DOPAS Training Workshop 2015

D2 2.2 The role of instrumentation and monitoring in an experiment

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Contents

- **Introduction**
  - Why monitoring
  - What is sensor
  - Analogue vs digital
  - How to get data out
  - Data collection, storage, presentation
  - Measurement chain

- **Why and how in the experiment**
  - Why (not) to use instrumentation/ to do monitoring
  - What to measure
  - How to measure
  - How often measure
  - What to do with measured data (data interpretation) ?
  - Typical failures

Contents

- **Common sensor types and their principles**
  - **Deformation (strain)**
  - **Pressure**
  - **Temperature**
  - **...**
- **EPSP – how it is done...**
  - **Overall EPSP**
  - **What is measured, why and where**
  - **Sensor selection**
  - **Technology used**
    - § **Sensors**
    - § **Data loggers**
  - **Data acquisition (DAQ) + Measurement system**
  - **Online demo**

Introduction

Monitoring in general with respect to DGR

Why monitoring?

- **Monitoring - Continuous or periodic measurement of radiological and other parameters or determination of the status of a structure, system or component.**
  (IAEA Glossary 2007)
- **In short – A way to know what happens in the repository**
- **Monitoring**
  - **Before anything starts**
  - **During construction phase**
  - **During disposal operation**
  - **After closure**

Sensors

- **A sensor is a device that measures a physical quantity and converts it into a signal, which can be read by an observer or by an instrument.**

  For example, a mercury-in-glass thermometer converts the measured temperature into expansion and contraction of a liquid that can be read on a calibrated glass tube.

  A thermocouple converts temperature into an output voltage, which can be read by a voltmeter.

  For accuracy, most sensors are calibrated against known standards.

(Wikipedia)

Analogue vs digital

“People are analogue, computers are digital”

- **Every sensor in principle is analogue**
- **Analogue signals are hard to transmit and work with without degradation at every step of transmitting or processing**
- **Digital signal e.g. 1s and 0s is THE language computers speak and can be transmitted over long distances without information loss**

Analogue vs digital

- **Quality of signal (measurement)**
  - **Analogue - S/N ratio (dB)**
  - **Digital - Resolution (bits)**

- **Conversion from analogue to digital is done by A/D convertor.**

- **Digital sensor means that conversion from analogue to digital is done by some electronics inside sensor.**

How to get data out?

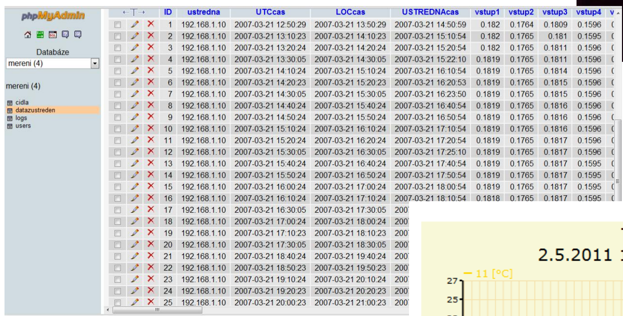
- **Signal**
  - **Analogue**
  - **Digital**
- **Cables – metallic, optic**
  - **Cheap and reliable**
  - **Not a good option after closure – cables can create preferential paths for water**
- **Wireless (radio; point to point link or mesh network)**
  - **Rock is not good for electromagnetic waves propagation**
  - **Custom made equipment, slow transmition, power source problems, limited lifetime**

Data collection, storage and presentation

- **Data acquisition system**
  - **Collects readings from sensors via data loggers**
  - **Stores readings into database (or elsewhere)**
- **Database (or other storage)**
  - **Stores all collected data for further processing**
    - **Primary data from sensors**
  - **Calculated values**
  - **Other info (sensors calibration etc.)**
- **User front end**
  - **Takes data from database and processes them to the form suitable for user**

Measurement chain

- **Sensor itself**
- **Amplifier/conditioner**
- **A/D convertor**
- **Data logger/measurement device**
- **Database**
- **UI front end**
- **User**



phpMyAdmin

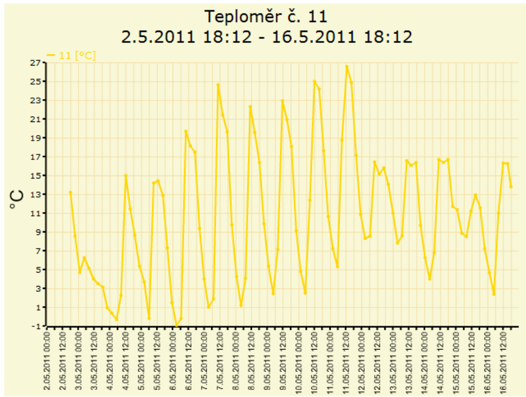
Databáze

mereni (4)

mereni (4)

