Sicherheit in Technik und Chemie

Bundesanstalt für Materialforschung und -prüfung

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Niches of fiberoptic sensing: from large-strain applications to acoustic emission monitoring

Pavol Stajanca

Division 8.6 Fibre Optic Sensors

Federal Institute for Material Research and Testing (BAM)

- National research, testing and advisory body for safety in technology and chemistry

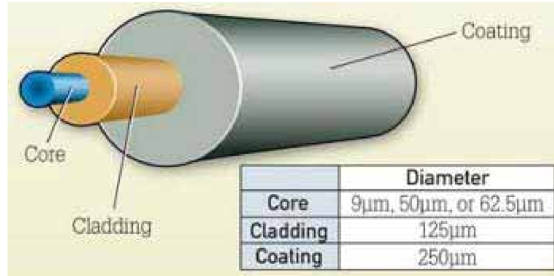
- **BAM**
  - Dep. 8: Non-destructive testing
    - Div. 8.6: Fiberoptic sensors

Various competences in fiberoptic sensing (FOS):

- Point sensors (FBGs, Interferometers)
- Distributed FOS (Rayleigh, Brillouin, Raman)
- Polymer optical fiber sensors
- Development of novel FOS techniques
- Application/integration of fibers in structures

Fiberoptic sensors (FOS)

- Compact
- Lightweight
- Electrically passive
- Immune to electromagnetic interference
- High temperature/pressure/chemical/radiation resistance
- Possibility of real-time remote sensing
- Multi-point & distributed sensing possible (long distances)



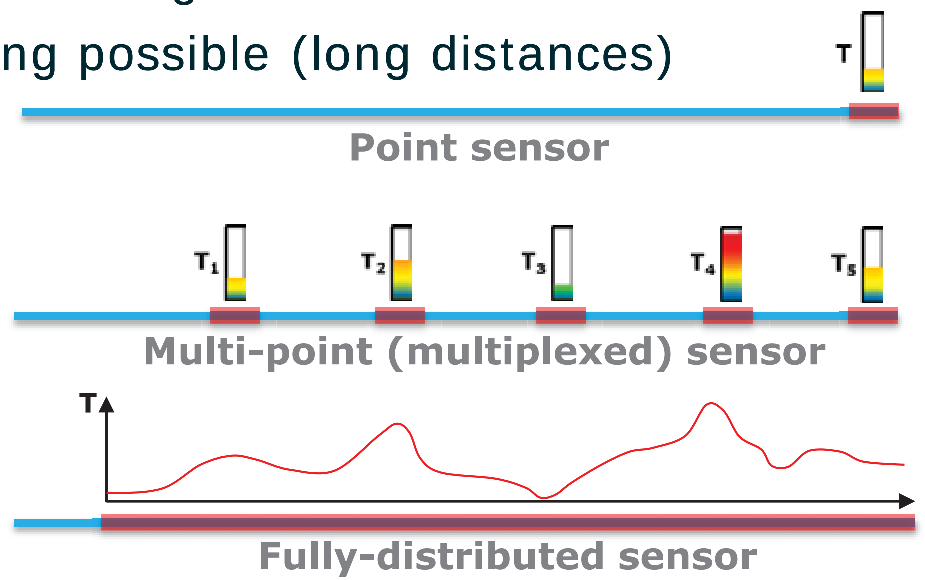
	Diameter
Core	9µm, 50µm, or 62.5µm
Cladding	125µm
Coating	250µm

Attractive for harsh, hazardous and difficult-to-access environments

Measurands:

- Strain
- Temperature
- Pressure
- Humidity
- Chemicals
- Radiation

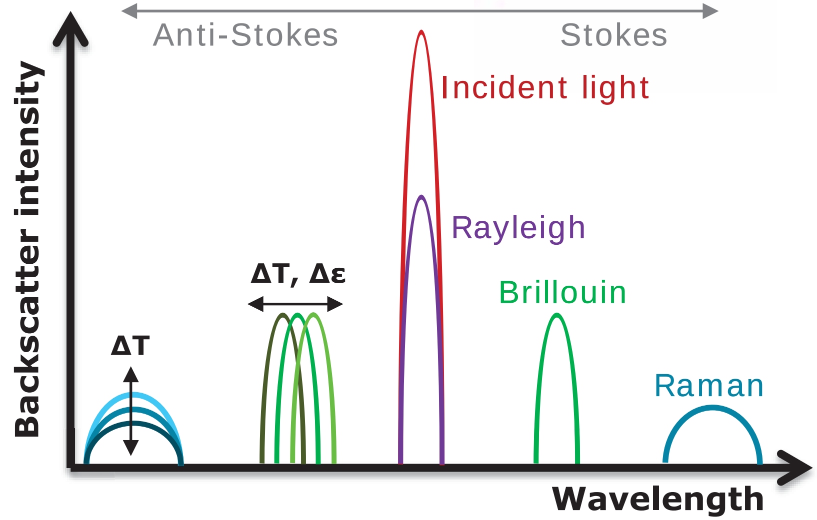
Most common

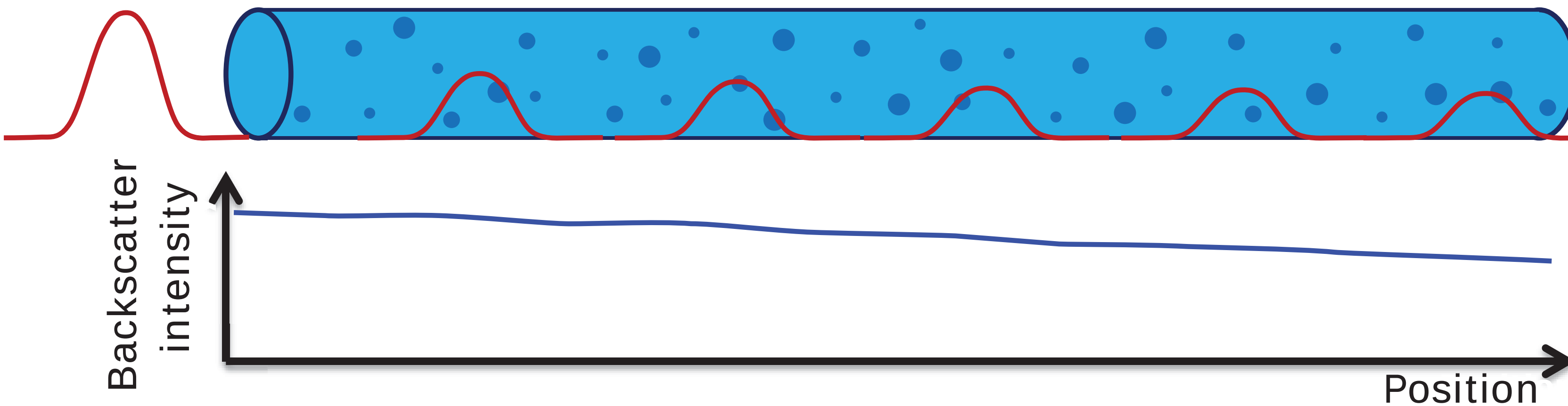


Distributed FOS

Light backscattering in optical fiber

- Rayleigh - Material inhomogeneities
- Raman - Thermal molecular vibrations (optical phonons)
- Brillouin - Coherent material lattice vibrations (acoustic phonons)





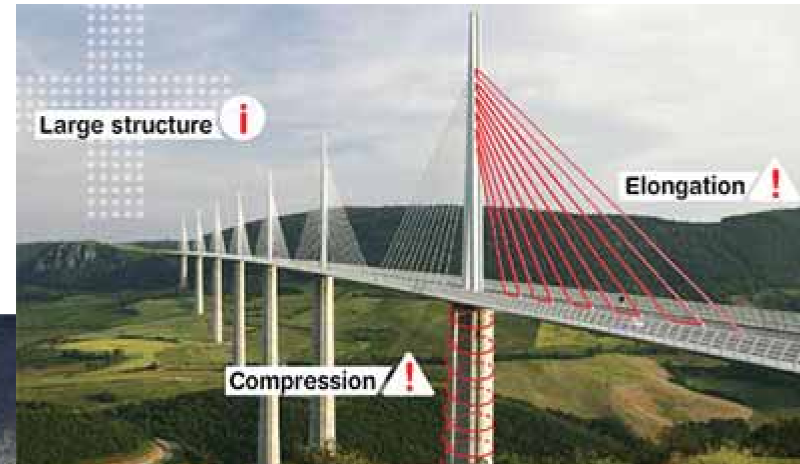
Spatially-continuous distributed measurement over extended distances

- Strain and temperature are the most common measurands

FOS markets

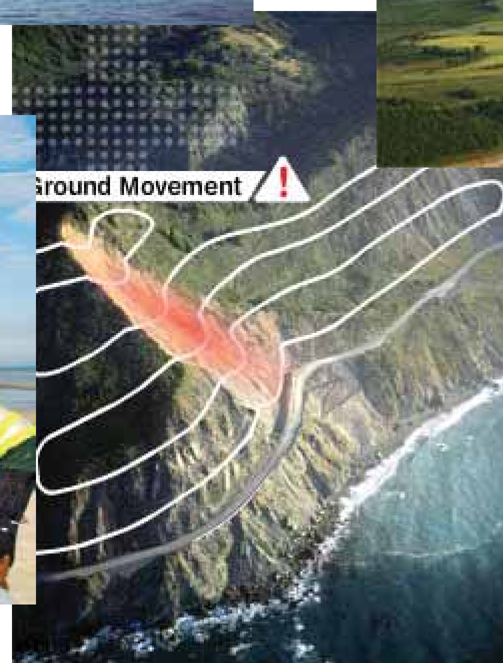
- Strain and temperature monitoring of large civil, energy and geotechnical structures

