

The role of the HADES URL in the better understanding of the Boom Clay pore water geochemistry

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Exchange meeting HADES 40

TABLOO Dessel, 2022-12-09



ONDRAF/NIRAS



ESV EURIDICE GIE

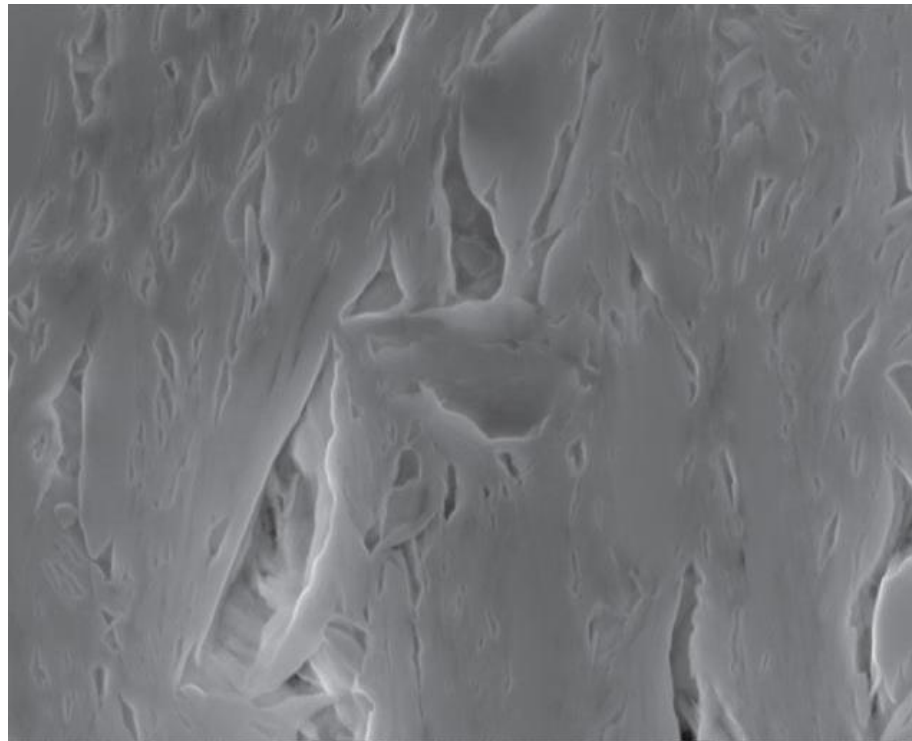
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Introduction

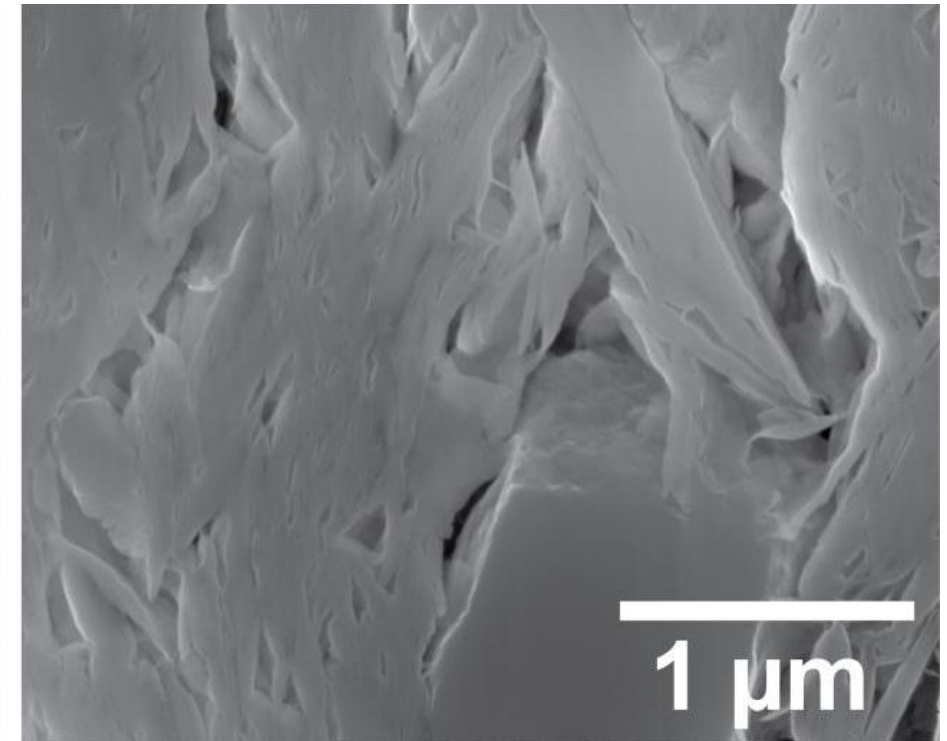
- The pore water composition of the clay host rock plays a role in a series of processes relevant to the safety assessment
 - Geochemistry determines the (im)mobility of radionuclides
 - Important input parameter in geochemical modelling, transport modelling, THM modelling, ...
 - Important parameter to evaluate the short and long term evolution of a geological disposal system as a whole
- Knowledge about the pore water composition is essential
- HADES URL, a unique infrastructure, made it possible to sample pore water from Boom Clay at *in situ* conditions

Challenges of sampling pore water from Boom Clay

- Boom Clay has a high water content (about 20 wt% or 40 vol%)
→ all standard pore water extraction techniques should be technically feasible
- Boom Clay has a low hydraulic conductivity ($\sim 10^{-12} \text{ m}\cdot\text{s}^{-1}$, Yu *et al.*, 2013)
→ difficult to extract pore water



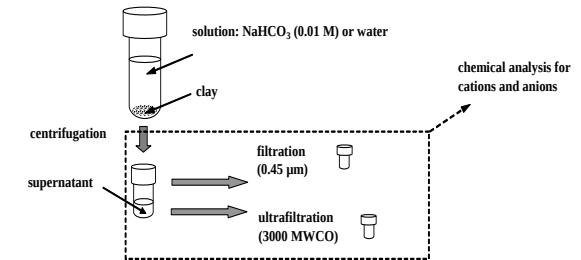
Desbois *et al.* 2010



First attempts to obtain pore water from Boom Clay

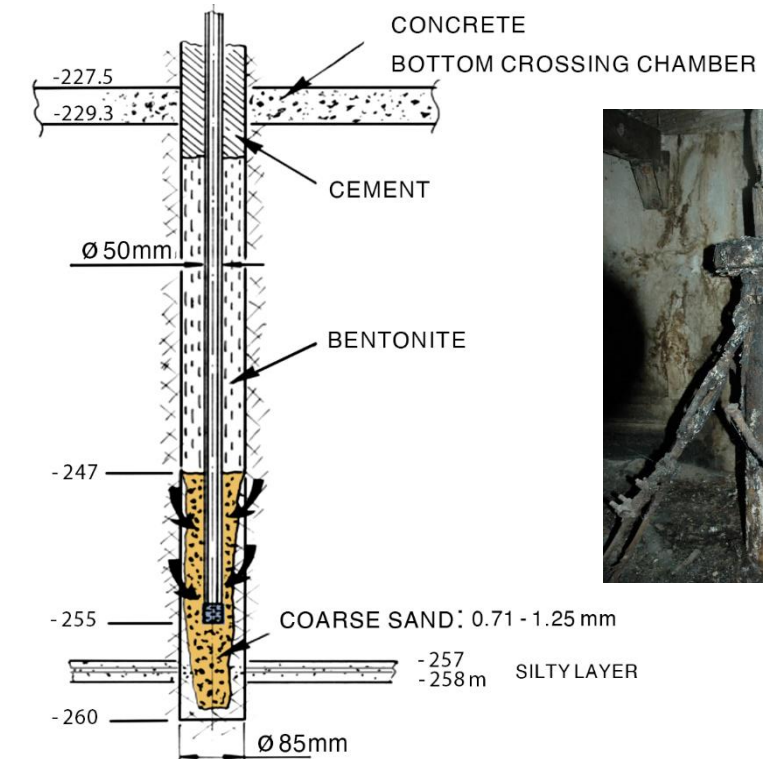
- Drilling of clay cores from the HADES URL + Aqueous leaching

- Batch experiments at different S/L ratio's
- Geochemical modelling required



- In situ sampling from piezometers in HADES URL

- Almost no experience in the early 1980's on pore water sampling from deep clay formations + No experience to place piezometers in URL
- Drilling and sampling according to the knowledge and best practice of that time
- Installation of the EG/BS piezometer underneath shaft 1 in September 1983
 - Air drilled
 - Over-dimension of the well, gravel used to fill it up



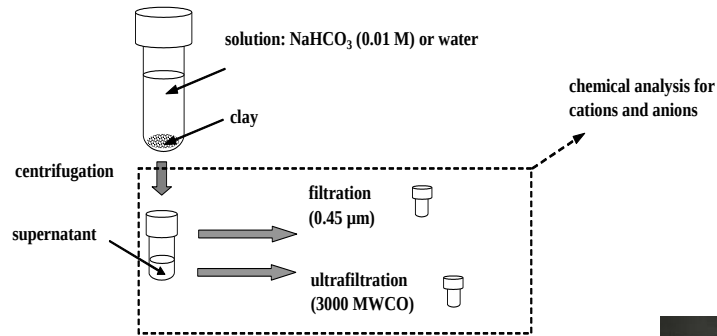
First chemical analyses of Boom Clay pore water

- Chemical analyses in surface labs
- On water obtained from the aqueous leaching of clay cores and on EG/BS water (Baeyens *et al.*, 1985, Henrion *et al.*, 1985)
- 14.9 mM NaHCO_3 solution, rich in humic acids with a large molecular size spectrum
 - reference Boom Clay pore water composition at *in situ* conditions at the Mol site
- It was assumed that the pore water is in equilibrium with the solid phase and that the pore water composition is constant over the thickness of the formation.



- Problem of oxidation of clay cores!
- Problem of measuring pH, Eh and pCO_2 in laboratory conditions!

Further exploring pore water extraction techniques



Aqueous leaching - clay cores



Mechanical squeezing - clay cores



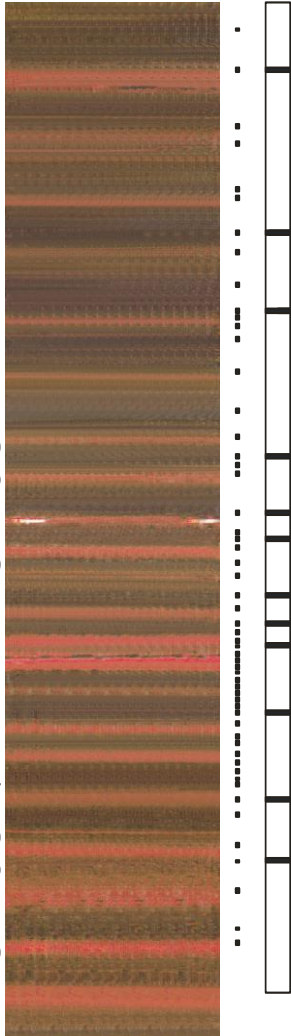
In situ - piezometers

- Pore water obtained from clay cores drilled from the HADES URL
- Pore water obtained *in situ* through piezometers installed in the HADES URL

→ Piezometers considered to provide the most representative pore water

De Craen *et al.* 2004a

Further exploring Boom Clay pore water composition



- More piezometers - multi-filter piezometers
- Perturbations avoided as much as possible, but still drilling with oxygen
- Enabling to study Boom Clay composition at different stratigraphic levels

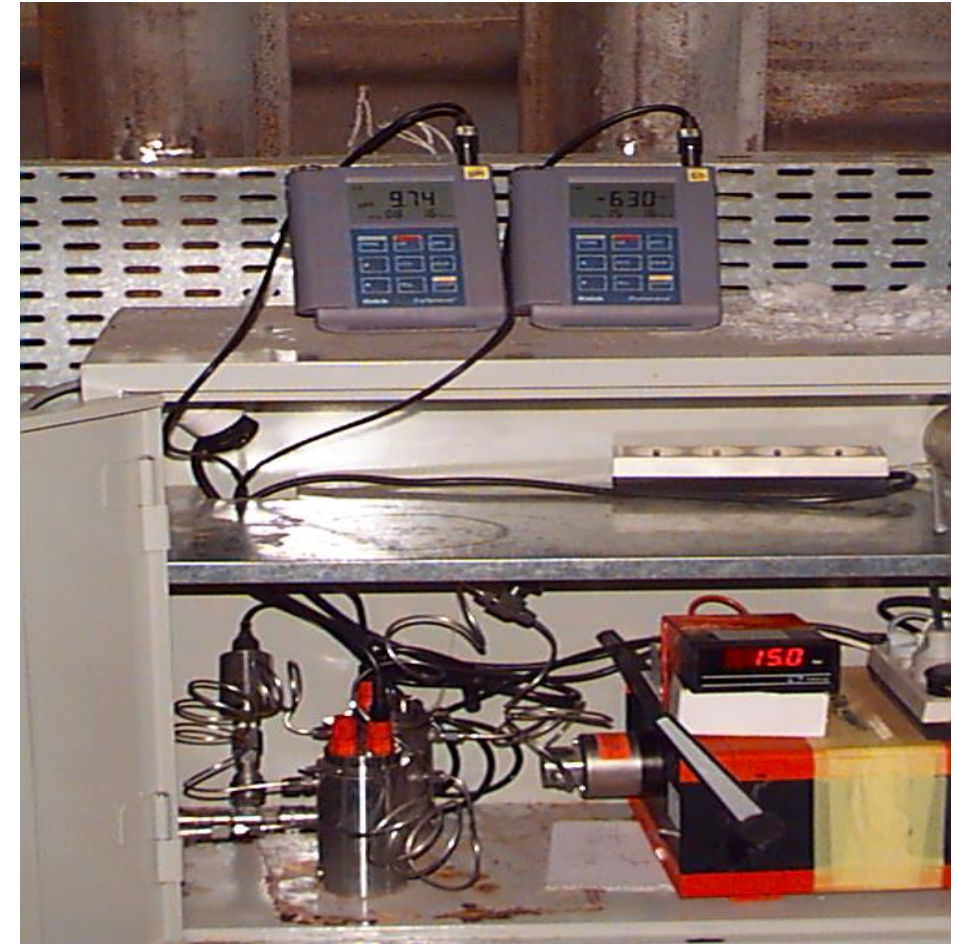


- Clear variations in dissolved organic carbon content, but very limited variations in chemistry
- Overall homogeneous composition of Boom Clay pore water at the Mol site, being a 15 mM NaHCO_3 -type water over the entire depth, with ~ 115 mg C/L

De Craen *et al.* 2004b, 2005

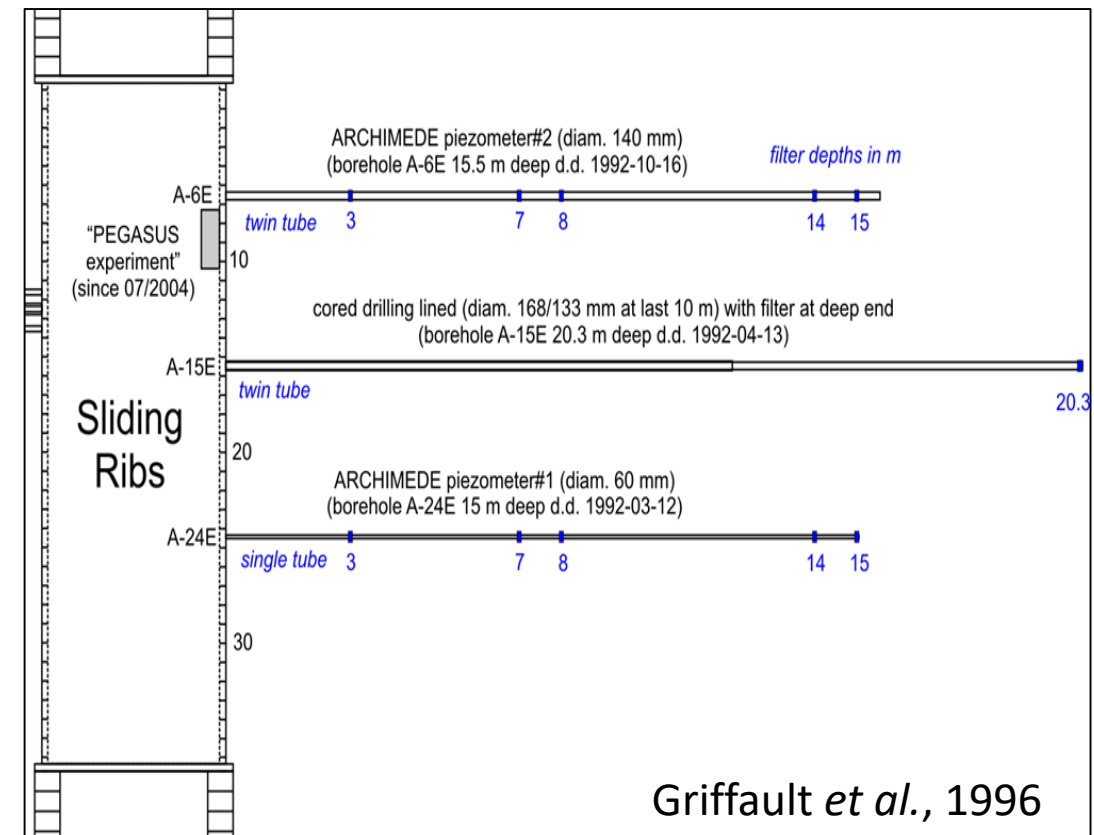
Further attempts to measure key geochemical parameters (pH, Eh) representative of *in situ* conditions

- 90's - bringing classical lab devices to HADES
 - Flow-through cells with classical glass electrode for pH measurement
 - Initially representative pH values of 8.0-8.5
 - With time, gas bubbles developed and hindered measuring pH values representative for *in situ* conditions
- It became clear that *in situ* pH measurements were far from obvious and that further developments were needed!



