International Conference

on Geological Barrier Systems, Host Rock Characterisation, and Site Selection relevant to Underground Repositories

The Importance of Host Rock Features for the Development of Repository Concepts

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Deep Geological Repository (DGR) Safety Case

General Objective of a DGR Safety Case:

- to demonstrate isolation and containment

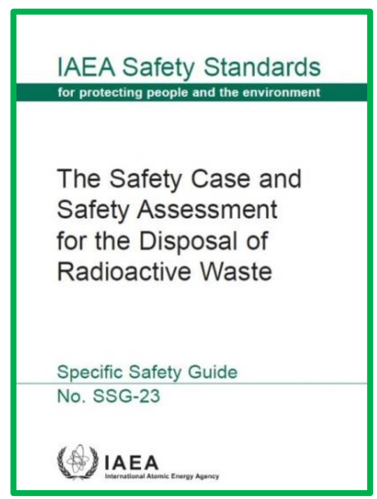
Isolation: keeps the biosphere separated from the major part of the waste (intrusion into the DGR and exposure to the waste)

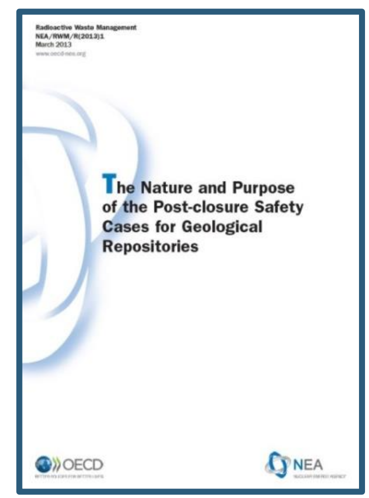
Containment: postpones and minimizes releases from the waste to the biosphere

International guidance:

IAEA Safety Standards, 2013:
The Safety Case and Safety Assessment for the Disposal of Radioactive Waste

NEA Report, 2013:
The Nature and Purpose of the Post-Closure Safety Cases for Deep Geological Repositories





(Source: CNSC e-Doc 3970082)

Deep Geological Repository (DGR) Safety Case

How to achieve the General Objective of demonstrating isolation and containment of the radioactive waste?

Approach:
Elaboration and Implementation of a Safety and Safety Demonstration Concept on mainly three data bases:

1. **Set of national/international legislation (e.g. atomic energy act, radiation protection ordinance, safety requirements)**
2. **Compilation of the types and amounts of radioactive waste**
3. **Structural-geologic characteristics of the geologic formation at the repository site, in particular the host rock**
4. **Development of an adjusted repository concept**

Data Basis 1: Legislation (Example Germany)

Laws:

- Atomic Energy Act
- Federal Mining Act

Safety Requirements

- Safety Requirements Governing the Final Disposal of Heat-Generating Radioactve Waste (BMU, 2010)

Ordinances/Standards:

- International Standards: IAEA Safety Guides and Standards, NEA-publications, ICRP recommendations, etc.
- Nuclear Standards: Radiation protection Ordinance, Subcriticality, Safeguards, etc.
- Engineering Standards: Eurocodes, regulations to ensure operational safety, fire protection, and adequate ventilation, etc.)

Data Basis 2: Waste Inventory

Heat-generating spent fuel and waste from reprocessing
(until nuclear phase out in 2022)

- ~ 10,500 tHM from NPPs
- ~ 6,700 tHM from Reprocessing
- 10 – 12 tHM from Research Reactors and Prototype NPPs

Radioactive waste with negligible heat generation
(until 2080)

- ~ 300,000 m^3 from decommissioning
- ~ 200,000 m^3 waste to be retrieved from the ASSE II mine and conditioned
- ~ 100,000 m^3 depleted uranium (potentially)

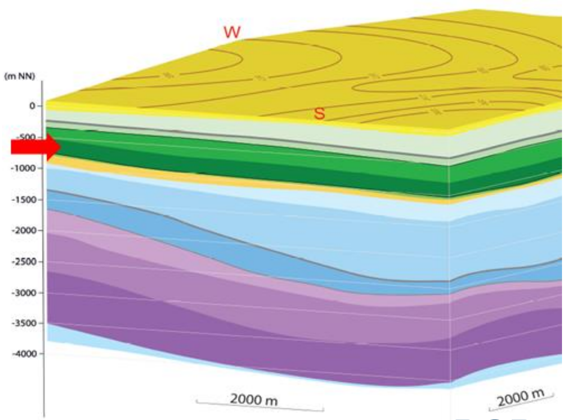
(Source: Nationales Entsorgungsprogramm, BMU, 2015)

