WGCPARIS2015
WORLD GAS CONFERENCE
"GROWING TOGETHER TOWARDS A FRIENDLY PLANET"

26th World Gas Conference | 1-5 June 2015 | Paris, France

FOLD project: Fiber Optic gas Leak Detection

Grégoire AUDOUIN[1] (TOTAL Exploration Production)

Olivier GENTILHOMME[2] (INERIS)

Déborah HOUSSIN[3] (Air Liquide)

Bruno RAGUIN[4] (GRTgaz)

[1] Instrumentation and Control Engineer
[2] Unité Dispersion Incendie Expérimentation et Modélisation (DIEM) Pôle Phénomènes Dangereux et Résistance des Structures (PHDS) Direction des Risques Accidentels (DRA)
[3] Safety Engineer
[4] Technical Division Engineer

WGCPARIS2015
WORLD GAS CONFERENCE
"GROWING TOGETHER TOWARDS A FRIENDLY PLANET"

26th World Gas Conference | 1-5 June 2015 | Paris, France

Table of Contents

Background

Commercially available internally-based leak detection systems can cover the detection of important leaks on a pipeline. But it does not provide an alert fast enough in case of leak below 2%-3% of total pipeline flow-rate and as a consequence won't cover for the risk of corrosion/pinhole leaks. There is a need to mitigate the risk of pipeline slow but long oil spillage or gas leakage. If this may be acceptable for conventional projects applying non permanent monitoring procedures (marching and inspection), this may not be tolerated in environmental sensitive part of the globe.

Aim

This project aims at exploring the detection potential of external leak detection systems within the context of a buried transmission gas pipeline environment (distributed sensing needed for linear asset protection) for the detection of leaks less than 2%-3% flow rate level that represents the floor of current mass balance or computational based detection systems. We produced test results of representative leakage situations on an operational buried gas pipeline and implementing several leak detection systems based on these fibre optic technologies to promote this technology and increase technology readiness levels and acceptance within oil and gas upstream or downstream projects and already operational industrial assets.

Facilities

At INERIS, there are several testing platforms (emission test bench, sensor laboratory, STEEVE Safety Platform for batteries, "Nano" platform...) but the one that will be used for the FOLD project is called the Fire Testing Site (FTS) mainly dedicated to fire and/or gas dispersion experiments (see Figure 1).

