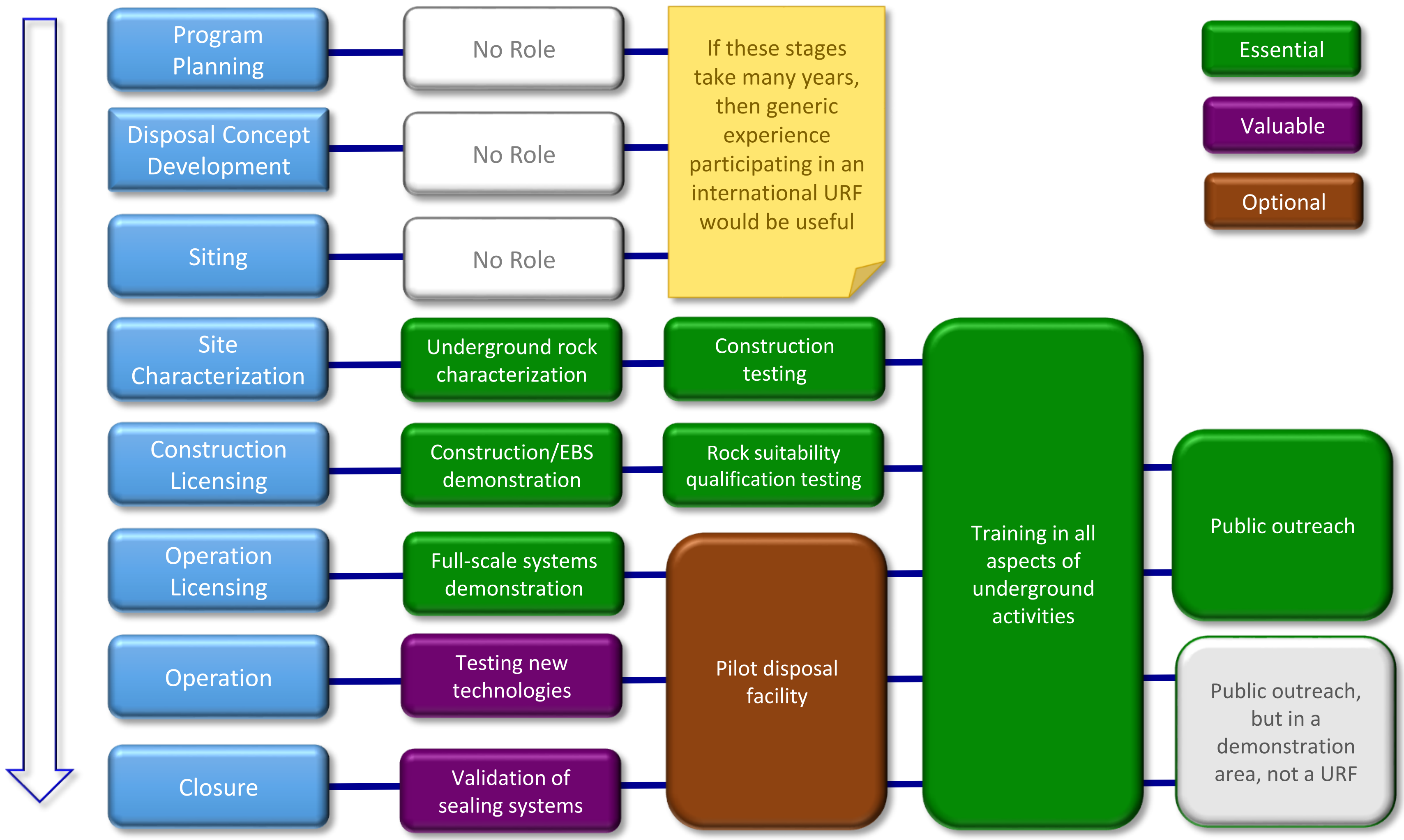
Evolving URF Objectives



Source: IAEA (2019)

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Part 3: History of URFs and Their Changing Role

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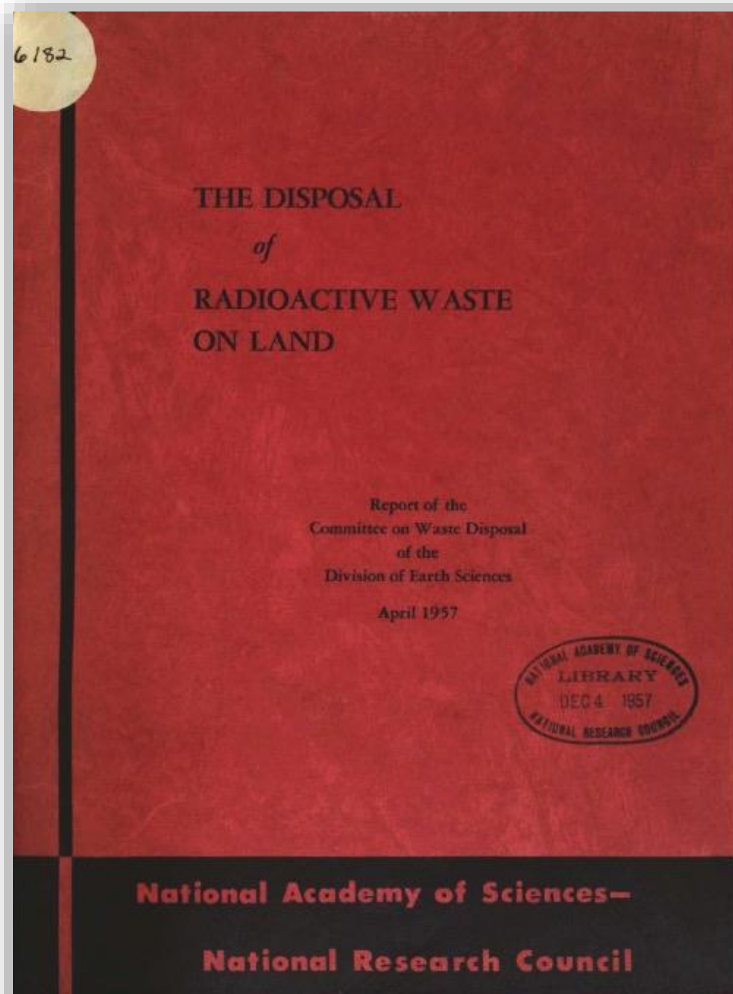
Where Geological Disposal Began

US National Academy of Sciences, 1957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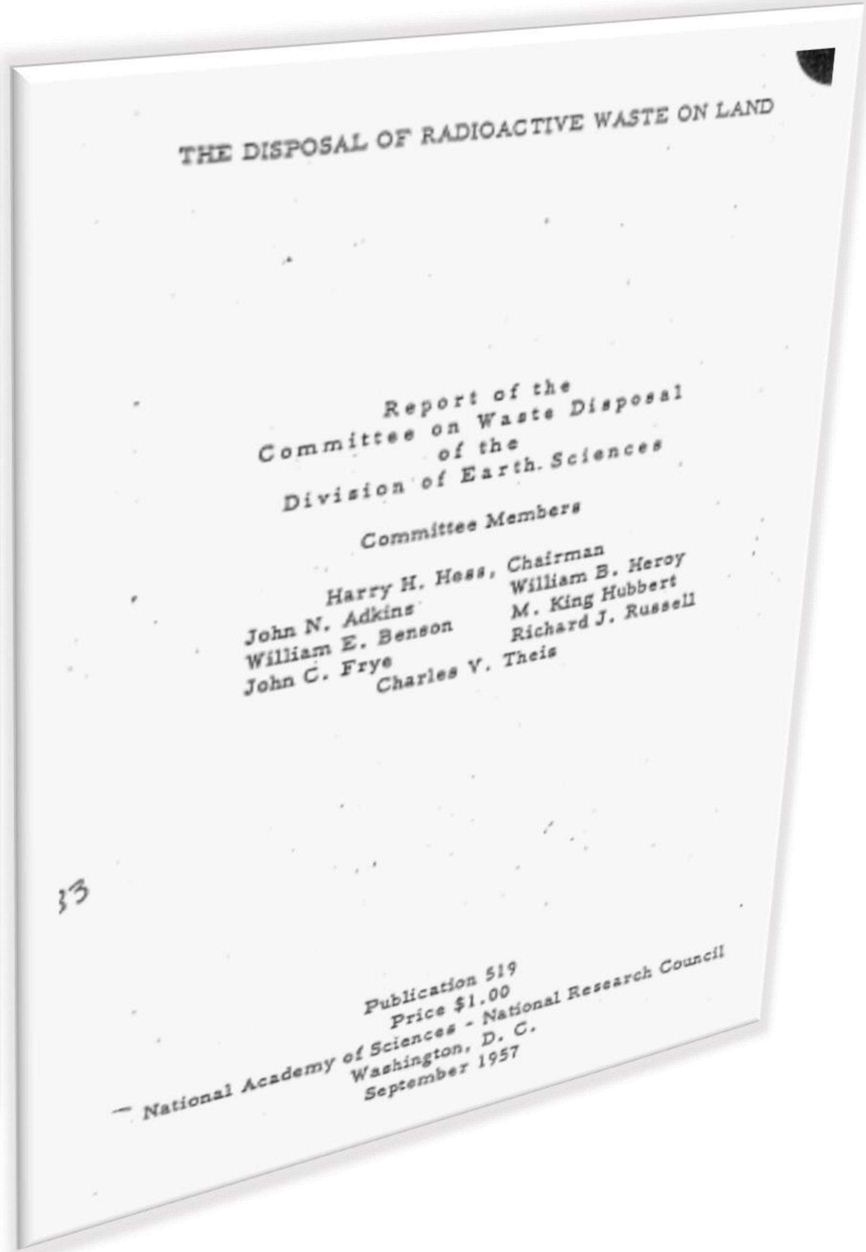
THE DISPOSAL
of
RADIOACTIVE WASTE
ON LAND

