COMPONENTS RESPONSIBLE FOR THE HEALTH EFFECTS OF INHALED ENGINE EMISSIONS

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HEALTH IMPACTS ACTIVITY
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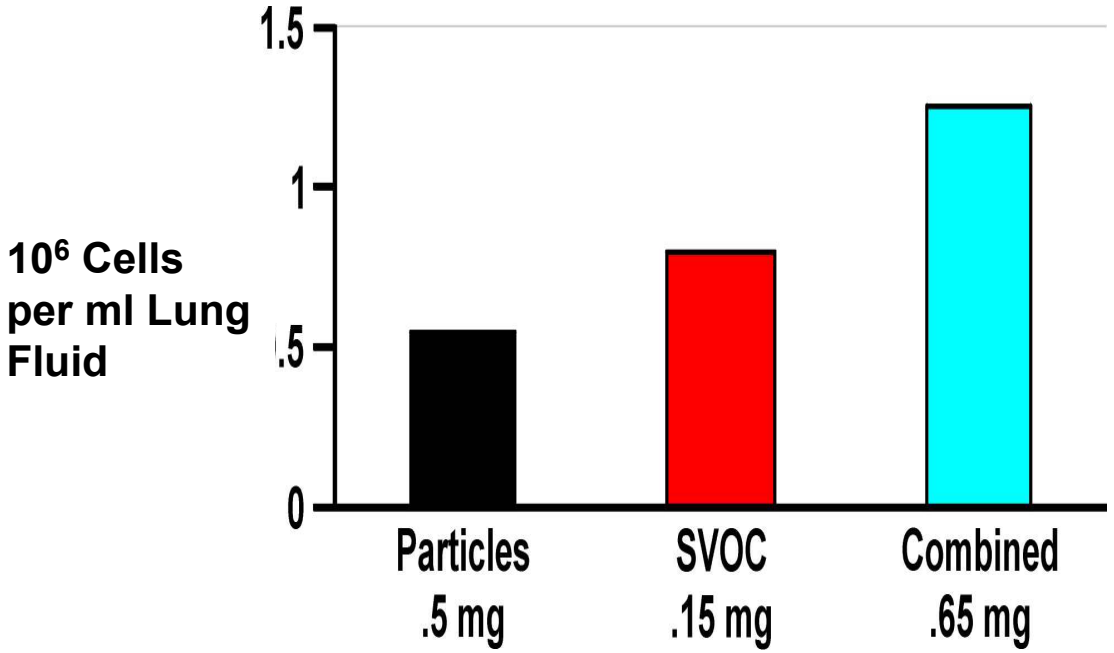
KEY ISSUES

- PM vs. non-PM
- Lube oil
- Nano-PM
- Benefits of emission reductions

DISCOVERED IMPORTANCE OF VAPOR-PHASE SEMI-VOLATILE ORGANIC COMPOUNDS

1. PM and vapor-phase SVOC from truck bore of Baltimore harbor tunnel
2. Instilled into rat lungs
3. Measured inflammatory responses in lung



