Ultra-Low NOx Measurement Utilizing Advanced Infrared Techniques

Joshua Israel, Horiba

OSAR Conference 2025

2025/04/17

HORIBA

IRLAM by HORIBA

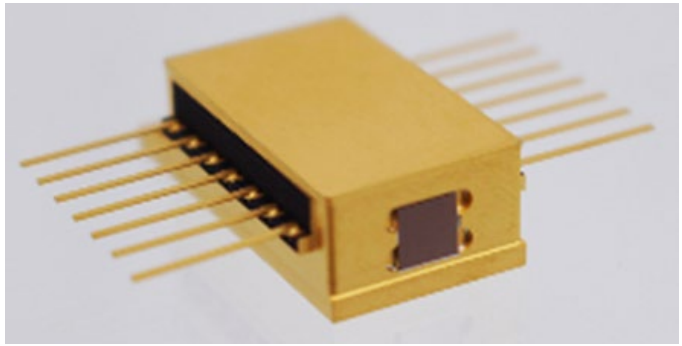
IRLAM : InfraRed Laser Absorption Modulation

High accuracy infrared spectroscopy technology developed by HORIBA

Quantum Cascade Laser (QCL)

Narrow-wavelength

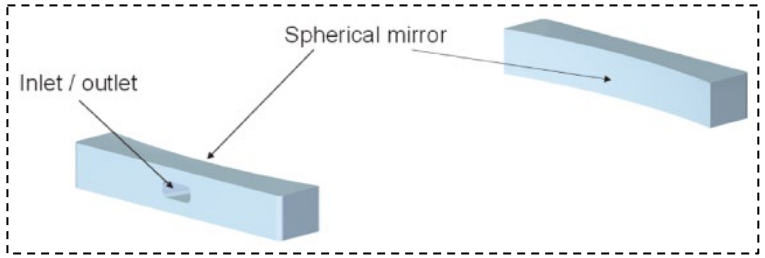
High directivity



Herriot Cell

Small volume → fast response

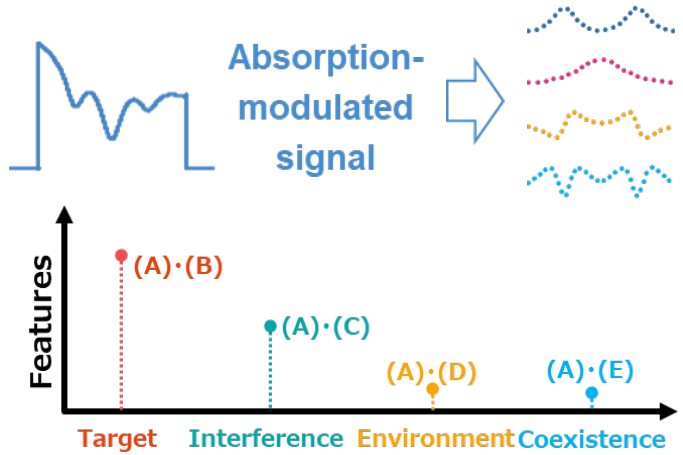
Long optical path



Signal Processing Algorithm

Extracts "features" from absorption signal

Computationally moderate



HORIBA IRLAM Portfolio

MEXA-ONE-XL-NX

NO, NO_2
N_2O, NH_3

XLA-11H

N_2O

XLA-13H

HCHO

OBS-ONE-XL

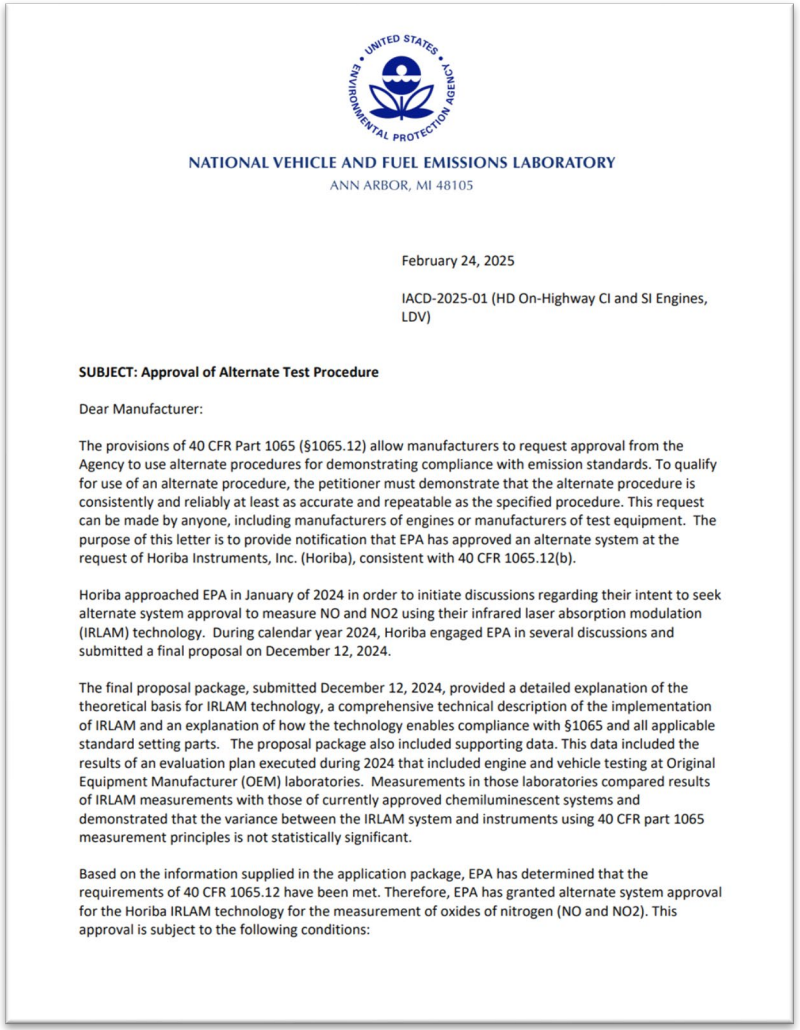
N_2O, NH_3

MEXAcube

NH_3, N_2O, HCHO
CO, CO_2, NO
NO_2, CH_4, THC

EPA Guidance Letter

Approved Feb 24, 2025



NATIONAL VEHICLE AND FUEL EMISSIONS LABORATORY
ANN ARBOR, MI 48105

February 24, 2025

IACD-2025-01 (HD On-Highway CI and SI Engines, LDV)

SUBJECT: Approval of Alternate Test Procedure

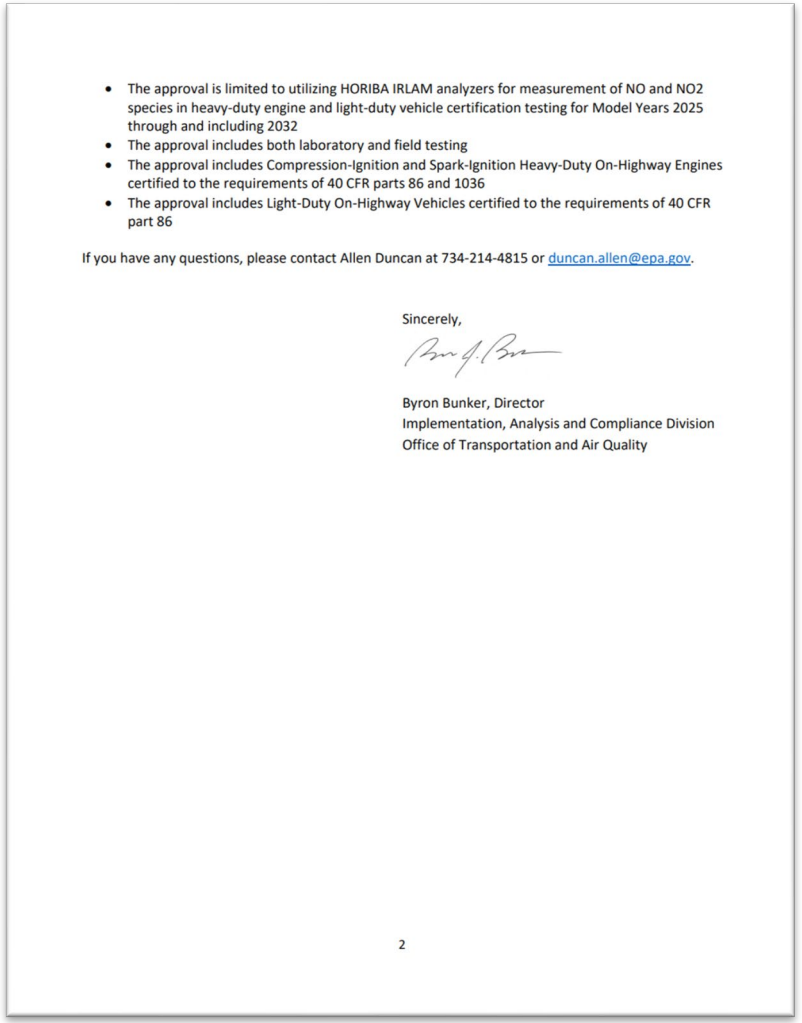
Dear Manufacturer:

The provisions of 40 CFR Part 1065 (§1065.12) allow manufacturers to request approval from the Agency to use alternate procedures for demonstrating compliance with emission standards. To qualify for use of an alternate procedure, the petitioner must demonstrate that the alternate procedure is consistently and reliably at least as accurate and repeatable as the specified procedure. This request can be made by anyone, including manufacturers of engines or manufacturers of test equipment. The purpose of this letter is to provide notification that EPA has approved an alternate system at the request of Horiba Instruments, Inc. (Horiba), consistent with 40 CFR 1065.12(b).

