

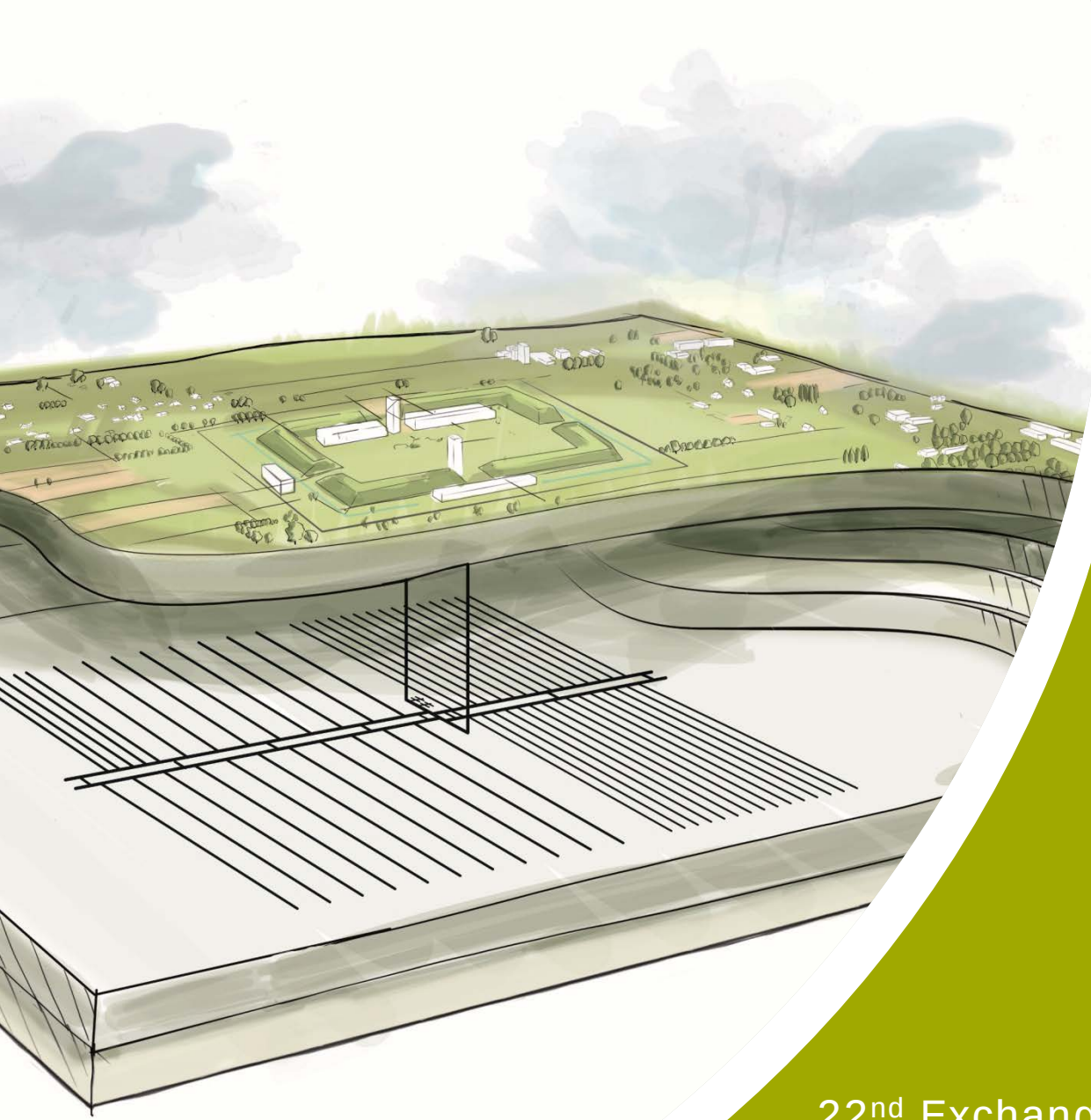


22ND EXCHANGE MEETING

The role of monitoring in radioactive waste disposal

Lakehouse Mol, Tuesday 1st October 2019

- 13:30 Welcome
Peter De Preter (EIG EURIDICE)
- 13:40 Monitoring strategies for radioactive waste disposal
Christophe Depaus (ONDRAF/NIRAS)
- 14:10 Involvement of local stakeholders in the research and development of monitoring strategies
– feedback from the EC project Modern2020
Axelle Meyermans (Antwerp University)
- 14:40 40 years of monitoring experience in the HADES URL: Performance assessment of installed sensors
Jan Verstricht (EIG EURIDICE)
- 15:10 Coffee break
- 15:30 The surface disposal project for category A waste: Monitoring of the future cAt site and disposal facility
Vanessa Cauwels (ONDRAF/NIRAS)
- 16:00 The surface disposal project for category A waste: Monitoring of the test cover
Eric Laloy (SCK•CEN)
- 16.30 Closure drink



ONDRAF/NIRAS

Monitoring strategies for radioactive waste disposal

The case of Geological Disposal

Christophe Depaus

ONDRAF/NIRAS

22nd Exchange meeting
Mol, Belgium
October 1st 2019



Outline

- **What's new since 2013 (18th E.M.)?**
- **From the law to the strategy**
- **Role of repository monitoring in a safety case**
- **High-level strategy elements: strengths and weaknesses**
- **Examples (of strategies) from abroad**
- **Belgium?**
- **Conclusions**

What's new since 2013 ?

w.r.t « monitoring » of GDF

- **EU project MoDeRn 2020**

- ☐ WP 2 : monitoring programme design basis, monitoring strategies and decision making

- **Belgian law of 3rd June 2014 (2011/70/Euratom)**

Art.4 :

- ☐ « The national policies [...] will contain:
 - modalities of reversibility, retrievability and monitoring for RW disposal;
 - for a period to be determined [...];
 - the modalities taking due account of the safety of the disposal system »

From the law to the strategy.

Meaning of modalities ?

- **Modalities may refer to several questions:**
 - What ?
Packages/elements of EBS/ host rock will be monitored ?
 - Where ?
In situ or in a pilot facility ?
 - When ?
before operation or/and during w. emplacement or/and after closure ?
 - (How ?)
 - refer to the means, tools and instrumentation
 - beyond the scope of WP2 (strategy)
 - beyond the scope of national policy !!

From the law to the strategy

Monitoring strategy for disposal?

- **Strategy** = plan/approach for successfully achieving a specified objective
- **Monitoring strategy** = high-level approach to repository monitoring including consideration of *what; where and when*.
- **The development of a monitoring strategy is important**
 - To comply with law and/or;
 - To initiate policies

...But first of all, to define the role of monitoring in the Safety Case
(= high-level approach)

Role of monitoring in a safety case

Key messages

▪ **Reminder / Monitoring definition (IAEA, SSG-31, 2014):**

« Monitoring refers to continuous or periodic observations and measurements to help evaluate the behaviour of components of a waste disposal system and the impact of the waste disposal system on the public and the environment. Most specifically, it covers the measurement of radiological, environmental and engineering parameters »

MoDeRn2020 adds to the definition:

- or other parameters/characteristics/indicators
- In order to support decision making during disposal process and to enhance confidence in the disposal process

Role of monitoring in a safety case

Key messages

- **Demonstration of safety does not / should not rely on monitoring...**
 - ... but the « monitoring programme should be used to strengthen the safety case and to build confidence in safety »;
 - ... and one of the objectives of monitoring is to « verify that the disposal system is performing as expected, as set out in the safety case » (IAEA, SSG-31).

Ambiguity ?!

→ **Monitoring outcomes must be used in the correct context**

Role of monitoring in a safety case

Key messages

- **Monitoring results cannot be (directly) compared to safety assessment model results. Why ?**
 - Safety assessment is based on the performance of barriers /SFs NOT a detailed evolution of system;
 - Safety assessment models use conservative/pessimistic assumptions and do not address all sub-system behaviour
 - Monitoring results can only be compared with models of (sub-)system evolution predicting parameters that are monitored
(« History matching »)

Role of monitoring in a safety case

Key messages

↔ IAEA : « To verify that the **key assumptions** made and models used to assess safety are **consistent** with actual conditions » (IAEA, SSG-31)

↔ requirement for kind of « calibration »

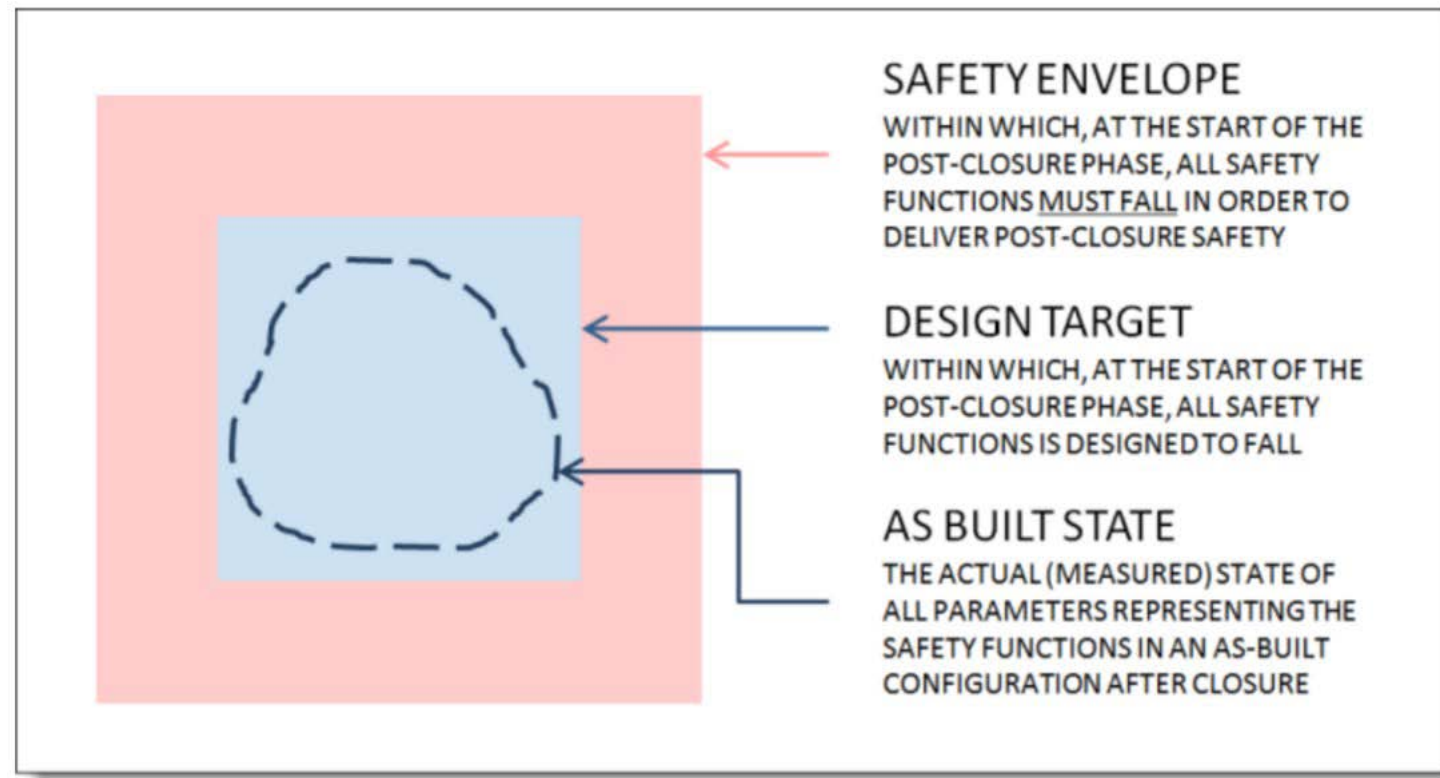
In short,

such monitoring results can be compared with the arguments made in a safety case to check whether the repository system is evolving in a way that has already been demonstrated to be safe.

Role of monitoring in a safety case

Key messages

- IAEA GEOSAF I & II developed an inspiring theoretical framework:



Role of monitoring in a safety case

Key messages

- **Monitoring might be undertaken as part of verifying compliance with design requirements**
- **Monitoring can be used** to check features of the repository evolution **to provide additional confidence in performance**

BUT

Should be designed so as **not to reduce the *overall* level of safety** of the facility after closure (**IAEA, SSR-5, 2011**)

Role of monitoring in a safety case

Key messages

In reality, monitoring might affect the performance of the multi-barrier system (MoDeRn2020, D2.1)...acknowledged as an outstanding issue :

« Is it better to know what's happening and accept a decrease in performance OR maintaining fully intact barriers and not know what is happening? »
(MoDeRn2020)

→ The extent to which monitoring affects performance should be addressed by monitoring strategy (MoDeRn2020)

Role of monitoring in a safety case

Key messages

- **Monitoring may be required to address regulators requirements or public concerns**
 - ↔ to demonstrate compliance with regulatory requirements (...)
 - ↔ to provide information for the public (IAEA, SSG-31)
- **Monitoring can provide the principal input for the periodic updates of the safety case**
- **Monitoring can provide information for R&R during operational period**

High-level strategy elements

Where, what, when

Where ?	What ?	When ?
In situ	Waste / EBS	Before operation
Pilot facility	Dummy packages / EBS	During waste emplacement
(URCF)	Geological barrier	After closure

e.g.

Strengths and weaknesses

?	Strenghts	Weaknesses
In situ	real repository conditions	wired systems may affect processes
Dummy packages	Sensors in the packages	THMC (B) : Ok Radiological: NOK
After closure	Provides confidence once waste/NF no longer accessible	Timeframe representative ?

(excerpts of MoDeRn2020 analysis)

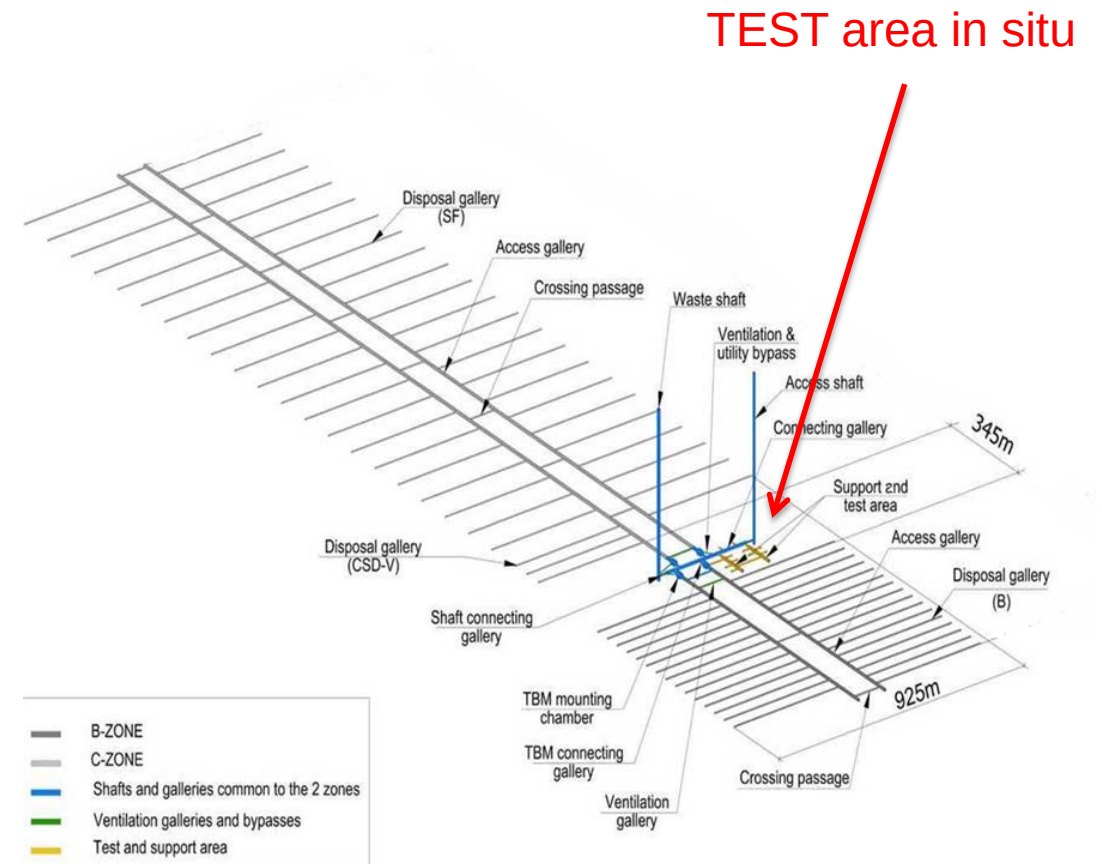
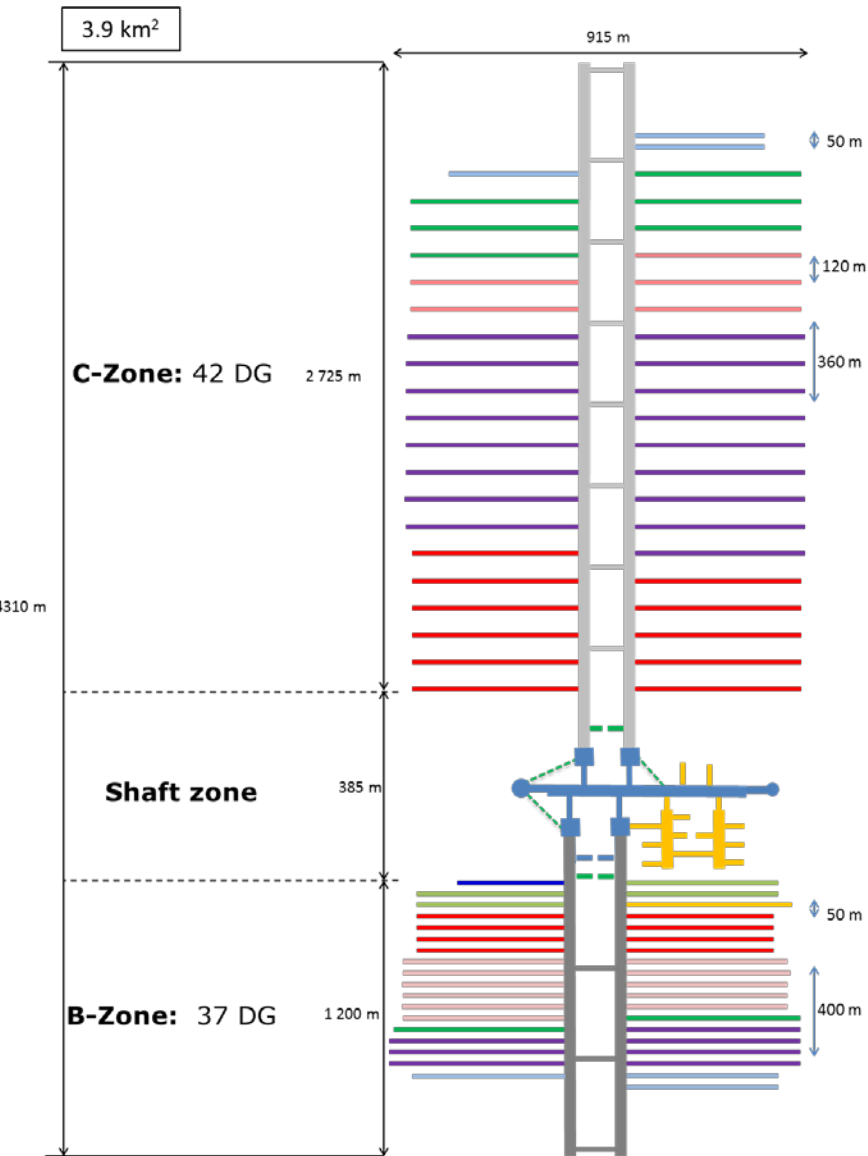
Examples from abroad

Strategies combining in ≠ ways what / where / when

?	ANDRA	SKB / POSIVA	NAGRA
Where	In situ	In situ	Pilot / UCRF
What	Broad scope Emplaced cells + EBS Pilot facility (with real waste)	Limited scope Dummy packages + EBS (plugs) UCRF	Real waste/EBS/Host rock (ENSI requirement) Hydrogeology (UCRF)
When	Pilot: Preliminary phase (10 years before operation) Operational phase	Operational phase	Operational phase until closure
How	Surveillance/current structures + standard disposal cells Pilot facility	URCF, in situ NO monitoring of full waste / EBS not to impair SF's	Not heavily instrumented UCRF in situ without real waste

Belgium ?

