MOVES
Motor Vehicle Emission Simulator

# Revising Start/Soak Relationships for Light-Duty Gaseous Emissions

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MOVES Review Work Group #4 Meeting

# Outline

- Intro: how MOVES currently does starts
  - Define “soak”
  - Defined in terms of Federal Test Procedure
    - “Cold start” – “Hot start” i.e., “Bag 1 – Bag 3”
  - Define operating modes for starts
- Goal: update start/soak curves
  - Using PEMS
  - How to estimate “start” using PEMS
- Test Program
  - Design, execution
- Results
  - Catalyst, coolant temperatures, emissions
  - Development of revised curves

# Intro: Emission processes

- **"Running emissions"**
  - *a.k.a.*, "Hot-running emissions," "Hot-stabilized emissions"
  - Emissions occurring while:
    - the engine is at operating temperature,
    - with the emissions-control system operating
  - Expressed as mass rate (g/hr)
  - Operating modes defined in terms of:
    - Speed, acceleration, power
- **"Start emissions"**
  - "Excess" Emissions occurring
    - During a "brief" period following engine start
    - At warm ambient temperature ( > 65F)
    - While engine temperature is between ambient and operating temperatures
  - Expressed as mass (g/start)
  - Operating modes defined in terms of time since key-off,
    - i.e., "soak time"

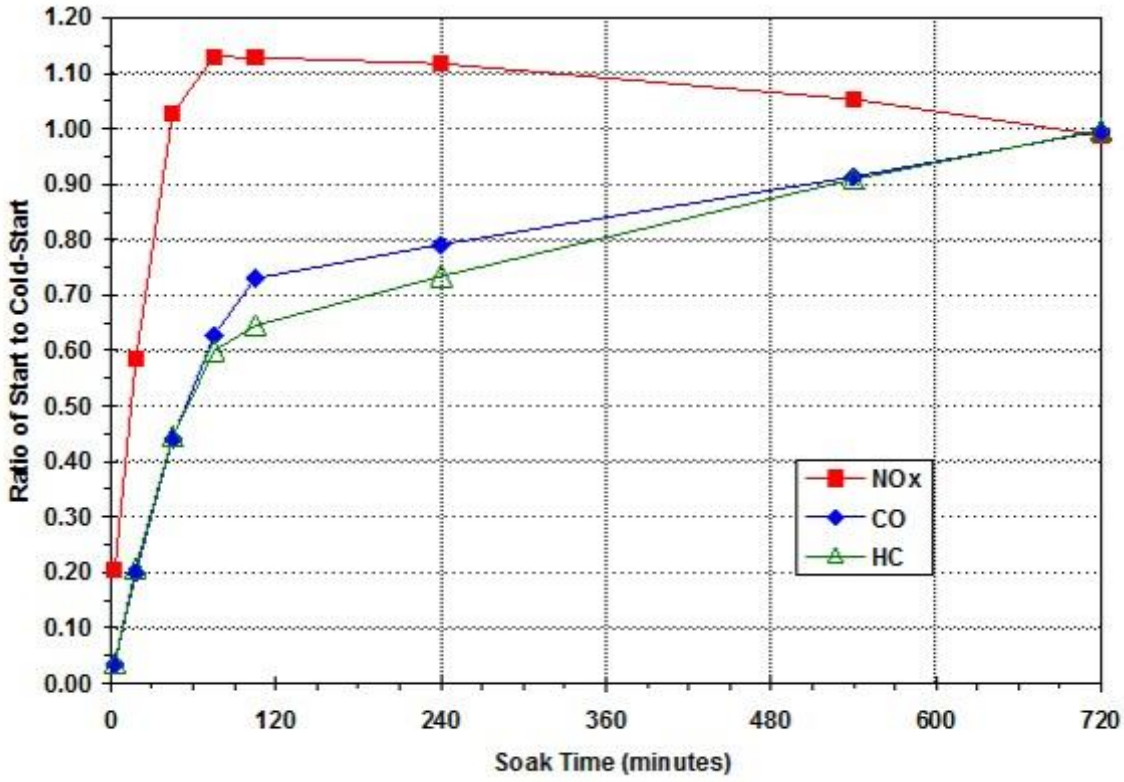
# How MOVES estimates LD start emissions

- Based on Federal Test Procedure
  - "Bag 1" Phase 1 (505 sec), following 12-hour soak
  - "Bag 2" Phase 2 (864 Sec), immediately
  - "Bag 3" Phase 1 (505 sec), following 10-min soak
- "Cold start" defined as
  - Bag 1 – Bag 3
- "Warm" and "hot" starts defined in relation to cold starts
- Operating modes defined as soak periods
  - Using "soak curves"
    - Sets of ratios that modify "cold start"

# Operating Modes for Start Emissions

| OpmodeID Code | Operating Mode Description |
|---|---|
| 101 | Soak Time < 6 minutes |
| 102 | 6 minutes ≤ Soak Time < 30 minutes |
| 103 | 30 minutes ≤ Soak Time < 60 minutes |
| 104 | 60 minutes ≤ Soak Time < 90 minutes |
| 105 | 90 minutes ≤ Soak Time < 120 minutes |
| 106 | 120 minutes ≤ Soak Time < 360 minutes |
| 107 | 360 minutes ≤ Soak Time < 720 minutes |
| 108 | 720 minutes ≤ Soak Time |

# Soak Curves used to develop MOVES rates




Fractions for each operating mode were adapted from a piece-wise regression for "conventional catalysts," used in MOBILE6.

The regression equation was evaluated at the center-point of each operating mode.

Source: Sabate, S. *Methodology for Calculating and Redefining Cold and Hot Start Emissions*. California Air Resources Board, El Monte, CA. March 1996. *Cited IN*: Glover, E.; Carey, P. *Determination of Start Emissions as a Function of Mileage and Soak time for 1981-1993 Model-year Light-Duty Vehicles*. EPA 420-R-01-058. November, 2001.

