INFLUENCE OF DOPING ELEMENT IN DISTRIBUTED HYDROGEN OPTICAL FIBER SENSORS WITH BRILLOUIN SCATTERING

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Outlines

1. **The French Waste repository project**
   1. Motivations for monitoring
   2. H2 term source
2. **Specifications for H2 sensors**
3. **Optical fibers sensors**
   1. states of art
   2. Brillouin backscattering
4. **Results**
5. **Conclusion**

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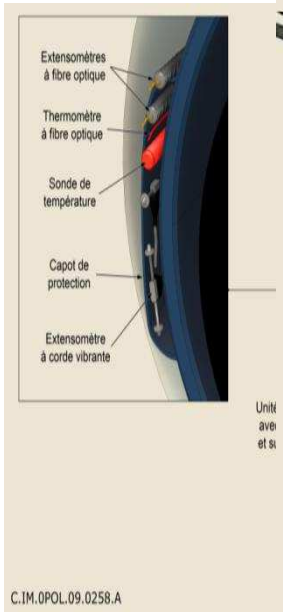
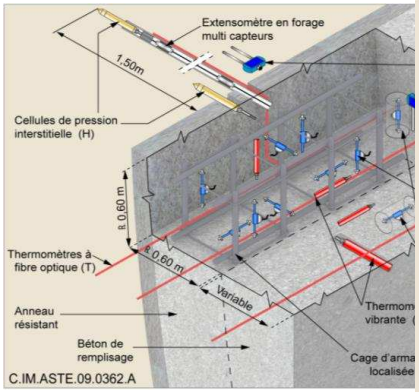
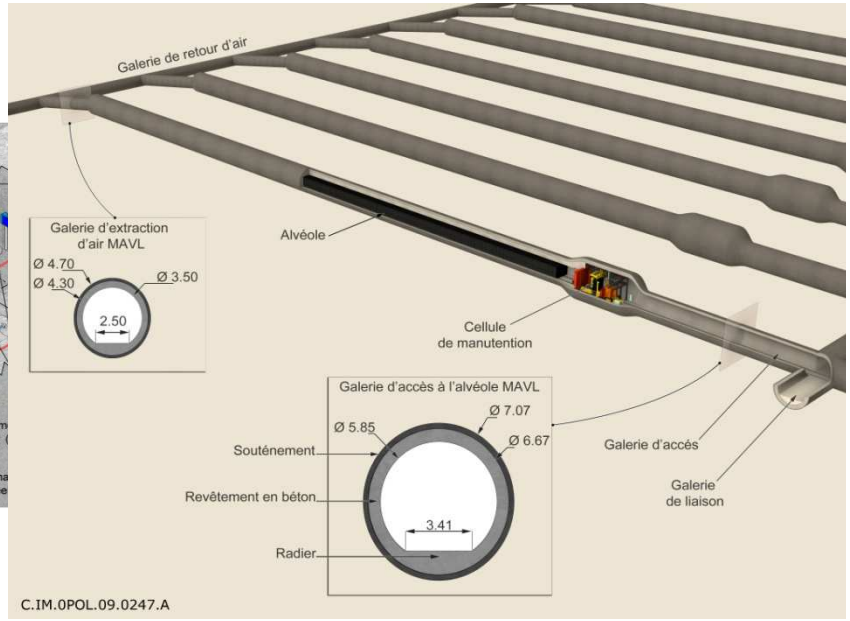