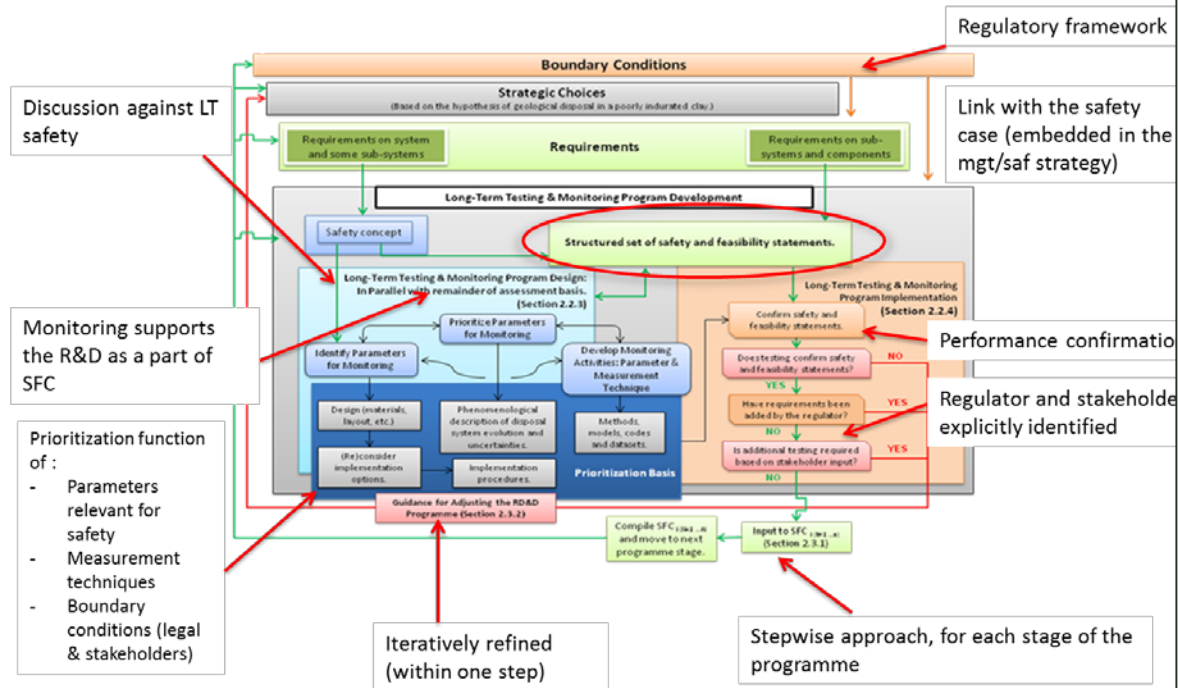
Where / when ?



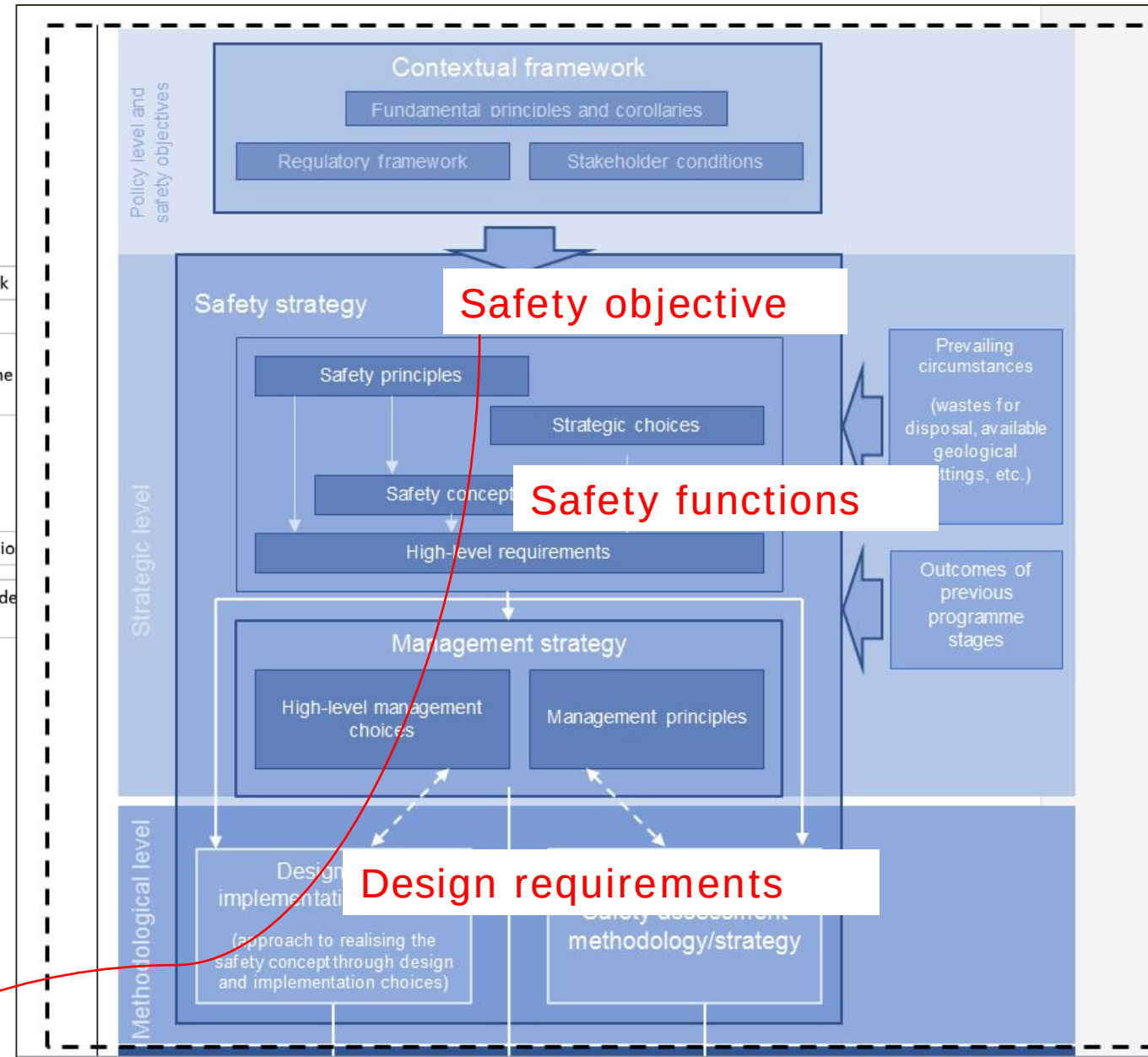
In parallel with the construction...

Belgium ?

What ?



Monitoring strategy such as presented in 2013



Vanessa's presentation (cAt)

Belgium ?

But seriously...

- Implementing such a strategy would require significant efforts and resources;
- But since 2013, there was another major change in the context (in addition to MoDeRn2020 and the law of transposition) :
 - **O/N was asked to investigate other potential host rocks than poorly indurated clays → The foreseen safety case can only be generic**
- Therefore, the focus shifted towards:
 - a watch of international monitoring programmes;
 - technological developments of monitoring techniques;
 - REX of monitoring in HADES → Jan Verstricht's presentation

Conclusions

- Monitoring strategy is the high-level approach which addresses the questions what/where/when (& how) to be monitored;
- Strategy frames the monitoring activities in order to comply with law and to address several concerns from the regulatory body, the public but also the scientific community and the implementers (≠ perspectives !?)
- Monitoring programmes can vary from country to country, ranging from broad to limited scope, from in situ to pilot or a combination thereof
- Degree of implementation of monitoring strategy seems to be strongly correlated to the national commitment towards GDF

22nd Exchange Meeting EIG EURIDICE

Involvement of local stakeholders in the research and development of monitoring strategies – feedback from the EC project Modern2020

1st of October, Mol

Axelle Meyermans
Göran Sundqvist
Anne Bergmans

With thanks to:
Pieter Cools, Hannes Lagerlöf & Anna-Laura
Liebenstund



This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement n° 662177

Introducing the Modern2020 project

- **General project aim:** Develop monitoring concepts and technologies to observe repositories for high level nuclear waste that will take into account the requirements of specific national contexts and public stakeholder expectations
- **Transdisciplinary EU project:** Project partners with techno-scientific expertise, social scientists, local public stakeholders (BE, FI, SE & FR)
- **Social Science – Research team:**
 - BE – University of Antwerp: Anne Bergmans, Axelle Meyermans, Pieter Cools, Anna-Laura Liebenstund and Céline Parotte
 - SE – University of Gothenburg: Göran Sundqvist, Hannes Lagerlöf



Monitoring in geological disposal = a sociotechnical challenge

- **Geological disposal** = internationally agreed solution for nuclear waste
 - ✓ Aim of **passive safety**
- Development of **monitoring technologies**
 - ✓ Opening up to **continuous vigilance**
 - ✓ Unclear relation to passive safety?
- **National differences** in the conceptualization of monitoring
 - ✓ Host rock and disposal concept, but also...
 - ✓ **Socio-political** explanations for these differences

Three topics of interest

- 1. Differences and similarities** between four European NWMOs (BE, FIN, FR, SE) in their **understanding of monitoring**
- 2. Linking monitoring to questions of (dis)trust**
- 3. Public participation** in monitoring R&D

Key suggestions for public participation in R&D

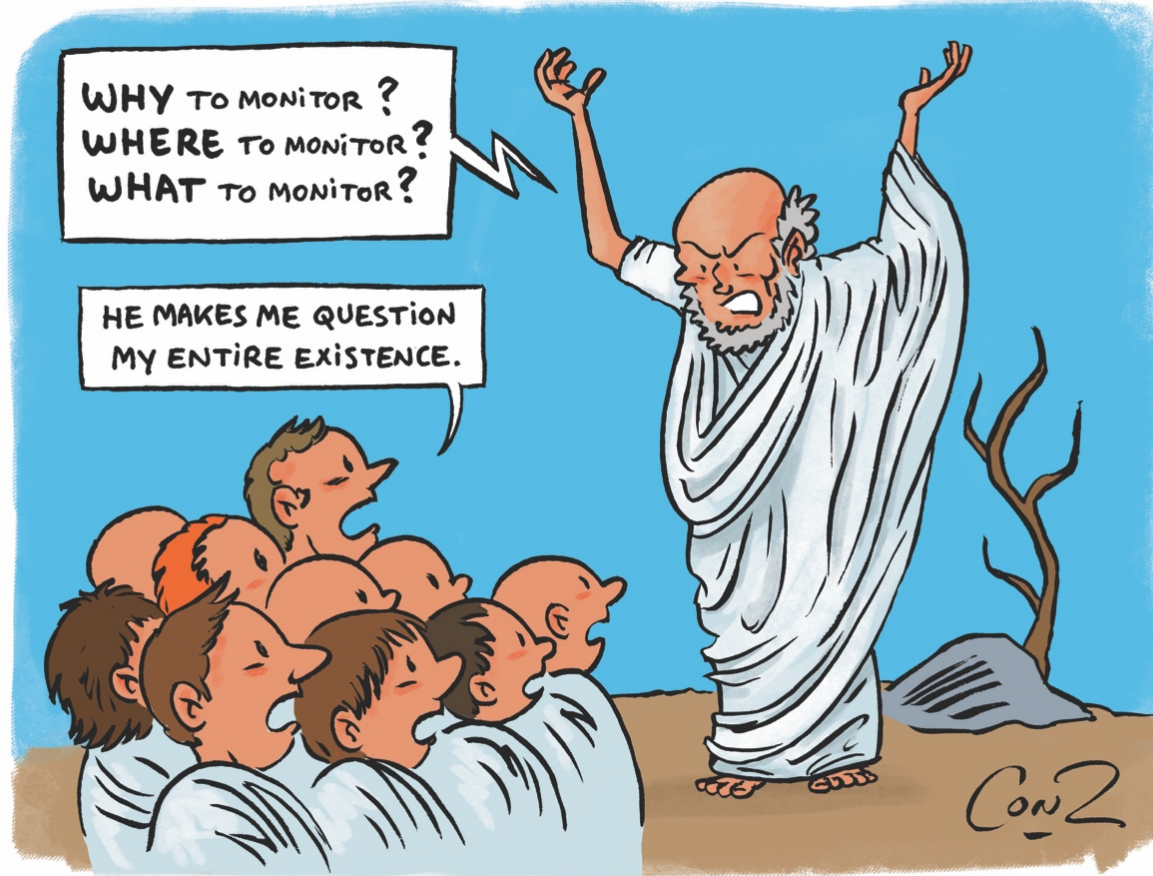


Organisation of local stakeholder participation within Modern2020

- Engagement of local stakeholders from Belgium, France, Finland and Sweden
 - ✓ STORA & MONA, Clis de Bure, Eurajoki municipality and Östhammar municipality
 - ✓ **'Liaison officers'** on the project level
 - ✓ Organisation of **'home engagement workshops'**
 - ✓ Online **'Delphi'** survey (two rounds)
 - ✓ **WP5 Workshop** with local stakeholders and technical experts

1. Striving for a consensus on monitoring?

AS THE ANCIENT PHILOSOPHER RADIUS ACTIVUS SAID:



1. Striving for a consensus on monitoring?

National comparison (based on D5.1, WP5, Modern2020)

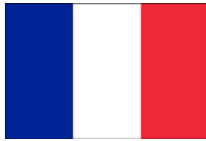
			
<u>ONDRAF/NIRAS'</u> <u>framing of monitoring</u> Monitoring is necessary; but unclear about what exactly will be monitored Socio-economic + environmental monitoring Will most probably be related to demands of reversibility	<u>Posiva's framing of monitoring</u> Monitoring does not increase safety per se (<-> STUK) Debate on EBS monitoring ('indirect' monitoring)	<u>Andra's framing of monitoring</u> "Surveillance": does the repository behave as expected? Monitoring is ensured during the operational phase Some connection with demand of reversibility	<u>SKB's framing of monitoring</u> Environmental monitoring since several years already Passive safety has been proven in advance by quality control systems Monitoring should not interfere with passive safety goals

1. Striving for a consensus on monitoring?

- Within Modern2020: aim of reaching a ***technical*** **consensus** on monitoring
 - ✓ Resulting from ***political*** ambitions → political and technical consensus are **mutually supporting** each other
- Advantage: reaching a **scientific consensus**
- However, risk of **concealing “political”** interests

2. Monitoring and *trust*

- Geological disposal: **delegation of trust** and safety to geology
- Monitoring: tool for **trust-building**?
- **Interviews and participatory observation** with involved local stakeholders

			
Surface disposal for low-level waste in Mol/Dessel → certain level of mutual trust Conditional	Culture of trust in the nuclear expert Participation on the technical level perceived as superfluous; however need of getting informed	General lack of confidence towards responsible NWMO Rather disinterested in monitoring R&D (more concerned with general waste disposal process)	Vital trust of local community in SKB Importance of the established veto right → more active role in NWM

3. Local stakeholder participation in R&D of monitoring systems

What kind of local stakeholder engagement in R&D?

- Conclusions from **survey** results
 - ✓ **Decisions about specific technical elements** should be left to technical experts
 - ✓ However, local stakeholder engagement remains important, because of
 - Right to **be informed**
 - Asking **critical questions**
 - **Encourage technical experts** to take local stakeholders' remarks, comments into account and to 'do the best job they can'

Yet, open questions remain:

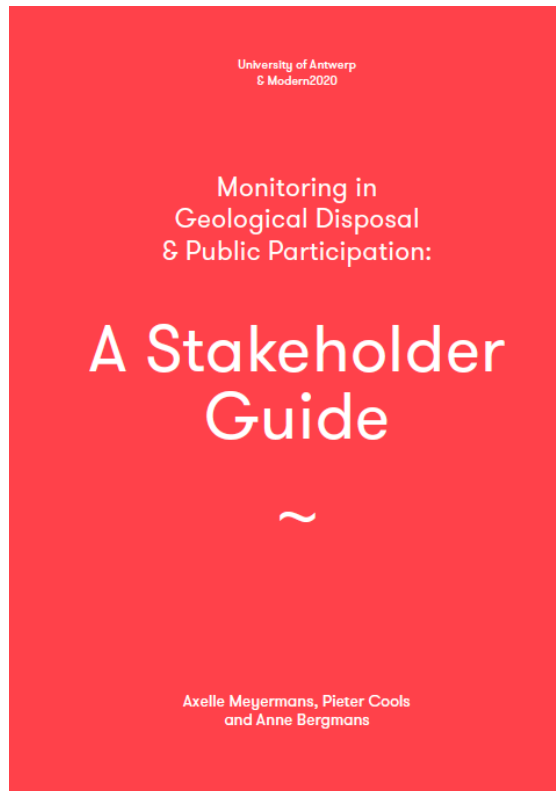
- **Discrepancies** between local stakeholders and technical experts (and between themselves)
 - ✓ Should local stakeholders be **involved on the technical/engineering level** of a specific R&D project?
 - 85% of technical experts disagree >< 44% of local stakeholders agree
 - ✓ Local stakeholder involvement has the **potential to improve the design** of monitoring systems.
 - 35,5% of local stakeholders agree >< 9,1% of technical experts agree
- Carefully assess on **what topics**, in **what phases** and **for what reasons** citizen stakeholders should be engaged → There must be something to **negotiate!**

Guidance on how to implement public participation in technical programmes

1. Be sensitive towards **consensus**
 - ✓ Acknowledge what is not agreed upon
2. Be sensitive towards **delegation of decision power to technical experts only**
 - ✓ Depending on level of trust
3. Be sensitive towards **what is opened for discussion**
 - ✓ How to discuss (socio)technical issues with local stakeholders?
 - ✓ Avoiding 'tokenistic' participation

If you want to know more...

...about repository monitoring and public participation in R&D



English and French version on <http://www.modern2020.eu/>

Thank you for your attention!
Questions, remarks?



This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement n° 662177

40 years of monitoring experience in the HADES URL

Performance assessment of installed sensors

22nd Exchange Meeting
“The role of monitoring in radioactive waste disposal”

Lakehouse Mol
1 Oct 2019

Jan Verstricht

jan.verstricht@euridice.be



ONDRAF/NIRAS



ESV EURIDICE GIE

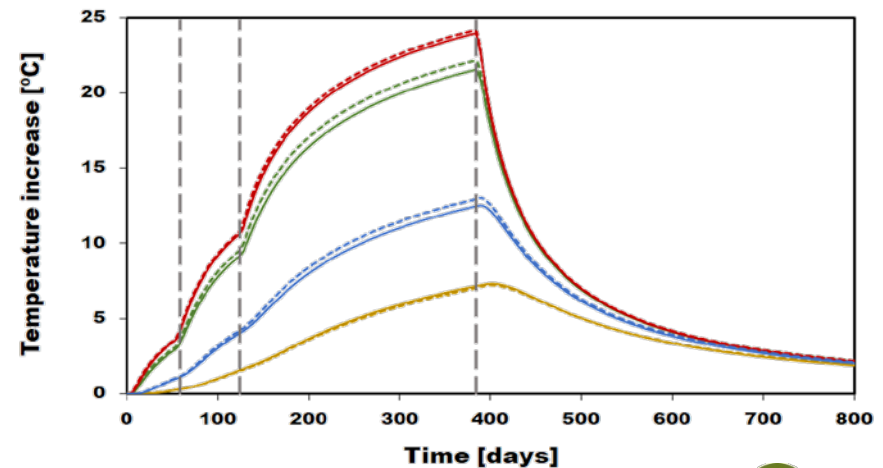


Outline

- General context of monitoring at HADES
 - Main reasons for monitoring
- How do sensors perform over longer term ?
- What have we learnt after 40 y
- Perspectives for repository monitoring

Why monitor at the HADES URL ?