Report of the
Committee on Waste Disposal
of the
Division of Earth Sciences

April 1957

National Academy of Sciences—
National Research Council


THE DISPOSAL OF RADIOACTIVE WASTE ON LAND

Report of the
Committee on Waste Disposal
of the
Division of Earth Sciences

Committee Members

Harry H. Hess, Chairman
John N. Adkins
William E. Benson
John C. Frye
Charles V. Theis
William B. Heroy
M. King Hubbert
Richard J. Russell

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Publication 519
Price $1.00
National Academy of Sciences - National Research Council
Washington, D. C.
September 1957

1960s: : Project Salt Vault, Kansas

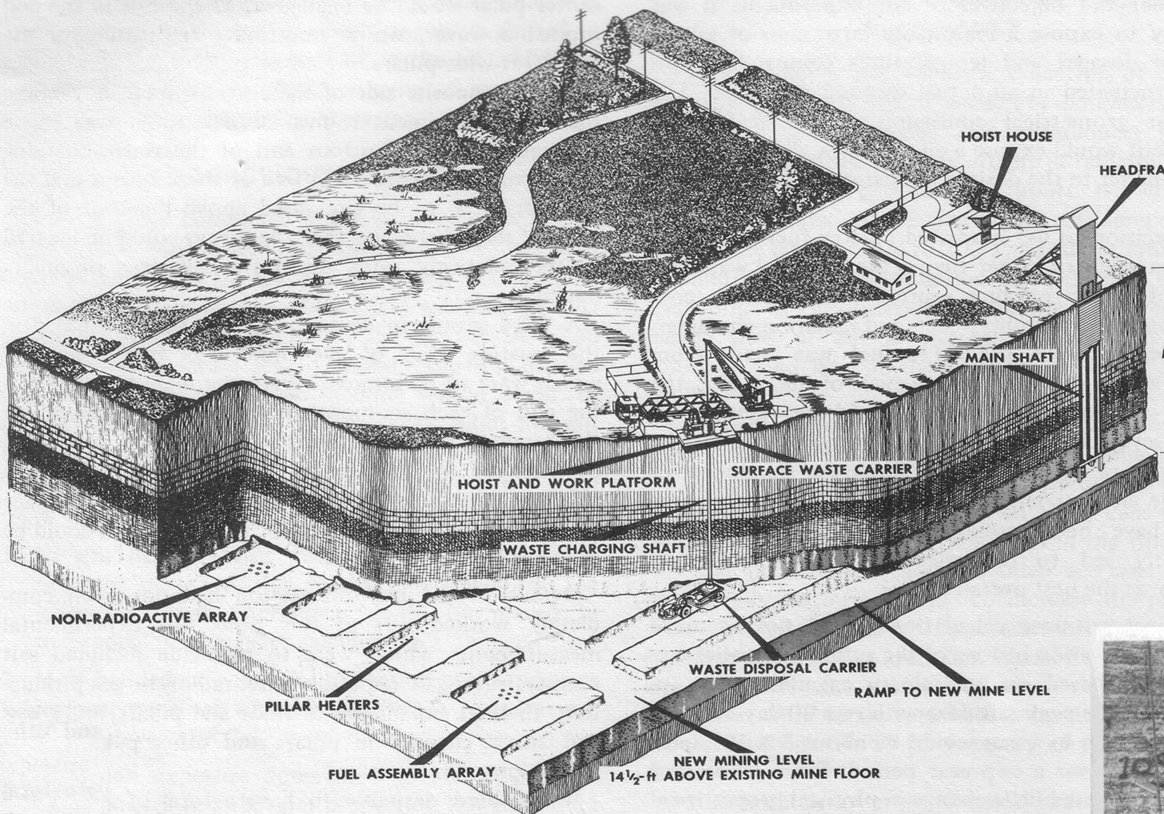

Fig. 14.1. Pictorial Cutaway View of the Project Salt Vault Experiment.

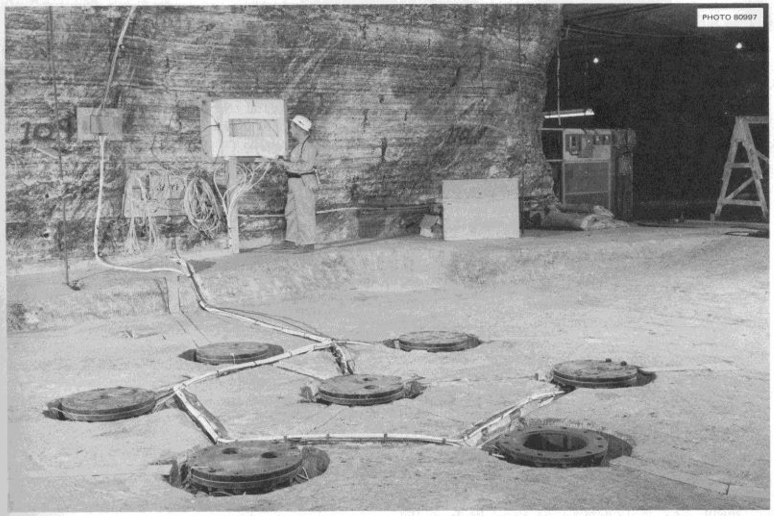

Fig. 8.3. Photo of Array in Room 1 Under Construction, Showing the Off-Gas Tube Bundle and Its Trench.

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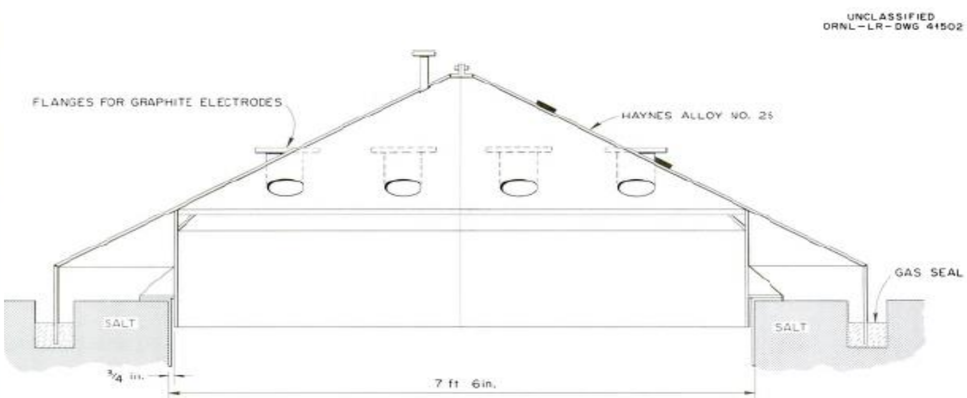
Even Before Project Salt Vault