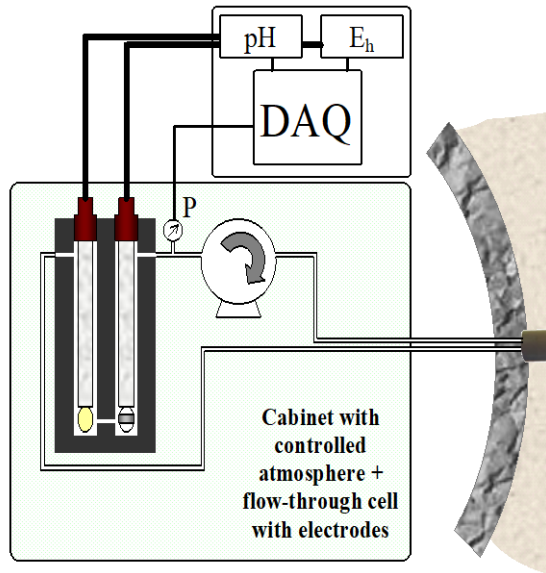
Further attempts to measure key geochemical parameters (pH, Eh) representative of *in situ* conditions

- 1992 – the ARCHICHEMEDE-Argile project: detailed study of the Boom Clay pore water chemistry and further attempts to measure pH and Eh *in situ*
 - BC pore water composition in line with previous analyses
 - *in situ* pH value of 8.2, measured with an optical pH fibre sensor (colorimetry)
 - Other test unsuccessful

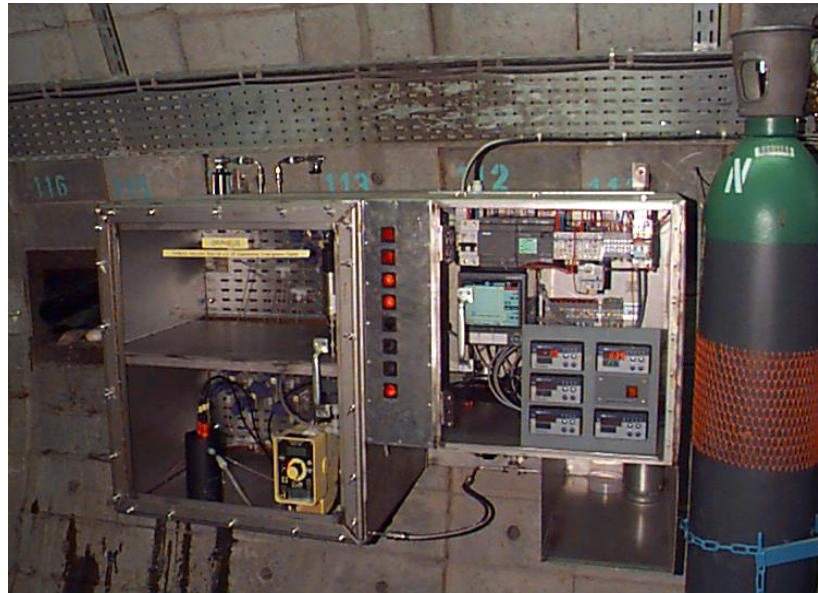


Further attempts to measure key geochemical parameters (pH, Eh) representative of *in situ* conditions

- 2000 – the ORPHEUS experimental set-up:
in situ measurement of pH and Eh in a closed circulation system
 - Xerolyt® pH and E_h glass electrodes used
 - Closed circulation system, controlled-atmosphere cabinet (argon flushed)



Moors *et al.* 2002

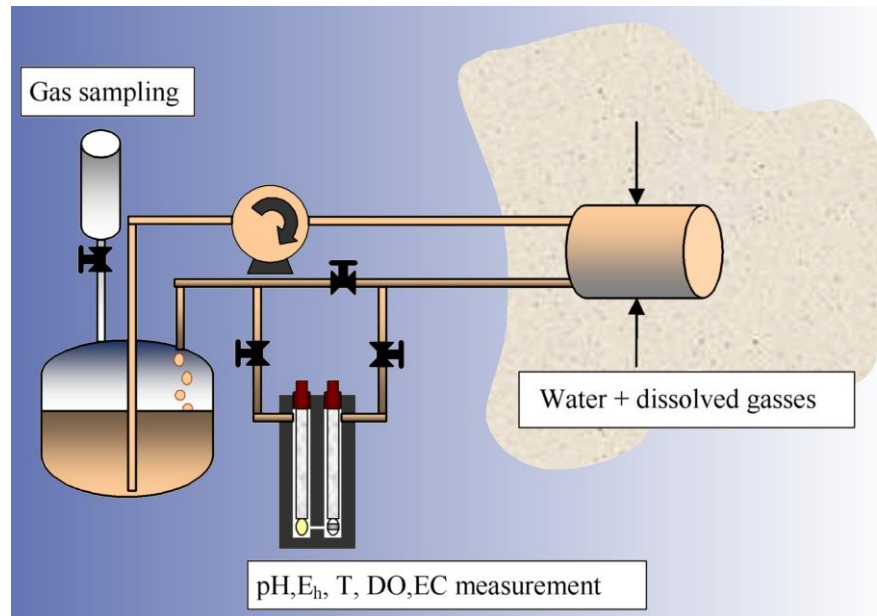


- A representative *in situ* pH of 8.5 ± 0.5
- Eh values of -275 ± 25 mV
- BUT perturbation of the system during long term pH measurements
 - Leaching of KCl from the glass electrodes
 - Leaching of organic substances causing microbial activity



Further attempts to measure key geochemical parameters (pH, Eh, pCO₂) representative of *in situ* conditions

- 2004 – the PEGASUS experimental set-up: closed circulation system especially designed for the sampling of dissolved gasses to determine partial gas pressures



- A suitable technique to accurately measure *in situ* partial gas pressures
- $p\text{CO}_2 = 2.85 \text{ mBar} = 10^{-2.55} \text{ atm}$

Moors *et al.*, 2005

Further attempts to measure key geochemical parameters (pH, Eh, pCO₂) representative of in situ conditions

- Lessons learned so far
 - Need of an URL for sampling pore water and for the analyses of key geochemical parameters at *in situ* conditions !
 - Progressive advancement in technology and understanding
 - first *in situ* measurement of Eh and pH
 - later also possible to sample dissolved gasses and measure CO₂ → calculate pCO₂
- Remaining issues
 - Oxidation still a problem
 - *In situ* measurement of pH and pCO₂ improved, but still far from obvious
 - Need for standardised sampling and analyses procedures and the accurate measurement of *in situ* geochemical parameters

A new milestone reached beginning of this century!

- Extension of the HADES URB (Shaft 2 and Connecting Gallery):
a new forced ventilation
- Drilling with nitrogen

**NEW
OPPORTUNITY**

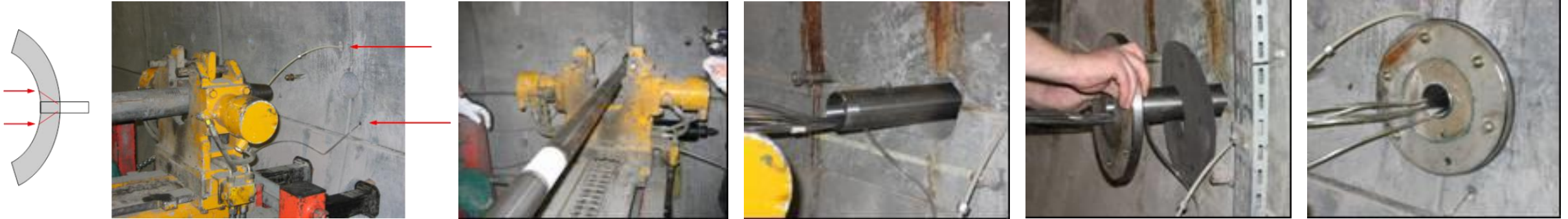
→ New

IT'S TIME
FOR A NEW
CHALLENGE

rch !

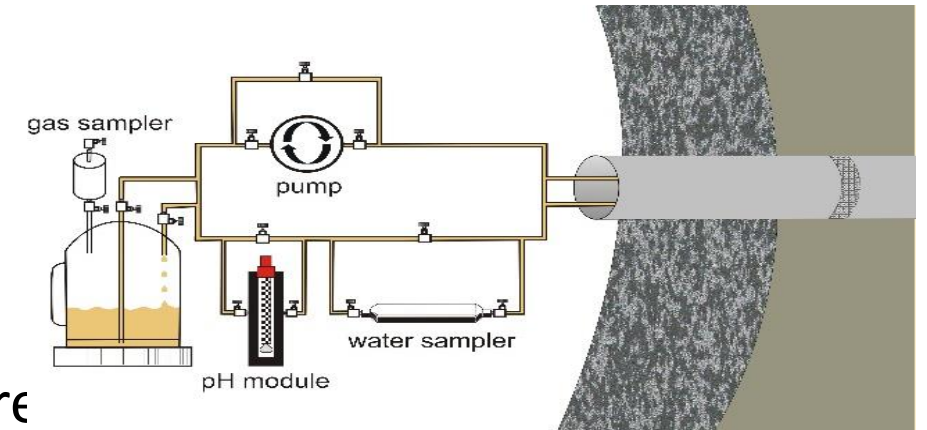
New and improved integrated methodology

- Borehole drilling and piezometer installation with nitrogen



- Piezometers equipped with an advanced experimental set-up for the simultaneous sampling of pore water and dissolved gasses, and the *in situ* measurement of pH

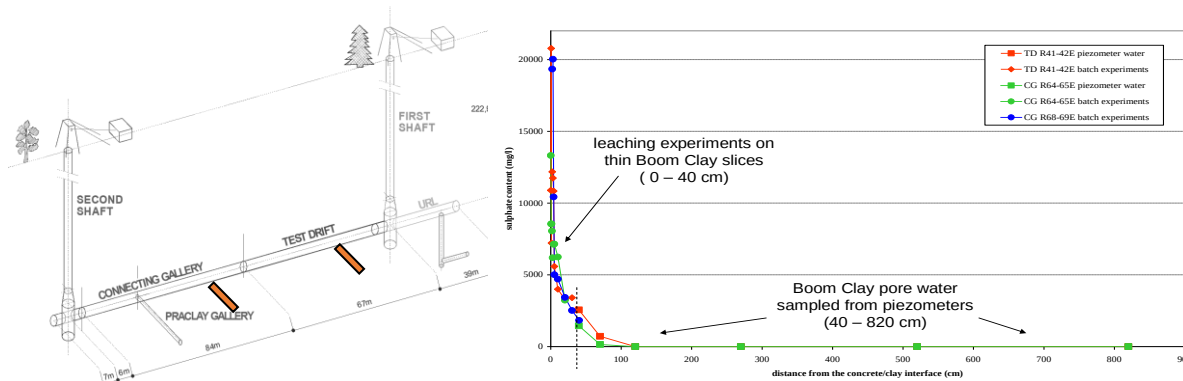
→ Better characterisation of Boom Clay geochemistry re
→ Also opportunity to study effect of perturbations on Boom Clay geochemistry



The effect of perturbations on the PW geochemistry

Oxidation

- 2004 – the NF-PRO experimental set-ups



Increased temperatures

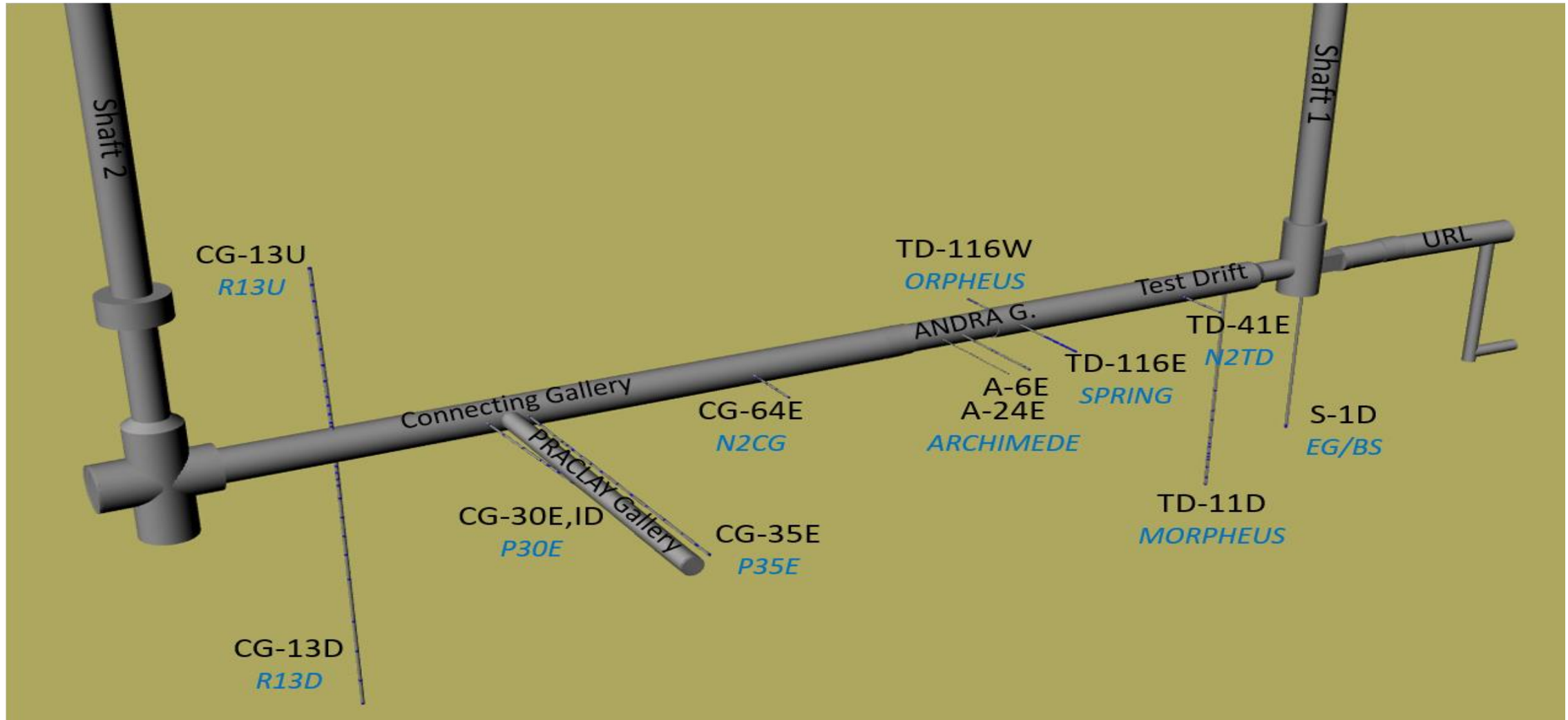
- 2006 – the PRACLAY experimental set-ups



... work in progress ...

De Craen *et al.*, 2008, 2011

HADES URL contributed to the better understanding of the Boom Clay geochemistry



Recent publications Boom Clay pore water geochemistry

- De Craen M., Moors H., Honty M., Van Geet M. The role of the HADES URL in the better understanding of the Boom Clay pore water geochemistry. GSL special publication on "Geological disposal of radioactive waste in deep clay formations: 40 years of RD&D in the Belgian program" (2022) 536.
- Honty M., Frederickx L., Wang L., De Craen M., Thomas P., Moors H., Jacobs E., Boom Clay pore water geochemistry at the Mol site: Experimental data as determined by in situ sampling of the piezometers. Applied Geochemistry, 136 (2022) 105156.
- Wang, L., Honty, M., De Craen, M., and Frederickx, L. Boom Clay pore water geochemistry at the Mol site: Chemical equilibrium constraints on the concentrations of major elements. Applied Geochemistry, 148 (2023) 105541.

Conclusions – the Belgian context

- HADES URL played an important role in the study of the Boom Clay pore water
 - In the past decades, significant progress has been made in the techniques and protocols to sample and monitor pore water
 - The use of nitrogen instead of compressed air to drill boreholes and installing piezometers limited the disturbances induced by oxidation of the clay
 - An advanced system was developed to simultaneously sample pore water and dissolved gasses and measure some key geochemical parameters such as pH, pCO₂ and E_h at *in situ* conditions.
- Resulted in a more reliable characterisation of the Boom Clay pore water and a better understanding of perturbing processes

Conclusions – the international context

- HADES URL was the first URL worldwide to study pore waters from clay-rich formations considered as potential host formations for radioactive waste repositories → pioneering work
 - Newer URL's such as Mont Terri in Switzerland or the Bure URL in France took advantage from the progress made in the HADES URL
- Precise and coherent summary of pore water sampling and monitoring methods, together with their limitations, represents a valuable contribution, and helps to interpret pore water chemistry also in other clay formations

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ESV EURIDICE EIG is an economic interest grouping between SCK CEN and the Belgian nuclear waste management agency.

ESV EURIDICE EIG

Boeretang 200 - 2400 MOL - Belgium



#Euratom

EURATOM Research and Training Programme

2021 – 2025

Seif BEN HADJ HASSINE
DG RTD, Euratom Research
9 December 2022



*Research and
Innovation*

Outline:



1. The Horizon Europe and Euratom programmes
2. Role of the Euratom programme in support of the URLs
3. An overview of the EURAD European Joint Programme



1. Horizon Europe and the Euratom Research and Training Programmes



“



With Horizon Europe, we step up our ambition for a sustainable future. The programme will maximise its impact by strengthening our scientific and technological bases, boosting our innovation capacity, driving the green and digital transitions and supporting an inclusive recovery.

Mariya Gabriel

Commissioner for Innovation, Research, Culture, Education & Youth

”



European
Commission |

Horizon Europe

The ambitious EU research and innovation framework programme (2021-2027)



to strengthen the EU's scientific and technological bases and the European Research Area (ERA)



to boost Europe's innovation capacity, competitiveness and jobs



to deliver on citizens' priorities and sustain our socio-economic model and values

Budget of around €95.5 billion for 2021-2027 (current prices)

HORIZON EUROPE

EURATOM

SPECIFIC PROGRAMME: EUROPEAN DEFENCE FUND

*Exclusive focus on
defence research
& development*

Research
actions

Development
actions

SPECIFIC PROGRAMME IMPLEMENTING HORIZON EUROPE & EIT*

Exclusive focus on civil applications



Pillar I EXCELLENT SCIENCE

European Research Council

Marie Skłodowska-Curie

Research Infrastructures



Pillar II GLOBAL CHALLENGES & EUROPEAN INDUSTRIAL COMPETITIVENESS

Clusters

- Health
- Culture, Creativity & Inclusive Society
- Civil Security for Society
- Digital, Industry & Space
- Climate, Energy & Mobility
- Food, Bioeconomy, Natural Resources, Agriculture & Environment

Joint Research Centre



Pillar III INNOVATIVE EUROPE

European Innovation
Council

European Innovation
Ecosystems

European Institute of
Innovation & Technology*

WIDENING PARTICIPATION AND STRENGTHENING THE EUROPEAN RESEARCH AREA

Widening participation & spreading excellence

Reforming & Enhancing the European R&I system

Fusion

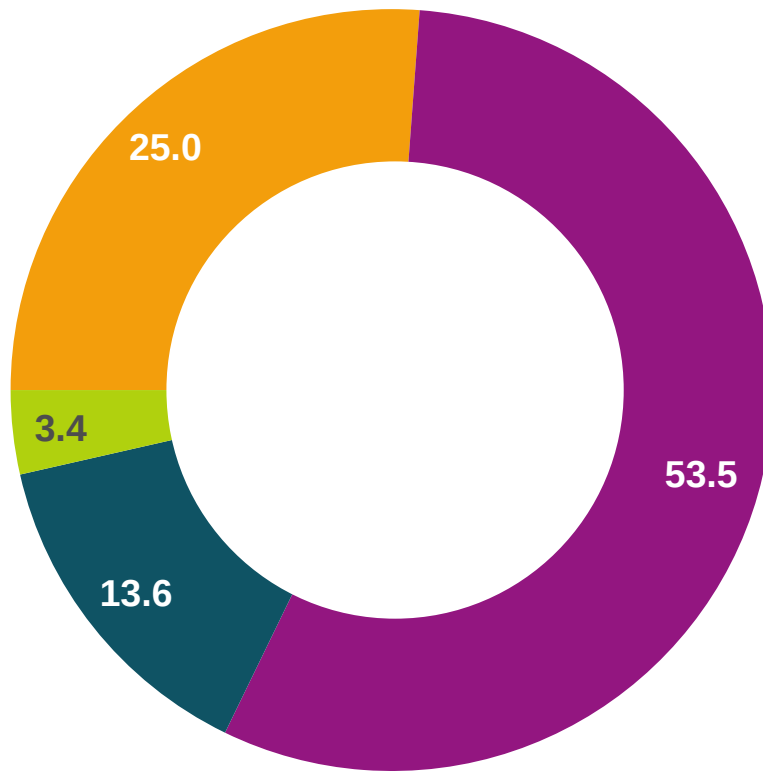
Fission

Joint
Research
Center

* The European Institute of Innovation & Technology (EIT) is not part of the Specific Programme

Horizon Europe Budget: €95.5 billion (2021-2027)

(including €5.4 billion from NGEU – Next Generation Europe – programme of EU for Recovery from COVID-19 crisis)



Political agreement December 2020

€ billion in current prices

- Excellent Science
- Global challenges and European ind. comp.
- Innovative Europe
- Widening Part and ERA

The Euratom Research and Training programme

What is it?

- Research and Training (R&T) programmes implemented by the European Commission (EC), under the provisions of the European Atomic Energy Community (Euratom) Treaty, in which all European Union (EU) Members States participate.

What is its role?

- To supplement and coordinate MS' programmes to perform joint and/or coordinated cutting-edge research, to support knowledge creation and knowledge preservation. To avoid duplication and achieve critical mass if needed.

How is it implemented?

- By Multi annual Framework Programmes (FP), 5 years +2 since FP7 and annual / biannual Work Programmes;
- Projects of up to five year duration are funded after calls for proposals evaluated by independent experts.