Data Basis 3: Characteristics of Geology at a Site

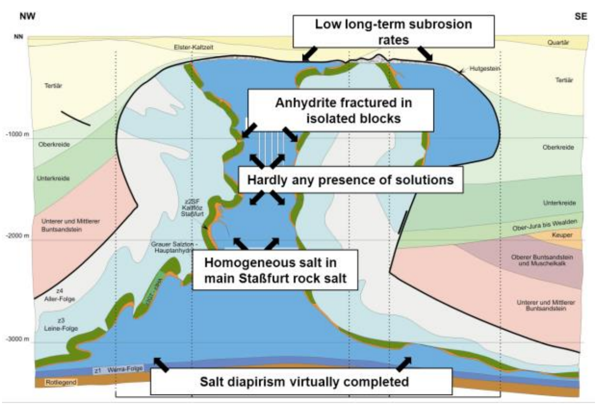
Geological Environment:

- Host rock (e.g. clay/shale, granite, salt, tuff); including CRZ (Containment providing Rock Zone)
- Overburden, adjoining rock formations, etc.

Examples of potential host rocks for a DGR:



source: BGR



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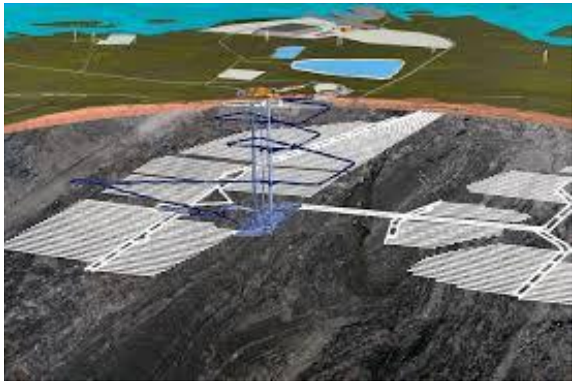

source: Posiva

Cretaceous Clay (Northern Germany)

Salt Dome (Gorleben Site, Germany)

Crystalline Rock (ONKALO, Finland)

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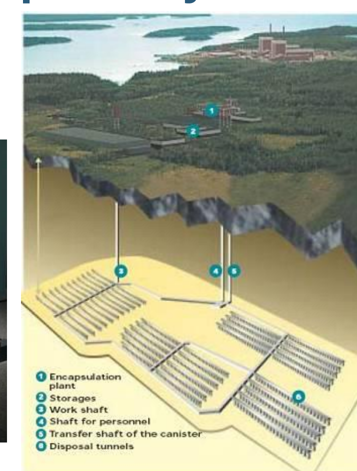
Approach for a Repository Concept

Repository Concept:

- **Repository mine (shafts, ramps, drifts, boreholes, emplacement cells)**
  - ➢ **adjusted to the existing (or anticipated) geological situation**
- **Waste Package (materials and their potential overpack e.g. stainless steel, copper, titanium)**
  - ➢ **tailored to the waste inventory and waste form (matrix: e.g. glass, bitumen, concrete)**
  - ➢ **designed for the boundary conditions in the mine (host rock features)**
- **Transport and emplacement/retrieval techniques and systems**
- **Engineered Barrier System (backfill, buffer and seal materials (e.g. crushed salt, bentonite, cement, grout), to fill/close and isolate the repository mine from the biosphere (drift and shaft/ramp seals)**

Example:
Generic concept for a repository in crystalline rock, (e.g. Finland)



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Measures for the Implementation of a Safety Concept

- Containerization of Radioactive Waste (adequate waste packages)
- Detailed Exploration of Host Rock and Overburden
- Excavation of Mine Openings (shafts, ramps, drifts, boreholes, …)
- Avoidance of Unnecessary Mining/Drilling Work in the CRZ
- Minimization of Moisture in the Vicinity of Waste Packages
- Restricted Temperature Increase
- Backfilling of Voids and Construction and Performance of High-Quality Drift and Shaft Seals

➢ **Implementation eventually requires state-of-the-art technology, at least in Germany**

➢ **If not available, RD&D activities are necessary including verification/validation of techniques and systems at full scale under realistic conditions ⇨ URL**

Rational of Underground Research Laboratories (URLs)

Definition (NEA 2013):

"Underground facility in which site characterization and testing activities are carried out along with technology development and demonstration activities in support of the development of deep geological repositories for radioactive waste."