Horiba approached EPA in January of 2024 in order to initiate discussions regarding their intent to seek alternate system approval to measure NO and NO2 using their infrared laser absorption modulation (IRLAM) technology. During calendar year 2024, Horiba engaged EPA in several discussions and submitted a final proposal on December 12, 2024.

The final proposal package, submitted December 12, 2024, provided a detailed explanation of the theoretical basis for IRLAM technology, a comprehensive technical description of the implementation of IRLAM and an explanation of how the technology enables compliance with §1065 and all applicable standard setting parts. The proposal package also included supporting data. This data included the results of an evaluation plan executed during 2024 that included engine and vehicle testing at Original Equipment Manufacturer (OEM) laboratories. Measurements in those laboratories compared results of IRLAM measurements with those of currently approved chemiluminescent systems and demonstrated that the variance between the IRLAM system and instruments using 40 CFR part 1065 measurement principles is not statistically significant.

Based on the information supplied in the application package, EPA has determined that the requirements of 40 CFR 1065.12 have been met. Therefore, EPA has granted alternate system approval for the Horiba IRLAM technology for the measurement of oxides of nitrogen (NO and NO2). This approval is subject to the following conditions:



- The approval is limited to utilizing HORIBA IRLAM analyzers for measurement of NO and NO2 species in heavy-duty engine and light-duty vehicle certification testing for Model Years 2025 through and including 2032
- The approval includes both laboratory and field testing
- The approval includes Compression-Ignition and Spark-Ignition Heavy-Duty On-Highway Engines certified to the requirements of 40 CFR parts 86 and 1036
- The approval includes Light-Duty On-Highway Vehicles certified to the requirements of 40 CFR part 86

If you have any questions, please contact Allen Duncan at 734-214-4815 or duncan.allen@epa.gov.

Sincerely,

Byron Bunker, Director
Implementation, Analysis and Compliance Division
Office of Transportation and Air Quality

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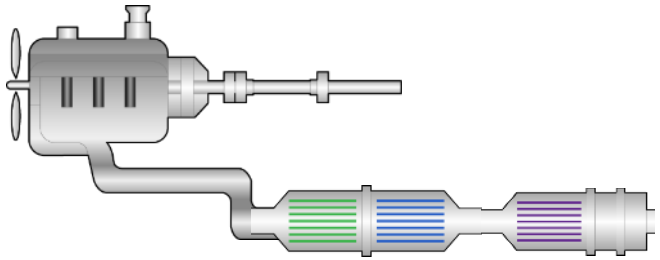
Link to EPA website: https://dis.epa.gov/otaqpub/display_file.jsp?docid=62326&flag=1

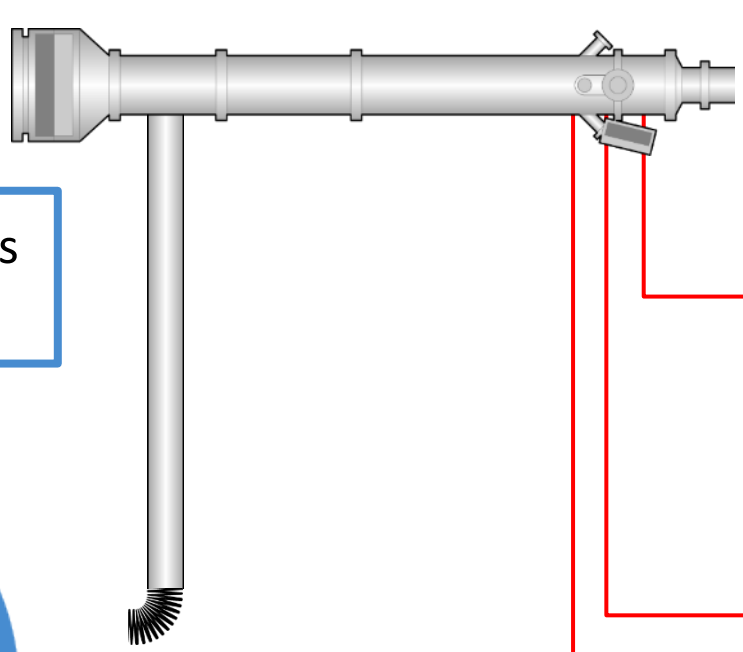
Test Program

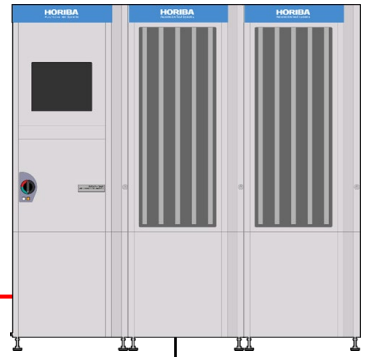
Multiple Test Programs
LDV and HD Engine

SULEV Vehicle

2026+ Compliant HD Engine







CVS System

- Full flow dilution tunnel (CFV)
- Bag system

Dilute Emissions Bench

- MEXA-ONE-C1
- Continuous dilute emissions and bag read capable
- CO2, CO, THC, CH4, NO_X (CLD)

IRLAM Dilute Emissions

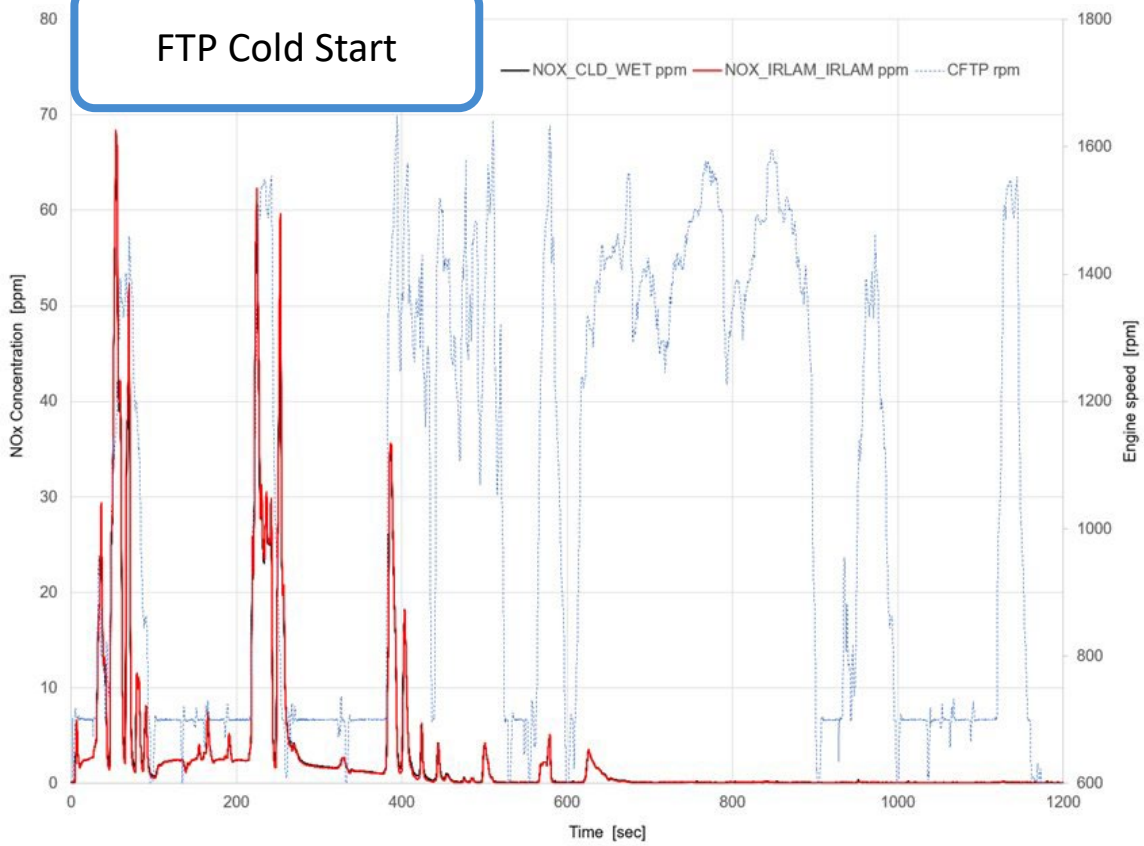
- MEXA-ONE-XL-NX
- Continuous dilute emissions
- NO, NO2, NH3, N2O (IRLAM)