Euratom Programme 2021-2025



The financial envelope for the implementation of the new Euratom Programme 2021-2025 shall be **€1.382 billion in current prices.**

€583 million for indirect actions in fusion research and development

€266 million for indirect actions in nuclear fission, safety and radiation protection

€532 million for direct actions undertaken by the Joint Research Centre

2021-27 Euratom EUR 1.98 Billion

Euratom Research and Training *** Complementing Horizon Europe	<i>(7 years)</i> <i>EUR 1,980 million</i>	(5 years) EUR 1,380 million
Indirect RTD		
• Fusion R&D	809	583
• Fission R&D Safety and radiation protection	370	266
Direct JRC		
• Fission Safety and safeguards	802	532
ITER (a dedicated EC Regulation, 7 years) EUR million		
	5,610	

EU/EURATOM Fission RTD Work Programmes

~ 20%

Waste Management and Geological disposal

- Decommissioning

~ 40%

Reactor systems

- Safety of existing nuclear installation (Gen II-III)
- Advanced nuclear systems for increased safety (Gen-IV)
- Partitioning, Transmutation and closed fuel cycle
- Cross-cutting aspects (e.g. fuels, materials, simulation, nuclear data)
- Other applications (e.g. cogeneration, support to Research Reactors)

~ 20%

Radiation protection

- Non-power applications

~ 20%

Research infrastructures

Training and mobility

Cross-cutting INCO

Euratom WP 2021-22 Topics	EUR million EC contr./prop	Total Budget (indicative)	Proposals (indicative)
1 Safety of operating Nuclear Power Plants and Research Reactors (RIA).....	3.0	18.0	6
2 Safety of advanced and innovative nuclear designs and fuels (RIA).....	3.0	13.5	4
3 Multi-recycling of spent nuclear fuel from Light Water Reactors (RIA).....	6.0	6.0	1
4 Advanced structural materials for nuclear applications (RIA).....	8.0	8.0	1
5 Safety of High Temperature Reactors (RIA).....	3.0	3.0	1
6 Harmonization of licensing procedures, codes and standards Fi/Fu (CSA).....	2.5	2.5	1
7 Development of tritium management in fusion and fission facilities (RIA).....	3.0	3.0	1
8 Towards an aligned harmonized regulatory framework RWM and DECOM (CSA)...	3.0	3.0	1
9 European Partnership for research in radiation protection (COFUND).....	30.0*	30.0*	1
10 Safe use and reliable supply of therapeutic radionuclides (RIA).....	3.0	3.0	1
11 Cross-sectoral synergies and new applications of nuclear technologies (IA).....	2.0	10.0	5
12 European Facility in Nuclear Research (CSA).....	9.0	9.0	1
13 Towards a European nuclear competence area (CSA).....	7.0	7.0	1
14 Socio-economic issues related to nuclear technologies (CSA).....	1.5	1.5	1
15 Support to Euratom National Contact Points (CSA).....	0.25	0.25	1
16 Support to the Sustainable Nuclear Energy Technology Platform (CSA).....	0.6	0.6	1
Other Actions: GIF, FISA2022/EURADWASTE'22 ...Eurofusion (COFUND 537*)....		0.7 .. 537 (fusion)	1
Overall Euratom Fission 2021-22 Call indicative budget (* include budget from years 2023-25 fission (20), fusion (343))		99.6 (fission)	28

Horizon Europe Euratom Call 2023-25: Overview Schedule

Event	Date
Publication of the WP 2023-25	End 2022 - Early 2023
Submission Call open.....	Spring 2023
Deadline	Autumn 2023
Evaluations	End 2023
Communication of outcomes	Early 2024
Negotiations/Finalisation of Grants	Spring 2024
Grant Agreement signature.....	Mid 2024
First projects expected to be launched	Mid 2024

EC Funding and Tenders portal

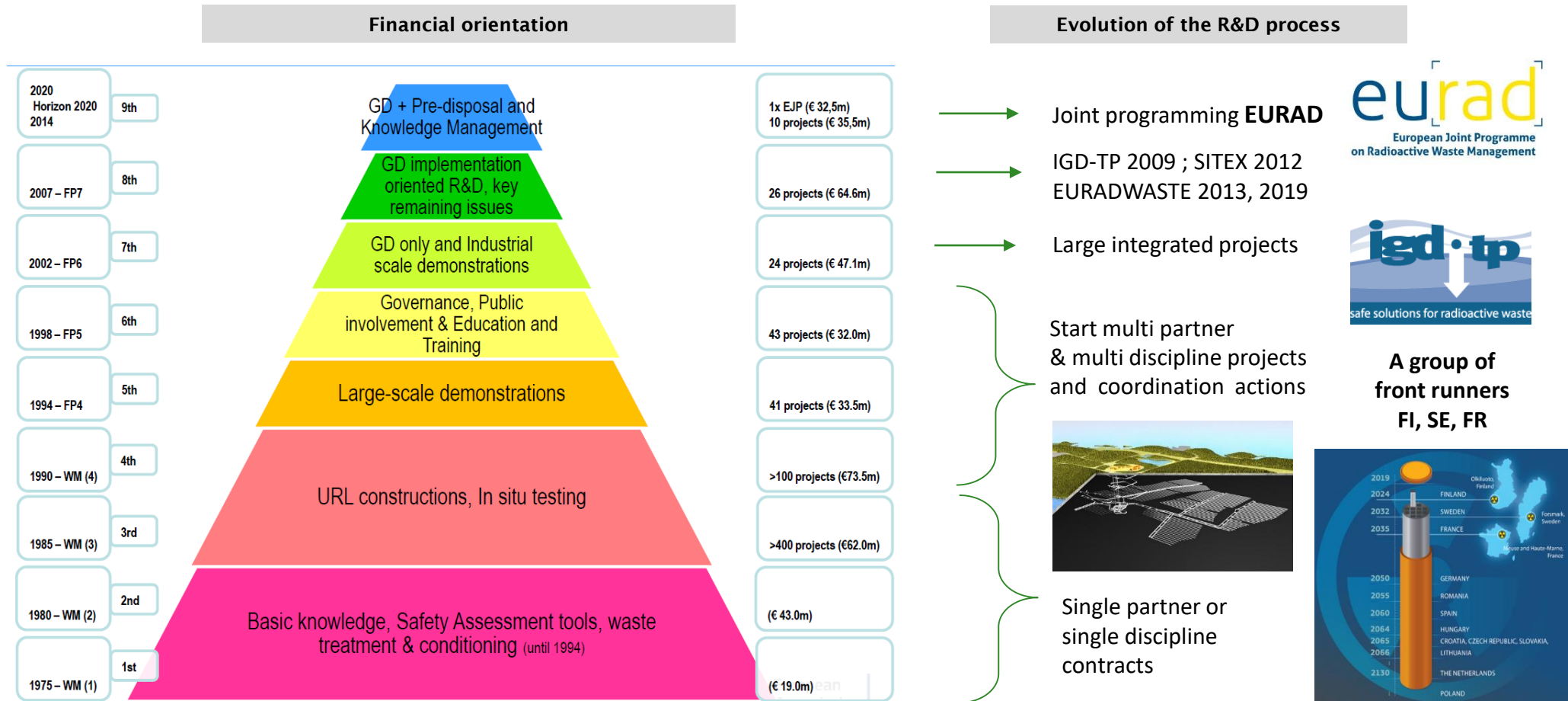
<https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/home>

2. Role of the Euratom programme in supporting the URLs



Waste Management and Geological Disposal

Strong effort of EC to support R&D on radwaste since more than 40 years and an evolution to federate all the actors, in an holistic view and including all types of radwaste



1975-79: Preliminary site investigations for URLs in Europe

- Relative **consensus on the geological repository** as a suitable long term solution
- **Site investigations** in the Boom clay formation in Belgium for building the first URL: the **HADES** facility
 - The focus is on hydrogeological and geotechnical characterisation
 - A safety assessment in 1979 for the radiological impact of a DGR in Mol
 - The Boom clay is found homogeneous and suitable
 - Draft application for authorisation to the Belgian authorities
 - Two important issues identified: the technical feasibility of the drilling and the general public perception
- **Other host rocks are also investigated in Europe** (ex. salt rocks such as the Asse salt mine in Germany)

1980-84: Construction of the HADES URL and internat. coop.

- Collection of **extensive geological data** in potentially suitable host rocks
- Focus on the **radiological impact** and the **release of the RNs**
- Additional **feasibility** studies and **design** refinements
- Construction of the HADES facility
 - First gallery in 83-84 (225m deep, 26m long and 3.5m diameter)
 - Preliminary excavation relied on pre-freezing techniques
 - Relatively low creep was measured
- Two important projects on **safety and performance assessment**: the PAGIS and the MIRAGE projects
- First **international cooperation** agreements (Canada, USA, Switzerland) and multilateral cooperation (NEA/OECD, IAEA)

1985-90: Refinement of the safety studies and future URLs

- Consensus on the relevance and **the need of in-situ research facilities**
- Extension of the HADES URLS with the support of ANDRA
- A **performance assessment** project (PACOMA) launched for the radiological impact of intermediate level and alpha contaminated waste
- ONDRAF/NIRAS publishes the first SAFIR I report based on the EC projects
- Specific research projects launched in the **German Asse site**
- **Investigations in France** for a future URL

1990-94: Host rock for future URLs in Europe

- Following the Boom clay formation in Belgium, the Asse salt rock in Germany, and the future clay formation in France, a new project is launched to identify **a suitable host rock in the UK**
- First research projects including **THMC coupled models** to feed the safety assessments (e.g. PRACLAY in 1990 about THM processes)
- Development of **numerical methodologies and tools** (e.g. the DOSEGEO, SOURCE and TEMPRES projects)
- An important **safety assessment** EC project, EVEREST, focused on the sensitivity of the performance assessment in all three types (**granite, clay and salt**)
- **The role of the URLs** in the safety assessment of the DGR is established

1994-2002: FP4 and FP5 Euratom programmes: S&T gaps

- **Testing and demonstration** of disposal concepts
 - The CLIPEX project in 1997 on the instrumentation to evaluate the performance of the excavation techniques
- Technical **issues related to the construction** (ex. backfills, seals)
 - The RESEAL project in 1996, then RESEAL-II in 2000
- **Long term behavior** of the SSC
 - The CORALUS project on the corrosion and dissolution of the Cogema glasses, followed by CORALUS-2 in 2000
- Characterisation of **groundwater flow and transport of the RNs**
 - The TRANCOM project in 2000 to investigate the transport properties of several RNs

2002-13: FP6 and FP7 programmes: integration & coordinat.

- Follow-up of specific technical studies:
 - FUNMIG followed TRANCOM on transport and retention of RNs in all three types of host rocks
 - MoDeRn on the monitoring techniques and their implementation
 - The FORGE project in 2009 on gas transport
- Further **integration and coordination** of RD&D on RWM:
 - ESDRED in 2004 on the demonstration of the DGRs (e.g. buffer design and construction)
 - The CARD project in 2006 that led to the establishment of the **IGD-TP** platform in 2009
 - LUCOEX in 2011 on identifying the relevant parameters for long term safety of DGR based on the URLs experiments
- The **Waste Directive** in 2011(Directive 2011/70/EURATOM)

2014-2020: Horizon 2020 and toward the EJP on RWM

- Differences in the national programmes and in the socio-political landscapes in Europe
- Need for further **integration and cooperation**:
 - **SITEX**, then SITEX-II for a platform with the TSOs
 - JOPRAD, toward the EJP
 - **EURAD** launched in 2019
- Projects dedicated to specific pending technical issues/gaps
 - CEBAMA, on cementitious SSC
 - Modern2020, following MoDeRn
 - BEACON, on the bentonite SSC
 - MIND on microbiological processes in DGRs
 - DISCO, on the spent fuel

3. The EURAD European Joint Programme on RWM

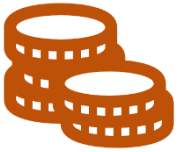


European Joint Programme on Radioactive Waste Management (EURAD)



5 years
2019-2024

“A step change in European collaboration towards safe radioactive waste management, including disposal, through the development of a robust and sustained science, technology and knowledge management programme that supports timely implementation of RWM activities and serves to foster mutual understanding and trust between Joint Programme participants.”



Budget: 59,9 M€
55 %EC contribution

Objectives :

- Implement a robust and sustained state-of-the-art **Science and Technology Programme**
- Identify and elaborate upon complex issues by bringing together interested actors to jointly conduct **Strategic Studies**
- Consolidate efforts across Member-States, organisations and generations on **Knowledge Management**
- Foster **mutual understanding** and **trust** between participants (incl. from Civil Society) and other stakeholders



10 R&D WPs



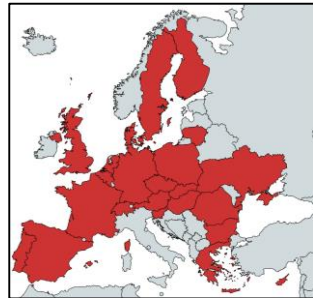
2 Strategic Studies



3 Knowledge Management
WPs

Ministries from 23 European countries recognising their role of directing RD&D at the national level, provided mandates to **51 organisations** acting as Beneficiary within EURAD:

- Waste Management Organisations
- Technical Support Organisations
- Research Entities
- ... with **61 linked third parties** & **3 international partners** also participating



eurad



EURAD programme has received funding from the European union's Horizon 2020 research and innovation programme under grant agreement n°847593.

Key achievements at mid-term

❖ Scientific excellence

EURAD provides cutting-edge science in areas of interest to a broad range of organisations :

- source term, engineered barriers, nearfield
- geosphere barrier, perturbing effects & clay material barriers
- methods, models, interactions and tools



100+ publications



8 State-of-the-Art

❖ Trust and mutual understanding

EURAD supports and encourages interactions between WPs (including civil society) and with external bodies, including participation of end-users

- Monthly 'Lunch-and-learn' sessions
- Lively interactions with international organisations
- Regular exchanges and workshops with civil society

❖ Support transfer of knowledge

The generations-lasting implementation of RWM requires large efforts in knowledge transfer between generations and programmes at different stages of development. Among the specific achievements are:

- KM and Networking Programme
- Population of the Roadmap
- School of RWM promoting students networking through trainings and mobility
- Production of guidance documents



110+ PhD/post-doc/master students



~ 900 individuals



Looking ahead

❖ Added value of & step change with EURAD is recognized with clear signals for a follow-up programme (EURAD- 2) on Radioactive Waste Management

- Integration of PREDIS project (predisposal research)
- Update of the Strategic Research Agenda
 - Covers all wastes types – Predisposal and disposal
 - Take stock and reflect on progress made since 2019 and capture emerging needs
 - Prepare as a guide fore a future EC partnership

❖ Joint Programming will fulfill expectations of end-users

- EURAD helps member states in their timely implementation of RWM activities
- Joint research work creates new knowledge, educates scientists and broadens capabilities
- Existing knowledge is made available & accessible in an efficient manner
- Trust and mutual understanding exists between the partners



FOR MORE INFORMATION

Coordination : Andra (France)

Website : <https://www.ejp-eurad.eu/>



European Joint Programme on Radioactive Waste Management



@EJP_EURAD

Publications – CORDIS (EC R&D Information Service)

**View all H2020 Euratom projects summaries
and public deliverables on CORDIS**

<https://cordis.europa.eu/>

H2020 Euratom projects (All)

[https://cordis.europa.eu/search?q=contenttype=%27project%27%20AND%20\(programme/code=%27H2020%27%20OR%20programme/code=%27H2020-Euratom%27\)%20AND%20\(%27euratom%27\)&p=1&num=100&srt=Relevance:decreasing](https://cordis.europa.eu/search?q=contenttype=%27project%27%20AND%20(programme/code=%27H2020%27%20OR%20programme/code=%27H2020-Euratom%27)%20AND%20(%27euratom%27)&p=1&num=100&srt=Relevance:decreasing)

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Thank you!

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CONTRIBUTION OF HADES URL TO THE DEVELOPMENT OF THE CIGÉO PROJECT, FRENCH INDUSTRIAL CENTRE FOR GEOLOGICAL DISPOSAL OF HIGH-LEVEL AND INTERMEDIATE LONG-LIVED RADWASTE IN A DEEP CLAY FORMATION

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² EURIDICE, Belgium

³ ONDRAF/NIRAS, Belgium

**24th Exchange Meeting
Tabloo Dessel
9/12/2022**

Outline

Context in France: Cigéo

Feedback in term of construction methods

Feedback in term of monitoring

Comparison of HM behaviour of galleries

- HM behaviour
- Excavation induced fractures network

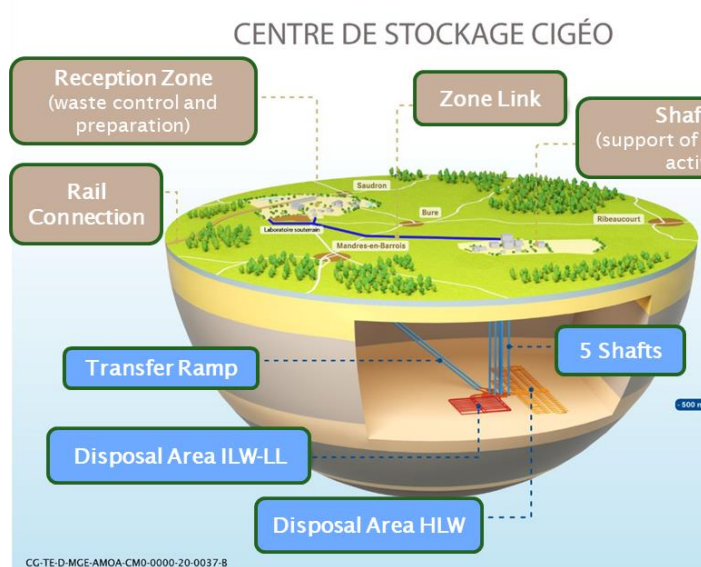
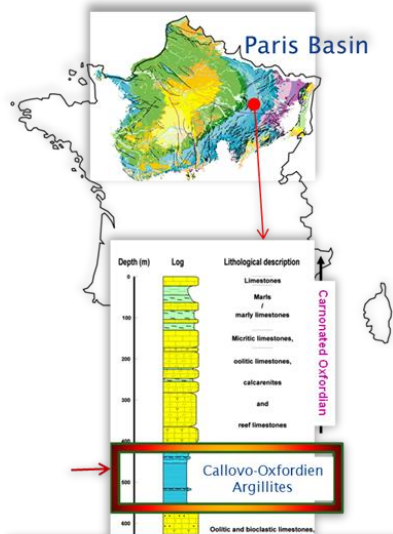
Feedback on seal experiment

Conclusion

Cigéo project

Location and overview

- Cigéo is the French nuclear waste deep geological repository
 - Emplace in the Callovo-Oxfordian claystone



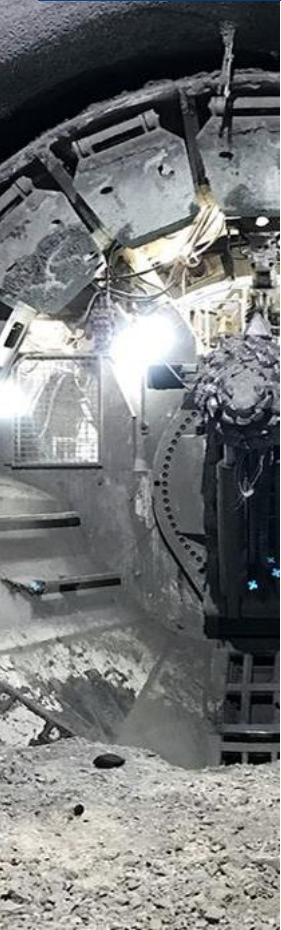
500 Metre depth
15 km² of underground footprint
85 000 m³ of waste
120 years of operation
25 Bn Euros

- Age : 160 million years
- Thickness : 130 - 170 m
- Depth : 420 - 580 m

Cigéo project

Different disposal cells

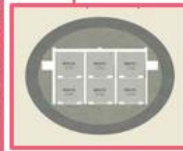
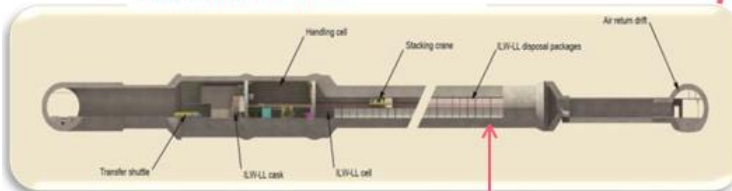
19/05/2022



