United States Nuclear Waste Technical Review Board

Workshop on recent Advances in Repository Science and Operations from International Underground Research Laboratory Collaboration, 24-25 April 2019, Burlingame CA.

The integration of URL science in the Swiss Radioactive Waste Management Programme

Dr. Irina Gaus, Head of Research and Development

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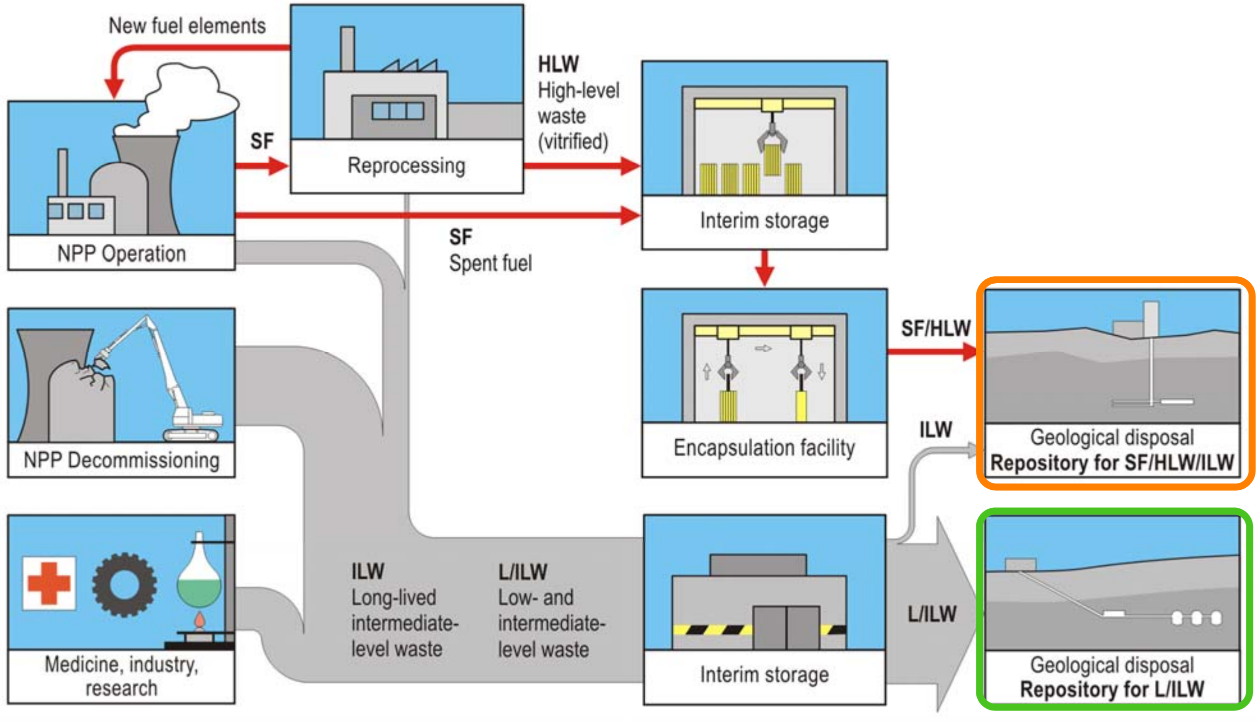
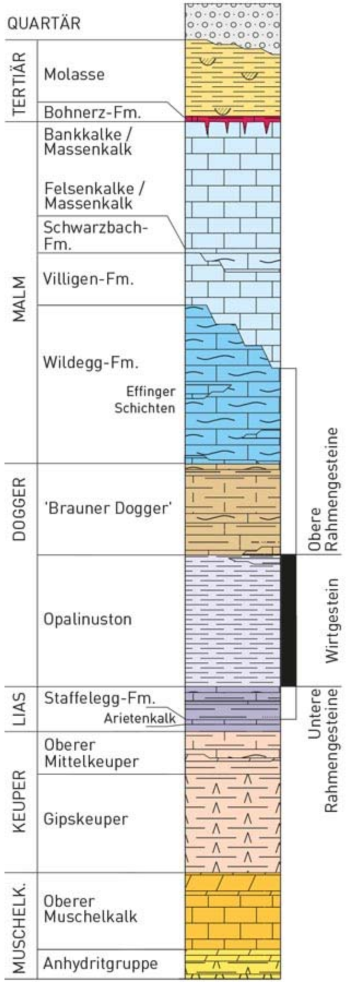
Swiss waste management concept



- Spent Fuel (SF) and vitrified high level waste (HLW) → HLW repository
- Long-lived intermediate waste (ILW) → HLW repository/ L/ILW repository
- Low and intermediate waste (L/ILW) → L/ILW repository

Opalinus Clay is the selected hostrock for both repositories



Host rock **Opalinus Clay**

- 100 m thickness
- 40-60% clay
- low hydraulic conductivity
- excellent sorption
- limited rock strength
- similar but more variable surrounding units (*Rahmengesteine*)

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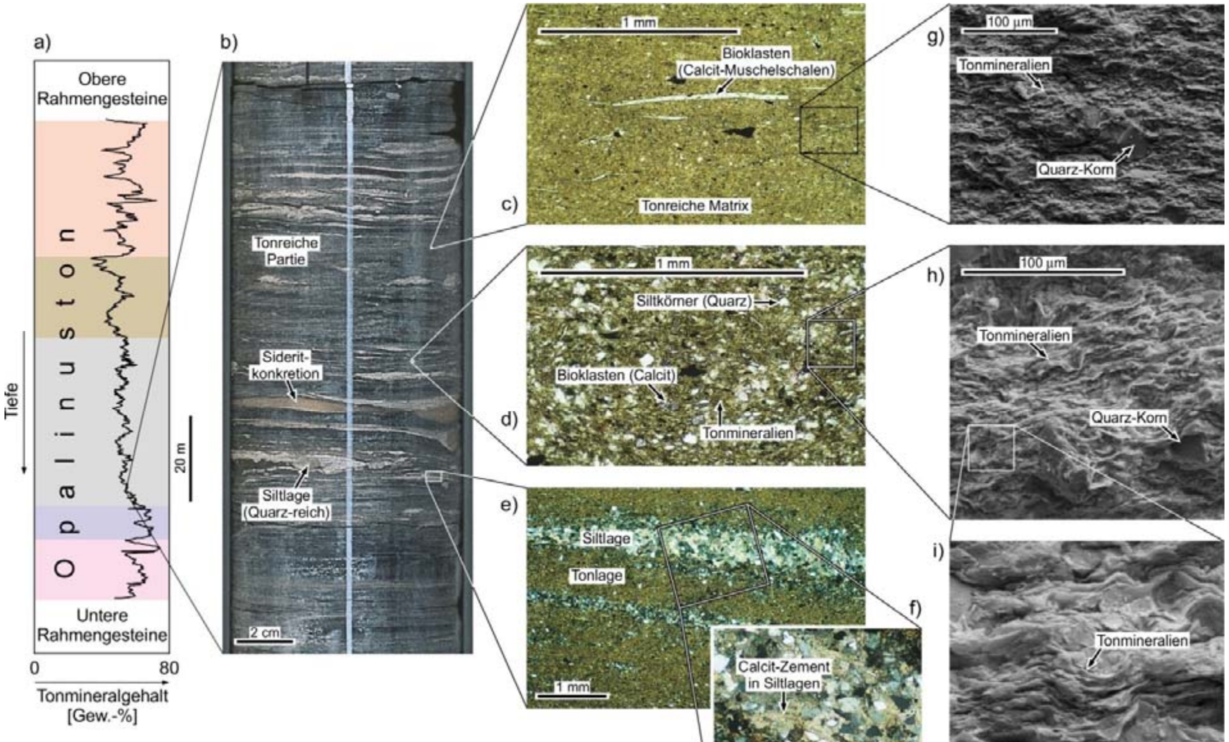
Opalinus Clay (OPA) characteristics

- Low hydraulic conductivity in the range of 10^{-12} to 10^{-14} m s^{-1} and a porosity of 0.12 and 0.15 in the siting regions.
- Generally 100 m thick and is surrounded by clay-rich confining units



Cores, platelets and REM images of OPA samples from the borehole at Benken

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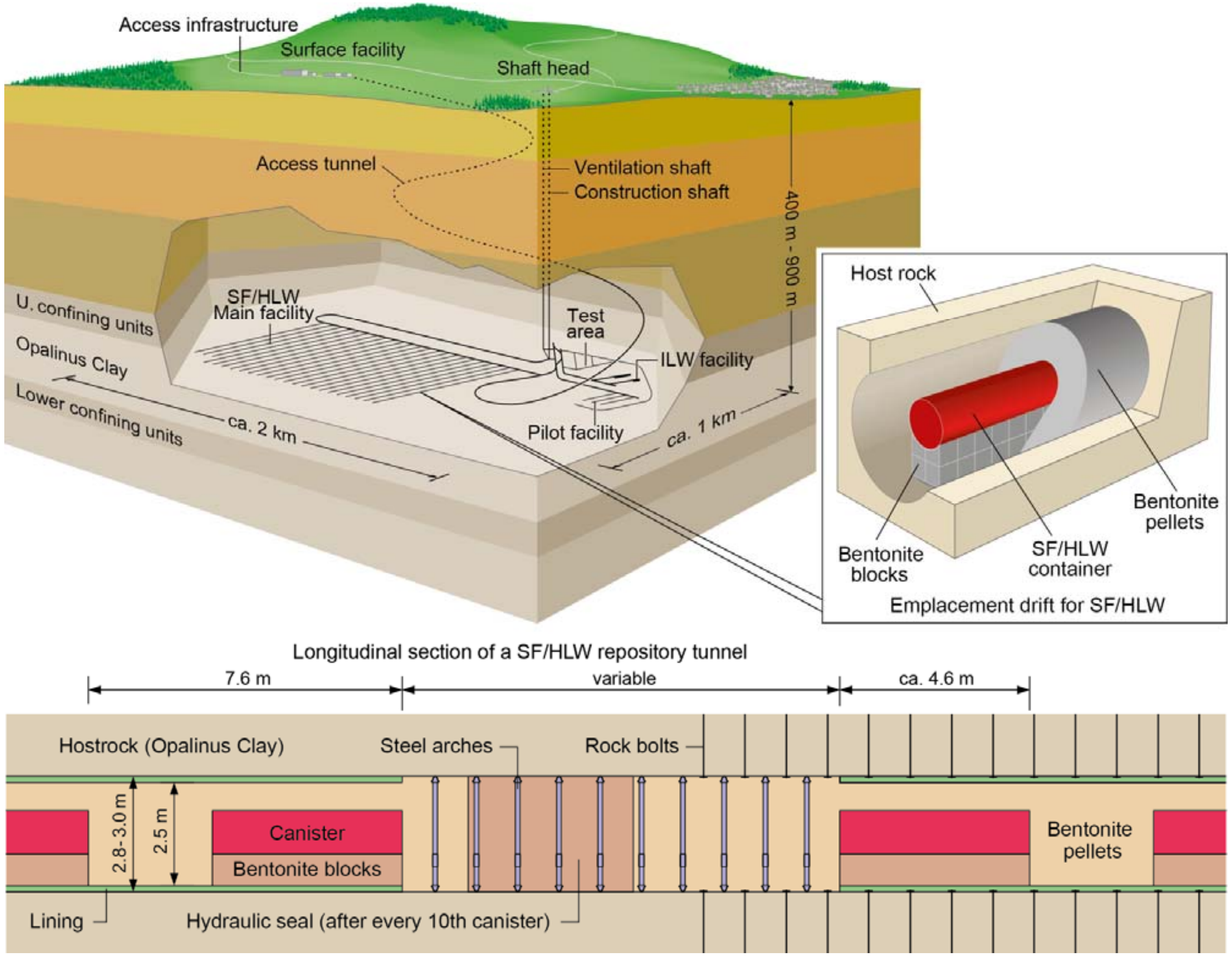
Swiss HLW repository concept



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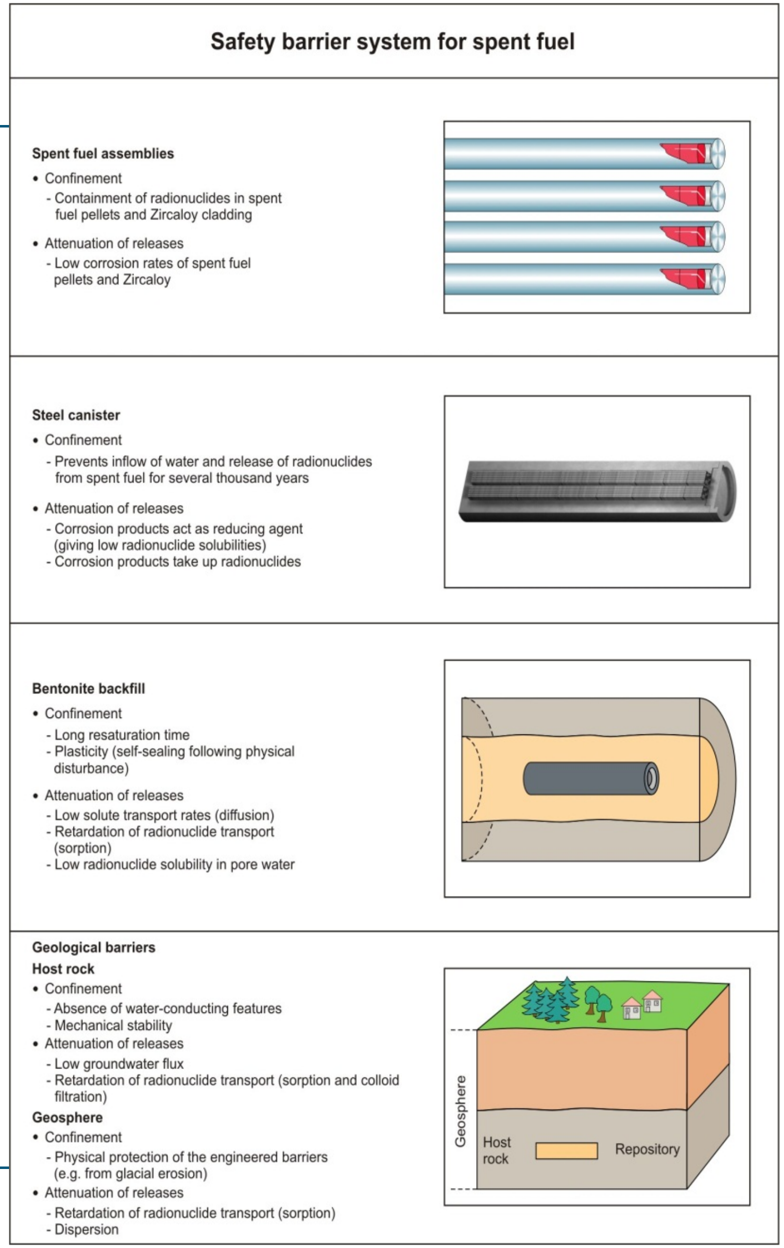
Passive barriers - multiple safety functions

- **System with multiple safety barriers**
  - Waste matrix (UO_2/MOX, glass)
  - Canister
  - Bentonite buffer
  - Host rock (Opalinus Clay + confining units)
- **Situated in stable environment**
  - At great depth
  - In stable geological environment
  - no significant resources
- **Provides 'Safety Functions'**
  - **Confinement and decay** within barrier system
  - **Low release** to environment
  - Long-term **stability** of system



URL contributions in context – where are they contributing?

	Boreholes and tunnels in siting region	Seismic surveys in siting region	Mont Terri URL	GTS and other URLs
Site suitability				
- Lateral extent	X	X		
- Tectonics	X	X		
- Host rock thickness	X	X		
Construction issues				
- Stress field	X		X	(X)
- Rock mechanics	X		X	(X)
- Tunnel lining			X	(X)
- EBS emplacement			X	(X)
Long-term safety issues				
- Barrier function of rock	X		X	
- Flow systems	X			
- Geochemistry	X		X	
- EBS processes			X	(X)
- Coupled processes in rock			X	(X)

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Two operating URLs in Switzerland

Mont Terri Project

Opalinus Clay

Grimsel Test Site

Crystalline rock

URLs initiated early in the HLW programme

1978 Concept report on nuclear waste management

1980 - 2000 Regional investigations in N. Switzerland (crystalline/sediments)

1984 Start of operation of the Grimsel Test Site (crystalline URL)

1985 Project Gewähr (crystalline) submitted

1988 Federal Council decision on Gewähr: investigations extended to clays / start of sediment programme

1996 Start of operation of Mont Terri (Opalinus Clay URL)

2002 Opalinus Clay project (feasibility study submitted to authorities)

2006 Feasibility study approved by Federal Council

2008 Start of Sectoral Plan process

2024 General licence application for the HLW repository

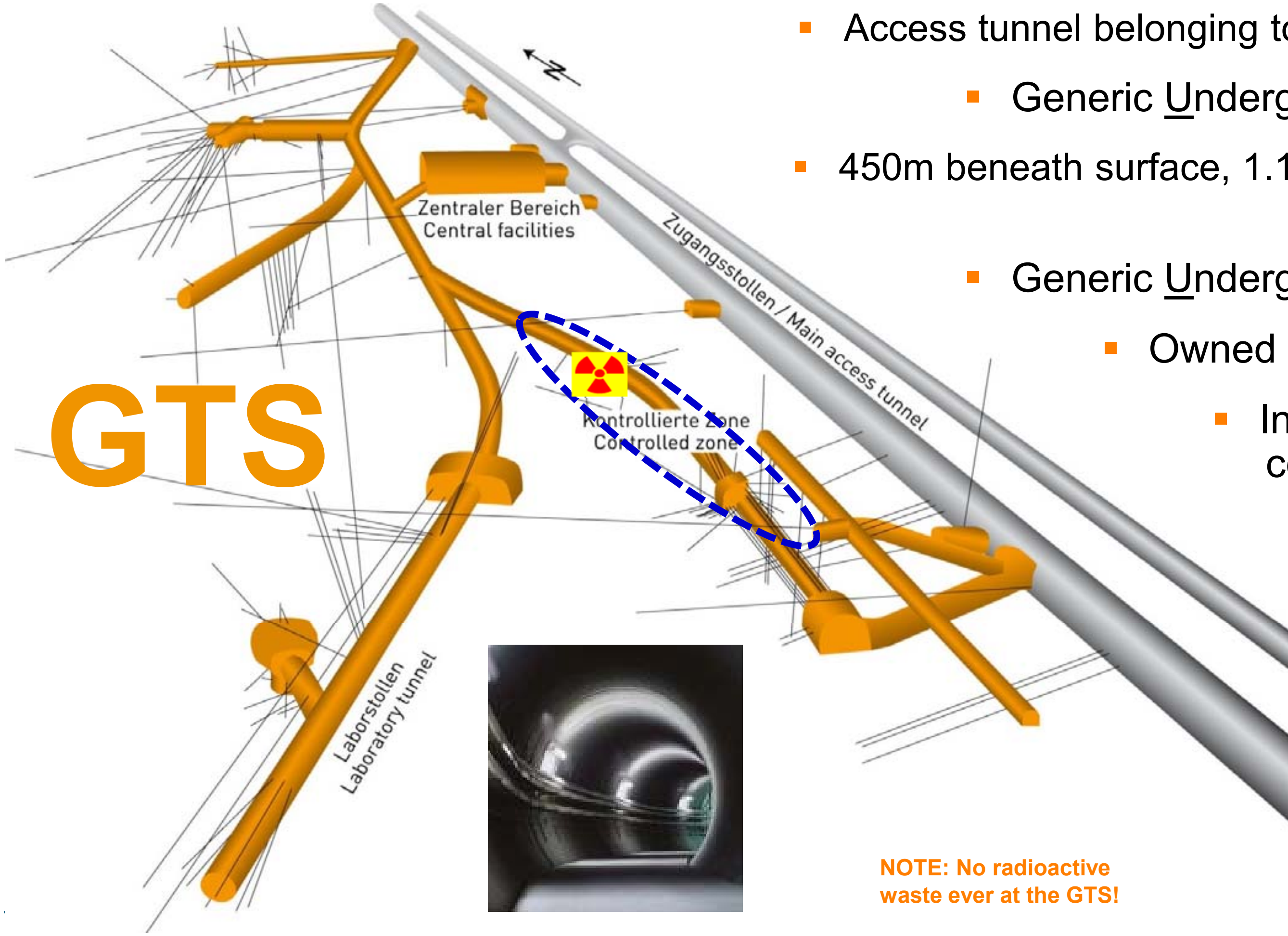
2029 Government decision

from 2035 Underground investigations / construction phase

from 2060 Start of repository operation

Grimsel Test Site – some facts

- Altitude of 1730m in granitic rock of the Aare Massif in central Switzerland
- Access tunnel belonging to local hydro-power company (KWO)
- Generic Underground Research Laboratory (URL)
- 450m beneath surface, 1.1km length, f 3.5m tunnels excavated with TBM / blasted
- Generic Underground Research Laboratory (URL)
- Owned and operated since 1984 by Nagra
- Includes an IAEA level B/C radiation controlled zone, which allows in-situ experiments with radionuclides



NOTE: No radioactive waste ever at the GTS!

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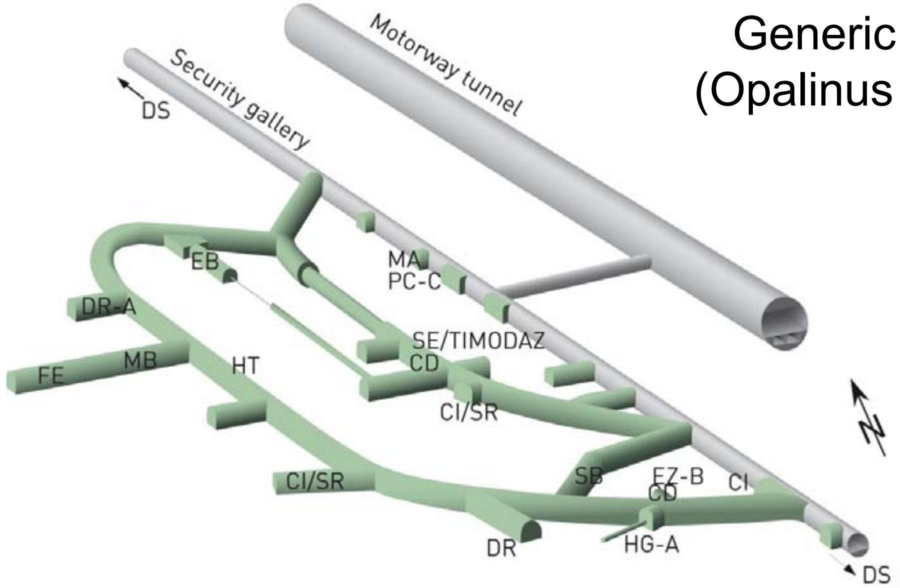
Mont Terri URL (MT) – some facts

Projet Mont Terri



Generic URL
(Opalinus clay)

- In operation since 1996
- Owned by the Canton of Jura
- Operated by Swisstopo

(Source Swisstopo, www.swisstopo.ch)