Sample Data, HD Engine

Heavy-duty Engine Testing

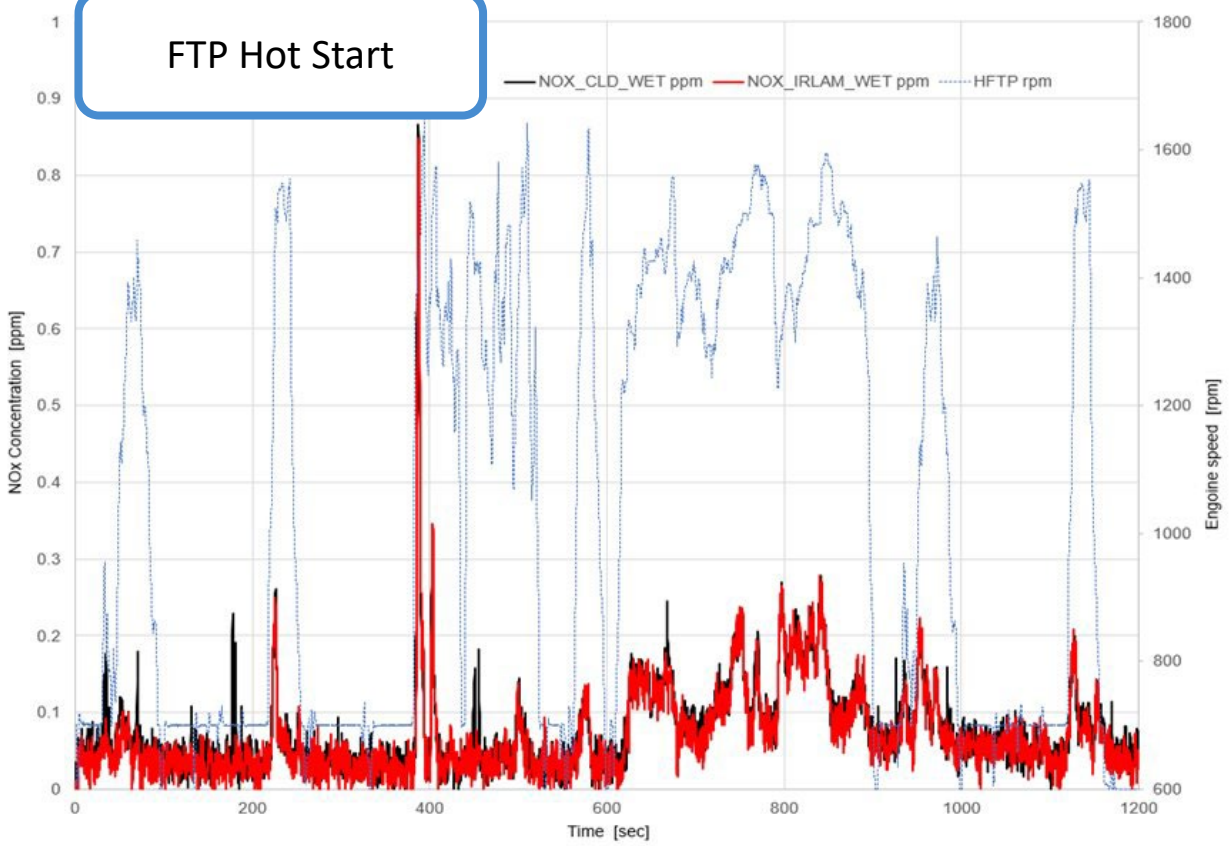
Excellent correlation with CLD
High and low NO_X concentrations

FTP Cold Start



Concentration Values (ppm)	Max Measured	Average Measured
Cold FTP	68.382	2.93

FTP Hot Start



Concentration Values (ppm)	Max Measured	Average Measured
Hot FTP	0.849	0.07

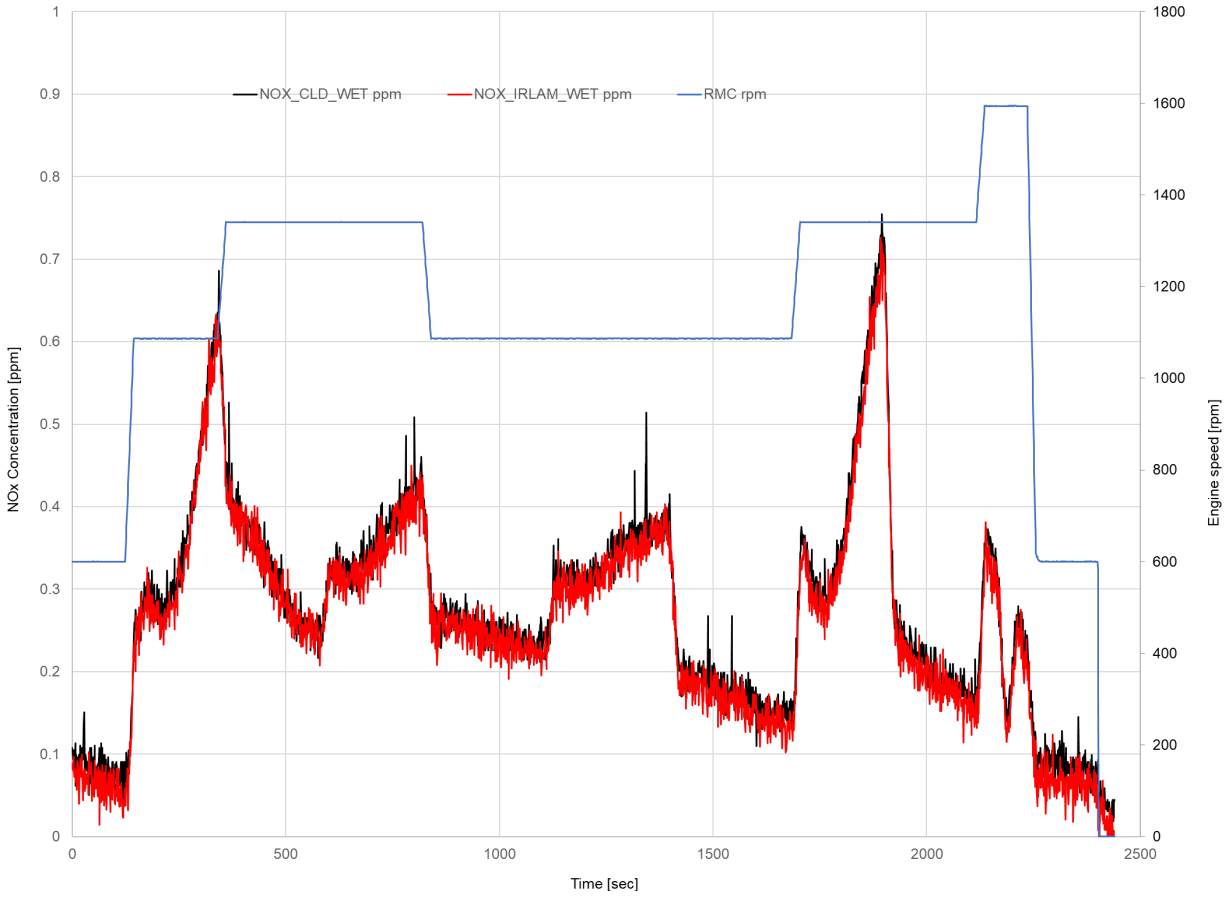
Sample Data, HD Engine

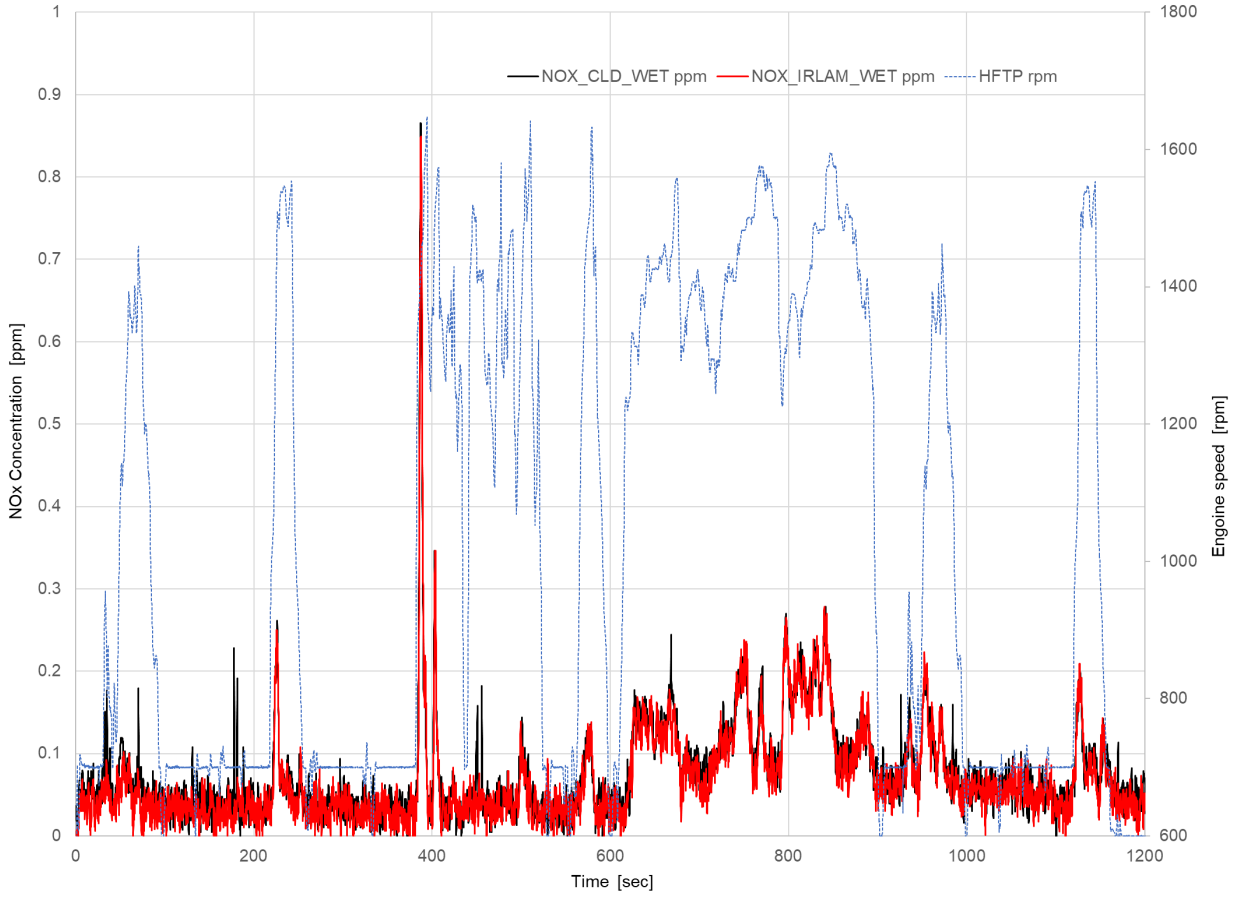
Ultra-low NOx concentrations

HD - RMC

Concentration Values (ppm)	Max Measured	Average Measured
Hot FTP	0.849	0.07

HD – FTP Hot Start





Test Results

Heavy-duty Engine Testing Results

Cold-Start FTP

	Test #	CLD NOX_dc (g/hp-hr)	IRLAM NOX_dc (g/hp-hr)	Diff Yref - Y
CFTP	1	0.2497	0.2479	0.0018
	2	0.2583	0.2571	0.0012
	3	0.2418	0.2376	0.0042
	4	0.2372	0.2357	0.0015
	5	0.2500	0.2501	-0.0001
	6	0.2427	0.2403	0.0024
	7	0.2439	0.2428	0.0011

