Rethinking Carbon Monoxide inside Motor Vehicles

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Presented to United Nations
Informal Working Group on
Vehicle Indoor Air Quality

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Donnay Disclaimers and Conflict of Interest Disclosures

1. Albert Donnay is a toxicologist and environmental health engineer specializing in carbon monoxide (CO) since 1999. He earns income consulting with: CO survivors, clinicians, attorneys, and manufacturers of CO-related technologies but is **NOT currently consulting on any matters involving vehicles.**
2. Donnay is **NOT speaking for clients** or other organization to which he belongs**,** none of which are affiliated with any vehicle manufacturers or part suppliers.
3. Donnay has no financial interest in any of products he describes. He has 2 US patents for non-invasive methods of testing CO in people, but he does ***NOT earn income*** from them.
4. This presentation includes some slides on vCO reprinted from the VIAQ archives, to remind VIAQ members what others have already presented on this topic. Inclusion of these slides does **NOT mean Donnay endorses their content** and does **NOT mean their authors endorse any of Donnay's content.**

Donnay Experience with Vehicular CO (vCO)

Personal

- **Repeatedly "gassed" by high vCO while bicycle touring and bike commuting in 1970s-80s** (causing headaches, dizziness, nausea, weakness)
- **Owned both gas and diesel hatchbacks and pre-1974 vehicles without catalytic converters** that accumulated 10-100ppm CO in the cabin, especially when backing up after a cold start
- **Parents repeatedly poisoned by undetected vCO** after mother retired, as she slept in late while father "warmed up" car in garage under bedroom
- **2 friends from high school committed suicide** as adults, each by idling their car in their garage, ***which also poisoned and could have killed others*** (1 reached 87% COHb, higher than CO literature)

Professional

- **Twice petitioned US NHTSA (unsuccessfully)** to require CO-sensing alarm and shutoff in all vehicles
- **Developed protocols for testing CO in vehicles,** both moving and parked and in garages and homes
- **Investigated poisonings and deaths caused by vCO** in various scenarios: while parked, driving, in buildings
- **Expert witness for defense in civil and criminal cases** that sought to hold driver responsible for injuries and deaths caused while they were unknowingly poisoned by vCO that was not their fault
- **Researched published data on vCO emissions** from on-road testing of vehicles in USA and Europe, identifying pattern of CO-specific by-pass device
- **Chair, STC34 working group on In-Vehicle Air Quality Standards** of the International Society of Indoor Air Quality and Climate (ISIAQ)

Why Rethink Carbon Monoxide inside Vehicles?

CO from vehicles
* more released per year than all other vehicle air pollutants except CO2
* does not correlate closely with emissions levels of Particulates or NOx
* #1 or #2 source of CO poisoning and deaths annually in USA, with furnaces
* causes >100K ED visits/year and >1K CO Deaths/year in USA

VIAQ decision to exclude CO from cabin air testing protocols
was based on ***incorrect belief*** that CO buildup in vehicles

a) is inevitable
b) cannot be mitigated
and therefore
c) does not need to be tested as a measure of VIAQ.

Buildup of CO inside vehicles is NOT inevitable and CAN be mitigated
Automakers already use some mitigation methods and could use more

vCO test methods and results
presented to IWG on VIAQ
by Jongsoon LIM of KTSA/KATRI in 2017

Proving Ground Test

➢ Proving Ground Test

- ✓ Proving ground driving test
  - Idling conditions, cruising speed conditions, acceleration conditions
- ✓ Test vehicle : Gasoline vehicle, 3,000 cc, sedan
- ✓ Measurement devices setting position :
  - Nose position of front seat, back seat
  - Center position of truck
  - Rear of vehicle