Per unit of mass, the vapor-phase SVOC was ~ 5x more toxic than PM

Seagrave et al., *Toxicologist* 60:192, 2001

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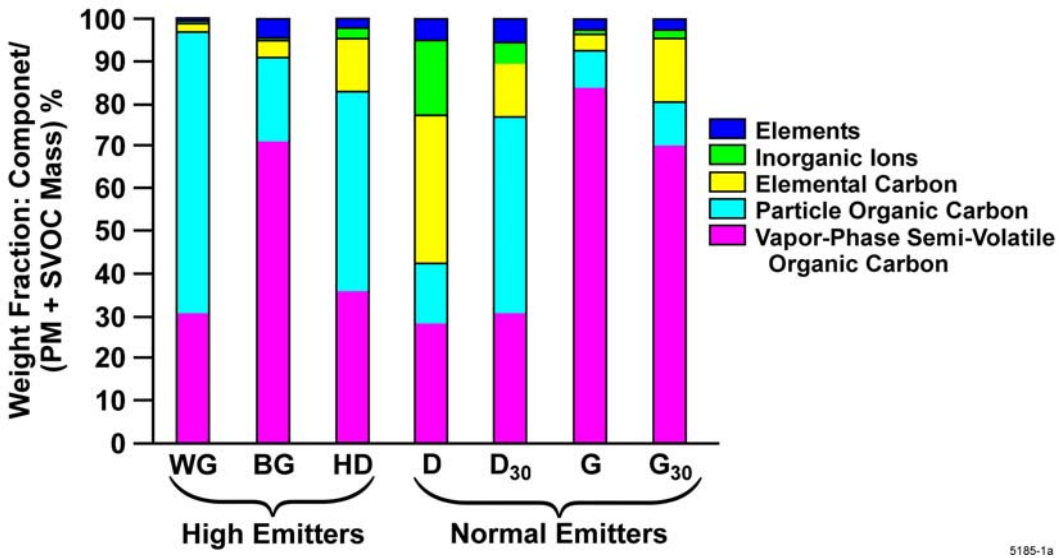
EXAMINED RELATIVE TOXICITY OF DIESEL AND GASOLINE EMISSIONS – AND CAUSAL COMPONENTS

- PM and VP-SVOC from in-use vehicles on chassis dyno.
- Analyzed composition
- Instilled combined fractions into rat lungs
- Analyzed composition-toxicity relationships

Samples

Gasoline (5)	G
Gasoline 30^{o}	G_{30}
White smoker gas.	WG
Black smoker gas.	BG
Diesel (3)	D
Diesel 30^{o}	D_{30}
High-emitter diesel	HD

Composition



Seagrave et al. *Toxicol. Sci.* 70: 212-226, 2002

Zielinska et al., *J. Air Waste Man. Assoc.* 54: 1138-1150, 2004

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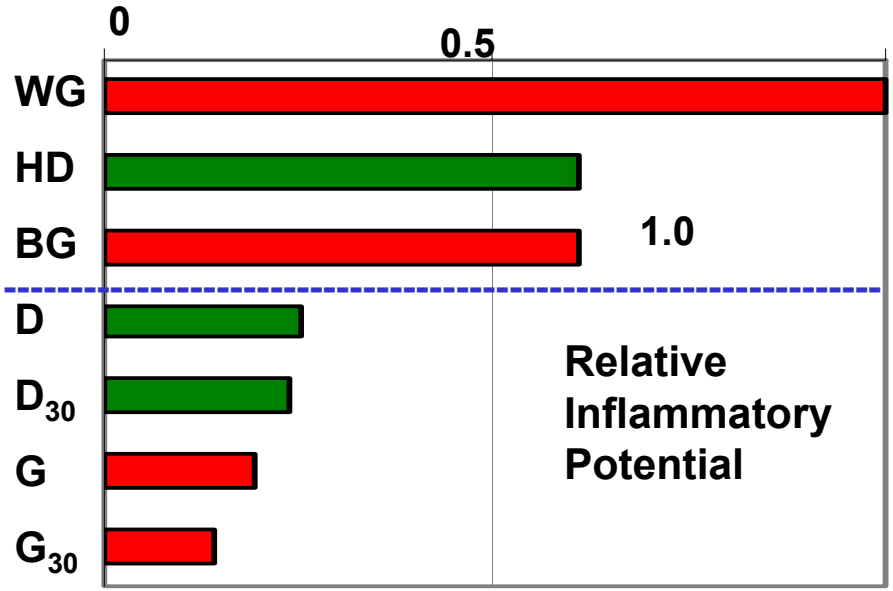
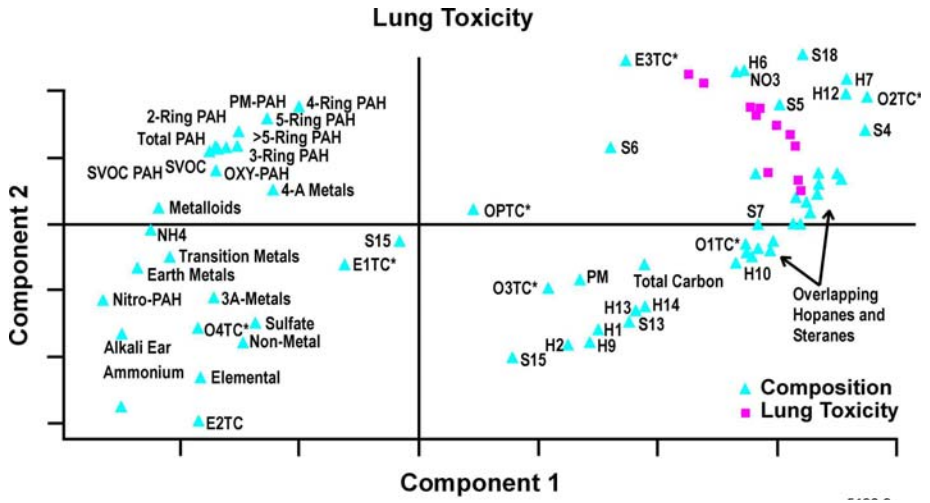
THE SAMPLES HAD A 5-FOLD RANGE OF TOXICITY AND TOXICITY WAS LINKED TO COMPOSITION