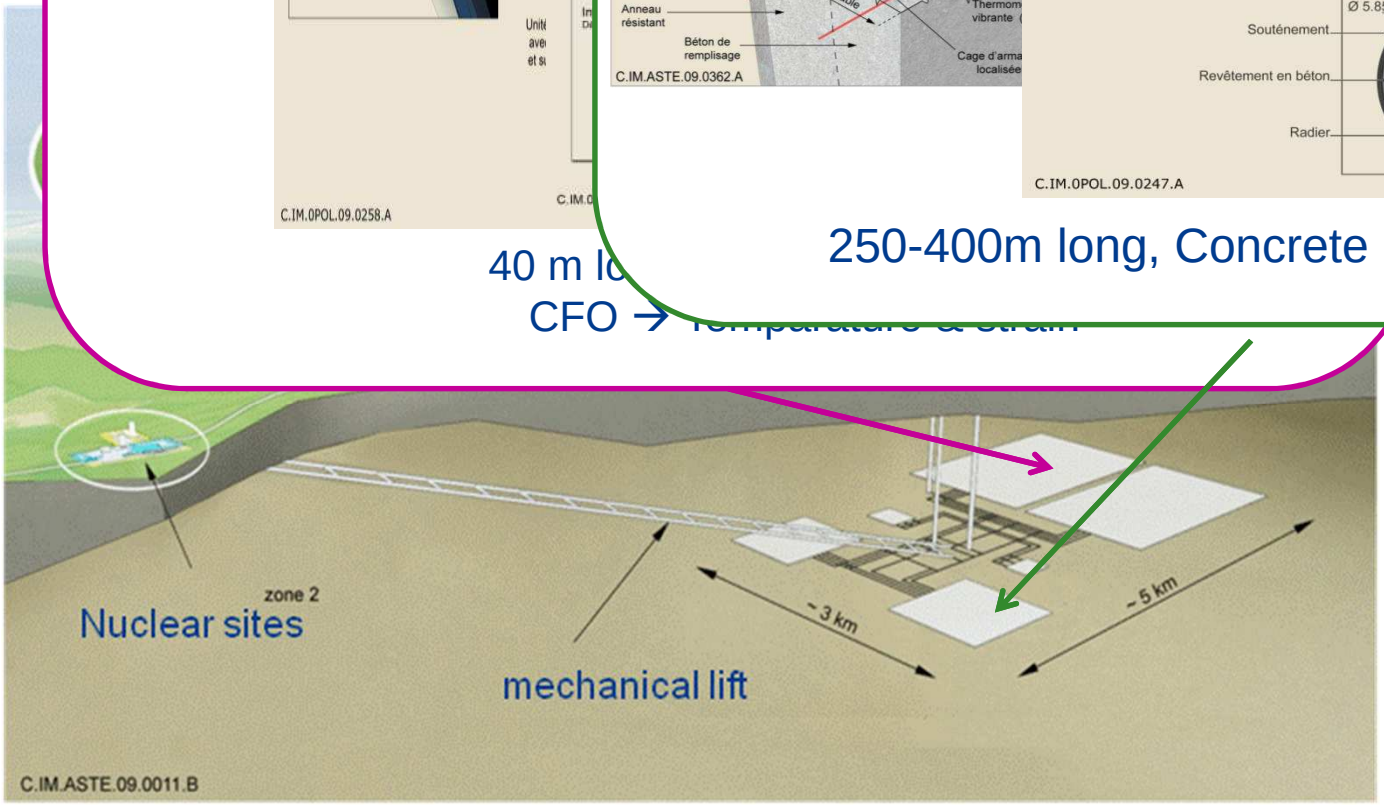


ILW concept



250-400m long, Concrete liners,Ø 8m

40 m l
CFO →



Motivations for monitoring

This strategy responds to several demands expressed in, among others:

- The Loi du 26 juin 2006 on management of radioactive waste and the Loi du 13 juin 2006 on transparency and security
- The 2008 Safety Guide for disposal (formerly RFS III.2.f)
- The Environmental Code, requiring to establish an environmental reference state consistent with the dimension of the industrial project

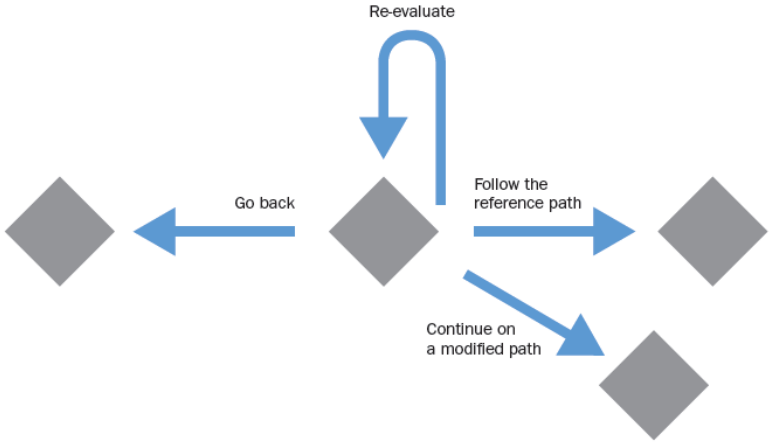
The **controls of waste** packages (for compliance to specifications before acceptance), as well as their monitoring in disposal

Repository Monitoring as an input to reversibility management and long term safety assessment

monitoring

Monitoring of the environment

Surveillance for **operational** security and nuclear safety

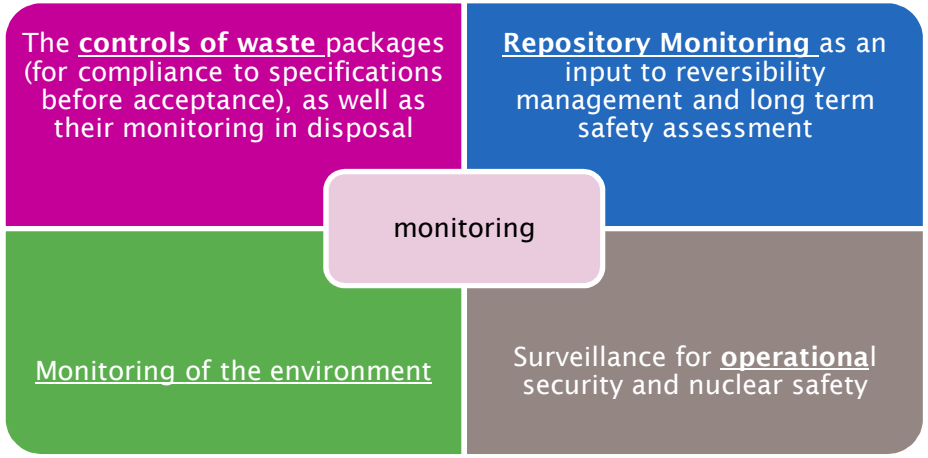


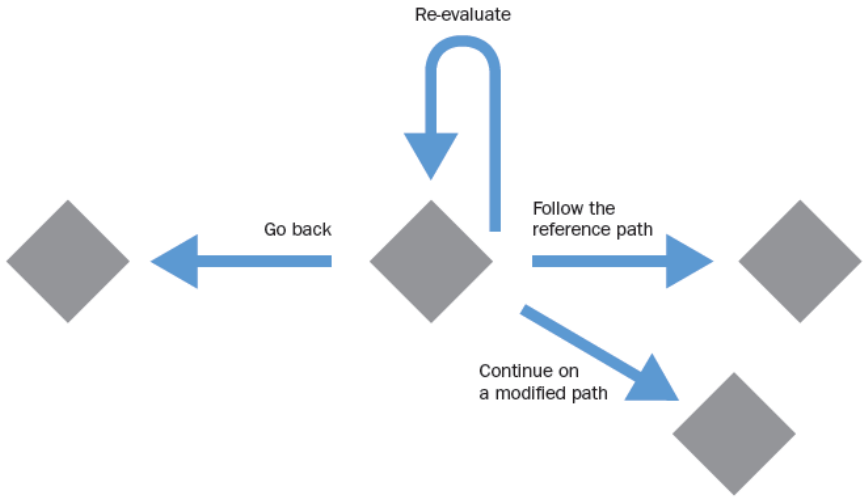
Motivations for monitoring

2008 Safety Guide for disposal
(formerly RFS III.2.f)
French environmental code…

Andra developed a combined strategy of controls and monitoring to provide needed knowledge:

- Prior to operations
  - To establish an environmental impact assessment of the installations
- During operations
  - To guarantee operational safety
  - To ensure **reversibility**
  - To obtain feedback that will be used for
    - + *Subsequent repository construction stages*
    - + *Periodic safety evaluations*
- With regards to **long term safety**
  - To confirm the basis of processes and evolutions contributing to the safety functions
  - To monitor after various closure steps