〈center of trunk〉

〈front and rear seat〉

〈rear of vehicle〉

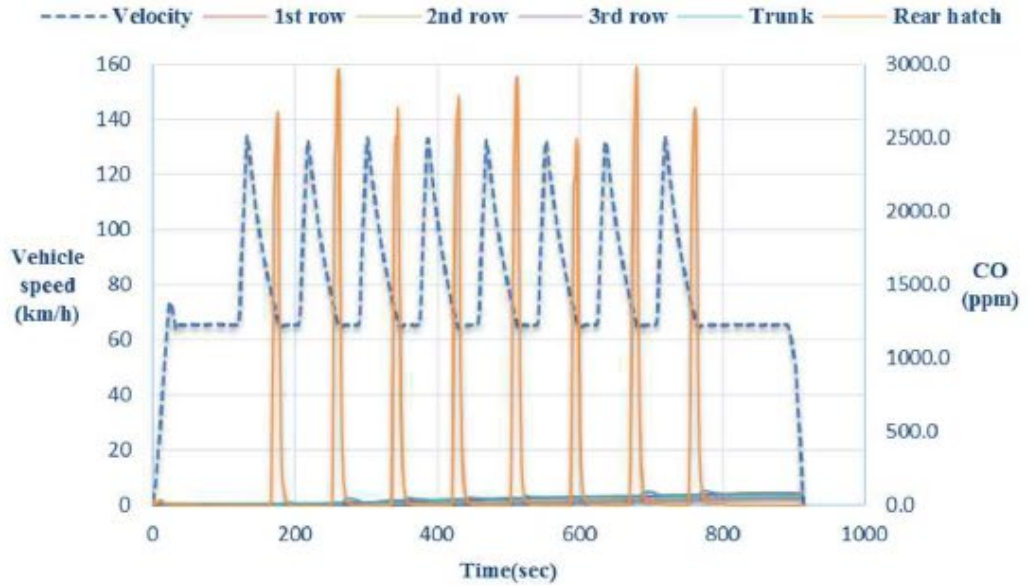
Tested 2016
Ford Explorer

Proving Ground Test

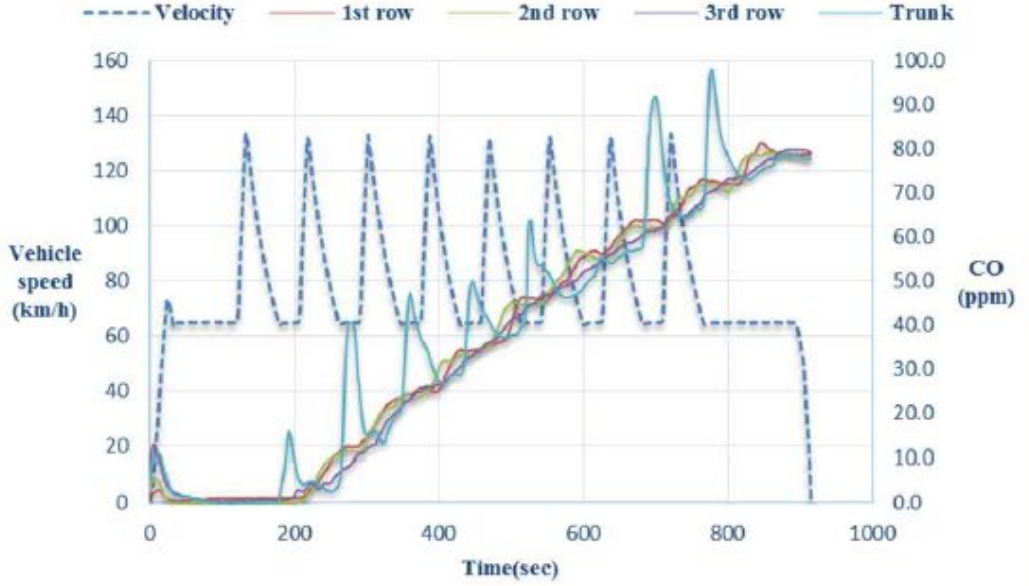
KATRI
Korea Automobile testing & research Institute

- ✓ Acceleration mode, (worst-case conditions)
- When accelerating, high concentration of CO was detected in rear area (max 3,000 ppm)
- When accelerating, CO entered into the trunk zone through the rear hatch (max 100 ppm)
- CO concentration was increased gradually from 40 ppm to 80 ppm in the cabin

Acceleration mode, CO results in rear hatch
(65~130 km/h, Sunroof closed, recirculation mode)



Acceleration mode, CO results in cabin
(65~130 km/h, Sunroof closed, recirculation mode)



Proving Ground Test

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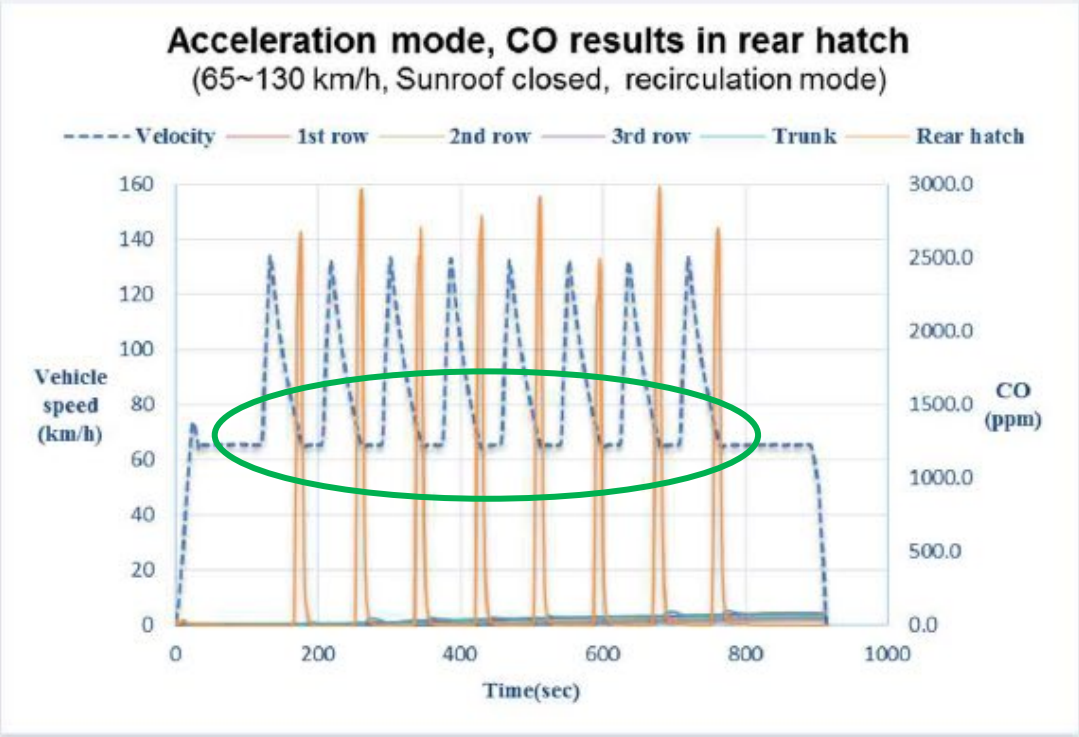
Corrected to match data shown below

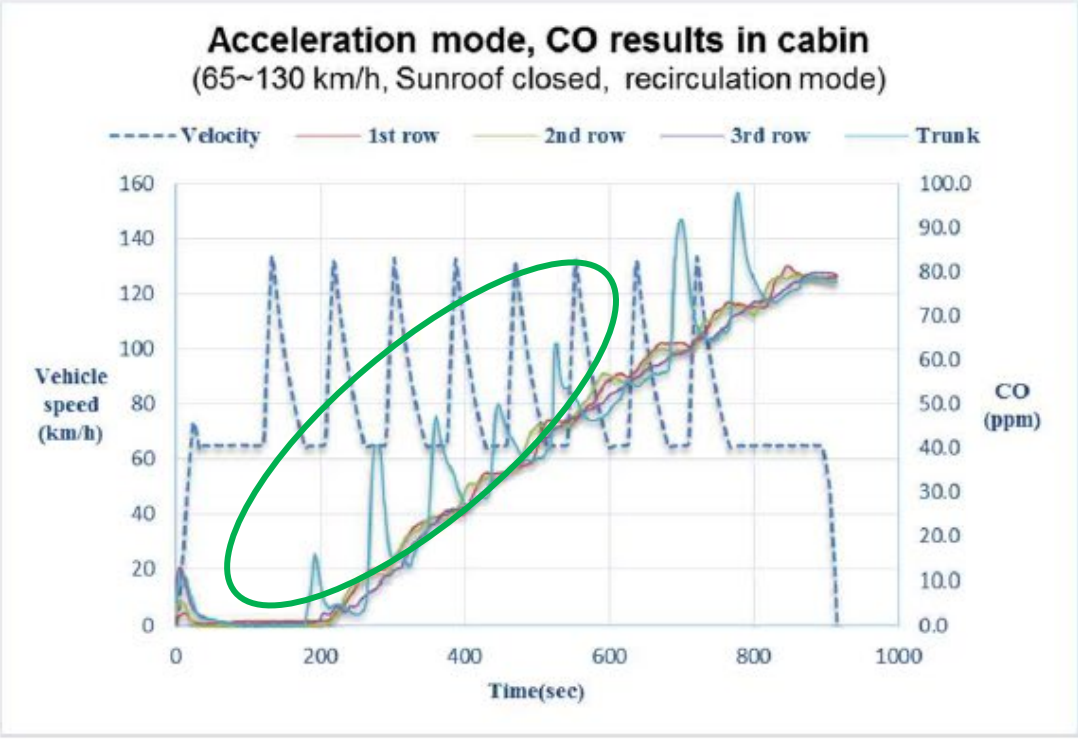
Deceleration
~~Acceleration~~ mode, (worst-case conditions)

