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In-Vehicle Exposure Research in California

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PRESENTATION ABSTRACT

A recent and successful measurement campaign on California roads showed that in-vehicle concentrations of vehicle-related air pollutants such as diesel PM (DPM) or ultrafine particle (UFP) number concentrations are many times higher than ambient concentrations. As a result, the time spent in vehicles is a significant contributor—sometimes the main contributor—to overall human exposure to air pollution. In this presentation, we will discuss two recent studies of in-vehicle measurements and future plans for continued exposure research.

In the original effort conducted by CARB investigators in 1997, Aethalometer black carbon (BC) measurements were made inside vehicles driven on freeway and arterial loops in Los Angeles and Sacramento, and focused on following diesel vehicles. To correct for over-sampling of diesel vehicles and to calculate representative in-vehicle exposures, in-vehicle BC concentrations were grouped by the type of vehicle followed, as determined by video tape records, for each road type and congestion level. These groupings were then re-sampled stochastically, in proportion to the fraction of statewide vehicle miles traveled (VMT) under each of those conditions. The statewide in-vehicle average was 4 μg m^{-3}, corresponding to DPM concentrations of 7 to 23 μg m^{-3}, depending on the Aethalometer response to elemental carbon (EC) and the EC fraction of the DPM. In-vehicle contributions to overall lifetime DPM exposures ranged from approximately 30 to 55% of calculated total DPM exposure on a statewide population basis, while average time spent in vehicles was only 6%.

In a follow-up study conducted in 2003, an electric vehicle was used to house a collection of real-time or near real-time particle measurement instruments including two CPCs and two SMPSs. In addition, real-time measurements were made of NOx, CO/CO_2, BC (by light absorption), particulate matter-phase PAH (PAS), and particle length (DC). Measurements were conducted on a variety of streets and freeways in Los Angeles. High correlations between UFP numbers and diesel vehicle-related pollutants were observed (e.g., Pearson's r^2~0.8 for NO, 0.8 for black carbon, 0.7 for PAH, and 0.9 for particle length). After compiling a video-assisted, real-time record of location, speed, acceleration, congestion, diesel truck density, and the vehicle-followed, multiple regression and ANOVA analyses showed that 60 to 80 % of the variability (i.e., R^2 of 0.6 to 0.8) in UFP count, black carbon, NO, and particulate-bound PAH concentrations was explained by the particular freeway segment as well as the diesel truck densities. In addition, annual average diesel truck counts for each freeway segment were found to be highly linearly correlated with UFP concentrations (Pearson's r^2~0.9), indicating good estimates of in-vehicle and roadway UFP concentrations can be made from existing truck counts. Other measures such as speed, total congestion, and vehicle followed were much less predictive of concentrations of these pollutants, although congestion was a decent predictor of CO and CO_2. UFP concentrations on freeways were more than an order of magnitude higher than in residential locations, indicating that urban freeway commuters likely receive the majority of their daily UFP exposure during their drive time.

The success of these previous studies has led to additional and important research efforts underway now. Under its research portfolio for the current year, CARB will be re-equipping an electric vehicle with new instrumentation for continued mobile monitoring of vehicle-related pollution in California.

Presentation Outline

- **Overview of in-vehicle exposures**
- **In-vehicle studies in California**
  1) **In-vehicle diesel PM exposures calculated from black carbon measurements (1997 chase study[1])**
  2) **Ultrafine particle exposures from 2003 measurements on Los Angeles freeways[2]**
  3) **Near future development of *next generation* mobile monitoring platform for exposure research**
- **Implications of in-vehicle exposures**

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[1]*Rodes, C., Sheldon, L., Whitaker, D., Clayton, A., Fitzgerald, K., Flanagan, J., DiGenova, F., Hering, S., Frazier, C., 1998. Measuring concentrations of selected air pollutants inside California vehicles. Final Report, Contract No. 95-339. California Air Resources Board, Sacramento, CA.*

