REQUEST ID: 20

Description of Technology

Request for Alternative Test Method

Methane Detection Technology

§60.5398b(b) Periodic Screening

The Environmental Protection Agency Emission Measurement Center

https://www.epa.gov/emc/oil-and-gas-alternative-test-methods

Exploration Robotics Technologies, Inc.

https://www.xplorobot.com

Contents

This document provides technical details for the proposed Alternative Test Method for methane detection and quantification. We cover the details of the Xplorobot Laser OGI sensor, the technique for data acquisition, the steps in data processing, analysis and reporting.

1. Definitions for the Alternative Test Method.

1.a. Xplorobot Laser OGI

The Xplorobot Laser OGI is a quantitative and commercially available device that detects methane emissions at a component level and visualizes methane emissions otherwise not visible to the naked eye. Xplorobot Laser OGI falls into the category of Active Optical Gas Imaging. The United States Environmental Protection Agency defines an Optical Gas Imaging Device (OGI) as a "device that visualizes emissions otherwise not visible to the naked eye" (Appendix K to Part 60, Title 40).

1.b. Xplorobot Inspector Software

Proprietary software designed to complement the **Xplorobot Laser OGI** device by analyzing inspection data to pinpoint and quantify methane emissions. This software aids in decision-making by enabling prompt response and corrective measures.

1.d. Digital Emission Tag

Digital Record for a specific component stored in the **Xplorobot Compliance Database** that certifies presence of methane emission from that component, thereby supporting regulatory compliance and auditing per 40 CFR § 60.5424b.

1.e. Digital Compliance Record

Digital Record for a specific component stored in the **Xplorobot Compliance Database** that certifies zero emission for that component, thereby supporting regulatory compliance and auditing per 40 CFR § 60.5424b.

1.f. Xplorobot Compliance Database

A secure digital storage, containing all compliance-related data, including **Digital Emission Tags** and **Digital Compliance Records** for each facility, site, equipment and component inspected using **Xplorobot Laser OGI**. This database provides accessible historical emissions information and compliance reporting to facility operators and regulatory authorities per 40 CFR § 60.5424b.

2. Description of Measurement Technology

2.a. General technology description

The proposed Alternative Test Method is a component-level method utilizing the **Xplorobot Laser OGI** hand-held device that measures column-integrated methane concentration with a Tunable Diode Laser Absorption Spectroscopy (TDLAS) sensor. During an inspection, **Xplorobot Laser OGI** simultaneously records methane concentration and high-resolution images of components inspected and uses a computer vision algorithm to create real-time visualization of emissions otherwise not visible to the naked eye. **Xplorobot Laser OGI** also records simultaneously the local wind speed and the ambient temperature at the site and uses a proprietary algorithm to estimate the methane emission rate in grams per hour.

Xplorobot Laser OGI creates a **Digital Emission Tag** for each emission source identified in the inspection. The **Digital Emission Tag** includes the date, time, site, equipment, component, concentration detected, emission rate estimate, wind speed measured, and the GPS location of the source. Furthermore, upon upload of the data collected by **Xplorobot Laser OGI** into a component-level **Xplorobot Compliance Database**, **Xplorobot Inspector** software automatically creates **Digital Compliance Records** for each component that was found either not emitting methane or emitting methane within allowable limits per EPA regulations or manufacturers specifications. **Digital Emission Tags** and **Digital Compliance Records** create an auditable trail for each inspection. They can also be used for calculations of fugitive emissions per 40 CFR 98 Subpart W on a leak/no leak basis.

Xplorobot Laser OGI sensitivity is 1 gram per hour as demonstrated in controlled release experiments at the Lawrence Berkeley National Laboratory (Figure 23) and field deployment with oil and gas clients (Figure 27) and confirmed with Semtec Hi Flow device. It is important to emphasize that 1 gram per hour is the device sensitivity for **Xplorobot Laser OGI** and that it is the result of the design of the device, selection of the characteristics of individual sensors and performance of the embedded software.

In blind testing at the Methane Emissions Technology Evaluation Center ("METEC") **Xplorobot Laser OGI** demonstrated a 90% probability detection level of 156 grams per hour (4 standard liters per minute) that is in the range of the 90% probability detection level for infrared OGI cameras operated by highly experienced LDAR inspectors (Zimmerle et al, 2020). It is important to emphasize that the 90% probability detection level reflects both the device sensitivity and the human inspector performance.

Xplorobot Alternative Test Method application proposes to use **Xplorobot Laser OGI** in the exact same manner and frequency as the requirements for OGI surveys established by 40 CFR 60 subparts OOOOa, OOOOb and OOOOc for periodic inspections of oil and gas facilities. emission rate in grams per hour.

2.b. Xplorobot Laser OGI and its elements

Xplorobot Laser OGI device, presented in **Figure 1** below, consists of the following elements:

Figure 1. Xplorobot Laser OGI device and its elements

Tunable Diode Laser Absorption Spectroscopy (TDLAS)

The TDLAS sensor emits a laser beam with the wavelength of 1653 nanometers that is absorbed by methane molecules, thus enabling determination of methane in the air column between the sensor and the point which reflects the infrared laser beam back to the device. TDLAS sensor determines the column-integrated methane concentration by comparing the energy loss for the 1653 wavelength to the energy loss in the adjacent wavelength in the laser spectrum. To visualize the reflection point of the infrared laser, the TDLAS sensor uses a visible green laser that is aligned with the infrared measurement laser.

High-Resolution Visual Camera

A high-resolution visual camera is employed to capture images during inspections. These images are used to visualize methane emissions that are otherwise not visible to the naked eye and to create **Digital Emissions Tags** and **Digital Compliance Records.** The proprietary Xplorobot computer vision software utilizes these images to precisely locate the sensor within 1 inch spatially and 0.5 degrees directionally, offering far greater accuracy than GPS, which suffers from drift and is typically only accurate to several meters.

Computer

An onboard computer serves as the main processing unit for the **Xplorobot Laser OGI.** It interfaces with all sensors, initiates the device, manages data acquisition, stores recorded information, and provides an inspection summary either through the device's screen or via a wired connection to an on-site computer. The computer runs the algorithm that visualizes methane emissions otherwise not visible to the naked eye and the algorithm that provides the initial emission rate estimate based on Xplorobot proprietary physics-based model.

Anemometer

An anemometer records local wind speed data, which is crucial for methane flow rate estimations and improves dispersion modeling. Accurate local wind measurements, time-synced with methane concentration measurements, are essential due to the highly variable nature of wind both spatially and temporally.

Thermometer (part of the Anemometer)

A thermometer records the ambient temperature at the inspection location.

GPS

A GPS unit records the approximate position of the inspection. This information is cross-referenced with a database of the Operator's site and equipment locations. If the coordinates match a known location, the site is automatically assigned to the inspection, reducing user data entry and minimizing errors.

Bluetooth/Wi-Fi/4G LTE

Xplorobot Laser OGI incorporates a Bluetooth device that connects it to the inspector’s smartphone to transmit **Digital Emissions Tags** to a cloud-based Xplorobot Compliance Database for immediate automatic notifications of the facility operator of the emission sources identified. Upon completion of the inspection, Wi-Fi or an ethernet cable is used to download the inspection data (all the methane measurements, visual images, wind and temperature readings and GPS coordinates) to a laptop or desktop computer for further upload to the cloud-based **Xplorobot Compliance Database**.

Xplorobot team is now working on adding a 4G LTE card to **Xplorobot Laser OGI** to provide additional options for the device connectivity to the cloud.

Touch Screen Display

The touchscreen display is the main interface of the Xplorobot Laser OGI device. It provides a user interface for performing the following tasks:

- Initiating the scan.
- Displaying column-integrated methane concentration (ppm-m) and wind speed readings at the laser's current location
- Visualizing methane emissions otherwise invisible to the naked eye for each emission point identified during the inspection.
- Creating **Digital Emission Tags** for each emission point identified during the inspection.
- Finishing the scan.
- Reviewing a summary of the scan, complete with information for each **Digital Emission Tag**.
- Saving the data acquired during the scan.

Figure 2 provides an example of the User Interface of the **Xplorobot Laser OGI.**

Figure 2. User interface of Xplorobot Laser OGI.

Battery

A Lithium-Ion battery is enclosed in the handle. The battery life of the device is approximately 4 hours of continuous scanning.

Miscellaneous

Other miscellaneous components in the device include the following:

- A Buzzer that serves as an aid during scanning. If the ppm·m level exceeds a predetermined threshold, the buzzer sounds to notify the person conducting the inspection of a potential methane emission location.
- A Real Time Clock (RTC) ensures accurate time measurements on the device. The time zone is automatically adjusted based on the device's location. The clock provides timestamps for all measurements and ensures post-inspection quality control by

verifying that the dwell (stare) time requirements are met.

2.c. Xplorobot Laser OGI range and sensitivity

Xplorobot Laser OGI range is 50 meters based on the TDLAS sensor specifications. We confirmed in field campaigns the ability of **Xplorobot Laser OGI** to detect thief hatch emissions from the ground and detection of fugitive emission sources inside oil and gas facilities from positions outside of the facilities' boundaries.

For component-level inspections where emission quantification is required, we recommend that the distance of the inspection does not exceed 7 meters based on the demonstrated accuracy of the emission quantification by Xplorobot Inspector software algorithms.