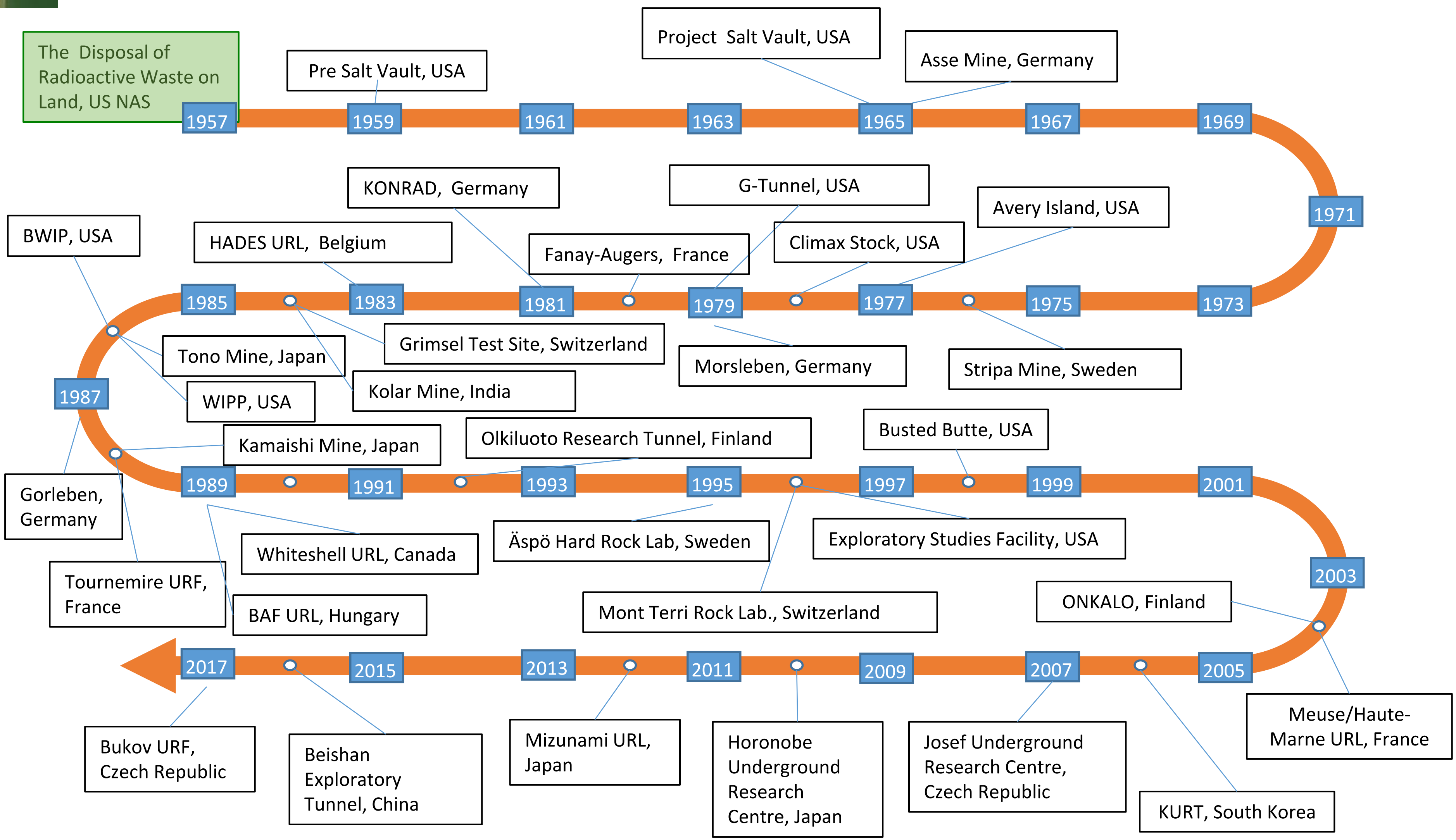
- First documented underground experiment in salt: 1959, Hutchinson, Kansas
  - Objective: study the basic feasibility of direct disposal of liquid radioactive waste in cavity in salt mine, which was proposed by the National Academy of Sciences in 1957
  - Key findings: direct disposal of liquid radioactive waste is not feasible because of several issues including gas generation and corrosion.



Source: Health Physics Division Annual Progress Report for Period Ending July 31, 1959, ORNL-2806

Source: IAEA (2019)

Timeline of Underground Research Facilities (URFs)



Source: IAEA (2019)

Historical Evolution of URF Activities

- **Basic research on geological disposal (1960s to 1980s)**
  - Demonstrate basic technical feasibility of geological disposal
  - Improve understanding and knowledge of properties and behavior of rocks and groundwaters in the deep geological environment
  - Formulate techniques and methodologies for site investigations and characterization
  - Understand the transport of radionuclides through host rocks
- **National repository concept development (1980s to 2000s)**
  - Study THMC phenomena associated with waste package and host rock interaction
  - Demonstrate technical feasibility of repository components such as EBS at a large scale
  - Formulate the repository design in detail
- **Demonstration and optimization of performance of the disposal system (1990s to present)**
  - Demonstrate construction, installation and operation of repository components at full scale
  - Optimize repository design and operation
- **Demonstration of industrialization (2000s to present)**
  - Full-scale testing in-situ system: dress rehearsal of disposal operations
  - Develop advanced technologies and techniques such as long-term monitoring sensors and technologies for performance assessment/ performance confirmation

Source: IAEA (2019)

Part 4: A Short Tour of Some Landmark URFs

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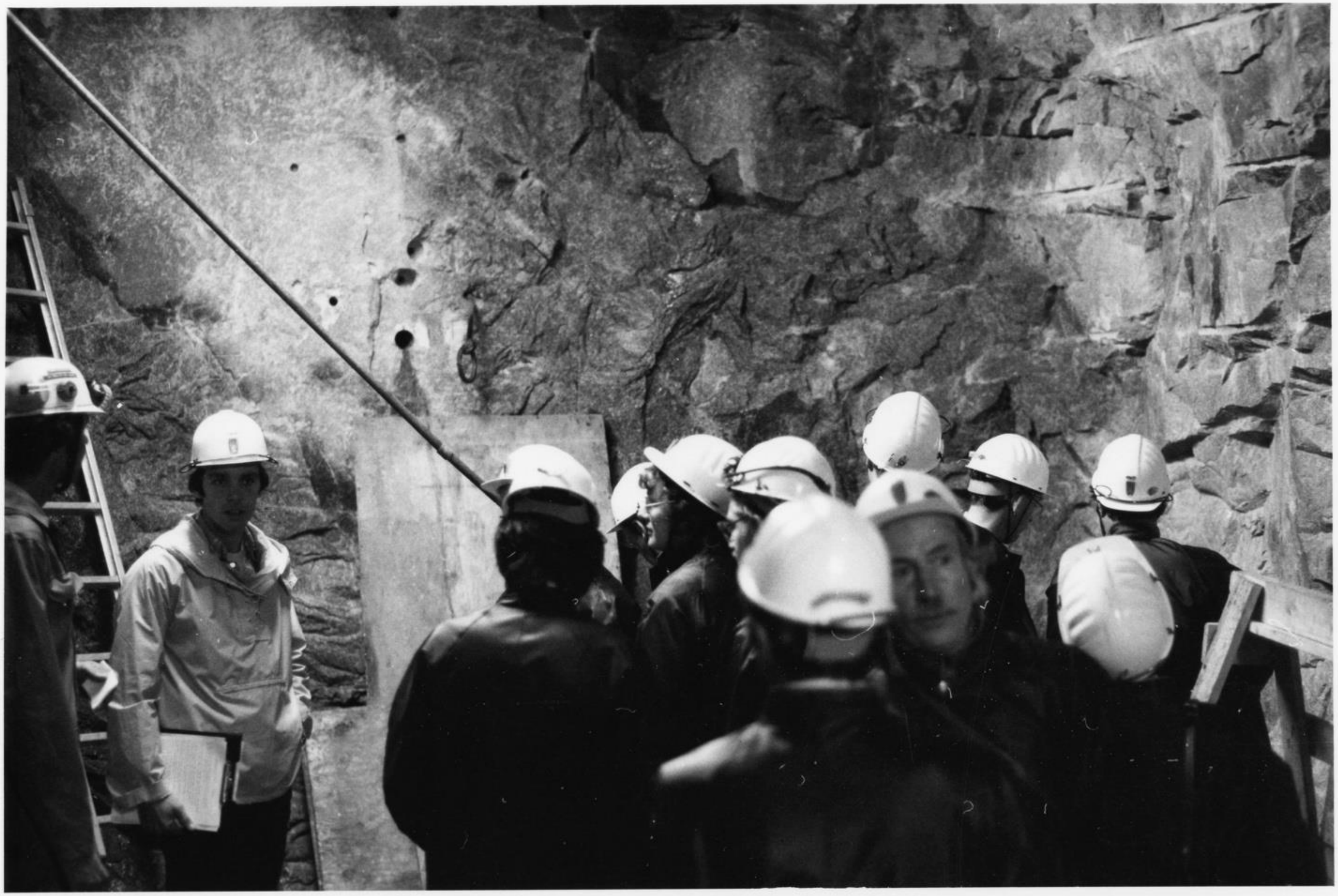
Stripa, Sweden: 1977 – 1992 (A Deeper Look)



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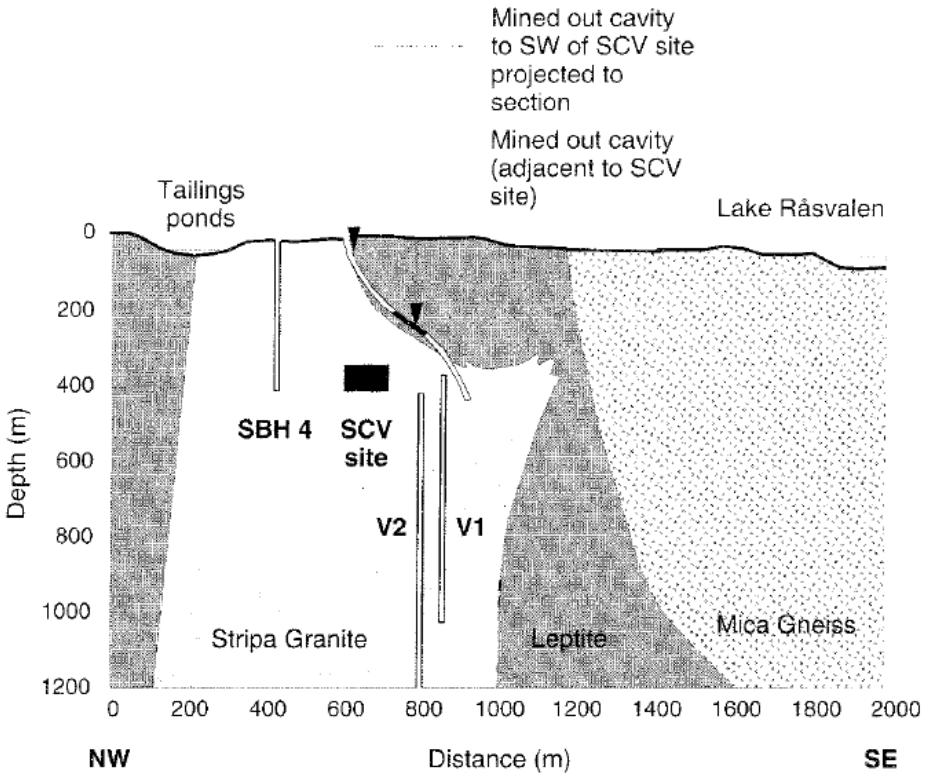
Rock Characterization Studies

