

Nubo Sphere's performance in ADED 2023

Breaking new ground: the latest advancements
in continuous methane emissions monitoring

Version 2, incorporating the complete results



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Executive summary

Our Nubo Sphere continuous methane monitoring solution was put to the test at the Advancing Development of Emissions Detection (ADED) campaign of 2023, a blind controlled-release testing campaign organized by the Methane Technology Evaluation Center (METEC), of Colorado State University (CSU). In the ADED 2022 campaign, Nubo Sphere used a common metal oxide (MOx) sensor to measure ppm concentration of methane in the air ([you can find the results here](#)). It showed great performance compared to other technologies and solutions. During the ADED 2023 campaign, Sensirion's proprietary photoacoustic-based laser spectroscopy sensor technology was under test, and performance improved dramatically in all aspects of the solution. This provides our Nubo Sphere solution with a field-leading price-to-performance ratio compared to the other nine continuous monitoring solutions participating.

At Sensirion Connected Solutions, we understand oil and gas operators' needs regarding emissions management. Our customers are looking for solutions that can reliably and quickly detect emissions in their facilities by maximizing true positives and minimizing both false negatives and false positives (false alarms). They want to be pointed towards the emitting equipment group and to know the urgency of that leak with respect to its emission rate. The ADED campaign is designed to evaluate methane monitoring technologies against those precise metrics: detection, localization and quantification of methane emissions under real-world conditions.

The ADED 2023 campaign lasted roughly three months, from February 8th to April 28th. It performed 254 experiments, including 535 individual controlled releases. Nubo Sphere detected 92% of all release experiments correctly, only missed 8% of experiments and did not send any false alarms (false positives) while achieving a 90% probability of detection of 0.8 kg/h. The lowest release rate correctly detected by our solution was 7.8 g/h—well below the 0.4 kg/h limit of detection proposed by the EPA for continuous monitoring solutions in their final NSPS oooob and EG ooooc rules. Nubo Sphere also demonstrated outstanding localization capabilities by assigning emissions to the right equipment group or even unit in 96% of all releases. Finally, it proved its superior quantification capability by quantifying cumulative emissions over all releases with 98.1% accuracy.

Nubo Sphere's performance in ADED 2023

We submit the Nubo Sphere continuous methane emissions monitoring solution to annual testing at Colorado State University's Methane Emissions Technology Evaluation Center (METEC) facility. This whitepaper covers the results of the 2023 testing campaign.

Sensirion Connected Solutions submitted the next-generation Nubo Sphere to the ADED 2023 campaign to test our innovative, photoacoustic-based laser spectroscopy sensor technology. This paper compares the results from both 2022 and 2023 showing how our new sensor technology has improved our solution's probability of detection, time to detection and localization and quantification accuracy. As a reminder: our commentary on Nubo Sphere's performance in the ADED 2022 campaign is available [here](#). Finally, we have updated this whitepaper for 2024 with commentary on key performance metrics.

Following publication of results from all continuous monitoring technologies tested in ADED 2023 (available [here](#)), our analysis confirmed that Nubo Sphere offers the best price-to-performance ratio of all continuous monitoring solutions. Nubo Sphere's performance excelled in metrics spanning false-positive rates, minimum detection limits, localization precision, detection time, and quantification accuracy. That means that operators can act decisively, knowing that Nubo Sphere is providing the information they need to remediate and report fugitive emissions.

In 2024, this is more important than ever. New methane emissions regulations from the US EPA, EU and Canadian government leave oil and gas operators faced with choosing monitoring solutions and practices that both comply with regulatory guidelines and offer an excellent price-to-performance ratio. This update offers guidance.

Lowest 90% probability of detection: **3.9 kg/h**

6.9%

Lowest false positive (FP) rate

68.6%

True positive (TP) rate

98.1%

Cumulated quantification accuracy

31.4%

False Negative (FN) rate

96%

located to the correct equipment unit or group

About ADED

Each ADED campaign comprises hundreds of single-blind experiments, with each experiment comprising at least one, and as many as five, controlled methane releases. Test participants set up their solutions around the METEC facility to monitor and report on these releases. ADED compares these reports to the facts.

