
Implementation of the Instrumentation

Lessons learned – reliability – selection and test programme

EURIDICE Instrumentation Day

Jan Verstricht

20 September 2004



ESV EURIDICE GIE

Outline

- Lessons learned from previous experiences
- Instrumentation challenges in the PRACLAY set-up
- Selection of main sensor types
 - host rock instruments
 - gallery lining instrumentation
- Test programme
 - selected and prospective sensor types
 - other tests
- Data management
 - from acquisition to report



Lessons learned from previous experiences

- general conclusions
 - instrumentation report + update
 - experiences abroad
- HADES experiences
 - CLIPEX
 - other: ATLAS, BACCHUS, CERBERUS, RESEAL...
- mock-up
 - mainly backfill type of sensors
 - important lessons for gallery lining



Instrumentation report (+ update)

- Large database of sensor types and experiences
- Importance of environment (host rock)
 - sensor type
 - installation
- Not always unique “best choice”
- Identification of common pitfalls



Experiences abroad

- Instruments adapted to environment and experiment conditions (heated, saturated,...)
- Asse mine (D)
 - high temperature tests, up to 200 °C
- FEBEX in situ (CH)
 - total pressure cells (fluid filled pressure pads) at elevated temperature (100 °C)
- Mont Terri (CH)



CLIPLEX experiences

- Multipiezometers confirmed as versatile tool
 - porewater pressure and other hydraulic parameters
 - characterisation of suction
- Miniature total pressure cells
 - not in clay host rock
- Extensometer
 - anchor and connecting rod system
- Inclinator required adaptations
 - casing
 - follow-up (survey) of reference points
- Limited accessibility (front Test Drift)
 - same conditions expected for e.g. gallery crossing
- Corrosion in oxidized zone



OPHELIE experiences

- corrosion and watertightness
 - detrimental effect of water flow
 - systematic screening of all materials (metals)
- gallery lining instruments
 - hydraulic lines to be avoided, especially in high temperature environment



Other HADES experiences

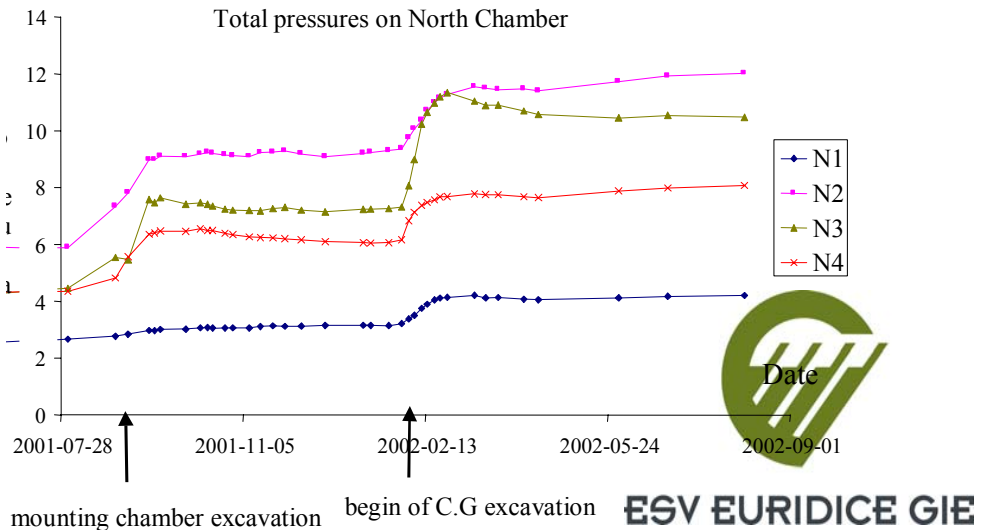
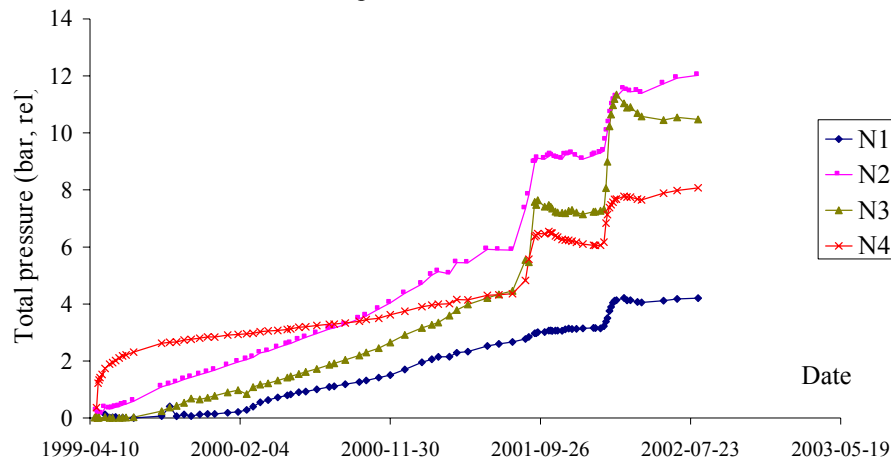
- RESEAL
 - miniature total pressure sensors for backfill swelling pressure
 - magnetostrictive extensometer type (“sonic probe”) – hermetically sealed
- SELFRAC
 - assessment of geophysical techniques
- Second Shaft
 - good performance of total pressure cells



Total pressure sensors before casting



Total pressures on North Chamber



PRACLAY Instrumentation Challenges

- Environmental conditions
 - elevated temperatures and temperature gradients
 - saturated medium with elevated water pressures and stresses
- Accessibility
 - reinforcement ring at crossing
 - general configuration
 - cabling and measurement heads at (heated) gallery intrados
 - cabling through lining and plug



Selection of monitoring techniques and sensor types

- Long term → Reliability
 - proven techniques
 - simple measurement principles
 - interpretation
 - visual observations
 - essential during excavation process (fracturing, convergence,...)
 - redundancy
- Applicability in experimental context
 - installation / access



Sensor types

- host rock
 - multipiezometers
 - total stress sensors
 - displacements sensors
- gallery lining
 - embedded strain gauges
 - pressure and load cells
 - displacements



Multipiezometer :

mother of all instrumentation lay-outs

- versatile instrument
 - pore pressure, hydraulic parameters, sampling
 - re-calibration of pressure transmitters
- mature technology
 - 20 years of experience
 - installation of 15 boreholes / 150 filters
- adaptations
 - integrated temperature measurement
 - without affecting local temperature field
 - observation of suction
 - maximum info during excavation
 - thermal gradients
 - thermal isolation
 - heat tracing of tubes



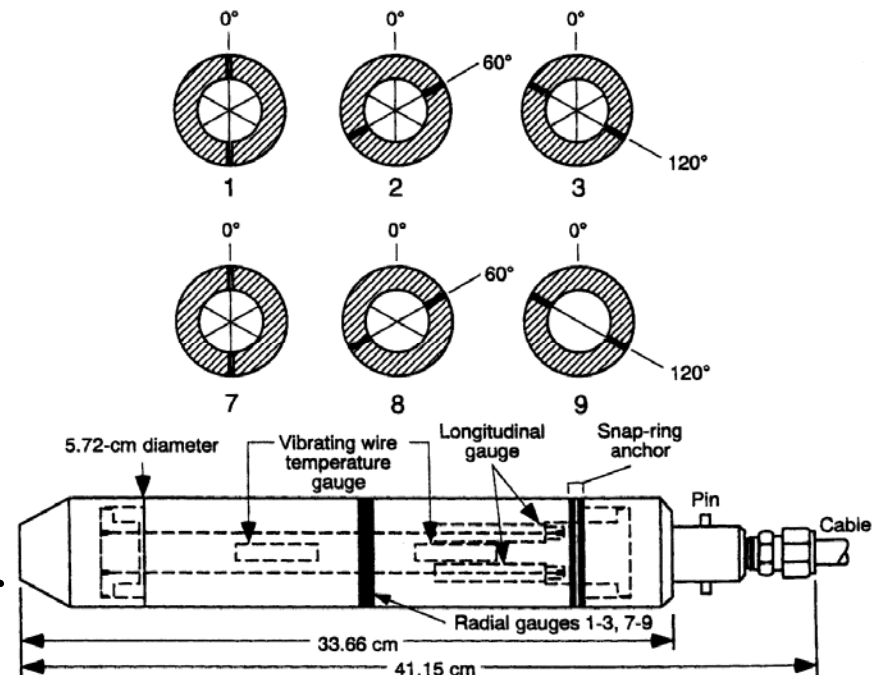
Temperature measurement

- point measurements
 - type T thermocouples (0.5 °C accurate)
 - AISI 316L sheath, flexible cable connection
 - optional: thermistors if very high resolution required
- distributed measurements (DTS)
 - fiber optic technique (back scattering)
 - interesting perspective for gallery intrados and along (deep) piezometers
 - spatial resolution < 1 m

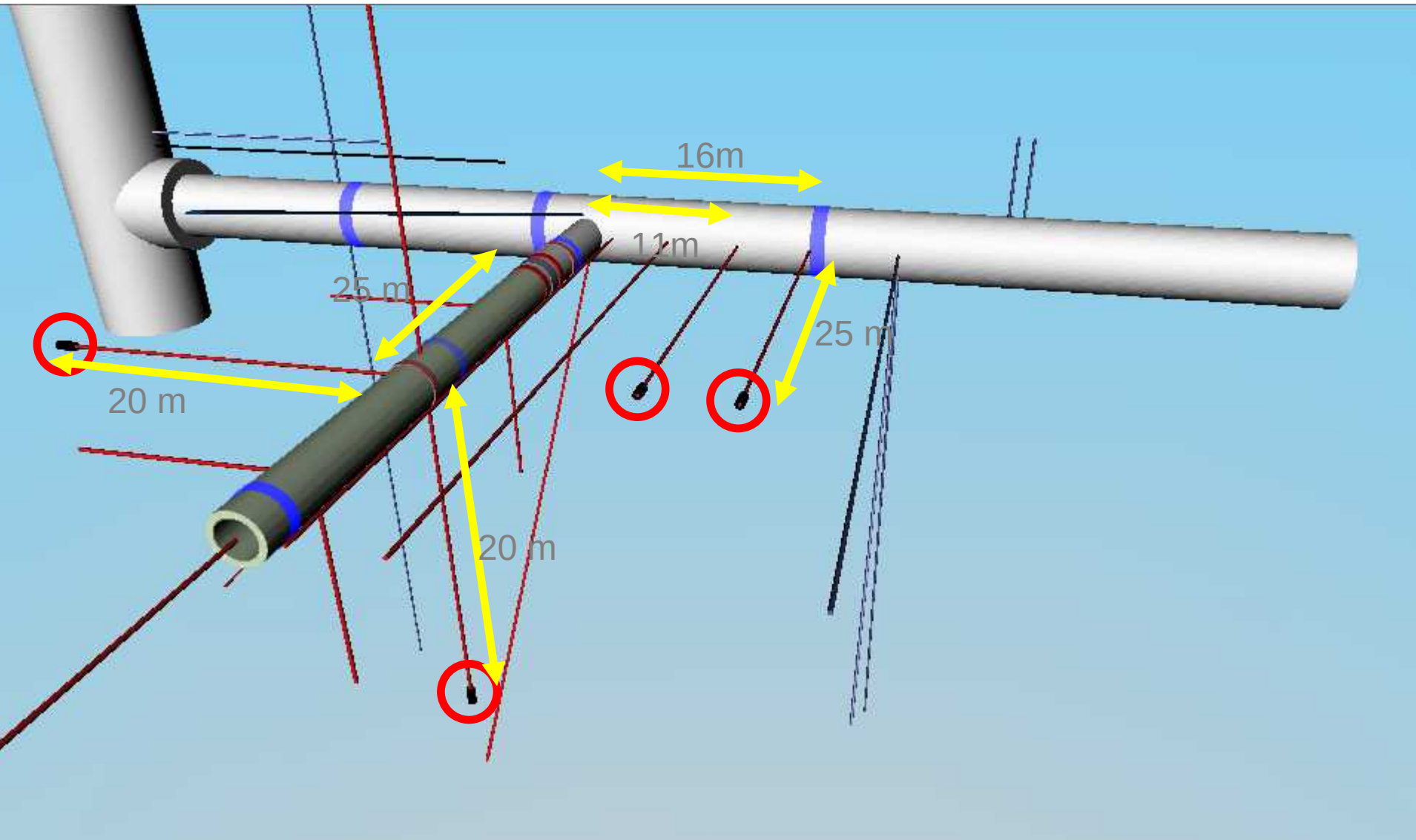


Total stress sensors

- biaxial stressmeter
 - simple design
 - stress orientation
 - first experience in ATLAS
 - adapted design
 - borehole diameter
 - measuring range
- Self-boring pressuremeter principle
 - permanent version under study



Total stress measurement set-up



Displacement in host rock

- convergence and expansion
 - in-place inclinometer above gallery
 - sensitivity of water column variations
 - extensometer from PG
 - special attention anchors and connecting rods
 - measurement head at gallery lining intrados
 - sonic probe and/or fiber optic system
 - extensometer plots installed in PG axis

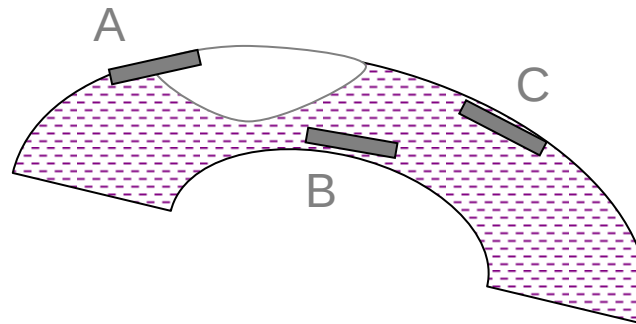
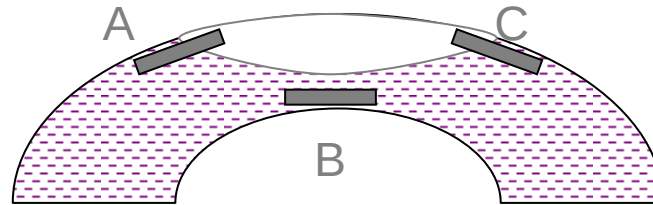


Sensors / Measurement techniques

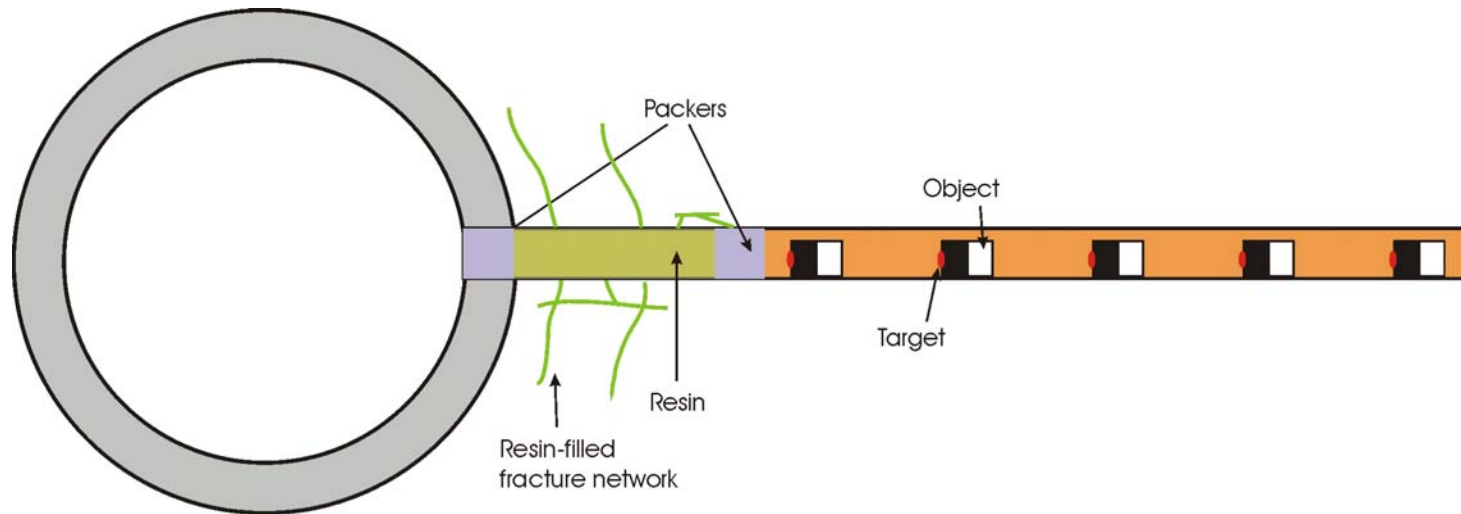
- Inclinator
 - in place inclinometer (Interfels) – chain of 2 and 3 m long segments
 - double lining (external steel casing around ABS inclino casing)
 - test of limited chain (5 x 2 m) + individual test of each sensor
 - calibration, temperature sensitivity



Assessment of electrolevel at elevated temperatures



Extensometer plots in PG axis

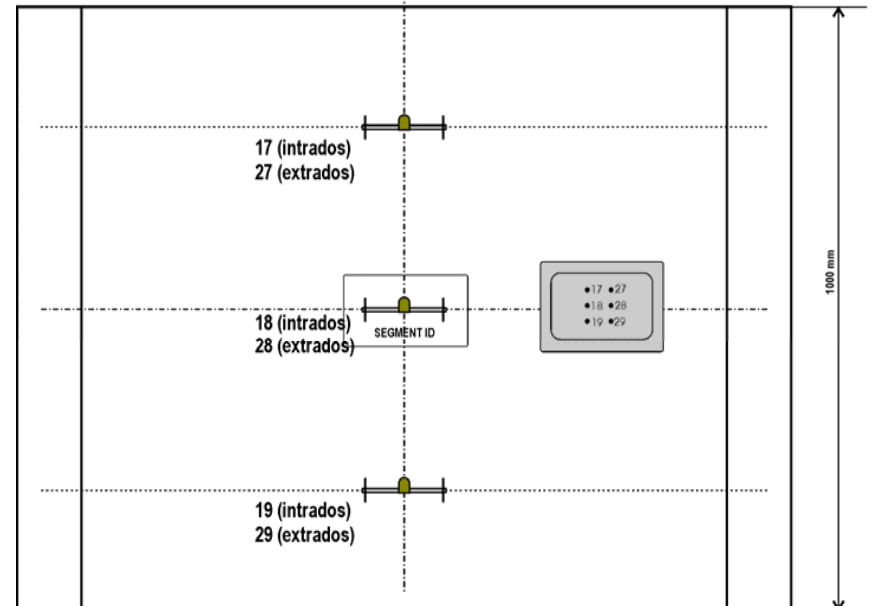
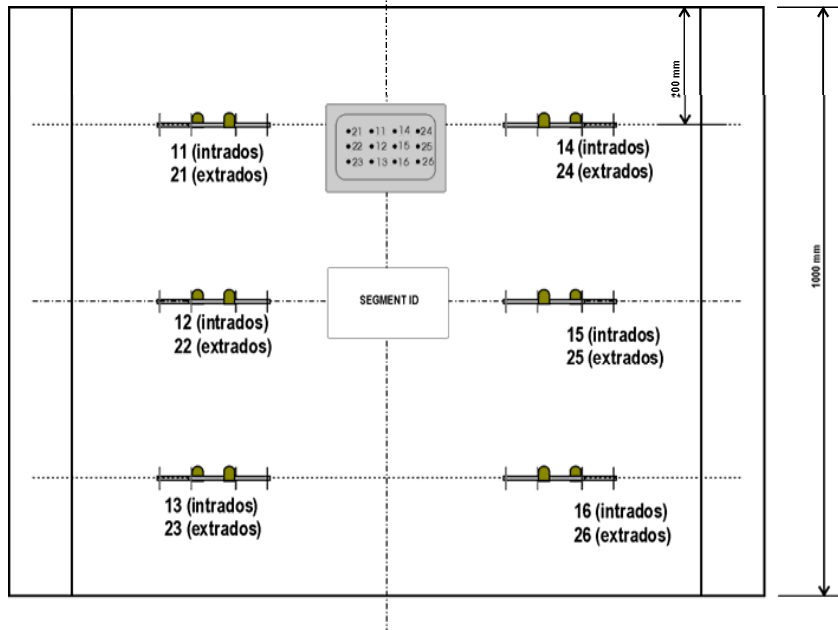
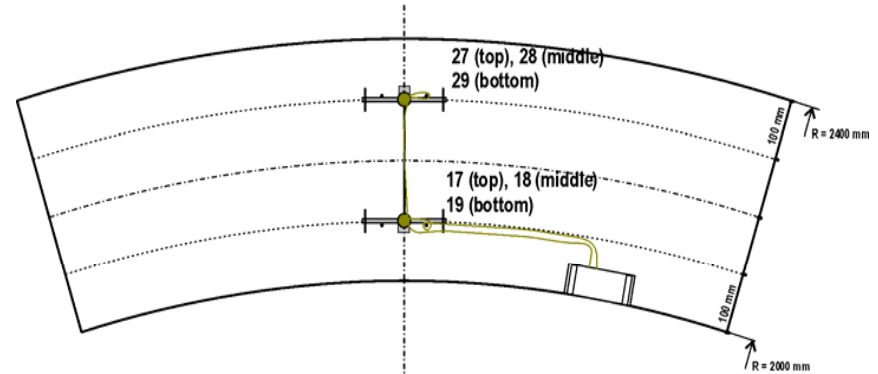
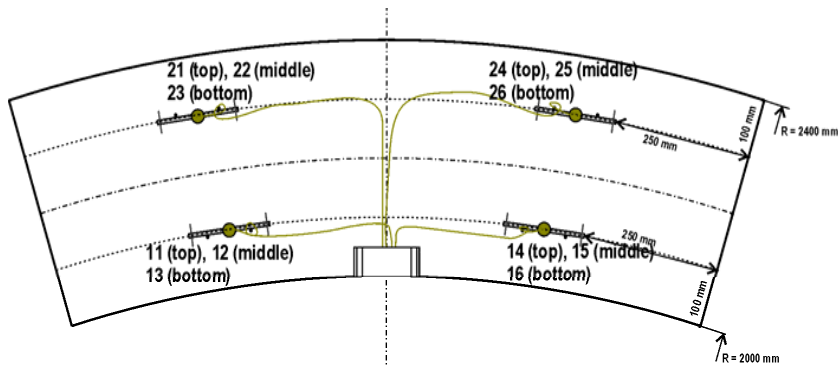