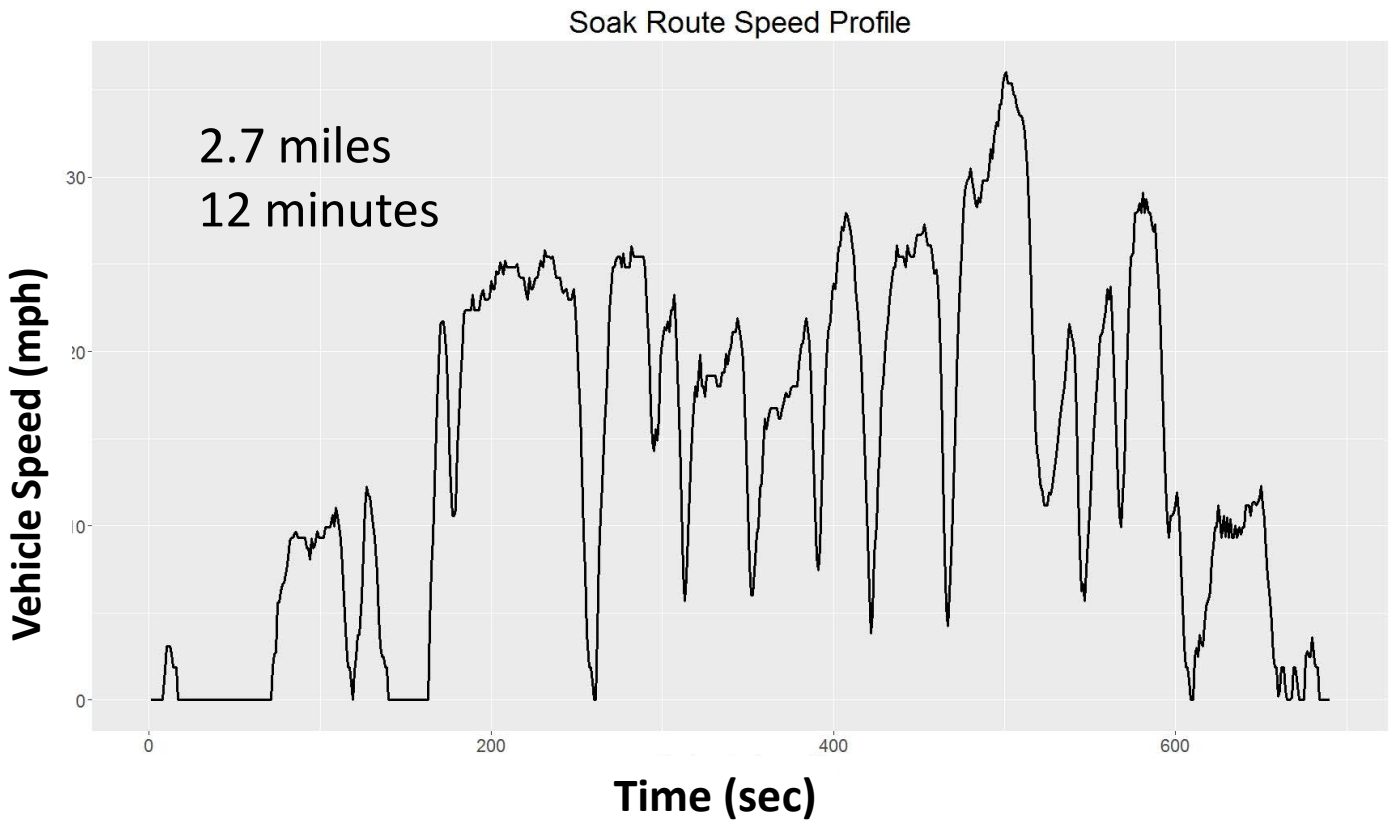
# The Test Program

- Goal: update soak curves in MOVES
  - For Tier-2 vehicles
- Method:  using portable emissions measurement systems (PEMS)
  - With multiple drives on same route
    - Starting and ending at the EPA Ann Arbor laboratory
  - Instrument:  Sensors SEMTECH-D
- Emissions
  - HC, CO, NOx
- All measurements at “warm ambient” temperature
  - T > 60°F

# The Vehicles

| Model Year | Make | Model | Displacement | Standard |
|---|---|---|---|---|
| 2009 | Saturn | Outlook | 3.6 L | Bin 5 (ULEV) |
| 2009 | Toyota | Camry | 2.4 L | Bin 5 (ULEV) |
| 2009 | Ford | Explorer | 4.0 L | Bin 4 |
| 2011 | Ford | F150 | 3.5 L | Bin 4 |

# The Route
## Starting and ending at Lab



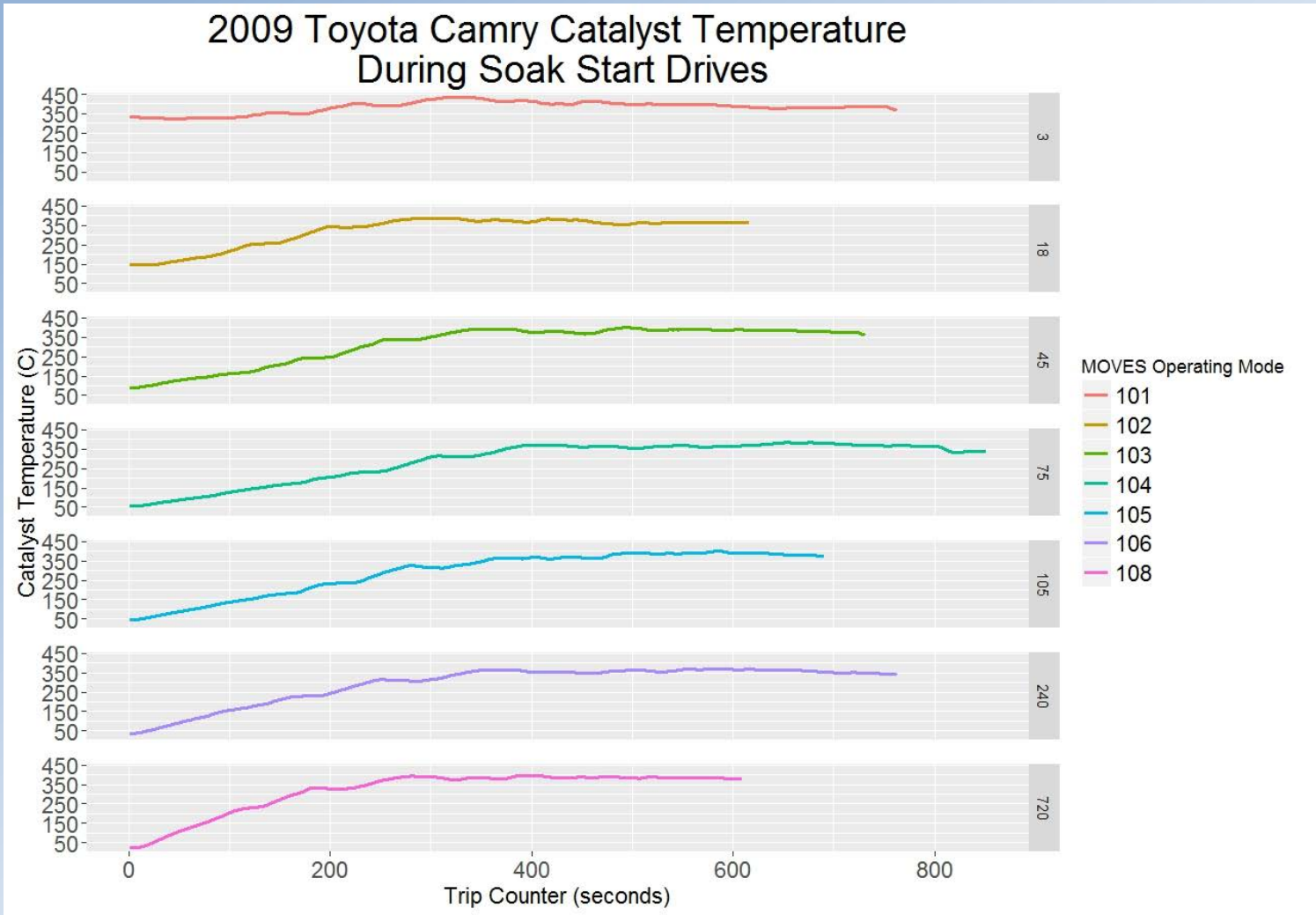
# Procedure and Drive sequence

- Soak indoors at ambient temperature
  - For periods of time equal to MOVES soak operating modes
- Install, warm up instrument
- Key on
- Idle for about 10-30 sec
- Leave laboratory building
- Drive the route
- Repeat

