What we can learn from a full-scale demonstration experiment after 4 years of DTS monitoring – the FE Experiment

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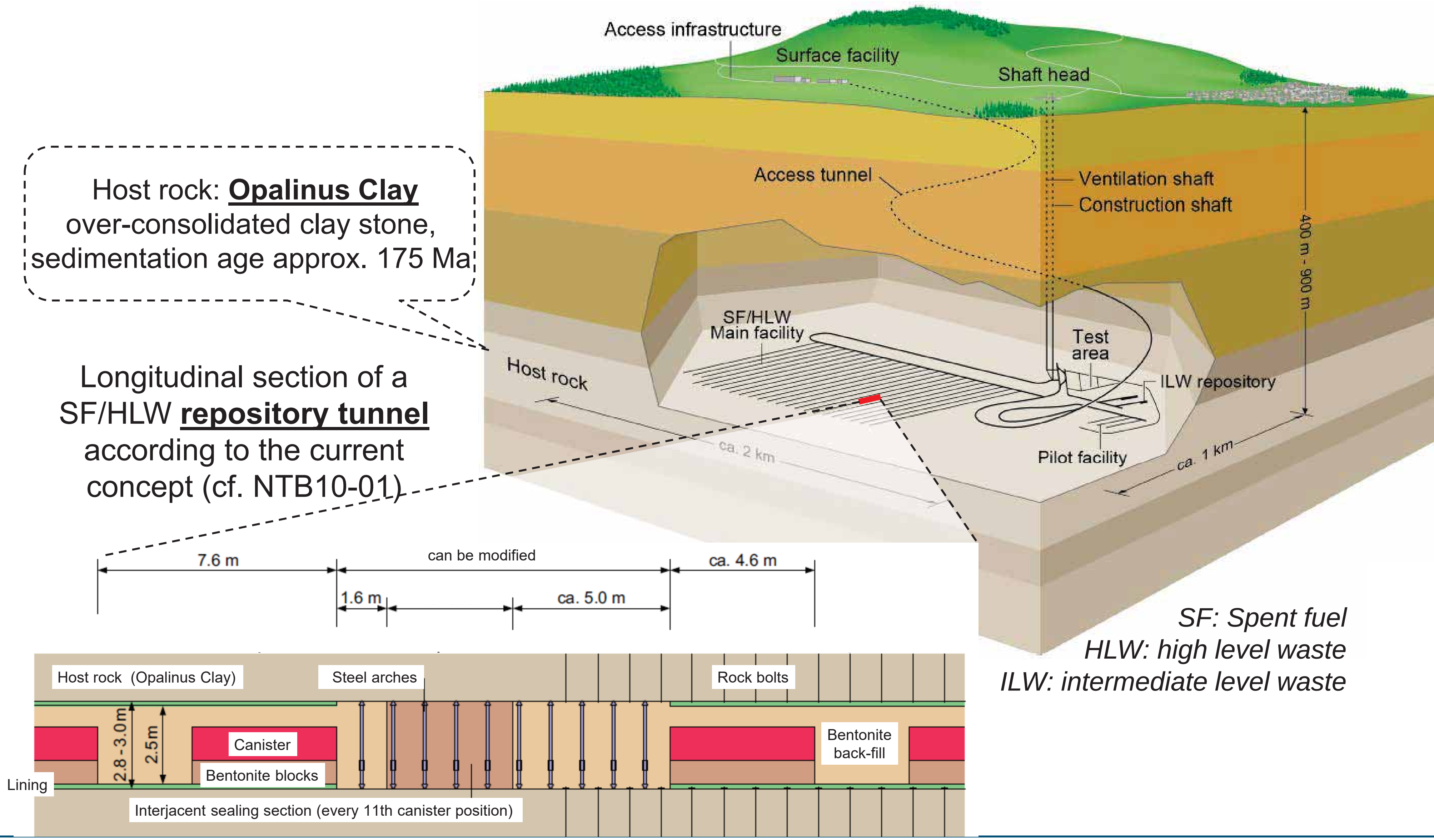
Swiss repository concept for SF/HLW

Host rock: **Opalinus Clay**
over-consolidated clay stone,
sedimentation age approx. 175 Ma

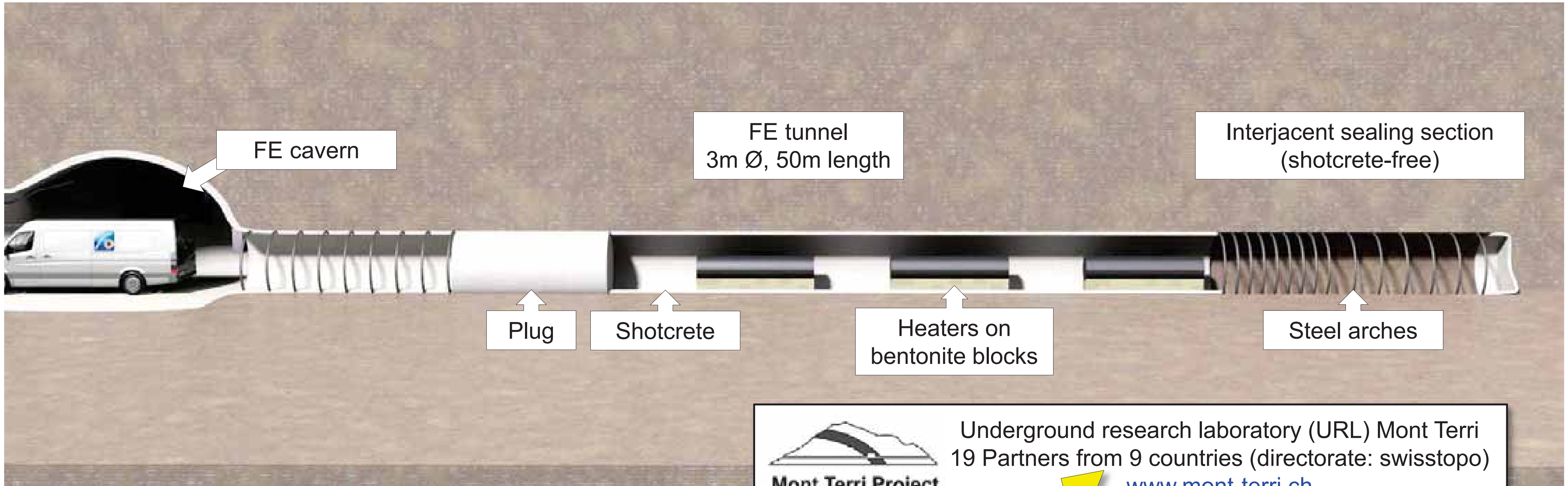
Longitudinal section of a
SF/HLW **repository tunnel**
according to the current
concept (cf. NTB10-01)



SF: Spent fuel
HLW: high level waste
ILW: intermediate level waste

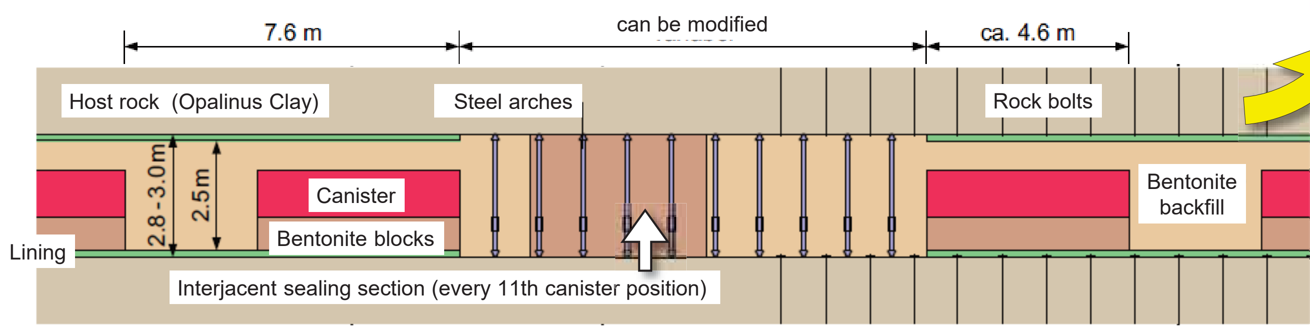
FE Experiment @ Mont Terri (Switzerland)

Visualisation without rock bolts, sensors and backfill



Mont Terri Project

Underground research laboratory (URL) Mont Terri
19 Partners from 9 countries (directorate: swisstopo)
www.mont-terri.ch



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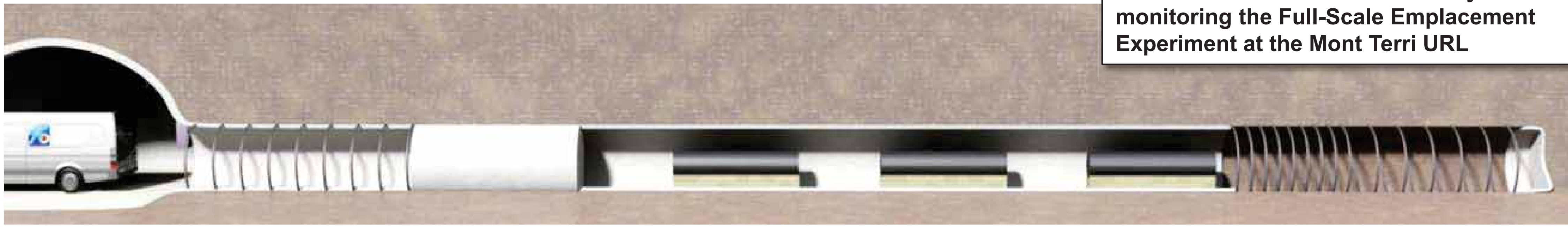
Full-Scale Emplacement (FE) Experiment

Presentation by Herwig Müller et al. (Nagra)
16:30
Lessons learnt after more than 7 years of monitoring the Full-Scale Emplacement Experiment at the Mont Terri URL



- **1:1 full-scale heater experiment** (according to Swiss SF / HLW concept) @ Mont Terri URL