Gallery lining strains

- Embedded strain gauges
 - intrados / extrados
 - rapid increase – frequent measurements
 - high temperatures in heating phase
 - mechanical properties concrete
- Based on vibrating wire type
 - optionally complemented by fiber optic gauges



Both intrados and extrados strain



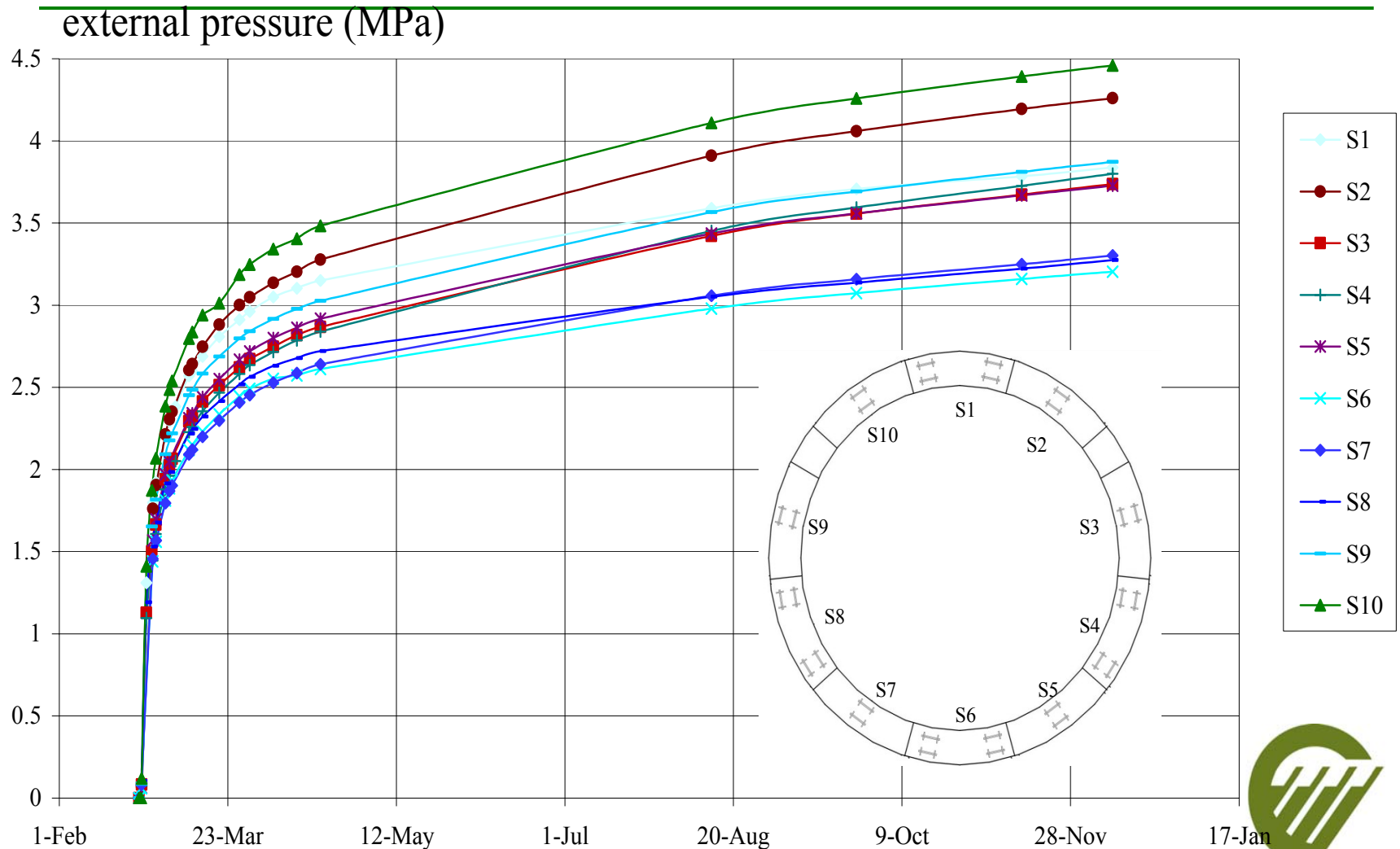
Embedding during segment casting



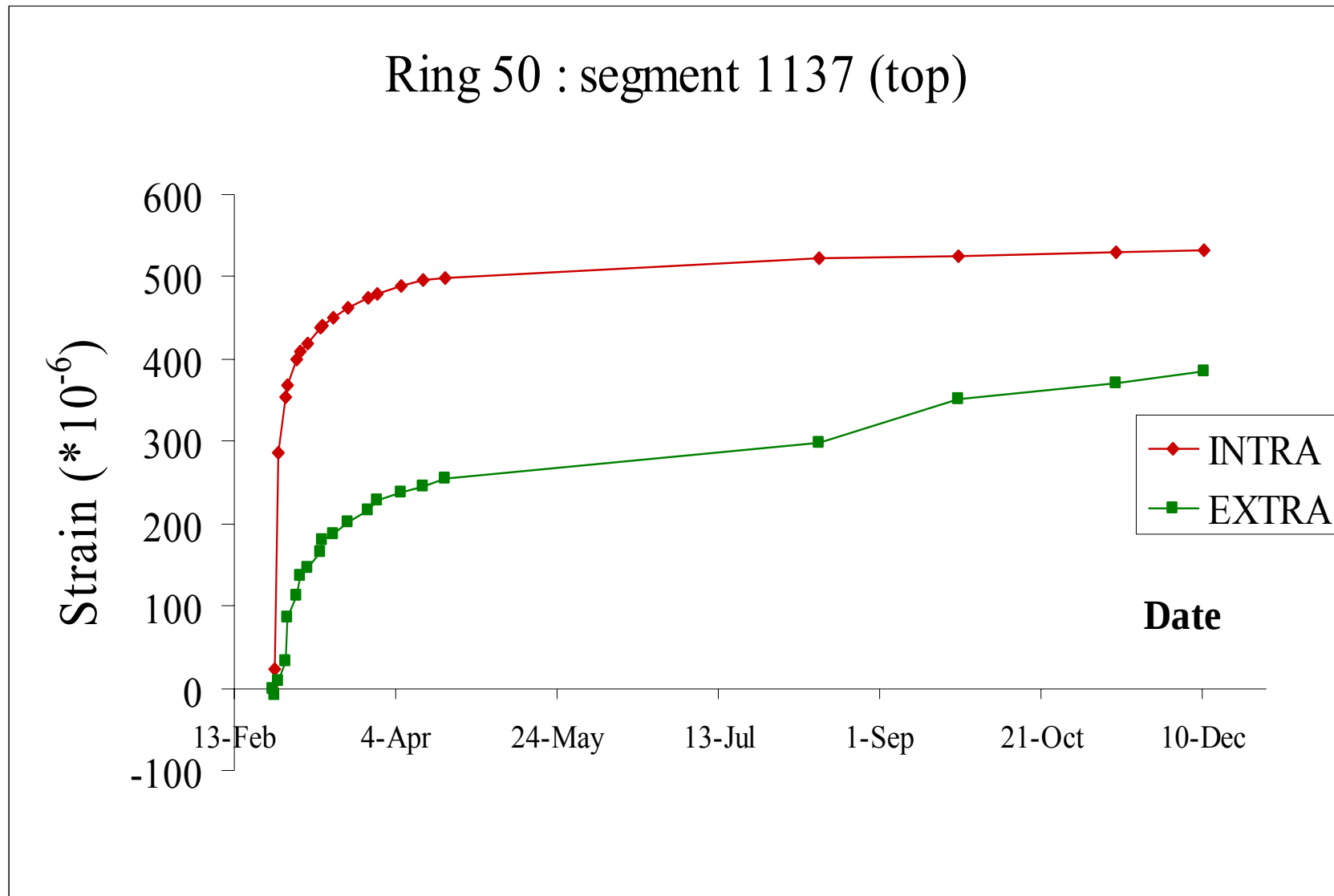
ESV EURIDICE GIE

Strain during and after installation

RING 50 - External pressure [MPa] ; $E=50\text{GPa}$



Significant bending in some segments



Segment pressure and load

- Complementary to strain gauges
 - direct measurements
- Bulky load cell configuration
 - compatibility with installation
 - representativeness of measurement set-up
- Temperature influence



Overall gallery displacement

- short term (after excavation)
 - convergence (wire extensometer)
 - optical survey
- long term: longitudinal expansion
 - fiber optic long base extensometer



Fiber optic instrumentation

- (distributed temperature measurements)
- strain gauges
 - back-up for the embedded vibrating wire SG
- long-base (2 x 15 m) extensometer in the gallery



Multipiezometer test programme

- Test of 2 m long section under hydrostatic conditions (test bench)
 - glued couplings at elevated temperature
 - thermocouple performance
 - calibration
 - thermal gradients inside piezometer tubing
 - tracing and thermal isolation of piezometer tubing
 - internal thermal isolation of multipiezometer room
- Assessment of suction measurement
 - flushing of filter and measurement of humidity



BSM test programme

- hydrostatic calibration
- tests at elevated temperatures



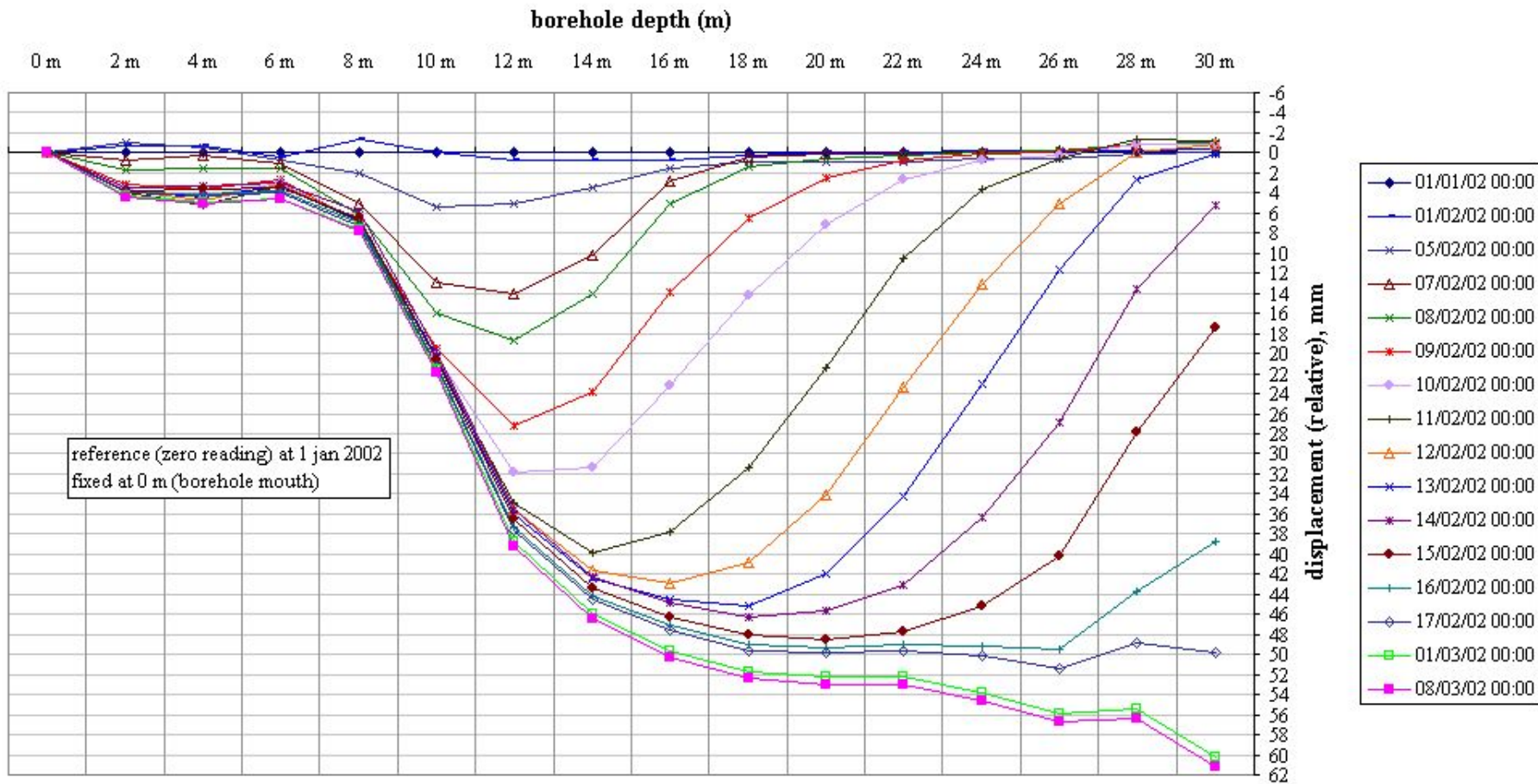
Inclinometer test programme

- Assessment of current type (electrolevel)
 - elevated temperatures
 - total accuracy of chain
- Assessment of other principles
 - capacitive, vibrating wire,...
- Optional: settlement gauge



Expected type of measurement

E1 - inclinometer
cumulative displacements



Full scale assessment of inclinometer set-up



ESV EURIDICE GIE

Pressure and load cells

- Assessment at elevated temperatures
- Load cell configuration
 - load cells preassembled to facilitate installation
 - correction load transfer in segment ring
- Compatibility with segment production and installation



Other tests

- Concrete lining
 - mechanical parameters
 - elastic modulus, creep, shrinkage
 - thermal conductivity
 - simulation of experimental conditions
 - temperature, humidity, stress state



Installation issues – Connecting Gallery

- drilling from CG
 - nitrogen drilling to avoid oxidation
 - P35E, optionally P33Id
 - core drillings
 - geochemical and geological characterisation
 - diameter $\approx$ reference piezometers
 - 125 mm drilling, 101.6 mm casing diameter
 - reinforcement ring: recessed cabling



Installation issues – PRACLAY gallery

- list of specifications
 - installation and access to sensors;
 - time for manual measurements
- design of segments
 - pressure cells, load cells
 - embedded strain gauges
- boreholes from PRACLAY gallery
 - limited diameter
- cabling/tubing through gallery and plug



Data Management

- Planning ahead on data structure
 - Measurement data: raw data, engineered data
 - Sensor data (calibration, corrections,...)
 - Environmental data
- Important considerations
 - Data integrity
 - Data access
 - Report generation



Data Management (2)

- acquisition
 - mostly automated, through distributed data-acquisition
 - manual measurements (optical survey, hydraulic parameters,...)
- processing
 - logging in database of raw measurement data
 - manual (“expert”) evaluation of quality of measurement data
- reporting
 - direct follow-up with alarm reporting on standard report screens
 - 3 monthly reports
- presentation
 - integration with GSIS system
- analysis
 - back-analysis with modelling people



Characterisation of geochemical perturbations in the Boom Clay Near Field around the PRACLAY experiment

Maarten Van Geet
Waste & Disposal
R&D Geological Disposal

Overview

- Relevance
- Expected Geochemical perturbations
- Objectives
- Methodology
 - Former tests
 - Sampling strategy
 - Originally considered sampling positions and scoping calculations
- Conclusions

Relevance

- The Near Field (NF) geochemistry (perturbations) is considered
 - Focus on the effects on R2 (retention and diffusion) safety function
 - For the present reference concept (supercontainer), scoping calculations on NF geochemistry are ongoing

Expected geochemical perturbations: oxidation

- Anoxic Boom Clay + air = oxidation (of pyrite and organic matter)



- Buffering capacity towards acidification, mineral dissolution/re-precipitation/cation exchange
- Changes in retention and diffusion of radionuclides
 - Porosity changes
 - Solubility/speciation changes
 - Sorption changes

Expected geochemical perturbations: temperature increase

- (HLW +) SF are responsible for Temperature increase
- Changes in clay mineralogy and pore water chemistry
 - CO₂ production from thermolysis of OM and changes of OM structure
 - ✓ On-going post-doc at IFP indicates release of CO₂ from kerogen at moderate temperature increase
 - Minerals sensitive to temperature

Expected geochemical perturbations: alkaline plume

- Caused by the use of concrete/cement
- Experimental set-up not necessarily related to PRACLAY gallery and thus not included during the PRACLAY experiment
- During dismantling, this topic will be included
 - Samples will be taken at the interface concrete - clay

Objectives of Research Plan perturbations

- observe and understand the phenomena of geochemical perturbations
- estimate the extent of the chemical perturbations
 - Next phase evaluate the effect on the R2 (diffusion and retention) safety function of the host rock
- make suggestions to performance assessment and R&D on how to take into account the effect of geochemical perturbations.
 - The concept used should be at least conservative

Former test: CERBERUS

- Evolution of pore water chemistry was observed
- No significant effects on mineralogy could be observed
- No significant effects on kerogen could be observed

What to measure

- Pore water is expected to react fast on oxidation and temperature increase
 - On-line measurements or frequent chemical analyses
- Mineralogical changes are only slight within the temperature/time range of the PRACLAY test
 - Limited amount of samples
 - Additional sampling at dismantling of the Praclay experiment