Main purpose:

- **to support the repository development process by facilitating research activities under an environment similar to the future repository. Main issues:**
  - **develop the technology and methodology required for underground experimentation**
  - **provide data to understand the behaviour and assess the performance of the repository system**
  - **demonstrate the robustness of the design and to show the potential areas of optimisation of engineering components and processes**
  - **train personnel for safe operation of a future repository**
  - **build confidence with stakeholders for their understanding of the important processes governing repository performance**

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Types of URLs

Purpose-built, generic URL (example):

"Facilities that are developed for generic research and testing purposes at a site that will not be used for waste disposal."

Examples of URL in claystone:

- **Mont Terry (Swisstopo, Switzerland): Opalinus clay, gallery from a highway tunnel, depth 250 – 300m, in operation since 1995**

Site-Specific URL (example):

"Facilities that are developed at a site that is considered as a potential site for waste disposal and may, indeed, be a precursor to or the initial stage of developing a repository at the site."

Example of URL in crystalline rock:

- **ONKALO (Eurajoki, Finland): Gneisses, schists, amphibolites and granite, a ramp up to - 455 m, research tunnels, 3 shafts, in operation since 2004**

Typical RD&D program for URLs

Main investigation groups:

1. Host Rock Characterization
   - geology, mineralogy, and geochemistry
   - hydrogeology and hydrochemistry
   - rock mechanics
   - thermal properties
2. Interaction Repository – Host Rock
   - disturbance by excavation (EDZ)
   - chemical compatibility (construction / sealing material)
   - mechanical / hydraulic loads
   - thermal impact (by heat generating waste)
3. Development / Verification of Repository Concept
   - development of waste emplacement / retrieval concept / technology
   - backfilling and sealing methods
   - refinement of excavation techniques, material specification, and monitoring techniques