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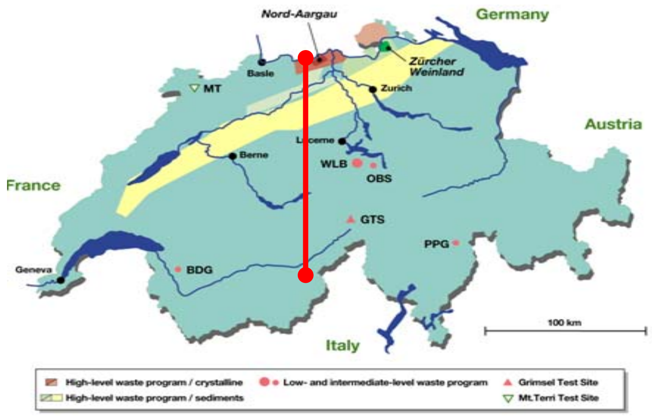
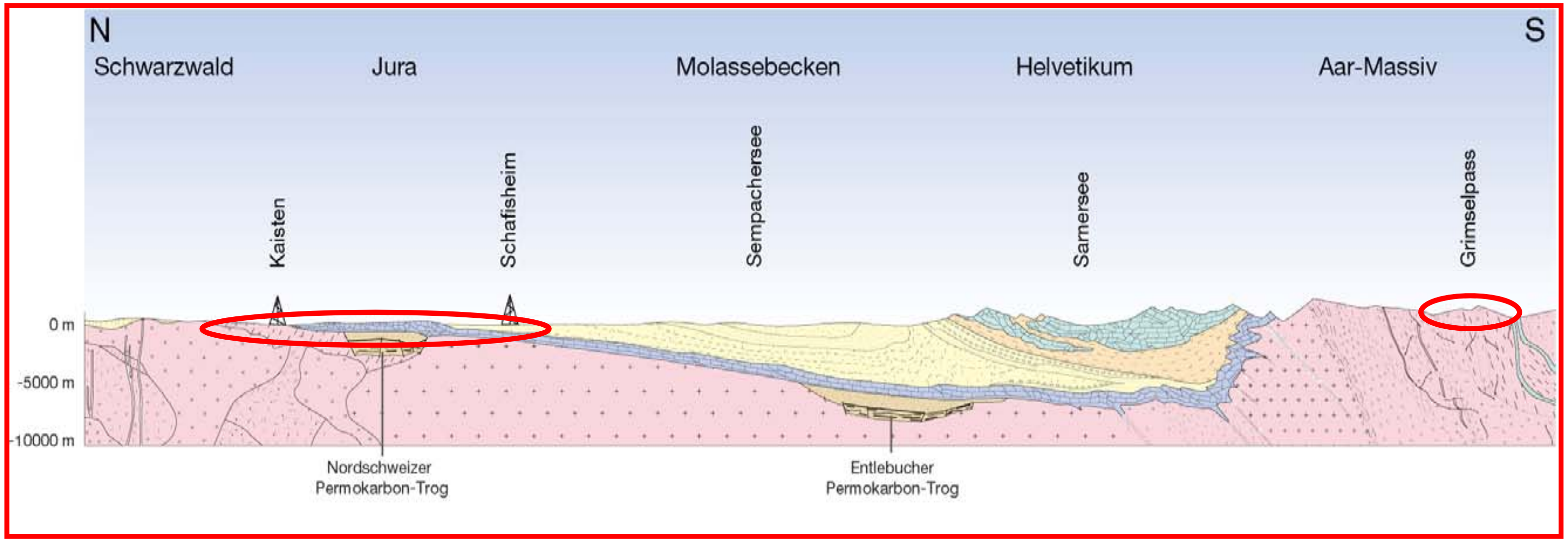
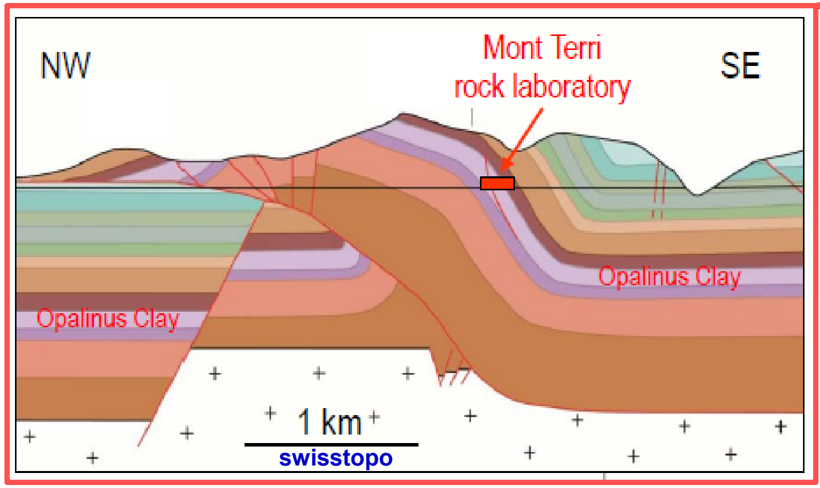
Nagra's drivers for establishing the URLs

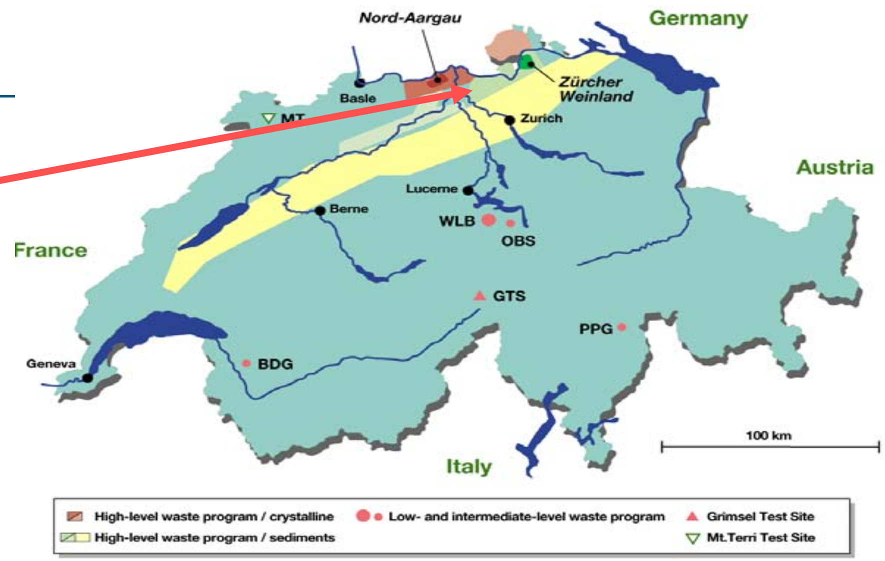
- For both the crystalline and the sedimentary rock programmes, it was recognized that many issues related to migration, construction and EBS behaviour must be studied in-situ
  - **GTS** (1984) – the development of Project Gewähr (1985) for crystalline rock in Northern Switzerland made it clear that URL studies would be important for future development





Nagra's drivers … *cont.*





- **MT** (1996) – the positive results from sedimentary studies in the 1990s pointed to Opalinus Clay as a suitable potential formation; the MT location was an opportunity for a URL in a preferred rock, although not in a potential siting region

- **Both URLs** had easy access (limited infrastructure needed) and represented opportunities to develop understanding in situ without having to wait for a disposal site URL

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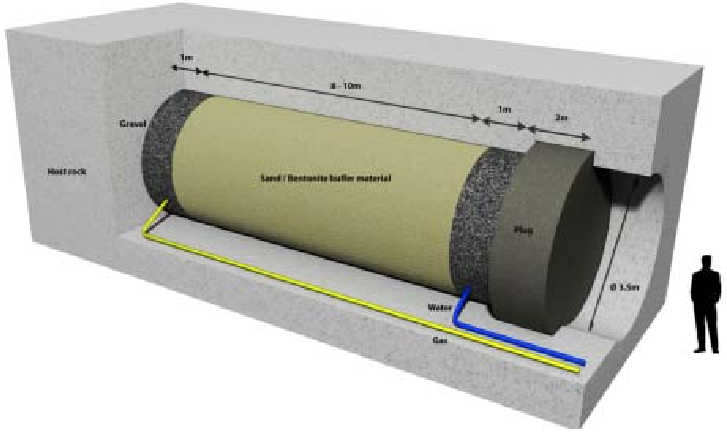
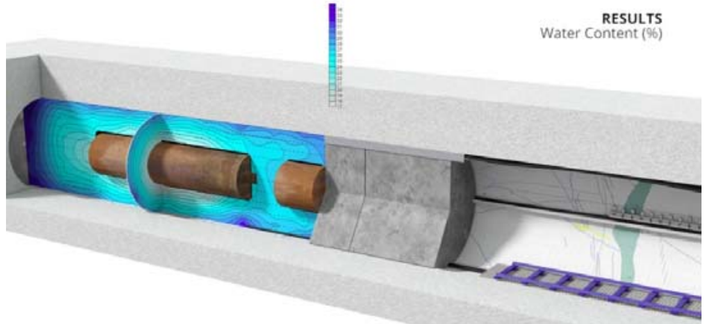
The research focus for URLs evolved

- **Start-up phase:** Exploration of intrinsic properties of the geological environment
  - Defining programmes to study the confinement by the rock
  - Developing experimental equipment and methods
  - Elementary technical feasibility studies
  - Collating fundamental geological data
- **Later phases:** Verification of characteristic parameters of processes expected in the lifetime of a repository
  - Tests on phenomena induced by the construction and operation of a repository and its consequences for confinement properties
  - Interaction tests: disposal materials ⇔ host rock
  - The study of migration and the fate of gases
  - Defining programmes to study the confinement by engineered barriers
- **For the past >15 years:** Additionally Long-term demonstrators and experiments under more realistic boundary conditions, more recently also optimisation of systems.

The GTS in the Swiss programme today

- Activities driven by Nagra RD&D priorities
  - As the focus of the Swiss national program shifted from crystalline rock to sedimentary rock formations, the focus of Nagra's activities at the GTS has also evolved to reflect the emerging RD&D priorities.
  - Emphasis has been thus placed on
    - behavior of EBS components under natural conditions or repository-induced effects (heat generation, gas) at medium and engineering scales, as well as their interactions.
- Communication/interaction platform with geological repository proponents and opponents
- Platform for international cooperation on scientific and engineering issues
- Training and know-how transfer



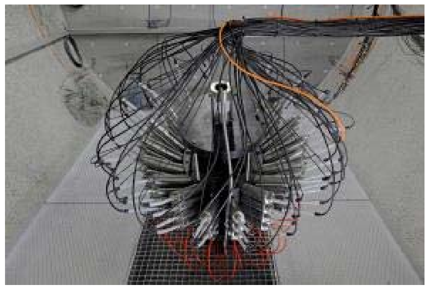


GTS Phase VI – Main projects

Project		Duration
LCS	Long-term Cement Studies	2004 - 2018
LTD ▌	Long Term Diffusion	2004 -
CFM ▌	Colloid Formation and Migration	2004 -
CIM ▌	^{14}C and ^{129}I Migration project	2017 -
iBET (CFM)	Bentonite Erosion Test	2018 -
TEM	Test & Evaluation of Monitoring Techniques/MODERN	2006 -
FEBEX	Full-scale HLW EBS Experiment	1996 - 2019
GAST	Gas Permeable Seal Test	2010 -
LASMO	Large scale Monitoring	2013 - 2019
MaCoTe	Material Corrosion Test	2013 -
HotBENT	High Temperature Bentonite project	2018 -
ISC	In-situ Stimulation and Circulation Test	2015 -
TSD	Thermal Spallation Drilling	2017 -
DTS	Distributed Temperature Sensing / Fluid Logging	2017 -

▌*Test with radionuclides, in Controlled Zone*



The Mont Terri URL in the Swiss Programme today

- The Mont Terri URL has provided the knowledge base for the Opalinus Clay, including investigation methods (drilling, sampling, geophysics), rock characterisation (mineralogy, porewater composition, transport parameters) and also geomechanics. The latter can only be partly transposed to the selected sites.
- Models and databases have been tested and verified for radionuclide migration.
- Detailed investigations regarding repository induced effects (THMC) have been conducted and are still ongoing in small scale and 1:1 scale experiments, including monitoring
- The focus is currently on very long term experiments. Rock characterisation is shifting to the selected sites, as sampling of site specific data now becomes possible with the deep drilling programme.




Mont Terri URL Phase 23 (06/18 – 06/19) – Main projects

Name	Experiment
CI	Cement-Opalinus Clay Interactions
CI-D	Diffusion across concrete/claystone interface
DR-B	Long term Diffusion Experiment
DF	Drilling Fluids for Opalinus Clay
FE-M	Full Scale Emplacement
FE-G	Monitoring the gas composition within the full-scale emplacement experiment
FS-A	Frictional properties of Opalinus Clay
FS-C	Imaging the long-term loss of faulted host rock integrity
GC	In situ geomechanical characterization of Opalinus Clay
GC-A	Characterization of EDZ – focus on sandy facies
GD	Geochemical Data
HA-A	Analysis and Synthesis of the Variability
HE-E	In situ Heater Test in Microtunnel
IC-A	Corrosion of Iron in Bentonite
MA	Microbial Activity
MA-A	Modular Platform for Microbial Studies
SO-C	Facies analysis of the upper Opalinus Clay and the transition to the Passwang Formation
TS	Testing different tunneling support in sandy facies during Extension of Gallery 2018/19

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URLs are major contributors to the succession of safety cases

Modelling and Experiments at smaller scale

Demonstration experiments at 1:1 scale in the URLs;
Large scale modelling

General Licence
Generic rock laboratories
(Mont Terri URL, Grimsel Test Site),
surface laboratories and modelling

Stepwise Approach:

Important questions contributing to the next decision at hand need to be clarified.

The whole body of knowledge is compiled at these milestone decisions

→ next 2024 - General Licence/Safety Case

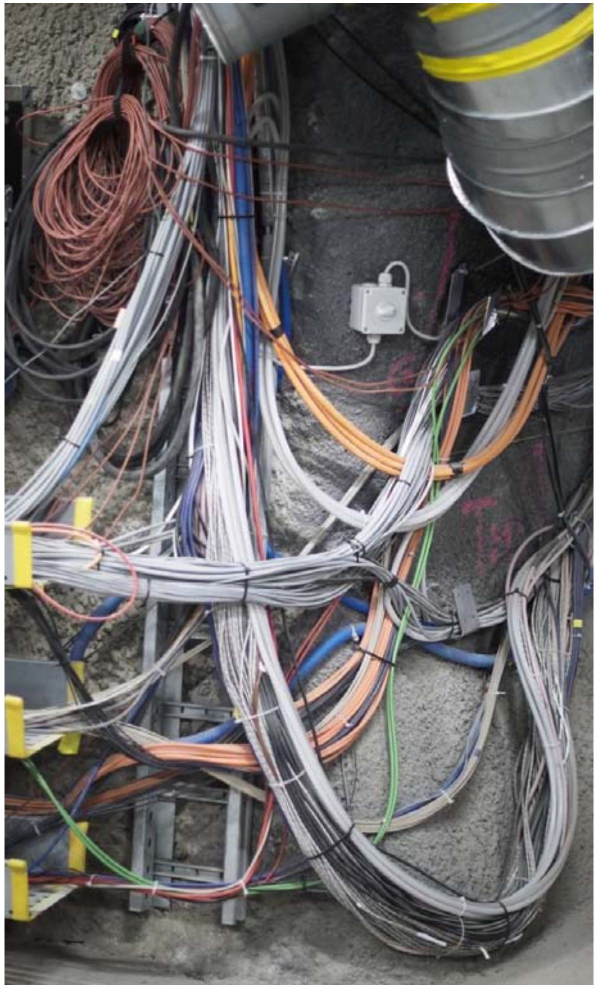
Experiments and rock characterisation at the selected sites

- Rock mechanics
- Properties host rock
- Retrievability, sealing ,…

Construction Licence
At the selected repository site(s) (>2030)

URL-related issues at the disposal site after site selection (>2030)

- Construction of the shaft/tunnel at the disposal site expected to start in 2030-2035
- A facility for underground investigations and a pilot facility are foreseen
- Questions related to the rock stress and the implications for construction, excavation disturbance, liners must be finally addressed at the disposal site. In contrast, the present URL studies should ensure technologies are available (conceptual design needed for the general licence).
- The pilot facility should be representative (dimensions and properties of barrier system and waste) and monitored to determine evolution with time to provide information
  - on safety-relevant conditions and processes and barrier effectiveness
  - for early recognition of unexpected developments
  - to support the safety assessment for closure
- The pilot facility is not a URL; validated models at full-scale should come from prior experiments where much more intensive and intrusive instrumentation is possible.



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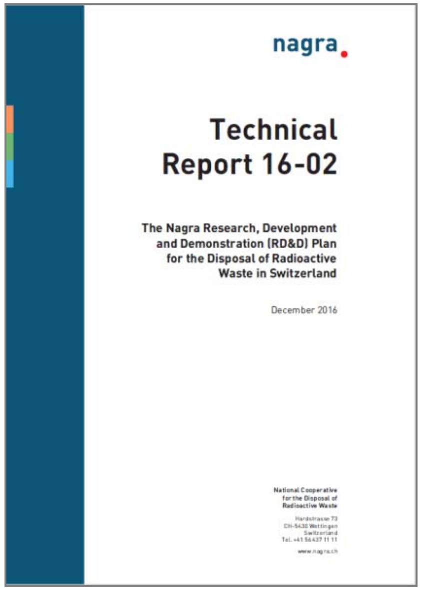
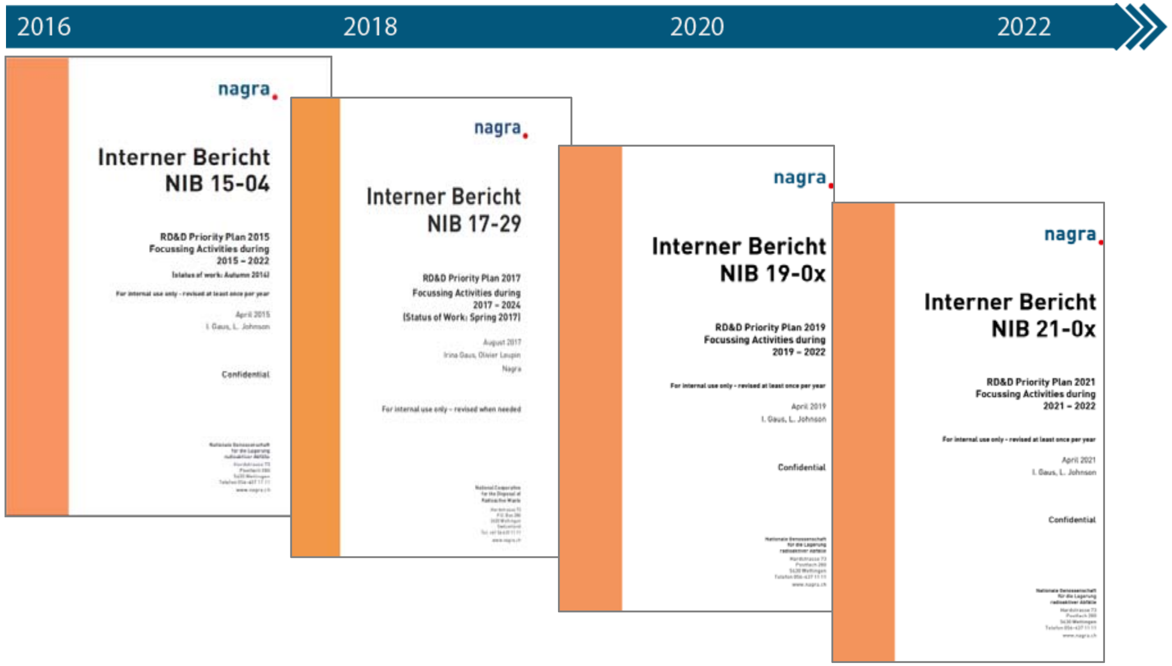
Prioritisation of RD&D: starting from the top



- **The RD&D plan** focusses on the activities in the next decade, with broad indications of RD&D activities beyond that. The RD&D plan is updated every 5 years.
- The identification of RD&D needs and setting of priorities occurs in the framework of the **priority plan,** updated ~every 1-2 years.



Certain RD&D priorities have an URL component

- The RD&D priorities are defined based on expert (top down-bottom up) judgement of the overall state of the programme using a risk based approach.
- Priorities are ranked based on:
  - Importance for the next safety case (2024)
  - Urgency & effort required to meet the priority
  - Risk of not reaching the expected outcome
  - Driver of the activity
- As part of these discussions also the need for a URL component to address the priority is assessed.

Description of the Priority	Importance for SV and/ or RBG	Urgency and Effort	Risk of failing	Driver of the activity			Origin	Target for SV and/or RBG
Transport of gas and water across a cement-clay interface	5	6	4	RBG			The mineral formation at the cement-clay interface has been studied in-depth, however its impact on transport has not been studied. Description of the transport properties of the interface region so it can be reflected in SA.	Define the extent to which cement-clay interactions inhibit saturation of the near field and gas and/or RN transport.
Sorption competition	5	4	4	RBG			Concentration dependence of sorption, impact of stable isotopes or similar elements on RN sorption, may significantly reduce Kd and impact dose rates.	Mechanistic understanding of competition effect (characterise binding sites), consistent model description and implementation to sorption model (link to RN4).
PSI topic "Modelling at different scales", part "Scaling of transport properties"	3	2	2	RBG	SV		Only RN transport (cement-clay; EGTS have own Priorities), scaling of transport parameters from lab to field scale, anisotropy at formation level.	Provide arguments and modelling approaches for a consistent description of transport processes at different scales and bounding of uncertainties, quantify effects of heterogeneity at formation scale (e.g. anisotropy)
Diffusion of safety-relevant anions	4	3	3	RBG			Further bound the transport of safety-relevant anions such as I-129, Cl-36 and Se-79, which define the dose rate.	Eliminate uncertainties in long-term behaviour of anions in clay rock and understand the factors influencing their transport.

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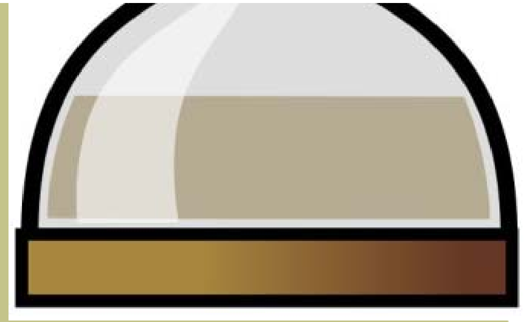
Defining URL activities (RD&D priorities) is based on many drivers

- investigating the characteristics of potential host rocks
- developing methodologies for how to do investigations
- developing understanding of processes occurring in the rock at relevant depths
- developing understanding of processes occurring when emplaced repository components interact with the rock and groundwater
- developing and verifying up-scaling procedures from sample to full scale
- testing components, techniques and instruments relevant to repository development
- developing and testing models of various processes
- confirming that models perform satisfactorily and demonstrating that repository components meet requirements
- building a solid technical and conceptual basis for monitoring at various project stages
- optimisation of concepts of repository components

URL bridges part of the time-space upscaling



Laboratory experiments

URL (*in-situ*)

Natural analogues

Well defined boundary conditions, simulated environment

Defined but complex boundary conditions, realistic environment

Boundary conditions less well defined, realistic environment

Dimension & duration of the „experiments“, observation period

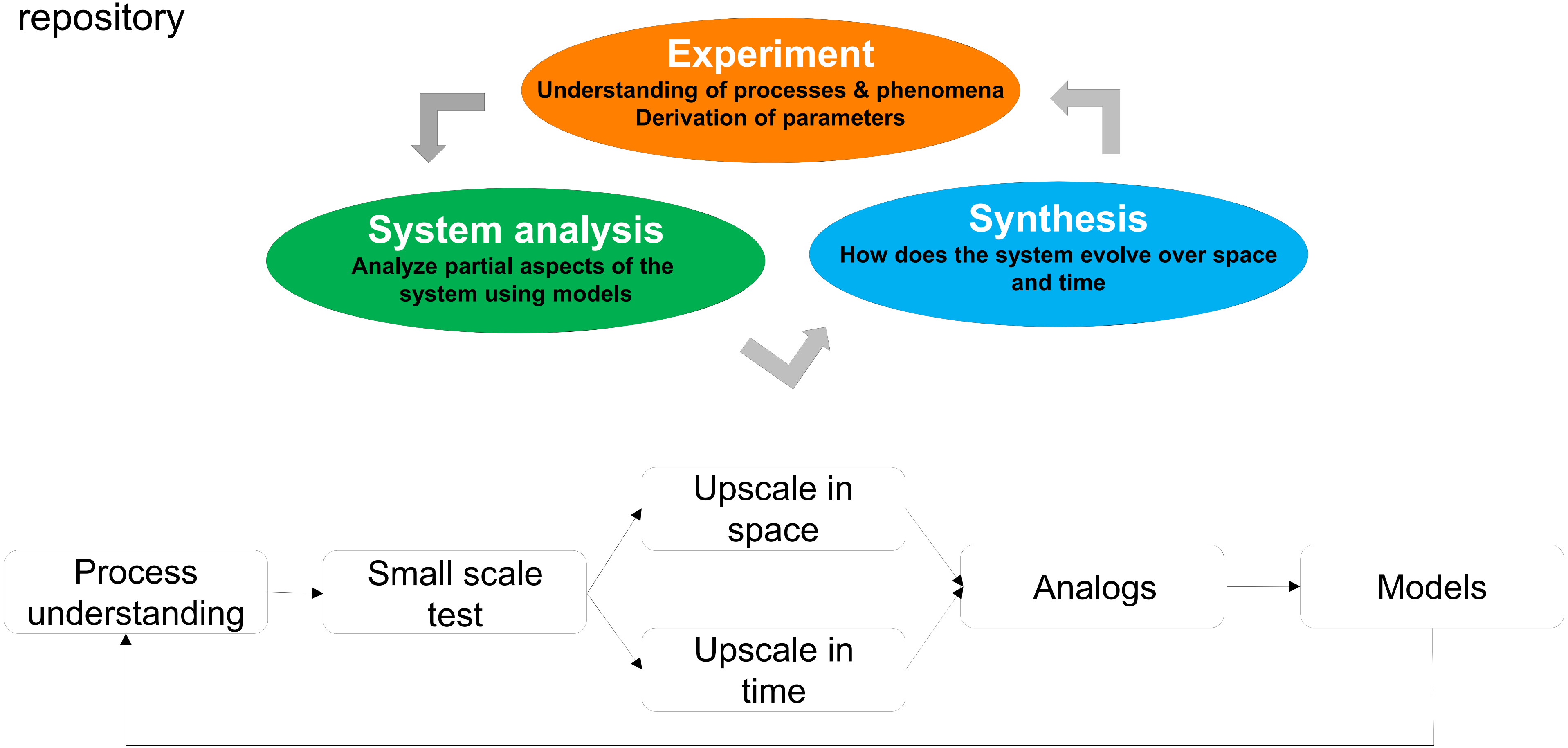
Weeks to years
mm / cm

Several years to decades
cm / m

Up to millions of years
100m / 1km

Integration of URL results is part of the safety case methodology

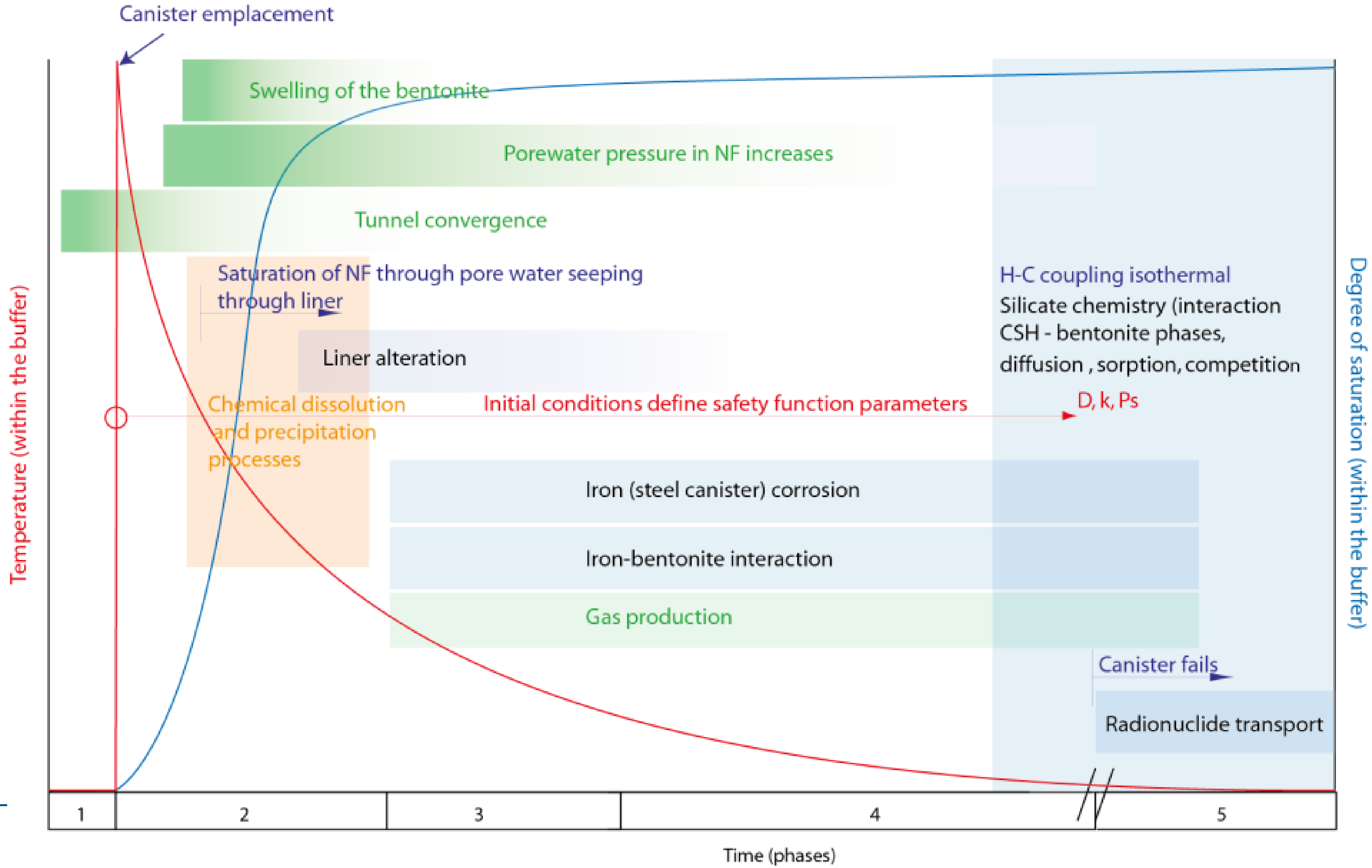
- Demonstrate that you understand the processes and assess the future evolution of the repository