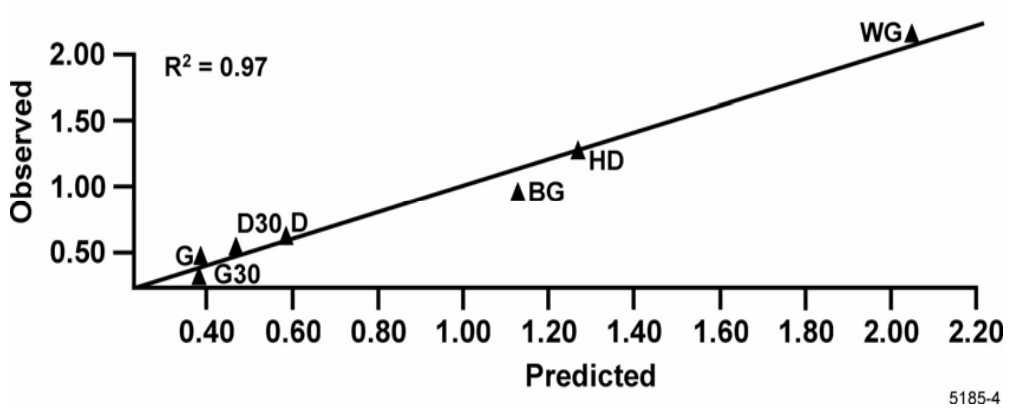


Emissions from high-emitters were more toxic per unit of mass



Hopanes & steranes, markers of crankcase lube oil, were most closely linked to toxicity !!

Same results from CNG buses



McDonald et al., *Environ Health Perspect.* 112: 1527-1538, 2004
Seagrave et al., *Toxicol. Sci.* 87:323-241, 2005

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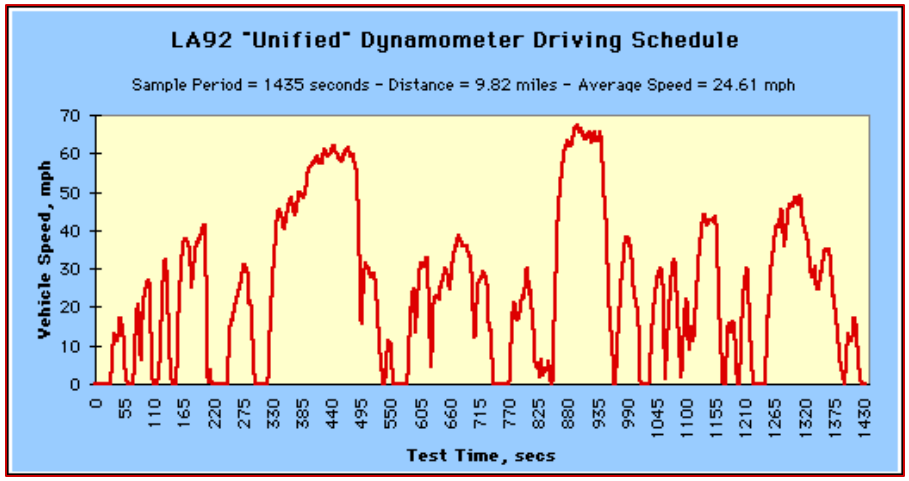
DISCOVERED THAT NON-PM EMISSIONS FROM GASOLINE ENGINES CAN HAVE CARDIOVASCULAR EFFECTS



