PRELIMINARY EVALUATION HEAT EDAR

Tim DeFries, Sandeep Kishan
Jim Sidebottom, Jim Kemper*,
Carl Fulper**

Eastern Research Group
* Colorado Department of Public Heath and Environment
** Environmental Protection Agency

GOAL OF EDAR EXHAUST TESTING

- Accuracy
- Repeatability
- Detection limit
- Drift

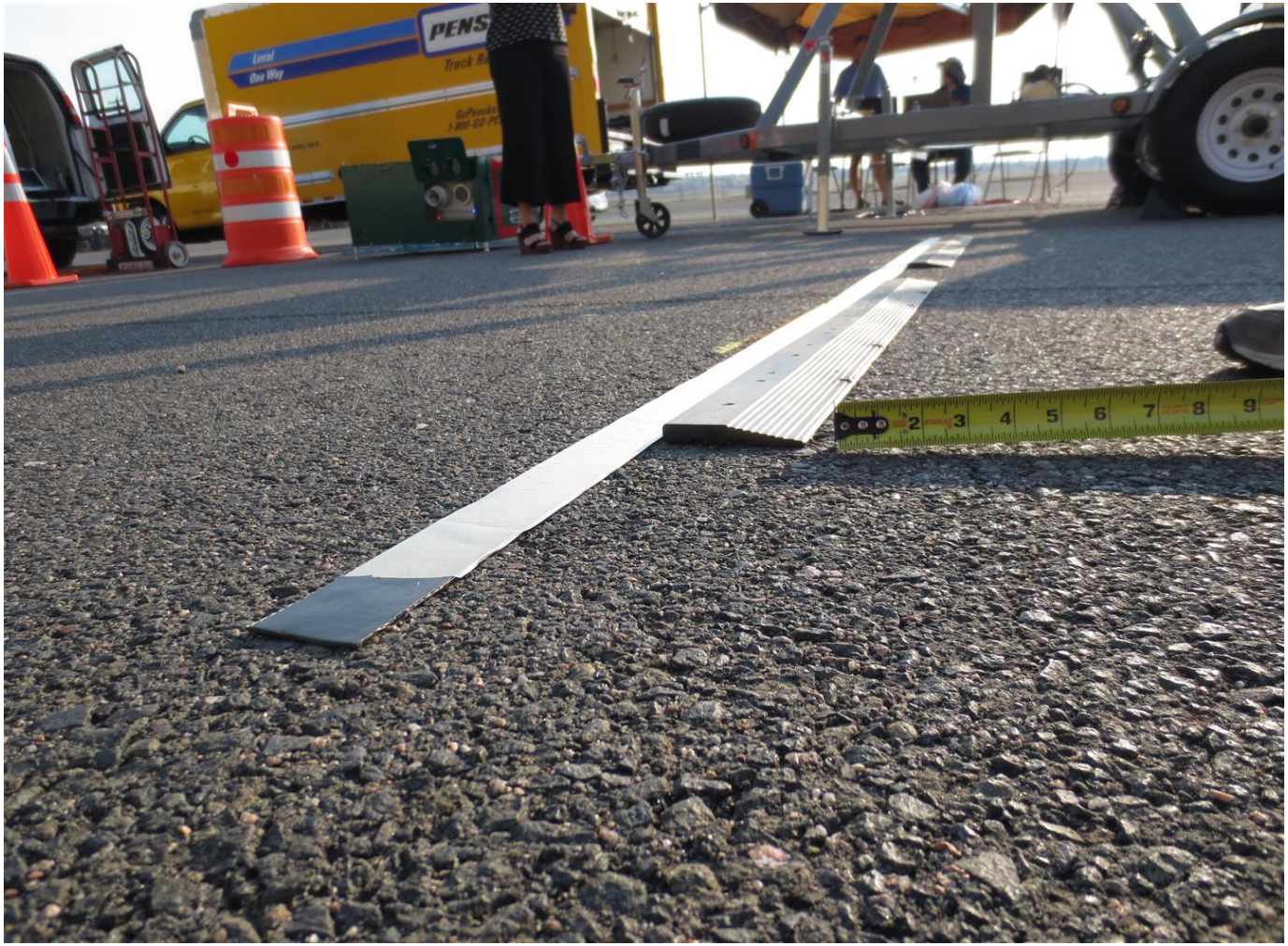
Hosted by Colorado Department of Public Health and Environment

TEST CONDITIONS

- SEP 14-15, 2015
- Bandimere Raceway parking lot, Denver
- Test vehicle:
  - RSD audit truck
  - Real exhaust routed 10 feet to the side of the vehicle
- Test gases:
  - 4 dry gas blends (composition unknown to HEAT)
  - Components: C_3H_8, CH_4, NO, CO, CO_2, balance N_2
- Vehicle speeds: 15, 30, 45, 60 mph
- Weather: Gusty wind
- Test gas release rate : 23, 30, 40, 50 scfm