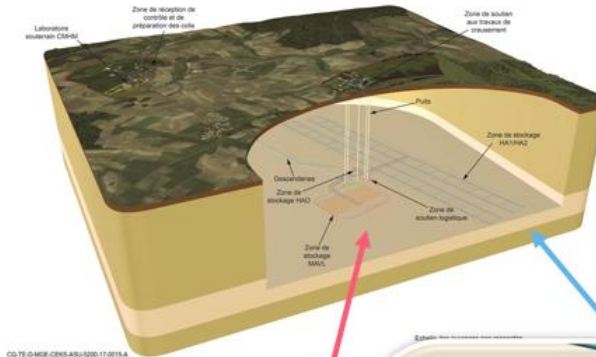
ILW-LL

IL-LLW disposal cells

Useful length: 500 m
Diameter: 9-12m



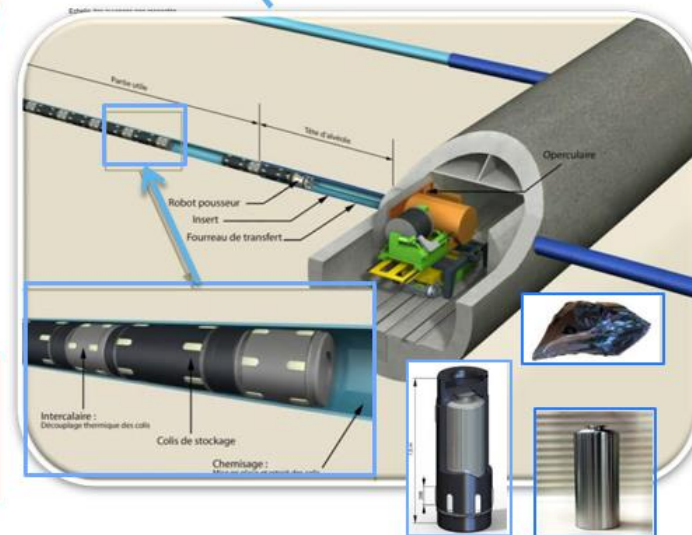
*IL-LL compacted "waffles"
in stainless steel canister*
DISTEC/DCC/22-0040



HLW

HLW disposal cells

Length: 80 - 150 m
Diameter: 80 - 90 cm



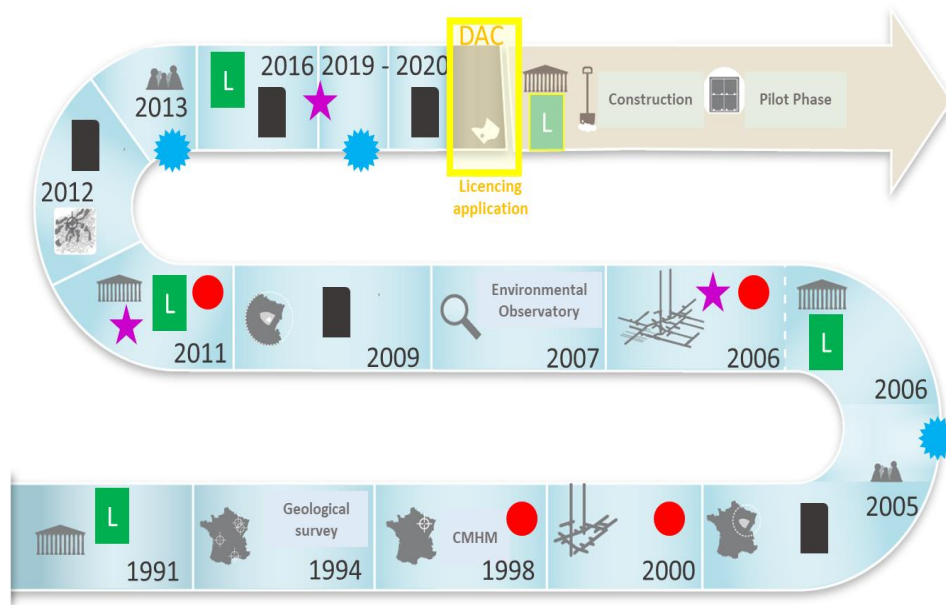
Cigéo project

Roadmap

- A step-by-step **Roadmap**, with decisional milestones
- **Safety Case gradual development** supported by an **URL**
- A continuous and strong **involvement of the French parliament**



Licence application before
end of December 2022



Reports (2005, 2009, 2012, 2016, 2020)



Laws
(1991, 2006, 2011, 2016)



International Peer reviews
(2006, 2011, 2018)



Public consultation
(2006, 2013, 2021)



URL development

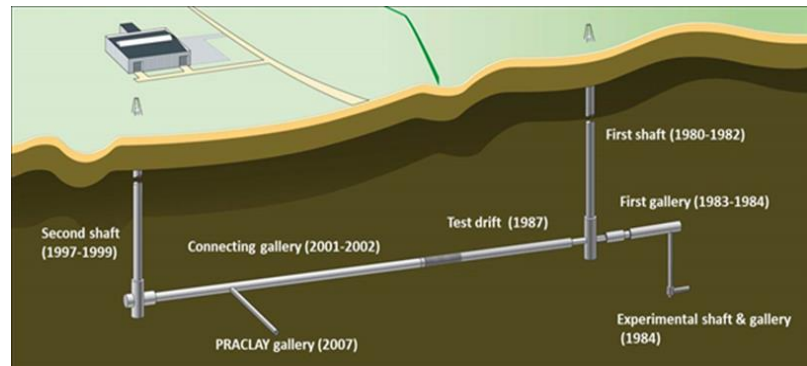
Cigéo project

Why Andra was interested in HADES?

- Before to have is one laboratory Andra relied on the work carried out in URL
 - Mont Terri URL in Opalinus clay
 - HADES URL in Boom Clay
- Work with HADES carried out through numerous cooperation projects
 - direct cooperation between Andra and ONDRAF/NIRAS & SCK CEN (Euridice),
 - European projects (CLIPLEX, RESEAL,...).

This was driven by a dual objective to:

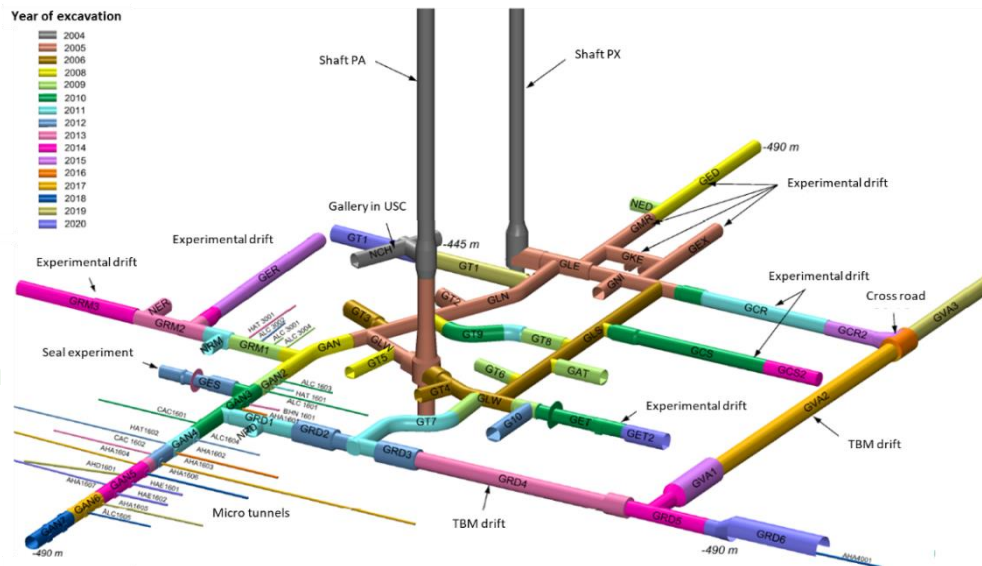
- Prepare Andra own experimental programs in the Meuse/Haute-Marne underground laboratory
 - methodology, experimental devices and protocols,...
- Have general knowledge on the behaviour of argillaceous rocks, in order to increase robustness of understanding
 - Similarity in terms of Hydromechanical behaviour
 - Seal experiment



Cigéo project

Meuse/Haute-Marne URL (CMHM)

- Depth : about 490 m in the middle of the Cox layer
- Started to be excavated in 2000
 - Cox layer reached in 2004
- Anisotropic stress field
- Two main phase
 - Up to 2009 focus on Cox properties characterisation
 - Up to known more focus on demonstration issue
- Now more than
 - 2 Km of galleries
 - 20000 measurement points



Construction issue

HADES

- Construction of gallery in deep clay/claystone
 - Different methods used at HADES

View of the Andra section in HADES with sliding steel arches



Test drift with semi-manual techniques, each ring is composed of 64 concrete blocks (60 cm thick) with wooden plates between the segments ©EIG EURIDICE

Tunnel boring machine equipped with a shield and a road header



©EIG EURIDICE

Construction issue

CMHM : Method of excavation

- Test different excavations and supports methods in parallel drifts to better understand the behavior of the drift by comparison (from low support to stiff support)
 - Mimic previous work performed in HADES but with a more systematic approach



Road header under shield



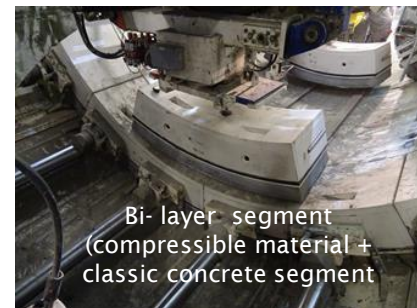
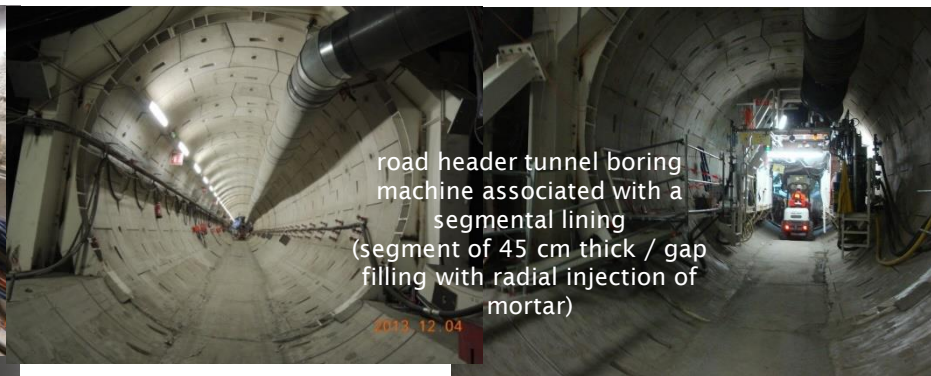
Construction issue

CMHM : Different types of support

Soft support



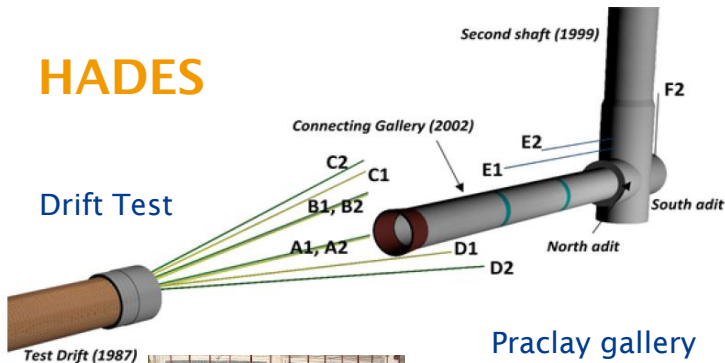
Stiff support



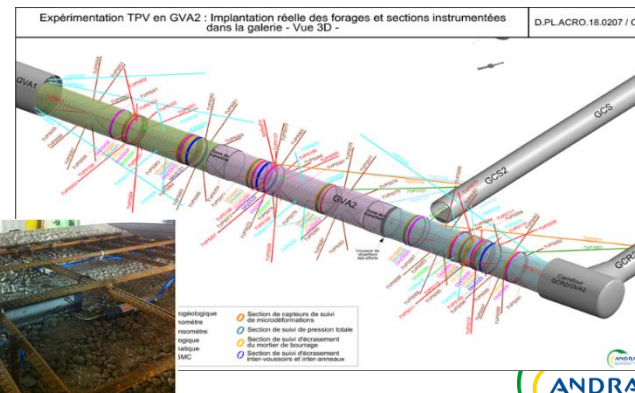
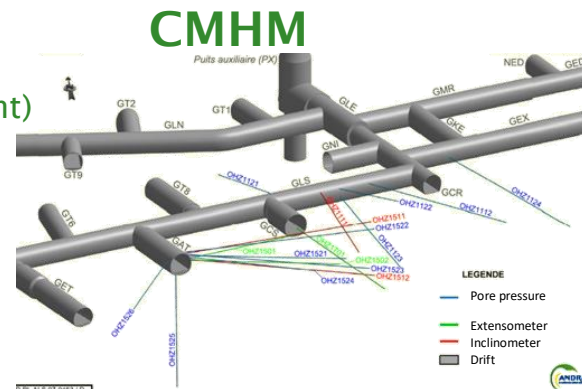
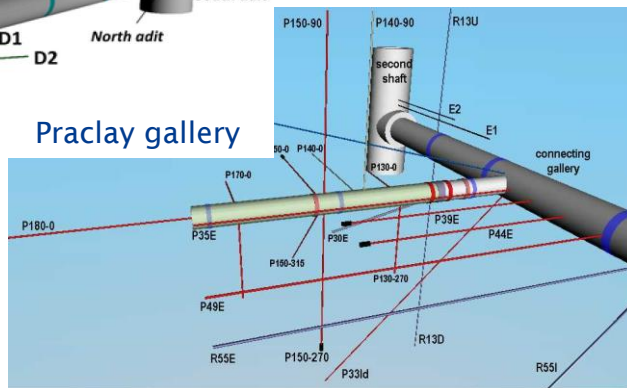
- Experimental set up: “Mine by experiment”
 - Boreholes (Displacement, pore pressure) emplaced before excavation
 - Convergence measurements, geological survey, boreholes (displacement)
 - Borehole to characterize EDZ (permeability measurements, velocity)

HADES

Drift Test



See Dizier et al presentation

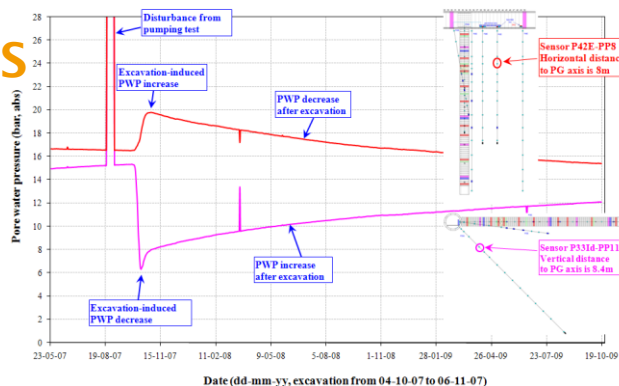


Hydromechanical behaviour of galleries

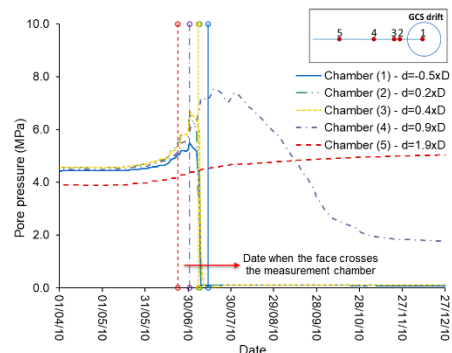
Similarities of the behaviour

- Similar trend observed during excavation
 - Strong coupling between mechanics and hydraulics leading to pore pressure evolution during excavations in a quasi-undrained condition
 - Anisotropy of the behaviour
- Two different laboratories in two different clay formations using similar but different instrumentation devices show similar hydromechanical processes
 - reinforces confidence in the reliability of results and the understanding of process

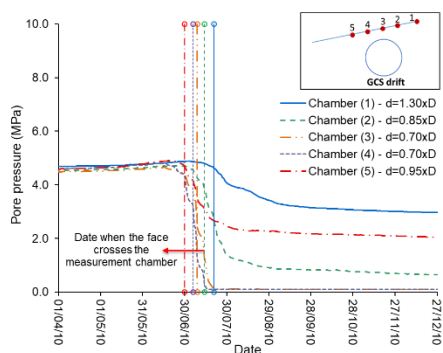
HADES



DISTEC/DCC/22-0040



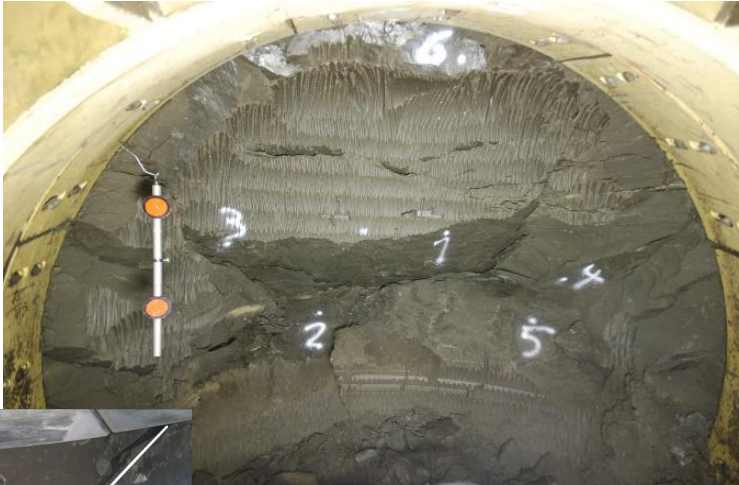
CMHM



The excavation damage zone

Shear herringbone fractures

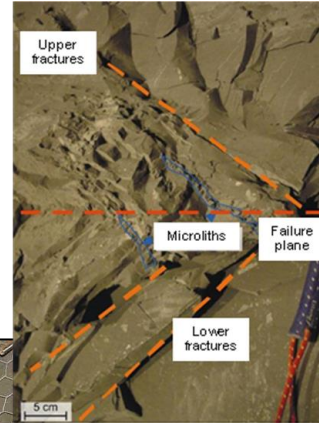
- Front and side wall



HADES



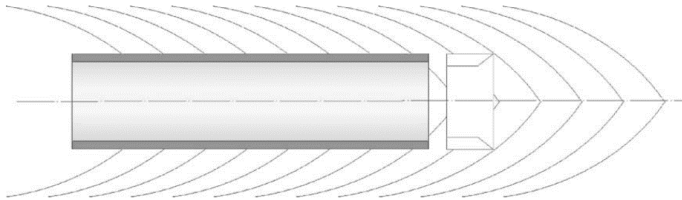
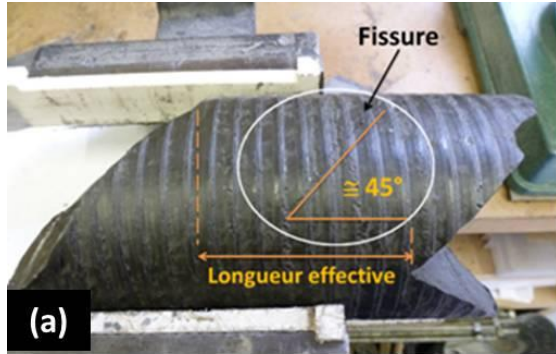
CMHM