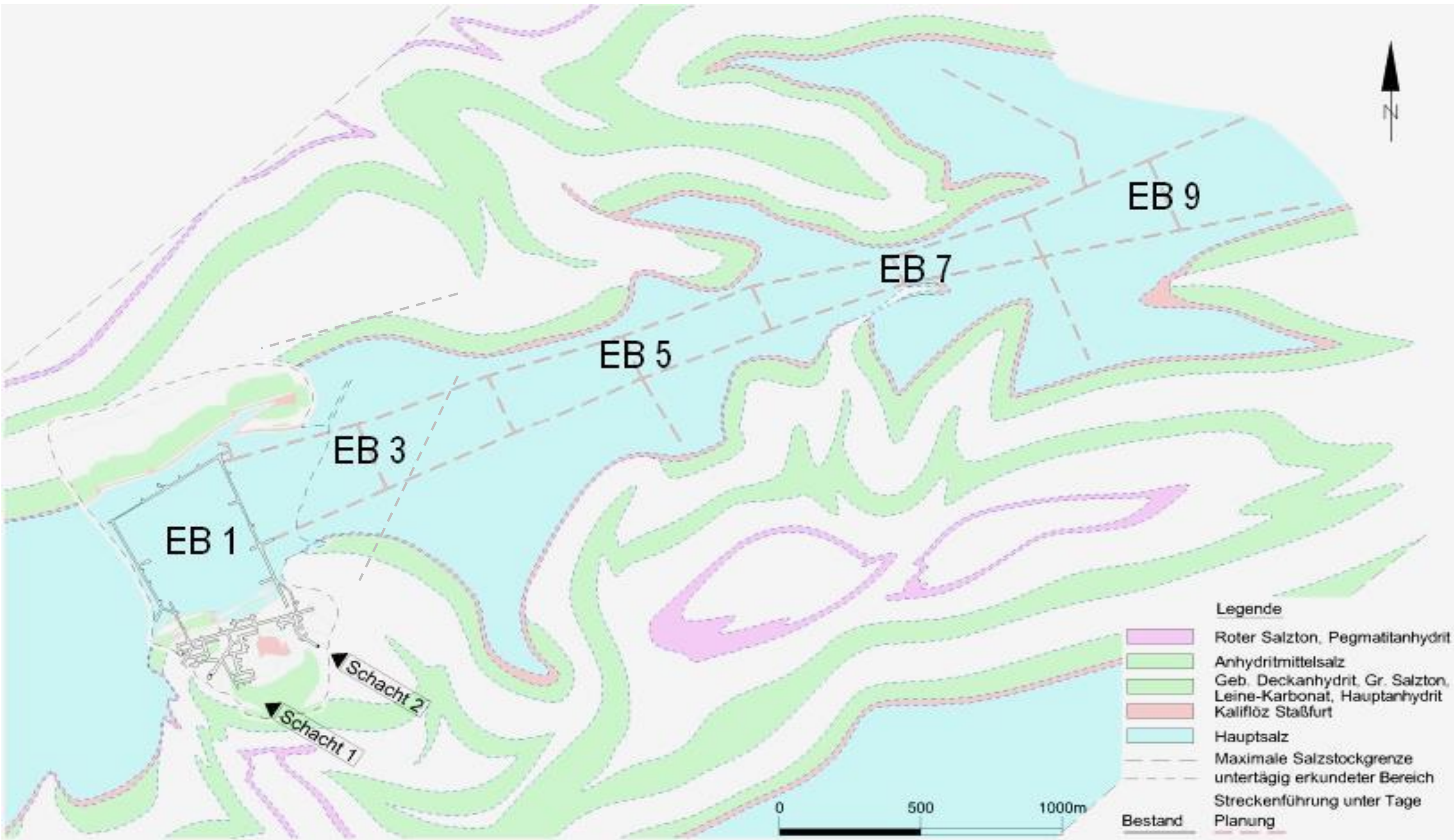
Host Rock Characterisation (examples of RD&D)

Rock Mass	▪ Mineralogy, geochemistry, texture/structure, sorption capacity, fluids ▪ Hydraulic properties (e.g. pores, fractures, faults, shear zones), migration tests ▪ Thermal properties (e.g. thermal conductivity, thermal capacity, coefficient of expansion), ▪ Geothermal flow ▪ Mechanical properties (e.g. density, volume, rigidity, deformation capacity, eff. strength)
Fractures / faults	▪ Frequency, orientation, fracture width ▪ Fracture / fault minerals, sorption capacity, microbial actvity ▪ Hydraulic properties (e.g. porosity, permeability, fluid pressure, diffusion coefficient)

Host Rock Characterisation: Example Gorleben RCF

Horizontal geological cross-section (840m below surface);