Hot-Start FTP

	Test #	CLD NOX_dc (g/hp-hr)	IRLAM NOX_dc (g/hp-hr)	Diff Yref - Y
HFTP	1	0.0047	0.0040	0.0007
	2	0.0044	0.0044	0.0000
	3	0.0051	0.0051	0.0000
	4	0.0052	0.0047	0.0005
	5	0.0052	0.0049	0.0003
	6	0.0045	0.0049	-0.0004
	7	0.0050	0.0041	0.0009

Hot start average difference: ~0.00029 g/bhp-hr (<1% of the MY27 NOx standard)

Statistical Analysis

Heavy-duty Engine Testing

Cold-Start FTP

T test If t is less than tcrit, then t passes the t-test.

T 0.443

$$t = \frac{\left|\bar{y}_{ref} - \bar{y}\right|}{\sqrt{\frac{\sigma_{ref}^2}{N_{ref}} + \frac{\sigma_y^2}{N}}}$$

Eq. 1065.602-5

F critical values	
90% CI	95% CI
1.782	2.179
Result	
PASS	PASS

F test If F is less than F_{crit90}, then F passes the F-test

F 1.193

$$F_y = \frac{\sigma_y^2}{\sigma_{ref}^2}$$

Eq. 1065.602-8

F critical values	
90% CI	95% CI
3.055	4.284
Result	
PASS	PASS

Hot-Start FTP

T test If t is less than tcrit, then t passes the t-test.

T 1.395

$$t = \frac{\left|\bar{y}_{ref} - \bar{y}\right|}{\sqrt{\frac{\sigma_{ref}^2}{N_{ref}} + \frac{\sigma_y^2}{N}}}$$

Eq. 1065.602-5

F critical values	
90% CI	95% CI
1.86	2.306
Result	
PASS	PASS

F test If F is less than F_{crit90}, then F passes the F-test

F 1.614

$$F_y = \frac{\sigma_y^2}{\sigma_{ref}^2}$$

Eq. 1065.602-8

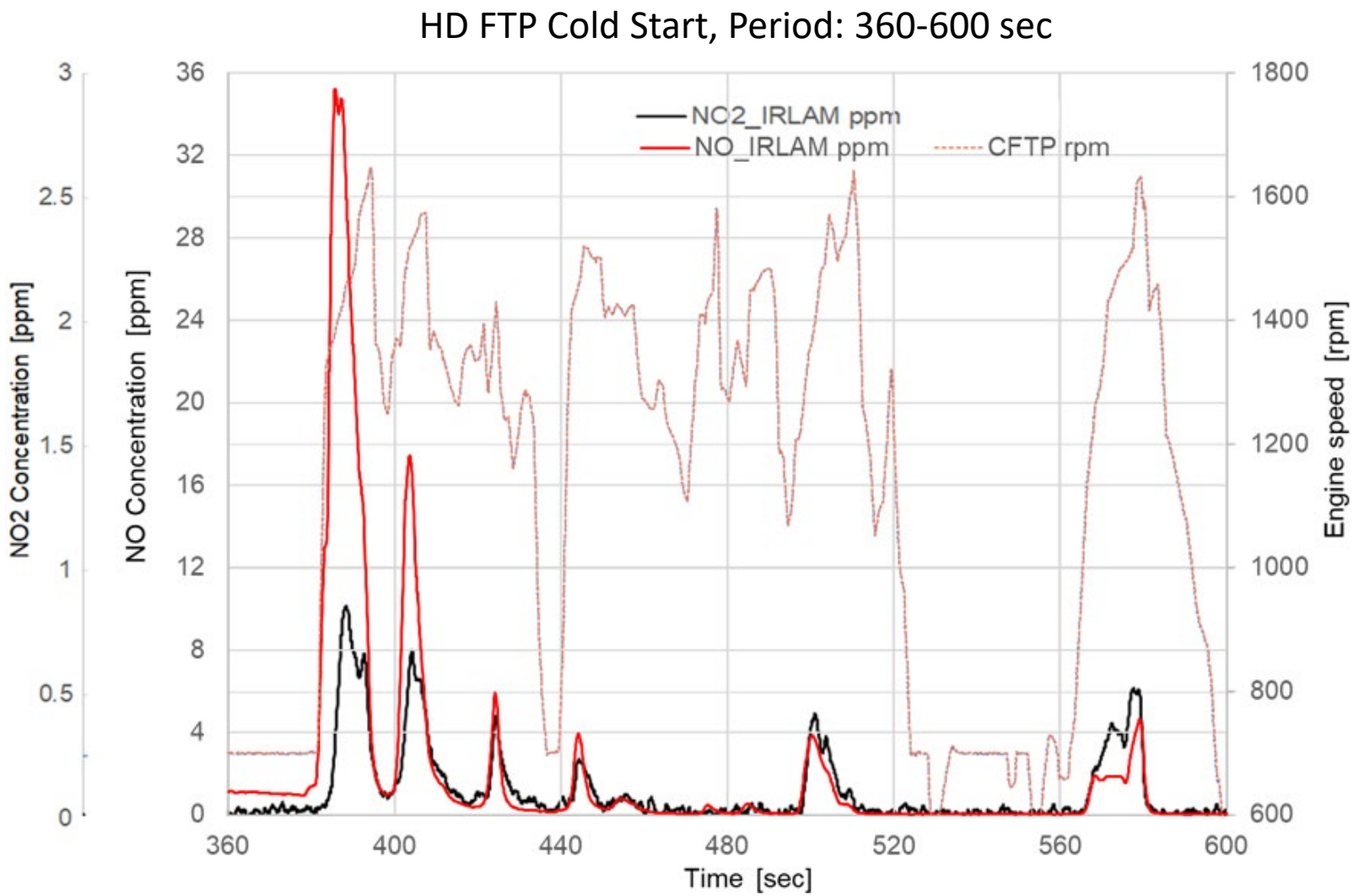
F critical values	
90% CI	95% CI
3.055	4.284
Result	
PASS	PASS

NO_2 Measurement

NOx Calculation

$NOx = NO + NO_2$

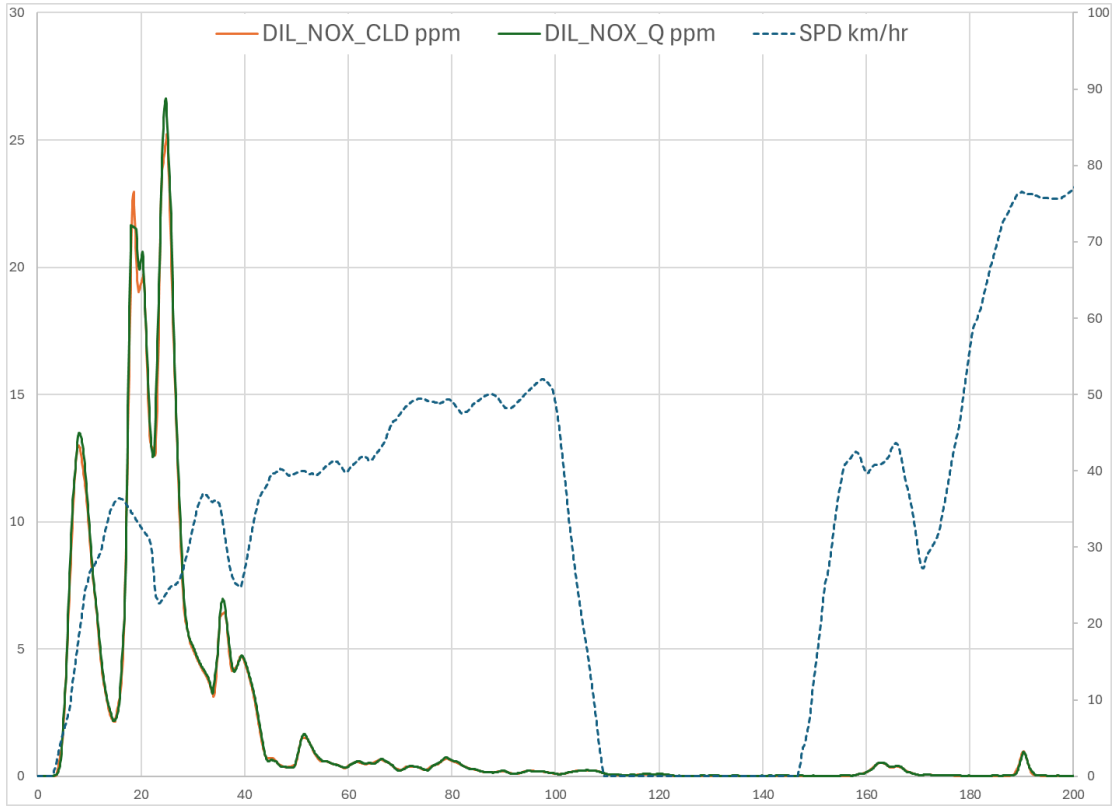
Real-time NO_2 without conversion catalyst