When ~~accelerating~~ **decelerating**, high concentration of CO was detected in rear area (max 3,000 ppm)

When ~~accelerating~~ **decelerating**, CO entered into the trunk zone through the rear hatch (max 100 ppm)

- CO concentration was increased gradually from 40 ppm to 80 ppm in the cabin





Real-road Driving Test

KATRI
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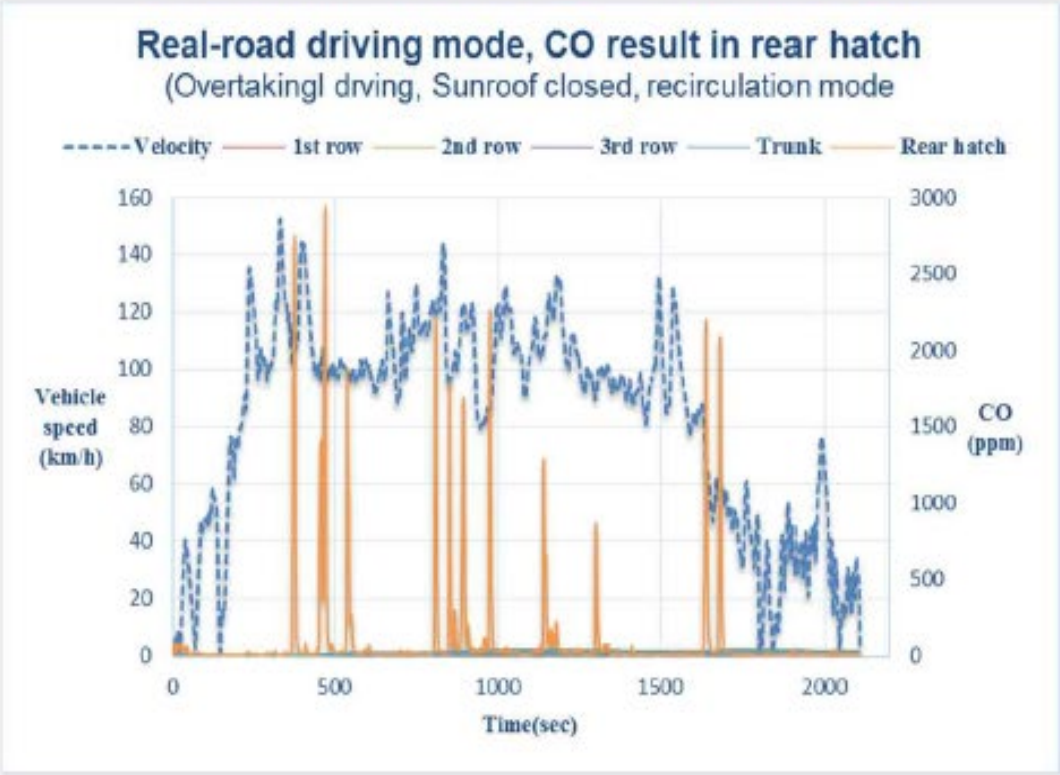
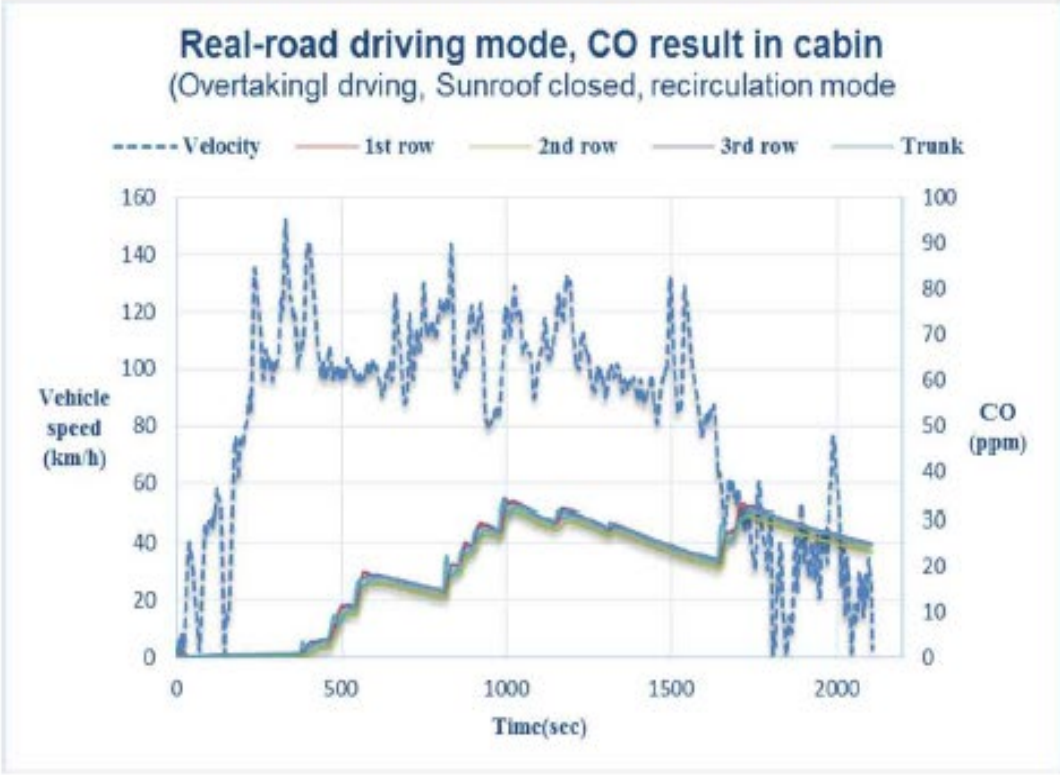
- CO was detected in cabin 20 ~ 35 ppm, in response to acceleration *and deceleration*
- Car acceleration : 11 times over 35 minutes