- Construction related objectives
 - at the pioneering phase (feasibility / safety of deep excavations)
 - industrial construction techniques (design validation and EDZ)
- Model validation / confidence building
 - geotechnical (THM) – natural barrier and EBS components
 - migration / solute transport – geochemical and microbiological
 - *input data for PA / safety case*



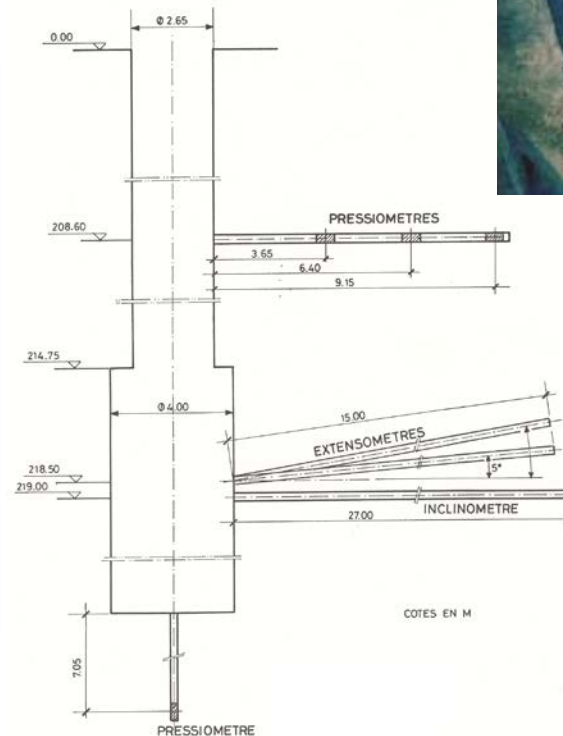
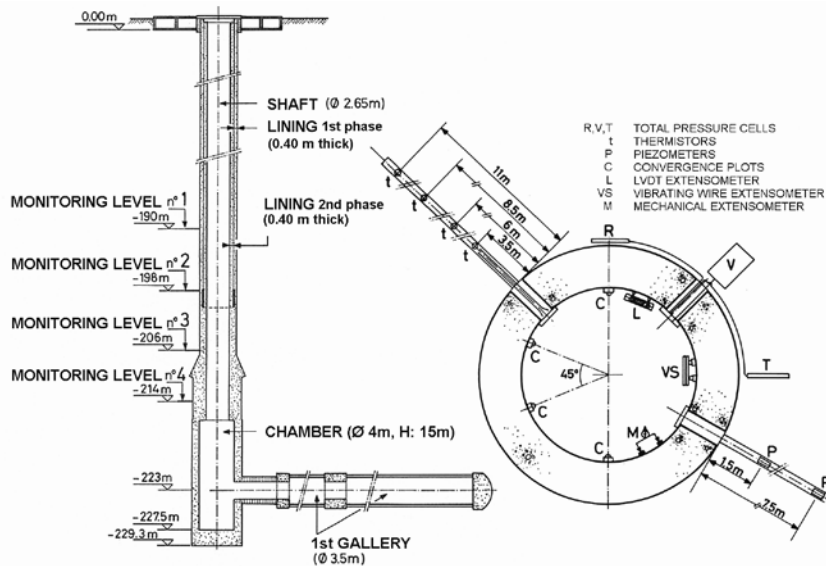
Can we / how to construct deep in the clay ?

Pioneering phase (1980s)

Deep construction possible?

What parameters?

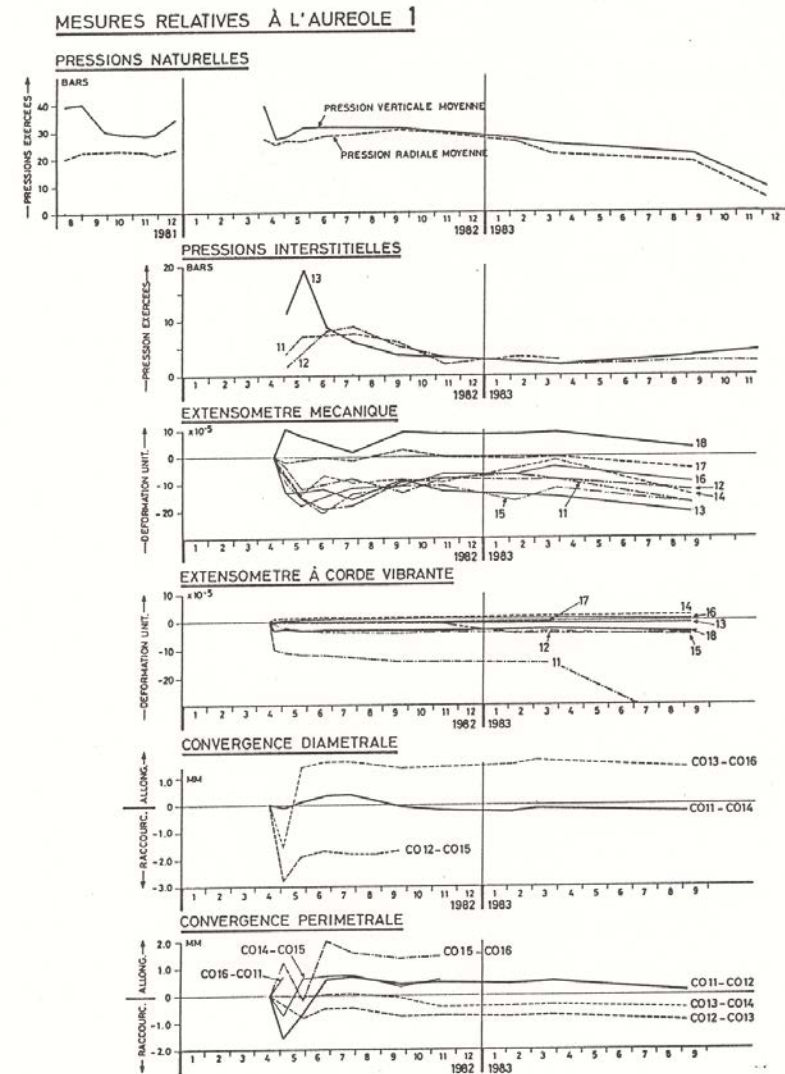
How to monitor these?



Shaft monitoring : freezing the way to go?

Important observations regarding THM behaviour of clay host medium

- High total pressure / large displacements
 - freezing combined with manual (slow) excavation
- High porewater pressures
- Temperatures
 - very slowly $\uparrow 0^\circ\text{C}$
- Shaft lining behaviour (deformations)
 - behaviour depending on shaft design



... and can the sensors handle it?

Variety of sensor types applied

Porewater pressure sensors and thermistors: reliable

Total pressure cells (flatjacks)

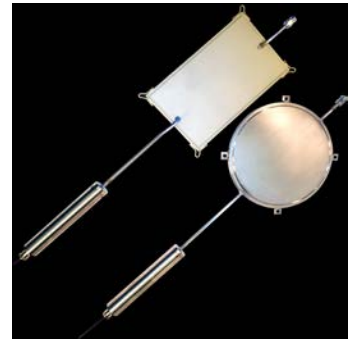
- vulnerable (hydraulic tubing/differential settlements)

Lining convergence: mixed results

mainly due to working conditions (moving work platform,...)

Pressiometer, inclinometer and extensometer

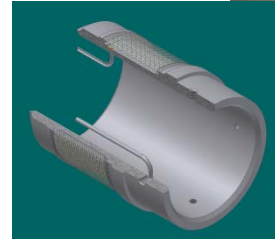
- robustness in deep applications ?



Monitoring inside the first gallery (URL)

Large variety of instrumentation

- strain gauges (lining deformation)
- multifilter piezometers (CP1)
- corrosion set-up's
- first EBS tests (BACCHUS)
- migration tests (clay core percolation tests)



How measure total stress in clay ?

- large boreholes, backfill grouting
 - installation procedures



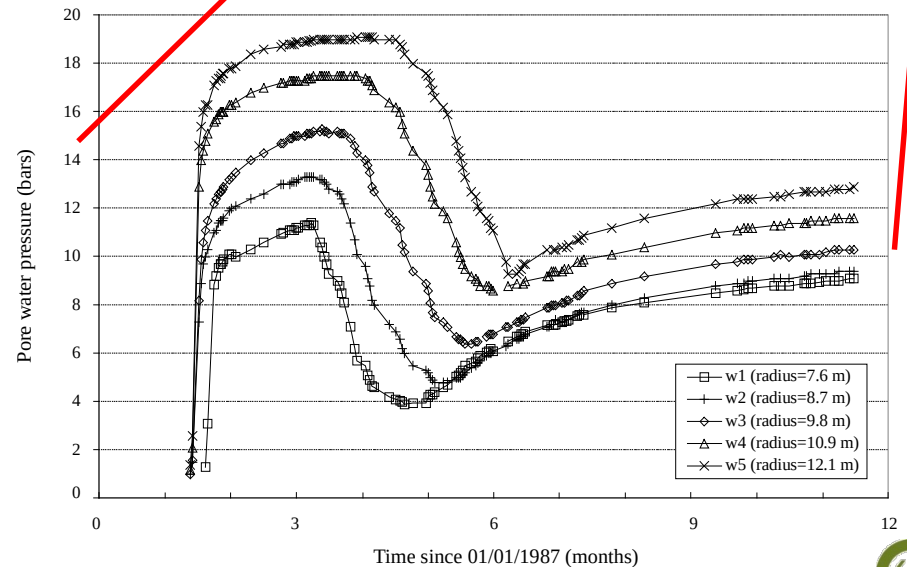
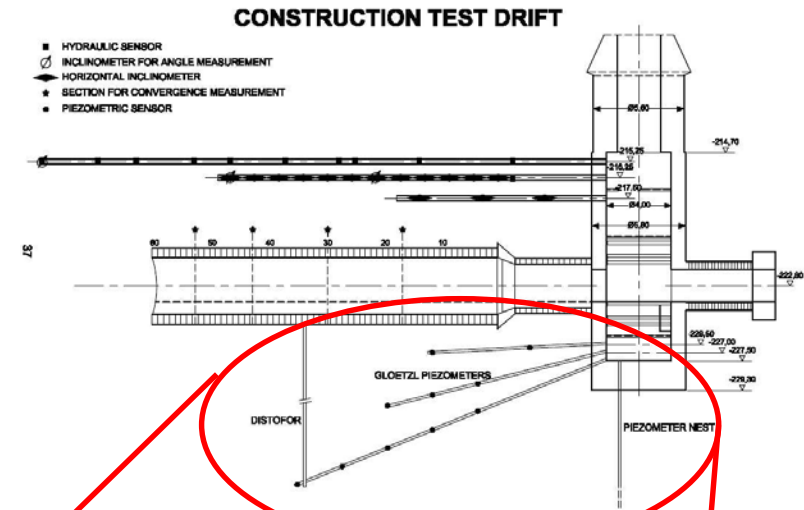
Lessons

- importance of non-intended observations
 - unfrozen clay behaviour
 - thermal effects, e.g. water inflow in heated corrosion test tubes

Construction in unfrozen clay? Yes, we can !



“Mine-by test”



From manual to industrial

Verification of industrial excavation technique

- short term excavation technique / tunneling machine
- comprehensive host rock monitoring programme (CLIPLEX)
 - HM: water pressure (H), total pressure (M), displacements (M)
 - porewater pressure
 - deformation in gallery lining



Watching the Connecting gallery excavation

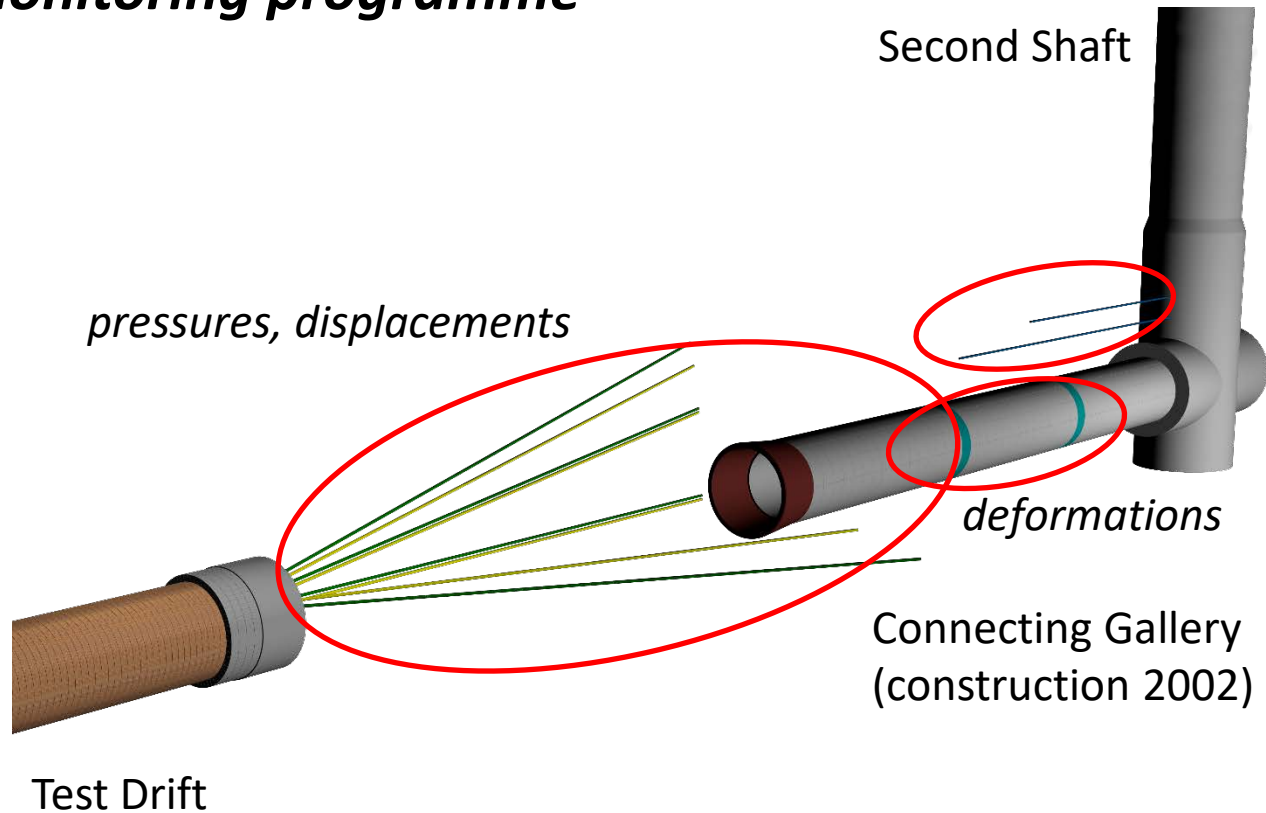
Does the novel construction method in deep clay perform as expected

- use of a shield → risk of blocking
- short starting distance
- use of wedge block system (adapted, 1st application at this depth)
- instantaneous convergence of Boom Clay
- geometry of the shield based on modelling