cidla
datazustreden
logs
users

ID	ustredna	UTCcas	LOCcas	USTREDNAcas	vstup1	vstup2	vstup3	vstup4
1	192.168.1.10	2007-03-21 12:50:29	2007-03-21 13:50:29	2007-03-21 14:50:59	0.182	0.1764	0.1809	0.1596
2	192.168.1.10	2007-03-21 13:10:23	2007-03-21 14:10:23	2007-03-21 15:10:54	0.182	0.1765	0.181	0.1595
3	192.168.1.10	2007-03-21 13:20:24	2007-03-21 14:20:24	2007-03-21 15:20:54	0.182	0.1765	0.1811	0.1596
4	192.168.1.10	2007-03-21 13:30:05	2007-03-21 14:30:05	2007-03-21 15:22:10	0.1819	0.1765	0.1811	0.1596
5	192.168.1.10	2007-03-21 14:10:24	2007-03-21 15:10:24	2007-03-21 16:10:54	0.1819	0.1765	0.1814	0.1596
6	192.168.1.10	2007-03-21 14:20:23	2007-03-21 15:20:23	2007-03-21 16:20:53	0.1819	0.1765	0.1815	0.1596
7	192.168.1.10	2007-03-21 14:30:05	2007-03-21 15:30:05	2007-03-21 16:23:50	0.1819	0.1765	0.1815	0.1596
8	192.168.1.10	2007-03-21 14:40:24	2007-03-21 15:40:24	2007-03-21 16:40:54	0.1819	0.1765	0.1816	0.1596
9	192.168.1.10	2007-03-21 14:50:24	2007-03-21 15:50:24	2007-03-21 16:50:54	0.1819	0.1765	0.1816	0.1596
10	192.168.1.10	2007-03-21 15:10:24	2007-03-21 16:10:24	2007-03-21 17:10:54	0.1819	0.1765	0.1816	0.1596
11	192.168.1.10	2007-03-21 15:20:24	2007-03-21 16:20:24	2007-03-21 17:20:54	0.1819	0.1765	0.1817	0.1596
12	192.168.1.10	2007-03-21 15:30:05	2007-03-21 16:30:05	2007-03-21 17:25:10	0.1819	0.1765	0.1817	0.1596
13	192.168.1.10	2007-03-21 15:40:24	2007-03-21 16:40:24	2007-03-21 17:40:54	0.1819	0.1765	0.1817	0.1595
14	192.168.1.10	2007-03-21 15:50:24	2007-03-21 16:50:24	2007-03-21 17:50:54	0.1819	0.1765	0.1817	0.1595
15	192.168.1.10	2007-03-21 16:00:24	2007-03-21 17:00:24	2007-03-21 18:00:54	0.1819	0.1765	0.1817	0.1595
16	192.168.1.10	2007-03-21 16:10:24	2007-03-21 17:10:24	2007-03-21 18:10:54	0.1818	0.1765	0.1817	0.1595
17	192.168.1.10	2007-03-21 16:30:05	2007-03-21 17:30:05	200				
18	192.168.1.10	2007-03-21 17:00:24	2007-03-21 18:00:24	200				
19	192.168.1.10	2007-03-21 17:10:23	2007-03-21 18:10:23	200				
20	192.168.1.10	2007-03-21 17:30:05	2007-03-21 18:30:05	200				
21	192.168.1.10	2007-03-21 18:40:24	2007-03-21 19:40:24	200				
22	192.168.1.10	2007-03-21 18:50:23	2007-03-21 19:50:23	200				
23	192.168.1.10	2007-03-21 19:10:24	2007-03-21 20:10:24	200				
24	192.168.1.10	2007-03-21 19:20:23	2007-03-21 20:20:23	200				
25	192.168.1.10	2007-03-21 20:00:23	2007-03-21 21:00:23	200				



Disposal specific

- Cables are not welcome after closure
- Very long distance to the surface (not easy to use wireless)
- NO access for service after disposal closure
- Where to get power for sensors and devices after closure?
- How to get data (measurements) out?
- Extremely long time span.

What about the experiments?

The role of the instrumentation in the experiments

Why (not) to use instrumentation?

- **Instrumentation is our "eyes" into what happens inside of our experiments**

Observer effect

- **Our instrumentation and/or process of measurement will have an impact on our experiment.**

  Even non-invasive methods do have an impact.

  Example: Chemical interaction between sensors and environment (corrosion,..). Preferential paths along cabling. Heat production. Gradient creation.

What to measure?

- Purpose of the experiment is a starting point – raison d'être of the instrumentation is to gather necessary supporting evidence

- Identification of key processes
  à What parameters to measure
- Identification of key places
  à Where to measure

- Minimalist vs maximalist approach (I can but should I?)
  - Do not disturb the experiment!
  - I want to know everything!

- Always try measure all parameters, which could influence the measurement itself (e.g. temperature)

How to measure?

- **Required parameters to measure drive the sensor selection**
  - **Phenomena**
  - **Range**
  - **Accuracy**
  - **Speed**

- **Diversify your portfolio**
- **Try to use several sensors of different type and principle for same parameter**
- **Check your sensor in advance**

- **Practical considerations**
  - **Will it fit into space? Will it impact the experiment? Will it survive? How much it costs?...**

How often to measure?

- **Highly depends on your application. However**

You can throw away only things you have (measured)

and even very slow processes can have a fast sudden change.

- **Practical considerations**
  - **Measurement itself can disturb the system (for example – the act of measurement heats up the sensor a bit)**
  - **Some measurements are slow by nature**
  - **You have to be able to handle the data flow**

How often to measure?