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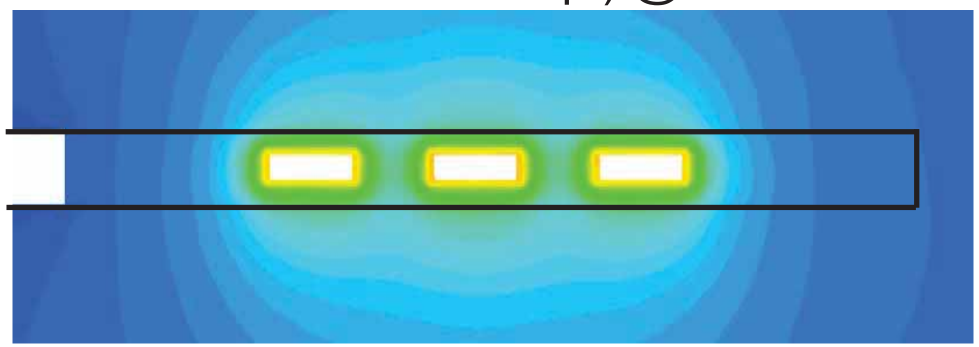
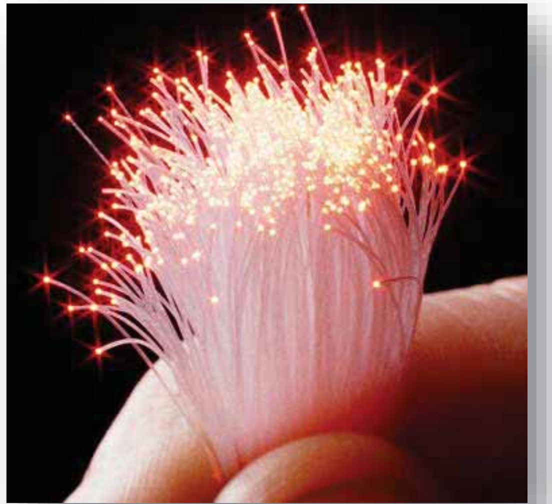


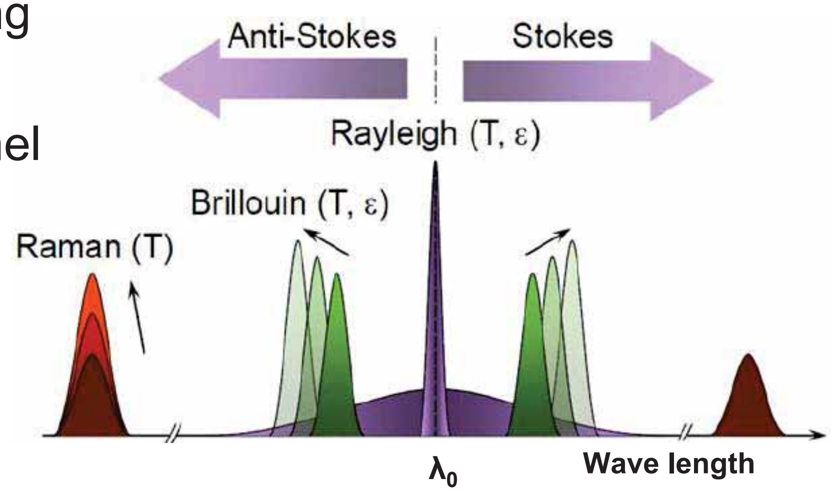
- Investigation of **repository induced thermo-hydro-mechanical (THM) coupled effects** on the host rock

Mont Terri Project

Fiber-optic sensors within the FE Experiment

- Besides standard sensors, fiber-optic sensors were installed.
- Fiber-optic cable is the sensor → connected to measurement unit.
- Temperature and strain distribution (profile) along fiber-optic cable.
  - Profiles of several kilometers length with 0.1 – 2.0 m spatial resolution.
- Advantages: No electronics at sensor, corrosion resistant, distributed measurement profiles with high spatial resolution over long distances.
- Distributed fiber-optic monitoring systems within FE Experiment:
  - Distributed temperature sensing (DTS, Raman) in boreholes and along tunnel wall.
  - Distributed strain sensing (DSS, Hybrid-Brillouin-Rayleigh) along tunnel wall.



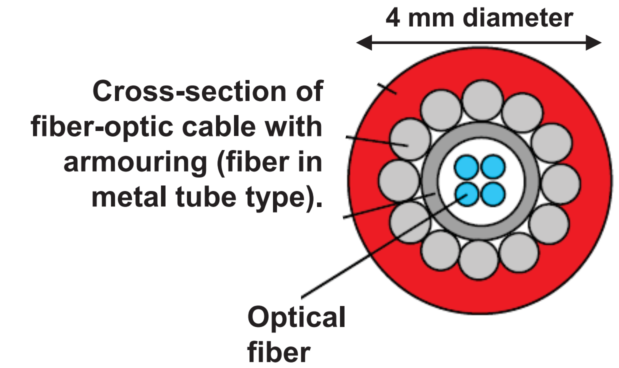


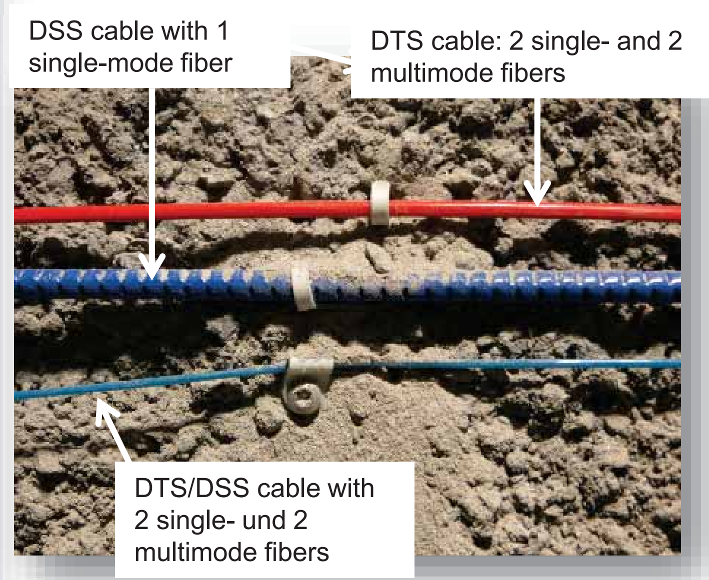
➢ Test and evaluation of different fiber-optic monitoring systems under repository like conditions in the FE Experiment

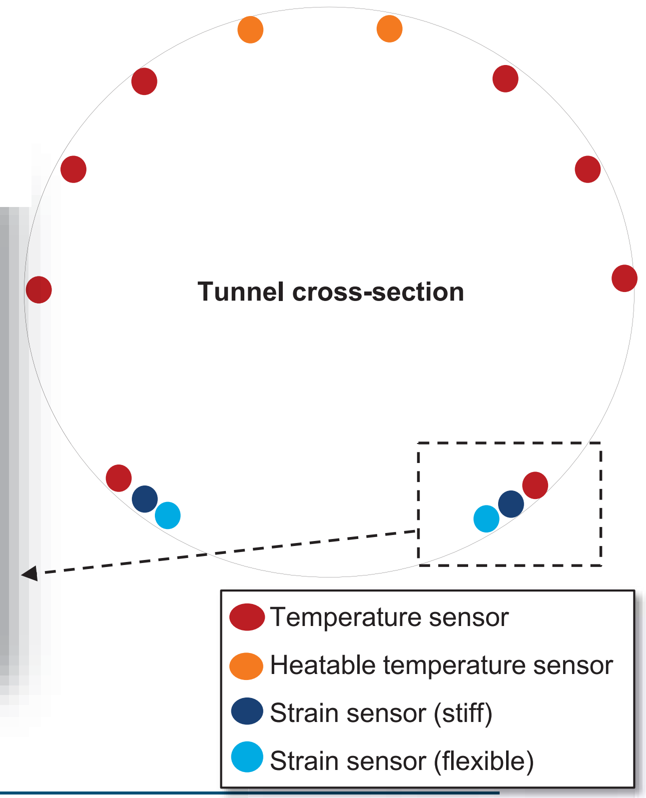
➢ Participation in WP4 (demonstrator experiments) of Modern2020 project.

Distributed fiber-optic sensors in the FE tunnel

- Different fiber-optic cables (sensors) installed.
  - Stiff vs. flexible, armoring vs. no armoring, loose or tight fibers.
  - Different producers