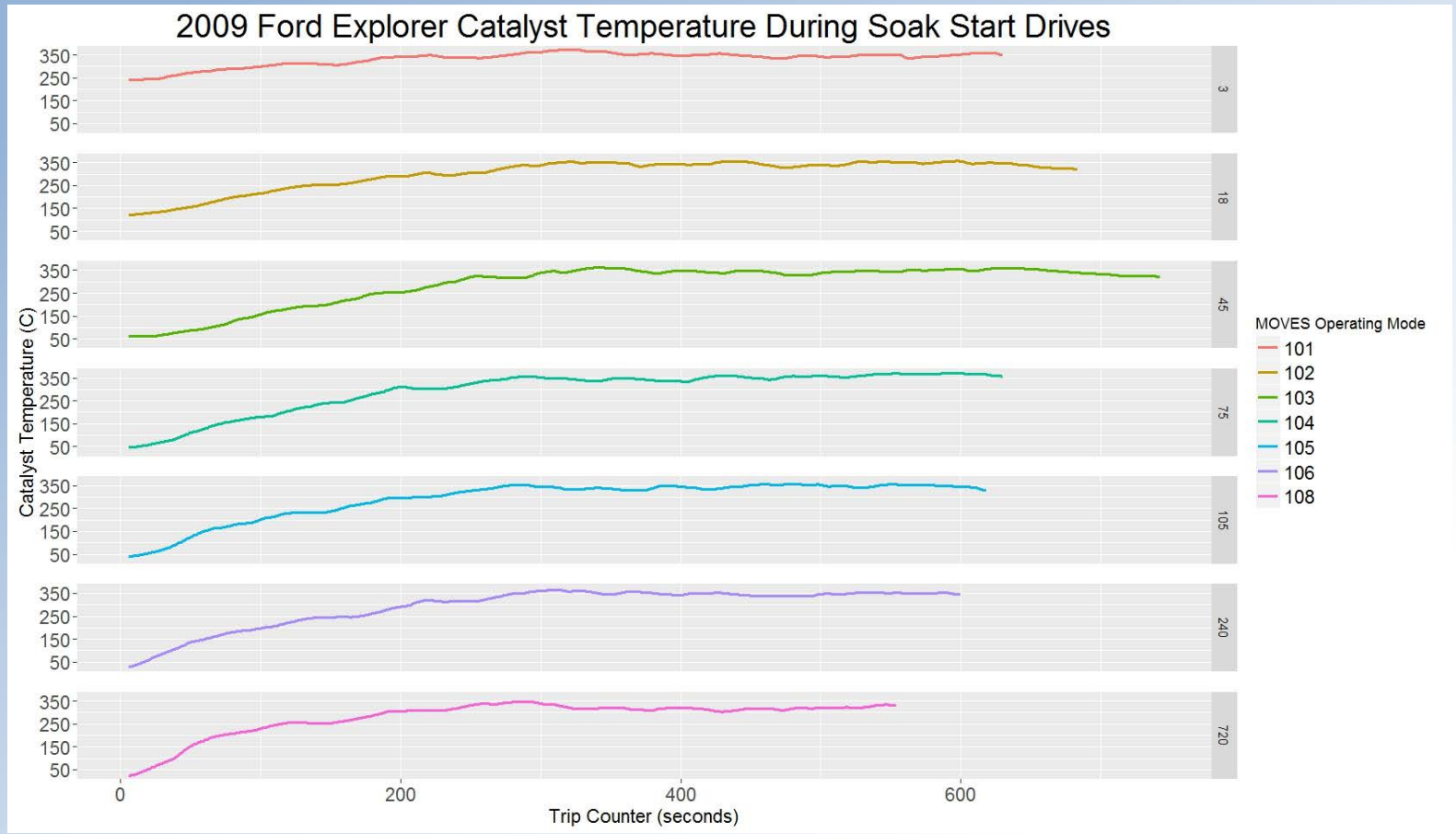
# Results

- Verify appropriateness of drive route
  - Ensuring complete start period is captured
    - Catalyst temperature
    - Oil temperature
    - Cumulative emissions
- Emissions results
  - Cumulative trends
  - Averaged by soak period
    - By vehicle
    - Across vehicles

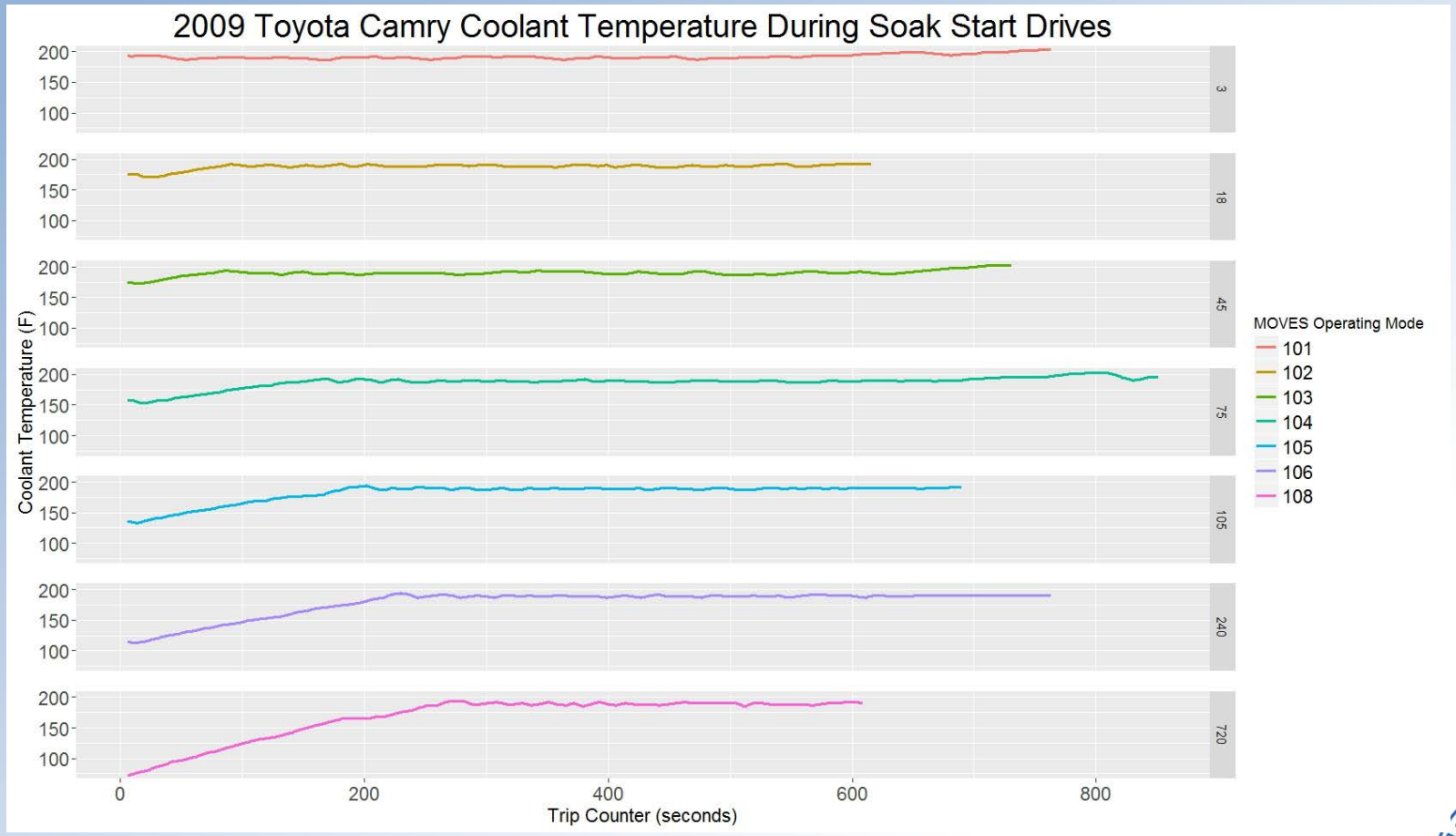
# Catalyst Temperature: 2009 Toyota Camry



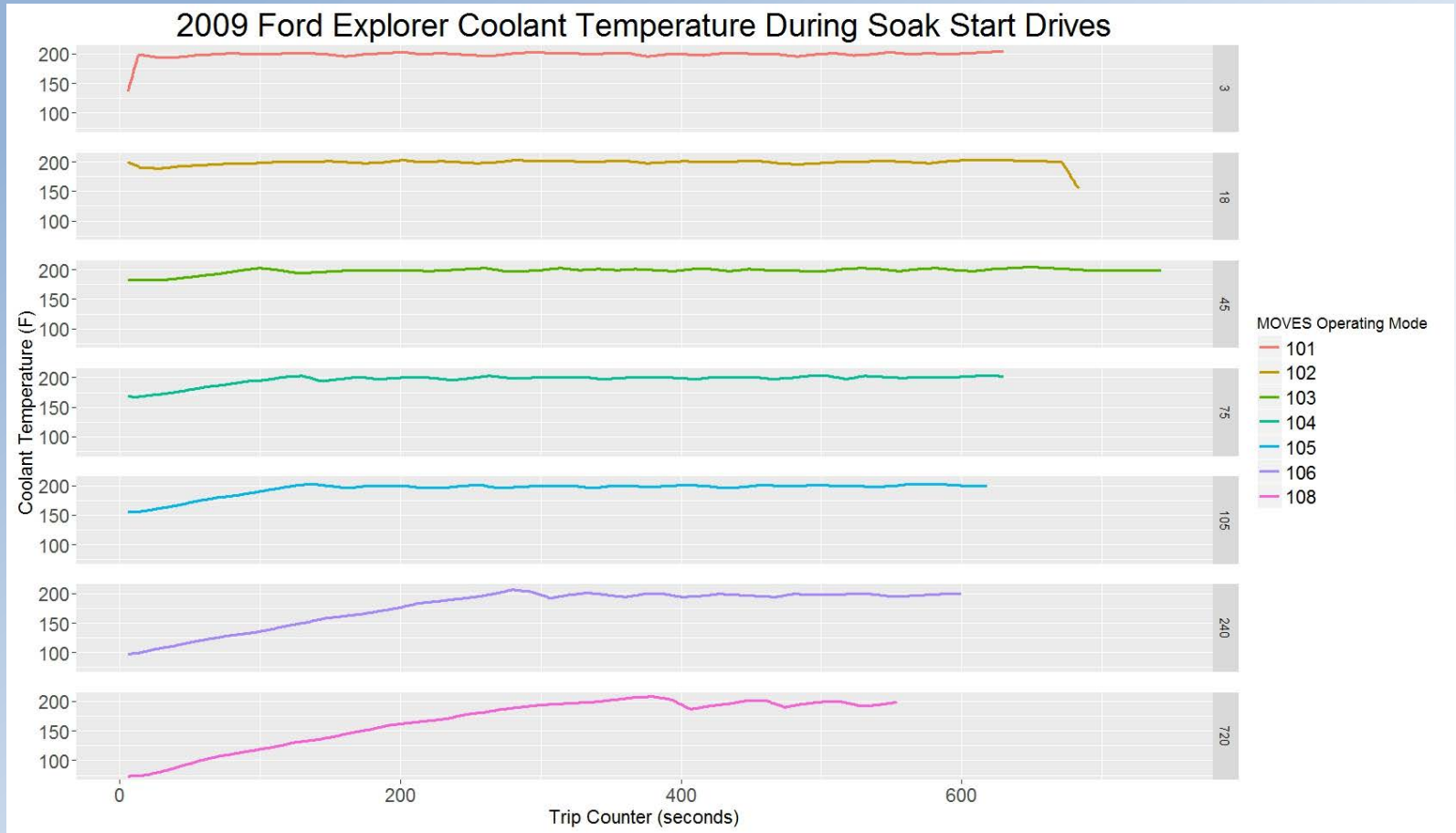
# Catalyst Temperature: 2009 Ford Explorer