Test Results

KATRI
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- ✓ CO gas enters into cabin in response to acceleration or high speed driving, especially for overtaking driving on highway, with HVAC in recirculation mode
- ✓ After repair, CO gas was not detected in most test modes, except acceleration mode with sunroof tilt open
- ✓ Hatch door sealing problems, air extractor design, sunroof tilt open, and tail pipe position may affect exhaust leaks into cabin

Test results for CO gas incursion		Before repair		After repair	
Sunroof		closed	tilt open	closed	tilt open
Idle mode		N.D.	-	N.D.	-
Cruising mode	80	N.D.	N.D.	N.D.	N.D.
	100	N.D.	N.D.	N.D.	N.D.
	120	N.D.	N.D.	N.D.	N.D.
	140	8~9 ppm	0~3 ppm	0~3 ppm	0~2 ppm
Acceleration mode		40~80 ppm	30~35 ppm	N.D.	10~15 ppm
Real-road driving mode	Careful driving	N.D.	-	N.D.	-
	Overtaking driving as traffic required	20~35 ppm	-	0~2 ppm	-

Allowed CO Exposures *versus* CO Peaks inside Ford Explorers

WHO for everyone anywhere, including in vehicles
= 4 mg/m3 (~3.5 ppm) average

RUSSIA for everyone in vehicles, per GOST 33554-2015
= 5 mg/m3 (~4ppm) maximum

INTERNATIONAL BUILDING CODE
Section 5000 for Parking Garages
= 35 ppm maximum

6 ppm in breath adds 1% COHb in blood

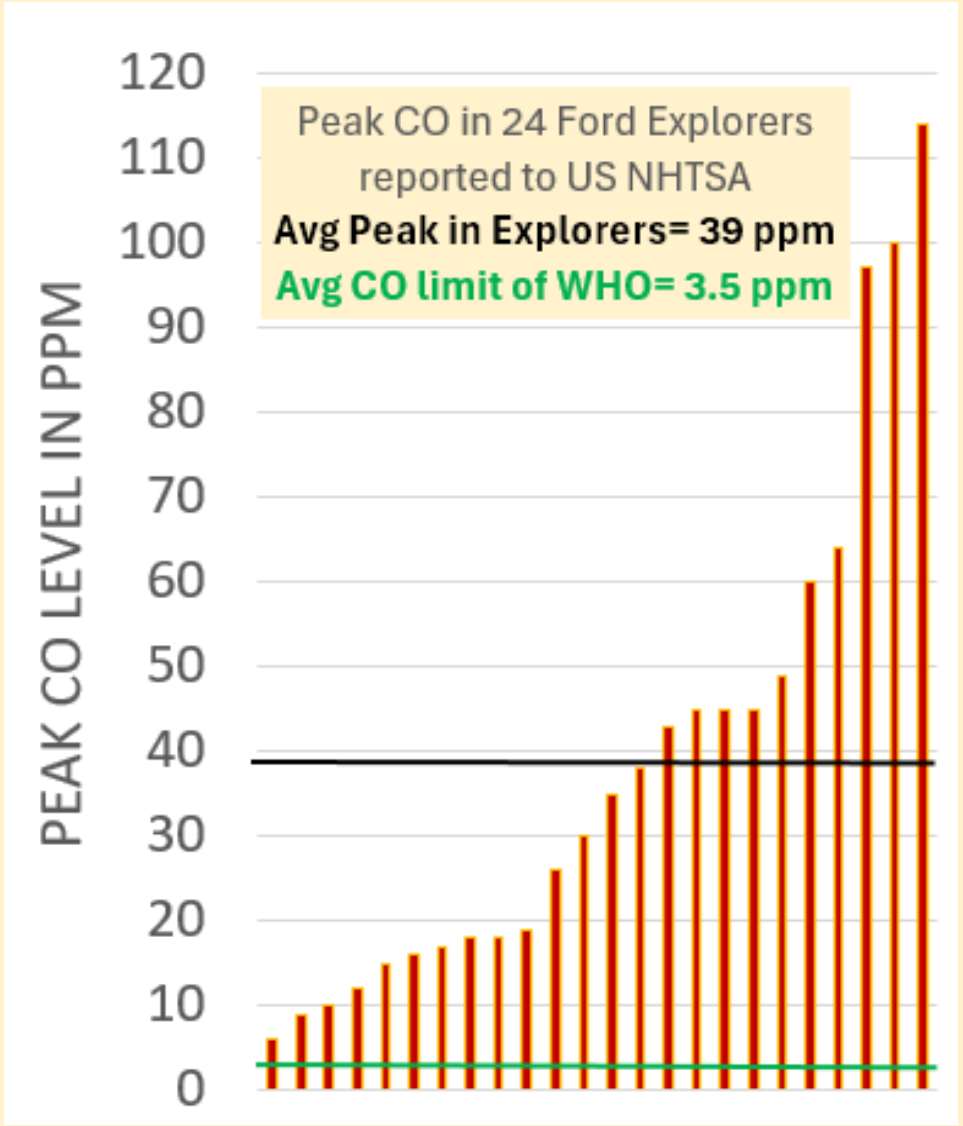
US Government Agency CO Limits

EPA for everyone outdoors
= **9 ppm average**

NIOSH for workers anywhere, including in vehicles
= **35 ppm average**

OSHA for workers anywhere, including in vehicles
= **50 ppm average**

CPSC for everyone in homes, RVs, or pleasure boats protected by UL2034 CO alarms = **69 ppm maximum**



CO Exposure inside Vehicles Impair Ability to Drive

Consistent with CO poisoning literature, drivers complained of

1. Severe Headaches
2. Difficulty Focusing
3. Difficulty Breathing
3. Impaired Vision
4. Misjudging Speed and Distance
5. Feeling Dizzy and Nauseous

Some CO poisoned drivers drive as if drunk, and when stopped by police, also walk and talk as if drunk.

U.S. Department of Transportation

National Highway Traffic Safety Administration

ODI RESUME

OFFICE OF DEFECTS INVESTIGATION
NHTSA
Authentic US Government Information
National Highway Traffic Safety Administration
uses a digital certificate to ensure
the content has remained unchanged

Investigation: EA 17-002
Prompted by: PE16-008, Consumer Reports
Date Opened: 07/27/2017 **Date Closed:** 01/17/2023
Investigator: Brian Smith **Reviewer:** Bruce York-B
Approver: Stephen Ridella
Subject: Exhaust Odor in Passenger Cab

MANUFACTURER & PRODUCT INFORMATION

Manufacturer: Ford Motor Company
Products: MY 2011 - 2017 Ford Explorer Including Police Interceptor
Population: 1,474,922

Problem Description: Complaints involving MY 2011 to 2017 Ford Explorers (including Police Interceptor models) report occupants smelling exhaust odors in the occupant compartment. Complainants expressed concerns about exposure to carbon monoxide.