https://fibercore.com



https://omnisens.com

https://cleanenergywire.org

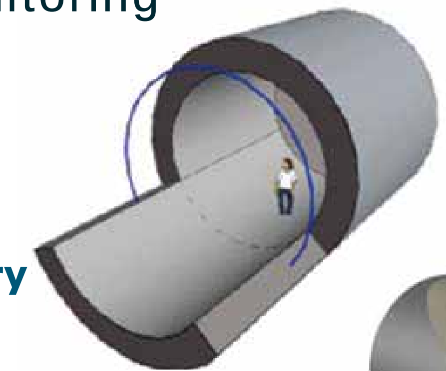


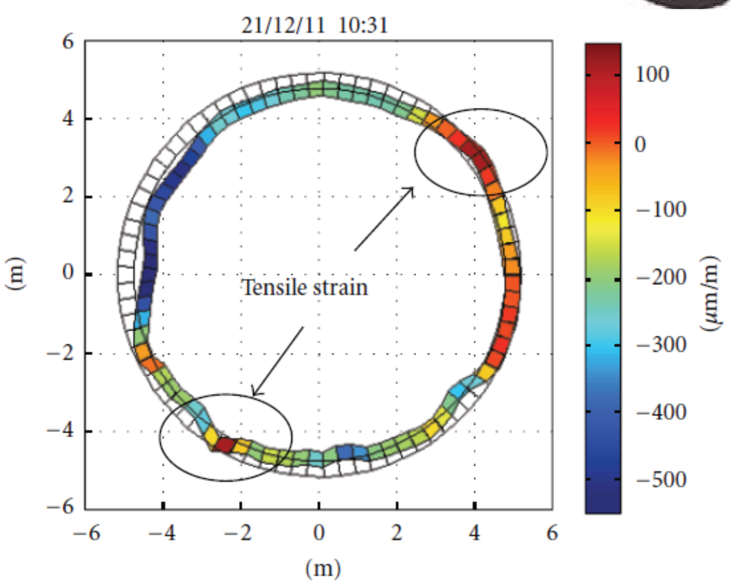
http:/powerspecialties.com

FOS in nuclear waste management

- Structural health monitoring (SHM)
- Temperature monitoring

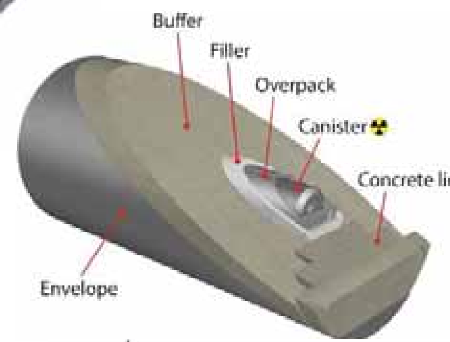
SHM of underground nuclear waste repository (ANDRA, France)

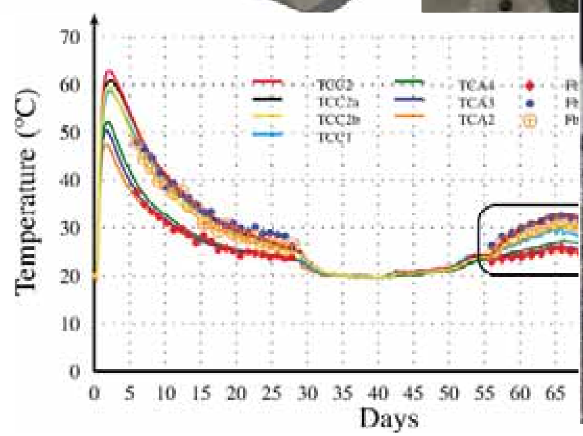




Delepine-Lesoille et al., J. Sensors 2012 (2012), 369375.

FBG temperature monitoring in nuclear waste containers (ONDRAF, Belgium)

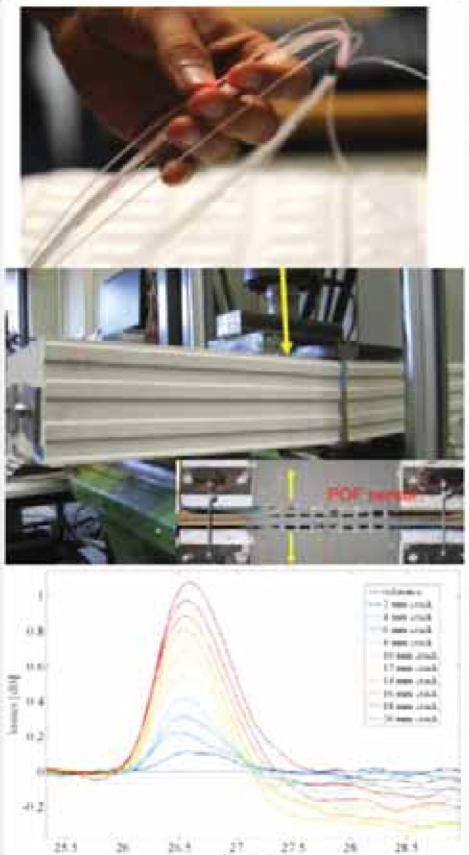




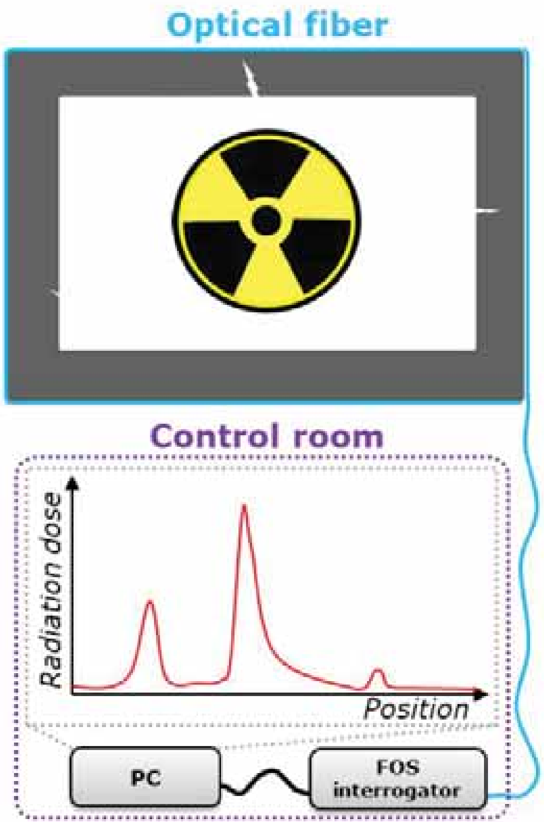
Kinet et al., IEEE Trans. Nucl. Sci. 63 (2016), 1955.

Alternative FOS applications

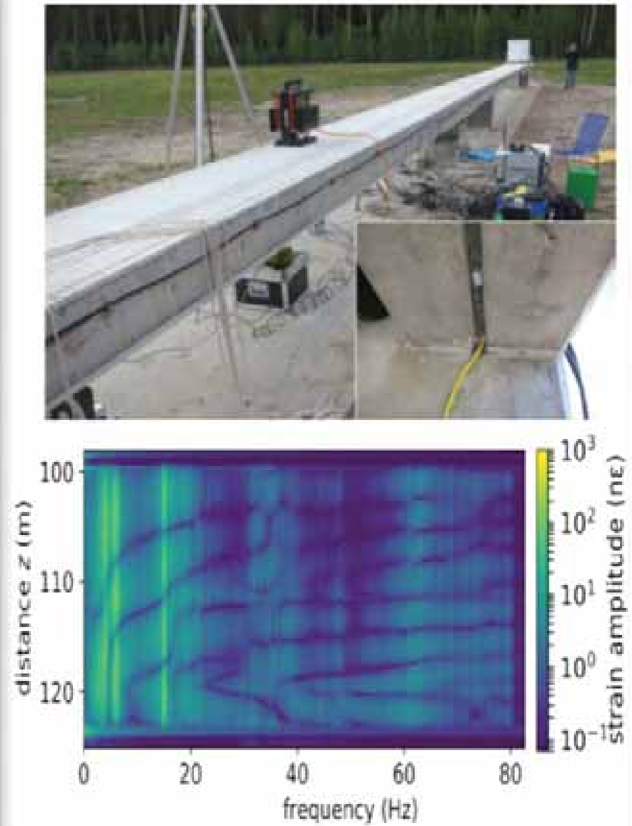
Polymer optical fibers for large-strain sensing