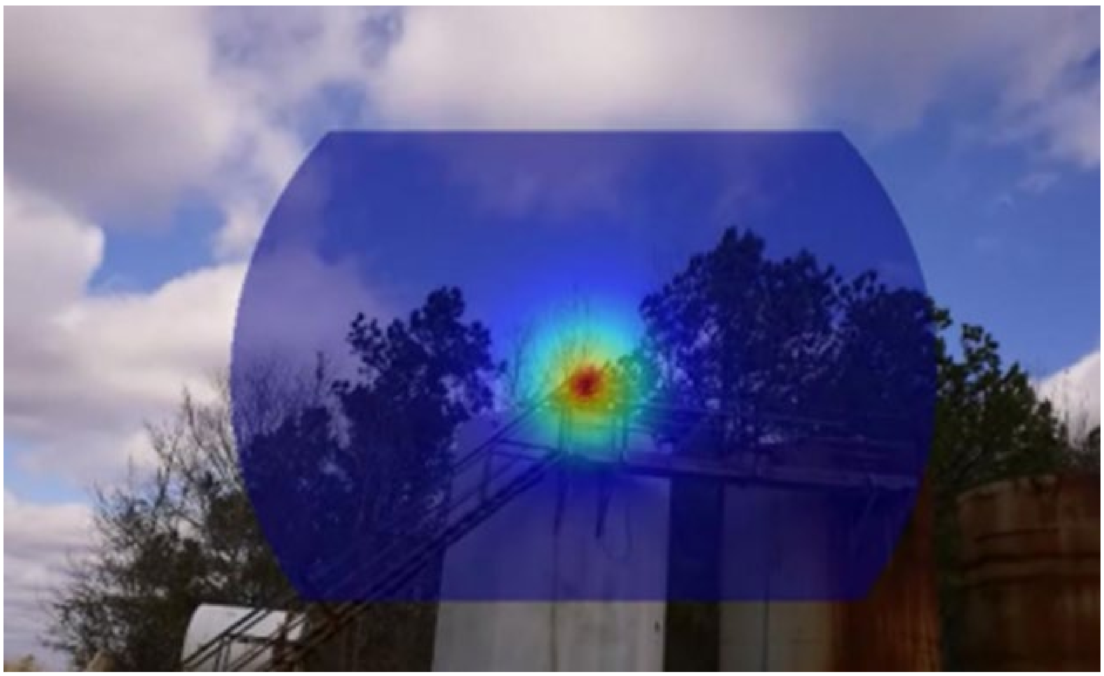

Figure 3. Detection of fugitive emission on a thief hatch vent.

Xplorobot Laser OGI sensitivity is 1 gram per hour as demonstrated in controlled release and field experiments. For example, in an orphan wells campaign led by the US Forest Service near Marietta, OH, Xplorobot Laser OGI detected multiple emissions sources that were quantified to be below 1 gram per hour by a Hi Flow device (see Figure 4)

Campaign Results: Marietta, Ohio

Work Completed:

Scope: 21 wells scanned in 3 days

Results: Xplorobot sensor detected 100% emissions (including 5 emission sources of ~1gph that an infrared OGI camera did not detect)

Emission Rates: Ranged from less than 1 gph to 1,600 gph

Average Rate: 225 gph per source

Observations for Xplorobot Results:

Easy to deploy in the field (4.5 lb. sensor in a shoulder bag)

Time-efficient detection/quantification/certification–2 min set-up and 3 min measurement per well

Accurate emissions estimates achieved in the range from 10 to 1,6000 gph

Well Name	Rate, g/hr	FLIR Detection	Xplorobot Detection
Porter Run 2	Zero Emission	Zero Emission	Zero Emission
Private #7	<1.0	No detection	Detection
Private #2	<1.0	Not tested	Detection
Rutherford Nancy 2	1.0	No detection	Detection
USA Joy 1	1.0	No detection	Detection
Edward Wiles #3	1.4	Not tested	Detection
USA #19	2.0	Not tested	Detection
Martin James #1	2.0	No detection	Detection
Edward Wiles #3	2.4	Not tested	Detection
Private #3	4.0	Not tested	Detection
Rutherford Nancy 3	8.0	No detection	Detection
Private #1	20.0	Not tested	Detection
Holiday Rueben #6	24.0	No detection	Detection
Zwick Bros #3	24.0	Not tested	Detection
Grace Joy 1	52.7	Detection	Detection
Undocumented 1	58.5	Detection	Detection
Private #5	100	Detection	Detection
Private 8	600	Detection	Detection
Charles Hall #6	800	Detection	Detection
Westbrook WM B	1,200	Detection	Detection
Private #9	1,600	Not tested	Detection

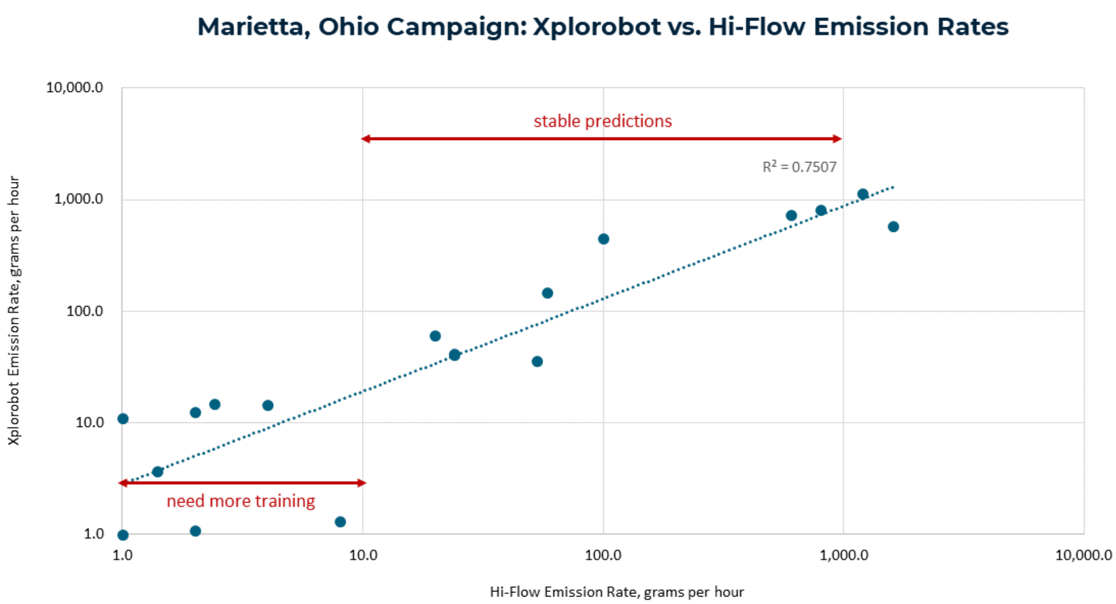

Figure 4. Emissions detection in an orphan well field campaign led by US Forest Service near Marietta, OH.

In blind testing at the Methane Emissions Technology Evaluation Center (METEC) **Xplorobot Laser OGI** demonstrated a 90% probability detection level of 156 grams per hour or 4 standard liters per minute that is in the range of the 90% probability detection level between 2.6 standard liters per minute and 7.7 standard liters per minute for infrared OGI cameras operated by highly experienced LDAR inspectors (Zimmerle et al, 2020). Note that, according to the findings of Zimmerle et al (2020), the 90% confidence level of detection is a combination of the sensitivity of the device (1 gram per hour for Xplorobot Laser OGI) and the skill level of the inspectors using the device (Figure 5).

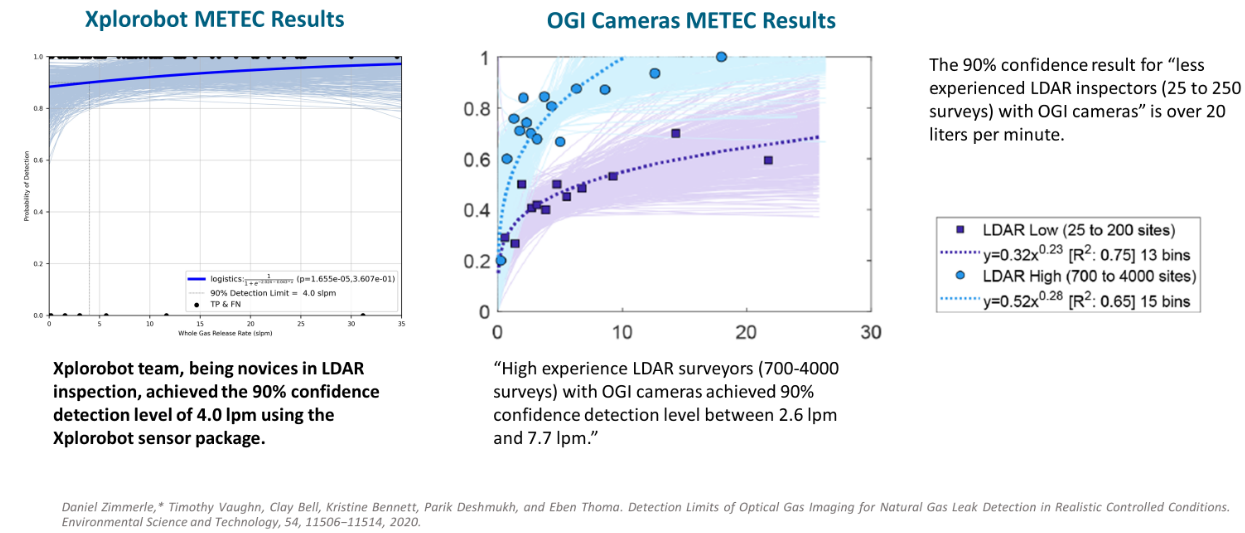

Figure 5. Results of blind tests at METEC for Xplorobot Laser OGI and for infrared OGI cameras (Zimmerle et al, 2020).

To compare the accuracy of detection between Xplorobot Laser OGI and Method 21, we performed a set of controlled release experiments with emission rates ranging between 0.4 grams per hour and 787 grams per hour as validated by a Hi Flow device. The exact comparison between a local concentration measurement and a column-integrated concentration measurement cannot be established as the column-integrated measurement is impacted not only by the distribution of the methane in the path of the laser but also by the aperture of the laser beam which varies between TDLAS sensors from different manufacturers. However, our experiments suggest that the Xplorobot Laser OGI measurement of 500 ppm-m corresponds to 500 ppm or lower measurements by a Method 21 device (Figure 6).