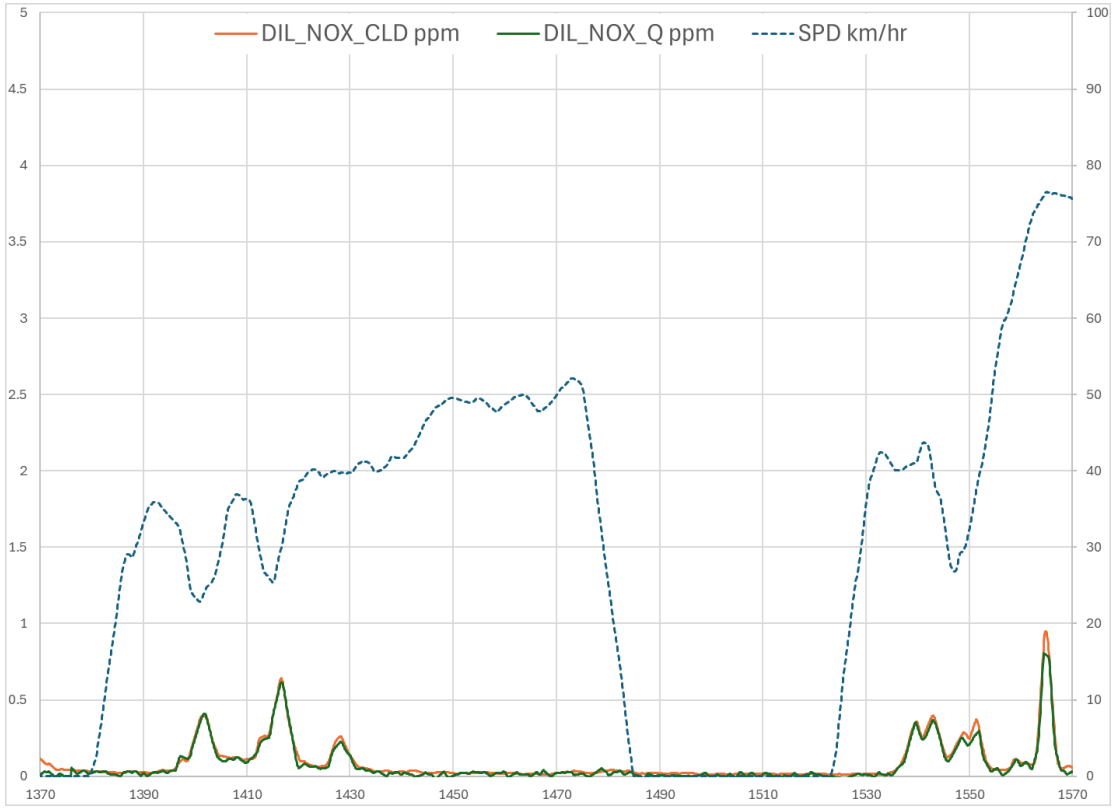
Sample Data, LDV

Light-Duty Vehicle Testing

Excellent correlation with CLD,
High and low NOx concentration



FTP-75 Cold Start
(Phase 1, first 200 sec)



FTP-75 Hot Start
(Phase 3, first 200 sec)

Concentration Values (ppm)	Max Measured	Average Measured	Bag Read
FTP-75	45.139	0.375	Phase 1 = 0.809 Phase 3 = 0.095

Statistical Equivalence

No statistically significant difference between IRLAM measurements and the regulatory reference method for NO + NO_2 (CLD)

FTP-75 Duty Cycle Statistical Analysis

T test If t is less than tcrit, then t passes the t-test.

T 0.2441

$$t = \frac{\left|\overline{y}_{ref} - \overline{y}\right|}{\sqrt{\frac{\sigma_{ref}^2}{N_{ref}} + \frac{\sigma_y^2}{N}}}$$

Eq. 1065.602-5

T critical values

90% CI	95% CI
1.761	2.145

Result

PASS	PASS

F test If F is less than F_{crit90}, then F passes the F-test

F 1.186

$$F_y = \frac{\sigma_y^2}{\sigma_{ref}^2}$$

Eq. 1065.602-8

F critical values

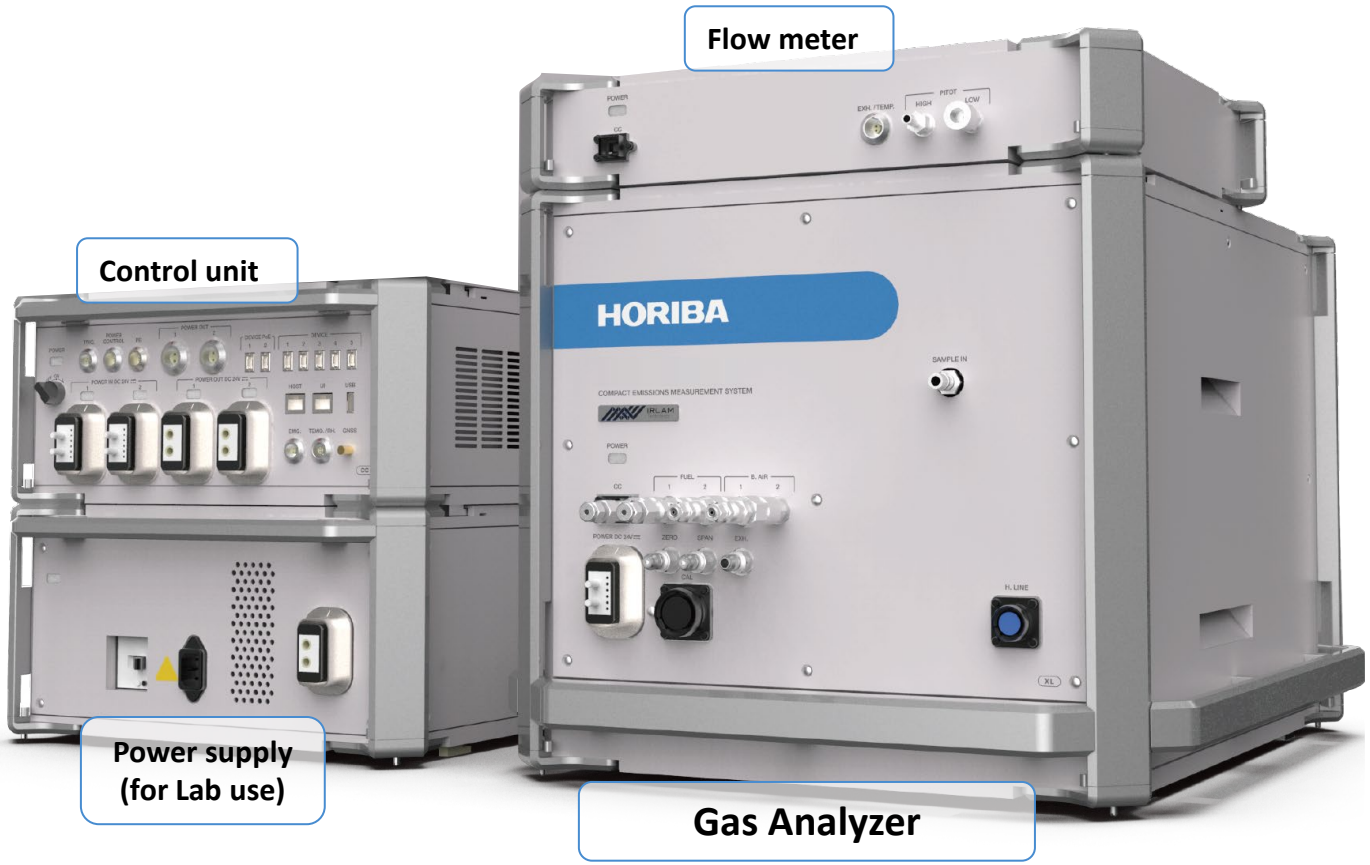
90% CI	95% CI
3.055	4.284

Result

PASS	PASS

Portable Emissions Measurement System

MEXAcube



Measured components and ranges

IRLAM by HORIBA

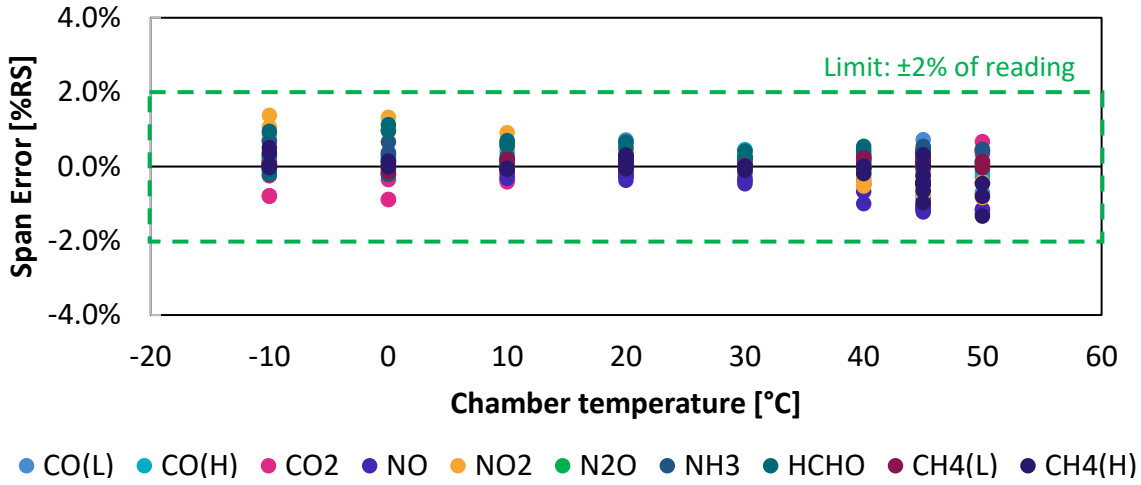
CO	0 - 8000 ppm, 0 - 12 vol%
CO_2	0 - 20 vol%
NO	0 - 2000 ppm
NO_2	0 - 800 ppm
N_2O	0 - 1000 ppm
NH_3	0 - 1500 ppm
HCHO	0 - 50 ppm
CH_4	0 - 2000 ppm, 0 - 10000 ppm