Polymer optical fibers for radiation monitoring



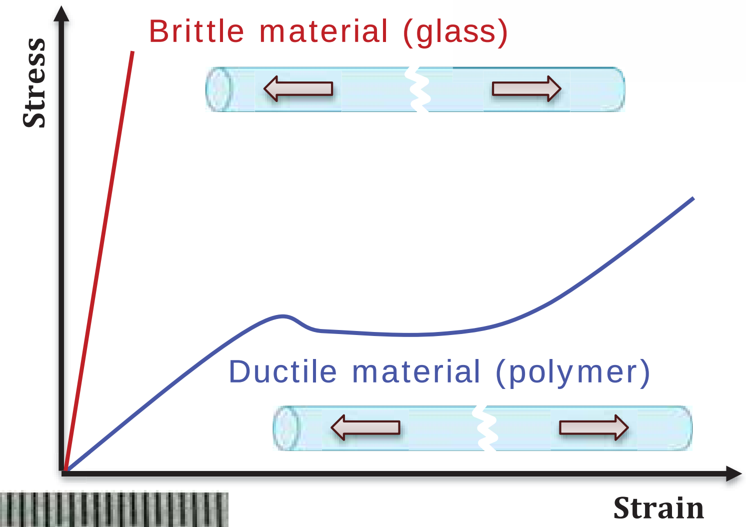
Distributed vibration/acoustic sensing



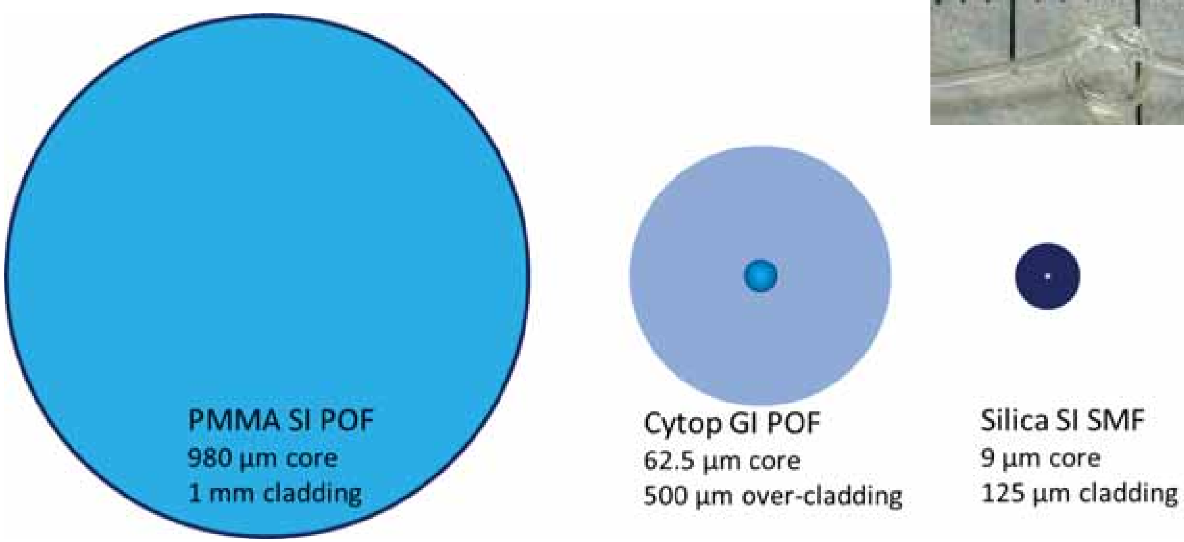
Polymer vs. glass optical fibers

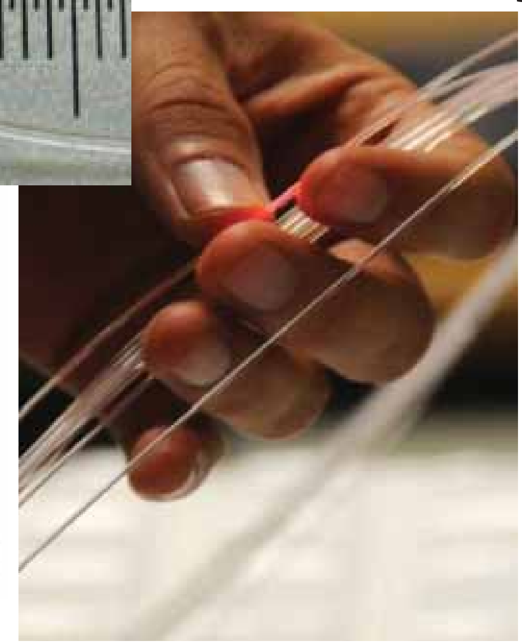
Polymer optical fibers (POFs)

- Higher elasticity and lower stiffness
- High ultimate strain limit (up to 100%)
- Easy handling (user friendlier)
- Ease of processing
- Cheap

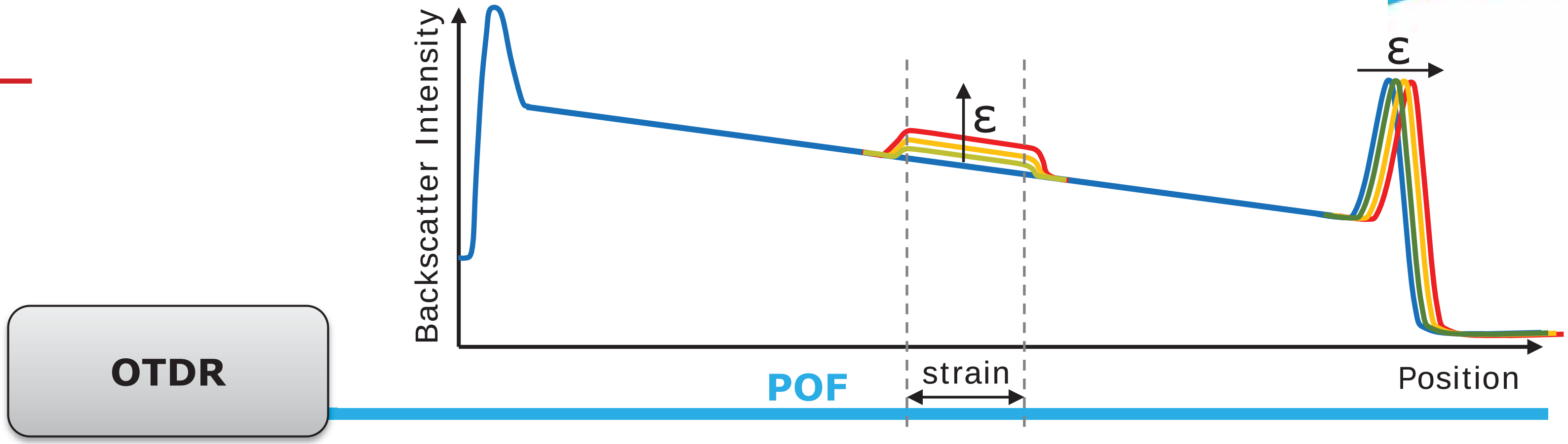


Drawback -> higher attenuation



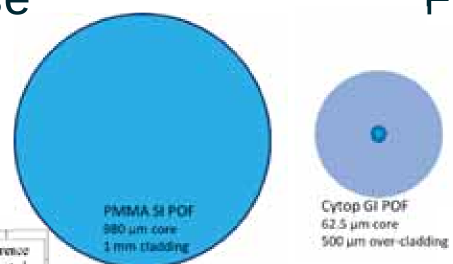


Rayleigh-based strain sensing with POFs



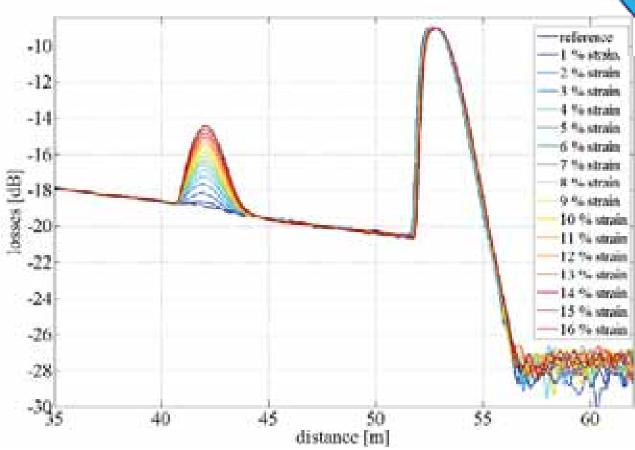
Local backscatter increase

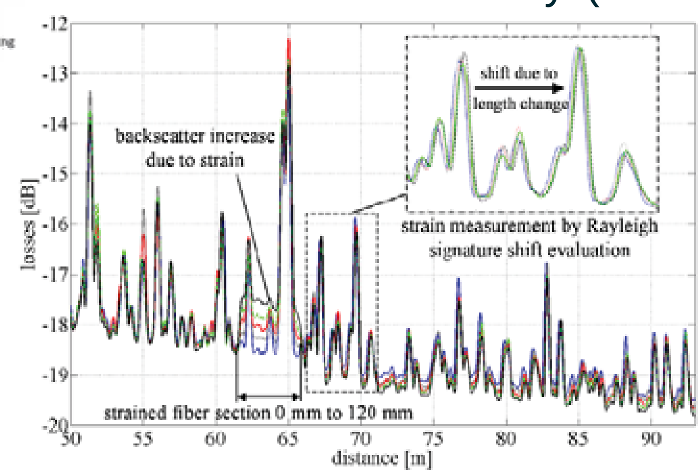
- Large-core PMMA POF
- Optical time-domain reflectometry (OTDR)



Fiber length-change measurement

- Perfluorinated Cytop POF
- Incoherent optical frequency-domain reflectometry (I-OFDR)





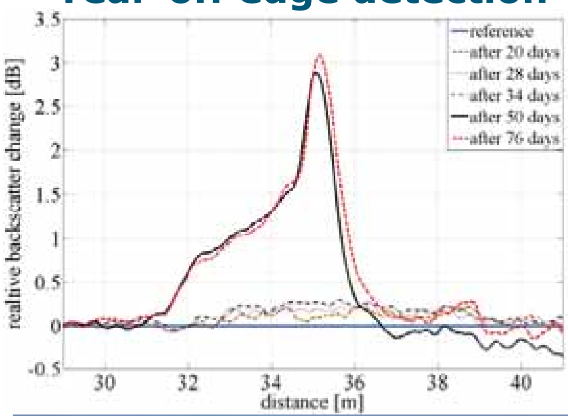
Liehr et al., IEEE Sensors 9 (2009), 1330-1338.

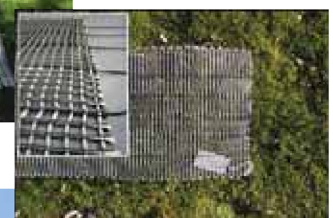
Large-strain sensing

PMMA POF

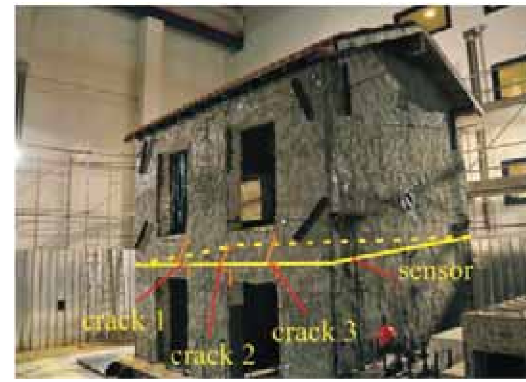
- Large 1 mm step-index PMMA POF
- Commercial OTDR interrogator

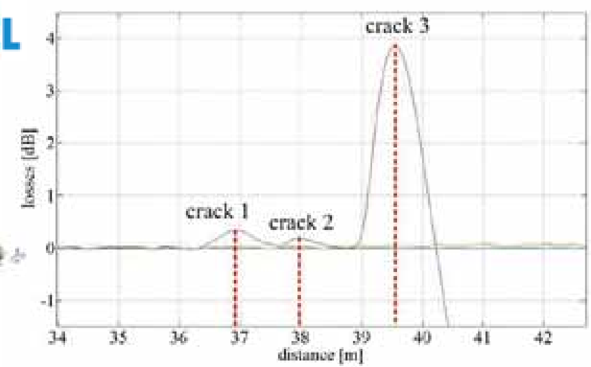
Tear-off edge detection





Crack detection



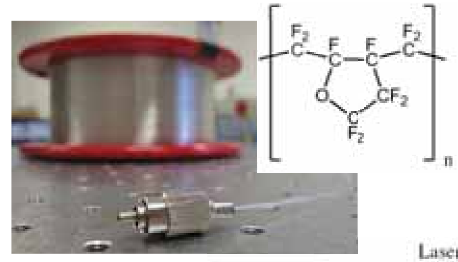


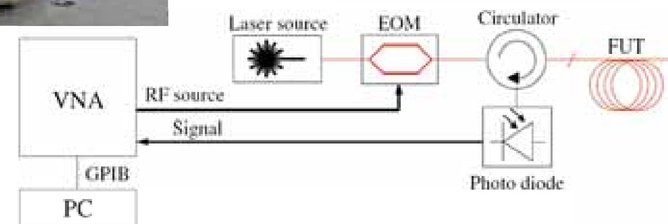
- Limited monitoring range (<100m) and resolution (>0.5m)

Krebber, Current Developments in Optical Fiber Technology (IntechOpen, 2013), 319-344.

