



ESV EURIDICE GIE

18th Exchange Meeting

Instrumentation and monitoring in radioactive waste repository research

Thursday 24 January 2013

Place: Auditorium Club House SCK•CEN, Mol

- | | |
|-------|---|
| 13:30 | Welcome and introduction – <i>Peter De Preter</i> (EURIDICE) |
| 13:40 | Contextual framework and strategy for the monitoring of geological disposal of radioactive waste – <i>Christophe Depaus</i> (ONDRAF/NIRAS) |
| 14.20 | 30 years of monitoring experience in HADES – <i>Jan Verstricht</i> (EURIDICE) |
| 15.00 | Coffee break |
| 15.15 | Monitoring aspects of the cAt-project – <i>Wim Bastiaens</i> (EURIDICE) |
| 15.50 | Perspectives on geological repository monitoring: confirmation, compliance, confidence building and societal vigilance – <i>Anne Bergmans</i> (University of Antwerp) |
| 16:30 | Closure drink |

A photograph of several hands of different skin tones stacked on top of each other in a circular formation. The hands are positioned over a background of dense green foliage. A semi-transparent green banner is overlaid on the lower half of the image, containing white text.

The cAt project in Dessel

**A long-term solution
for Belgian category A waste**

Monitoring aspects of the cAt project

18th Exchange Meeting

Wim Bastiaens – Joris Craeybeckx

24/01/2013



***An integrated project of surface disposal in Dessel
for Belgian low-level and medium-level radioactive short-lived waste***

Outline

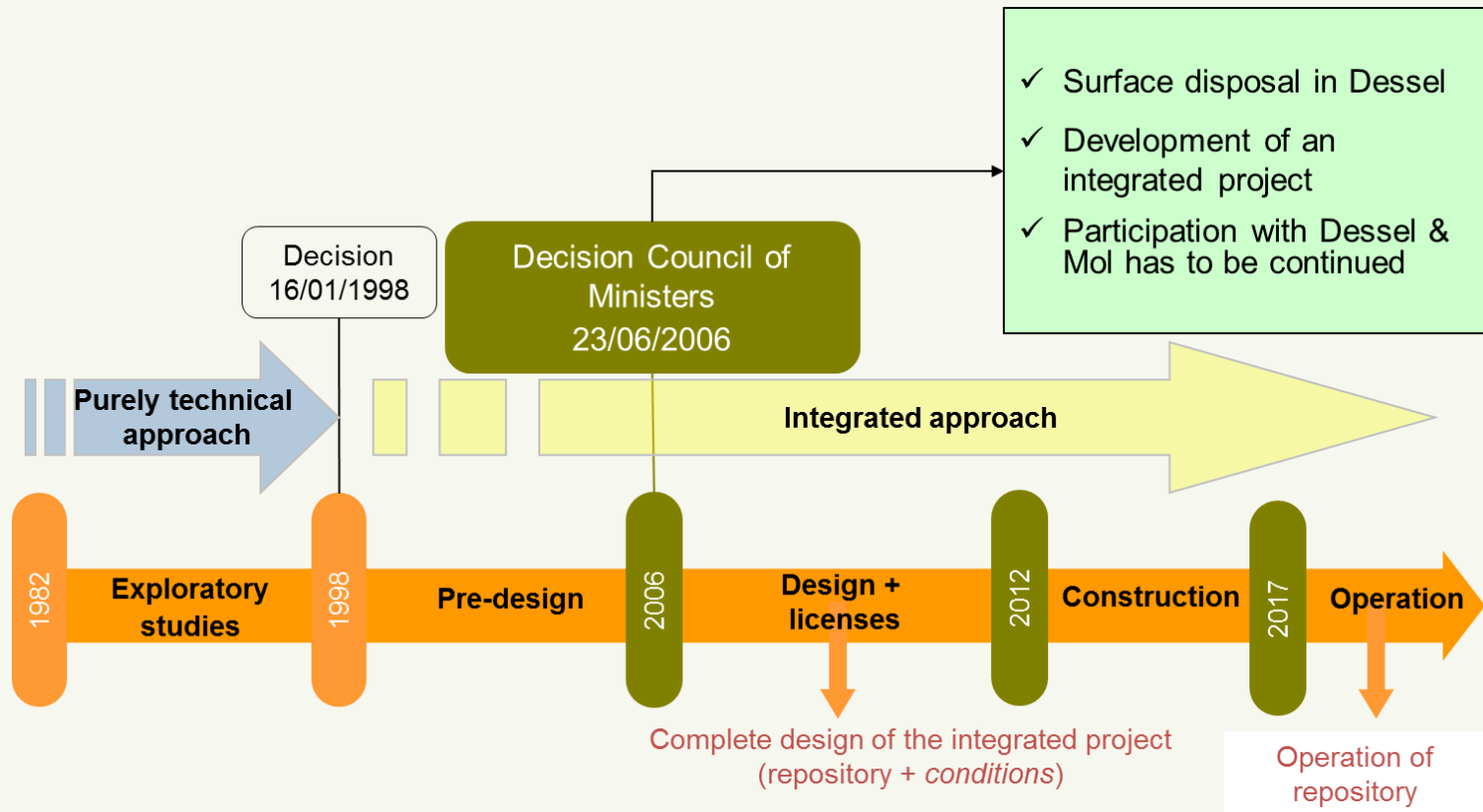
- Introduction
- Aim and principles of monitoring
- Types of monitoring
 - *(Site investigation)*
 - *(QC during construction/production)*
 - Radiological monitoring
 - Structural monitoring
 - Other monitoring aspects
- Conclusions



**An integrated project of surface disposal in Dessel
for Belgian low-level and medium-level radioactive short-lived waste**

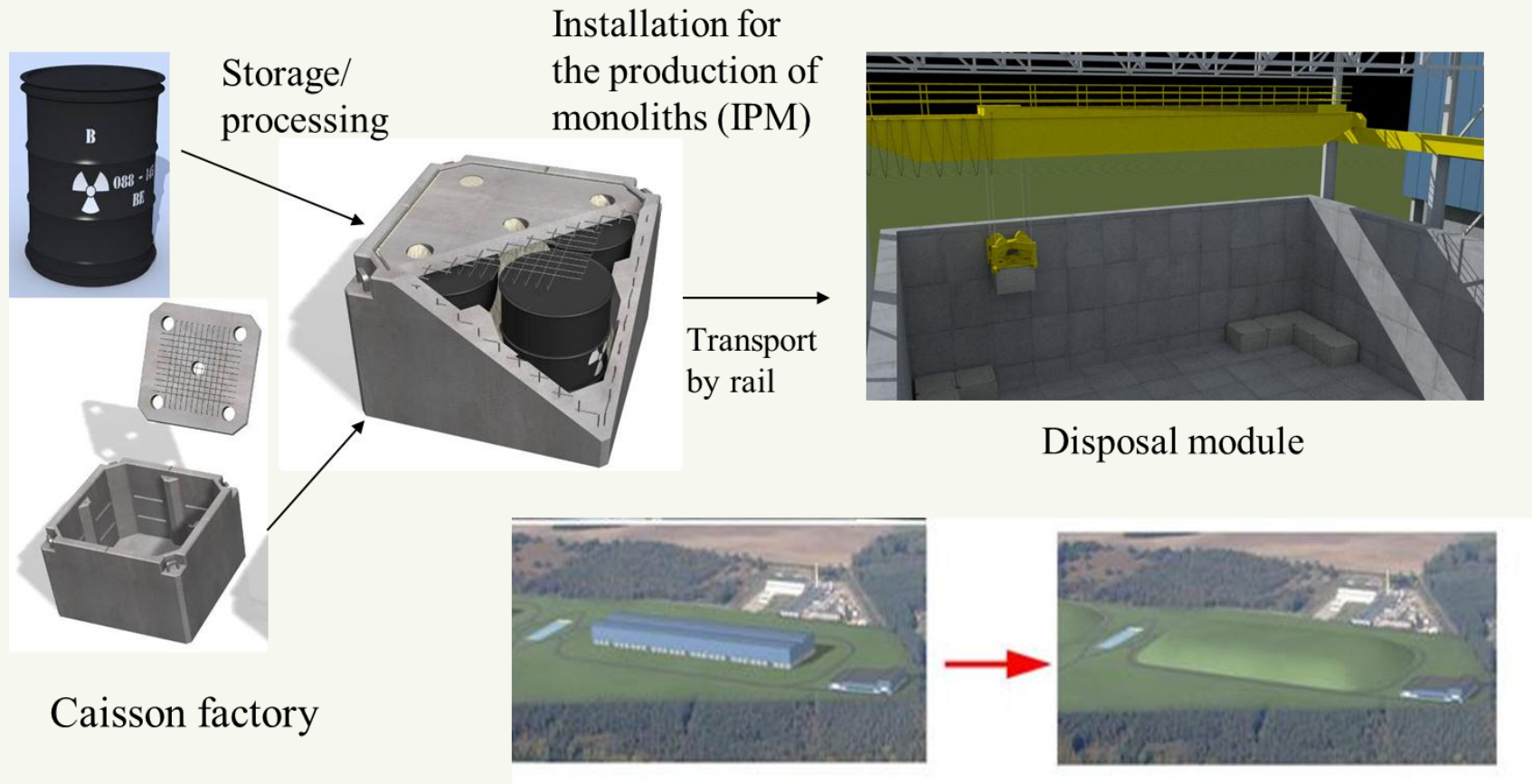
Introduction – cAt project

- Surface disposal of short-lived, low and medium level waste



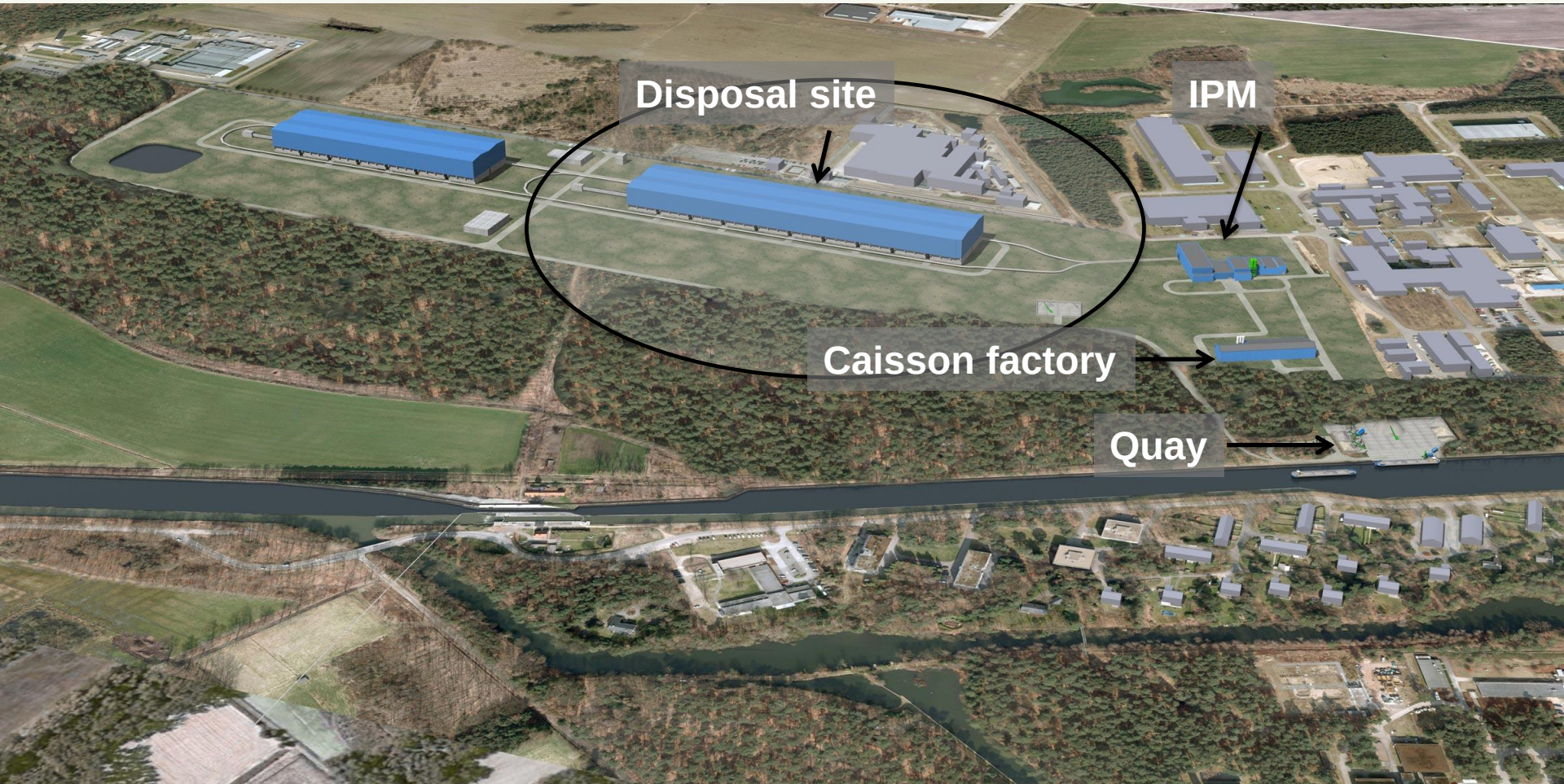
**An integrated project of surface disposal in Dessel
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Introduction – disposal concept



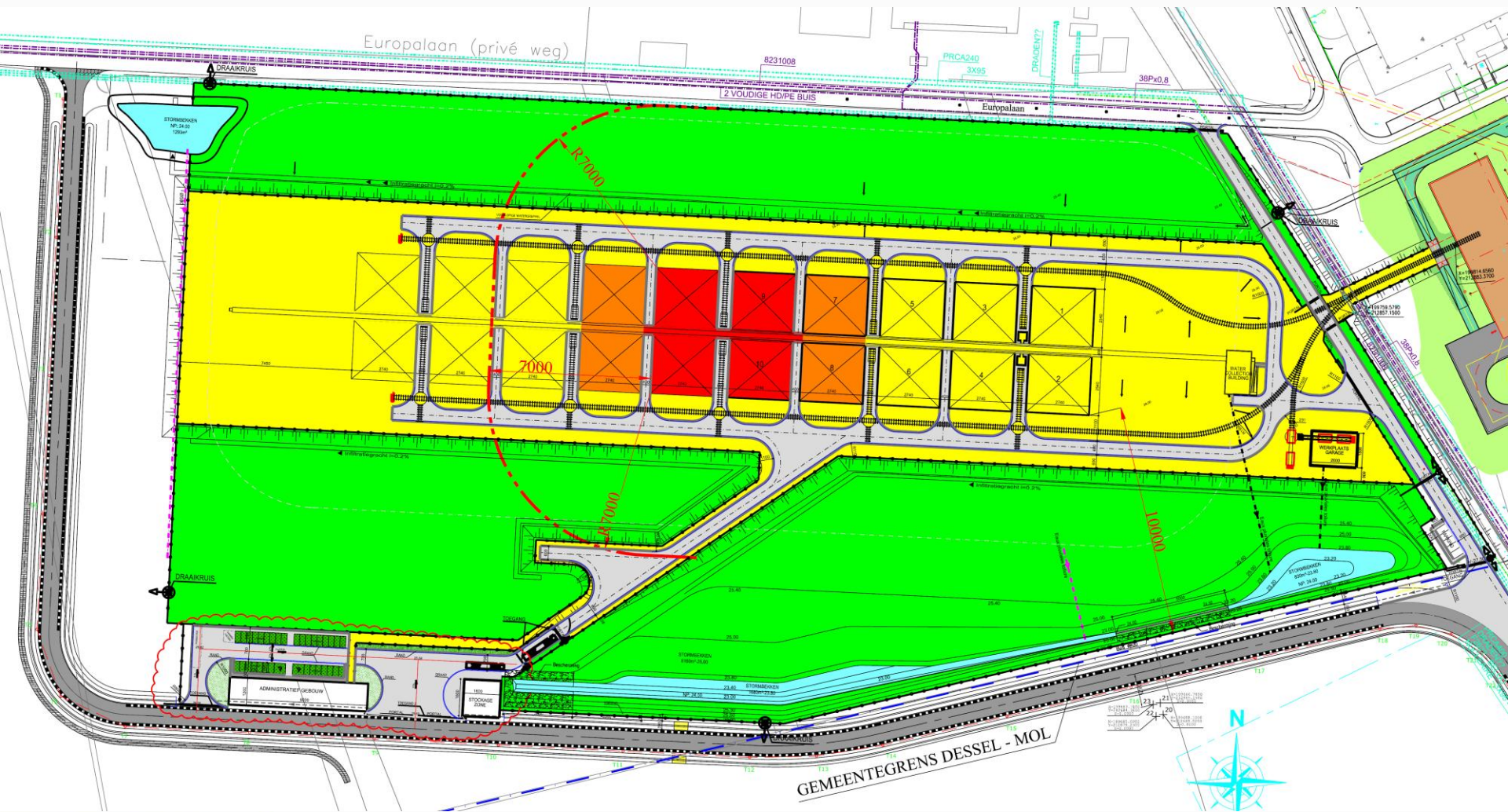
**An integrated project of surface disposal in Dessel
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Introduction – project site



**An integrated project of surface disposal in Dessel
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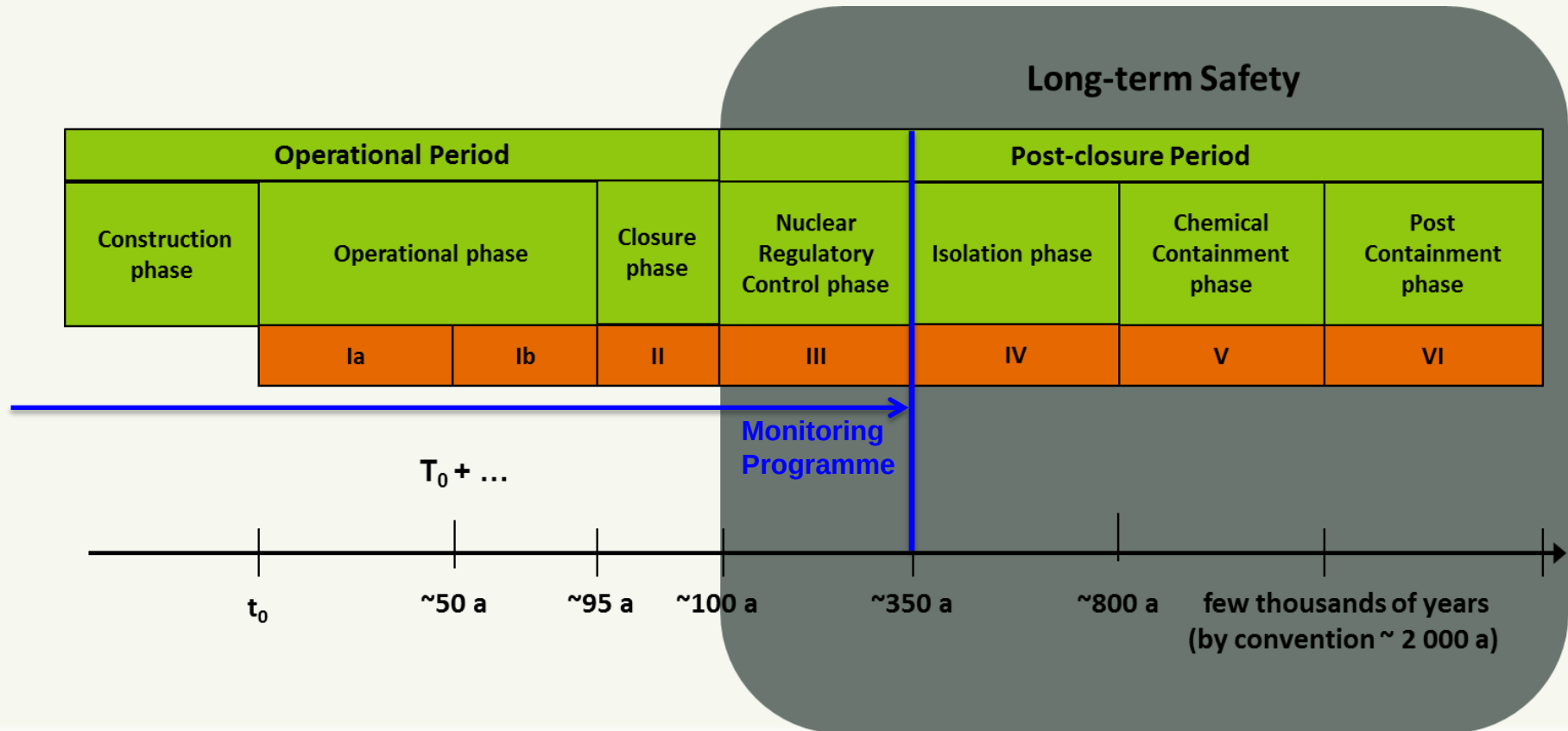
Introduction – project site



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Introduction - Timeframe

- Monitoring programme will evolve over time



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Aim of monitoring

- Confirm **conformity** with all legal requirements (e.g. licence)
- Support important **decisions**, e.g.
 - Transition from one phase to the next
 - Initiate remediating measures
- Provide return on experience (**REX**)
 - Evolution of system
 - Continued validity of model assumptions



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Principles of monitoring

- For each type of measurement and timeframe, define
 - objective
 - location
 - frequency
 - measurement method and device
 - initial values
 - levels
 - investigation level
 - alarm level



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Site investigation

- Geology & mechanical characterisation
- Hydrogeology
- Seismology
- Environmental/radiological characterisation
- Settlements
- ...