➢ ***prediction based on data from surface core drillings***



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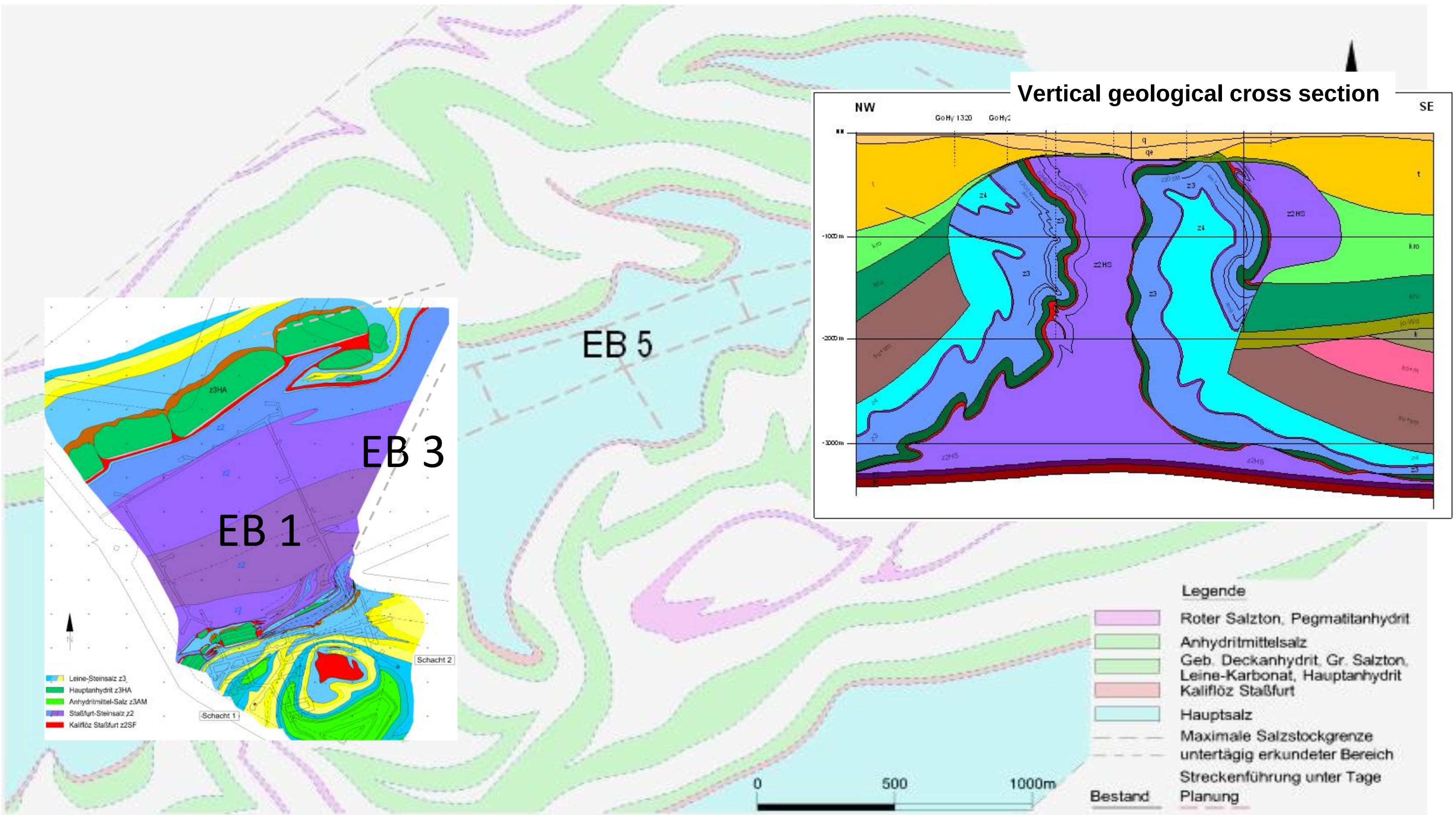
Host Rock Characterisation: Example Gorleben RCF

Horizontal geological cross-section (840m below surface);

Results of Underground Exploration: identified structure and dimensions of formations differ from prediction based on data from surface core drillings