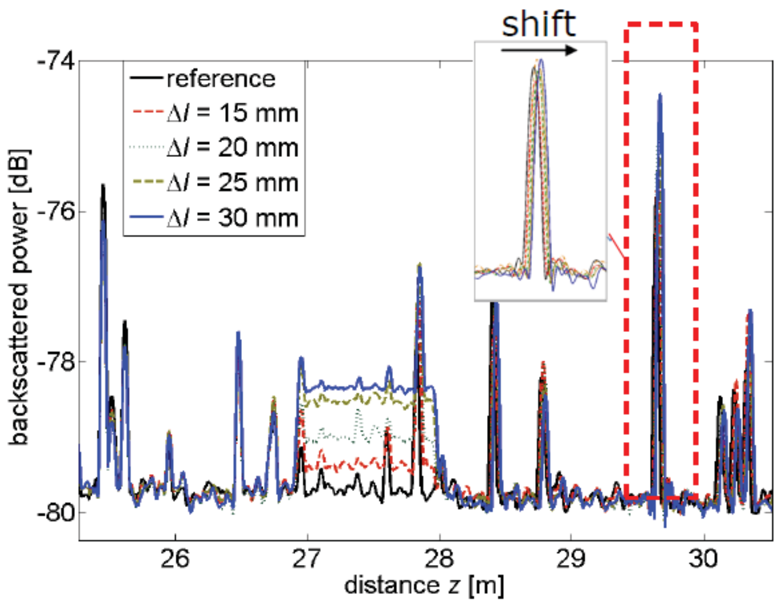
Large-strain sensing

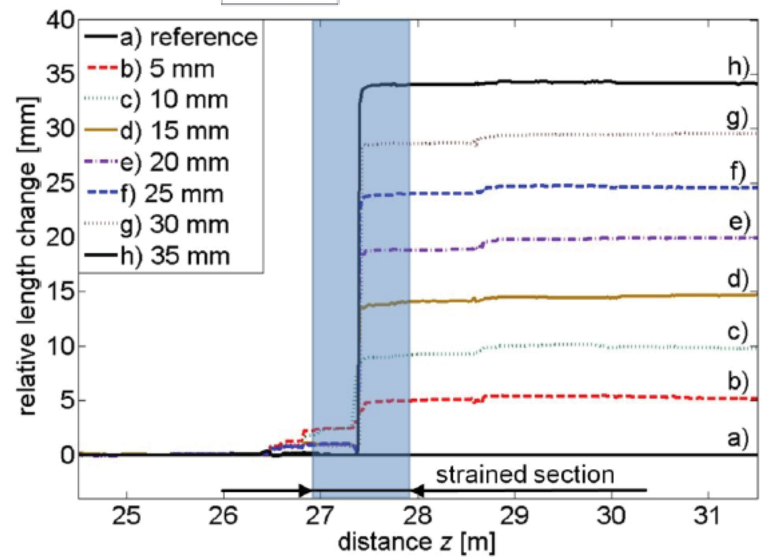
Cytop POF





- Low-loss graded-index Cytop POF
- Self-developed I-OFDR interrogator



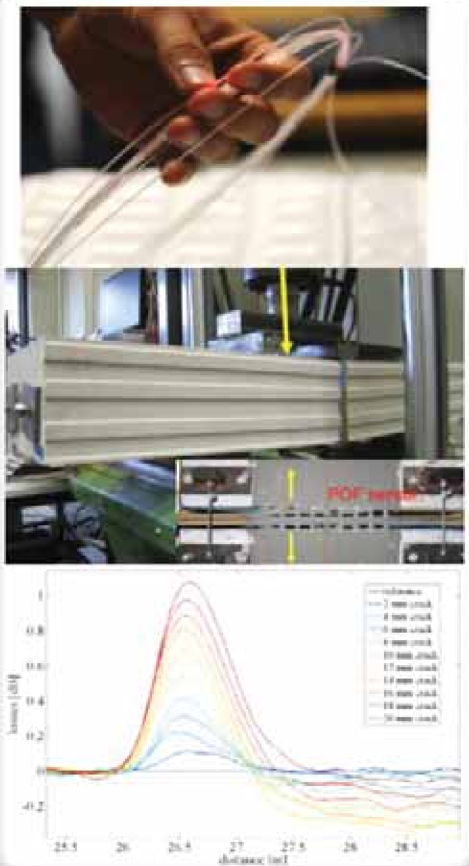


Liehr et al., Meas. Sci. Technol 21 (2010), 094023.

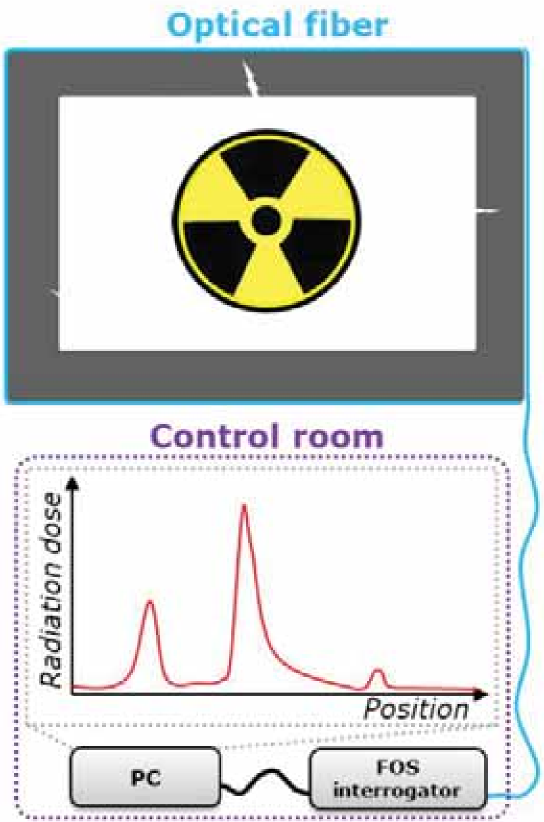
- Improved performance
  - Extended monitoring range up to 500 m
  - Strain limit in excess of 100%
  - Spatial resolution down to single millimetres

Alternative FOS applications

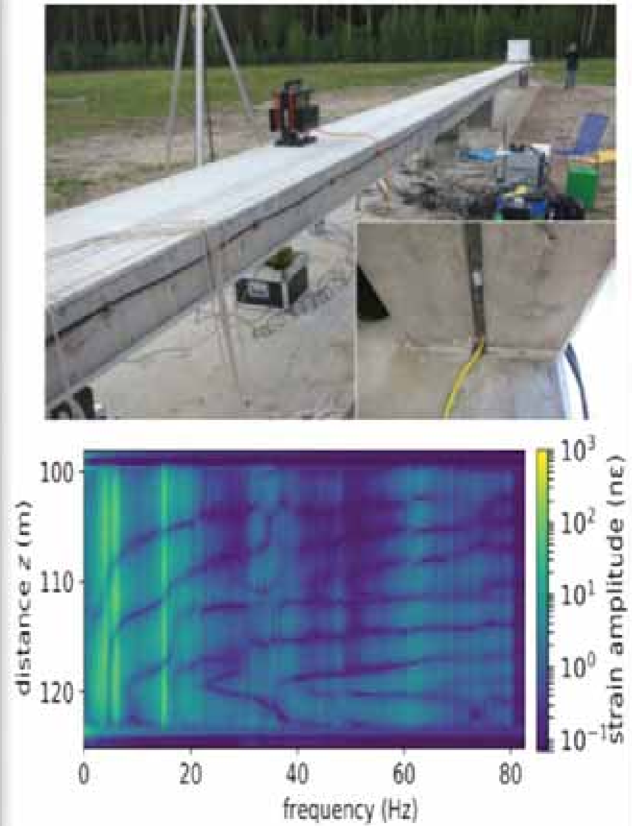
Polymer optical fibers for large-strain sensing



Polymer optical fibers for radiation monitoring



Distributed vibration/acoustic sensing

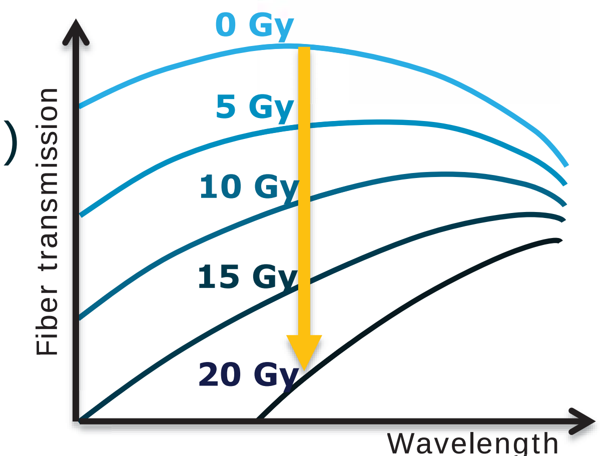


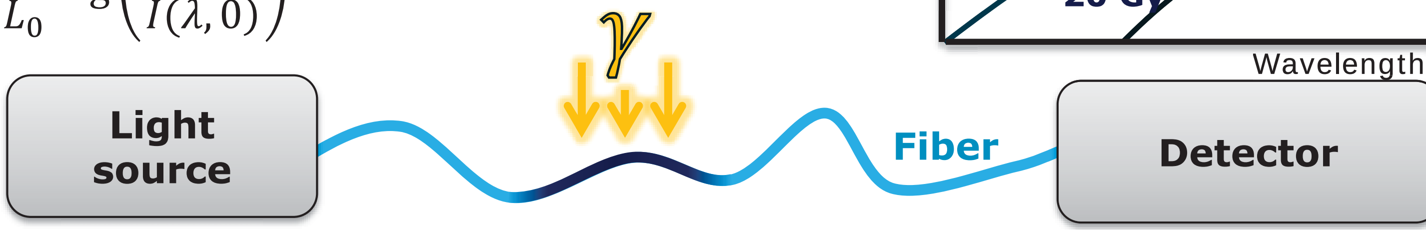
Radiation-induced attenuation (RIA)