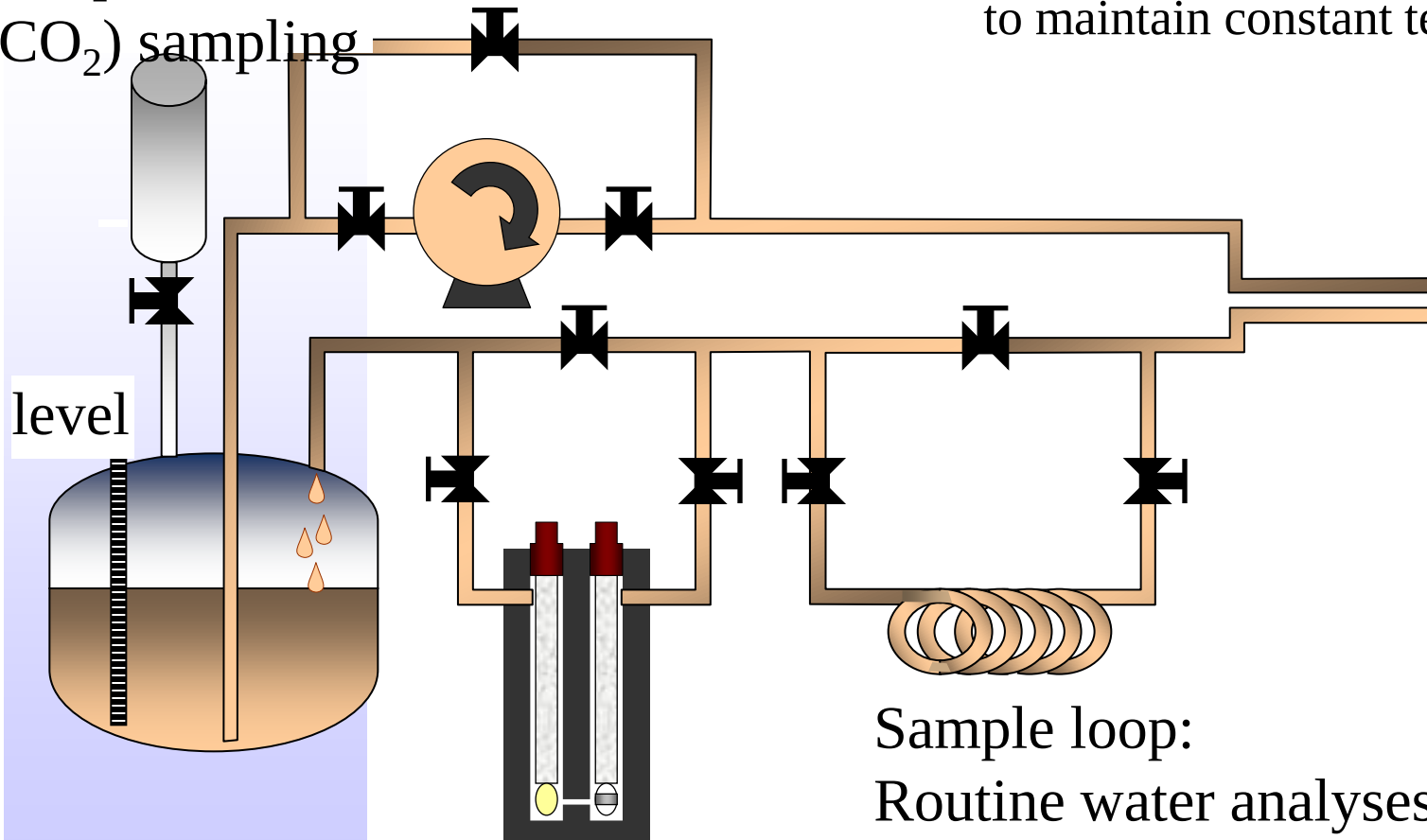
Sampling strategy

- Before the excavation of the PRACLAY gallery
 - Drilling and coring at the position of the filters with minimum disturbance (avoid oxidation as much as possible)
 - Installation of multi-filter piezometers
- During the PRACLAY experiment
 - No drilling/coring
 - Frequent follow-up of pore water chemistry without disturbing pressure measurements
 - **Sampling for the geochemical study may never disturb the THM measurements (major goal of the project)**

Sampling strategy

Gas-phase
(CO₂) sampling

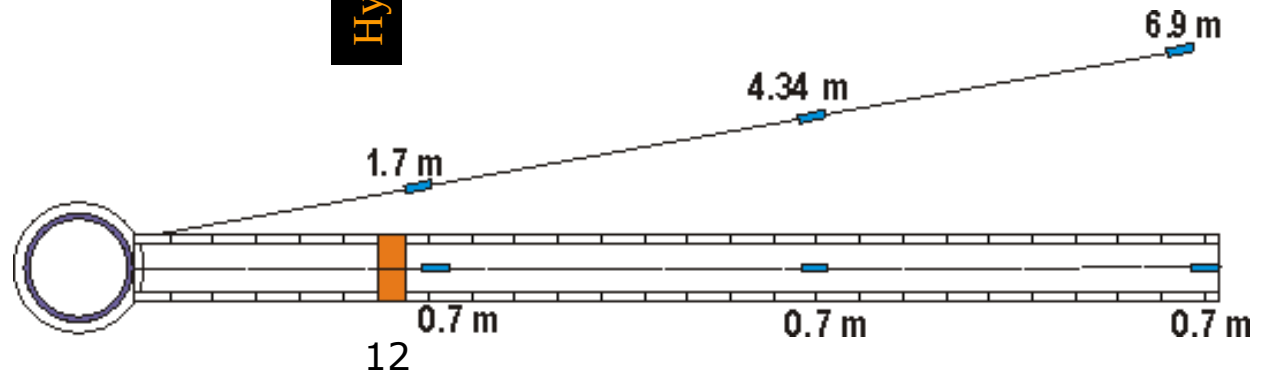
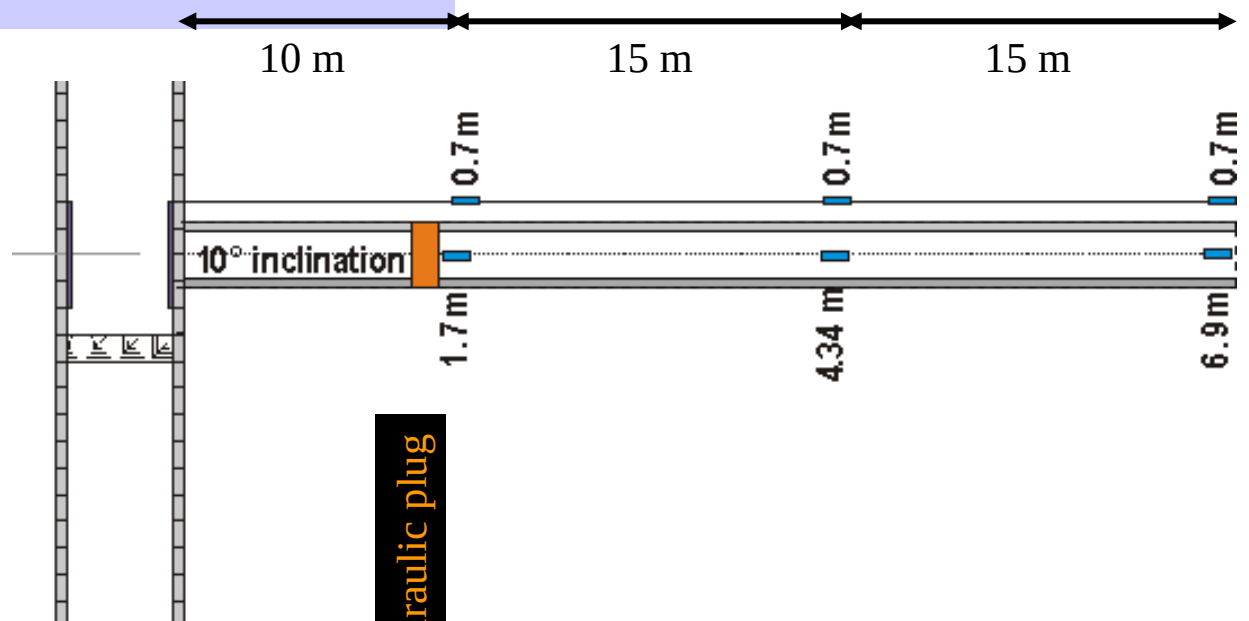
Heating of tubes and cabin
to maintain constant temperature



Eh - pH

Sample loop:
Routine water analyses

Originally considered sampling positions

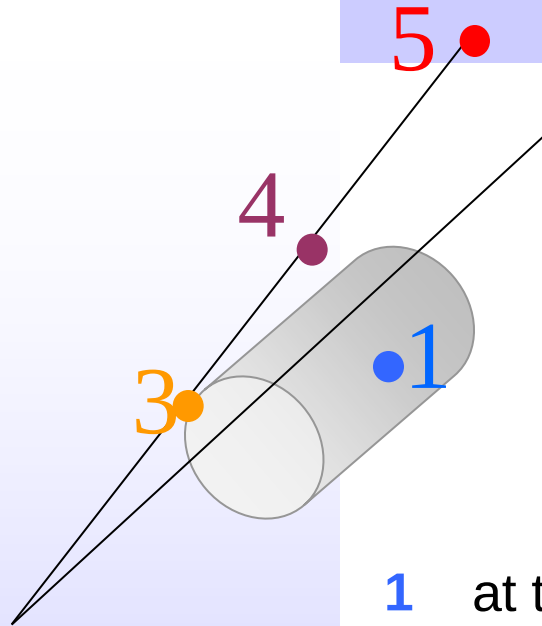


View from above

Side view

Scoping calculations of CO₂ production

Observation nodes

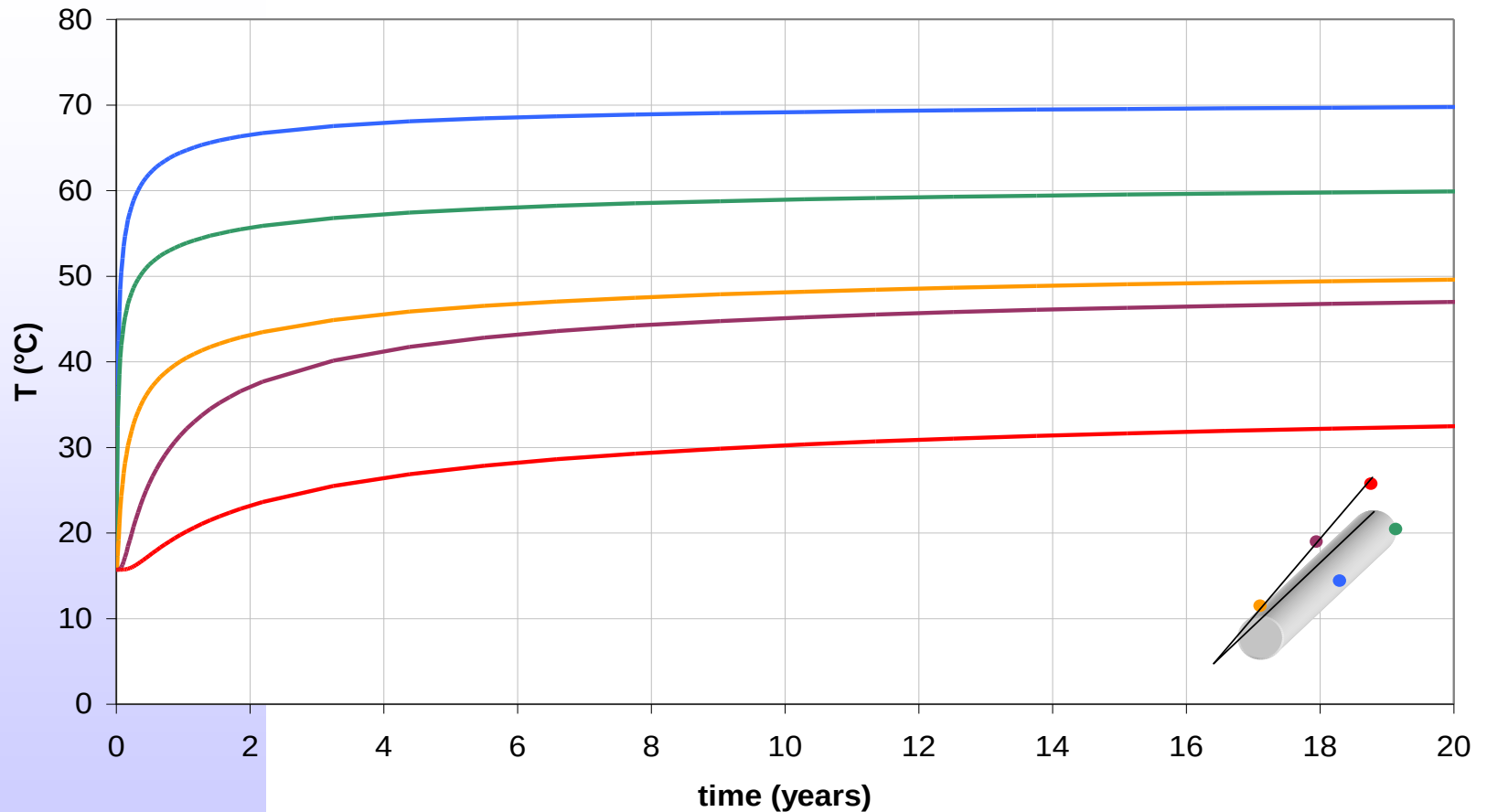


- 1** at the middle of the heater at 0.7 m radial distance
- 2** at the end of the heater at 0.7 m radial distance
- 3** at the beginning of the heater at 1.7 m radial distance
- 4** at the middle of the heater at 4.34 m radial distance
- 5** at the end of the heater at 6.9 m radial distance

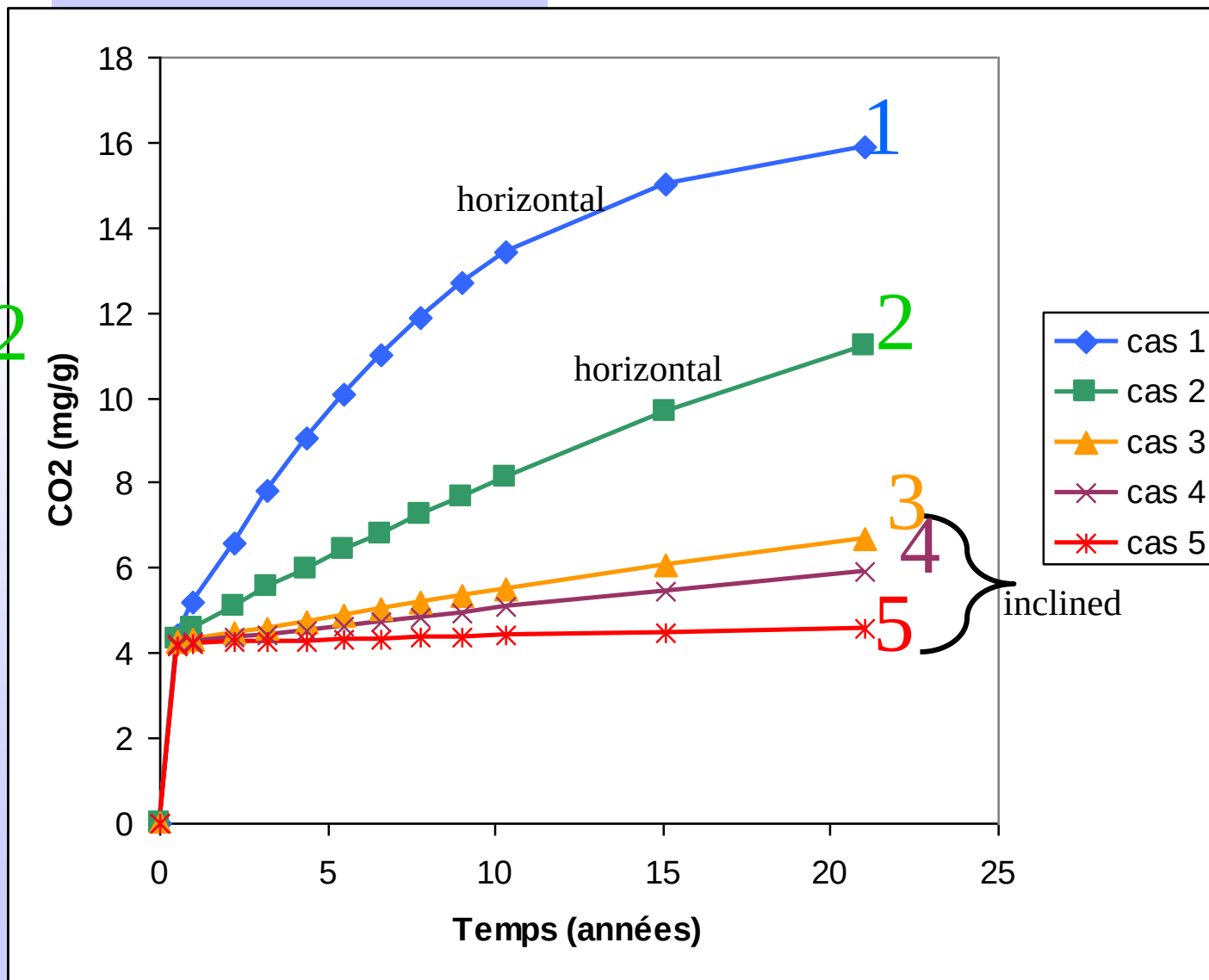
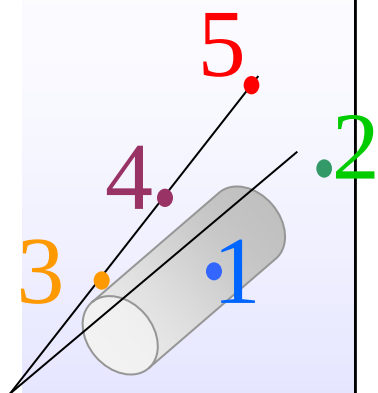
inclination:
10°

Temperature profiles expected at nodes

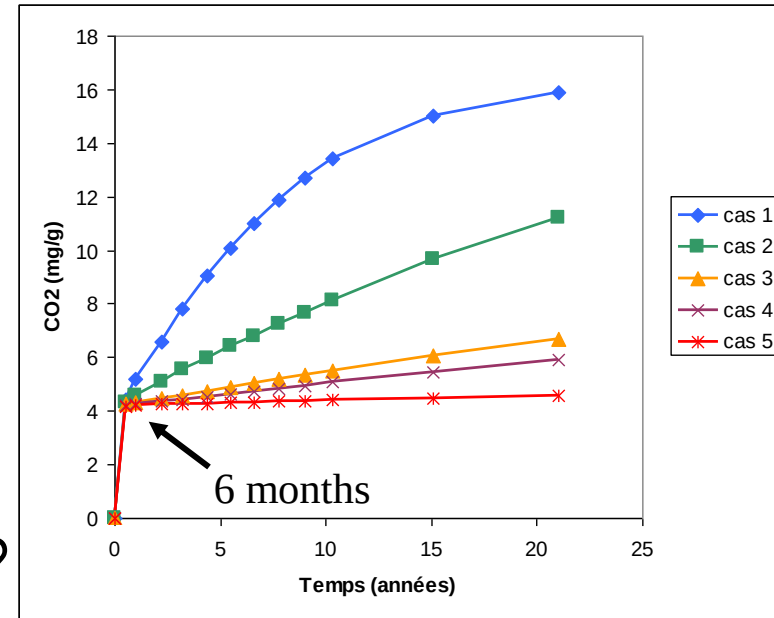
Temperature evolution in monitoring points



Simulated CO₂ production (mg CO₂/g kerogen)

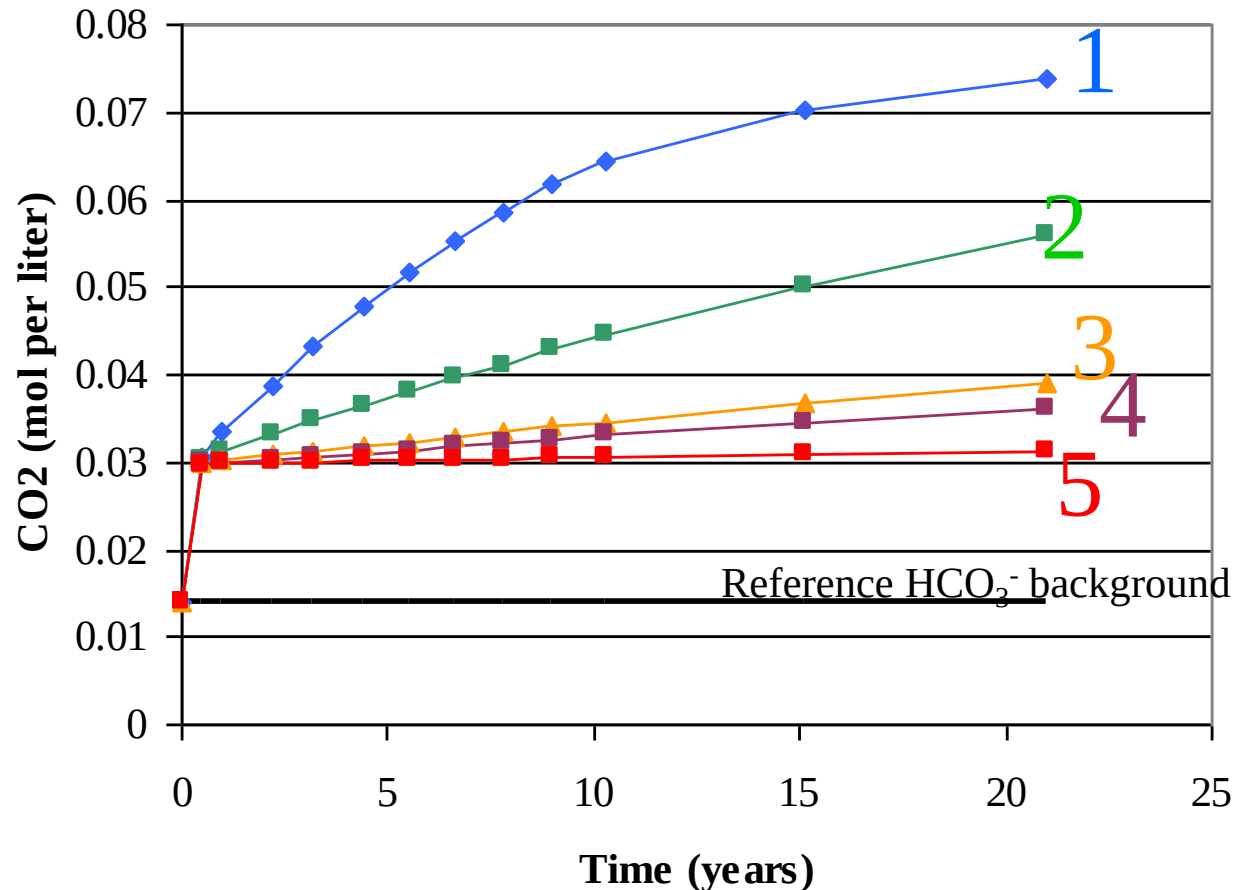


Simulated CO₂ production



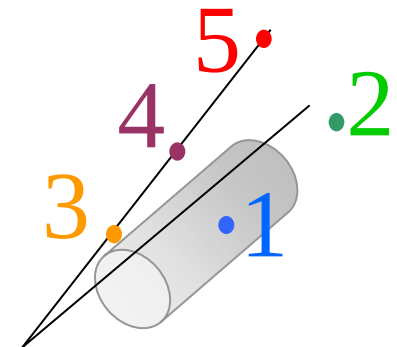
- Important CO₂ production in the first 6 months
 - Not enough experimental data?
 - Related to flash release during pyrolysis?
 - Probably better modelled after long-term experiment
- Continuous CO₂ production increase in horizontal piezometer
- Limited difference in filters of inclined piezometer and hardly any increase after 6 months

