CANADA'S LEADING DEVELOPER OF INDUSTRIAL OPTICS AND PHOTONICS SOLUTIONS

Stand-off weeper/seeper pipeline leak detection

Assessment of INO's Optical Technologies for Stand-off Leak Detection in Hazardous Liquid Petroleum Product Pipelines

TransCanada
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Pipeline and Hazardous Materials Safety Administration

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Project Background

- Current leak detection systems for liquid petroleum pipelines are either unreliable in the detection of weeper/seeper leaks or extremely expensive.

- Team: Institut National d'Optique (INO) and Electricore, Inc. with support from TransCanada and Institut National de Recherche Scientifique (INRS).

- Goal: the development of a transportable leak detection system (LDS) demonstrating the ability to externally locate, identify, and assess small liquid and gaseous leaks (weeper/seepers) from a safe standoff distance.

- Project funded by PHMSA.

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Project Objectives

- Assess the stand-off capabilities of INO developed instruments for the detection of vapors from liquid petroleum pipeline leaks.

- The prototype sensor on a mobile platform would include one or more of three spectroscopic instruments:
  - Standoff UV laser induced fluorescence (**LIF**) device,
  - A UV Enhanced Raman remote sensor, and
  - An open path, active, laser based Differential Optical Absorption Spectroscopy (**DiAL** or DOAS) sensor.

- Evaluate the remote capability, up to 100 yards, for several concentrations of vapors from petroleum products (typically transported by pipelines) in a laboratory and in a simulated pipeline setting.

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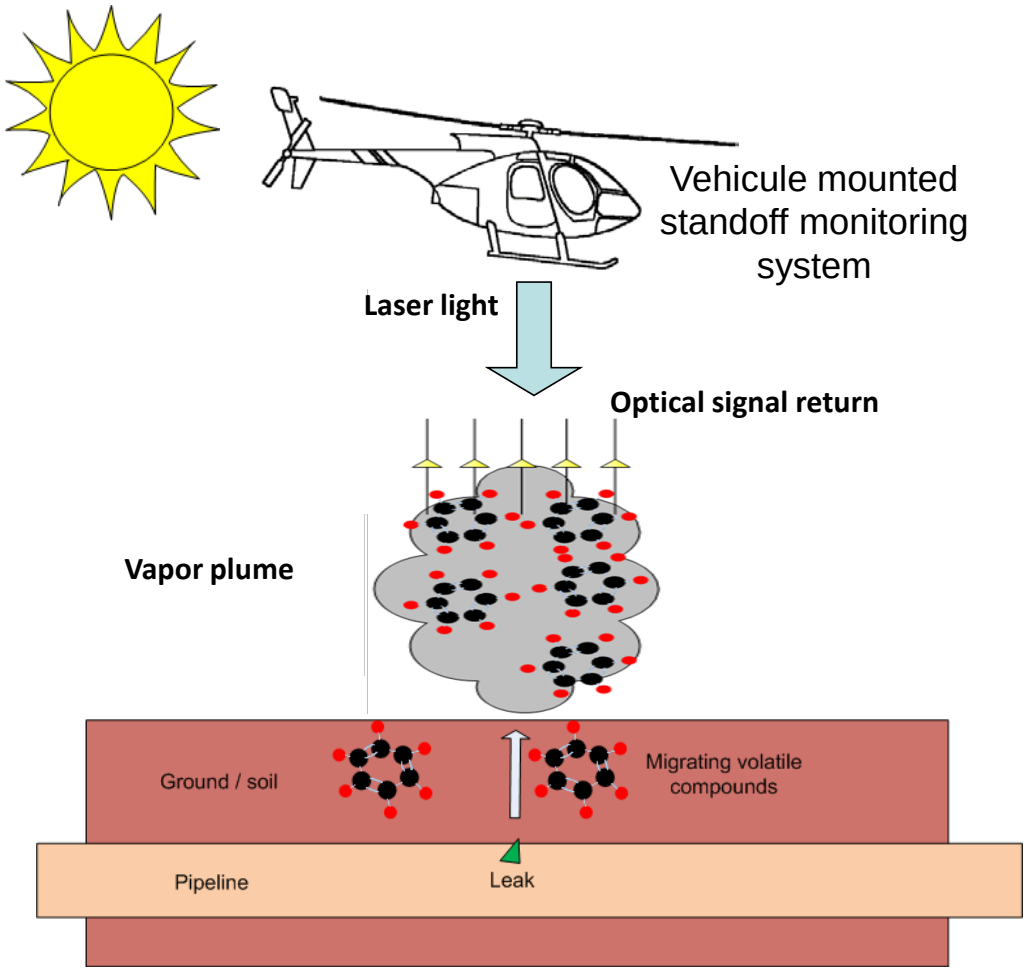
CONOPS



- A successful optical remote leak detection system (LDS) would need to detect as well as a pig with an acoustic LDS, that is: 0.1 l/min (~1 barrel per day).
- All of the concepts at the moment of project start relied on some form of infrared spectroscopy, active (with lasers) or passive.

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CONOPS

Flight height: 150 to 300 ft (50 to 100 m)
Flight speed: 80-120 knots (150 -220 km/hr – the lower for helicopters, the higher for fixed wing)
Flight trajectory: Along the pipeline ROW, slightly to the side (~15 ft (5 m) from center)
Flight length: hundreds of kilometers (hours of data)
Lateral field of view: All of ROW (60 to 90 ft (20 to 30 m))
Simultaneous positioning by GPS and IMU
Frequency of inspection for oil pipeline: every two weeks
Data product: leak zone size and geographical position
Smallest detectable leak: 0.1L/min (ideal)
Spatial resolution/detection accuracy: 30 ft (10 m)
Time from survey to delivery of data products: 12 hours.

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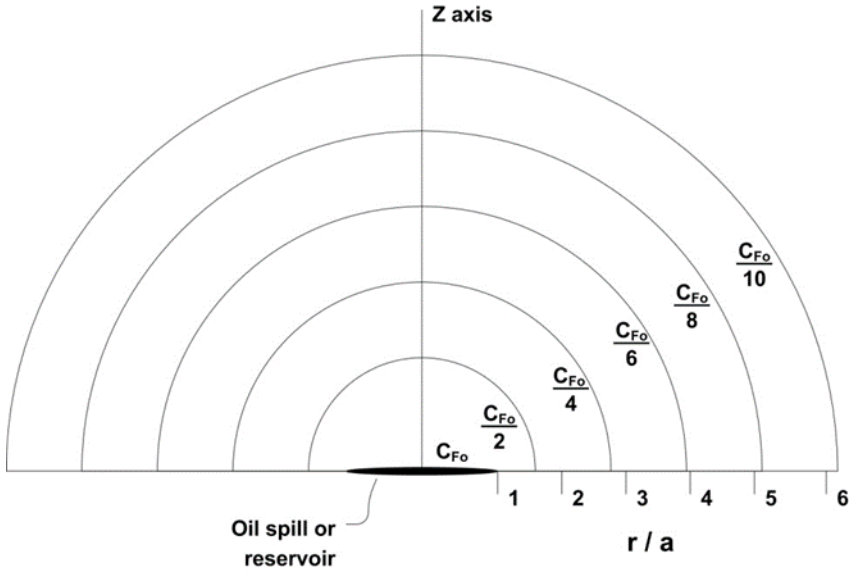
Modeling of leak

- Isotropic evaporation of petroleum product from reservoir (pan).
- No gravity effect. No wind.
- Relies on vapor pressure of molecular specie at ambient temperature.
- Pan radius proportional to leak size.



$$C_F = \frac{2C_{F_0}}{\pi}\sin^{-1}\left(\frac{a}{r}\right)$$

Where:
a = pan radius
r = distance from pan in the x-y plane
z = distance from pan in the z axis
C_F = concentration at distance r or z
C_{Fo} = concentration at the surface of the liquid in the pan

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Modeling of leak (cont'd)

- ***Pentane*** was used for the feasibility study of broadband IR Differential Absorption LiDAR (**DiAL**) and UV Raman LiDAR, being the most abundant and having the highest vapor pressure of the liquid alkanes (at normal temperature and pressure).
  - **Pentane** is the more abundant of alkanes with **300 ppm of average concentration between 1 and 6 m from the ground for a 0.1 L/min leak at 25°C**.
- ***Benzene*** was used for the feasibility of the UV-fluorescence and UV-absorption LiDAR, being the most abundant and having the highest vapor pressure of the molecular species having optical resonances in the usable UV. ***Toluene*** is also a good candidate for modeling.
  - Using a liquid fraction of 0.22% and a vapor pressure of 95.8 torr at 25 °C, the **average benzene concentration over 5 meters close to the ground (between 1 and 6 m from the ground), for a 0.1L/min leak, directly over the leak, is estimated between 3 and 5 ppm.**
- The quantities used are those of an average crude oil seeping at 0.1 l/min.

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UV *Raman* LiDAR approach

When laser light illuminates molecules – Whatever the laser emitter wavelength -- Molecules responds by emitting well defined wavelengths of light – A unique signature

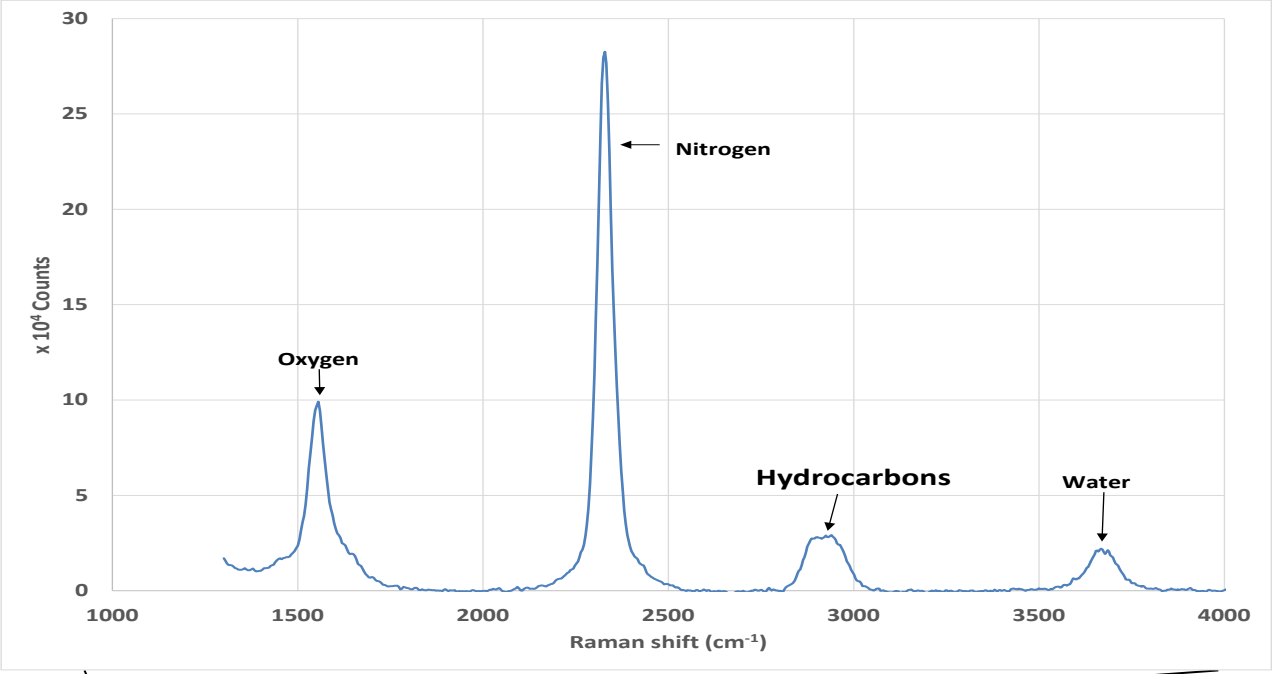
Strength of the signal determines amount of molecules in the atmospheric volume being sampled.