Radiation-induced material defects (color centers)

- Strongly material & wavelength dependent
- Typically viewed as negative effect

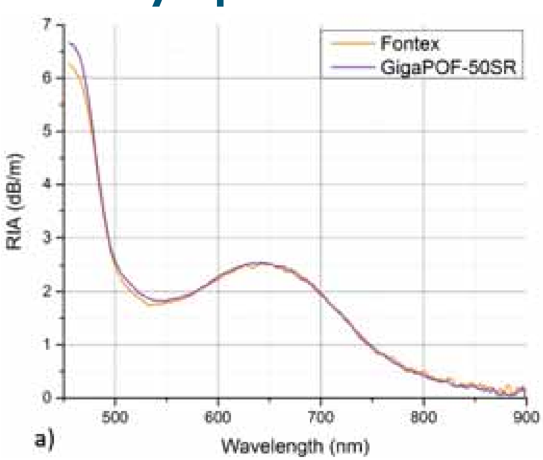
$$RIA(\lambda, D) = -\frac{10}{L_0}\log\left(\frac{I(\lambda, D)}{I(\lambda, 0)}\right)$$





- RIA magnitude related to total absorbed dose

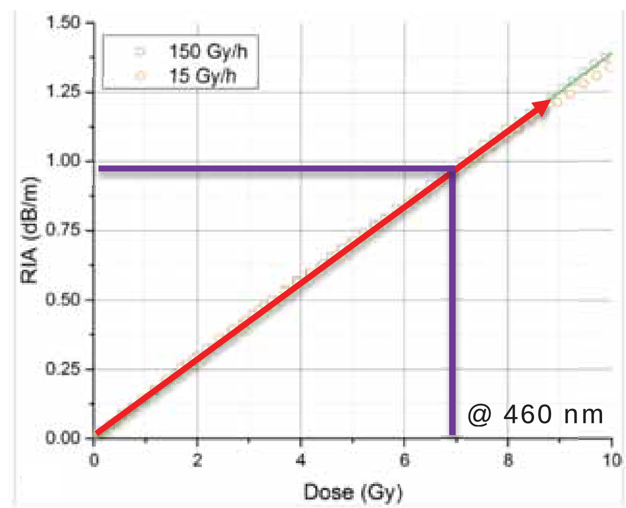
Cytop POF RIA



Sensitivity

140 dBm^{-1}/kGy (@ 460 nm)

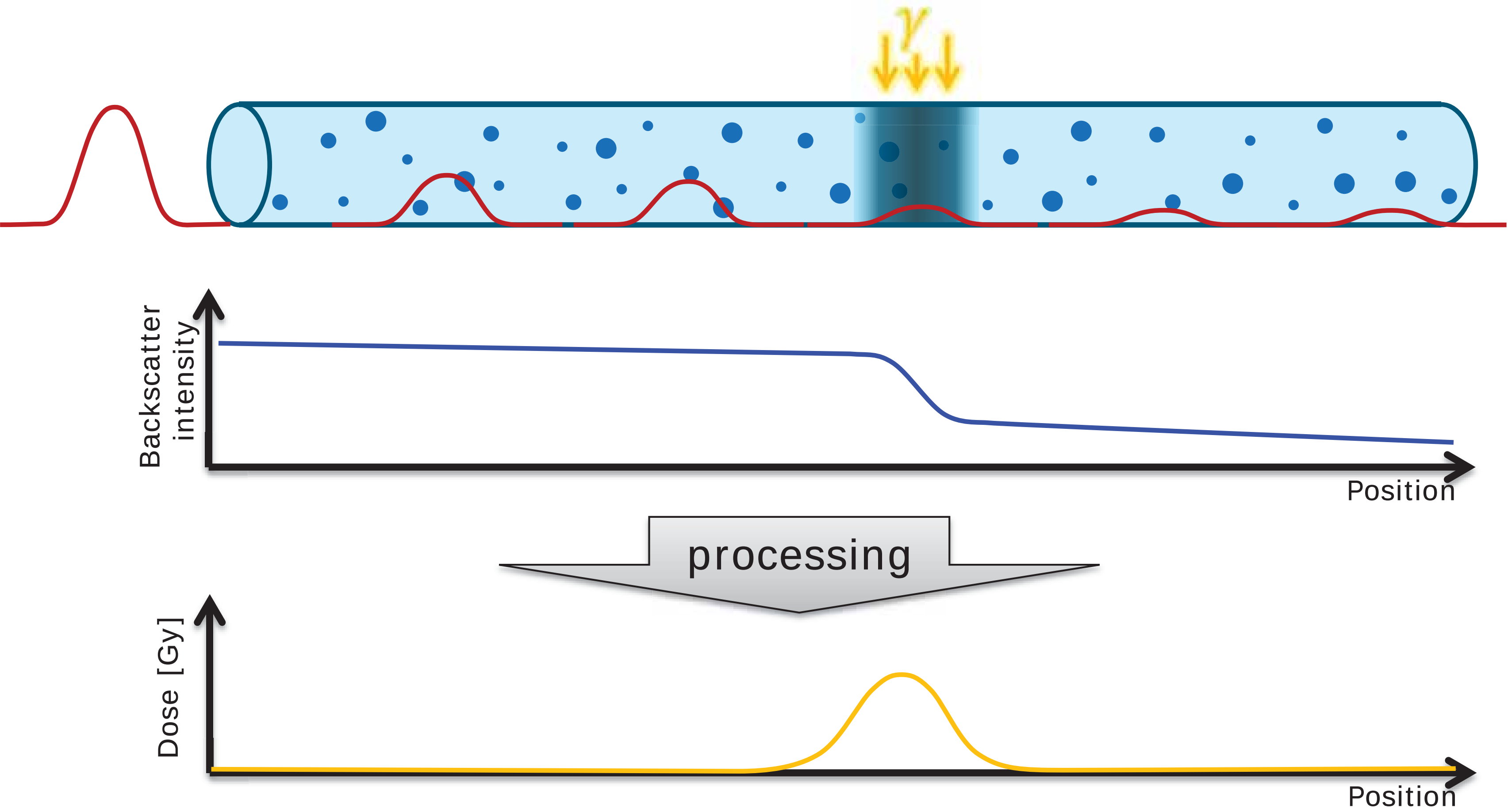
50 dBm^{-1}/kGy (@ 650 nm)



Stajanca & Krebber, POF 2017 Conference (2017, Aveiro, Portugal), p. 5.

Fiberoptic distributed radiation measurement

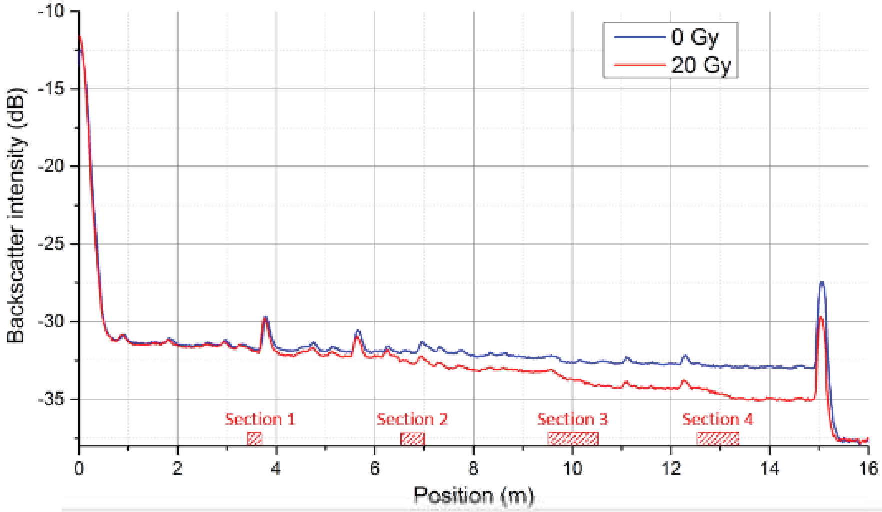
Distributed measurement of fiber attenuation profile