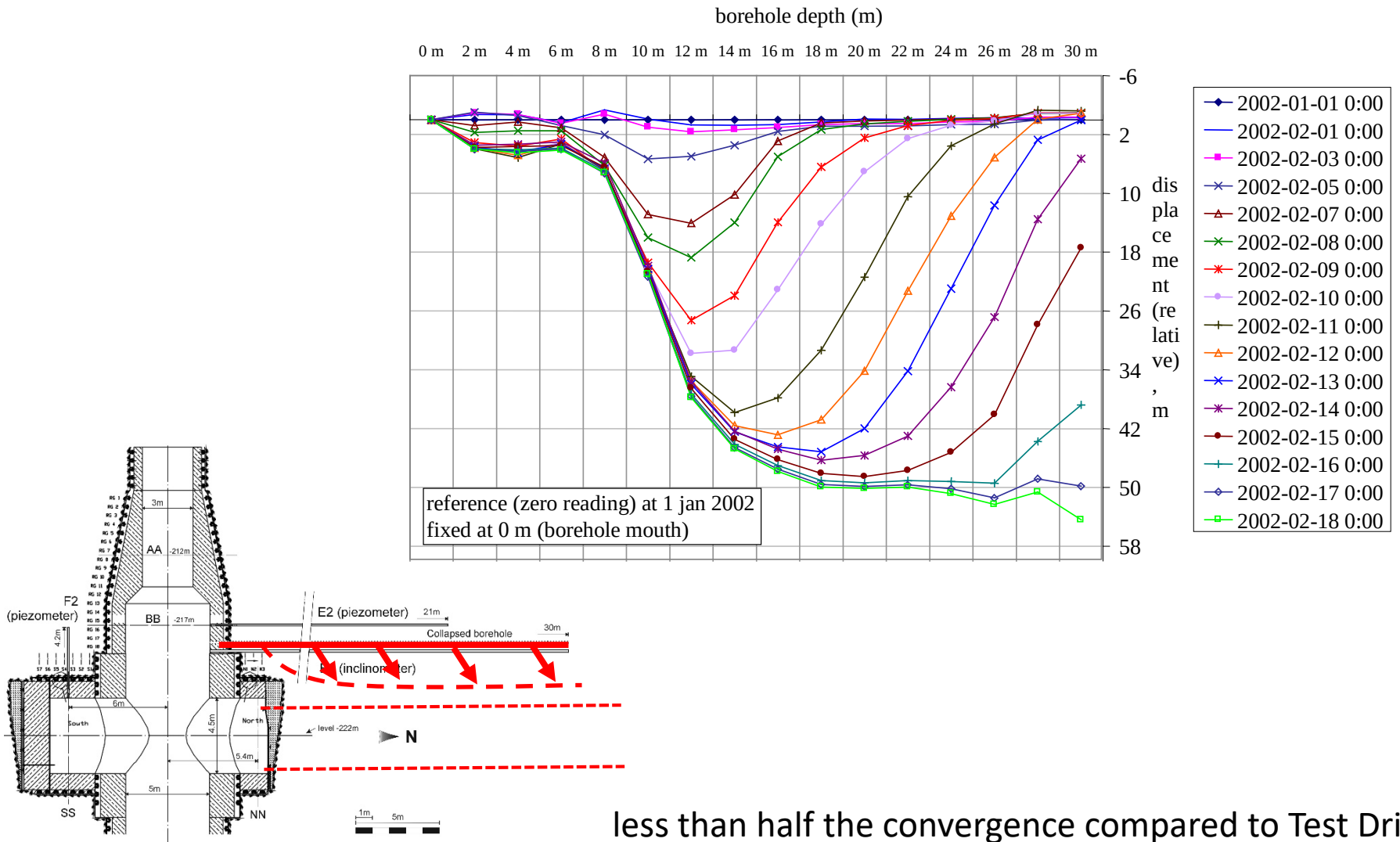


Watching the Connecting gallery excavation

CLIPLEX monitoring programme

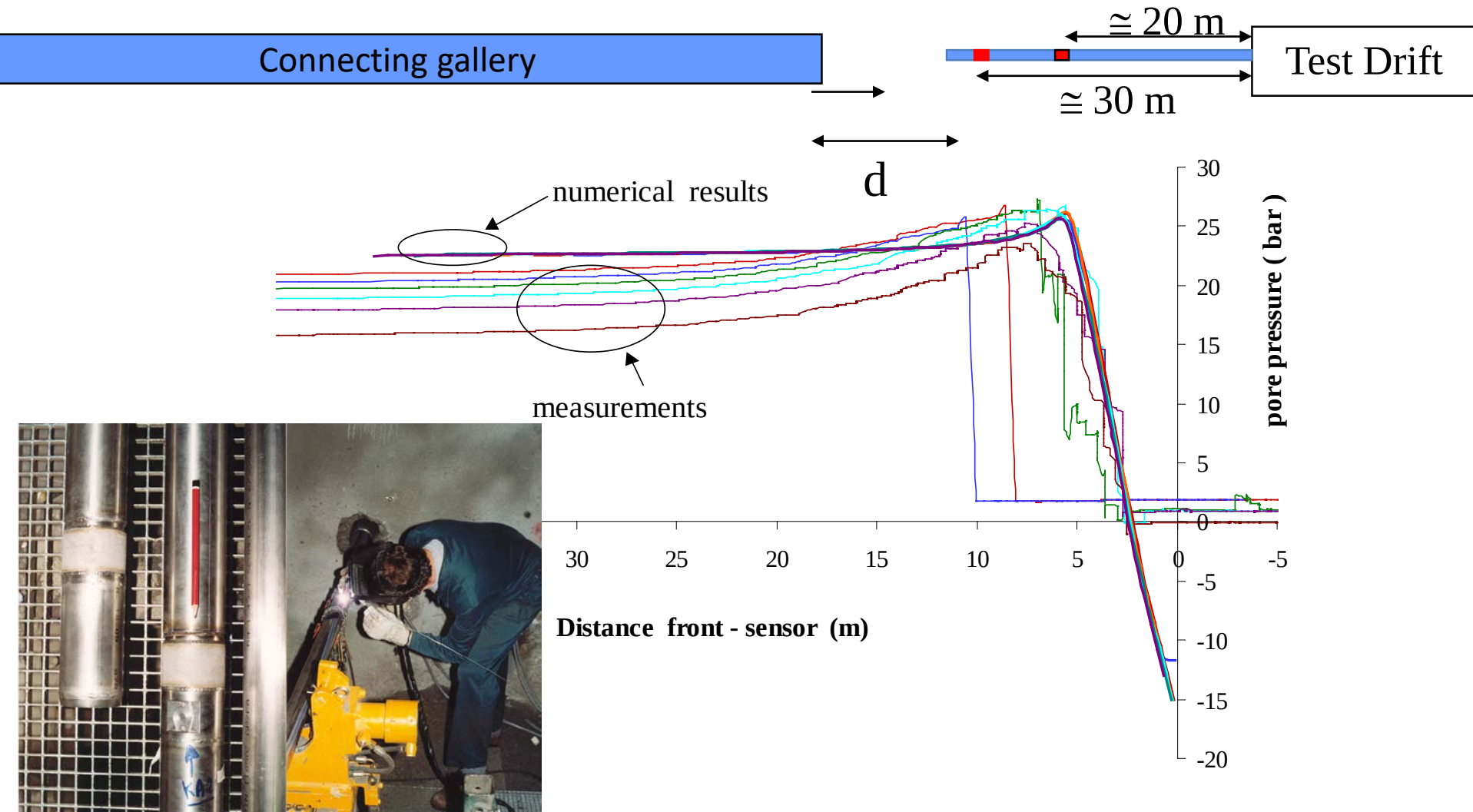


Inclinometer : host rock radial convergence

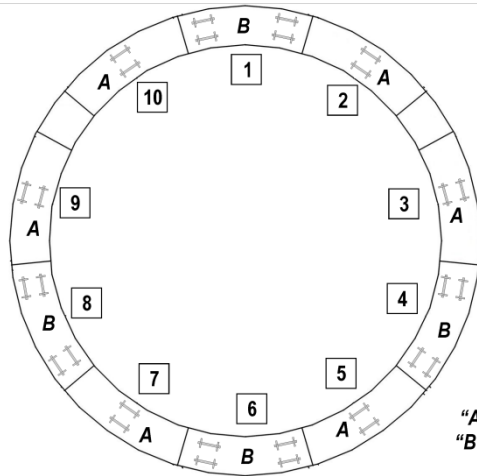


less than half the convergence compared to Test Drift

Observed and expected porewater pressures



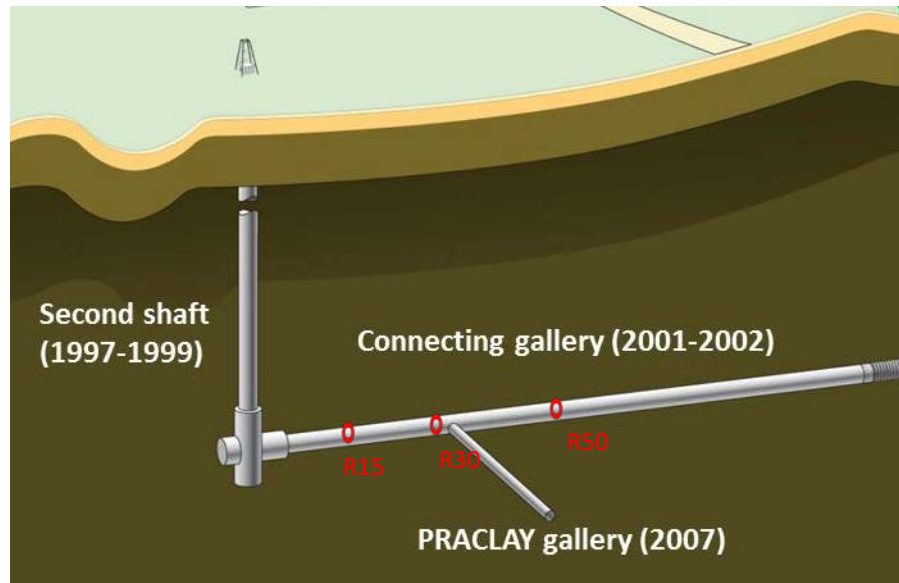
Gallery lining deformation monitored for > 17 y



circumferential strain

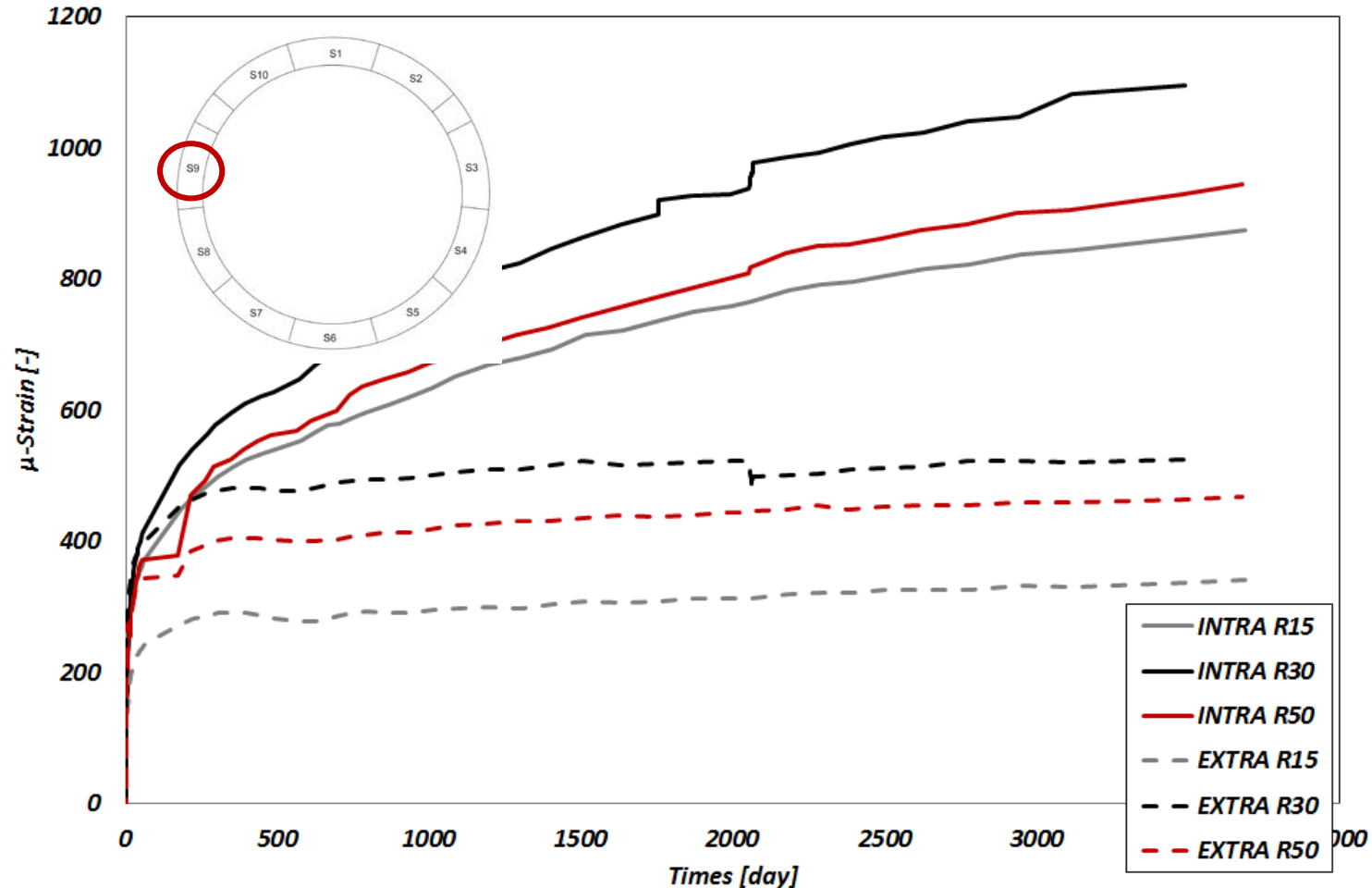
- intrados
- extrados

"A" = 6 gauges
"B" = 12 gauges



Long-term evolution of gallery lining behaviour

Bending (inner/outer strain) depends on segment position in ring

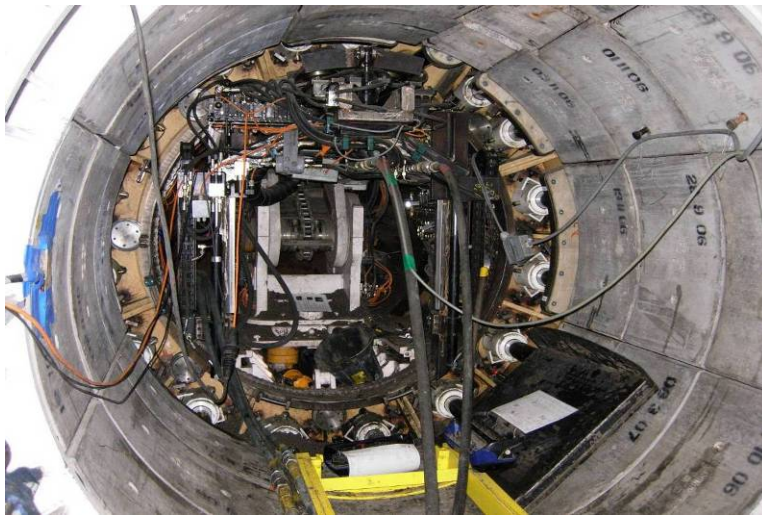


After 4 years in the host clay...

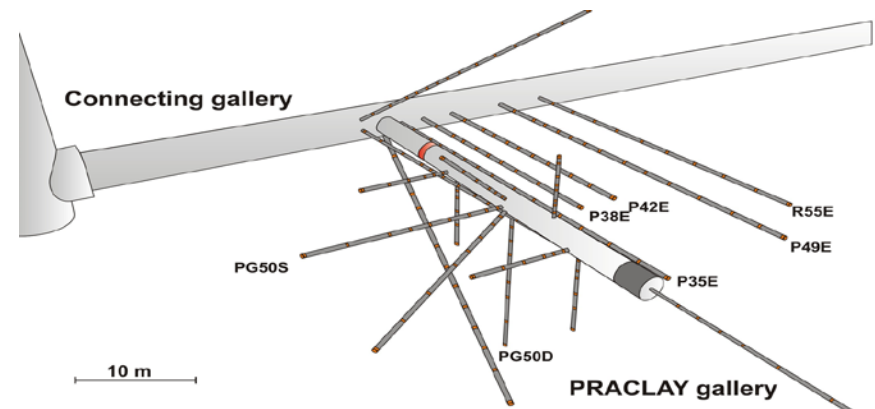


PRACLAY gallery excavation

excavation works (2007)



extensive monitoring network
about 1100 sensors



Monitoring : input for model improvement

THM coupling phenomena

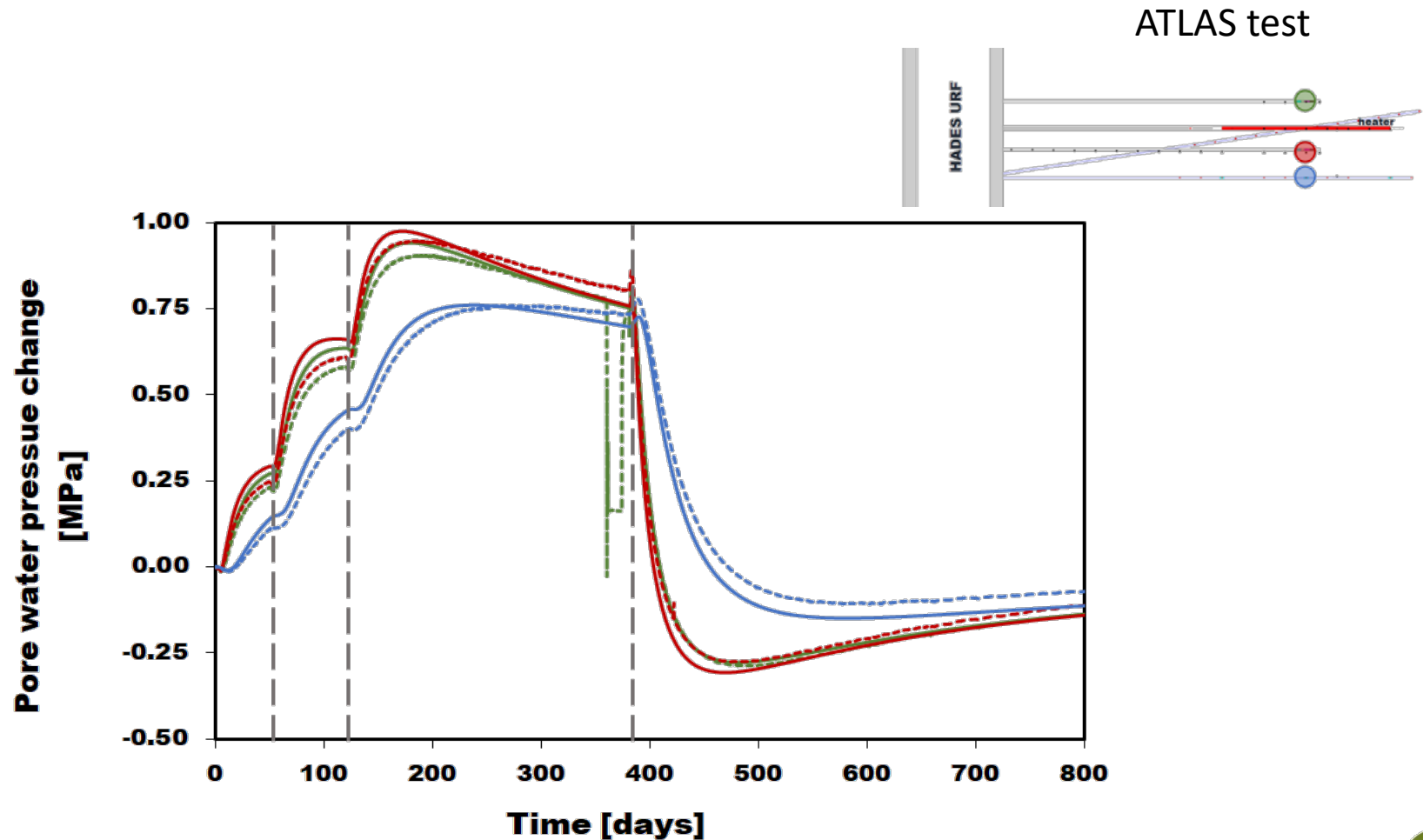
- related to excavations + long-term follow-up
 - e.g. reference piezometers in Connecting Gallery
- purpose built set-ups
 - ATLAS, RESEAL,...

Migration / solute transport

- upscaling of lab results in time and space

Interpretation of measured data by modeller

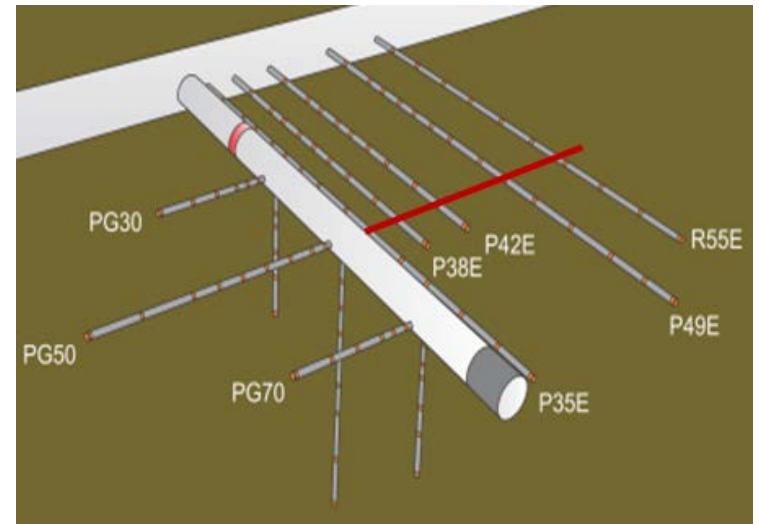
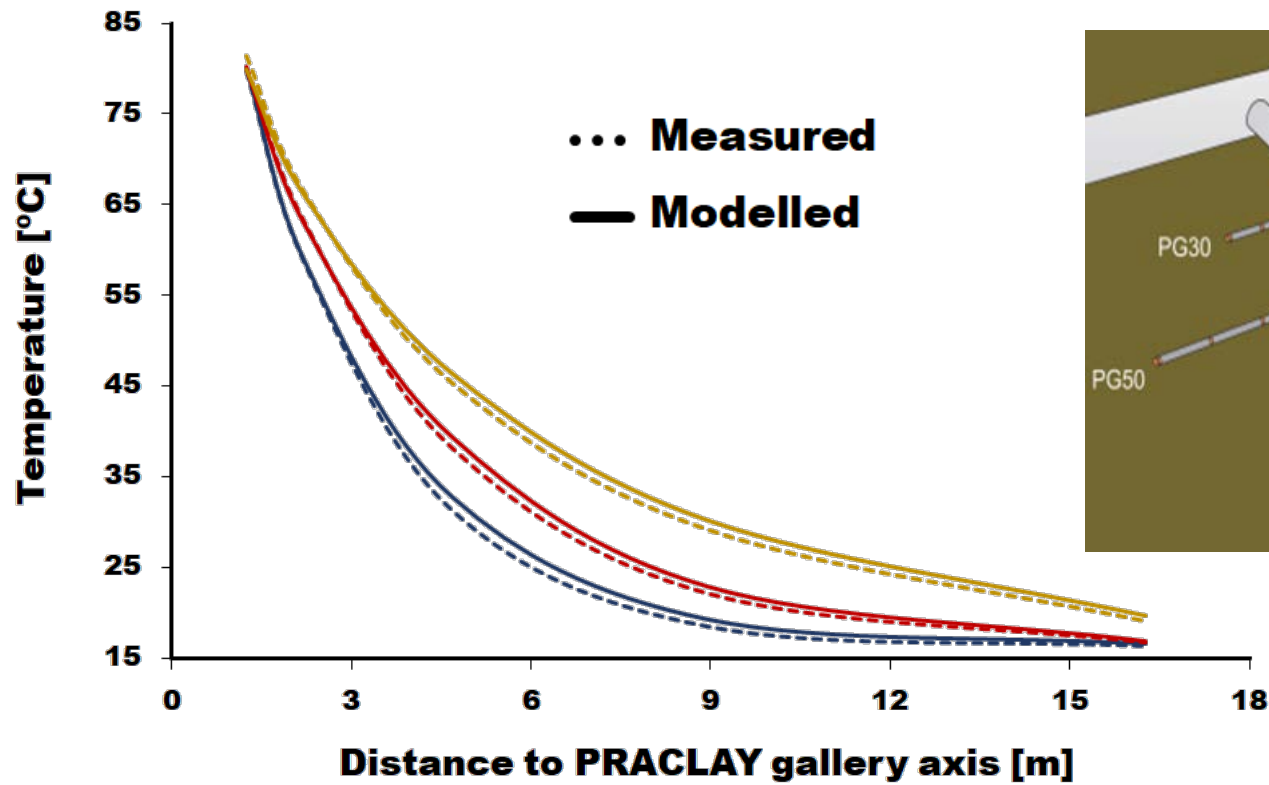
Do we understand the THM behaviour?



Interpretation of measured data by modeller

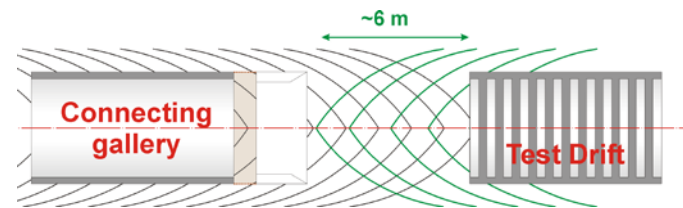
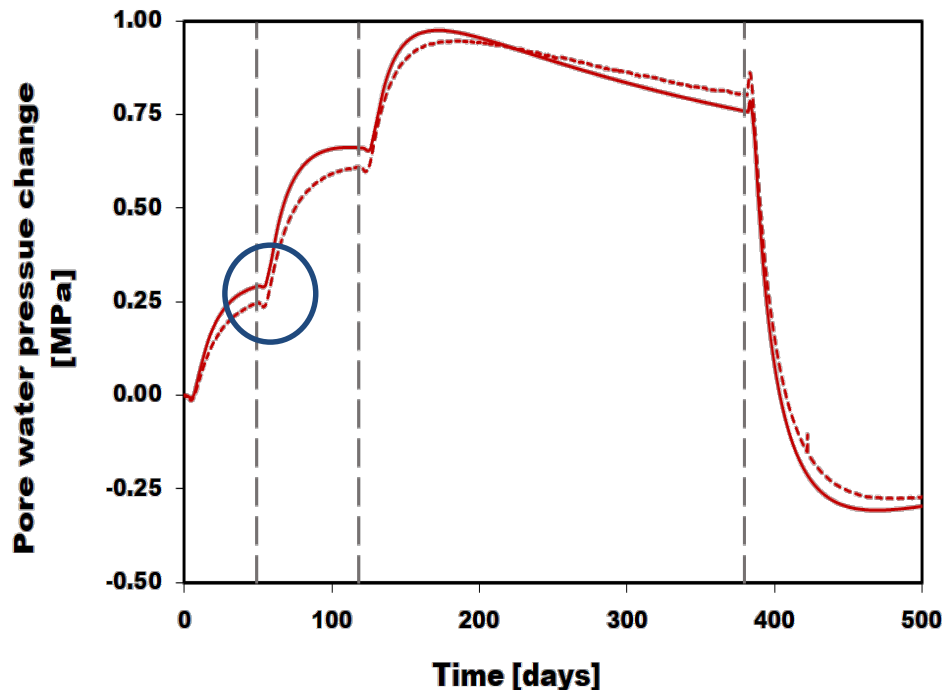
Do we understand the THM behaviour at larger scale?