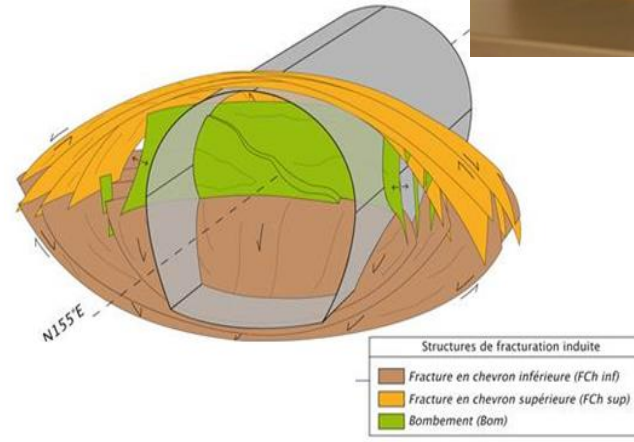
The excavation damage zone

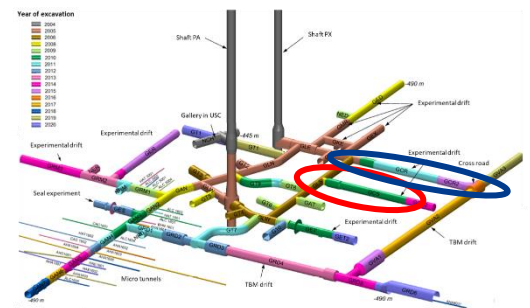
Shear herringbone fractures

HADES



CMHM



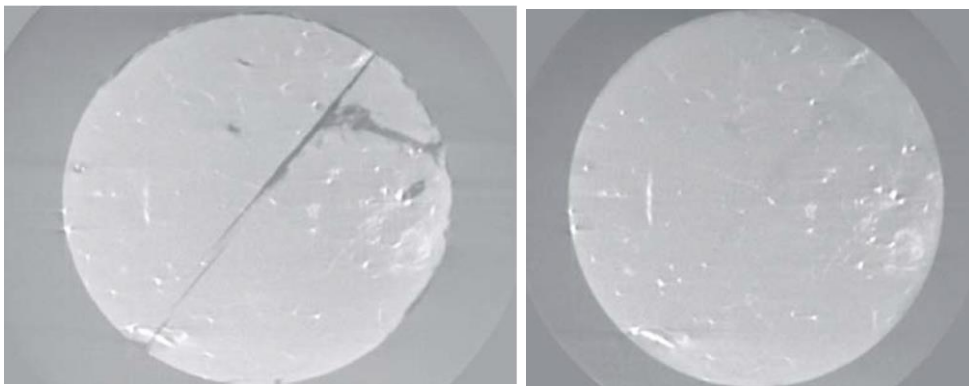


The excavation damage zone

Self sealing behavior

- Self sealing on Boom Clay deeply investigated in laboratory and in situ in the framework of SELFRAC (Vervoort et al. 2006, Bernier et al 2007)
- Show similarities even if rates are really different

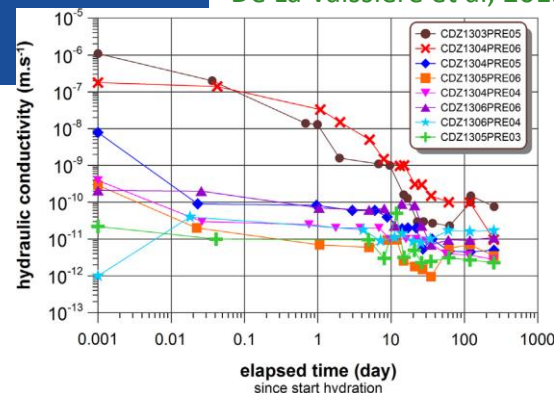
Boom clay



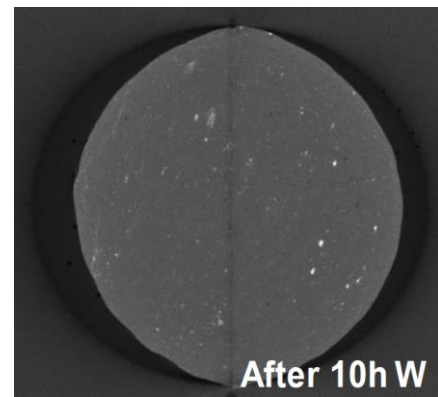
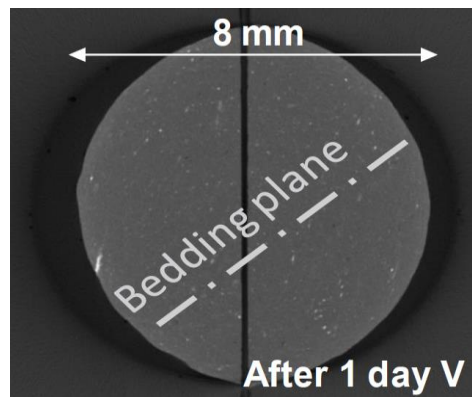
Bernier et al, 2006

DISTEC/DCC/22-0040

De La Vaissière et al, 2015



Callovo-Oxfordian claystone

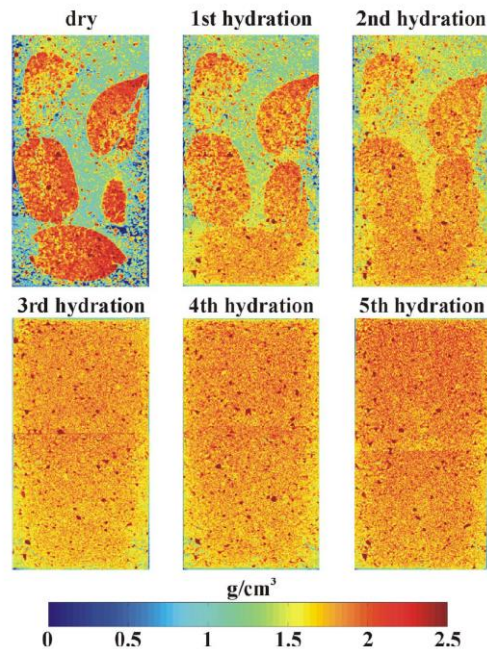


Di Donna et al, 2019



Seal experiment

- Bentonite behavior in seal is nearly independant of the surrounding rock
- Result obtained at HADES could be used to increase Andra Knowledge
 - Emplacement of swelling clays in the form of compacted blocks or in the form of powder/pellets mixture has helped to extend the range of solutions in relation to the performance expected for seal
 - Several small scales experiments have been performed to evaluate the swelling pressure and the permeability of the mixture



Reseal project
(Van Geet et al, 2009)

FSS pellet /powder mixture



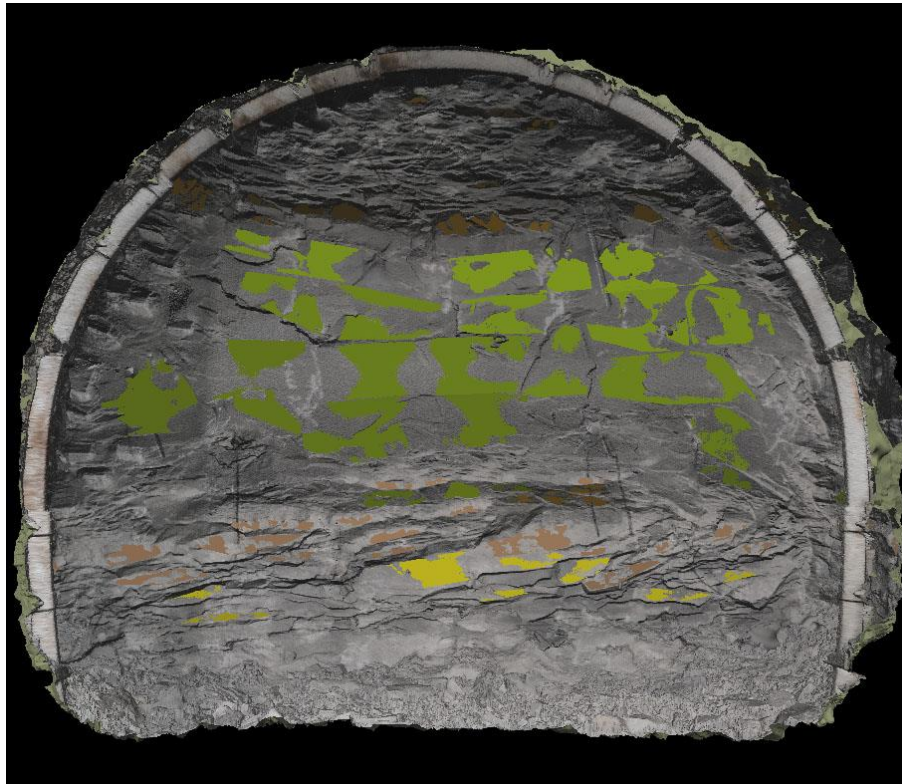
FSS mixture after
hydration
(Bernachy et al, 2020)

Outcome from HADES to Andra research program

HADES was the first URL in clay formation

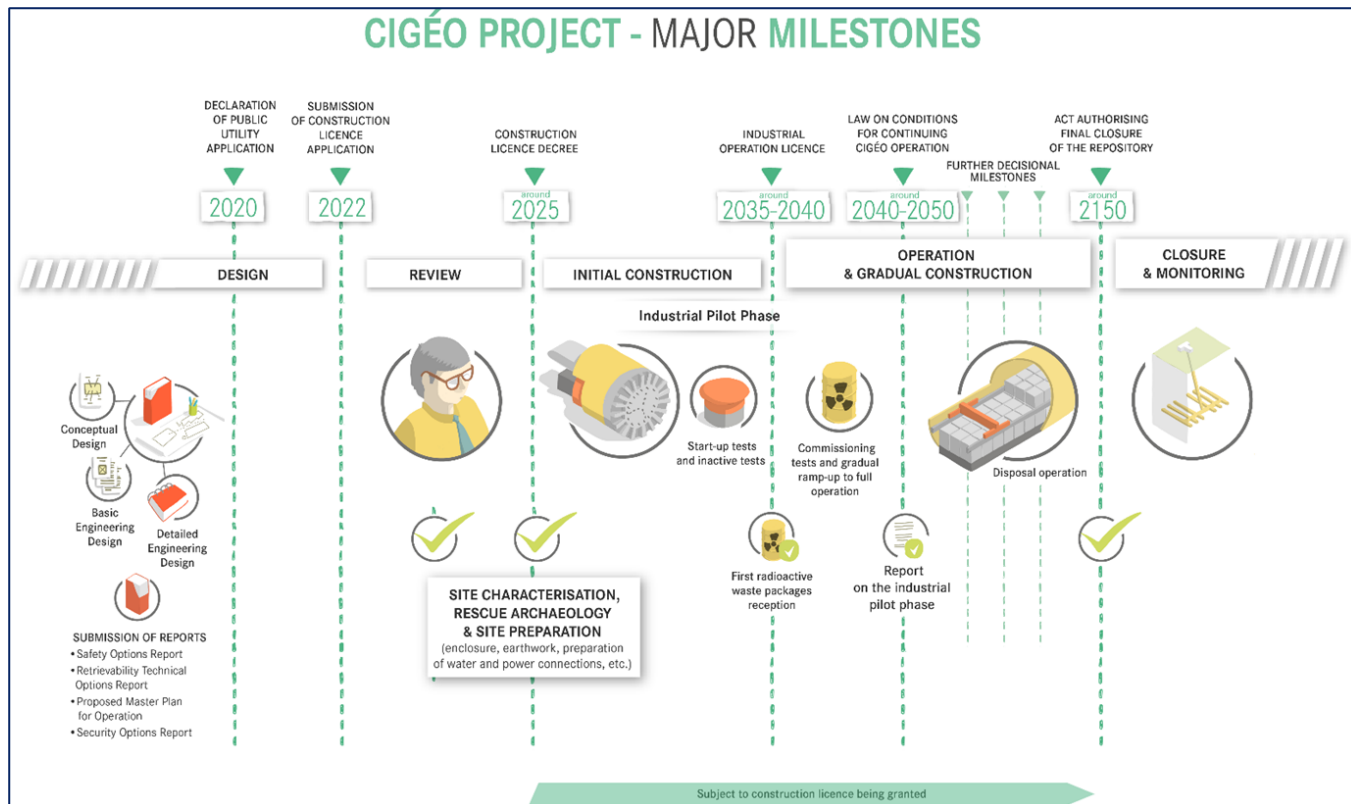
- Help to prepare Andra own experimental programs in the Meuse/Haute-Marne underground laboratory
 - Give experience in the construction of underground structures in clay at great depths,
 - Feedback on instrumentation for the hydromechanical monitoring of structures and around opening
 - Have enabled the CMHM to be developed more rapidly
- Despite the differences in responses between the plastic poorly indurated Boom Clay and the stiffer indurated Callovo-Oxfordian claystone, several processes show similar trends and give confidence to our understanding
 - HADES and CMHM show that different methods, even with road header under a shield, are effective to excavate and support gallery in clay/claystone
 - Strong coupling between mechanics and hydraulics leading to pore pressure evolution during excavations in a quasi-undrained condition
 - Shear fractures appear at the front and/or ahead the front face due to stress change regarding the strength of the clay/claystone
 - Self sealing of the excavation fracture network
 - Long term behaviour of the structures at CMHM shows that the convergence of the galleries continues over time of observation
 - Valuable data both for the design/construction of seals, for the knowledge about physical processes of seal hydration
- Although the fundamental processes are to some extent the same, their relative importance and response rates are different but comparison provides robustness to the understanding of the processes

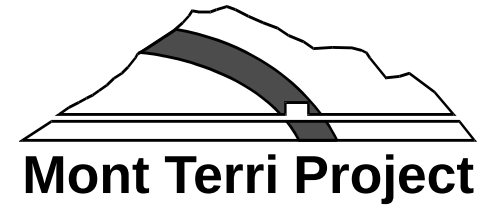
Thank you for your attention



Cigéo : next milestones

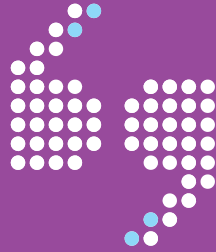
- **Cigéo project :**
mature but still
tremendeous works
and numerous step
to become a reality
- **Andra :**
reorganization to
ensure a smooth
mutation **from design**
stages to construction
and operation





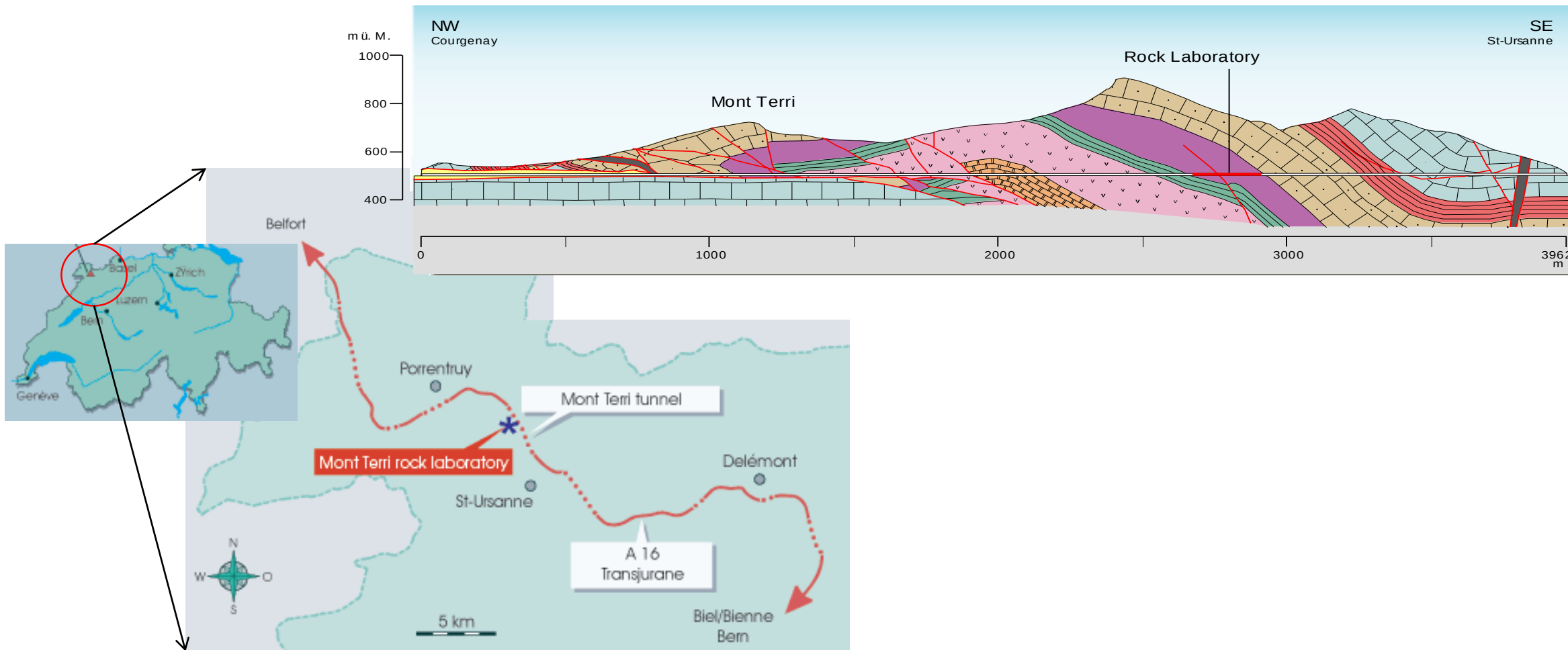
25 years of cross-fertilization between HADES and Mont Terri Rock Laboratory

Nussbaum Christophe, Bernier Frédéric, Bleyen Nele,
Bossart Paul, Bruggeman Christophe, De Cannière
Pierre, Fierz Thomas, Jaeggi David, Neerdael
Bernard, Valcke Elie and Volckaert Geert



Mont Terri Rock Laboratory

Mont Terri Rock Laboratory - location

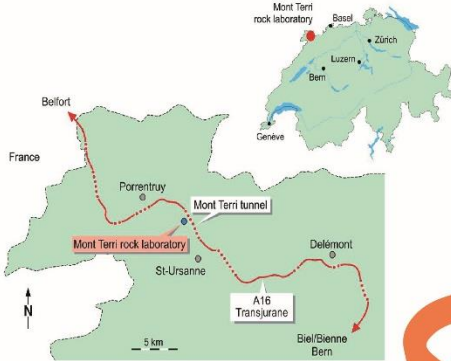


Mont Te

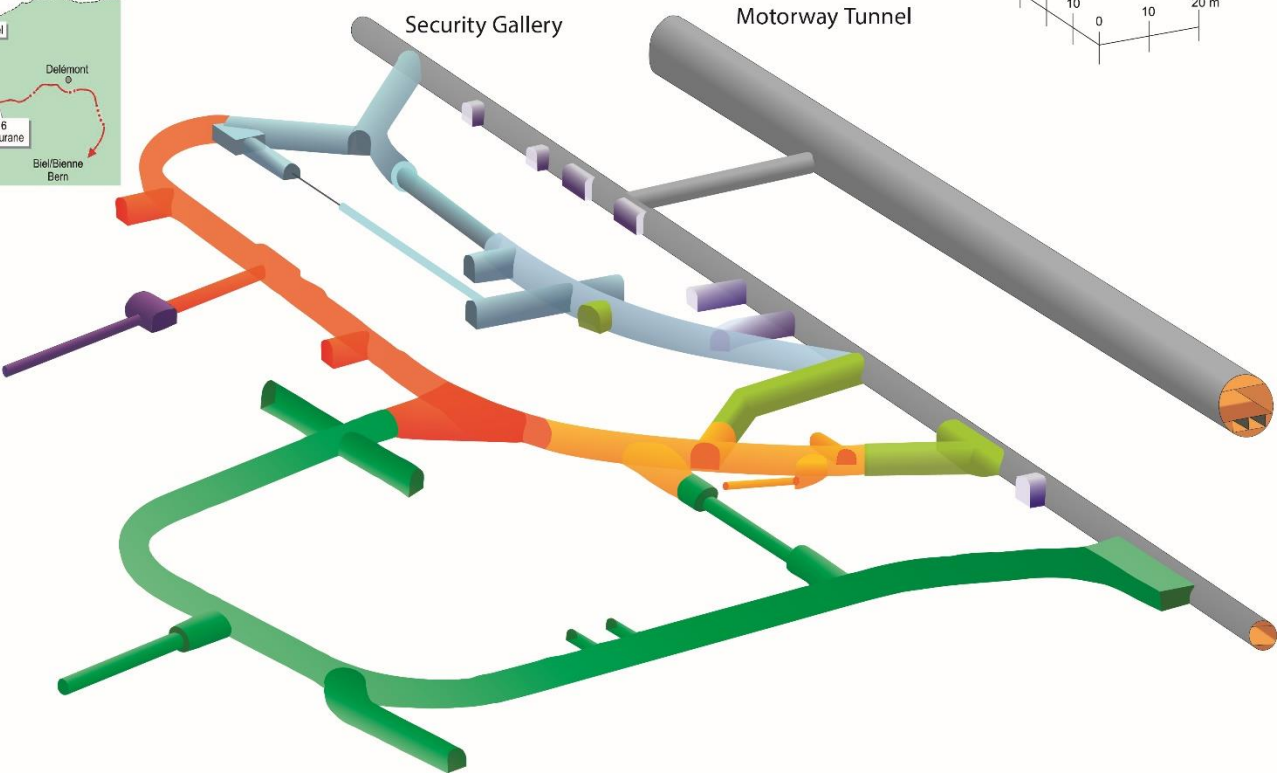
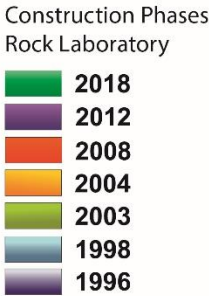
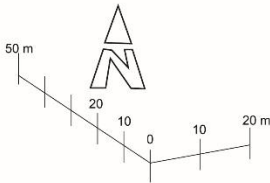