Flame Ionization Detector

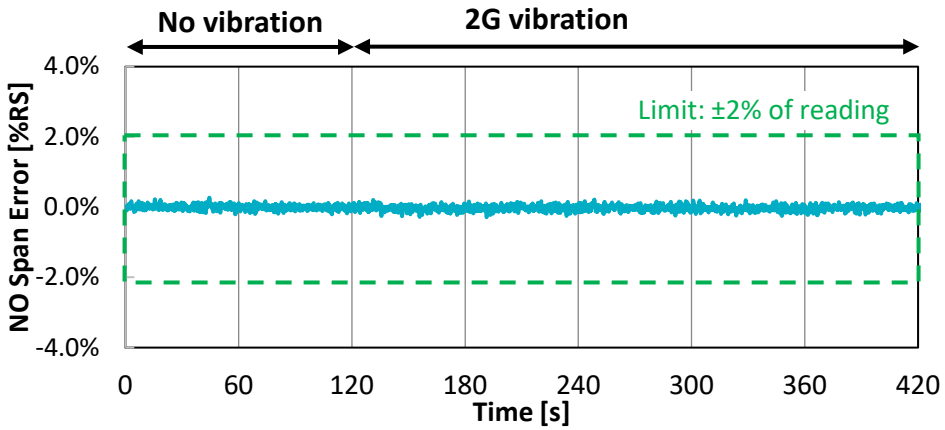
THC	0 - 10000 ppmC

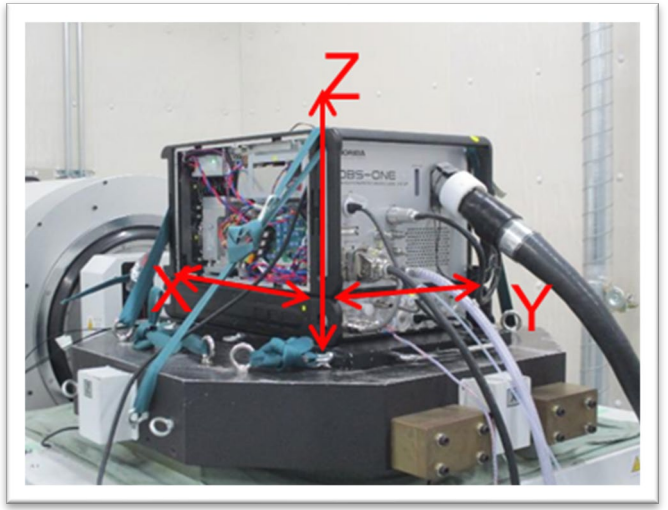
Robust Design for On-board Testing

Ambient temperature -10 ～ 45 °C

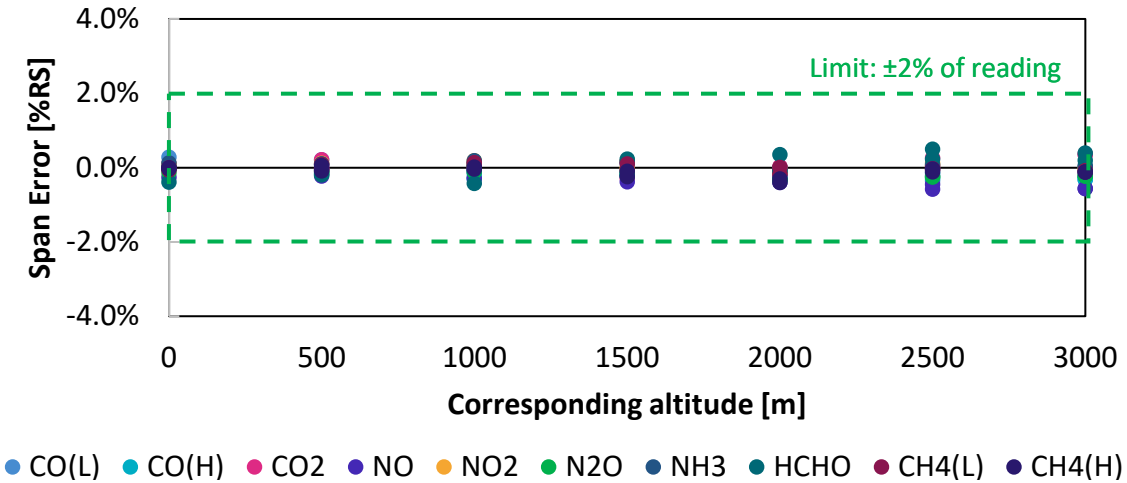


Random vibration 2G, Multi-axis

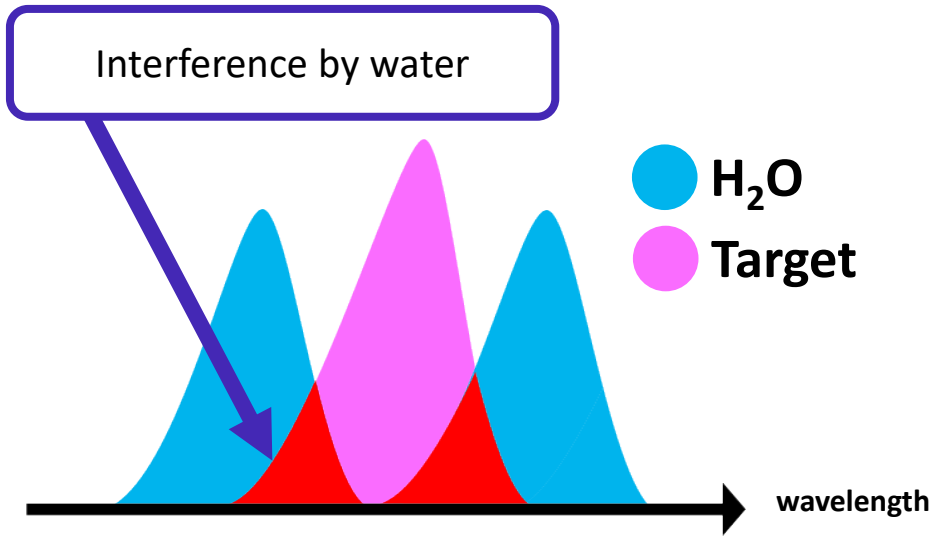




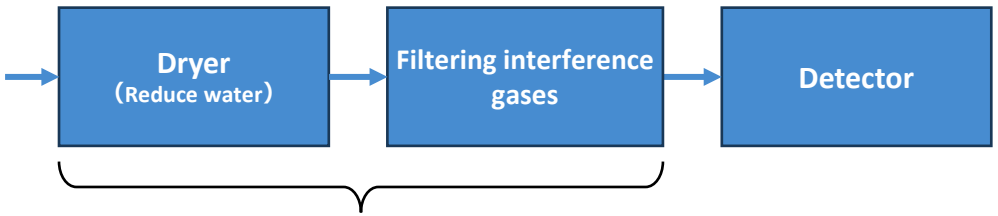
Ambient pressure 100 ～ 70 kPa (0 ～ 3000 m equivalent)