PRACLAY test



... and describing new phenomena

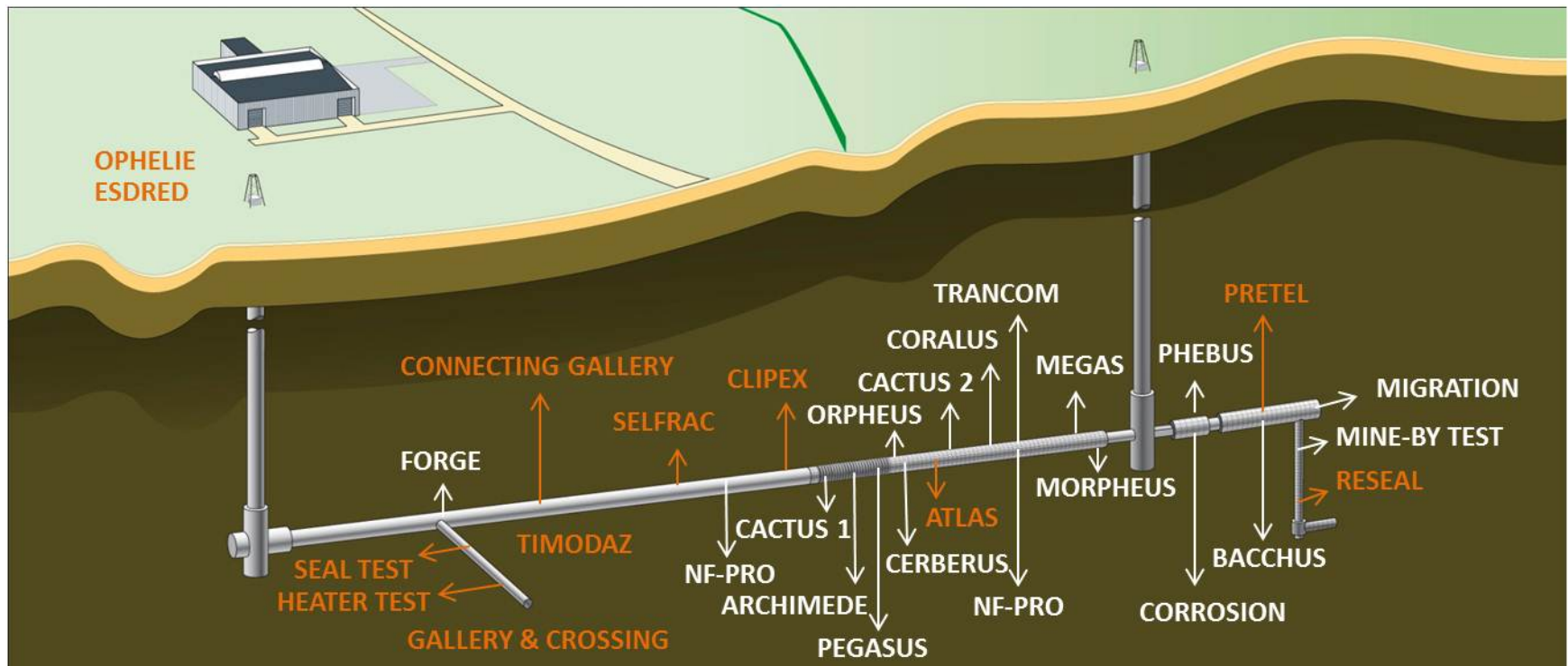
- anisotropy phenomena
 - small temporary decrease of pore pressure prior to increase when heating starts – later also seen in Bure
- fracturing



What do we learn from all the installed sensors?

Several thousand sensors installed since start of HADES

- about 1100 in PRACLAY



Projects managed by EIG EURIDICE

How to assess sensor performance ?

Systematic approach

- many long-term experimental set-ups
 - both finished or still running, with many sensor technologies
 - each setup is unique (objectives, duration,...)
- assess these by different criteria
 - *sensor installation*
 - *environmental conditions*
 - *operational track record*
 - *quality of measurement data*
- systematic / uniform assessment so that
 - results of different cases can be compared
 - database can be updated with time

Results of a first application: CLIPLEX set-up

Long-term reliability of sensors depending on technology

- piezometer casing (porewater pressure): most reliable – and versatile
 - accessible – calibration approach for long-term set-ups
- total pressures
 - flat jacks: robust sensors
 - miniature sensors: more vulnerable
 - 25 % failed – all but one in same borehole
- displacements
 - inclinometers / deflectometer / extensometers
 - some more failures or unreliable measurements
 - robustness - measurement principle – installation procedures
 - updated version more reliable
- lining deformation (embedded strain gauges)
 - only 2 out of 270 gauges failed in 17 year time span



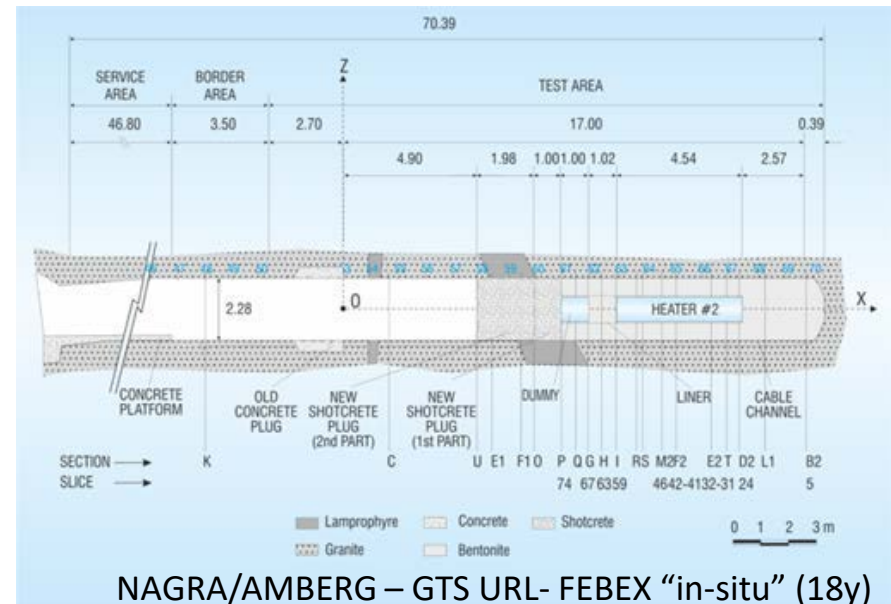
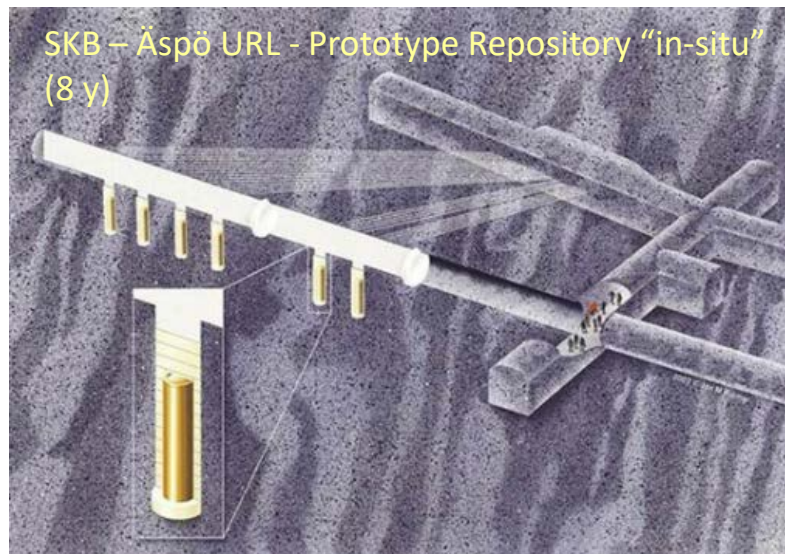
We are not alone...

Sensor performance typically included in monitoring demonstrators

- both finished or still running - long-term experiences available for many sensor types

Overall comparison within collaboration projects

- e.g. EC monitoring project “Modern2020”
 - assessment within task for qualification of monitoring components



NAGRA/AMBERG – GTS URL- FEBEX “in-situ” (18y)

Results - Lessons learnt

Monitoring at HADES

- demonstrated ***feasibility*** of underground construction
- helped ***developing technology*** for repository construction
- gave essential ***input for THM(CB) characterisation/modelling***
- has shown feasibility/potential for ***long-term monitoring***
 - not only technology - also data management / visual observations / ...



Results - Lessons learnt

Assessment methodology

- good approach to bring the experience in a uniform format
- approach for current and future monitoring set-ups
- more advanced analysis – input to reliability engineering

Project implementation

- installation procedures (manufacturer $\leftrightarrow$ implementer)
- data management (in particular longer term – e.g. when projects end)

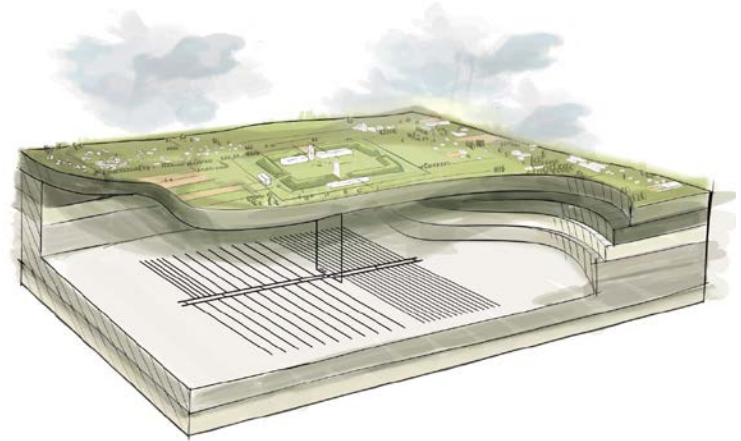
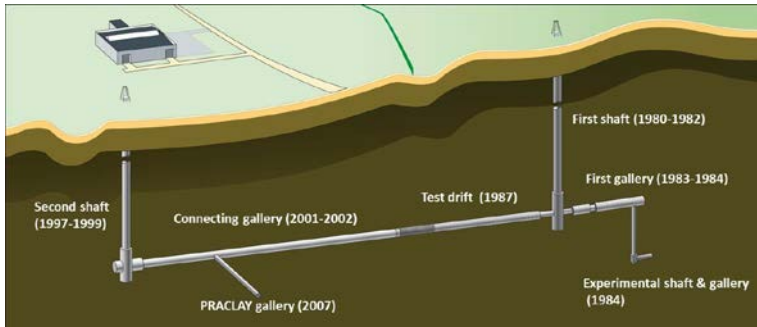
Monitoring technologies

- pressures vs. displacements

Results - Lessons learnt

- routine geotechnical sensors need to be adapted for deep underground conditions (mechanical robustness, watertightness,...)
- we are therefore often working with prototypes or at least customized versions – not always thoroughly tested
- testing at short-term cannot always reveal long-term issues
- sufficient resources (including time) are needed for testing
- methodology to be further worked out
 - e.g. systems testing as applied elsewhere with similar challenges

Perspectives for repository monitoring



Challenges

- non-accessible sensors
 - maintenance – calibration – reliability – unexpected measurements
- long-term nature
 - follow-up of sensors AND measurements
- cabling/wiring to be limited / avoided
 - non-intrusive technologies: distributed fiber optics / wireless transmission / geophysical methods

Perspectives/trends for repository monitoring

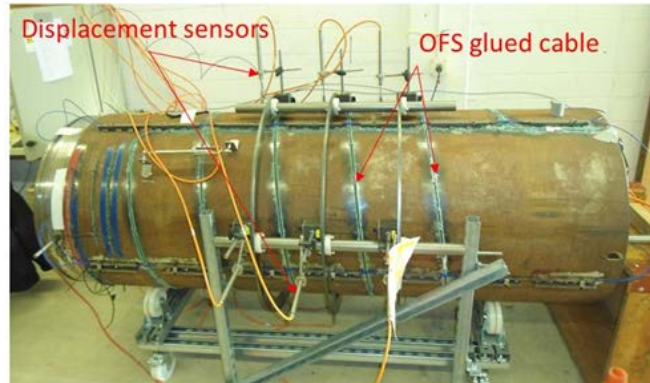
- monitoring mainly focused on pilot facilities / witness structures
 - phased repository implementation
 - near-field monitoring of repositories (in particular EBS and near field) could be rather limited - depending on context / country

Alvar Aalto stool 60



Louis XV chair

- Finland: minimalist approach (no repository monitoring near waste packages)
- France: “baroque” extensive instrumentation for disposal tube (retrievability)



- limited or non-intrusive monitoring technologies
 - distributed fiber optics / wireless technologies / geophysical methods
- sensor qualification methodology



ONDRAF/NIRAS

Monitoring of the future near surface disposal site and facility

Vanessa Cauwels

ONDRAF/NIRAS

22nd Exchange meeting
Mol, Belgium
October 1st 2019

Table of contents

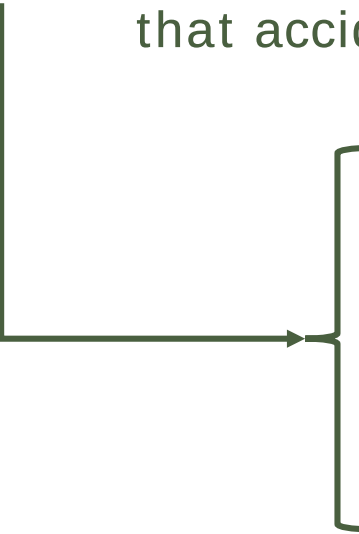
- Safety objectives and safety functions of the disposal facility in Dessel
- Configurations of the disposal facility
- Monitoring programme
 - ◆ Radiological monitoring programme
 - ◆ Physical and structural monitoring programme
 - ◆ Monitoring of the drainage system

Safety Objectives – safety functions

Disposal = Final step in the management of radioactive waste

Safety Objective = Protection of man and environment

- ◆ Now and in the future
- ◆ Against the dangers of ionising radiation
- ◆ By preventing accidents and, if an accident occurs, to limit the consequences of that accident

- 
- Shielding of external radiation from the radioactivity in the waste (only during operational period)
 - Isolation of the waste from the biosphere
 - Containment of radionuclides

Safety Objectives – safety functions

■ Follow-up and control

- ◆ Control on

To verify that design requirements (DR) of Systems, structures and components (SSC's) are met

 ks
- ◆ Control on (production or maintenance and disposal activities) **tional** activities

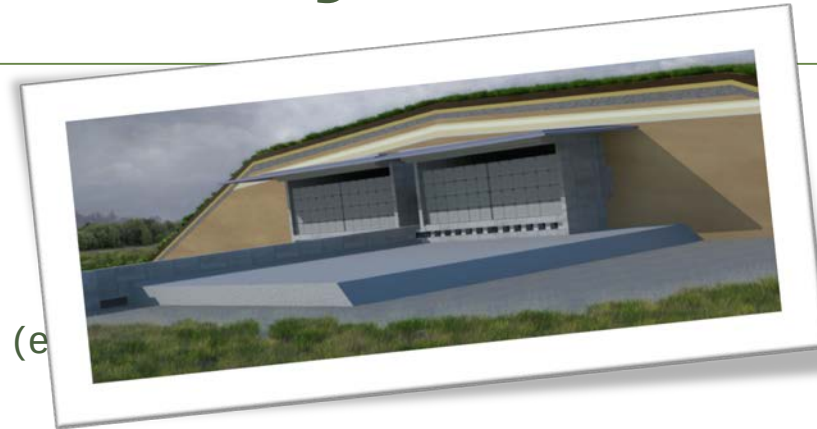
Safety Objectives – safety functions

SSC? DR?

- **SSC**

- ◆ = systems, s
- ◆ contributing

- **DR**



ility (e

Belgian laws, FANC
requirements,
stakeholders,...

Safety concept

Design choices

Existing waste and
current production

Design inputs

limit water flow through
protective barriers

Design
requirements

sufficient slope of the
earth cover to allow
water run-off

Criteria of
conformity

Settlements and
movements

Safety Objectives – safety functions

■ Follow-up and control

- ◆ Control of To verify that design requirements
- ◆ Control of (DR) of Systems, structures and (production of components (SSC's) are met monoliths and disposal activities)
- ◆ Control of To understand and confirm the and after operation
- ◆ Optimisation behaviour of the disposal installation in it's environment

Table of contents

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Configurations of the disposal facility

Operational Period				Post-closure Period				
Construction phase	Operational phase		Closure phase	Nuclear Regulatory control phase	Phase IV	Phase V		Phase VI
	Ia	Ib	II	III	IV	Va	Vb	VI
	$t_0 + \dots$							
t_0 Start operations	~50 a	~95 a	~100 a		~350 a End Regulatory Control	~1000 a	~2 000 a	10 000 a

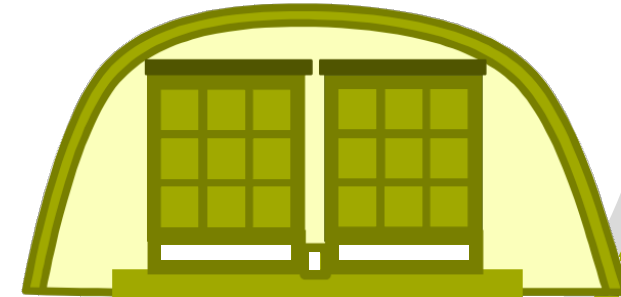


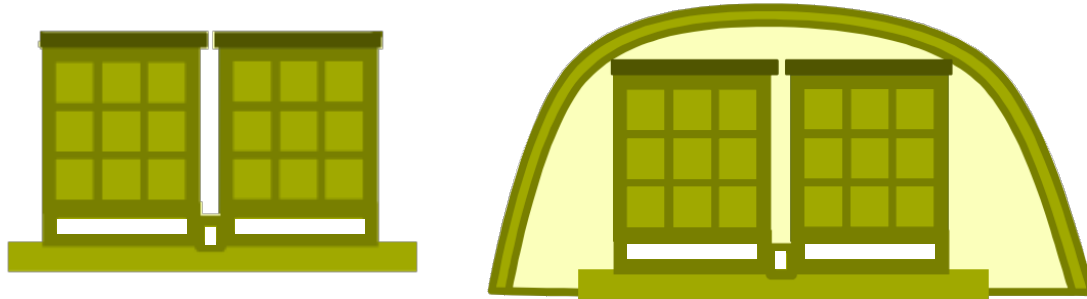
Table of contents

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Monitoring programme

Radiological monitoring programme

■ Monitoring during operational period (Ia en Ib)



- Disposal activities → external radiation
- Water possibly present in drainage system and potentially contaminated