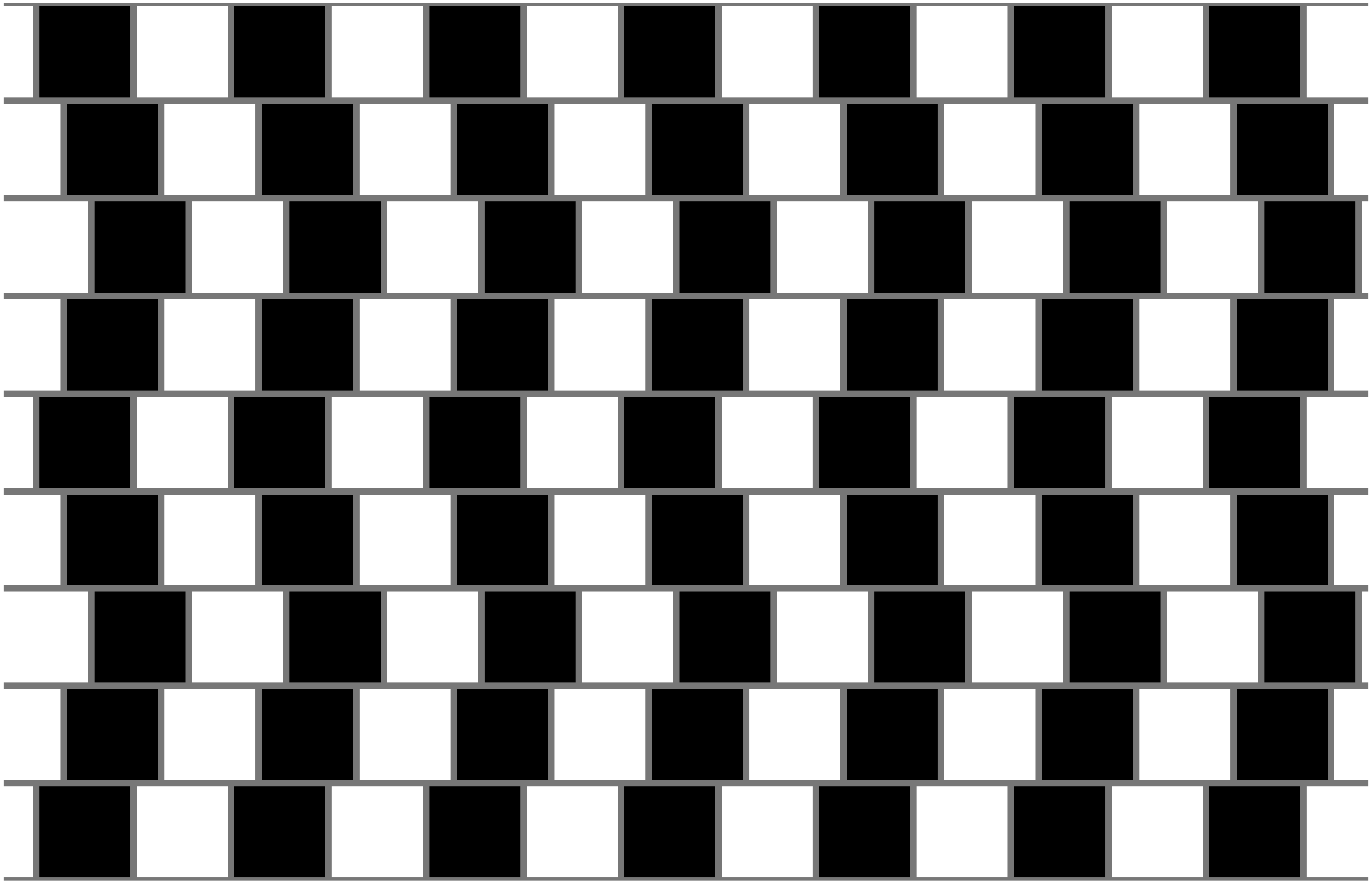
- ***PLACEHOLDER SLIDE – example of interval/frequency of measurement importance (external poster in Josef gallery)***

Data interpretation

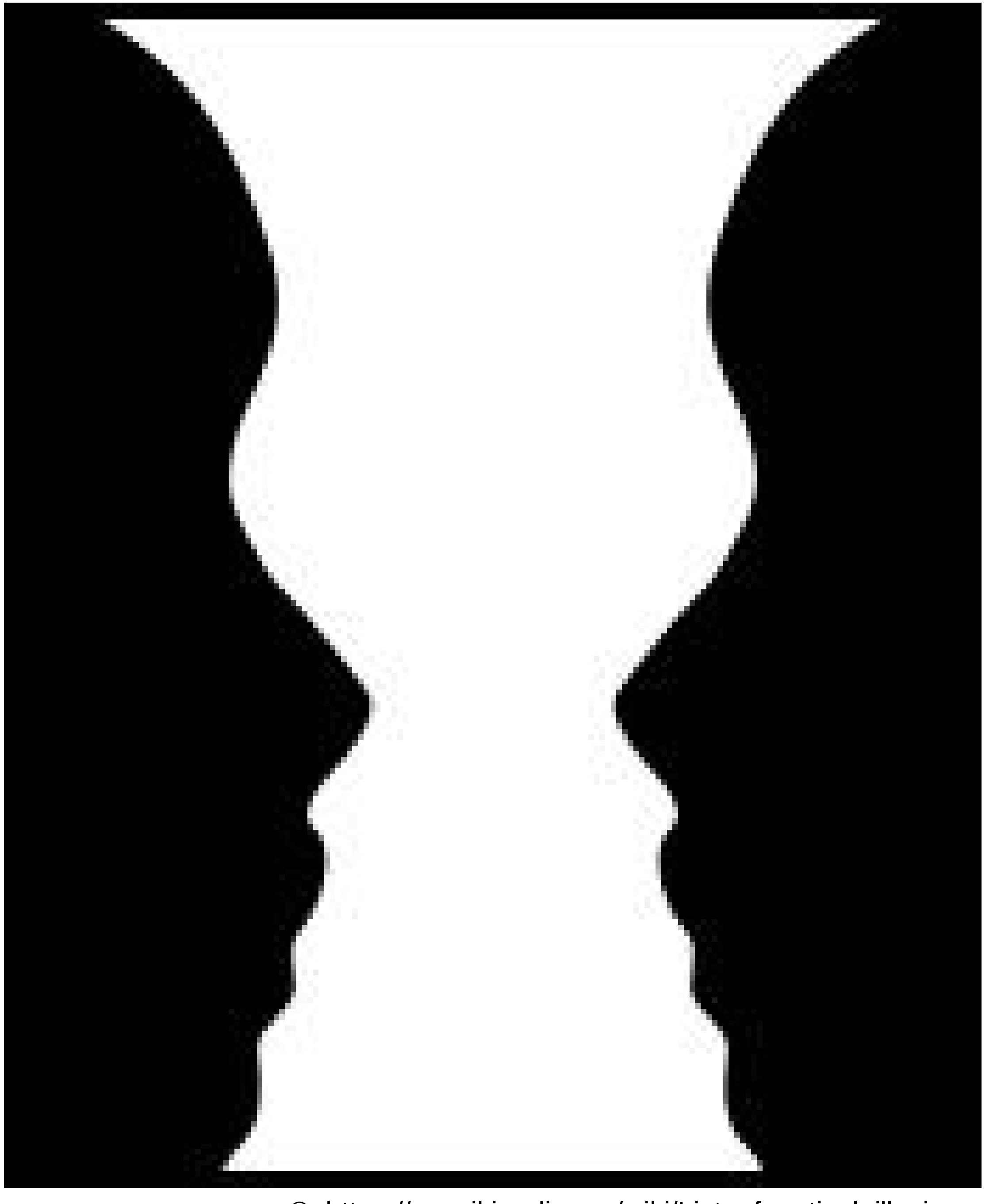
- **The measured data are useless without interpretation**