ABOVE/TRANSVERSE SET-UP: EDAR ABOVE ROADWAY

ABOVE/TRANSVERSE SET-UP: PAVEMENT RETRO-REFLECTOR



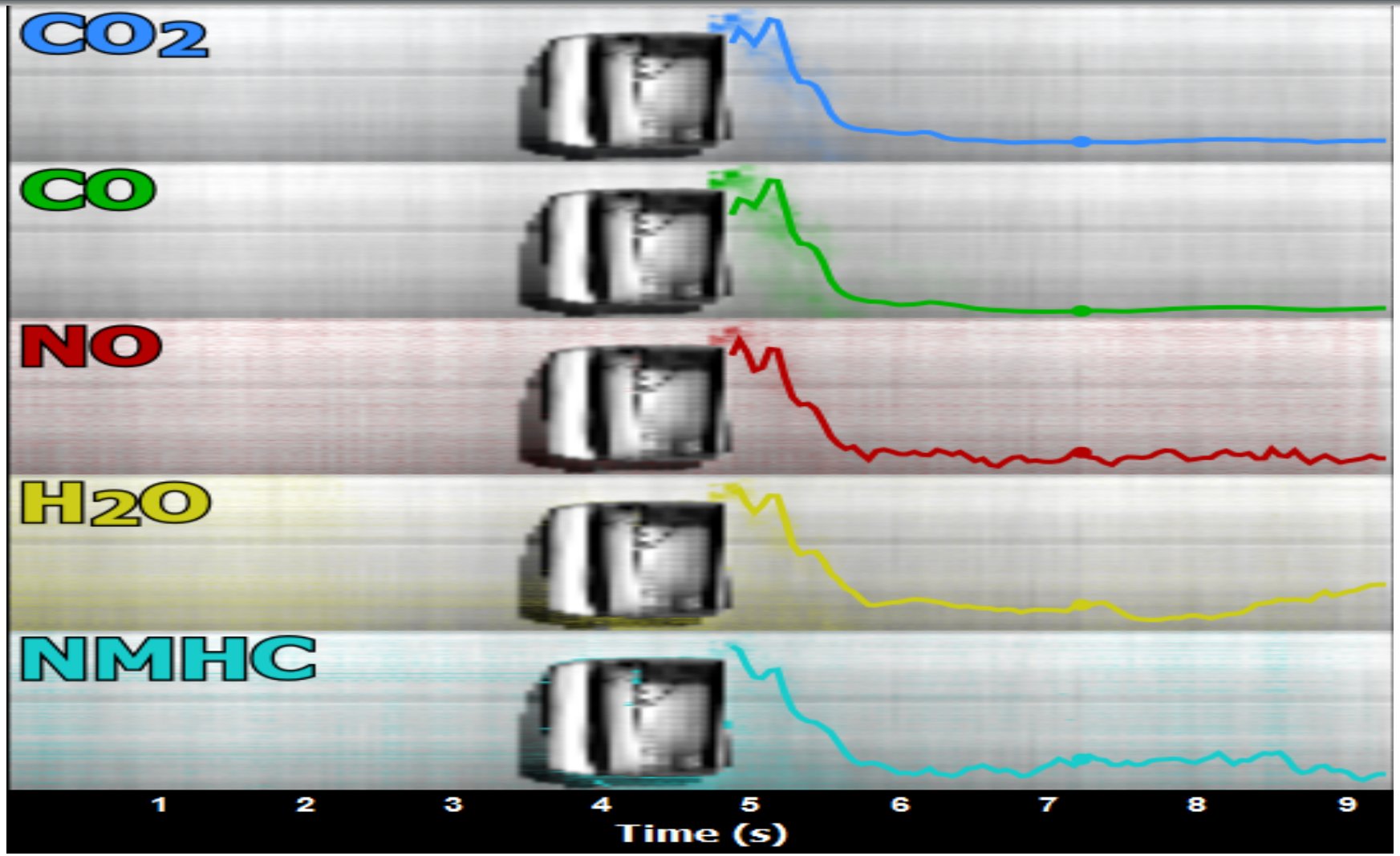
CDPHE – AUDIT TRUCK

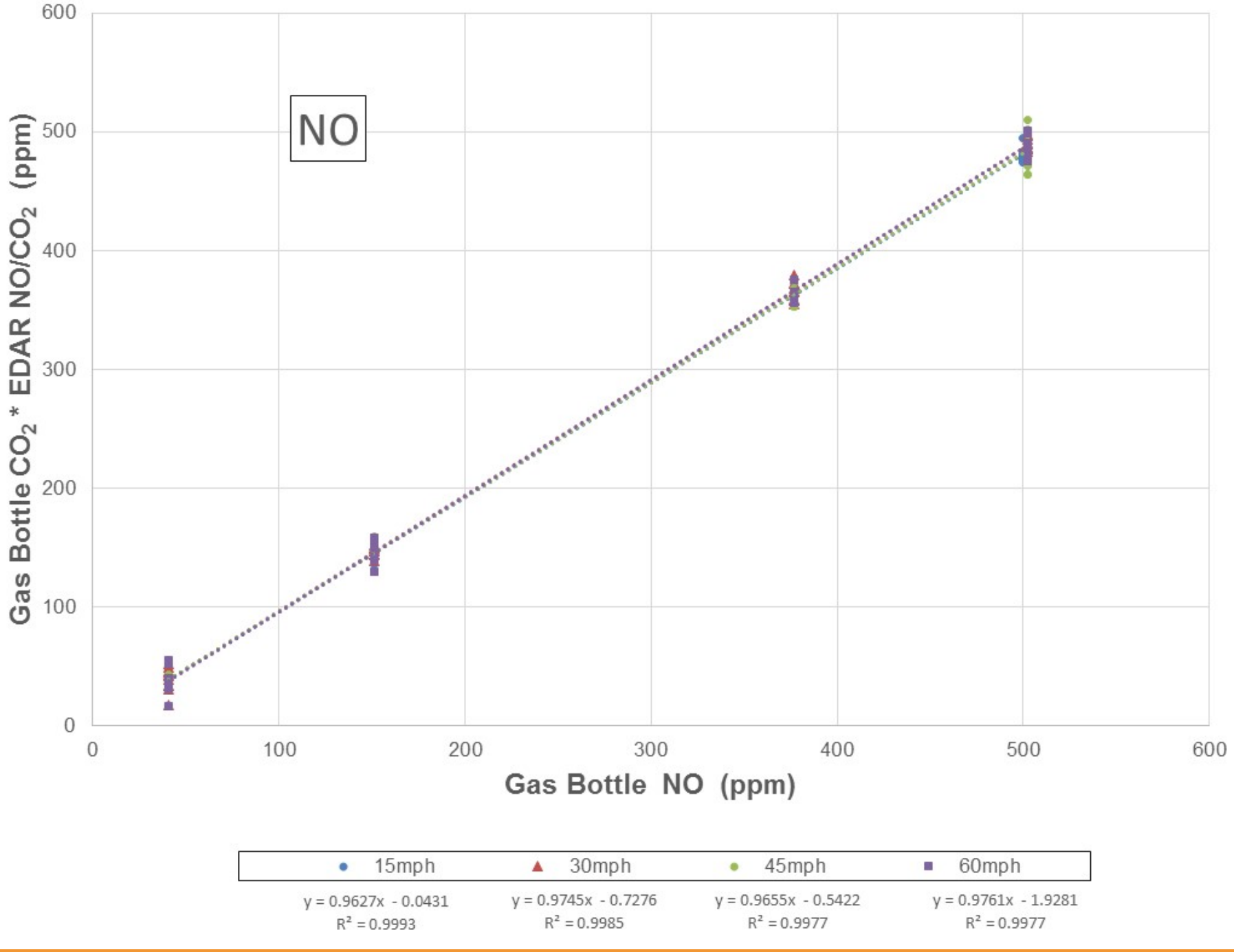
CDPHE AUDIT TRUCK: EXHAUST ROUTED AWAY

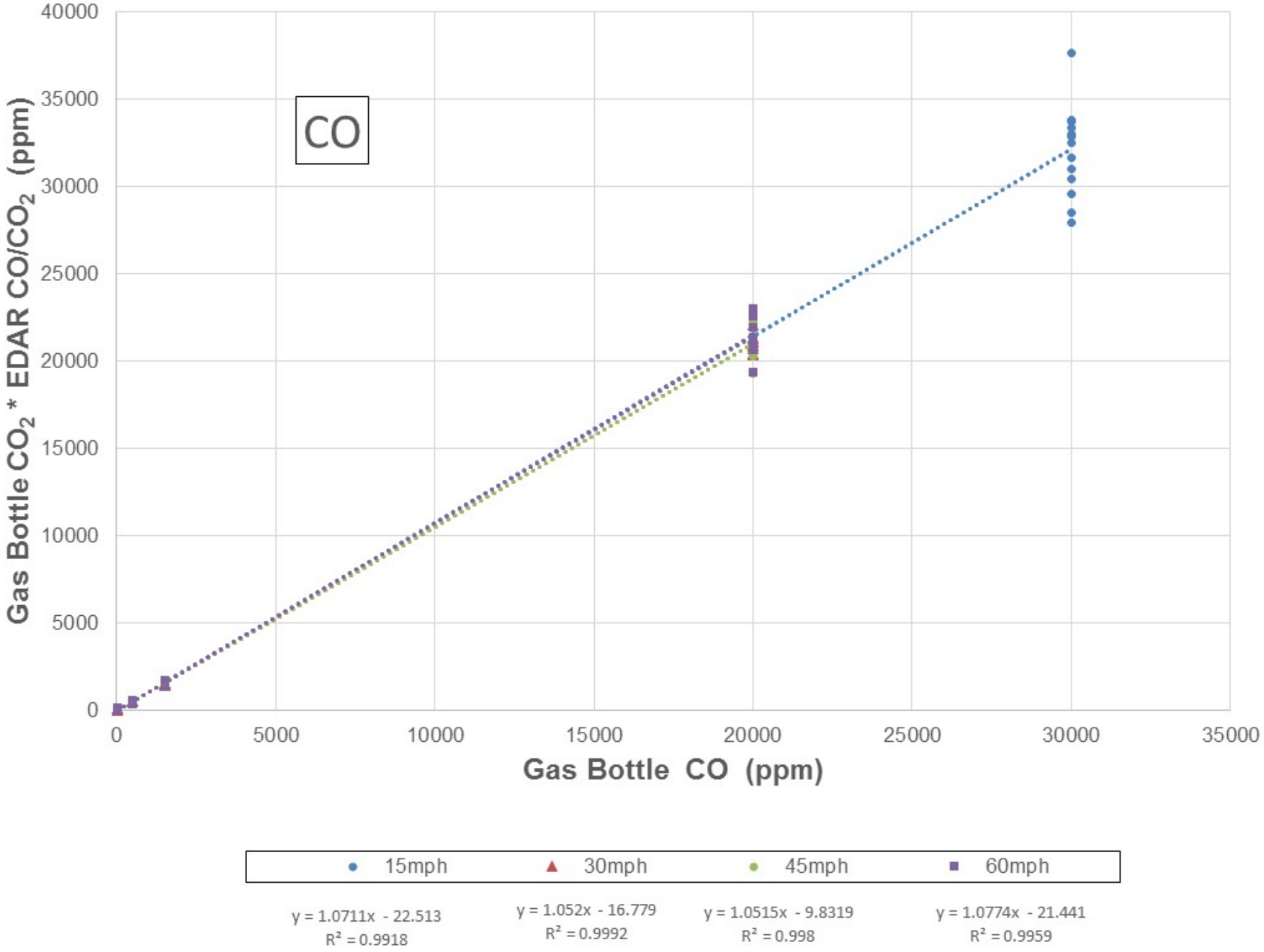
QC OF RESULTS