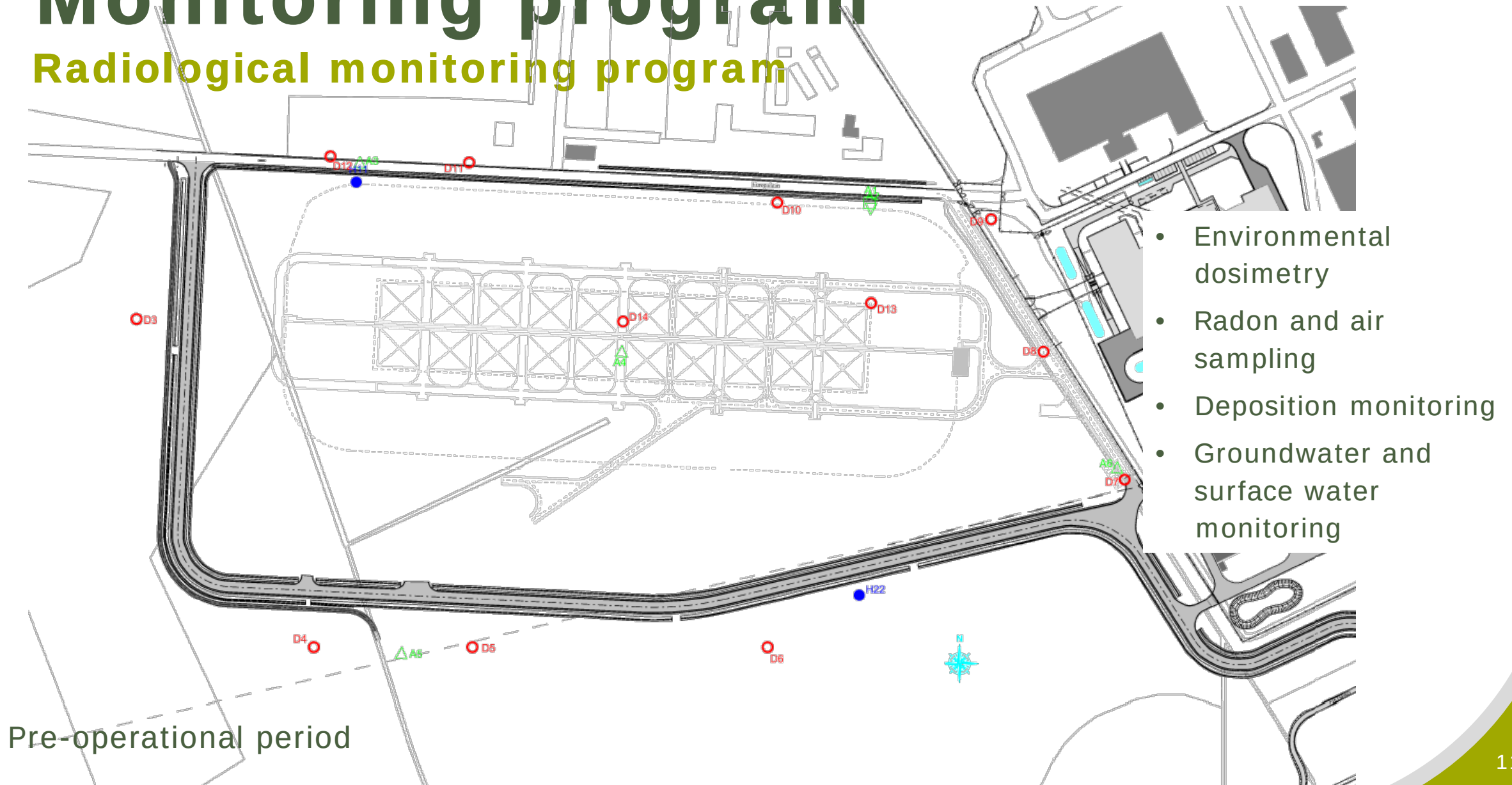
■ Post-closure period



- No more disposal activities
- Potential gradual leaching into the aquifer underneath the repository

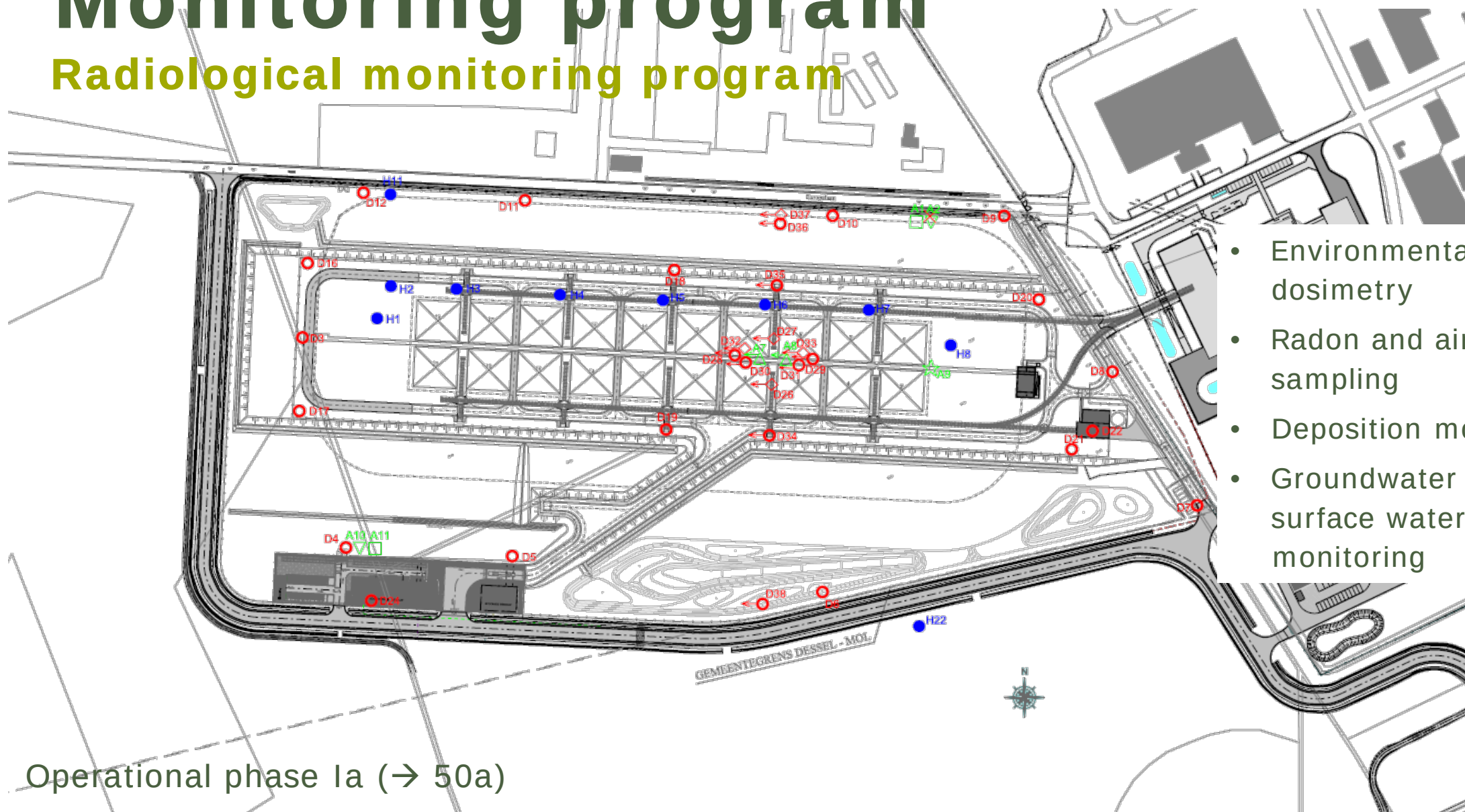
Monitoring program

Radiological monitoring program



Monitoring program

Radiological monitoring program

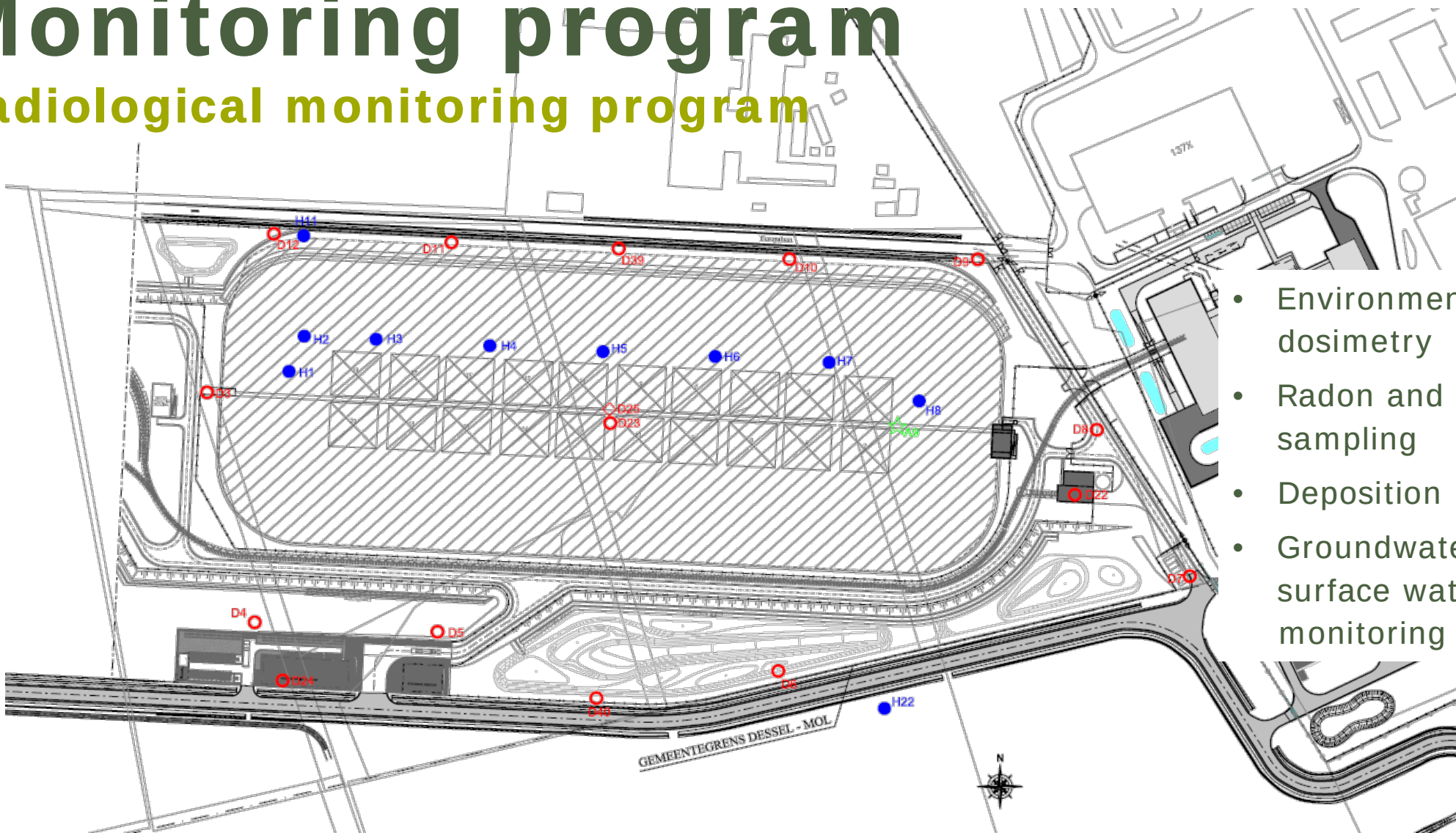


- Environmental dosimetry
- Radon and air sampling
- Deposition monitoring
- Groundwater and surface water monitoring

Operational phase Ia (→ 50a)

Monitoring program

Radiological monitoring program

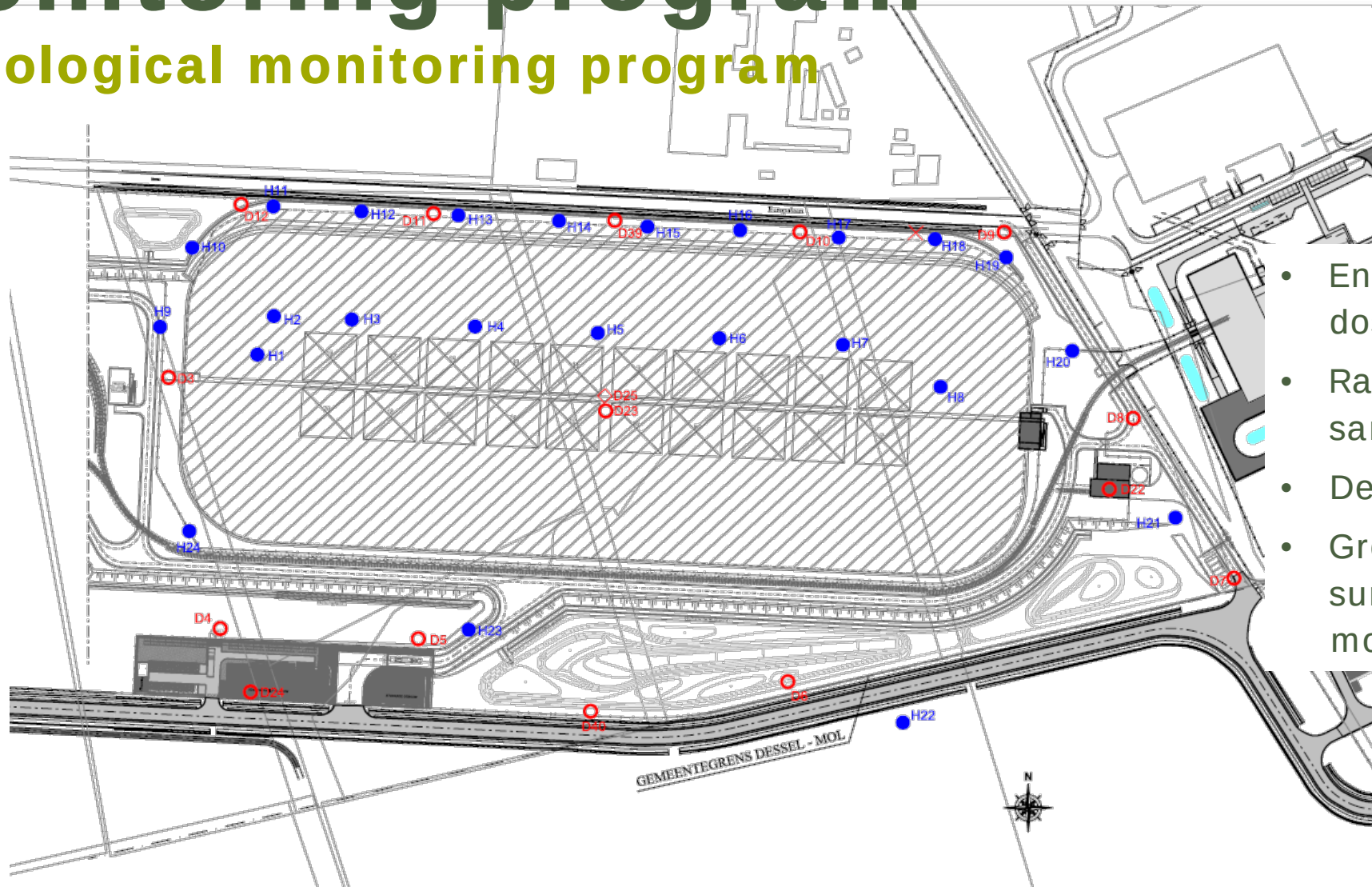


- Environmental dosimetry
- Radon and air sampling
- Deposition monitoring
- Groundwater and surface water monitoring

Exploitation phase Ib (50 – 95 a)

Monitoring program

Radiological monitoring program



- Environmental dosimetry
- Radon and air sampling
- Deposition monitoring
- Groundwater and surface water monitoring

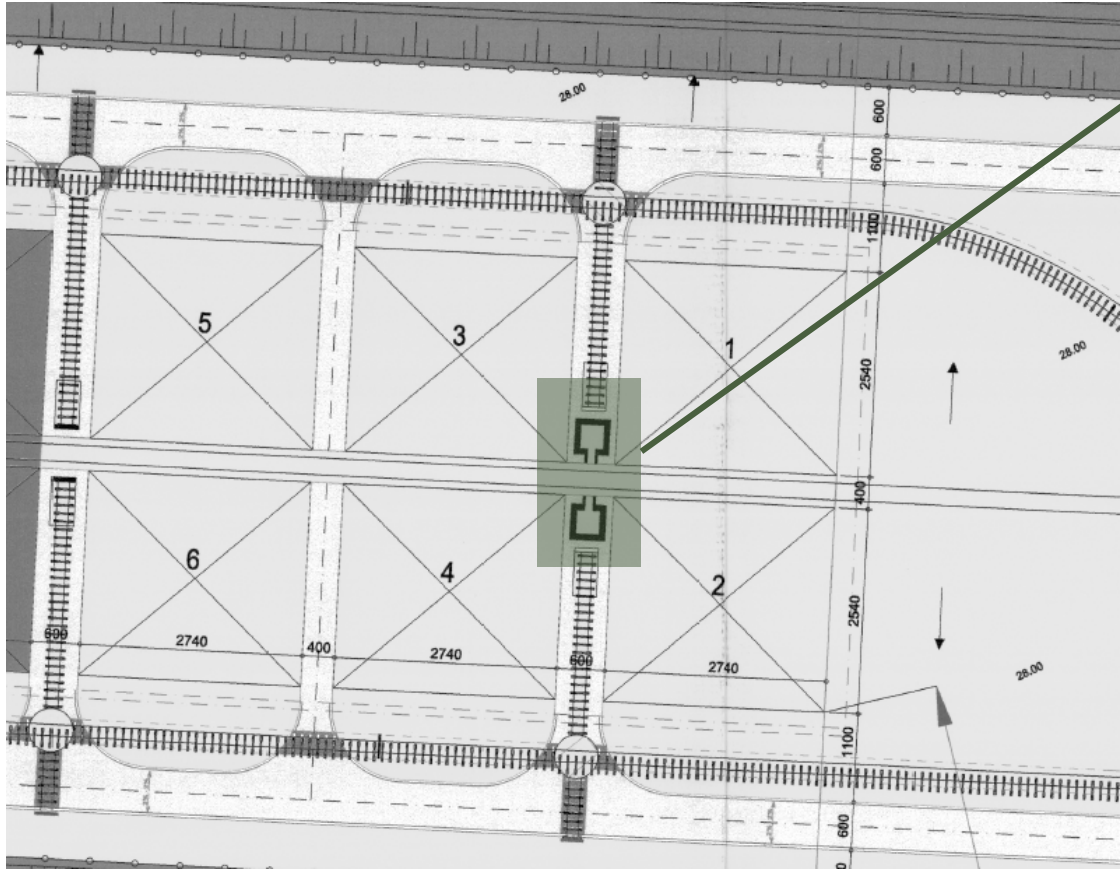
Closure phase II (95 – 100 a) and regulatory control phase

Table of contents

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Monitoring programme

Physical and structural monitoring programme



Sample rooms

with witness monoliths and test specimens

- Non destructive measurements via active monitoring (built-in instrumentation)
- Destructive testing once every 2 to 5 years

Goal:

- Confirmation of expected degradation rate
- Confirmation of compressive strength
- Confirmation of expected carbonatation rate

Monitoring programme

Physical and structural monitoring programme



Inspection rooms

Inaccessible for humans, accessible for an inspection robot

- Detection of traces of water
- Detection of cracks in concrete floors and walls ($> \sim 300 \mu\text{m}$)

Frequency

- Modules in operation: once a year
- Modules next to modules in operation: once every 2 years
- Closed modules: once every 4 years

Goal

- Confirmation of absence of degradation processes

Monitoring programme

Physical and structural monitoring programme

- Monitoring of modules:
 - ◆ Inspection during construction (e.g. Temperature evolution)
 - ◆ Visual inspection after construction (e.g. Absence of cracks)
 - ◆ Settlements and movements of modules (as expected)
- Monitoring of the cover
 - ◆ Settlements and movements of the cover
 - ◆ Visual inspection (absence of biological or physical degradation – erosion, perturbation,...)
- Weather station and accelerometers (cfr seismic activity)