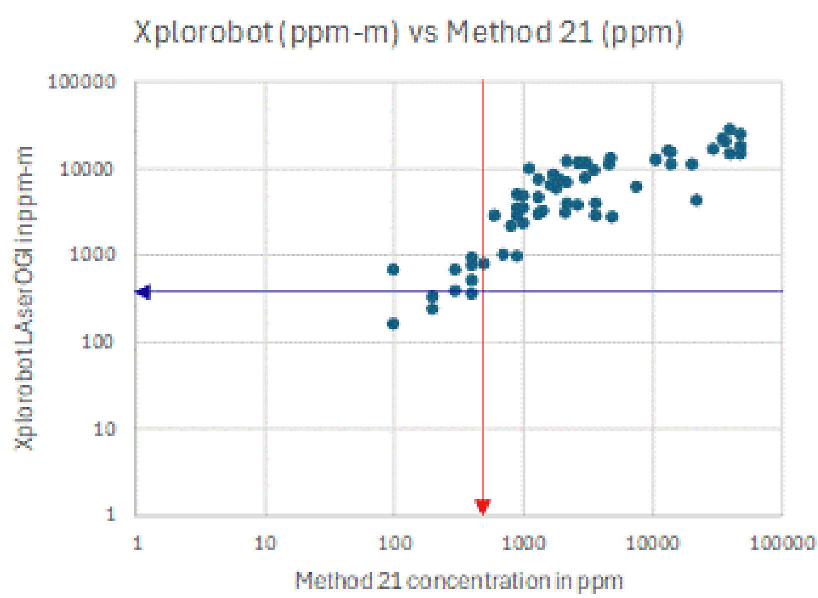

Figure 6. Equivalence between Xplorobot Laser OGI and Method 21.

Xplorobot Laser OGI can detect emissions that are typically challenging to be detected by infrared OGI cameras due to the absence of thermal contrast between the gas and the surrounding media, such as emissions from under wraps and emissions from buried components. Figures 7 and 8 provide examples of such emission detections.

Figure 7. Emissions were detected under a bubble wrap, and the recording on the regulator after the wrap was removed.

Figure 8. Emission detected under gravel and recorded on tubing after gravel was removed.

2.d. Temporal and spatial scale.

Xplorobot Laser OGI spatial resolution is 0.4 cm at 1 meter distance and 20 cm at 50 meter distance based on the laser aperture of the Original Equipment Manufacturer and the accuracy of the emission localization of the computer vision software in the device. Figure 9 presents examples of the spatial resolution of the emission detection. This spatial resolution makes **Xplorobot Laser OGI** a Component-Level Alternative Test Method per 40CFR §60.5398b.

Figure 9. Examples of component-level emission source detection in oil and gas facilities recorded from distances of 3 meters and 1 meter.

2.e. Inspection procedure and recording a Digital Emission Tag.

Under the proposed ATM, LDAR surveys are conducted using the **Xplorobot Laser OGI** device. Inspectors systematically scan equipment components—such as valves and flanges—by walking around the equipment, using a green laser to track inspection of each component. While scanning, **Xplorobot Laser OGI** continuously records column-integrated methane concentration in PPM-m, visual images (used for visualization of emissions otherwise not visible by a naked eye), GPS data, wind speed, and ambient temperature. Figure 10 illustrates the typical procedure for employing the **Xplorobot Laser OGI** in LDAR surveys.

*Figure 10. Scanning equipment and components with **Xplorobot Laser OGI** device.*

Xplorobot Laser OGI displays column-integrated methane concentration measurements by the TDLAS sensor on the device screen. The **Xplorobot Laser OGI** alert threshold for methane emissions alert is set at a column-integrated concentration of 50 ppm-m. When the concentration measured exceeds 50 ppm-m, the device emits a beeping noise, alerting the person conducting the inspection of an emission source presence. The concentration display turns yellow for values between 50 ppm-m and 500 ppm-m and red for values above 500 ppm-m.

When an inspector identifies a potential emission point at the 500 ppm-m threshold, they use the green location laser to investigate the area of possible emission and locate the point of emission. Upon locating the emission point, the Operator presses the "**Digital Emission Tag**" button on the device touch screen to visualize the methane emission otherwise not visible to the naked eye in real-time on the **Xplorobot Laser OGI** screen. Figure 11 shows an example of emission visualization on the screen of **Xplorobot Laser OGI**.

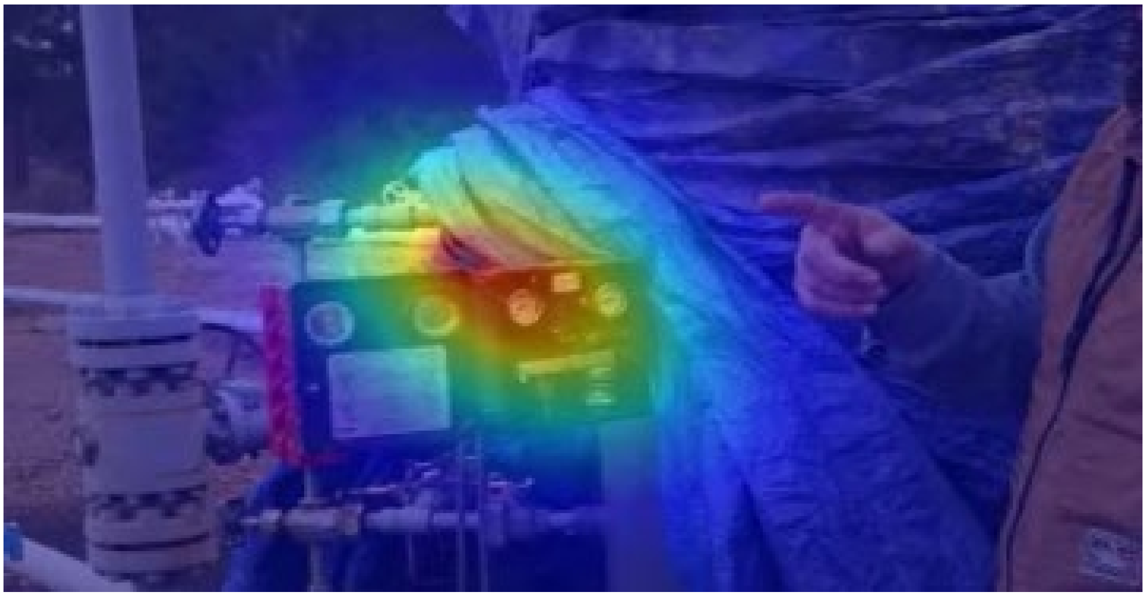

Figure 11. Detection of the emission (column-integrated concentration above 500ppm-m) and visualization of the emission otherwise not visible to the naked eye by the Xplorobot Laser OGI device.

Pressing the "**Digital Emission Tag**" button automatically creates a **Digital Emission Tag** that consists of the following information:

(i) Visualization of the emission.

(ii) Column-integrated methane concentration (in ppm-m) at and in the vicinity of the emission point.

(iii) Estimate of the emission rate in grams per hour

(iv) GPS location of the recorded emission (the sensor position during the scan).

(v) Date and time of the recorded emission.

(vi) Wind speed and temperature at the emission location.

The real-time visualization of the emission is based on high-resolution photographs to provide attribution of the emission to a specific component. The same high-resolution photograph or 3D model of the component (created based on the photographs) is used to precisely locate the emission source on the equipment. By recording all information required for emissions reporting and creating a visualization of the methane emission, **Xplorobot Laser OGI** digitally captures all the required information for emissions reporting per the requirements of 40 CFR § 60.5424b.

Digital Emission Tags can be uploaded directly into the cloud-based Xplorobot Compliance Database via a Bluetooth connection on an inspector smartphone running Xplorobot App. Upon the Digital Emission Tag upload, Xplorobot Compliance Database generates an email alert to all stakeholders involved in the emission mitigation process.

2.f. Xplorobot Inspector Software and Digital Compliance Records

Upon inspection completion, all visual, methane, GPS, and meteorological data captured by **Xplorobot Laser OGI** is securely transferred via an ethernet cable or WiFi connection to a computer running proprietary **Xplorobot Inspector** software that includes an oil and gas operations database of sites, equipment, and components. Each **Digital Emissions Tag** is supplemented with information on the specific site, equipment, and component (using GPS information to link with the site and equipment/component database or manual input). Each **Digital Emissions Tag** is classified as a fugitive emission, as-designed emission, and allowable emission. Other classifications can be added per operator's requirements.

In the course of an inspection, **Xplorobot Laser OGI** records methane, visual, GPS and meteorological data to document compliance for components and equipment that do not emit methane or emit methane within design or allowable limits. As equipment and components are scanned, **Xplorobot Laser OGI** accumulates records of methane concentrations that are zero or below the proposed Detection Threshold for Xplorobot Laser OGI at 500 ppm-m. All records of methane column concentration are downloaded into **Xplorobot Inspector** upon completion of the inspection. **Xplorobot Inspector** processes these records and creates **Digital Compliance Records** for components or equipment that do not emit methane or that emit methane within design limits.

Xplorobot Inspector can create **Digital Compliance Records** in the form of 2D concentration maps (usually appropriate for individual components such as flanges or valves) or 3D concentration maps on equipment models (usually suitable for large and complex equipment, such as compressors, which contain a considerable number of potential emission sources in close proximity). Figure 12 provides examples of **Digital Compliance Records**.