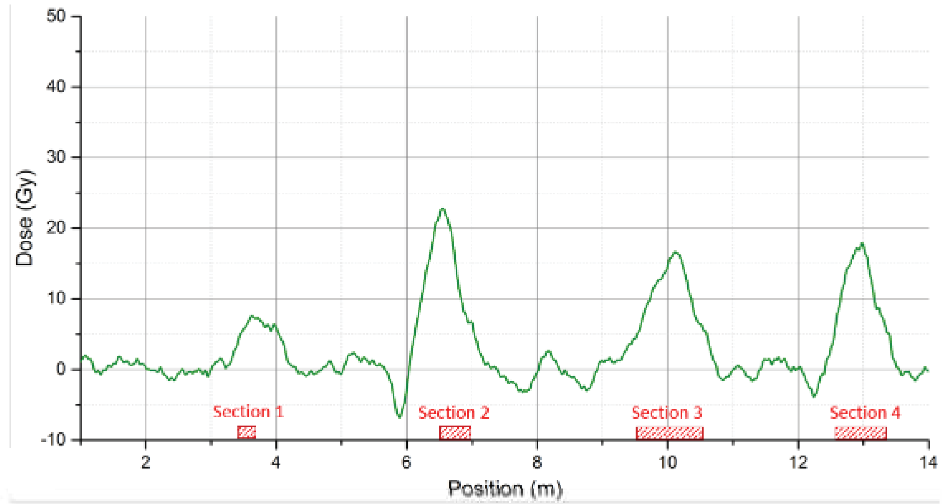


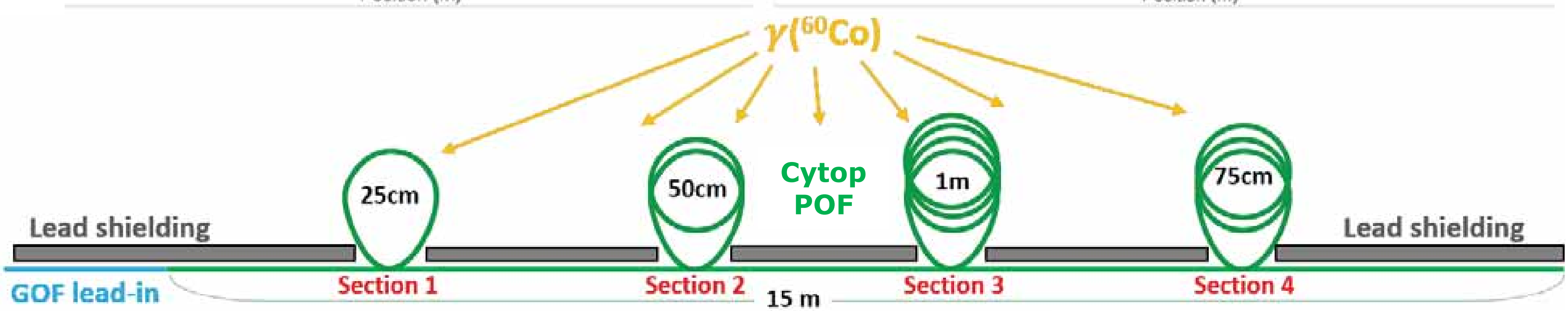
Distributed dose detection with POF

Distributed RIA measurement

- Cytop POF + 650 nm OTDR
- Gamma irradiation (20 Gy) with ^{60}Co source





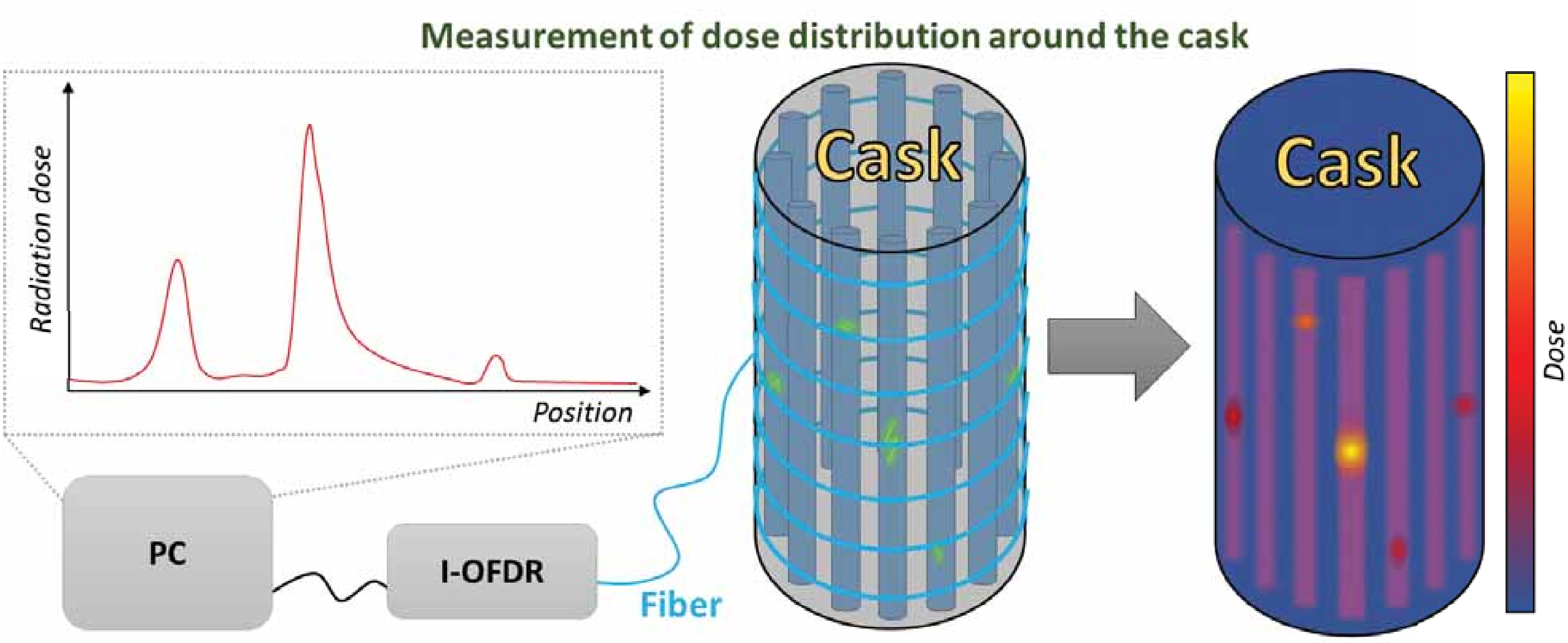


Stajanca et al., Sensors 17 (2017), 1959.

Fiberoptic distributed radiation monitoring for NWD applications

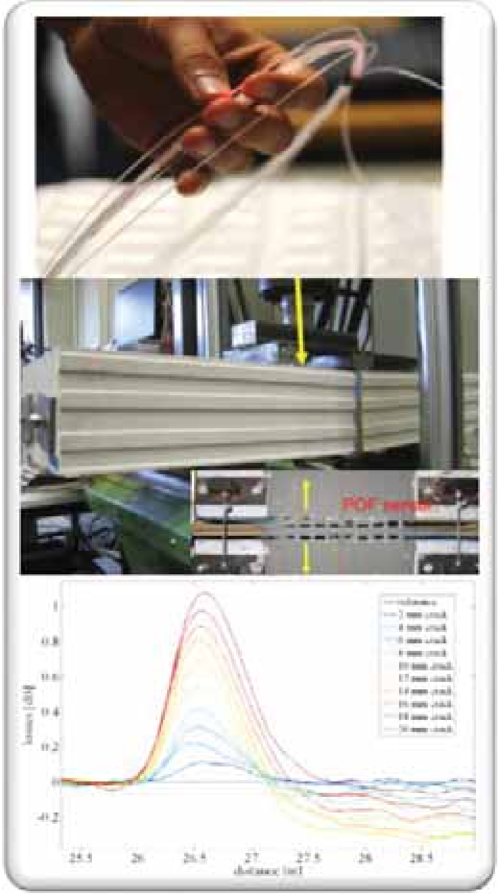
High-resolution & high-sensitivity distributed dose measurement

- Radiation leak detection
- Short-term NW container integrity control

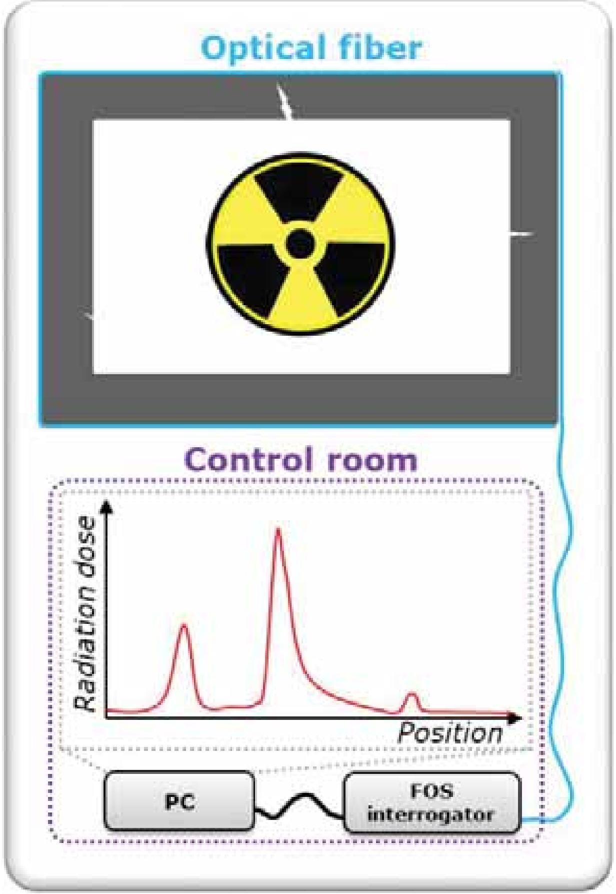


Alternative FOS applications

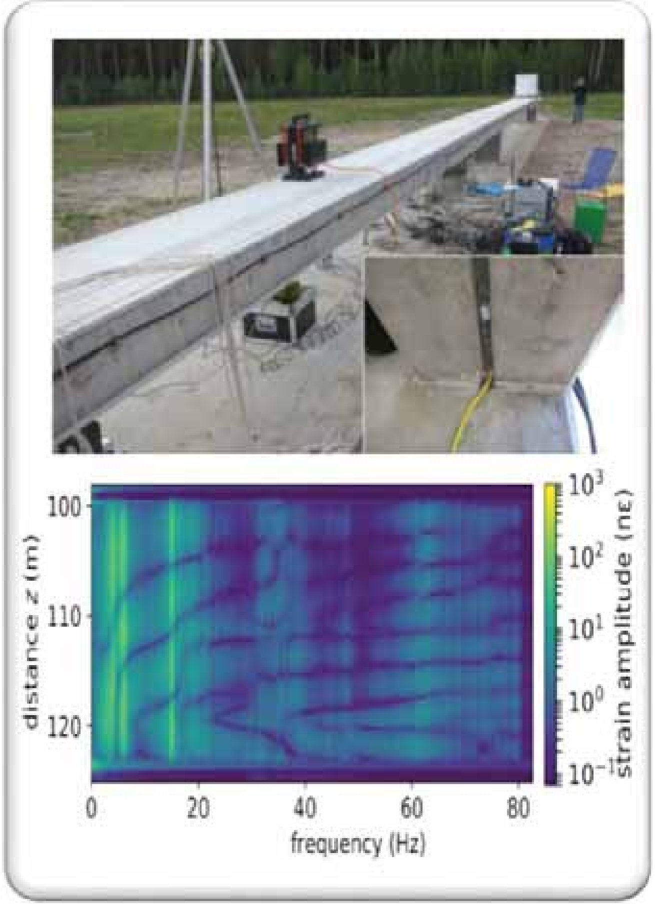
Polymer optical fibers for large-strain sensing