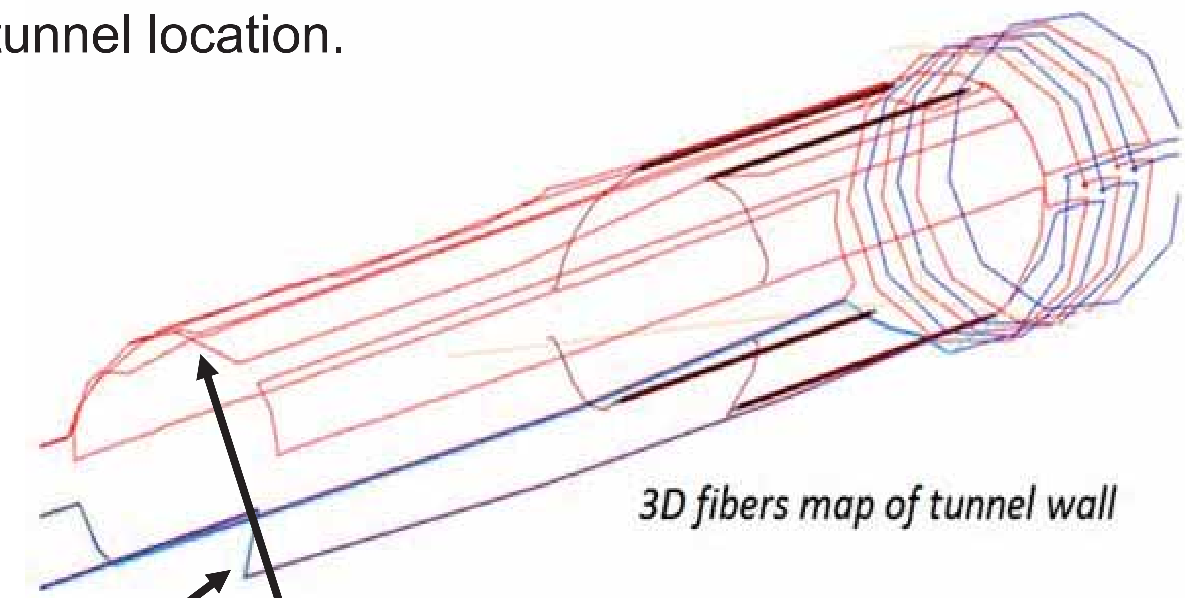


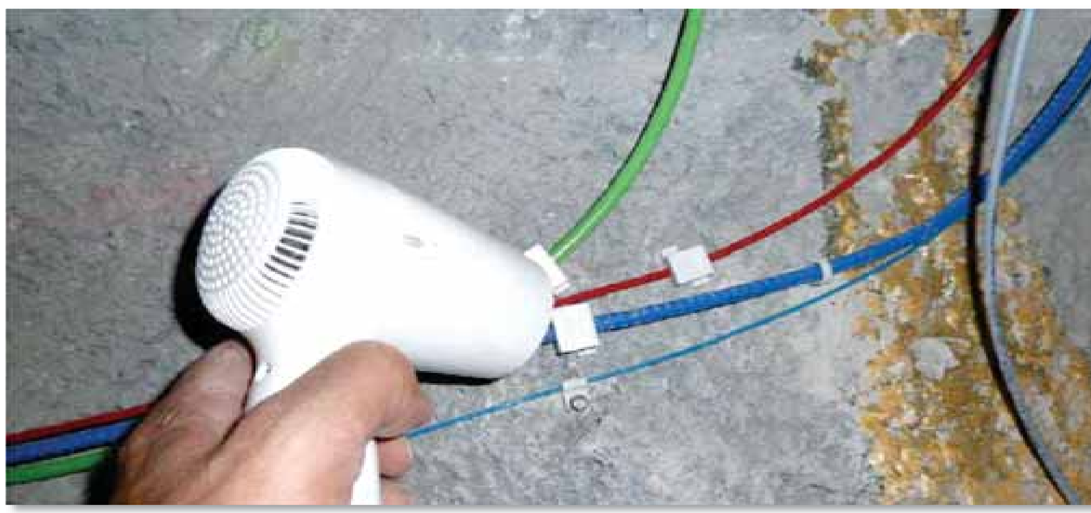


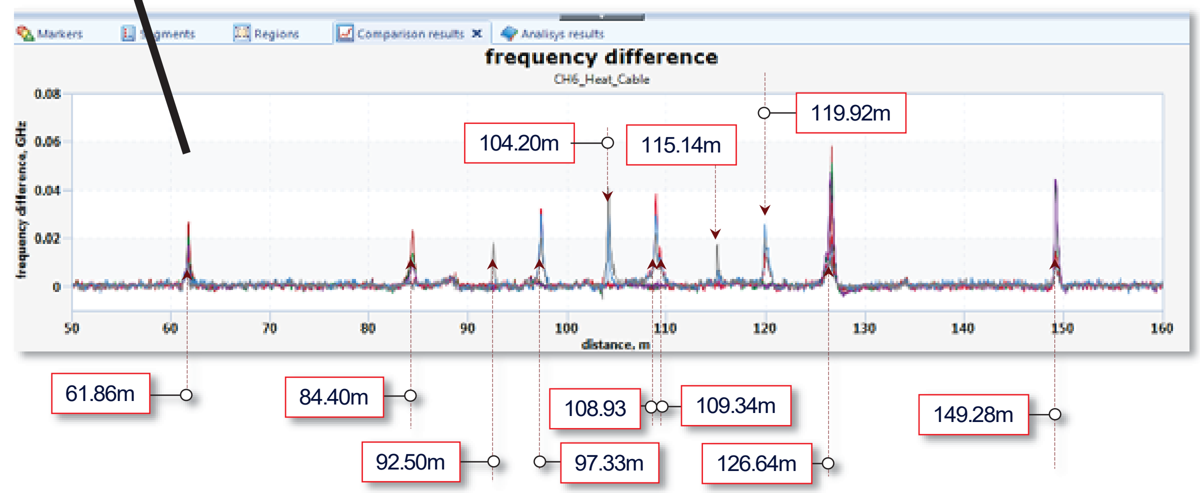


Fingerprinting

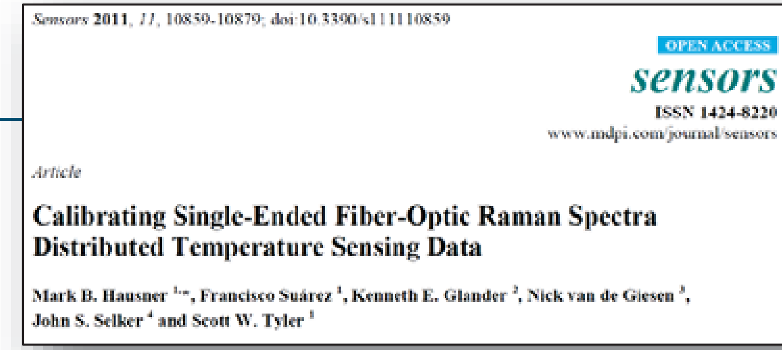
- Fingerprinting → convert cable meter into tunnel location.
- Hair dryer or ice spray was used.
- Crucial step during installation.
  - Quality control measures needed.
- Change of interrogator requires extensive data processing due to different spatial measuring intervals.







DTS calibration



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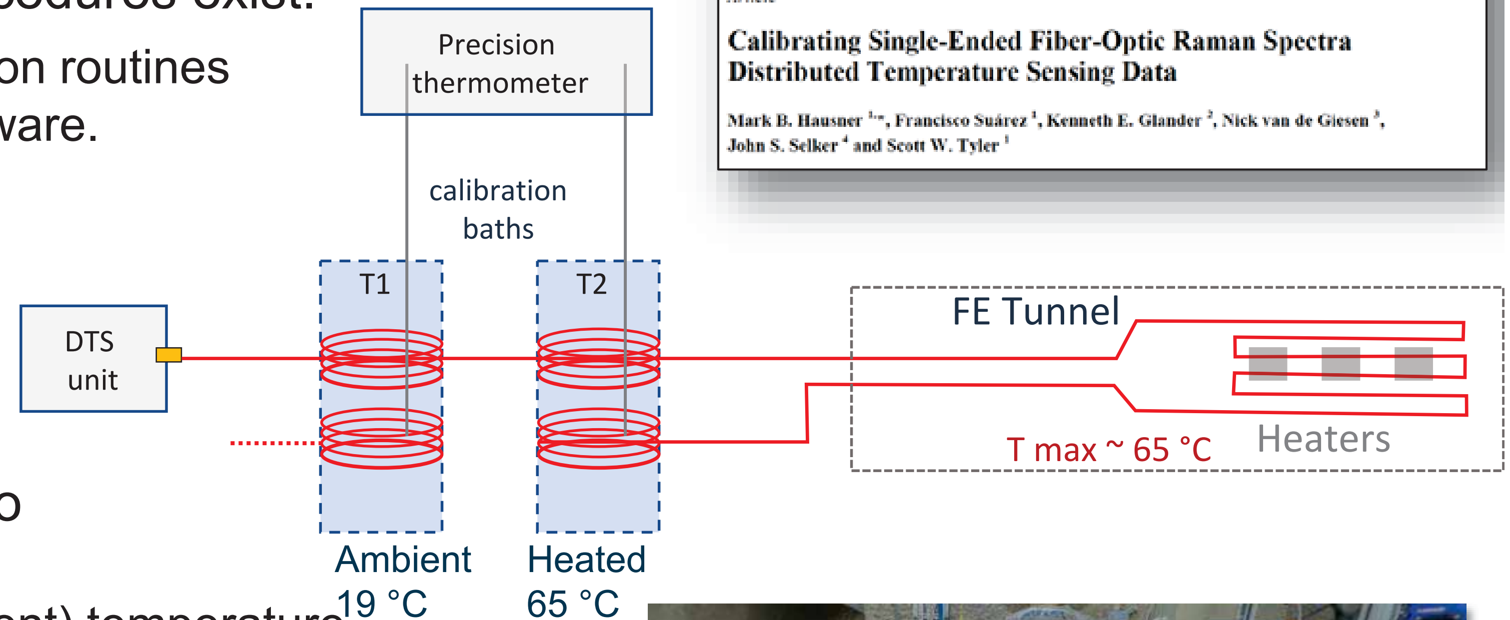
Article

Calibrating Single-Ended Fiber-Optic Raman Spectra Distributed Temperature Sensing Data

Mark B. Hausner [1,*], Francisco Suárez [1], Kenneth E. Glander [2], Nick van de Giesen [3], John S. Selker [4] and Scott W. Tyler [1]

- Different DTS (Raman) calibration procedures exist.
  - Factory setting or pre-installed calibration routines using the DTS device's calibration software.
  - Best method: Using raw data (Stokes/Anti-Stokes signal).
    → single ended measurements.
    → Hausner et al. 2011.