1996 4.3 L General Motors V-6 engines

- 3 in-use Chevrolet S-10 pickup trucks
- Mid-range mileage (40-70k miles)
- Normal emissions

(California) Unified Driving Cycle

- 3-phase cycle mapped from chassis dynamometer to engine stand
- 2 engines used for 2 cold starts/day

Gasoline blended to 2002 U.S. national average regular unleaded

- No added oxygenates
- Reid vapor pressure = 10.3 psia
- 275 ppm sulfur, 30% aromatics

Pennzoil® 10w-30 lube oil

Exposed animals at 1:110 to 1:12 dilutions

- PM ≈ 7, 30 & 60 µg/m^3
- CO ≈ 8, 50, & 80 ppm
- NOx ≈ 2, 10 & 20 ppm

Also filtered emissions at high level

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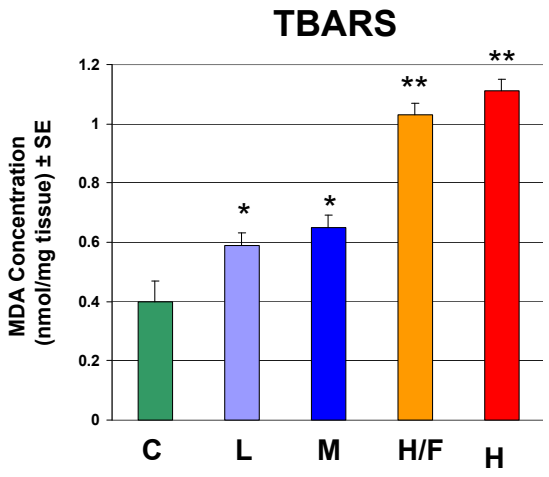
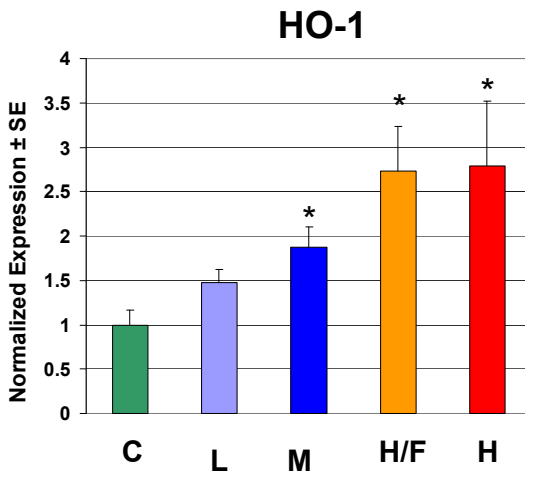
FOUND EFFECTS IN VESSELS NEAR HEART

- Exposed ApoE$^{-/-}$ mice for 7 weeks
- Measured responses in aorta near heart

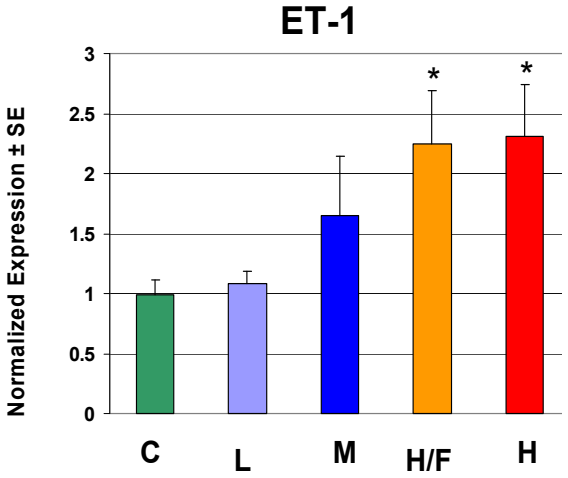
1. Effects in vessels outside the lung
2. Non-PM components drove these effects