[1]*Fruin, S.A., Winer, A.M., Rodes, C.E., 2004. Black carbon concentrations in California vehicles and estimation of in-vehicle diesel exhaust particulate matter exposures. Atmospheric Environment 38, 4123-4133.*

[2]*Westerdahl, D., Fruin, S., Sax, T., Fine, P., Sioutas, C. 2005. A mobile platform approach to measuring ultrafine particles and associated pollutant concentrations on freeways and residential streets in Los Angeles. Atmospheric Environment 39:3597-3610.*

1 In-Vehicle Concentrations

- **Air exchange rates in vehicles are high**
- **Concentrations:**

In-Vehicle ~ Centerline > Roadside >> Ambient

Examples of in-vehicle-to-ambient concentration ratios:

Benzene: 4 to 8 times higher[1], 15-20% of total expsoure

Diesel PM: 5 to 15 times higher[2], 30 - 50% of total exposure

1,3-butadiene: 50 to 100 times higher[3], likely >50% of total exposure

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[3]*Duffy, B.L., Nelson, P.F., 1997. Exposure to emissions of 1,3-butadiene and benzene in the cabins of moving motor vehicles and buses in Sydney, Australia. Atmospheric Environment 31(23), 3877-3885.*

Effect of Following Specific Vehicle Types on In-vehicle Concentrations

- *Sacramento and Los Angeles, 1997*
- *Real-time measures of fine particle counts and black carbon*
- *Diesel vehicle chase-study design*

Los Angeles

Vehicle Type Followed	Black carbon (µg/m³)	Number of vehicles
(Urban background)	~1	
(Roadway background or gasoline passenger car [PC])	4.8	~355
Diesel tractor trailer	13	47
Diesel transit bus, high exhaust	16	12
Diesel passenger car	19	8
Gasoline-powered PC, smoky	19	6
Diesel transit bus, low exhaust	95	16

Reference: Charles Rodes et al., 1998. RTI, Sierra Research, Aerosol Dynamics; SCAQMD co-funding

In-Vehicle Diesel PM Concentrations & Exposure Results

(adjusted to simulate realistic driving conditions)

- **High congestion areas: 11 to 33 µg/m³**

  (Los Angeles and San Francisco Bay Area)
- **Moderate congestion areas: 6 to 17 µg/m³**
- **5 to 15 times calculated ambient concentrations**
- **30 to 55% of total diesel PM exposure**
  - ***In-vehicle time most important route of exposure on a per-time basis***
- **Based on estimated ambient and indoor concentrations and time activity patterns, <u>on-road</u> diesel PM emission reductions yield 2 to 5 times more health benefit than equal <u>off-road</u> emission reduction**

2 2003 Field Study Route

Continuous pollutant measure-ments:

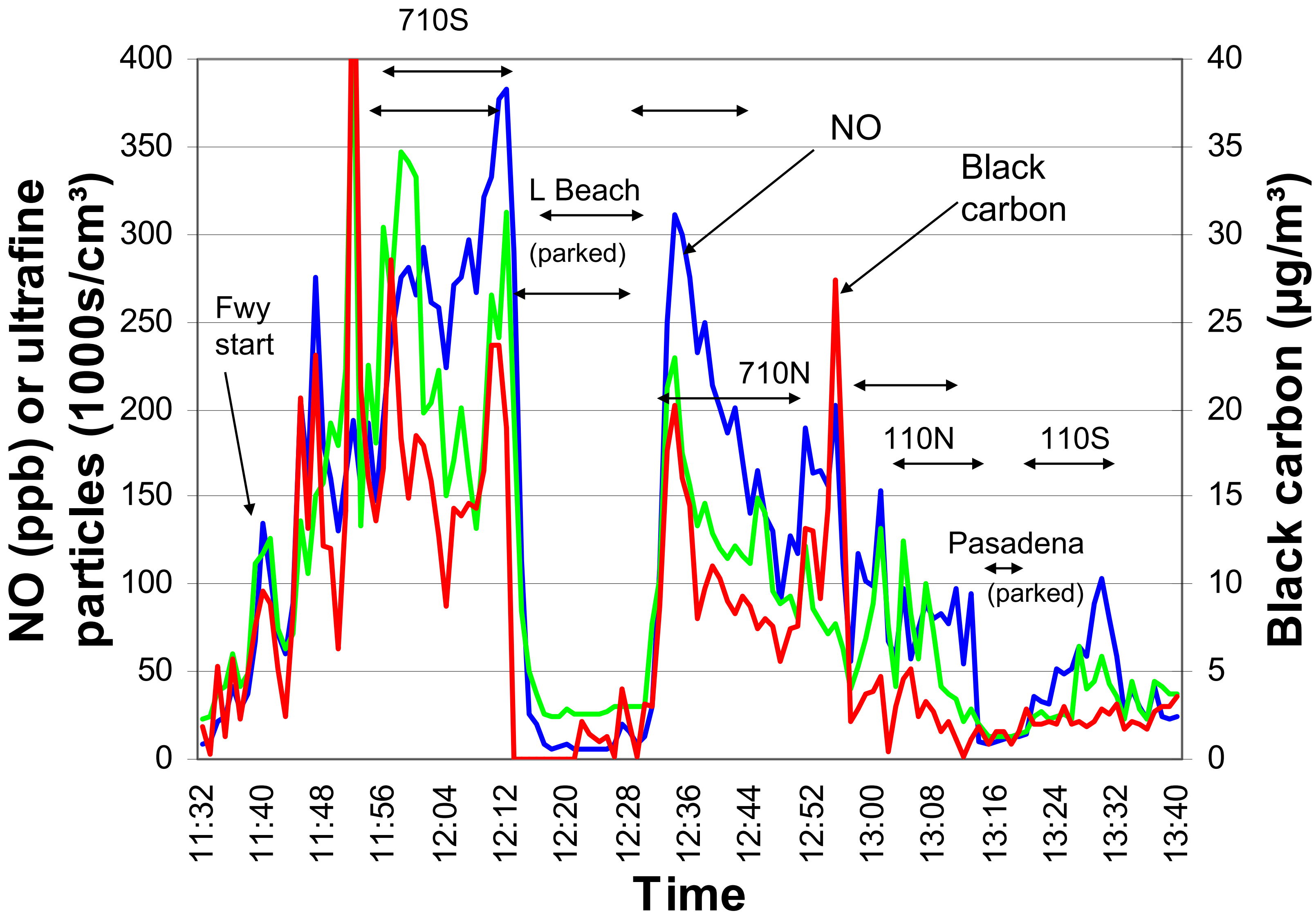
Black carbon, ultrafine particles, NO, NO_2, CO, CO_2, particle-bound PAHs, PM2.5

Mobile Monitoring Platform Used for 2003 Study

Our next generation unit will evolve from this platform

Source: D. Westerdahl et.al., 2005.