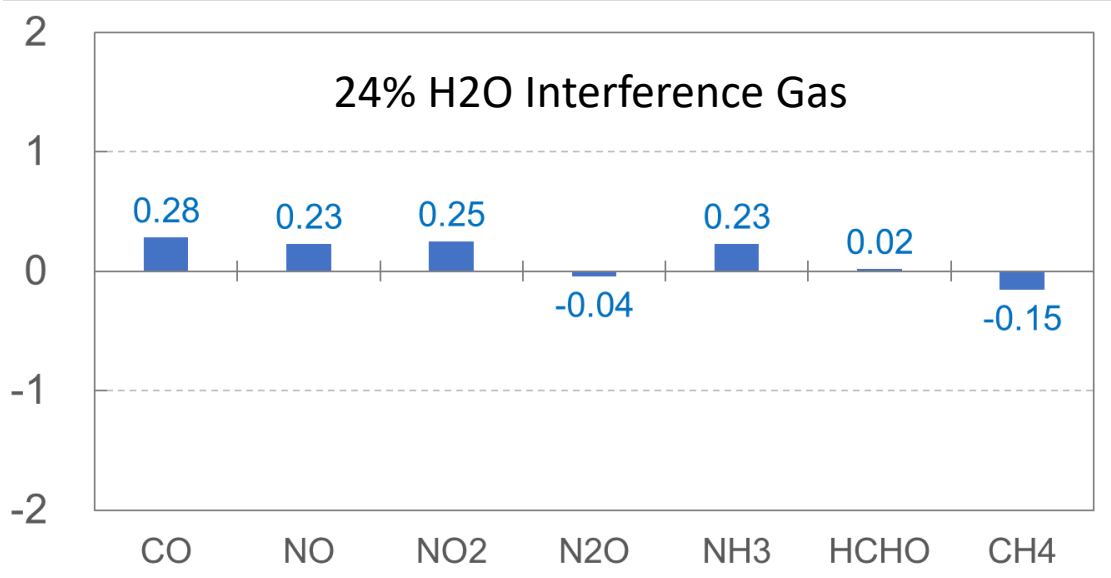


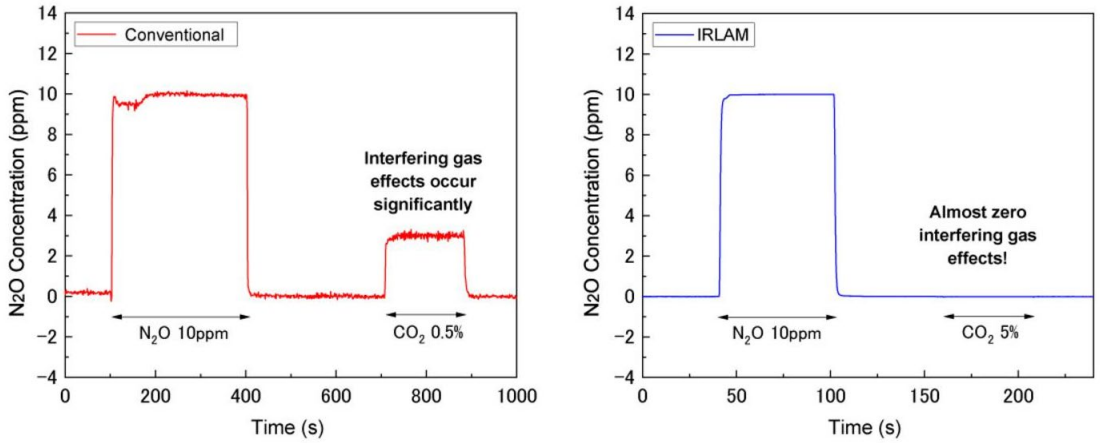
Near-zero Interference



Previous Technologies



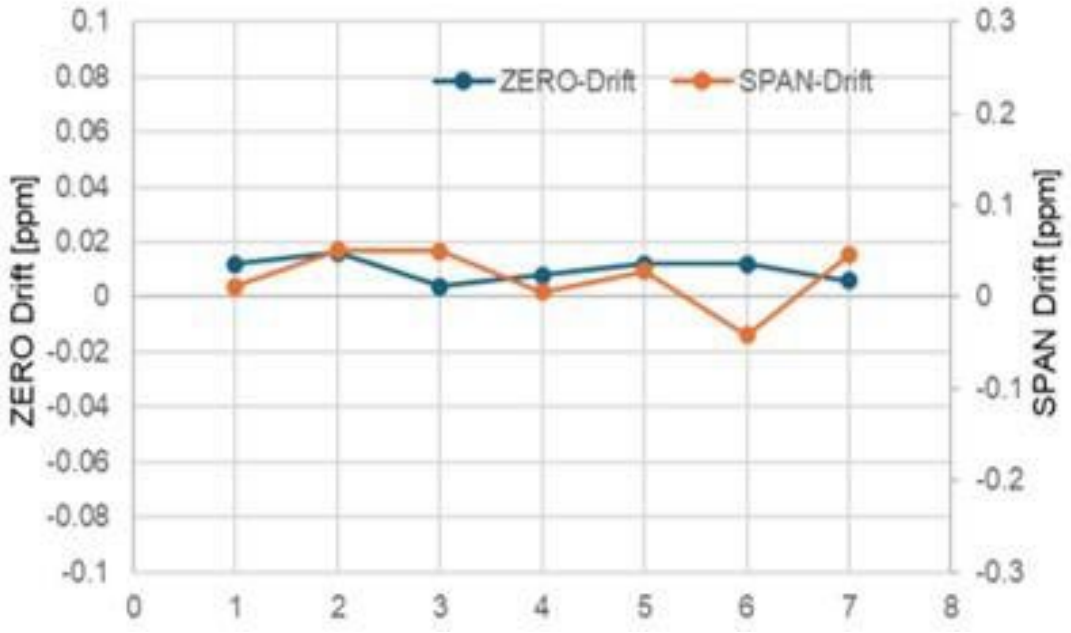




5% CO_2 Interference Gas

Drift / Noise Performance

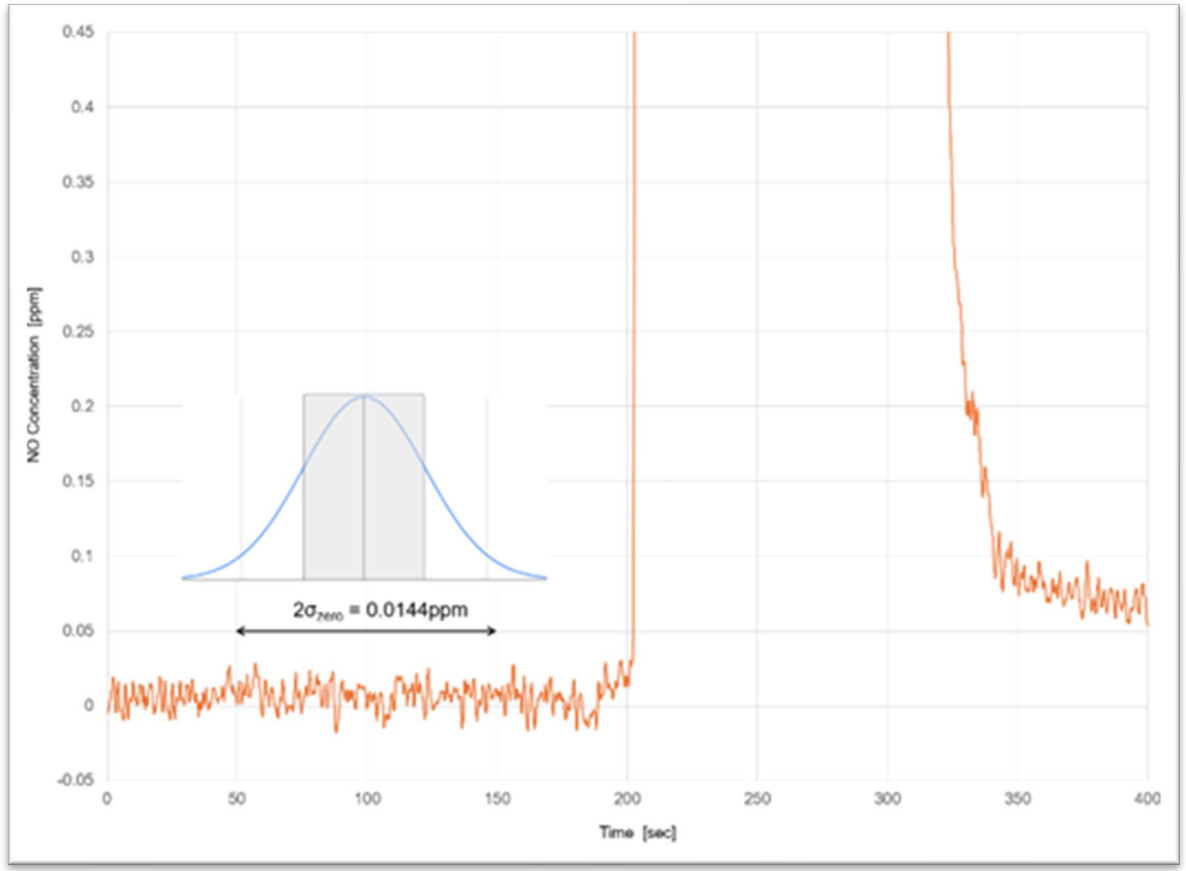
No meaningful zero drift observed throughout testing



IRLAM NO Low-Range, Cold FTP Dataset

Average Drift:

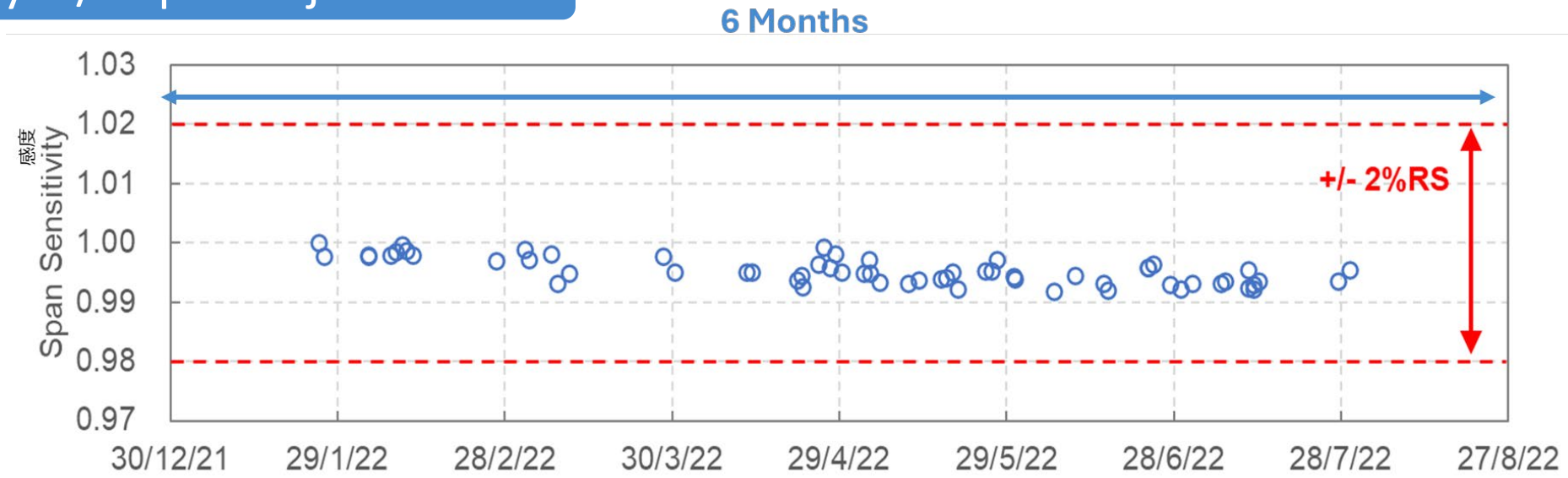
- Zero drift ~0.01 ppm
- Span drift ~0.5 ppm (100 ppm fs)

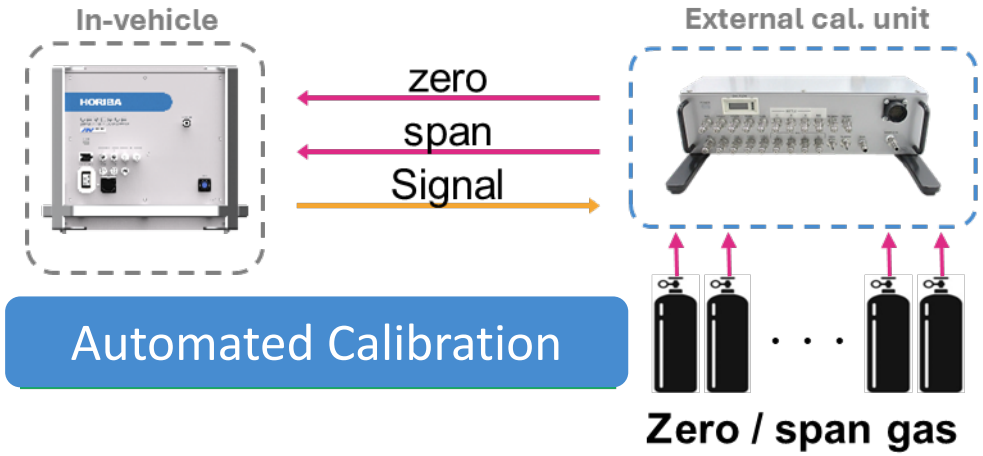


2σ zero noise for NO and NO2 channels ~0.015 ppm.

Calibration Stability / Automation

Stability w/o span adjustment



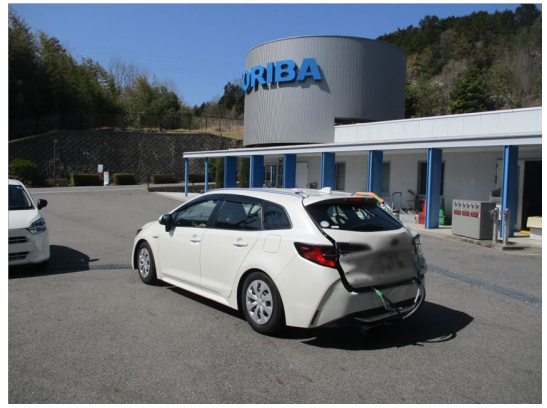


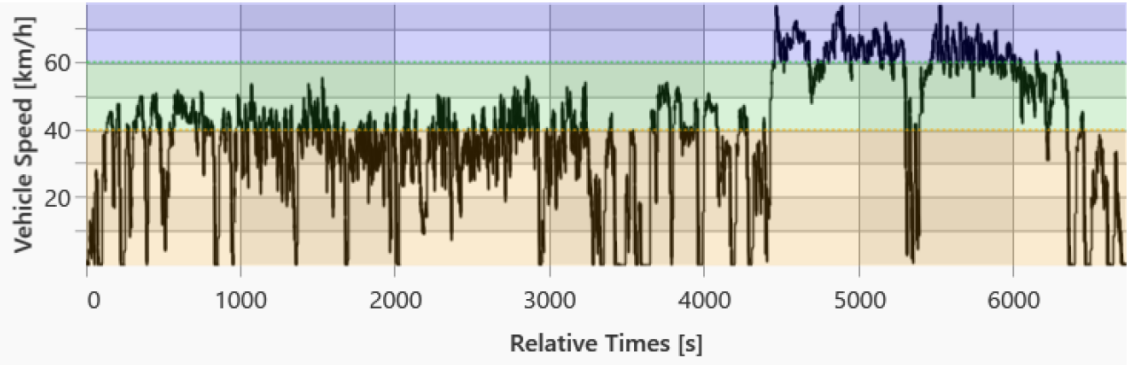
Automated Calibration

PEMS Correlation

OBS-ONE-GS02 MEXAcube

1.8L / Gasoline / NOVC-HEV





Trip

	Urban	Rural	Motorway
Avg. Speed	24.0 km/h	47.8 km/h	65.5 km/h
Distance	21.5 km	30.7 km	21.4 km
Duration (h:min:s)	0:53:47	0:38:31	0:19:39

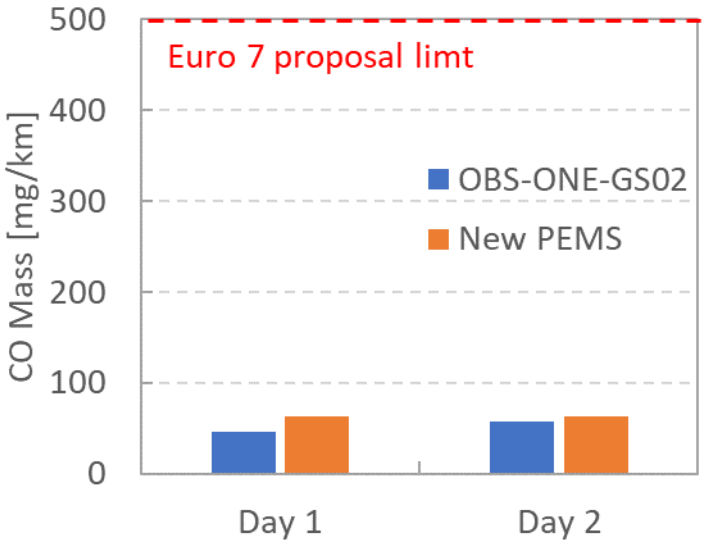
Total Distance	73.6 km
Total Duration (h:min:s)	1:51:57

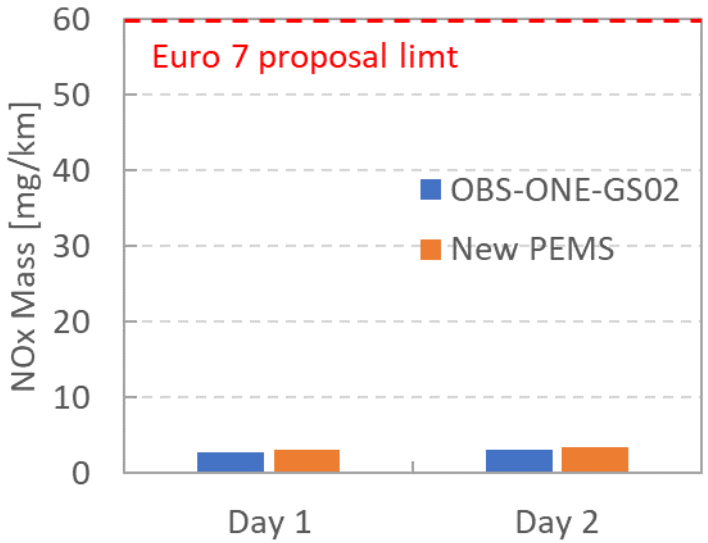
※ Trip composition is based on JRDE.

PEMS Correlation

	CO [mg/km]	CO2 [g/km]	NO [mg/km]	NOx [mg/km]	NO2 [mg/km]	N2O [mg/km]	NH3 [mg/km]	HCHO [mg/km]	CH4 [mg/km]
OBS-ONE-GS02	57.0	117.9	2.3	3.0	0.7				
MEXAcube	63.5	117.1	3.0	3.2	0.2	0.4	1.1	0.012	1.6
Difference	6.5	-0.8	0.7	0.2	-0.5				
	11.3%	-0.7%	30.4%	6.6%	-71.4%				
Euro 7 proposal limit (LDV)	500			60			20		

* Masses were calculated with same exhaust flow rate from pitot tube.





2025 and Beyond

- Expanded instrument portfolio
- Continued demonstrations for CARB and EPA; Inclusion in EU7
- Publication of research

Omoshiro-okashiku

Joy and Fun

Terima kasih

நன்றி

Gracias

谢谢

Danke

Σας ευχαριστώ πάρα πολύ

Tack ska du ha

धन्यवाद

THANK YOU

شُكْرًا

Grazie

ขอบคุณครับ

Obrigado

Большое спасибо

ありがとうございました

Cảm ơn

Merci

감사합니다

Dziękuję

HORIBA