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QC during construction/production

- QC: Quality Control
- Ensure good quality of components
- Destructive and non-destructive testing during entire production process
- Example: concrete modules
 - Raw materials
 - Process control (concrete plant)
 - Controls on fresh concrete
 - Control of curing conditions
 - Controls on hardened concrete
 - Samples
 - End product



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Radiological monitoring

- Pathways
 - Operational safety
 - Normal operation: only **external radiation**
 - Accidental conditions: RN mainly by **atmospheric** pathway
 - Long-term safety
 - Slow and gradual leaching scenario: RN mainly by **hydrogeologic** pathway
 - Define **relevant radionuclides** for these pathways
- Measurements
 - Dose rate
 - Air
 - Soil & deposition
 - Groundwater
 - Surface water & sediments
- What follows are some examples – not exhaustive



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Radiological monitoring – Dose rate

- Site

- Integrated dose



- On-line dose rate



- Periodic surveys



- Personnel



	Pré-operationele periode	Constructie fase	Exploitatie fase I.a	Exploitatie fase I.b (plaatsing afdekking)	Exploitatie fase I.b (na plaatsing afdekking)	Sluitingsfase	Nucleaire areglementaire controlefase
Omgevingsdosis	T	T	T	T	S	S	J
TLD's voor modules in opvulling	n.a.	n.a.	M	n.a.	n.a.	n.a.	n.a.
Periodieke dosisdebiet monitoring	n.a.	n.a.	W	n.a.	n.a.	n.a.	n.a.
Eénmalige dosisdebiet monitoring	E	E	n.a.	n.a.	n.a.	n.a.	n.a.
Actieve dosisdebietmeting	n.a.	n.a.	C	C	C	C	C

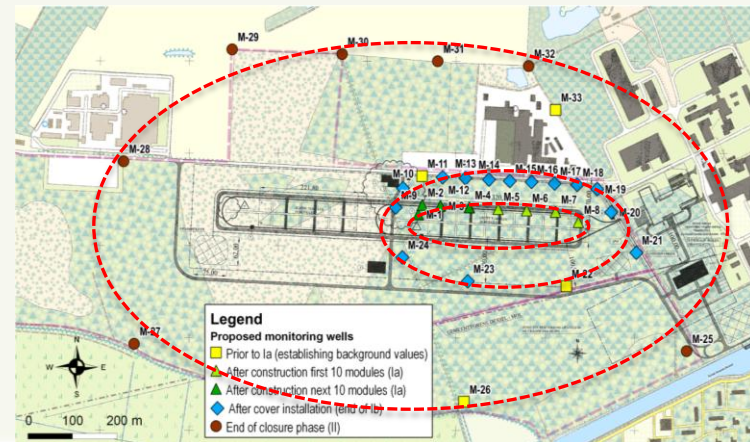
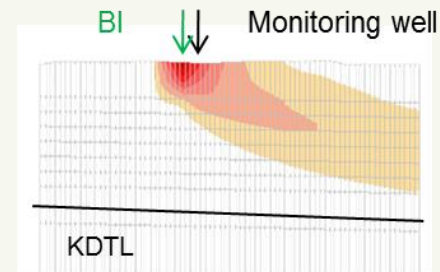
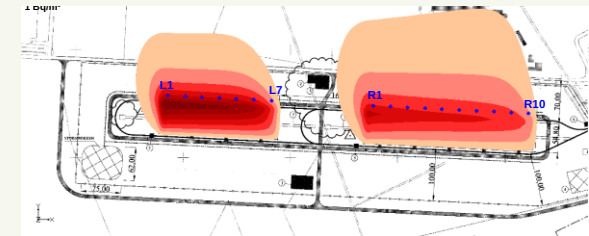
J Jaarlijks
 M Maandelijks
 T Trimestrieel
 S Semestrieel
 W Wekelijks
 C Continue
 E Eénmalig/fase



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Radiological monitoring – Groundwater

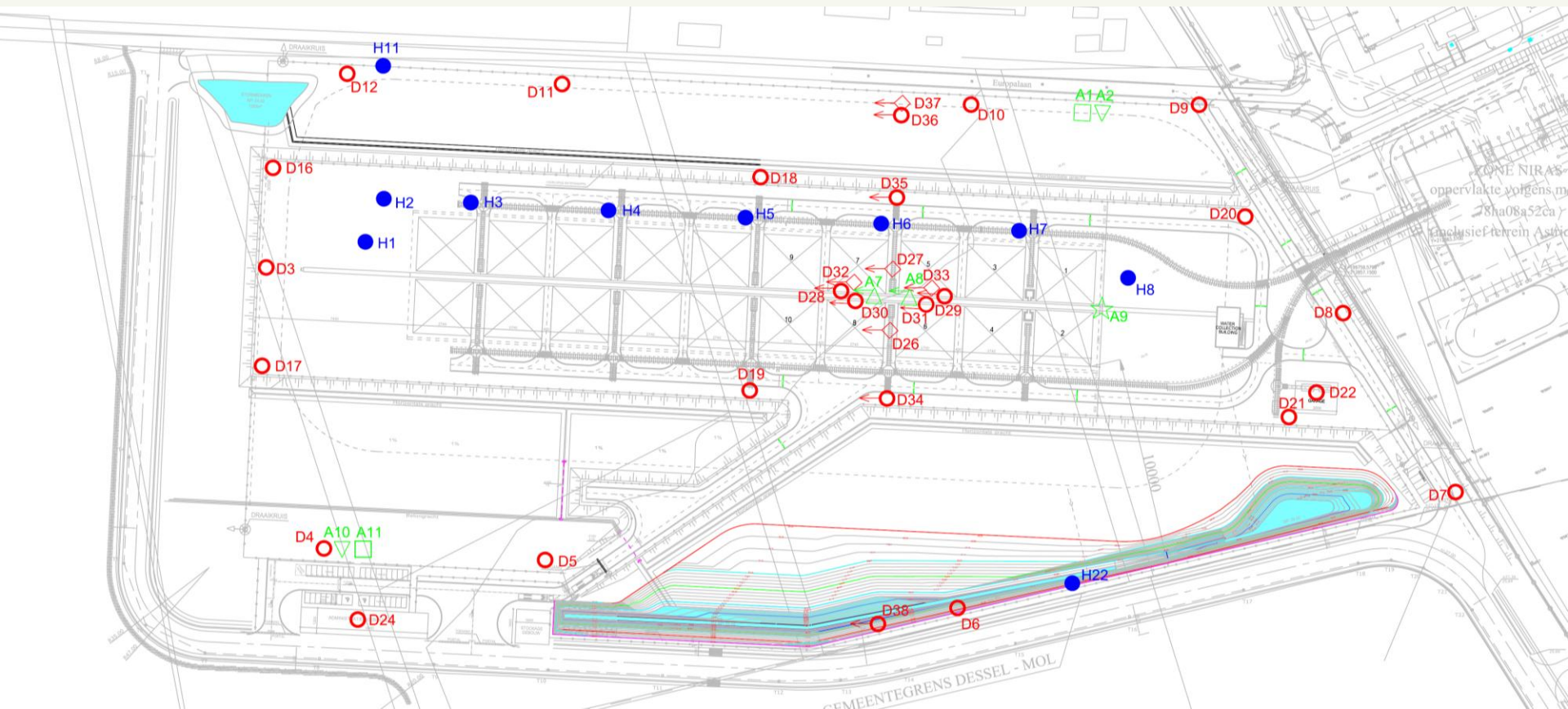
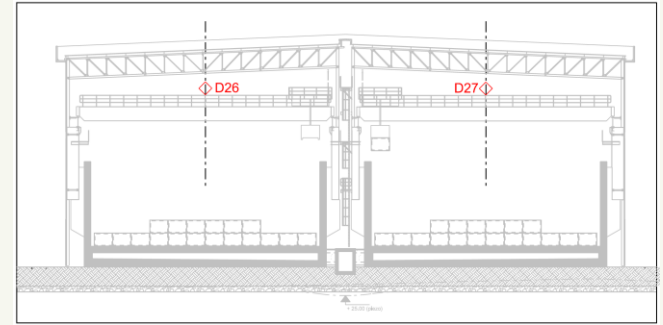
- Based a.o. on evolution in time and space of gradual leaching scenario
- Define time belts: locations with equal travel time from the source
 - Belt 1: ~ 5 years
 - Belt 2: ~ 10 years
 - Belt 3: ~ 10- 20 years
- Measurements on water samples
 - Total alfa/beta
 - Gamma spectroscopic
 - Precursors (e.g. ^3H)
 - *Alfa/beta spectroscopic when triggered*



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Radiological monitoring - locations

- Groundwater (mainly belt 1)
- Dose (rate)
- Air & deposition



Radiological monitoring - locations

- Surface water & sediments
 - Hooibeeek, canal, ponds, Witte Nete



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Structural monitoring

- Concrete components
- Inspection rooms
- Settlements & displacements
- Multi-layer cover
- Meteorological monitoring
- Seismic response of structure
- Other aspects



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Structural monitoring – concrete

- Evolution of concrete properties
 - Limited amount of direct monitoring



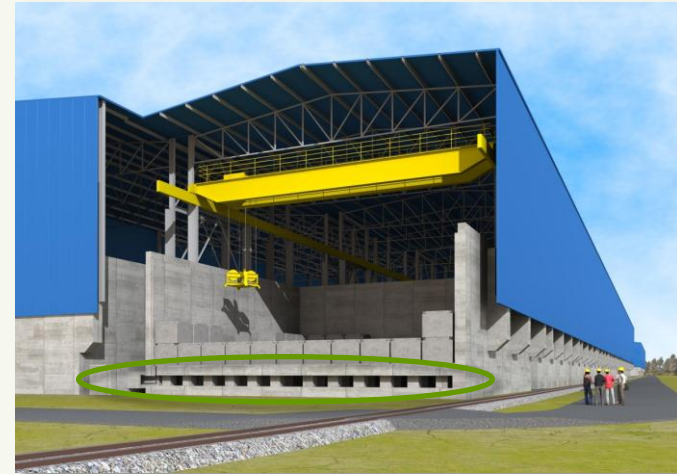
- Non destructive testing
- Witness structures
 - Sampling rooms in between disposal modules & witness structures
 - Destructive and non destructive measurements
 - Identical conditions
 - Accessible during fase Ia and Ib (~ 100 years)



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Structural monitoring – inspection room

- Accessible from central inspection gallery
- Monitor close to the source
 - Alertness
 - Equivalent to ANDRA's 'unique point of exit'
 - Integrated view on system's performance
 - One of the elements in the closure decision
- Visual inspection by an inspection robot to check the presence of
 - Cracks
 - Water
 - Anomalies
- Assess contamination (if any) on swipe samples



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Structural monitoring – inspection room

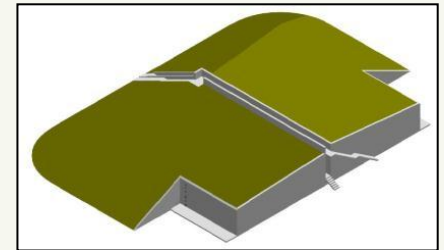
- Drainage system: 3 drainage points in each module
 - Collect water
 - Malfunction of roof structure
 - Percolating water (cover)
 - Condensation
 - Monitoring
 - Amount
 - Composition (e.g. ^3H)



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Structural monitoring

- Settlements & displacements
 - On-line follow-up of settlement & inclination of modules/equipment
- Multi-layer cover (test cover)
 - Monitoring of surface erosion, sliding, vegetation, overall performance
- Meteorological monitoring
 - Wind, temperature, snow thickness
- Seismic response of structure
 - Accelerations of steel roof structure
- Other aspects
 - Maintenance related issues (e.g. rain water system)
 - Water levels



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Other aspects – continued measurements

- Continue aspects of site characterisation
 - Monitor evolution (check continued validity of model assumptions)
 - Improve knowledge (increase measurement database)
- Examples:
 - Hydrogeologic measurements
 - Seismic investigations



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Conclusions

- Monitoring is an important aspect of the cAt-project
 - During project **design**
 - Site investigations
 - Large scale testing (loading test, demonstration test, test cover)
 - During project **construction**
 - QC during construction
 - Initial values
 - During project **operation**
 - Radiological monitoring
 - Structural monitoring
- Monitoring programme **will evolve** in time
- Monitoring programme is **well advanced** and is a part of the cAt **safety case** (submission to FANC 31st January 2013)



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A photograph of several hands of different skin tones stacked on top of each other in a circular gesture, symbolizing unity and teamwork. The hands are positioned over a background of lush green foliage. A semi-transparent green banner is overlaid on the lower half of the image, containing the title and subtitle text.

The cAt project in Dessel

**A long-term solution
for Belgian category A waste**



ONDRAF/NIRAS

Contextual framework and Strategy for the monitoring of geological disposal of radioactive waste

Christophe Depaus & Maarten Van Geet

Belgian Agency for Radioactive Waste and Enriched Fissile Materials



Outline

1st part: Contextual framework (= regulatory framework & guidelines): 3 questions

1) Which boundary conditions are provided by the contextual (regulatory) framework ?

- International law (nuclear & environmental) and recommendations
- Belgian legal framework:
A.R. « Wenra » - chapter 4 (May 2011) + technical guides

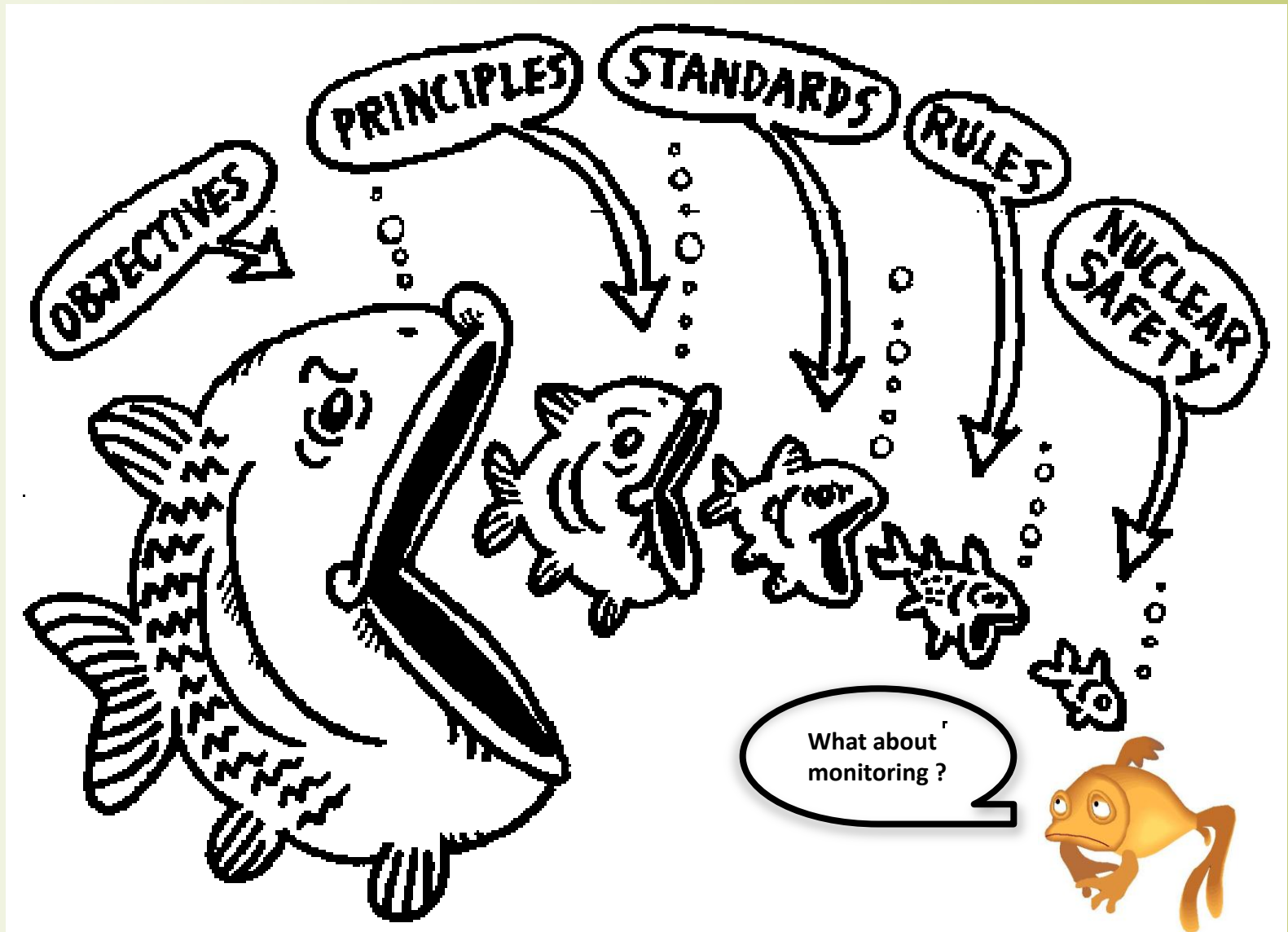
2) Does the contextual (regulatory) framework suggest a « technical content » for the monitoring programme ?