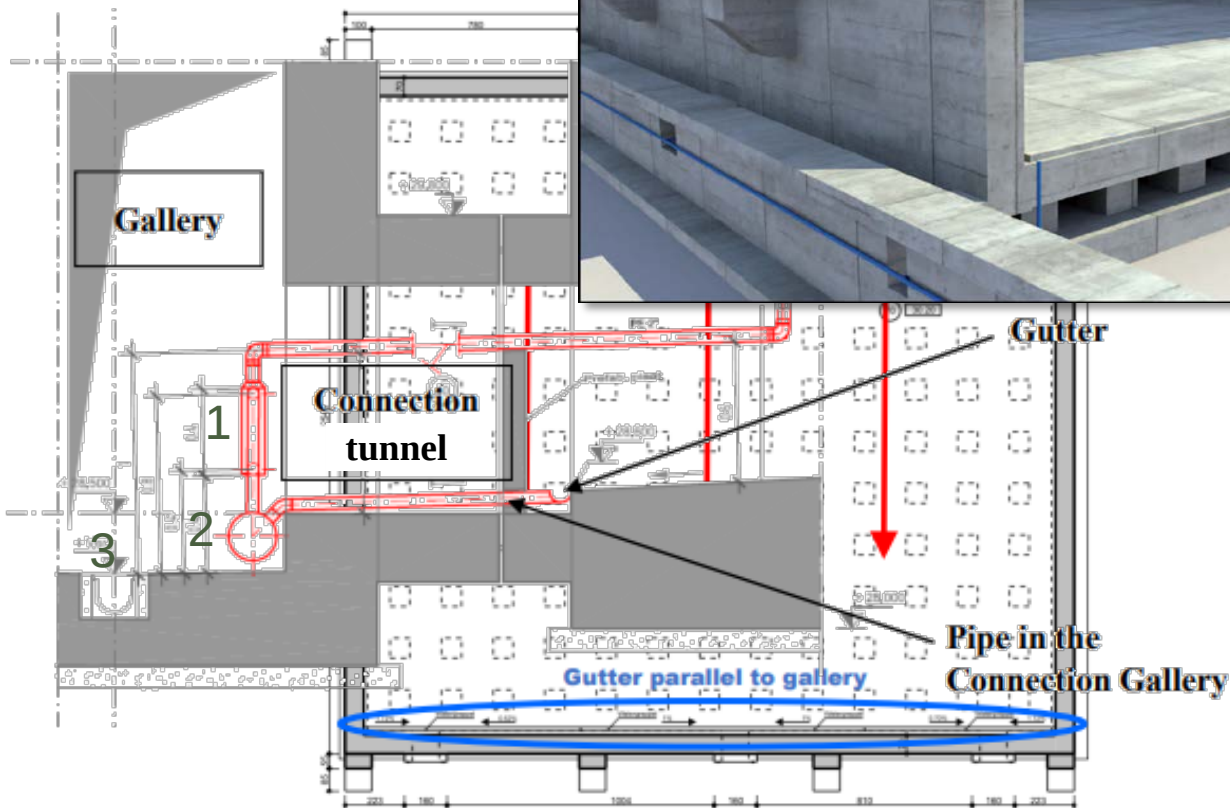
Table of contents

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Monitoring programme

Monitoring of the drainage system

■ Monitoring of the drainage system

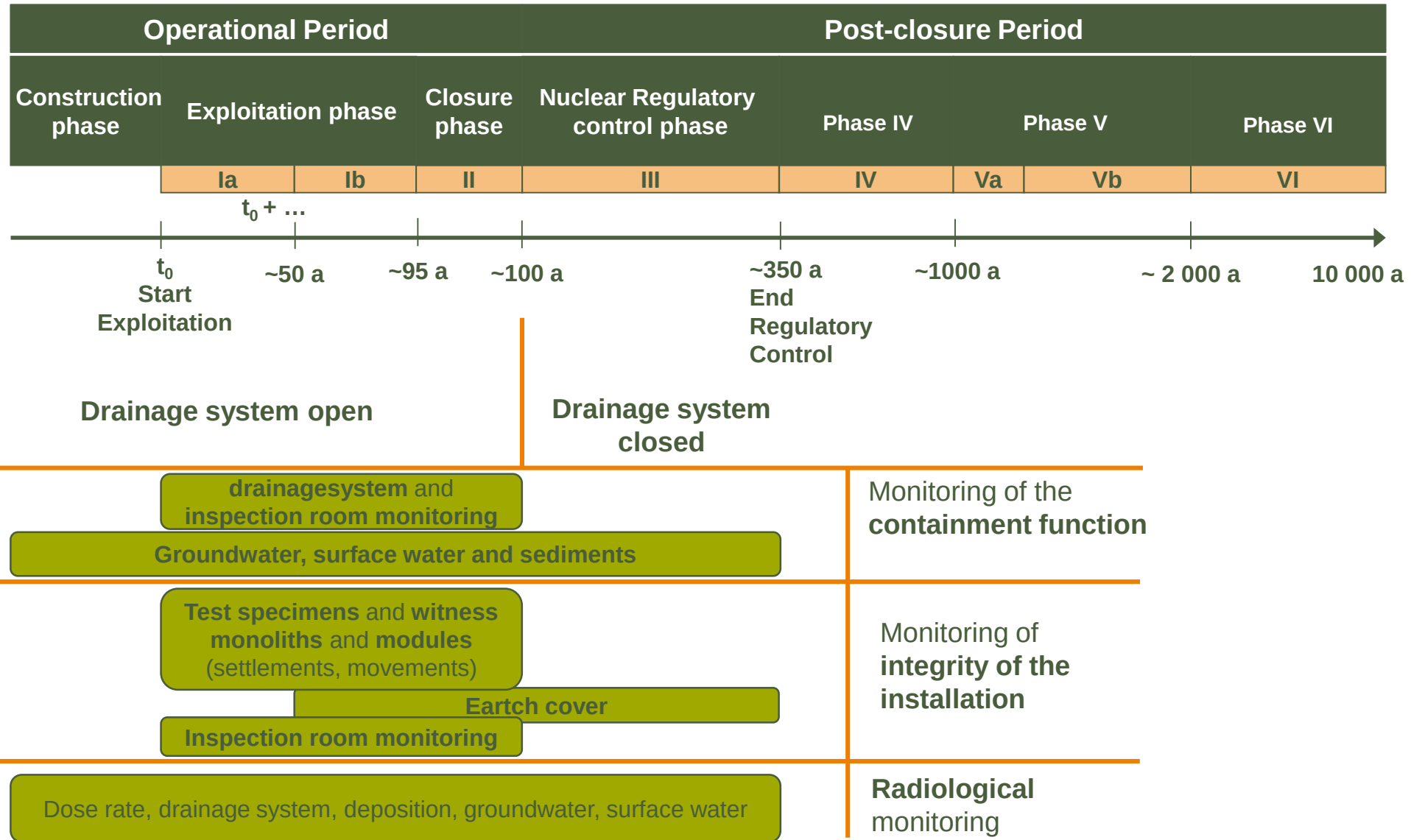


- Control 1: water coming from a module (3 recipients)
- Control 2: water coming from an inspection room (2 recipients)
- Control 3: water coming from the inspection gallery

Table of contents

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Conclusion



Test Cover instrumentation

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22nd Exchange Meeting EIG EURIDICE
October 1, 2019



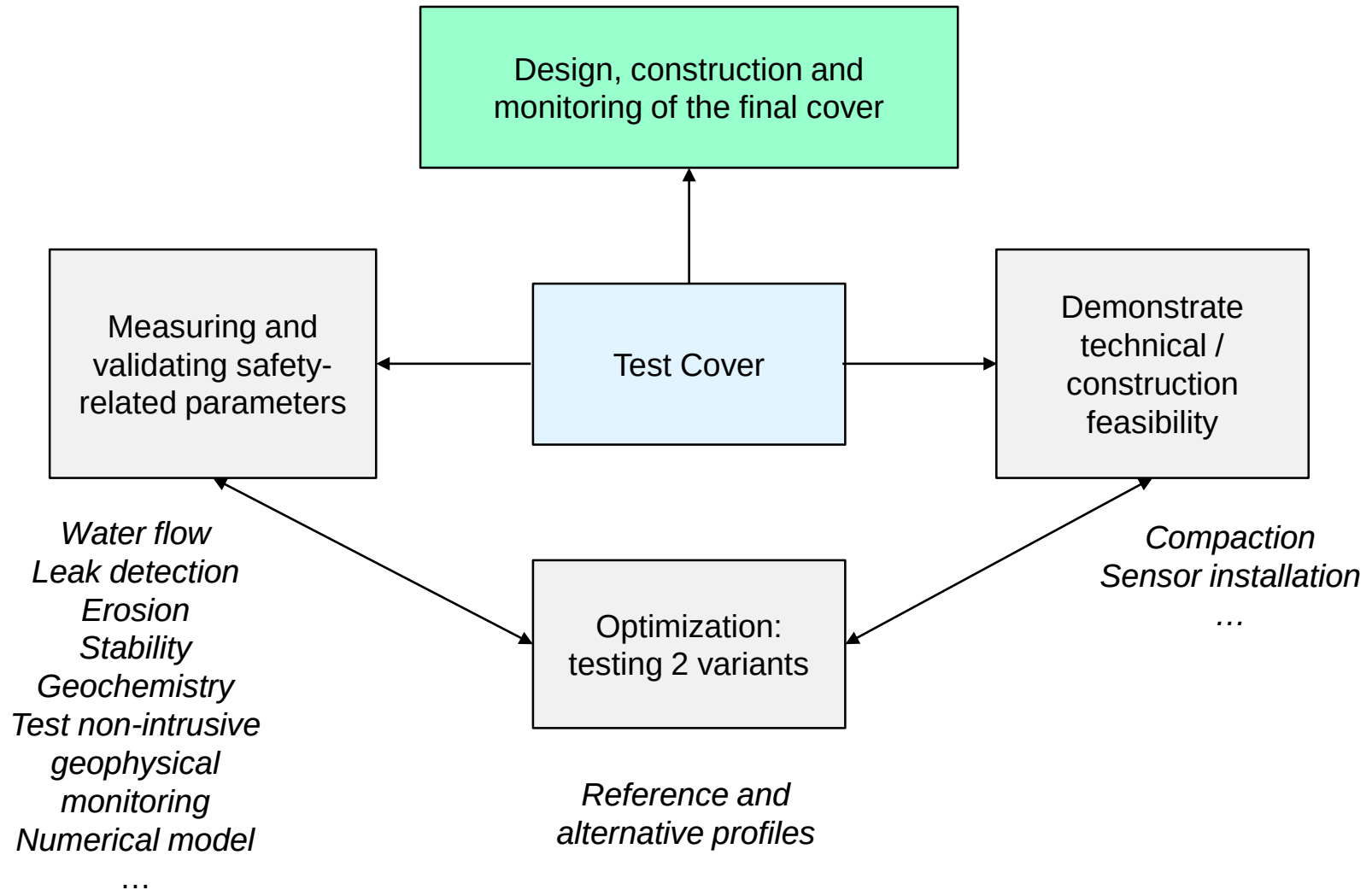
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

- Objectives
- Instrumentation
 - Experimental layout
 - 3D model of instrumentation
 - Example devices
- Conclusions

Earth cover for the Category A waste disposal

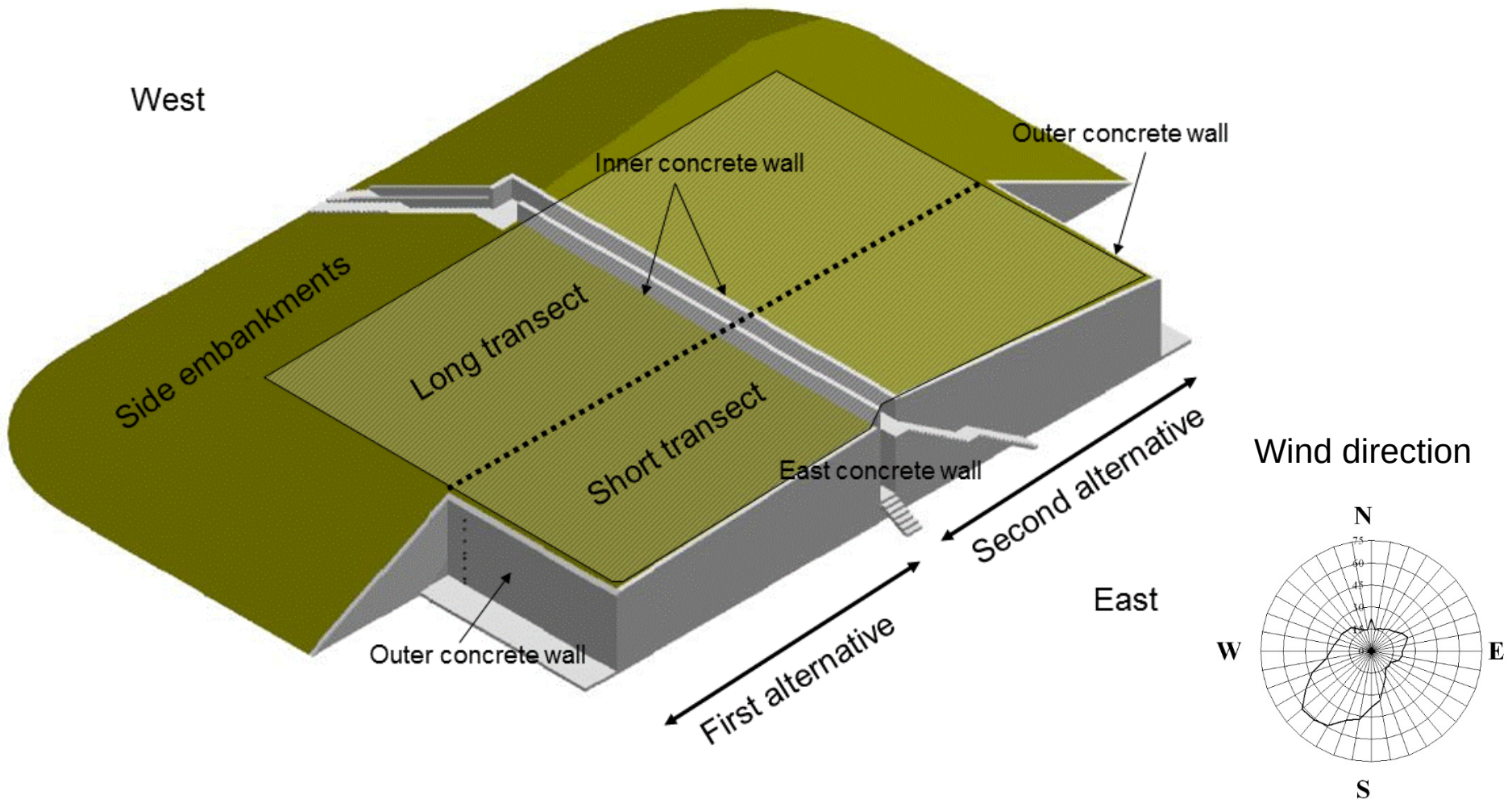


Objectives

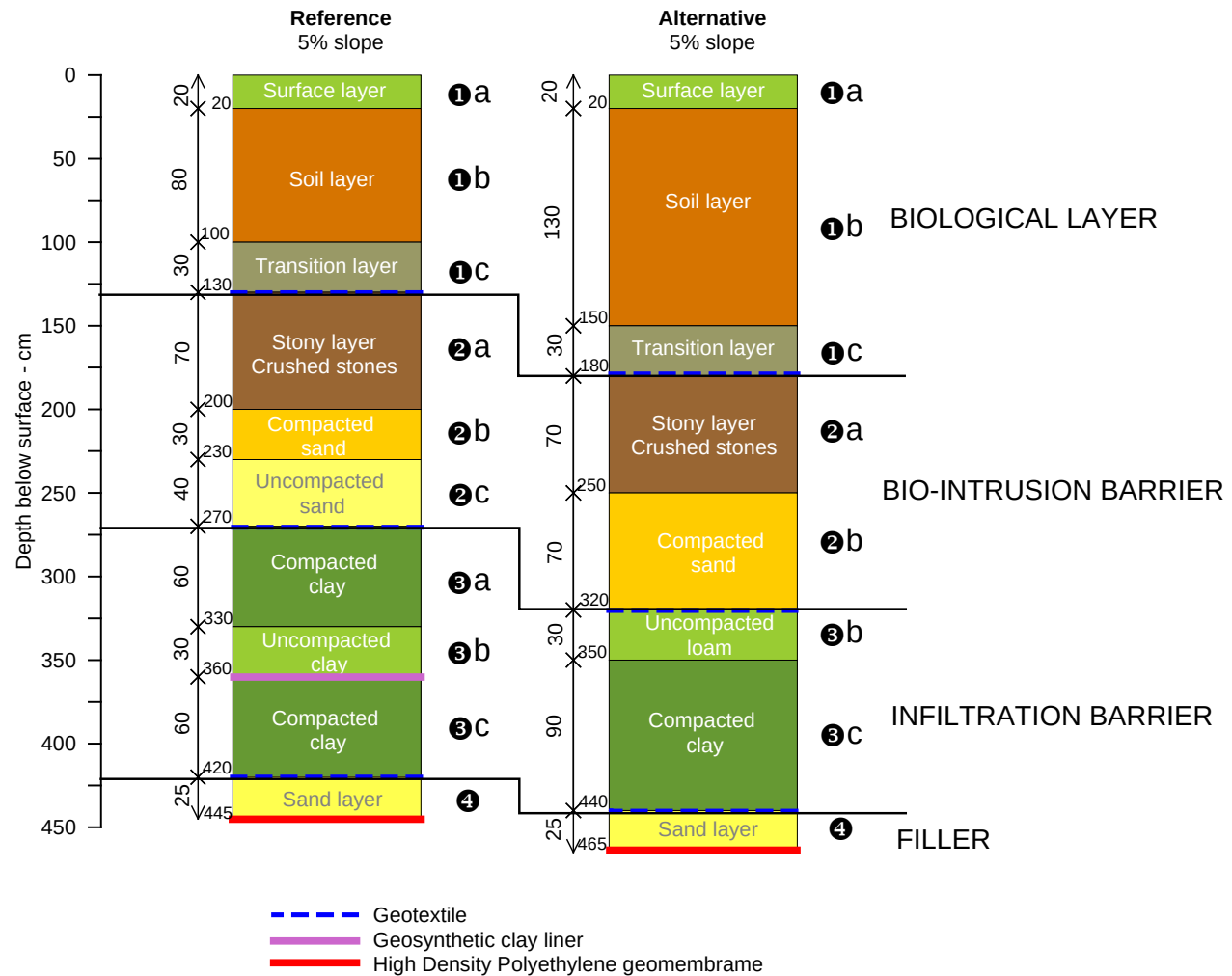


Instrumentation

Experimental layout



Layering





Measurement devices (1)

- Micrometeorology
 - 2 stations: rainfall, radiation budget, air and surface temperature, barometric pressure, wind speed and direction, relative humidity
- Water balance
 - Vol. water content by TDR (278 probes among which 34 long, vertically oriented “spatial” TDR probes)
 - Soil water potential by pF-meters (48 sensors)
 - Runoff and lateral drainage and vertical percolation (gutter and pipe network, 16 storage and measuring tanks)
 - Deep percolation (pipe network, 8 tipping buckets + small storage tanks)
- Erosion
 - Manual emptying and quantification of sediments in runoff gutters and storage tanks
- Settlements and displacements
 - Horizontal displacements by inclinometry (series of inclinometer casings)
 - Vertical displacements by inclinometry (4 vertical casings)
 - Settlement by external topographic survey

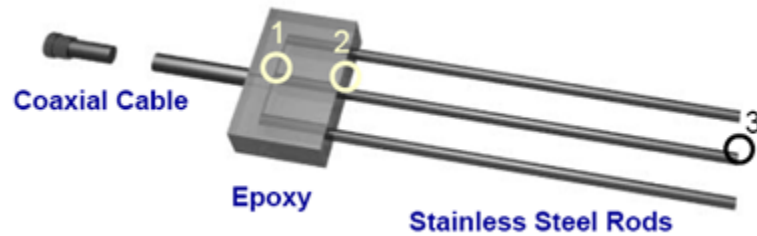
Measurement devices (2)

- Chemistry
 - In situ pore water sampling for pore water composition (56 pore water samplers)
 - Gaseous CO₂ and O₂ sampling (30 sampling systems)
- Non- or lowly invasive geophysical measurements
 - Ground Penetrating Radar for larger scale water content monitoring (series of horizontal tubes = inclinometer casings)
- Biology
 - Visual assessment of vegetation dynamics, destructive sampling for root development
- Material characterization
 - Reservation tubes for online destructive sampling
- Concrete
 - 3 small concrete chambers equipped with T, RH and CO₂/O₂ sampling probes
 - Top slab: T, RH, TDR
 - Base plate: T, RH, TDR