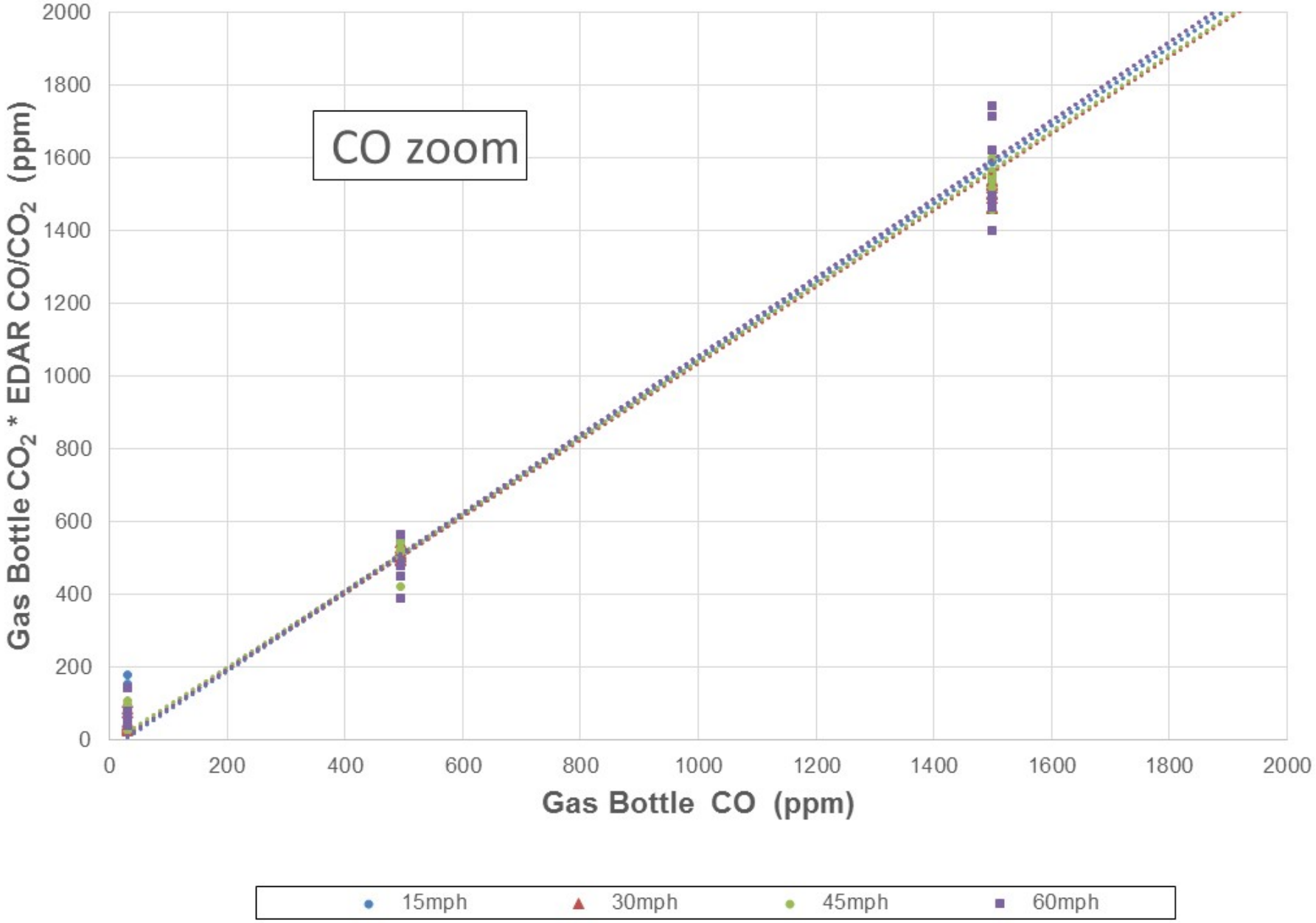
- Planned 171 test runs (excluding set-up checking runs)
- Blind to HEAT
- Runs repeated if EDAR QCflags were not met
- Obtained measurements on about 244 runs
- Selected all runs that had:
  a) acceptable QC flags and
  b) no evidence of real audit truck exhaust from wafting