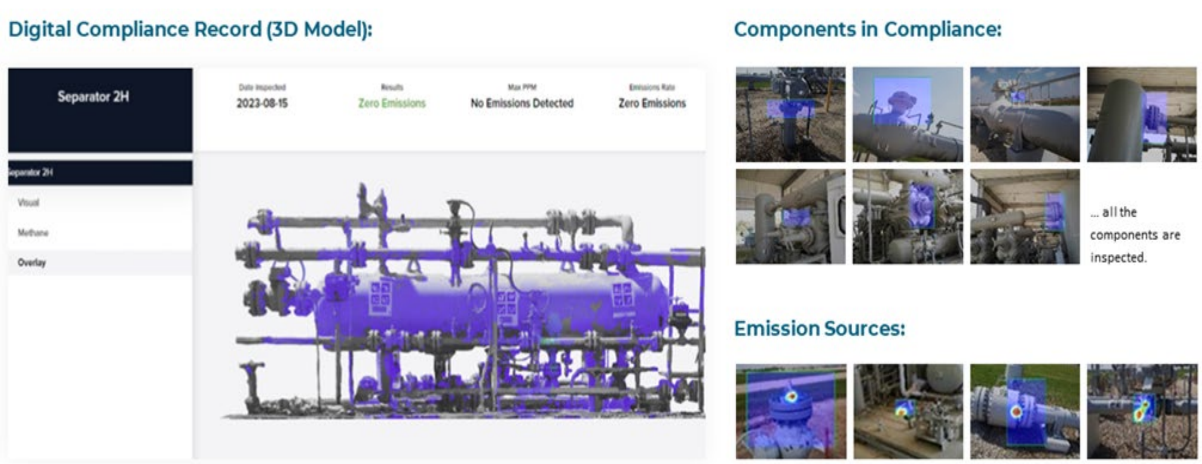

Figure 12. Digital Compliance Records include 3D and 2D methane concentration maps for equipment and components.

2.g. Compliance Database and Operator Notification

All **Digital Emissions Tags** are uploaded to the **Xplorobot Compliance Database** for recordkeeping per 40 CFR 60.5420b(c) and 60.5424b(c).

Upon upload of a **Digital Emissions Tag**, **Xplorobot Compliance Database** automatically notifies (by email or other means of electronic communication) all stakeholders in reporting, repairing, and mitigating the emissions (see Figure 13). When repairs are completed, **Xplorobot Laser OGI** is used to verify the repair and **Digital Records of Compliance** are then created and documented in the **Xplorobot Compliance Database**.

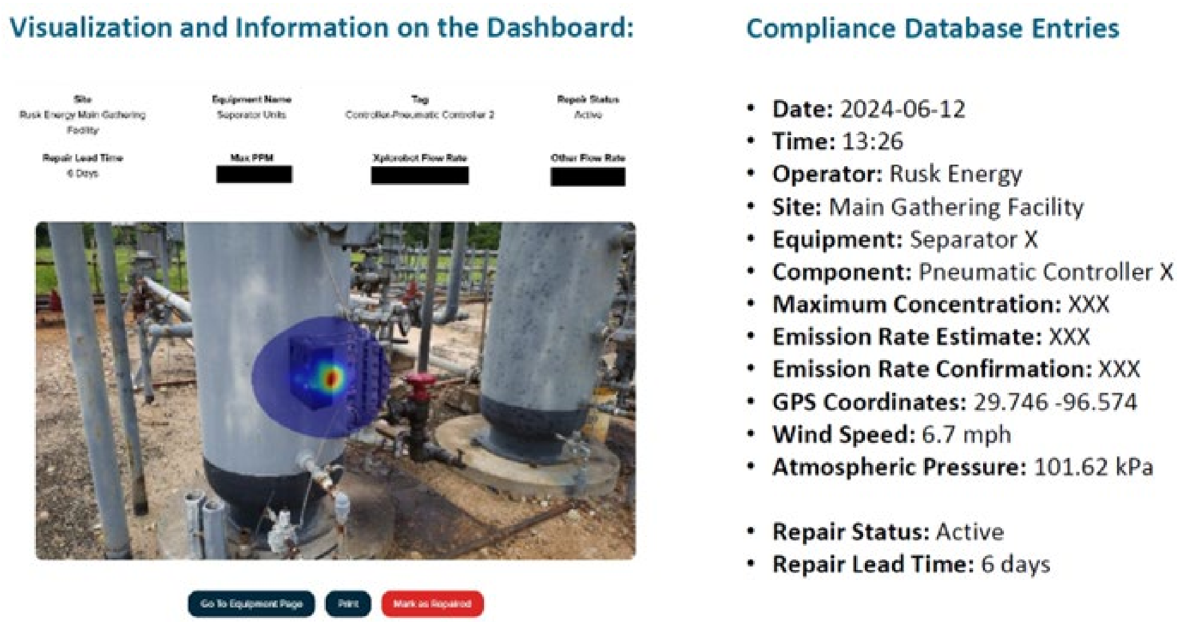

Figure 13. Example of a Digital Emission Tag notification.

Digital Compliance Records stored in the **Xplorobot Compliance Database** provide auditable records of zero emissions to enable quality control of the LDAR programs and component-level (bottoms-up) to site level (top-down) reconciliations. Importantly, the ability to access historical **Digital Compliance Records** for components found to be emitting methane in subsequent inspections allows the Operator to define the duration of the emissions to estimate the emissions volume for reporting under 40 CFR 98 Subpart W.

2.h. Methane Emissions Management Dashboard

Xplorobot facilitates access to all data in the **Xplorobot Compliance Database** utilizing a map- based **Methane Emissions Management Dashboard** that provides an “operations view” (Figure 14) of all the sites and equipment with all emission sources. The Dashboard provides access to all the **Digital Emissions Tags** and **Digital Compliance Records** stored in the **Xplorobot Compliance Database**. It allows tracking of repairs and post-repair verifications.

The **Methane Emissions Management Dashboard** also provides an “analytics view” (Figure 15) of the emissions source counts and volumes on regional, site, and equipment levels. The Dashboard provides functionality for emissions analytics, site, equipment, component-level compliance, and historical inspection records. The Dashboard autonomously generates all fugitive emissions reports required per 40 CFR § 60.5424b.

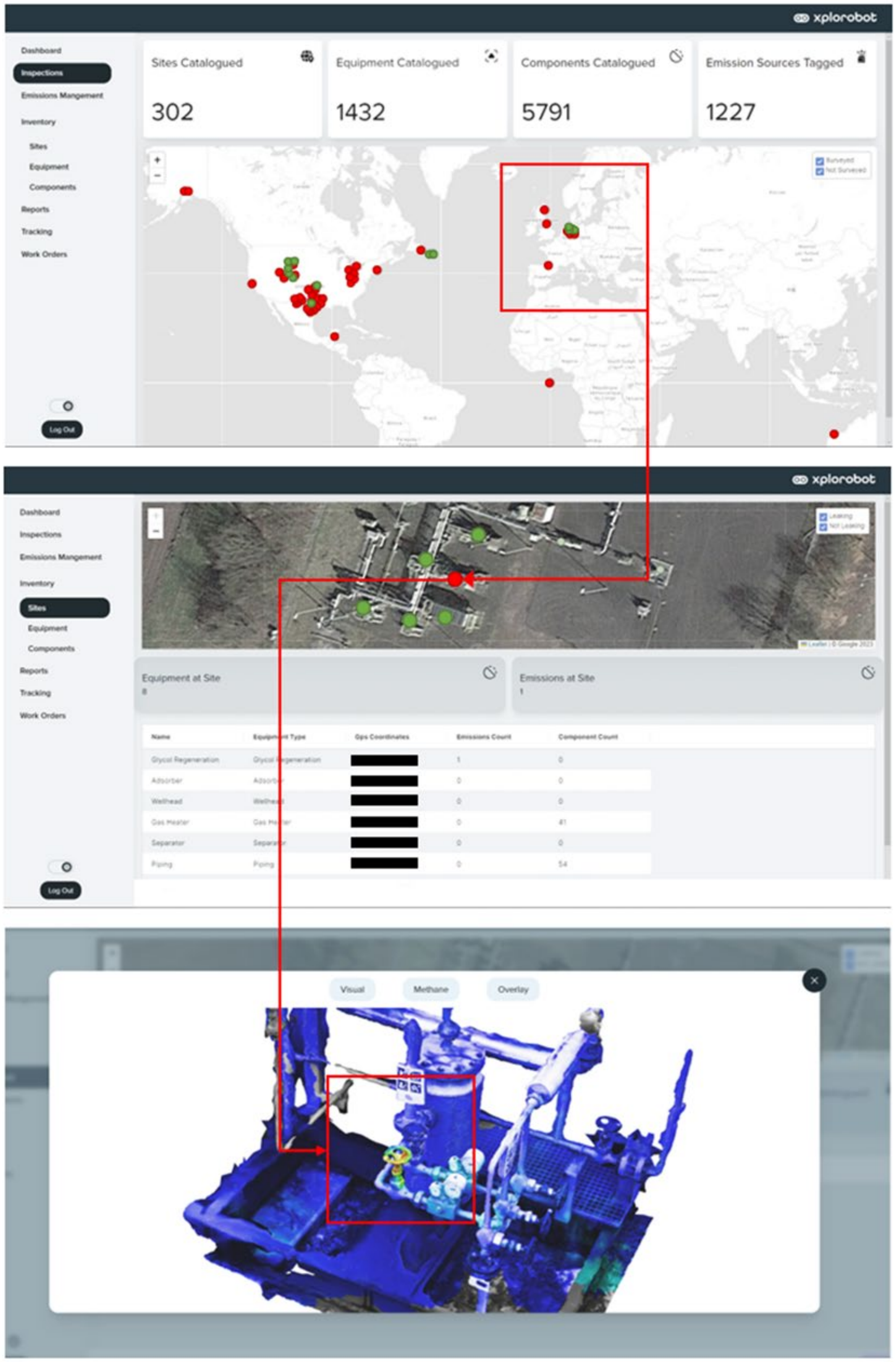

Figure 14. The Methane Emissions Management Dashboard "operations view" provides access to information for specific sites, equipment, and components as well as all the inspection results through a map-based interface.