3) Issues, gaps & limitations

2nd part: ONDRAF/NIRAS Monitoring Strategy



Part I: Regulatory framework Synopsis



International & European law as boundary conditions... which obligations ?

- **The Joint Convention (on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management)**
 - *Adopted in 1997, e.i.f in 2001. Belgium is a State Party since September 2002. « Incitative » convention (soft law) but still binding for the State through the peer review process every 3 years. Warning: JC is split in two parts: SNF & RW. JC specifies:*
 - « operation, maintenance, **monitoring, inspection** and testing of a spent fuel management facility are conducted in accordance with established procedures” (art 9, (iii) for SNF + art 16 (iii) for RW on “operation of facilities”)

International & European law as boundary conditions... which obligations ?

- « active or passive institutional controls such as **monitoring** or access restrictions are carried out, if required [...]» (art. 17 (ii) RW on “institutional measures after closure”)
- « The legislative and regulatory framework shall provide for:
 - [...]
 - a system of appropriate institutional control, regulatory **inspection** and documentation and reporting»
(art. 19.2 (iv))

→ Monitoring & surveillance (inspection) are obviously recommended both on the operator and regulator sides (JC binds the State as a whole) but no specific modalities.

International & European law as boundary conditions... which obligations ?

- **Council Directive 2011/70/EURATOM (establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste)**
 - *Is doubly binding for the European States(2013 & 2015).*

The directive specifies:

- « a system of **appropriate control**, a management system, regulatory **inspections**, documentation and reporting obligations [...], including appropriate measures for the post-closure periods of disposal facilities» (art. 5 on “national framework”)
- « [...]to regularly **assess**, verify and **continuously improve**, as far as is reasonably achievable, the safety of the radioactive waste and spent fuel management facility [...]» (art. 7.2 on “licence holders”) → **Performance Confirmation/challenging**



International & European law as boundary conditions... which obligations ?

- « *the concepts or plans for the post-closure period of a disposal facility's lifetime, including the period during which appropriate **controls** are retained [...]*» (art. 12 (e) on “contents of national programme”)

Let us notice that the preamble (17§) of the directive mentions the conclusions of the ENSREG report (2009) where:

«[...] Features such as reversibility, retrievability and **monitoring** in geological disposal appear to be key issues that need to be thoroughly assessed in terms of repository safety»

→ Requirement for inspection, (continuous) control and monitoring of the facilities. The idea of « performance confirmation » is expressed.

International & European law as boundary conditions...which obligations ?

Council Directive 96/29/EURATOM (laying down BSS for the protection of the health of workers and the general public against the dangers arising from ionizing radiation):

« Whereas the **operational protection of exposed workers**, [...] requires [...] **monitoring of areas** and working conditions [...] » ; « The **scope** of the precautions and **monitoring** [...] must be **appropriate to the risks** [...] » (art. 18) (graded approach);

individual exposure monitoring (dosimetry); corrective measures (art.41) ; ...

+ **environmental law** (quoted in the 2011/70 preamble)

e.g. Aarhus Convention (1998)	--	85/337/CEE & 97/11/CE + <u>2003/35/CE</u> (projects)
Espoo Convention (1991)		
Kiev protocol (2003)	--	<u>2011/42/CE</u> (programs)

International & European law as boundary conditions...which obligations ?

- **Directive 2001/42/EC (on the assessment of the effects of certain plans and programmes on the environment*):**

« Member States shall **monitor the significant environmental effects** [...]» (art.10)

* and applicable for nuclear facilities (<> 2003/35/CE & 97/11/CE)

- **Directive 96/61/EC (on integrated pollution prevention and control) – « IPPC directive »** establishing a.o. the **BAT principle** and associated monitoring :

« The permit shall contain **suitable release monitoring requirements**, [...]»; «the operator regularly informs the competent authority of the **results of the monitoring of releases** and [...] affecting the environment»

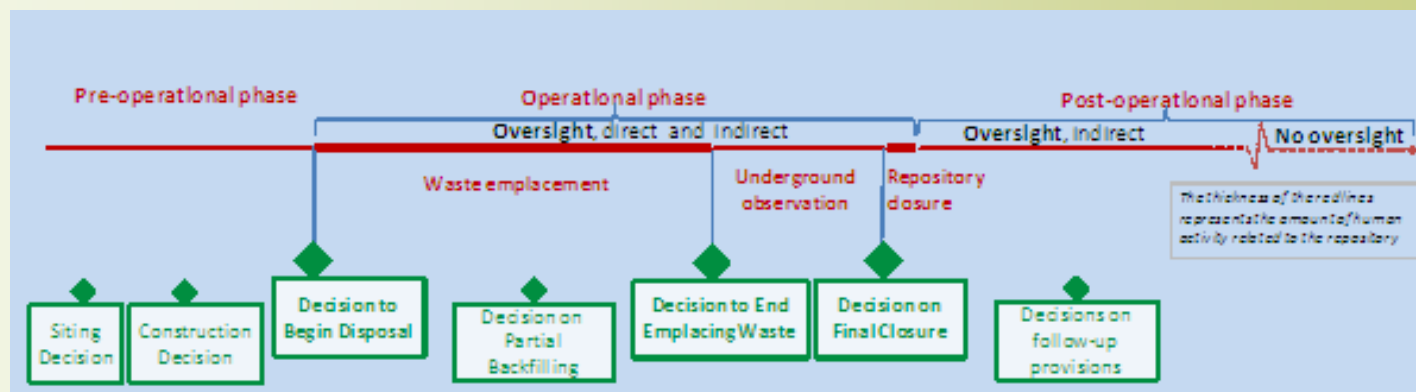
+

« classic » industrial activities legislation e.g. **Directive 2006/21/EC** (on the management of waste from extractive industries):



International recommendations

- Only « recommendations » ?



- **ICRP -122** recommends different levels of oversight...
- **WENRA** group provides dispositions for the monitoring programme:
 - Before starting construction, the licensee shall establish a baseline state of the environment both for supporting the **monitoring programme** and for evaluating the impact of the facility on the environment **(1)**

International recommendations

- **Monitoring programme** for construction, operation, decommissioning and closure, and as appropriate after closure (monitoring has to be carried out at each step)
- **Monitoring objectives** are to:
 - demonstrate adequate protection of man & env. and demonstrating compliance with the regulatory requirements (compliance purpose) _ (2)
 - confirm that the disposal facility and system behaves and evolves as expected in the safety case; (performance confirmation)_ (3)
 - identify any deviations (performance confirmation(PC)/challenging)
 - confirm and refine the key assumptions in the safety case & enhance understanding of the env. & the system (PC & process understanding)
 - acquire data for supporting decision-making (data record, stepwise process) _ (4)
 - provide background information for any post-closure surveillance programme (stepwise process)



Belgian regulatory framework

... and the A.R. « WENRA » in line with WENRA recommendations

especially regarding **(1)** – baseline; **(2)** – compliance; **(3)** – evolution & **(4)** – decisions + its iterative nature

- In particular: RN releases; radiological impact; evolution of key parameters
- In case of dysfunctions: consequences must be assessed, therefore

Limits and use conditions; means to detect dysf. ; possibilities to repair; calibration pgm (!! Safety & system performances !!)

- In case of deviation → actions for remediation...
→ How to expect data values outside the unexpected ranges ?
- The access to the repository has to be backfilled and sealed ASAP (closure phase)

• Technical guides (generic & geologic)

Regulatory framework: in summary ?

Monitoring (strategy) specifications (1/2)

Attributes	Description	Sources of law
Status	(Appropriate) monitoring & (regular) inspection are conducted in accordance with procedures... Monitoring programme is mandatory	Joint Convention (JC), 2011/70/Euratom (future) Belgian law (A.R. « WENRA »)
Purpose/roles	Improving continuously the safety Compliance purpose with regulatory requirements Performance confirmation (of the system) Process understanding Assessment of radiological impact To support safety-oriented decisions	2011/70/Euratom WENRA recommendations, IAEA (DS 357; SSG-14), Belgian A.R. « WENRA »(draft)
Definitions	Monitoring/surveillance/inspection	WENRA group; IAEA DS 357 Belgian law plans to follow WENRA
Implementation/ timeline	Plans for monitoring have to be drawn before construction A monitoring programme must be implemented during construction, operation, decommissioning and closure and as appropriate after closure	IAEA DS 357, WENRA recommendations
Modalities	Monitoring programme is a stepwise process Monitoring programme has to remain flexible Monitoring must be periodically reviewed, especially to move on from one stage to the next Monitoring should be designed following the graded approach of the repository programme	WENRA recommendations IAEA SSR-5 A.R. « WENRA » IAEA DS 357

Regulatory framework: in summary

Monitoring (strategy) specifications (2/2)

Attributes	Description	Sources of law
Constraints (general)	-Monitoring is designed/implemented so as not to reduce the overall safety after closure -The disposal is passively safe design and should not require/rely on post-closure monitoring -Post-closure monitoring may be performed for public assurance. In general, the monitoring programme must take into account the societal expectations...but how to predict social motivations in 100 yrs ? -Periodically reviewed -Operator has to assess the consequences of dysfunctions of monitoring -In case of deviations, remediations have to be proposed... -Accesses to the repository for the monitoring programme has to be backfilled and sealed ASAP (at the closure phase max.) → No regulatory requirement, at the Belgian level, to maintain post-closure monitoring (passive safety). In case, this monitoring must be performed without invasive means.	IAEA DS 357, SSG-14 Belgian law (A.R. « WENRA »)
Link with the <u>safety case & management system</u>	-The monitoring programme should be driven by (and inform) the safety case. The results are used <u>to strengthen the SFC</u> and build confidence in safety. -The monitoring programme should <u>adhere to the management system principles</u> - <u>LT safety - operational safety interface</u>: the monitoring programme should confirm that the performances of the barriers are not compromised by the operational activities	IAEA DS 357

Does the regulatory framework suggest a « technical content » for monitoring ?

- **Monitoring for baseline information:**

Groundwater flow in HR & environment ; geochemistry of groundwater ; background levels of radioactivity; geomechanical properties of the HR; ...

- **Monitoring conditions of emplaced waste packages**

- **Monitoring of disposal facility structures:**

Mechanical properties (rock stresses, deformations in walls and lining, deformation and loads on rock support...)

- **Monitoring of the perturbations**

Monitoring of the THMC disturbances: (T) temperature distribution, thermal conductivity(M): stress field, deformation, fractures (H): permeability, water pressure (C): composition and mineralogy of interstitial water, pH, redox,...

- **Monitoring of the changes in the geosphere**

temperature, stress, groundwater pressure, solute chemistry and mineralogy... using boreholes drilled to acquire the baseline information

- **Environmental database**

Meteorology, hydrology ,concentration of pollutants ,localised erosion, slope evolution, geothermal heat flow, seismic activity,...measurements from the surface

Issues, gaps, limitations...

General issues/gaps:

- **Compatibility** of a potential **independant** monitoring program regulator vs operator ?
(e.g. LT safety and security aspect (HI))
- « **Demonstration** » of **compliance** monitoring vs SFC... Expectations overestimated?

« Submission of a robust safety case would always be the principal method for demonstrating confidence in the safety [...] however, data collected through a monitoring programme [...] would help to support the basis for having confidence in safety »

(MoDeRn, Expert Stakeholders Workshop, June 2011)

- « Verifying that the disposal system is functioning as expected » - Timescales !
- **Nuclear safeguards** for spent fuel with a dedicated monitoring (DIV; satellite imagery, 3D laser scanning, passive seismic,...) → Interface safety/security
- **Retrievability/Reversibility** → monitoring strategy
(e.g. monitoring of the integrity of waste package)



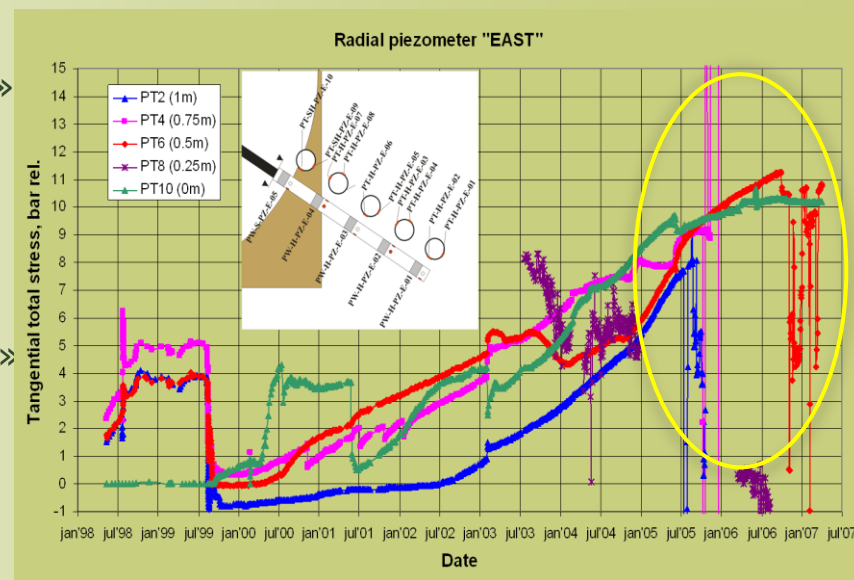
Issues, gaps, limitations & communication

Limitations (examples):

- By physical challenges (longevity of equipment; inability to directly measure parameters of interest; spatial variability...) (IAEA DS 357)
- The limitation in time is however not obviously mentioned...

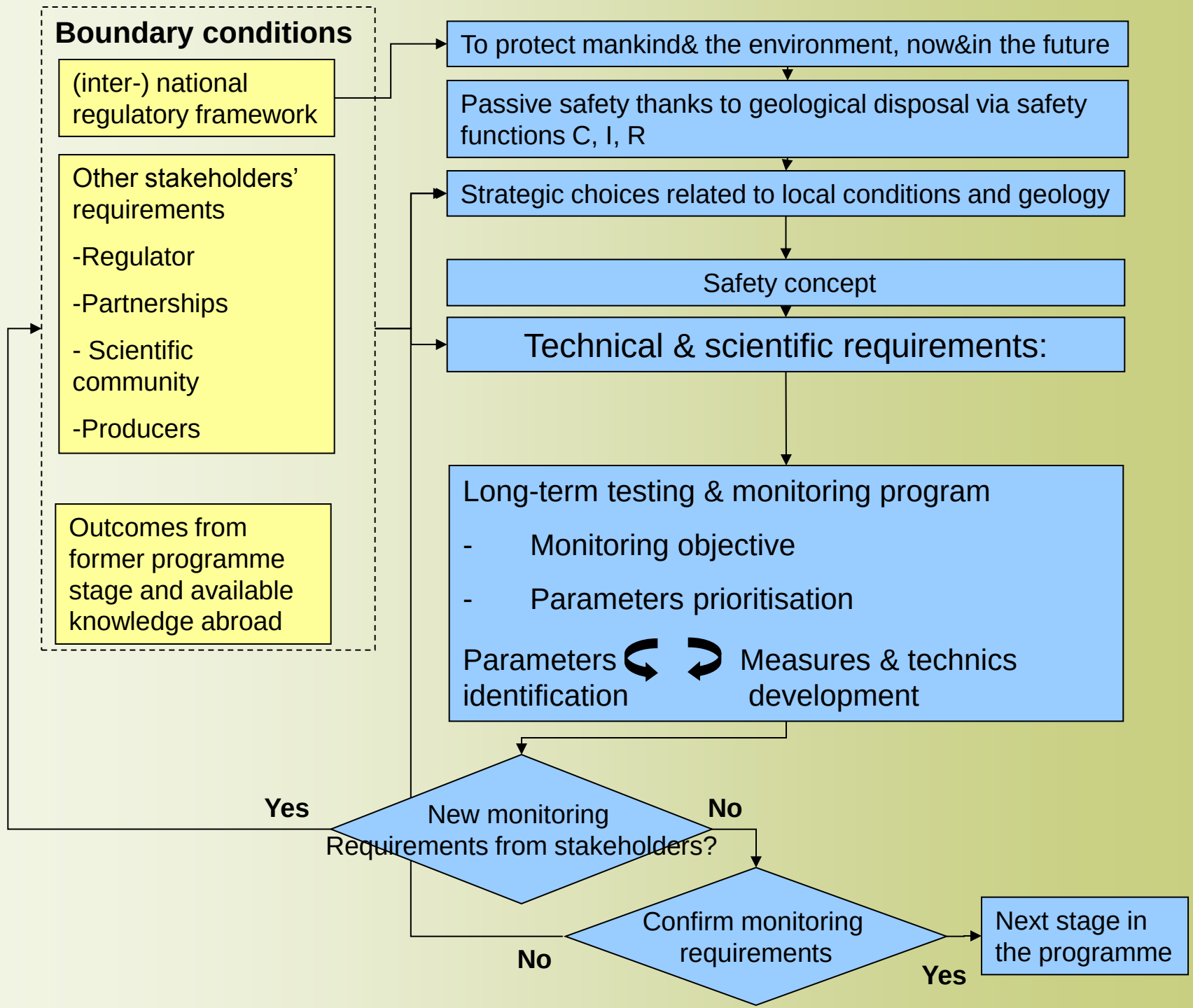
Communication issues (examples)

- « Users of monitoring information should be all concerned parties **including [...] the public** » **but...** « only well-trained and **experienced staff** should be entrusted with the monitoring and associated activities »... **because...**
« **information should be analysed with care** to determine its significance within the safety case»
- Transparency vs safeguards

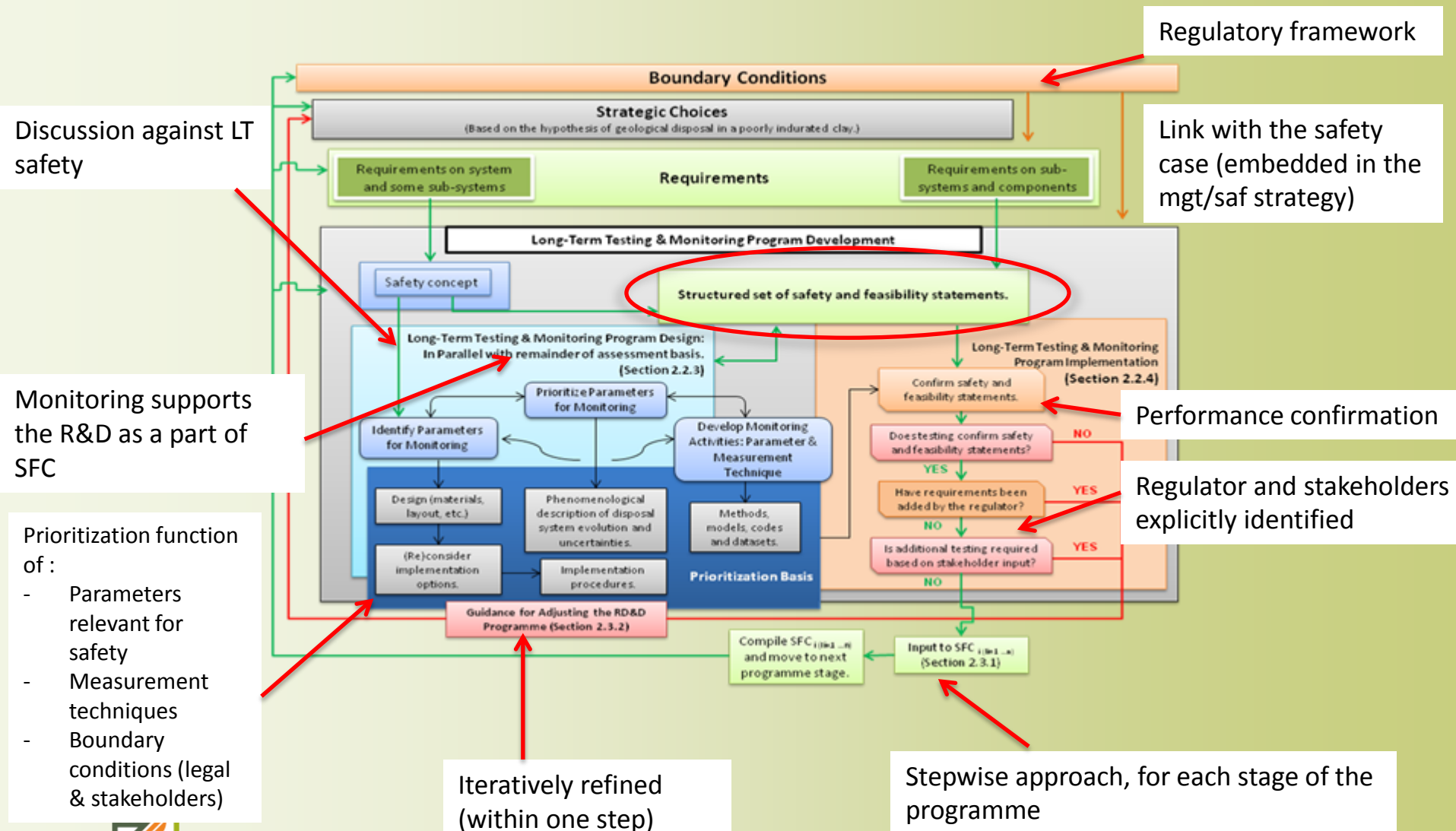


Part II: Monitoring Strategy

Monitoring strategy: simplified view



Ondraf/Niras Monitoring Strategy (the real one !)