- **Do you trust your sensors?**

Let’s try it…



© https://en.wikipedia.org/wiki/List_of_optical_illusions



© https://en.wikipedia.org/wiki/List_of_optical_illusions

Data interpretation

- **The measured data are useless without interpretation**

- **Do you trust your sensors?**

- **Data validation**
- **Safety checks**
- **Cross checking**

- **Analytical tools**

Typical failures

- **Water**
- **Mechanical damage**
  - **Installation**
  - **Overload**
- **Electrical problems**
  - **Ground loops**
- **Durability and temporal stability**

Typical failures - corrosion

Cables & Sensors

- **Pressure cell**

Thermometer

- **Cables**

Mechanical damage

Common sensor types

What could be on my shopping list…

Principles of the sensors

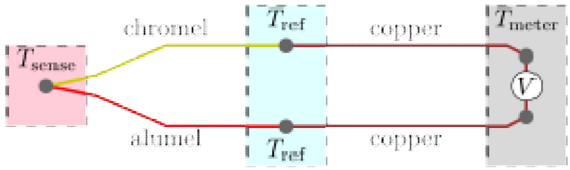
- **“Electromagnetic” sensors – change of electro magnetic properties and/or generation of electricity**
  - **Voltage/current**
  - **Resistivity**
  - **Inductivity**
  - **Hall effect***
- **Vibrating wire sensors – change of oscillation frequency (pitch) by changing of wire tension**
- **Fiber optic**
- **…**

*) **Hall effect** is the production of a voltage difference (the Hall voltage) across an electrical conductor, transverse to an electric current in the conductor and a magnetic field perpendicular to the current. It was discovered by Edwin Hall in 1879. (Source: Wikipedia)

Temperature

- **Thermocouples**
  - **E,J,K,M,N,T**
  - **B,R,S**
  - **C,D,G**
  - **P**
  - **…**

IEC 584-1
EN 60584-1



K-type thermocouple (chromel–alumel) – © Wikipedia.org

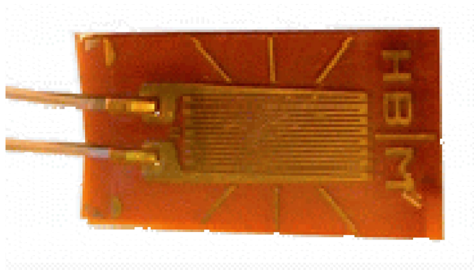
- **Resistance temperature detectors (RTD)**

- **Thermistors**
  - **PTC**
  - **NTC**

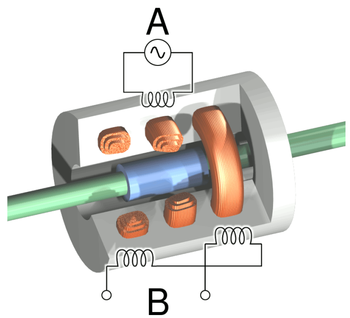
https://en.wikipedia.org/wiki/Thermocouple
https://en.wikipedia.org/wiki/Resistance_thermometer
https://en.wikipedia.org/wiki/Thermistor

Strain (deformation)

- **Resistive strain gauges**
  - **Metallic**



  - **Piezoresistors**



©https://en.wikipedia.org/wiki/Linear_variable_differential_transformer

- **Linear variable displacement transducer (LVDT)**
- **Vibrating wire strain gauges**

https://en.wikipedia.org/wiki/Strain_gauge

Force (pressure)

- **There are no “direct” force/pressure sensors with electric output. The force/pressure is usually measured as deformation of elastic element.**

- **Membrane**
- **Rod**
- **Cantilever**
- **…**

Water content and humidity

- **Relative humidity**
  - **Capacitive sensors**
  - **Thermocouple psychrometry**

- **Water content**
  - **Time Domain Reflectometry (TDR): Dielectric constant**
  - **Frequency Domain (FD): Capacitance and Frequency Domain Reflectometry**
  - **Amplitude Domain Reflectometry (ADR): Impedance**
  - **Time Domain Transmission (TDT)**
  - **Resistance blocks**
  - **Heat discipation**

TDR – electromagnetic pulse propagation speed is measured -> dielectric constant
FD – capacince is measured based (oscillator freq is measured – rods in sample make capacitor)

EPSP experiment

Monitoring implementation

EPSP overall

- **Experiment objectives (as stated in DoW)**
  - **systematic test and application of Czech based materials and technologies;**
  - **comparison with the results produced for the consortium members of this project;**
  - **development and testing of new construction techniques such as sprayed bentonite;**
  - **application of low pH concrete or shotcrete as structural and sealing materials for the plug;**
  - **comprehensive monitoring program, which will be pre-assessed during planning phase, of plug and surrounding rock as one basis for its modelling and performance assessment activities.**