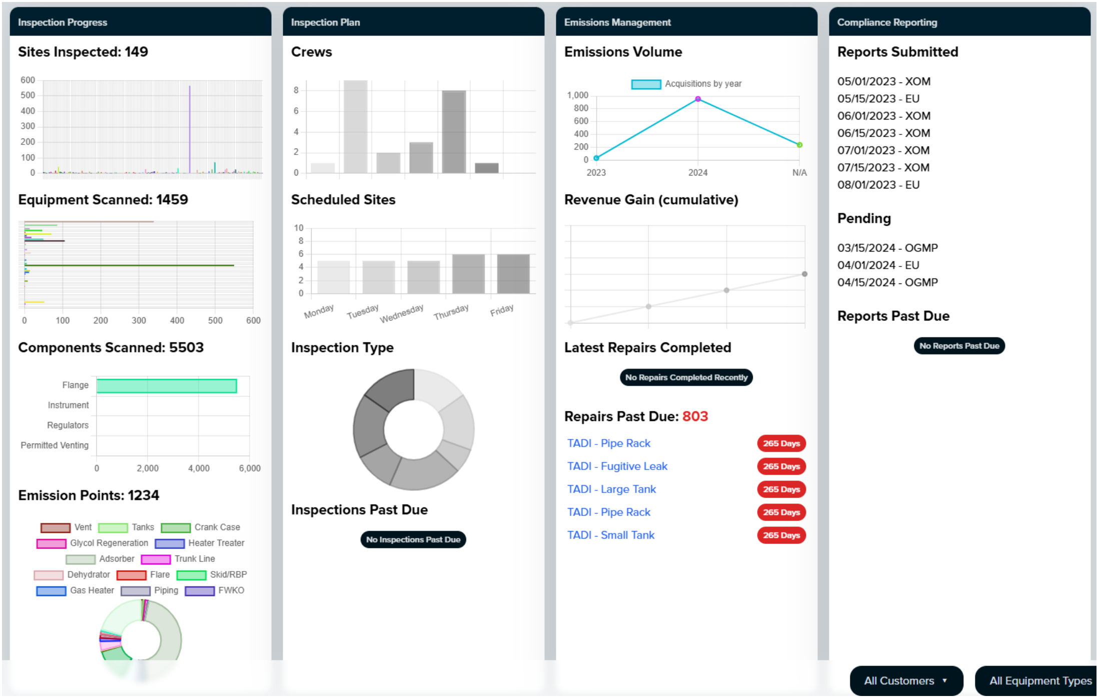

Figure 15. The Methane Emissions Management Dashboard "analytics view" provides emission sources counts and volumes and enables automatic generation of reports per 40 CFR § 60.5424b

Together, all the **Digital Emission Tags** and **Digital Compliance Records** stored in the **Xplorobot Compliance Database** and accesses through the **Methane Emission Management Dashboard** create a full digital track record of all inspections conducted with **Xplorobot Laser OGI** devices and facilitate emissions mitigation, regulatory reporting and auditing of the LDAR program efficiency and accuracy. Figure 16 provides a diagram of data flow in the proposed Alternative Test Method.

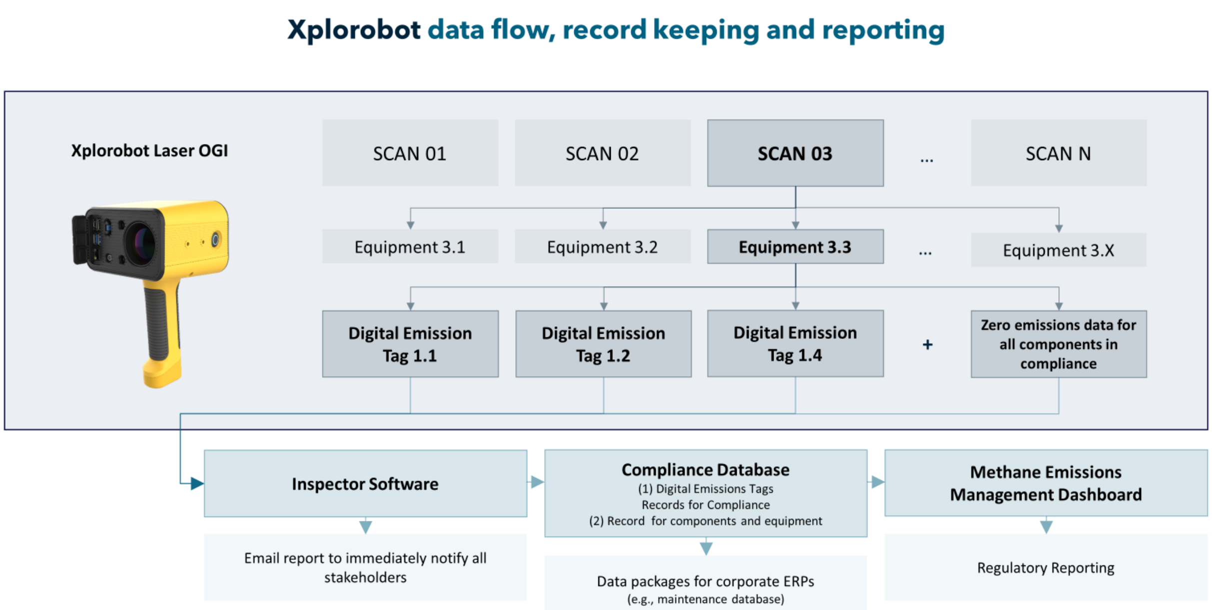

Figure 16. Data flow, recordkeeping and reporting for the proposed Alternative Test Method.

2.i. Description of the real-time Visualization Algorithm

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3. Technology Accuracy Validation and equivalence to Infrared Optical Gas Imaging

The **Xplorobot Laser OGI** device was tested alongside other technologies over a 4-day period under the Advancing Development of Emissions Detection (ADED) protocol. The goal of the experiments was to identify emissions points throughout the facility. The team was not briefed on the number of emission point(s), if any, present in each experiment, the location of the emission point(s), or the emission rate.

The Xplorobot team consisted of Xplorobot employees with no formal training in LDAR inspection or experience working in oil and gas or oilfield services companies. METEC results demonstrate that using **Xplorobot Laser OGI** does not require significant expertise or training to achieve high-accuracy results.

In ADED testing, **Xplorobot Laser OGI** demonstrated a 91.4% true positive rate and 2% false positive rate. Figure 17 below provides a comparison of **Xplorobot Laser OGI** results with the published results from other technology providers (Clay et al., 2023).

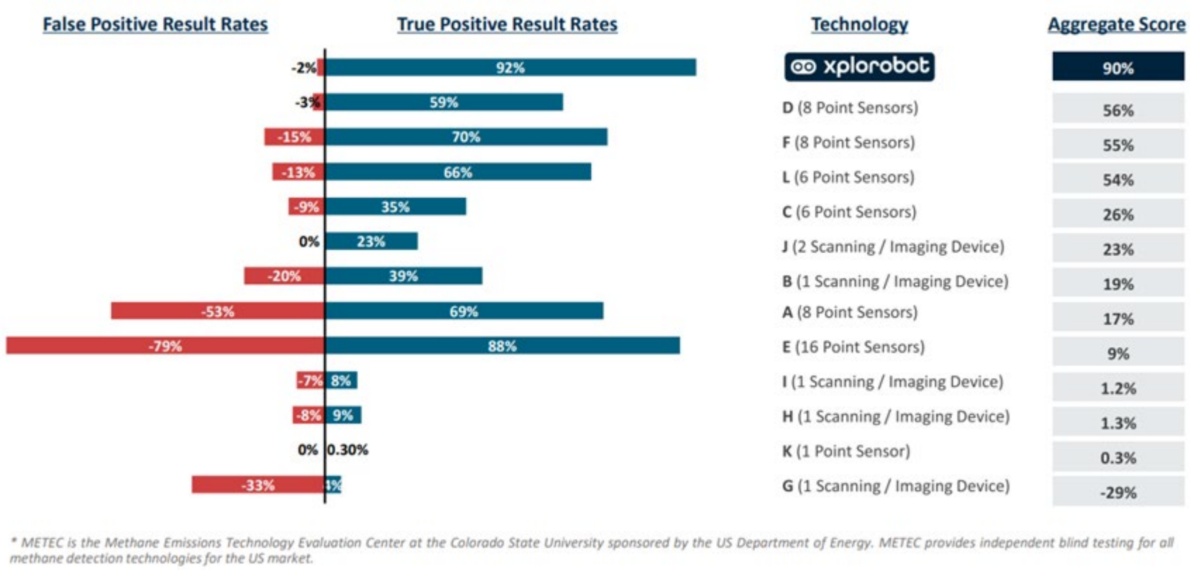

Figure 17. Comparison of the single-blind test results for Xplorobot Laser OGI against other technologies tested at METEC.

At the request of Xplorobot, the blind testing at METEC focused primarily on emissions below 10 liters a minute to define the 90% confidence detection limit for **Xplorobot Laser OGI**. Figure 18 presents the distribution of the flow rates in the blind testing experiments.