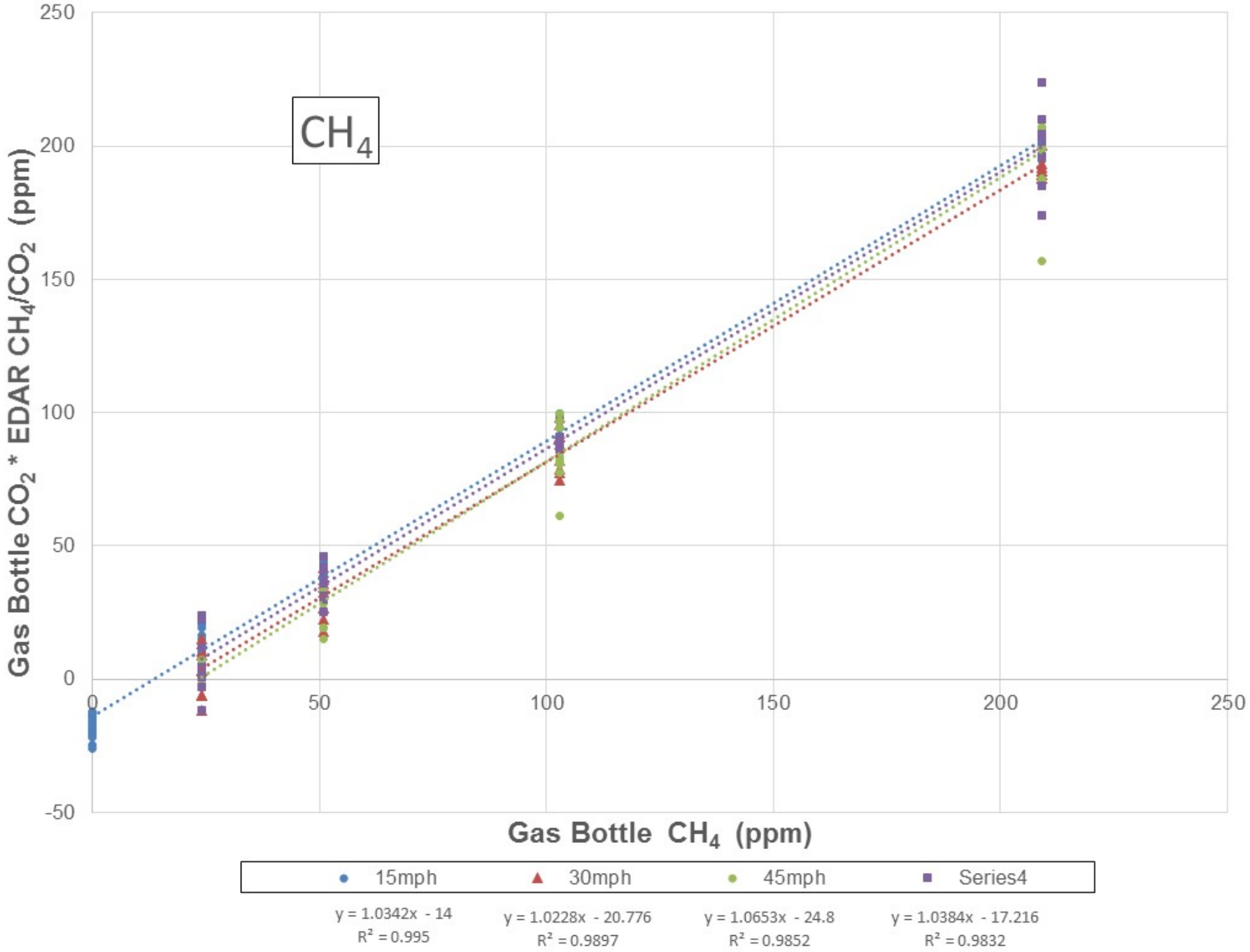
RUN 340-A: ABOVE/TRANSVERSE, 12.5 MPH

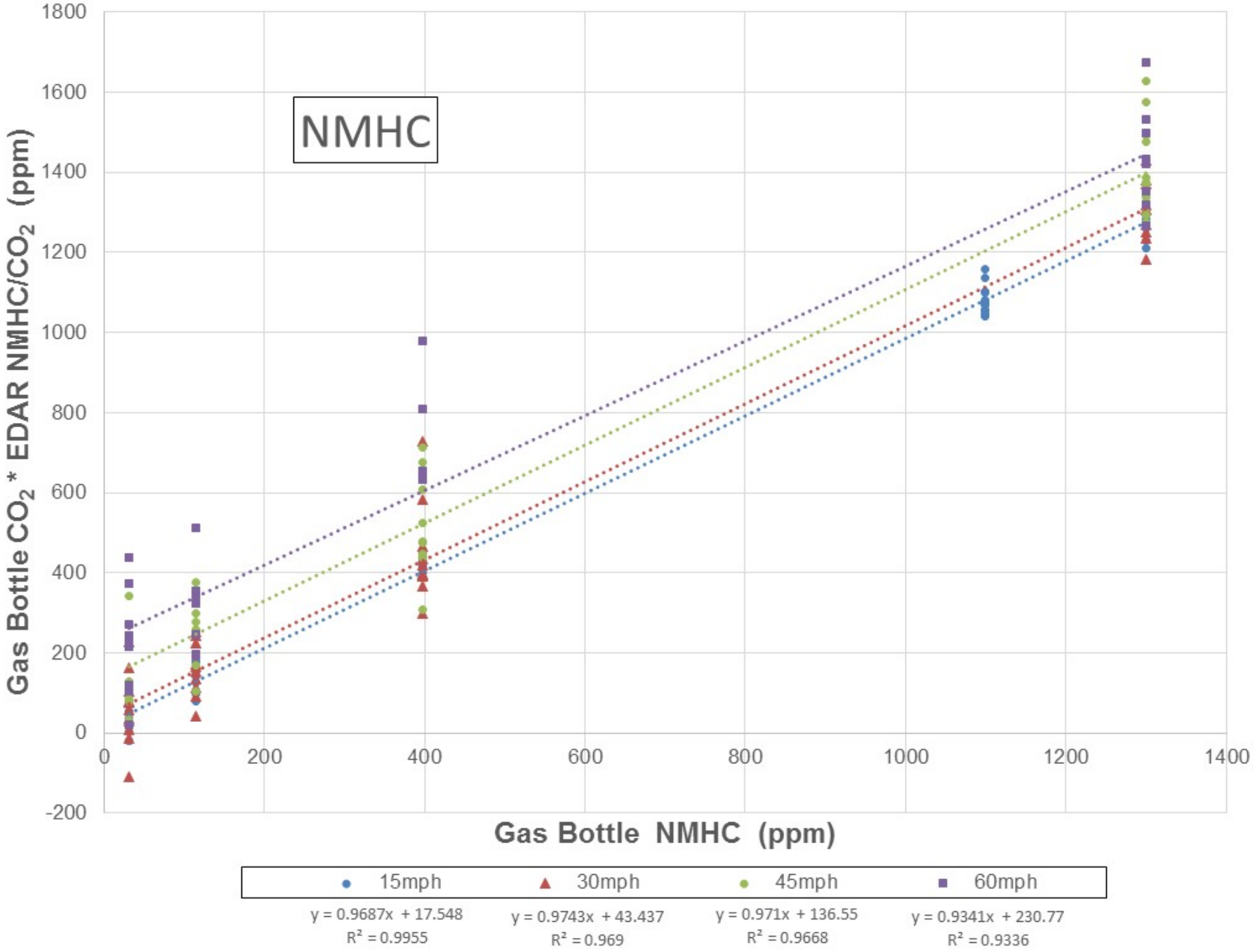


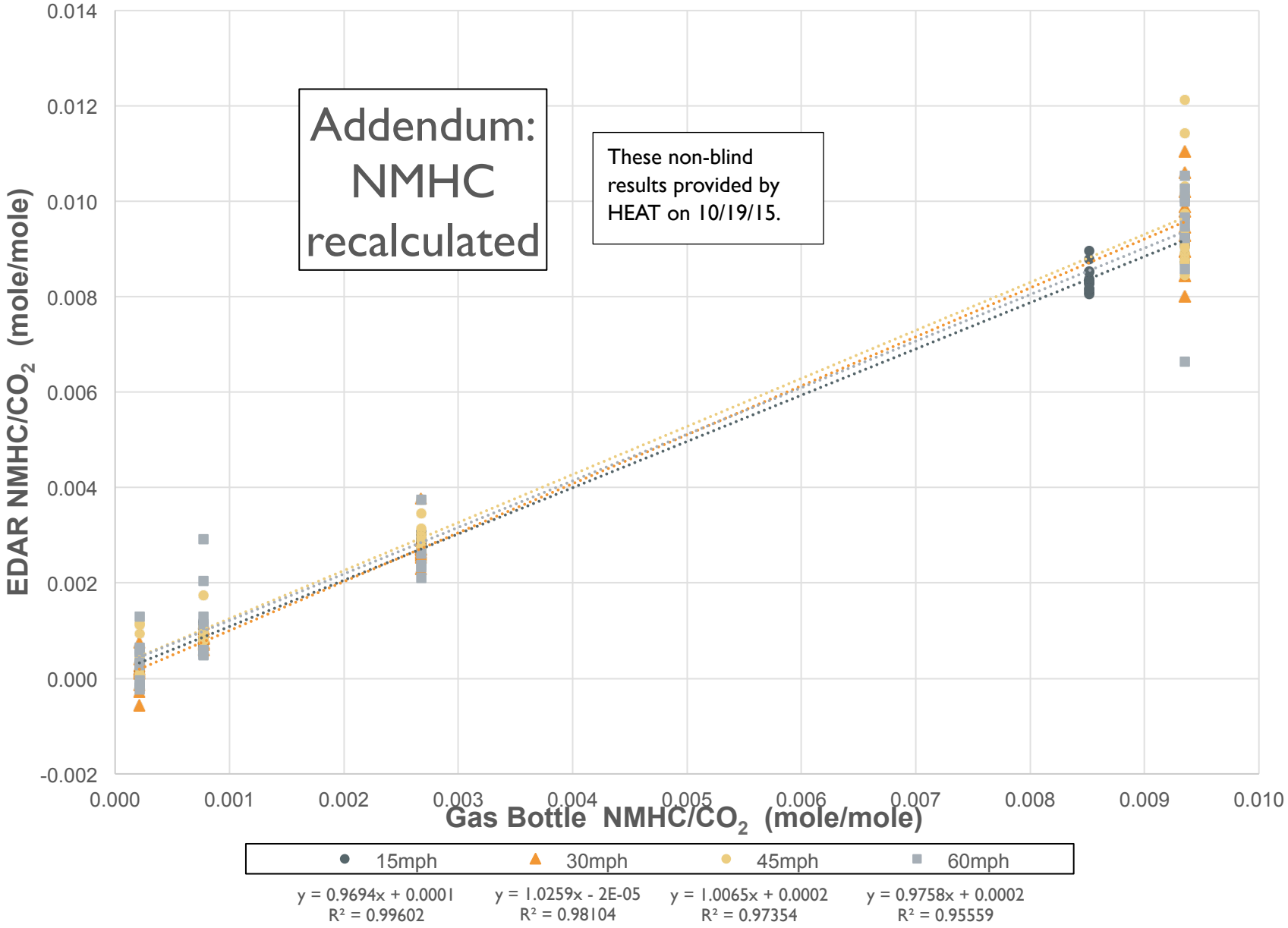

NO
Gas Bottle CO_2 * EDAR NO/CO_2 (ppm)
Gas Bottle NO (ppm)
0
100
200
300
400
500
600
15mph
30mph
45mph
60mph
y = 0.9627x - 0.0431
R² = 0.9993
y = 0.9745x - 0.7276
R² = 0.9985
y = 0.9655x - 0.5422