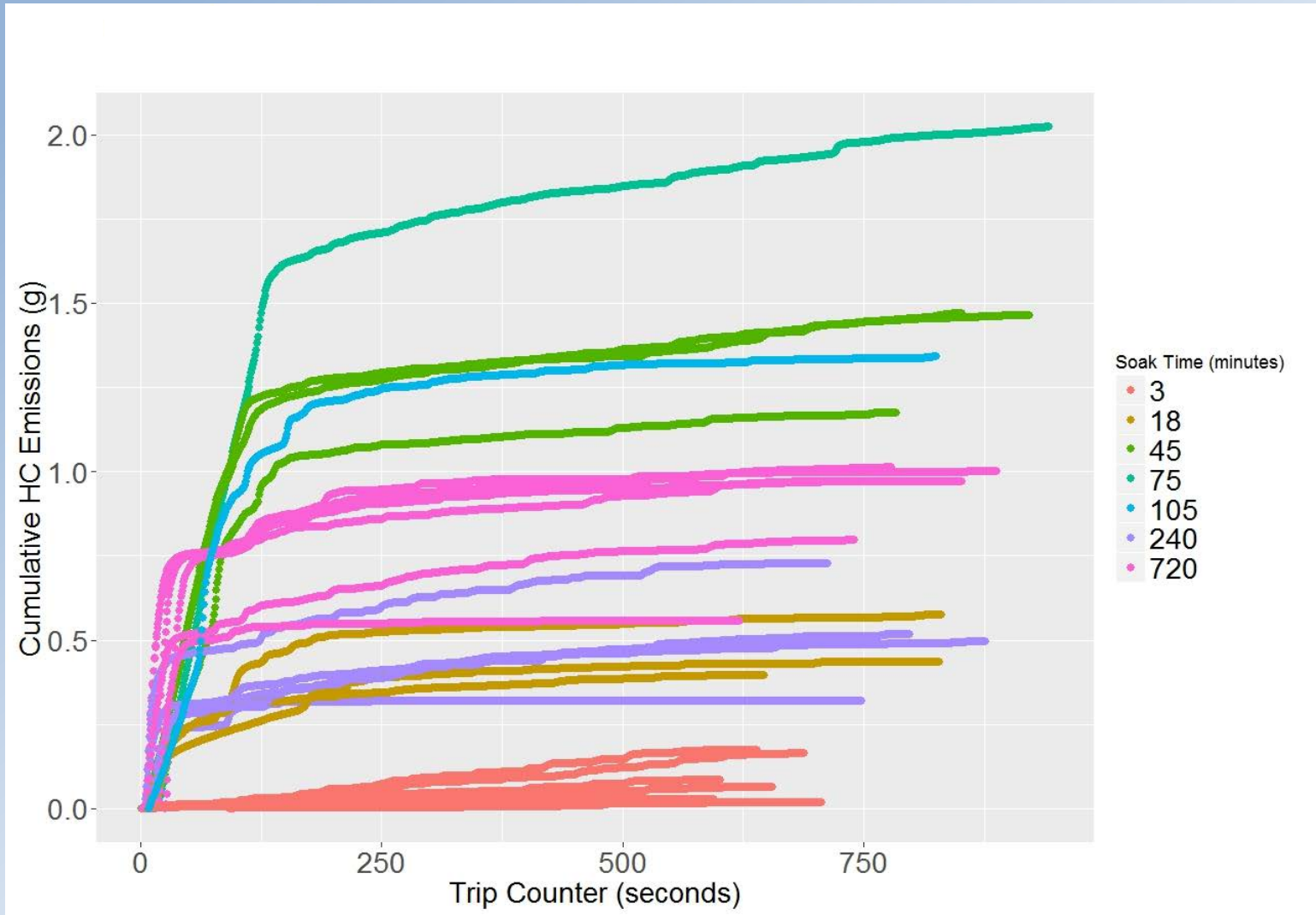
# Toyota Camry: Coolant Temperature



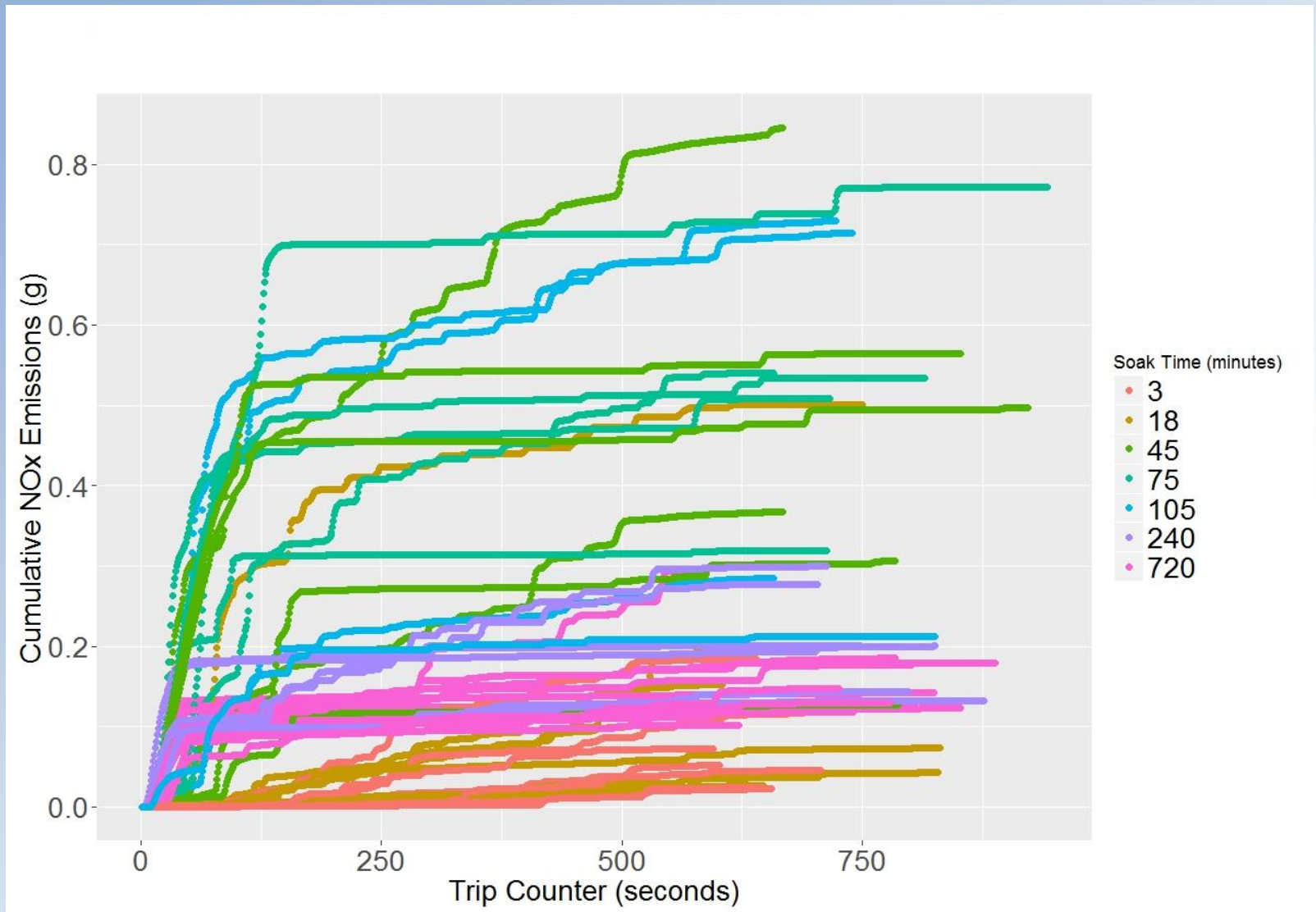
# Ford Explorer: Coolant Temperature



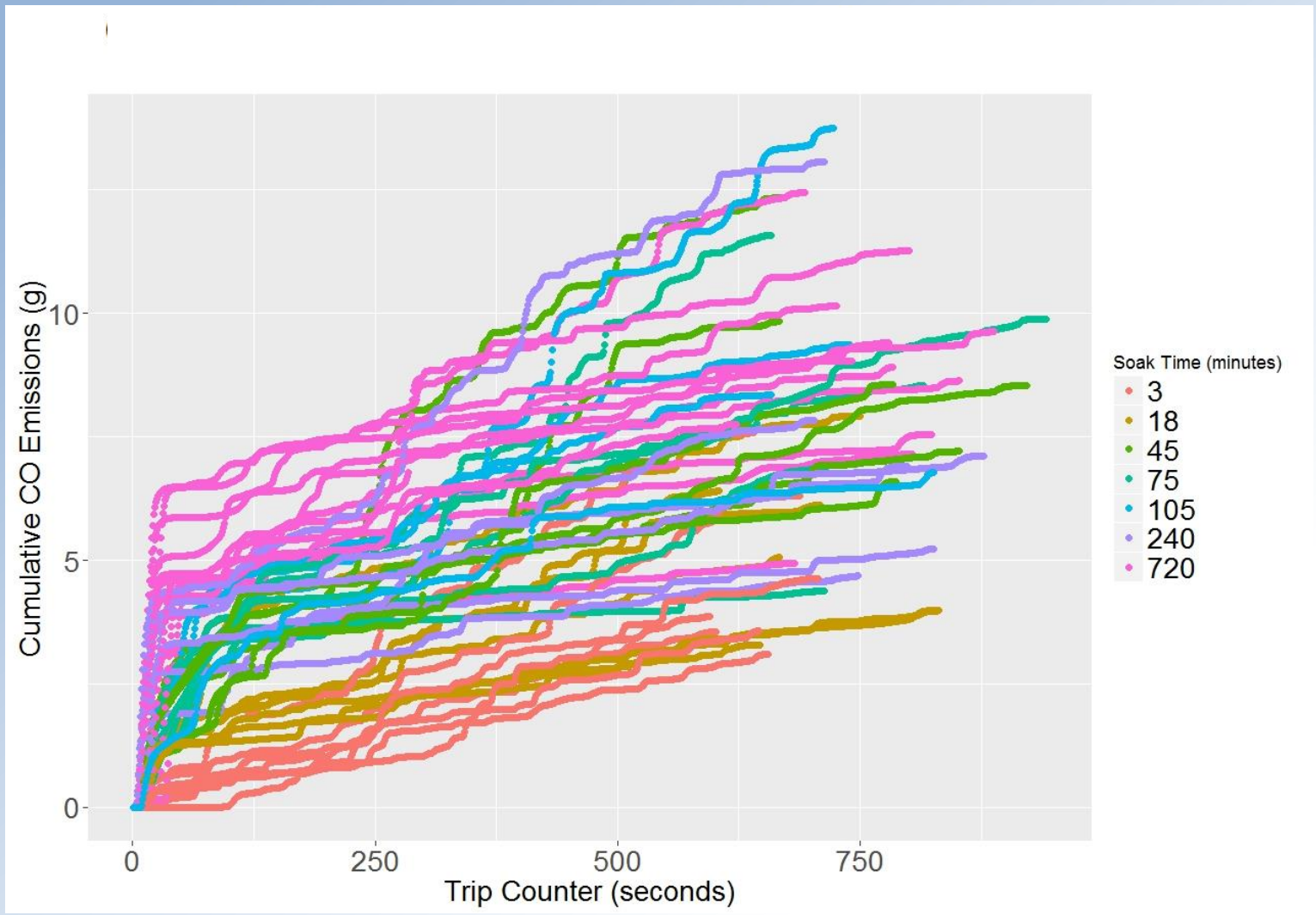