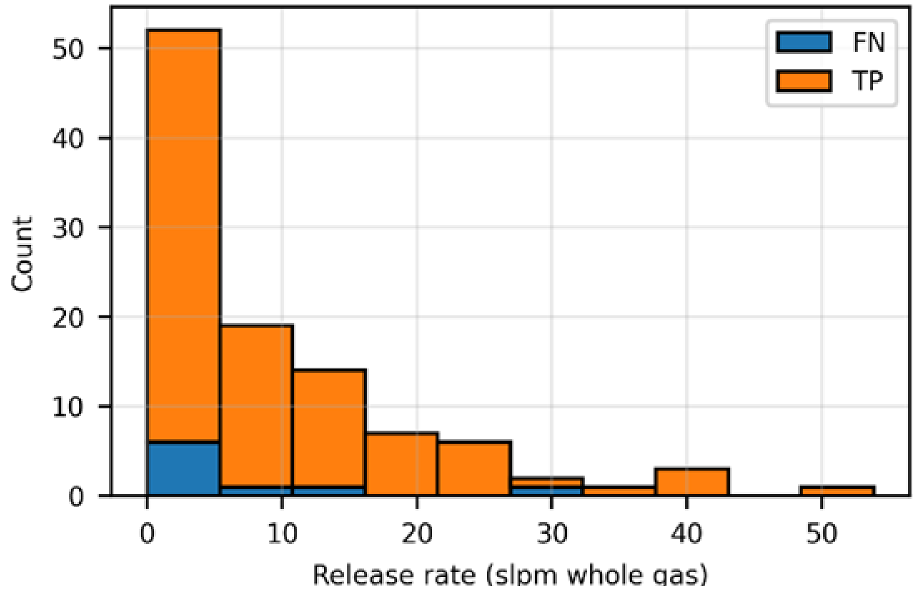

Figure 18. Emissions rate distribution in the METEC blind tests for Xplorobot Laser OGI, focused on emissions below 10 liters per minute.

Xplorobot Laser OGI achieved the 90% detection limit of 157 grams per hour or 4 standard liters per minute. Figure 19 presents the probability of the detection curve for **Xplorobot Laser OGI** achieved at METEC.

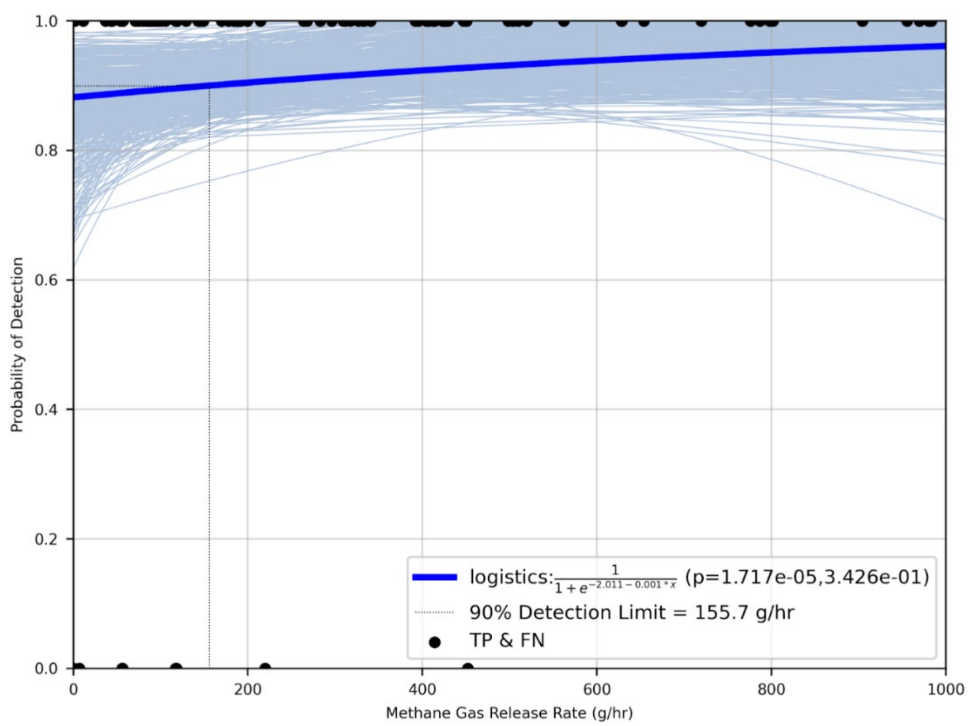

Figure 19. Probability of detection curve for Xplorobot Laser OGI achieved at METEC.

The results of the blind testing for **Xplorobot Laser OGI** allow a direct comparison with the results of Infrared Optical Gas Imaging Cameras at the same facility. Zimmerle et al. (2020) presented the results of blind tests of Infrared OGI cameras at METEC in which the inspectors performing the tests were separated into two groups: "Less experienced LDAR inspectors" and "Highly experienced inspectors."

The less experienced group performed 20 - 250 LDAR surveys prior to the testing, while the highly experienced inspectors performed 700 - 4000 LDAR surveys. The highly experienced LDAR group achieved a 90% confidence detection level between 2.6 - 7.7 standard liters per minute, while the less experienced group's 90% confidence of detection was over 20 standard liters per minute. Figure 20 presents the results of 90% confidence levels for Infrared Optical Gas Imaging operated by Less Experienced LDAR Inspectors and High Experience LDAR Inspectors from Zimmerle et al. (2023) with an overlay of the probability of detection curve for **Xplorobot Laser OGI**.

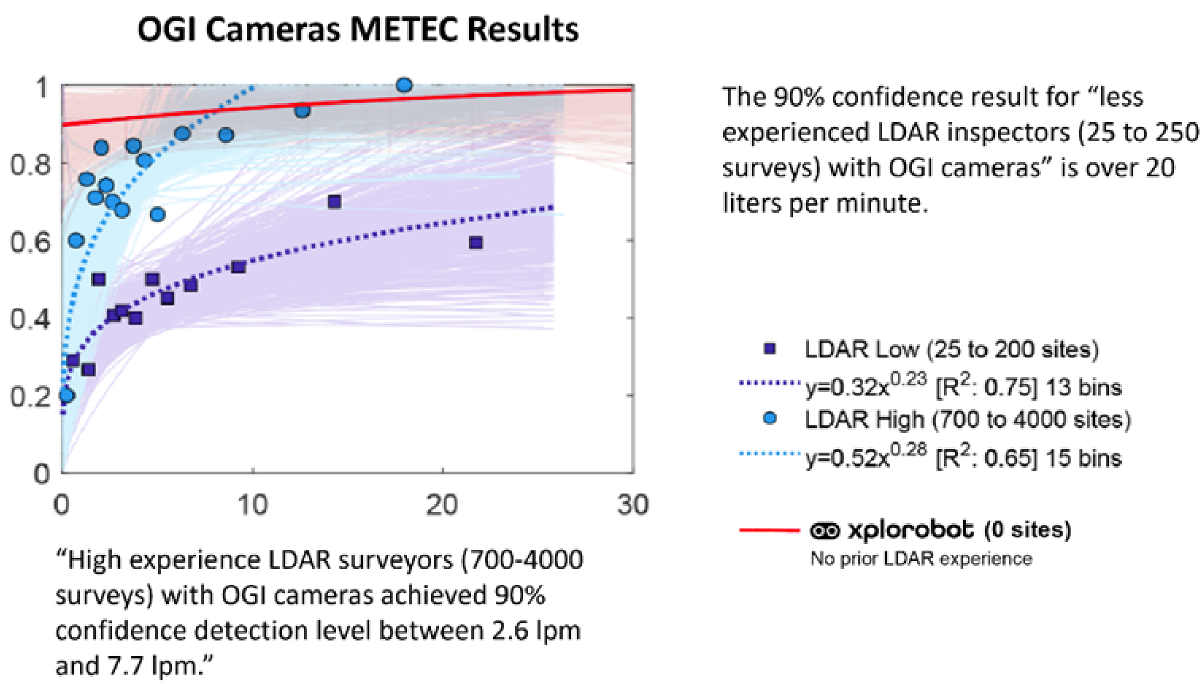

*Figure 20. Probability of detection for Infrared OGI cameras operated by High Experience LDAR Inspectors and by Low Experience LDAR inspectors from Zimmerle at al. (2020) with an overlaid probability of detection curve for **Xplorobot Laser OGI***

The 90% confidence level results for **Xplorobot Laser OGI** (157 grams per hour or 4 liters per minute) fall in the range of the results for Infrared Optical Gas Imaging operated by High Experience LDAR inspectors (between 2.6 and 7.7 liters per minute). Thus, the METEC blind testing results for **Xplorobot Laser OGI** matched the detection accuracy of Infrared Optical Gas Imaging cameras operated by Highly Experienced LDAR inspectors (between 700 and 4000 LDAR surveys).

Numerous additional field deployments demonstrated the accuracy of **Xplorobot Laser OGI** as compared to to Infrared Optical Gas Imaging. In a blind trial with one of the largest United States pipeline operators, Xplorobot team with **Xplorobot Laser OGI** devices worked concurrently (but not side-by-side) with the operator's in-house LDAR team with infrared OGI devices. In the first compressor station **Xplorobot Laser OGI** devices identified 20 emission sources while infrared OGI devices identified 5. In the second compressor station, **Xplorobot Laser OGI** devices identified 11 emission sources while infrared OGI devices identified 6. Most of the additional emission sources identified by **Xplorobot Laser OGI** were in the category of low contrast between the temperature of gas versus the temperature of background media, wind conditions and small emission rates.

Xplorobot Laser OGI detected methane emissions in field conditions with temperatures ranging from minus 20 Celsius (minus 4 F) in field data acquisition for Carbon Creek Energy in February of 2023 to plus 44 Celsius (110 F) in field data acquisition for Diversified Energy in Ft. Worth, TX in April and in wind conditions up to 25 mph.