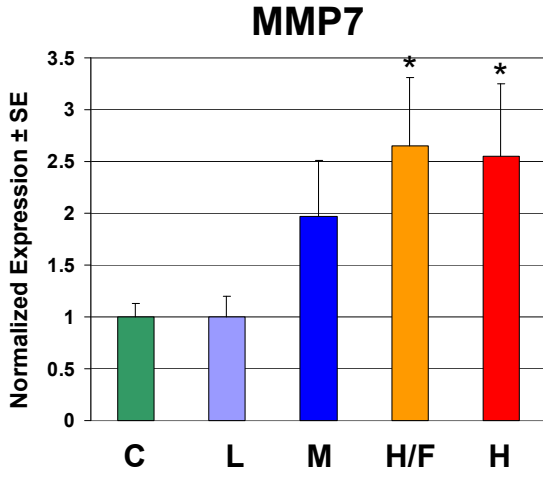
Oxidative stress





Vascular remodeling





What caused it – NOx? CO? VOCs?

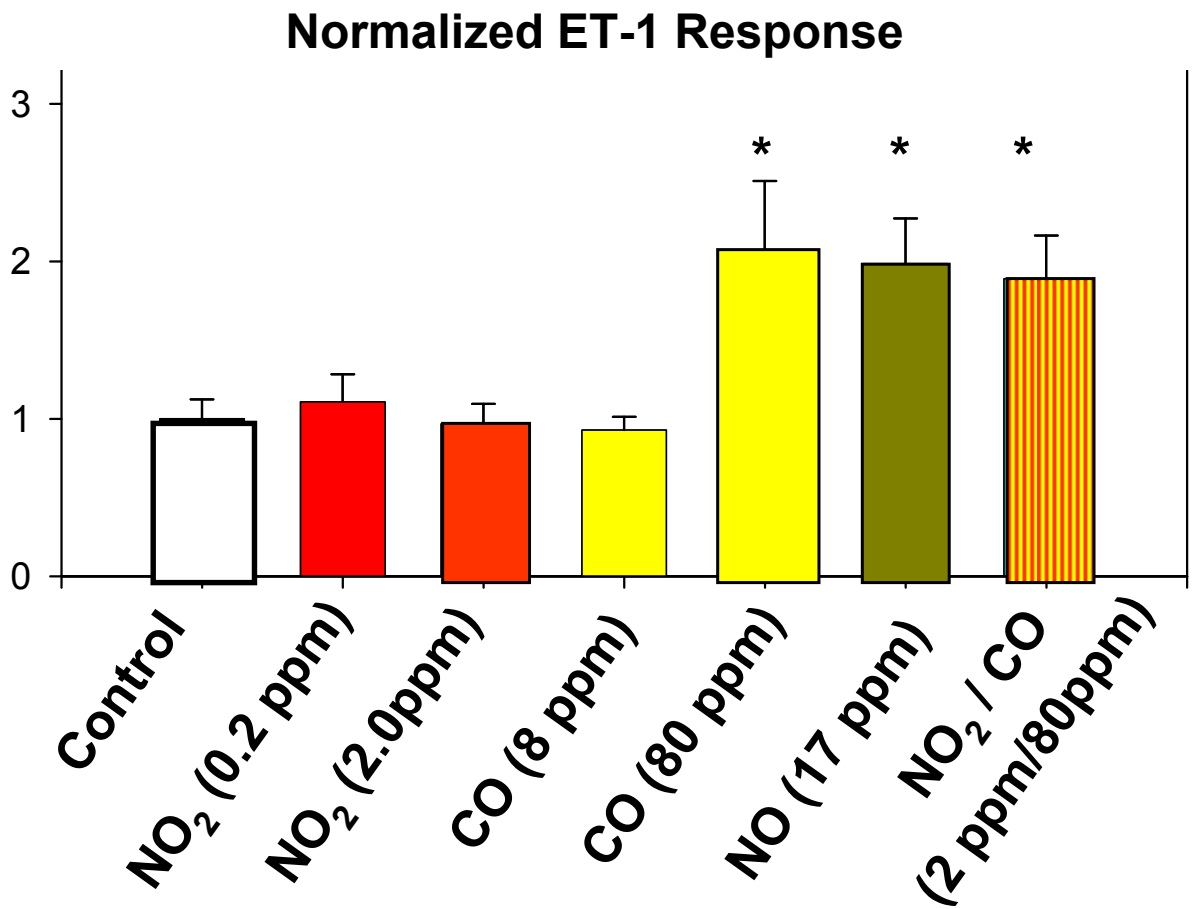
Lund et al. *Toxicol. Sci.* 95:485-494, 2007