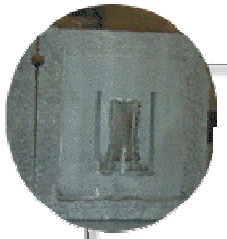




H2 Source term

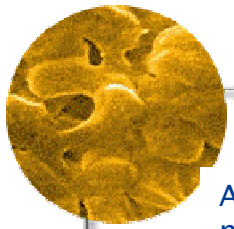
- Evaluation of all processes responsible for the production of gases (corrosion, radiolysis)
- Individual assessment for each engineered structure
- Hydrogen is the dominant gas (> 99%)
- Corrosion is responsible for more than 90% of the gases produced

Metal corrosion (waste form; package; structural elements)



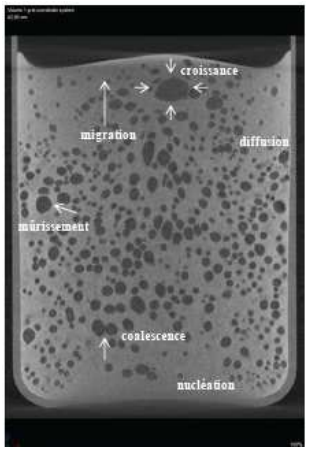
Radiolysis of cementitious materials

Radiolysis of organic materials



Activity of micro-organisms

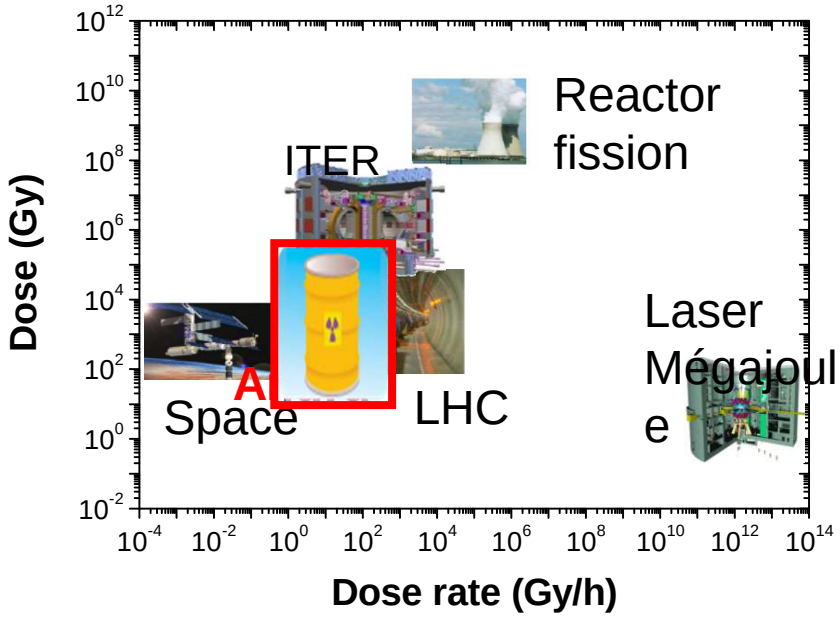
slow reaction



- Production of hydrogen over 100 000 years
- Main production phase: 0-5000 years
- Water availability and its possible impact on corrosion rates are not taken into account

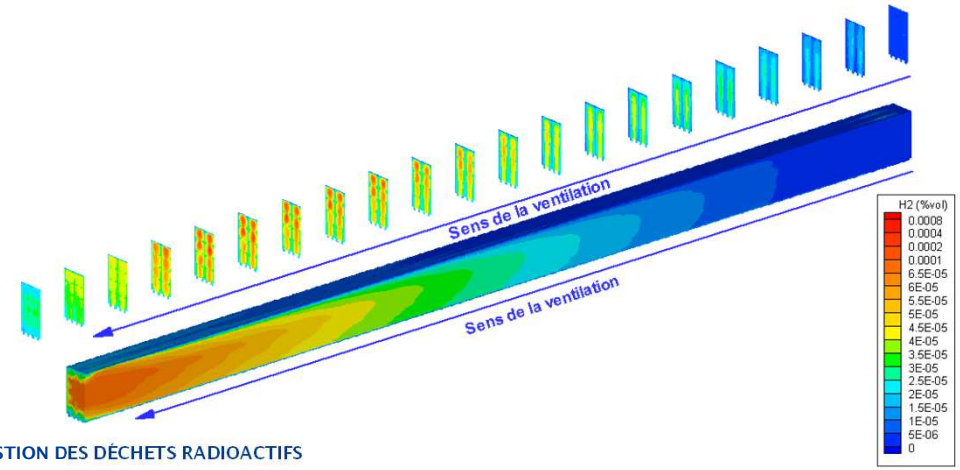
Requirements for long term sensors

- **Hostile conditions**
  - Gamma radiations
  - 100°C,
  - alkaline environment…
  - No access, free maintenance



Specifications

- Durability (>100years)
- Non invasive
- No cross-sensitivy
- Sensing
  - Sensitivity: 0,1 [0-4%] and 1% [4%-100%]
  - Spatial resolution <1m
  - Remote sensing > 500m