Early studies of flow in fractured granitic rocks

1. Fore-runner project: 1977 – 1980 Swedish American Cooperation Project (SAC) between SKBF and LBL
   - fracture hydrology, fracture properties, hydrochemistry
   - in situ stress
   - large scale permeability tests
2. International Stripa Project Phase 1: 1980 – 1985
   - training and learning about fracture hydraulics
   - studies of a large fracture zone
   - tracer studies in a single fracture zone
3. Stripa Project Phase 2: 1983 – 1988
   - fracture characterisation techniques, including borehole geophysical methods
   - hydrochemistry: patterns of flow circulation from surface to depth
4. Stripa Project Phase 3: 1986 – 1992
   - exploration of an undisturbed rock volume: site characterisation, prediction and validation tests (SCV)



Source: OECD/NEA
International Stripa Project: Overview Volume II, 1993

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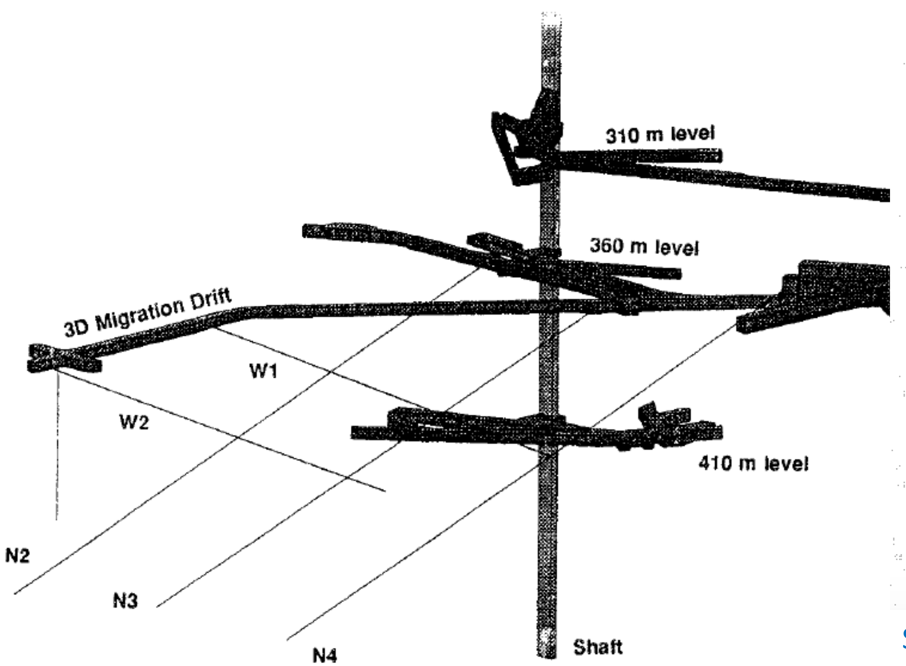
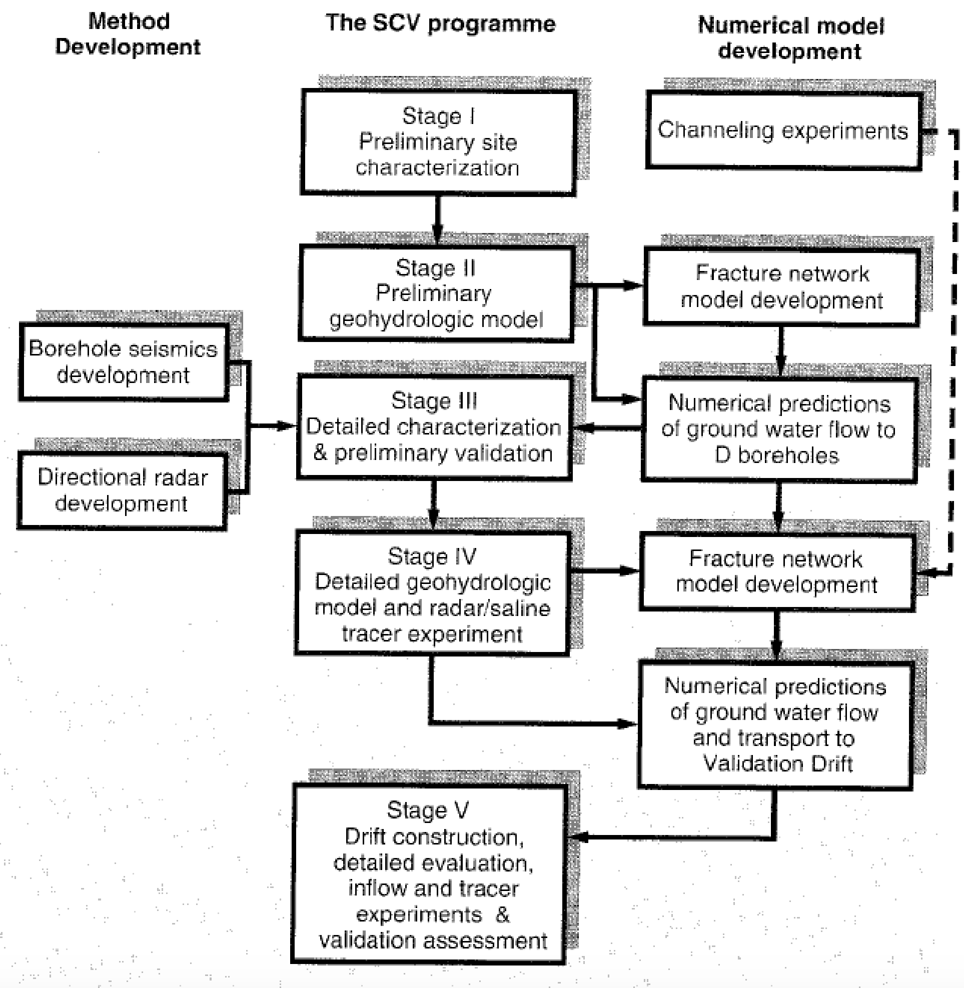
Site Characterisation and Validation – SCV project

- Preliminary characterisation using 5 boreholes
- Predictions made for subsequent boreholes ('simulated drift')





Source: OECD/NEA
International Stripa Project: Overview Volume II, 1993

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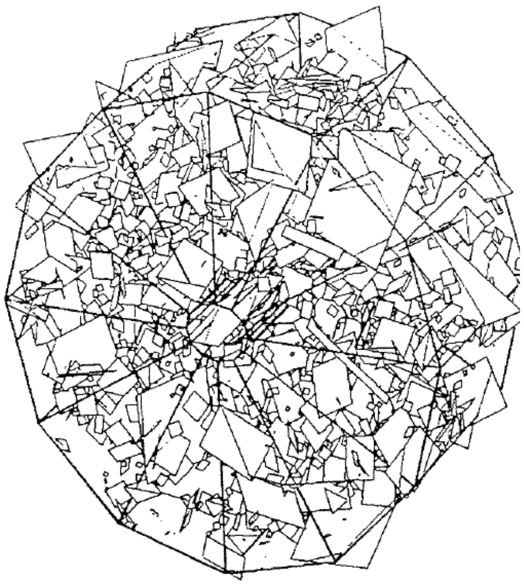
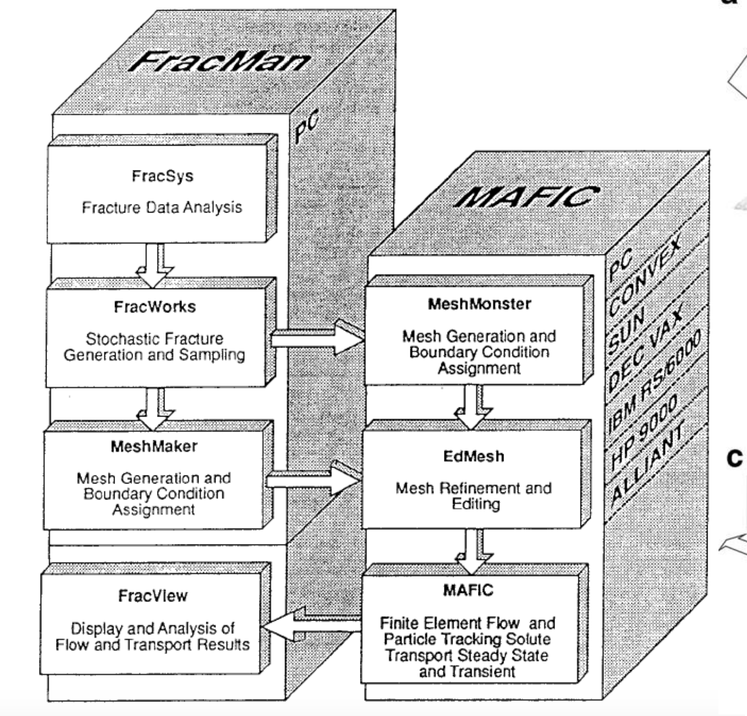
Multiple Flow Models Developed Based on Stripa Data