Simulated CO₂ concentration in Boom Clay pore water



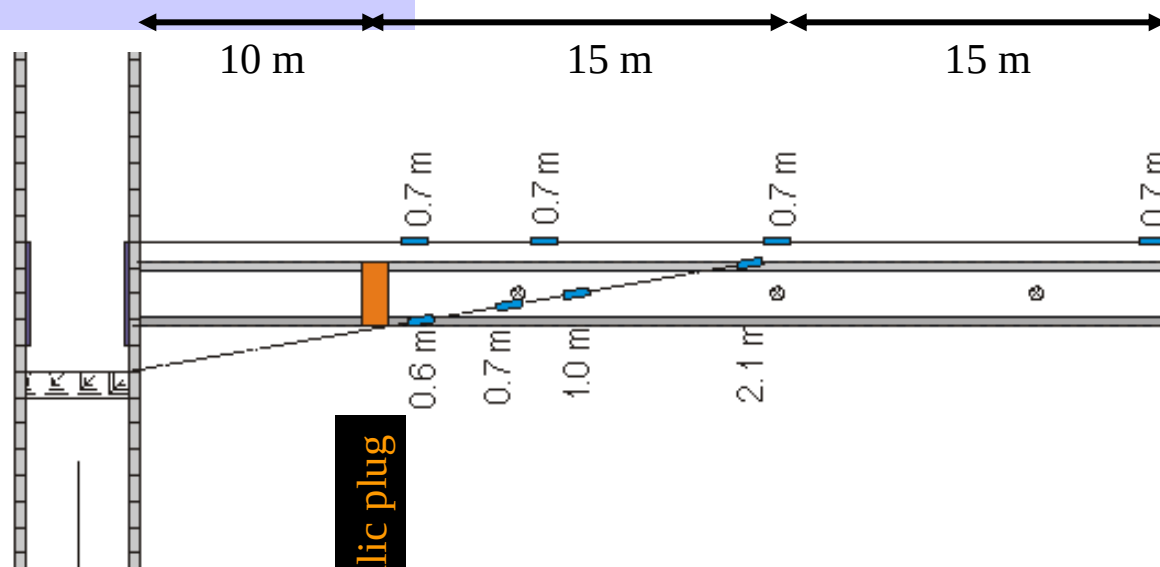
Assumptions

- 3% OM
- Of which 80% kerogen
- All CO₂ dissolved in pore water

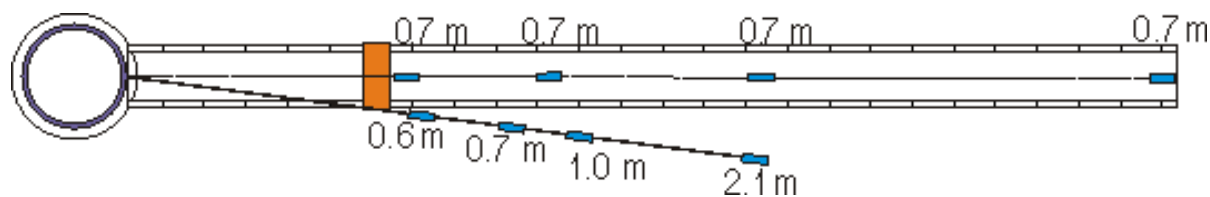


Newly proposed sampling positions

View from above



Side view



Conclusions

- Set-up should allow a follow-up of geochemical perturbations
- CO₂ production expected to be substantial
- CO₂ increase should be measurable around PRACLAY heater test
- Optimisation of filter position is needed

The PRACLAY experiments: context and objectives

F. Bernier

EURIDICE Instrumentation Day

20 September 2004



PRACLAY history

- 1990-2001: Demonstration of a well defined reference design for vitrified HLW (SAFIR 2)
- 2002-2004: Review of the design
 - 3 alternative designs (SC, borehole, sleeve)
- 2003-now: Generic experiments
 - THM/C behaviour of the host rock at large scale
 - some components of the system (crossing, lining, horizontal plug, backfill)
 - demonstration and scientific goal

PRACLAY has to reply to the following question:

- Is the Boom Clay suitable, in terms of performance of the disposal system, to undergo the thermal load induced by the vitrified HLW?

⇒ Important milestone for the disposal strategy

PRACLAY has to overcome some uncertainties

- What will be the disposal sequence?
- Horizontal plug or not?
- Saturation degree of the system before the installation of the waste?
- Alternative designs not fully fixed and will still evolve before 2050

⇒ PRACLAY has to be independant of the design

PRACLAY has some limits

- Short heating period (~10 years) compared with a real repository
- Different boundary conditions
- Different heat source
- No radioactive source
-

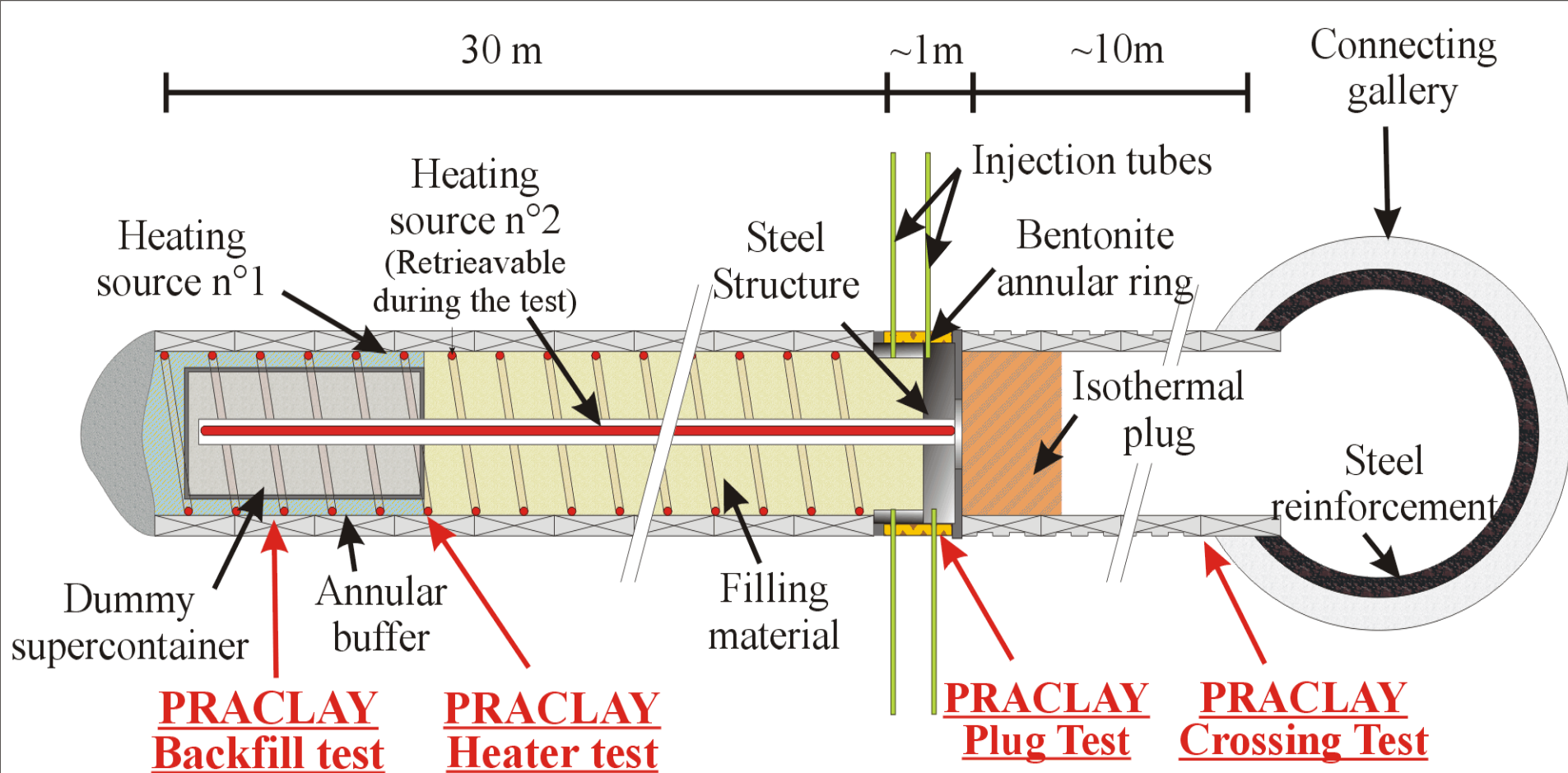
⇒ PRACLAY will reproduce in a conservative way the most critical state and phenomena that could occur in the host rock

PRACLAY is designed to fit the most penalizing conditions

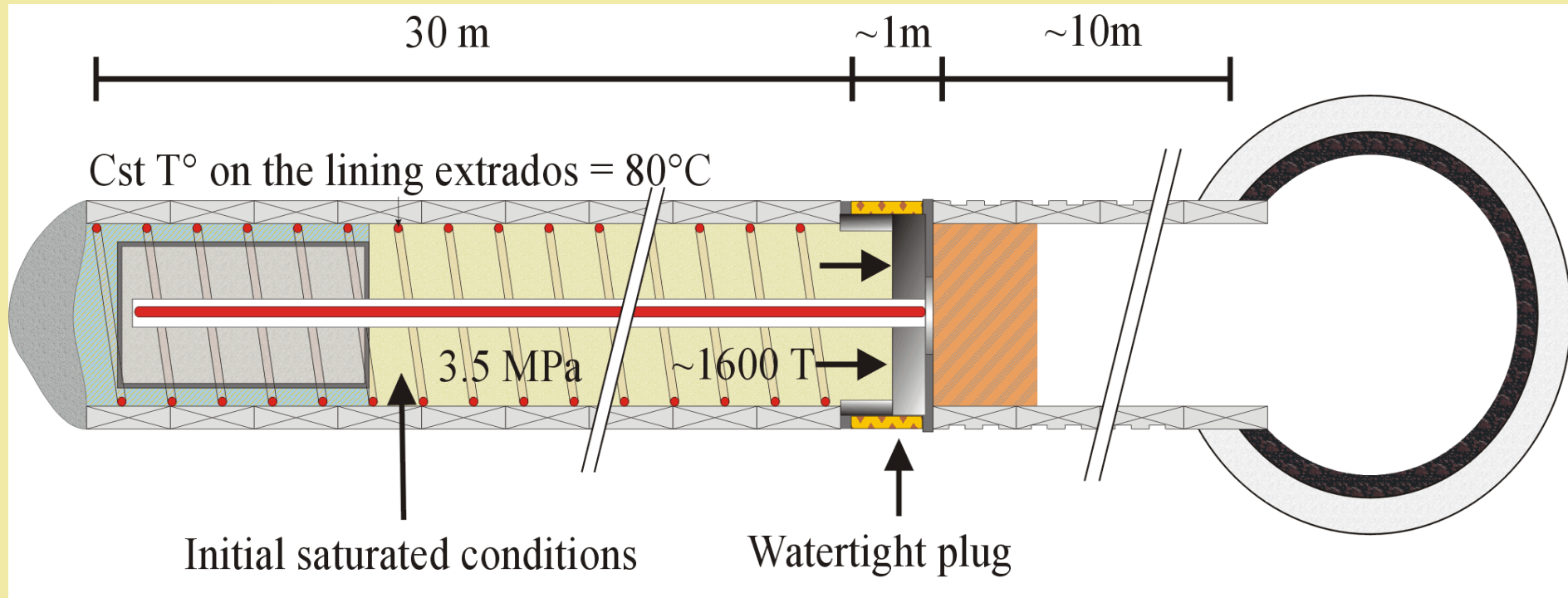
- Small period between the excavation and the installation of the experiment
- Undrained conditions
- Saturated conditions before the heating phase
- About 10°C above the maximum temperature expected in B.C. in real disposal conditions

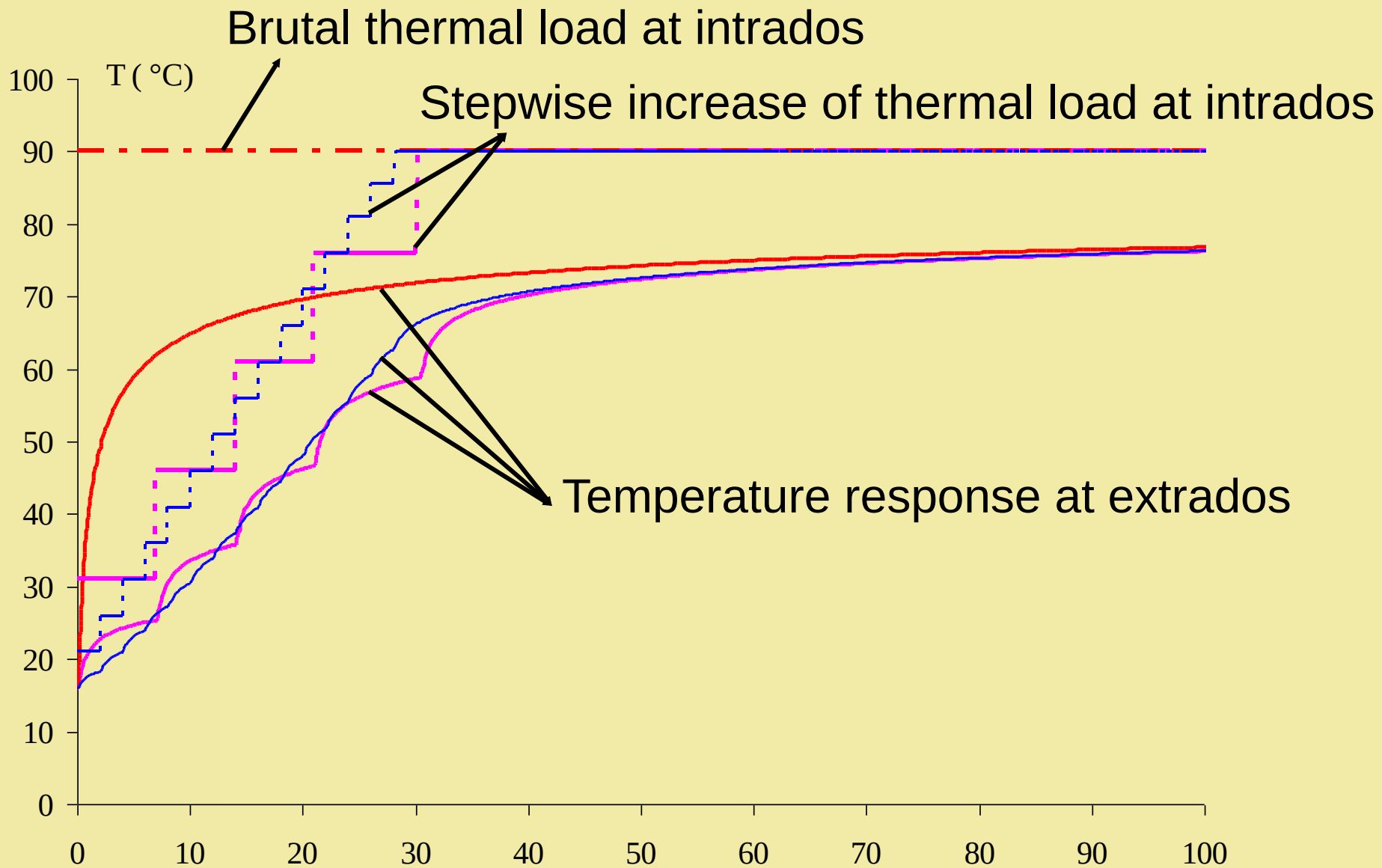
⇒ PRACLAY will be representative for all design respecting the temperature criterium:
100°C max. in the EB and BC