Conclusions (monitoring strategy) – 1/2

- **Monitoring is closely related to R&D and starts at the first stage of the project (before the construction)**
- **Monitoring programme has to be regularly updated (BAT) and adapted to move on from one stage to the other (site selection, construction, operation,...)**
- **Monitoring focuses a.o. on the confirmation of the safety performances of the disposal as well as process understanding (ongoing R&D) but has to deal with other interests (security & safeguards)**
- **Monitoring is performed by multiple agencies (operator & regulator). An integrated view should probably be developed but independency must be maintained**
- **Monitoring state-of-the-art is under continuous development**



Conclusions (monitoring strategy) – 2/2

- **Monitoring is multiply constrained by law, at different levels (hierarchy; nuclear/environmental;...)**
- **If law matters for monitoring activities, monitoring matters for environmental law (standards are based on baseline monitoring)**
- **Monitoring programme cannot compromise the passive safety and the safety cannot rely on monitoring activities**
- **Some expectations (stakeholders) are still under debate and could influence the monitoring activities but these expectations should decrease as the project moves forward in time**
- **Monitoring programme may be related to other open questions like e.g. reversibility and retrievability**

→ Regulatory framework is still growing... let's be careful

→ The design of the monitoring program is certainly not a stand-alone activity for engineers only...

→ The monitoring program can certainly not meet all the expectations

A photograph of a curved, metallic interior structure, possibly a tunnel or a large container. The surface is made of large, curved metal panels. On the left, there is a bright, rectangular light source. To its right, a blue object is visible. The text "Thank you for your attention !" is overlaid in the center. The email address "c.depaus@nirond.be" is at the bottom. The number "25" is in the bottom right corner.

Thank you for your attention !

c.depaus@nirond.be

30 years of monitoring experience in HADES

18th Exchange Meeting

“Instrumentation and monitoring in radioactive waste repository research”

SCK•CEN Club-House – Mol
24/01/2013

Jan Verstricht

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Outline

Reasons / needs for monitoring (objectives)

Monitoring implementation cases

- construction related (shafts & galleries)
- field characterisation / investigation of phenomena
- THM(C) model validations
 - upscaling from lab results
- description and results
- experiences / lessons learnt
 - “critical success factors”

Challenges and perspectives for repository monitoring

Reasons / needs for monitoring

Construction related objectives

- feasibility / safety of deep excavations in Boom Clay (1980-1987)
- assessment of advanced construction technique (1995-2007)
 - applicable (validation of the design)?
 - influence on host formation properties

In situ characterisation of the host clay formation

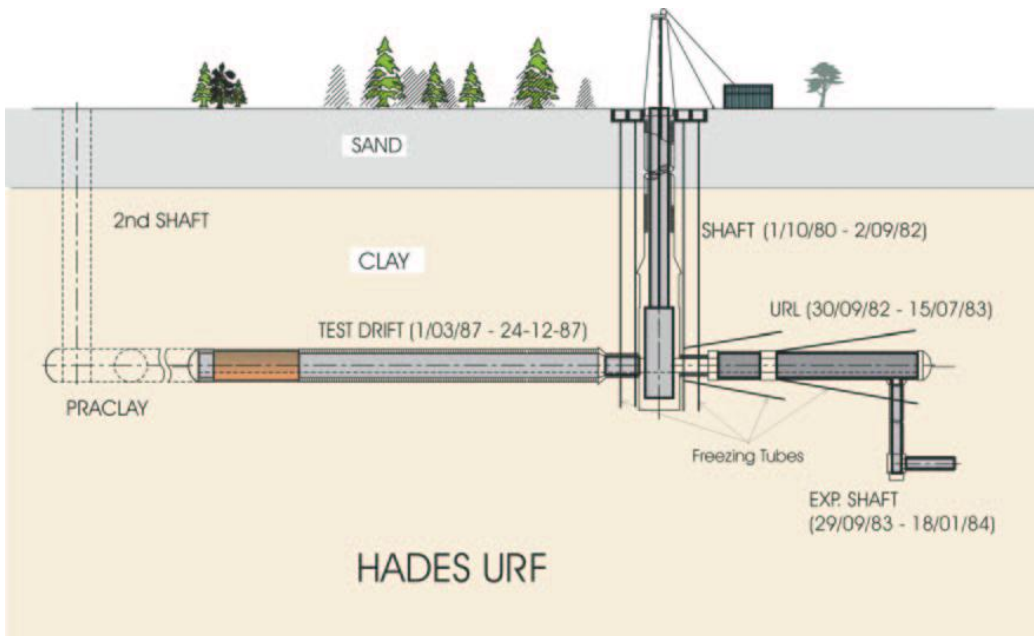
Model validation / confidence building

- geotechnical (THM) – natural barrier and EBS materials
 - migration / solute transport
 - geochemical, microbiological phenomena and understanding
- *input data for PA*

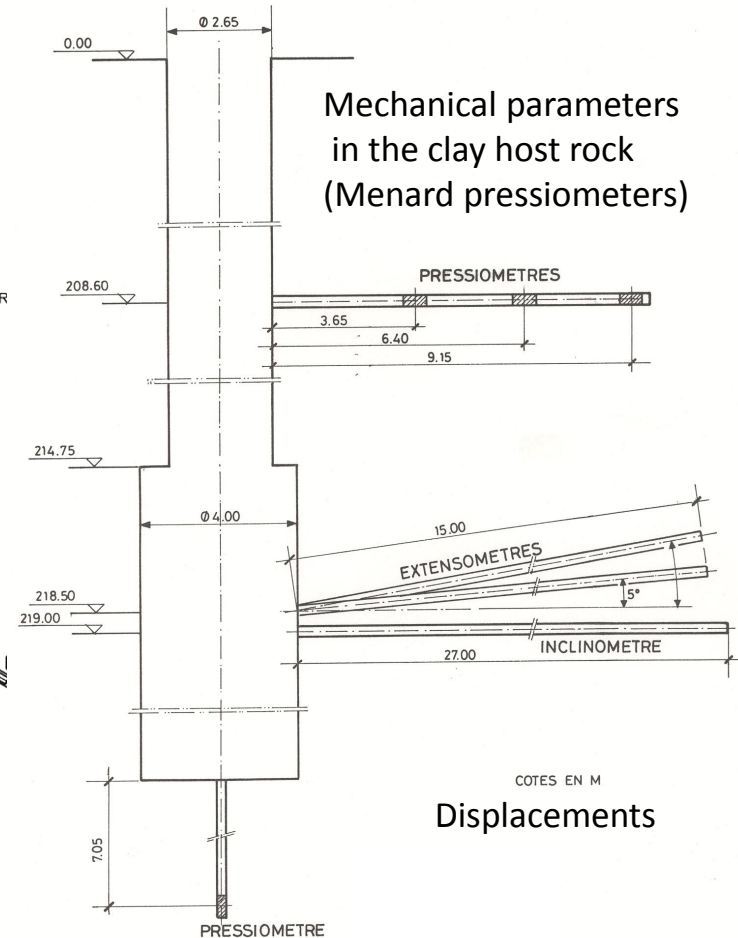
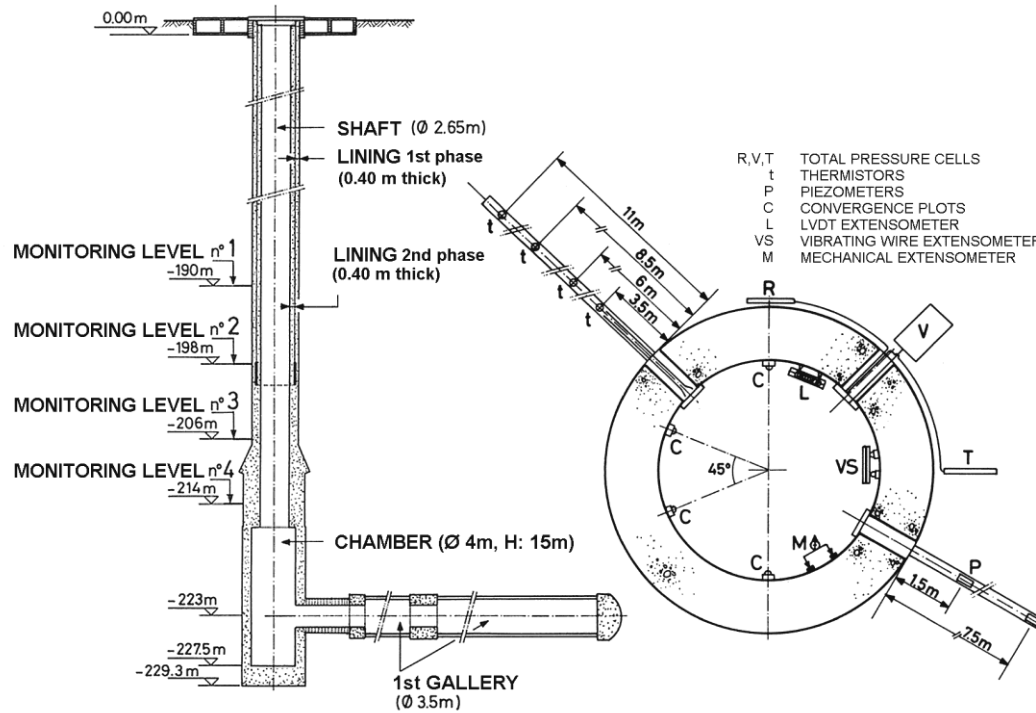
Monitoring in the pioneering phase

Case studies

- First shaft
- Mine-By test (Test Drift)
- Sliding ribs



Monitoring of the first shaft



Rather extensive monitoring set-up

Main results of the shaft monitoring

High total pressures, due to freezing

- equilibrium around 2 MPa
- combined with manual excavation – quick and large convergence near bottom part

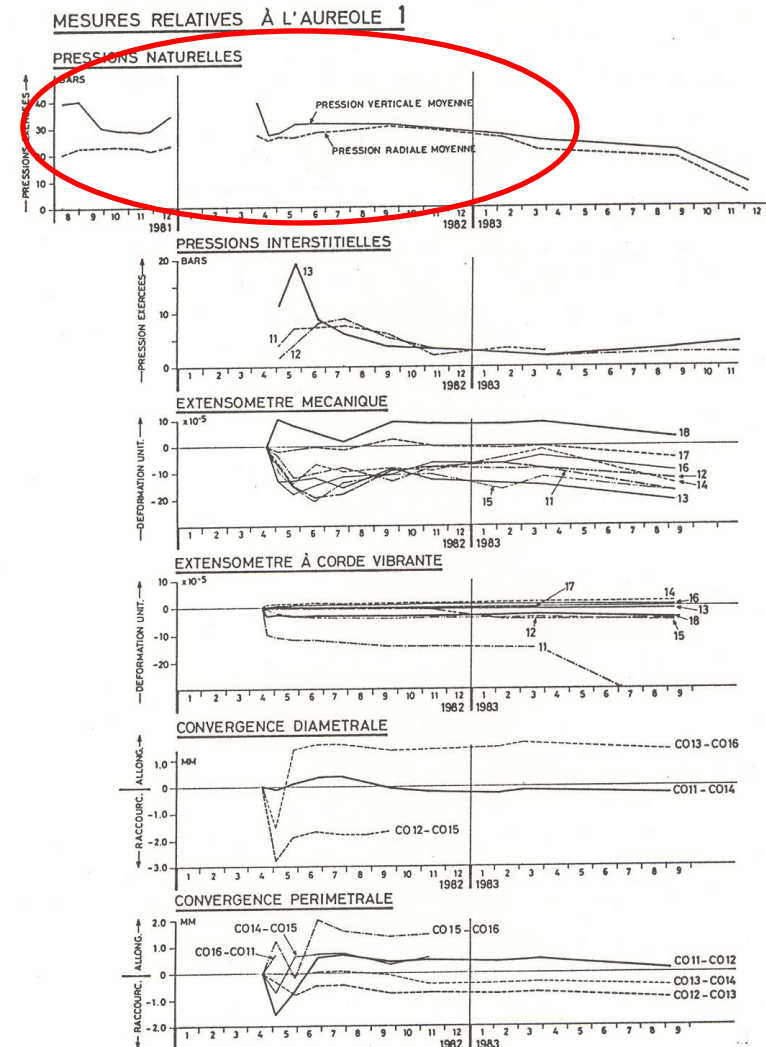
High porewater pressures

- higher in frozen environment
- higher in clayey (vs. silty)
- equilibrium between 5 and 10 bar

Temp > 0° only after 2 years

Deformation on shaft lining

- different upper and bottom part:
- upper part (dual layer) : compression and ovalisation
- bottom part (monolithic): expansion



... and a first assessment of sensor performance

Total pressure cells:

- vulnerable due to hydraulic tubing
- displacement of clay host rock around shaft lining

Porewater pressure sensors and thermistors reliable

Pressiometer, inclinometer and extensometer

- deformation of access tubes

Convergence measurements inside lining: mixed results

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

Monitoring inside the first gallery (URL)

First attempt to measure total stress through “stress monitoring stations” (SMS) complicated by