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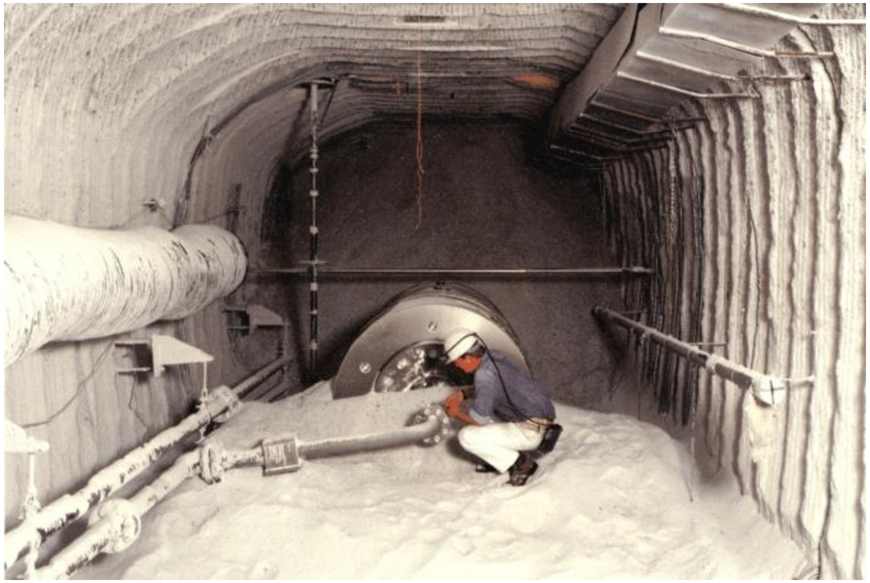
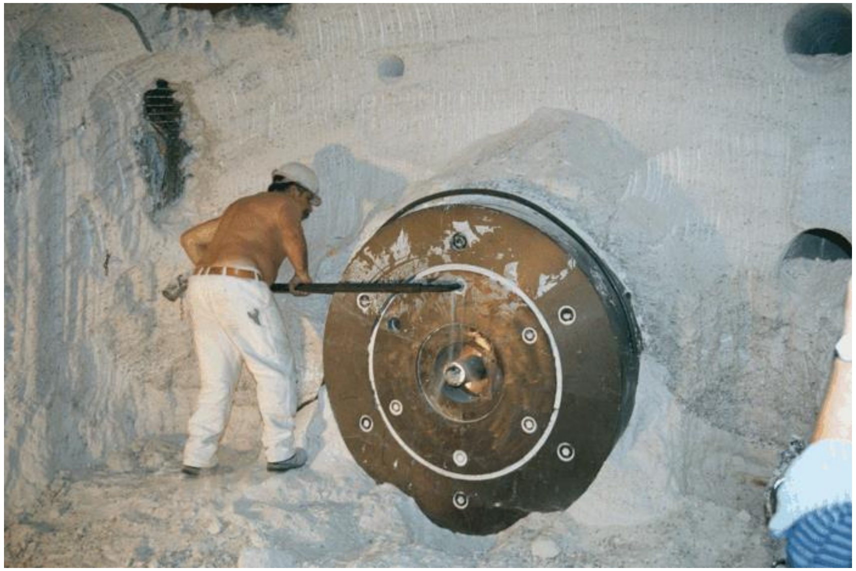
Interaction Repository - Host Rock (examples of RD&D)

Excavation damaged zone	▪ **Construction techniques and resulting characteristics of EDZ** ▪ **Depth, extent, characterization of fracture network** ▪ **Hydraulic, mechanical, chemical, thermal properties, sorption capacity** ▪ **Colloid generation, migration and retardation in EDZ, migration tests** ▪ **Microbial activity** ▪ **THMC-interaction between EDZ and adjacent barriers (buffer, backfill, seal) / repository components (lining)**
Chemical compatibility	▪ **Interaction of repository components (seal, buffer, backfilling) and corrosion products with groundwater** ▪ **Consequences of modified hydrochemical environment due to alteration of repository components on geosphere**

Interaction Repository - Host Rock



1990: Installation of test casks and monitoring system



10 years later: dismantling and cask removal

Example: In-situ heater test

in the Asse salt mine (800m level) with electrically heated casks (POLLUX®-Casks) to validate predicted host rock and backfill behaviour

Development/Verification of Repository Concepts (exa. RD&D)

Full-scale tests of integrated functions of disposal components	▪ **Construction / preparation of disposal drift and borehole,** ▪ **Test of safety and reliability of emplacement equipment** ▪ **Test of safety and reliability of retrieval equipment**
Construction of buffer and drift seal	▪ **In-situ test of nearfield barriers (disposal container, buffer)** ▪ **Develop / optimize techniques for construction, demonstration of technical feasibility, effectiveness (tightness und mechanical stability)** ▪ **Hydraulic, mechanical, chemical, thermal properties, sorption capacity of barriers** ▪ **Modification of properties during saturation of clay and gas invasion phase**