Monitoring

- **Identification of key processes**
- **Identification of key places in experiment**

- **Selection of suitable sensors**
- **Selection of installation places**

- **DAQ & Measurement system**

à Project of monitoring (DOPAS deliverable D3.18)

EPSP monitoring timeline

- **Preparatory phase**
- **Construction work up to the completion of the inner plug**
- **Testing of the inner plug**
- **Completion of the construction of the experiment (bentonite emplacement, filter, outer plug)**
- **Trial operation**
- **The main experimental program**

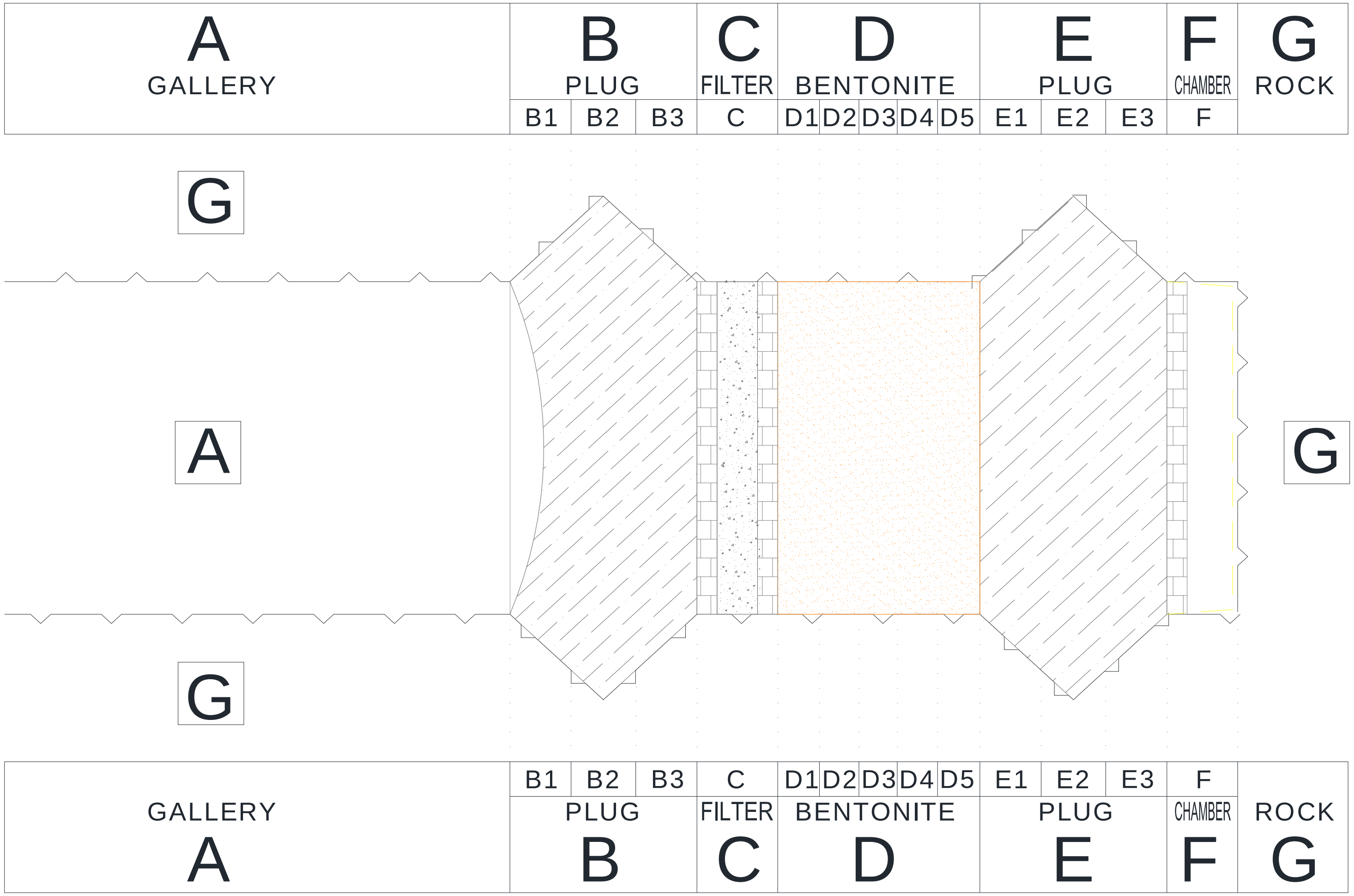
What, why and where?

- **Construction phase – focus on concrete structures**
  - **Temperature evolution**
  - **Deformations (shrinkage)**

- **Experimental program – focus on EPSP performance**
  - **Water movement monitoring**
  - **Bentonite monitoring**
  - **Structural response of EPSP and host rock**

What, why and where

- **Profiles**



What, why and where

- **Water movement inside the experiment is monitored in terms of water in-/outflow, water content distribution within the bentonite seal and water (pore) pressure distribution.**

- **The mechanical response of the plug is monitored by means of strain gauges installed at key locations in the concrete plugs and instrumented rock bolts positioned within the rock. Moreover, contact stress measurement is deployed between the rock and the plug.**

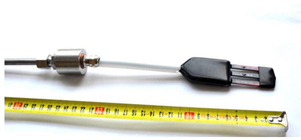
What, why and where

- **Temperature distribution is monitored since it is important not only during the construction stage (hydration heat) but also during the loading of the experiment as a reference base for sensor compensation.**

- **The swelling pressure of bentonite sealing is monitored using pressure cells.**

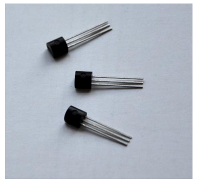
Sensors

- **Water (moisture movement)**
  - RH sensors (E+E 071)
  - TDR sensors (DECAGON 5TE)
  - Outflow from drain