- large boreholes
- backfill grouting



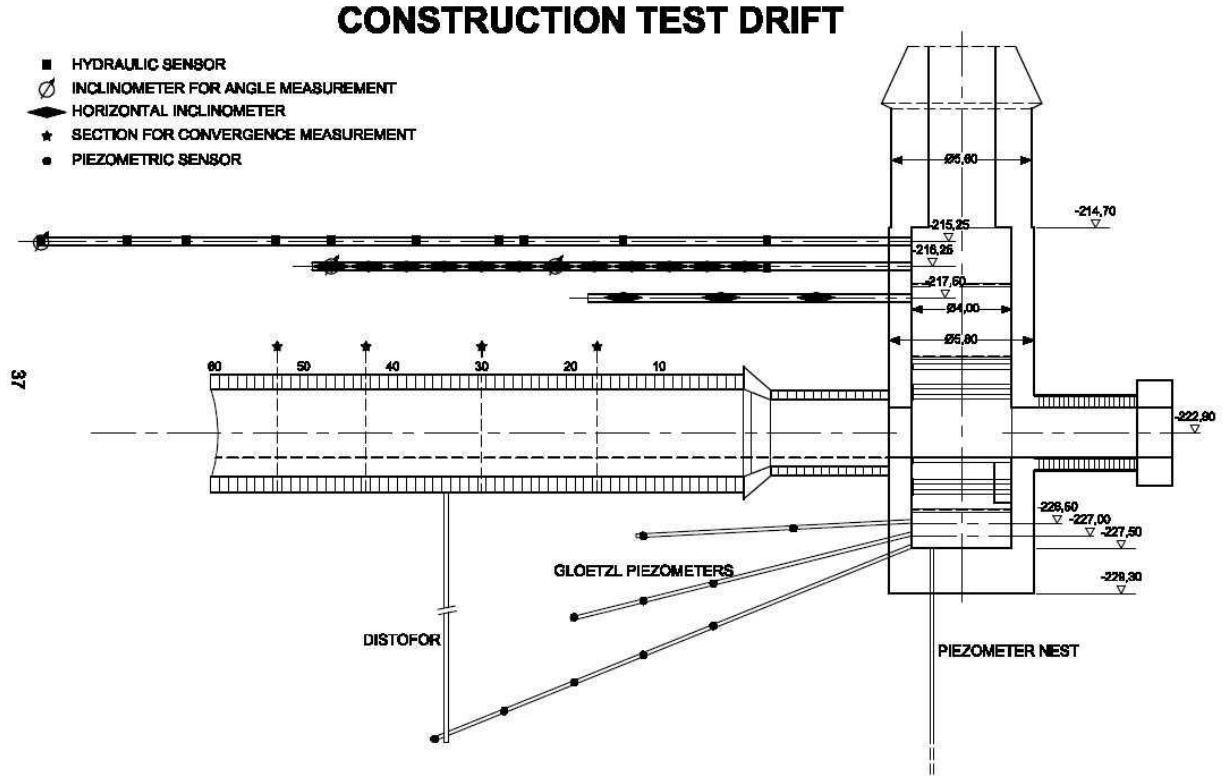
Large variety of instrumentation

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

Lessons

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

Mine-by test of the Test Drift



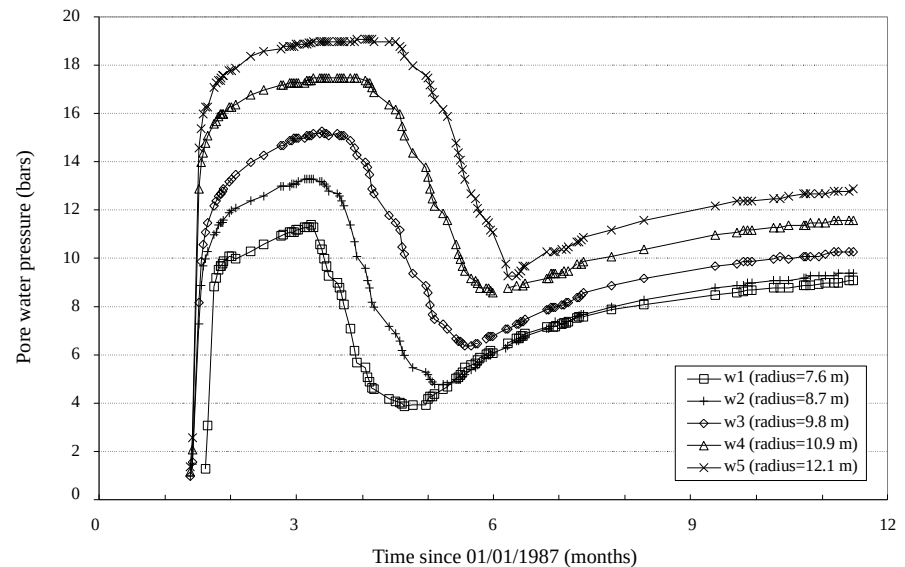
Mine-by test of the Test Drift

Piezometer data and displacement data proved very useful for back analysis

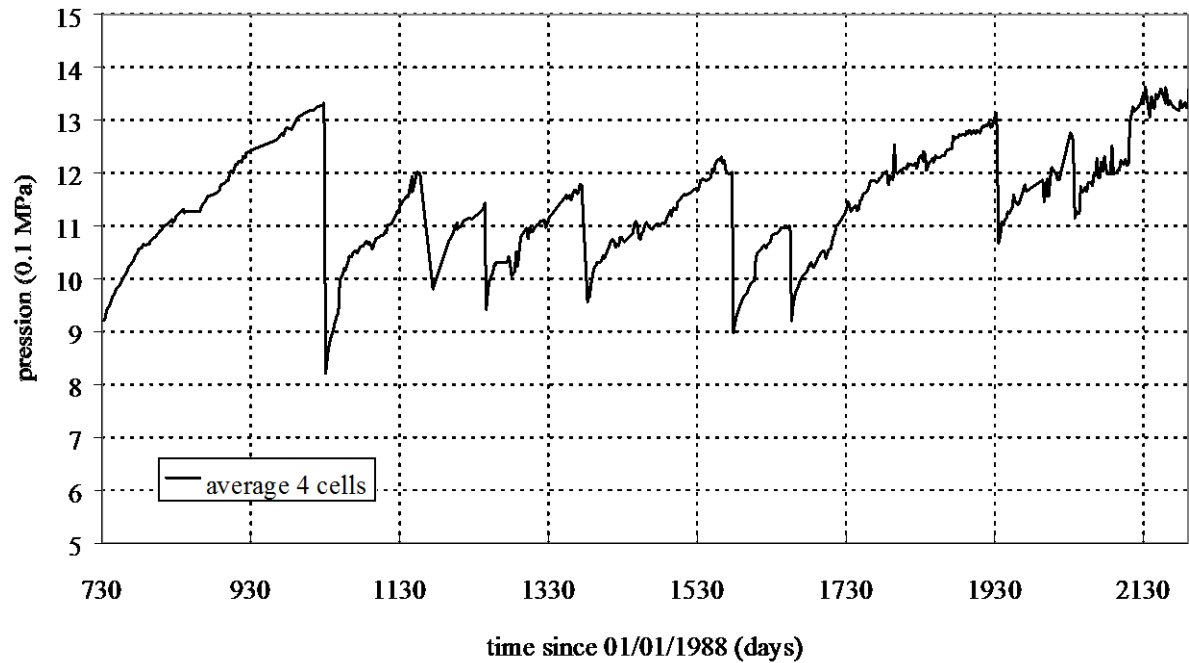
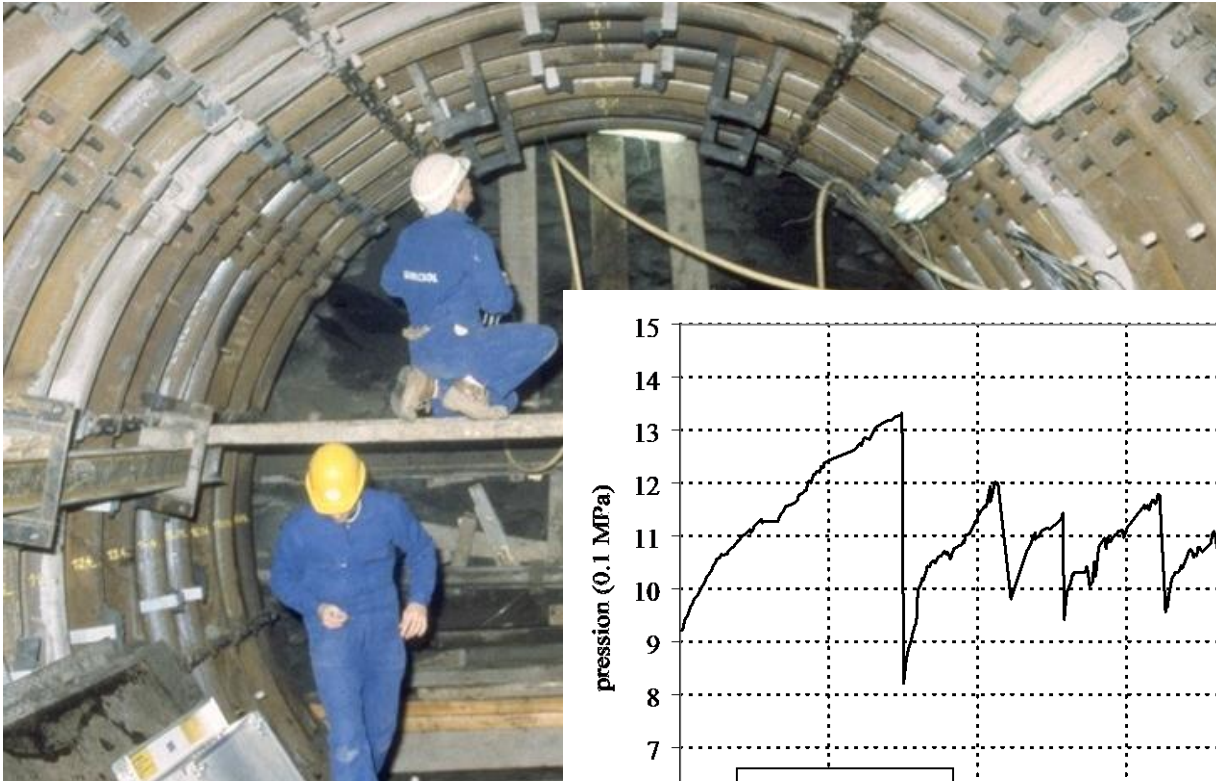
- comparison with 2nd phase excavations

Sensors in gallery lining total pressure, load cells up to 10 y lifetime

- mixed results



Monitoring of the sliding ribs



Monitoring of industrial excavation techniques

Verification of design

- short term excavation technique / tunneling machine
- comprehensive host rock monitoring programme (CLIPLEX)
- longer term monitoring cases
 - porewater pressure evolutions
 - build-up of stress in gallery lining



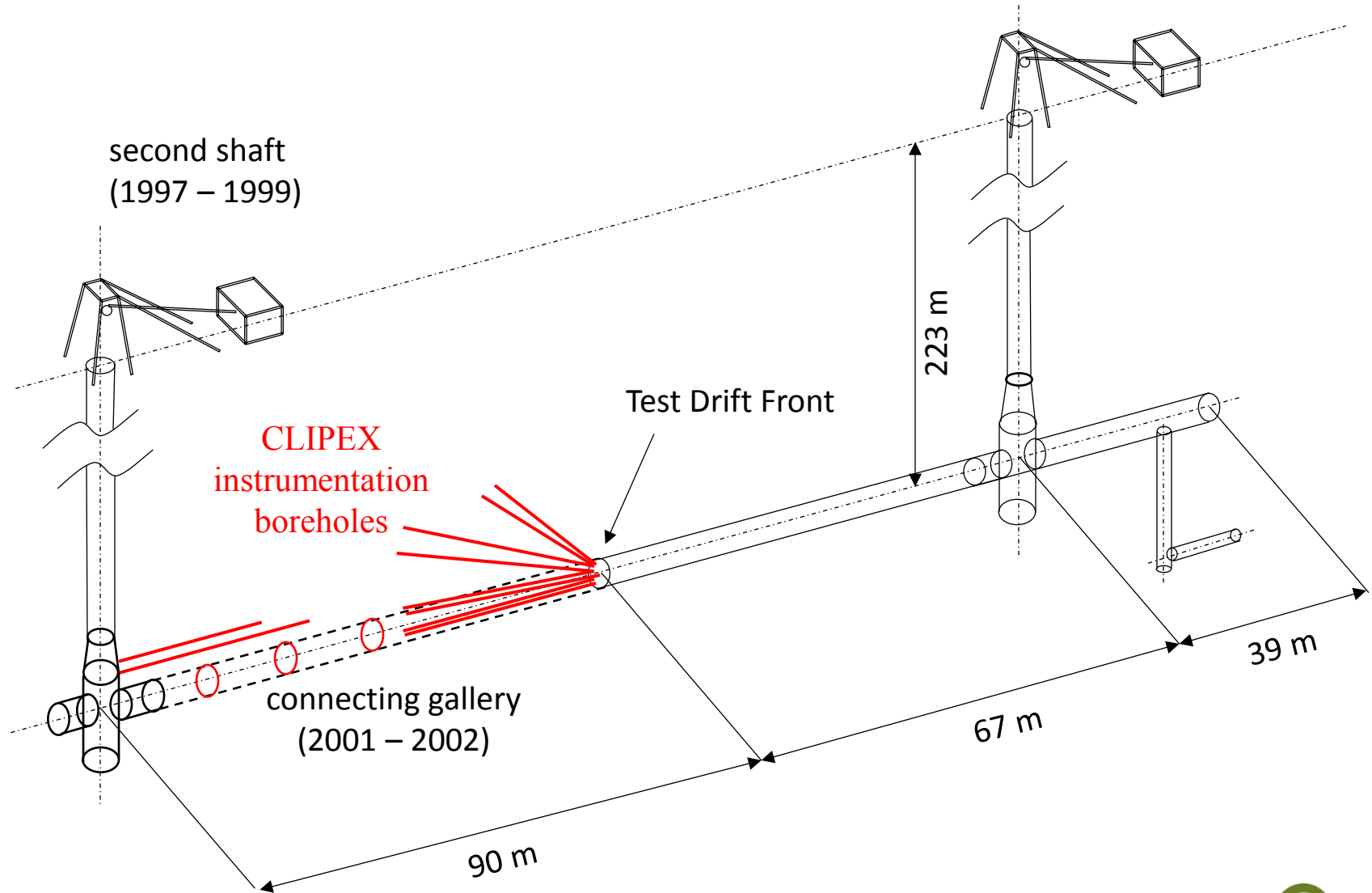
Connecting Gallery Excavation

New construction method entailed some risks

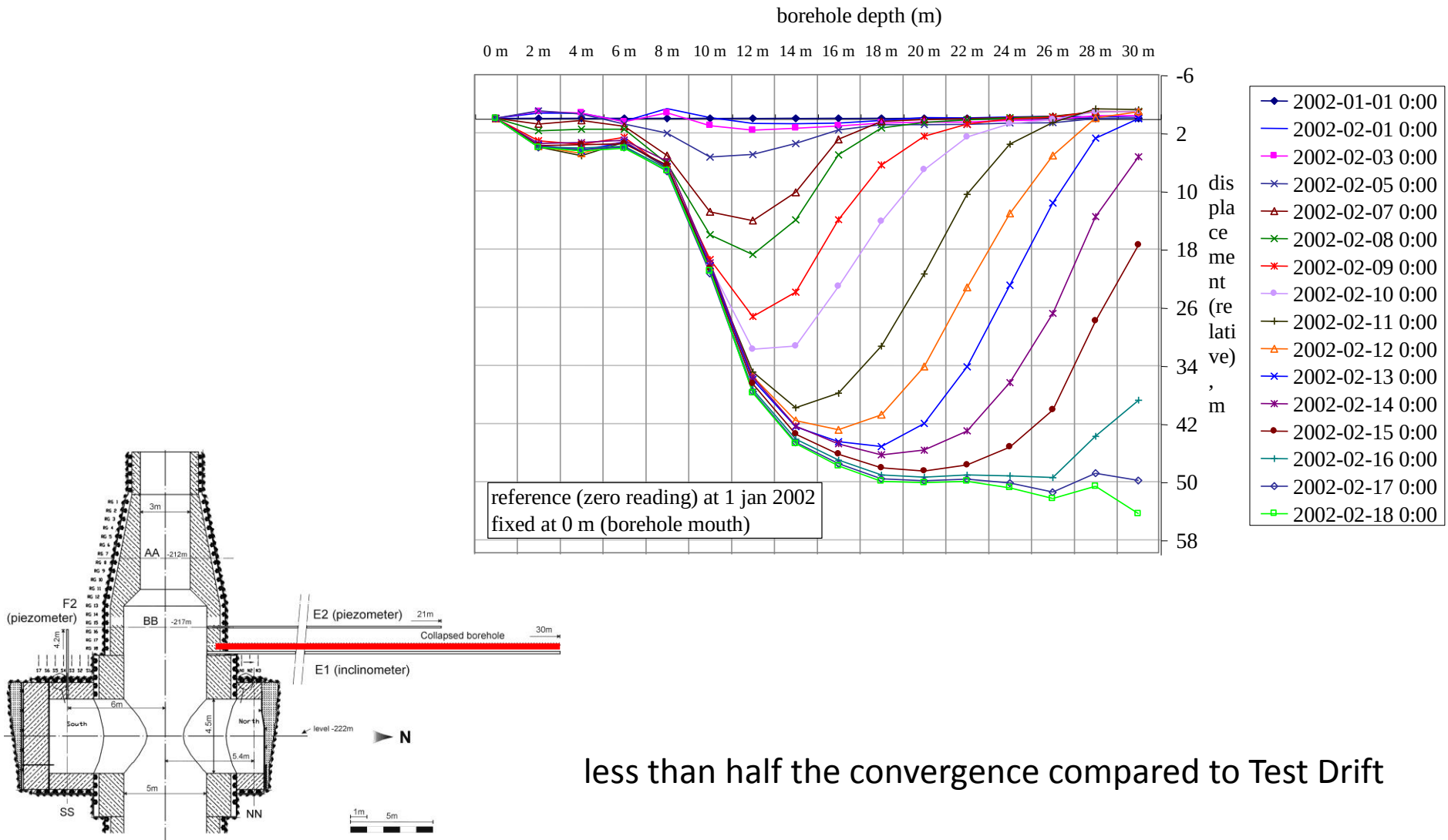
- use of a shield → risk of blocking
- short starting distance
- use of wedge block system
 - world first at this depth
 - adaptations were necessary
- instantaneous convergence of Boom Clay
- geometry of the shield based on modelling



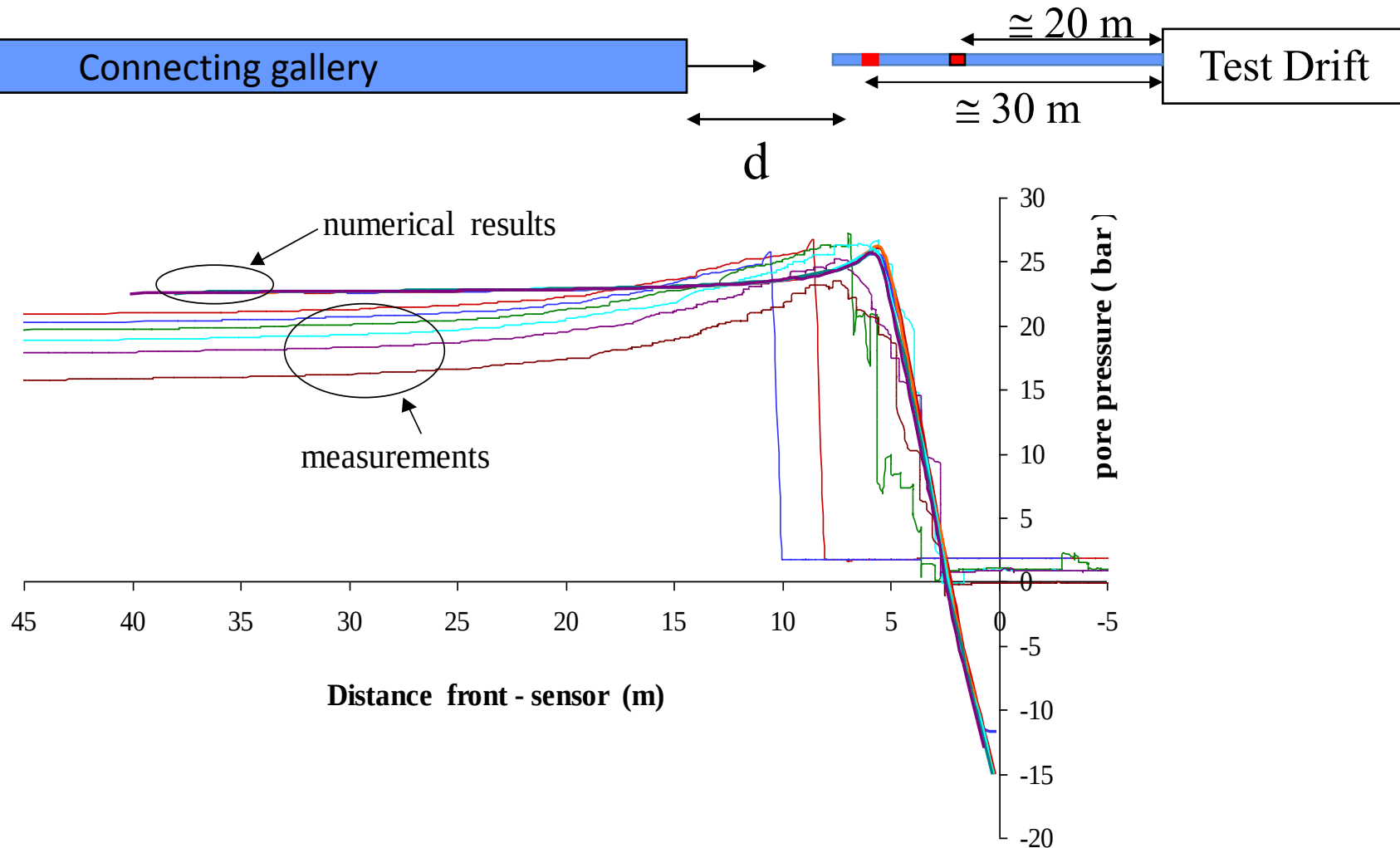
Three instrumented areas (CLIPLEX)