The PRACLAY experiments

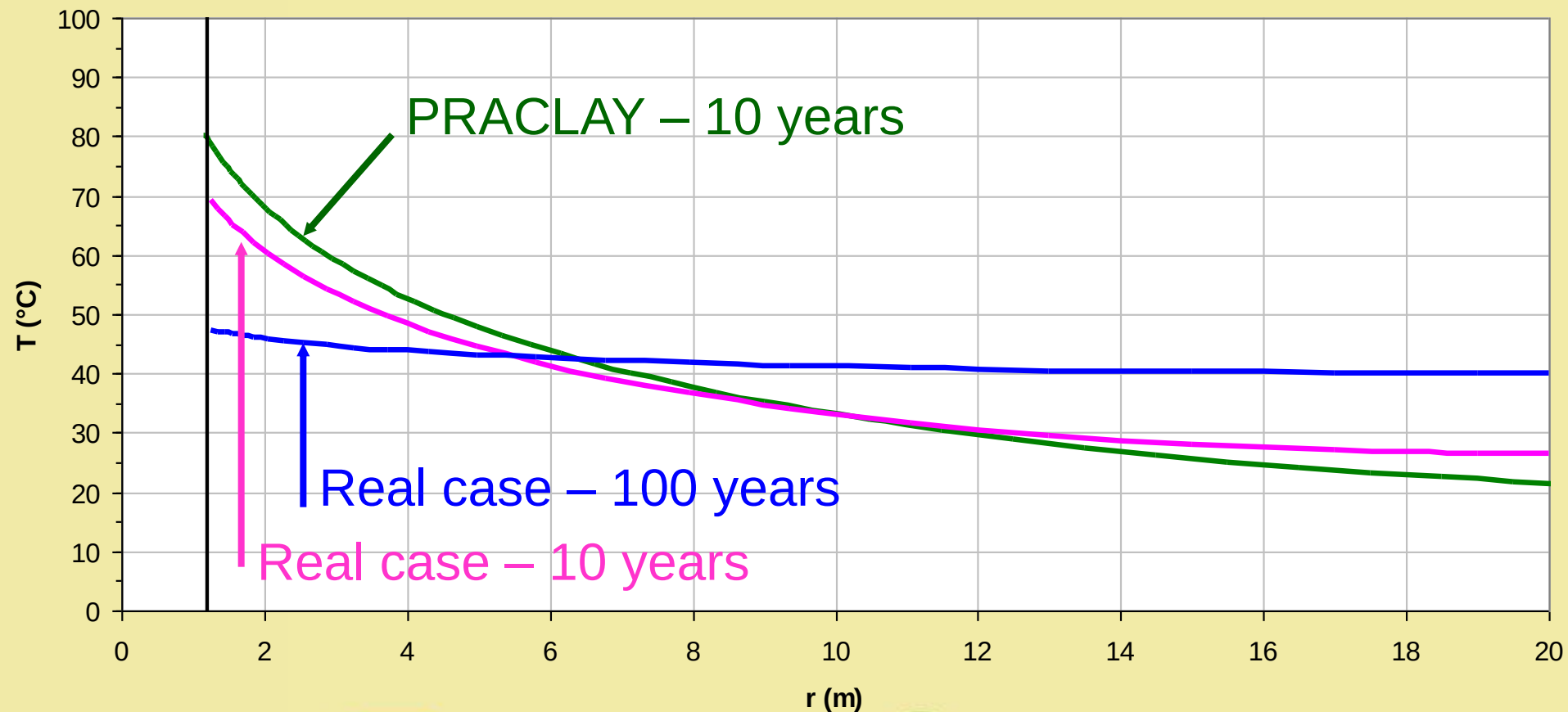


The initial and the boundary conditions

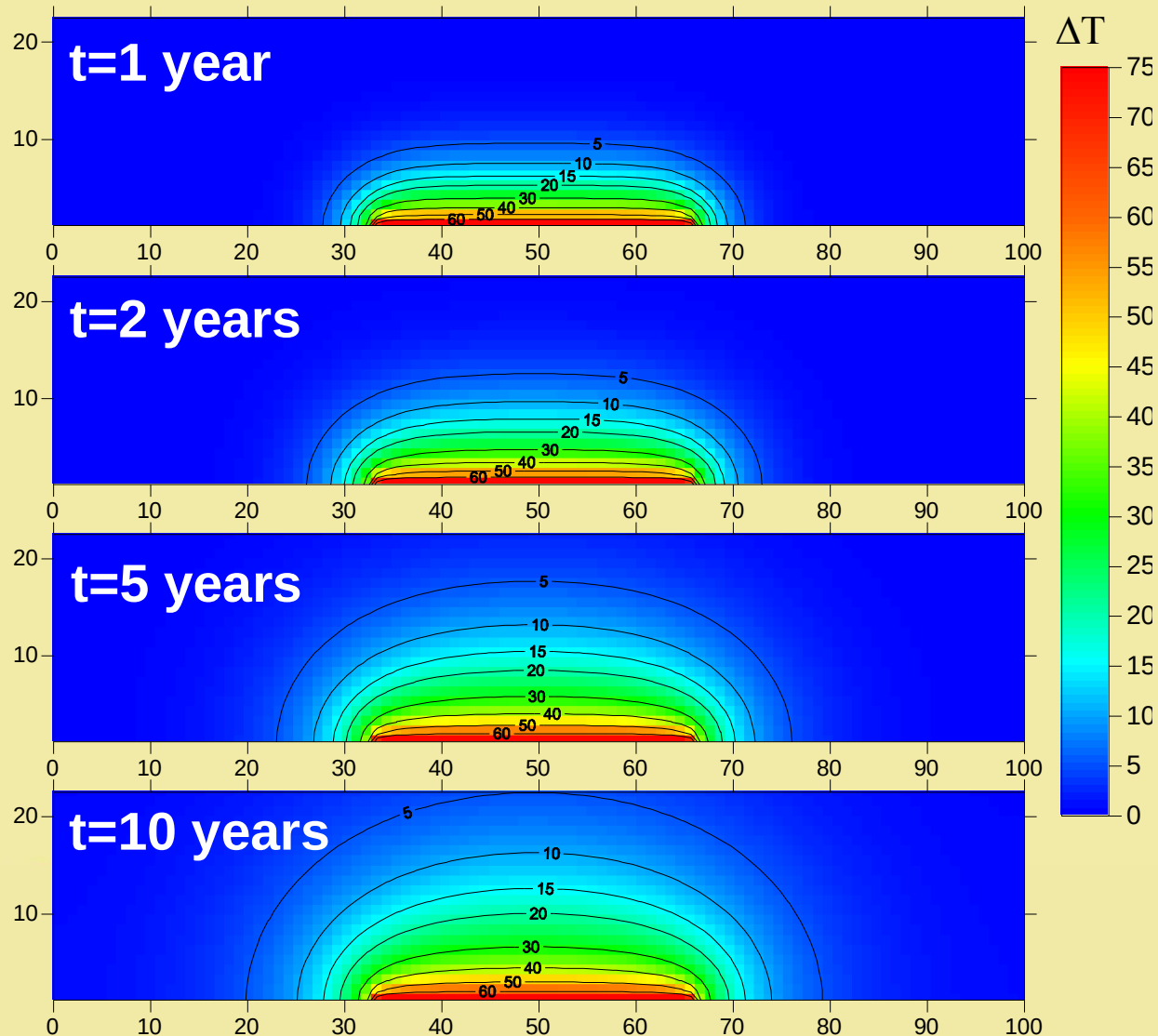




Temperature profile: Comparison PRACLAY – Real case



Isotherms around the heater are representative in the central part



Main objectives of the PRACLAY experiments

- Configuration similar to a real repository
- Combined effect of the EDZ and the TDZ
- Effect of the thermal load on the stability of the lining (retrievability)
- Assessment of our knowledge level of the THM/C behaviour of Boom Clay
- No radionuclide migration experiment
- Feedback analysis

Planing

- General design 2004
- Characterisation programme 2005-2008
- Construction of the PRACLAY gallery and installation of tests 2007
- Start of the heat phase 2008
- Preliminary conclusions 2013
- Start of the cooling phase 2019

Long time span of the project: ~20 Y

- Robust design
 - experiments layout
 - instrumentation
- Sufficient flexibility
- Levelling and integration of the different research aspects: modelling, scientific results and demonstration target
- Integration of the research from different disciplines and overcoming the typical slang and the different background
- Importance of knowledge management

Thank to:

- Weetjens Eef, Xavier Sillen and Xiang Ling Li for the modelling results



THM scoping calculations and instrumentation lay-out

from model to the field

EURIDICE Instrumentation Day

Jan Verstricht, Xiang Ling Li

20 September 2004



ESV EURIDICE GIE

Outline

- processes and phenomena
- modelling approach
- scoping calculations and results
- main conclusions / questions
- instrumentation lay-out
- planning



Processes / phenomena in host rock

- gallery excavation
 - HM disturbance of host rock
 - evolution pore pressure as function of time and distance
 - total stress & fracturing
 - displacements (convergence)
 - geochemical (oxidation of pyrite and organic matter)
- heating phase
 - THM evolution
 - pressures, stresses, displacements (expansion)
 - geochemical (CO₂ production, pH evolution, ion exchanges)



Processes / phenomena in/on gallery lining

- gallery excavation
 - build-up of external/internal stress
 - special attention to crossing
 - and response (large-scale deformations)
 - hydraulic disturbances (desaturation, suction,...)
- heating phase
 - heat flux – temperature distribution (source term)
 - stress evolution (increase)
 - axial expansion / uplift



Processes / phenomena in/on gallery plug

- performance of the gallery plug as a mechanical and hydrological barrier.
 - hydration and swelling of bentonite;
 - deformation of steel structures;
 - global displacements of plug structure;
 - performance (hydraulic isolation function).

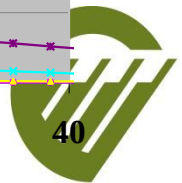
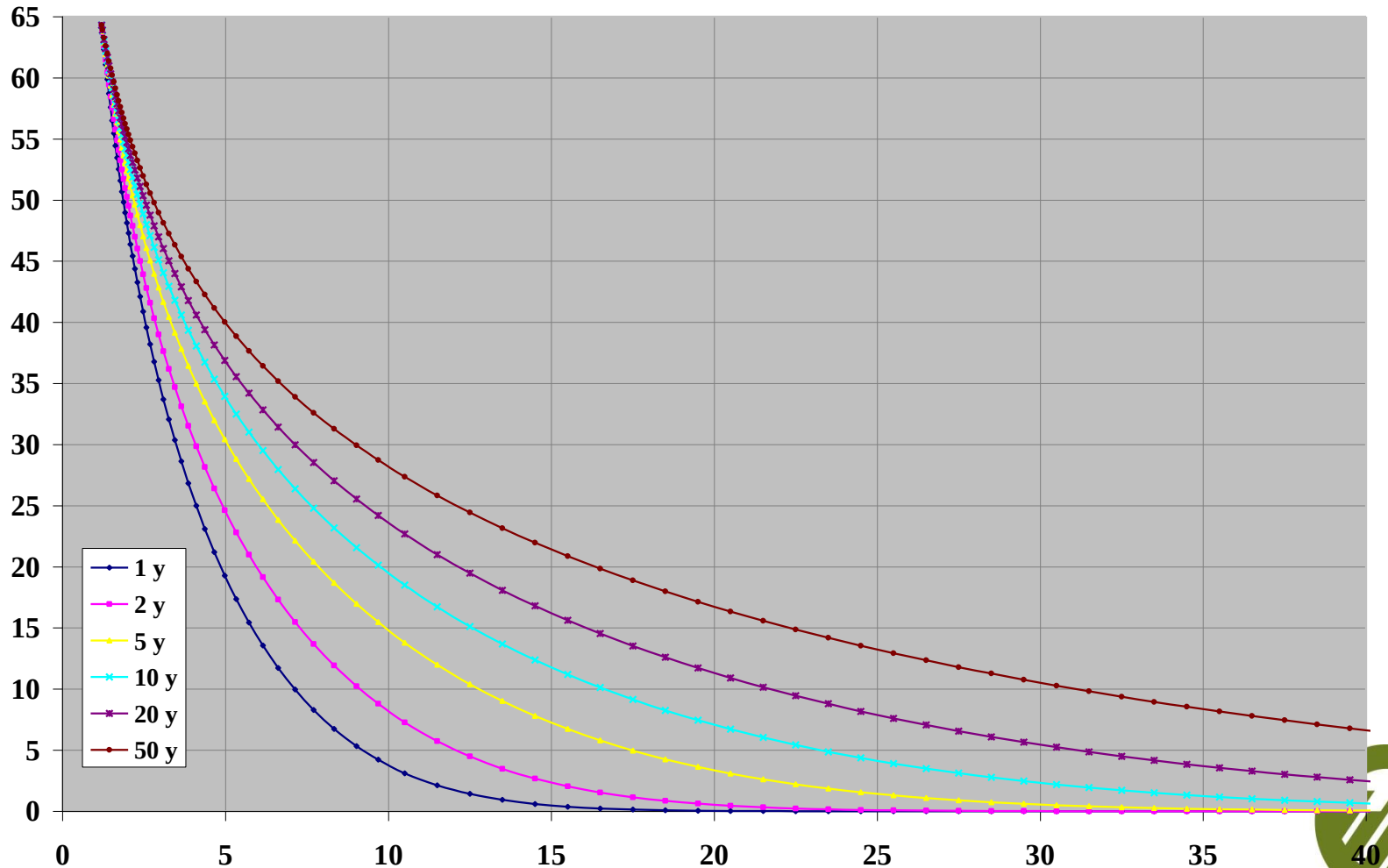


Modelling Results

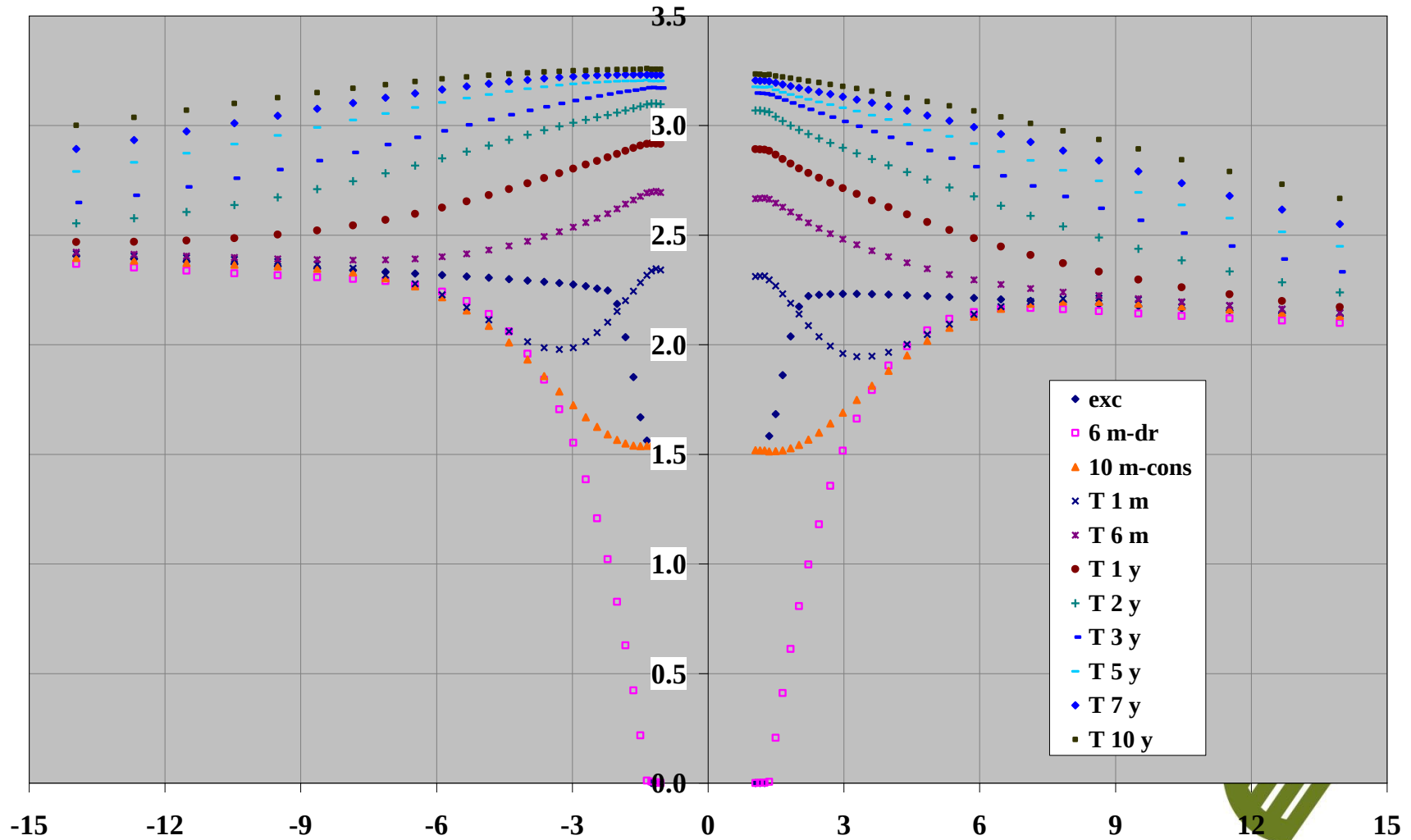
- hypotheses
 - gallery excavation/lining, followed by
 - 6 months drained,
 - 4 months undrained at ambient temperature
 - heating
 - constant temp 80 °C at gallery extrados
 - during 10 years
 - cooling ?



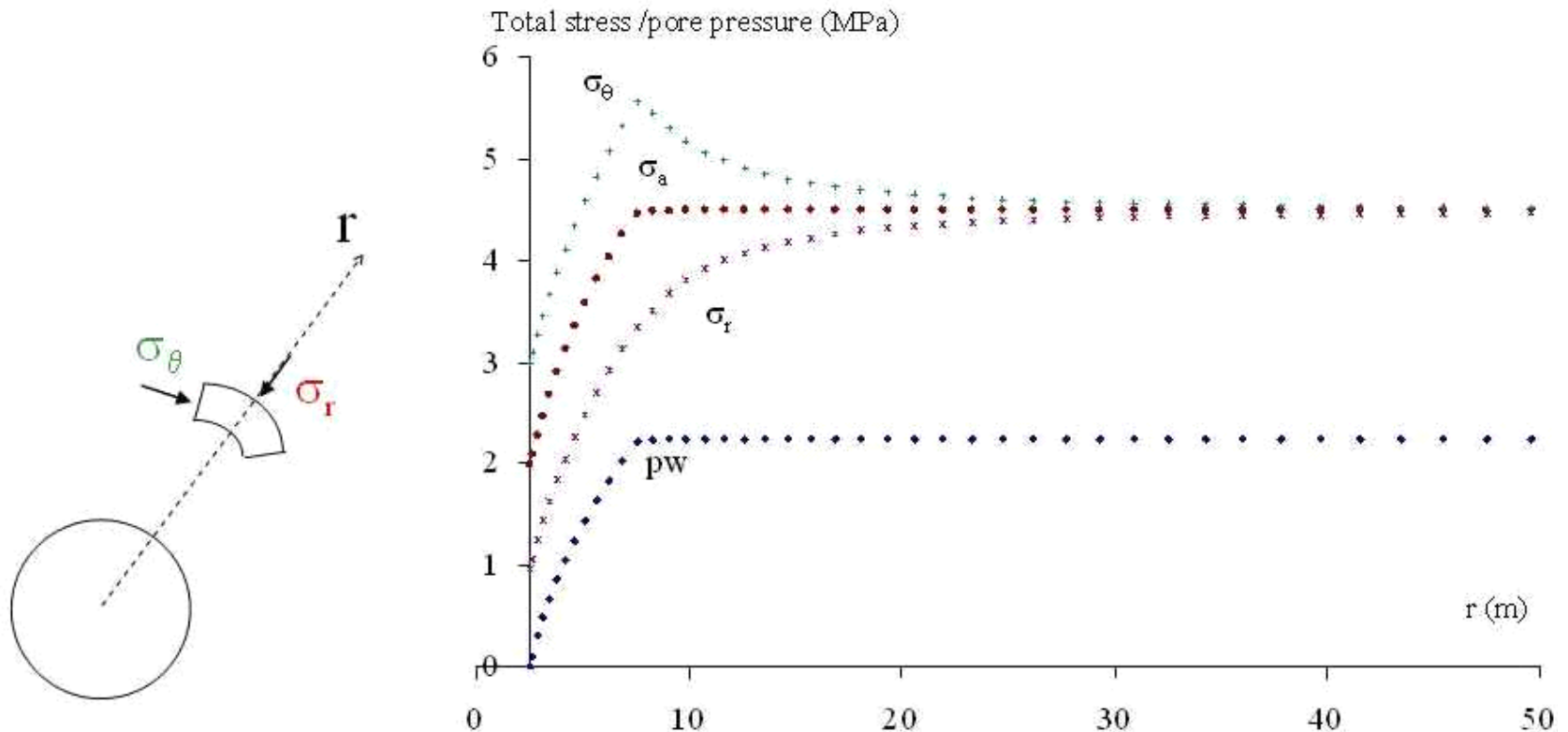
Temperature increase = $f(r)$



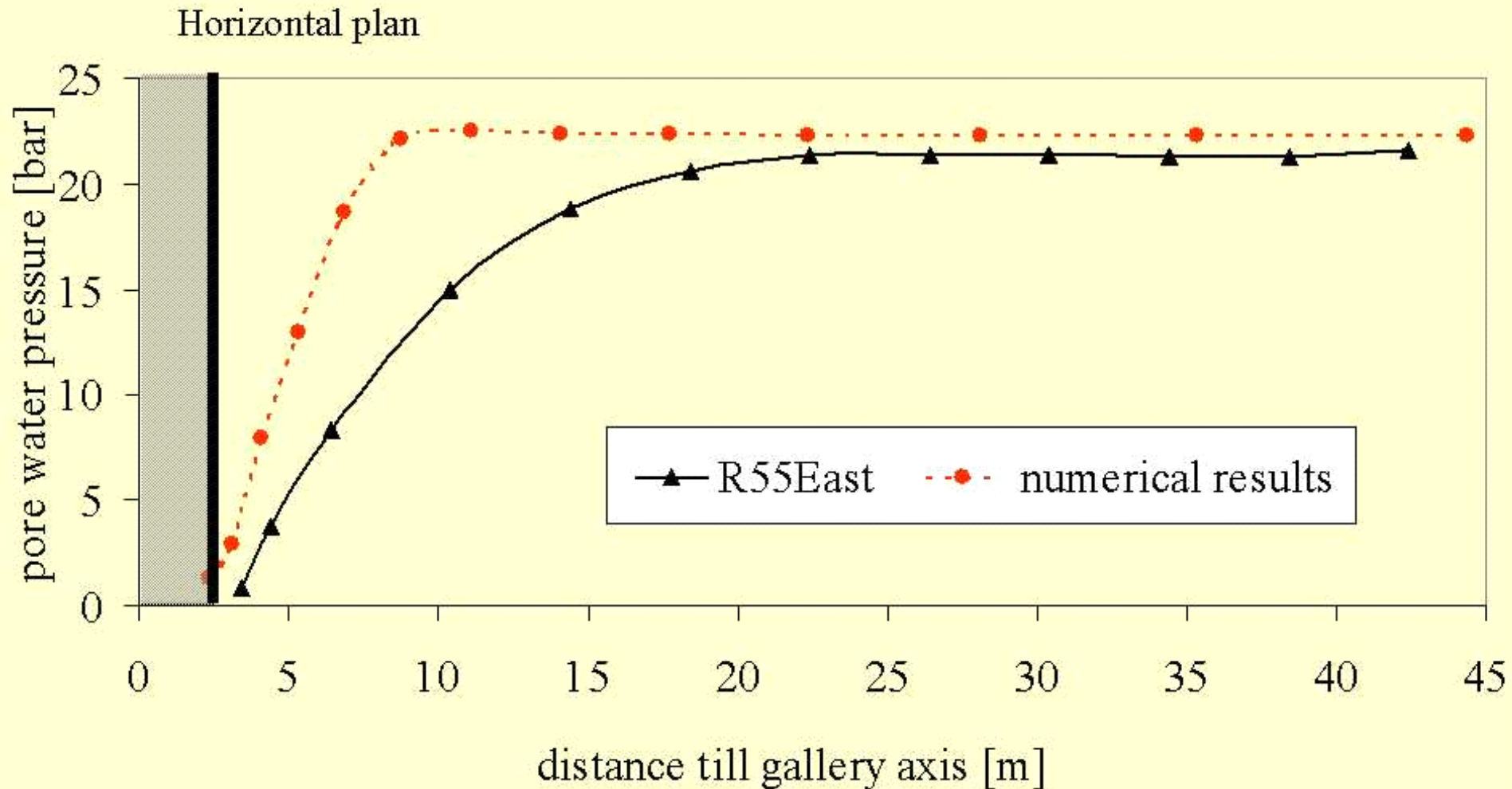
Porewater pressure = f(depth)