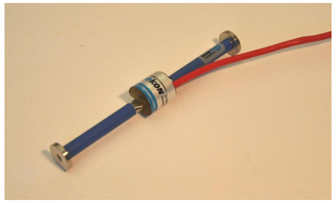
- **Stress state**
  - Piezometers (GeoKon – 4500SHX-10MPa)
  - Pressure cells (GeoKon - 4810X-10MPa)

- **Temperature sensors**
  - Dedicated analogue and digital sensors (DS18B20 and LM35DZ)
  - Compensation thermometers inside other sensors (thermistors)



Sensors

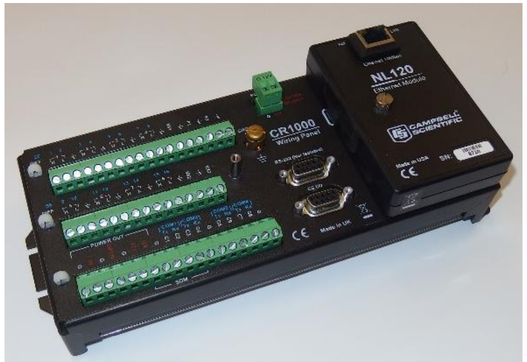
- **Mechanical response of experiment**
  - **VW strain gauges (GeoKon 4200A-2)**



- **Response of rock mass**
  - **Instrumented rock bolts (VW) (GeoKon 4911-4X)**
- **Technology**
  - **Amount, flow rate, pressure of pressurisation media**
  - **Status of technology**
  - **Energy consumption**

Data Loggers

- **Campbell scientific CR1000 and AVW200**
  - **Vibrating wire sensors**
  - **Thermometers**
  - **TDR (via SDI-12)**



- **In-house built data loggers**
  - **Temperature sensors**
  - **Humidity sensors (optionally)**

Data Loggers

- **Directly connected (via convertors)**
  - **Humidity sensors**

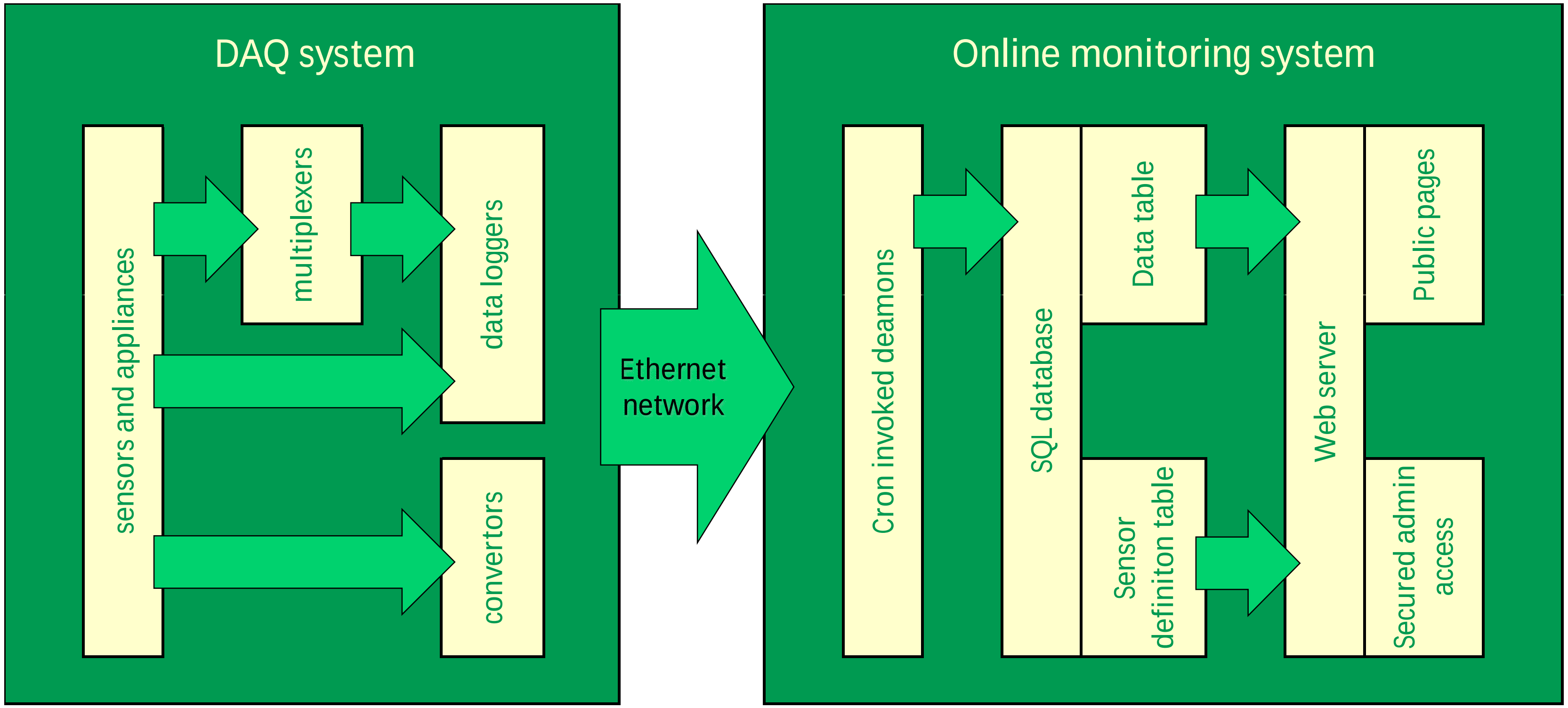
- **GeoKon**
  - **VW sensors**
  - **Thermistors**