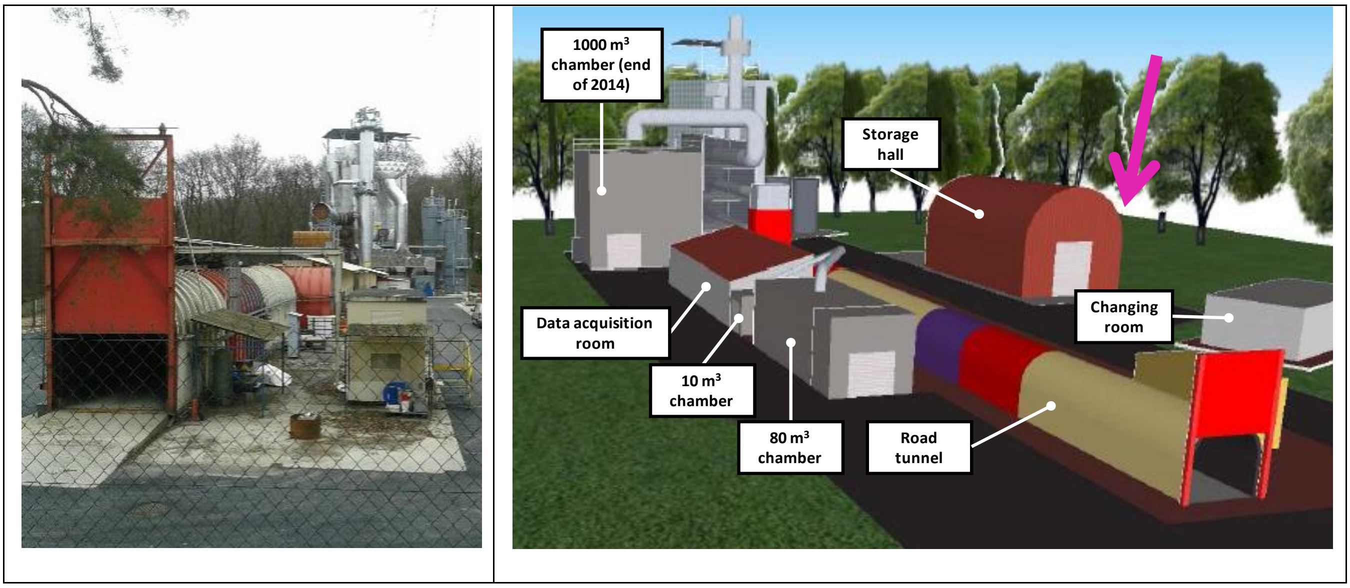

Figure 1: Picture and schematic view of the INERIS Fire Testing Site (FTS)

The FTS had been fully upgraded last year but the construction of a 1000 m^3 testing chamber is still scheduled for the end of 2014. It is currently made up of 3 different testing chambers hence allowing to perform experiments of different scales: a 10 m^3 chamber (mainly used for source term characterisation), a 80 m^3 chamber (used for investigation of gas dispersion in small/medium environment) and a fire tunnel (representative of a road tunnel with a 1/3 scale, used for investigation of smoke or gas dispersion in medium environment). All outlets from these chambers are connected to a gas treatment system before being evacuated in open air through a chimney. The testing site also accommodates service buildings for data-acquisition, storage....

The FOLD facility will be located quite close to the storage hall on top of a hill (see arrow in Figure 1).

Overall description

The leaking pipe will be buried in a trench. As shown in Figure 2, this trench will have overall dimensions of l × L × H = 3 / 4, 5 m × 30 m × 2 m and will be filled with q4-compressed quarry sand[5]. The pipe will be a real one, with an internal diameter of 400 m and a total length of 30 m. It will be buried mid-depth and laterally slightly offset from the centre. When no test will be carried out, the whole facility will be protected from the rain by a plastic film.

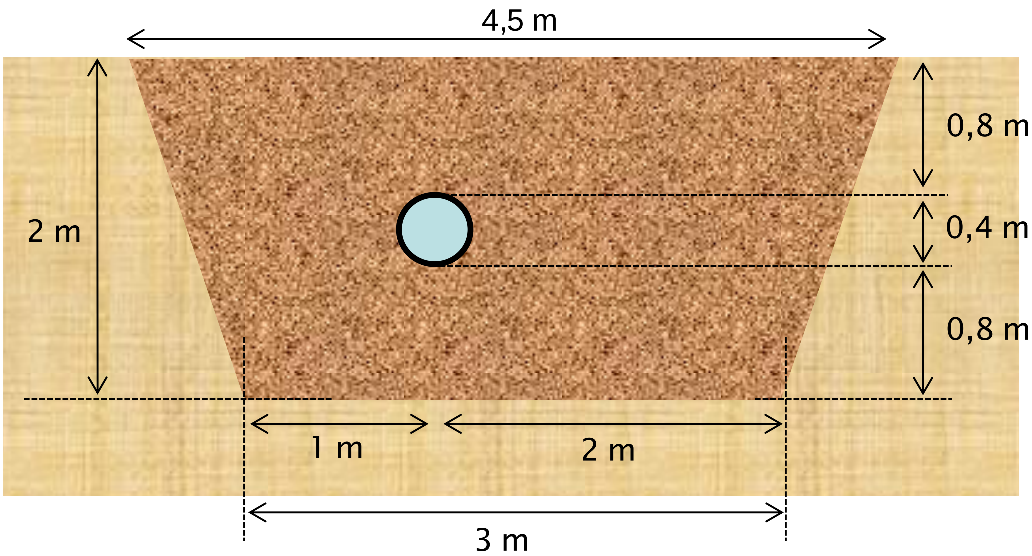

Figure 2: Front view of the leaking pipe buried in the sandbox

Leakages from the buried pipe

All leakages will take place from the external surface of the buried pipe. As opposed to the real conditions, the pipe will not be filled with pressurised gas but will rather constitute a simple cylindrical envelope aimed at housing all pipes required to feed each leakage point with gas (see Figure 3).

The experimental facility should allow investigating:

- 5 different leakage orifices : ∅1, ∅3, ∅5, ∅7
- 3 different leakage directions :upward, on the side and downward

[5] Particulate size on the order of 400 μm

For the ∅12 mm leakage orifice, note that only the downward release will be considered. Thus there will be 13 available leakage points. Each leakage will be tested separately from each other. The FOLD project does not intend to trigger simultaneously several leakages.