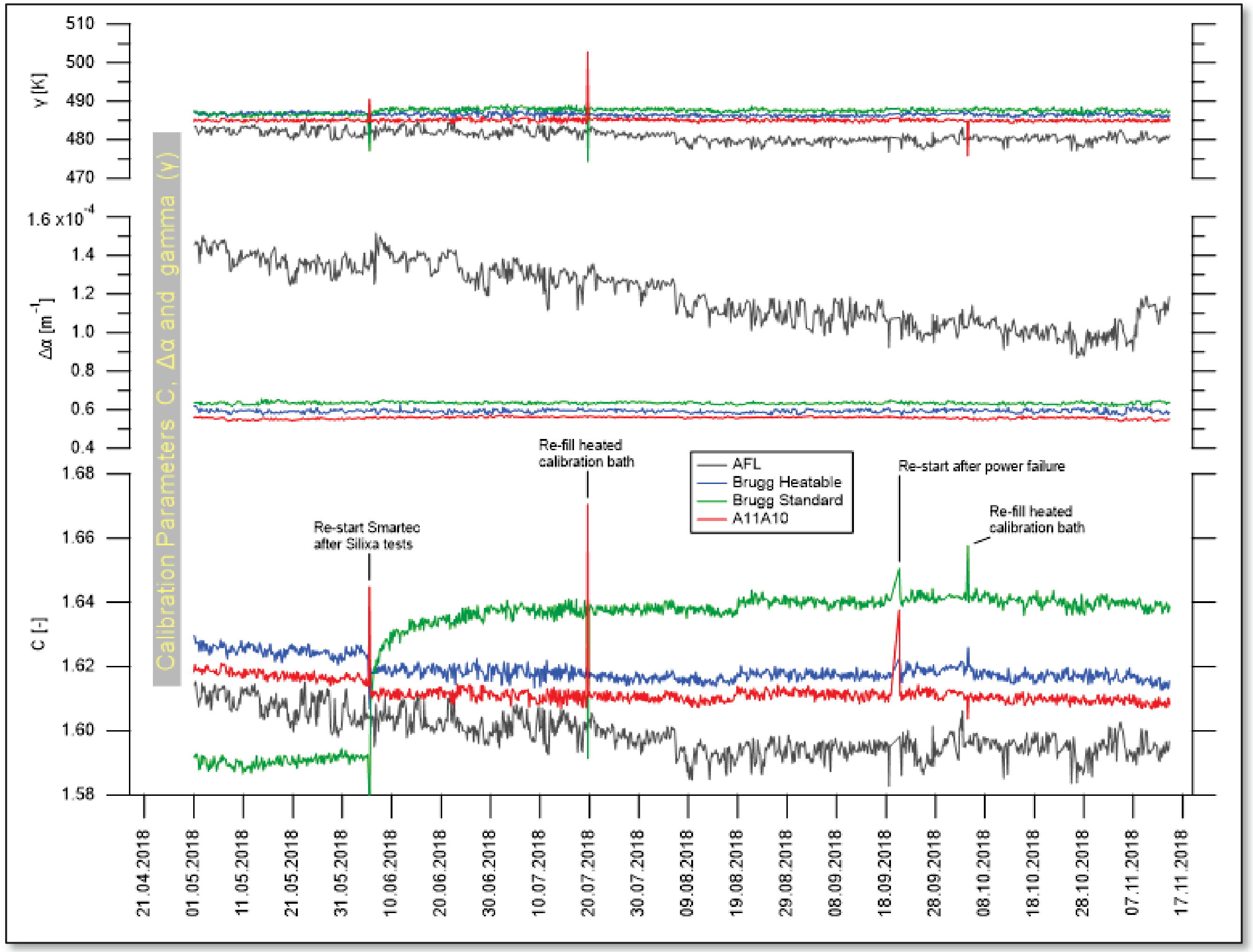
- Calibration baths with precision temp. sensors are needed for calibration or to determine accuracy.
  - Baths with high (heated) and low (ambient) temperature covering the expected temp. range.
  - Uniform temp. needed → mixer and good insulation.
  - At least 10 m, best 20 – 30 m of fiber-optic cable installed.

- FE database (FEIS) → calibration coefficients → "on-the-fly" for every single measurement → raw data conversion into temperature → average measurement accuracy of 0.1 - 0.3°C depending on FO cable type and DTS unit.

DTS calibration

$$T(z) = \frac{\gamma}{\ln \frac{P_S(z)}{P_{aS}(z)} + C - \Delta\alpha z}$$

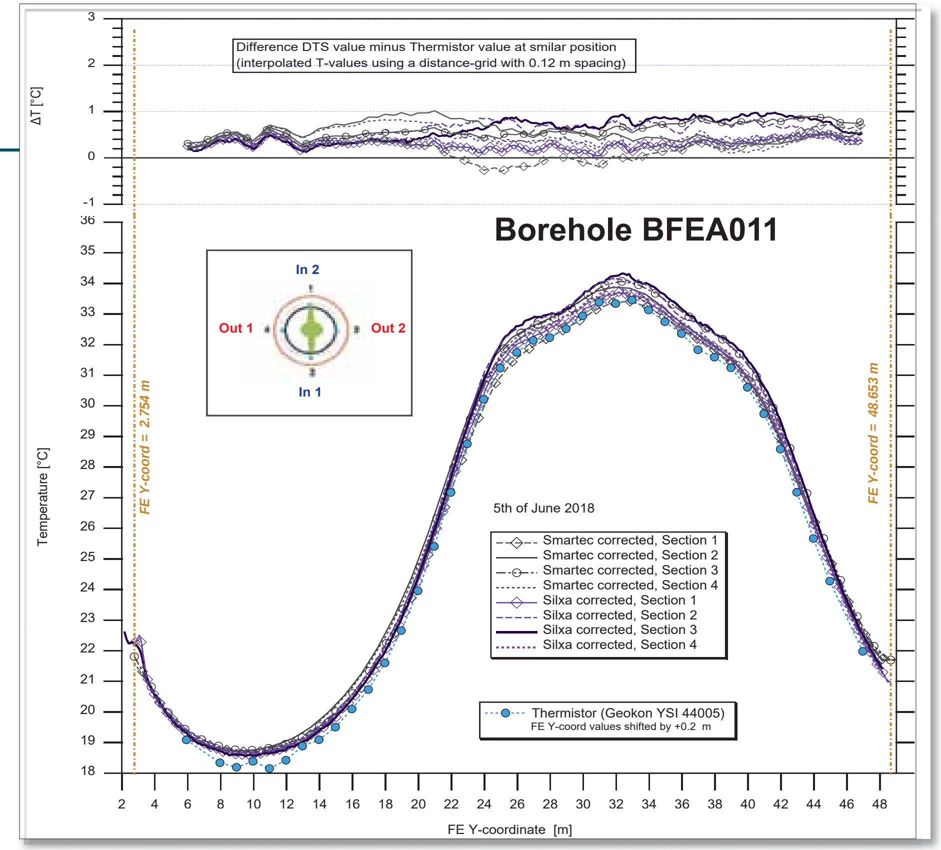
- Each fiber-optic cable needs individual calibration.
- Each DTS unit (interrogator) needs individual calibration.
- Calibration parameters are not constant. They change over time, e.g. with changing temperature inside the interrogator measurement unit.
  - Determination of calibration parameters for every single measurement.
- Locations along the fiber-optic sensor can be identified where the data quality is affected e.g. by light step losses.
  - Compensation in FE database (FEIS).
  - For standard "point" sensors, similar investigations are not possible.

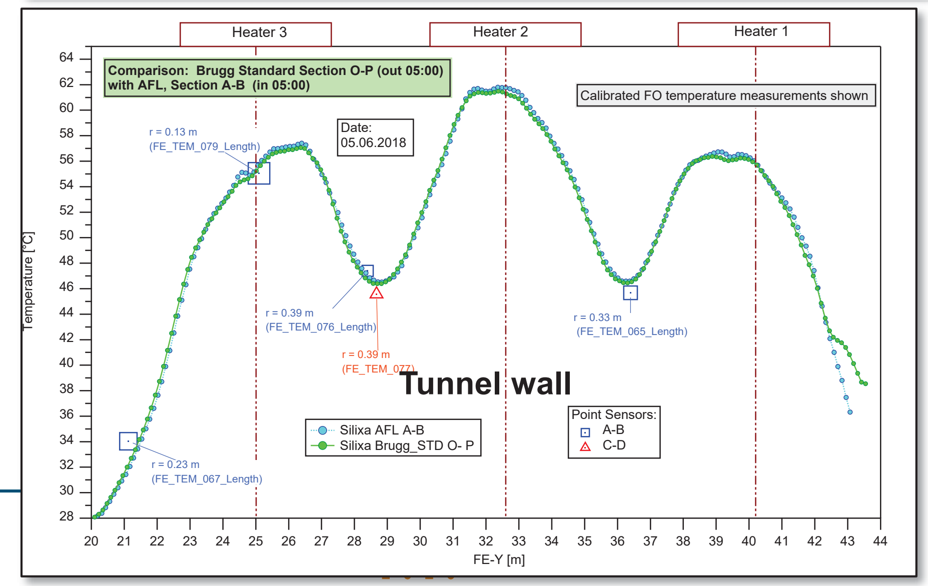


Variations of DTS calibrations parameters over time

Comparison of DTS to conventional temperature sensors

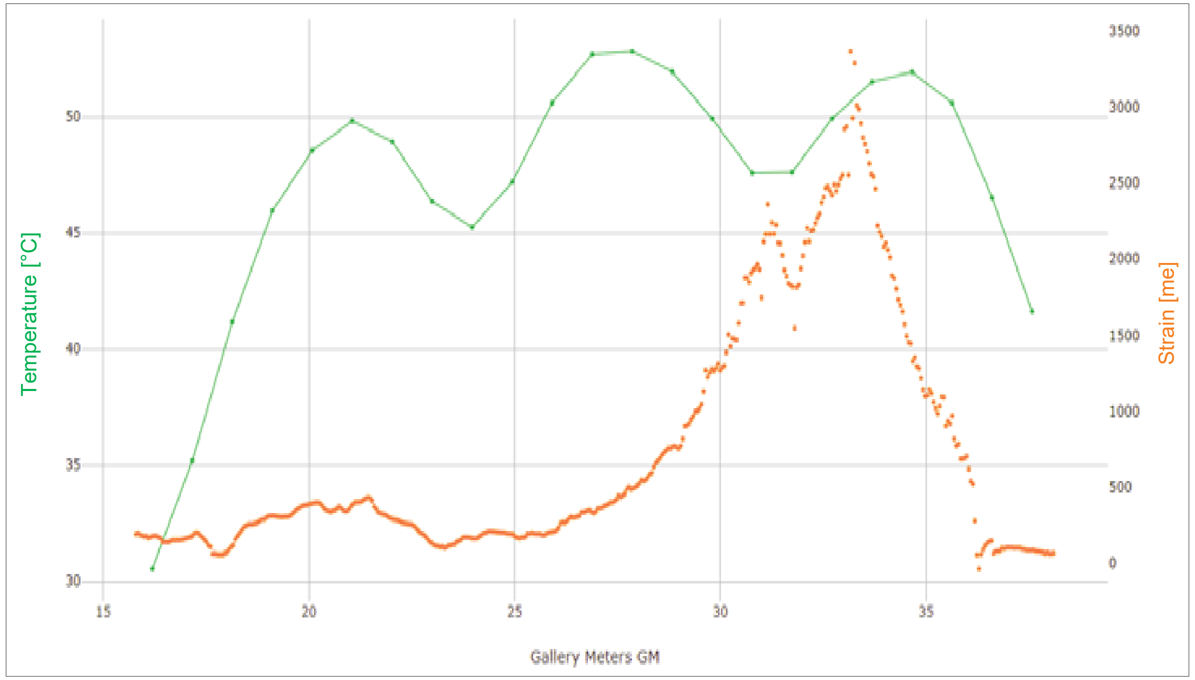
- In general good agreement.
- Small to moderate temperature gradients (<1°C/m): Very good agreement between DTS and standard point-type temperature sensors.
- High temperature gradients (of up to 6°C/m): Direct comparison with standard point-type temperature sensors is difficult due to DTS spatial resolution (FE: 0.25 – 1.02 m).
- DTS instruments with higher spatial resolution (<0.25 m) exist.
- ➢ FE Experiment: DTS provides reliable, detailed spatial temperature data at the scale of a emplacement drift.
  - Practically cannot be realized using conventional temperature sensors.