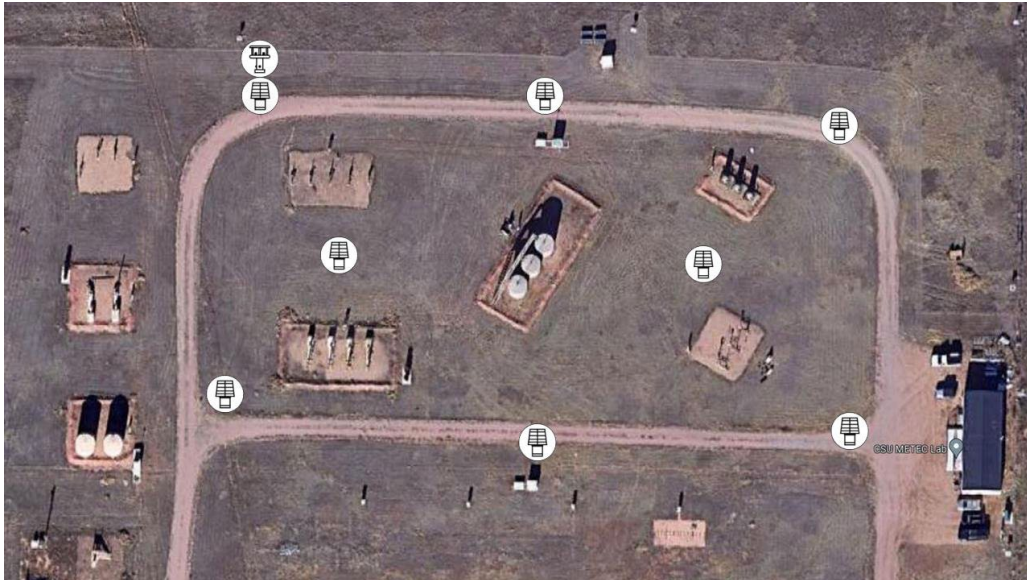


Image 1: ADED 2023 Nubo Sphere testing set up (8 sensor nodes and 1 wind meter)

In Nubo Sphere's 2023 test, METEC performed 254 total experiments between February 8 and April 28, including 535 individual controlled releases.

- Roughly 490 of these individual releases occurred during multiple-emission experiments.
- 269 emissions were below 1 kg/h CH₄.
- 306 releases lasted less than 3 hours, while fewer than 100 releases lasted longer than 6 hours.

ADED is a rigorous test. This has two aims: accumulating a sample size adequate to deliver meaningful results, and replicating emissions scenarios that monitoring solutions may encounter in real-world application.

The ADED 2023 campaign delivered on the latter. During testing, Nubo Sphere experienced wind gusts up to 29.3 m/s, heavy wind and snow, and temperatures ranging from -23.3 °C to 26.8 °C. None of these conditions impacted Nubo Sphere's performance or uptime.

About Sensirion's innovative, low-cost methane sensor technology

The next-generation CH₄ sensor uses mid-infrared laser absorption spectroscopy based on photoacoustics, a proven measurement principle for many applications. Using photoacoustics allowed us to miniaturize the established working principle of laser spectroscopy, while simultaneously increasing cost-efficiency. By measuring the distinct absorption pattern of methane molecules, we can accurately and reliably determine the absolute concentration of methane in ambient air.

Detection performance – enabling “LDAR 2.0”

Nubo Sphere’s probability of detection curves versus emission rates (left) and versus wind normalized emissions rates (right) are below. Nubo Sphere achieved method detection limits (MDL) of 3.9 kg/h and 2.1 (kg/h)/(m/s) respectively during ADED 2023. The MDL dropped significantly compared to 2022 (5.5 kg/h and 3.4 (kg/h)/(m/s)), with smaller uncertainty bounds.