FAILURE REPORT SUMMARY

	ODI	Manufacturer	Total
Complaints:	1,558	4,959	6,517
Crashes/Fires:	15	21	36
Injury Incidents:	86	461	547
Number of Injuries:	127	530	657
Fatality Incidents:	0	0	0
Other*:	0	3	3

***Description of Other:** Two fatality claims,a police claim (2 fatalities),and a civilian claim (1 fatality) were submitted to Ford. ODI reviewed the claims and excluded them from the fatality count. ODI has nothing to add to Ford's assessment of these claims in their IR response.

Crashes from CO poisoning occur anytime, anywhere

from complaints filed with US NHTSA about Ford Explorers, MY 2011-2019

15 Ford Explorer crashes reported to NHTSA
all involved drivers who lost consciousness

All but 2 drove straight off the road
All but 1 lucky enough not to hit any other vehicles

1 veered off road into a dumpster and caught fire,
instantly killing Deputy Sheriff who had COHb =19%,
while passenger died during fire with COHb = 27%,

→ *both were non-smokers, for whom normal COHb is <1%*

Sources of CO that may accumulate inside vehicles to levels that impair driving and sicken occupants

1) **Exhaust from driver's own vehicle**,
only partly under driver's control

2) Other **CO sources beyond driver's vehicle**,
all beyond the driver's control

3) **CO sources inside the cabin**,
most under the driver's control

CO from DRIVER'S vehicle

Gets inside cabin through

a) **inadequate design of critical parts and CO intrusion pathways**
such as drain plugs in lift gate that did not fit securely and fell out,
air extractors that curl up with age and then fail to seal,
rear-facing windows that can be opened

b) **defects in original assembly**
such as missing seam tape and wiring gaskets

c) **unsealed holes introduced by upfitters**
such as when adding roof lights or antennas to police fleets

d) **wear and tear causing cracks and leaks in critical parts**
such as manifold, muffler, cat-con, and gaskets around doors and windows

e) **choices made by driver**
such as setting HVAC to Recirculate, accelerating and decelerating quickly,
driving with window in rear hatchback open, and attempting suicide

CO sources BEYOND driver's vehicle

Gets inside cabin through same pathways as CO from driver's vehicle

Comes from:

a) other vehicles driving ahead or along side of driver's vehicle
b) other vehicles parked and idling near driver's vehicle, if also parked
c) industrial air pollution (typically not released at ground level)
d) wildfires, building fires, and vehicle fires

Occupants of electric and hybrid vehicles are equally at risk

CO sources IN CABIN of driver's vehicle

Comes from:

a) exhaled breath of occupants
   1-6 ppm from non-smokers
   7-35 ppm in people with medical conditions and smokers after smoking
   50-999+ ppm from smokers while smoking
b) second-hand smoke from cigarette, joint or pipe
c) use of gas or charcoal appliances in cabin
d) burning incense and/or candles in cabin

* Cabin CO sources build up regardless of whether engine is on or off
* CO accumulate most when windows are closed and fan is off
* Occupants of electric and hybrid vehicles are equally at risk

Common CO Exposure Scenarios Involving Vehicles

1. Vehicle Occupants **exposed to vCO that builds up while vehicle is in motion**, either
   1a) **by their exhaust,** especially **after cold start**, and **when backing up**, **accelerating or decelerating**, and **with windows closed and fan on recirculate**
   1b) **by exhaust of other vehicles** driving ahead of them or along side, especially **in heavy traffic and tunnels**
2. Vehicle Occupants **exposed to vCO that builds up in cabin when not moving**, either
   2a) **because tailpipe is blocked by snow or mud**
   2b) **vehicle is stuck in traffic jam,** or **parked and idling**, especially if in a garage
3. Building Occupants are **exposed to vCO from vehicles left idling in an attached garage** or **idling at a loading dock**, or **near an open door or window**, either deliberately or inadvertently (common problem with keyless fobs)
4. Both vehicle occupants and event staff exposed to vCO during “Drive Through” events, esp. driving through buildings such as car washes or large tents such as for COVID testing
5. Bicyclists and pedestrians **exposed to vCO from passing vehicles,** especially **vehicles whose catalytic converter(s) are missing, degraded, or bypassed**

CO emissions from gas engines are much higher when:

1. Cold engines are “cold started,” especially if in cold weather, because typical catalytic converters do NOT reduce CO to CO2 until heated to over 400C, which takes 1 to 2 minutes.

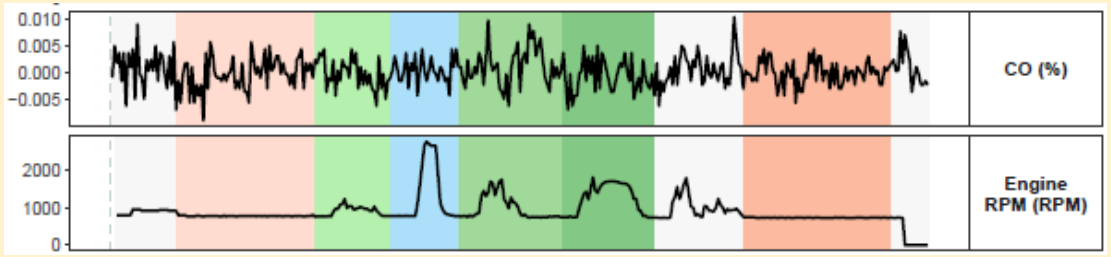
   Until catalytic converter is hot,
   tailpipe releases 50,000 to 150,000 ppm CO (=5 to 15%)
   versus < 200 ppm CO when working optimally

2. Catalytic converter is missing or no longer effective and needs replacement

3. Exhaust controls are programmed to bypass catalytic converter during
   Startup (allowed in past by US EPA until rule change proposed in 2023)
   Accelerations (still allowed by US EPA if disclosed by automaker in advance)