Raman generates very weak returns for a given laser power.

The lidar system can be “tuned” to any high concentration molecule.

The challenge is in designing sensitive eye safe systems.

Raman signatures



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UV *absorption* LiDAR (or DiAL) approach

When laser light illuminates molecules – and the laser emitter/receiver is “tuned” to a specie of molecules – the molecules absorbs the laser light – A unique signature

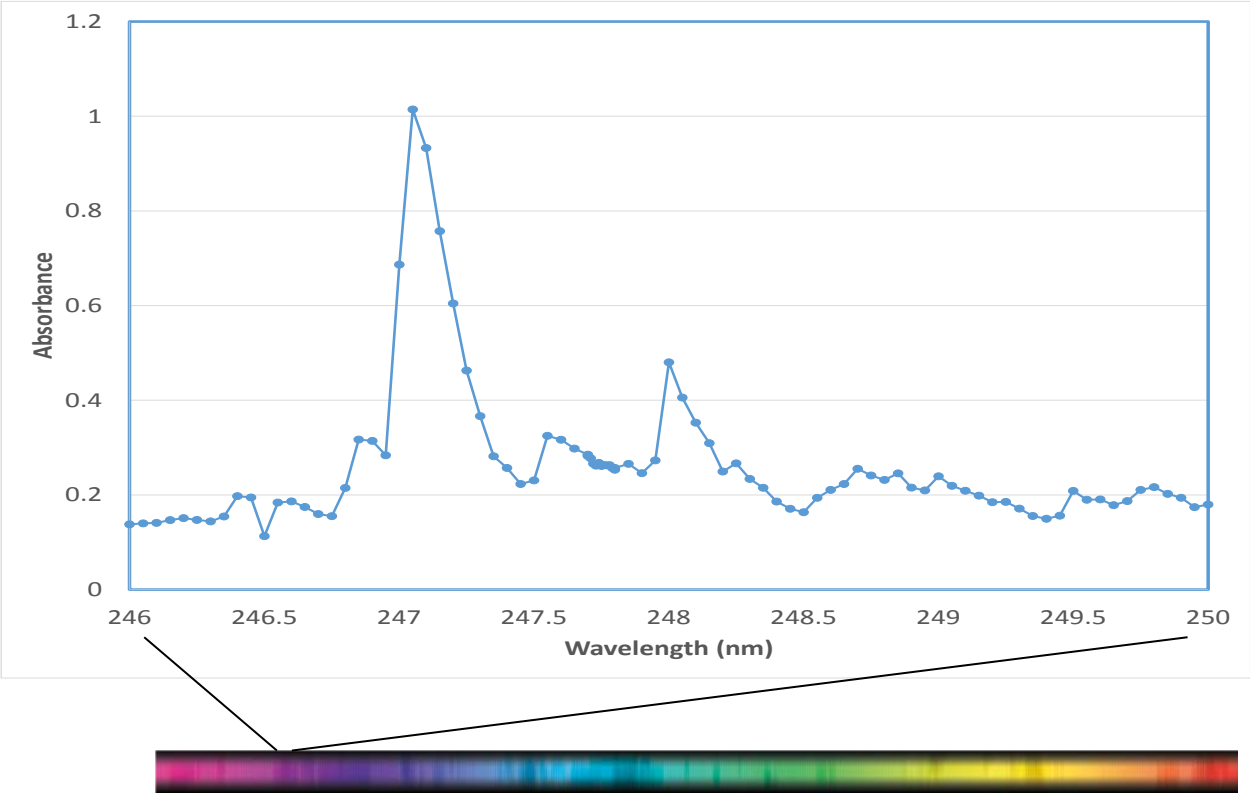
Decrease in signal strength (backscatter) determines amount of molecules of interest in the atmospheric volume being sampled.

Backscattering from the ground generates strong returns for a given emitter strength.

The lidar system can be “tuned” to another molecule.

The challenge is in designing simple user friendly systems.

Benzene absorption signature



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UV *fluorescence* (LIF) LiDAR approach

When laser light illuminates molecules – and the laser emitter is “tuned” to that molecule – The response is the emission of a well defined spectrum of light – A unique signature

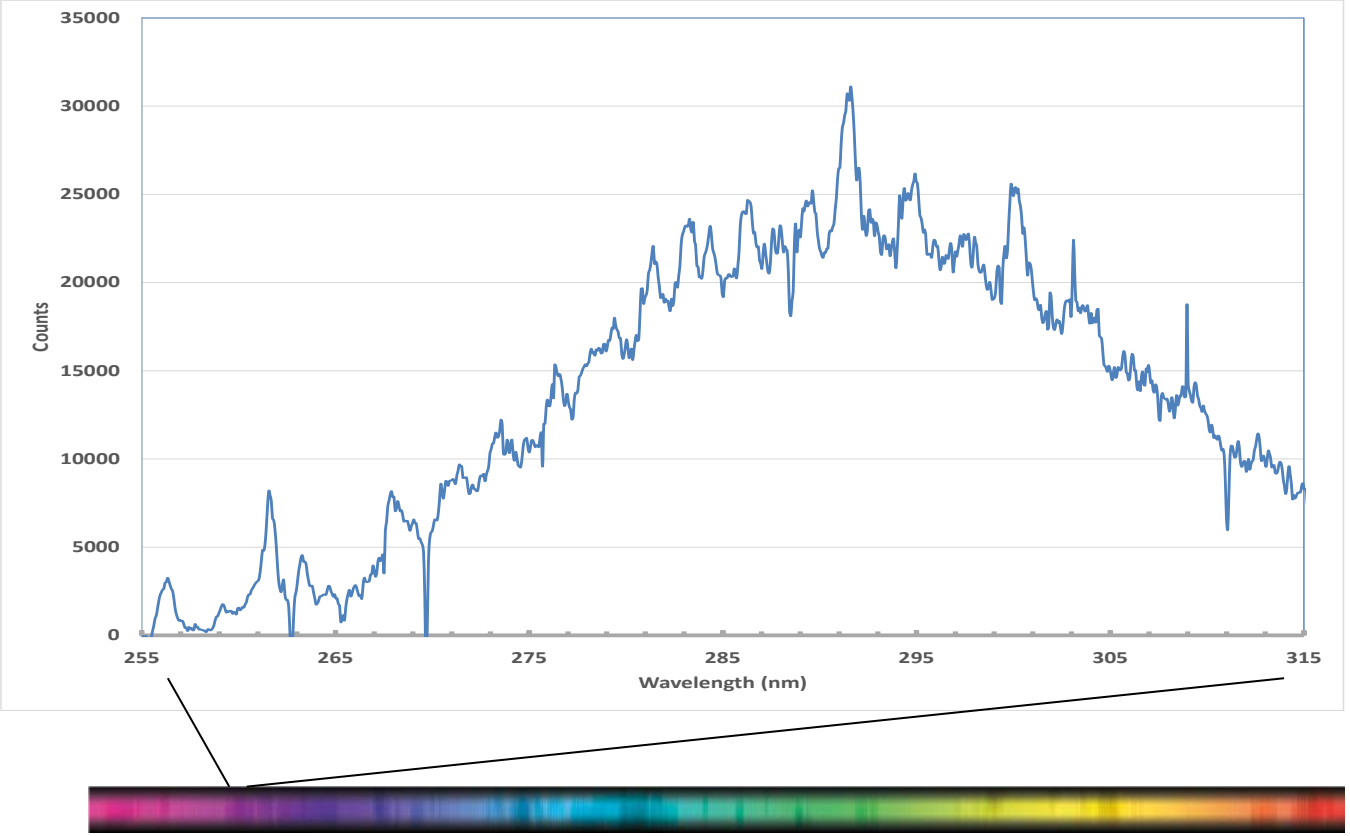
Strength of the signal determines amount of molecules of interest in the atmospheric volume being sampled.

Fluorescence generates strong returns only for a small number of species at atmospheric pressure.

The lidar system can be “tuned” to another molecule.

The challenge is in calibrating the measurement and in designing user friendly systems.

Benzene fluorescence signature



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IR *absorption* LiDAR approach

When laser light illuminates molecules – and the laser emitter/receiver is “tuned” to a specie of molecules – the molecules absorbs the laser light – A unique signature

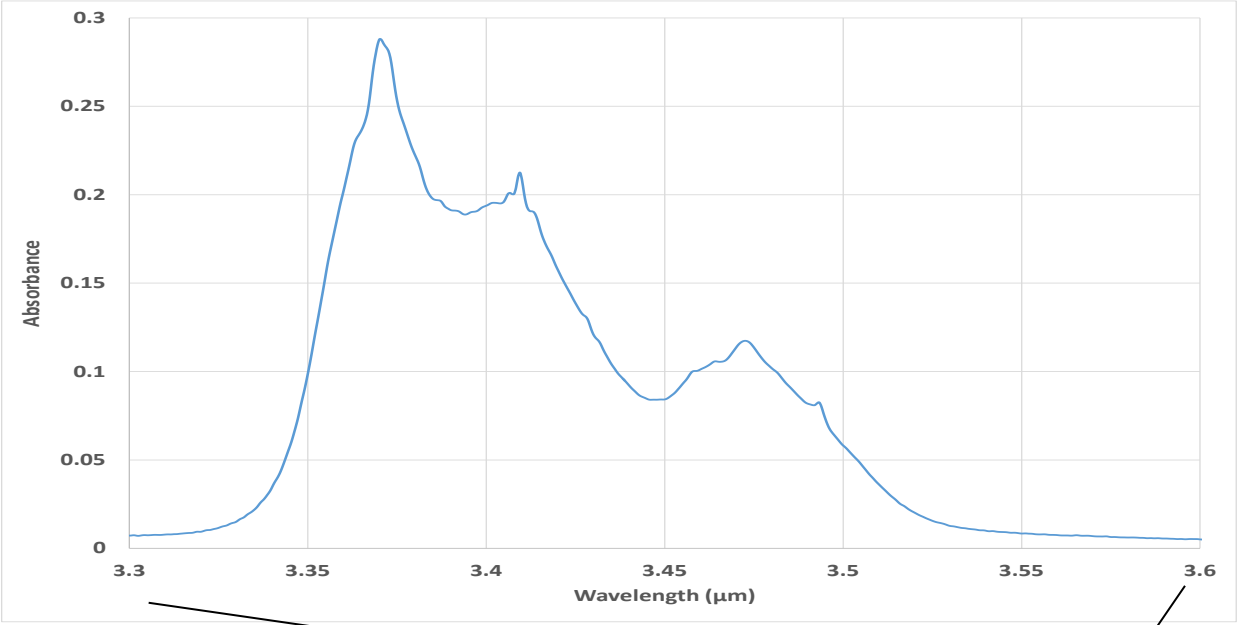
Decrease in signal strength (backscatter) determines amount of molecules of interest in the atmospheric volume being sampled.

Backscattering generates strong returns from the ground for a given emitter strength.

The lidar system can be “tuned” to another molecule.

The signature of complex molecules in the IR is difficult to distinguish from the signature from the ground.