Objective:
Description of the future system - assessment of its performance

Example 1:

Complete HLW system



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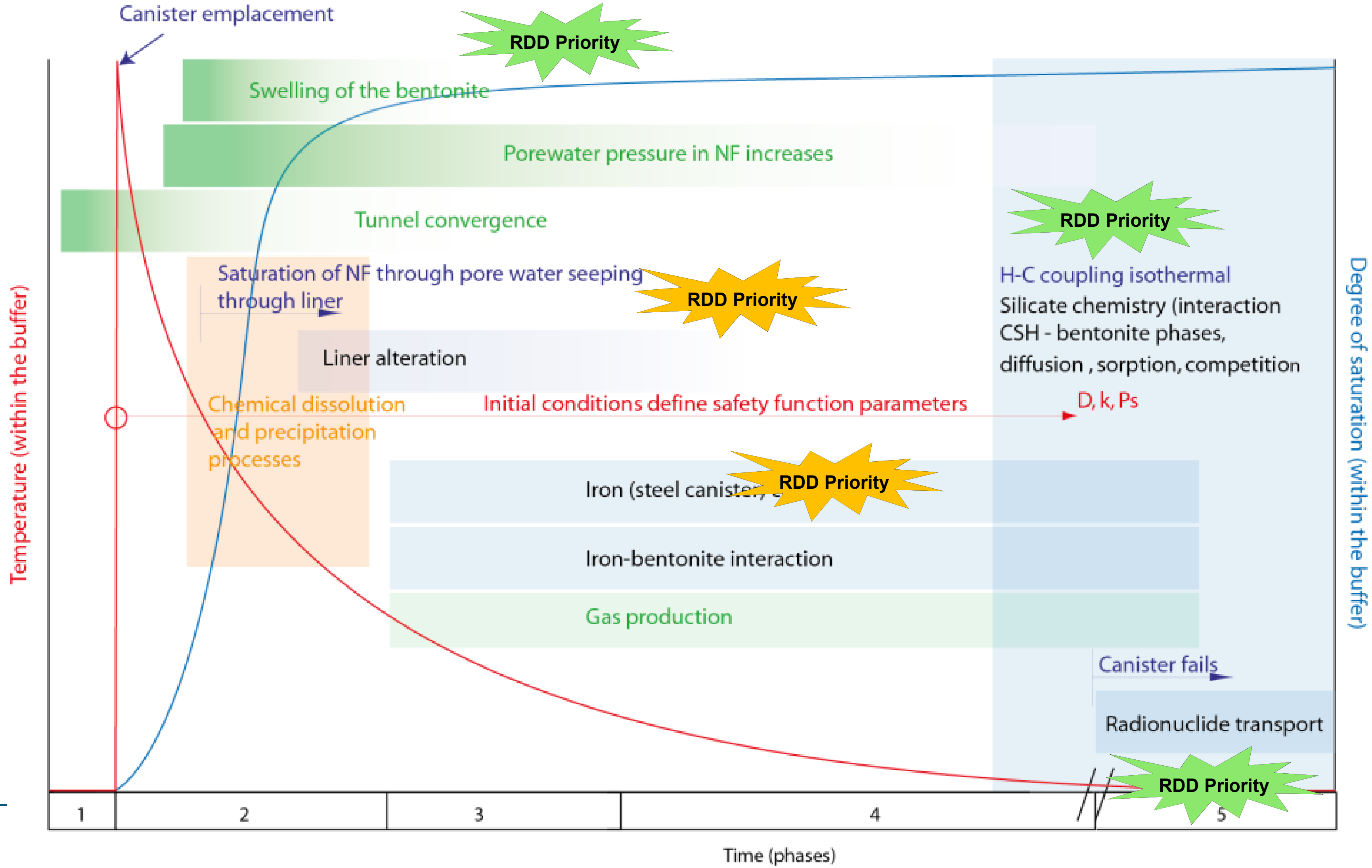

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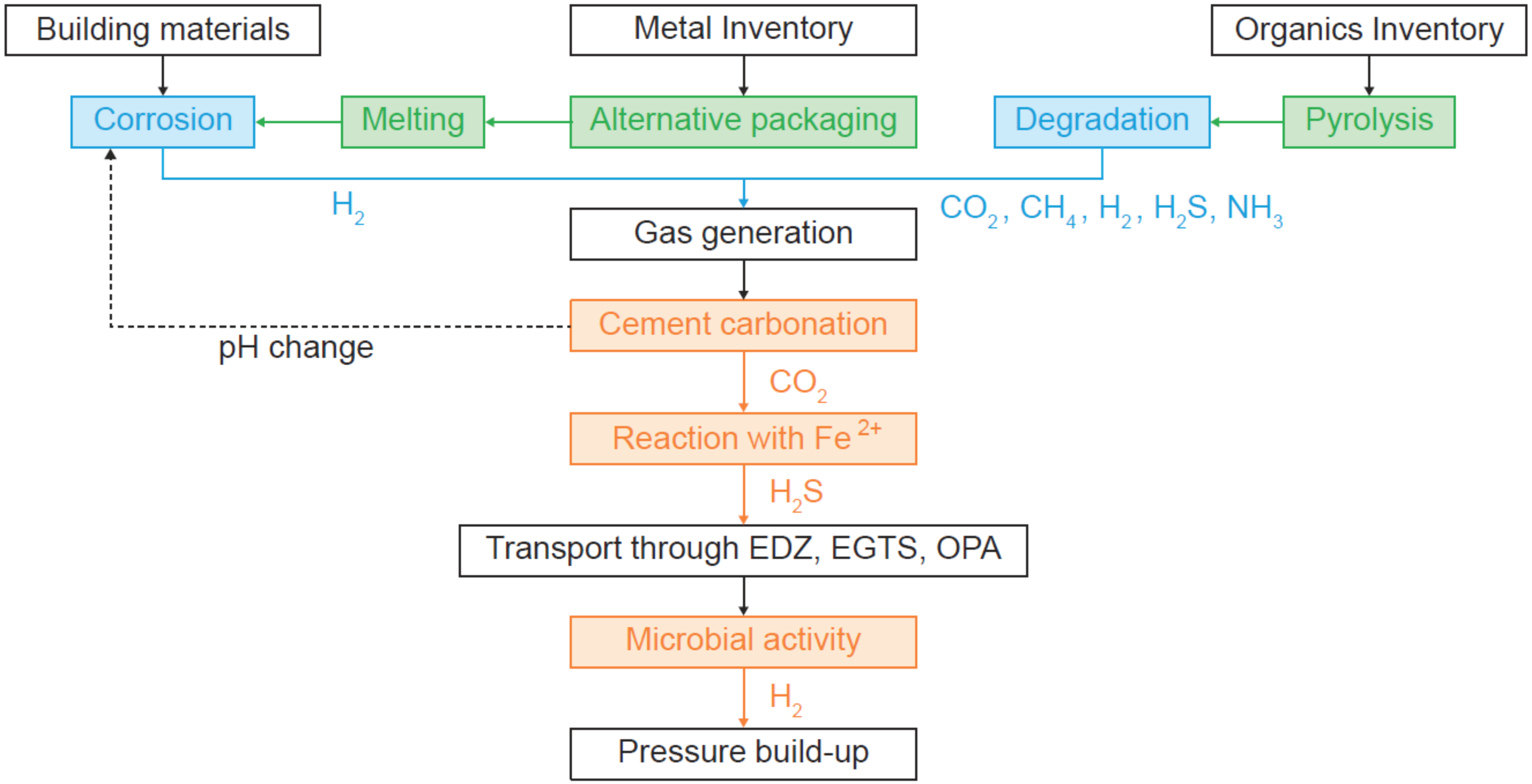
Example 2:

Evolution of the gas generation in the LLW repository

→ Sensitivity analysis in the model chain allows to identify aspects that need to be reinforced with RD&D



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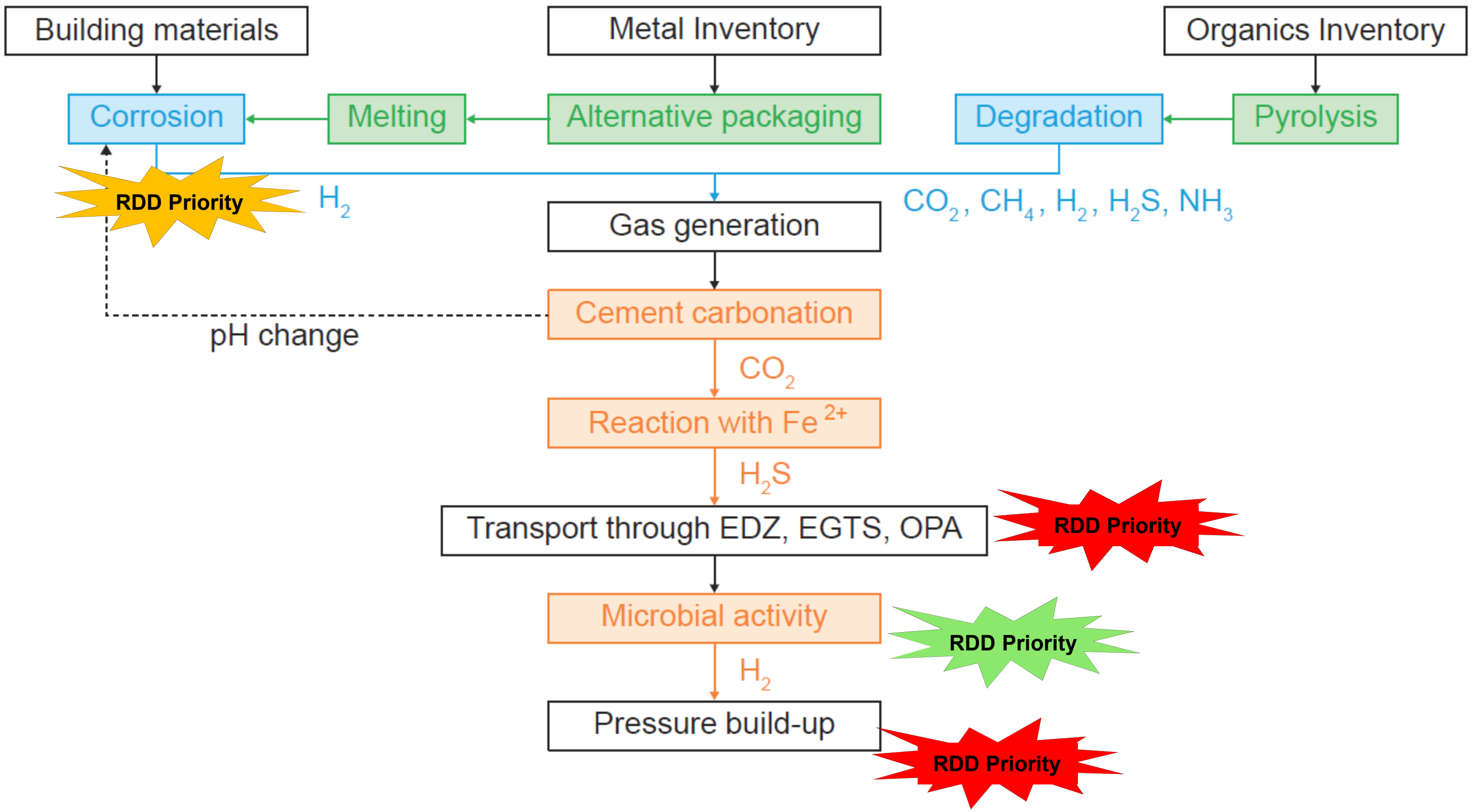

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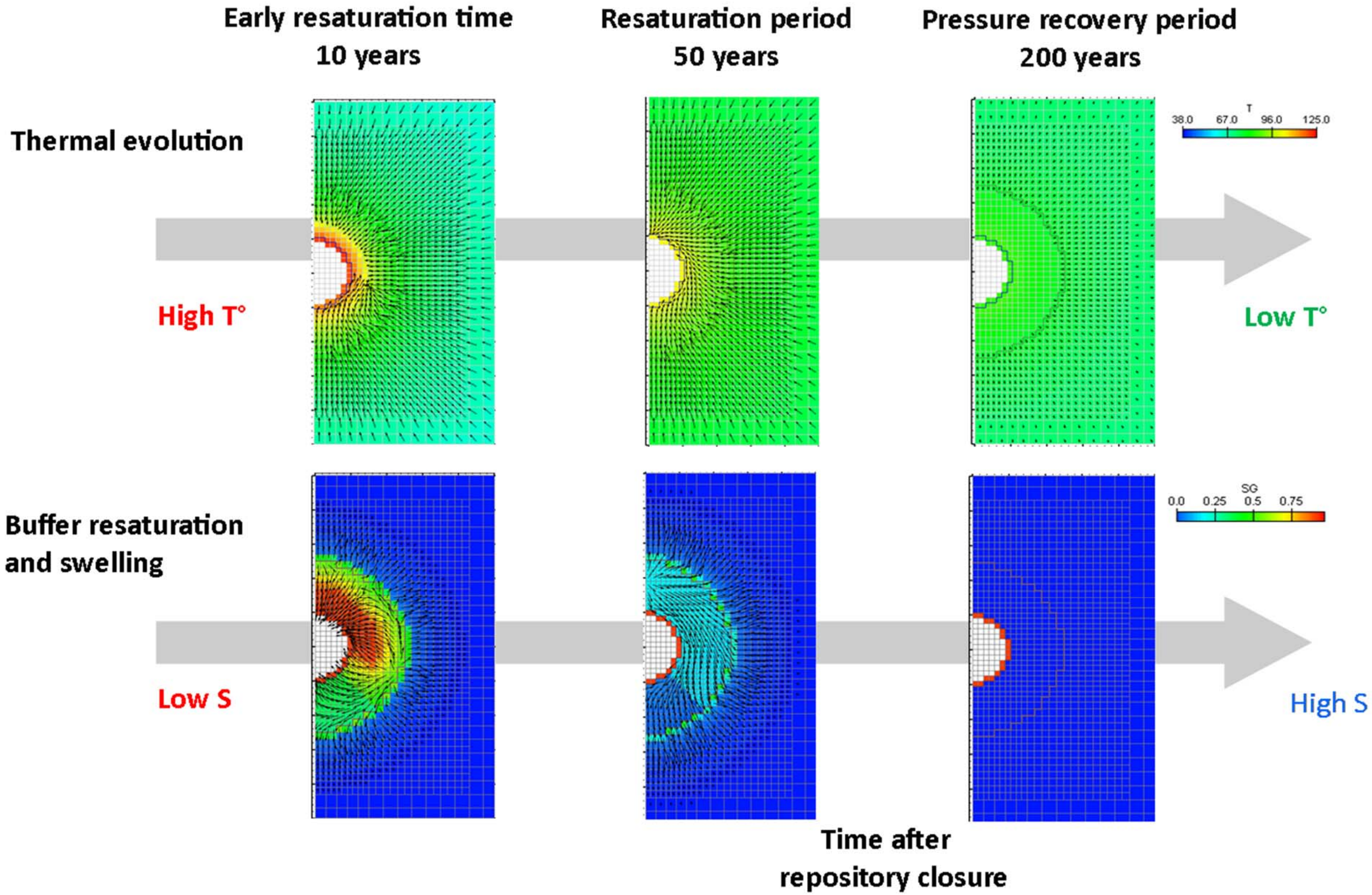
Objective:
Description of the future system - assessment of its performance

Example 3:

Early thermo-hydraulic (TH) transient



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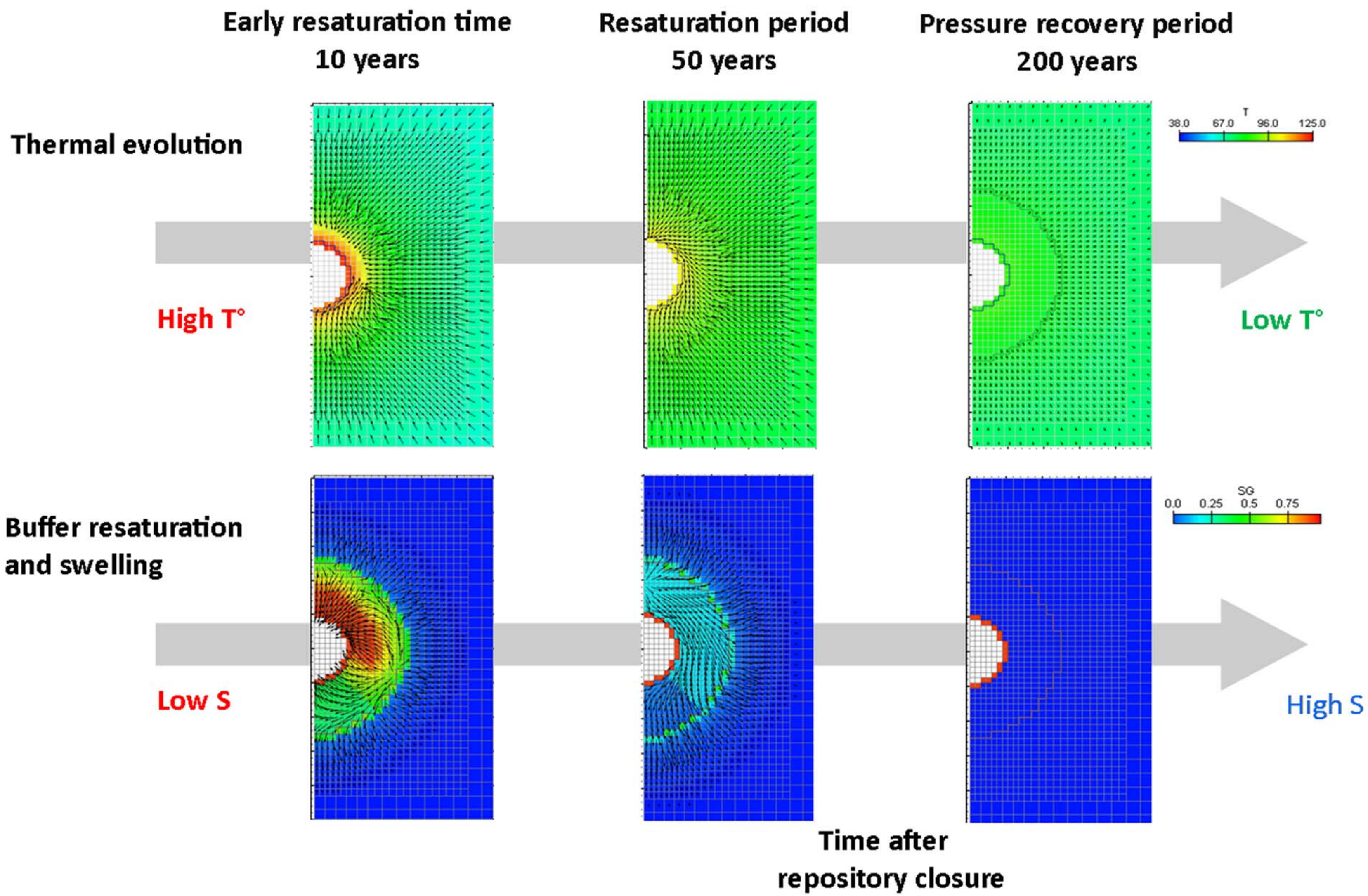
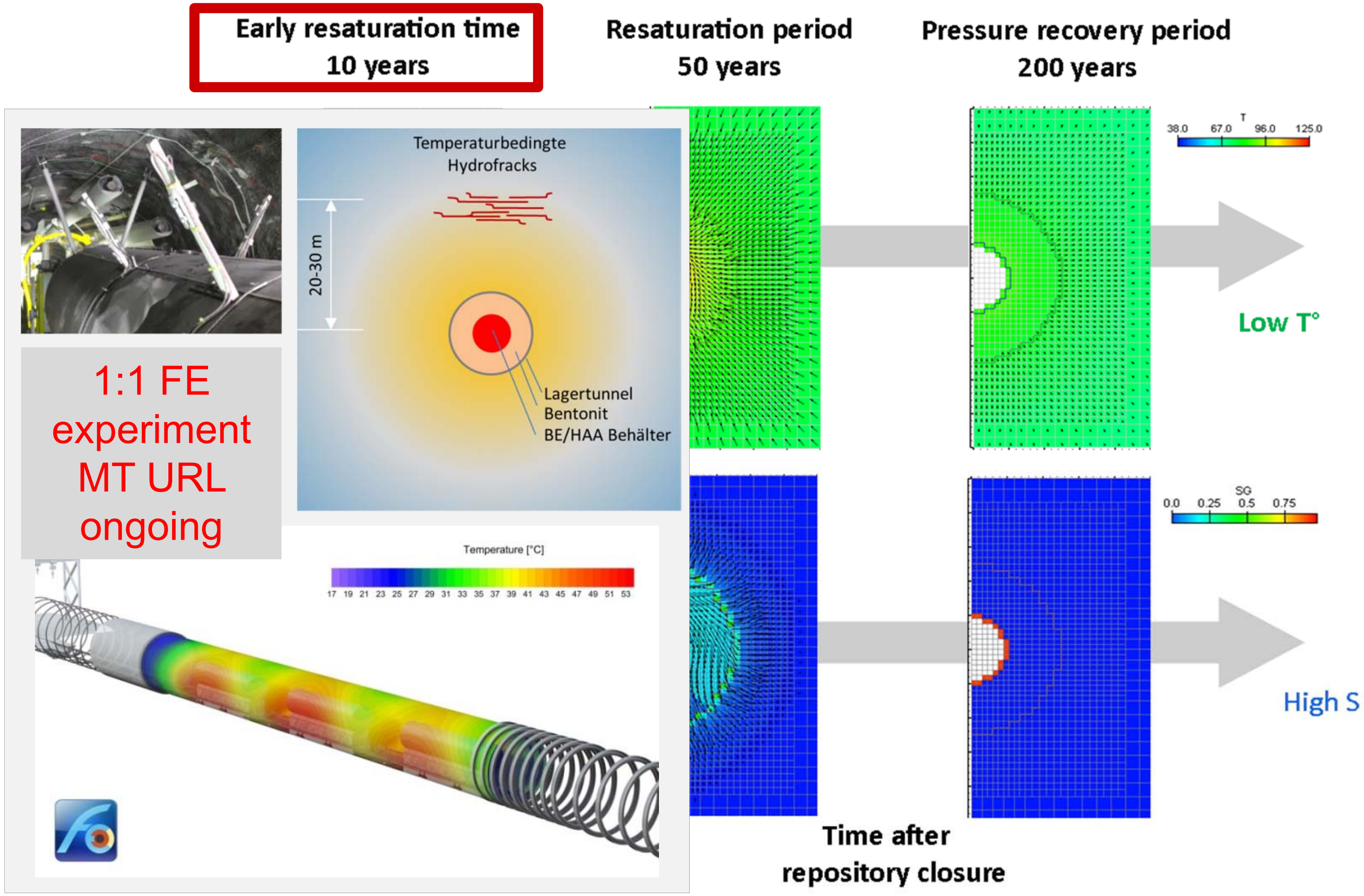