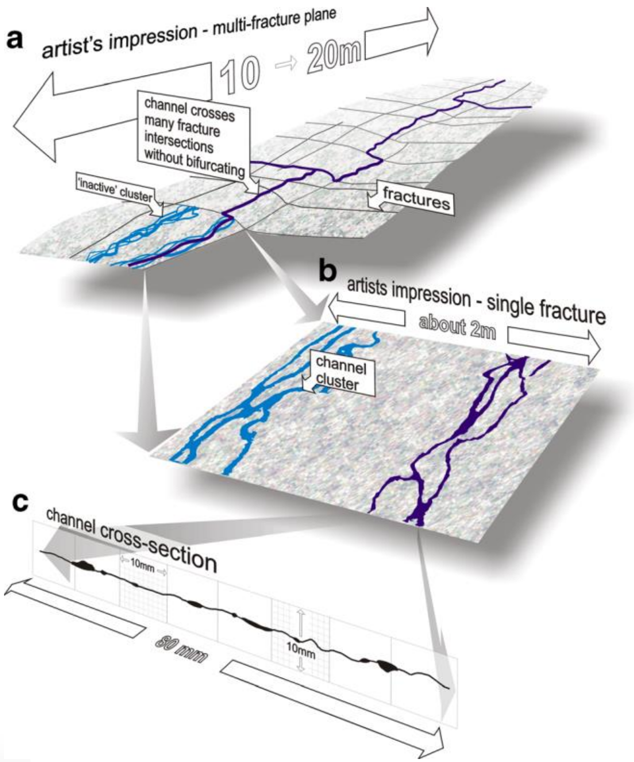
- Data raised doubts about deterministic equivalent porous-media flow models, hence, discrete fracture network, stochastic continuum, and more recently, sparse-channel models for hydrological flow were developed.



NAPSAC (Herbert)



FRACMAN-MAFIC (Dershowitz)



Black et al., 2017, Hydrogeology Journal

Source: OECD/NEA: International Stripa Project: Overview Volume II, 1993

The Important "Discriminating" Result from Stripa

- *"However…results [using Stripa data] show that the safety of a carefully designed repository is only affected to a small extent by the ability of the rock to retain the escaping radionuclides. The primary role of the rock is to provide stable mechanical and chemical conditions in the repository over a long period of time so that the function of the engineered barriers is not jeopardized." (SKB, SKB '91, TR-92-20).*
- Key Finding: Hydrology (and associated uncertainties) in fractured rocks have low risk-significance with respect to long-term safety.
- The misplaced focus of Stripa objectives on hydrological flow-models illustrates the problem with conducting R&D when not guided by a top-down, safety assessment of the entire repository system.

Äspö Hard Rock Laboratory; Sweden: 1990 – today (Crystalline rock)

Notice the focus is now on geochemistry, and emplacement and performance of EBS components

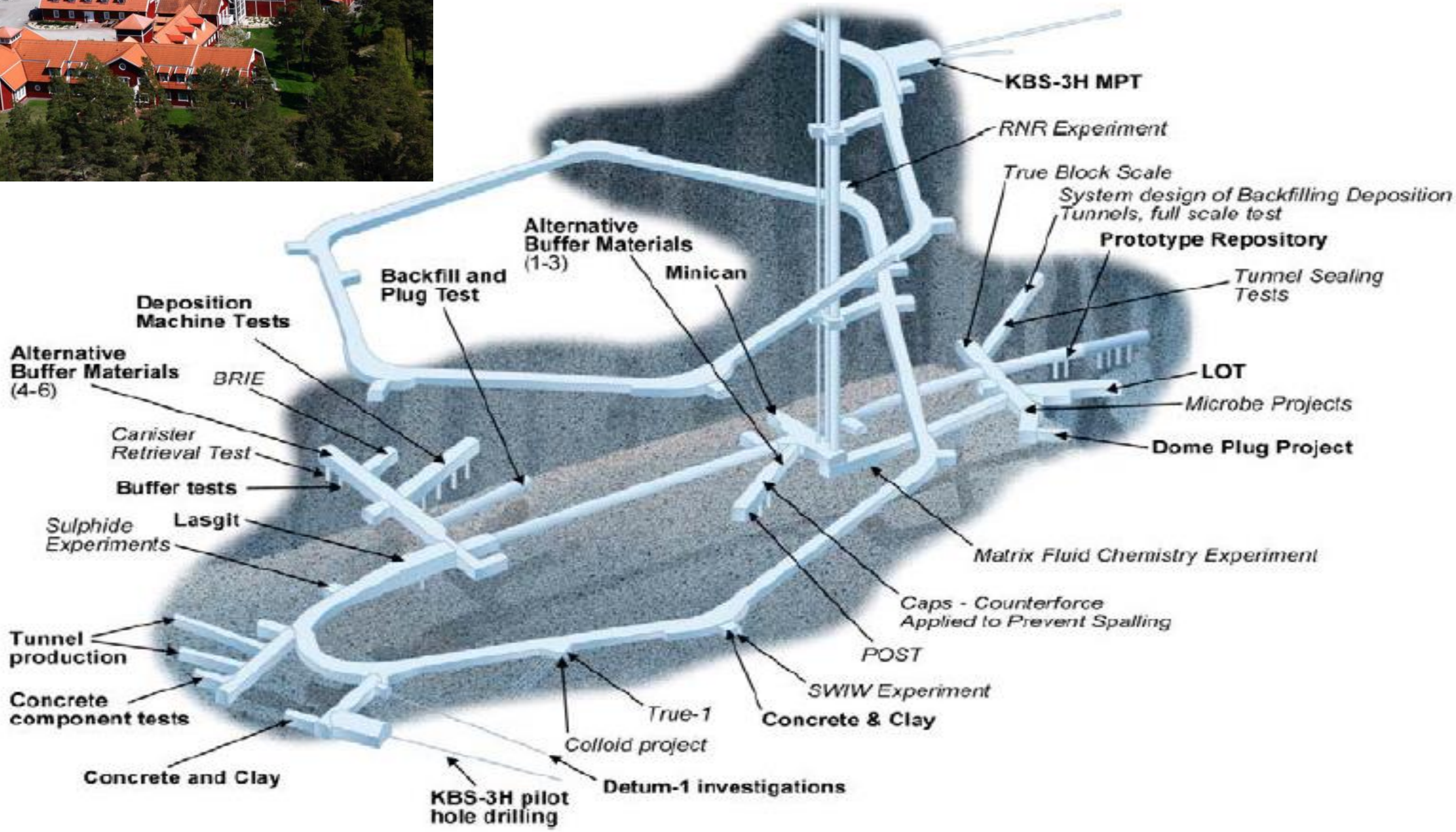
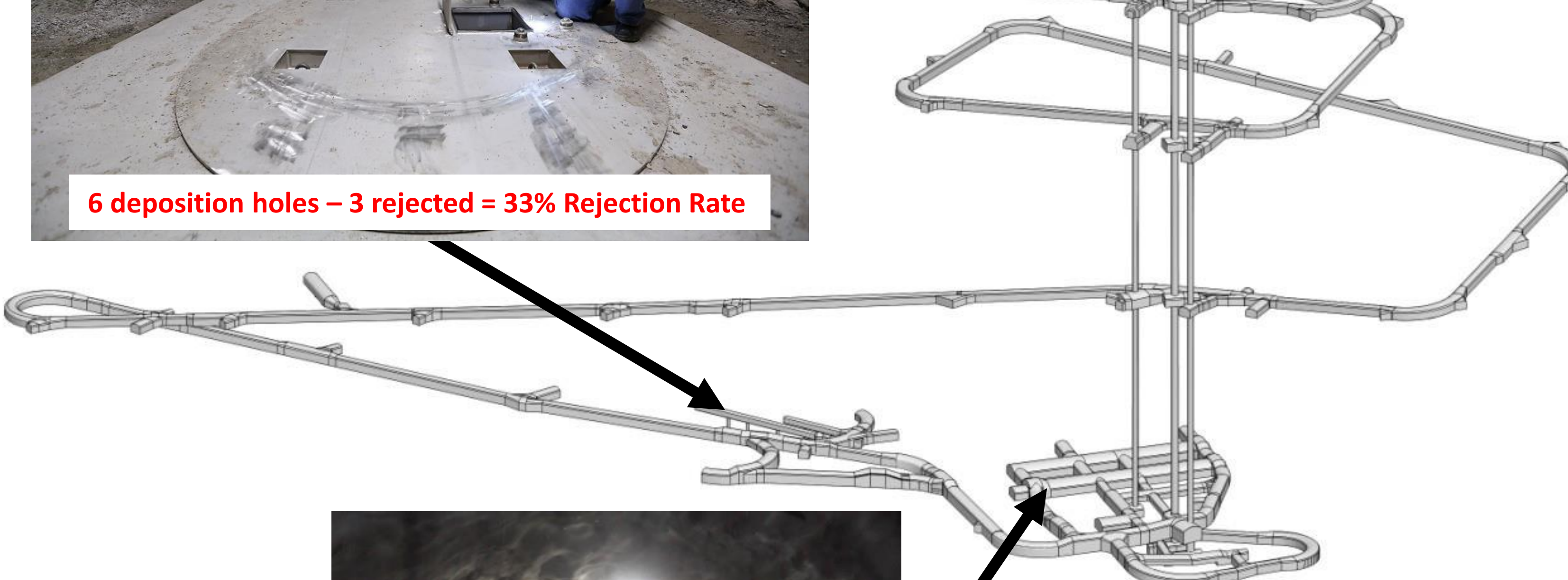