Polymer optical fibers for radiation monitoring



Distributed vibration/acoustic sensing



Distributed acoustic sensing (DAS)

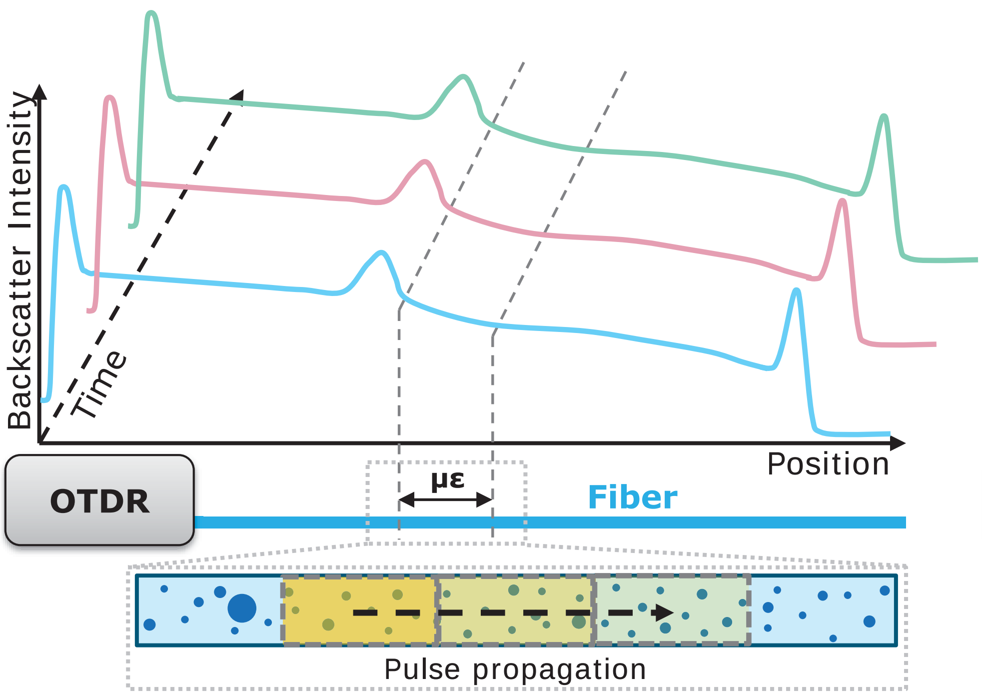
Coherent vs. Incoherent detection

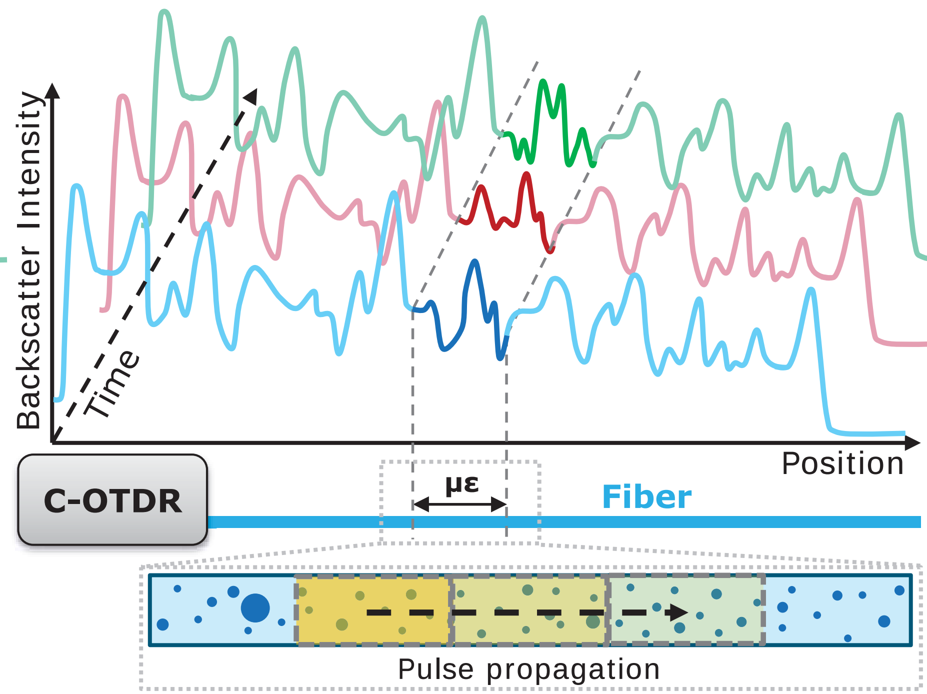
OTDR

- Incoherent pulsed light source
- Detects overall amount (amplitude) of light reflected from scattering centers at given fiber position

C-OTDR

- Coherent pulsed light source
- Detects superposition (interference) of light reflected from scattering centres at given fibre position

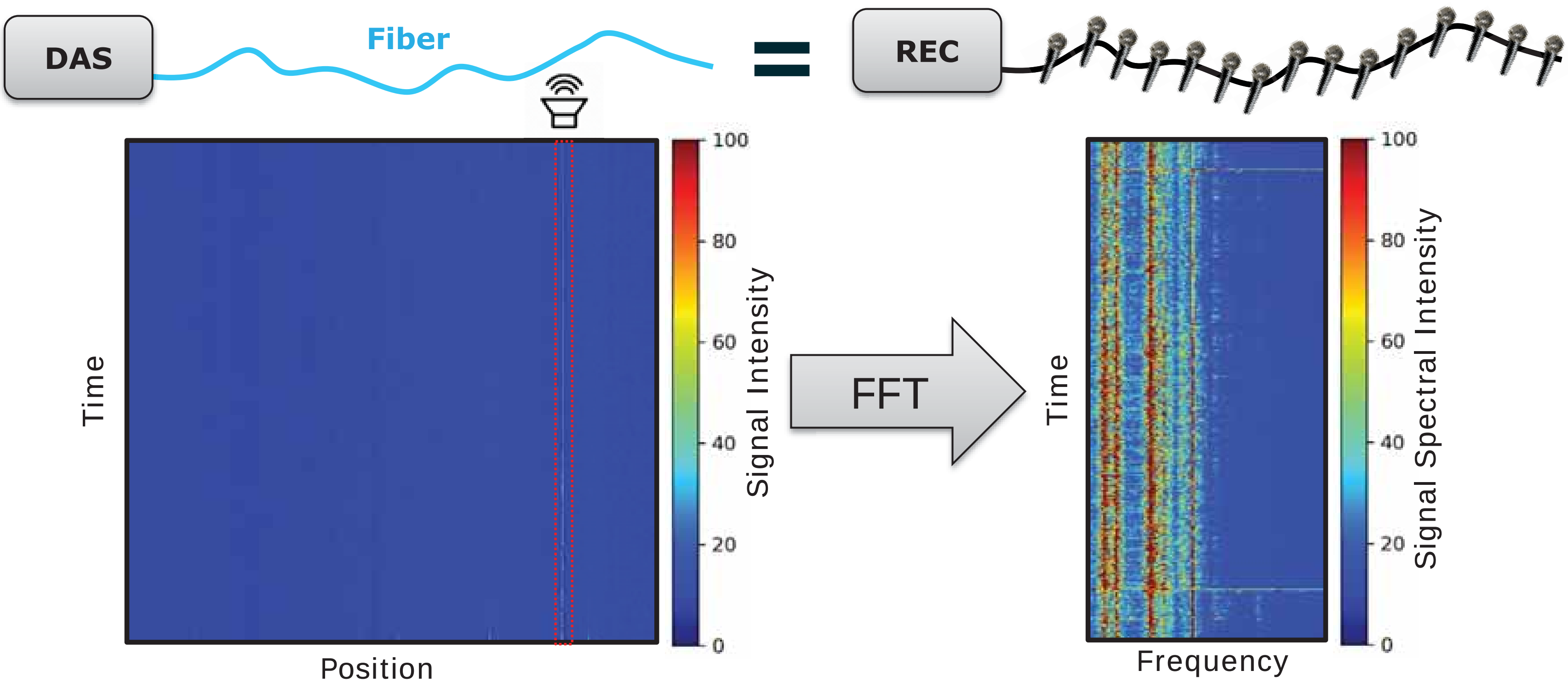




Distributed acoustic sensing (DAS)

Highly-dynamic strain (vibration) measurement

- Acquisition rate up to 100 kHz
- Monitoring range up to 80 km
- Spatial resolution down to 1 m
- Sensitivity down to nanostrains