R² = 0.9977
y = 0.9761x - 1.9281
R² = 0.9977

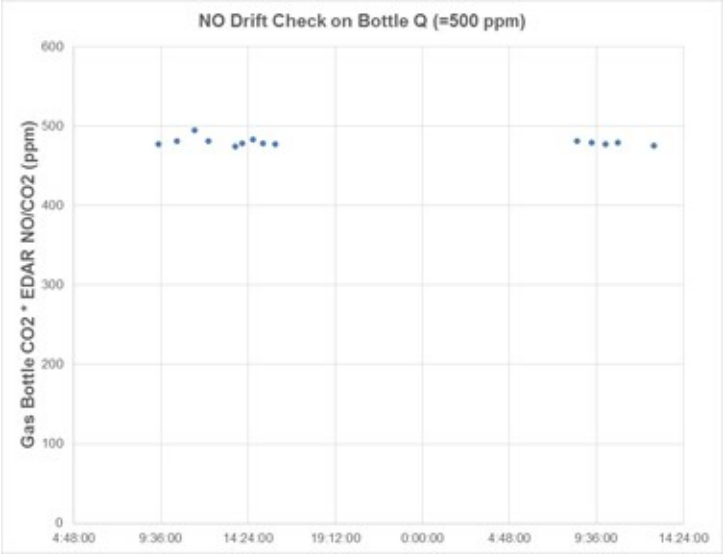

CO
Gas Bottle CO_2 * EDAR CO/CO_2 (ppm)
Gas Bottle CO (ppm)
0
5000
10000
15000
20000
25000
30000
35000
40000
15mph
30mph
45mph
60mph
y = 1.0711x - 22.513
R² = 0.9918
y = 1.052x - 16.779
R² = 0.9992
y = 1.0515x - 9.8319
R² = 0.998
y = 1.0774x - 21.441
R² = 0.9959