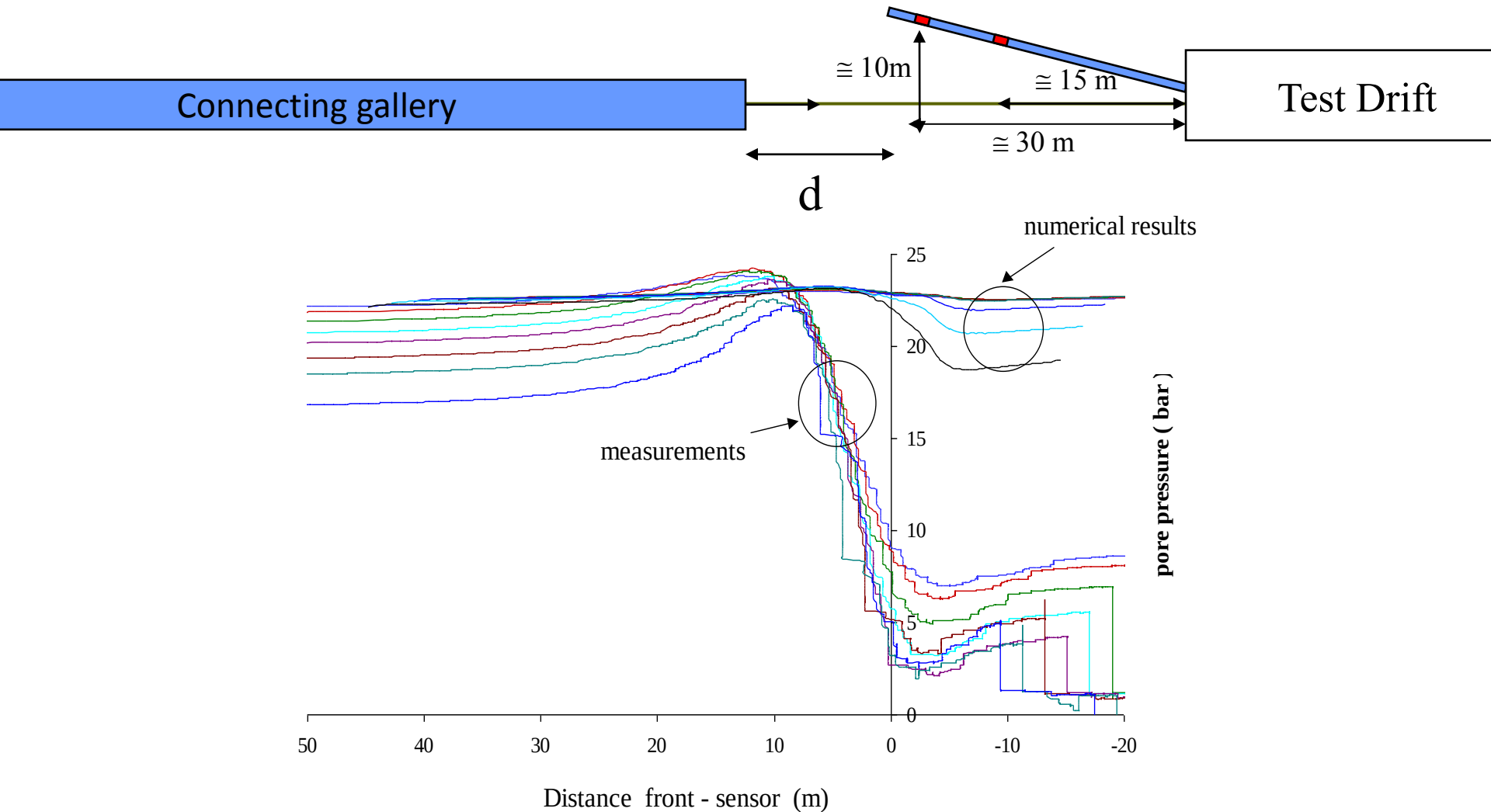
Inclinometer : host rock radial convergence



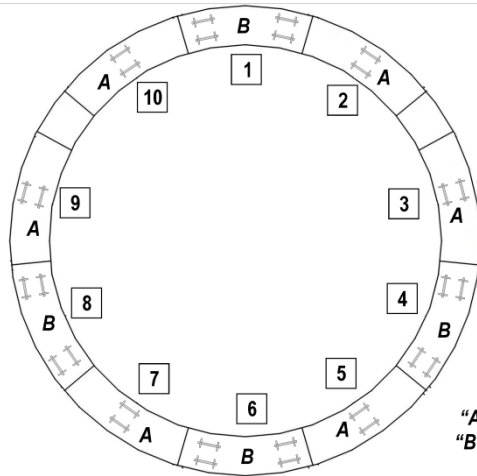
Observed and expected porewater pressures



Observed and expected porewater pressures



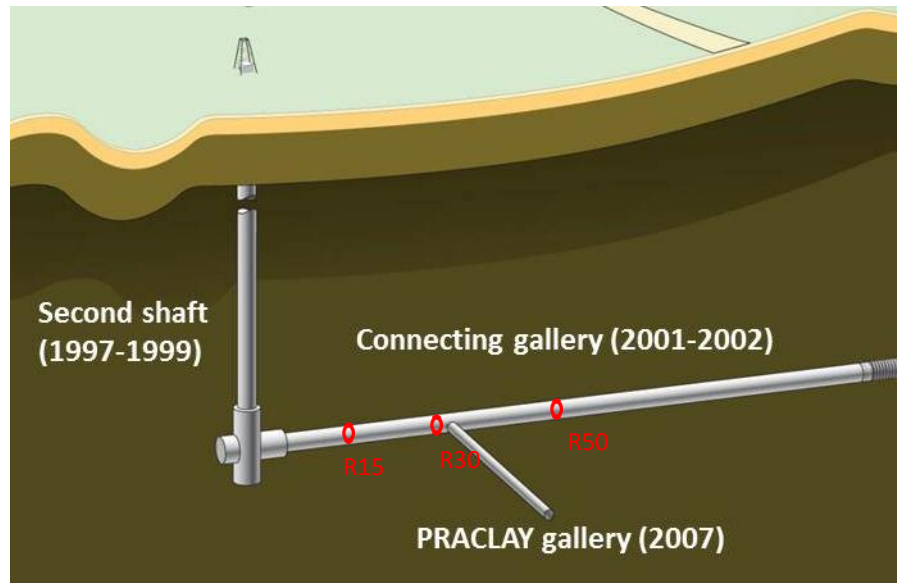
Monitoring of gallery lining



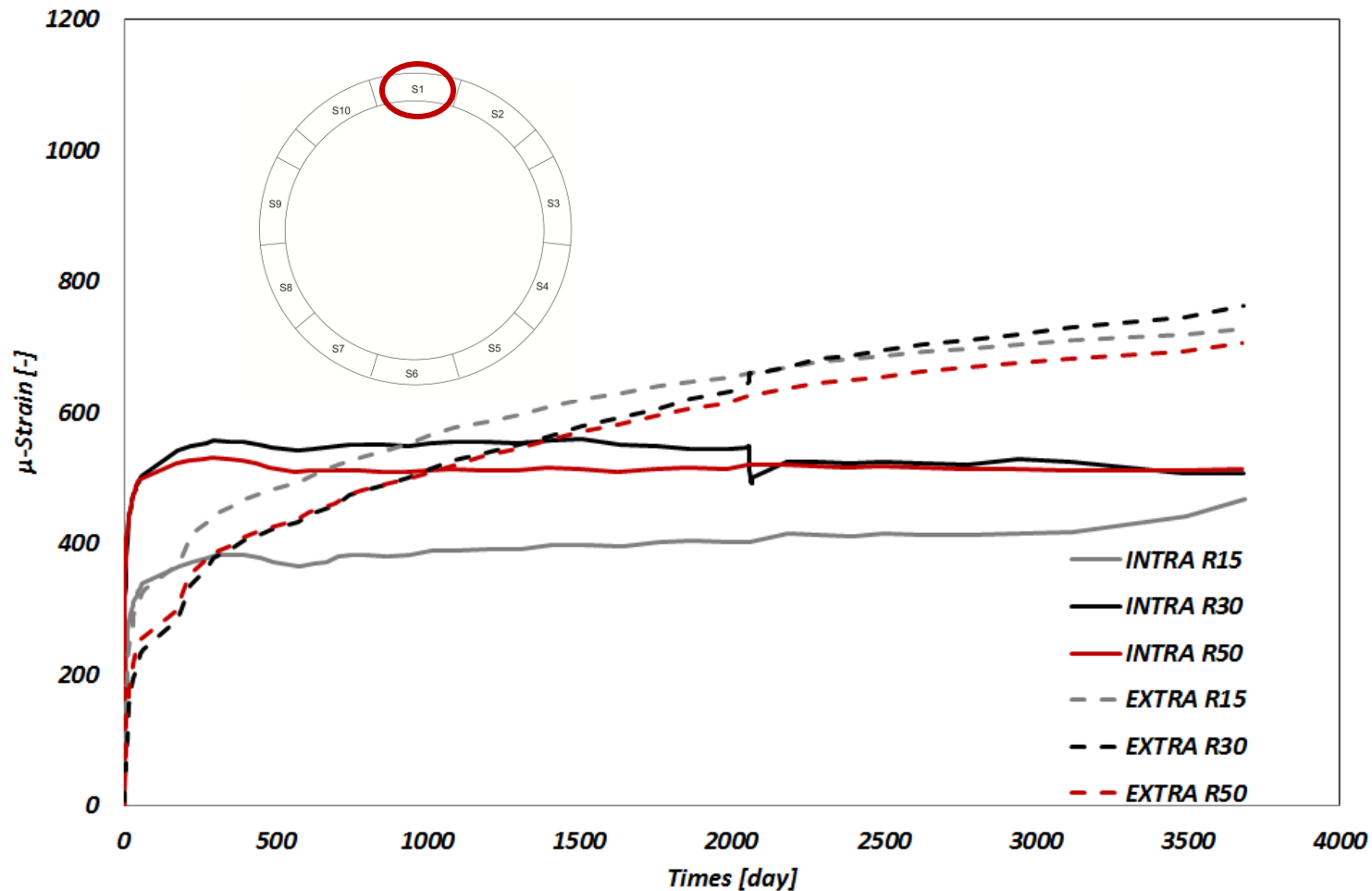
circumferential strain

- inside
- outside

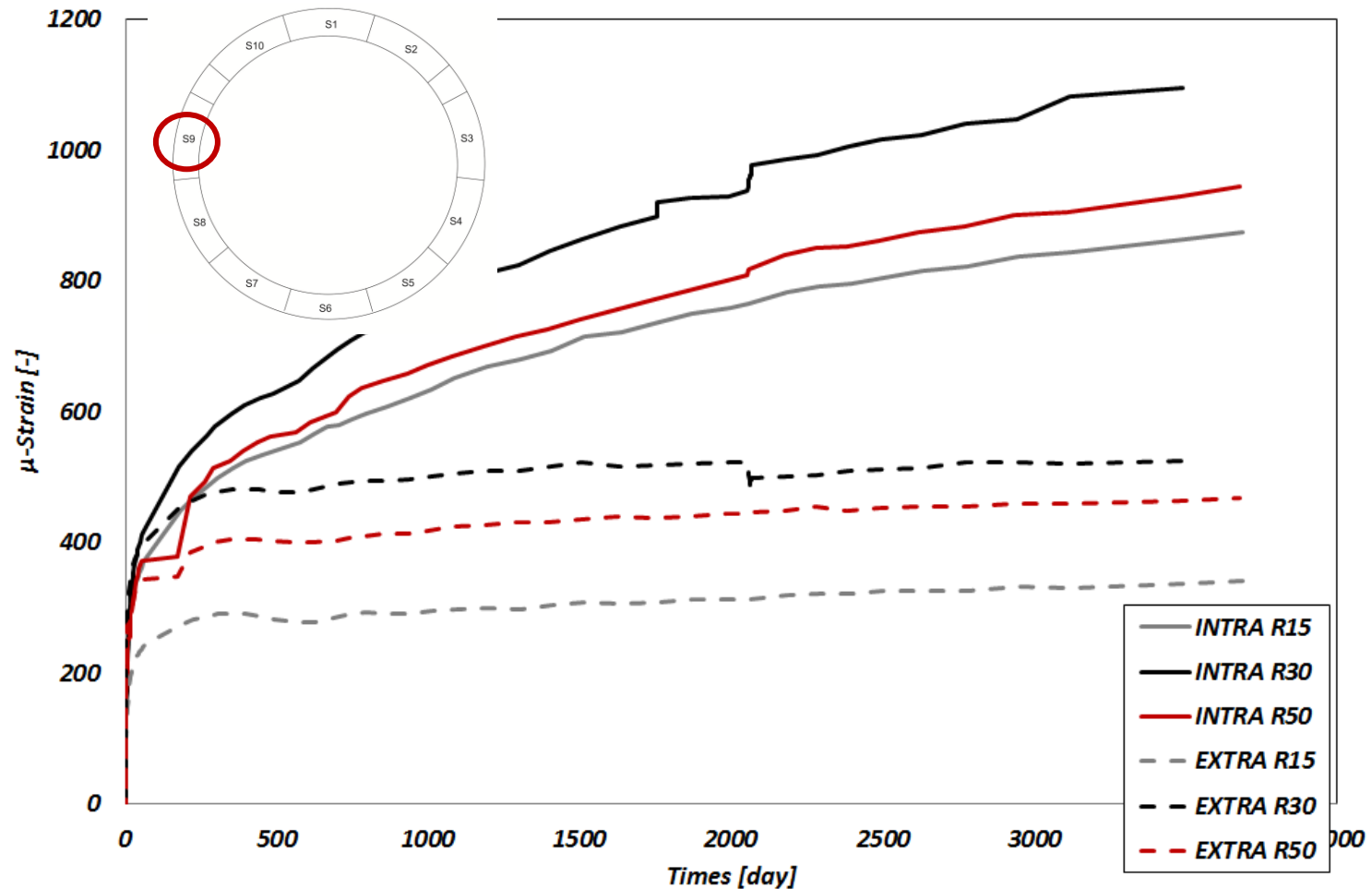
"A" = 6 gauges
"B" = 12 gauges



Consistent strains measured along the three rings



Bending (inner / outer strain) depends on position



After 4 years in the host clay...

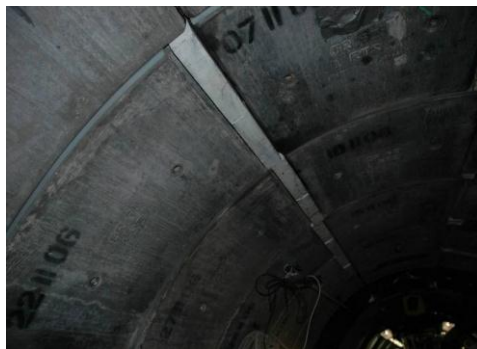
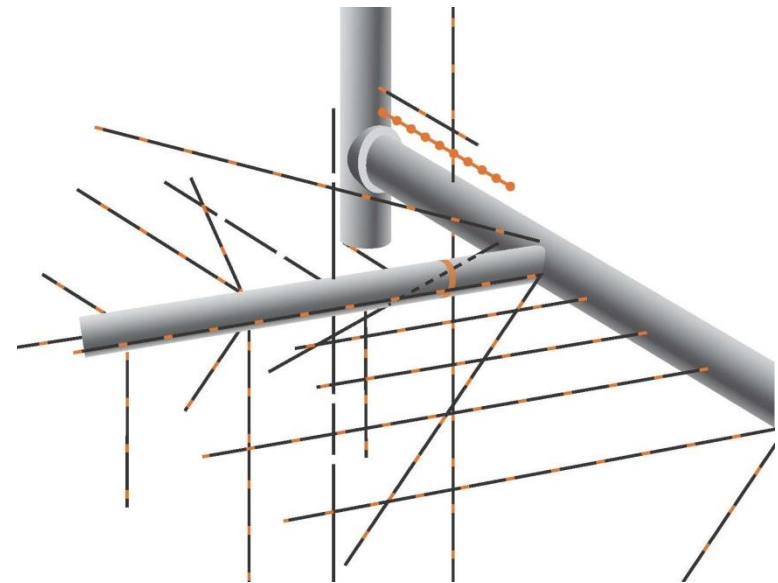


PRACLAY Gallery Excavation

excavation works (2007)



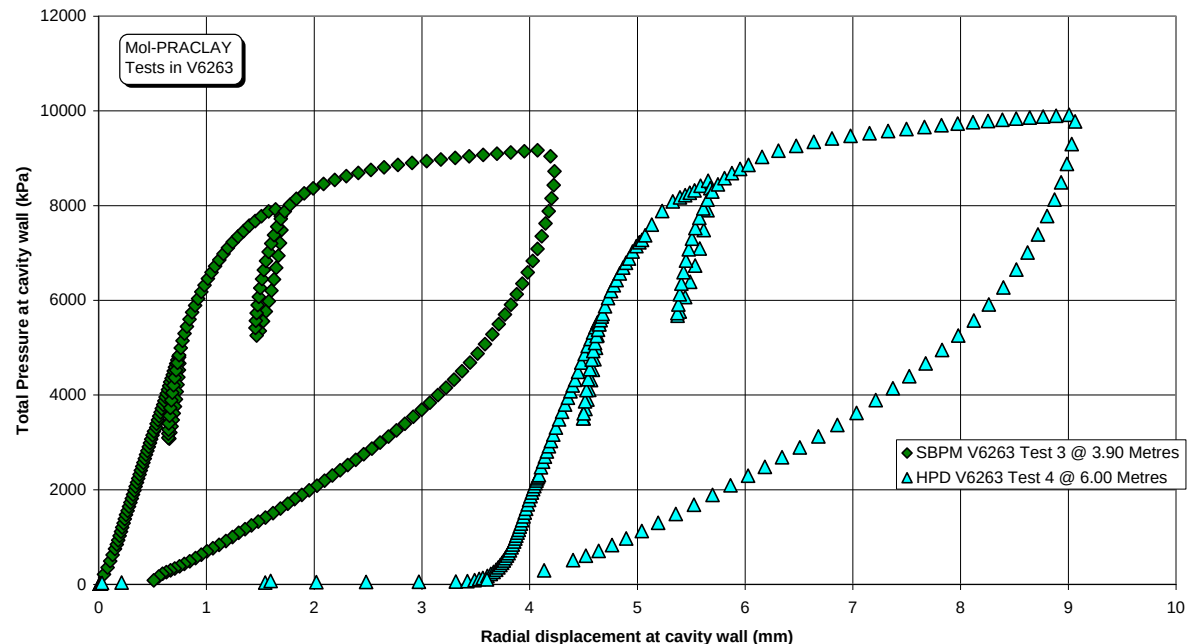
extensive monitoring network



Field characterisation

Hydro-mechanical parameters

- (self-boring) pressuremeter / dilatometer / hydrofracturing to get better estimate of total pressure (in addition to other mechanical parameters)