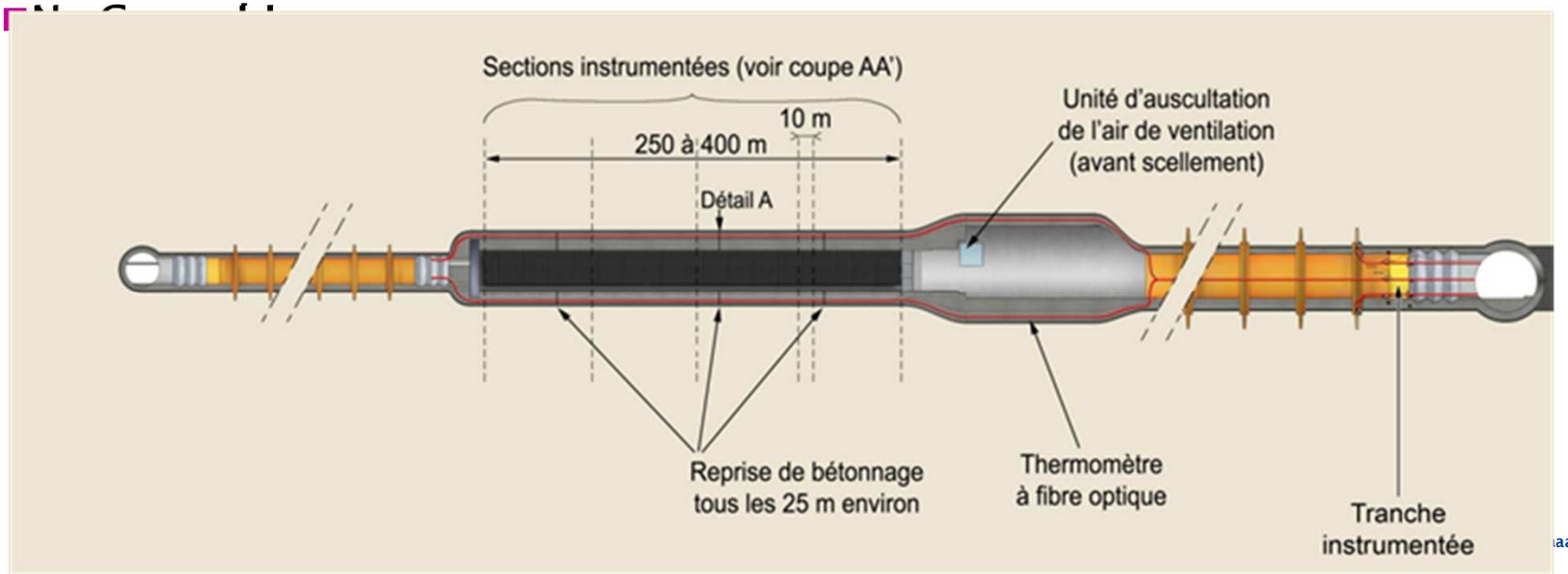
Optical fiber sensors

Advantages:

- Embeddable
- Long Gage Lengths (If Needed)
- Chemically Inert
- Serial Multiplexibility (WDM)
- or completely distributed measurement

Advantages:

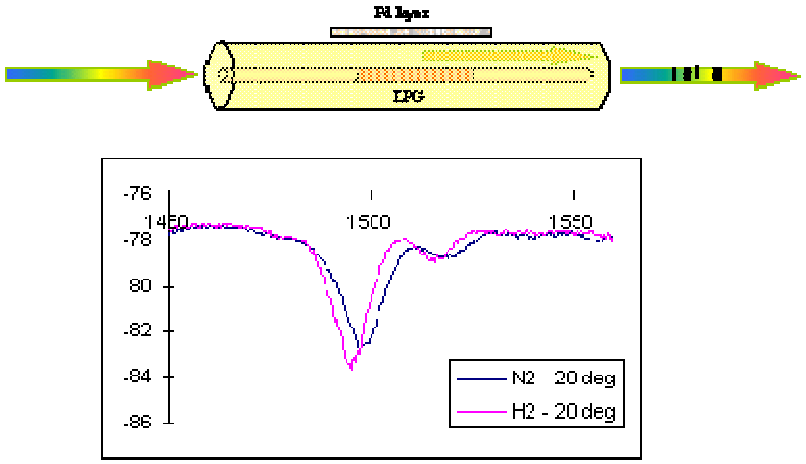
- Compatibility With Telecom
- Very Small Gage Lengths (If Needed)
- No Sparks
- Can Have Very Long Stand-off Distances



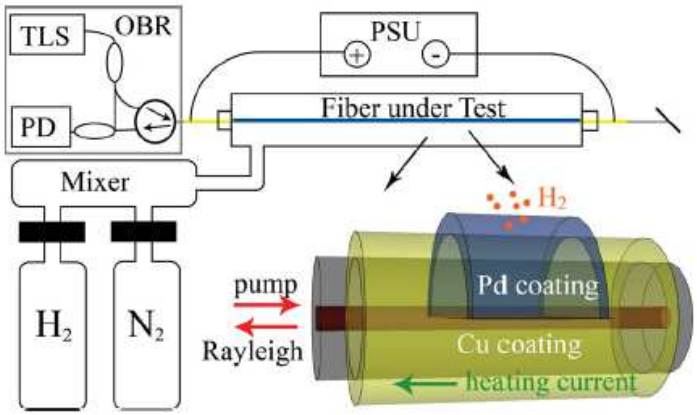
State of art

Hübert, *et al* "Hydrogen sensors – A review" Review Article Sensors and Actuators B: Chemical, Vol. 157, no 2, October 2011, pp. 329–352

Bragg technology

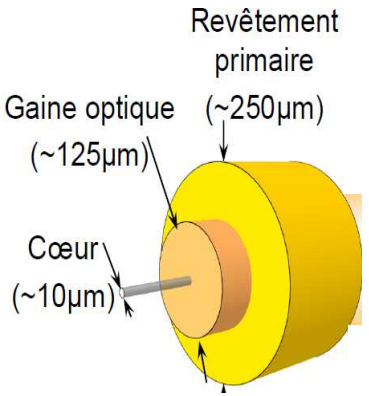


X. Bevenot, A. Trouillet, C. Veillas, H. Gagnaire, and M. Clement, Sens. Actuators B 68, 57–67 (2000).



Tong Chen, Appl. Phys. Lett. **100**, 191105 (2012)
Distributed hydrogen sensing using in-fiber Rayleigh scatterin

- aging of the layer
- No a fully distributed system



Distributed optical fiber sensors

Optical fiber sensors have long been considered an alternative solution for sensing in hazardous environments, *e.g.* corrosive and explosive atmospheres as H2.