Alkanes absorption signature



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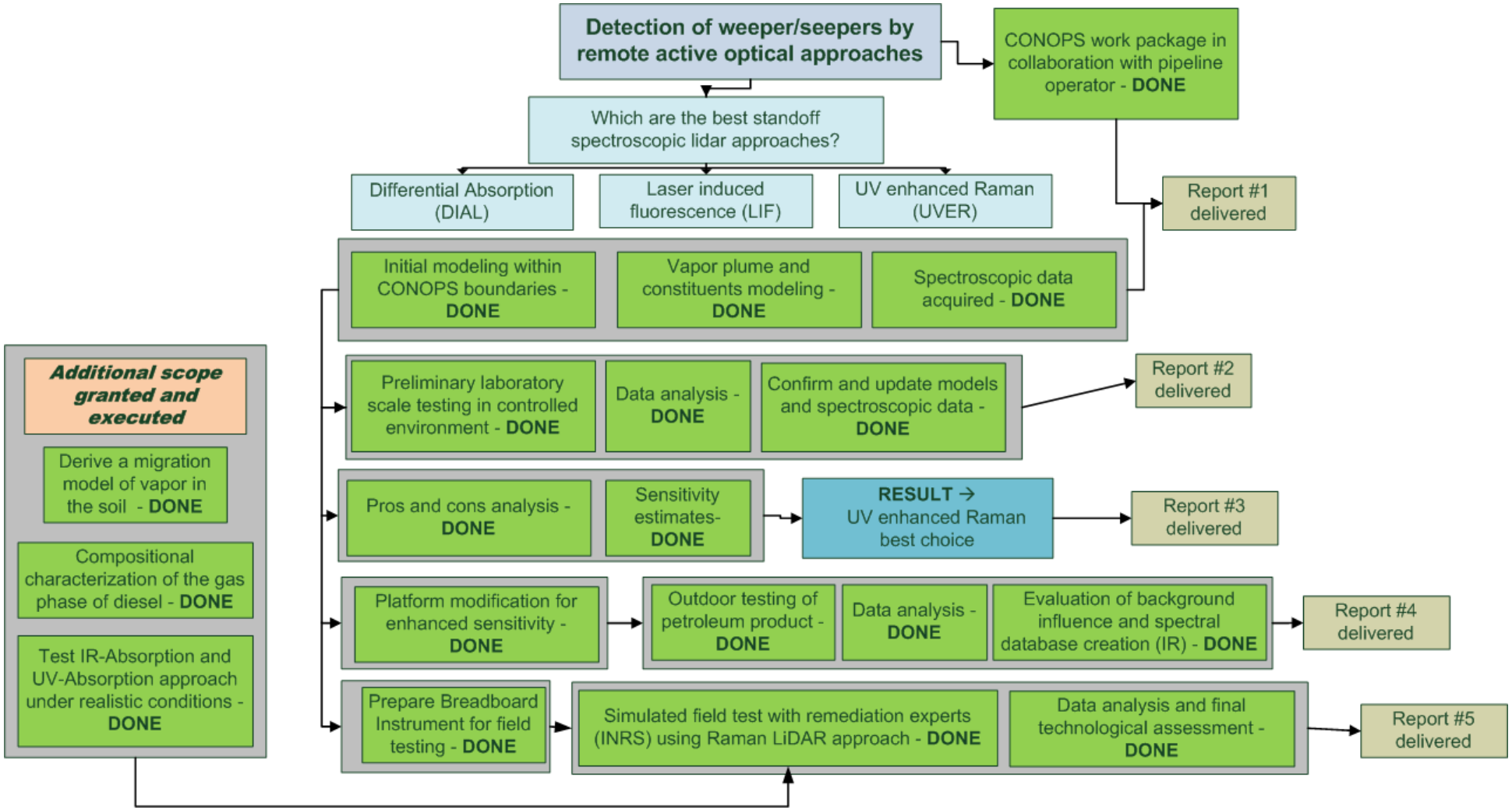
Project flow



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Project scope change

- As presented in a previous slide, ***UV-DiAL (Differential Absorption Lidar)*** was not part of the original approaches.
- The INO platform did not have a tunable UV laser system at project start. This was remedied in the course of project.
- Also motorized, fast wavelength tuning was added to the platform. This was necessary for testing UV-DiAL.
- It was added to the project scope because of conclusions on performances of the Raman approach.
- Modeling and measurements of the vapor phase migration in the soil and in the air was also added for a more comprehensive study of leak detection.

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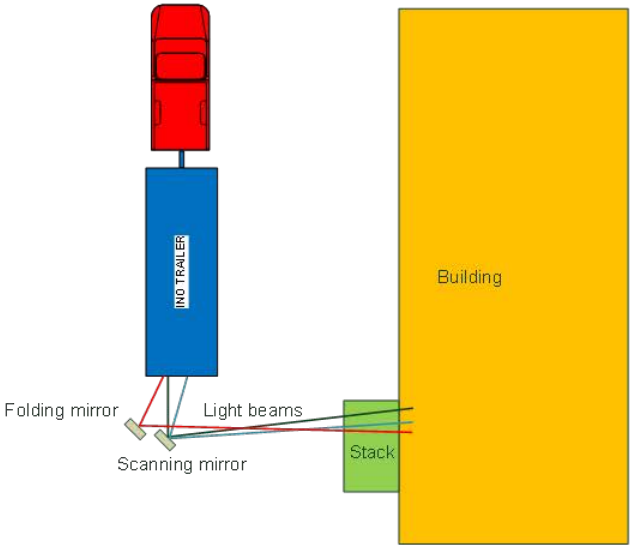
Species tunable deep-UV LiDAR system

- The same platform is used for Raman, LIF and UV-DiAL.
- Changes are made when going from one modality to the other.
- For outdoors tests, the platforms (UV and IR) are mounted in a mobile laboratory.
- Folding mirrors on pan and tilt units mounted outside the mobile laboratory are used to point or scan a mock-up pipeline or exhaust stack, whatever is the application.

Spatially resolved Fluorescence, Raman and Absorption

- Detection of specific molecules
- Multi-purpose system



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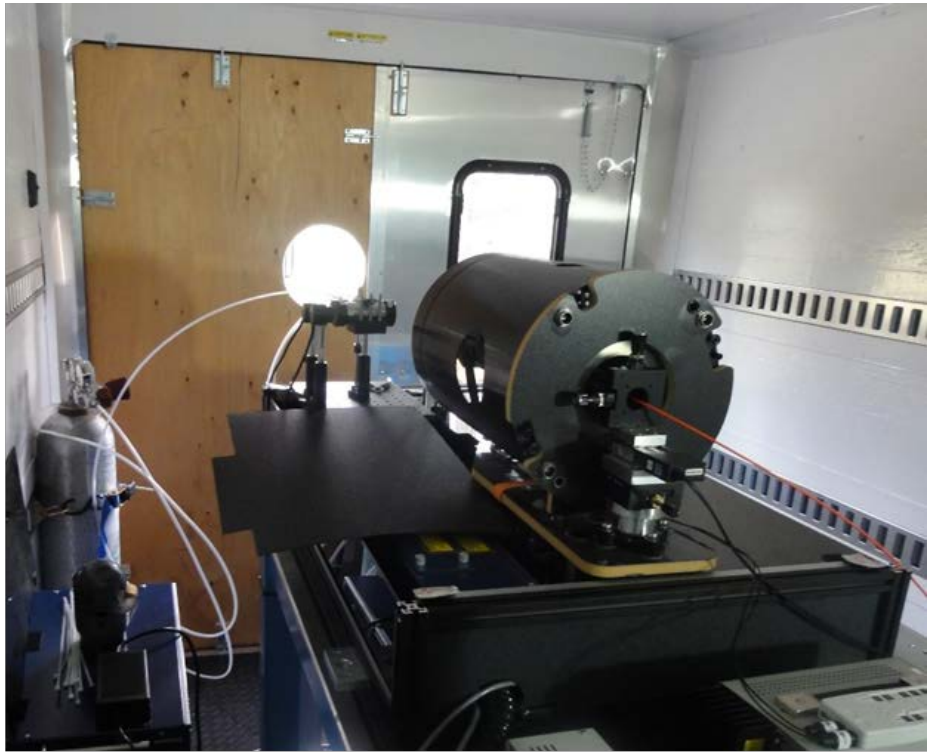
UV and IR prototype platforms



UV DiAL breadboard prototype in mobile laboratory

Also for UV-enhanced Raman and LIF

IR DiAL breadboard prototype in mobile laboratory

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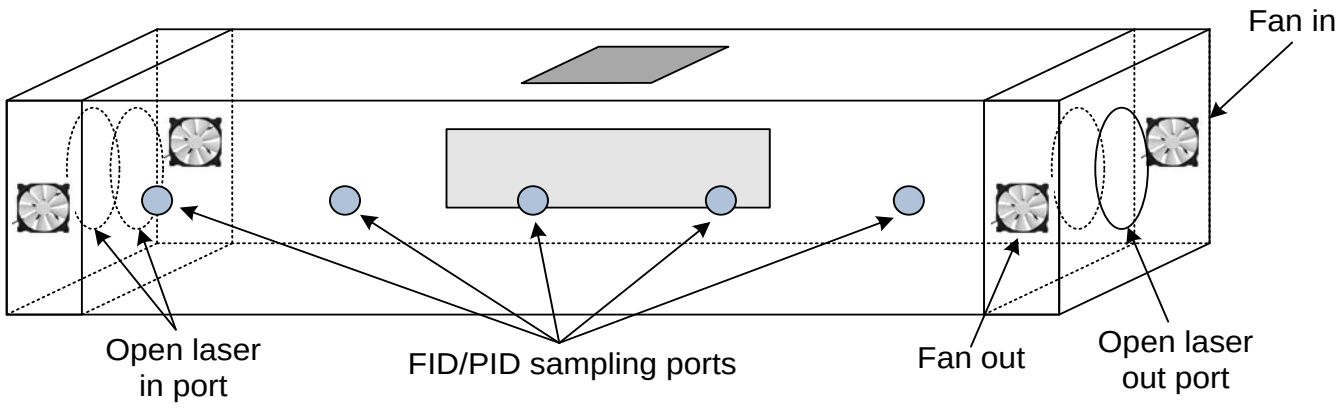
Initial feasibility outdoors testing setup

2m open optical path cell



- Initial experimental feasibility was done with a windowless horizontal gas cell.
- Pans were placed inside the cell and allowed to warm up by sunlight.
- In colder weather, pans were heated.
- Concentration measurements were done with FID/PID instrument.

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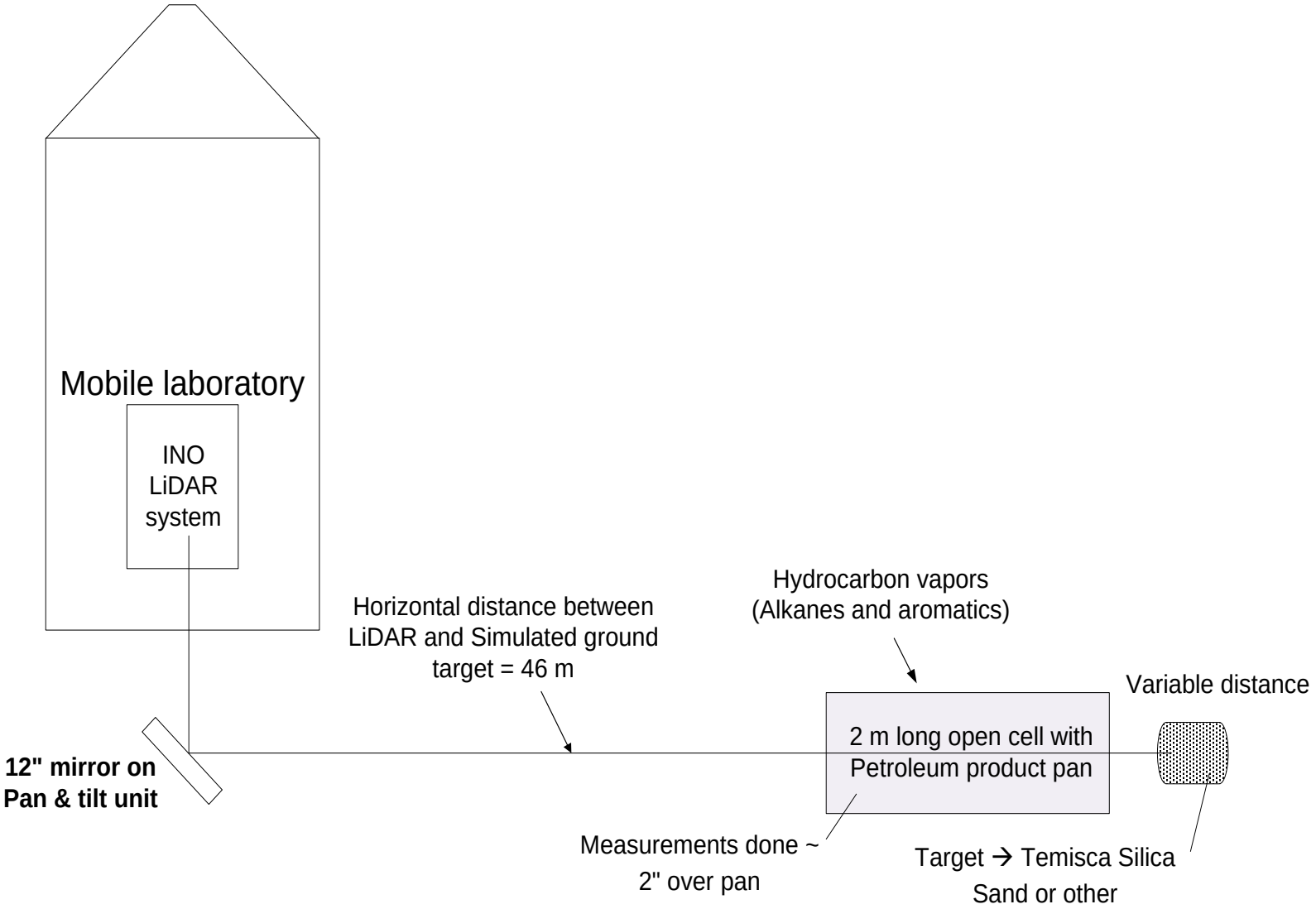
Outdoors feasibility setup