Distributed strain sensing

- Fiber-optic cables can be used as multi-purpose sensors.
- Strain distribution can be measured, too.
  - Strain is important monitoring parameter.
  - Brillouin and Rayleigh sensing → distributed strain sensing (DSS) → sensitive to both, strain and temperature.
  - Temperature compensation needed.
- Some fiber-optic cables show problematic behaviour → hysteresis, thermally induced strain → pre-test for sensor selection.
- The use of different cables in parallel for redundancy is strongly recommended. This allows excluding possible distortions resulting from the cable behaviour.
- High strain can affect the DTS data quality.

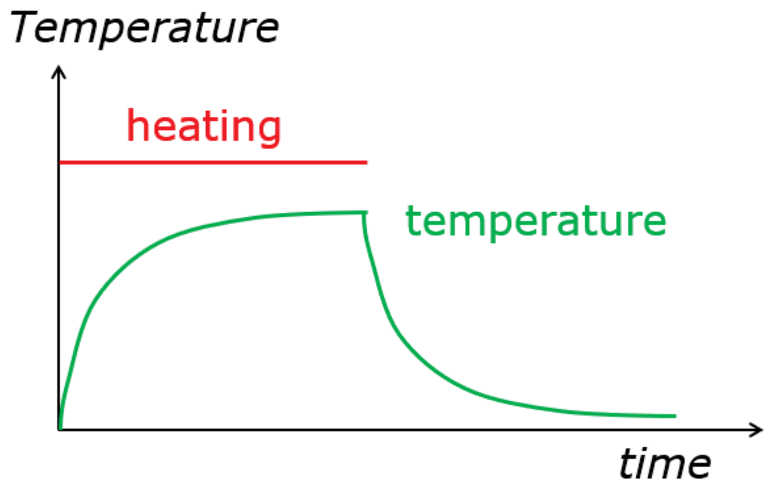


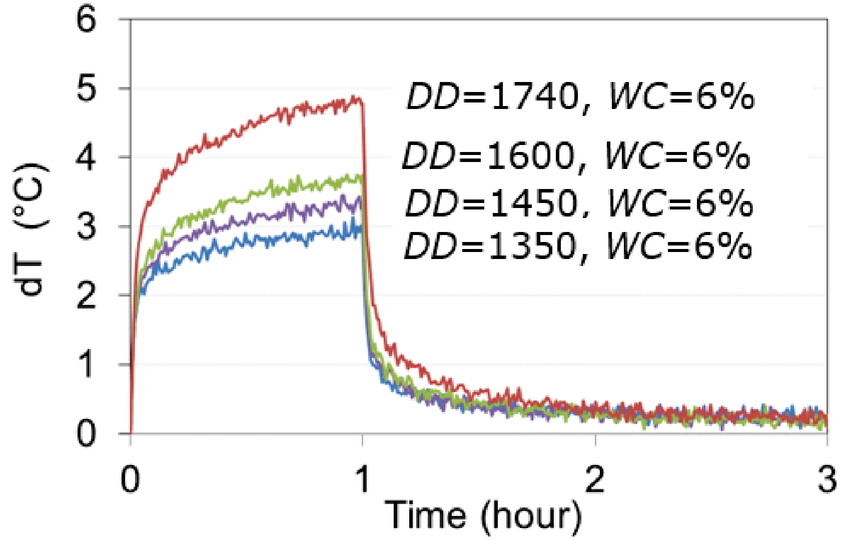
Temperature and strain distribution along tunnel wall measured with the same fiber-optic cable.
Measurement date: 07.04.2019

Active DTS: Heatable fiber-optic sensors and DTS

- Fiber-optic cables can be use as multi-purpose sensors.
- Determination of bentonite (tunnel backfill) properties at scale of emplacement drifts.
- Electrical heating of entire fiber-optic cable combined with DTS.
  - Active DTS.
  - Analysis of heating and cooling response along cable.
- → Density and water content distribution.
- → Detection of “air pockets” in bentonite → quality control during backfilling.

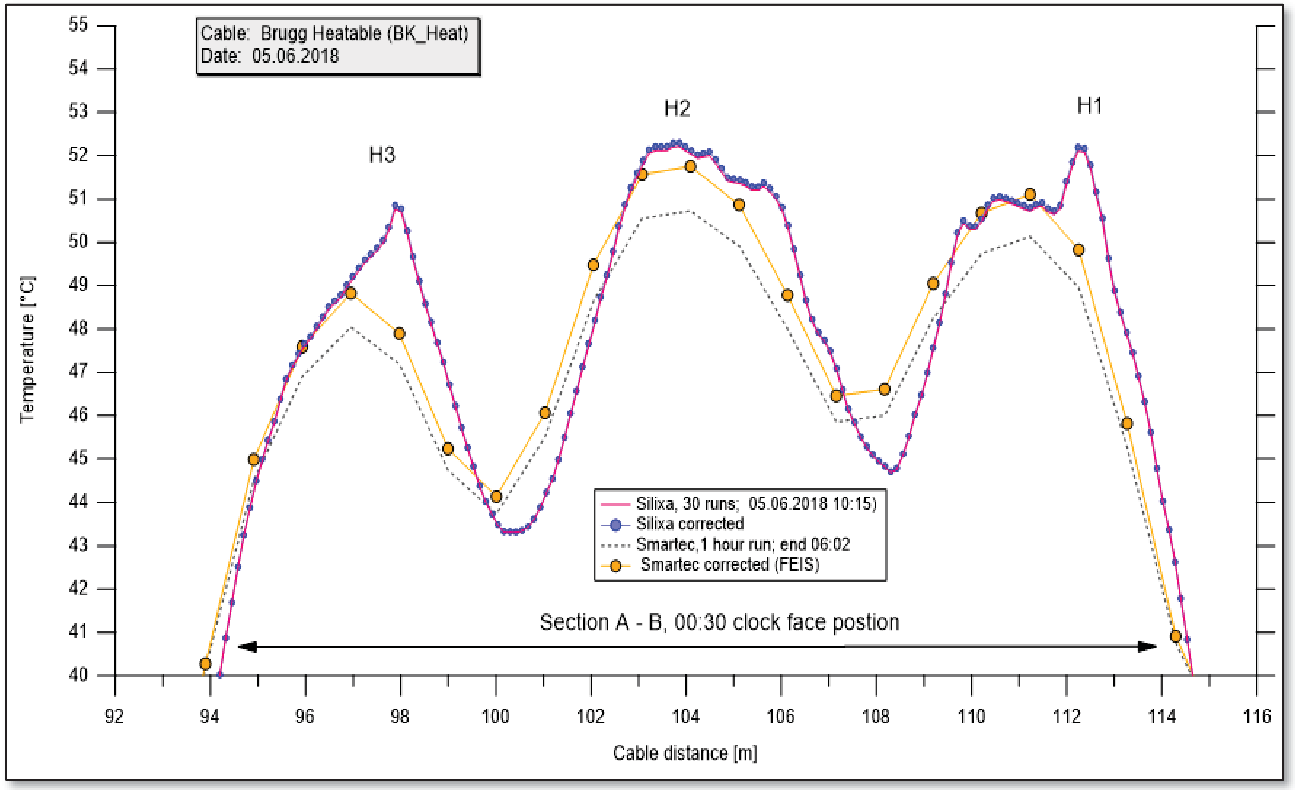
Posters by Firat Lüthi et al. & Sakaki et al. about heatable fiber-optic sensors and DTS





Practical limitations

- Fiber-optic instruments (interrogators) are very sensitive to dust intrusion.
- FE Experiment: DTS unit failed twice due to dust intrusion.
- Swap of DTS units → different spatial measuring intervals.
- Modelers are not yet accustomed to high-resolution spatial data in their simulations.
  - Level of detail is not within the scope of their modeling objectives.
  - Models' grid or cell sizes are insufficient for handling a fine spatial resolution.