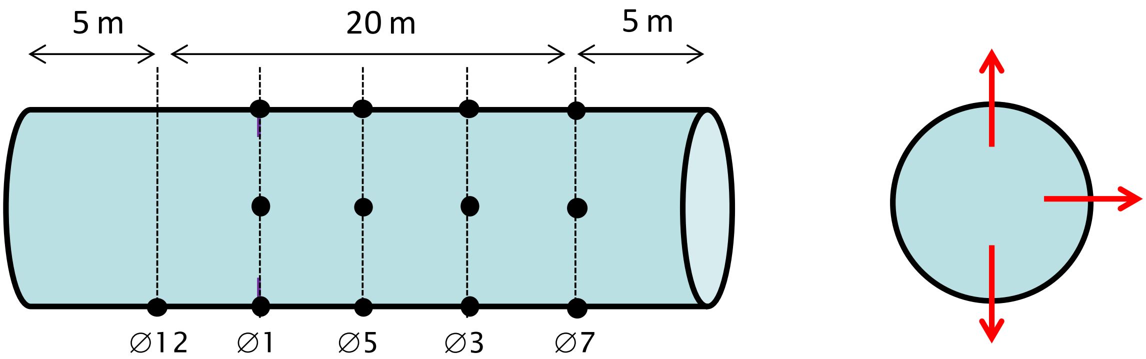

Figure 3: Position of the leakage points on the buried pipe

For ease of tracking, each row of leakages along the pipe will be attributed to the same orifice (see Figure 3). Furthermore, to avoid any important deterioration of the ground that may influence the results between two neighbouring leakages, the following sequence is proposed for the orifices: ∅1, ∅5, ∅3 and ∅7. The first and last positions will be located 5 m from each end of the pipe. The other positions will be equally distributed along the remaining distance.

Gas will be supplied from several bundles of cylinders (cf. Figure 4). Starting from the storage, the main line will be equipped with a manual valve, a remotely-operated valve, an excess flow valve and a purge line. This line will have a diameter of 2" and its length will be kept as small as possible (safety considerations).

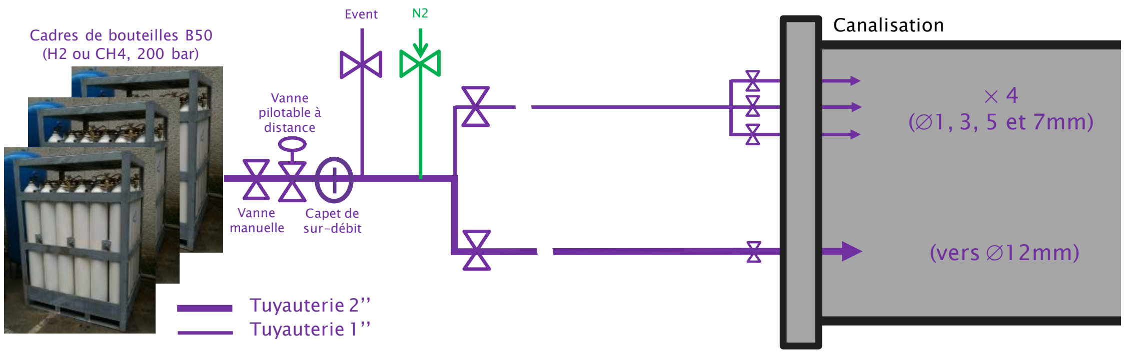

Figure 4: Gas feeding line

The main line will be divided into two secondary lines of different diameters: 1" and 2". The 1" secondary line will feed the orifices ∅1, ∅3, ∅5 and ∅7 whereas the 2" secondary will be solely used for ∅12. The diameters were chosen so as to reduce as much as possible the pressure losses within these lines[6]. This is of paramount importance since they will connect the gas storage to the buried pipe and therefore can be quite long (few tens of m).