CatCon patterns in road-test Time Series Data* on vCO and RPM

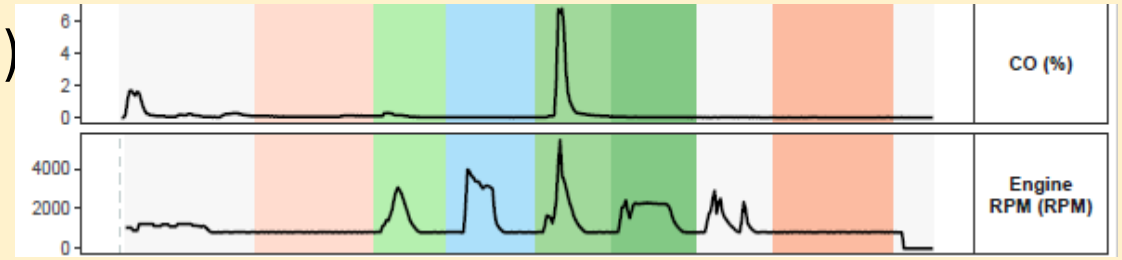
1. **Optimal CO control** (27 of 216 = 13%)
   tailpipe CO < 200 ppm (<0.02%) during all RPM spikes; 5 also had low CO cold start



CO%

RPM

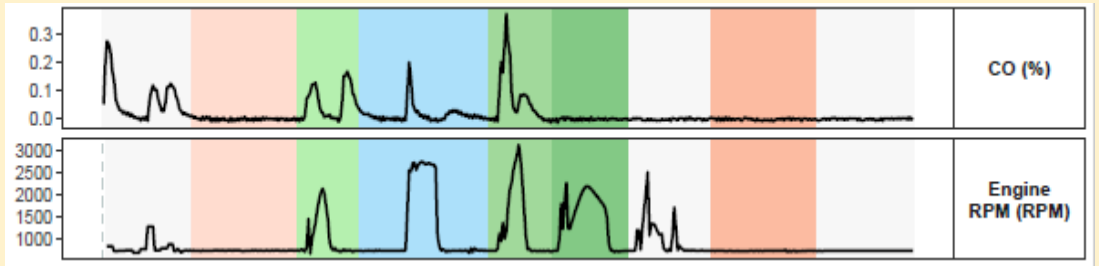
2. **Above average CO control** (85 of 216 =39%)
   tailpipe CO < 500 ppm after cold start, and **1 or 2 RPM spikes defeat CatCon**



CO%

RPM

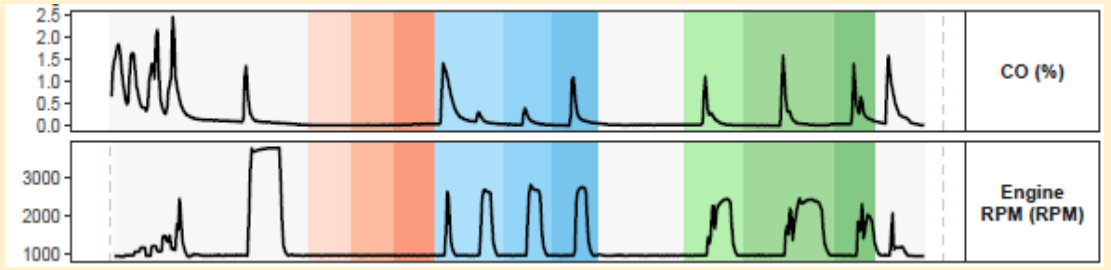
3. **Below average CO control** (54 of 216 =25%)
   tailpipe CO < 500 ppm after cold start.
   and **3 or 4 RPM spikes defeat CatCon**



CO%

RPM

4. **No effective CO control** (50 of 216 =23%)
   tailpipe CO > 500 ppm after cold start, and **all RPM spikes (>4) defeat CatCon**



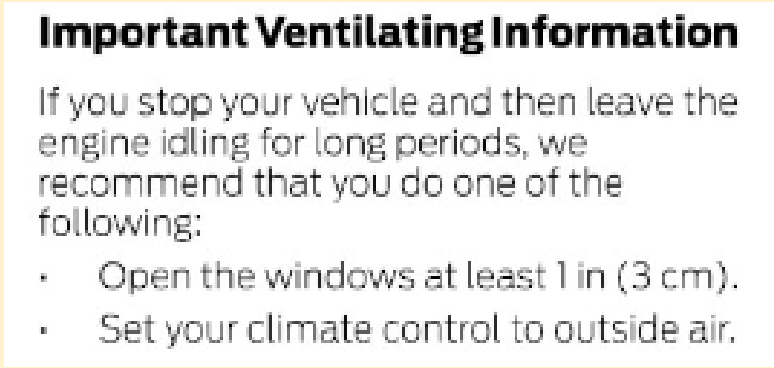
CO%

RPM

* Time series examples are from public draft 3DATX report by Thomas and Sandhu, 2022

How NOT to Reduce Unintentional CO Poisoning from Vehicles

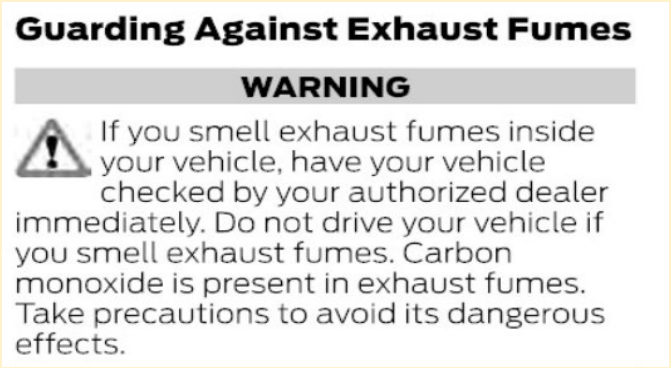
1. **Add WARNING about CO and Exhaust Fumes to Owner's Manual** (no cost)
   example from 2018 Ford Explorer



Important Ventilating Information

If you stop your vehicle and then leave the engine idling for long periods, we recommend that you do one of the following:

- Open the windows at least 1 in (3 cm).
- Set your climate control to outside air.



Guarding Against Exhaust Fumes

WARNING

If you smell exhaust fumes inside your vehicle, have your vehicle checked by your authorized dealer immediately. Do not drive your vehicle if you smell exhaust fumes. Carbon monoxide is present in exhaust fumes. Take precautions to avoid its dangerous effects.