Image: SKB (2019)

Underground Rock Characterization Facility ONKALO, Finland (2004-present)



Tunnel-backfill emplacement and floor levelling investigations

Images: Posiva (2019)

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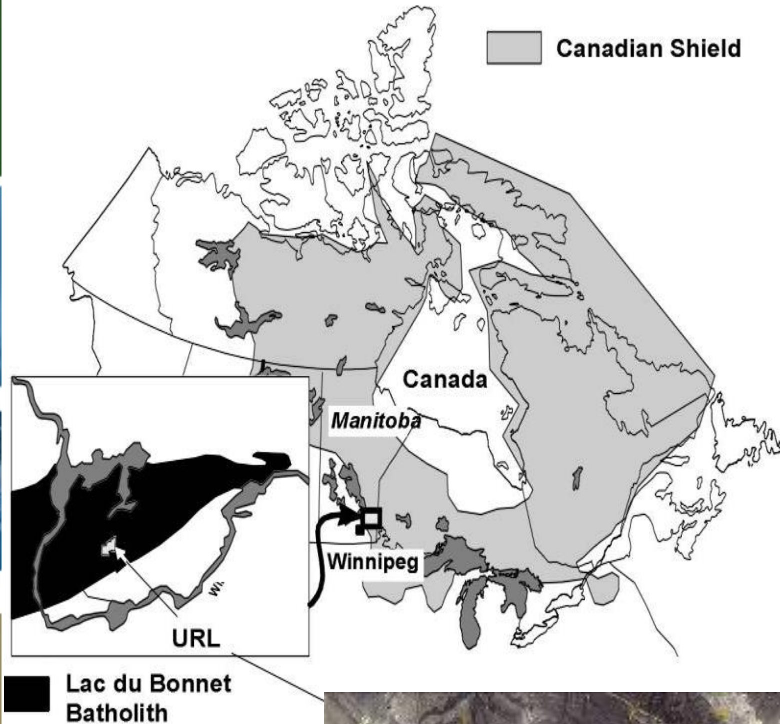
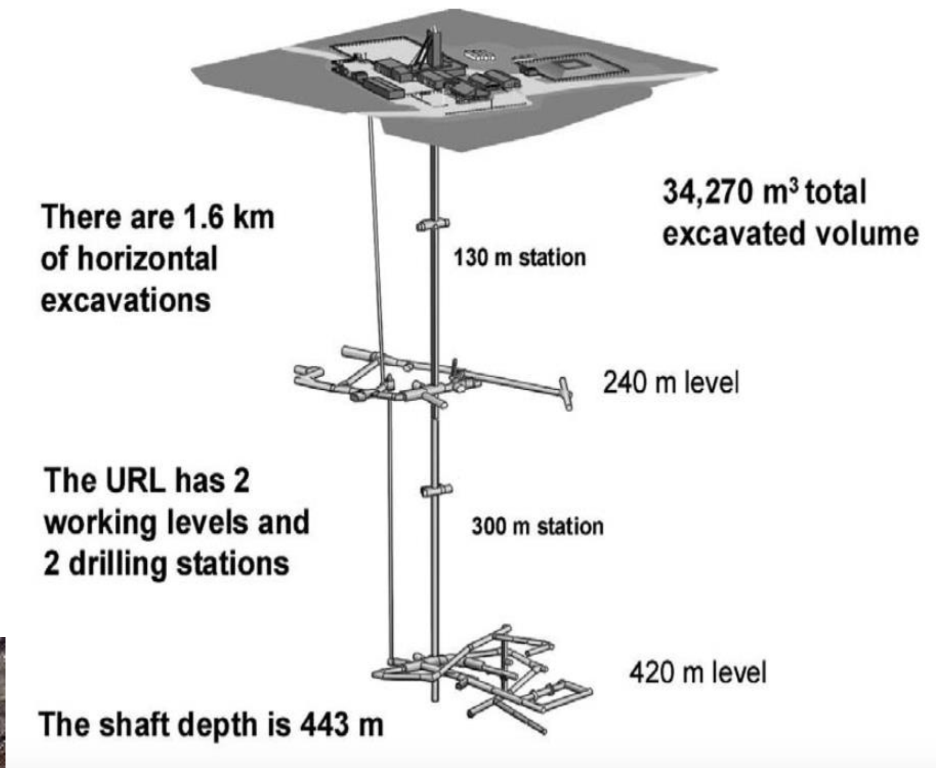
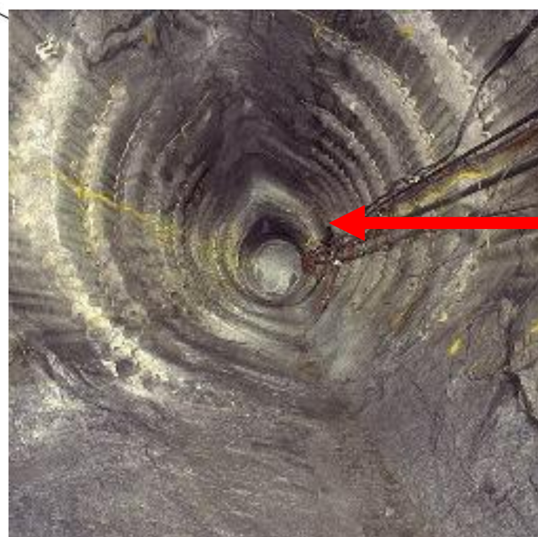
Canada: 'the URL', Lac du Bonnet: 1984 - 2003







Key Finding: Rock spalling with increasing depth, arising from anisotropic stresses, has guided the Canadian used fuel program to consider in-room EBS emplacement, instead of emplacement in vertical or horizontal deposition holes.

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Asse Mine, Germany: 1965 – 1995 (Salt)

Technology for trial canister disposal

Source: IAEA (2019)

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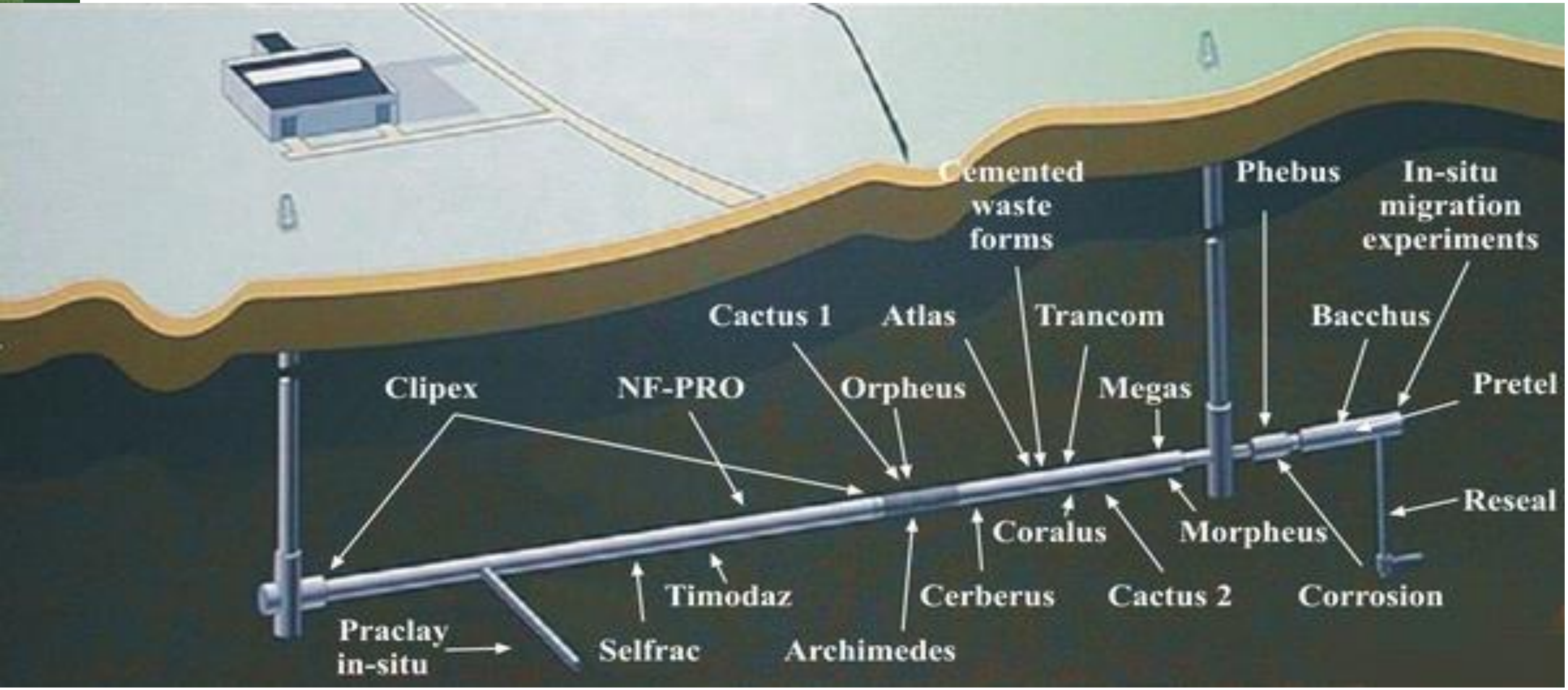
‘HADES’ URL, Mol, Belgium: 1980 – today (Clay)