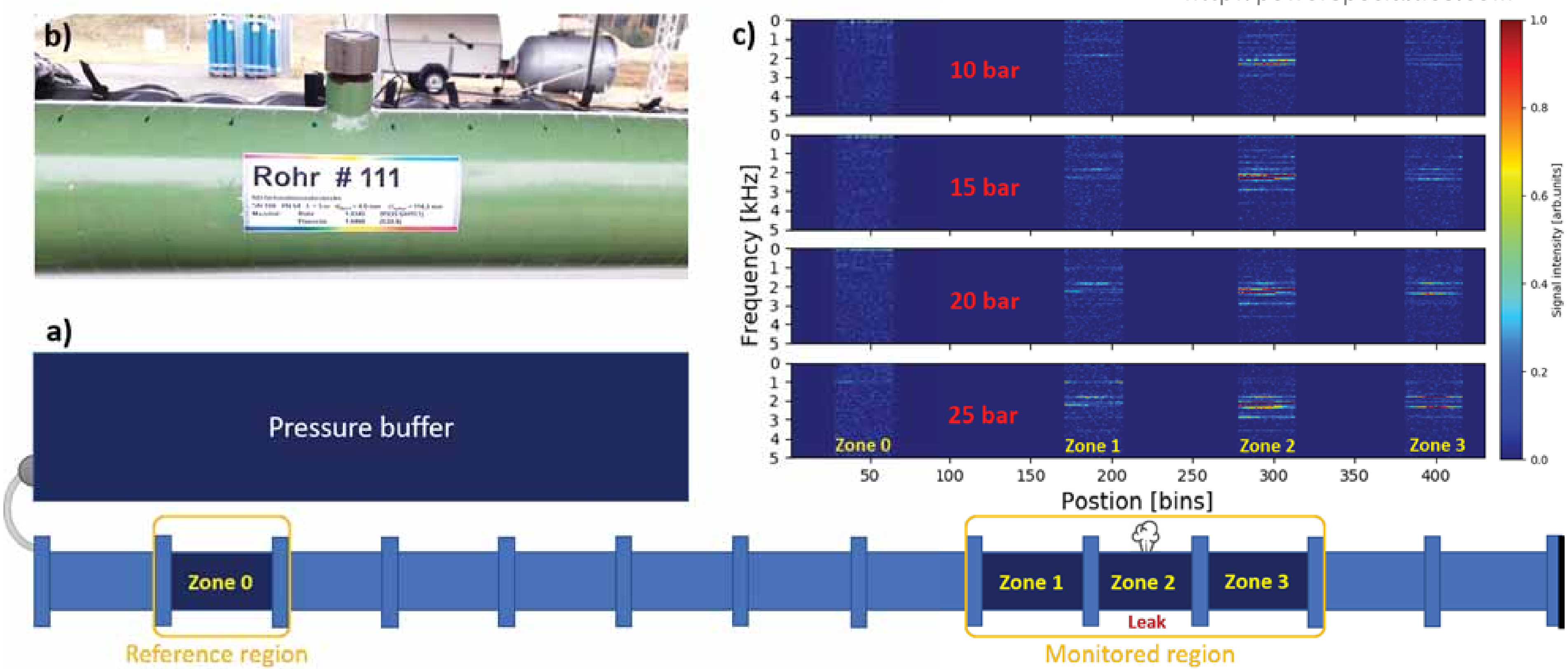


Distributed acoustic sensing (DAS)

Applications

Monitoring of large/extended structures

http://powerspecialties.com

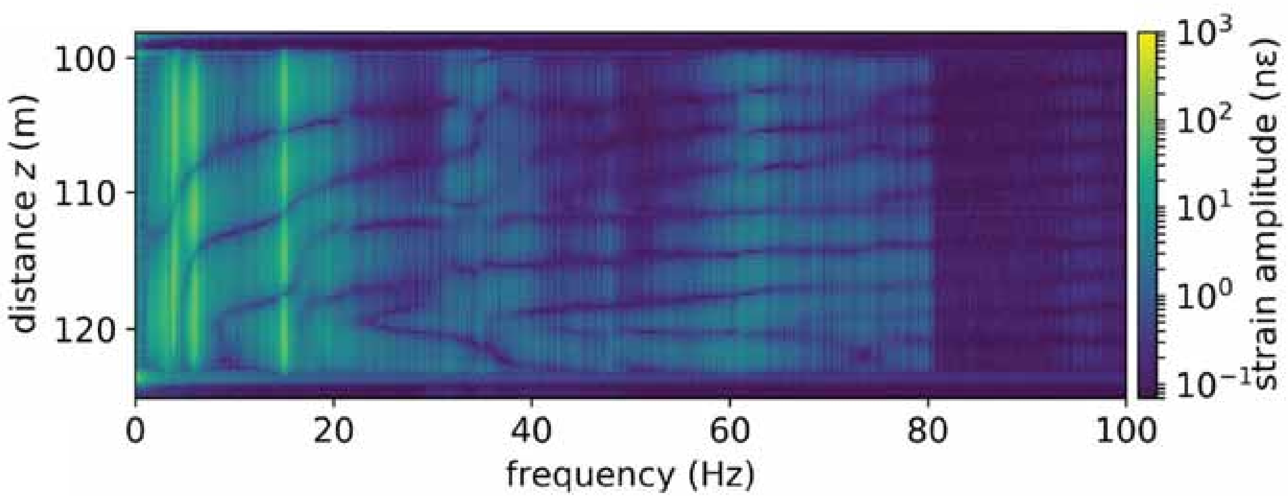


Stajanca et al., Sensors 18 (2018), 2841.

Distributed acoustic sensing (DAS)

Applications

Monitoring of large/extended structures



Liehr et al., Opt. Express 26 (2018), 10573-10588.

Distributed acoustic sensing (DAS)
Applications

NWD-relevant applications

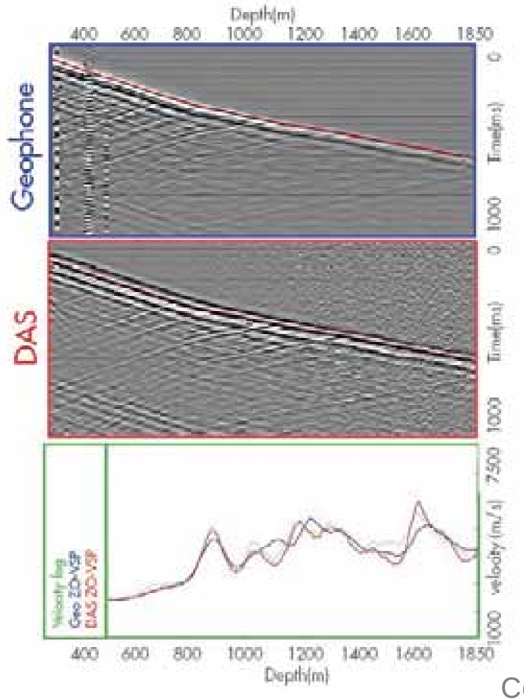
- Perimeter control (third-party intrusion)
- Seismic/geological monitoring

By Idobi, CC 3.0

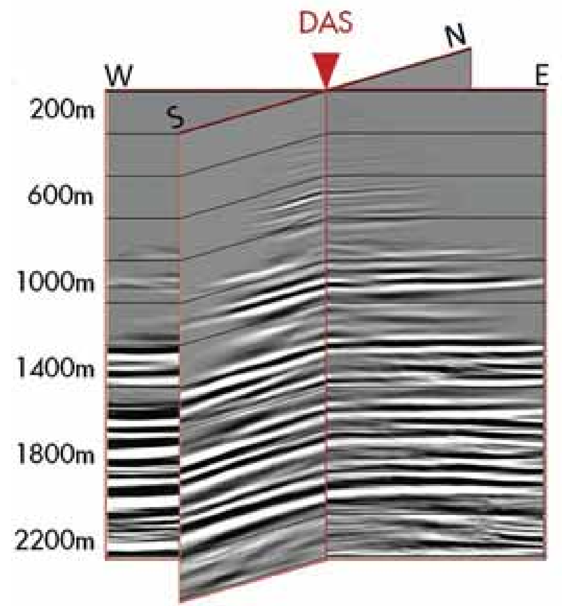
https://openpr.com

Daley et al. Geophys. Prospect. 64 (2016) 1318-34.

VSP checkshot



2D/3D VSP imaging



Cox et al., CSEG Recorder 2 (2012) 7-13.

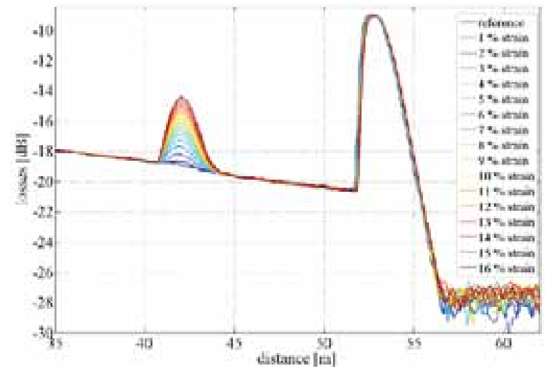
Summary

POFs for strain sensing

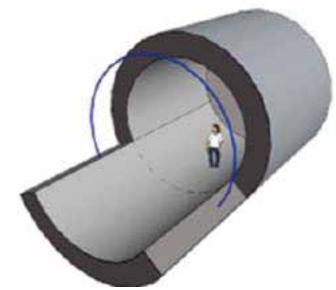
Large strain limit

Easy integration

- SHM of repository parts



Liehr et al., IEEE Sensors 9 (2009), 1330-1338.

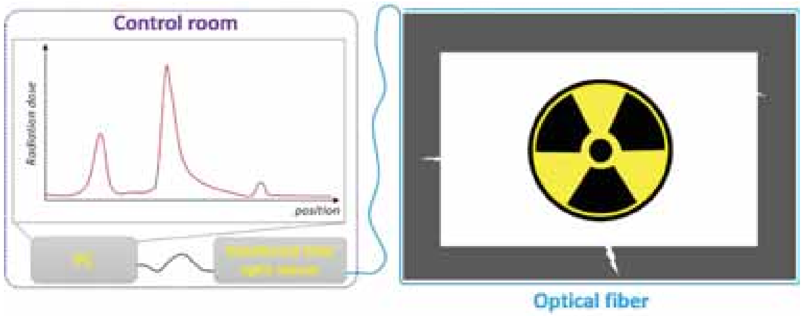


Delepine-Lesoille et al., J. Sensors 2012 (2012), 369375.

Distributed radiation sensing

Detection and dosimetry of radiation

- Radiation leak detection
- Container radiological profiling



Distributed acoustic sensing (DAS)

High-sensitivity vibration measurement

- Repository perimeter control
- Repository geological monitoring

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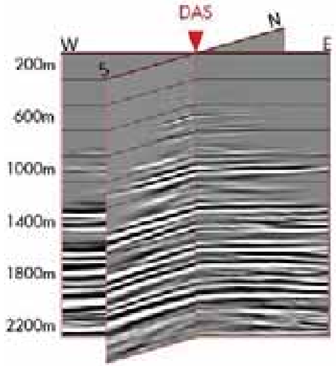

Cox et al., CSEG Recorder 2 (2012) 7-13.

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- POLYTEC project consortium
- TRIPOD project consortium
- BAM AGIFAMOR project consortium
- BAM BLEIB project consortium

Sicherheit in Technik und Chemie

Bundesanstalt für Materialforschung und -prüfung

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