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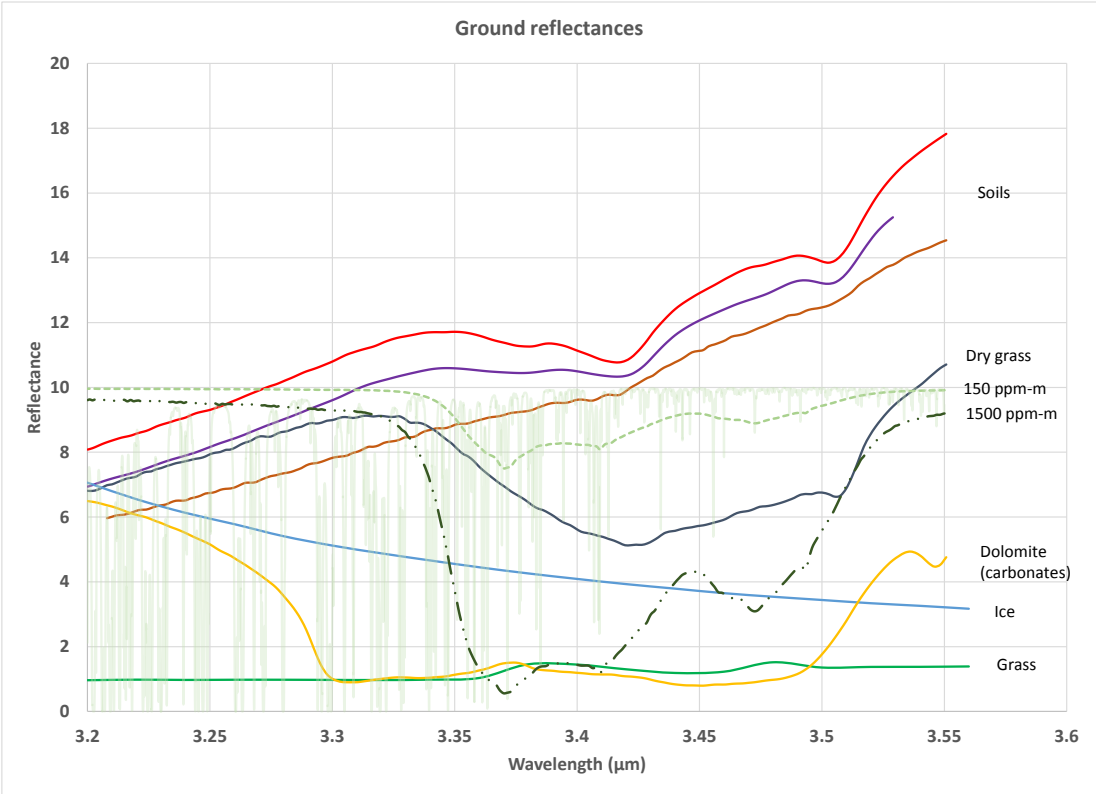
Initial feasibility studies

- For imaging of leaks, with the required resolution of 10 m over the entire ROW and at the required platform speed, the measurement time is 250 ms. Feasibility is done with this number in mind.

- ***For the IR absorption platform***:
  - Optical absorption from alkanes is significant.
  - The strength of the return signal depends on the reflectivity of the ground.
  - Unfortunately, alkanes have a very broadband spectral signature in the 3.4 to 3.6 µm range. This spectral signature could be difficult to distinguish from that of the ground's spectral reflectivity.
  - In spite of this drawback, ***it is very feasible to detect small weeper/seeper leaks using broadband or multi-wavelength IR absorption LiDAR with return from the ground***.



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Initial feasibility studies (cont'd)

- ***For the UV-Raman platform***:
  - All alkanes (and aromatics) present in crude oil have a Raman peak in the vicinity of 3000 cm^{-1}.
  - If the optical measurement integrates the Raman returns in a sufficiently large spectral band, all the hydrocarbons contribute to the signal.
  - Raman LiDARs do not depend on a reflection from the ground and are independent from excitation wavelength.
  - The major drawback is the very small Raman cross-sections.
  - In order to have a measurable signal in 250 ms, the laser at 355 nm needs to be relatively high power.
  - ***The laboratory testing confirmed the initial modeling and it is feasible to detect small weeper/seeper leaks using a 355 nm Raman LiDAR at a distance of 50 m and flying at 80 knots.***

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Initial feasibility studies (cont'd)

- ***For the UV-LIF platform***:
  - In contrast with the other two originally planned platforms, the UV-LIF platform's feasibility was done using benzene.
  - Benzene has useable absorption and fluorescence peaks in the deep UV, between 225 and 270 nm.
  - The expected concentration of benzene is much lower than that of alkanes,
  - It was shown that at atmospheric pressure, in nitrogen, there is very strong quenching of the fluorescence; an unexpected result.
  - ***It would be close to impossible to detect small weeper/seeper leaks using a fluorescence LiDAR. It is not the best approach, by far.***

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Initial feasibility studies (cont'd)

- ***For the UV-DiAL platform***:
  - Although INO proposed the use of fluorescence originally, it would be possible to use optical absorption as a means of detecting leaks, practically the same hardware being used in both cases.
  - **No initial feasibility was done for UV-DiAL**, although the spectroscopic data was available because of the work on fluorescence of benzene and toluene.
  - The model was also available because of the IR-Absorption work.
  - Although UV-DiAL of benzene was not originally listed, it was analyzed along with the other modalities over the entire project.
  - ***It was experimentally demonstrated that UV-DiAL detection of weeper/seeper leaks was feasible, especially in light of the non interfering ground spectral reflectivities.***

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Pros and cons analysis

Pros

Alternative 1	Alternative 2	Alternative 3	Alternative 4
IR-DIAL	Raman	Fluorescence	UV-DIAL
Safe optical operating conditions;	Excitation wavelength independent (could work in the solar blind region for daytime operation);		**Simple measurement technique;**
Most alkanes have very similar absorption signatures in the MWIR; Alkane specific measurement;	Very high selectivity (no interference from water) but relies on C-H molecular bonds in saturated chains which are found in all alkanes and some aromatics (BTEX);	No interference from water;	No interference from water;
Well known absorption signatures of most molecules;	**Most hydrocarbons have a peak close to 3000 cm-1, so they all contribute the signal strength;**		
Well-developed laser system;	**Simple laser system, simple and commercially available optical sub-systems;**	There are resonant lines for benzene that match the wavelengths of commercially available UV/VIS laser sources (e.g. 247 nm);	There are resonant lines for benzene that match the wavelengths of commercially available UV/VIS laser sources (e.g. 247 nm);
Can be easily modified for methane or other molecules;	Can be easily modified for methane or other molecules;		
Strong return signals, except when target is wet soil or water;	**Does not necessitate a reflection from the ground nor from particulates;**	Does not necessitate a reflection from the ground nor from particulates;	**Returns from particulates and molecules are measured; does not necessitate a reflection from the ground;**
Little loss of sensitivity in bad visibility;	Raman signal insensitive to environmental conditions (no quenching, not affected by presence of water, ...);	Fluorescence in the solar blind region is insensitive to sunlight;	Laser return in the solar blind region of the optical spectrum is insensitive to sunlight;
	Easily calibrated; Scalable – just add power	Can be calibrated with the nitrogen Raman if it is measurable;	

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Pros and cons analysis (cont'd)

Cons

Alternative 1	Alternative 2	Alternative 3	Alternative 4
IR-DIAL	**Raman**	**Fluorescence**	**UV-DIAL**
	Very small cross-sections (small generated signal for a given excitation energy);	The BTEX content is highly variable and usually fairly low;	**The BTEX content is highly variable and usually fairly low;**
A laser having a fast switching capability between the multiple wavelengths or having multiple simultaneous wavelengths is required;	**Requires high power UV radiation;**	The laser needs to be tuned to two different but very specific optical wavelengths;	The laser needs to be tuned to two different but very specific optical wavelengths;
	Requires large receiver telescope if a reasonable laser power is to be used (bulky);	The required tunable laser systems are not yet easily field deployable or maintenance free.	The required tunable laser systems are not yet easily field deployable or maintenance free.
High optical resolution is required (from laser or spectrometer);		**Impossible to measure BTEX with commercially available lasers and with defined CONOPS**	
Path integrated measurement – no spatial resolution possible along laser beam path;	Reduced sensitivity in reduced visibility;	High transmission losses in the atmosphere at deep UV wavelengths and in reduced visibility;	Reduced sensitivity in reduced visibility;
Highly dependent on soil optical properties;	Solar radiation interferes with measurement when not in the solar blind region (lower SNR);	Short gating times are minimally needed to get only the BTEX fluorescence signal and avoid signals from the ground;	
Potentially prone to interference from other complex molecules and water vapor;	Possible interference from fluorescing species;	The LIF LiDAR's tested sensitivity does not take into account interference from other naturally occurring fluorescing species;	The UV DIAL sensitivity does not take into account interference from other naturally occurring absorbing species;
Requires complex data analysis in order to reduce false alarms		Difficulty in calibration if laser power is such that the nitrogen Raman is not measurable	

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Pros and cons analysis (cont'd)

- The preliminary analysis showed that Raman was the modality to test.
- This was done using the crude vapor plume model at hand.
- Other modalities could be used if Raman turned out to be unusable.

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Modifications to the UV platform

- The UV platform was modified and optimized for UV-Raman. It was modified so that the optical measurement covers (adds) the Raman returns over a sufficiently large spectral band for all the hydrocarbons to contribute to the signal.

- Multiple iterations of modifications were performed to enhance sensitivity and lower potential instrument cost (manufacture and maintenance) of the simplified system.

- The final design used the full waveform approach;
  - The measurement is spatially resolved along the laser beam path;
  - The spatial resolution depends on laser pulse length and detection electronics bandwidth;
  - A lower cost system with this design is possible.
  - This design could be used for all modalities (IR-absorption, UV-LIF and UV-DiAL).