4. Additional control release and field testing

4.a. Lawrence Berkeley National Laboratory tests in the 1 gram per-hour to 20 grams per-hour range

To define the detection limits for **Xplorobot Laser OGI**, we performed controlled release experiments at the Lawrence Berkeley National Laboratory in September 2023 and February 2024. We used gas with a 5% methane concentration and varied the emissions rate from 0.5 liter per minute (approximately 1 gram per hour of methane) to 20 liters per minute (approximately 40 grams per hour of methane). Xplorobot Laser OGI detected emissions of 1 gram per hour and above at LBNL.

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Figure 21. Experimental setup at the Lawrence Berkeley National Laboratory.

Xplorobot Laser OGI detected emissions for all the experiments at the Laboratory. Figure 22 presents the results of the maximum concentration detected for each emissions rate in the experiments.

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Figure 22. Methane concentration in ppm-m recorded by the Xplorobot Laser OGI device at the Lawrence Berkeley National Laboratory.

4.b. Alberta Methane Emissions Program (AMEP) tests range from 3 to 1200 grams per hour.

Xplorobot performed controlled release experiments at the Alberta Methane Emissions Program (AMEP) in March and October 2023. The emissions rates in the controlled rate experiments ranged from 3 grams per hour to 1200 grams per hour. **Xplorobot Laser OGI** detected the emissions in all the experiments at the site. The temperatures at the site ranged from minus 10 Celsius to plus 5 Celsius, and the wind speeds ranged from 1 mile to 12 miles per hour. Figure 23 presents an example of the detection results at AMEP.

AMEP Well Head – control rate experiment

Experiment	Known flow rate	Max concentration measured	Result
1	0.1 m3/day	2,052	Detection
2	1 m3/day	9,040	Detection
3	10 m3/day	11,300	Detection
4	20 m3/day	12,416	Detection
5	40 m3/day	13,798	Detection

Key observations:

- Emissions of 0.1m3/day (~3 grams/hour) and above are clearly detected
- Wind speed range during the experiment was between 0.5 miler per hour and 7.5 miles per hour

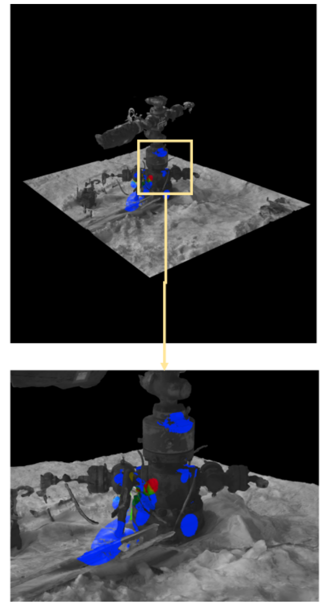

Figure 23. Example of controlled rate release experiments at the Alberta Methane Emissions Program.

4.c. Confirmation of the 1 gram per hour detection limit in field conditions by oil and gas operators

From September 2023 to June 2024, **Xplorobot Laser OGI** was used at multiple client facilities in Colorado, Texas, Louisiana, Pennsylvania, Ohio, West Virginia, Germany, Australia, The United Kingdom, and France. When possible, we used the Semtec High Flow device to record the emissions rates detected by **Xplorobot Laser OGI** and establish the lower detection limit in real field deployment conditions. We recorded emissions rates at client sites ranging from 0.3 to 10,000 grams per hour. Figure 24 provides an example of **Xplorobot Laser OGI** detecting emission below 1 gram per hour at a client site as validated by the High Flow device.

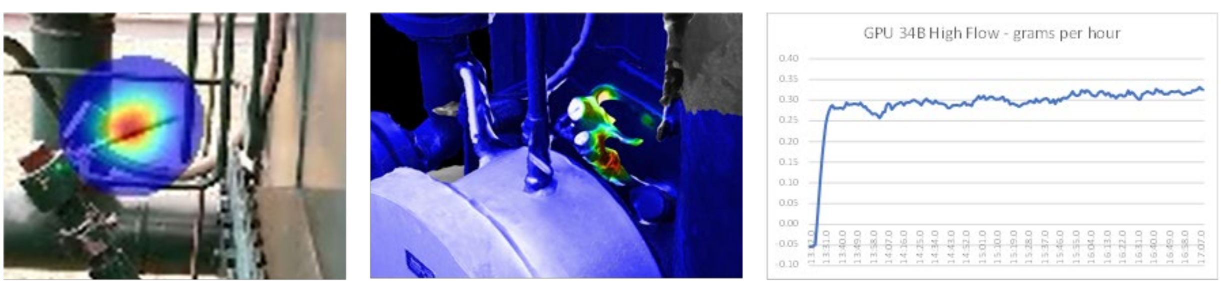

Figure 24. Xplorobot Laser OGI detection of emission below 1 gram per hour in field conditions.

4.d. Confirmation of the 1 gram per hour detection limit in Orphan Wells campaigns

In May of 2024, Xplorobot team worked on an orphaned wells campaign in the Osage Nation in Oklahoma led by the Lawrence Berkeley National Laboratory. Figure 25 presents the results of emission detection in the range from 1.7 grams per hour to 1,450 grams per hour as confirmed by Semtec Hi Flow Device.

Campaign Results: Osage Nation

Work Completed:

Scope: 57 wells scanned in 3 days

Results: Emissions quantified on 16 wells (14 – single source, 2 – double sources)

Emission Rates: Ranged from 1.7 gph to 1,118 gph

Average Rate: 184 gph per source, 52 gph per orphaned well

Observations for Xplorobot Results:

Easy to deploy in the field (4.5 lb. sensor in a shoulder bag)

Time-efficient detection/quantification/certification–2 min set-up and 3 min measurement per well

More neural network training is required for rates below 10 gph

Site	Well	Hi-Flow Emission rate gph	Xplorobot Maximum ppm-m	Max Wind mph
BallRanch	5	1.7	750	4.5
MaryWyrick	5	2.7	700	4.2
BallRanch	3	4.3	100,000	2.6
BallRanch	12	6.3	1,466	1.8
BallRanch	19	8.9	5,976	2.4
MaryWyrick	2	16.6	5,031	3.2
MaryWyrick	10	46.9	18,537	4.7
MaryWyrick	4	94.4	50,000	3.1
Terhune	81B	213	23,922	12.2
29N9E27	OR01	230	30,708	19.1
Enru Chuck	02a	260	10,158	10.3
BallRanch	7	471	19,389	3.0
BallRanch	15	475	32,196	6.0
MaryWyrick	6	1118	48,372	6.3
Lucy	1	1450	50,870	11.0

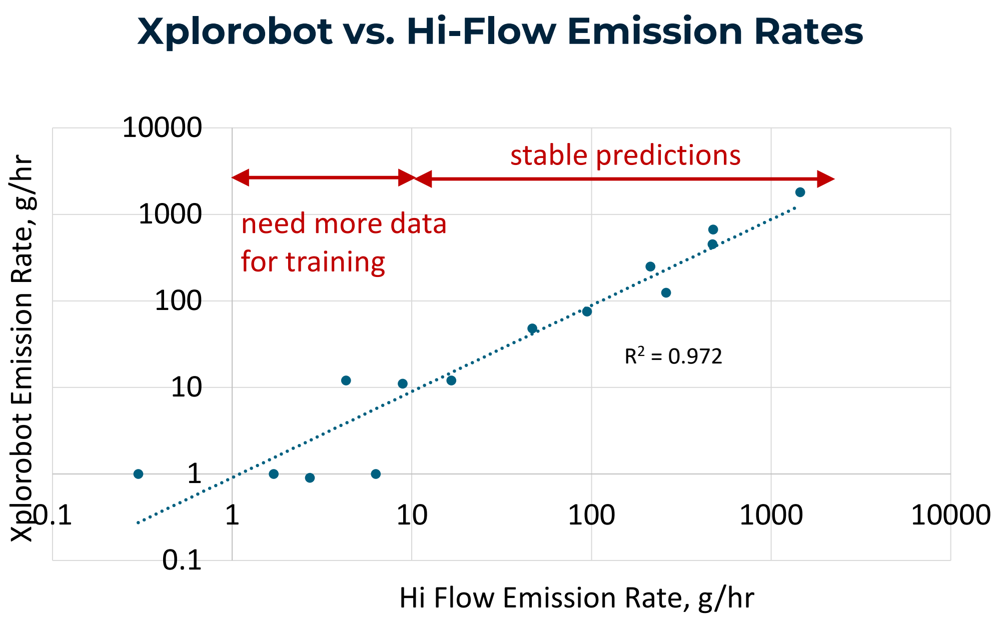

Figure 25. Xplorobot Laser OGI detection of emission at 1.7 grams per hour in field conditions.

In May of 2024, Xplorobot team worked on an orphaned wells campaign near Marietta, OH led by the US Forest Service. Figure 26 presents the results of emission detection in the range from below 1 gram per hour to 1,600 grams per hour as confirmed by Semtec Hi Flow Device.