Just before entering into the pipe, the two secondary lines will be again divided into several feeding lines (respectively 12 and 3 for the 1" and 2" secondary lines). Each feeding line will be connected to a specific leakage point via a manual valve that could be operated from outside the sandbox. Attention will be made not to impose sharp bends to the feeding lines so as to control the pressure losses. Moreover, given the fact that the space within the pipe is rather limited to house all required 13 feeding lines, it is very likely that part of these lines will enter the pipe from one side and the other part from the other side.

Figure 5 focuses on the leakage point. A bursting disc will be positioned just upstream of the orifice. Its purpose is twofold. While closed, the disc will prevent sand to be ingested into the feeding line. It is also hoped that the noise emanating from the opening disc will be similar to the one generated by a real leakage and it will be interesting to check whether this sound can be tracked down by the fibre optic detection system. The bursting disc will be of "star" technology and not of fragmentation to avoid clogging of the orifice.

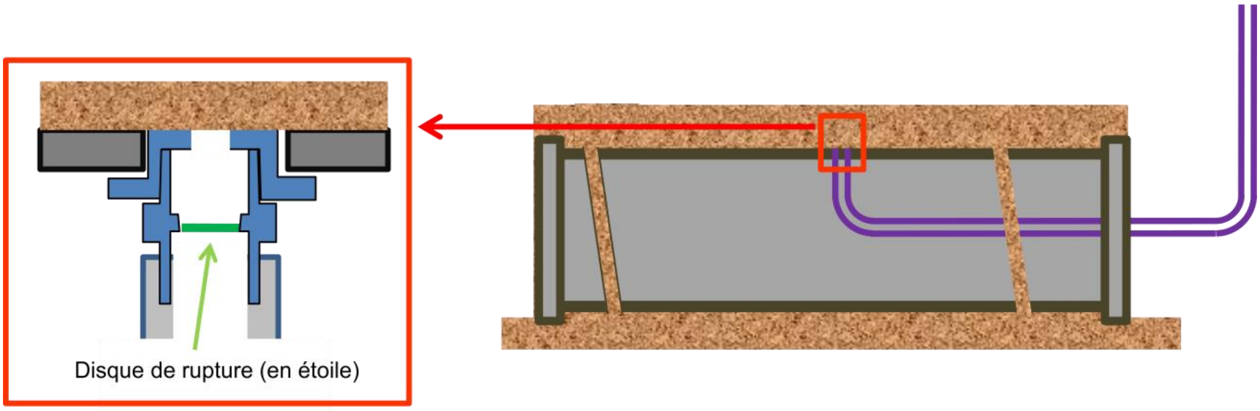

Figure 5: Close-up view of the leakage point

[6] To make sure that most of the pressure losses will occur only through the orifice and not all along the secondary line, the diameter of this latter was chosen so that the cross-section area is at least ten times higher than the orifice section area.

Figure 6: Test bench simulating the pipeline leaks at different radial location

Leak detection systems

The leak detection systems will use an optical cable with a 1 - 2 cm external diameter and a 500 m length (see Figure 6). The cable will contain several optical fibre cores of multimode or mono-mode type to accommodate several interrogation techniques. Three distributed sensing interrogators were supplied by vendors to take part to the FOLD project and were connected to the extremities of the optical fibre cable.

Figure 7 shows the proposed positioning of the cable around the pipe. This positioning may evolve as long as the sand operations have not started. There will be 5 - 10 passages of the optical cable as it will circulate at the desired position in the sand, then will go out, make a U-turn to get back in the sand at a new desired position and so on...