Start Mont Terri project

Rock laboratory in security tunnel for highway tunnel



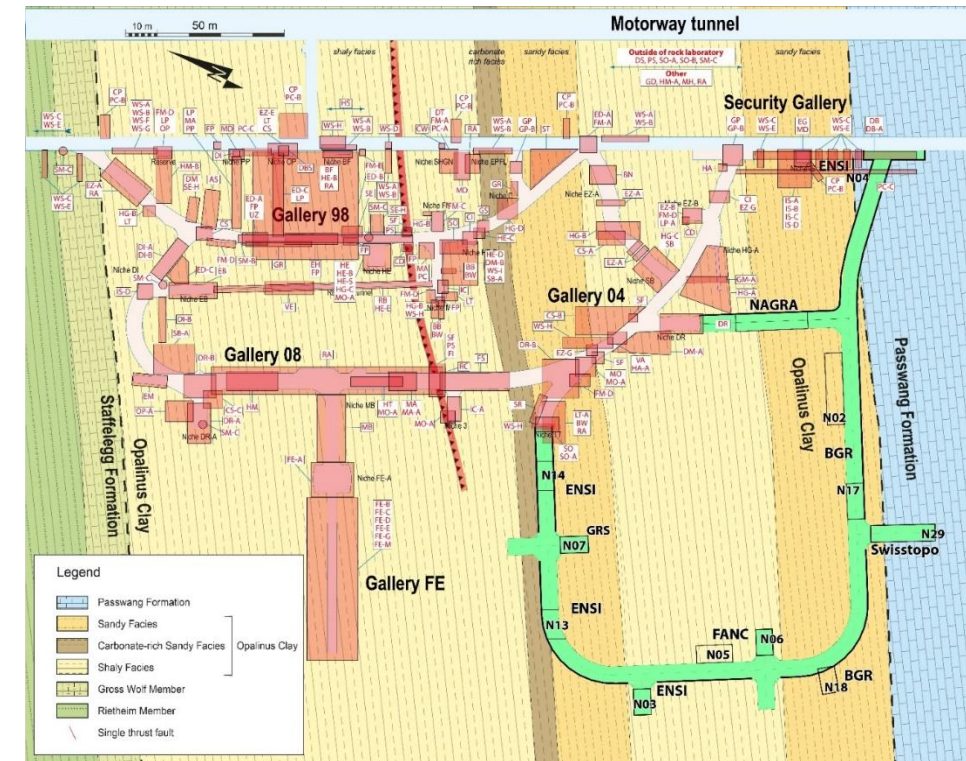
Rock Laboratory Mont Terri

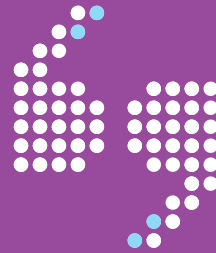


Mont Terri Project - aim

- Broad investigations of processes closely related to the safety functions of a repository for radioactive waste hosted in a clay formation

→ > 160 experiments have been / are being performed to increase our knowledge of the complex behavior of clay formations in response to coupled thermal, hydraulic, mechanical (THM), chemical (C) and (micro-)biological (B) processes





Collaboration between HADES and Mont Terri Rock Laboratory



Start Mont Terri project



Start of niche excavation in 1996



France



Japan



Belgium



Switzerland



SNHGS
(Patronate)

1996

1998

2004

2008

2018

2022

...

5 partners: **SCK CEN**,
Nagra, SNHGS,
Andra, PNC

22 partners from 9
countries

Collaboration HADES – Mont Terri



Start Mont Terri project



1996

1998

2004

2008

2018

2022

...

Knowledge transfer HADES → Mont Terri regarding

- Excavation in clay formations
- Operation of URL

Collaboration SCK CEN / HADES – Mont Terri

Transfer of knowledge on excavation

- !! Methodology used in HADES could not be transferred 1:1 to the Mont Terri site, due to geo-hydromechanical differences between both clay formations
- OPA: highly consolidated hard claystone
↔ BC: poorly-indurated, “plastic” clay
- OPA: thrust and folded anticline structure at Mont Terri
↔ BC: quasi-horizontal stratification around HADES
- But still more applicable than available knowledge on excavation in granite
- Knowledge and lessons learned from HADES still applicable, though needed to be adjusted for OPA





Start Mont Terri project



1996

1998

2004

2008

2018

2022

...

Knowledge transfer HADES → Mont Terri regarding

- Excavation in clay formations
- Operation of URL

Knowledge transfer SCK CEN ↔ Mont Terri

- Experimental design (*in situ*)
- Methodology
- Interpretation of results

Collaboration SCK CEN / HADES – Mont Terri

Transfer of knowledge on experimental design and interpretation

!! Geo-physico-chemical differences between both clay formations

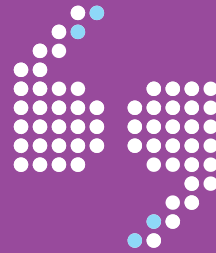
	OPA	BC
Porosity	11-16%	~38%
Water content	3.5-8%	~19%
Hydraulic conductivity (⊥ bedding)	$0.6-2 \times 10^{-13}$ m/s	$2-4 \times 10^{-12}$ m/s
Clay minerals	Similar except smectite (~0 wt%)	Similar except smectite (~14 wt%)
Accessory minerals	rich in carbonated and sandy facies Presence of celestite	Low carbonate content No celestite
Organic material (OM)	More mature OM	Immature OM
Porewater chemistry	Half-diluted sea water based	0.15 M NaHCO ₃ based – high DOC

Collaboration SCK CEN / HADES – Mont Terri

Transfer of knowledge on experimental design and interpretation

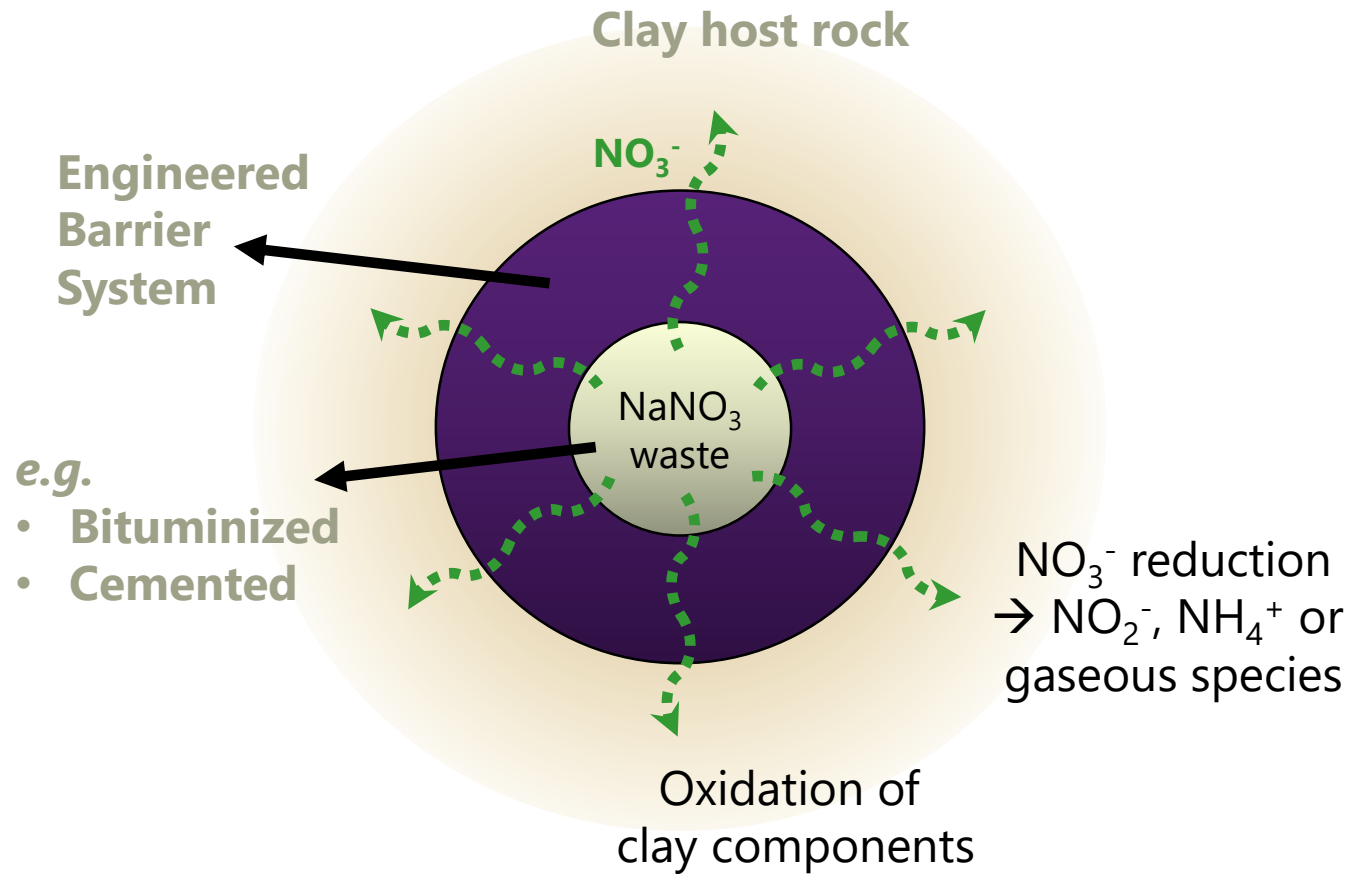
- Despite geochemical and mechanical differences between OPA and BC: fruitful collaboration and knowledge transfer from one URL to the other and vice versa
- Covering areas as broad as **geochemistry**, **diffusion**, **microbiology** and **THM experiments** and recently **gas transport**



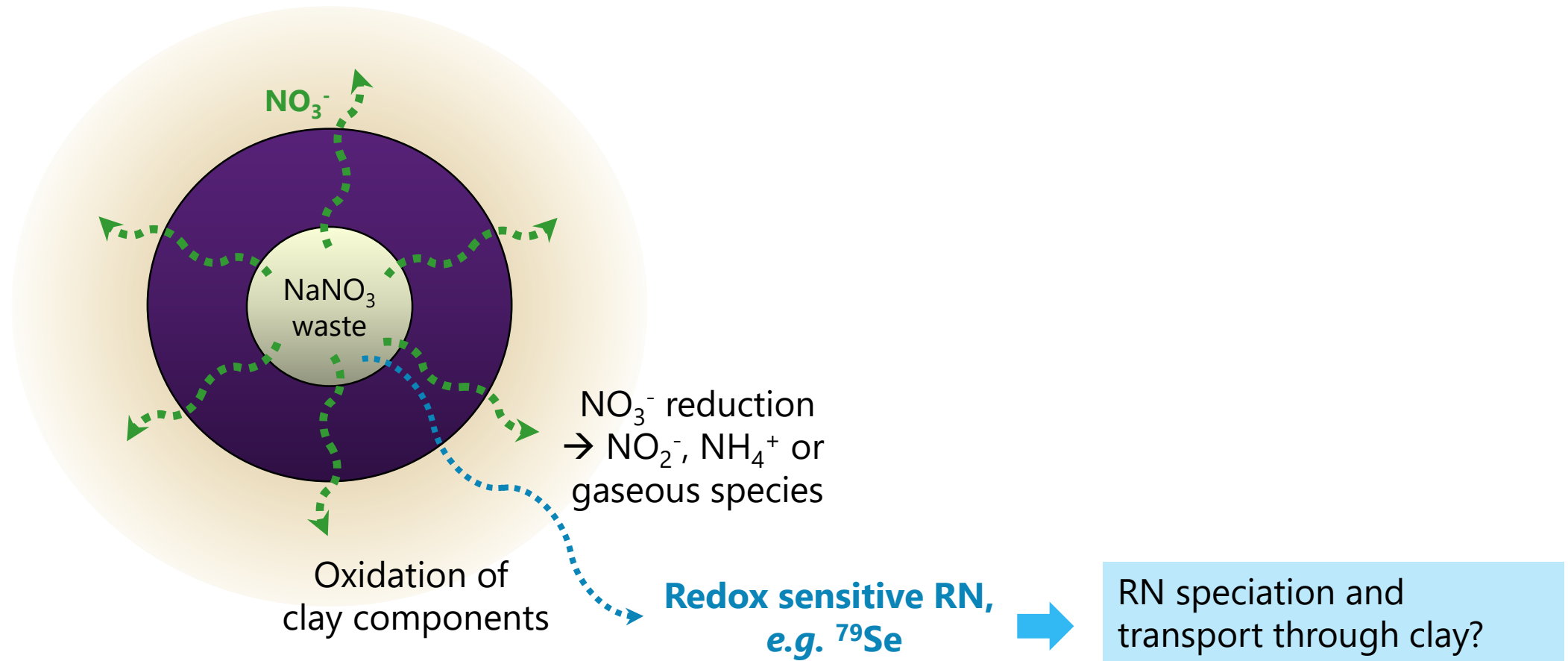


Example of fruitful collaboration:
Experiments assessing nitrate reactivity
in clay formations

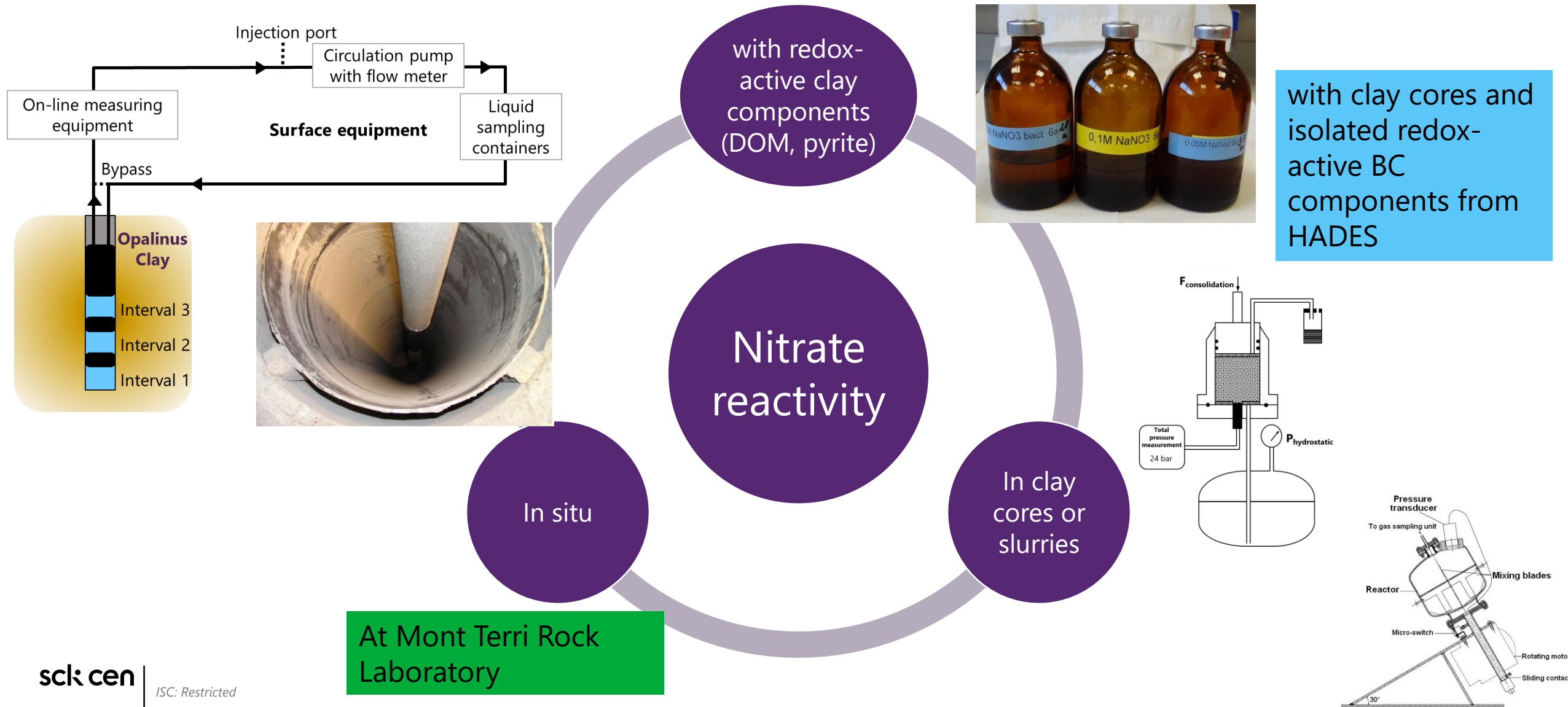
Perturbations by nitrate plume in the near field?



Perturbations by nitrate plume in the near field?