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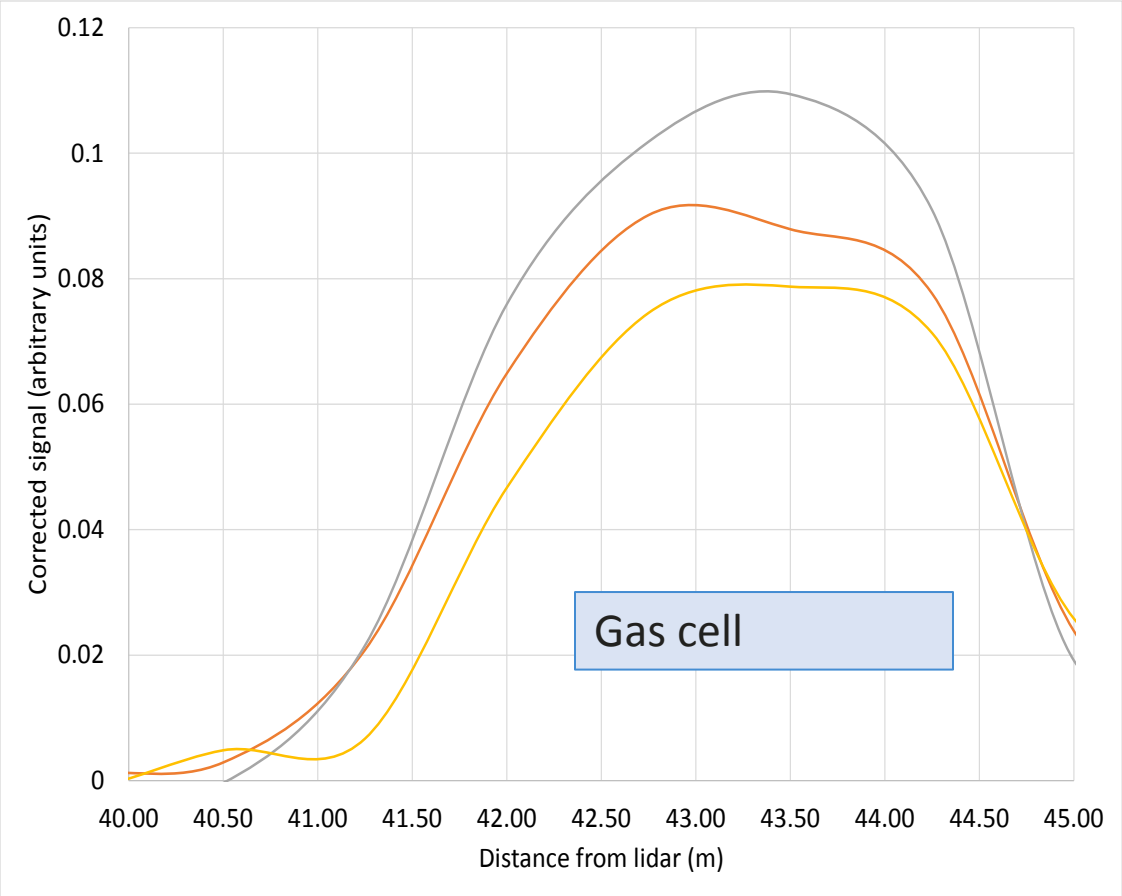
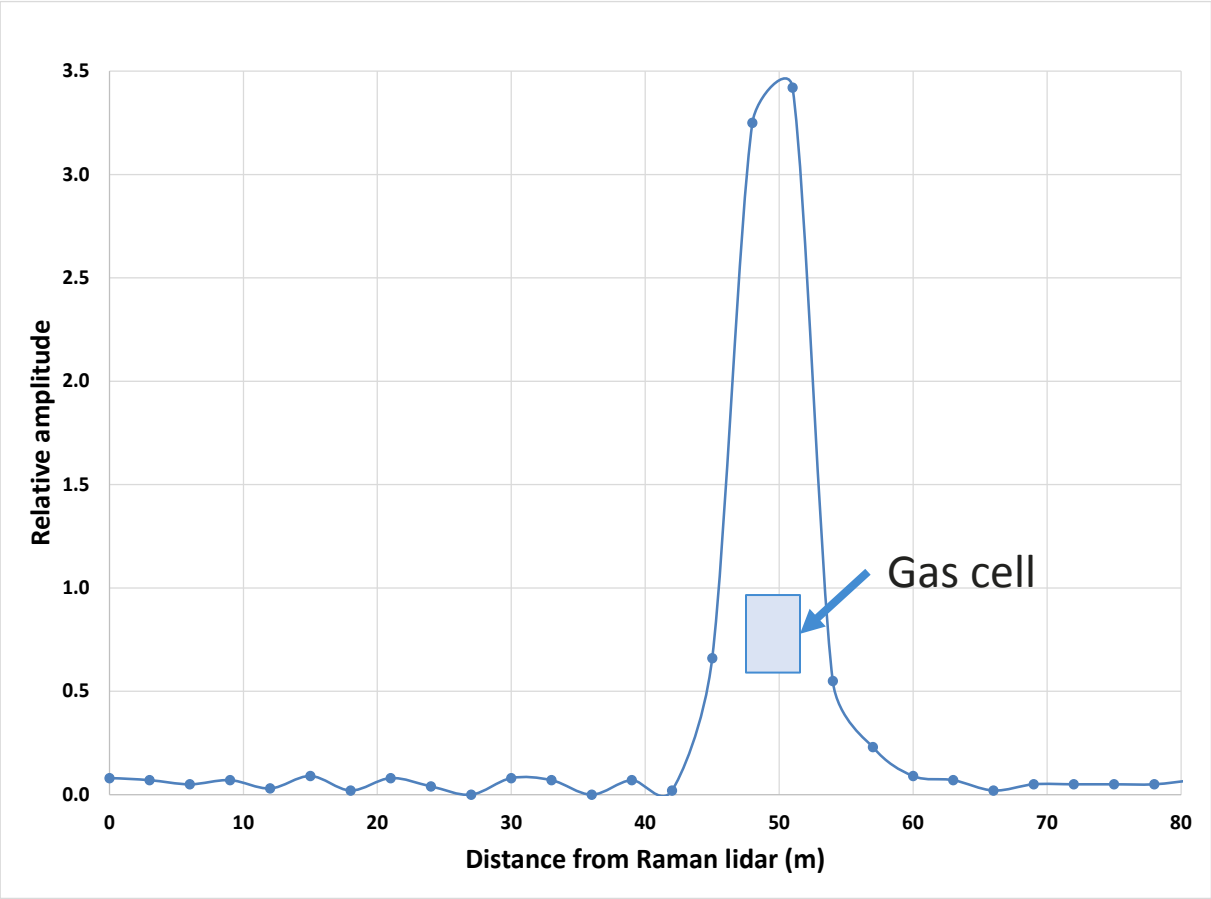
Raman results in windowless gas cell



Spatially resolved measurement of gasoline (upper curve), pentane (middle curve) and diesel (lower curve) in windowless gas cell.



Typical Raman signal from ~2 000 ppm of pentane over a 2 m path using 500 pulses of 25 mJ. The windowless cell is at 50 m from the Raman LiDAR. A background signal measured in the same environmental conditions was subtracted from the raw measurement.

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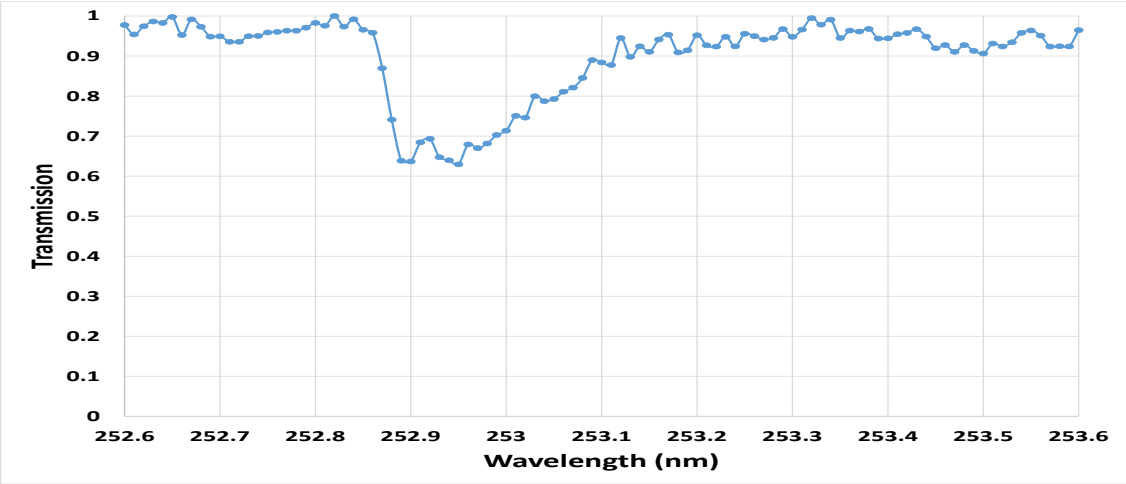
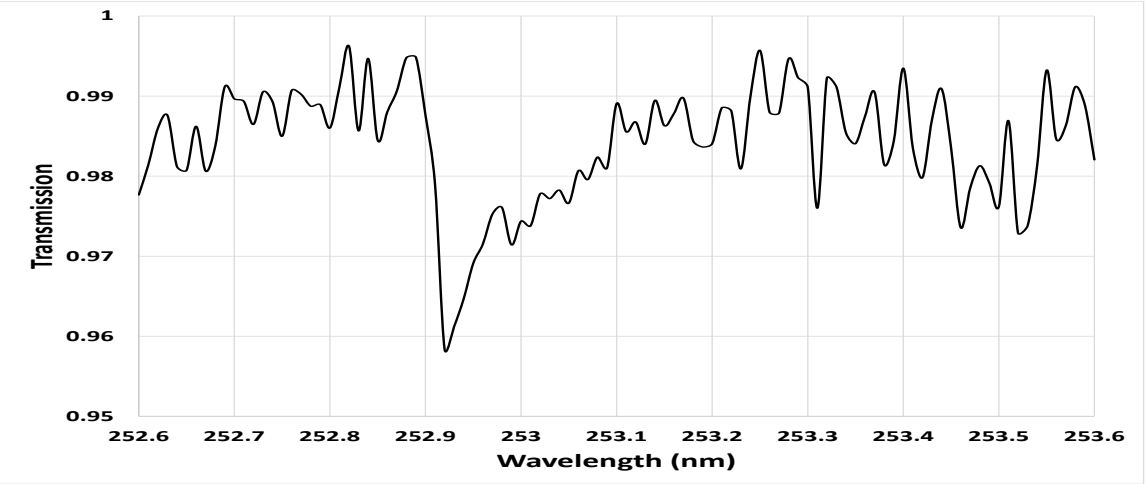
UV-DiAL results in windowless gas cell



UV absorption spectrum of benzene above a heated gasoline pan in 2 m long windowless gas cell (250 to 300 ppm-m)



UV absorption spectrum of benzene in a 10 ppm-m reference gas cell (with windows, in the mobile laboratory)

- In order to measure a leak with any kind of certainty would require measuring an absorption of less than 1% from a reflection from the ground at 50 m
  - → It is estimated that a 0.1 L/min leak of diesel would produce ~30 ppm-m of benzene.
- This is feasible, even though it was not shown to be possible with the INO platform in its current state.
- 10 ppm-m corresponds to approximately 2% absorption.
- 30 ppm-m would represent 6 to 7% absorption at 0.017 nm measurement resolution.

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Stand-off weeper/seeper pipeline leak detection

Simulated leak results

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Underground leak simulation (INRS)

- The intermediate scale tests were performed at Institut National de la Recherche Scientifique (INRS) in Quebec City.
- An underground leak was simulated in a large container filled with sand.
- Simulation of airborne measurements achieved from ground based installation using a tilted mirror mounted 5 m over the contaminated sand.
- There was no movement of the laser beams.
- Analysis of the air/vapor composition above and under ground during the whole experiment with a PID/FID instrument for the monitoring of hydrocarbon concentration at various locations in the simulator.
- This is used as reference measurements to correlate with the UV-Raman / IR-absorption data.