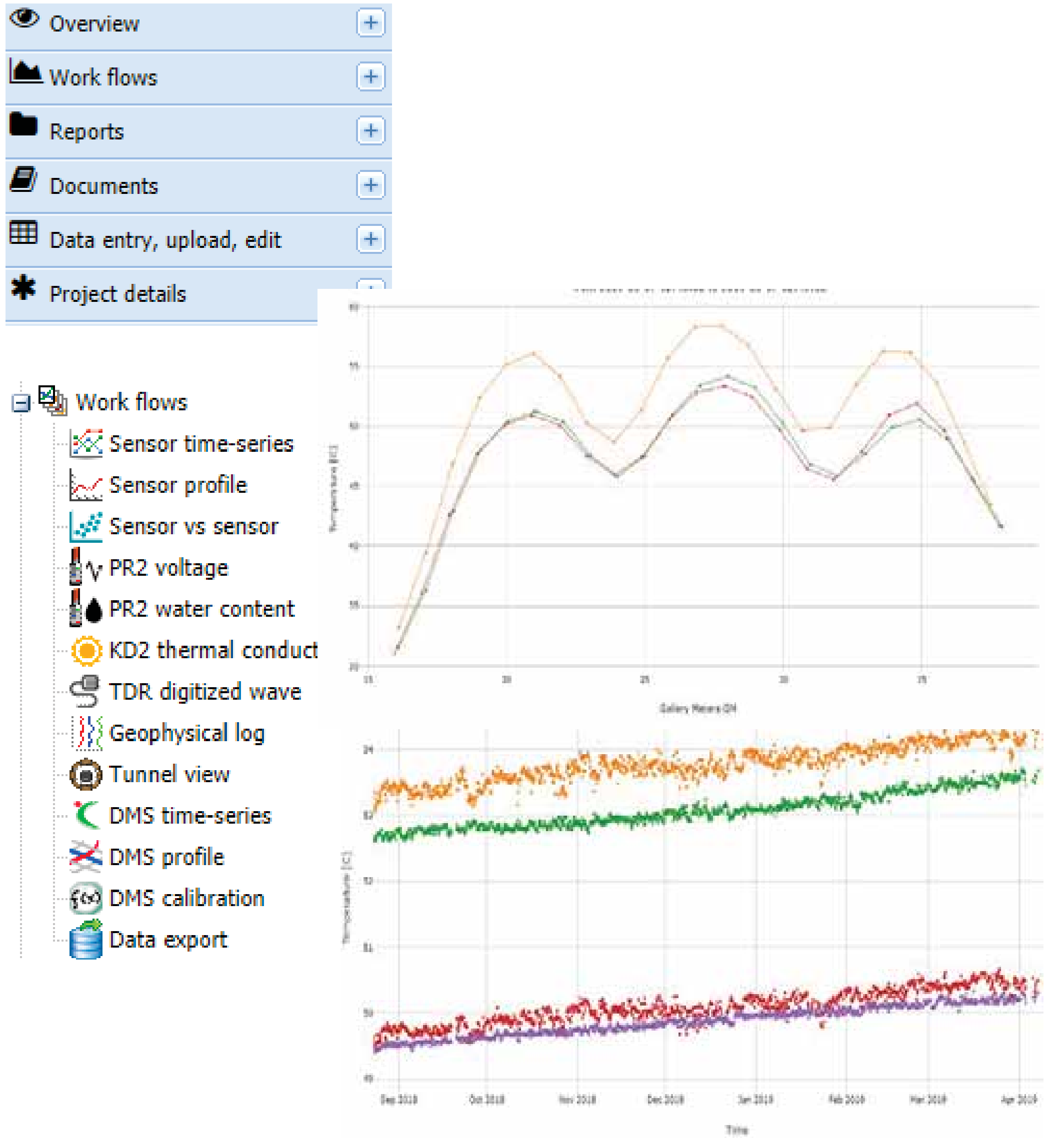


Longitudinal temperature distribution along tunnel wall (00:30h position) measured with 2 different DTS units.

FE Information System (FEIS)

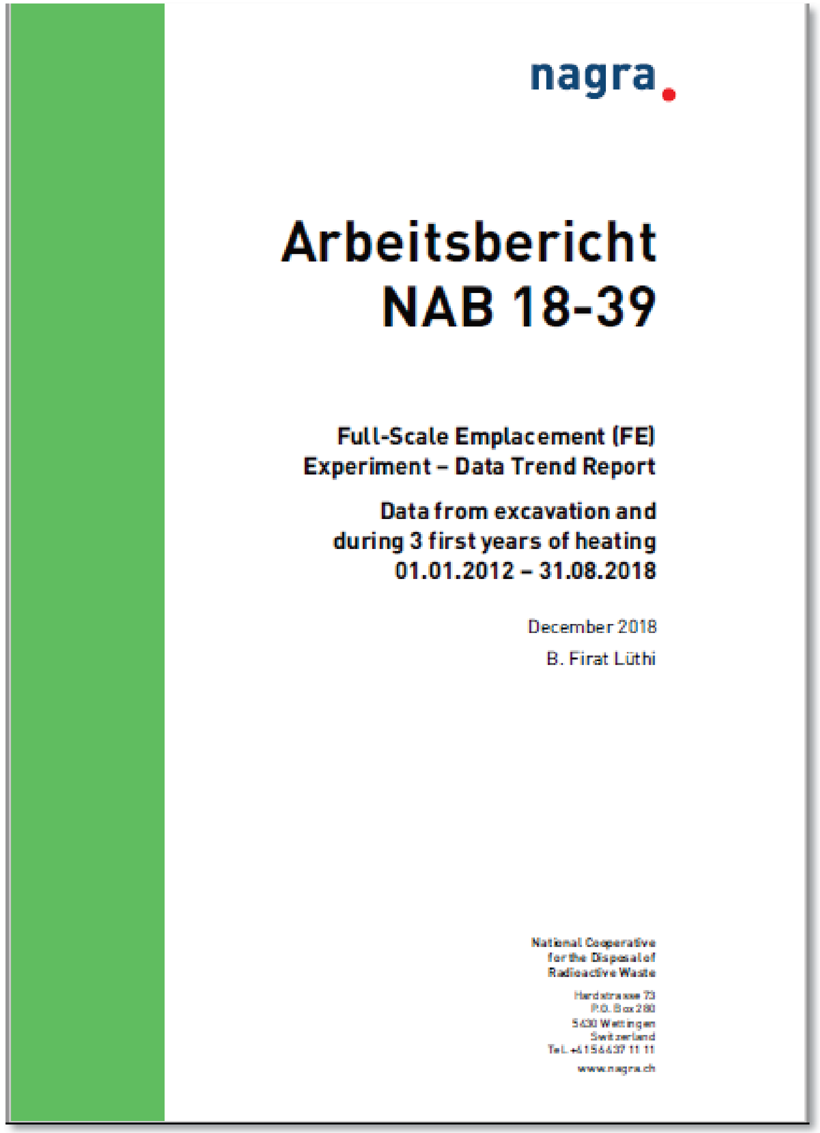
Poster by Yeatman et al.:
3D Overarching Scientific Information System for the FE experiment

- DTS data create new challenges for data management.
  - DTS and DSS generate a lot of data.
  - Data come in the form of profiles.
  - Specific profile format is untypical for standard databases.
- Development of the FE Information System (FEIS).
  - Overarching database and information system for all FE sensors.
  - Internet browser application. Incorporates SQL database.
  - Fast access to and export of sensor data. Workflows for comparison of fiber-optic to standard sensors.
  - Dynamic calibration coefficients are calculated for each DTS measurement as the data are added to the database.
  - FEIS relates the location of distributed measurements along a FO cable to FE project locations in 3D-space. The routines account for varying spatial resolution that can result from different measuring units and instrument settings.



FE Information System (FEIS)

- Many internal and external stakeholders are interested in the FE monitoring data.
  - Stakeholders have different backgrounds, different interests, different way of data use.
- Data sharing concept.
- FEIS offers various access levels for each user.
- Information data can be downloaded or viewed.
- Experience of FE Experiment: Most stakeholders prefer a condensed summary of the monitoring data (e.g. annual reports and annual data deliveries), rather than having direct access to the database.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Arbeitsbericht
NAB 18-39

Full-Scale Emplacement (FE)
Experiment – Data Trend Report

Data from excavation and
during 3 first years of heating
01.01.2012 – 31.08.2018

December 2018
B. Firat Lüthi

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for the Disposal of
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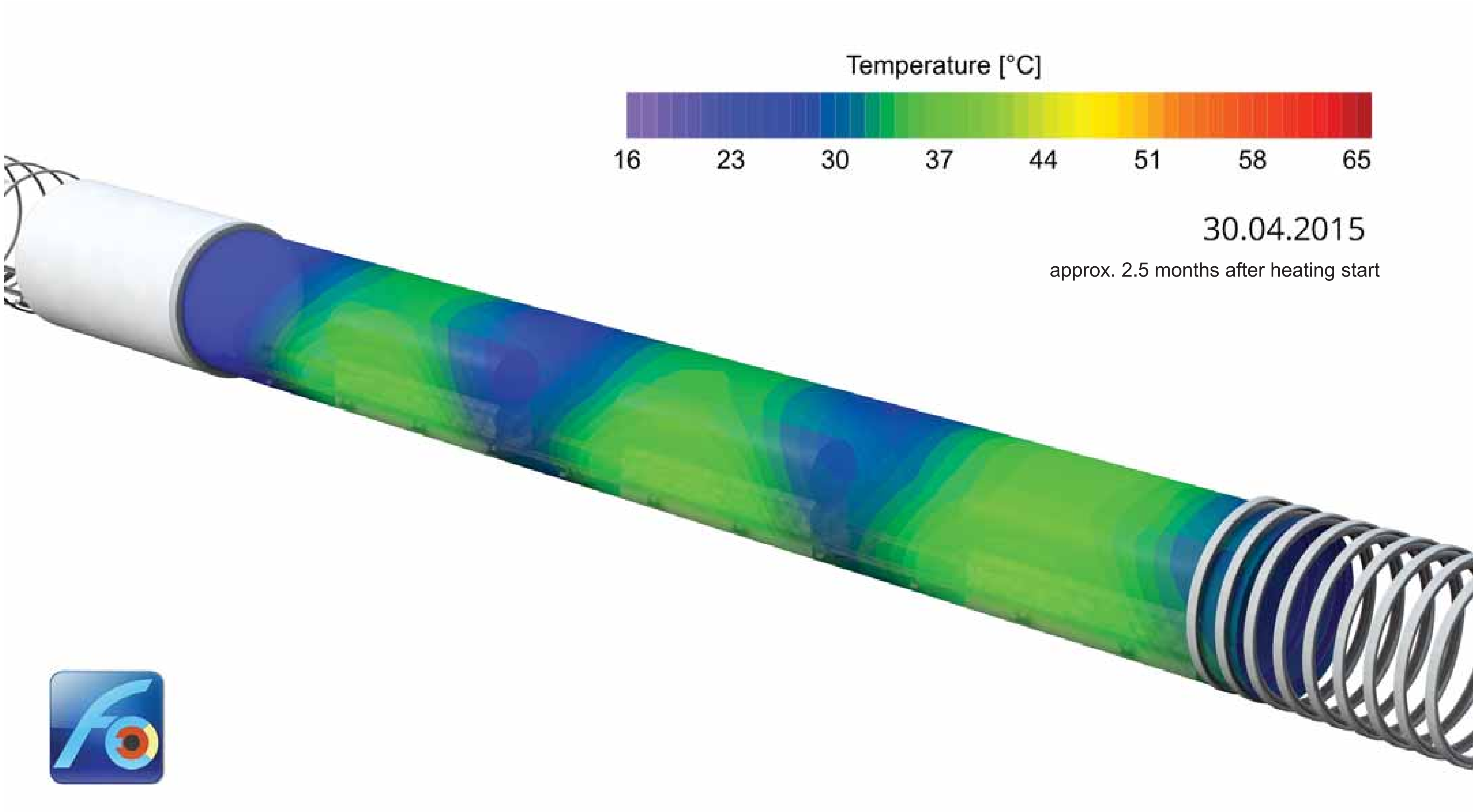
Temperature distribution at FE tunnel wall by means of DTS