# Saturn Outlook: Cumulative HC Emissions



# Saturn Outlook: Cumulative NOx Emissions



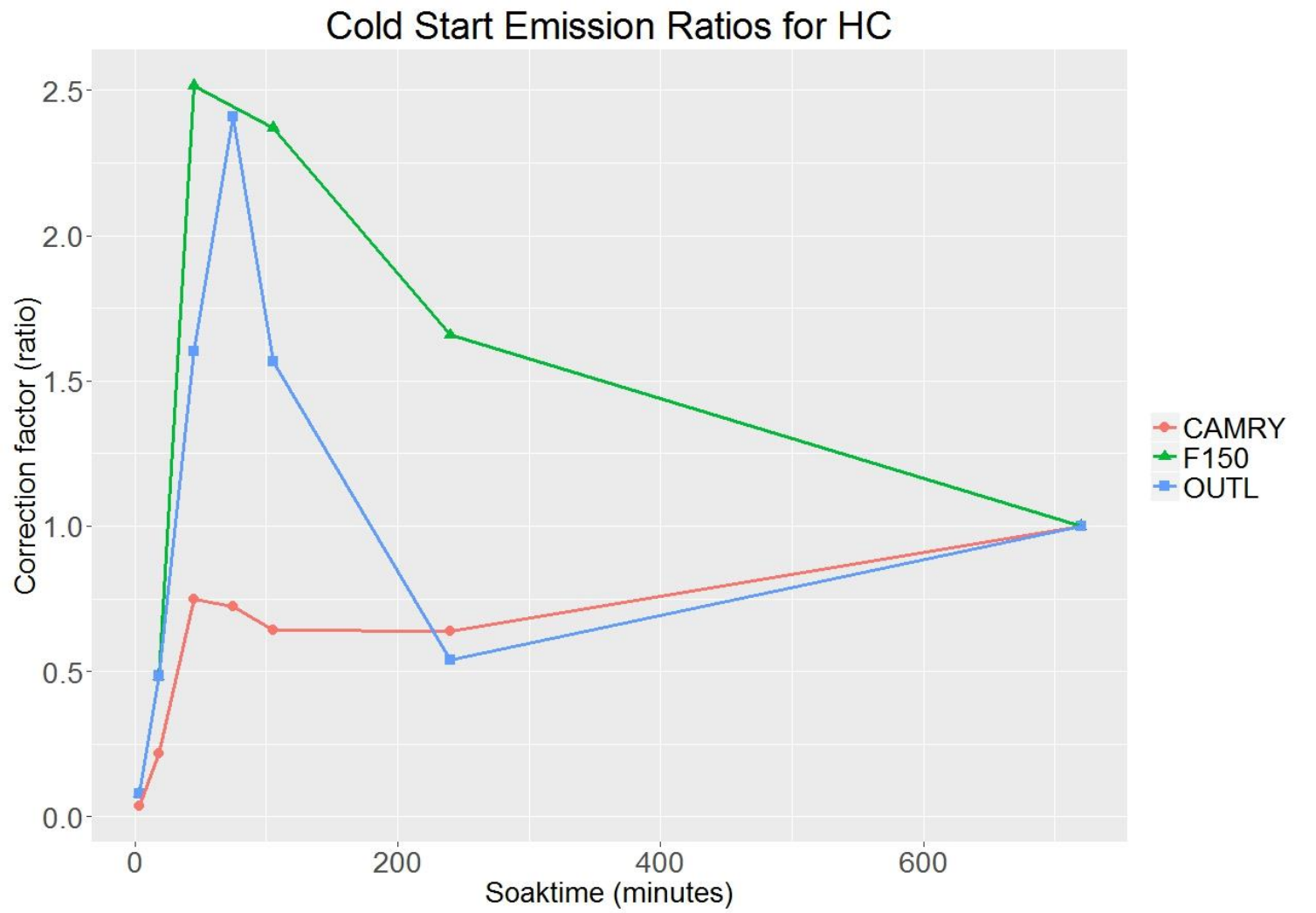
# Saturn Outlook: Cumulative CO Emissions