- **In-house on-line measurement system**

Sensor protection

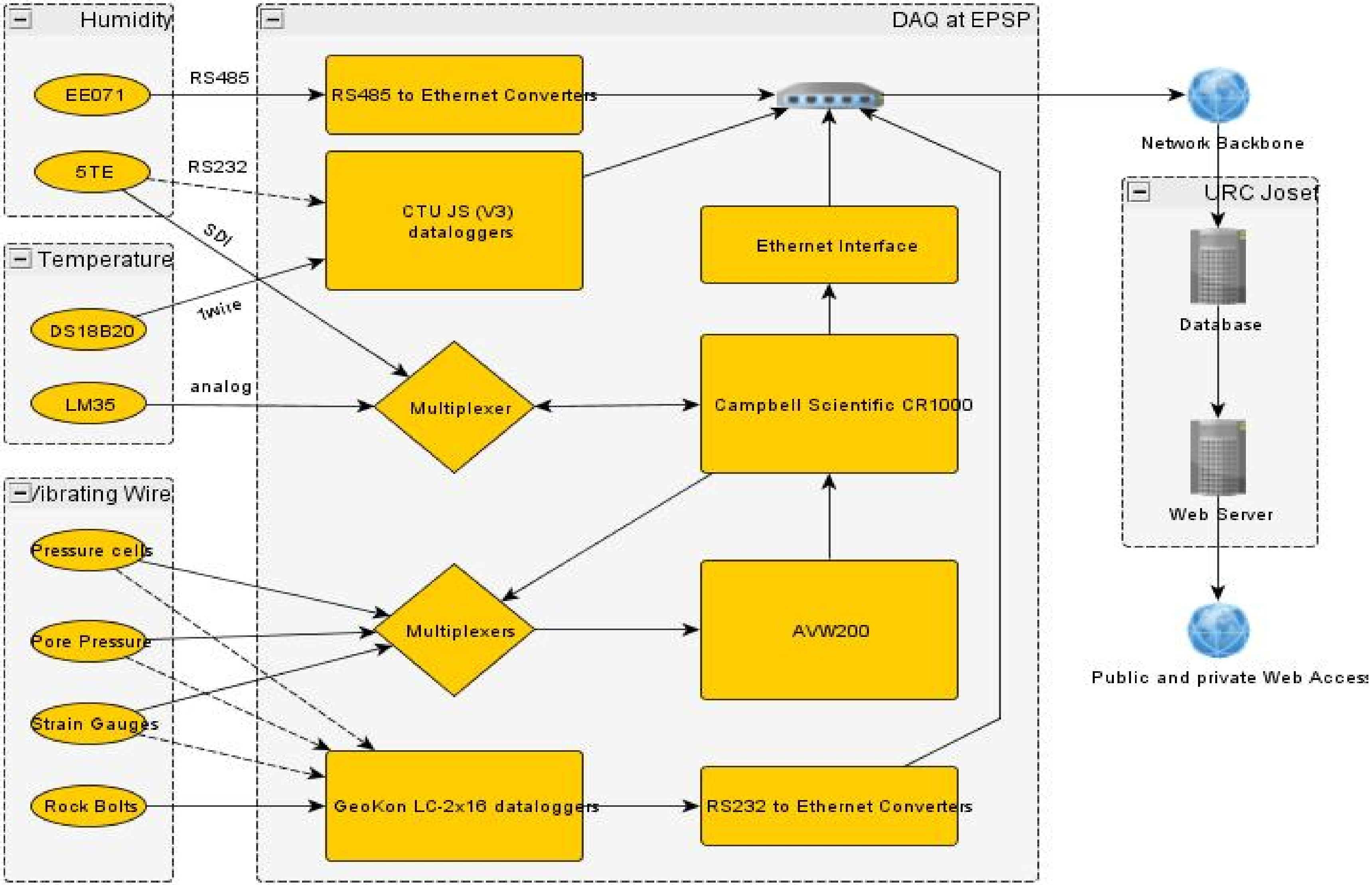
- **Sensors and cables protected by stainless steel casing**

DAQ* + measurement system



*) data acquisition

DAQ + measurement system



Monitoring

Experiment | Čidla/Sensors | Vizualizace/Visualisation | Stav/Status | Deník/Log | Období/Time period change | Web kamera/WebCam | O systému/About

Seznam čidel / List of sensors

Zobraz záznamů 10 Hledat: 113

číslo n.	typ type	popis desc	jednotky units	x	y	z	r	alfa	od from	do till	akce action	hodnota value	datum date
113.01	10 - Teploměr	analogový teploměr / analog thermometer	°C	0,05	0,00	0,00	0,08	177	2014-09-18 00:00:00	2024-12-31 00:00:00	Graf / Graph	**19,00 °C**	02.11.2014 05:57
113.11	10 - Teploměr	digitální teploměr / digital thermometer	°C	0,05	0,00	0,00	0,08	177	2014-09-18 00:00:00	2024-12-31 00:00:00	Graf / Graph	**19,00 °C**	01.11.2014 23:10

Zobrazuji 1 až 2 z celkem 2 záznamů (filtrováno z celkem 57 záznamů)

Předchozí Další

Výsledky měření

113.01: analogový teploměr / analog thermometer

Návod

Kliknutím na odkaz "graf" u čidla se pod tabulkou čidel zobrazí graf zvoleného čidla. Průběh dalších čidel lze do grafu přida/odebrat stejným způsobem.
Pozor - načtení grafu trvá delší dobu!

Pozn.: Naměřené hodnoty uvedené v tabulce nemusí být plně aktuání. Pocházejí vždy z poslední obnovy dat (obvykle každý den v 04.00). Grafy však vždy používají plně aktuální data.

Hint

Click on "graph" link to display graph. Graph will be loaded bellow the sensor table. More sensors can be added/removed to graph in same way.
Warning - it takes some time to load a graph!

Upozornění

První zvolené čidlo nelze z grafu odebrat.