Source: IAEA (2019)

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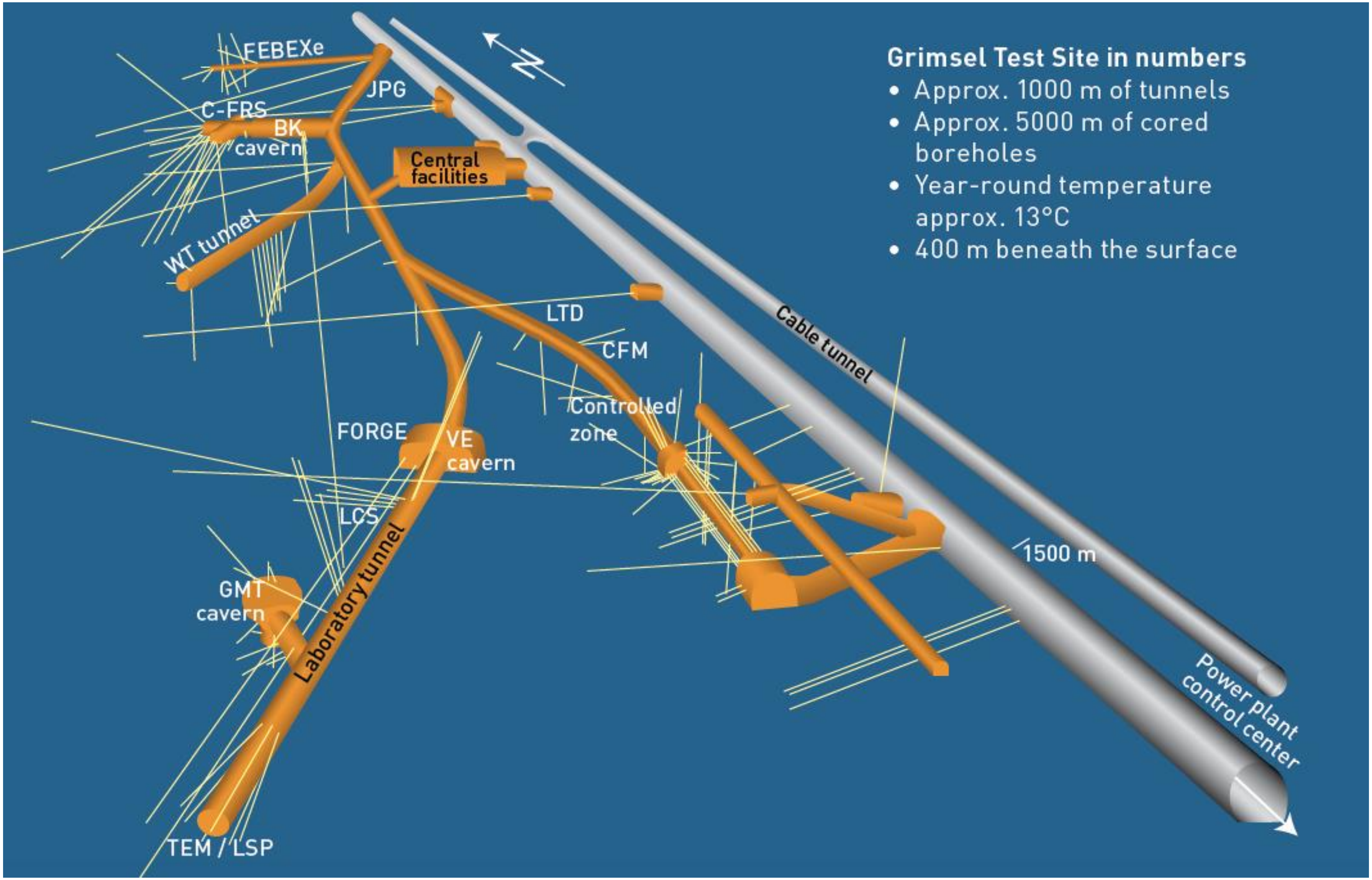
Grimsel Test Site, Switzerland, 1984 – present (Crystalline rock)



Source: IAEA (2019)

Bure URF, France: 2000 – present (Clay)

Image: Andra (2019)

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Bure URF (Clay)

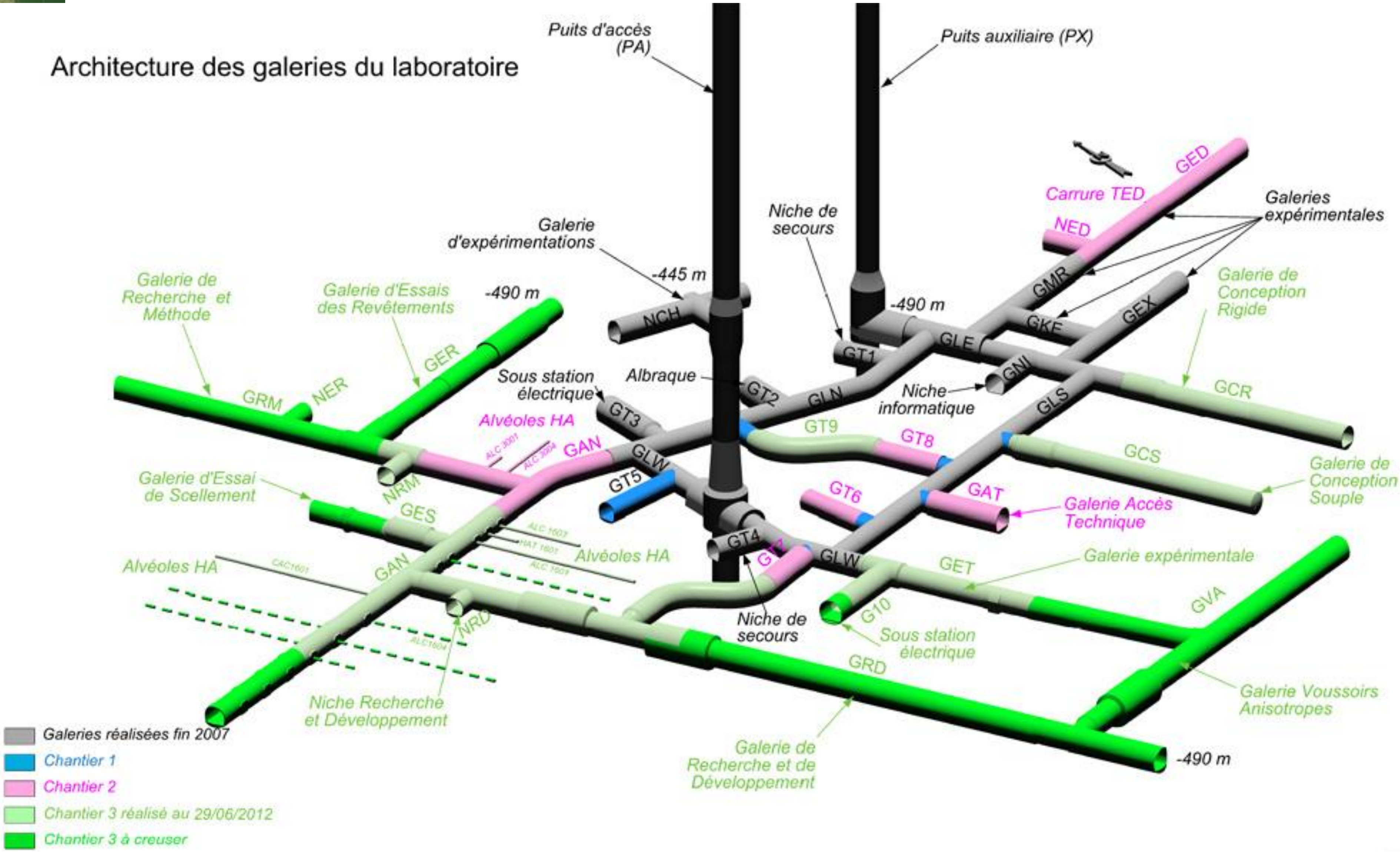

Image: Andra (2019)