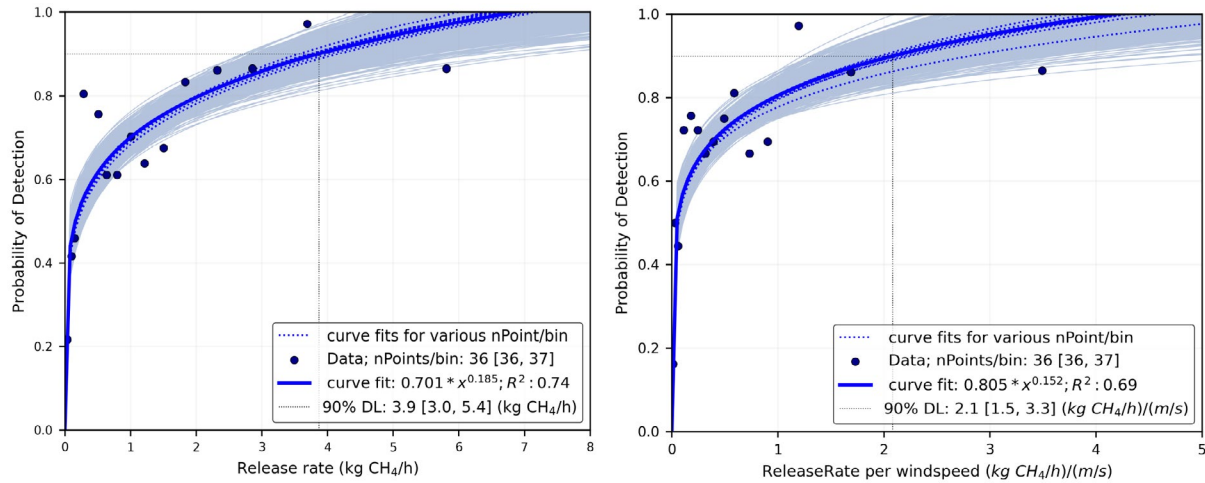


Figure 1: Probability of detection curves versus emission rates (left) and versus wind normalized emission rates (right) as reported by METEC, CSU.

Improved results in probability of detection (POD) come with Nubo Sphere’s improved true positive and false negative rates. The former increased from 58.7% to 68.6% from last year’s to this year’s campaign, while the latter dropped from 41.3% to 31.4% (see Figure 2).

During ADED 2023 testing, Nubo Sphere notably issued no detection reports without methane present on site, **achieving the lowest false positive (FP) rate of all originally ten continuous monitoring solutions tested of only 6.9%.**

ADED places false positives in two categories: “no controlled release” and “excess detection”. Nubo Sphere’s 28 FP reports were split between the two categories. Excess detection reports (20 FP events accounting for 71.4% of all FPs) occurred when Nubo Sphere over-reported the number of emissions in multi-emission events (events with up to five simultaneous emissions). No controlled release reports (8 FPs accounting for 28.6% of all FPs) only occurred when Nubo Sphere estimated the start of emissions too early—but always when there was, in fact, a controlled release.

ID	Count		FP (%) [†]				DL90 [‡] (kg CH ₄ /h)
	Controlled Release	Detection Reports	All	No Controlled Release	Excess Detections	FN (%)	
Result from the current study for all participating CM solutions							
D	547	403	6.9	28.6	71.4	31.4	3.9 [3.0, 5.5]
B	547	300	7.7	39.1	60.9	49.4	5.5 [4.4, 7.4]
F	547	444	10.6	8.5	91.5	27.4	6.2 [3.7, 16.7]
P	547	423	13.2	23.2	76.8	32.9	6.0 [4.1, 11.6]
N	417	223	18.4	29.3	70.7	56.4	14.1 [7.3, 55.3]
L	256	254	35.0	95.5	4.5	35.5	10.2 [5.3, 61.8]
O	357	324	34.6	33.0	67.0	40.6	18.2 [7.9, 90.5]
Q	547	260	38.1	21.2	78.8	70.6	11.7 [7.7, 22.6]
A ¹	547	487	47.8	61.8	38.2	53.6	NA
Results from <i>Bell et al.</i> for the 4 CM solutions that participated in both studies.							
D	574	376	10.4	79.5	20.5	41.3	5.7 [3.8, 11.5]
F	574	516	22.5	39.7	60.3	30.3	3.8 [2.5, 7.3]
B	445	250	31.2	61.5	38.5	61.3	64.4 [16.1, NA]
A	574	986	59.8	26.9	73.1	31.0	11.7 [4.3, NA]