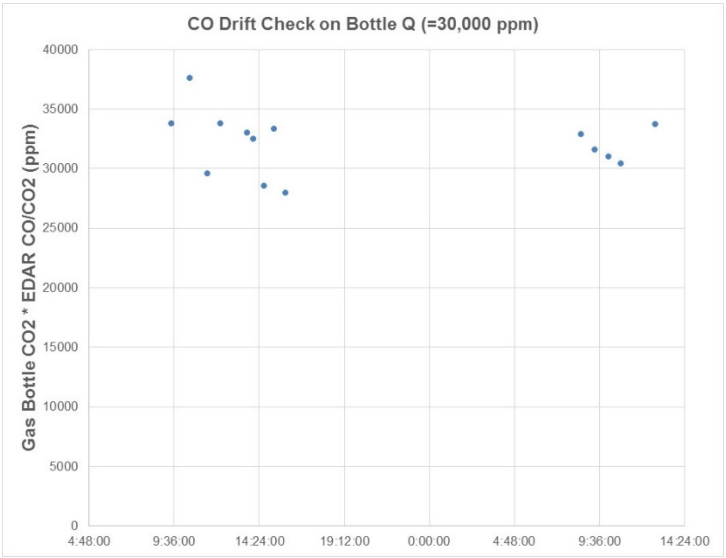

CO zoom
Gas Bottle CO_2 * EDAR CO/CO_2 (ppm)
Gas Bottle CO (ppm)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
15mph
30mph
45mph
60mph

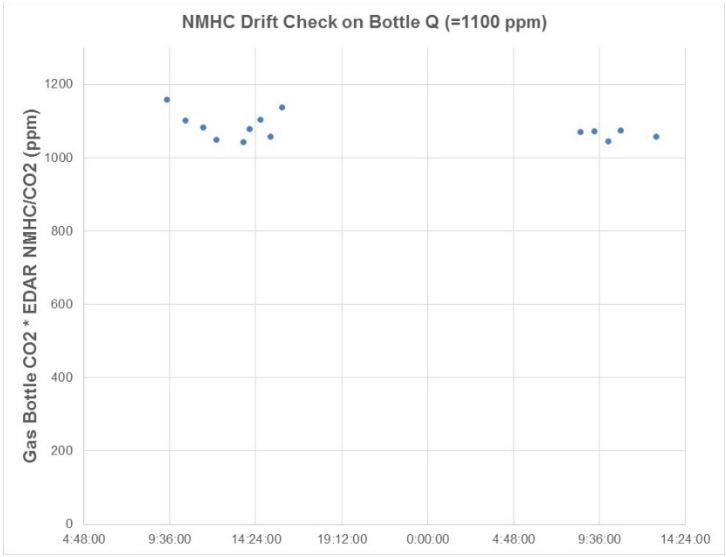

CH4
Gas Bottle CO2 * EDAR CH4/CO2 (ppm)
250
200
150
100
50
0
-50
0
50
100
150
200
250
Gas Bottle CH4 (ppm)
15mph
30mph
45mph
Series4
y = 1.0342x - 14
R² = 0.995
y = 1.0228x - 20.776
R² = 0.9897
y = 1.0653x - 24.8
R² = 0.9852
y = 1.0384x - 17.216
R² = 0.9832


NMHC
Gas Bottle CO_2 * EDAR NMHC/CO_2 (ppm)
1800
1600
1400
1200
1000
800
600
400
200
0
-200
0
200
400
600
800
1000
1200
1400
Gas Bottle NMHC (ppm)
15mph
30mph
45mph
60mph
y = 0.9687x + 17.548
R² = 0.9955
y = 0.9743x + 43.437
R² = 0.969
y = 0.971x + 136.55
R² = 0.9668
y = 0.9341x + 230.77
R² = 0.9336


Addendum: NMHC recalculated
These non-blind results provided by HEAT on 10/19/15.
EDAR NMHC/CO2 (mole/mole)
Gas Bottle NMHC/CO2 (mole/mole)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
0.000
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.010
15mph
30mph
45mph
60mph
y = 0.9694x + 0.0001
R² = 0.99602
y = 1.0259x - 2E-05
R² = 0.98104
y = 1.0065x + 0.0002
R² = 0.97354
y = 0.9758x + 0.0002
R² = 0.95559


NO Drift Check on Bottle Q (=500 ppm)
Gas Bottle CO2 * EDAR NO/CO2 (ppm)
600
500
400
300
200
100
0
4:48:00
9:36:00
14:24:00
19:12:00
0:00:00
4:48:00
9:36:00
14:24:00


CO Drift Check on Bottle Q (=30,000 ppm)
Gas Bottle CO2 * EDAR CO/CO2 (ppm)
40000
35000
30000
25000
20000
15000
10000
5000
0
4:48:00
9:36:00
14:24:00
19:12:00
0:00:00
4:48:00
9:36:00
14:24:00


NMHC Drift Check on Bottle Q (=1100 ppm)
Gas Bottle CO2 * EDAR NMHC/CO2 (ppm)
1200
1000
800
600
400
200
0
4:48:00
9:36:00
14:24:00
19:12:00
0:00:00
4:48:00
9:36:00
14:24:00

Mean ± 1 Standard Deviation
for Bottle CO2 * EDAR molePollutant/moleCO2

Bottle Label	Bottle Value NO (ppm)	NO @ 15mph (ppm)	NO @ 30mph (ppm)	NO @ 45mph (ppm)	NO @ 60mph (ppm)
D	41	41 ± 3	39 ± 10	37 ± 4	38 ± 11
C	151	145 ± 4	146 ± 4	149 ± 6	146 ± 10
B	377	360 ± 2	365 ± 8	362 ± 7	365 ± 7
Q	500	480 ± 5			
A	502	488 ± 5	489 ± 5	484 ± 13	489 ± 8

Bottle Label	Bottle Value CO (ppm)	CO @ 15mph (ppm)	CO @ 30mph (ppm)	CO @ 45mph (ppm)	CO @ 60mph (ppm)
D	30	59 ± 57	52 ± 26	60 ± 28	63 ± 33
D*	30	32 ± 4	37 ± 8	36 ± 7	48 ± 6
B	494	509 ± 15	513 ± 16	497 ± 33	477 ± 64
C	1500	1532 ± 27	1507 ± 28	1536 ± 43	1554 ± 124
A	20000	21395 ± 575	21027 ± 507	21021 ± 747	21530 ± 1192
Q	30000	32116 ± 2517			

* After discarding suspected outliers: 2/10 @ 15mph, 3/11 @30mph, 5/10 @ 45mph, 2/9 @ 60mph.