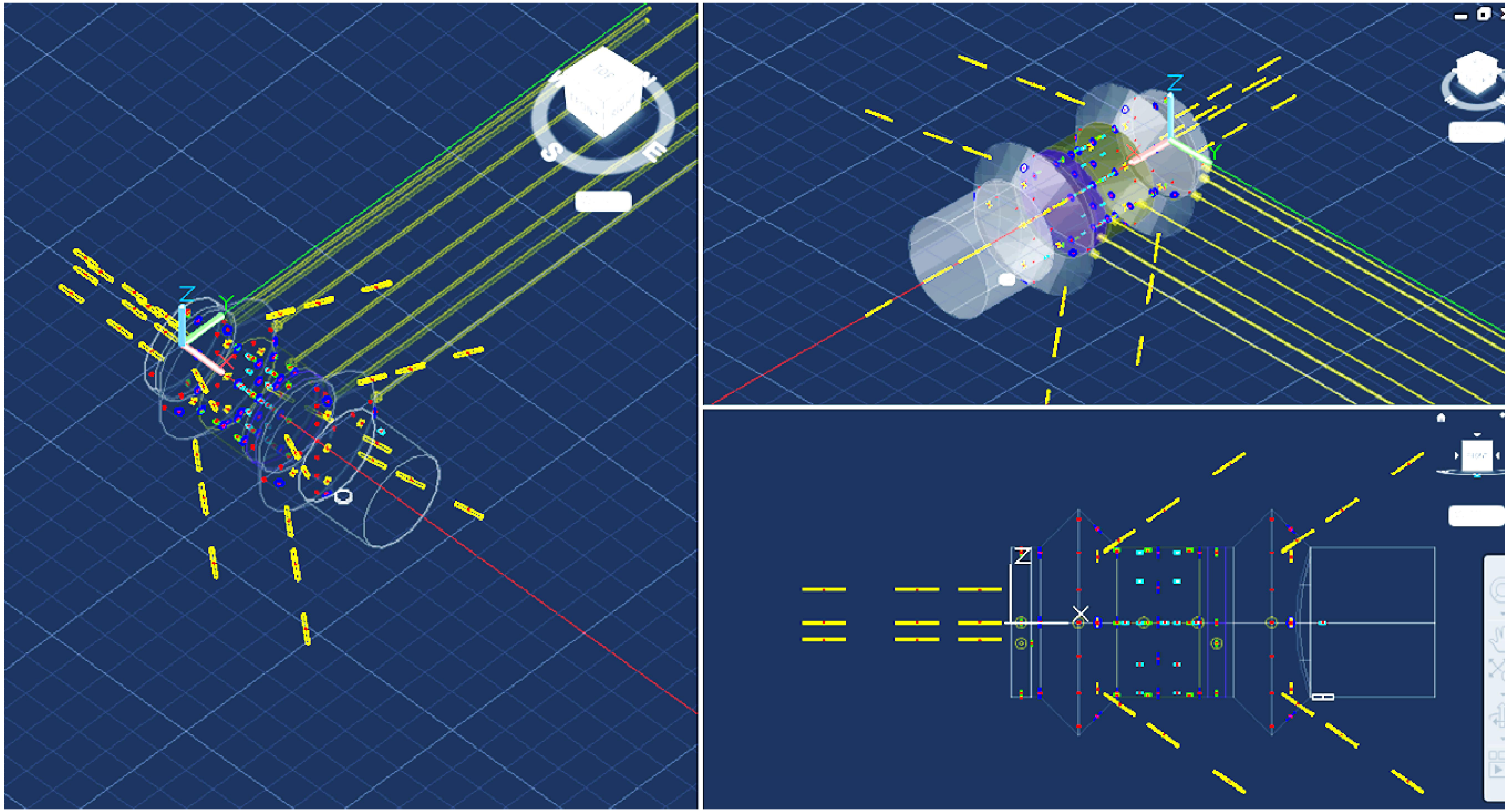
Výběr jiného experimentu nebo období způsobí vymazání aktuálních grafů.

Important notice

First sensor can not be removed from graph.

Selection of another experiment or change of data period causes graph reset.

Monitoring – 3D model



Sensor selection process

- **Sensors with good track record used where possible**

- **“New” sensors**
  - **References**
  - **Sample sensors tested in advance**

References

- **IAEA glossary**
  http://www-pub.iaea.org/MTCD/publications/PDF/Pub1290_web.pdf

- **DOPAS Deliverables**
  - **D2.1 Design Basis and Criteria Report**
  - **D3.15 Detail design of EPSP plug**
  - **D3.17 Interim results of EPSP laboratory testing**
  - **D3.18 Testing plan for EPSP instrumentation and monitoring**

List of recommended further reading:

- **Modern Project deliverables (http://www.modern-fp7.eu/)**
  - **State of art is good start**
    http://www.modern-fp7.eu/fileadmin/modern/docs/Deliverables/MoDeRn_D2.2.2_State_of_art_report.pdf

  Note: There is new MODERN2020 project (http://www.modern2020.eu/ - should be online by the end of 2015)

- **Wikipedia articles about sensors:**
  - **https://en.wikipedia.org/wiki/Thermocouple**
  - **https://en.wikipedia.org/wiki/Resistance_thermometer**
  - **https://en.wikipedia.org/wiki/Thermistor**
  - **https://en.wikipedia.org/wiki/Strain_gauge**
  - **https://en.wikipedia.org/wiki/Linear_variable_differential_transformer**

List of recommended further reading:

- **GeoKon Manual library (manuals include theoretical background) - http://www.geokon.com/Manuals**
  - **Vibrating wire and other sensors**

- **Decagon – www.decagon.com**
  - **TDR and other soil sensors**
  - **Education section http://www.decagon.com/education/**

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