Figure 2: False positive rates as measured at ADED 2023. Nubo Sphere, letter D, performed the best in this category, with the lowest rate of false positives (Note: 6.9% overall FP rate split in 28.6 % No Controlled Releases and 71.4 % Excess Detections as per updated pre-print dated Feb. 8th, 2024).

Considered in light of Nubo Sphere's field-leading minimum detection limit (3.9 kg/h with a 90% probability of detection), Nubo Sphere's low rate of false positives stands out further above the field. METEC calls this ability to detect small leak rates without generating false positives the solution's "balance of sensor sensitivity". By detecting smaller leaks without sacrificing reporting reliability, solutions with a good balance of sensor sensitivity offer the best LDAR support for operators. The lowest true positive event Nubo Sphere detected had a rate of only 7.8 g/h.

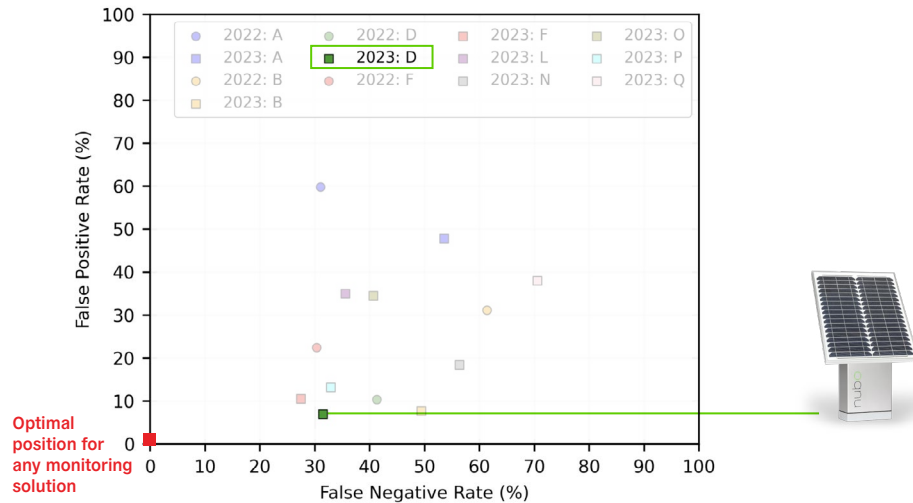


Figure 3: ADED's balance of sensor sensitivity. Nubo Sphere's low rate of false positive and false negative generation makes the solution ideally suited for LDAR applications.

Meanwhile, Nubo Sphere achieved a mean time to detection in ADED 2023 of less than 4.9 hours. In many cases, the solution required only minutes after the start of an emission event to raise the alarm.

This is a significant improvement on performance in ADED 2022, when Nubo Sphere achieved a mean time to detection of 20.7 hours. This improvement is thanks to next-generation photoacoustic-based laser spectroscopy sensor technology, as well as improved data analytics.

METEC calculated detection time using true positive detections by calculating the time difference between the start of a controlled release and the time when they receive a matched detection report.

There is one metric that ADED test campaigns don't address: end of emission detection. We understand that Nubo Sphere should quickly inform operators when an emission event has ended. During ADED 2023 campaign, Nubo Sphere was theoretically able to inform operators of the end of emissions on average 6.5 h after the emissions had ended. We see both detection times as an opportunity for further improvement.