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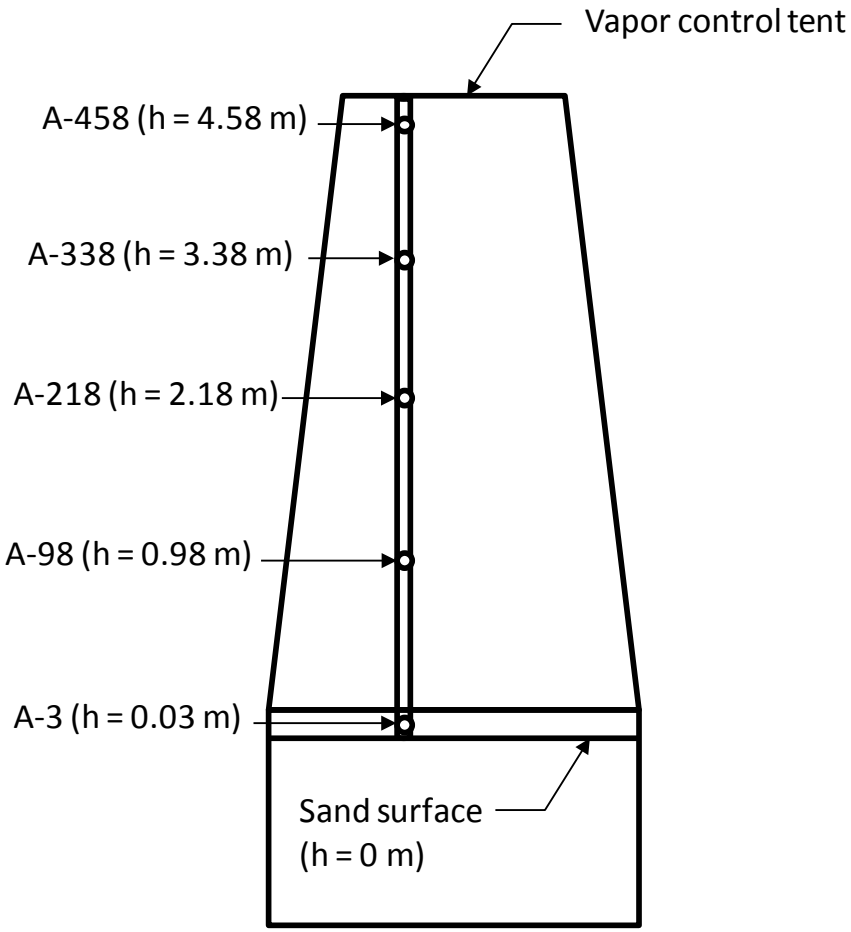
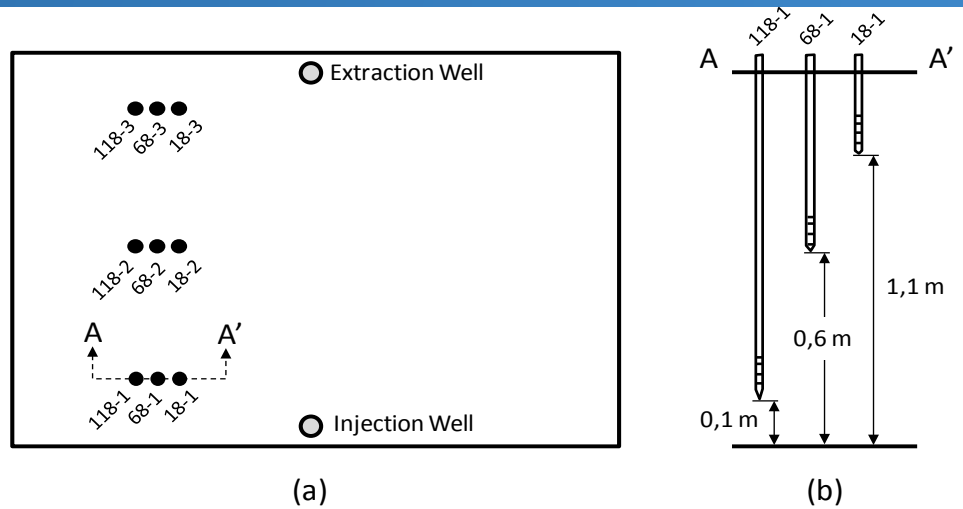
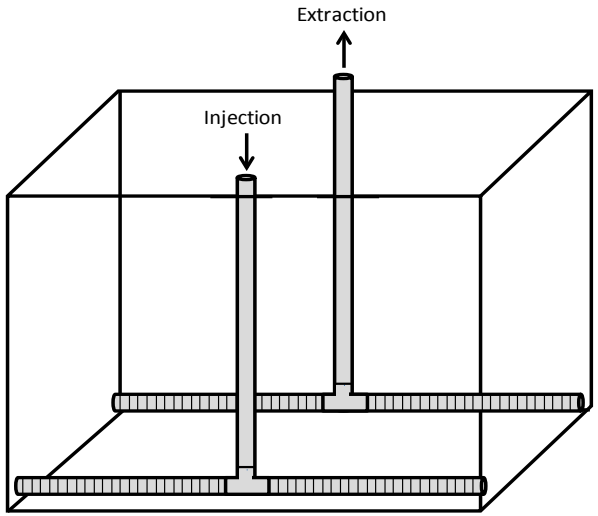
Underground leak simulator (INRS)



Air monitoring ports above the sand surface (h = height measured from the sand surface)





Injection and extraction ports for liquid petroleum and vapor sampling ports in sand container. (a) Top view, (b) Side view

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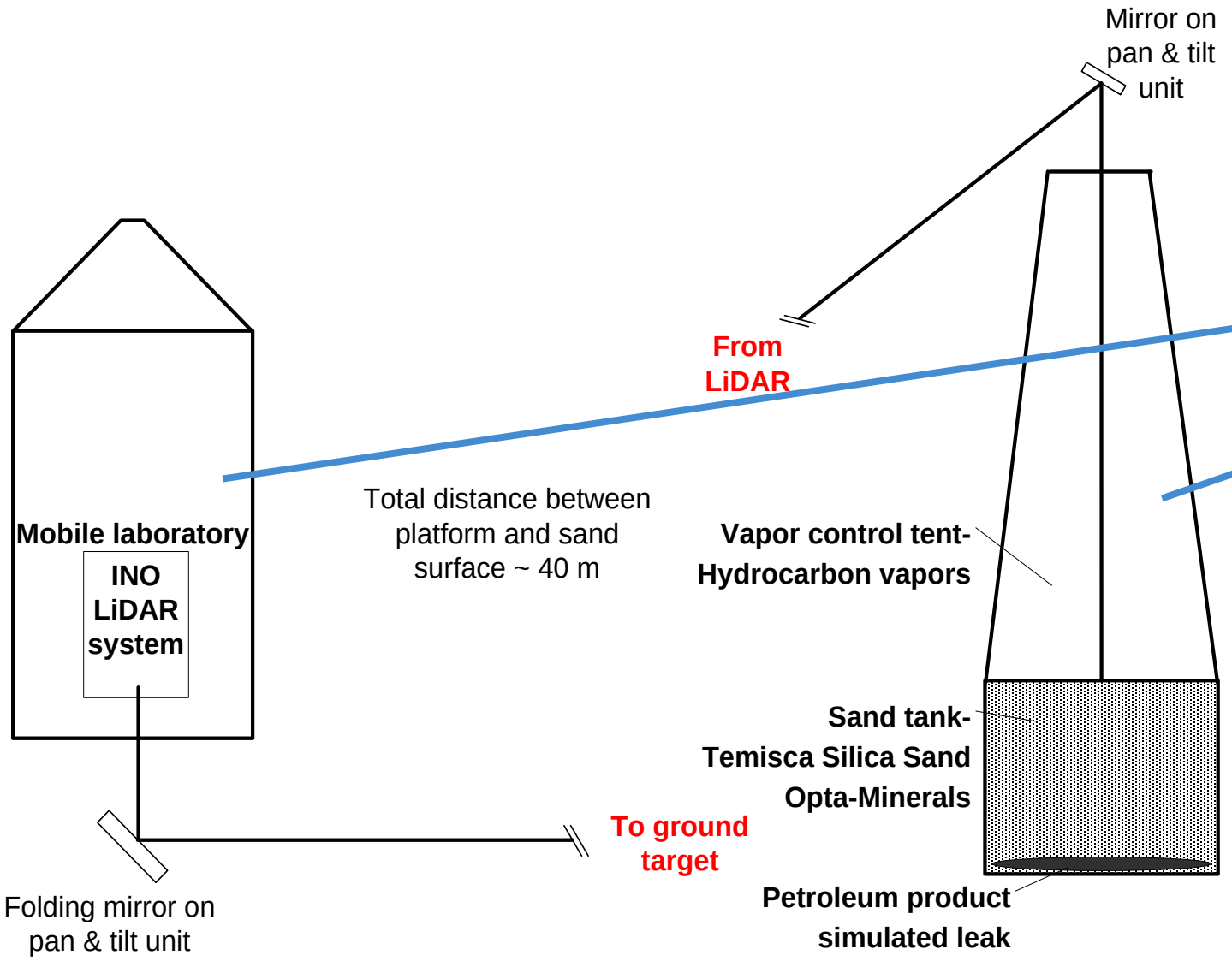
Simulated leak test setup



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Timeline of petroleum products injection/evaporation

Date	Time	Cumulative time (hrs)	Event
2014-09-09	09:58	0.00	Start of diesel injection
2014-09-09	14:57	4.90	End of diesel injection (100 L injected)
2014-09-10	09:28	23.50	Start of diesel injection / extraction
2014-09-10	11:20	25.37	End of diesel injection / extraction (15 L)
2014-09-10	11:25	25.46	Start of diesel pans experiment (5 pans on sand)
2014-09-10	12:00	26.03	* Improvement of the sealing at the base of the tent
2014-09-10	15:12	29.23	End of diesel pans experiment
2014-09-10	15:25	29.45	Start of pentane pans experiment (5 pans on sand)
2014-09-10	16:00	30.03	End of pentane pans experiment
2014-09-18	11:05	217.12	Start of gasoline pans experiment (6 pans on sand)
2014-09-18	16:00	222.03	End of gasoline pans experiment

Timeline of experiments done on the intermediate scale leak simulator

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Reference measurements

- ***For FID/PID readings***;
- Each sample port, both in soil and in the air, was connected to 7.6m of polyethylene tubing.
- A 15 cm Norprene tubing adaptor was inserted at the tip of the polyethylene tubing to allow vapor readings.
- Samples were collected by inserting the analyser sampling tip directly into the Norprene adaptors.
- Sampled air was introduced into the analyzer using the internal pump at a flow rate of 1 L/min.
- All measurements were taken following adequate purges.