FOUND THAT NO AND CO CAUSE SOME, BUT NOT ALL EFFECTS

Exposed mice to these gases, alone and in combination at the high and low concentrations in the gasoline study

1. CO and NO <u>did</u> reproduce effects on some responses
   (ET-1, HO-1, MMP-9)
2. NO_2 was <u>not</u> a cause
3. CO and NOx <u>did not</u> reproduce effects on other responses
   (TBARS, TIMP-2)

- Other non-PM components (VOCs?) are also important



Campen, Lund et al., new unpublished results

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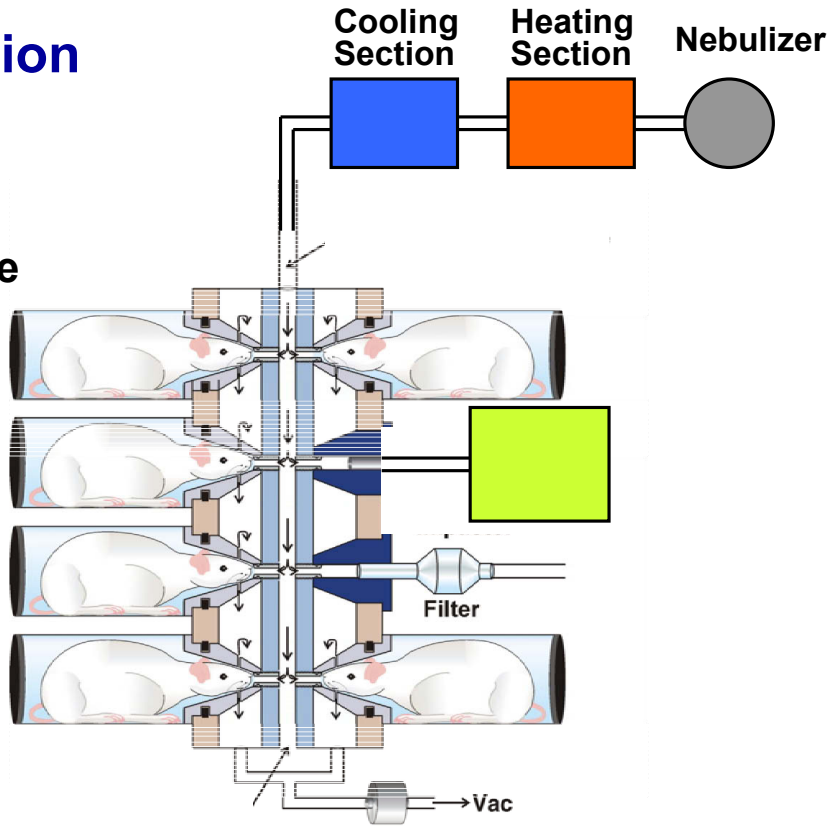
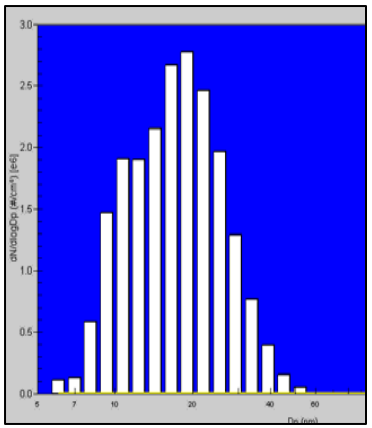
EXAMINED THE HEALTH IMPORTANCE OF OIL-DERIVED AND SULFATE NANOPARTICLES

- **Aerosolized by vaporization-condensation**
  1. New and used diesel crankcase oil
     - Shell Rotella-T® 10W-40
     - 2000 Cummins 5.9L ISB on HD cert. cycle
  2. Sulfate
     - Sulfuric acid
- **Exposed mice by inhalation**
  - 6 hr/day x 7 days
  - 15-25 nm particles at 10^6 particles/cc
- **Measured:**
  - Lung inflammation
  - Lung tissue oxidative stress
  - Lung histopathology
  - Function of systemic immune system
    - Cell proliferation
    - Antibody formation