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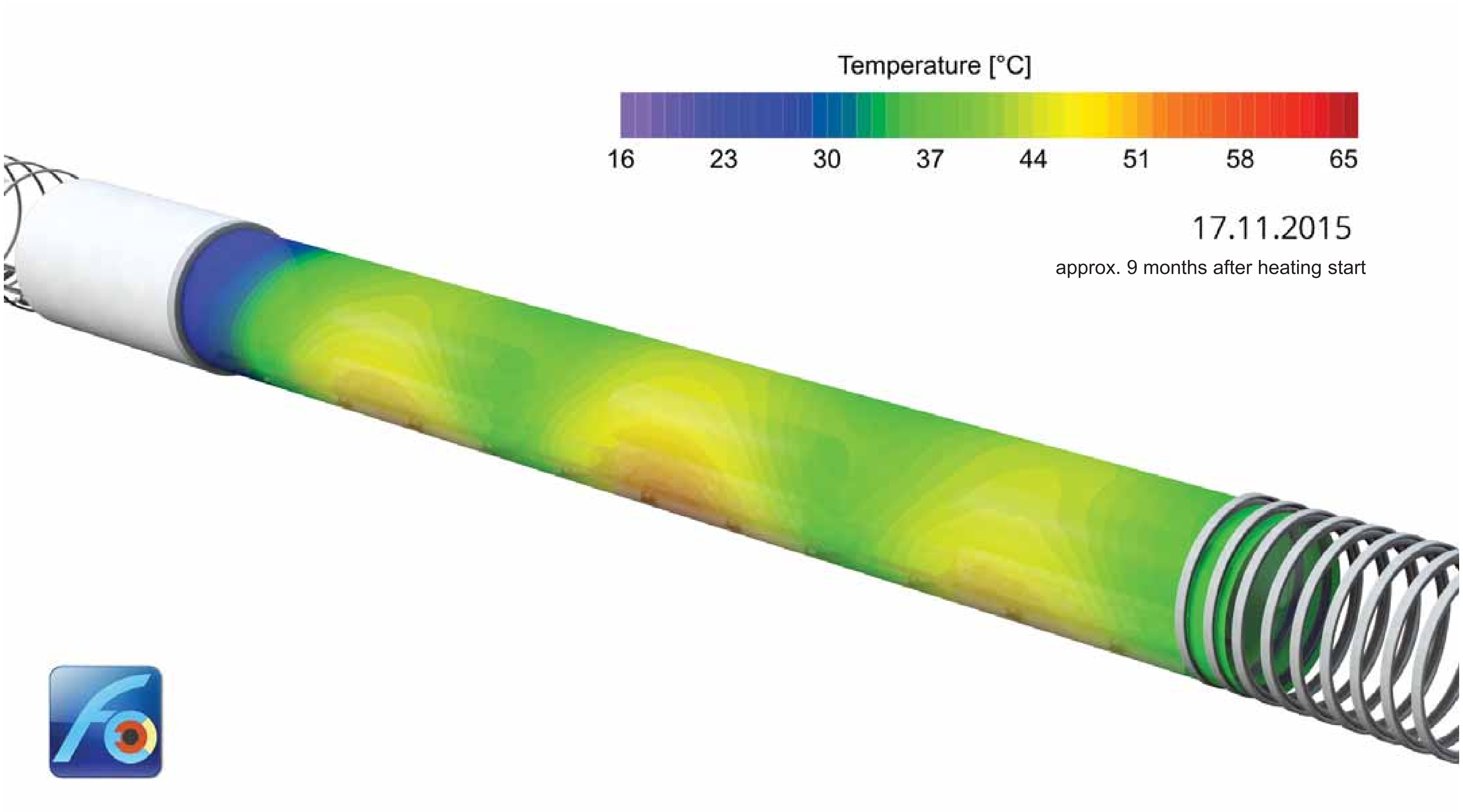

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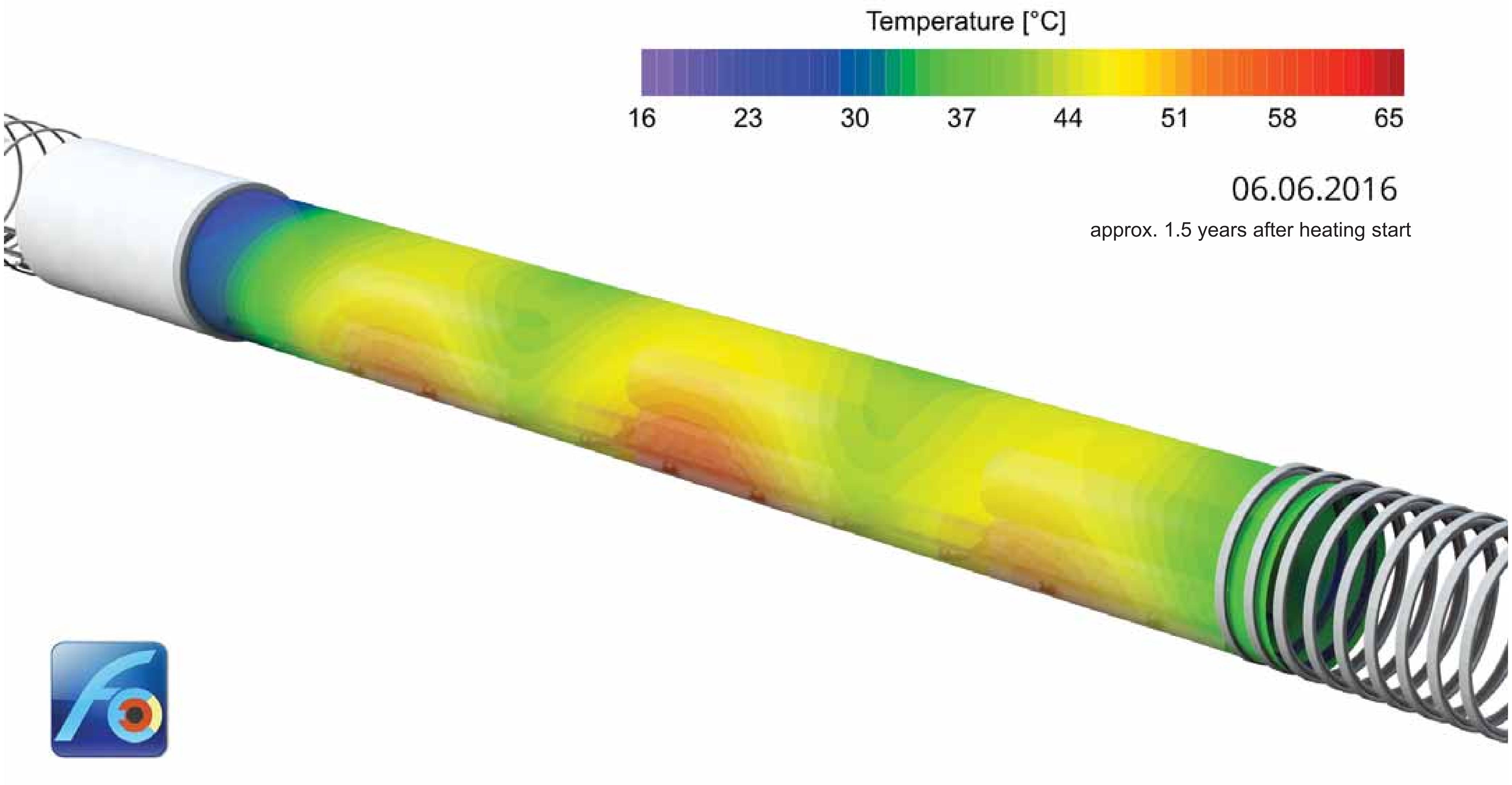

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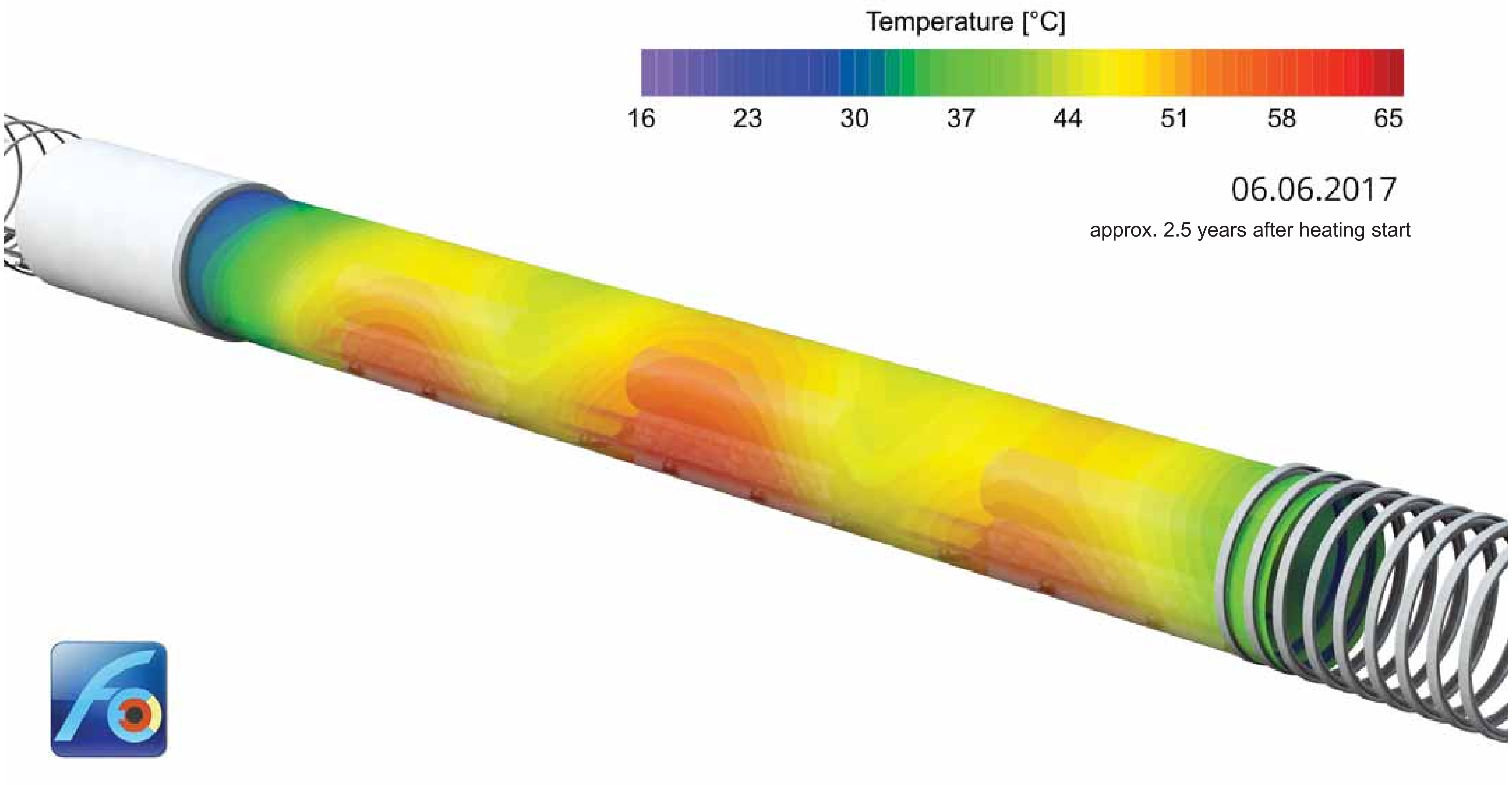