2. **Add CO to CO2 Catalytic Converter** (as US EPA has required since 1974, >$500 each)
   * Most CatCons do not lower CO emissions until they heat up to over 400 C
   * Lower CO level is still enough to cause CO poisonings and deaths in vehicles
   * 23% of randomly tested exhaust systems defeat CatCon every time RPMs spike
3. **Add Warning Sound if driver exists vehicle while engine is idling** (estimate <$1 each)
   * NHTSA proposed warning in 2011 for vehicles started by fobs but did not adopt it
4. **Add Engine Shutoff after 30 or 60 minutes if vehicle is left idling** (estimate <$1 each)
   * Some automakers have voluntarily installed shutoffs in some models with fobs but idling time is too long to prevent CO poisoning, especially if in a closed garage
   * Congress in 2019 directed NHTSA to publish a shut-off requirement by Nov 2023 and start enforcement by Sept 2024

How to Reduce CO Poisoning Inside Vehicles

6 Steps, including 4 taken by Ford*

1) * **SEAL ALL SEAMS, PLUG ALL HOLES, and CHECK FIT ALL DOOR AND TRUNK GASKETS**
2) * **INSTALL TAILPIPES THAT OPEN DOWNWARD** (Ford replaced straight tips of all fleet vehicles.)
3) * **INSTALL AIR EXTRACTORS** that stay closed during rapid acceleration and deceleration and **EXHAUST MANIFOLDS** that do not crack
4) * **PROGRAM HVAC TO PROTECT OCCUPANTS** when high CO is detected rising inside or outside by overriding fan and vent settings as needed
5) **STOP PROGRAMMING EXHAUST CONTROLS to defeat CatCon** at startup and when accelerating
6) **INSTALL CO-SENSING CONTROLLER** in cabin, such as behind the grille of an air vent outlet, and install second at air vent inlet outside (already in vehicles with Electronic Climate Control)

Could Mitigate Most vCO Scenarios

a) Inadvertent vCO exposure with engine ON

✓ 1a) in driving Gear, moving or not moving, or

✓ 1b) in Park if automatic or Neutral if not

b) Inadvertent vCO from other vehicle(s) and/or other external sources of CO when:

✓ 2a) Engine is ON, or

ALARM 2b) Accessories and Engine are OFF

c) Non-vCO sources inside the cabin when:

✓ 3a) Engine is ON, or

ALARM 3b) Accessories and Engine are OFF

d) Attempted Suicide using vCO

ALARM 4a) via hose from tailpipe into cabin

ALARM 4b) by idling vehicle inside closed garage

ALARM 4c) by burning charcoal inside the cabin

CO- and NO_2-sensing **Air Control Module** installed at AIR INLET also should be installed at AIR OUTLET inside cabin (cost < $5)

Air "Classification" or "Control" Module = ACM

combines CO and NO2 sensor(s) to control air inlet for vehicle cabin in response to gasoline engine exhaust, diesel exhaust and skunks

(located under hood at base of windshield or on firewall)

Began with Mercedes and Lexus in 1998. Now offered as standard or option by all major automarkers on all vehicles with electronic climate control, including Ford, GM and Chrysler

ACM manufacturers include Bosch, Casco Products, City Technology, Denso, Kostal City Technology, Figaro Engineering, FIS, MicroChemical Systems, NGK, Paragon, SAIA-Burgess Electronics, and SGX SensorTech

Very competitive and fast-growing global market with wholesale prices to automakers now under $5/unit

RANGE OF ACM SPECIFICATIONS

- Simultaneously detect CO starting in 1-10ppm range and NO_2 starting in 50-50ppb range
- Air speeds from 0.5-10 m/s
- Accuracy +/-10% to +/-20%
- Response time = 1-3seconds in air moving 5m/s at 25C
- Operating Temp = -40C to upper range of +80 to +125C
- Relative Humidity = 10-95%.
- Leak proof to dust, splashing water and acid fog
- 2 year warranty but expected design life = 15 years, even if stored outdoors in AZ or AK.

SCOPE OF LIFE TESTING [Siemens]

For auto market, ACM must survive:

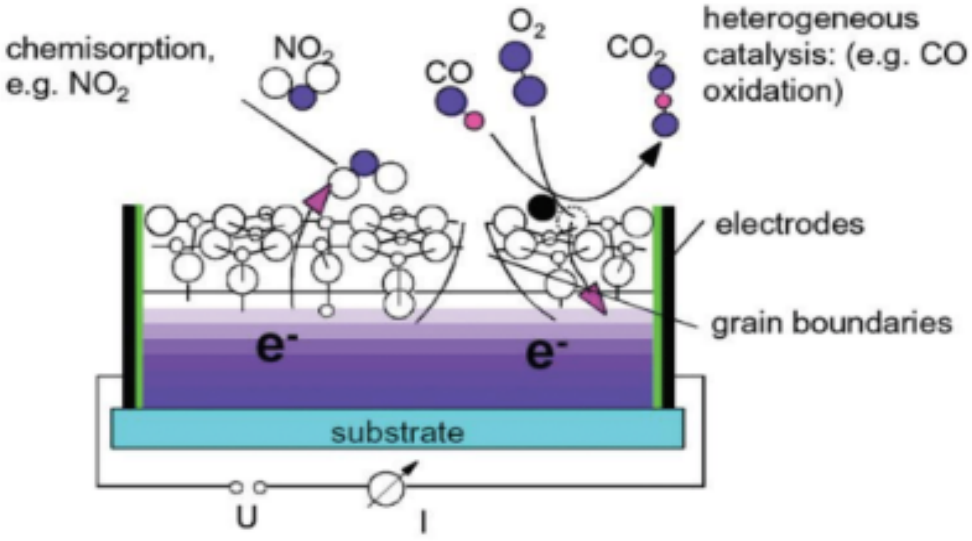
- 12,000 operating cycles and 54,000 on/off cycles
- Shock, drop and 22hr vibration tests
- Wetting with one agent after another, aerating for 1 hour, and then working to specs 2, 8 and 24 hours later.