Time Series: NO, Ultrafine Particle Number, and Black Carbon



High Emitter of Black Carbon, PM2.5

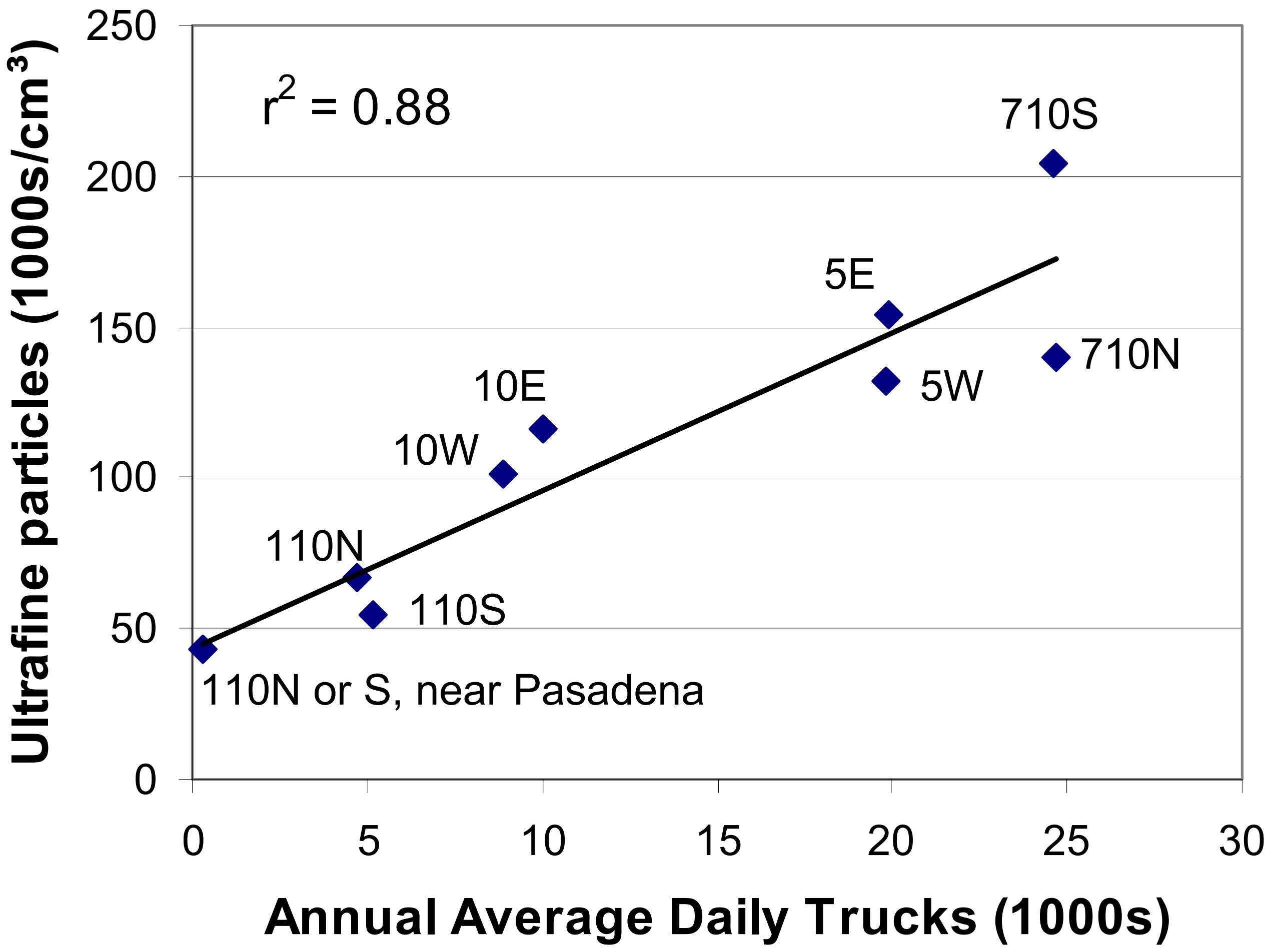
High Ultrafine Particle Emitter

Gasoline-powered van

Average In-Vehicle Concentrations (Four Days)

Location or roadway	Ultrafine particle conc. (#/ cm^3)	NO (ppb)	Black carbon (μg/m^3)	CO_2 (ppm)	Avg. min. per run
Residential Street (Long Beach)	27,000	19	1.4	420	14
110N freeway near Pasadena (~300 trucks/day)	43,000	150	1.6	770	15
110N freeway (~3000 trucks/day)	67,000	230	3.9	850	10
710S freeway *(Diesel dominated)* (~25,000 trucks/day)	200,000	400	14	850	21