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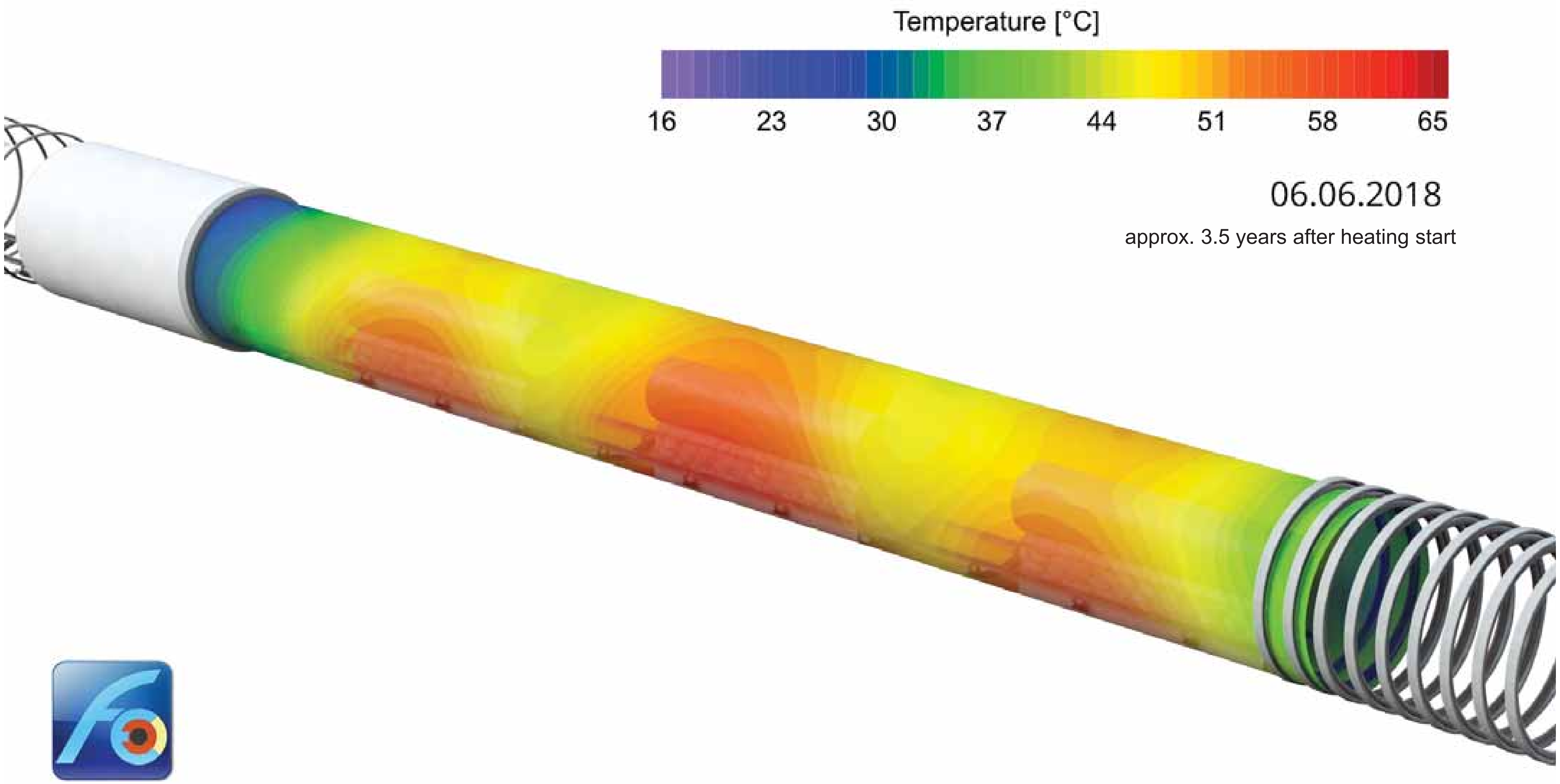

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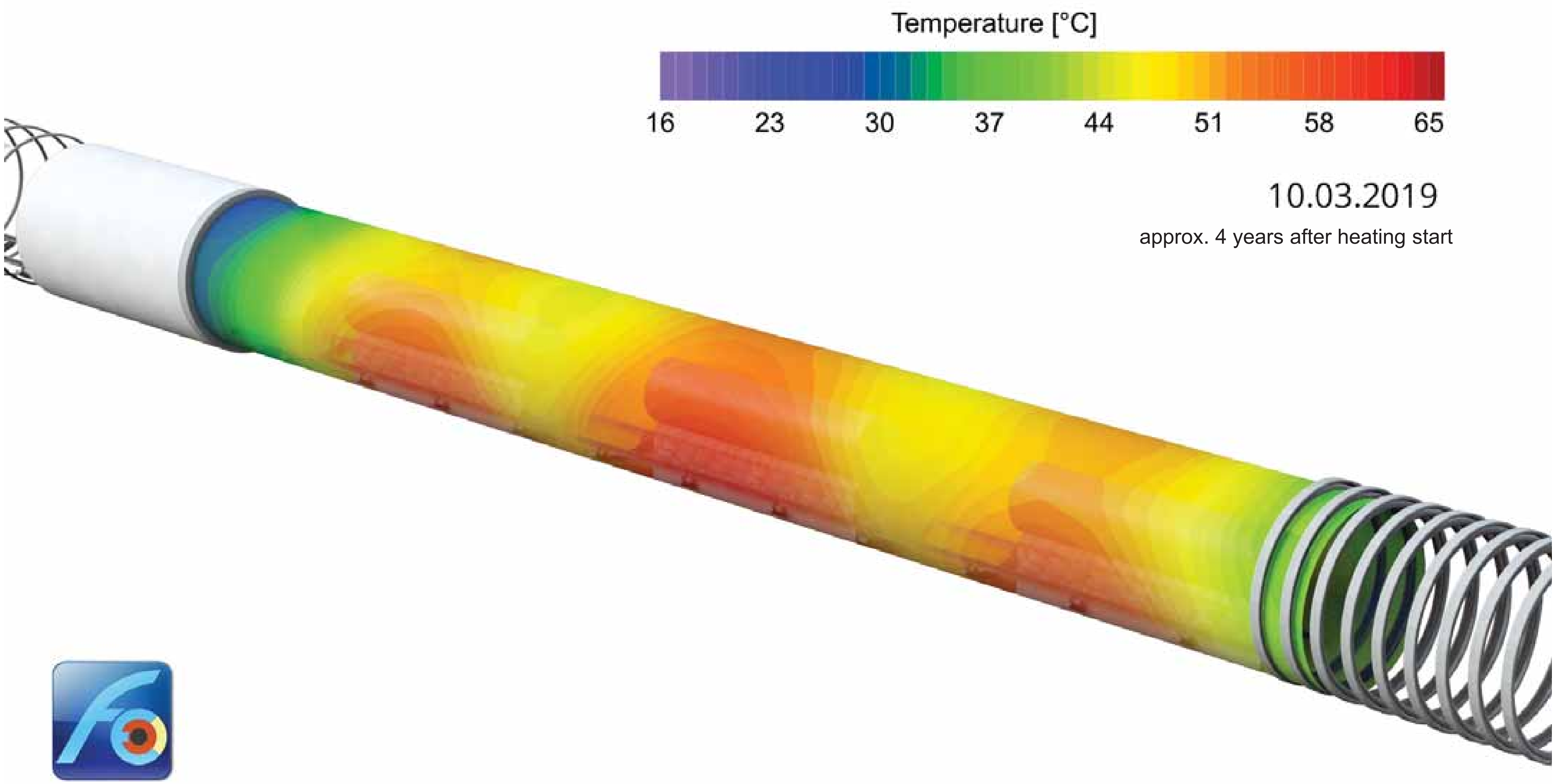

Conclusions

- Demonstration and evaluation of DTS technology under repository like conditions in the FE Experiment.
- **DTS**
  - Comprehensive calibration set-up is required covering the expected temperature range.
  - **Spatial and temporal variations of the temperature field within high-level waste emplacement drifts can be determined sufficiently accurate** → new insights into heat transport in the buffer and host rock.
  - Selection of DTS-unit and fiber-optic sensors → different accuracy and resolution → performance.
  - Fiber-optic cables can be used as multi-purpose sensor.
- FE Information System (FEIS) and data sharing.
  - Overarching database including DTS data.
  - Easy to use workflows and dynamic calibration of each DTS measurement.
- Promote the advantages of innovative monitoring technologies such as the DTS monitoring and FEIS for different stakeholders.

- Acknowledgements: This work was partly funded by the Swiss State Secretariat for Education, Research and Innovation (SERI) as part of the Modern2020 project (Euratom research and training programme 2014–2018, grant agreement No 662177).

thank you
for your attention

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