Example 3: Understanding the TH transient - upscaling in time



Example 3: Understanding the TH transient - upscaling in time

Early resaturation time
10 years

Resaturation period
50 years

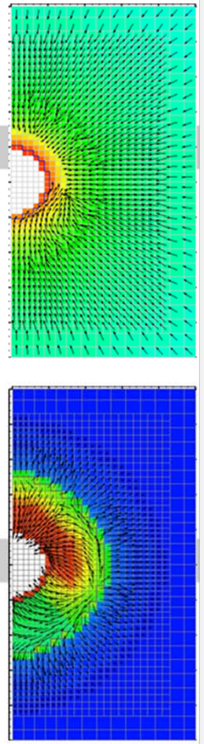
Pressure recovery period
200 years

Thermal evolution

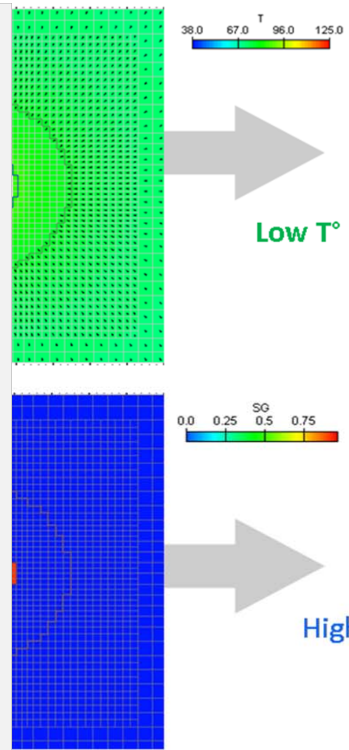
High T°

Buffer resaturation and swelling

Low S



1:1 FEBEX – Dismantling after 18 years of heating at the Grimsel Test Site

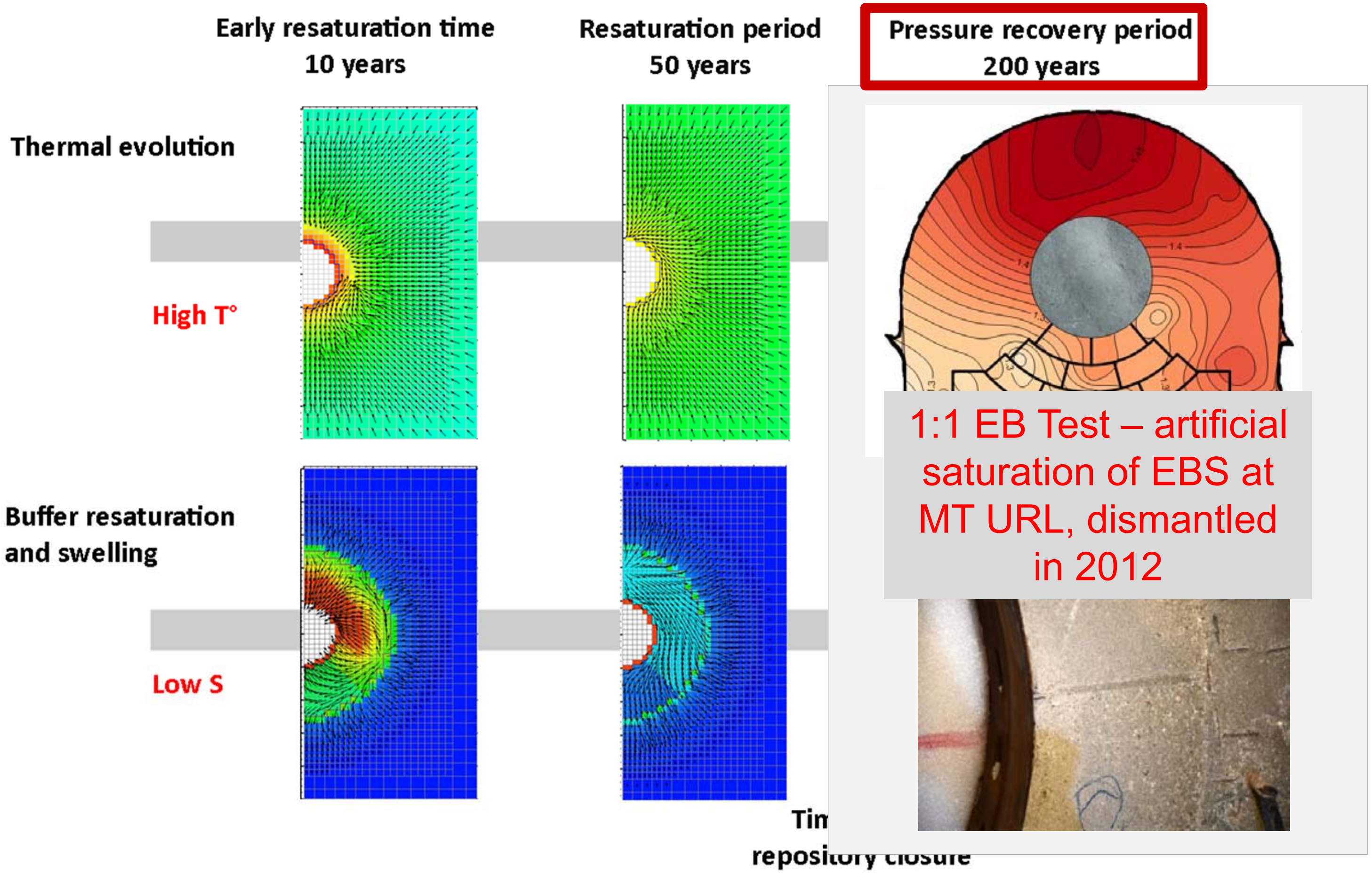


Low T°

High S

Refer Vos talk

Example 3: Understanding the TH transient - upscaling in time



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Conclusion on how to identify RD&D activities in a URL

- Our understanding of the system continuously improved over the last 40 years
- The evolution of the repository is described in sufficient detail such that its performance can be assessed over the whole period in terms of fullfilling its safety functions
- For safety relevant aspects storyboards, model chains and decision frameworks are in place. Weaker aspects in the argumentation are being addressed by additional RD&D
- URL activities are needed to
  - Reduce the remaining safety relevant uncertainties in process understanding
  - Address the most sensitive aspects in the decision and model chains
  - Test the performance of alternative options
- URL activities do not provide direct input for the safety case, the outcomes are part of the continuous integration of the knowledge base provided by lab experiments, natural analogues and upscaling in time and space.

Concluding remarks (also based on the additional material section)

- The need for a URL was recognized at Nagra very early (1984). Two generic underground research laboratories (URLs) are operating in Switzerland, the Grimsel Test Site in crystalline rocks (granite/granodiorite) and the Mont Terri in sedimentary rocks (Opalinus Clay).
- Nagra's present programme of work at the URLs is developed through the RD&D programme and Waste Management Programme as a result of consideration of safety-related requirements, input from reviews and time needed to obtain the results. A risk based RD&D priority planning approach drives the RD&D programme as a whole.
- The Nagra URL programme evaluates opportunities for collaboration at the Swiss URLs and in other URLs.
  - At Mont Terri Nagra supports activities from development of techniques for characterisation of clay-rich formations to parameter determination, understanding, conceptualisation, parameterisation of their properties and evaluation of repository-induced effects.
  - At the Grimsel Test Site, Nagra supports experiments addressing predominantly engineered barrier aspects.
- At both URLs large-scale and full-scale long-term projects to demonstrate the transient behaviour of the repository components have been initiated with a very long planning horizon.
- **International collaboration in URLs is key for ensuring excellence, competence building, networking and optimal use of resources.**

thank you
for your attention

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Additional material

- Swiss site selection process for the geological disposal facilities
- Where/how do current URL activities contribute to the next safety case

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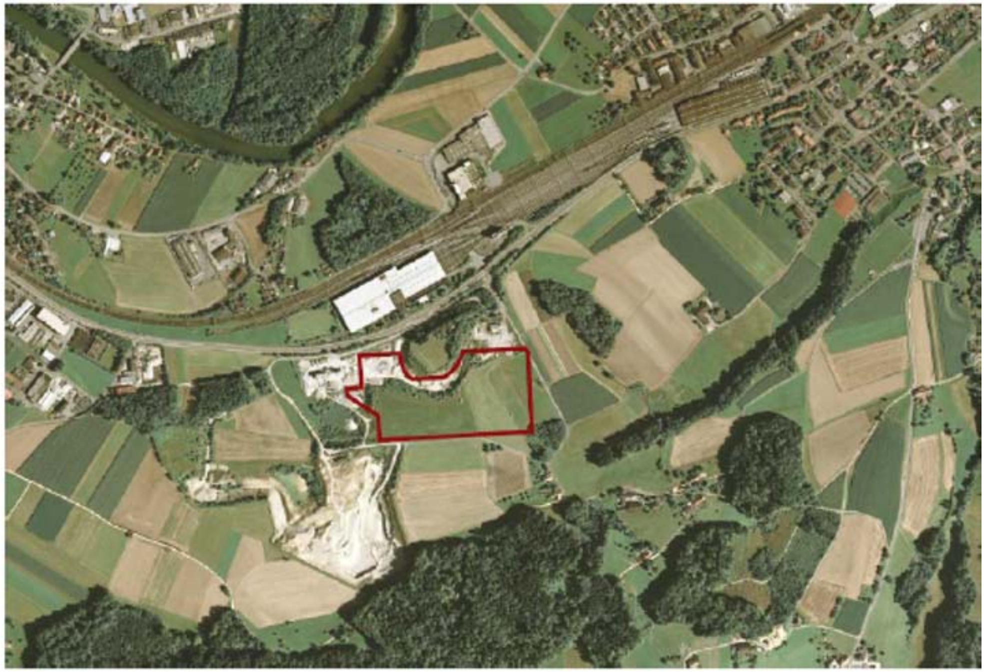
Legal framework / Nuclear Energy

- Sep 30, 2016: “Energy Strategy 2050” approved by Parliament
  - **No general licence for new NPPs**
  - No interdiction on technology in general, research allowed
  - Existing NPPs may operate as long as they are considered safe
  - **Spent fuel reprocessing:** Reprocessing definitely banned (moratorium extended by another 4 years to bridge gap)
- May 21, 2017: “Energy Strategy 2050” confirmed in referendum

Site selection in Switzerland…always in someones garden

Potential site in Northern Switzerland



Potential site in the US

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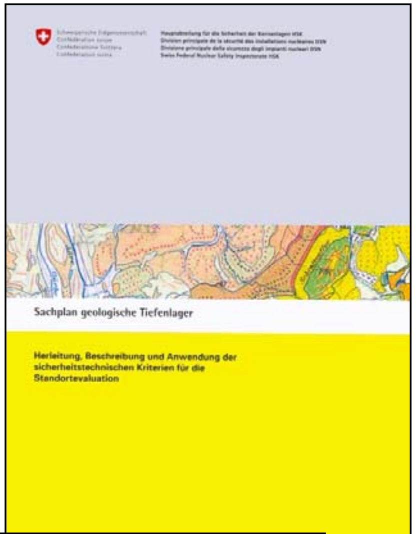
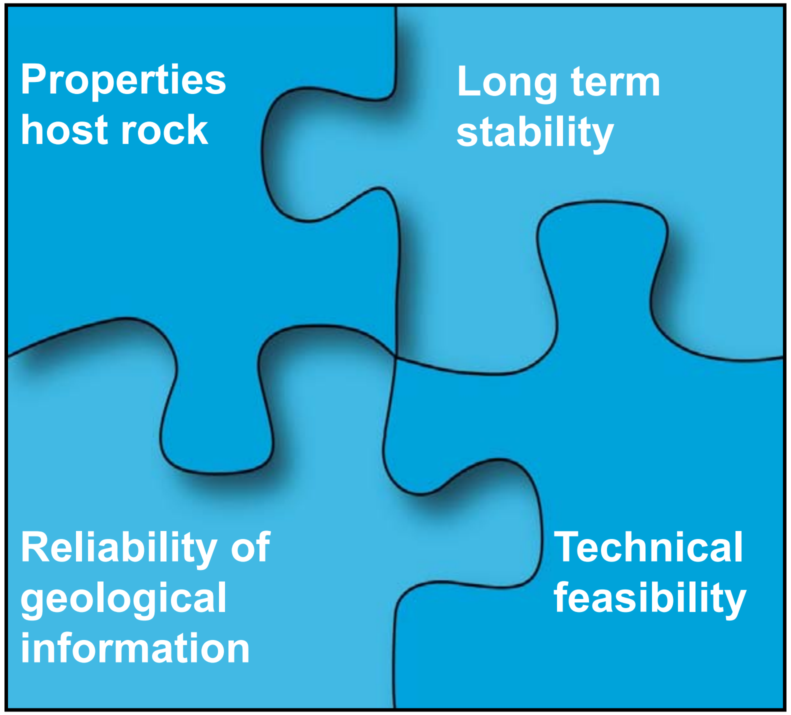
The 'Sectoral Plan' (the rules for site selection)[1]



- Process & responsibilities
- Criteria (safety, environmental impact, socio-economic issues)

Safety: 13 technical criteria (4 related groups)

The documents

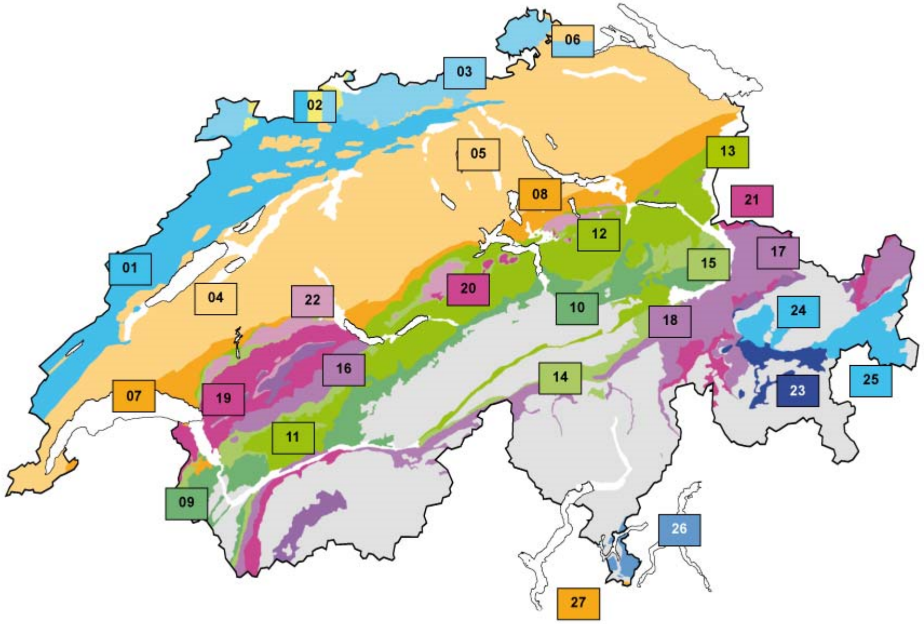


[1] available in English

Site selection: Key principle and criteria

Group of criteria	Criteria
1. Properties of host rock	1.1 Spatial extent 1.2 Hydraulic properties 1.3 Geochemical conditions 1.4 Migration paths
2. Long-term stability	2.1 Durability of properties 2.2 Erosion 2.3 Repository induced effects 2.4 Resource conflicts
3. Reliability of geological information	3.1 Characterisation of host rock 3.2 Spatial explorability 3.3 Temporal predictability
4. Suitability for construction	4.1 Rock mechanical properties 4.2 Underground access

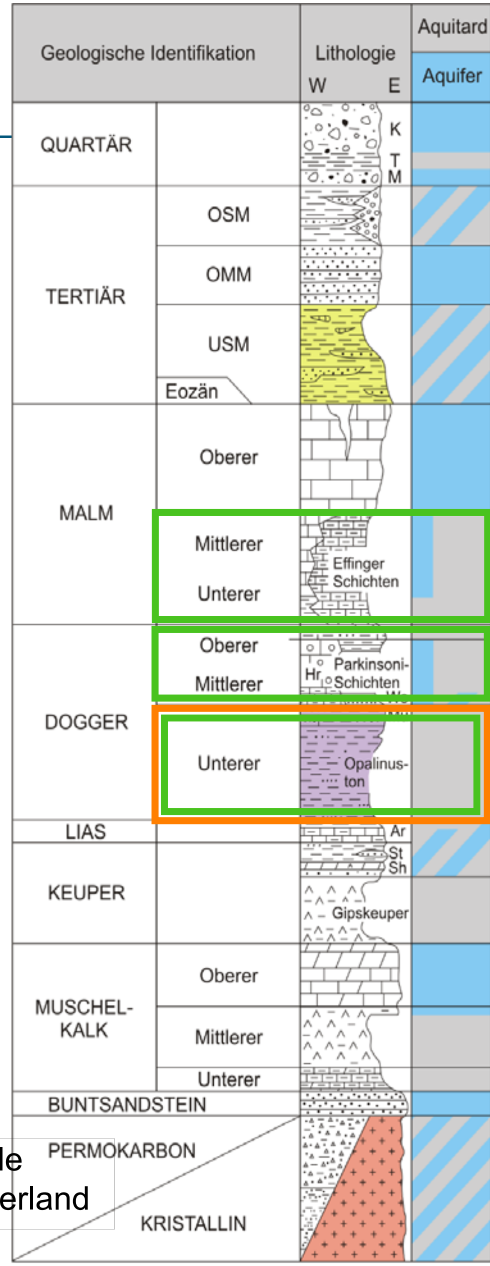
Geological barrier: Which rocks are suitable



Quality as radionuclide barrier, sufficient strength, sufficient thickness & extent

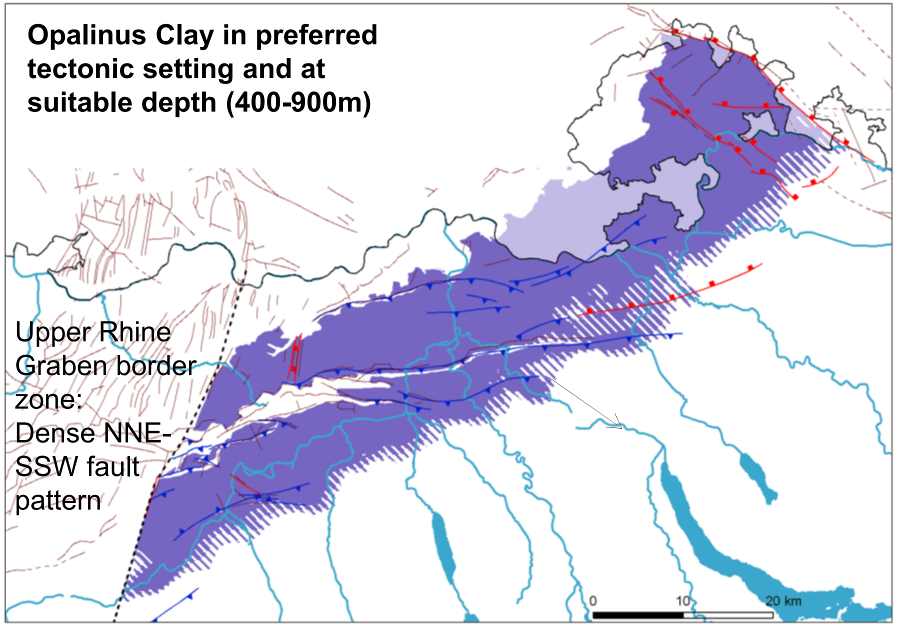
After pre-selection of 26 potential host rocks:

- **HLW repository**: Opalinus Clay
- **L/ILW repository**: Opalinus Clay, 'Brauner Dogger', Effinger Schichten Marl (Helvetikum, Alps)

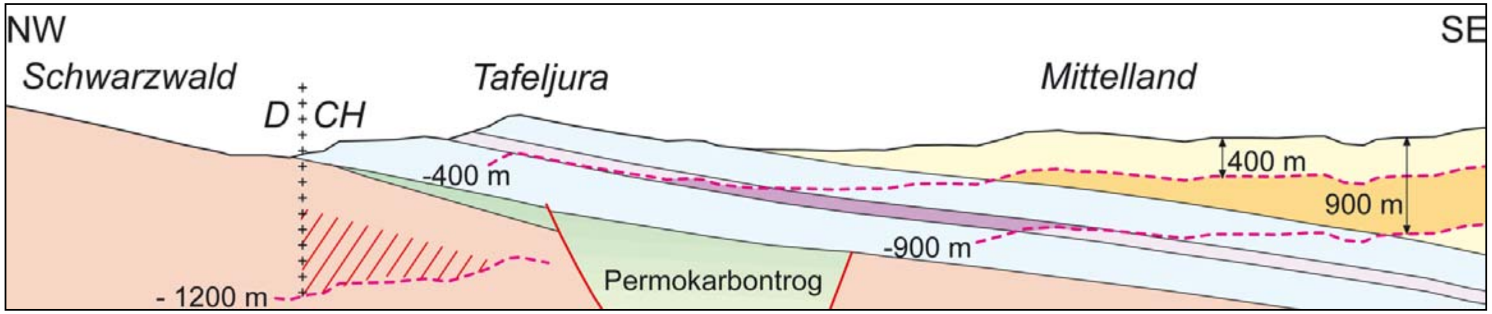


Example: Profile Northern Switzerland

Site Stage 1: preferable local configurations



Proposed siting regions accepted by the Swiss government in 2011 after an intensive review phase