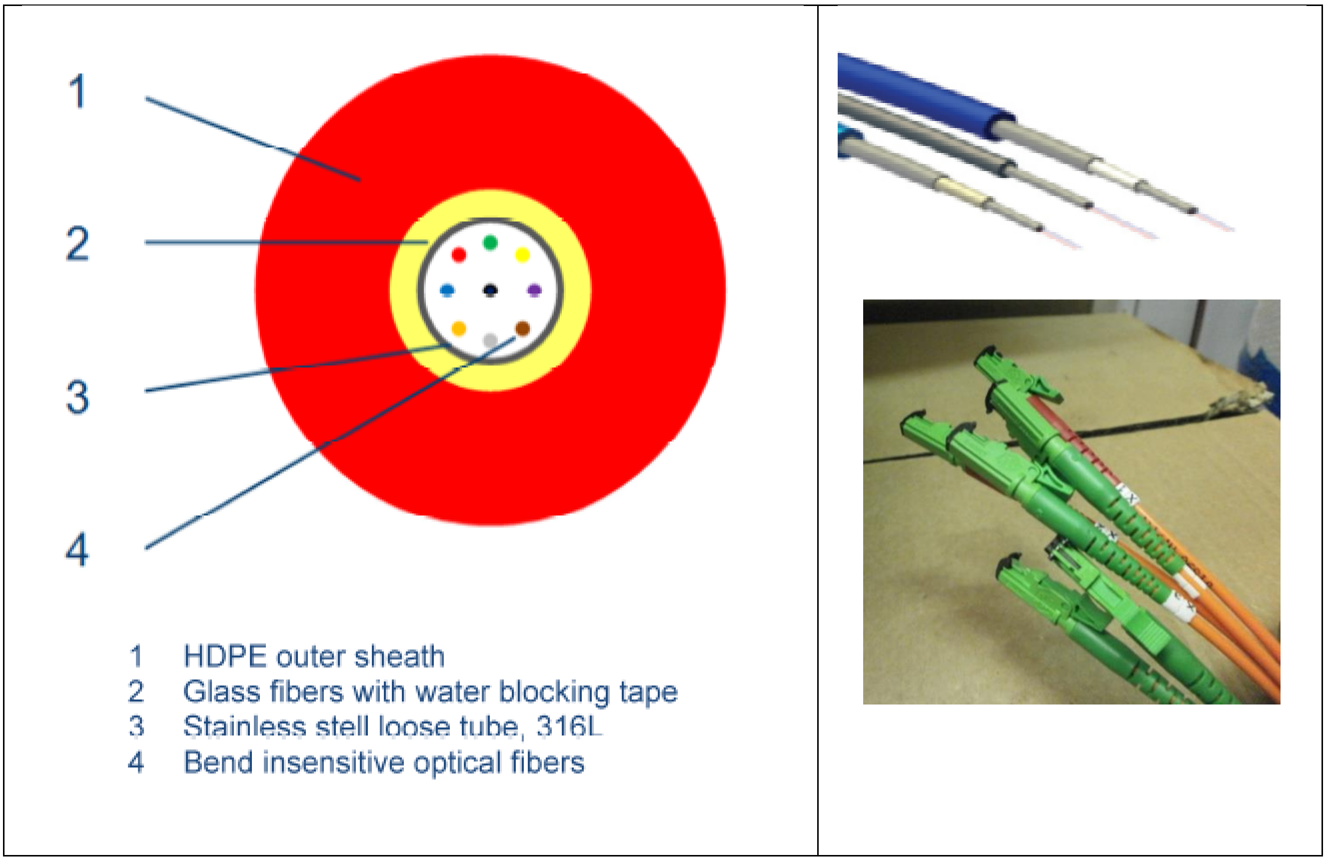

Figure 7: Optical cable composition

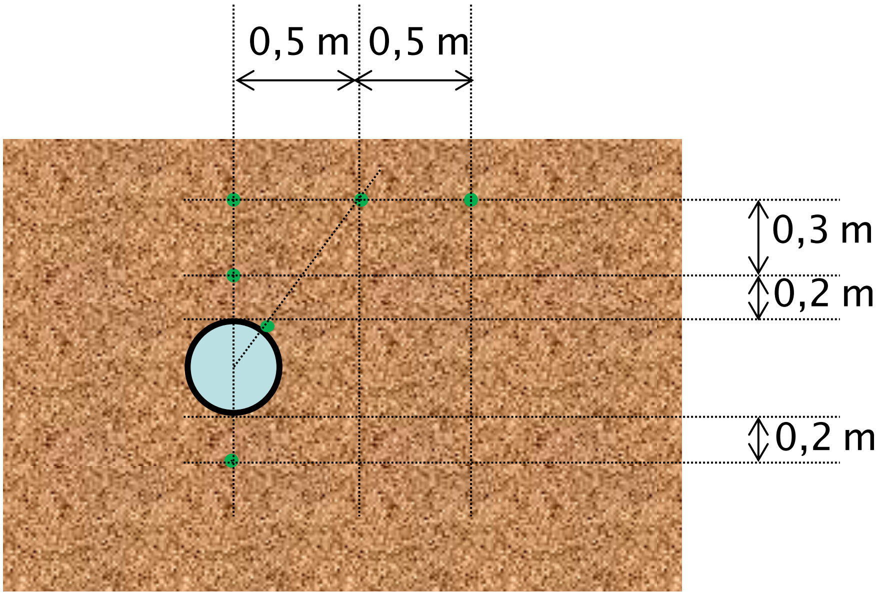

Figure 8: Proposed location for the optical cable in the vicinity of the buried pipe