Model validation

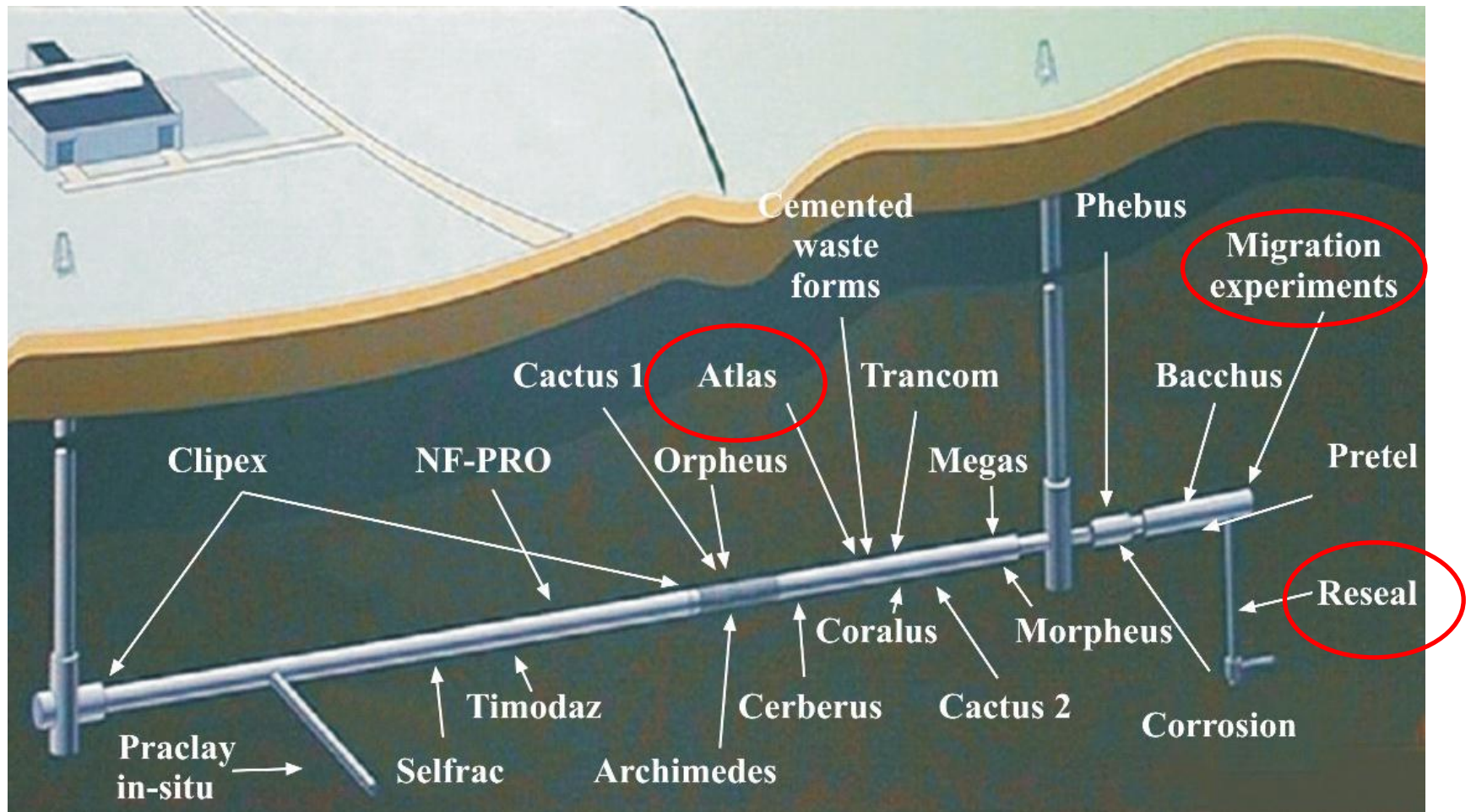
THM coupling phenomena

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

Migration / solute transport

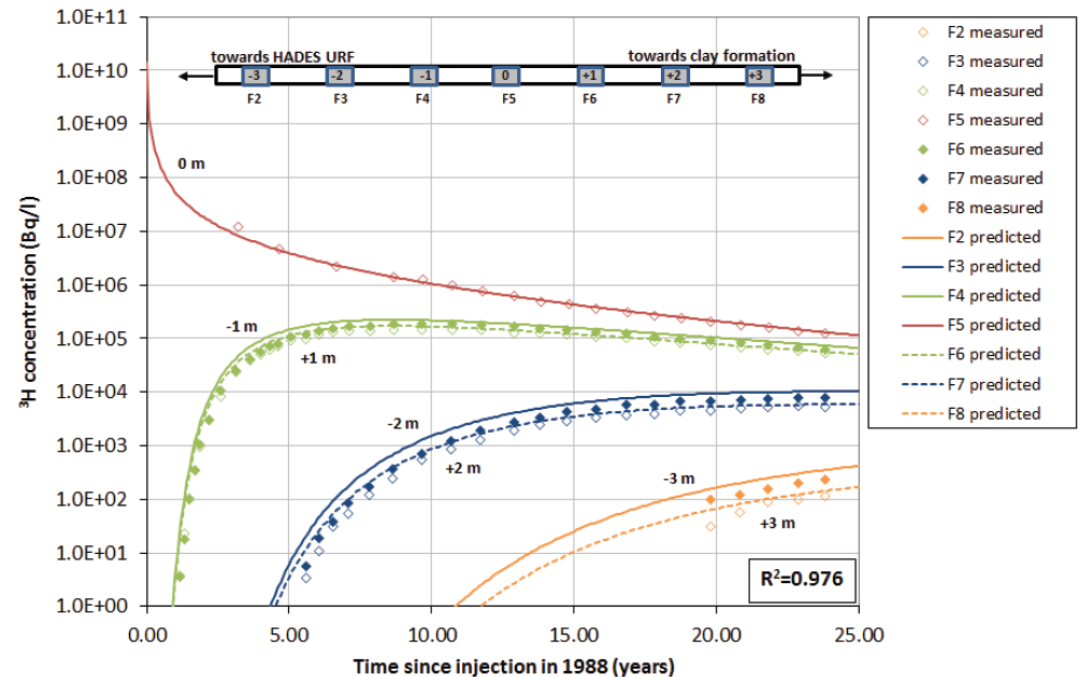
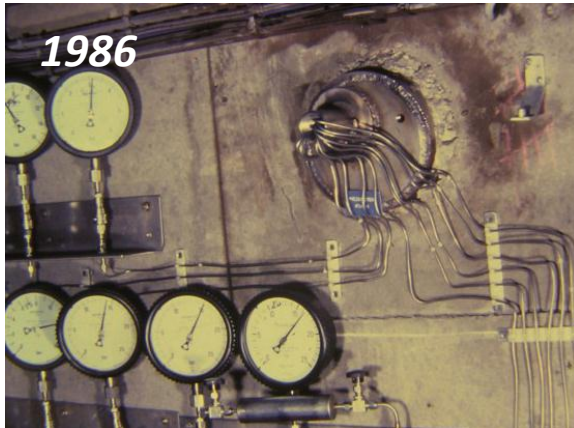
- upscaling of lab results in time and space

Experimental set-ups



CP1 – long term monitoring

Concrete Plug 1 – long term model validation of solute transport ... also of the piezometer concept



E. Weetjens (2012)

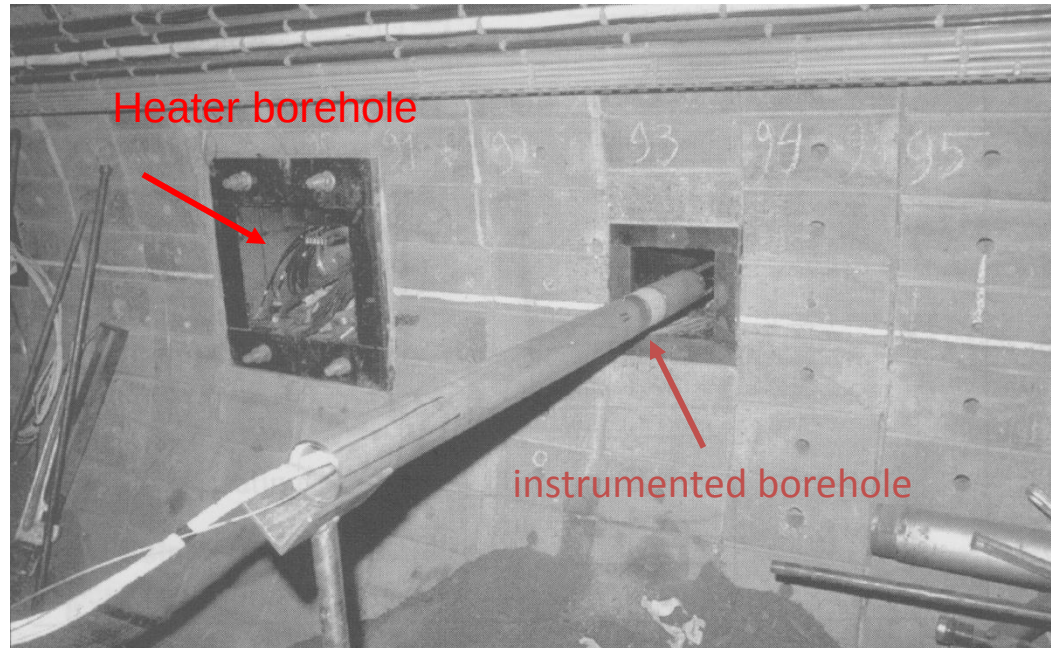
ATLAS – a “simple” T → HM test

Another 20 y old test set-up

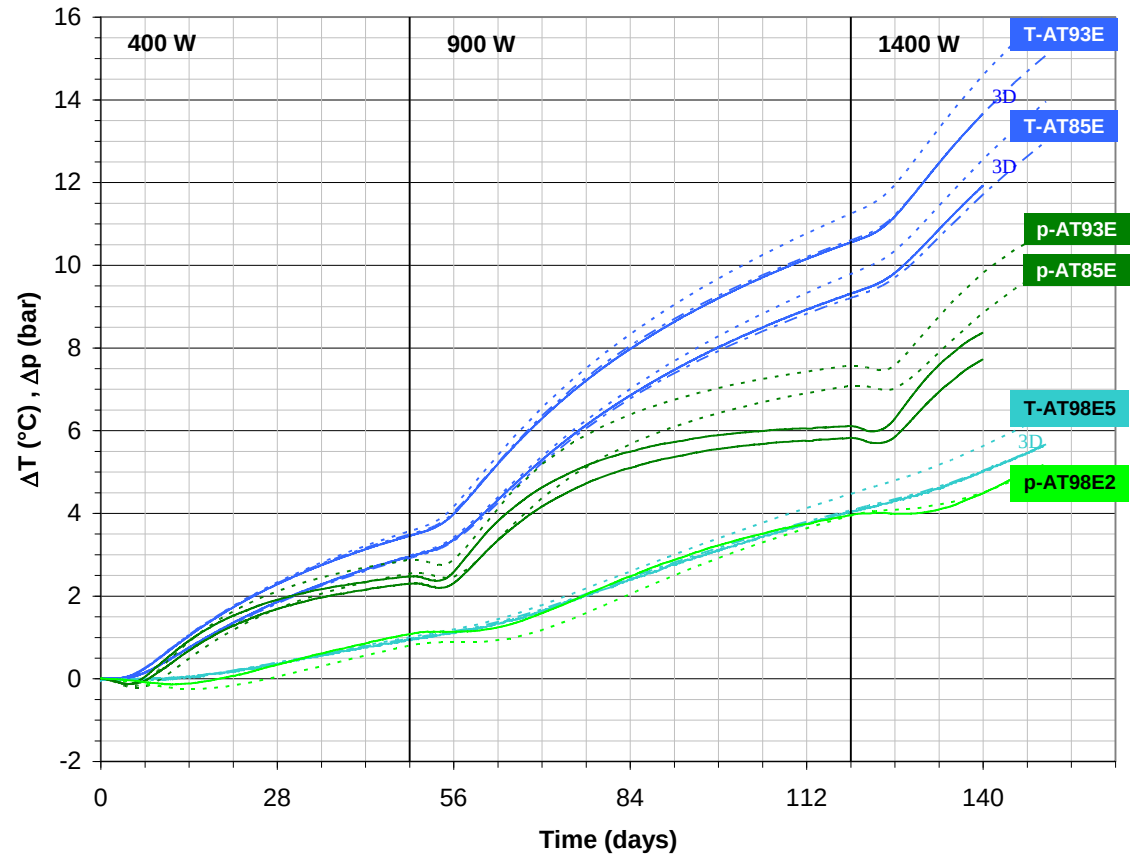
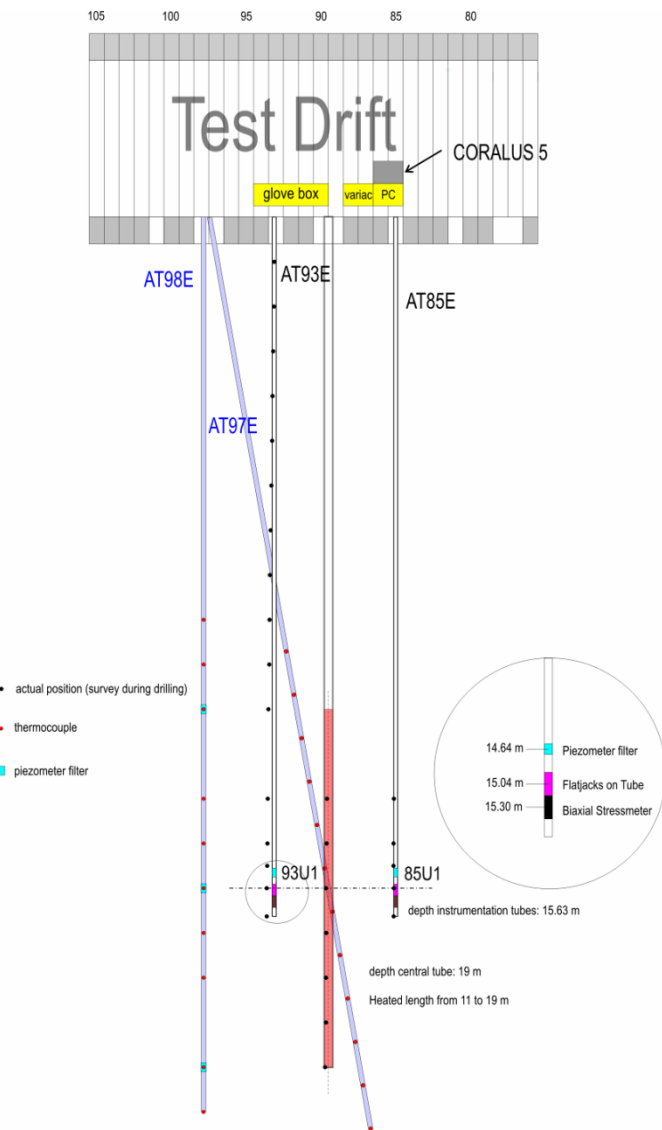
- Part of the EC INTERCLAY-II project (1990-1994)
- An experiment for modellers (blind predictions)
 - No radioactive source (CERBERUS)
 - No backfill material (BACCHUS)
 - Focus is on the behaviour of the Boom Clay
- Second life in 1996
- upgraded in mid 2005
 - to investigate anisotropy
- in total 4 test campaigns

ATLAS – a “simple” T → HM test

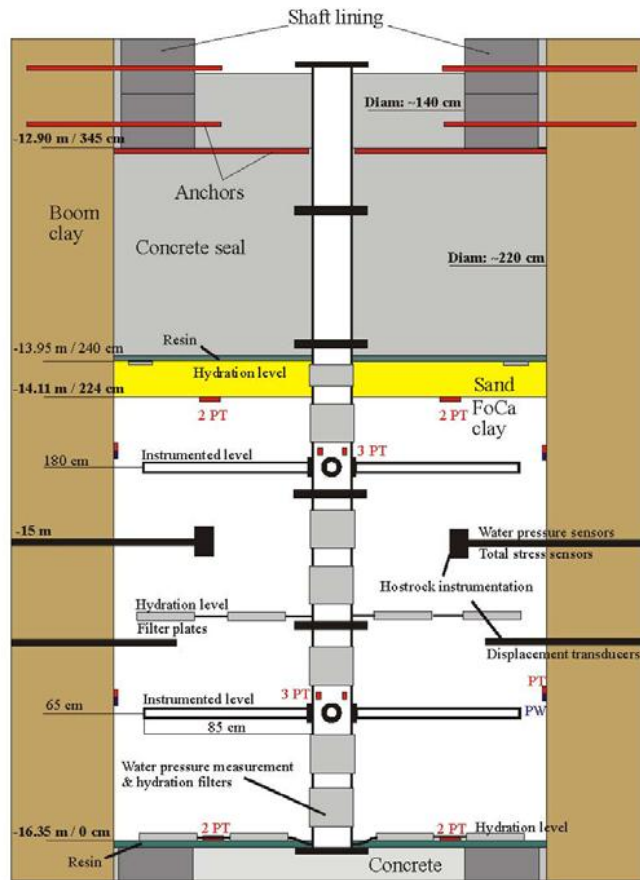
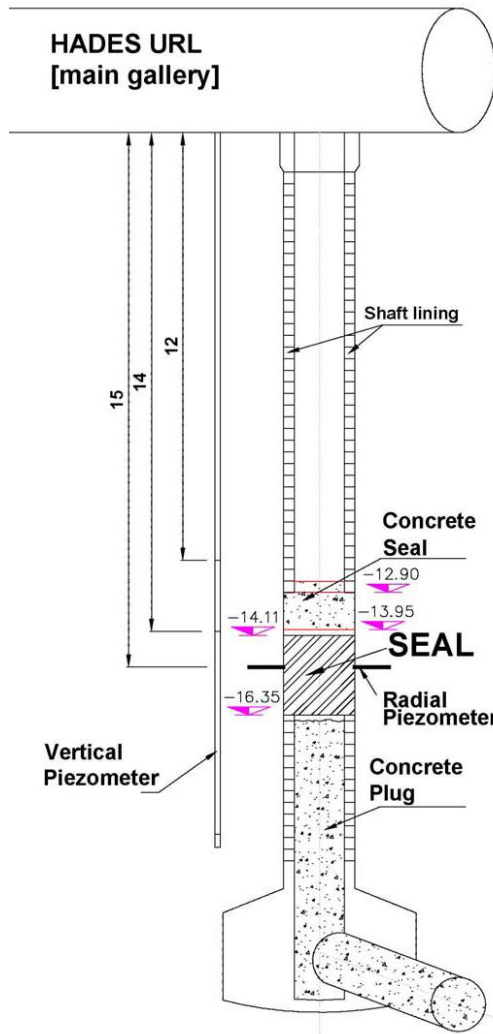
Original test set-up (1992)



ATLAS – upgrade in 2007



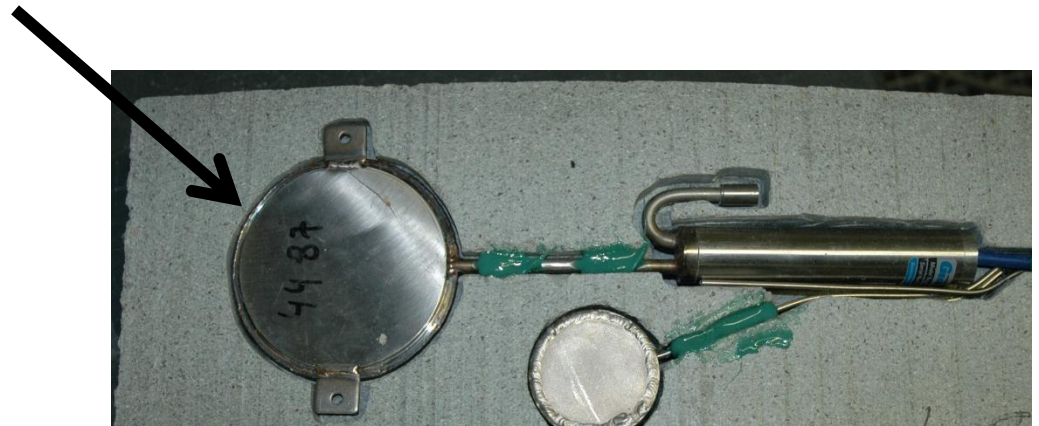
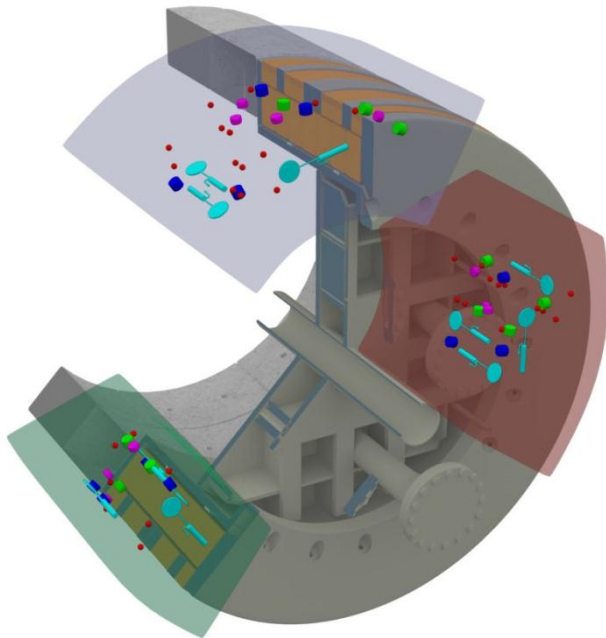
EBS instrumentation – RESEAL set-up



PRACLAY SEAL

total pressure cells and piezometer filters

- large surface might influence bentonite hydration...