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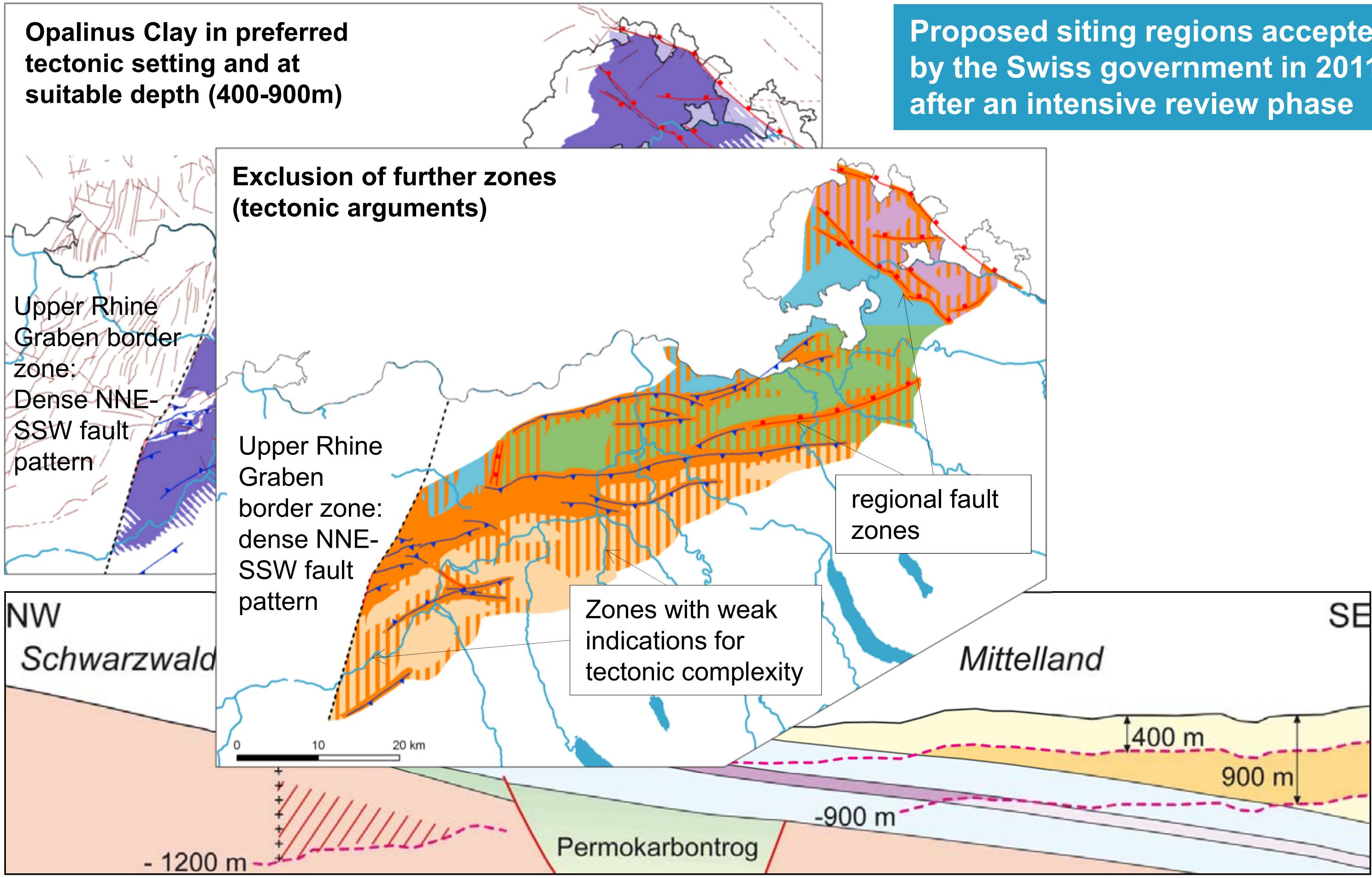
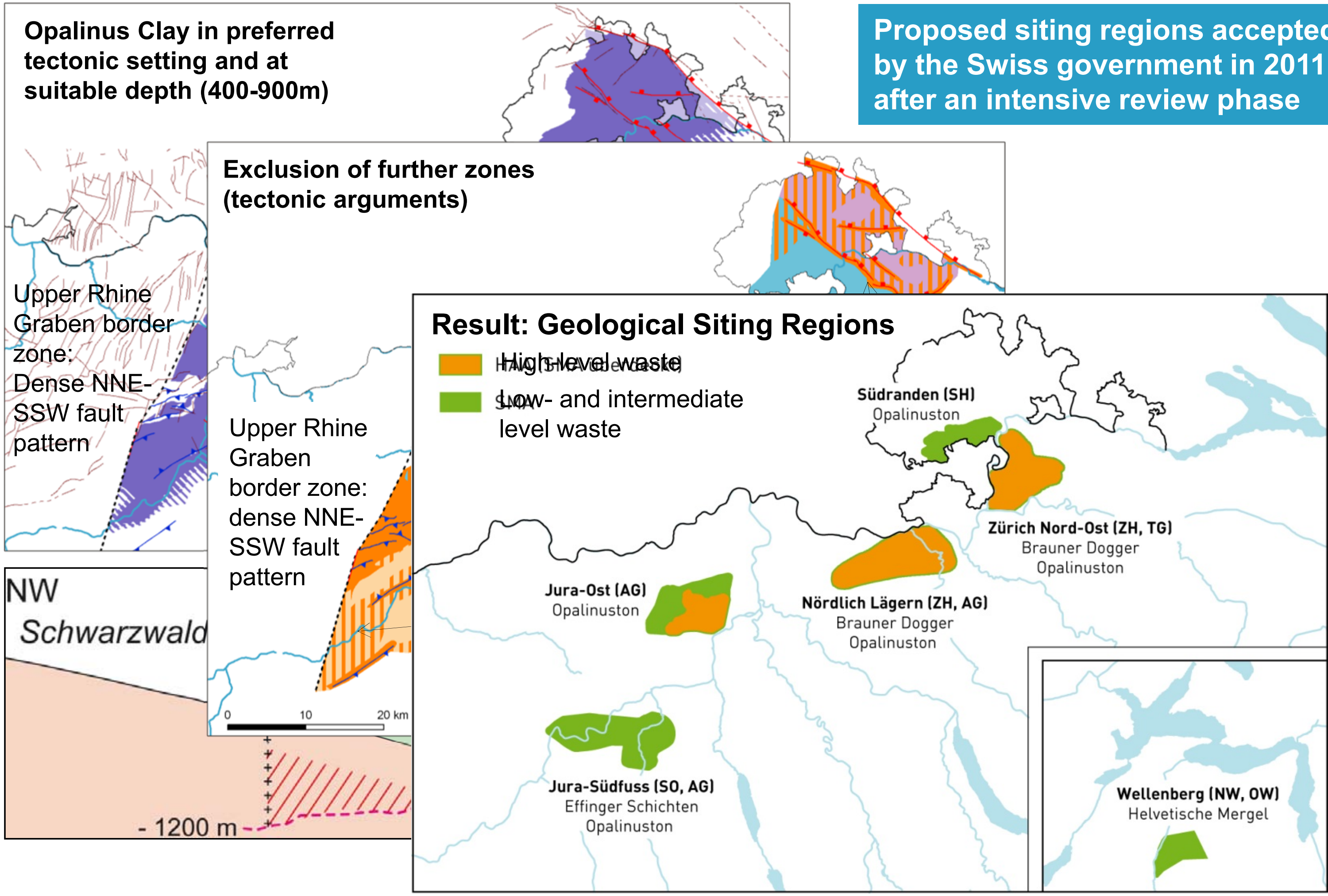
Site Stage 1: preferable local configurations

Proposed siting regions accepted by the Swiss government in 2011 after an intensive review phase



Site Stage 1: preferable local configurations



Proposed siting regions accepted by the Swiss government in 2011 after an intensive review phase

Contents

- Nuclear Power in Switzerland: phasing out after 60 years
- Site selection for geological repositories: restarted in 2008
  - Stage one: the initial selection (2008-2011)
    - Rocks and repository options
  - Stage two: narrowing down to 2+ per waste category (2012-2018)
    - barrier function, explorability, rock strength, long-term evolution
  - Stage three: exploration and decision (2019 – 2029?)
    - 3D-seismics
    - Quarternary investigation program
    - Drilling strategy

Site Selection Stage 2: Geological investigations

- Investigation in third party drill holes
  → broadened rock data base

- Fill-in 2D-seismic survey and reprocessing of legacy surveys
  → improved and homogenized structural data base

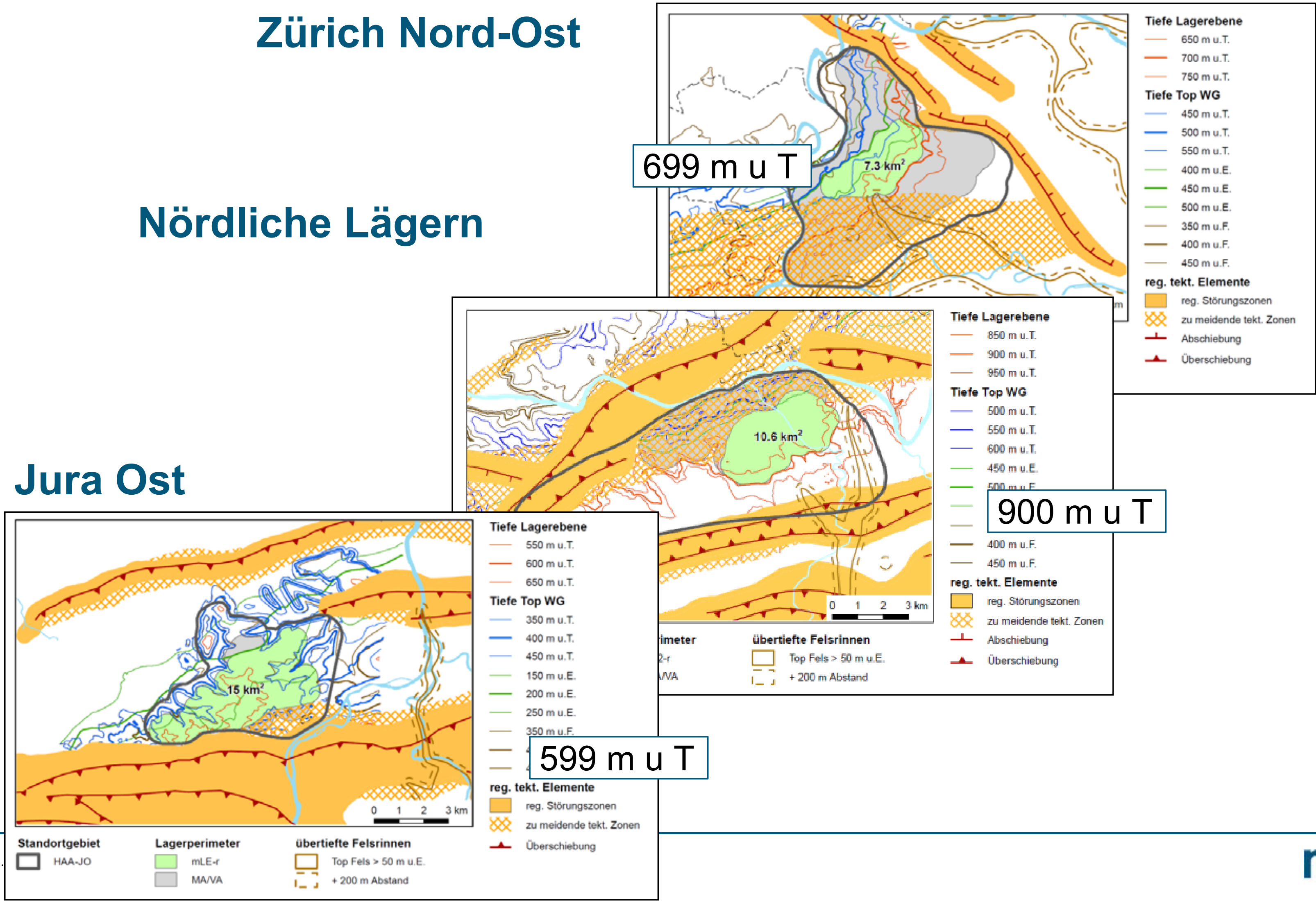
- Quarternary deposits: compilation and analysis of exitisting data; process studies; modelling work;
  →landscape evolution scenarios
  →process understanding (e.g. drainage evolution, ice flow, subglacial hydrology)

Site Selection Stage 2: decision by the Federal Government (Nov 2018)

Zürich Nord-Ost

Nördliche Lägern

Jura Ost



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Contents

- Nuclear Power in Switzerland: phasing out after 60 years
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  - Stage two: narrowing down to 2+ per waste category (2012-2018)
    - Barrier function, explorability, rock strength, long-term evolution
  - Stage three: exploration and decision (2019 – 2031?)
    - 3D-seismics
    - Quarternary investigation program
    - Drilling strategy

Site Selection Stage 3: Selection of the final site(s)

- 3D-seismics (2015-2017)
  - for structure
  - neighboring elements included
  - completed (no permitting problems)
  - Processing and interpretation
- Quarternary deposits (2017 – 2019)
  - for geological long-term evolution scenarios
  - 2D-seismics completed
  - Drilling for dating, sediment fill, depth determination
- Deep drillings (2019-2021)
  - for geological barrier properties
  - encircling most promising areas
  - 3-5 cored boreholes per site **to apply for general license for one site (2024)**

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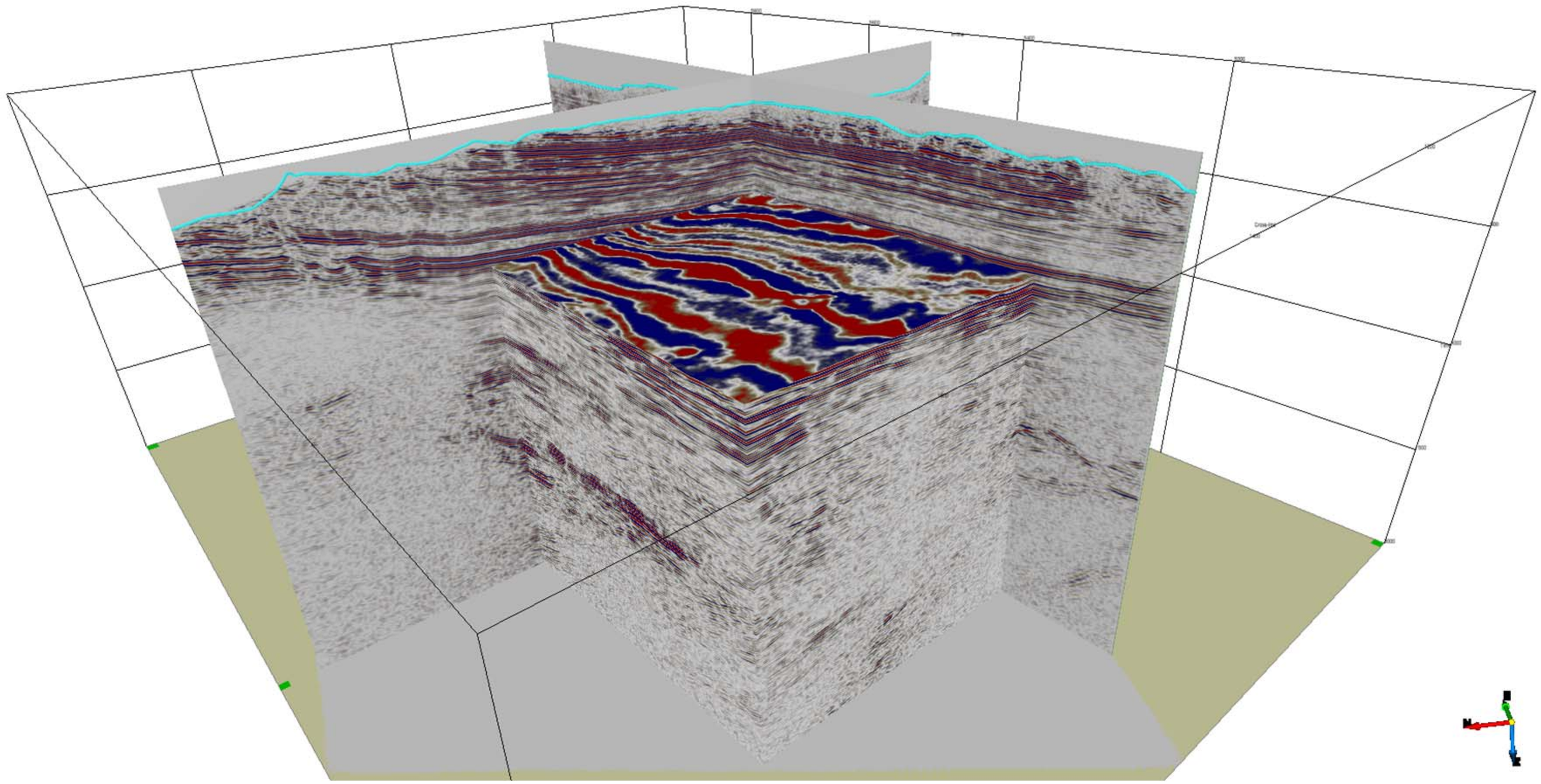
Example result 3D seismics: data volume Jura Ost



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Deep boreholes – drilling started in April 2019

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Additional material

- Swiss site selection process for the geological disposal facilities
- Where/how do current URL activities contribute to the next safety case

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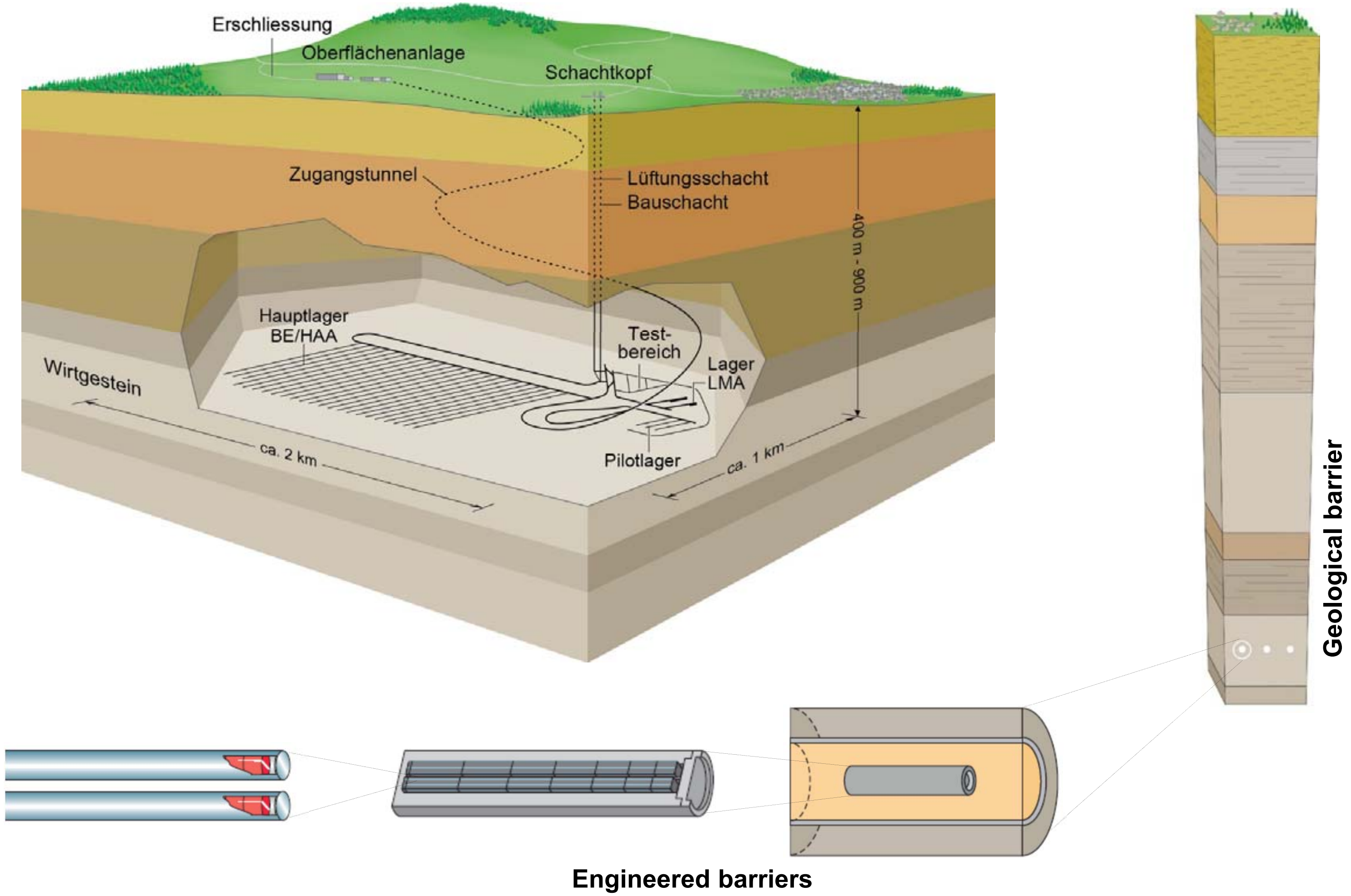
Where/how do current URL activities contribute to the next safety case



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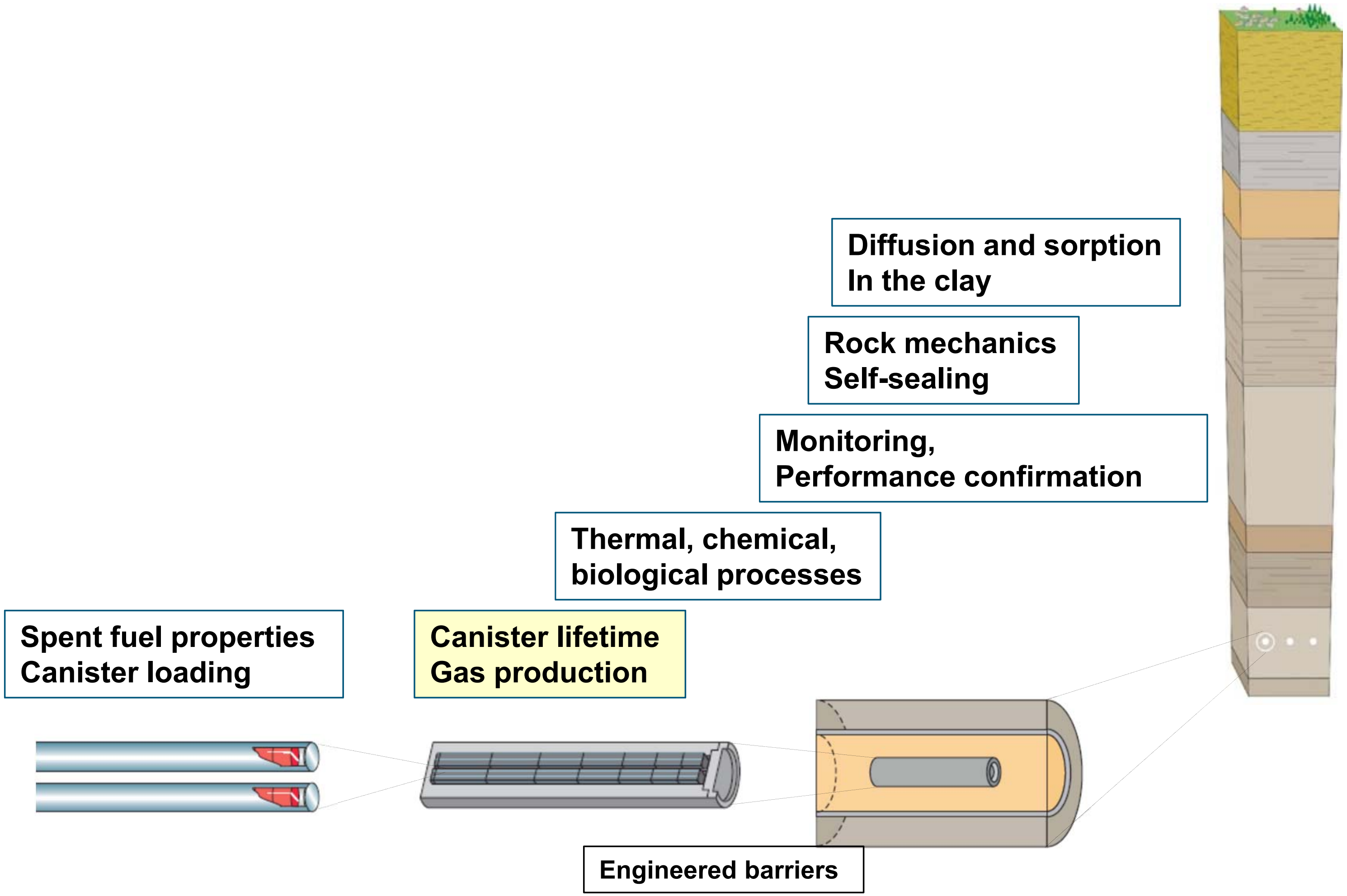
Where/how do current URL activities contribute to the next safety case



Material Corrosion Test (MACOTE)

Reliable corrosion rate data needed to support canister lifetime predictions

Aims:

- Provide in-situ experimental evidence of steel and copper corrosion under **anoxic** conditions
- Provide evidence of corrosion products and material interactions (copper-bentonite, steel-bentonite)
- Explore the influence of the hydrochemical and microbial environment

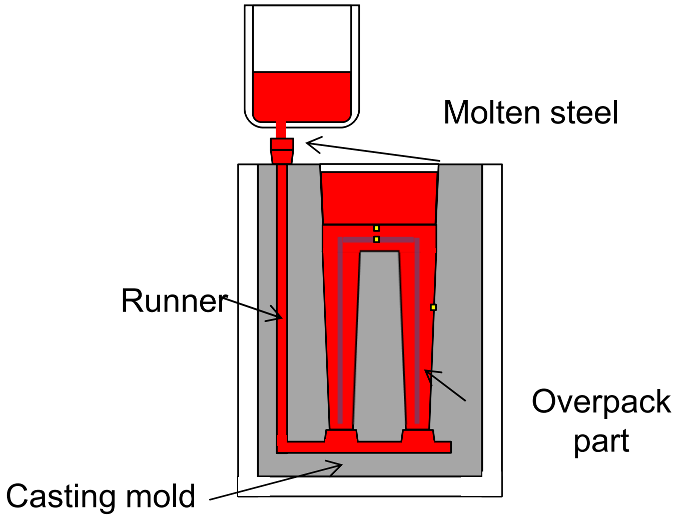
<u>Preliminary</u> results from 1 year modules:

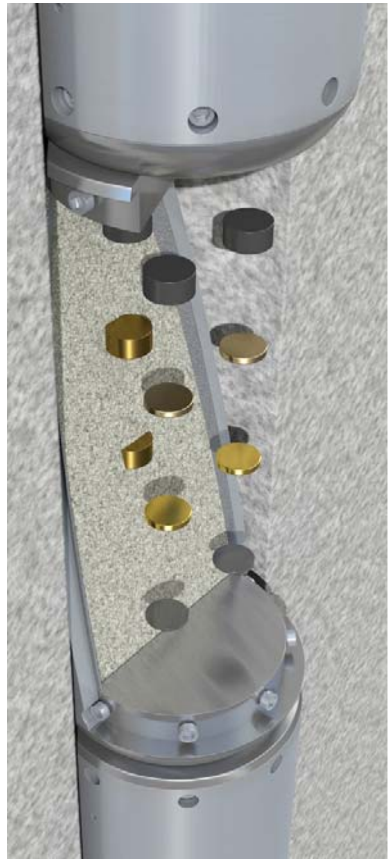
- Steel (carbon and stainless) - Fe_2O_3, Fe_3O_4, FeOOH
- Wrought Copper - CuO, Cu_2O
- Copper (cold sprayed and electrodeposited) – CuO, Cu_2O

Metals being tested:

Carbon steel & copper coatings

Cast steel manufactured by Kobe Steel





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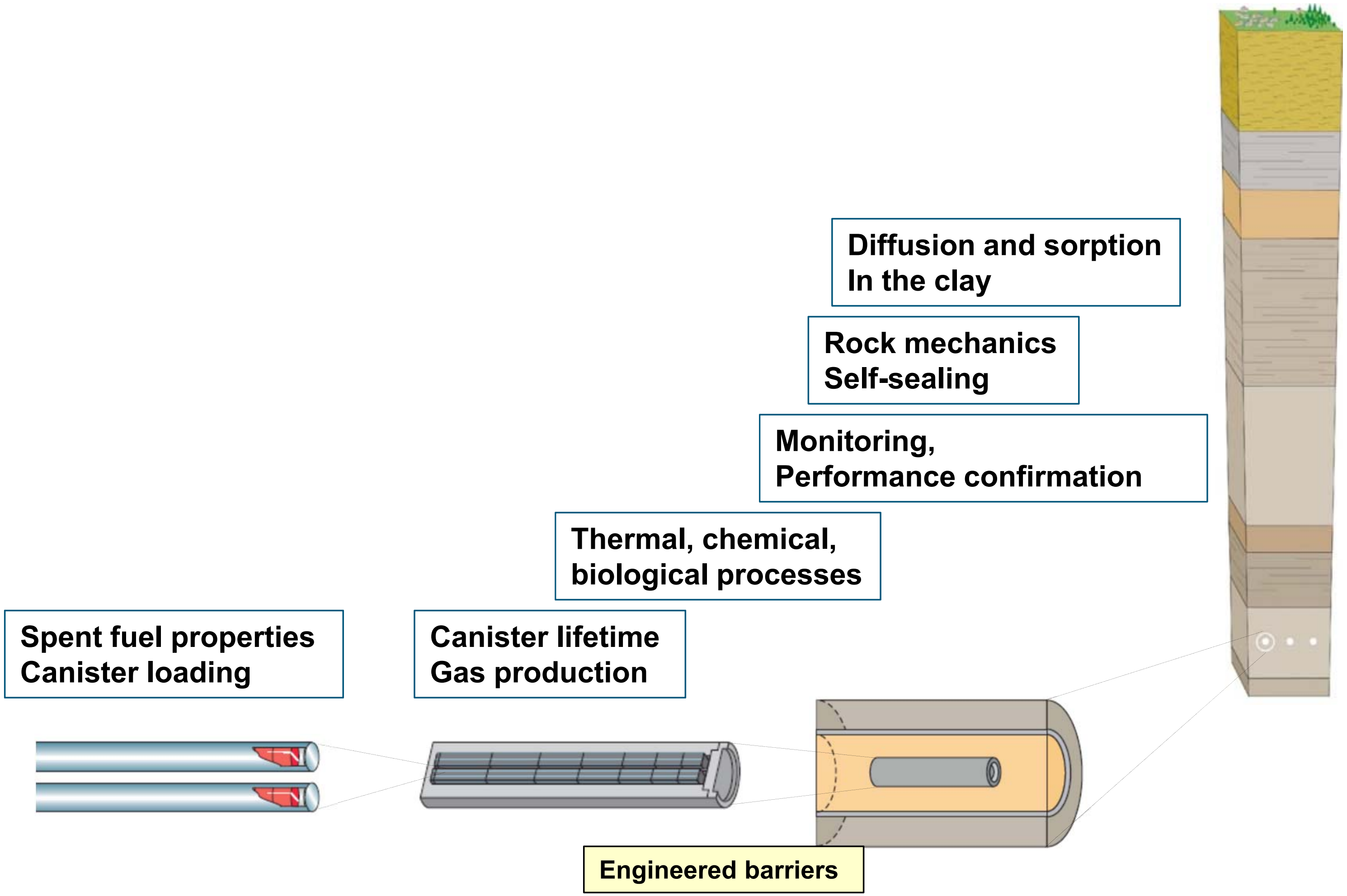

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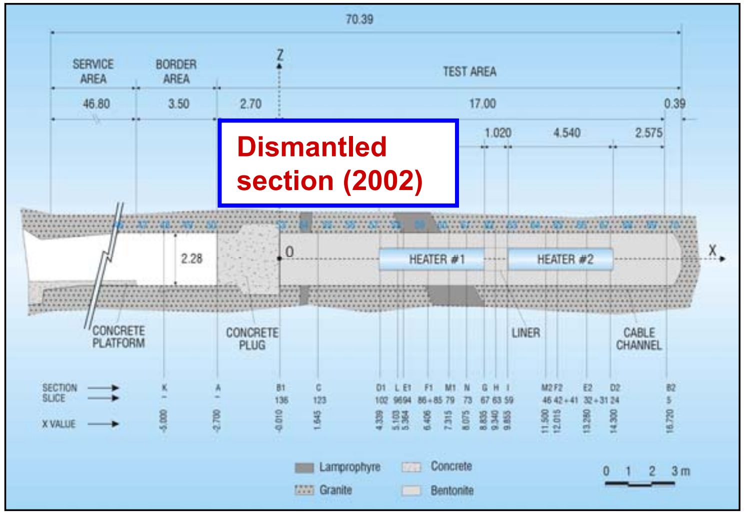
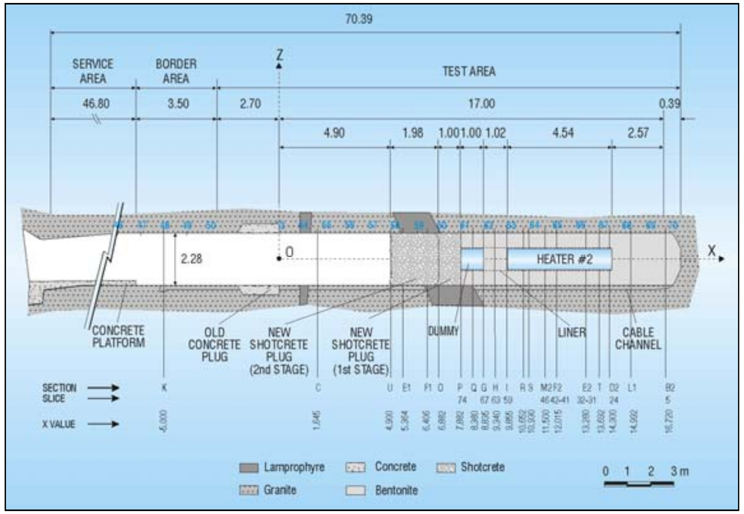
FEBEX at GTS: Bentonite buffer 18 years @ 100 ^{o}C (1997 – 2015)

- Dismantling in 2015
- 11 partners
- Results and analysis in 18 reports, various papers
- Synthesis report 2019





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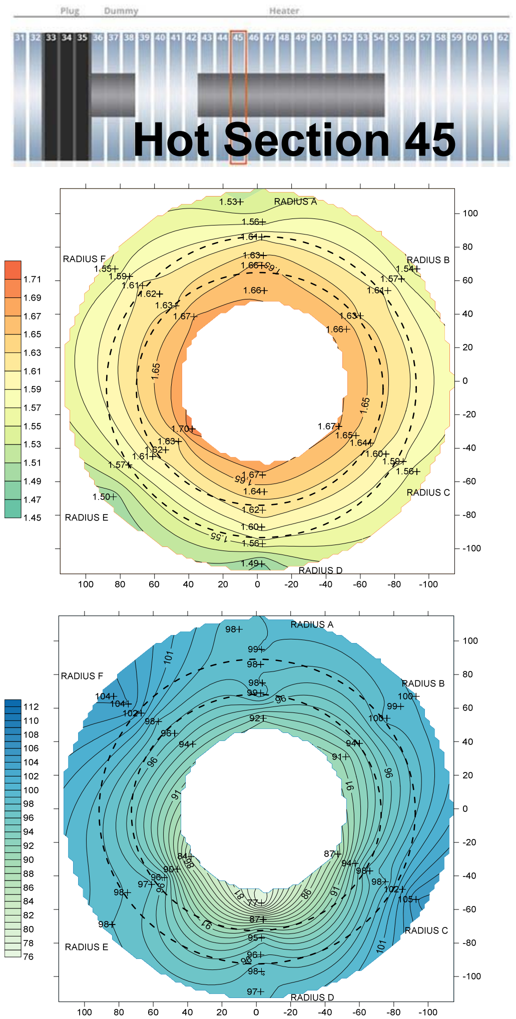
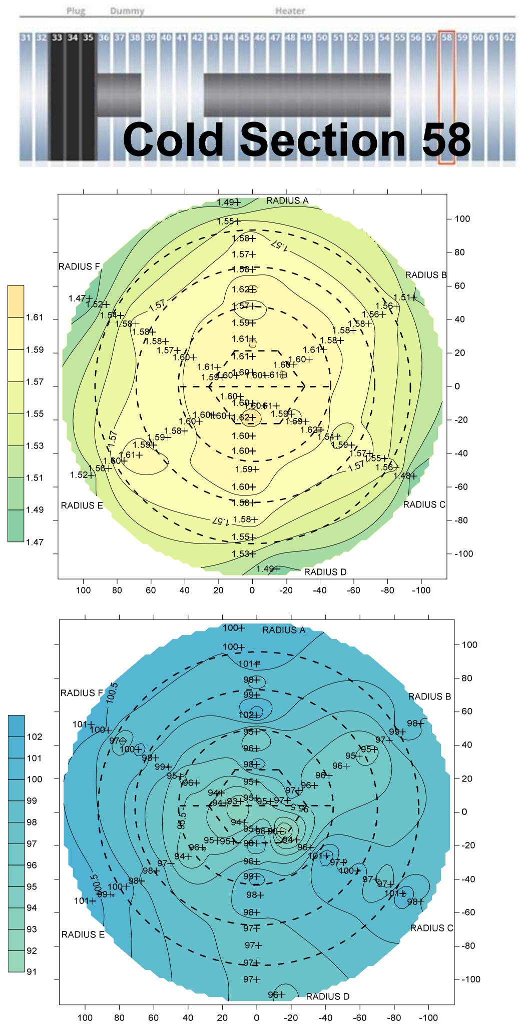
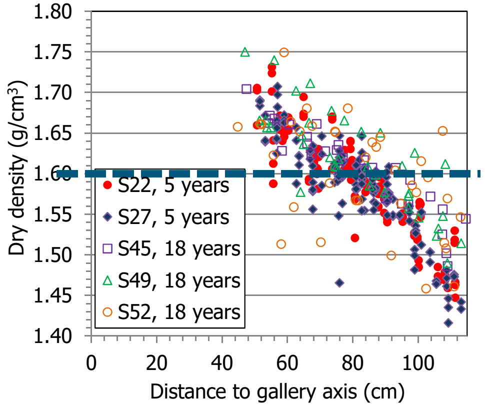
Buffer at Dismantling - Onsite Analysis - Dry Density & Saturation

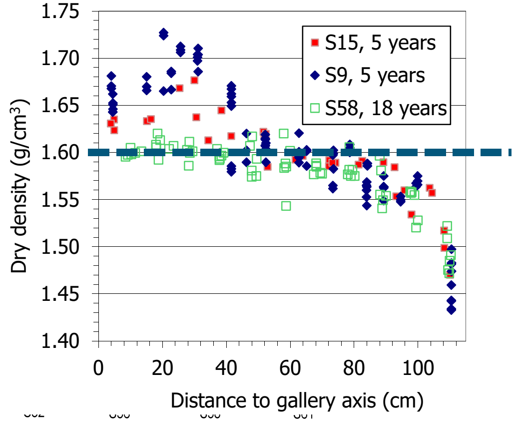


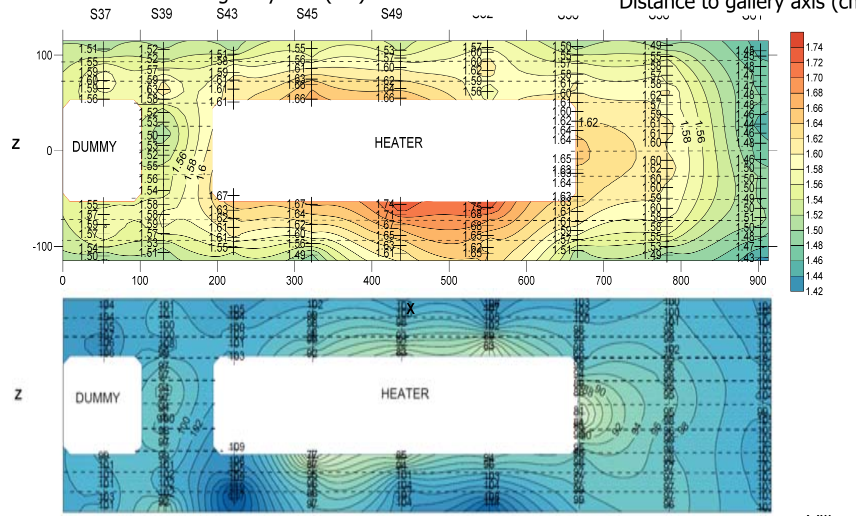


Hot Sections 2002/2015



Cold Sections 2002/2015





Villar et al. 2016

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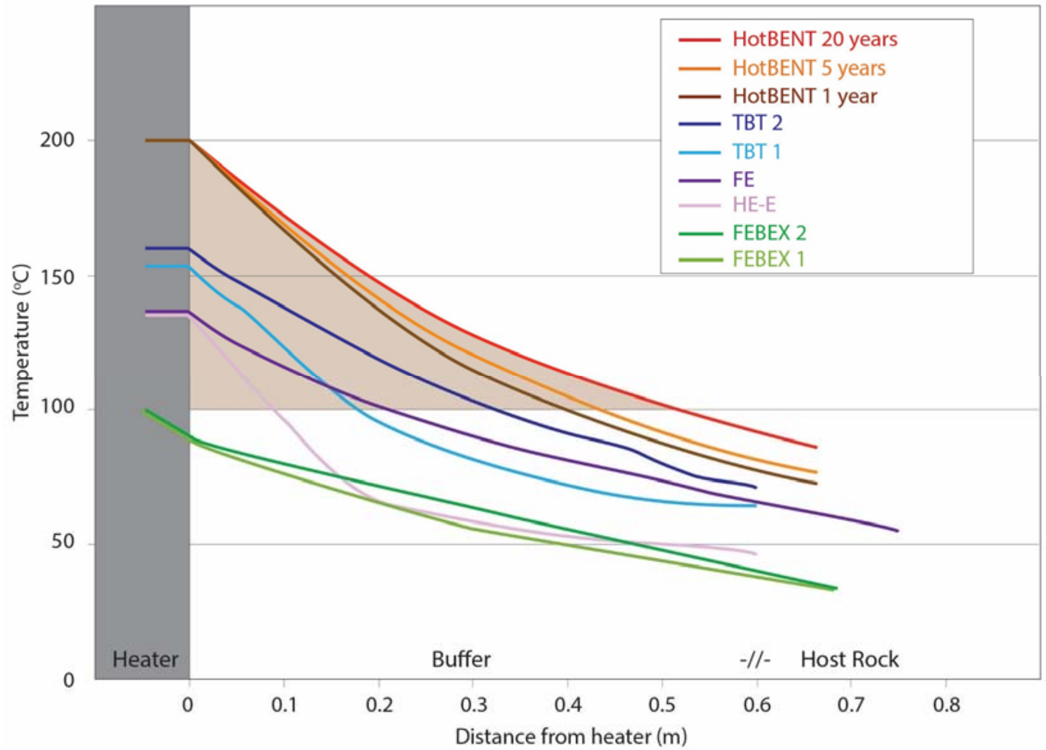
Next step: Exploring optimisation - HotBENT Experiment at the GTS

Options of repository optimisation with respect to design, space, emplacement strategies and costs

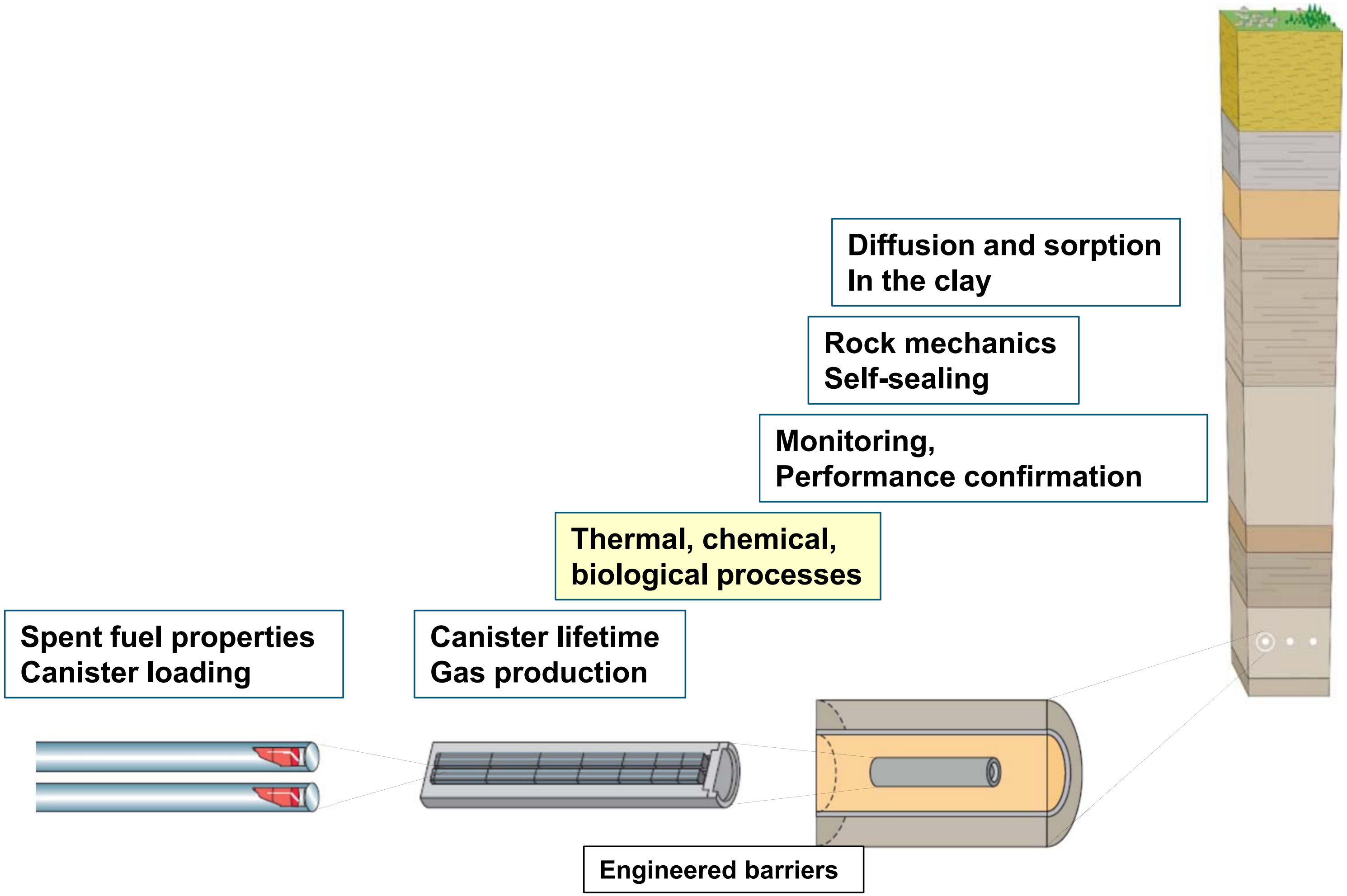
- Increase data base on buffer/host-rock performance under higher T conditions (up to 200°C) and at **realistic scales**
- Upscaling/changing of boundary conditions of bentonite bufffers of lab and modelling knowledge to large, 1:1 scales with its inherited and commonly observed gradients

Bentonite volume above 100 °C

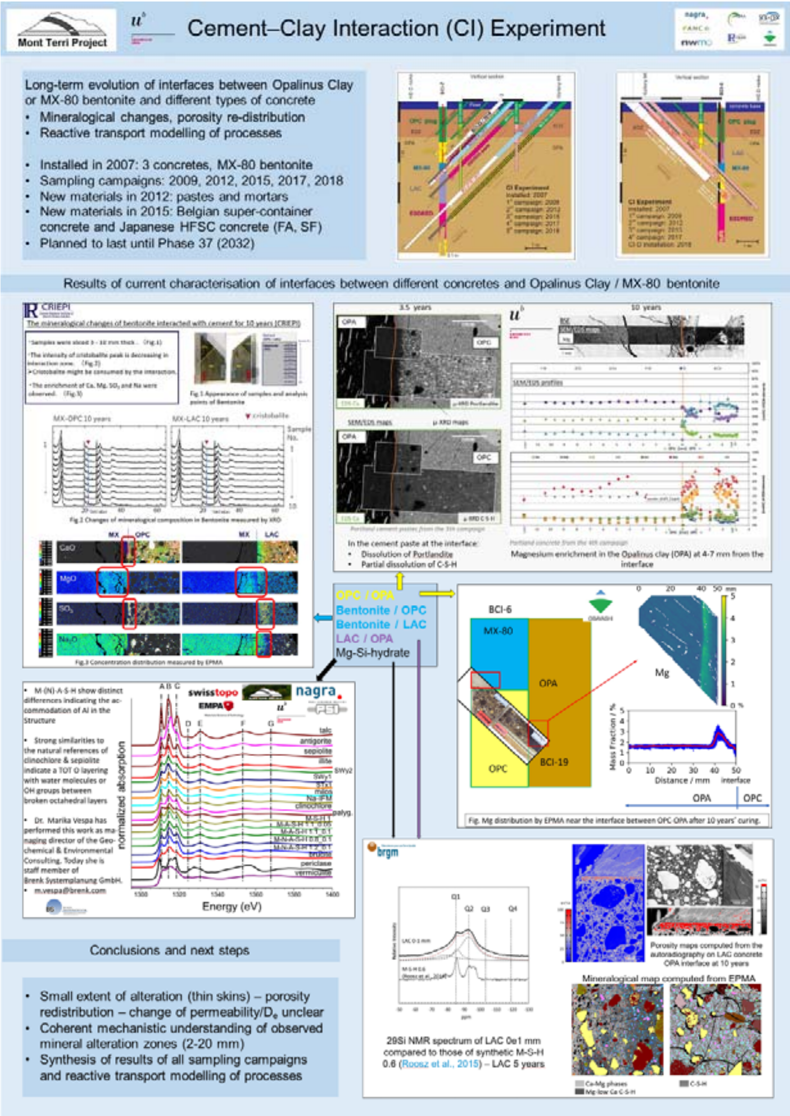
- Experiments to date (measurements)
- HotBENT model results