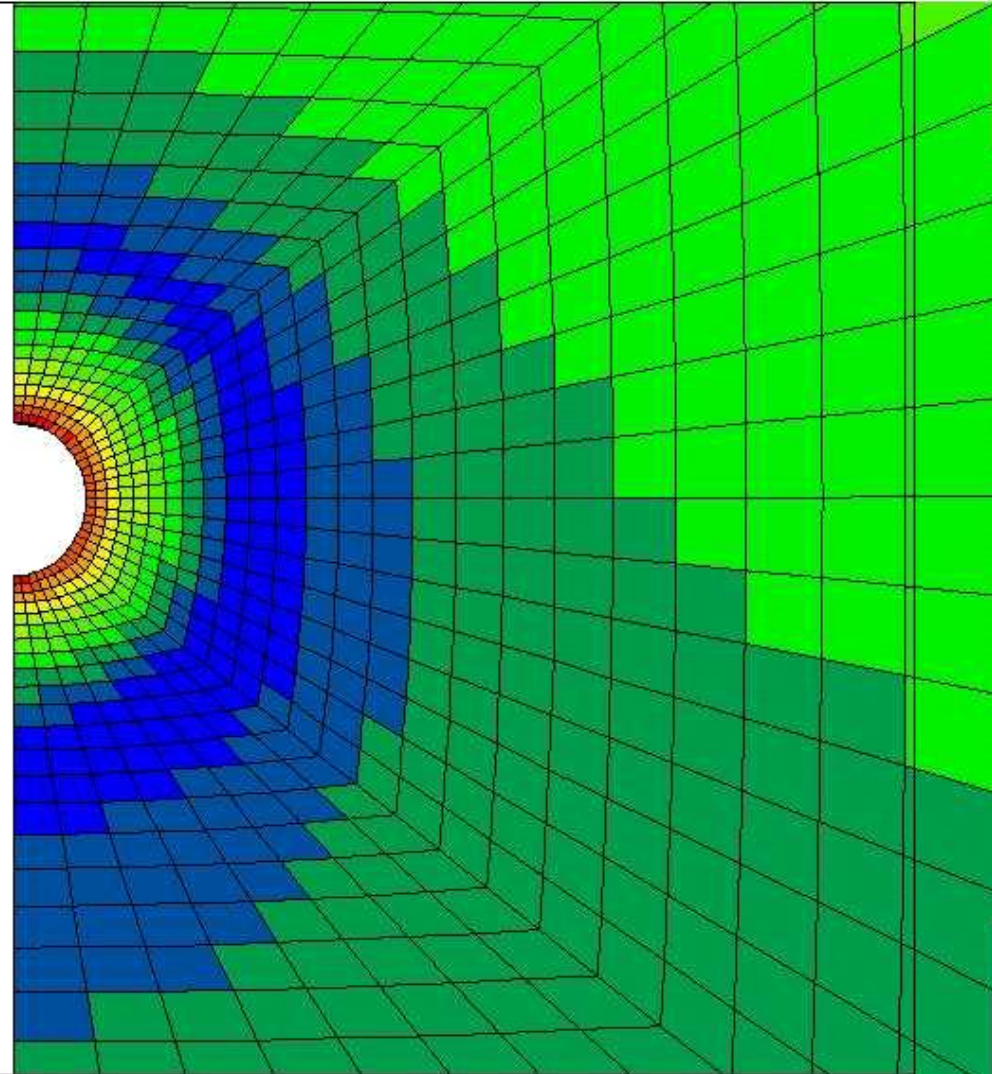
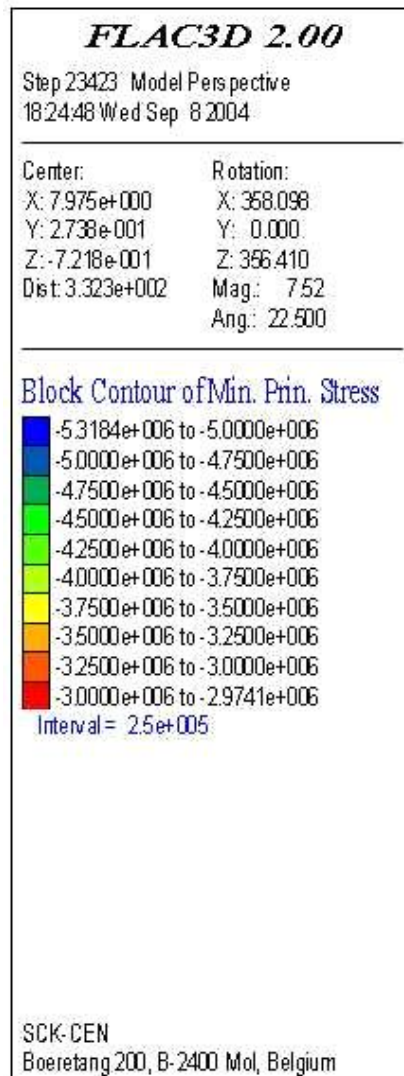
Limited extent of disturbance predicted



Observed affected zone is larger



maximum tangential stress about 4 m from gallery wall



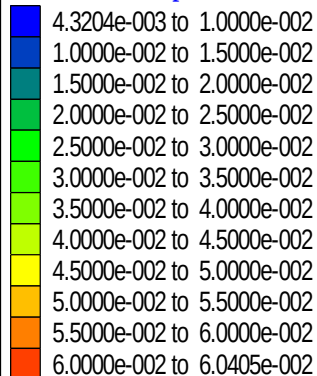
Six to seven cm convergence at gallery wall

FLAC3D 2.00

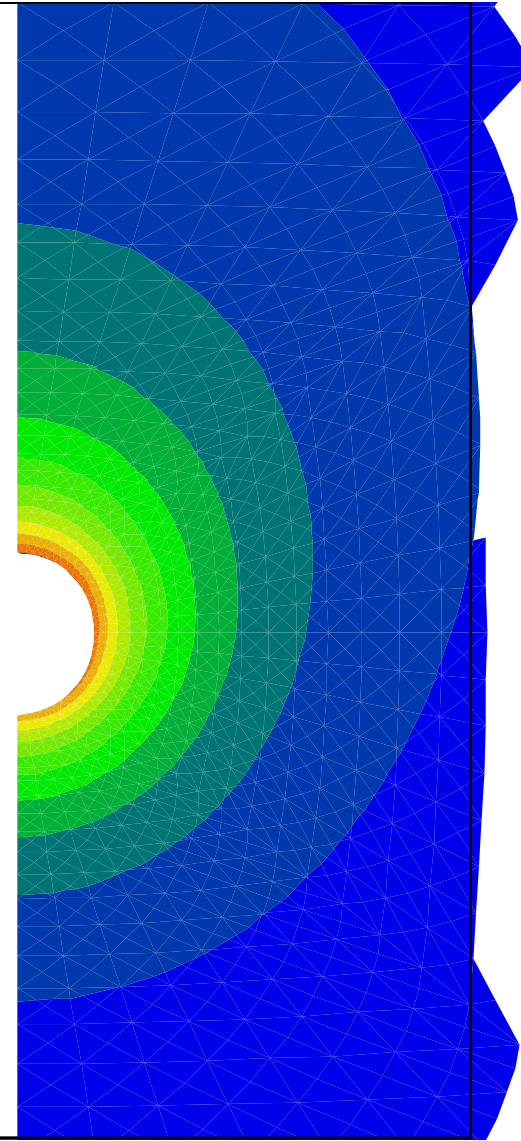
Step 23423 Model Perspective
18:35:39 Wed Sep 8 2004

Center:	Rotation:
X: -7.987e-001	X: 358.098
Y: -3.352e-001	Y: 0.000
Z: 1.036e+000	Z: 356.410
Dist: 3.323e+002	Mag.: 7.52
	Ang.: 22.500

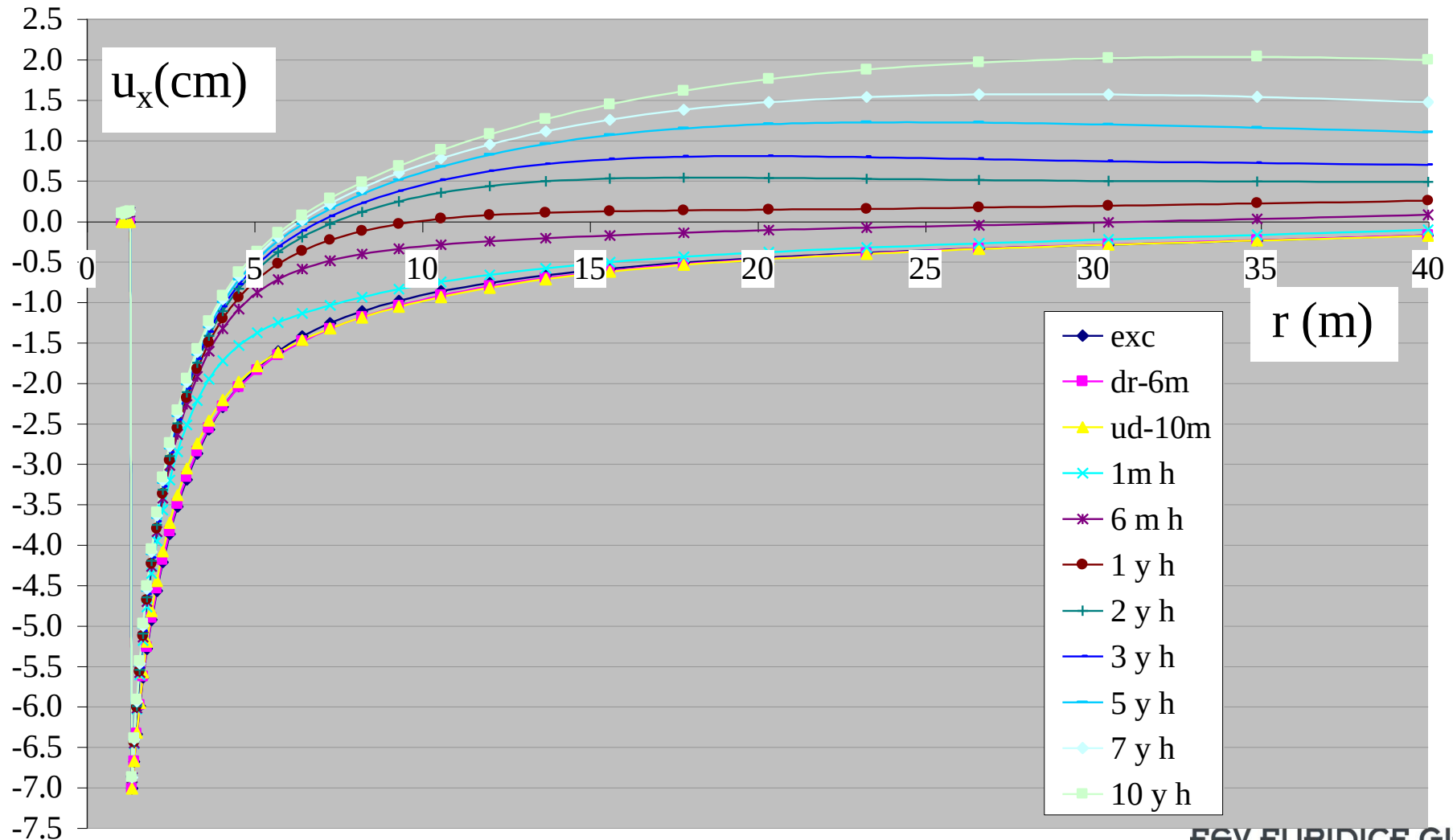
Contour of Displacement Mag.



Interval = 5.0e-003



Displacement = f(depth)



Main conclusions from the model predictions

- validation / backanalysis of model parameters
 - magnitude
 - temperature influence
- zones to be monitored
 - large gradients expected around hydraulic plug and crossing
 - total stress : maximum expected between 10 and 15 m
- measurement ranges for sensors
- optimisation of gallery lining
 - validation of dimensioning

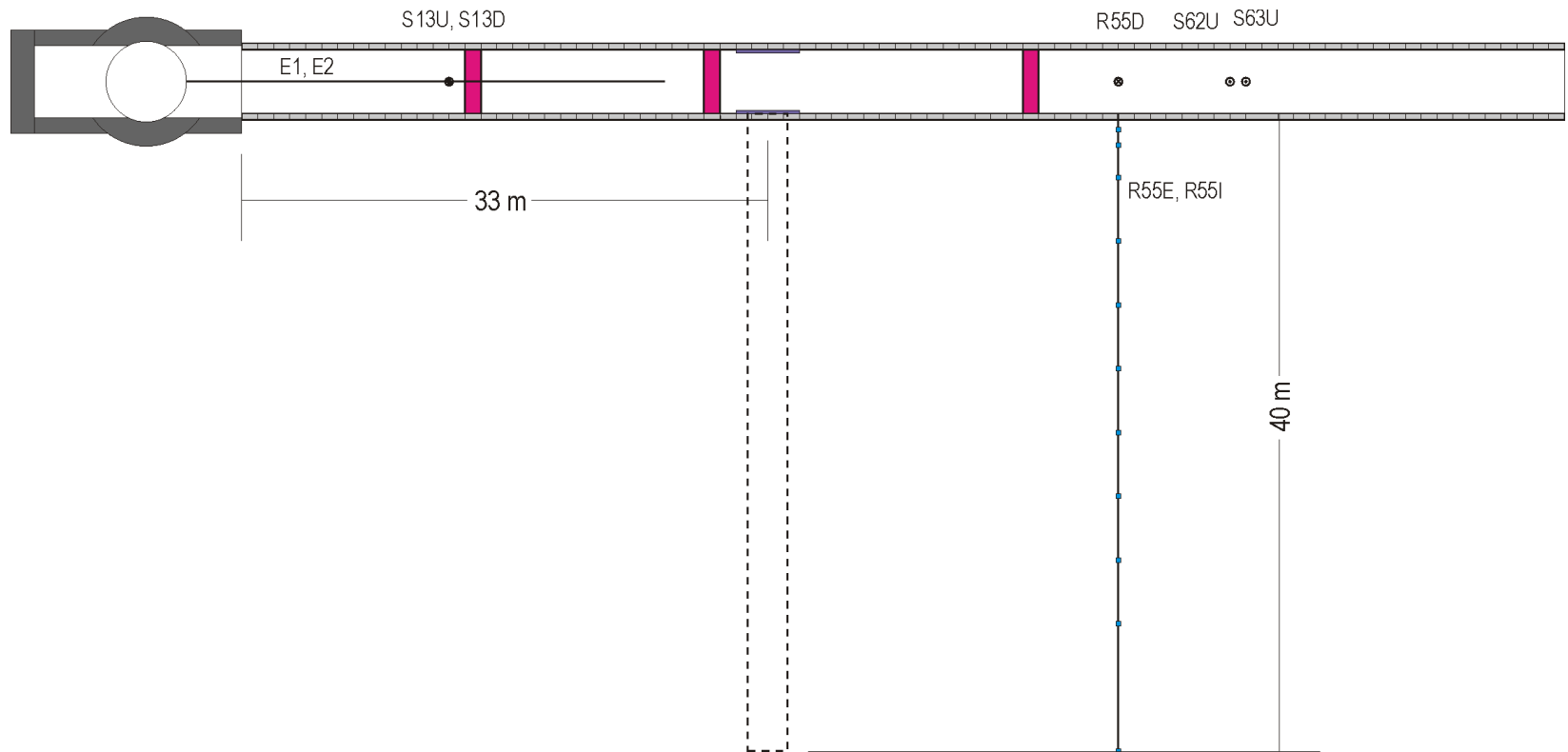


Instrumentation lay-out : design considerations

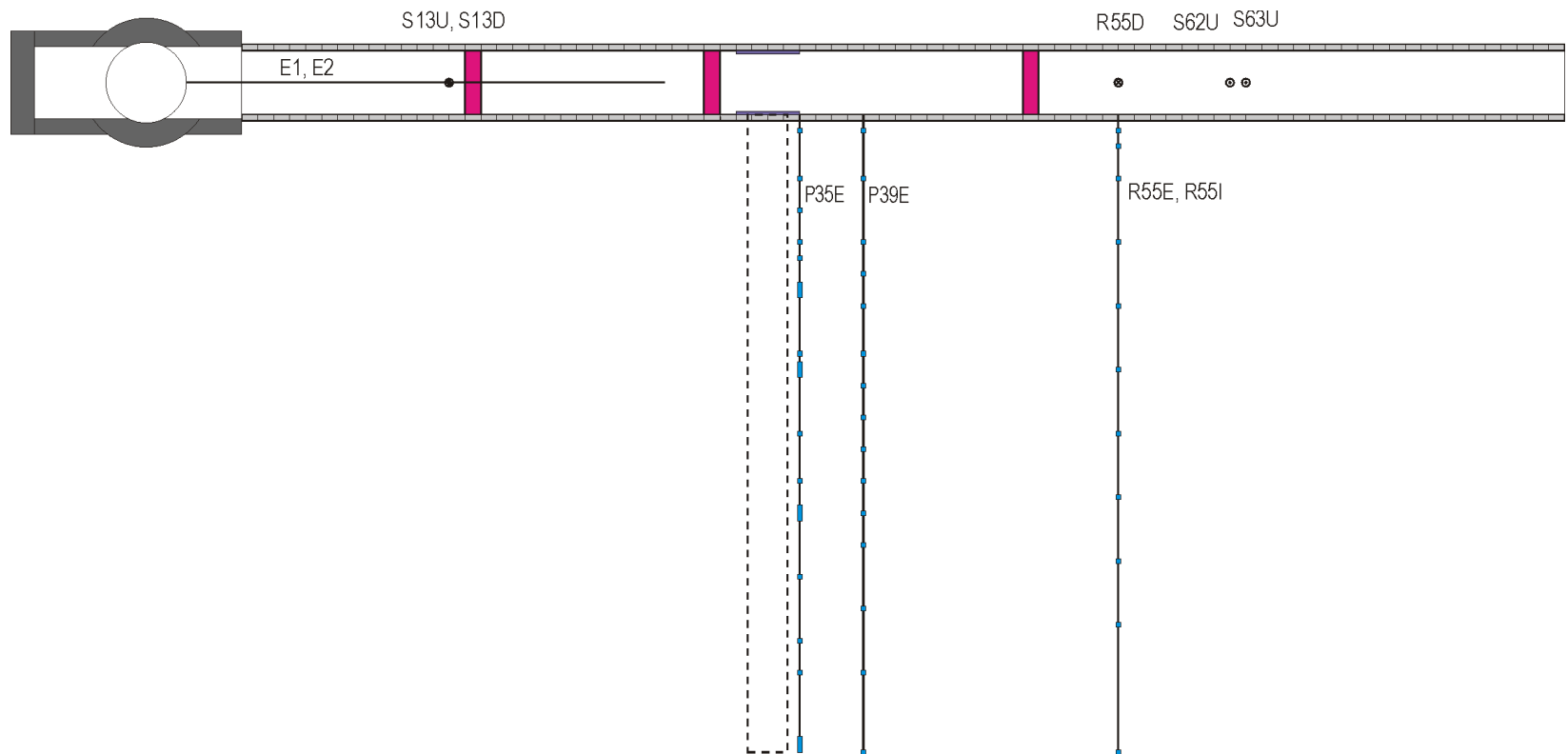
- Available sensor techniques
 - long-term reliability is principal factor
 - cf. next presentation
- Installation opportunities
 - drillholes from connecting gallery
 - drillholes from PRACLAY gallery
 - integration in structural and experimental set-ups
 - drillhole from surface
- Existing instrumentation