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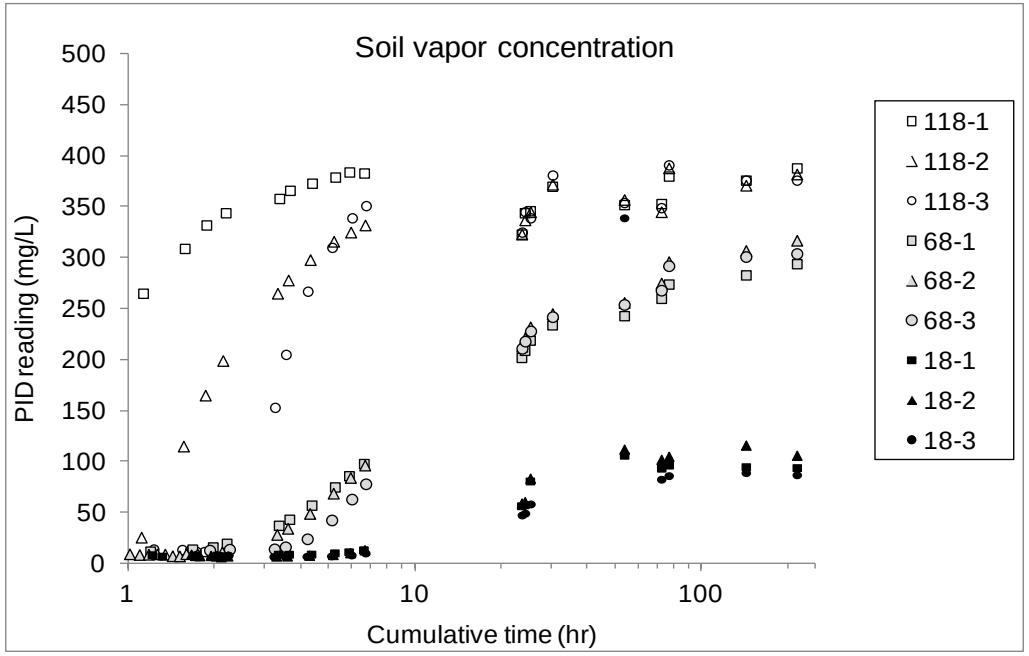
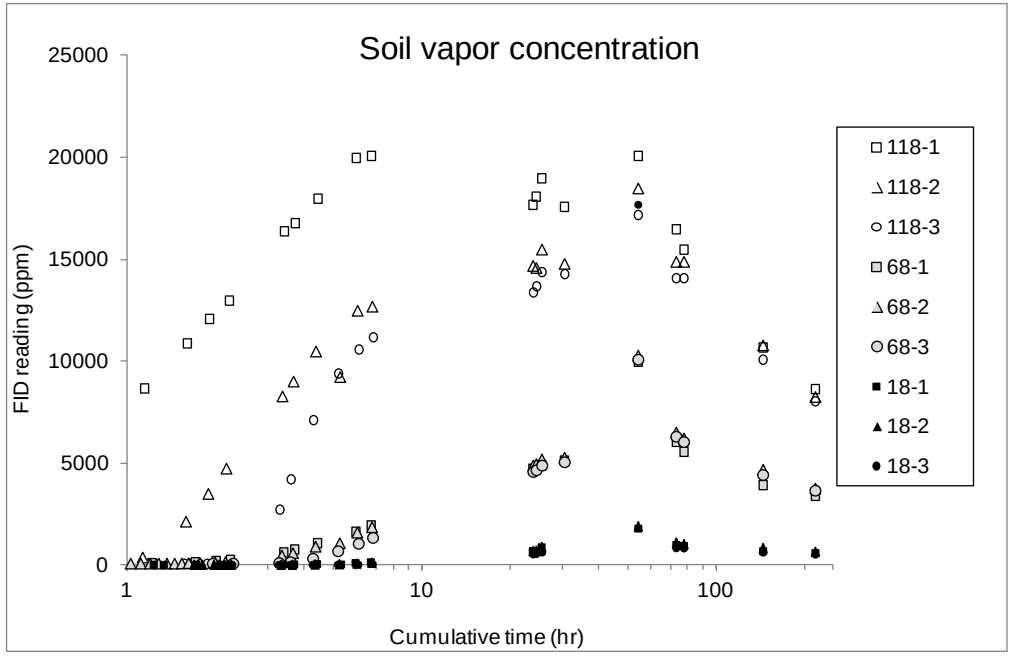
Diesel vapor behavior in ground





- It takes more than 24 hours for the vapor to migrate and stabilize to the top layer (18-x) after injection of 115 liters of diesel (non consecutive). Concentrations are evolving more than 200 hours after injection.
- Vapor composition changes with time after stop of diesel injection (FID readings changes differently from the PID readings).
- There is a vapor concentration gradient between the leak and the air/ground interface (at least when the diesel is not renewed).

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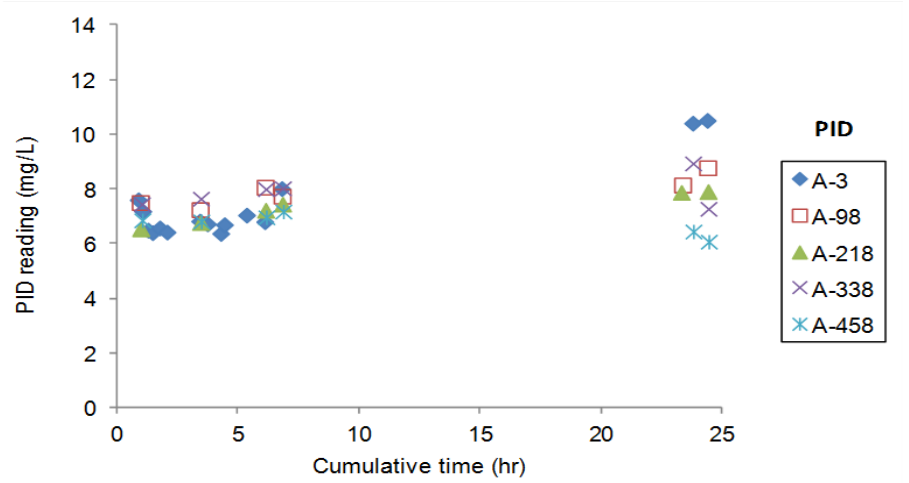
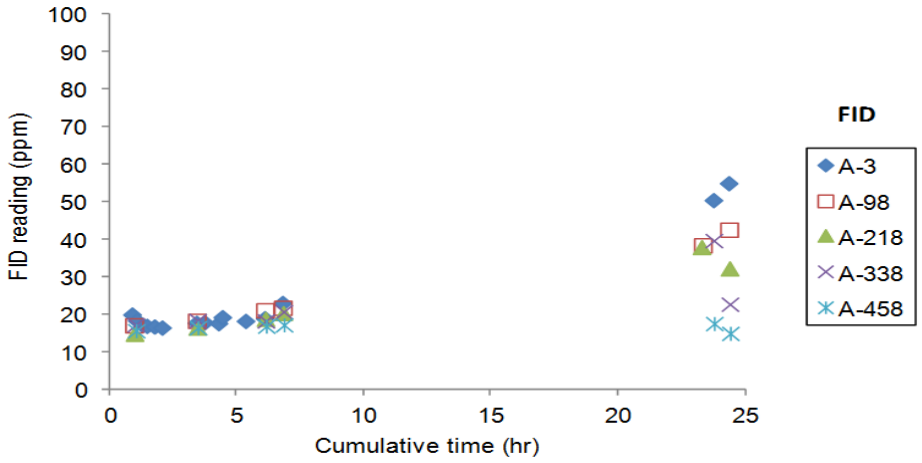
Diesel vapor behavior above ground





FID/PID readings above ground during and after Diesel injection at base of container

- There is a strong offset from the start (polythene tent?)
- There is a strong gradient at the ground to air interface after 24 hours.
- There is a vertical gradient in the air → vapor does not migrate easily above ground.
- There is a much higher vapor concentration in the ground than above ground after 24 hours.
- Continuous injection/extraction for days, if not weeks, would be required for stationary conditions.

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Other tests

- After 25 hours, pans were placed in the tent to enhance vapor concentration above ground.
- Pans of diesel, pentane and gasoline were tested in succession.
- This simulates a ground saturated with petroleum product vapor although the liquids in the pans were not continuously renewed, as would be the case with a continuous leak.
- When the tent is well sealed at the bottom, the vapor concentration gradient above ground is much less;
  - → In open air, the gradient would be even stronger than that originally measured.
  - → Tests should be done outdoors without a tent to contain vapors (or at least have a very large tent).
  - → Using pans is much quicker than simulating a leak in a pre-determined soil.
  - → Liquid should be renewed in pans at the rate of the simulated leak.

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Lessons learned from the simulated leak setup

- Analysis of these reference measurements showed a major concern as to the validity of the vapor plume model used in the previous phases.
- ***There is a strong vertical concentration gradient with the highest concentration very close to the ground*.**
- This has no effect on the estimates of limits of detection.
- It has an impact on the number of molecules an excitation laser beam interacts with. ***It has an impact on the minimum detectable leak size***.
- It also has an impact on the eventual design of an optimized measurement hardware.
- Tests should be done in open air, with drafts and wind.
- Leak detection systems usually measure concentration of hydrocarbons in the vapor phase around a leak. ***It is clearly a challenge to correlate a measured concentration to an actual leak size*.**
- To elaborate a standardized testing procedure for leak detection system would be beneficial for the industry as it would allow comparing performances of different systems.

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Lessons learned from the simulated leak setup

- For leak detection from an airborne platform using optical techniques, the leak needs to have “lived”.
- A leak cannot be detected instantaneously, just after start of leakage.
- The vapor plume that starts in the ground, close to the liquid petroleum product, needs to migrate towards the surface. This can take quite a while, on the order of multiple days or weeks.
- The techniques described here try to detect all alkanes, but the lighter components will evaporate more rapidly and diffuse into the atmosphere more readily, depleting the vapor plume over the leak of the more volatile fraction when the leak is very small.
- The leak must have created a large enough pool for the vapor plume to be detected.

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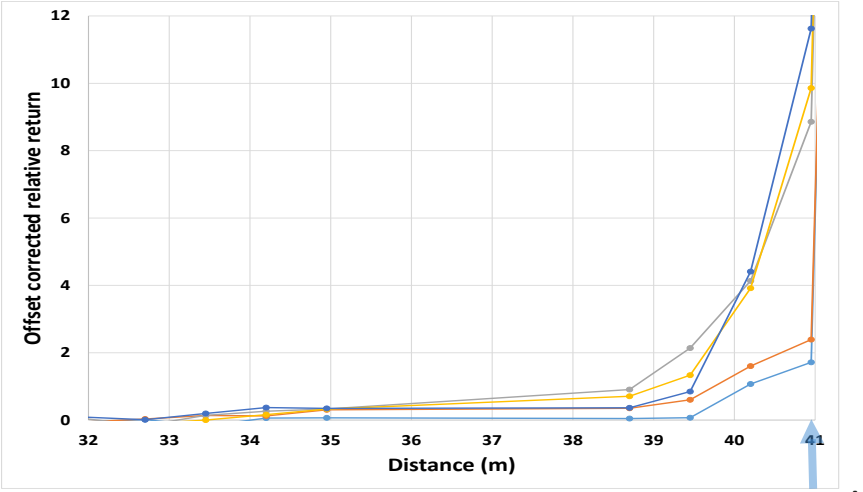
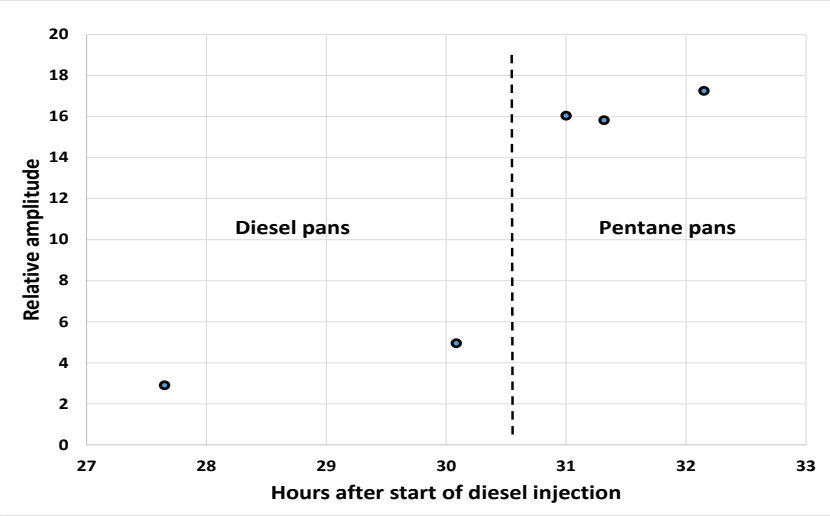
Results for the optimized Raman platform





- Spatially resolved Raman clearly shows the concentration gradient just above ground.
- The modified Raman platform can measure the hydrocarbon vapors from the simulated leak (diesel pans).
- The hydrocarbon vapor is concentrated within the first meter or meter and a half.
- Spatial resolution is limited by the laser pulse length (6 ns).
- Better spatial resolution is required because fluorescence starts when the laser hits the ground and strongly interferes with the Raman close to the ground.
- Raman measurements with pans behave as those made with FID/PID.