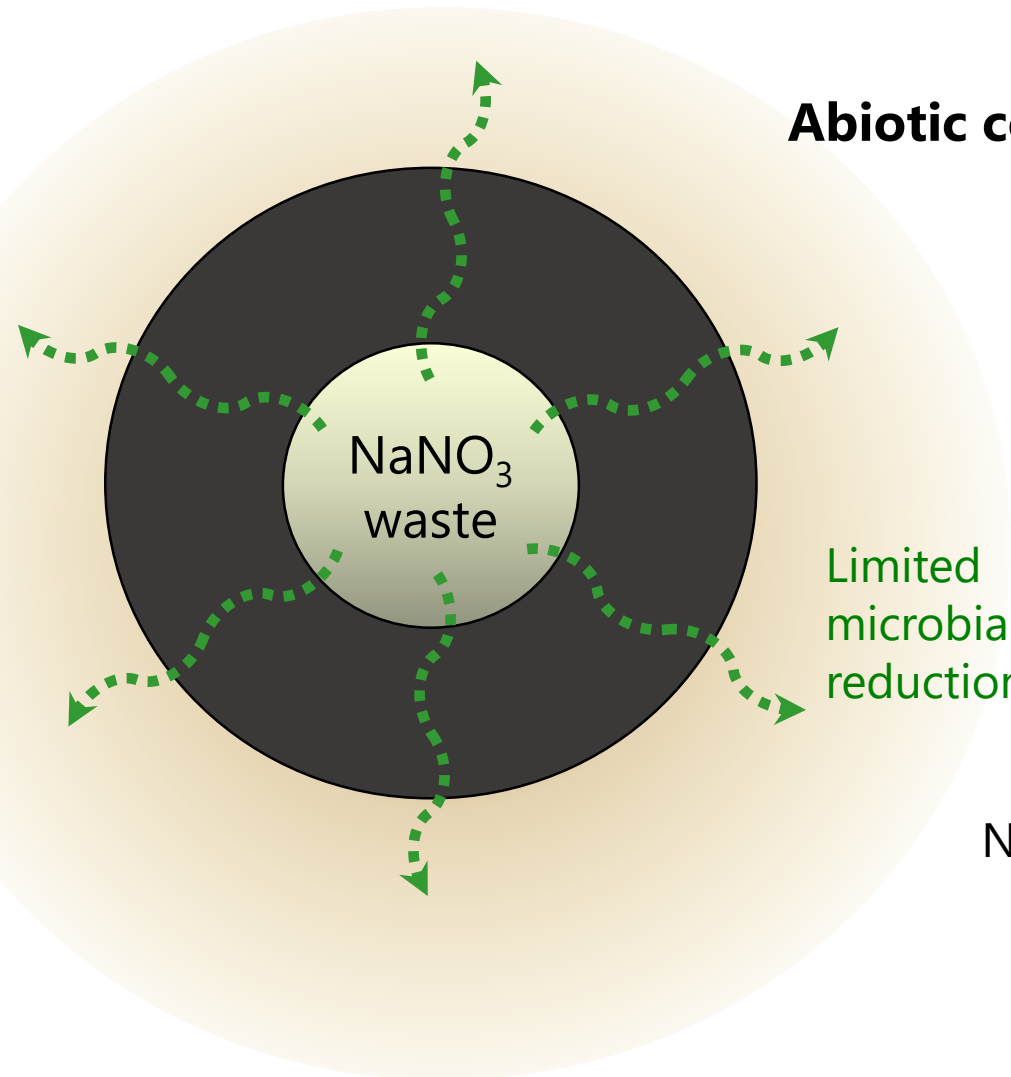
20 years of research on nitrate reactivity in BC and OPA



20 years of research on nitrate reactivity in BC and OPA

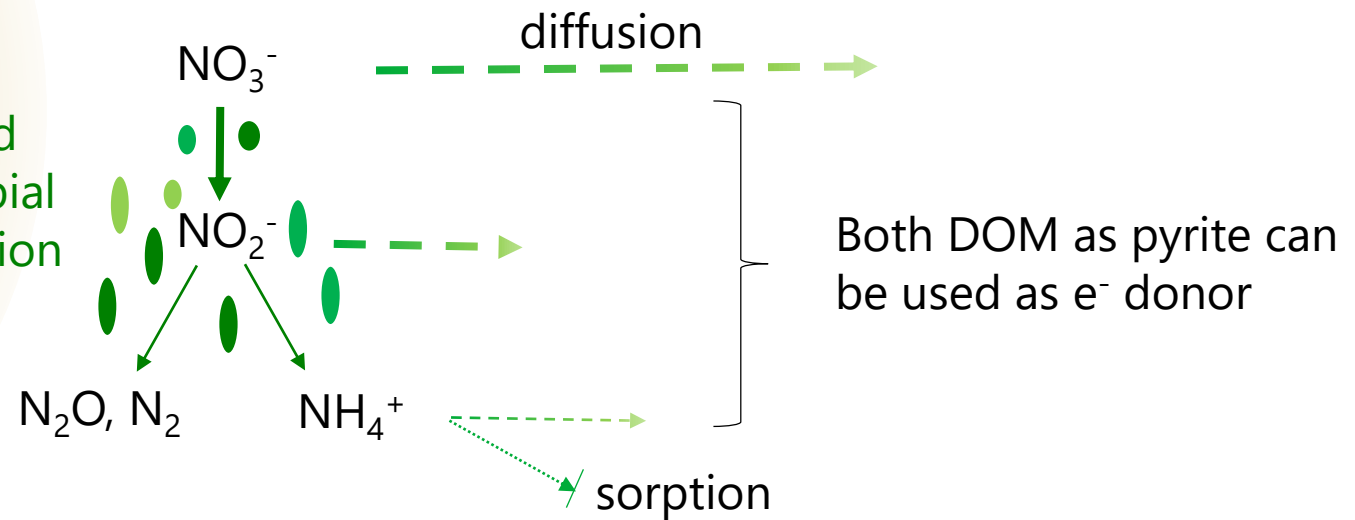
- The experimental programs at SCK CEN and Mont Terri have been running simultaneously
 - Abiotic vs biotic lab tests
 - *In situ* / in percolation tests: taking into account both diffusion + possible reactivity
 - With/without bitumen degradation products such as acetate, but also H₂
- ➔ Knowledge obtained in these experiments allows us to make hypotheses on the fate of nitrate in a clay formation surrounding a disposal facility and the possible perturbation of the reducing capacity of the clay

20 years of research on nitrate reactivity in BC and OPA - conclusions

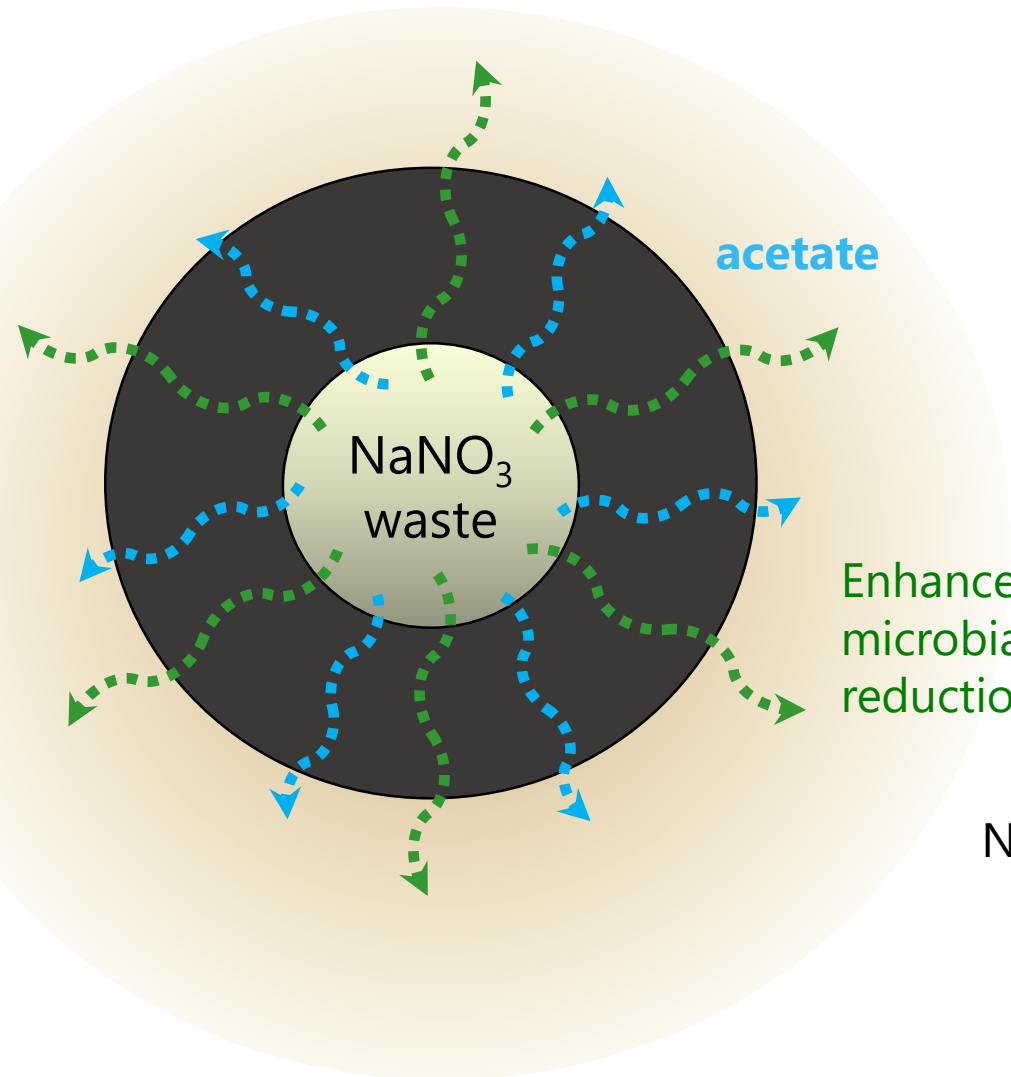


Abiotic conditions: nitrate diffuses as a non-reactive anion

In niches without microbial restriction:



20 years of research on nitrate reactivity in BC and OPA - conclusions

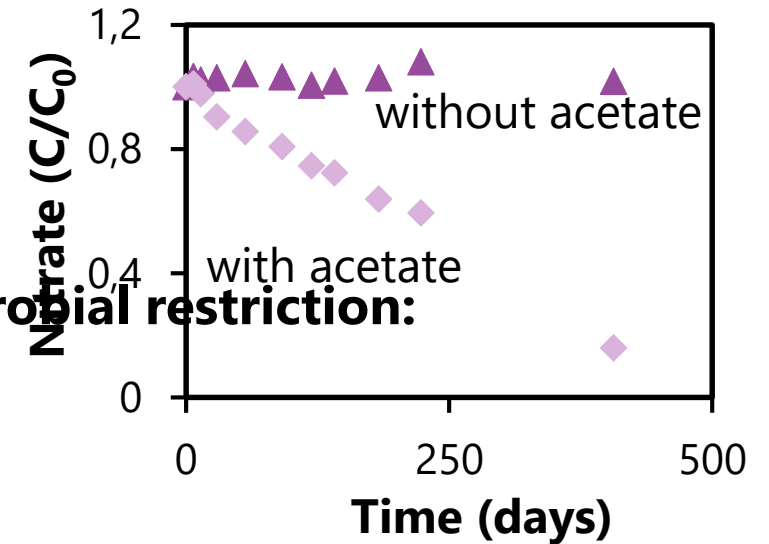


In BC pore water

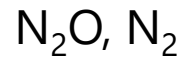


In nic

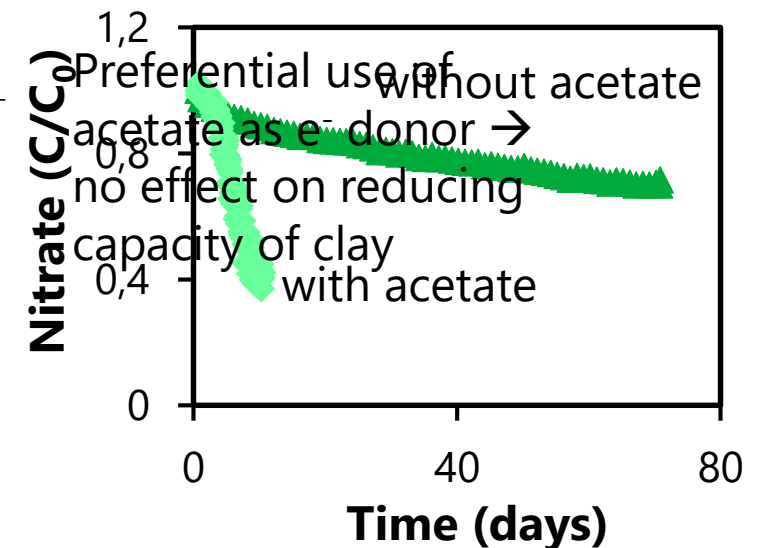
microbial restriction:

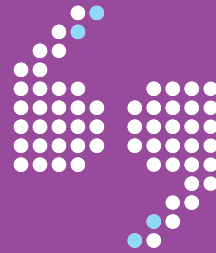


Enhanced microbial reduction



In situ in OPA

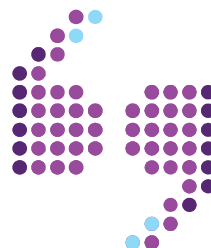
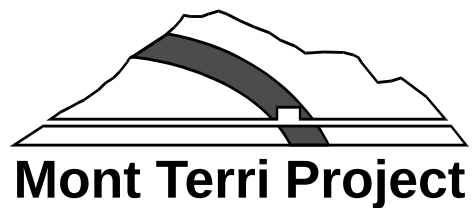




Conclusions

Conclusions

- Despite the physicochemical and hydromechanical differences between Boom Clay and Opalinus Clay → plenty of collaboration and cross-fertilization possible
- Exchanges between both rock laboratories resulted in
 - knowledge transfer from one clay formation to the other one and vice versa
 - building confidence in new experimental methods, monitoring techniques, interpretation and modelling works, in different multi-disciplinary fields
 - fruitful integration of available knowledge
 - In the case of 'nitrate reactivity' experiments → both experimental programmes complemented each other and helped in building confidence in the expected ongoing processes



Thank you for your attention!

Questions?





Underground Research Laboratories, an Important Support to the Belgian Regulatory Body's R&D and the Management of Uncertainties

Frédéric Bernier¹, Valéry Detilleux², Frank Lemy², Guillaume Pochet¹, Maryna Surkova¹, Geert Volckaert¹, Chantal Mommaert²

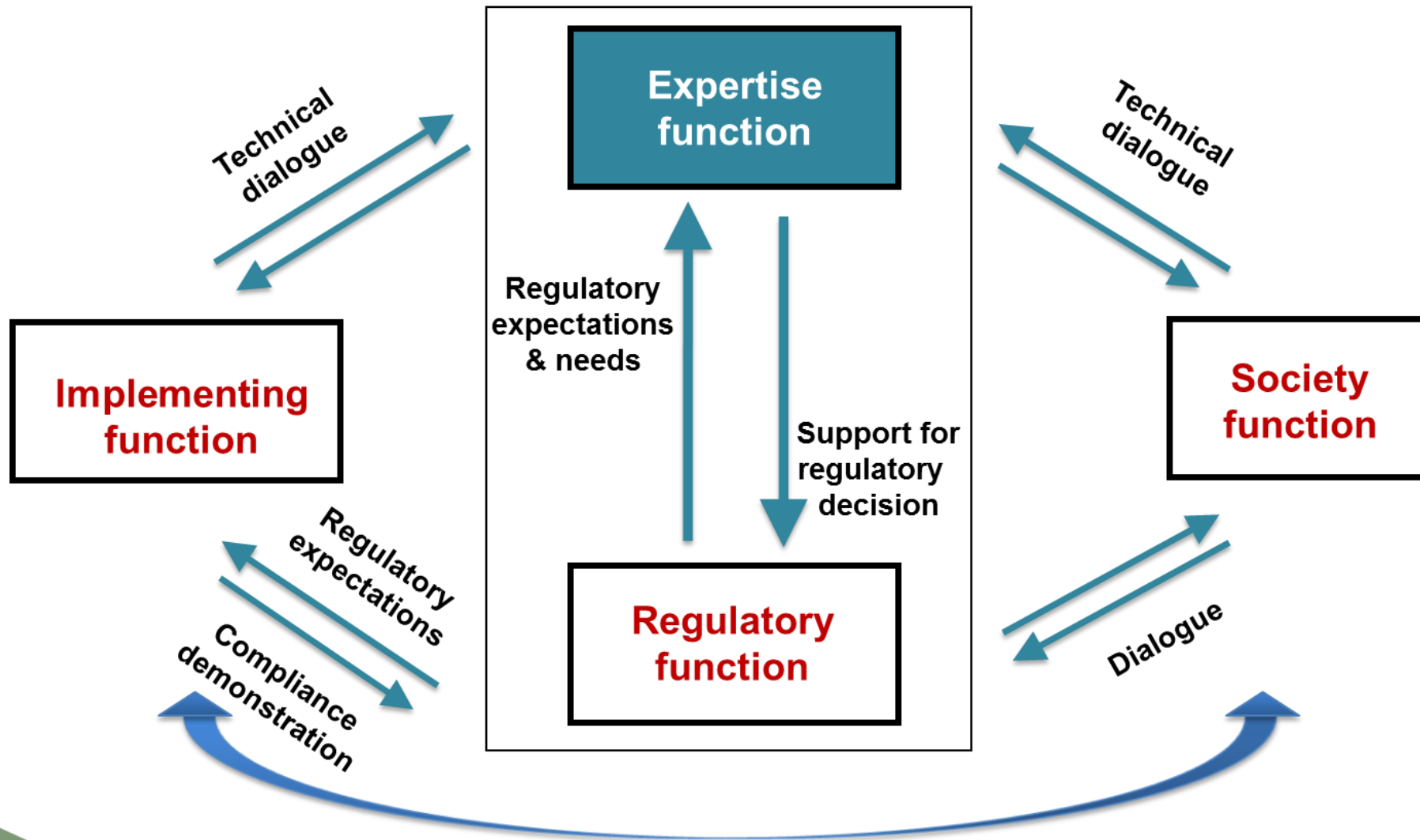
¹ FANC, ² Bel V

What the Regulatory Body is responsible for?

- FANC and Bel V form together the Belgian Regulatory Body
- Protection of the people and the environment from harmful effects of ionizing radiation
 - common objective with the operator
- Service to government and people
 - independent position
- More specifically in the context of radioactive waste management
 - establishment of safety requirements → regulation
 - oversight of the of the waste management activities
 - Nuclear Operators & Waste Management Organisation
 - advices on proposals for national waste management policies
 - involvement in the decision making process
 - review of safety cases

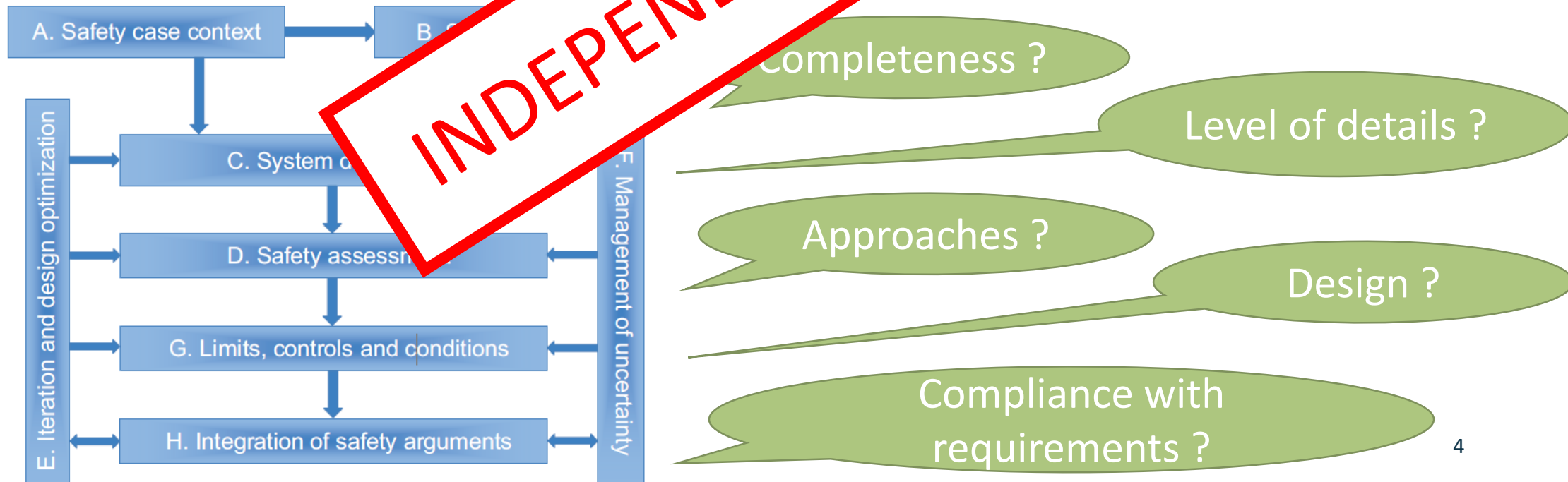
How the regulator interacts with stakeholders?