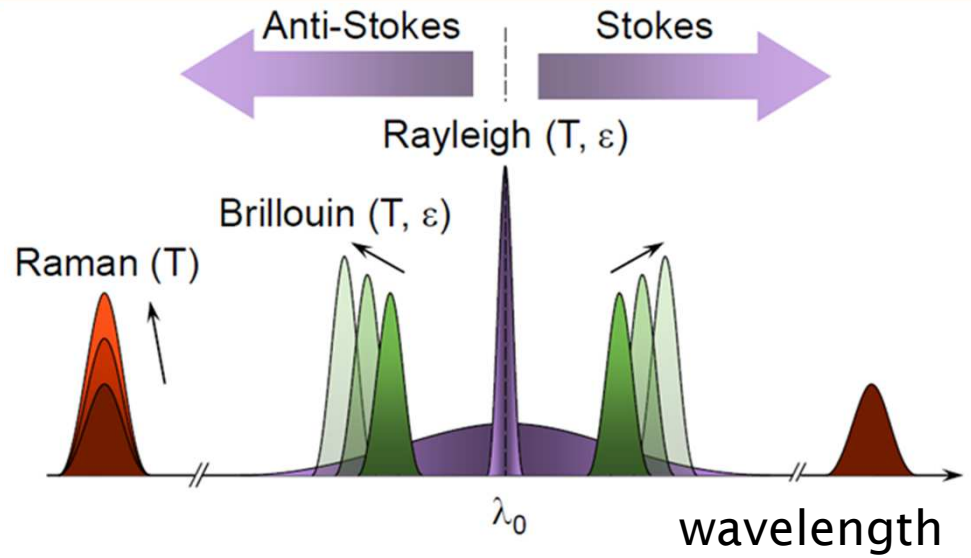
Continuous monitoring in space and time

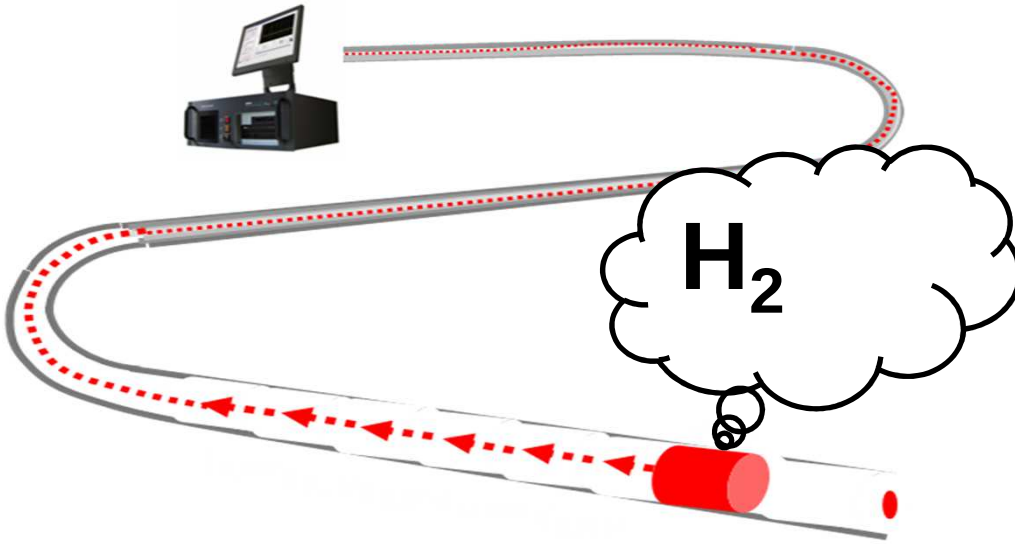
Temperature and strain measurements

$$\nu_B = C_T \Delta T + C\varepsilon \Delta\varepsilon$$

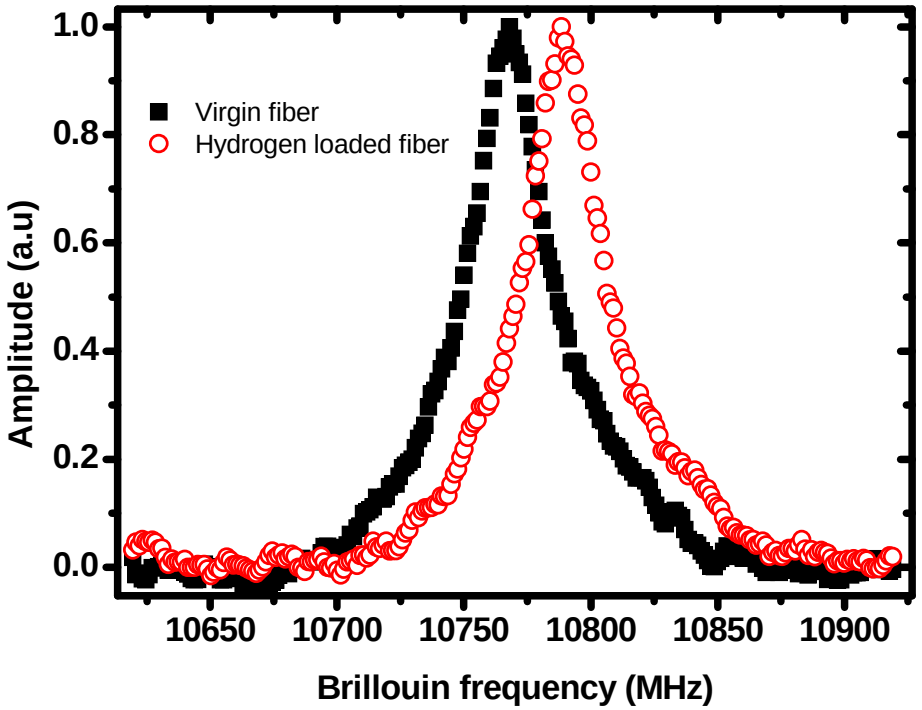
Complementary of traditionnal ponctual sensors like thermal conductivity, chemical, …