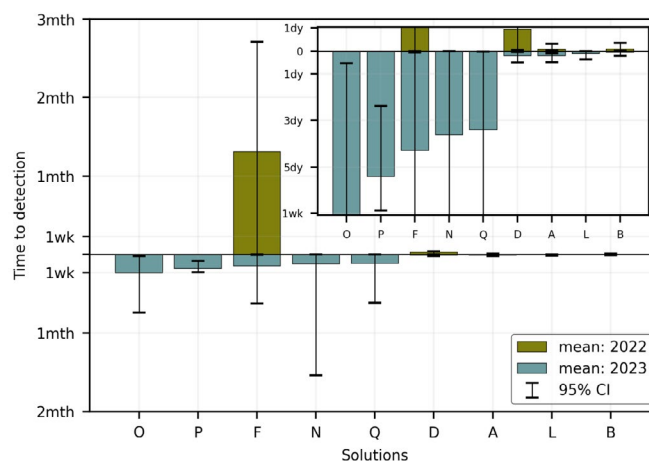


Figure 4: The mean time to detection of solutions tested in ADED 2023, sorted from longest to shortest. Bars above the zero line indicate results of the ADED 2022 campaign. Nubo Sphere is D.

Given the advent of the US EPA's Super Emitter Program, fast detection will be critical for operators hoping to quickly end large emissions events and avoid costly fines, levied based on the size of the emission. It's also worth noting that Nubo Sphere maintained 100% uptime through the duration of the 2023 testing campaign. This is an important metric for EPA approval of continuous monitoring solutions. To learn more about the Super Emitter Program, please see our article on EPA methane emissions regulations [here](#).

Localization performance – increased follow-up efficiency

Out of all the true positives reported by Nubo Sphere, 96% were attributed to the correct equipment group (up from 52.8% in 2022). Out of these, 27.2% were also attributed to the correct equipment unit. This means that Nubo Sphere will direct repair crews to the correct equipment group (on average releases are localized within ± 5 m of the actual emission source) in almost every case, thus improving the efficiency of their work and saving costs. Only 4 % of reported true positives were attributed to the incorrect equipment group but still correctly within the perimeter of the facility.

Furthermore, 10 out of 11 releases below 50 g/h were located to the correct equipment group (3 to the correct equipment unit even). This demonstrates our solution's overall performance with respect to small emissions.

Per the official metrics of the ADED protocol, localization precision differs from accuracy in that accuracy weighs precision against all detection reports. Accounting for false positives, which are minimal from the Nubo Sphere solution, Nubo Sphere achieved the highest localization accuracy of 93.1% at the facility level. Localization precision indicates where the solution localizes true positives within the facility, making it an important indicator of how well a solution finds the sources of emissions.

It's worth noting that Nubo Sphere achieved this result with only eight sensor nodes deployed. The METEC facility is 8450m². Monitoring this area with fewer sensors yields a smaller sensor density, measured in sensors/m². Of all fixed-point sensor networks, Nubo Sphere has the second lowest sensor density, according to METEC, allowing for cost efficient monitoring of large facilities.

			Source Localization (Equipment Unit)					
			Precision (%)			Accuracy (%)		
ID	Sensor Density (sensors/m ²)	Count of TPs	Unit Level	Group Level	Facility Level	Unit	Group Level or Better	Facility Level or Better
Result from the current study for all participating CM solutions								
B	0.000118	277	89.5	9.4	1.1	82.7	91.3	92.3
L	0.000118	165	86.7	10.9	2.4	56.3	63.4	65.0
O	0.000118	212	76.4	12.7	10.9	50.0	58.3	65.4
N	0.00213	182	51.6	41.8	6.6	42.2	76.2	81.6
F	0.00118	397	40.8	53.9	5.3	36.5	84.7	89.4
Q	0.00154	161	28.0	54.0	18.0	17.3	50.8	61.9
D	0.000947	375	27.2	68.8	4.0	25.3	89.3	93.1
P	0.00071	367	27.0	56.9	16.1	23.4	72.8	86.8
A ¹	0.000947	254	26.0	49.6	24.4	13.6	39.4	52.2
Results from Bell et al. for the 4 CM solutions that participated in both studies.								
B	0.000118	172	70.9	15.7	13.4	48.8	59.6	68.8
A	0.000947	396	28.0	39.4	32.6	11.3	27.1	40.2
F	0.000947	400	24.8	50.2	25.0	19.2	58.1	77.5
D	0.000947	337	0.0	52.8	47.2	0.0	47.3	89.6