Regulatory body and its supporting organizations



Technical expertise is essential to support the regulatory function

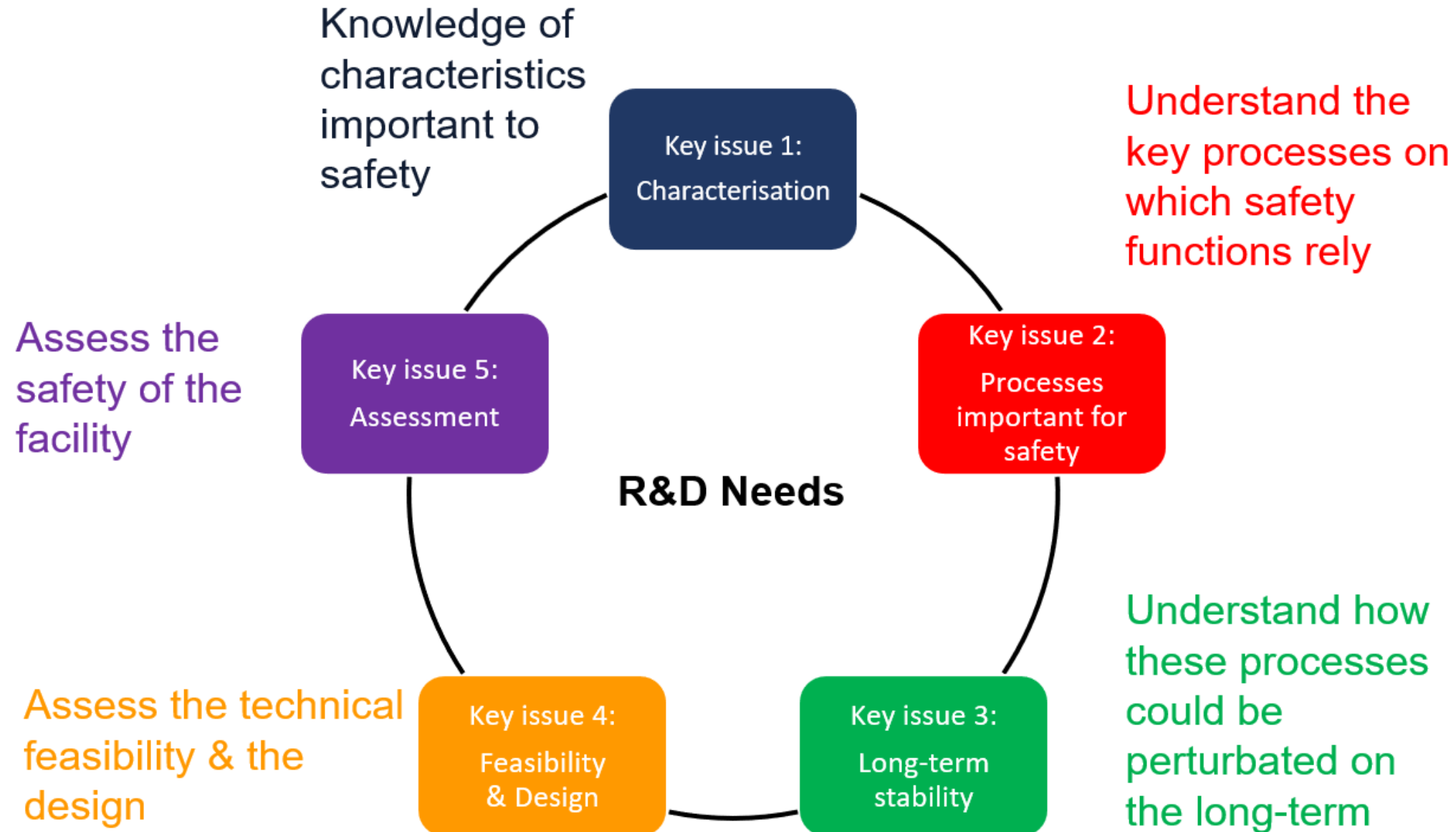
- Verification of the adequacy, completeness and justification of technical requirements and guidance
- Informed decisions with full knowledge of the facts
- Justification of advices and decisions
- Capacities to understand and assess various cases



FANC and Bel V are implementing a R&D program to develop their expertise in support to the regulatory function

- Not a duplication of the WMO RD&D programme
 - focus on safety issues in order to
 - develop & maintain competent staff, to acquire capabilities for independent assessment
 - identify potential gaps in safety cases
 - support advices and decisions
 - not necessary to undertake independent research if the regulatory body is satisfied that the operator is undertaking appropriate research that is of sufficient quality (IAEA - SSG14)
- Evolves according to the decision-making process

The R&D programme is structured along 5 axes



Participation in Tournemire and Mont-Terri



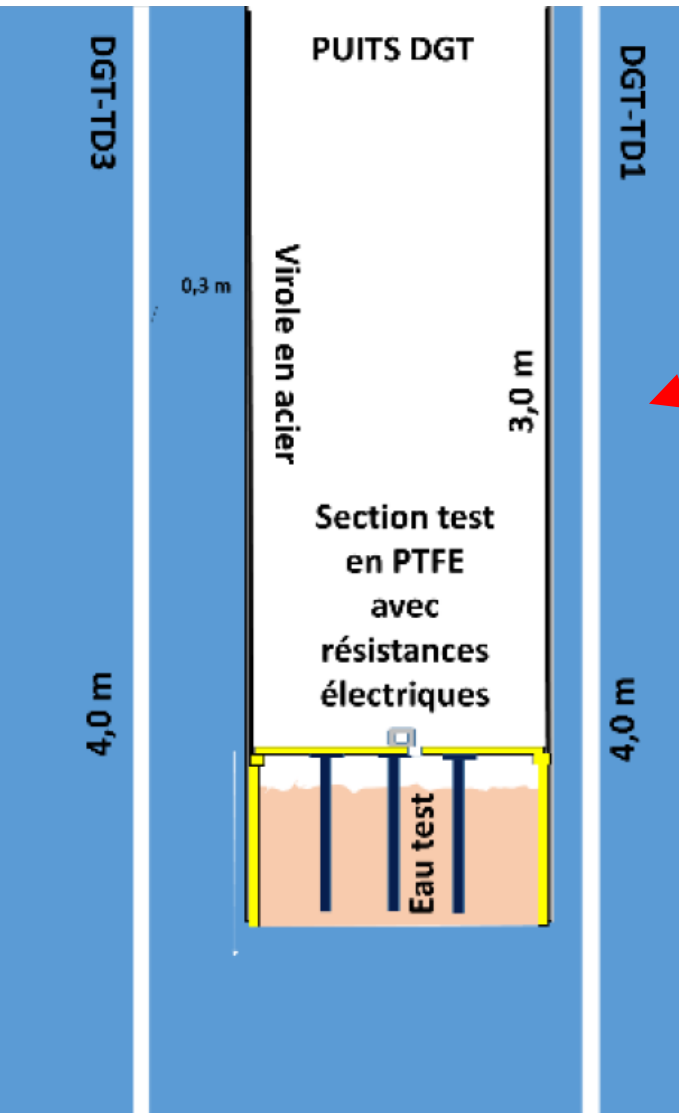
- The participation in URL's is essential to develop a broad, coherent and independent Regulatory Body's vision
- Direct access to information and exchanges with internationally recognised experts allow to save a significant amount of time and to increase the efficiency and credibility of the Regulatory Body

Independent research includes the diffusion of radionuclides in a thermal gradient

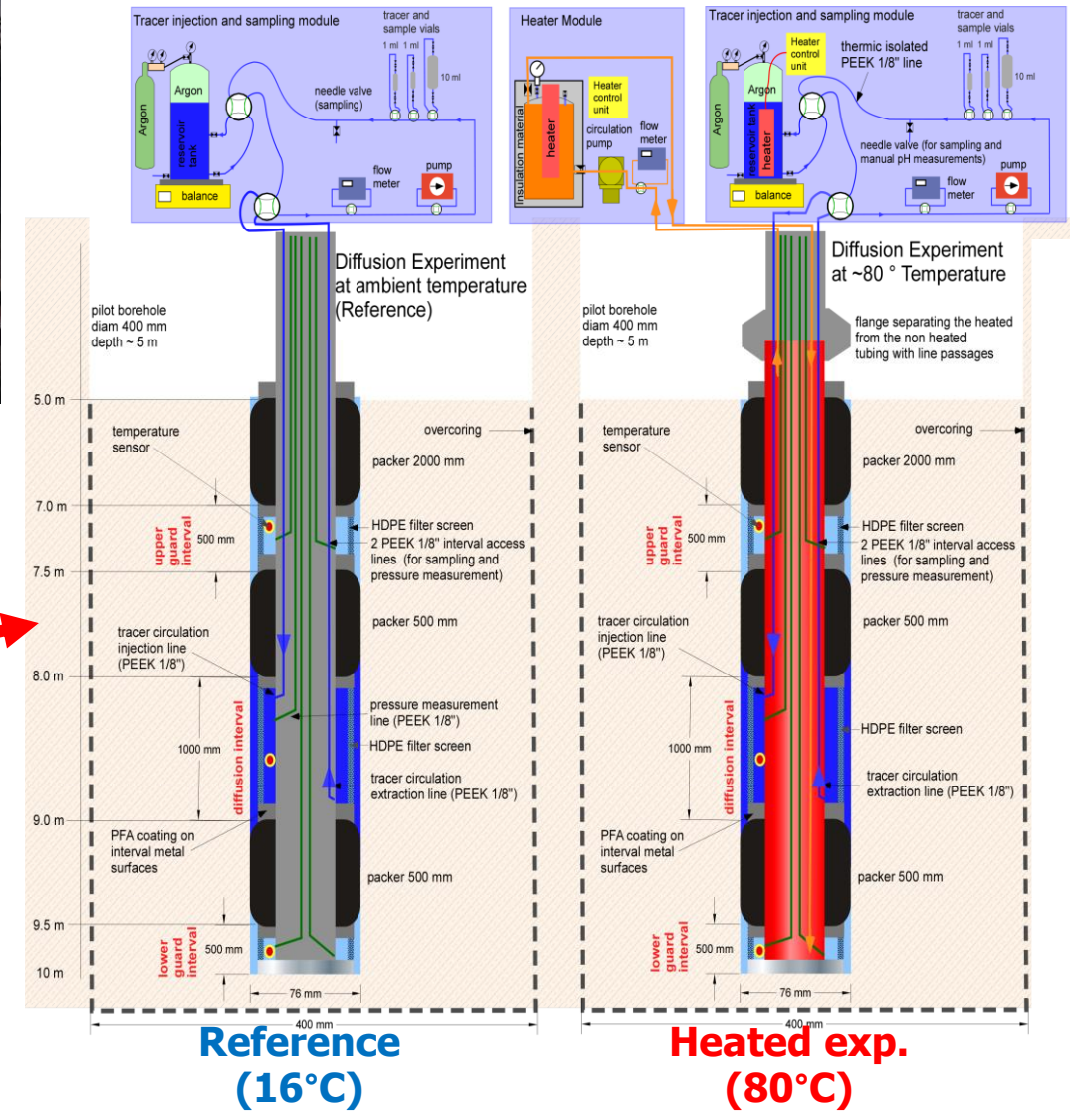
- While experiments have been carried out in surface laboratories (Van Loon & al.; 2005; Sánchez & al., 2008), there is a lack of experimental data regarding the effect of temperature on radionuclide diffusion under in situ conditions
- Case of premature canister failure
 - essential to estimate the possible increase in diffusion rates to better assess the possible contamination of the near-field – retrievability
- Stakeholders acceptance

Two in-situ experiments were launched at Tournemire and Mont-Terri

DIGIT experiment - Tournemire



DR-C experiment – Mont Terri



The scientific and technical survey of results from other URL's (HADES, Bure, ...) also constitutes an important source of knowledge

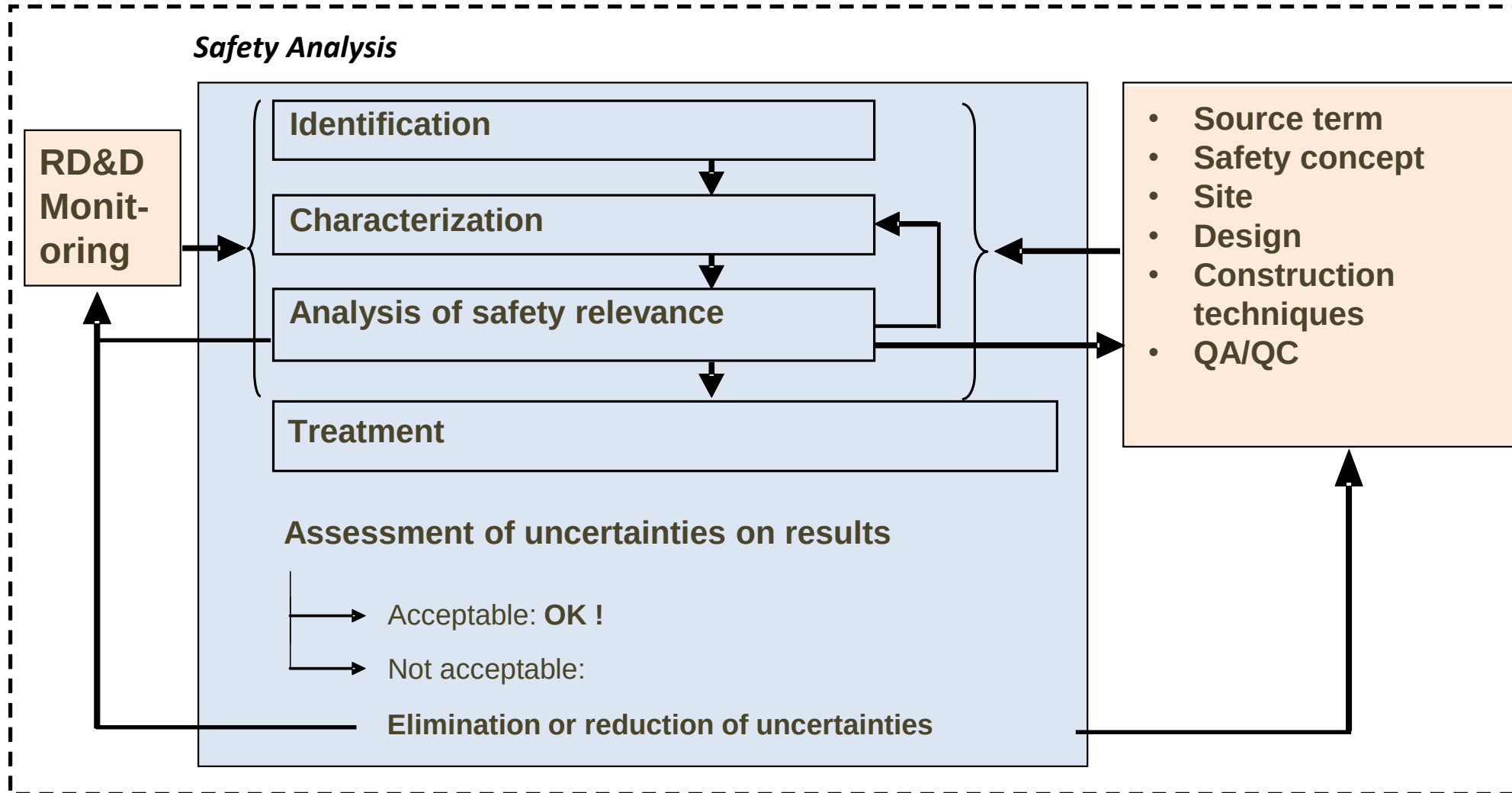
- The investigation of processes observed for different host rocks and engineered components, allows a better understanding of the phenomena at play and the relative importance of the associated parameters
- It contributes to the validation of the models obtained by comparing modelling results with experimental results
- The highlighting of similar processes observed in different laboratories is also of particular importance. Despite the differences in the host rocks some observed characteristics and processes present similarities building confidence in the understanding of geological disposal systems

URLs' in-situ experiments contribute to decrease uncertainties

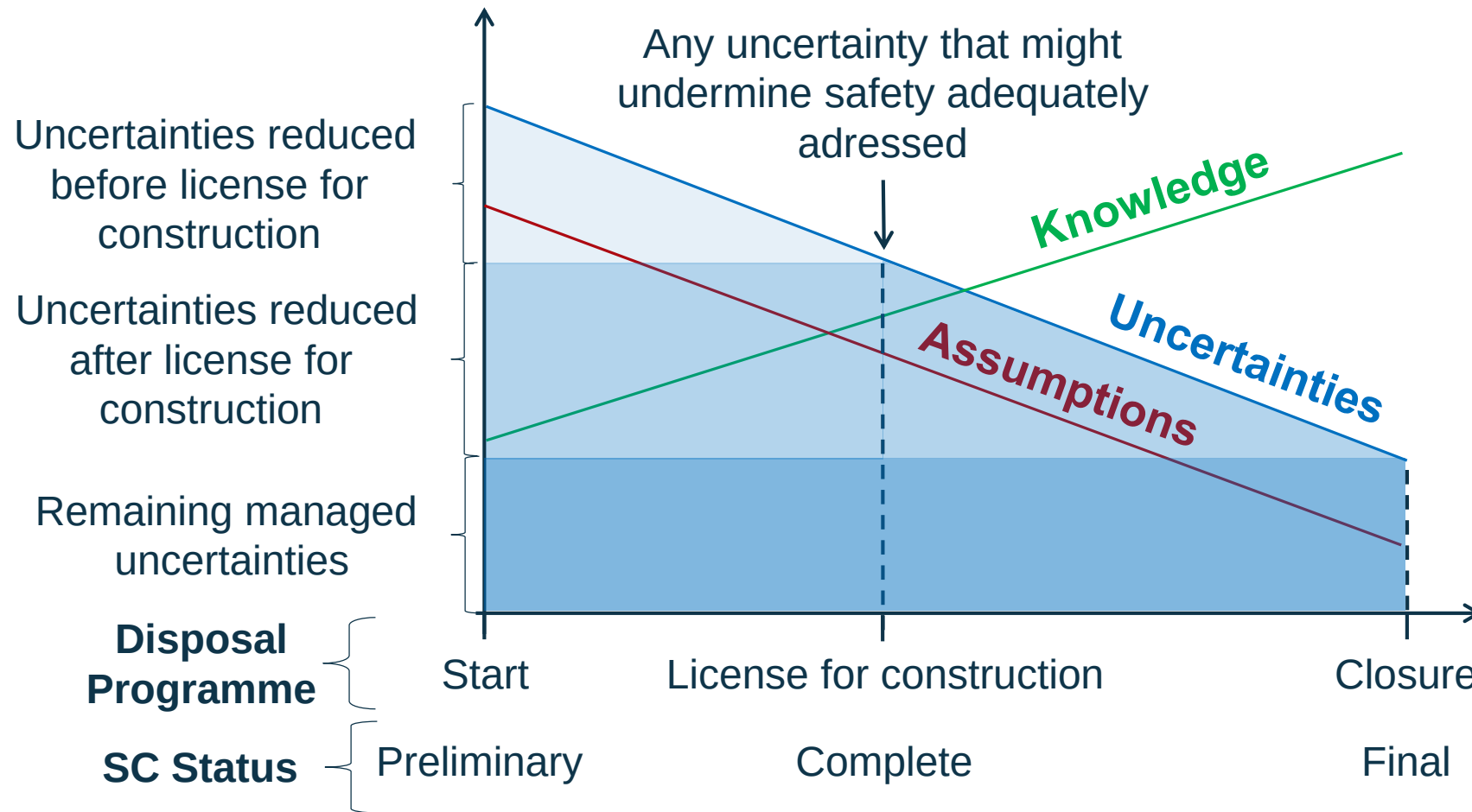
- barriers characteristics including the initial state and conditions
- understanding of Hydro-Mechanical processes
- radionuclide transport processes
- influence of the temperature
- hydration processes of engineered materials
- degradation processes (e.g. corrosion, alkaline front, ...).

However such experiments lead sometimes to “new” uncertainties and processes that were not identified before

Uncertainty Management



Expectations according the decisions steps



Conclusions (1)

- To support its missions, the Belgian Regulatory Body conducts its own independent Research and Development programme dedicated to the understanding of the disposal system and processes that can influence radionuclide transport
- The R&D programme includes in situ experiments supporting the identification and characterization of uncertainties. An important issue is the influence of a thermal gradient on the transport of radionuclides

Conclusions (2)

- The participation in URL's experiments provides a unique opportunity to identify experimental challenges and to collaborate with internationally recognized experts in various disciplines relevant to the safety case
- The Research and Development objectives set by the Regulatory Body differ from those set by the WMO. The Regulatory Body will mostly investigate issues directly related to safety with the objective to verify the adequacy of the approaches followed by the WMO