Campaign Results: Marietta, Ohio

Work Completed:

Scope: 21 wells scanned in 3 days

Results: Xplorobot sensor detected 100% emissions (including 5 emission sources of ~1gph that an infrared OGI camera did not detect)

Emission Rates: Ranged from less than 1 gph to 1,600 gph

Average Rate: 225 gph per source

Observations for Xplorobot Results:

Easy to deploy in the field (4.5 lb. sensor in a shoulder bag)

Time-efficient detection/quantification/certification–2 min set-up and 3 min measurement per well

Accurate emissions estimates achieved in the range from 10 to 1,6000 gph

Well Name	Rate, g/hr	FLIR Detection	Xplorobot Detection
Porter Run 2	Zero Emission	Zero Emission	Zero Emission
Private #7	<1.0	No detection	Detection
Private #2	<1.0	Not tested	Detection
Rutherford Nancy 2	1.0	No detection	Detection
USA Joy 1	1.0	No detection	Detection
Edward Wiles #3	1.4	Not tested	Detection
USA #19	2.0	Not tested	Detection
Martin James #1	2.0	No detection	Detection
Edward Wiles #3	2.4	Not tested	Detection
Private #3	4.0	Not tested	Detection
Rutherford Nancy 3	8.0	No detection	Detection
Private #1	20.0	Not tested	Detection
Holiday Rueben #6	24.0	No detection	Detection
Zwick Bros #3	24.0	Not tested	Detection
Grace Joy 1	52.7	Detection	Detection
Undocumented 1	58.5	Detection	Detection
Private #5	100	Detection	Detection
Private 8	600	Detection	Detection
Charles Hall #6	800	Detection	Detection
Westbrook WM B	1,200	Detection	Detection
Private #9	1,600	Not tested	Detection

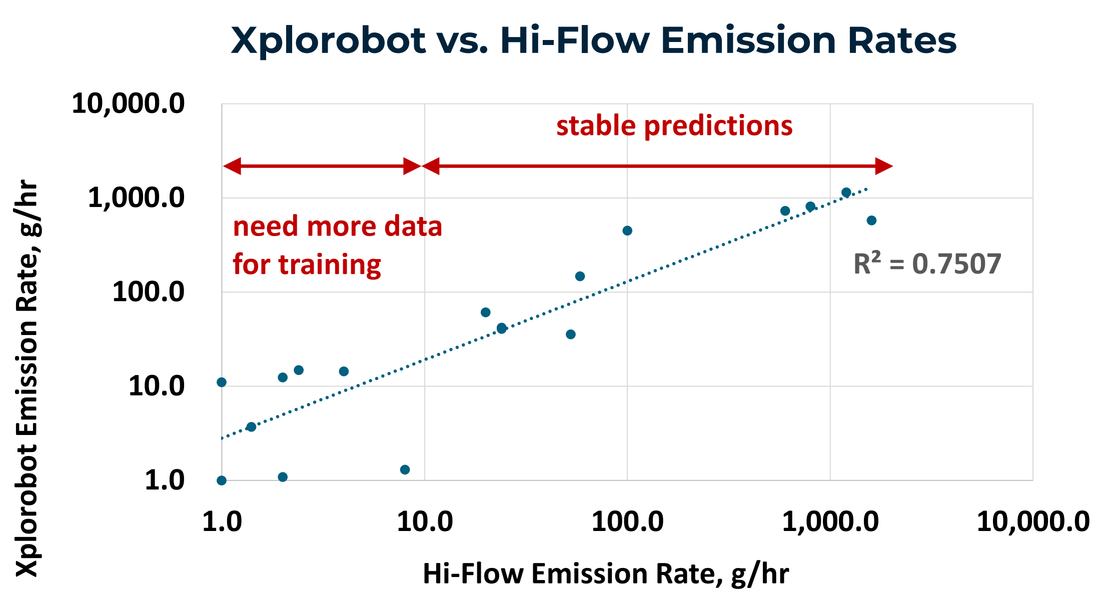

Figure 26. Xplorobot Laser OGI detection of emission at and below 1 gram per hour in field conditions

5. **Case study – field deployment by an oil and gas operator in West Texas.**

In November of 2023, **Xplorobot Laser OGI** was used at a site in West Texas to successfully identify emissions that were not identified by previous surveys with infrared OGI cameras. Figure 27 below provides a case study by the operator as published in their annual ESG report.

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Figure 27. Case study of the Xplorobot Laser OGI deployment published by a client.

6. **Technology Limitations**

The main limitation of **Xplorobot Laser OGI** is the requirement to have a reflection point to return the laser beam back to the device. Detection of methane emission or certifying zero emission is performed by pointing the laser beam directly at the component being inspected and reflecting the laser beam from that component. In the case of open vents and flares, detection of methane emission may not be possible if (1) open vent or flare is observed against an open sky and does not have any reflection points behind it and (2) methane plume is raising vertically up and does not extent below the edge of the vent or flare. We recommend installing a reflection point (a small metal plate welded above the vent or flare) to use **Xplorobot Laser OGI** for open vents or flares. Alternatively, other methane emission detection solutions can be used for those emissions point per LDAR plan adopted by the facility operator.

When inspecting a storage tank thief hatch or pressure relief valve (PRV) from ground level, the laser should be aimed to reflect off the thief hatch or PRV. If necessary, the inspector should step back to a position where they can achieve this reflection. Figure 28 provides an example of detecting emissions from a thief hatch at ground level.

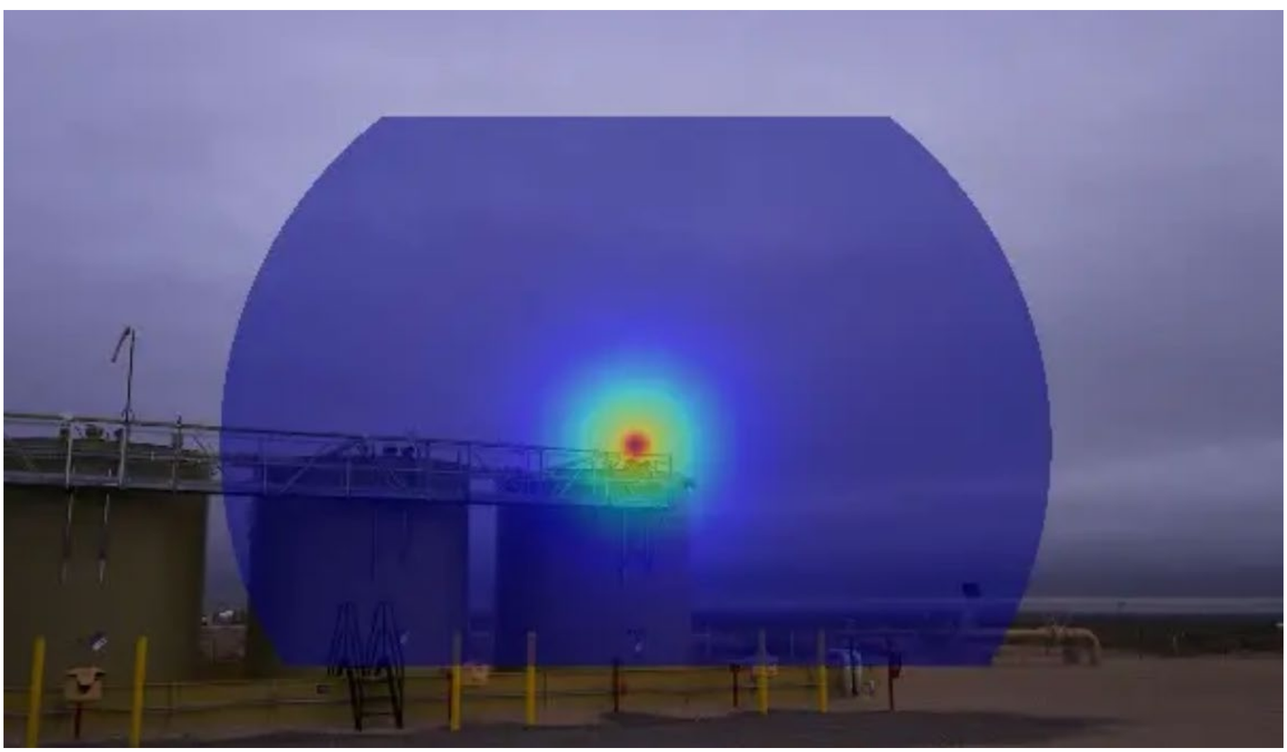

Figure 28. Emission detection from the ground with the laser reflected from the thief hatch.

7. Quantification of the emission rate

Data collected by **Xplorobot Laser OGI** is used to estimate the emissions rate by utilizing physical modeling of the methane plume dynamic. Based on **Xplorobot Laser OGI** field campaign experience, the behavior of the methane plume in the vicinity of the source is driven by a combination of three factors: (1) wind dispersion, (2) buoyancy and (3) jet flow of methane out of an emission point. The relative contributions of these three regimes depend strongly on the wind conditions and the pressure differential between the gas inside the equipment and the atmospheric pressure. In enclosed spaces (such as inside compressor stations), ventilation plays the role like that of wind outdoors. Figure 29 provides examples of the three factors that we identified in field experiments.

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Figure 29. Three factors present in near-field emission detection result is significantly different behavior than that expected from wind dispersion models.

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Figure 30. Example of Xplorobot methane emission rate prediction for a set of 431 controlled experiments in Denver, CO

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8. Description of alternative technology analytics

Currently, the algorithm provides predictions within +/- 30% in high wind conditions (above 5 miles per hour) and +/- 50% in low wind conditions (below 5 miles per hour) for emissions rates above 10 grams per hour or 0.25 standard liters per minute. The Xplorobot team is adding data from field and controlled rate experiments to improve the accuracy of emission rate predictions for emissions below 10 grams per hour or 0.25 standard liters per minute.

All raw data, the **Digital Emission Tags** and **Digital Compliance Records** are stored in **Xplorobot Compliance Database** and are used to create reports per 40 CFR § 60.5424b and 40 CFR 90 Subpart W.

Digital Emission Tags are attributed to specific components and completed with the information listed in Section 2.1 and stored in the **Xplorobot Compliance Database**. Specific emission factors can be calculated for each equipment and component type based on all the **Digital Emission Tags** for each individual operator, across multiple operators, for individual regions or types of sites.

Digital Emission Tags and **Digital Compliance Records** can be used to establish accurate component counts and create detailed emission reports on a component level.

Frequency of emission and their estimated rates for each component type can be used to identify root causes and optimize mitigation plans. For example, emissions on the same equipment from different vendors type can be compared to identify best-in-class vendors. The effectiveness of emission mitigation can be compared between different maintenance vendors or for different maintenance frequencies.

9. Quality control of input data

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10. Quality Control of output results

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11. References

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