McDonald et al. *Toxicologist* 96:230, 2007

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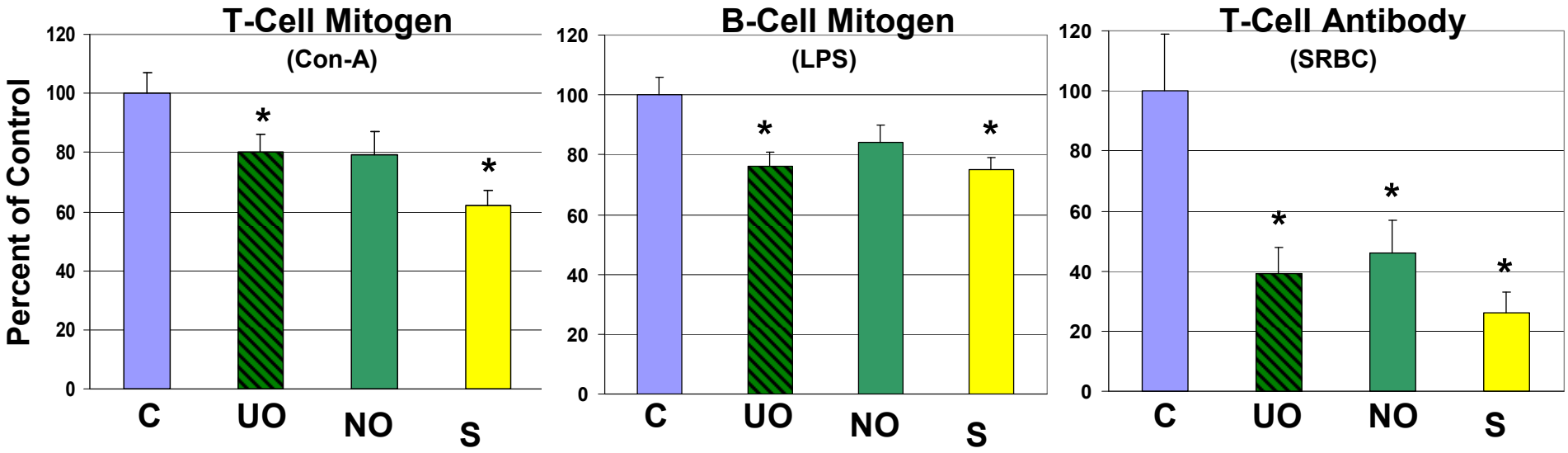
RESPONSES TO HIGH LEVELS OF "NANOCONDENSATES"

Exposure did not cause:

- Significant indications of lung inflammation
- Detectable lung pathology
- Indications of oxidative stress in plasma

Exposure did cause:

- Some stress to lung tissue
- Reduced function of immune cells outside the lung
  - Reduced cell division in response to stimulus
  - Reduced formation of antibody to foreign protein



Mitchell et al. New Data, and McDonald et al. *Toxicologist* 96:230, 2007

DEMONSTRATED HEALTH BENEFITS OF DIESEL EMISSIONS REDUCTION BY RETROFIT

Evaluated benefits of simulated retrofit by comparing effects of:

350 ppm S pre-2007 cert. fuel
No after-treatment

15 ppm S fuel (BP-15)
Catalyzed PM trap

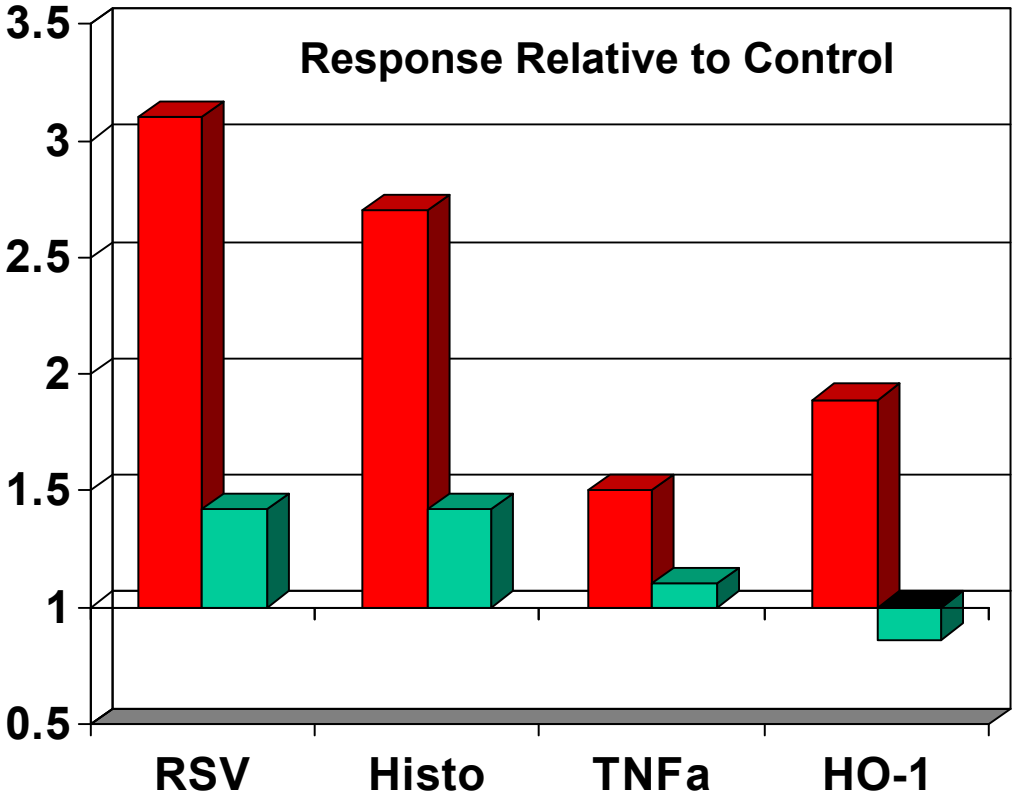
- **Yanmar YDG5500E diesel generator at same load and dilution**
- **Exposed mice 6 hr/d x 7d**
- **Measured:**

  Clearance of Respiratory Syncytial Virus (RSV)

  Histopathology (HISTO)

  Pro-inflammatory cytokine (TNFα)

  Indicator of oxidative tissue stress (heme-oxygenase-1 [HO-1])



Health effects were eliminated or reduced to non-significant levels

McDonald et al. *Aerosol Sci. Technol.* 38: 62-78, 2004
McDonald et al., *Environ. Health Perspect.* 112: 1307, 2004

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INITIATING LONG-TERM STUDY OF 2007-COMPLIANT HD DIESEL EMISSIONS (ACES)

Exposure:

- 2007-compliant ~400-450 hp engine/after-treatment system
  - Engine to be selected from 4 candidates in Phase 1 at SwRI
- Variable-duty cycle on AC dynamometer
- 2007-compliant (ultra low sulfur) petroleum-based fuel
- Whole emissions diluted to 3 concentrations (not yet specified) + control
- Expose 6 hr/day, 5 days/wk

Evaluation of Biological Effects

- 2 yr exposure of 166 Wistar rats/group for carcinogenicity (begin in fall of '08)
- Interim evaluation of 20 Wistar rats/group at 1, 3, 12, and 24 mo
  - Respiratory function
  - Bronchoalveolar lavage
  - Histopathology and lung cell proliferation
  - Additional measurements selected by HEI
- 3 mo exposure of 120 C57BL/6 mice/group, with evaluation at 1 & 3 mo
  - Bronchoalveolar lavage
  - Lung histopathology and cell proliferation
  - Additional measurements selected by HEI

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BOTTOM LINES

The problem is emissions - not diesel emissions

- All competing combustion technologies emit pollutants that can be hazardous at some level
- Small differences among current technologies at equal masses
- High emitters of all technologies are the main problem

There is no single "magic bullet"

- Particles, VP-SVOCs, and gases can all have effects
- Lube oil emissions are important
- Nanoparticles can have effects
- Hazards are not all in the lung

Cleaning up diesels is undoubtedly reducing health impacts

- Retrofits help
- 2007-2010 "on-road" emissions ???

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