¹ One of the sensors installed failed during the study.

Figure 5: Sensor density and localization performance of Nubo Sphere, ID D in the table, and competing solutions. Letters B, L and O are scanning/imaging solutions, each deploying only one sensor. Fixed-point sensors are lettered N, F, Q, D, P, and A. Note that N and Q deployed 18 and 13 sensors, respectively, compared to Nubo Sphere's eight.

Quantification performance – a significant leap forward

When comparing quantification performance, it is important to note that the experimental design of ADED 2022 and ADED 2023 are different. Therefore, we cannot directly compare the quantification capabilities of MOx and photoacoustic-based laser spectroscopy sensor per release. However, by analyzing the cumulative emissions of all true positive releases for both ADED campaigns, we get a good idea of Nubo Sphere's laser spectroscopy quantification capabilities.

Our algorithm quantified 95.5% of all reported true positives (up from 69.1% last year). More importantly, thanks to our photoacoustic-based laser spectroscopy sensor's enhanced quantification capabilities, Nubo Sphere quantified cumulated emissions with 98.1% accuracy, versus 46.7% last year with MOx technology (see Figure 6).

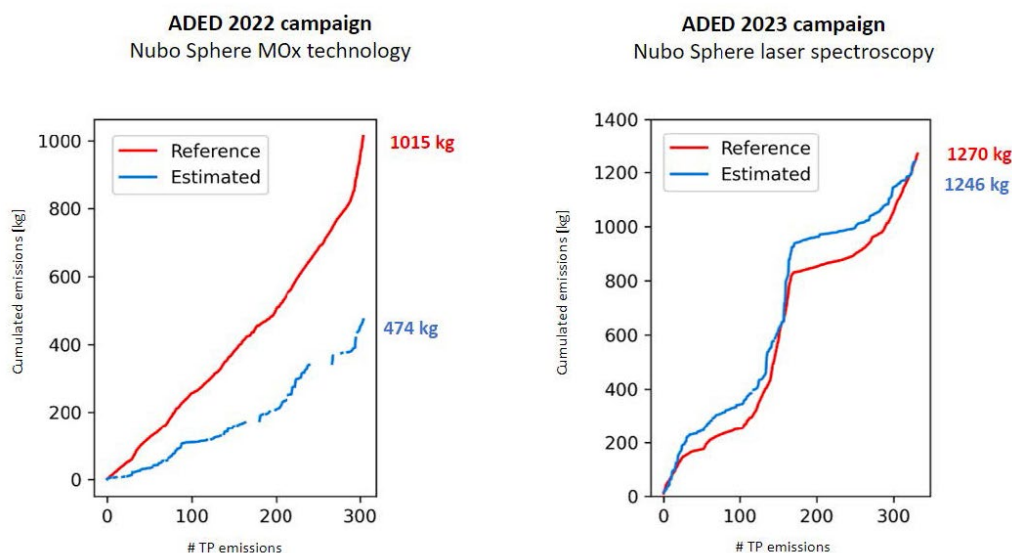


Figure 6: Estimated cumulated emissions for ADED 2022 (left, using MOx) and ADED 2023 (right, using next generation photoacoustic-based laser spectroscopy sensor technology)

Differentiated analysis of Nubo Sphere's performance in ADED 2023

When interpreting Nubo Sphere's performance on the level of the experiment, rather than on the level of individual releases, the solution's performance stands out. This is due to the nature of multiple-emission experiments used during ADED testing.