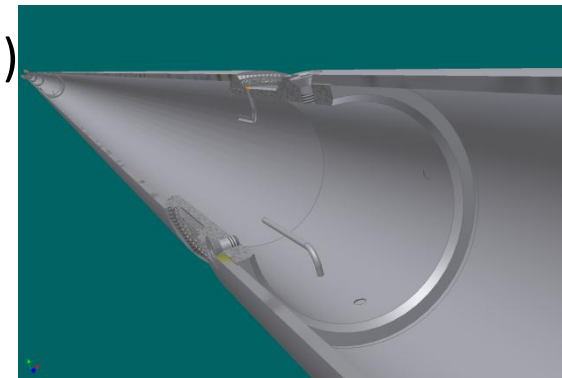
Assessment of sensors according to parameter

- pore(water) pressure
- total pressure
- moisture content (suction/unsaturated materials)
- displacements
- mechanical strain
- physico-chemical phenomena
 - oxidation
 - corrosion

Pore pressure – most used parameter

Successful deployment of multifilter piezometer

- installation adapted to Boom Clay characteristics
 - self sealing, no packers needed
- due to strong HM coupling – sensitive to many phenomena
 - short- and long-term anisotropic influence of gallery excavation on porewater pressures
- versatile instrument, also for “active use”
 - sampling
 - hydraulic parameters (permeability, storage)
 - looping for on-line analysis
 - migration / solute transport
 - gas transport investigations
- allows for regular calibration



Total pressure

Performance of total pressure sensors depends on

- sensor characteristics (stiffness $\leftrightarrow$ host formation)
- installation
 - borehole drilling alters the total stress field

Rather good results in backfill and at interfaces

- inside host clay formation: better approximation by combining different techniques, including active methods: (self-boring) pressuremeter, dilatometer, hydro-fracturing
- change in total pressure is often also a good indicator

Unsaturated state

Different methods for determination of hydration / saturation degree

- suction through RH
 - vulnerable for liquid water
- close to saturation: psychrometer / tensiometer
- direct moisture determination: TDR, n- γ probes
- indirect methods: thermal properties

Important for bentonite EBS performance

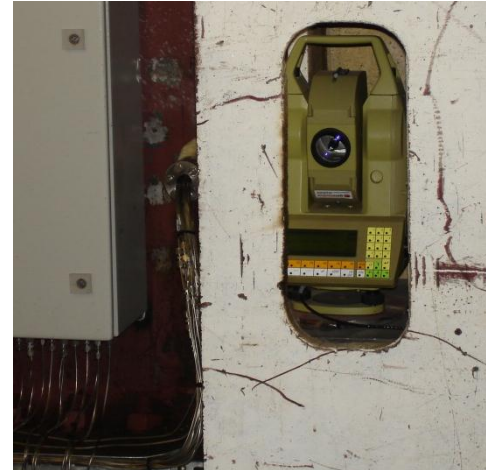
- much experience (being) gained

Different techniques for displacement monitoring

direct optical methods

→ most reliable but require access

- total station
 - manual borehole survey
 - automatic total station



inclinometer

- e.g. CLIPEX example – excavation of Connecting Gallery

extensometer

- MPBX : anchoring problem in clay boreholes
- magnetostrictive devices (RESEAL)
- inductive transducers (PRACLAY Seal)
- fiber-optic long-base gauges (around PRACLAY Gallery)

Experience gained after 30 y of monitoring

Successful implementation depends on adapting available (sensor) technology to the environment

Monitoring : more than instrumentation and sensor technology

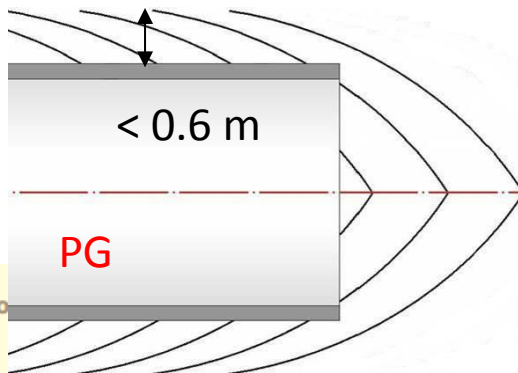
- visual observations (routine and ad-hoc)
- clear understanding of the geo-environment and of the sensors helps us in a correct interpretation of the observations

Knowledge management

- sensor expertise (technology, installation procedures,...)
- information technology
 - from mainframe and data storage on cassette tapes to Web-interface for data presentation

The power of observation

Important knowledge gained by field observations
e.g. fracture pattern around excavations



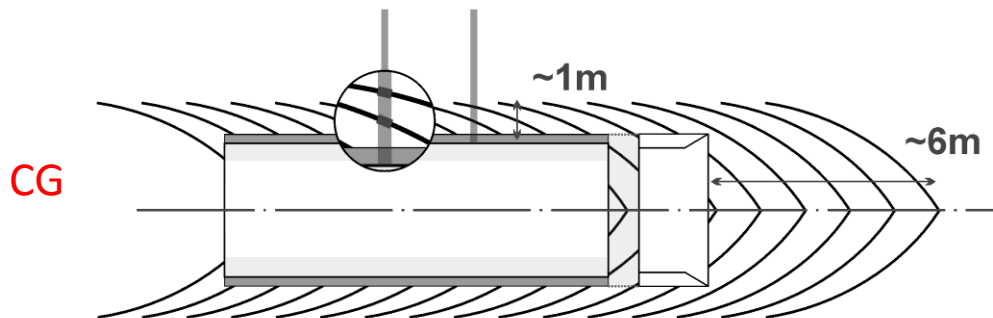
GEOTECHNICAL INSTRUMENTATION

The Power of Observation

Ralph B. Peck

in winter, enough ore must be accumulated in the summertime to last through the winter. So every steel plant has an

consulted me, and that I had said the same thing. But then Terzaghi went on the say, "However, there may be some



Experience gained after 30 y of monitoring

Increasing confidence in monitoring by combining different observations (“redundancy”)

- several sensors of the same type (spatial variability)
- different sensor principles for the same parameter
- different – coupled – parameters
 - stress – strain, H-M coupling
- point measurements versus geophysical techniques
 - “non-intrusive” (in the monitored zone)
 - to deal with spatial variability
 - confirmation of e.g. lab-derived parameters (e.g. elastic parameters through micro-seismic techniques)

Experience gained after 30 y of monitoring

As all field instrumentation engineers know...

“the devil is in the details”

“c’est le détail qui tue”

‘t zijn de kleine dingen die het doen....



- enough resources to be planned for extensive (prototype) testing
- baseline characterisation of sensor (determination of sensor characteristics in the field) to allow improved interpretation and diagnostics

Succes factors for monitoring

Technical aspects

- sensor robustness / adapted to field conditions
 - installation (construction site , watertightness, corrosion (oxidized zone, galvanic corrosion) ,...
- cabling
 - essential for sensor reliability
 - may affect environment / breaching of barrier
 - e.g. dam safety – sinkholes due to cabling from abandoned sensors
- data reduction / signal diagnostics
 - treatment of “wrong” / “unexpected” data
- do the sensor (and installation) alter the field conditions?

Management aspects

Success factors for monitoring

Technical aspects

Management aspects

- design/contracting/installation/follow-up
- record keeping / documentation / as built plans
- management of measurement data
 - ! access to monitoring data
 - automated monitoring: follow-up?
 - “increased data $\neq$ improved data”
 - GSIS project
 - response plan: what if measurements/observations indicate deviation from “expected” value?

The Golden Rule

The golden rule is: **The people who have the greatest interest in the monitoring and instrumentation data should be given direct responsibility for obtaining the data.** Or put another way, who has the motivation to do these nit-picking tasks with enough care?

Dunniclif, 2011

Challenges for repository monitoring

Long term monitoring

- reliability/recalibration/ (powering)
- data management / record keeping
- nothing is happening ...
 - transient phenomena (temperature, porewater pressures, oxidation,...)

Environmental conditions

- radiation
 - less an issue with SuperContainer design
- chemical (corrosion)
- thermal
 - although no suffering from diurnal or seasonal variations
- hydraulic

Challenges for repository monitoring

Inaccessible sensors

Minimal invasive cabling

Geological environment – spatial variations

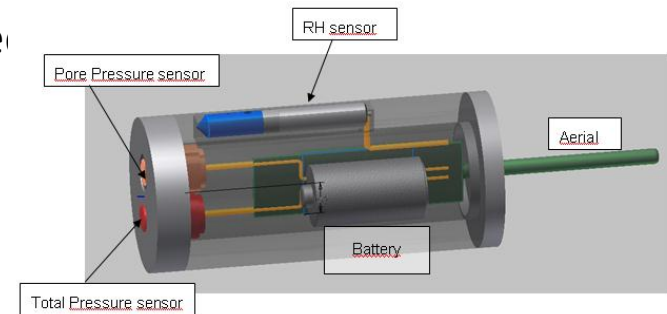
Sensor market – niche

- customized versions, limited production, prototypes
- take advantage of technical developments elsewhere
 - e.g. consumer electronics (VW sensors and MP3 players, Kinect® sensor for scanning excavation fronts...
 - fiber optic technology based on developments for data communication

Perspectives for repository monitoring

Sensor and monitoring technologies

- fibre optics
 - also alleviates cabling issues
- MEMS / miniaturisation
- wireless techniques
 - autonomous power (thermo-electric generation)
- geophysical techniques
 - numerical capabilities allow increase techniques (tomography)



wireless sensor prototype developed by AITEMIN

Conclusion

Broad experience gathered in the field of

- sensor technology and availability
- implementation (installation techniques)
- instrumentation and data management

Successful monitoring programme also depends on a clear framework regarding

- design / specification / manufacturing
- testing and installation
- follow-up (maintenance, reporting)

Sensor expertise needs to be secured for longer term

- knowledge management
- sharing of sensor experiences at international level



UNIVERSITY OF GOTHENBURG

Perspectives on geological repository monitoring: confirmation, compliance, confidence building and societal vigilance

18th EURIDICE Exchange Meeting
“Instrumentation and monitoring in radioactive waste repository research” – Mol, 24/01/2013



Content

- Context of this presentation: MoDeRn
 - General description
 - Social sciences contribution (Tasks 1.3 & 1.4)
- Research results for T1.3 & T1.4
 - On monitoring objectives & strategies
 - (How) can monitoring contribute to confidence building?

CONTEXT OF THIS PRESENTATION

**MoDeRn: MONITORING DEVELOPMENTS
FOR SAFE REPOSITORY OPERATION AND
STAGED CLOSURE**

The MoDeRn Project (FP7 – 232598)

- Collaborative project co-funded by the European Commission – EURATOM (FP7 – 232598)
 - On **strategies and technologies for repository monitoring** in view of **long term safety**
 - Duration: 1st of May 2009 – 31 October 2013 (4 1/2 years)
 - 18 partners from 12 countries; coordinated by Andra
- Aim: providing a **framework for the development and possible implementation of near-field monitoring activities** and associated **stakeholder engagement** during relevant phases of the radioactive waste disposal process.
- Published project documents: **www.modern-fp7.eu**

Social Sciences Contribution

(UA – UEA – UGOT)

- Look at monitoring as a socio-technical combination
 - Relationship between monitoring and decision-making
 - Potential role of monitoring in building confidence in a repository system: What could be contributing factors?
 - Different stakeholders' understanding of and expectations towards (repository) monitoring
 - for this research: focus on local stakeholders
 - (local) Stakeholders' interest in discussing monitoring issues and how to put that in practice

- Understanding the experts

- Document review and interviews with technical specialists

**Task 1.3 -
Report D1.3.1**

- Role of monitoring in building public confidence

- Literature review of experiences: published accounts of relationship between stakeholders and monitoring activities in the nuclear sector and other contexts

- Reflection on the notions of vigilance and social trust

- Drawing on literature on relations between experts and citizens
- Focus on institutional arrangements

- Exploratory engagement activity

- Explore potential for (lay) stakeholder engagement in identifying monitoring objectives and strategies

**Task 1.4 -
Report D1.4.1**

Exploratory Engagement Activity

- Research driven, small scale
- Outside of national disposal programmes
- Volunteers from local communities on existing nuclear sites (varied experience with RW issues)
 - Belgium, Sweden, UK
- Three stages:
 - National workshop(s) – common 'protocol'
 - Technical visit (with subset of national participants) to research facilities in Switzerland
 - National feedback meeting

INTEGRATED CONCLUSIONS T1.3 & T1.4

**ON MONITORING OBJECTIVES &
STRATEGIES – WHY AND WHAT ?**

Why monitor ?

- Assumption among expert community that monitoring adds to public confidence building
- Participants in T1.4 acknowledge **potential** role of monitoring in public confidence building

BUT

- Different expectations with regard to monitoring
- Monitoring is only one aspect of confidence building

Why monitor ?

- Add to stakeholder confidence in safety of the repository
 - Compliance: with prevailing regulations & standards
 - Optimisation: in view of refinement or improvement

Important difference in emphasis on:

- PERFORMANCE **CONFIRMATION** (implementers & regulators)
- versus
- **CHECKING** EXPECTED BEHAVIOUR (citizen stakeholders)

Dealing with uncertainty

Optimisation

- Objectives are guided by what is technically feasible today
- BUT no excuse not to monitor certain parameters
- Importance of accompanying science programme
 - Lab simulations to complement monitoring
 - ▶ BUT: transferability of results?
 - Continuous search for monitoring alternatives
 - ▶ BUT: within limits (time and expenses) ⇨ societal choice

Optimisation

- Create decision milestones to encourage optimisation
 - e.g. restrict operational licence in time
- Stimulates continuous search for improvements
- Ensures sustained implementer performance

What does it mean: to monitor?

Monitoring is understood broadly, and could cover

- any data gathering relating to behaviour of a repository and its natural and social environment
- a period from site investigation to post-closure

Different from the technical research in MoDeRn:
focus on repository monitoring or near field
monitoring

What to monitor ?

T1.3

- Technical specialists assume 'lay' stakeholders to focus on environmental and post-closure monitoring
- Focus on environmental monitoring seemingly confirmed by literature reporting on cases of citizen and stakeholder involvement with monitoring
- BUT also attention to other issues: e.g. socio-economic impact monitoring

What to monitor ?

T1.4

- Local citizens **less concerned with what parameters and where** exactly to monitor
- BUT focus on comprehensiveness of programme
 - Does it measure **all that is relevant** to be sure that it is safe today and will remain safe in the long term?
 - Will it be able to detect less likely or unexpected events?
 - Does it have a broad scope in both space and time?

INTEGRATED CONCLUSIONS T1.3 & T1.4

**(HOW) CAN MONITORING
CONTRIBUTE TO CONFIDENCE
BUILDING ?**

Monitoring as vigilance

⇒ **keeping an eye / remaining 'on guard'**

- Not for experts alone to decide 'How much and for how long?' and 'How to organise it?'
(cf. Weinberg, 1972)
- Broad scope in space and time
 - Including post-closure
 - but no specification on what and where

Monitoring as vigilance

⇒ **keeping an eye / remaining 'on guard'**

- Comprehensive monitoring programme
 - Including monitoring of repository system conditions, environmental conditions and socioeconomic conditions, evolutions in knowledge and technology
 - (SE) : Need to know 'what happens in reality'

Recognition of trade-offs

- (BE) : What and how to monitor is determined by trade offs between the financial context, the social and political context and the level of knowledge and technology
- ⇒ This should be recognised and made explicit !

Monitoring requires a response plan

- Monitoring means you are prepared to respond in case of unexpected results
 - ≠ unexpected results equals something is wrong
 - ≠ action equals retrieval of waste
- To respond to worst case scenario, a 'plan B' should be available
- Need to maintain the capability to do so
 - Maintain knowledge, skills, (financial and material) resources, memory, ...

Monitoring - product and process (views from participants in T1.4)

- Implementer to act as monitor
- Regulator to monitor the monitor
- Additional mechanisms for building trust: e.g.
 - Independent oversight bodies
 - International guidance (rather than regulations)
 - ...
 - Active stakeholder engagement

Active stakeholder involvement

⇒ claimed virtues from literature

- Increasing confidence in monitoring and management programmes
 - Awareness and understanding of the nature of the problem
 - Awareness and understanding of the science underpinning its management

(e.g. Gray 1989; Burger and Gochfeld 2009; Hartwell et al 2011)
- Mediate relationship between citizens and experts
 - Enhancing social capital and community well being
 - Enhancing mutual understanding
 - Fostering more active forms of citizenship

(e.g. Ottinger 2009; Conrad and Hilchey 2011)

Active stakeholder involvement

⇒ lessons from MoDeRn

- Have an actual voice in decision-making on various steps in the disposal process
- Critical reflection in preparation and design / implementation / follow-up
- Enabling stakeholders to engage their own 'independent' expertise

Some examples from literature (D1.3.1)

- Involvement in **developing** the monitoring programme: 'co-defining' objectives and strategies
 - E.g. Belgian LILW repository; the Port Hope Area Initiative (Canada)
- Involvement in **following up** monitoring programme and activity: engagement in oversight, organising independent scrutiny
 - E.g. Local information en oversight committee (CLIS) around Bure URL (France); Municipal Monitoring Commission for the decommissioning of the Vandellòs I l'Hospitalet de l'Infant NPP (Spain)
- Involvement in **conducting** monitoring activity: participatory monitoring
 - E.g. Three Mile Island Citizen Radiation Monitoring Programme; Nevada test site Community Environmental Monitoring Programme (USA)

Active stakeholder involvement

⇒ lessons from MoDeRn

- Monitoring is part of a bigger story
 - Engagement with stakeholders on monitoring should be part of a wider process of consultation and participation dedicated to the question of geological disposal
 - Continuation of such a wider engagement process can be part of a broader approach to monitoring
- Public arenas at a local level to discuss safety issues and monitoring results
 - From T1.4: no agreement on active participation in monitoring

On communicating monitoring results

- Monitoring data must be made publicly available
 - Cf. Aarhus convention
 - BUT not necessarily in real time
 - AND with instructions on how to interpret them
- Priority on periodic reporting: aggregated data in context
 - Need for raw data to be available on demand to verify interpretation
 - Open reporting, also of regulatory inspection and audit
 - Different translations of the same message for different audiences
- Important to start dialogue in research phase
 - Swiss field trip stimulated further discussion and nuancing of beliefs and expectations

- Burger, J. and M. Gochfeld (2009) Changes in Aleut Concerns Following the Stakeholder-Driven Amchitka Independent Science Assessment, *Risk Analysis* **29**(8): 1156-1169.
- Conrad, Cathy C. and Krista G. Hilchey (2011) A review of citizen science and community-based environmental monitoring: issues and opportunities, *Environmental Monitoring and Assessment* **176**(1-4): 273-291.
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THANK YOU