Examples of tested devices

TDR for water content monitoring

Classical three rod probe



Long probe for spatial application



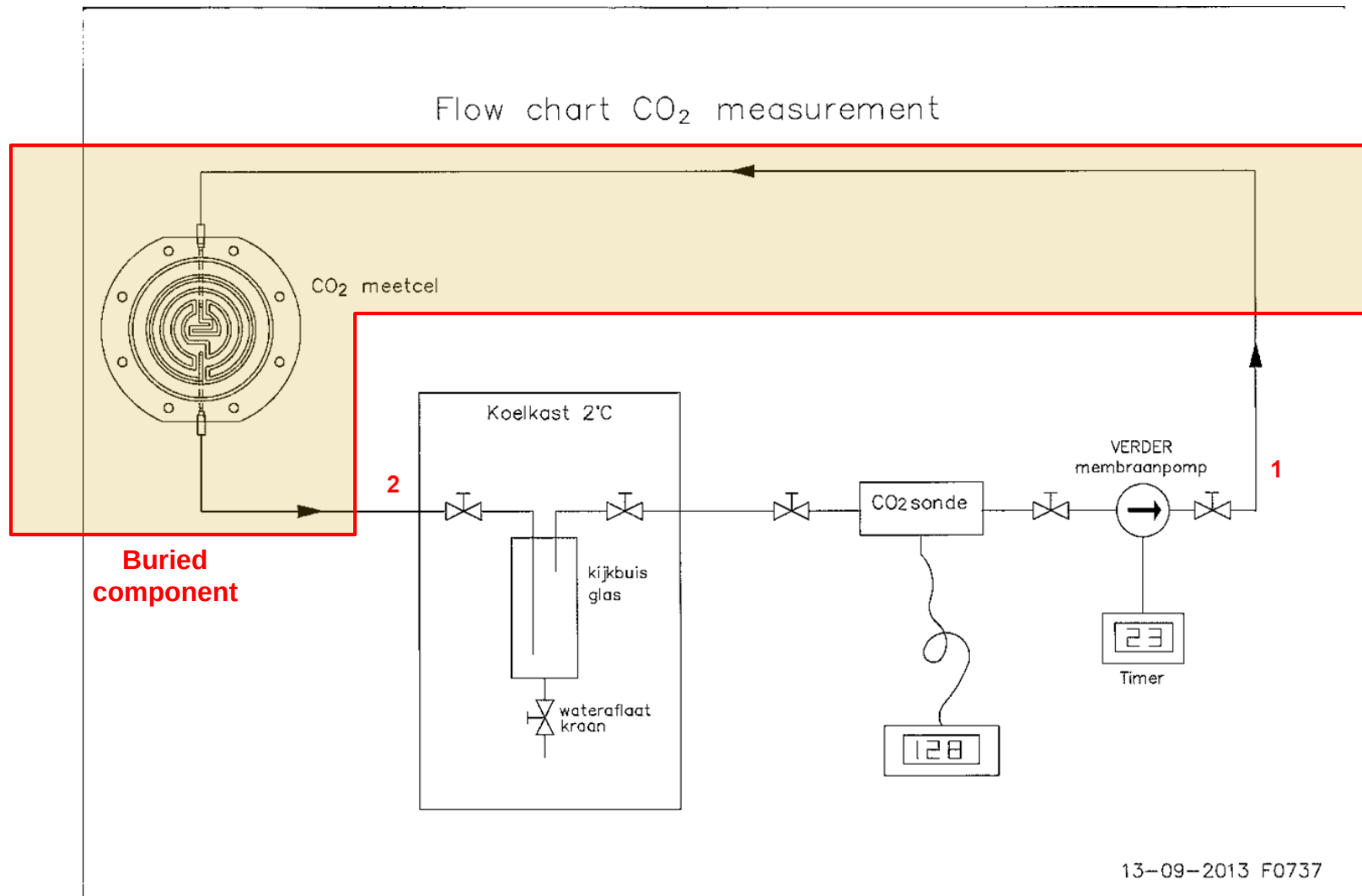
Sensor survival to compaction



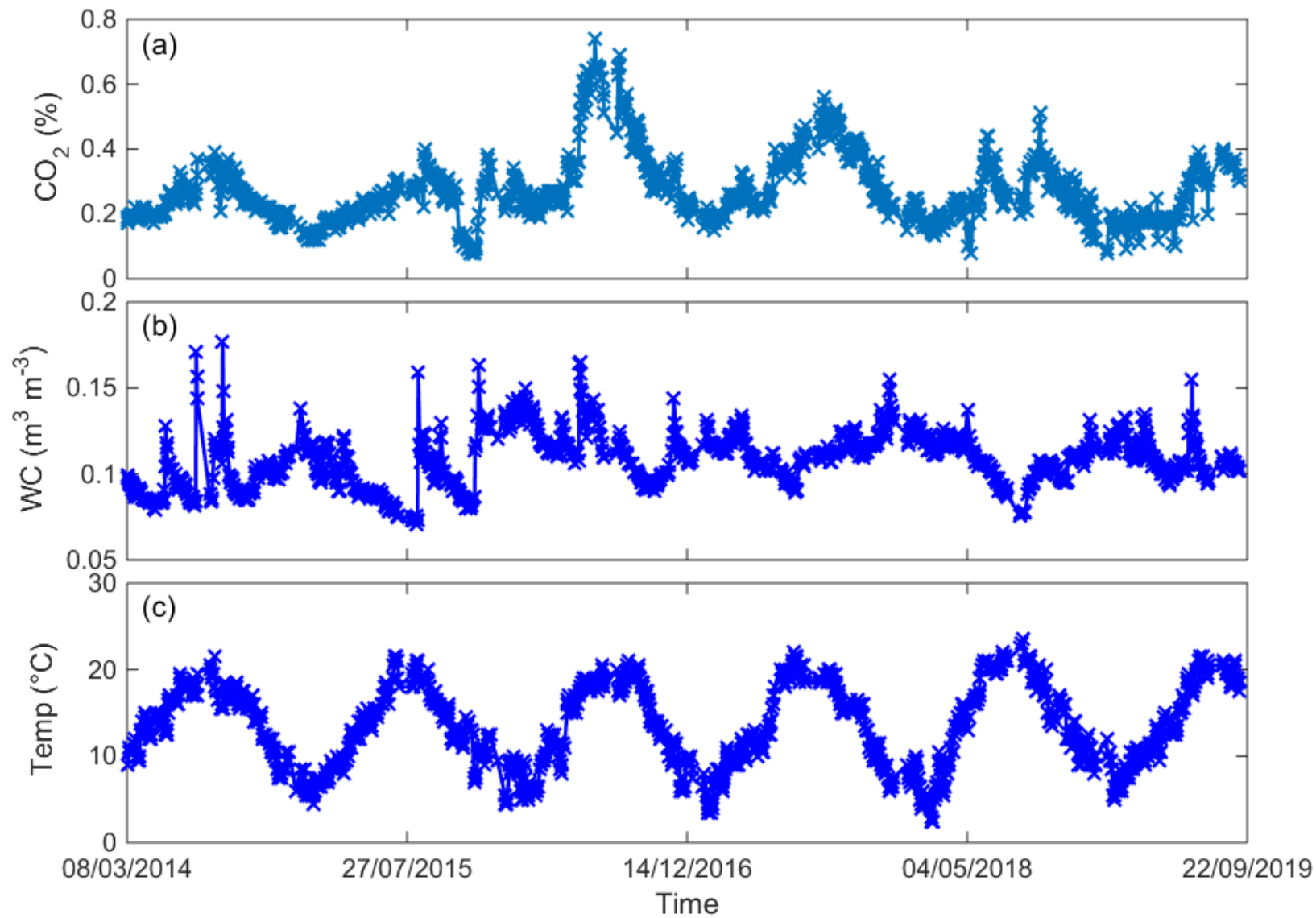
Gaseous CO₂ sampling



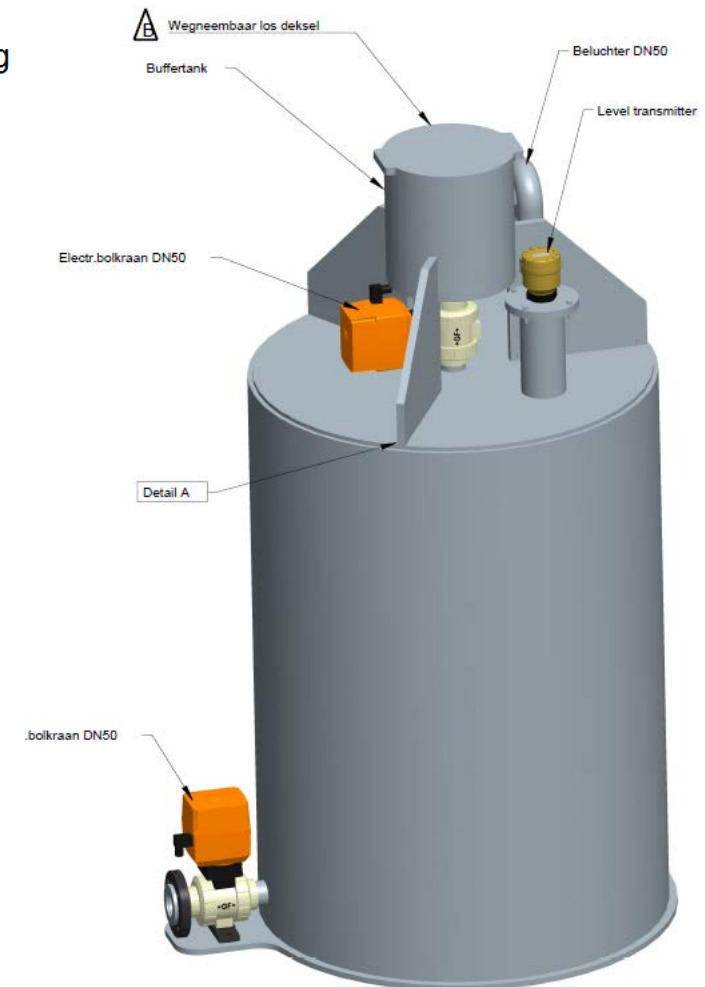
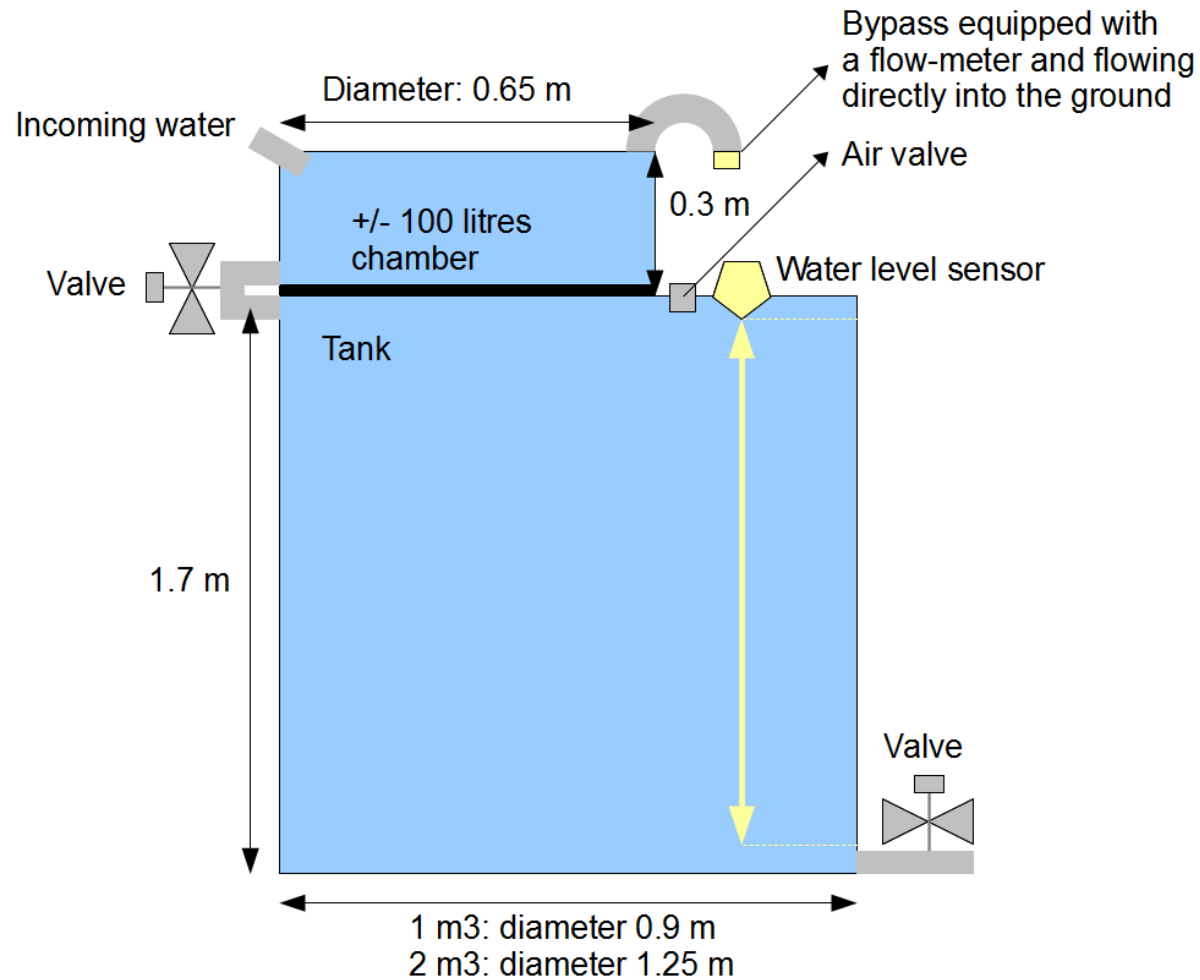
Design of CO₂ measurement system



13-09-2013 F0737

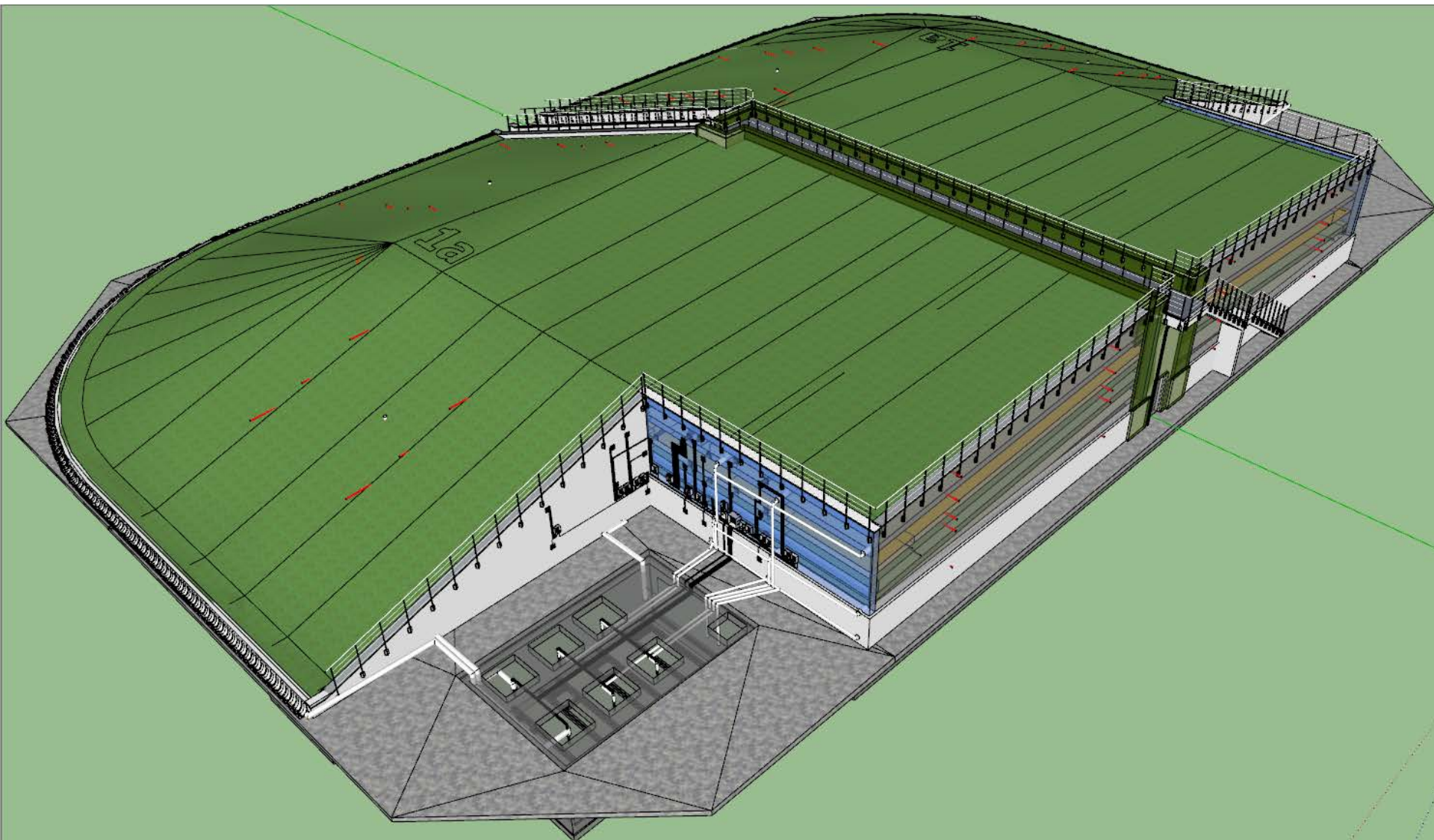


Storage and measuring tank

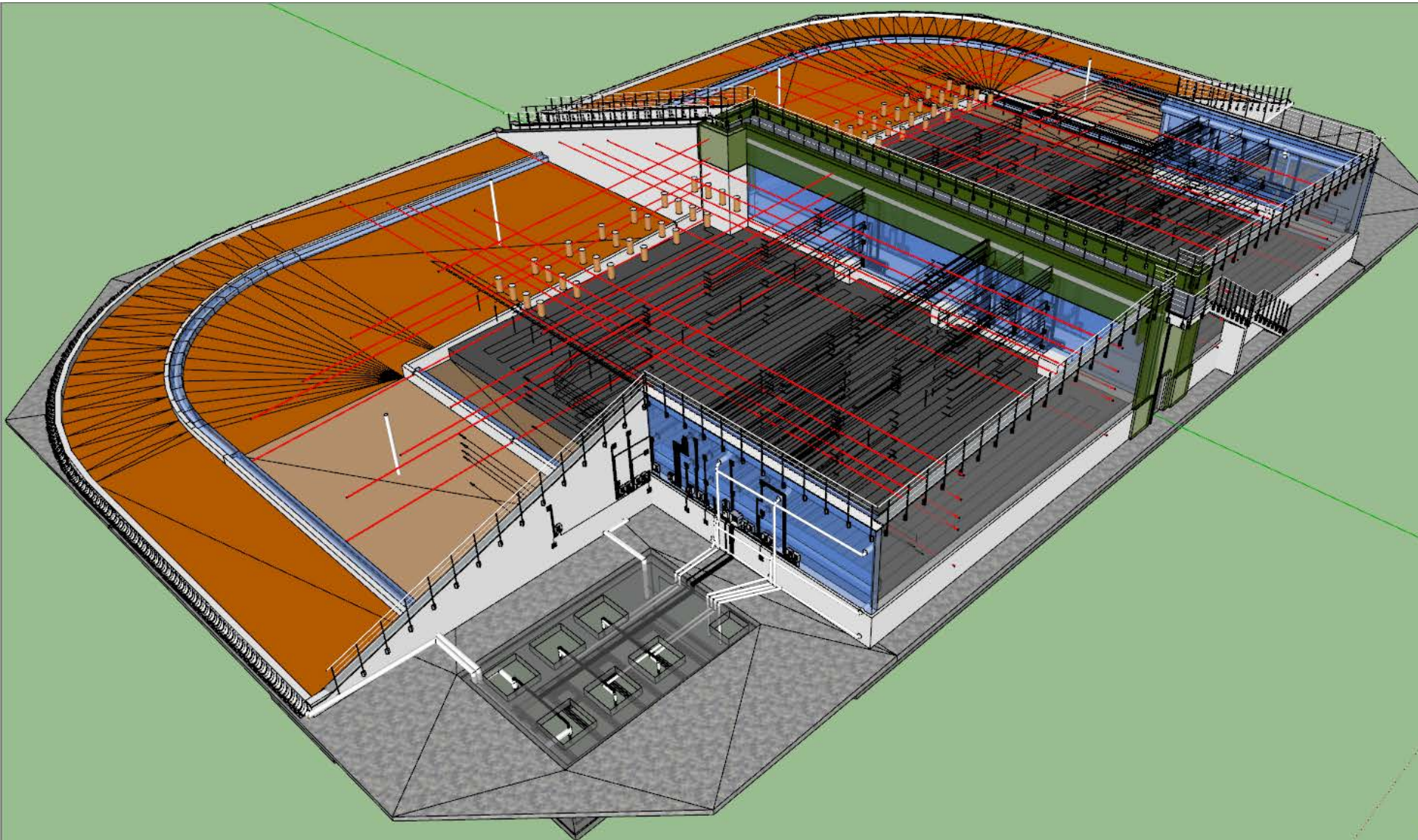


3D model of instrumentation

View from top



Instruments



Conclusions

- Instrumentation plan 90% ready – should be finished in the next months
- Still need to work on data transfer and storage
- Construction will probably start in fall 2020?