Bottle Label	Bottle Value CH4 (ppm)	CH4 @ 15mph (ppm)	CH4 @ 30mph (ppm)	CH4 @ 45mph (ppm)	CH4 @ 60mph (ppm)
Q	0	-18 ± 4			
D	24	13 ± 5	2 ± 9	3 ± 3	8 ± 13
C	51	42 ± 4	32 ± 8	27 ± 7	36 ± 7
B	103	96 ± 5	87 ± 8	85 ± 11	89 ± 2
A	209	200 ± 6	192 ± 5	198 ± 14	200 ± 14

Bottle Label	Bottle Value C3H8 (ppm)	NMHC @ 15mph (ppm)	NMHC @ 30mph (ppm)	NMHC @ 45mph (ppm)	NMHC @ 60mph (ppm)
D	32	28 ± 33	60 ± 89	150 ± 93	223 ± 131
C	115	133 ± 36	159 ± 68	263 ± 91	316 ± 104
B	398	428 ± 17	448 ± 123	530 ± 126	744 ± 150
Q	1100	1079 ± 34			
A	1300	1274 ± 36	1305 ± 75	1397 ± 100	1424 ± 128

Overview of Running Loss Data Collection by EDAR (SEP 16-17, 2015, Denver)

Participants: CDPHE, HEAT, ESP/Envirotest/Opus, ERG

Goal:

Collect EDAR data during artificial running losses (metered butane releases) with real exhaust emissions for running loss detection/quantification development

Test Design Parameters:

EDAR Configuration: Above/Transverse, Side/Vertical, Side/Horizontal

Test Vehicles: Dirty exhaust Clean exhaust

Butane Release Location: Top of Fuel Tank, Fuel Fill Door, Top of Engine

Butane Release Rate: 16, 8, 4, 2, 1, 0.5, 0.25, 0.125, 0.0625 scfh

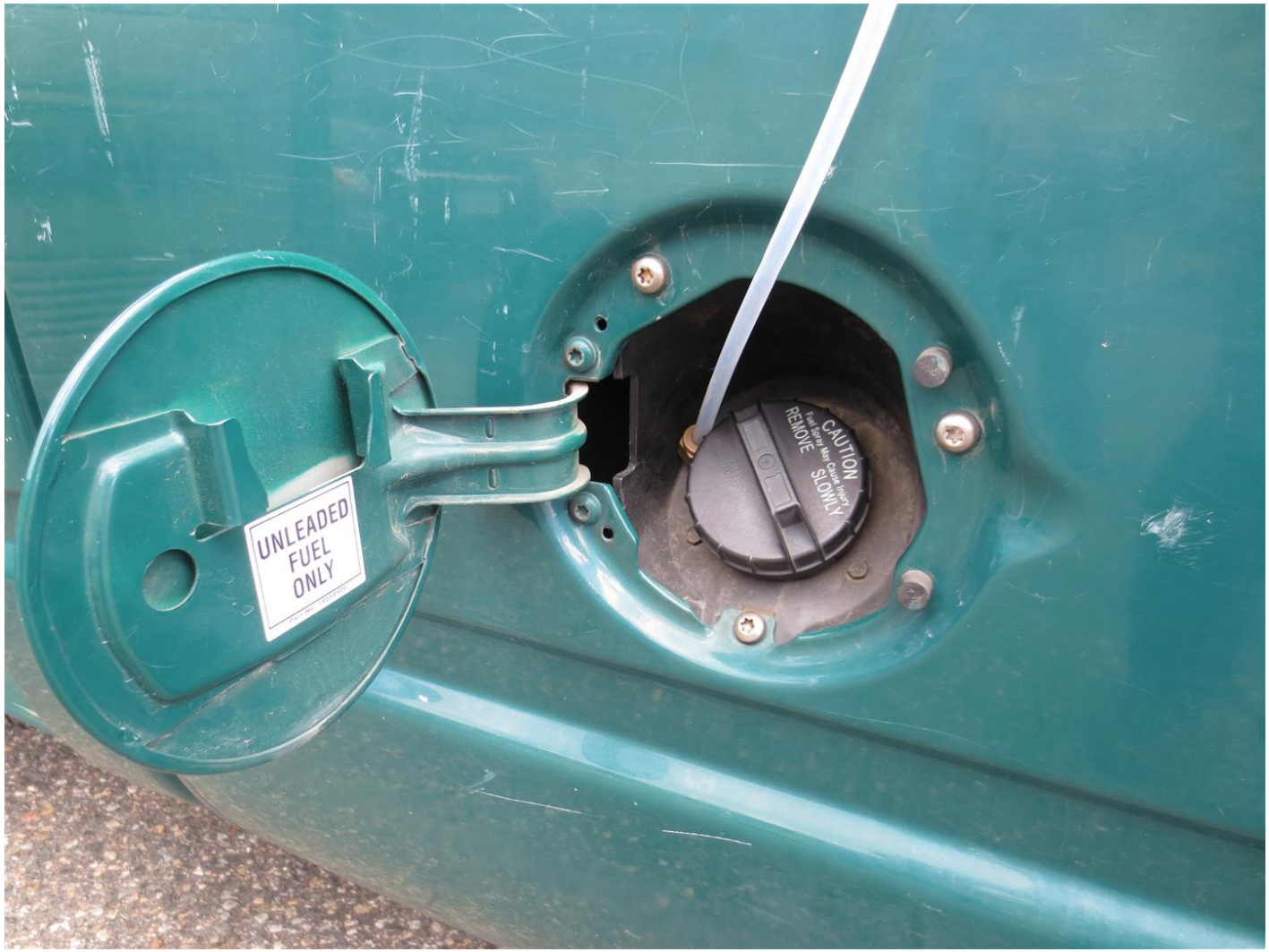
(116, 58, 29, 15, 7, 3.6, 1.8, 0.9, 0.5 cc/s)

Vehicle Operation: Steady Speed (12.5, 25, 50 mph) Stop and Go

1381: Pick-up: Fuel fill door (left side of vehicle)