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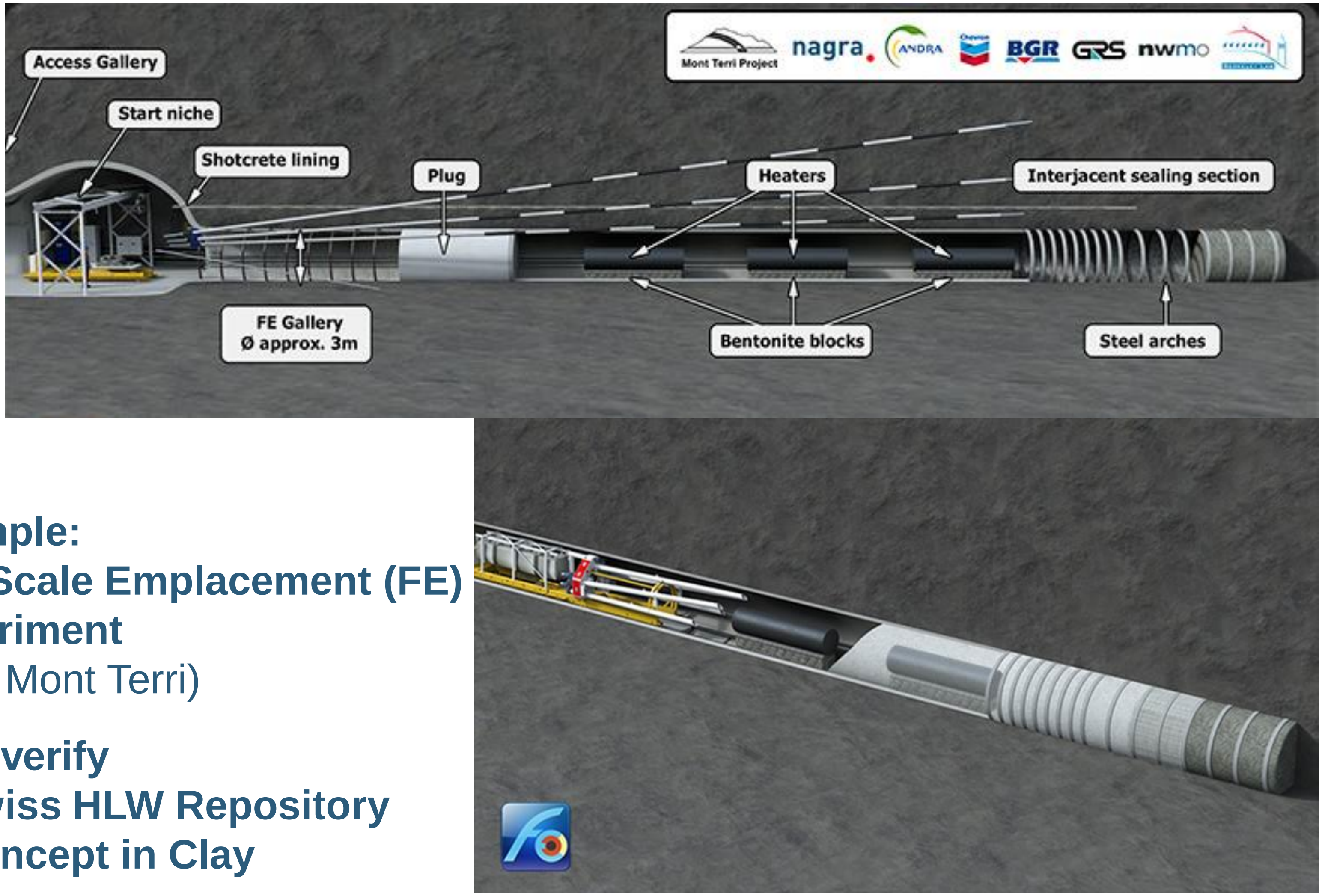
Development/Verification of Repository Concepts



Example:
Full-Scale Emplacement (FE) Experiment
(URL Mont Terri)

- **to verify Swiss HLW Repository Concept in Clay**

(source: Nagra)

Summary and Conclusions

Main reasons underpinning the importance of rock characterization are:

- **to provide real data about structure and nature of the host rock at emplacement level and in the surrounding rock formations**
- **to verify model calculation through data measured in situ, thus improvement of the safety assessments**
- **to demonstrate constructability and effectiveness of engineered barriers**
- **to demonstrate safety and reliability of selected transport and emplacement / retrieval technique under in-situ conditions**

➢ **Targeted exploration activities and accurate data acquisition play a key role in developing technical repository concepts!**

➢ **Demonstration of constructability of geotechnical barriers as well as construction and operation of technical components in URLs may help to facilitate the implementation of a repository**

Thank you for your attention!

Russian/French/German-Workshop on URLs, October, 2018

(field trip to the vicinity of Krasnoyarsk City (Yenisei River)