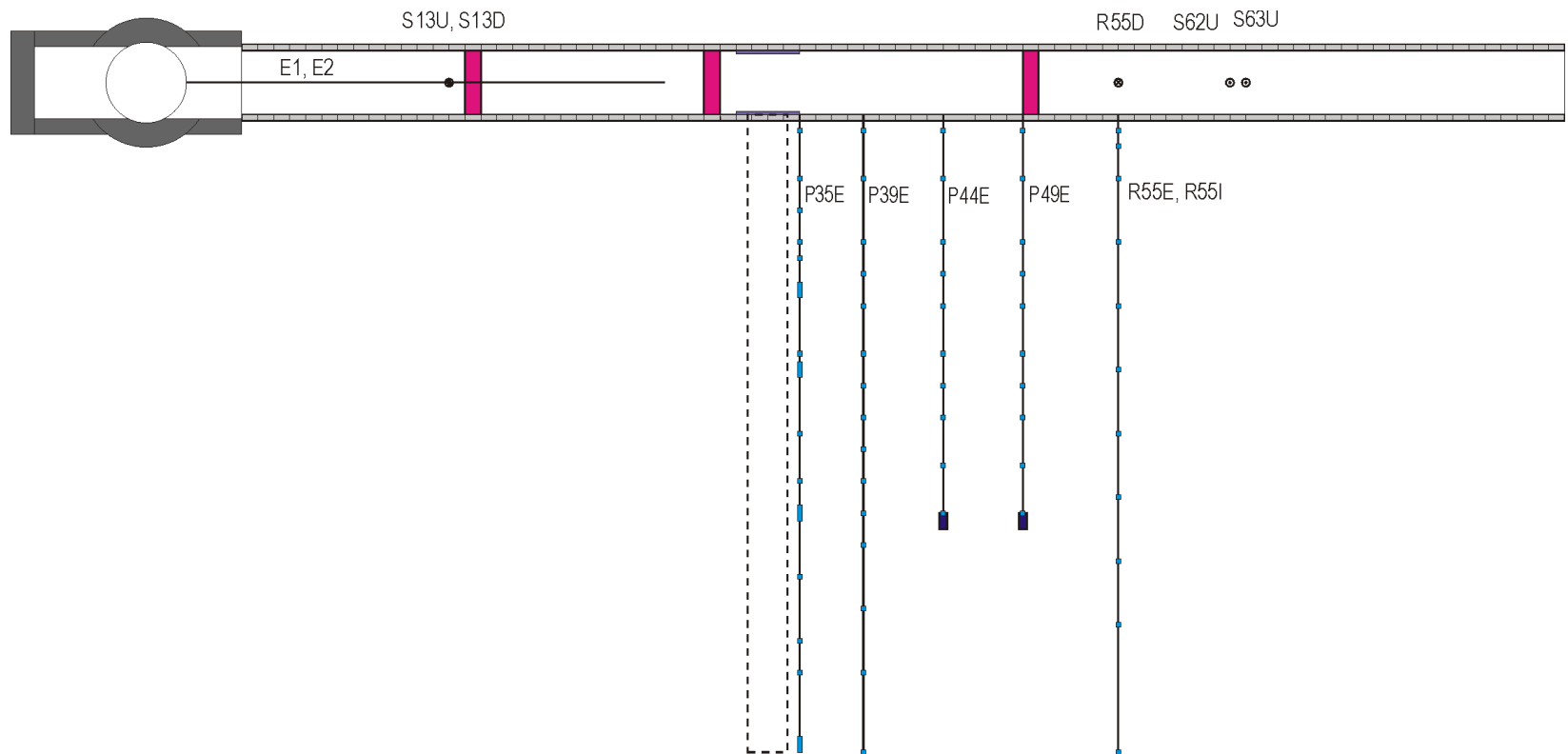
Current configuration (plan view)



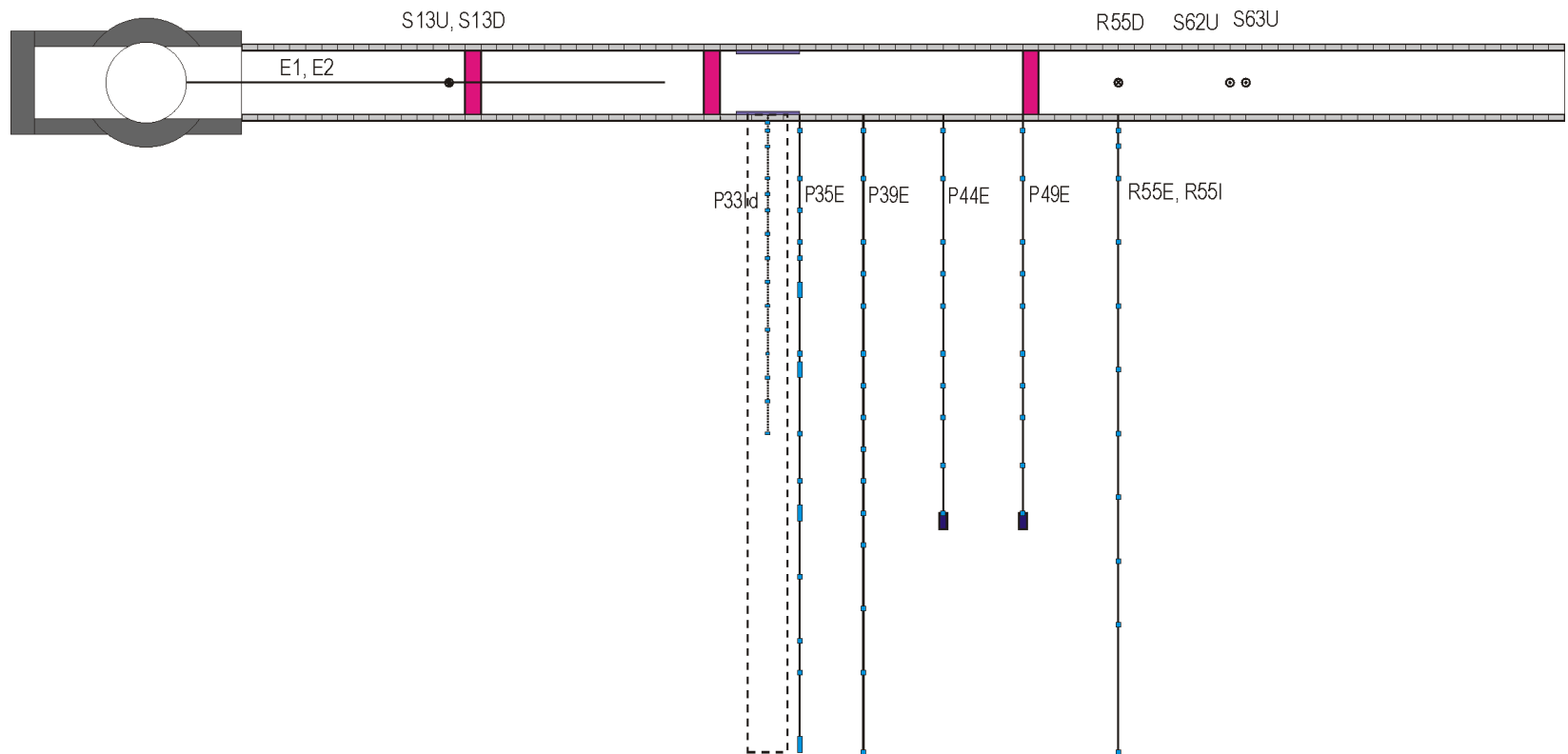
40 m long boreholes from CG



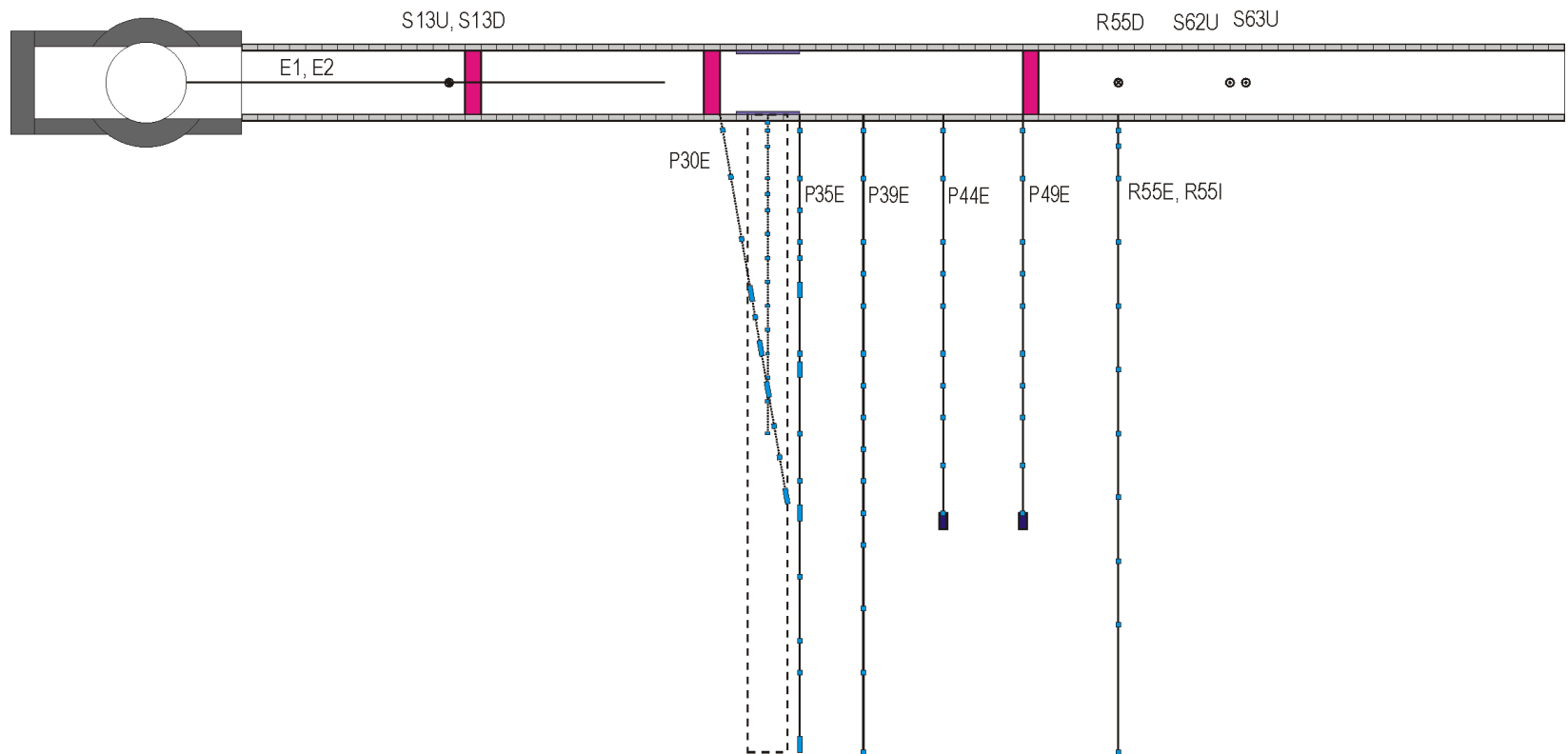
Two short (25 m) boreholes with stressmeter



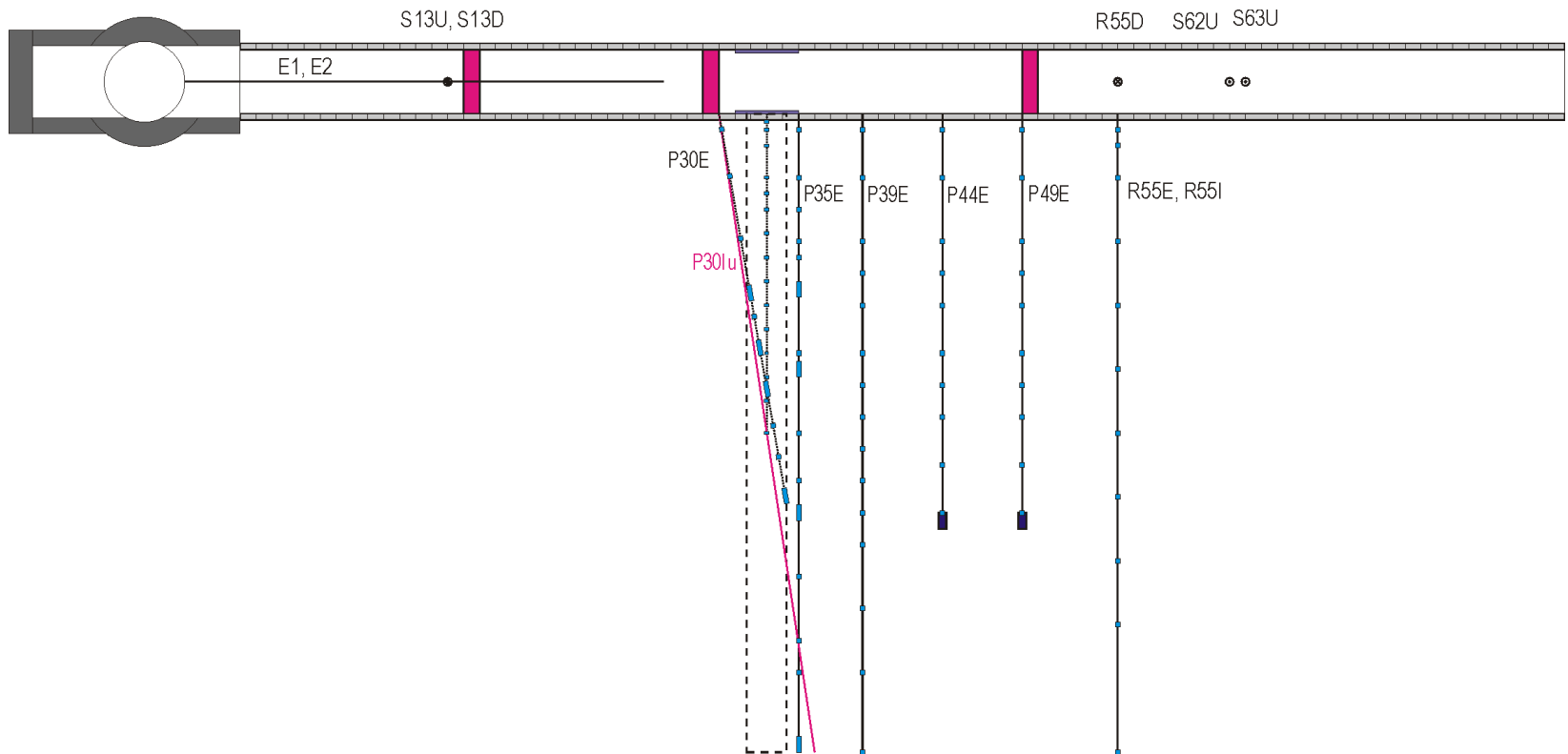
inclined multipiezometer (45° down)



Piezometer underneath PG



Inclinometer above PG

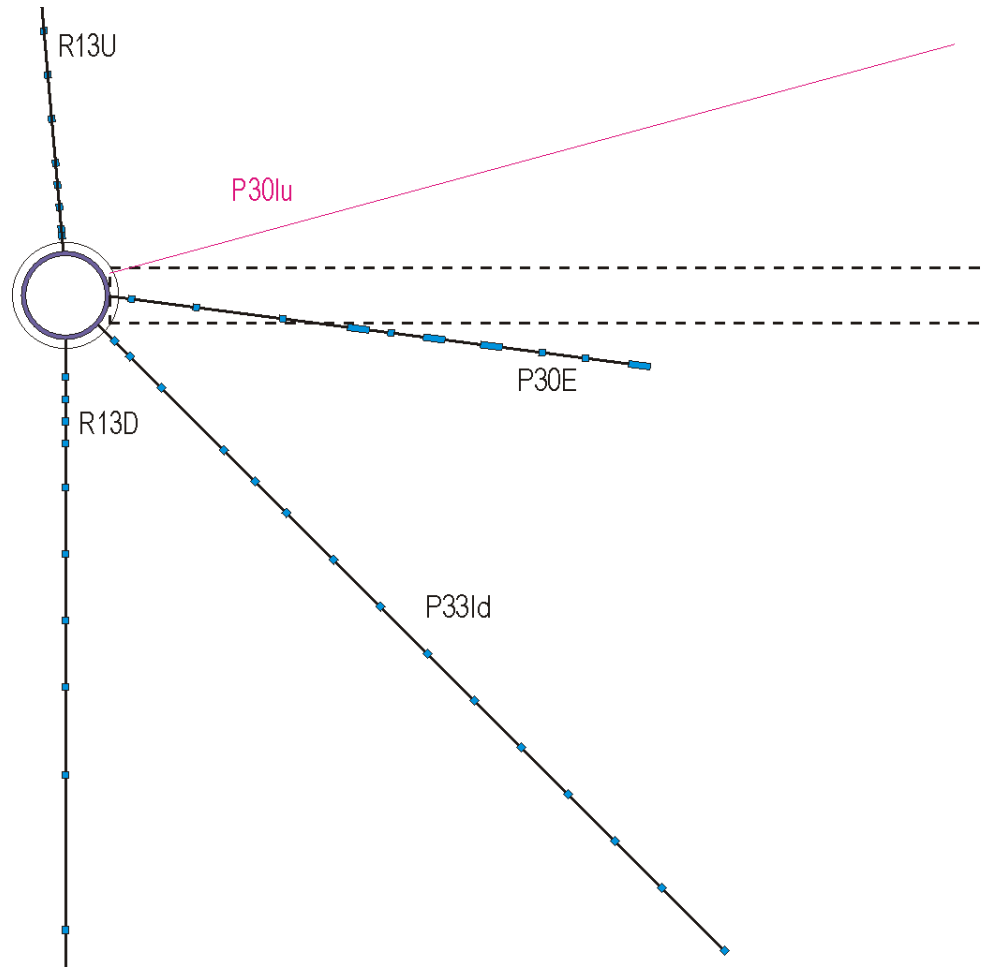


Boreholes from Connecting Gallery

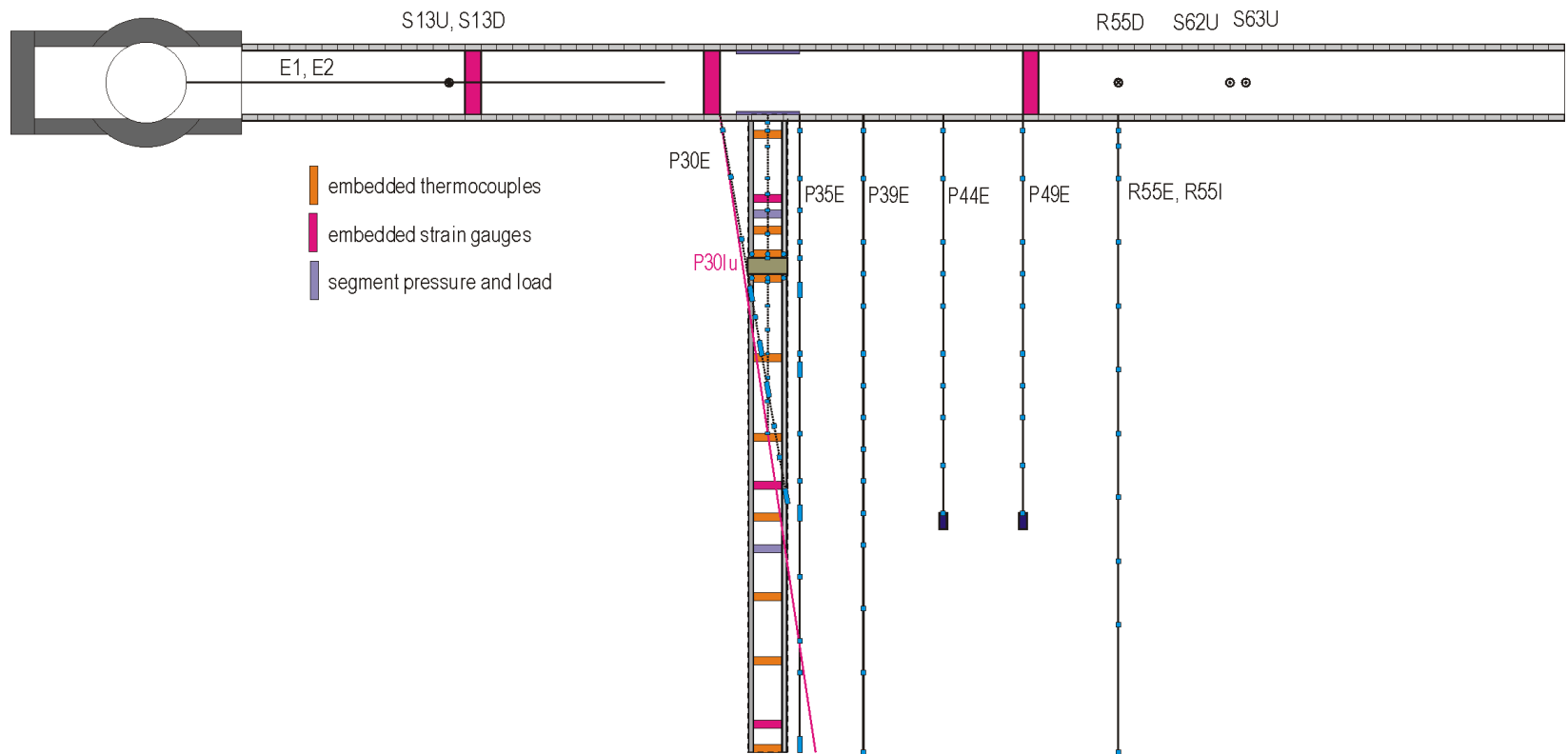
- 2 multipiezometers inclined
 - 45° inclination under gallery (P33Id), 40 m deep, 15 filters
 - slight inclination close under gallery (P30E), 25 m deep, 10 filters
- 4 multipiezometers parallel with test-gallery
 - at 0.7 m (P35E) from lining: 40 m deep, 15 filters
 - at 5 m (P39E) : 40 m deep, 15 filters
 - at 10 m (P44E) : 25 m deep, 10 filters
 - at 15 m (P49E) : 25 m deep, 10 filters
- 1 inclinometer above gallery
 - 15° inclination, 40 m deep borehole
- optional: geophysical boreholes
- gallery axis: extensometer plots