Where/how do current URL activities contribute to the next safety case



Two examples in the poster session

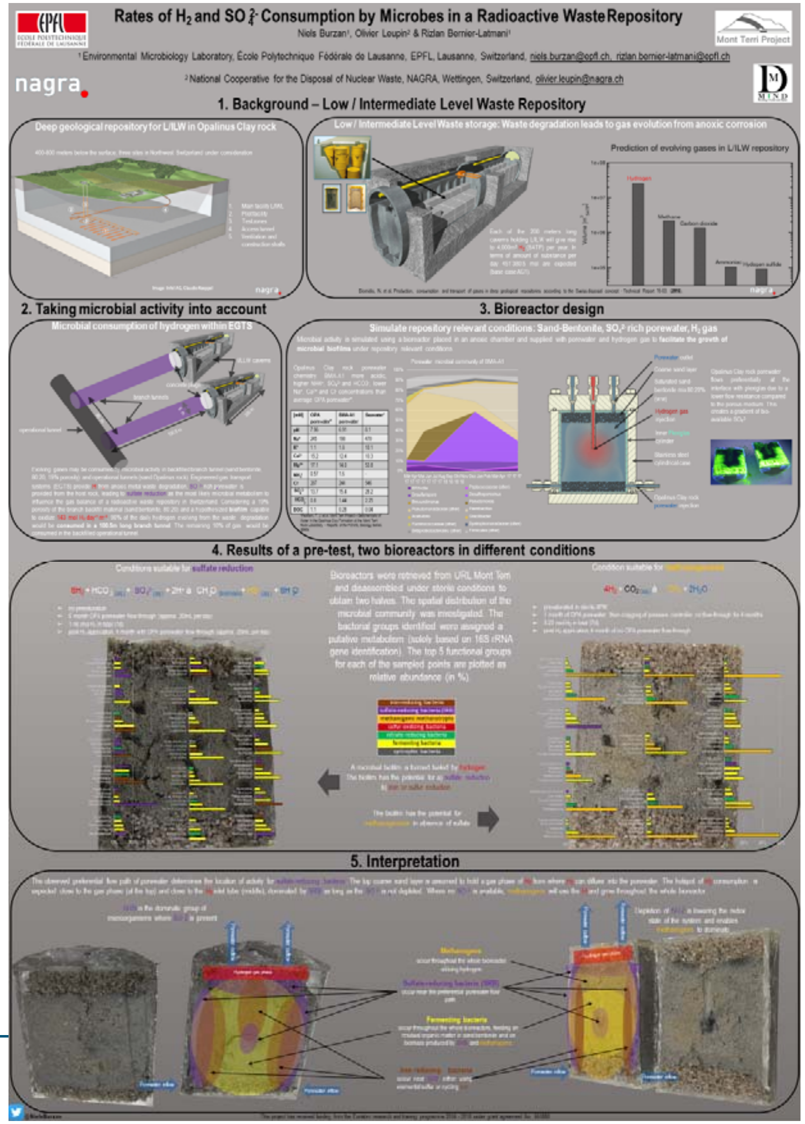


Mont Terri URL

Cement-clay interfaces → affecting potentially flow regime in the repository

Mont Terri URL

Optimisation: biologically induced H2 consumption in sand-bentonite



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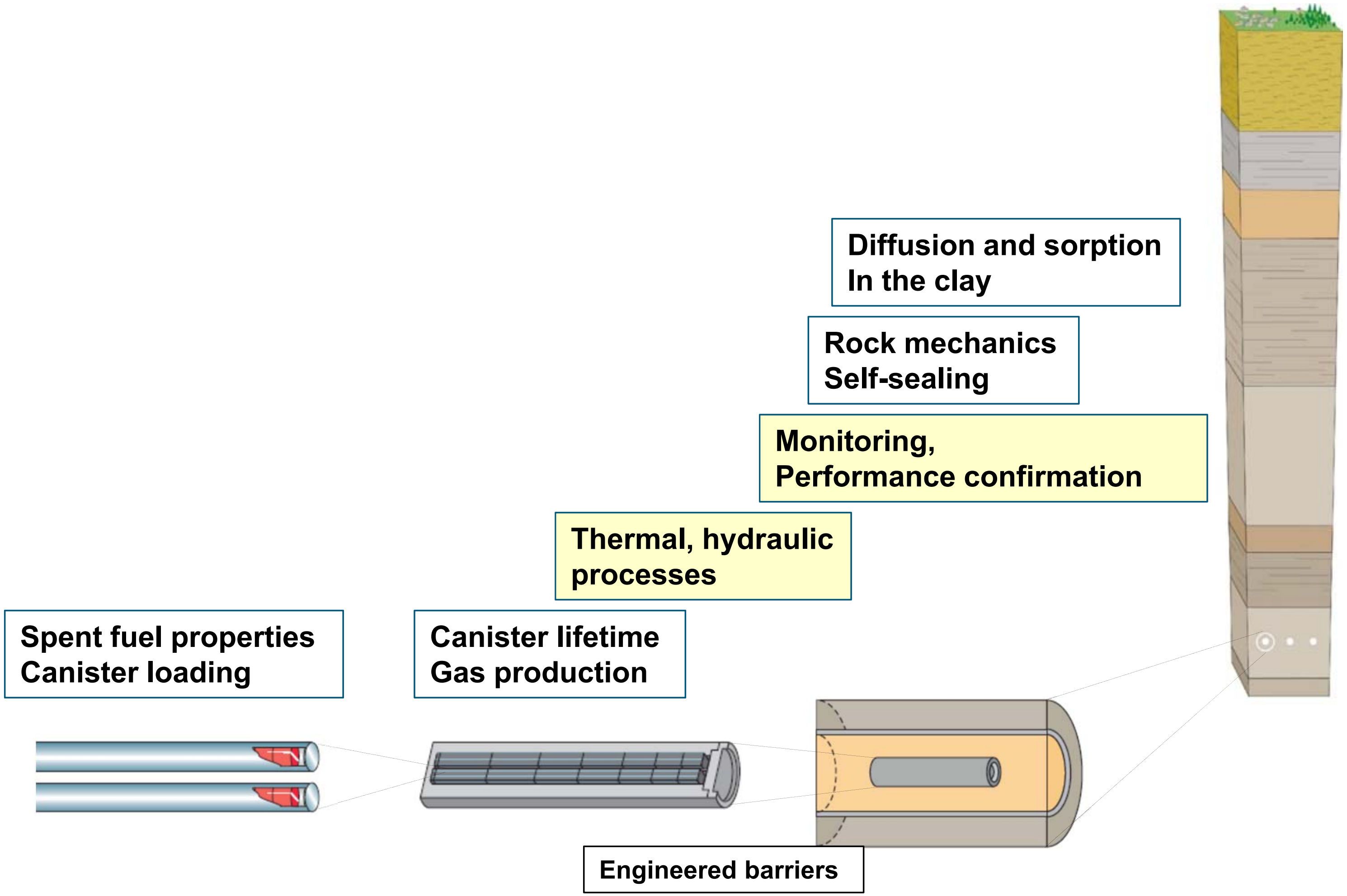
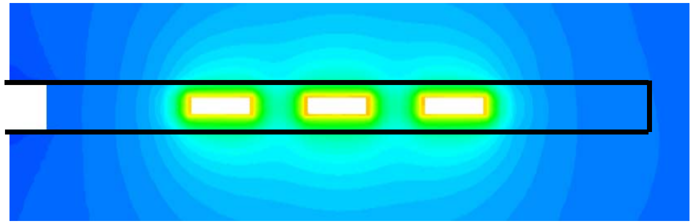
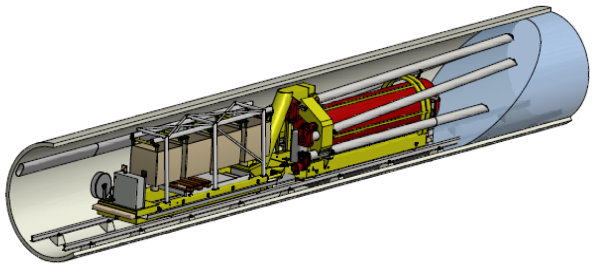


Mont Terri URL: FE – Full Scale Emplacement Experiment

- **Objectives**
  - Demonstration of buffer emplacement technology and buffer requirements for the license application (2024)
  - Confidence building in early time thermo-hydro mechanical evolution of the HLW disposal system requires full-scale and long-term validation experiments (long observation times in Opalinus Clay in the order of 10s of years needed due to low hydraulic and thermal diffusivities)





- In the current Nagra planning less than 15 years are foreseen for the operation of the on site rock laboratory

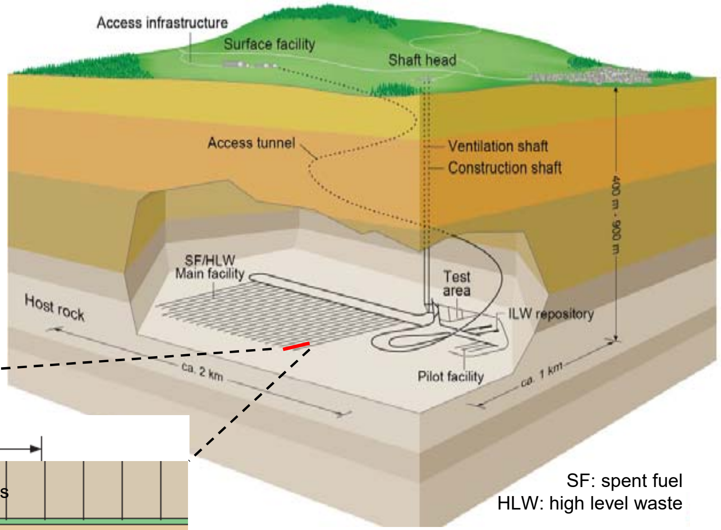
- 1:1 Experiment to be initiated in an off-site laboratory (Mont Terri URL) as a basis for further licensing steps and public acceptance.

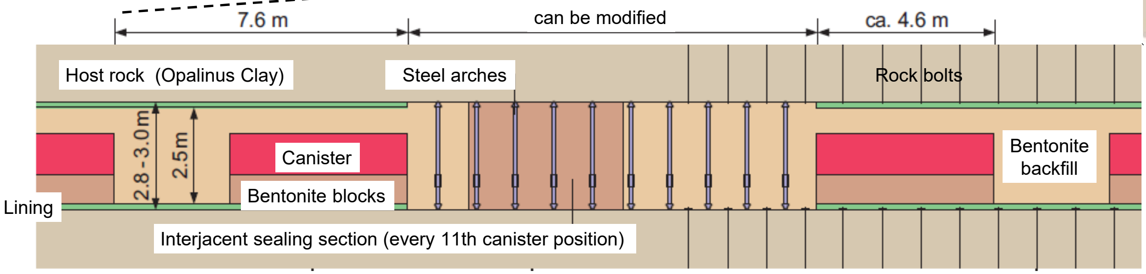
LUCOEX

Mont Terri Project

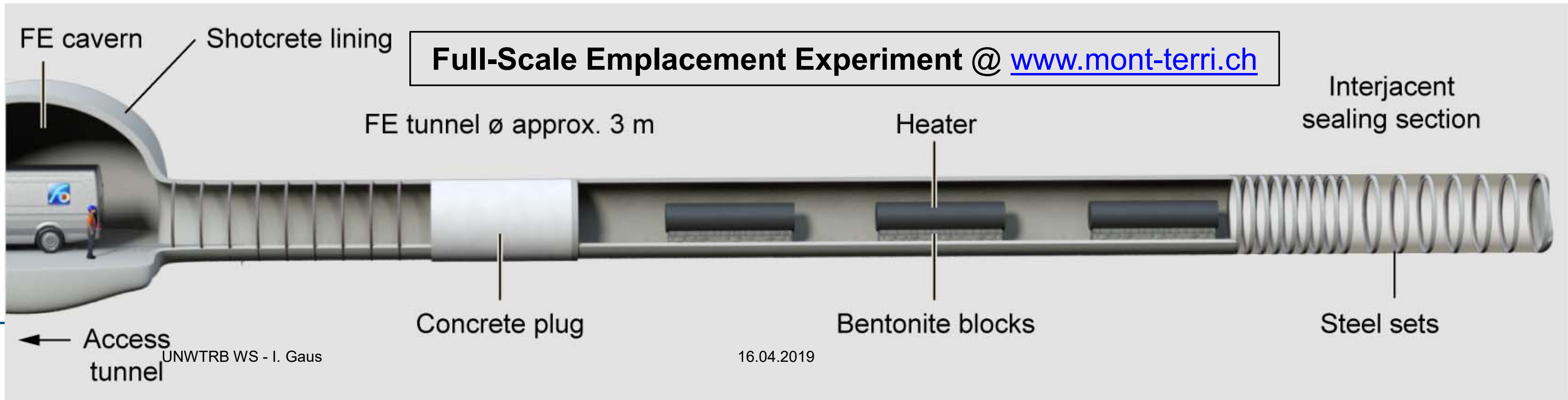
FE-experiment: from repository concept to the experimental layout

Host rock:
Opalinus Clay
over-consolidated
clay stone sedimented approx. 175 Ma ago



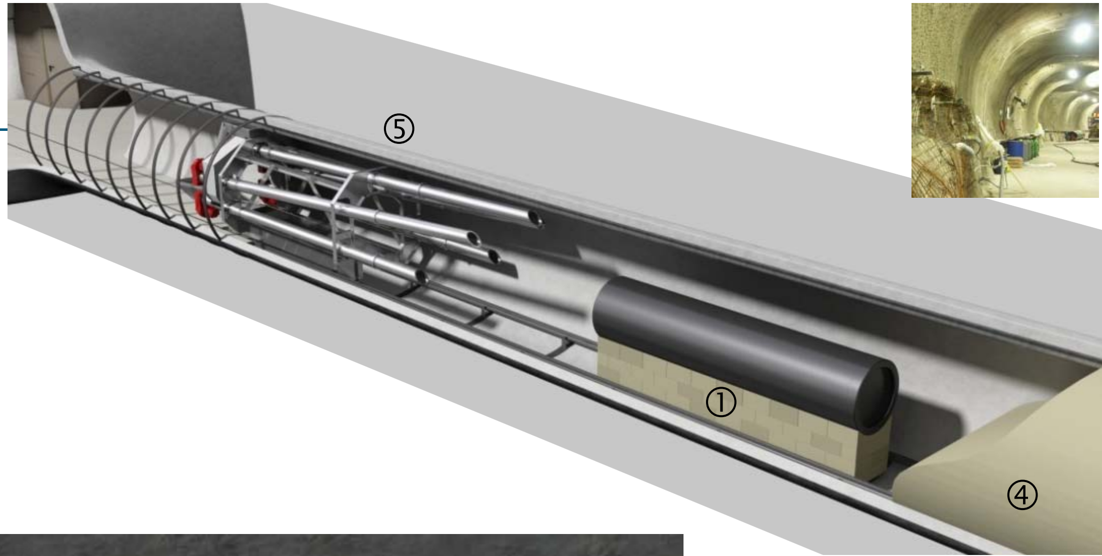


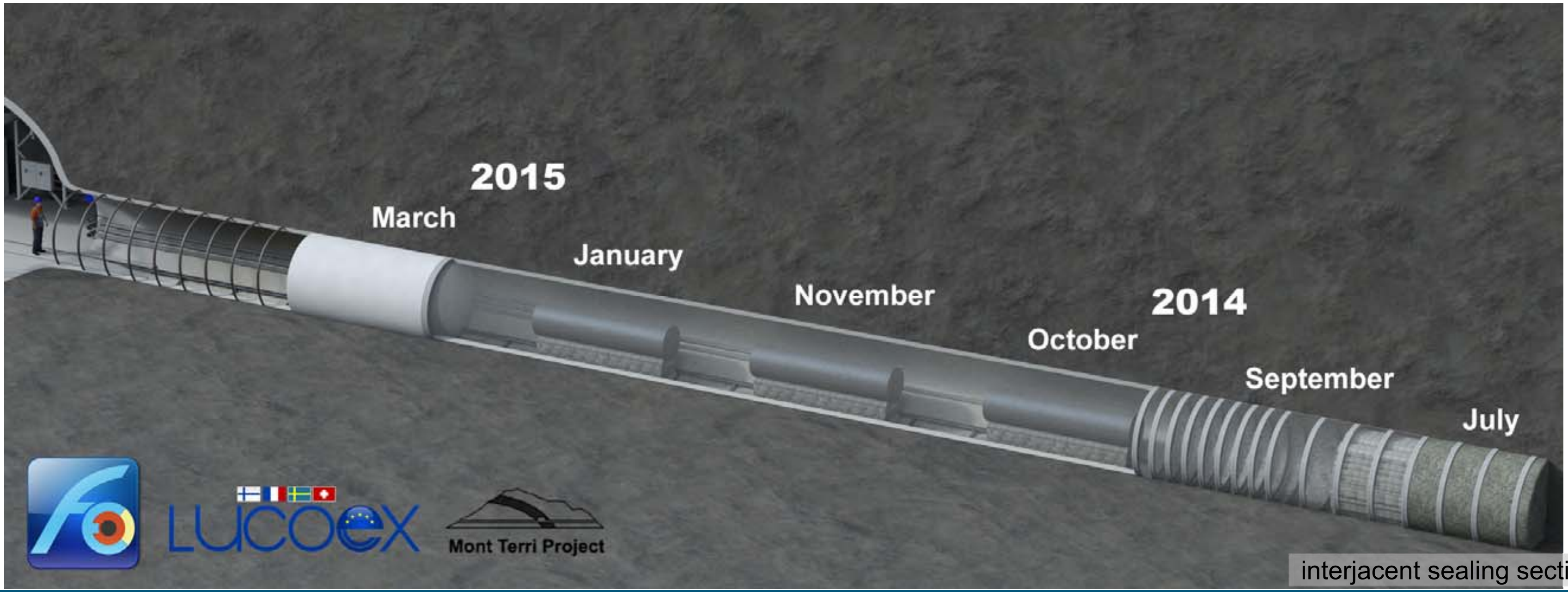
Longitudinal section of a **SF/HLW repository tunnel** according to the Swiss concept (cf. NTB10-01)



FE-experiment: Overview

① bentonite block production
② emplacement in ISS
③ emplacement of pedestals & heaters
④ granulated bentonite material production
⑤ prototype backfilling machine development
⑥ full-scale pre- / mock-up tests
⑦ backfilling shotcrete section & heaters
⑧ construction of plug (finished 17th of March)

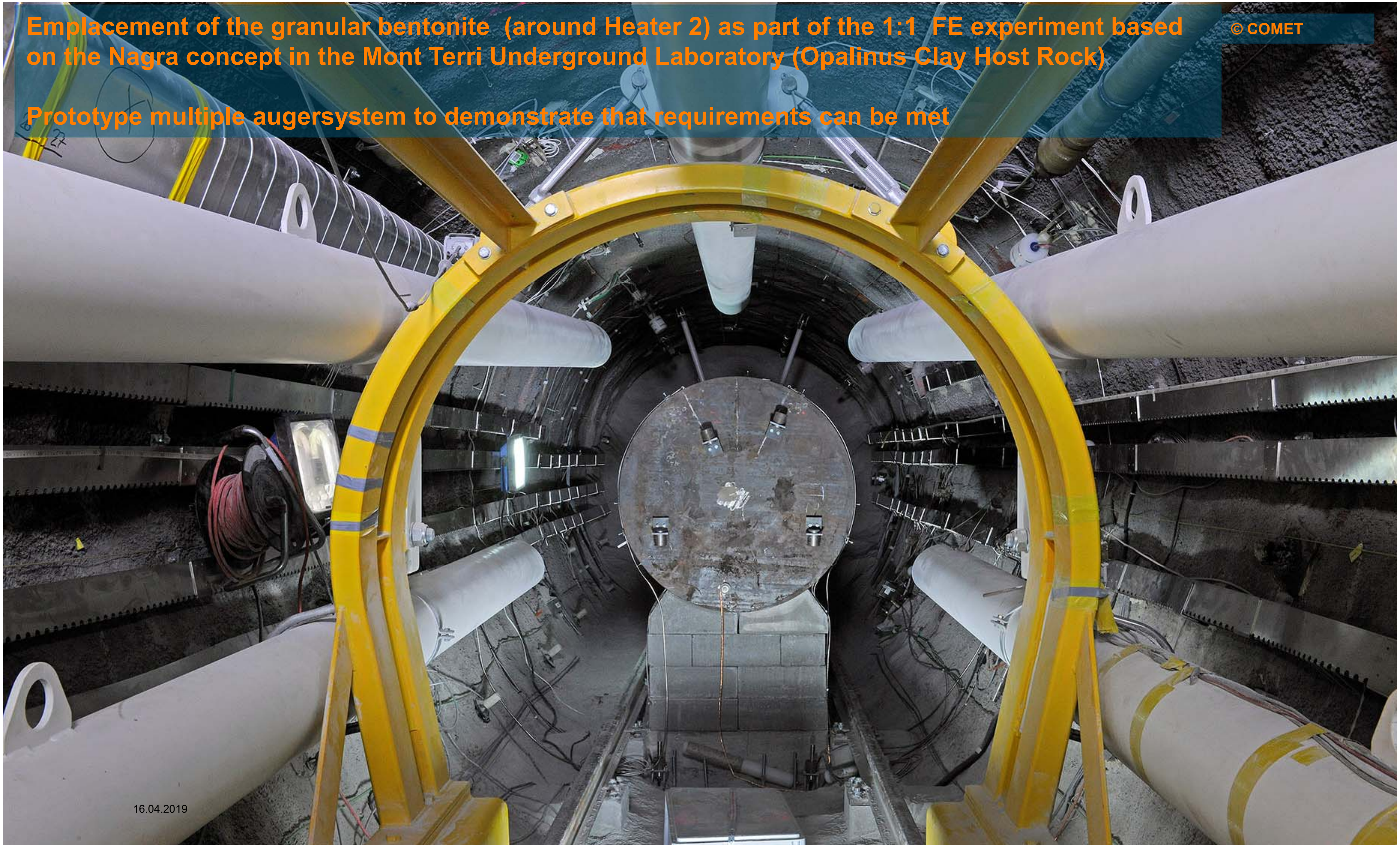




interjacent sealing section (ISS)

Emplacement of the granular bentonite (around Heater 2) as part of the 1:1 FE experiment based on the Nagra concept in the Mont Terri Underground Laboratory (Opalinus Clay Host Rock)

Prototype multiple augersystem to demonstrate that requirements can be met



FE-experiment: Monitoring and System behaviour

- **Expected:** the observed THM behaviour the system evolves as foreseen → hydraulic overpressures limited so far
- **Surprise:** almost immediate oxygen consumption in the bentonite
  - *See separate poster on FE-G experiment (Giroud et al., 2019)*

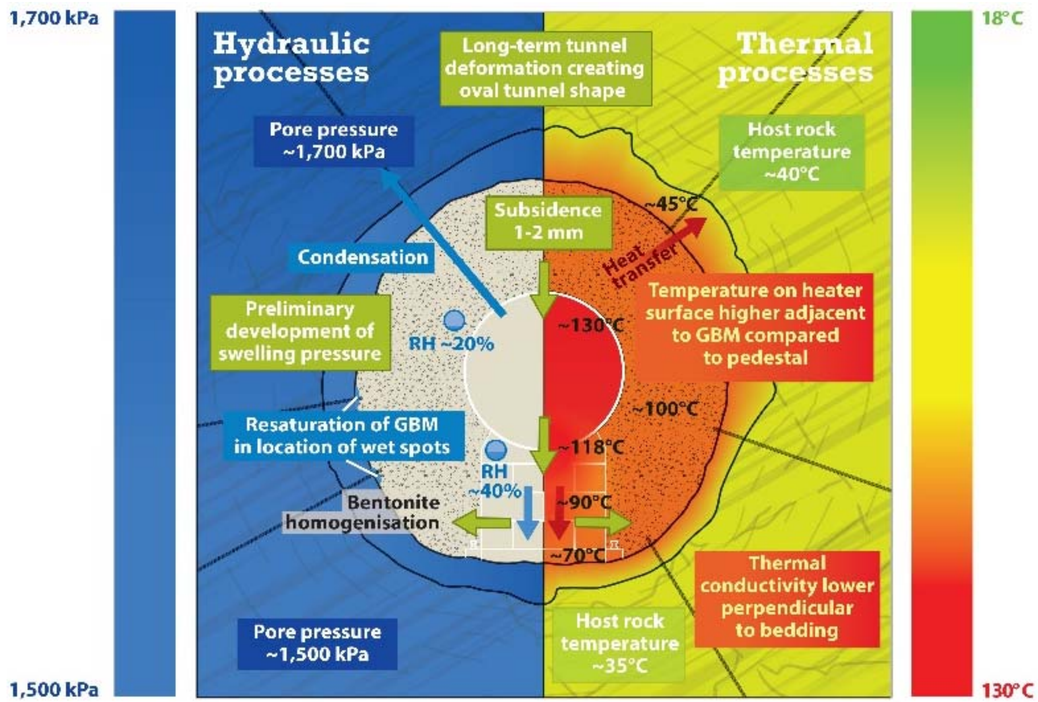
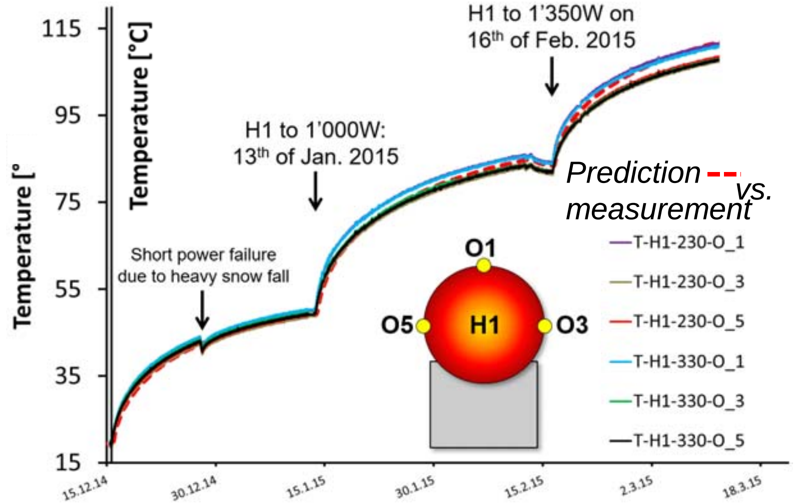
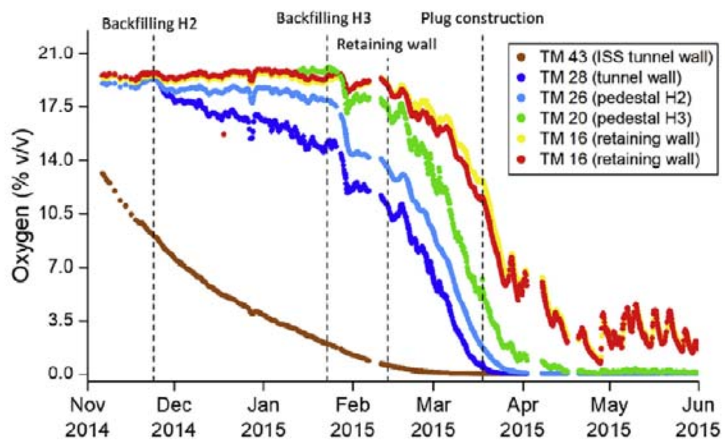