Survived Wetting Agents include:

water, snow and ice, road salt, acid rain, transmission fluid, motor oil, battery acid, axle fluid, brake fluid, hydraulic oil, refrigerants, coolant, gasoline, diesel, biodiesel, natural gas, glass cleaner, ethanol, methanol, hydrogen, and soap

Advanced Features of Paragon ACM in BMWs (manufactured by Applied Sensor)

1. Dynamic software detects and adapts MOX sensor sensitivity to different driving environments such as urban, rural, traffic jams, and tunnels.
2. Self diagnostics with automatic compensation for sensor tolerances yield consistent performance over the life of the vehicle
3. Software controls temperature of sensor so it can operate in wide temperature range without being influenced by speed or temperature of air stream.
4. MK III Universal model designed for armored cars and trucks detects irritant gases, CS, CN, and tear gas.
5. The MK III+ for luxury cars offers bi-directional interface that receives information from other parameters that can influence the sensor's pollution reading – incl. window fog, humidity, outside temperature, car speed, windshield washer use and status of the climate compressor



Proposed Automatic Response to CO Sensors when accessories or engine are ON

When inside CO is rising faster,
such as when someone is smoking in the cabin:

1. CO DETECTOR installed in the cabin
repeats VOICE WARNING such as
"CARBON MONOXIDE DETECTED RISING INSIDE"
and THEN SOUND SOS ALARM and FLASH STROBE
to alert occupants who may be blind, deaf, or asleep

2. HVAC is auto-set to MAX FAN ON and FRESH AIR ,
and OPEN WINDOWS are LEFT OPEN

3. If engine is ON while vehicle is in PARK,
or while in NEUTRAL with BRAKE ON,
ENGINE is SHUT OFF after a few minutes (3 NOT 30)
to reduce risk of poisoning occupants

STOP VOICE WARNING AND UNLOCK HVAC WHEN:
CO inside is same or lower than CO outside
or when DRIVER opens a window or restarts vehicle

When outside CO is rising faster,
such as driving in heavy traffic or inside a tunnel

1. CO DETECTOR installed in the cabin
repeats VOICE WARNING such as
"CARBON MONOXIDE DETECTED RISING OUTSIDE"
2. HVAC is auto-set to FAN OFF and RECIRCULATE
and any OPEN WINDOWS are SLOWLY CLOSED
3. If engine is ON while vehicle is in PARK,
or while in NEUTRAL with BRAKE ON,
ENGINE is SHUT OFF after a few minutes (3 NOT 30)
to reduce risk of poisoning occupants

STOP VOICE WARNING AND UNLOCK HVAC WHEN
CO outside is lower than inside,
or when DRIVER opens a window or restarts vehicle

Proposed Automatic Responses to CO Sensors when accessories AND engine are OFF

When inside CO is rising faster,

such as when someone is smoking in the cabin,
burning incense or candles, or using a gas grill

CO DETECTOR installed in the cabin
repeats VOICE WARNING such as
"CARBON MONOXIDE DETECTED RISING INSIDE"
and THEN SOUND SOS ALARM and FLASH STROBE
to alert occupants who may be blind, deaf, or asleep

STOP WARNINGS WHEN:
CO level inside starts falling
OR when accessories or engine are turned ON

When outside CO is rising faster

such as when wildfire smoke envelops
a parked vehicle

No need for vehicle to warn of this condition as vehicle may not be occupied

If anyone is inside vehicle,
they are already relatively protected
since the level CO inside is not rising as fast

Recommended specifications for vCO dataloggers

1. need small, portable, diffusion type
2. need hydrogen-corrected CO sensor
3. need fast response: T90 < 5 seconds
4. need to set recording interval < 1 minute
5. need to see from 1 ppm to at least 1000
6. need to be able to bump test and calibrate
7. user can set any level of instant CO alarm
8. user can download results in CSV format
9. user can recharge batteries
10. cost is $100 to $500 retail
11. larger multi-gas dataloggers ($500-$5000) can record CO with other gases that may be higher (CO2, H2S, NO, NO2) or lower (O2) inside vehicles than outside

Recommendations for Deploying vCO dataloggers

- 4 vCO dataloggers per vehicle
- Affix dataloggers with sensor facing up
- Air should flow ACROSS sensor hole, not directly AT the sensor hole

TWO vCO DATALOGGERS OUTSIDE

1) at air inlet below windshield
2) on top of rear bumper above tailpipe

TWO vCO DATALOGGERS INSIDE

3) at center air outlet in dashboard
4) inside trunk or rear hatch back

Optimal Scenarios for Testing vCO *when wind <10km/hr*

Test Worst Case First

1. Close all windows and open all vent grills
2. **Start cold vehicle in 1-car garage**
3. **Turn heat ON, Set FAN to MAX RECIRCULATE**
4. **Idle 1 minute, then drive** 10 meters in reverse
5. Park there, open all windows 3 cm,
   TURN FAN OFF, and idle for 5 minutes
6. **Set FAN to MAX FRESH AIR**,
   leave windows open, and idle for 5 minutes
7. Close windows, **set FAN to MAX RECIRCULATE**
8. Drive forward at posted speeds,
   first 10 min on highway with long ramps
   then 10 min on city streets at rush hour
9. **Accelerate and decelerate very quickly**

Then Test Best Case

1. Close windows and open all vent grills
2. **Start hot vehicle in 1-car garage**
3. **Turn heat OFF, Set FAN to MAX FRESH AIR**
4. **Immediately drive** 10 meters in reverse
5. Park there, open all windows 3 cm,
   LEAVE FAN ON, and idle for 5 minutes
6. **Set FAN OFF**,
   close windows fully, and idle for 5 minutes
7. Close windows**, set FAN to MAX FRESH AIR**
8. Drive forward at posted speeds,
   first 10 min on city streets at rush-hour
   then 10 min on highway with long ramps
9. **Accelerate and decelerate very slowly**

Checklist for automakers seeking to reduce risk of, and liability for, preventable vCO exposures

1. Are all seams sealed, holes plugged, and gaskets fitted?
2. Is exhaust system without any cracks or holes from the manifold to the tail pipe?
3. Does the tail pipe opening face down?
4. Do the air extractors have a fail-safe design?
5. Are CO-sensing ACMs installed at air inlet and outlet?
6. Is HVAC programmed to protect occupants as long as ACM detects quickly rising CO inside or outside?
7. Are emission controls NOT programmed to bypass catalytic converter during startup and acceleration?
8. Are automatic CO controls in a randomly selected vehicle that is tested for CO buildup under best and worst case scenarios able to keep CO level in the cabin below some allowed limit, or to shut off the engine if vehicle is parked?

More information on vCO

Slides from this presentation:
https://tinyurl.com/COinVehicles2023

Donnay CO News Update from Nov 2018
with reports about vCO poisoning caused by
Ford Explorer Police Interceptor Utility vehicles
https://tinyurl.com/COnewsNov2018

Donnay poster on CO-sensing
Air Control Modules from 2013
US EPA conference on Air Sensors:
https://tinyurl.com/COposter2013

Donnay collection of PubMed references
about poisonings and deaths caused
by CO from vehicles and/or inside vehicles
https://tinyurl.com/vCOreferences

US NHTSA Closing Report into “Ford Explorer Exhaust Odor” (EA17-002) with results of vCO testing, completed in 2019 but not released until 1/17/2023
https://tinyurl.com/NHTSAea17002