Vertical plane



Gallery instrumentation

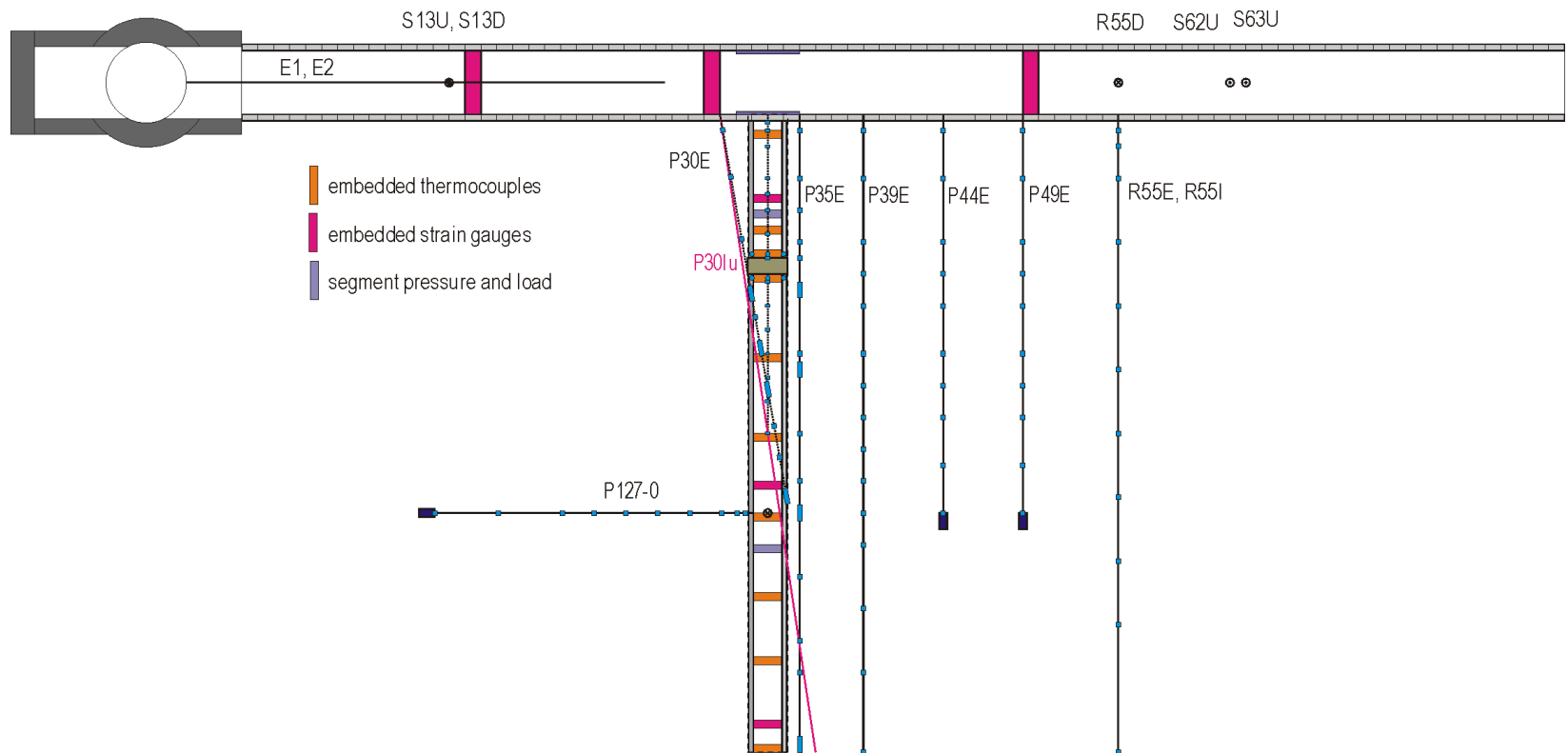


Instrumentation integrated in PG lining

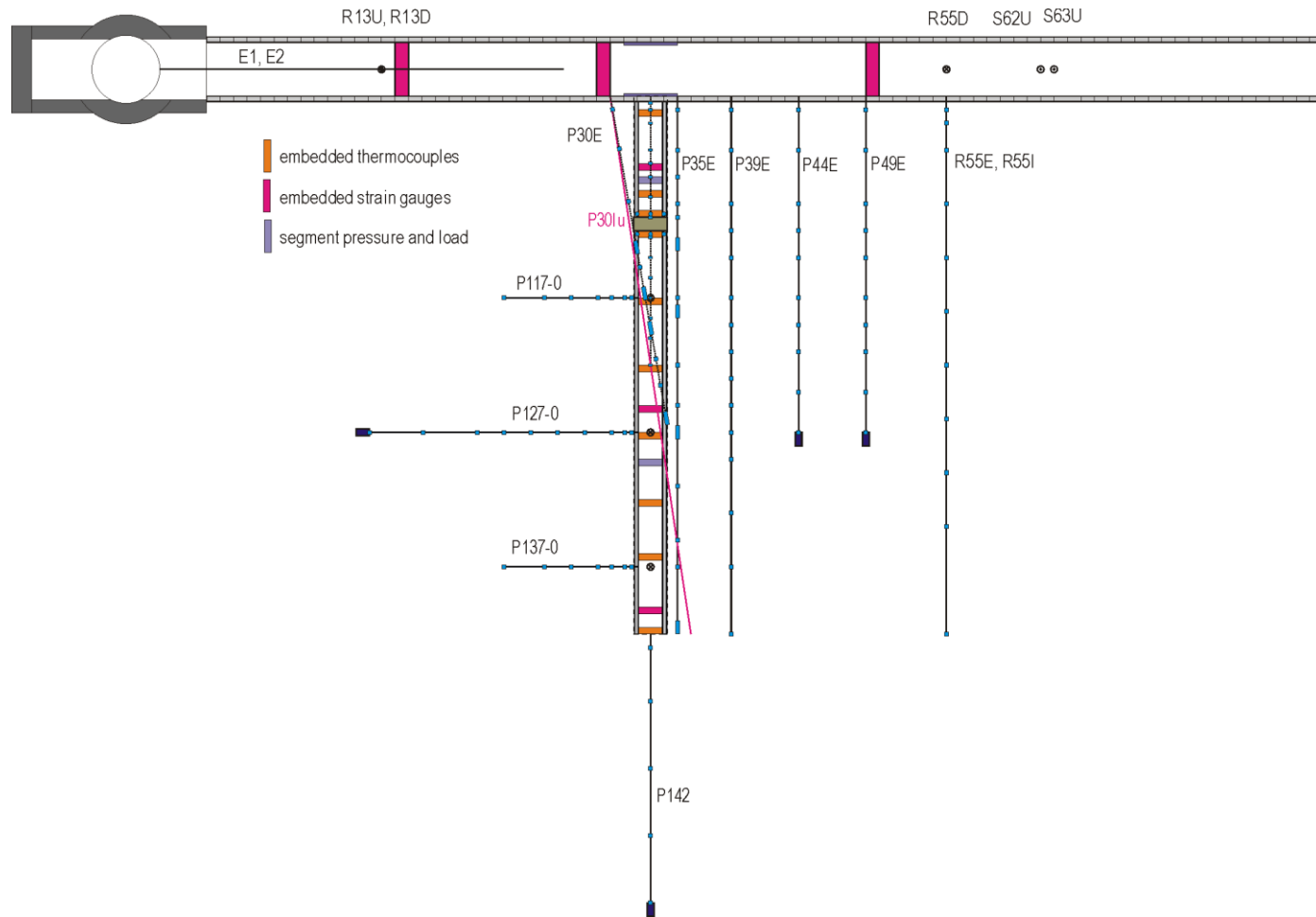
- 2 sections with extrados piezometers
 - 9 and 11 m deep, 4 piezometers/section
- 3 sections with embedded strain gauges
 - 5, 23 and 38 m deep, with 4 or 8 tangential + 2 axial
- 2 sections with extrados pressure and load cells
 - extrados pressure on all segments (8x)
 - segment load at 3 segment interfaces
 - adapted segment design necessary
 - 6 and 27 m deep
- 10 sections with temperature sensors
 - intrados, middle, extrados
 - also to determine heat flux
- measurement plots
 - optical survey and convergence measurements



Multipiezometers in central plane of PG



Additional multipiezometers from PG

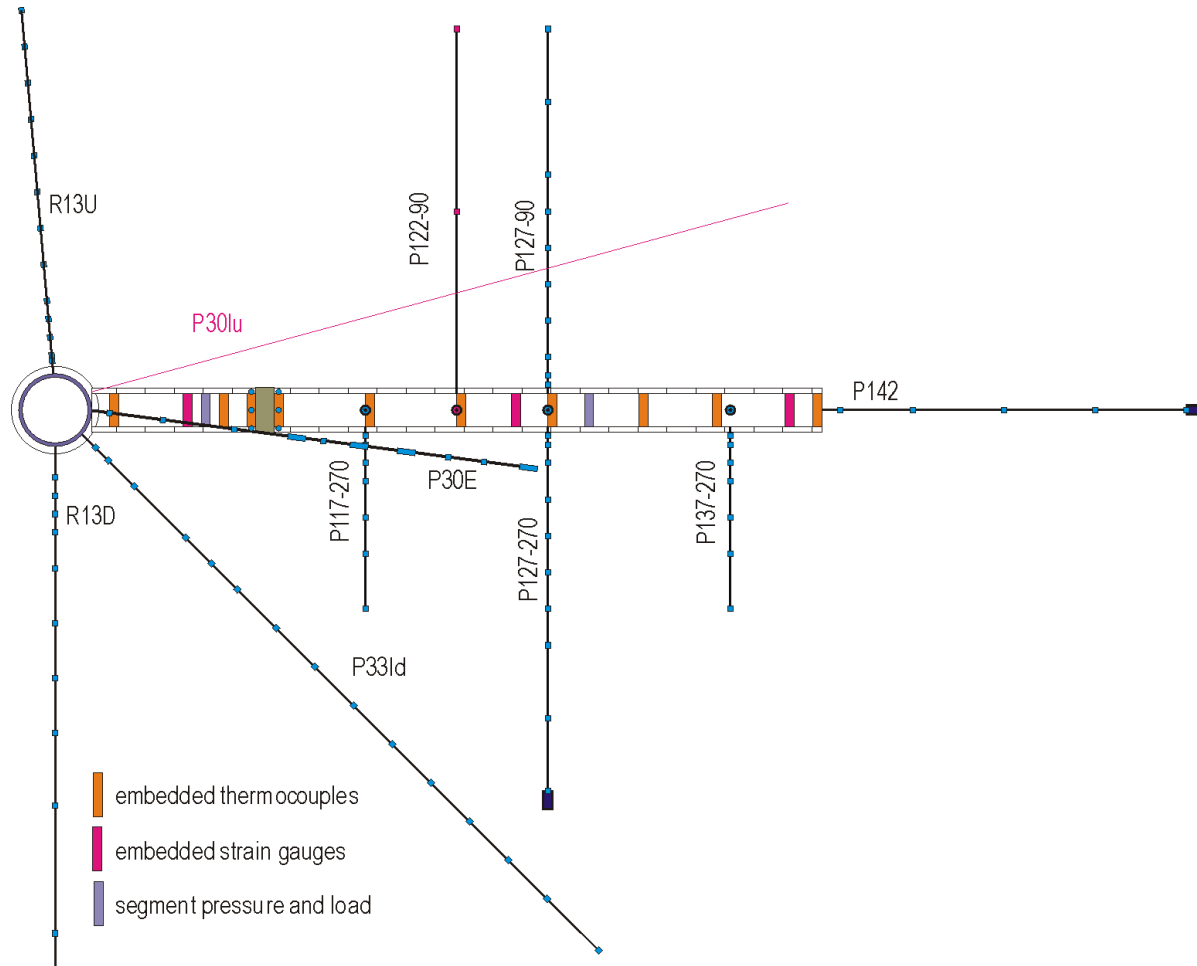


Boreholes from the PRACLAY Gallery

- 3 sections with multipiezometers
 - main section at 25 m depth with 4 x 20 m deep boreholes, 10 filters each
 - 2 with biaxial stressmeters
 - two auxiliary sections (15 and 35 m) with each 2 x 10 m deep boreholes, 7 filters each
- 1 multipiezometer (horizontal) at gallery end
 - 20 m deep and with 5 filters
- 1 section at 20 m with two extensometers
 - anchor points at 10 and 20 m

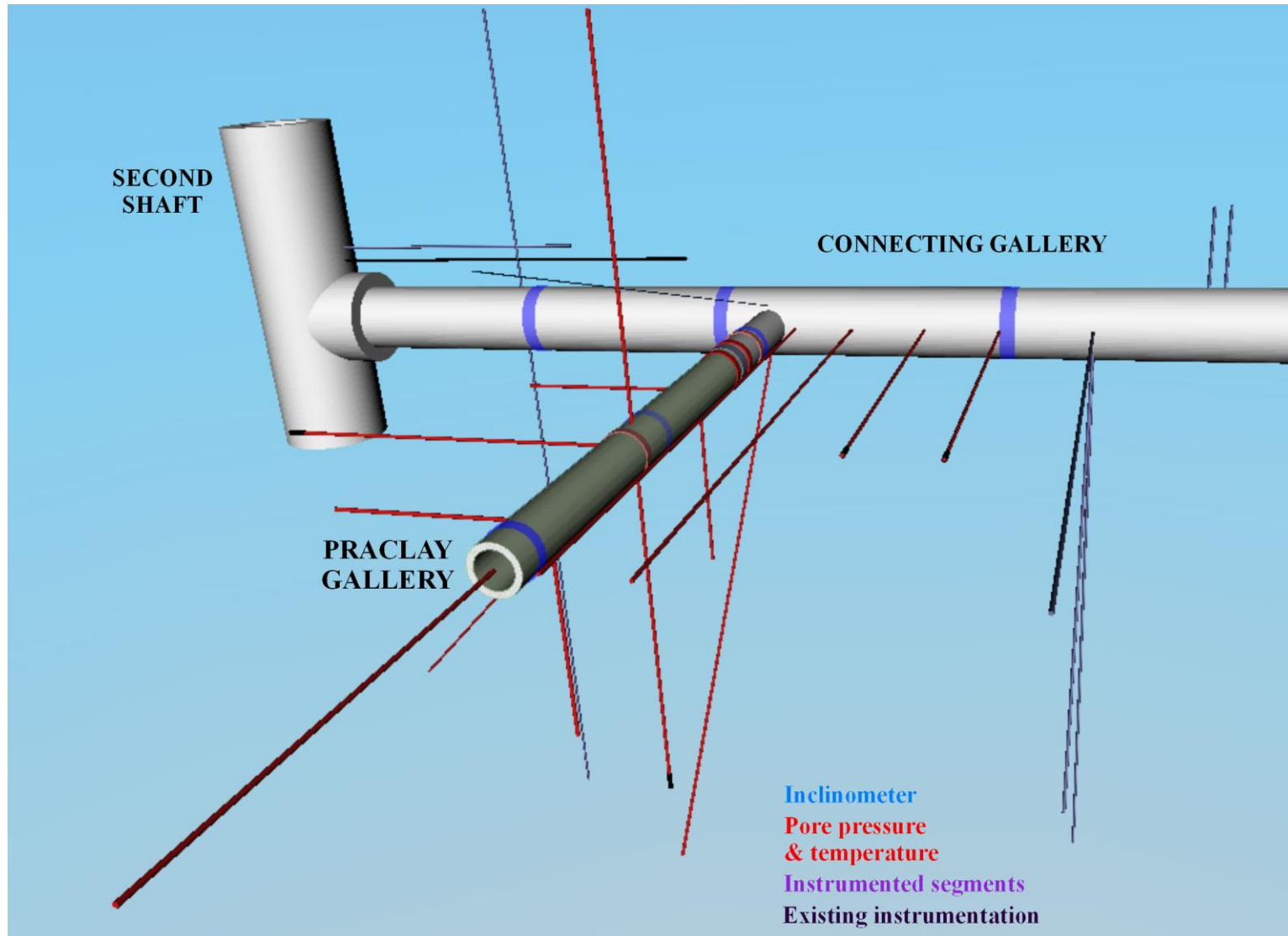


View in vertical plane





General instrumentation lay-out



EURIDICE GIE

Optional boreholes for geophysical characterisation

- Complementary to point measurements
 - spatial view of host rock quality in function of time (excavation, heating)
- Four to six boreholes from CG around PG opening, 10 to 15 m deep
- Transmitters and receivers for in-hole and cross-hole measurements
- Depending on results from SELFRAC set-up





Planning - budget

- Boreholes from CG : 375 000 €
 - mid 2005
 - multipiezometer costs: 210 000 €
 - material: 55 000 €
 - preparation work: 65 000 €
 - installation costs: 85 000 €
 - inclinometer: 40 000 €
 - installation : 15 000
 - material: 25 000
 - geophysical: 75 000 €
 - material: 25 000
 - installation: 50 000



Planning – budget (2)

- Gallery lining instrumentation : 200 000 €
 - embedded strain gauges (3 sections)
 - material and installation: 50 000 €
 - pressure and load cells (2 sections)
 - material and installation: 50 000 €
 - long – base extensometer (fiber optic)
 - offer expected from supplier
 - thermocouples (10 sections)
 - material and installation : 30 000 €
 - other: optical survey points, convergence plots, thermocouples, piezometer filters



Planning – budget (3)

- Boreholes from PG : 360 000 €
 - immediately after construction (2006/3-4)
 - multipiezometer costs : 270 000 €
 - material, preparation and installation
 - drilling costs to be confirmed (x 2)
 - extensometer costs :
 - installation : 40 000 €
 - material : offer expected from suppliers (50 000 €)