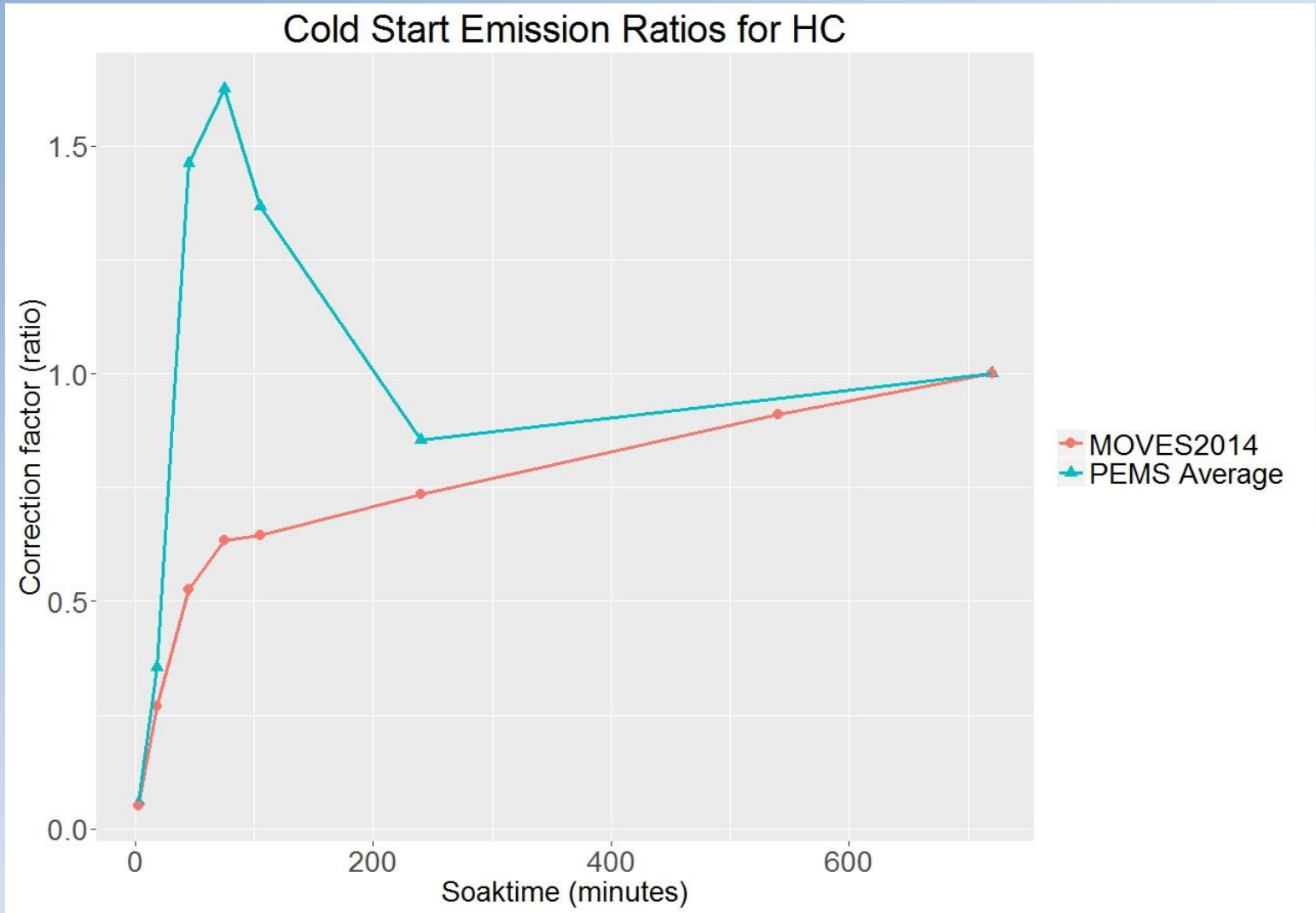
# Developing soak curves

- Average results, by vehicle
  - Within MOVES soak periods
  - Subtract 3-min soak values from all others
    - Analog to subtracting “hot-start” from “cold-start”
- Average across vehicles
  - By MOVES soak period
  - As emissions
- Normalize to cold start
  - Interpolate 3-min soak
  - Interpolate 540 min soak
    - Measuring 9-hour soak not feasible
- Show application to emission rates
  - For cars

# THC: Soak Curves by vehicle



# THC: Proposed Soak Curve



# California Air Resources Board: Update to EMFAC2017

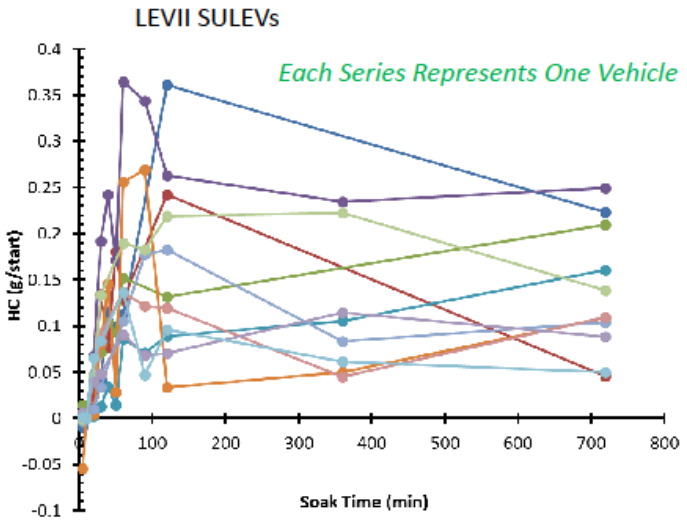
## Warm Starts: HCs

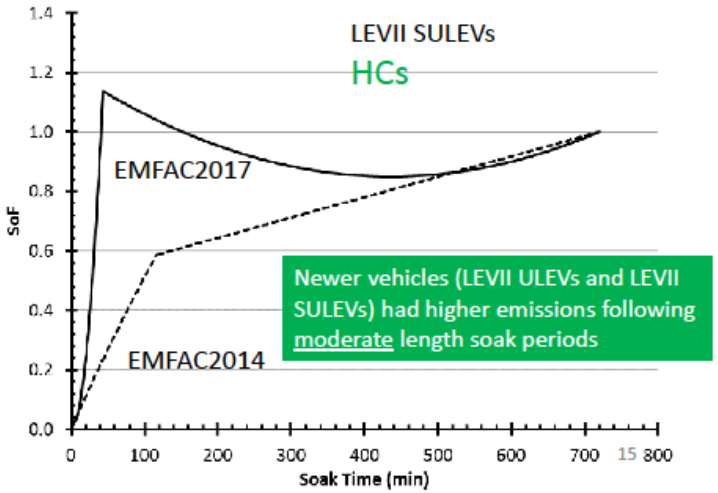
EMFAC uses SoFs to compute warm start ERs

**Warm StER(odo) = StER(odo)*SoF(t), t = soak time**

VSP included UC testing following various soak periods (12 hr, 6 hr, 90 min, 20 min etc.)

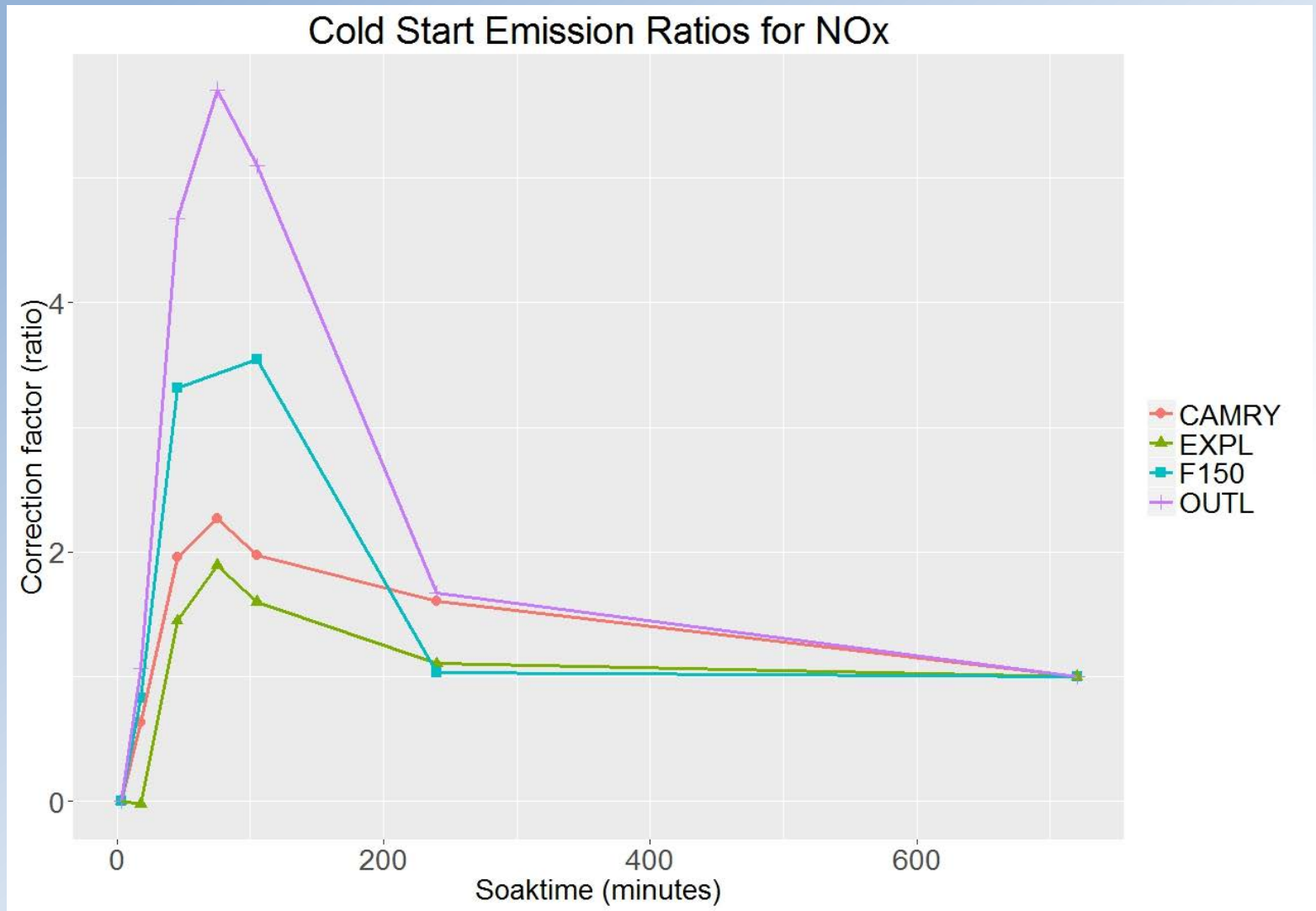
- These data were used to derive new SoFs