As discussed in our commentary on Nubo Sphere's performance during ADED 2022, we use a differentiated analysis to interpret Nubo Sphere's performance by looking only at the experiments, rather than at the single releases. This means that we analyze the 254 experiments that were performed during ADED 2023 (roughly 85% were multiple emissions, i.e., experiments during which several simultaneous releases took place at different locations and emission rates) to determine whether we detected at least one release during each experiment correctly. If we had, we interpreted that experiment as a true positive and used the maximum emission rate out of all single releases during this multiple-emission experiment as an input for our POD curve. There are two reasons for taking this approach: the maximum emission rate would likely be the one we detected correctly, but even in cases where we missed that specific release (=FN), by always choosing the maximum, we have taken an honest and conservative approach.

The first important metric to discuss is the rate of false positives. With our differentiated analysis, we achieve 0 false positives, meaning that every time we reported an emission there was a corresponding, ongoing controlled release at METEC. Most false positives were a consequence of Nubo Sphere reporting more releases than were simultaneously ongoing, and mostly associated with low-wind conditions (<1.5 m/s). For example, we reported a single release as two emissions. This is consistent with ADED 2022 results.

As with false positives, most false negatives are a result of us reporting fewer releases than were simultaneously ongoing. For example, we reported three releases when there were five ongoing. Using our differentiated analysis, false negatives drop from 31.5% to 10% (vs. 41.3% to 18.2% last year).

Finally, the probability of detection also improves according to our differentiated analysis. While the original minimum detection limit was 3.9 kg/h, we reached 0.8 kg/h with our differentiated analysis (see Figure 7 below).

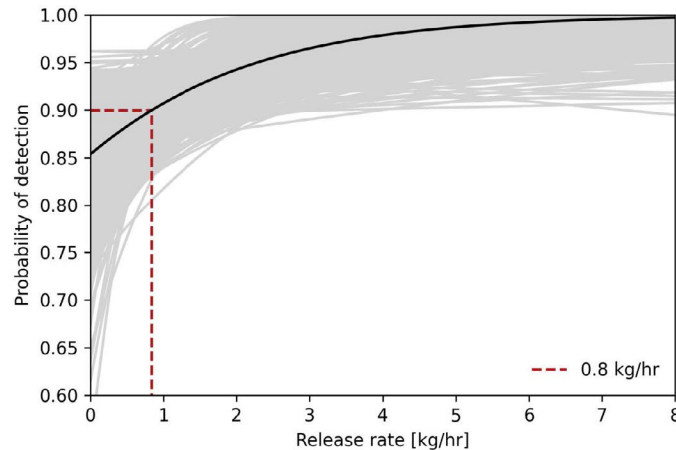


Figure 7: Probability of detection curve versus emission rate using an experiment-based analysis by Sensirion.

Outlook

Sensirion's proprietary photoacoustic-based laser spectroscopy sensor technology improved Nubo Sphere's performance in ADED 2023 testing remarkably over its already strong performance in the 2022 campaign. Nubo Sphere's performance also clearly stands out against other continuous monitoring solutions under test at ADED 2023. Operators can expect reliable detection of methane emissions and leak localization at the equipment group level, independent of wind speed or methane release rates.

As ADED 2023 was just the first intensive field test for Sensirion's next generation Nubo Sphere solution, stay tuned for more results to be published in the near future and also from ADED 2024. Meanwhile, we are working on fully exploiting the capabilities of Sensirion's ground-breaking methane sensor technology to further improve our time to detection, localization and quantification accuracy, especially with an eye on large emission events >100 kg/h, so that operators can react as quickly as possible to critical emissions in their facility. Moreover, we are working on very low (~0.5 m/s) wind conditions to become less relevant for the performance of Nubo Sphere as well as improving Nubo Sphere's performance on complex midstream sites which are not well represented by METEC. Stay tuned and reach out if you want to know more!

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