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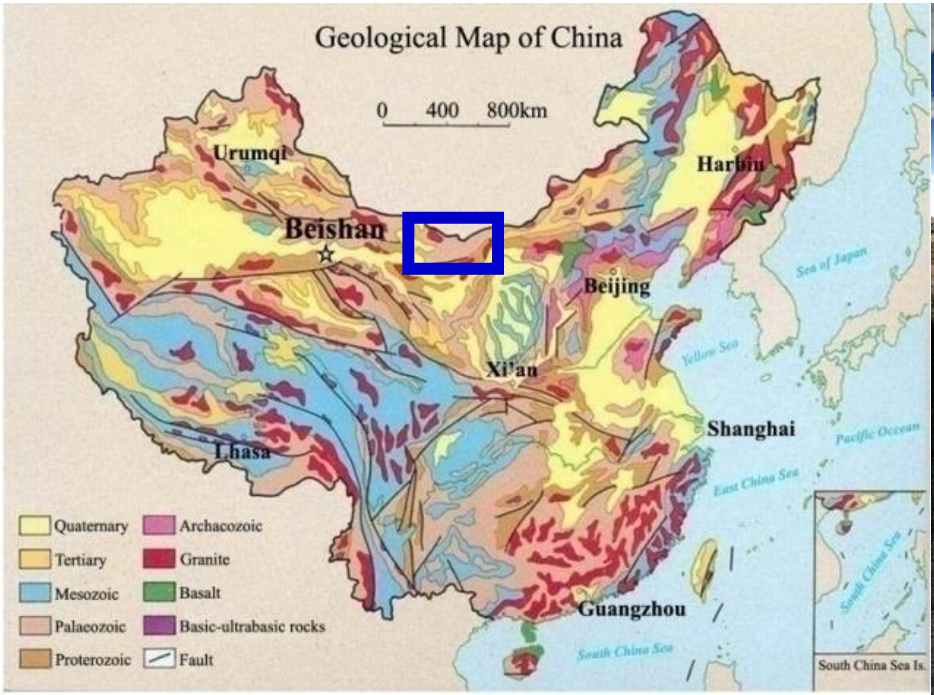
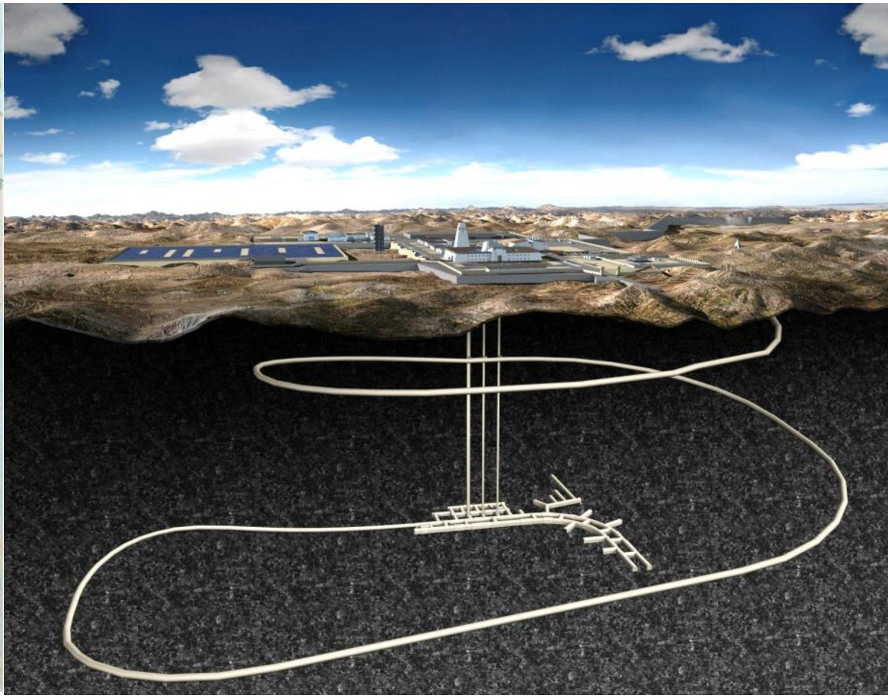
Planned China URL (BRIUG), Beishan Site, Gobi Desert



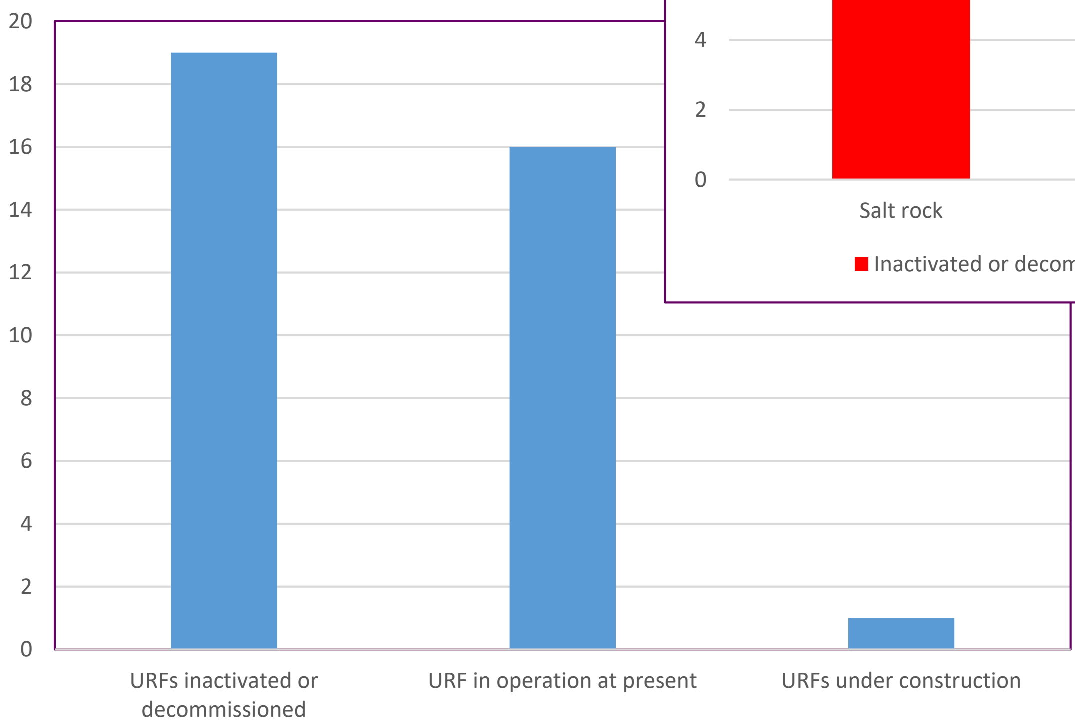


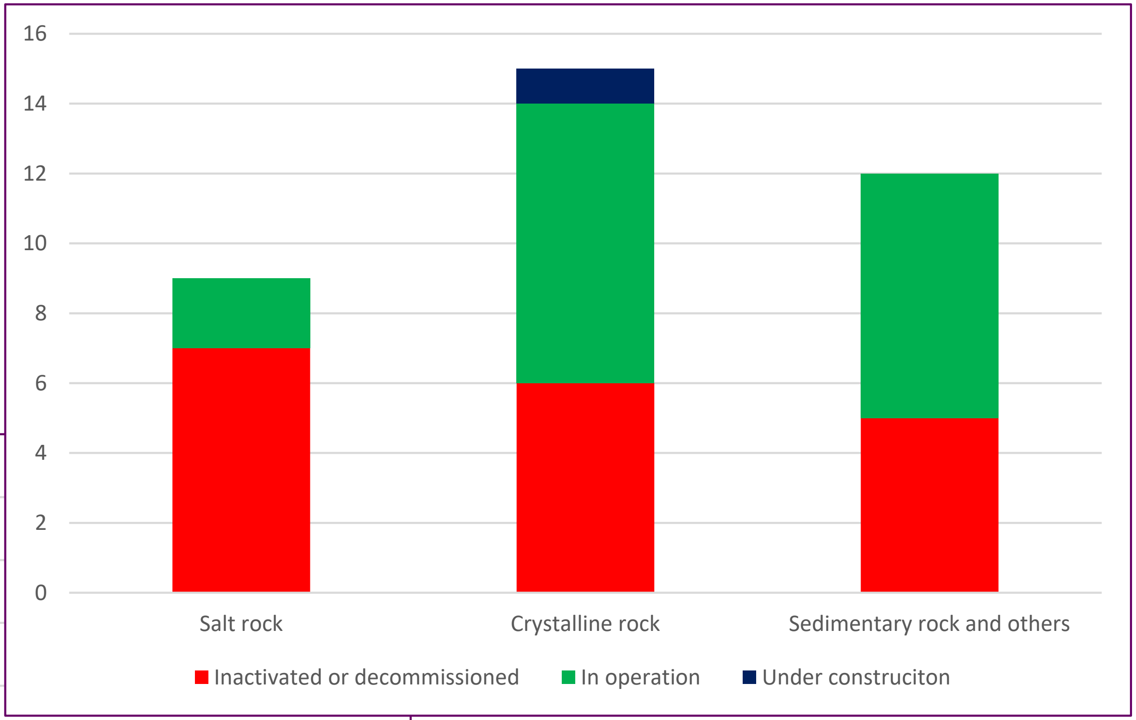
- China Atomic Energy Authority approved a Beishan URL, December, 2018.
- 9 candidate sites.
- Shaft sinking planned to start in 2020.

Images: BRIUG (2019)

Summary: Current Global Status of URFs

- Over 50 years, more than half of URFs have been inactivated or decommissioned and more will be closed in next few years, with a few new ones planned.





Source: IAEA (2019)

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