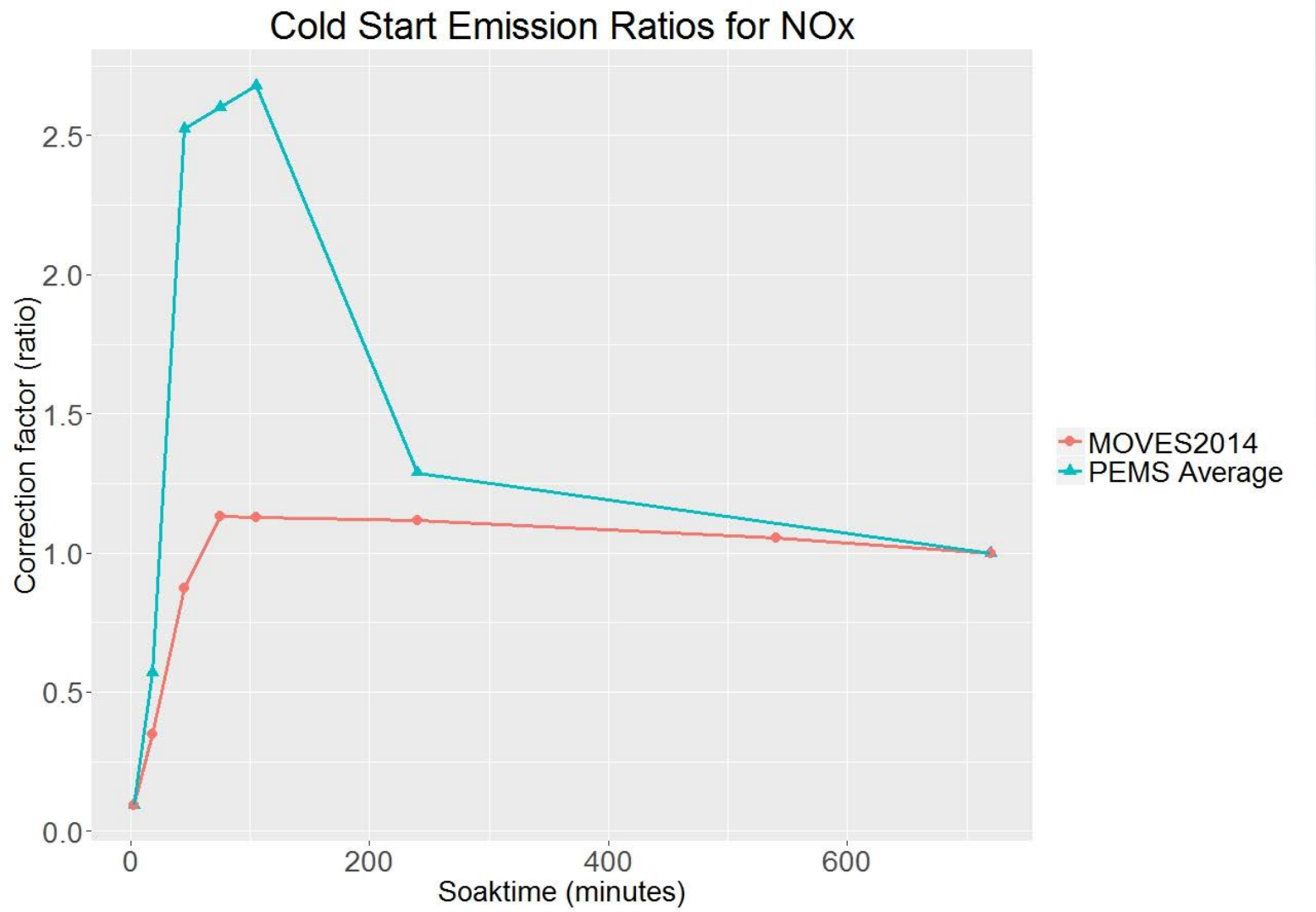




Source: Kamboures, M.A.; Hancock, B.; Pournazeri, S.; Long, J. *In-Use Emissions from LEVII Certified Vehicles*. California Air Resources Board. Presented at: 27th Real World Emissions Workshop, Long Beach, CA. March 29, 2017.

# NOx: Soak Curves by Vehicle



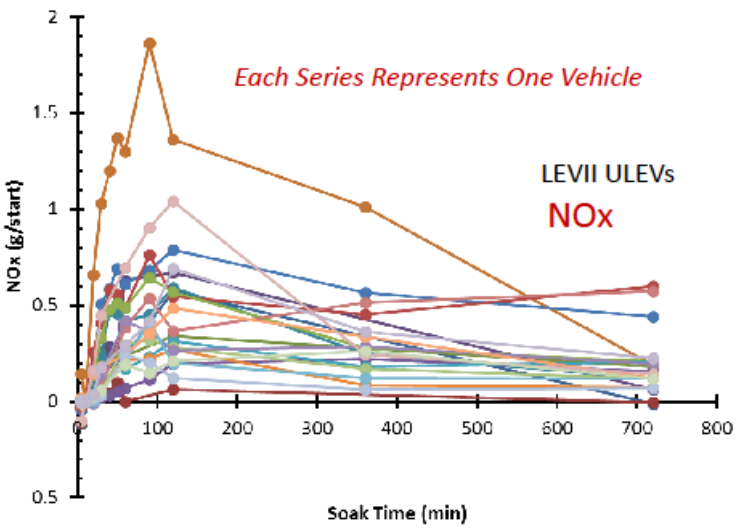
# NOx: Proposed Curve

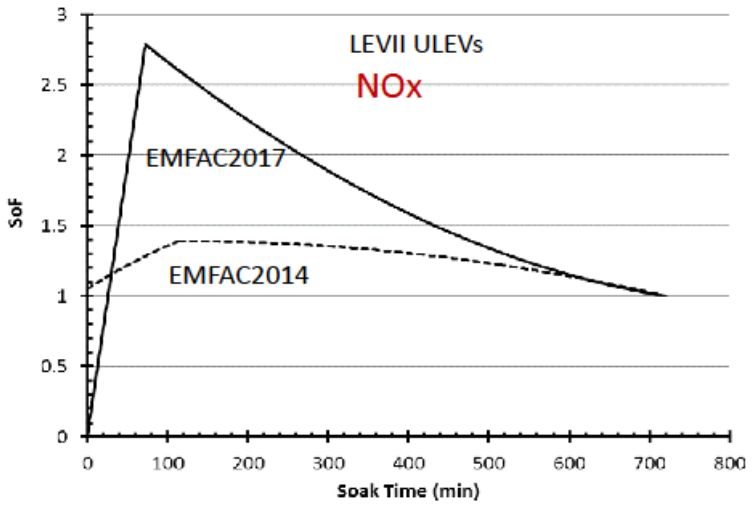


# California Air Resources Board: Update to EMFAC2017

## Warm Starts: NOx

Newer vehicles (LEVII ULEVs and LEVII SULEVs) had higher emissions following moderate length soak periods AND lower emissions following very short soak periods