→Interest in distributed fiber optic sensors for H2





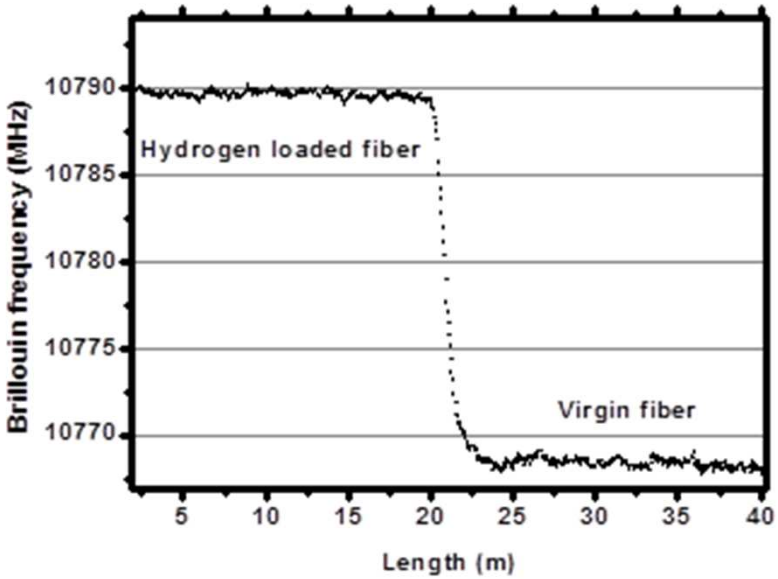
Brillouin scattering

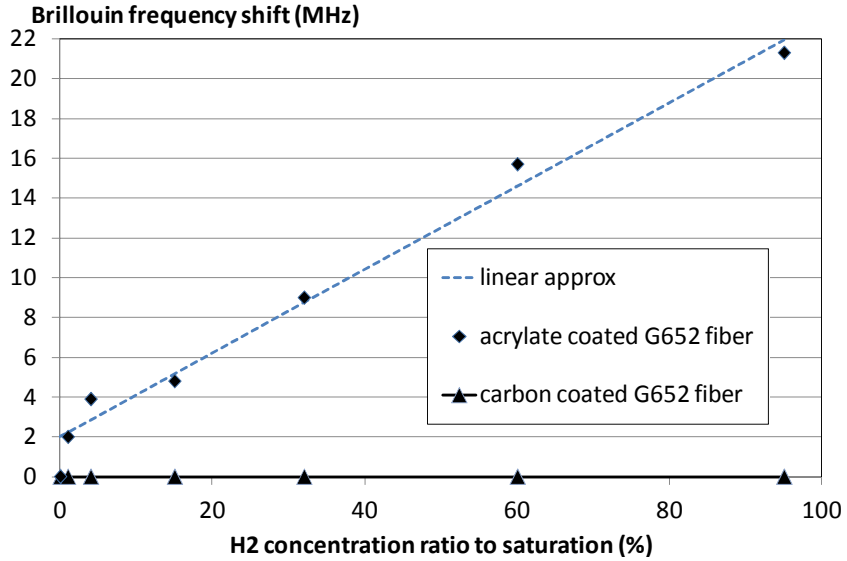


$$\nu_B = \frac{2n_{eff}V_A}{\lambda_0}$$

- Brillouin effect is sensitive to the presence of [H2]
- intensity is not affected by the gas
- H2 induce a Brillouin frequency shift

Brillouin scattering





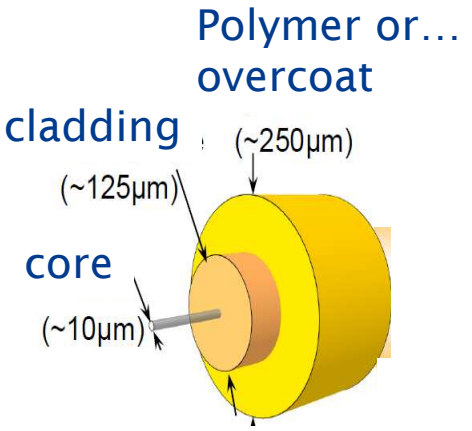
Spatial resolution is about 2.5m

At RT, in the acrylate-coated fiber, the Brillouin frequency shift is approximately linear with hydrogen concentrations in the silica core, with a factor of 0.21MHz/%H2. Our device sensitivity is in the order of **1MHz; It corresponds to 5%H2**

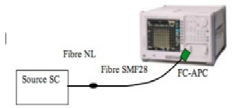
Influence of the doping

Objective: Change the sensing performance by modified the glass matrix

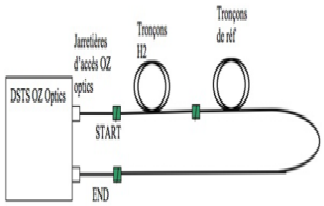
Fibre type	Doping concentration (mol%)
GeO_2-doped	3,4
fluorine	1,25
highly GeO_2-doped	28