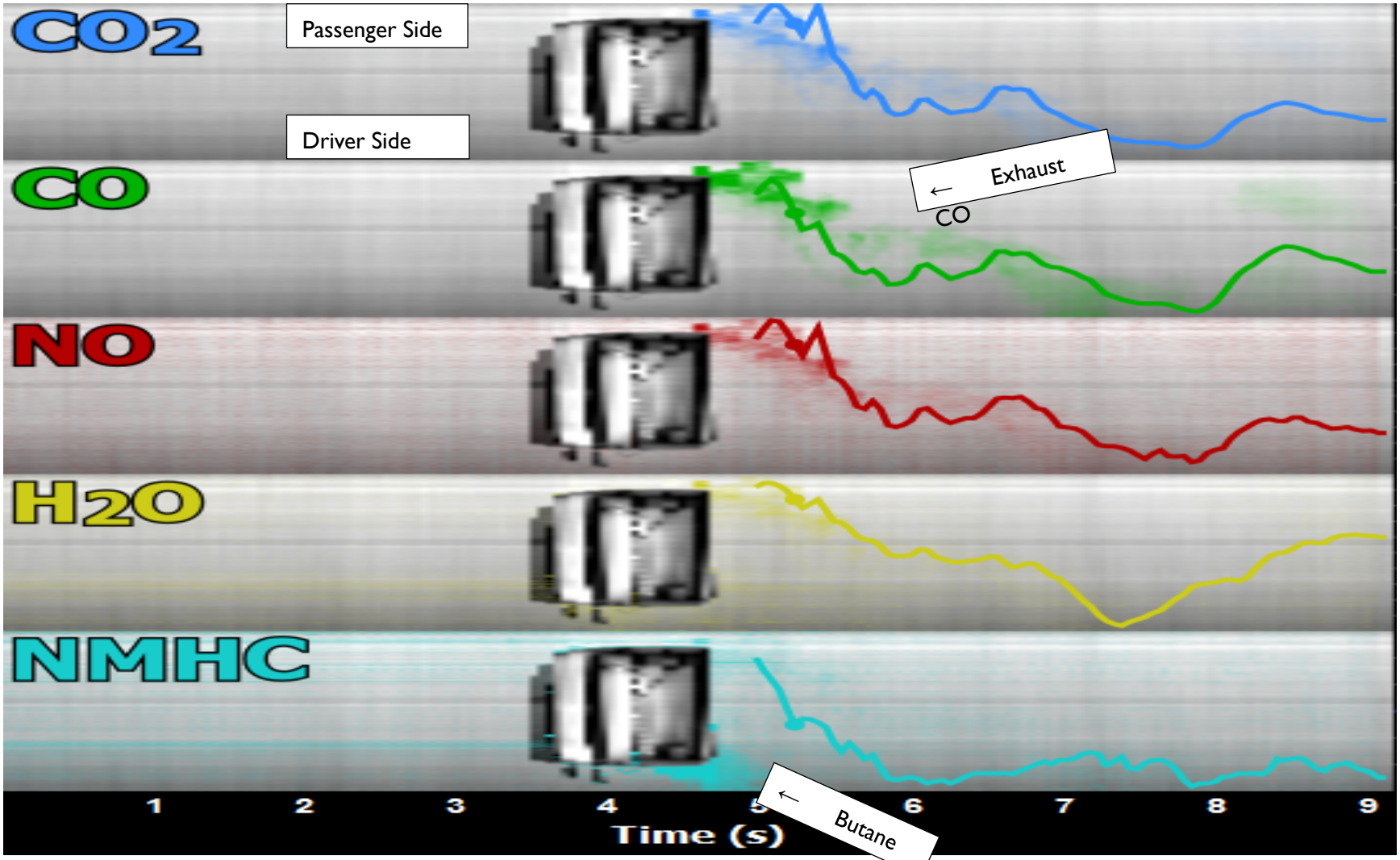
1366: Butane metering

1361: Fuel Fill Door butane release point



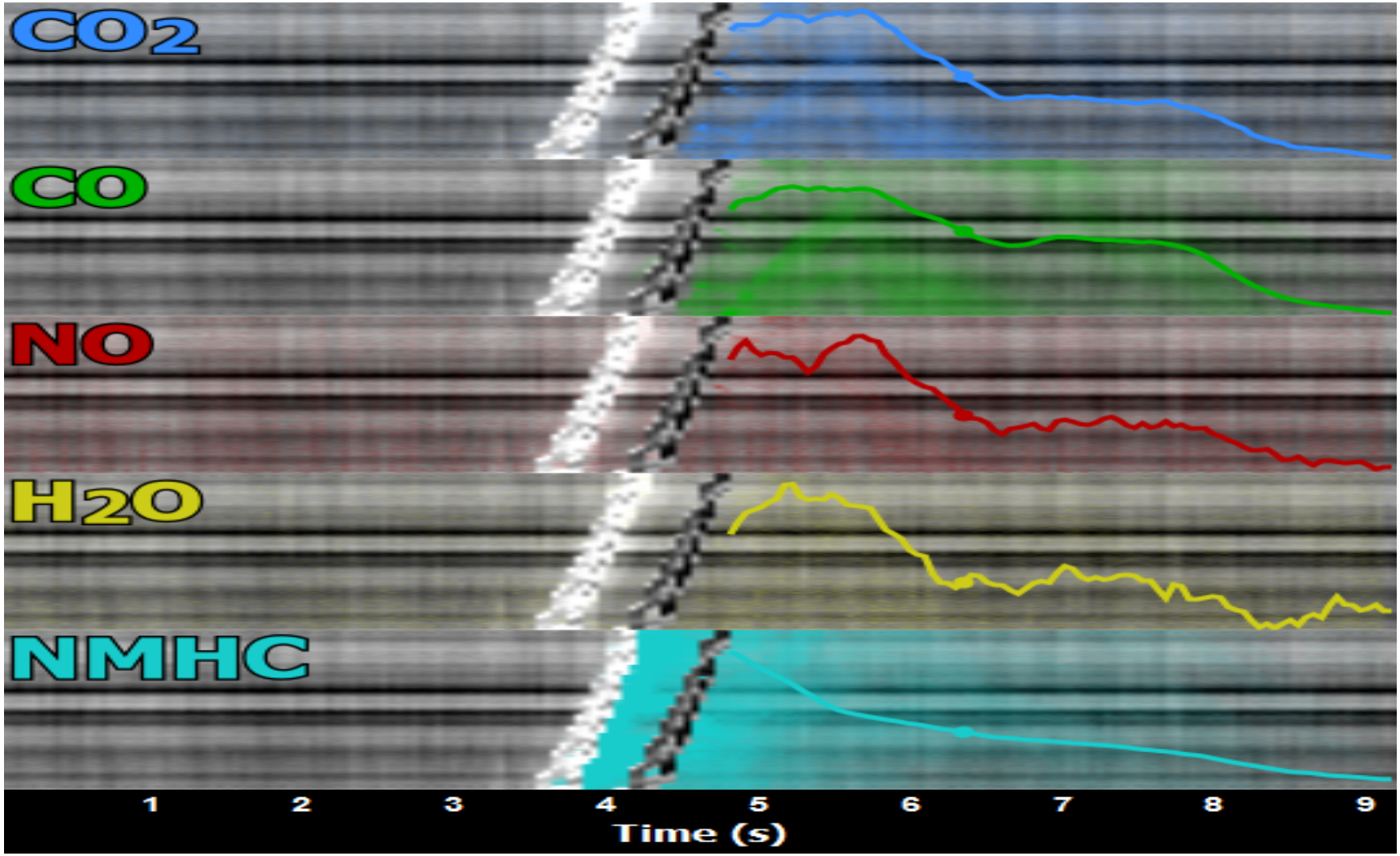
1363: Top of Tank release point

Run 510-A: Above/Transverse, 12.5 mph, 1 scfh butane from Fuel Fill Door.



1408: Side/Horz set-up: EDAR and 45deg mirror

Run 1001-A: Side/Horz, 15 mph, 16 scfh butane from Top of Engine.



SUMMARY

- EDAR measured NO, CO, and CH_4 concentrations with
  - high linearity,
  - low bias,
  - low speed dependence,
  - and low drift

  over a wide range of concentrations and vehicle speeds.
- EDAR is capable of making independent measurements of non-methane hydrocarbon and CH_4
- Evaporative Emissions evaluation under way
  - 800 test runs conducted in Texas

QUESTIONS

Sandeep Kishan

(512) 407 1830

sandeep.kishan@erg.com