Ultrafine Particle Number by Freeway Segment versus Average Daily Truck Count

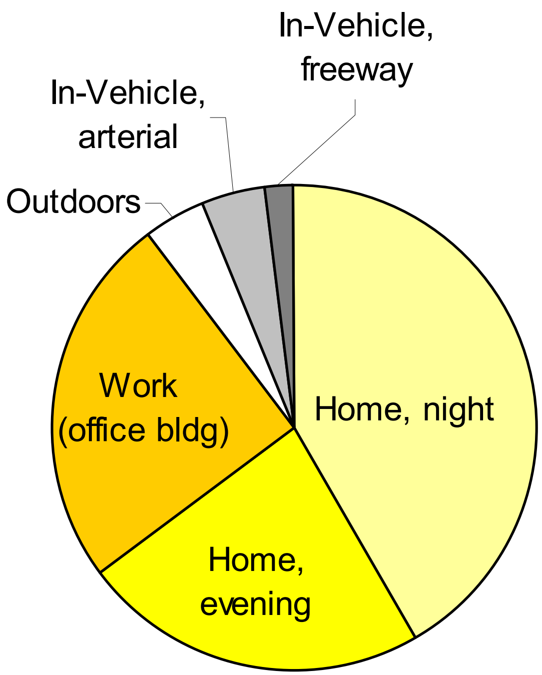


Estimates of In-Vehicle Fraction of Total UF Particle Exposure in Los Angeles

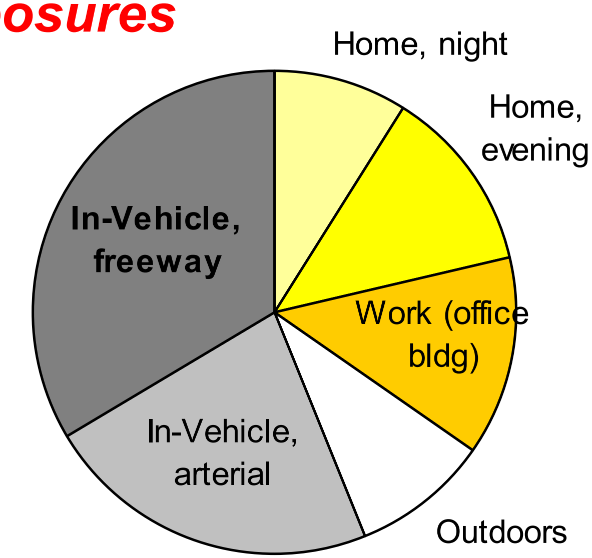
Location	Time (Hrs)	Typical Concentration (1000s/cm³)
Residential	9	2 (night)
Residential	5.5	5 (evening)
Workplace	7	5
Outdoors	1	20
In-vehicle arterial	1	50
In-vehicle freeway	0.5	150

>50% exposure from in-vehicle time

> 6% of day driving can give up to 50% of our exposures



Average Time Spent



Contribution to Exposure

Key Findings

- In-vehicle exposures larger or majority fraction of overall exposures to vehicle-related pollutants
- Ultrafine particle exposure depends on:
    - Length of your commute
    - Diesel truck volumes
    - Types of vehicles followed
- Location of emissions matter:
    - On-road emissions produce greater overall exposures than off-road
    - Exhaust at low and rear of vehicle produces greater in-vehicle impacts than exhaust at high and front of vehicle
- Reductions in on-road diesel emissions are critical to reducing in-vehicle UFP exposures

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Next Steps

- **Design of next-generation mobile platform underway**
  - **CARB & UCLA collaboration**
  - **Evolves from original *proof-of-concept* unit**
  - **Modules with more and better instruments**

- **Permanent platform for research:**
  - **Spatially-resolved concentration maps**
  - **Characterization of sharp concentration gradients and their effects**
  - **Determine relative importance of regional versus local emission sources**
  - **Support and enhance other research**

- **Deployment in April 2006 for pilot work in Wilmington, California**