Fibre Interrogation

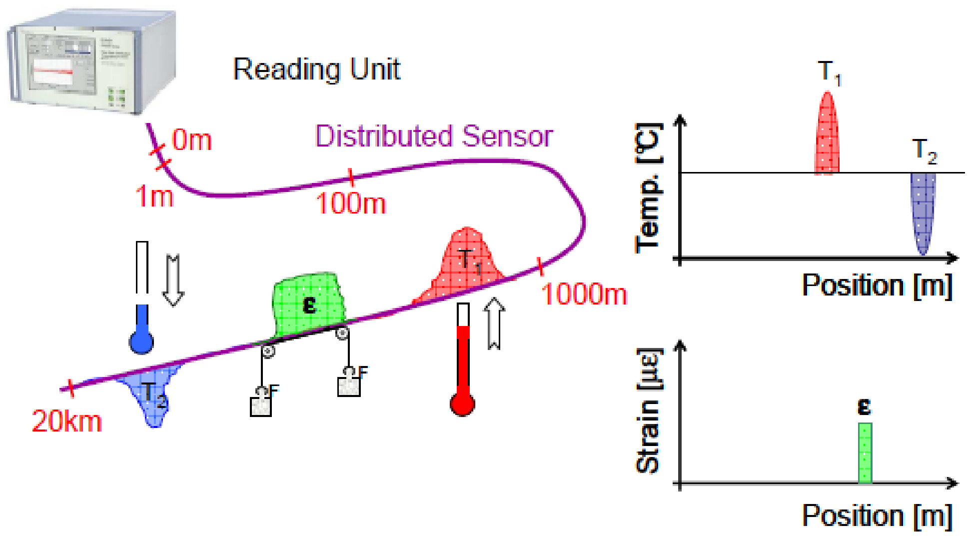

Figure 9: Distributed Temperature & Strain Sensing

Fibre optics used for leak detection is being implemented on different projects which are currently under development. If Rayleigh back-scattering within fibre cores enables distributed acoustic sensing (DAS), Raman back-scattering results in a similar distributed temperature sensing (DTS). This principle is used for flow-assurance purposes but also the Joule-Thomson cooling effect resulting from a gas leak can be detected using this principle. In the case of an oil pipeline, the detection is feasible only if the temperature gradient between the fluid transported and the surrounding ground is very significant. If the temperature drop is obvious fluids like LNG or ammoniac thanks to the phase change, this still need to be demonstrated for fluids in gaseous phase. As a result, detection reliability could come from a combination of several principles, using multiple equipments on different optical fibres in the same telecom cable. Some vendors have demonstrated that DAS interrogation could bring a new approach for the detection of even smaller leaks or enabling early alerts based on small temperature gradient sensing, leak noise or burst detection. Additionally, several technological innovations in fibre optic distributed sensing and its data processing has been noticed within the industry without qualification or full scale test results reached by a third party.

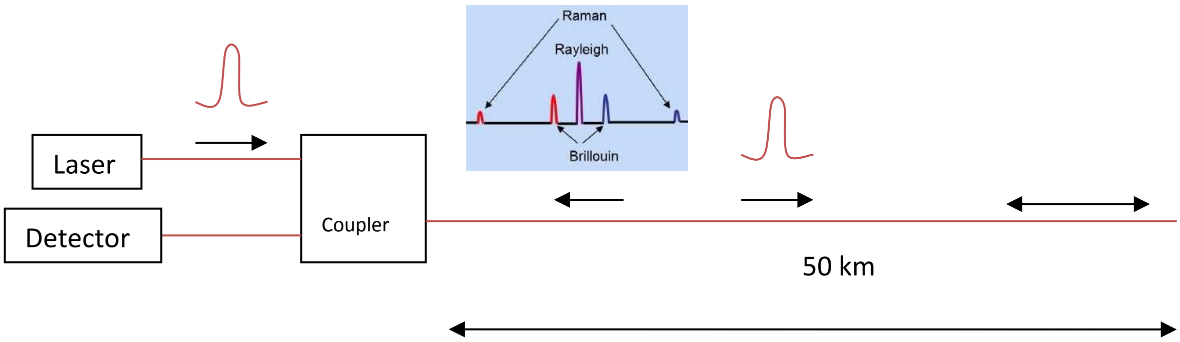

Figure 10: Fiber optic interrogation

As a summary, the dependence of backscattered light on temperature, strain and acoustic environment within an optical fibre results in the possibility to interrogate a standard telecom fibre in different ways:

- **DTS (Distributed Temperature Sensing): Raman scattering** - Can be used for leak detection when a temperature gradient is produced due to a leak
- **DAS (Distributed Acoustic Sensing) or DVS (Vibration): Rayleigh scattering -** Shock detection over the pipeline length can be used for security or specific applications (pigging monitoring, seismic activity, landslides, flow assurance, leak detection…)
- **DSTS (Distributed Strain and Temperature Sensing): Brillouin** Scattering - Geotechnical threat detection (landslide) and leak detection

To briefly explain the physics behind the system of "Rayleigh scattering based distributed fibre optic sensing": A laser transmits a coherent pulse of light along an optic fibre and the photons interacting at a molecular level cause the fibre to act as a distributed interferometer. For each interval, the time to travel to and from the laser is used to locate precisely where the backscattering occurred. When the pulse has had time to travel the full length of the fibre and back, the next laser pulse can be sent along the fibre. Changes in the reflected intensity of successive pulses from the same region of fibre are caused by changes in the optical path length at that section of fibre. The optical path length of the scattered light is affected by variations in temperature, strain and vibration along the fibre. Dedicated optoelectronic devices have then been designed by several suppliers to enable permanent generation of these pulses and real time analysis of their backscattered signals.

Fibre cable behaves for vibration sensing as numerous distributed microphones spread along the pipeline. Signal processing algorithms can then classify any sound sequences into specific potential threat alerts displayed in a dedicated Human Machine Interface. For example, repeated and regular impacts on soil around the pipeline trench will trigger an "excavation" alert to inform the security team of a threat at a specific location. The most appropriate decision can then be taken to ensure intruders are prevented from reaching the pipeline itself.

Test matrix

The industrial partners plan to carry out the following tests:

Substrate	Sand
Released gas	CH4 + H2
Released pressure	40, 70 and 100 bar
Orifice	1, 3, 5, 7 mm

Table 1: Current testing matrix

In total, 20 tests are currently scheduled. Since the experimental campaign is supposed to last only one month, there will be on average 1 test per day. The testing matrix will not be defined in advance but will evolve throughout the campaign depending on the previous results. In other words, a dichotomy approach will be used meaning that the minimum leakage that is detectable by the optical fibre system will be determined by a sort of "try-and-guess" work.

Independent instrumentation

Besides the optical cable, the experimental facility will also be equipped with instrumentation from INERIS. To know precisely the leakage flow rate, the pressure and temperature will be measured near the gas storage but also upstream of the orifice.

The sand temperature will be measured as close as possible to each passage of the optical cable along the pipe and for each axial location where a leakage will take place. This instrumentation may prove very useful to understand the behaviour of the optical fibre during an experiment. More thermocouples will be located at the interface between the sand and the retaining walls so as to check that there is no interaction between the thermal field induced in the sand by the leakage and the walls. For safety reasons, concentration measurements will be carried out above the sand surface.

Conclusions

The project expects to establish guidelines for project purposes on the choice of fibre optic based leak detection system the most suitable for a specific pipeline, depending on the fluid type, its geometry, and all the operational conditions.

Additionally the obtained data enables to assess the feasibility of the targeted leak detection flow-rate as defined in the risk analysis. The operational decisions can then be made with a high degree of confidence of the real performances of the leak detection system, especially should the pipeline transport a dangerous fluid (acid gas) or go through "environmentally sensitive areas such as natural parks or protected environments.

The final aim of this project is to optimize the fibre position during pipe lay so that leak detection performance is maximised. Indeed, at project stage, a fibre optic cable is laid very often anyway for communication purposes within the pipeline trench. There is no extra cost to give guidelines on the best position for the fibre optic to be used as a leak detection sensing device.