Illustration of the THM processes in the FE Experiment during heating





Gas monitoring in backfilled tunnel

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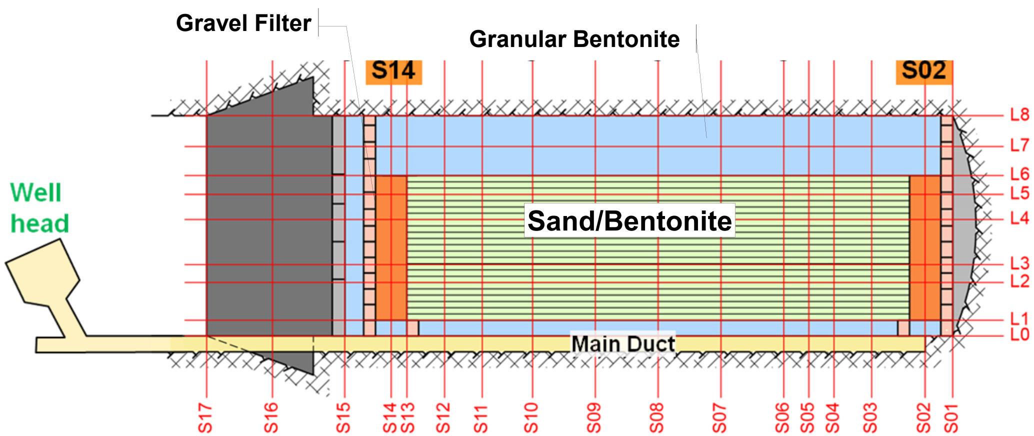
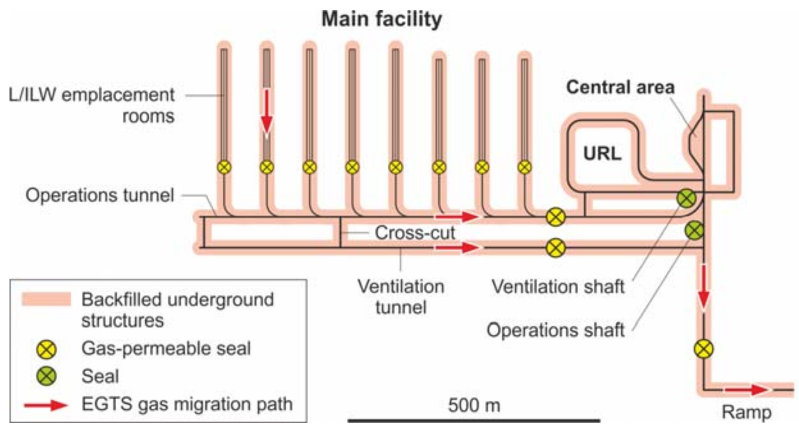
GTS: Performance testing of «Gas Permeable Seals» at the 1:1 scale

Objectives of the GAST

- Demonstrate the effective functioning of gas permeable seals
- Validate and improve current conceptual flow models for sand / bentonite
- Determine up-scaled water and gas permeabilities of sand / bentonite





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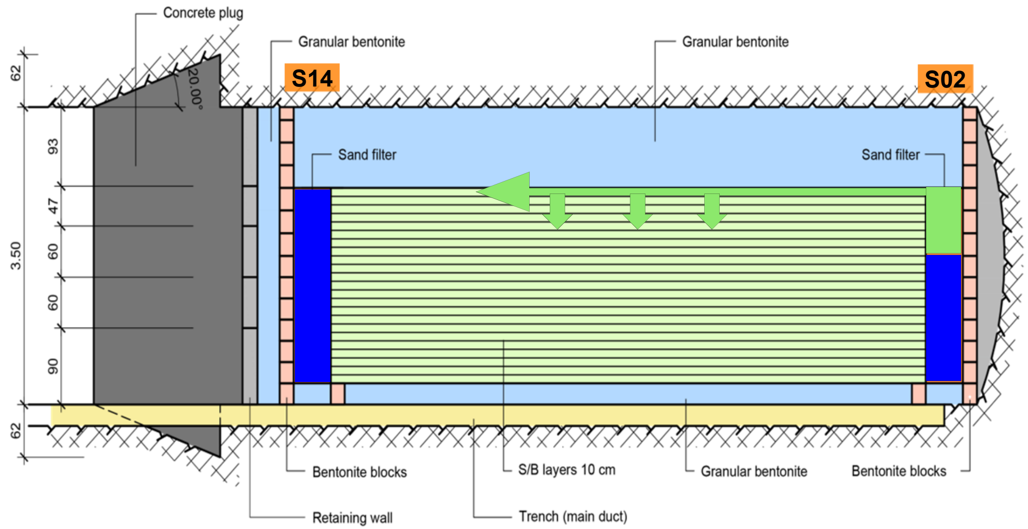
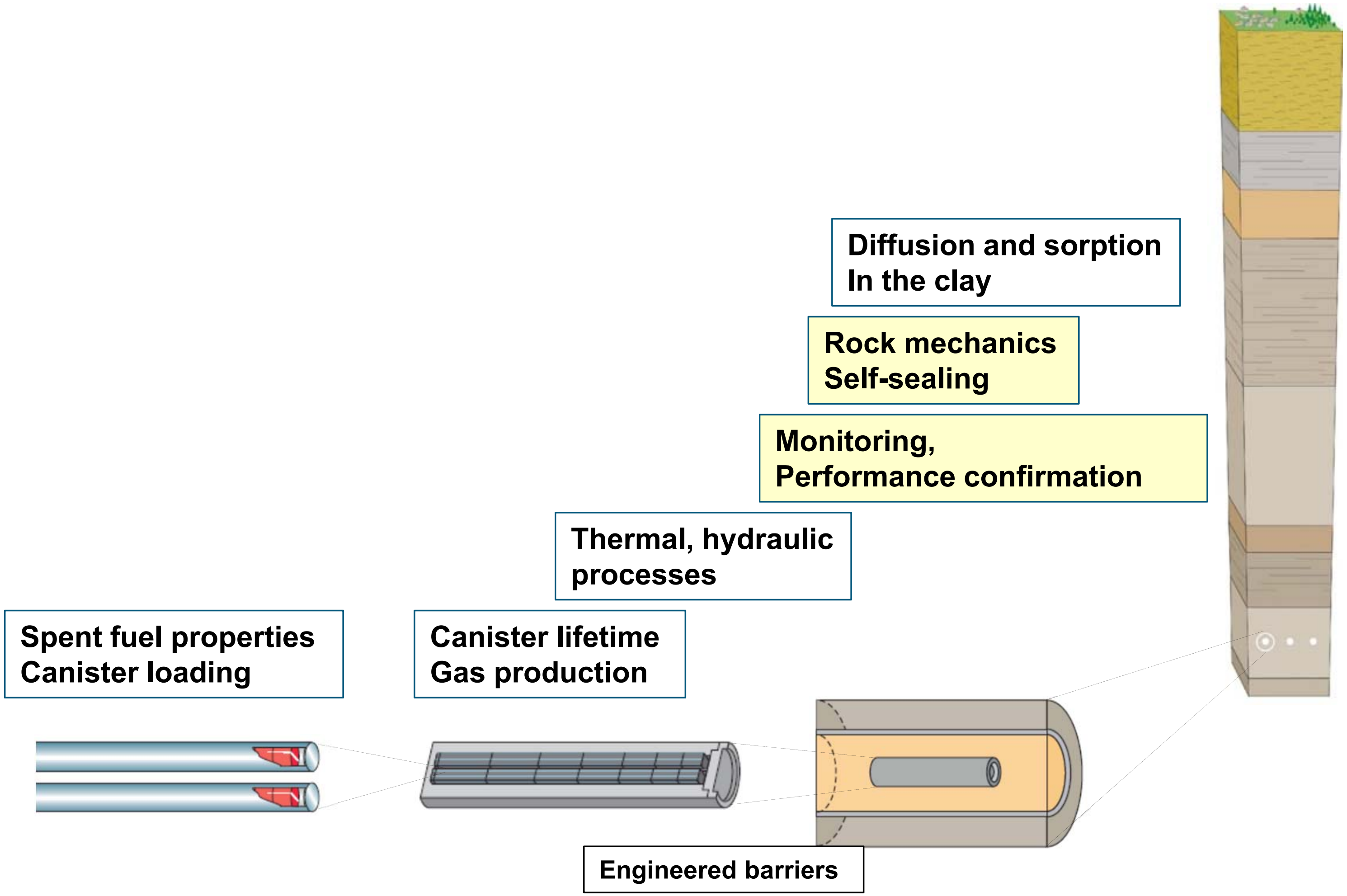
GTS GAST experiment - current status

- **GPT1** - Gas threshold pressure test series 1: performed in 2018
- **Gas entered sand/bentonite** and developed a flowpath in the **upper layers** of sand/bentonite
  - Highly heterogeneous flowpath
  - Low pressure zone in upper centre of sand/bentonite due to ongoing saturation of headspace
  - No indication of any changes in granular bentonite



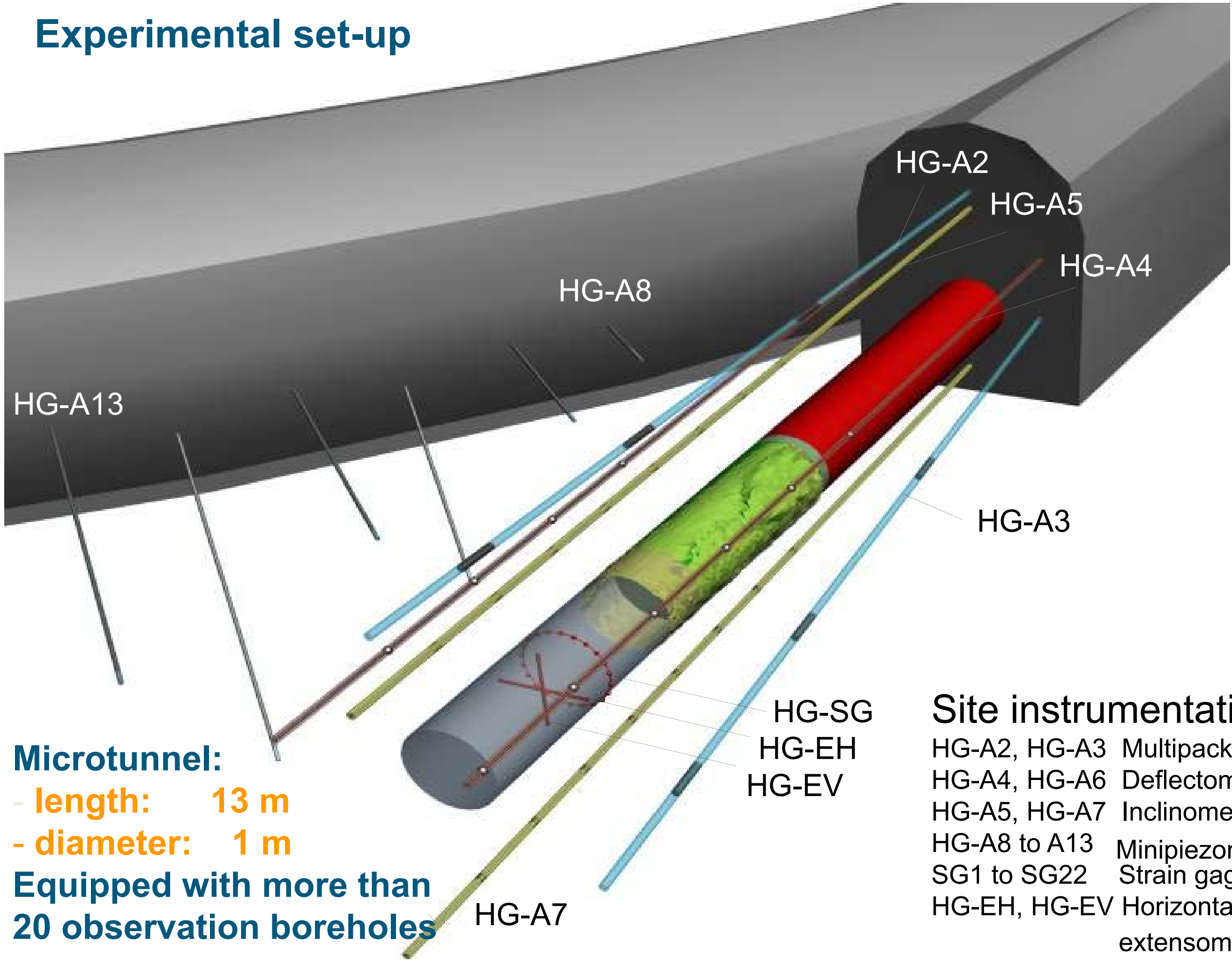
- Analysis ongoing:
  Gas entry pressure <300 kPA (expected range)
- Next steps:
  - Continue saturation at approximately 2 MPa at both filters
  - GPT2/and next series of gas breakthrough tests expected in approximately 2 years

Where/how do current URL activities contribute to the next safety case



Mont Terri URL - HG-A – Gas path via EDZ around seal sections

Experimental set-up



Microtunnel:
- **length: 13 m**
- **diameter: 1 m**

Equipped with more than 20 observation boreholes

Site instrumentation:

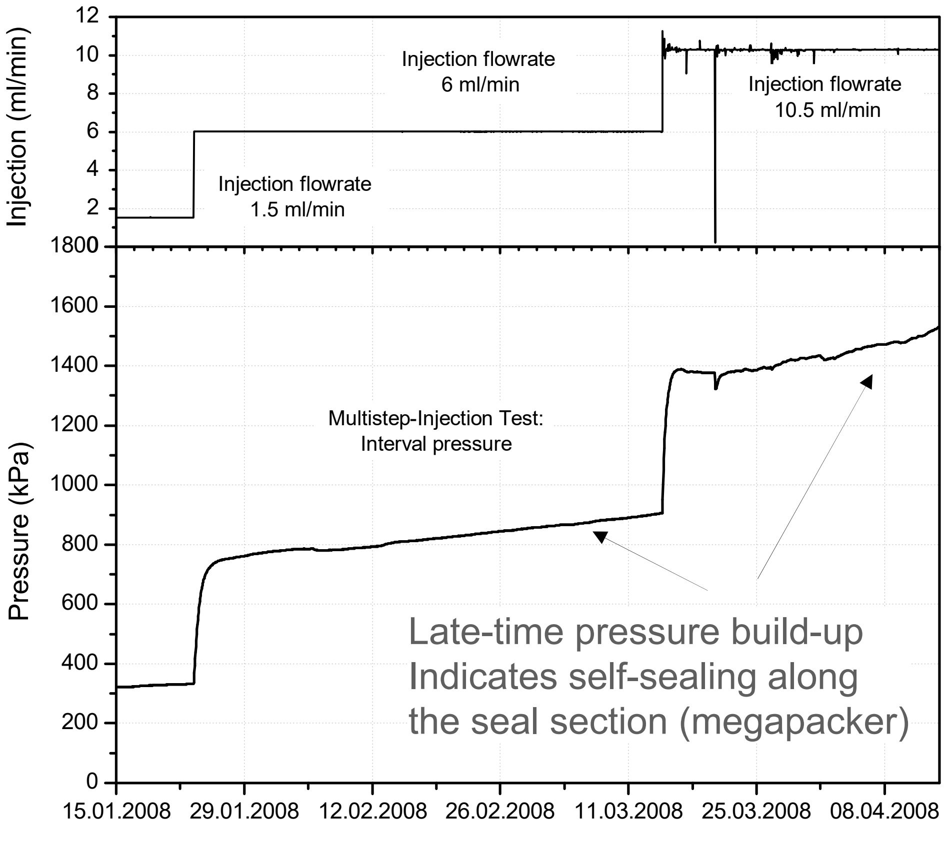
HG-A2, HG-A3 Multipacker systems
HG-A4, HG-A6 Deflectometer chains
HG-A5, HG-A7 Inclinometer chains
HG-A8 to A13 Minipiezometers
SG1 to SG22 Strain gages
HG-EH, HG-EV Horizontal/vertical extensometer

Mont Terri URL - HG-A – Gas path via EDZ around seal sections

The mega packer – sealing the microtunnel

Mont Terri URL - HG-A – Gas path via EDZ around seal sections

▪ Self-sealing: Response to long-term water injection



Self-sealing of EDZ around the packer:

- **Approximately 2 orders of magnitude reduction in permeability within 2 years**

(… yet 1.5 orders of magnitude higher than undisturbed rock)

Detailed repository design and construction → not the priority now

- For the general licence application (2024), the conceptual design is the target

- Feasibility needs to be demonstrated but detailed design and demonstration emplacement and retrieval technology development is required for the construction licence and operational licence (>2040)

- Few URL activities take place now:
  - Continued monitoring and interpretation of ongoing large scale sealing experiments
  - Testing of tunnel reinforcement techniques during the current extension of the Mont Terri URL

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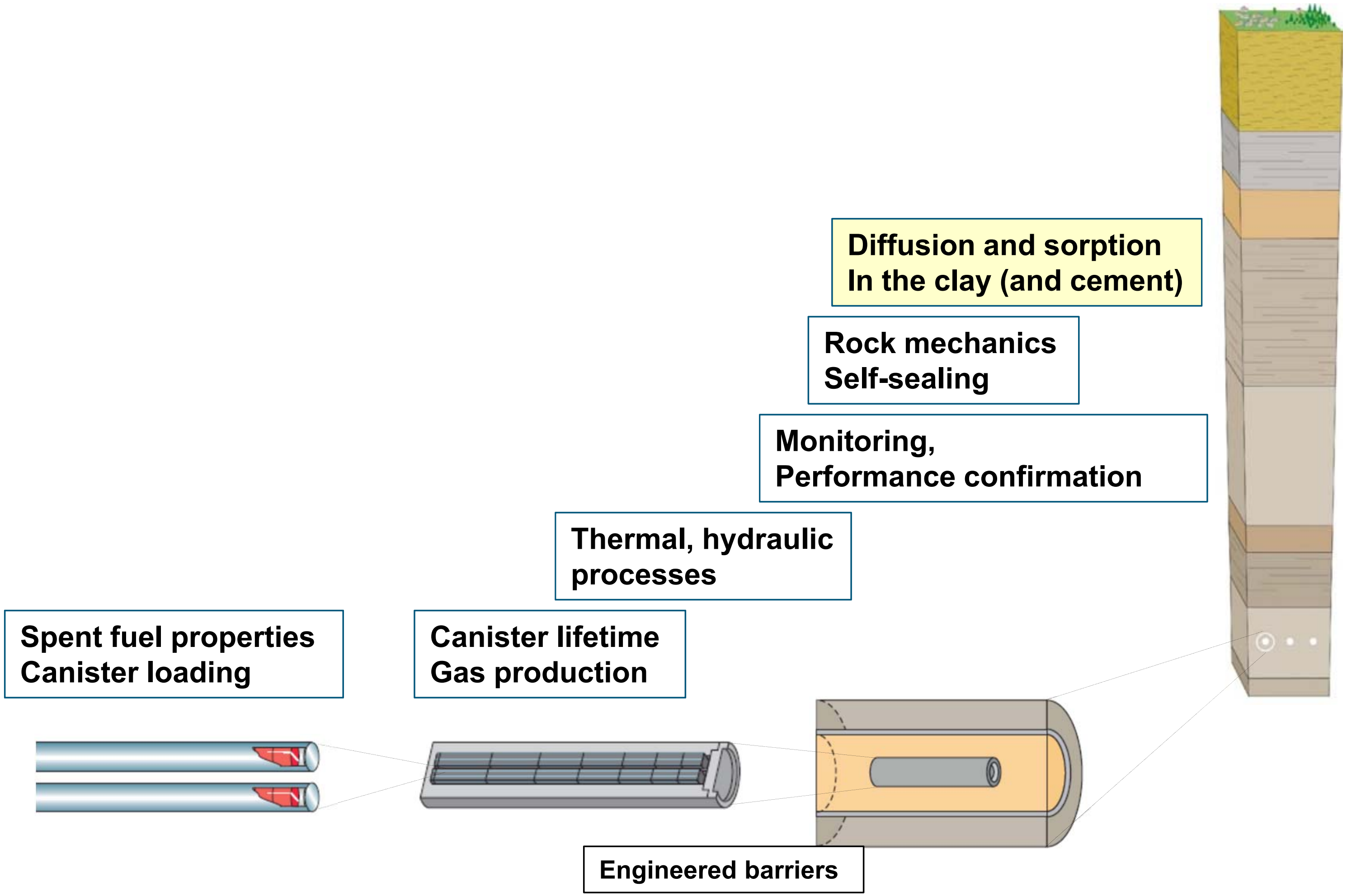
Where/how do current URL activities contribute to the next safety case



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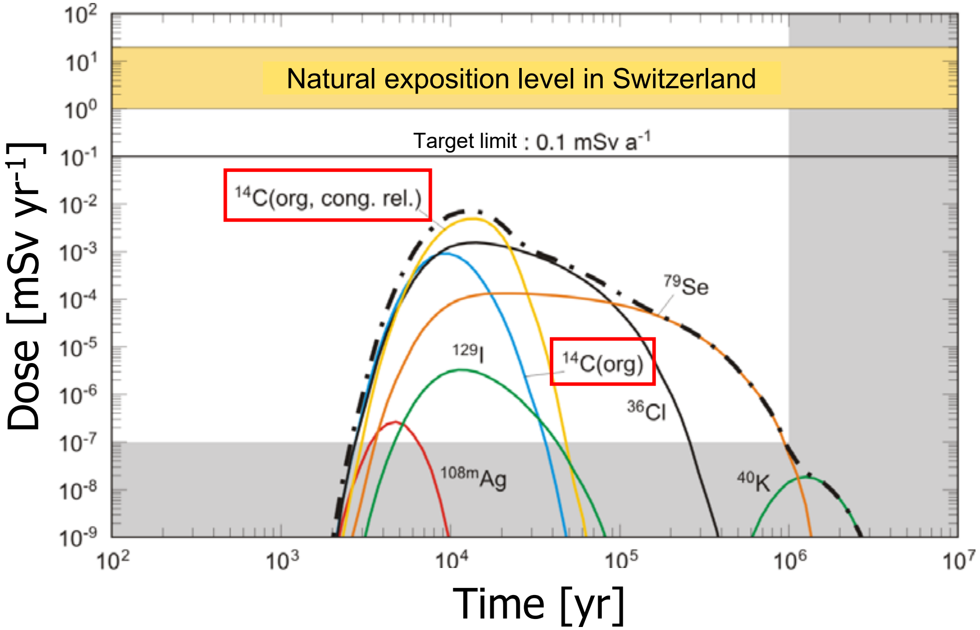
Cement-based barriers - Carbon-14 dose estimations

Among the dose dominating radionuclides in LLW (TRU) PA



Calculated dose from a generic L/ILW near field

- C-14 instant release: → $^{14}C_{inorg}$ ($^{14}CO_3^{2-}$ very low dose contribution)
  → $^{14}C_{org}$ (spent ion exchange resins etc.)
- ^{14}C fractional release (10^{-4} yr^{-1}): → $^{14}C_{org,\ congruent\ release}$ (activated metals)

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GTS: ^{14}C and ^{129}I Migration Project (CIM)

Objectives:

- Study role of cement in **Carbon-14** and **Iodine-129** retardation as they cause highest dose from TRU wastes
  - ➔ In-situ transport and sorption of C-14 and I-129 through 14 year old cement and the granitic host rock
- Upscale and confirm sorption data from laboratory experiments

Concept:

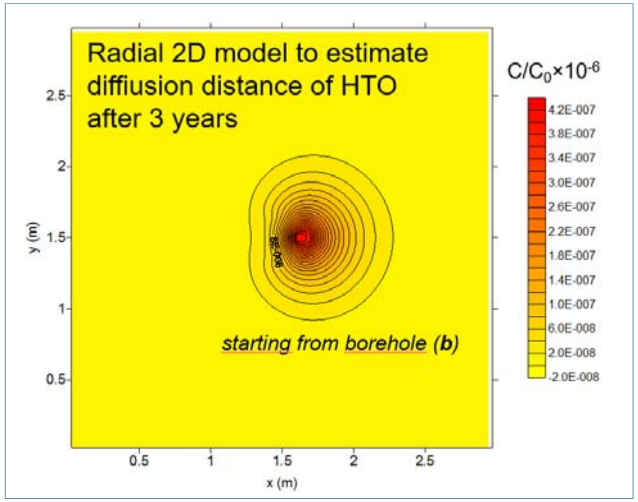
- Simulate near-field of a L/ILW repository
- Circulate radionuclide bearing cocktail inside cementitious backfill of a large diameter borehole

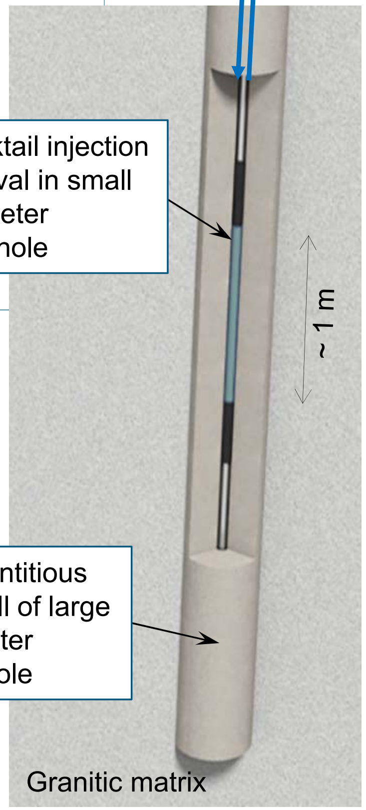
Radionuclides / tracers

- C-14 as formate ion ($HCOO^-$)
- Iodine-129 as Iodide (I^-)
- Cs-134 as Cs^+
- Ba-133 as Ba^{2+}

Conservative tracers:

- H-3 as HTO
- Cl-36 as Cl^-





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How do URLs contribute to confidence and acceptance?

- Large number of documents presenting Nagra's research activities (flyers, blogs, journals, etc.)
- About 1500 visitors at GTS per year (June – October), about 5000 visitors in the Mont Terri URL
- Information at the web in multiple languages
- Organise media events (topical sessions, anniversaries, etc.)
- "Day of open door" (two times a year)
- Participate in national exhibitions
- Organise summer schools for universities and partner organisations
- Support local tourism and local supply chain as much as possible


Mont Terri URL visitor centre


Guided tour in the Mont Terri URL


Internationale Kooperation –
21 Partnerorganisationen aus 12 Ländern