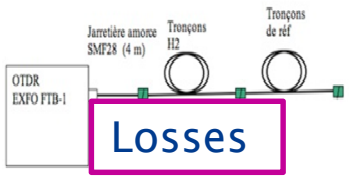
Hydrogen Tank
T°C
Pressure control



Transmission analyses

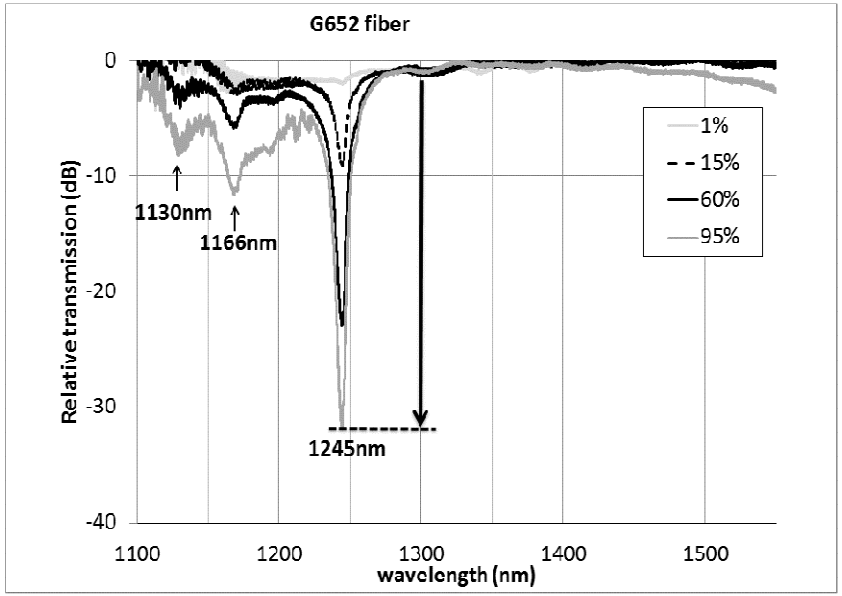


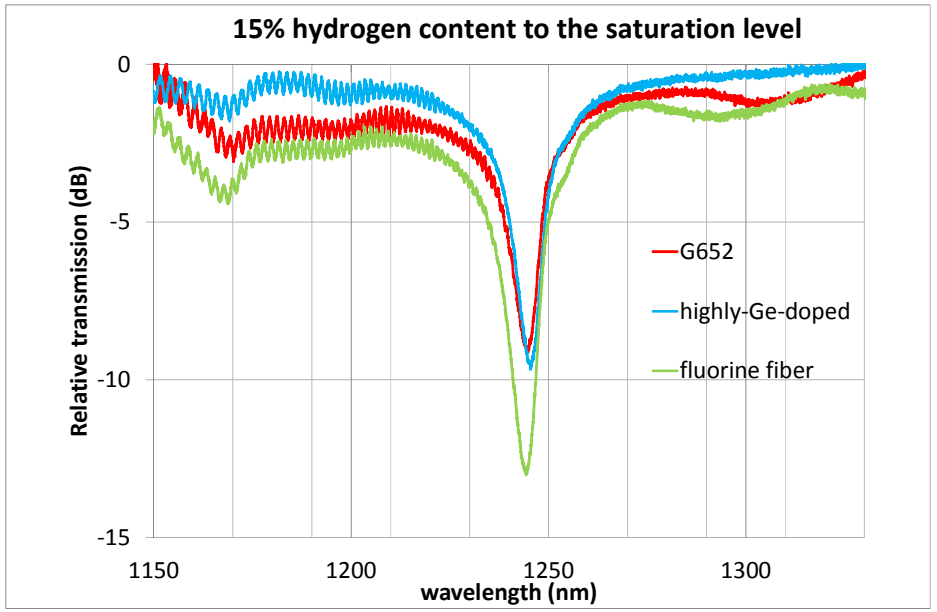
Brillouin measurement



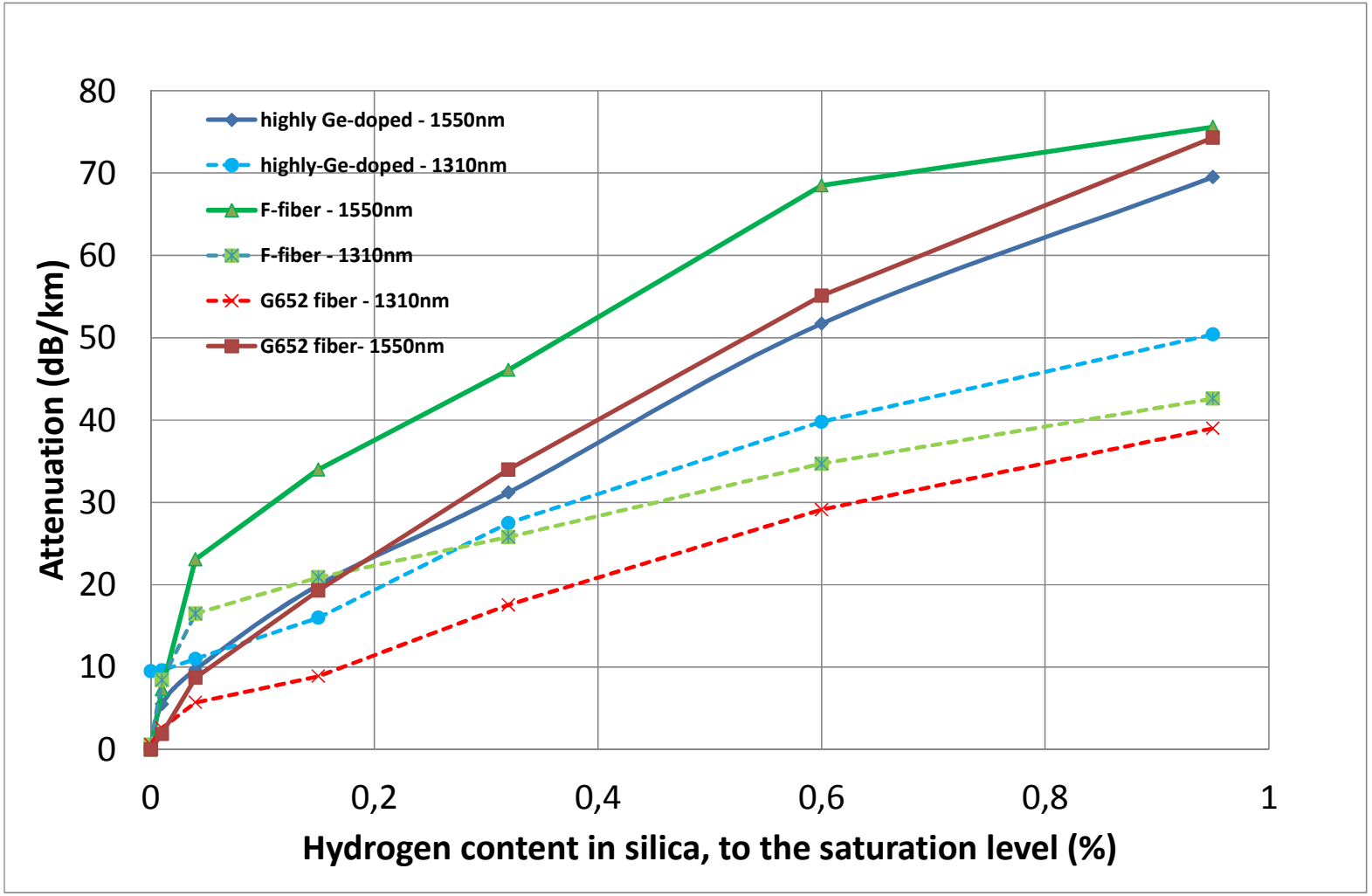
Losses

Transmission results

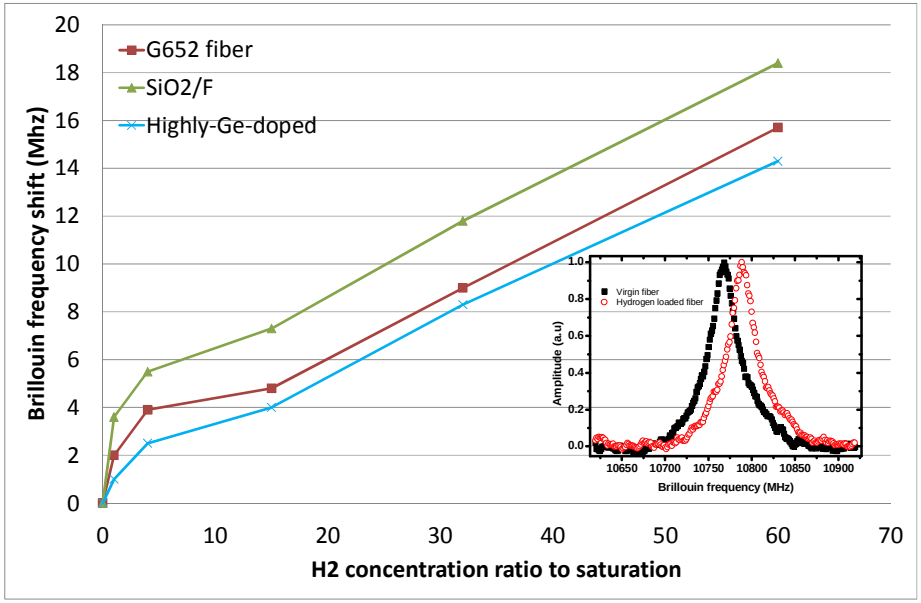


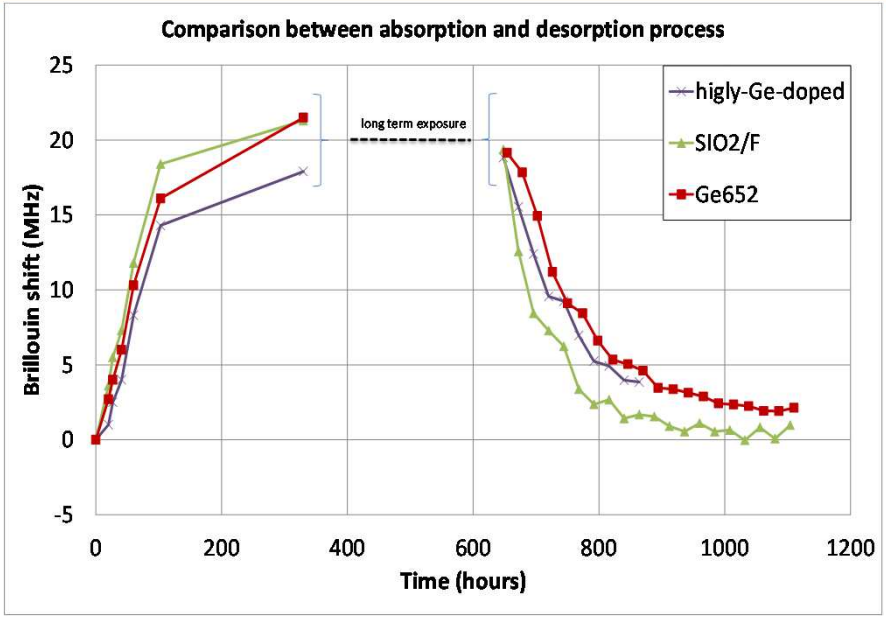


Attenuation

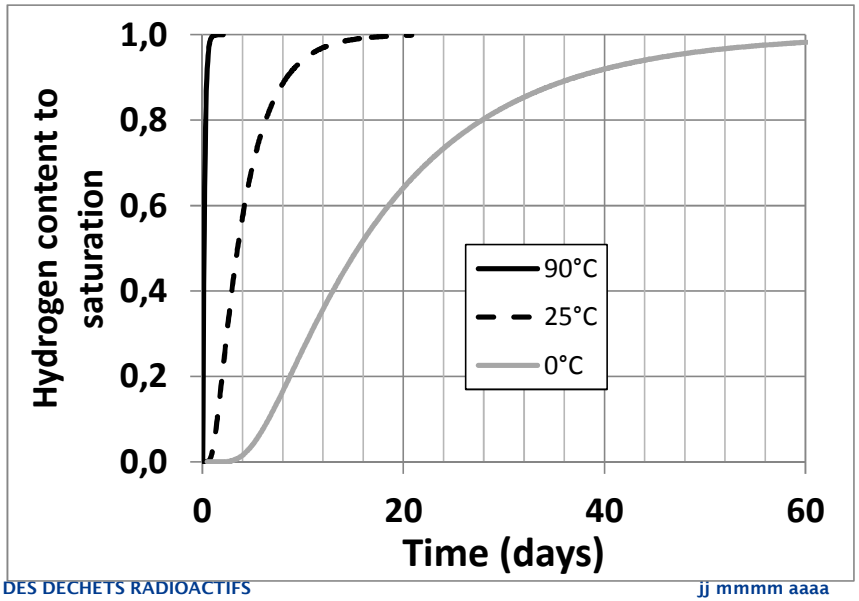


Brillouin measurment





$$D=2.83.10^{-4}\ exp(-40190/RT)$$



Conclusion

Objective

- H2 long term monitoring in harsh environment
- Distributed measurement in order to localize the gas source

Results

- **Optical fiber based on Brillouin backscattering effect is offered a new H2 monitoring system**
  - Spatial resolution = 2,5m/ distance range >100 m
  - Sensibility 0,1mHz/ % [H2]
  - Durability / ATEX

Prospect

- New optical fibers are in development
- reduce the response time
- Reduce the cost (expensive)

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Question ?

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Conclusion

Optical fiber based on Brillouin backscattering effect is offered a new H2 monitoring system

+

- Distributed measurement
  - 2,5m
  - >100 m (distance range)
- Harsh environment
- Sensibility
  - 0,1mHz/ % [H2]
- Stability
  - Reversible behaviour
  - Durability
- ATEX

−

- Cost
- Response time (doping plays a role)
- Selectivity (not yet evaluated)
- Seems to work well in confined spaces

Doping effect

- Fluorine doping increases the response time and recovery time
  - Numerous prospect to design new fibers
  - Coating of the fibers will be investigated
  - Mechanism has to be clearify