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Conclusions/discussion on Raman measurements

- The final Raman platform would need to be further enhanced by using gating on the detectors, a smaller optical bandwidth and a smaller detection footprint on the ground.
- The problem is that a large number of the molecules to be detected are very close to the ground.
- The hardware, as built, could not resolve the portion just above ground where the concentration is maximum.
- A high pulse energy, high power (10 W) laser would be needed in a final platform.
- With the platform as is, and without the contribution of the molecules closest to the ground, ***Raman could eventually detect better than concentration length products between 100 and 500 ppm-m*** **as measured with the PID and FID if measurement time was not an issue.**
- <u>In light of the additional cost of the proposed hardware, and of the weak concentration encountered over the simulated leak, INO suggests to abandon the Raman technique for remote leak detection from an airborne platform.</u>

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IR-DiAL revisited

- IR-absorption showed great sensitivity for hydrocarbons detection.
- As mentioned in the third report, both IR absorption LiDAR and UV-Raman LiDAR have potential as far as life cycle cost goes.
- The major concern with IR is that the “signature” of the return signal depends on the spectral reflectivity of the ground.
- It may be difficult to distinguish between variations of the ground reflectivity vs hydrocarbons presence.
- Because of its native high sensitivity, it was decided to test IR-absorption during the INRS testing phase.
- Measurement procedures are similar and at the same time as those with the Raman platform.

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IR-DiAL revisited (cont'd)

- INO devised three strategies to look at the best approach to reduce false alarms due to ground spectral signatures.
- These involved using spectral libraries of known ground reflectivities and the absorption spectrum of a typical crude.
- The best wavelength pairs (or multiple wavelengths) are determined for minimum interference from water and maximum signal difference.
- Without going into details of the metrics;
  - ***The minimum detectable concentration-length product is estimated at ~250 ppm-m.***
  - ***250 ppm-m Limit of detection is still limited by ground spectral signature.***

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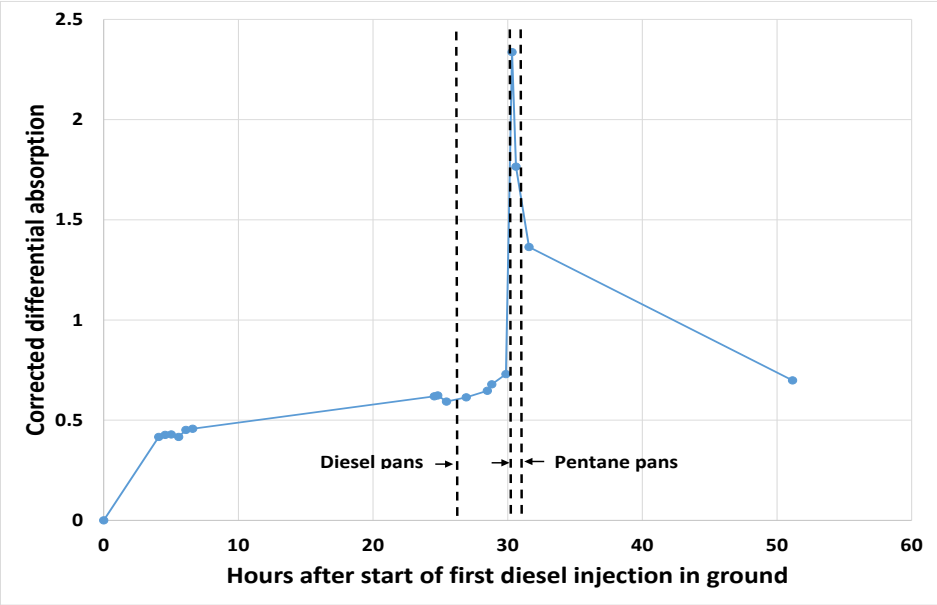
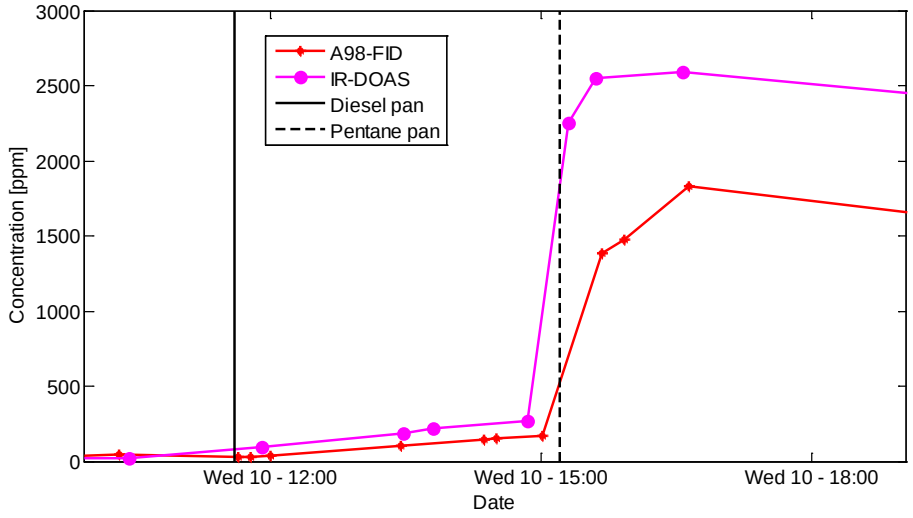
Two wavelengths IR-DiAL results





A sandblasted aluminum plate is placed over the sand to minimize effects of ground spectral signature in tests.

- IR-DiAL measures alkanes rapidly (300 ms) without sampling, unlike the FID/PID instrument. They both give the same behavior for the vapor.
- IR-DiAL is a path integrated measurement, in contrast with the Raman measurement. It measures the total alkane concentration along the laser beam path.
- Clearly, the alkane concentrations above the simulated leak and above the pans are similar.

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UV-DiAL for leak detection

- UV-DiAL was not tested at INRS.
- In this approach, only benzene (or toluene or both) is detected.
- Benzene has a more selective signature in the UV than alkanes in the IR, which practically eliminates the problem of varying ground spectral reflectivities.
- Benzene is in much smaller concentration than the whole of the alkanes.
- Benzene evaporates rapidly.
- The INO UV-DiAL platform is not optimized for rapid leak detection.
- ***An estimate of limit of detection of 1.5 to 2.5 ppm-m of benzene was found in the outdoors tests with the windowless gas cell.***
- Benzene is 1.71 % of vapor molecules, hydrocarbons with an alkanes portion are 94.75 % in vapor sampled 8 days after injection in the sand container. In fresh vapor (as in a diesel jerrican), benzene is 2.85 % and hydrocarbons containing alkane are 82%. <u>In alkanes equivalent, this would give a limit of detection between 40 and 140 ppm-m</u>.
- <u>In light of this, UV-DiAL of benzene would be the most sensitive approach, even though the effective LODs of the different techniques are all in the same range.</u>

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Project conclusions

- Lidars are well known and routinely used remote measurement approaches.
- Lidars have been used for airborne natural gas pipeline leak detection.
- UV-Raman, UV-DiAL and IR-DiAL are almost equivalent in terms of LOD when looking at vapor plume detection, be it through alkanes or aromatics or both.
- Other requirements such as cost, mass, size, power, false alarms, ease of use need to be considered. Absorption techniques, UV or IR, are preferred.
- The right technique might differ from pipeline to pipeline, depending on vapor migration through the ground, soil temperature (in particular frozen ground), soil cover (in particular snow) and the like. None of this is considered in the feasibility presented here.
- Only iterative field trials will determine the most adequate approach and validate that the technology correctly addresses the problem.
- INO is looking into promising alternatives, especially with UV-absorption, and would appreciate the opportunity to participate in field trials, on simulated leaks or real pipelines.
- Engineering challenges remain to get a mobile platform mountable system.

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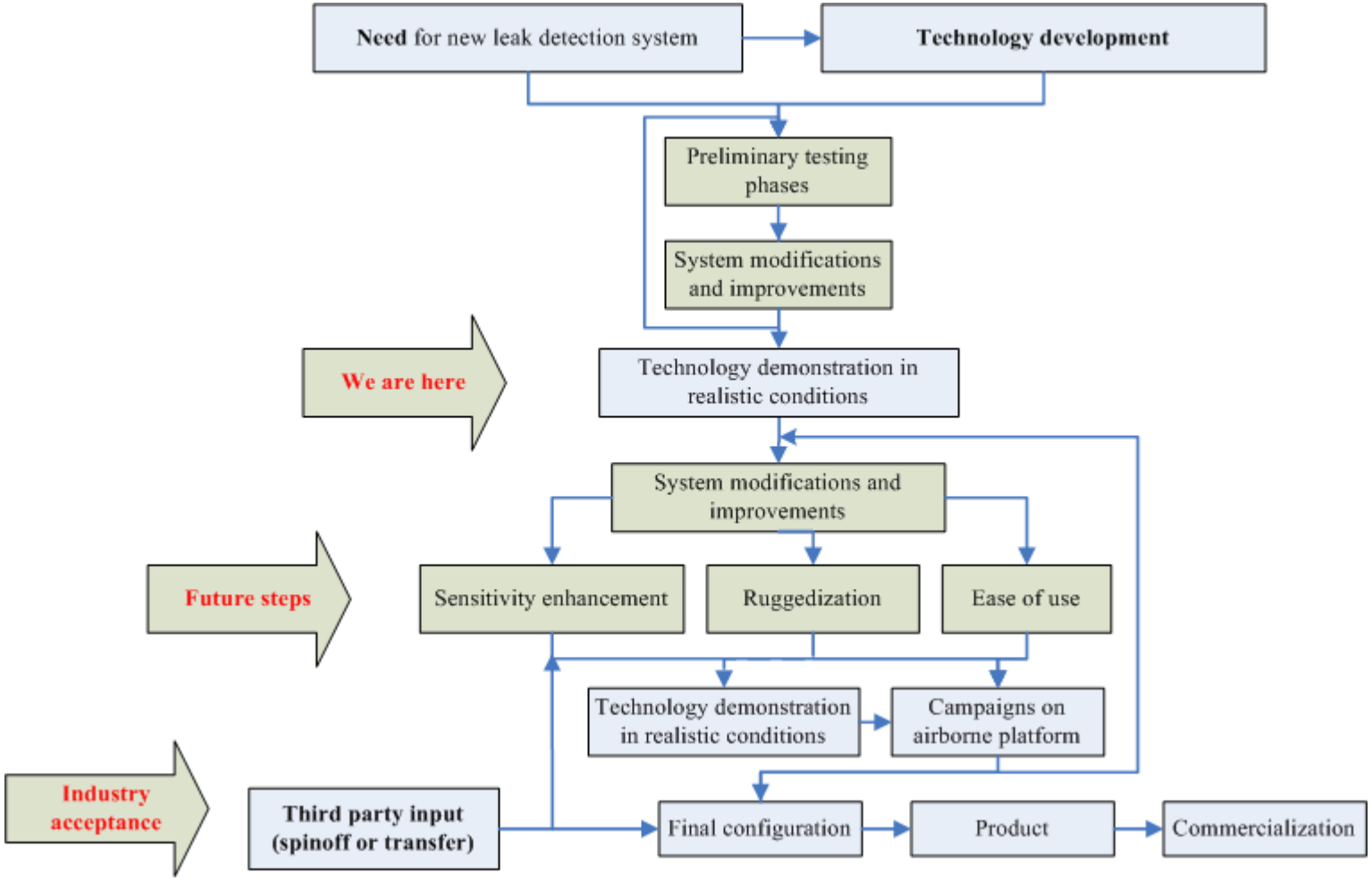
Follow on work



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Stand-off weeper/seeper pipeline leak detection

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