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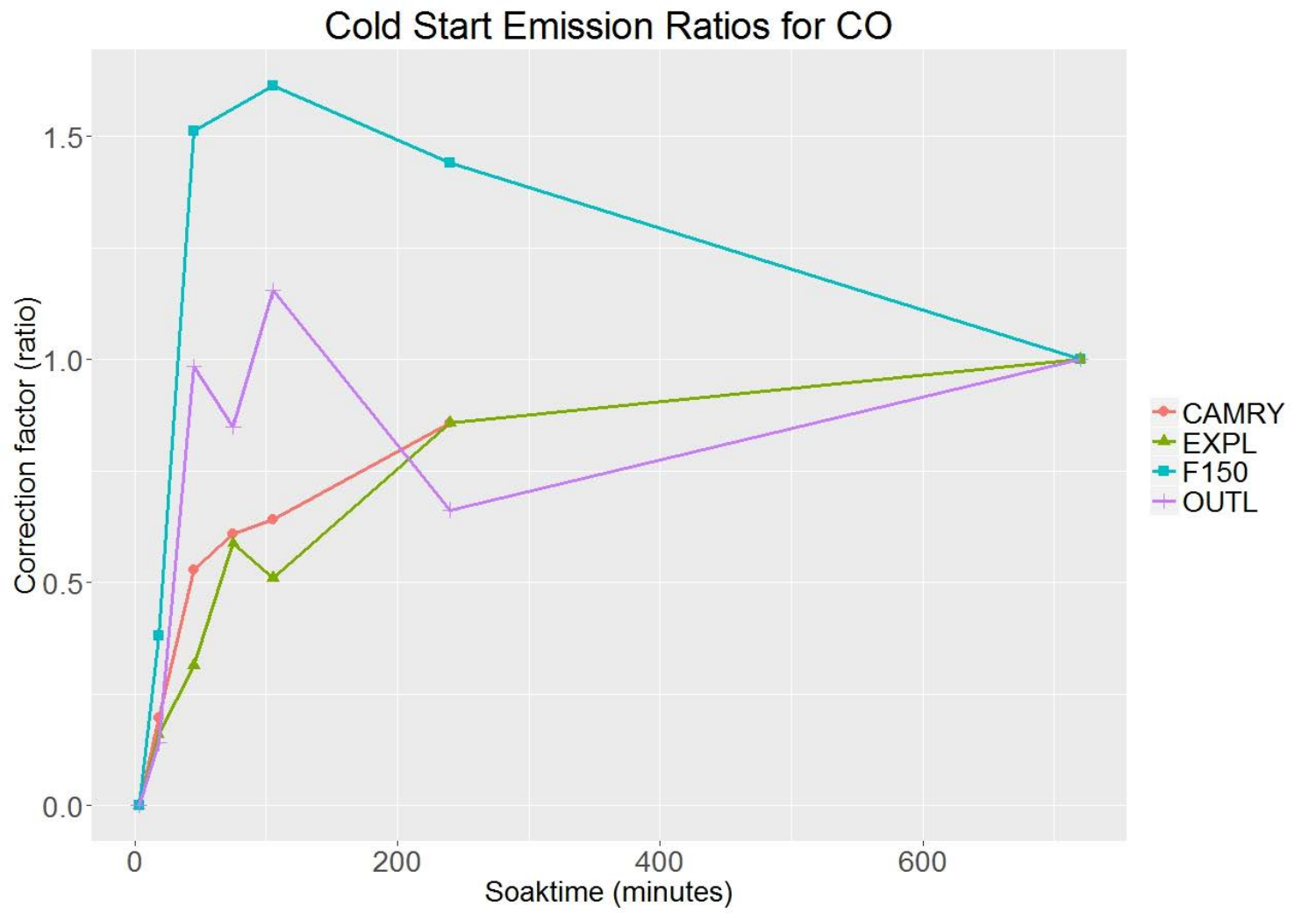
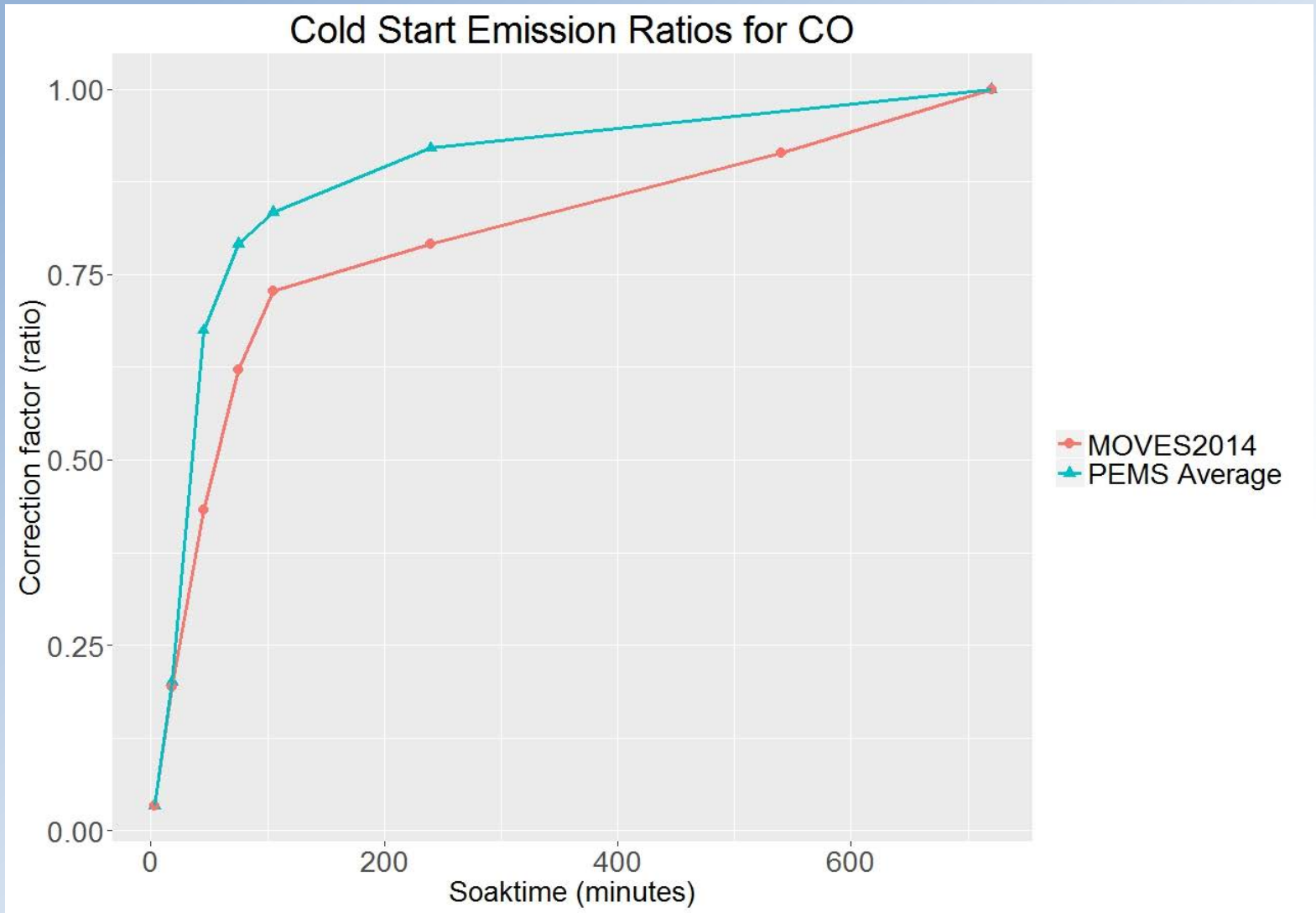
Source: Kamboures, M.A.; Hancock, B.; Pournazeri, S.; Long, J. *In-Use Emissions from LEVII Certified Vehicles*. California Air Resources Board. Presented at: 27th Real World Emissions Workshop, Long Beach, CA. March 29, 2017.

# CO: Soak Curves by vehicle



# CO: Proposed Soak Curve



# Summary and Conclusions

- Practical to measure start emissions using PEMS
  - Can emulate “FTP-based” approach
- Start/soak relationships differ from older results
  - Corroborated by other findings
  - HC, NOx, emissions highest at shorter soak periods
    - Catalyst quick warm-up strategies not operative
- We propose to update MOVES rates
  - For model years 2004 and later
  - Using revised soak curves
    - For HC, CO, NOx
    - Use HC curve for Particulate matter (PM) rates
  - For “warm” to “hot” starts only (opmodes 101-107)
  - NOT updating Cold-start rates themselves (opmode 108)
    - Still based on FTP