Exposure to Diesel Exhaust Particulate Matter in Vehicles: Implications for Exposure Assessment and Control Priorities

ARB Chairman's Seminar

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Scott Fruin

Research Division

Acknowledgements

- Measuring Concentrations of Selected Air Pollutants Inside California Vehicles (1998)

- Primary investigators
  - RTI: Charles Rodes (PI)
    Linda Sheldon (Co-PI)
  - Sierra Research: Frank DiGenova
  - Aerosol Dynamics: Susanne Hering
  - ARB: Steve Hui

- Co-funded by SCAQMD
  - ftp://ftp.arb.ca.gov/carbis/research/apr/past/95-339a.pdf

Outline

- Exposure assessment, exposures in vehicles
- Why diesel exhaust?
- Previous DPM exposure assessment
- Overview of field study
- Methods
- Results
- Uncertainty analysis
- Policy implications

Exposure Assessment

- For many pollutants, most exposure occurs in home
- Exposures often highly variable
  - Differences in people's activities
  - Steep indoor gradients possible
- Exposures often not known
  - Expensive to measure
  - Adds uncertainty to epidemiology studies

Exposures in Vehicles

- **Previous in-vehicle studies**
  - **Concentrations of vehicle-related pollutants typically 5 to 10 times higher than ambient**
  - **Usually VOCs, few PM studies**
- **Typical time spent in cars**

Why is Diesel Exhaust a Concern?

- **Probable carcinogen**
  - **ARB TAC determination, 1998**
  - **Majority of air pollution cancer risk (?)**
- **Diesel vehicles cleaner but still uncontrolled**
- **Particle number and UF particles may be a new health concern**

Previous DPM Exposure Assessment

- CMB used to determine ambient motor vehicle PM concentrations
- DPM fraction estimated with EMFAC
- Extrapolated statewide, weighted by population

Previous Exposure Assessment

- Indoor concentrations calculated for nine microenvironments
  - Created artificial precision
  - In-vehicle concentrations assumed to equal ambient

Previous Exposure Assessment

CA activity patterns used to link indoor distributions with people[1]

- 2962 24-hr sequences of 100 activities in 50 locations
- Exposure distributions captured variability, but not uncertainty

[1]Wiley et al., 1991

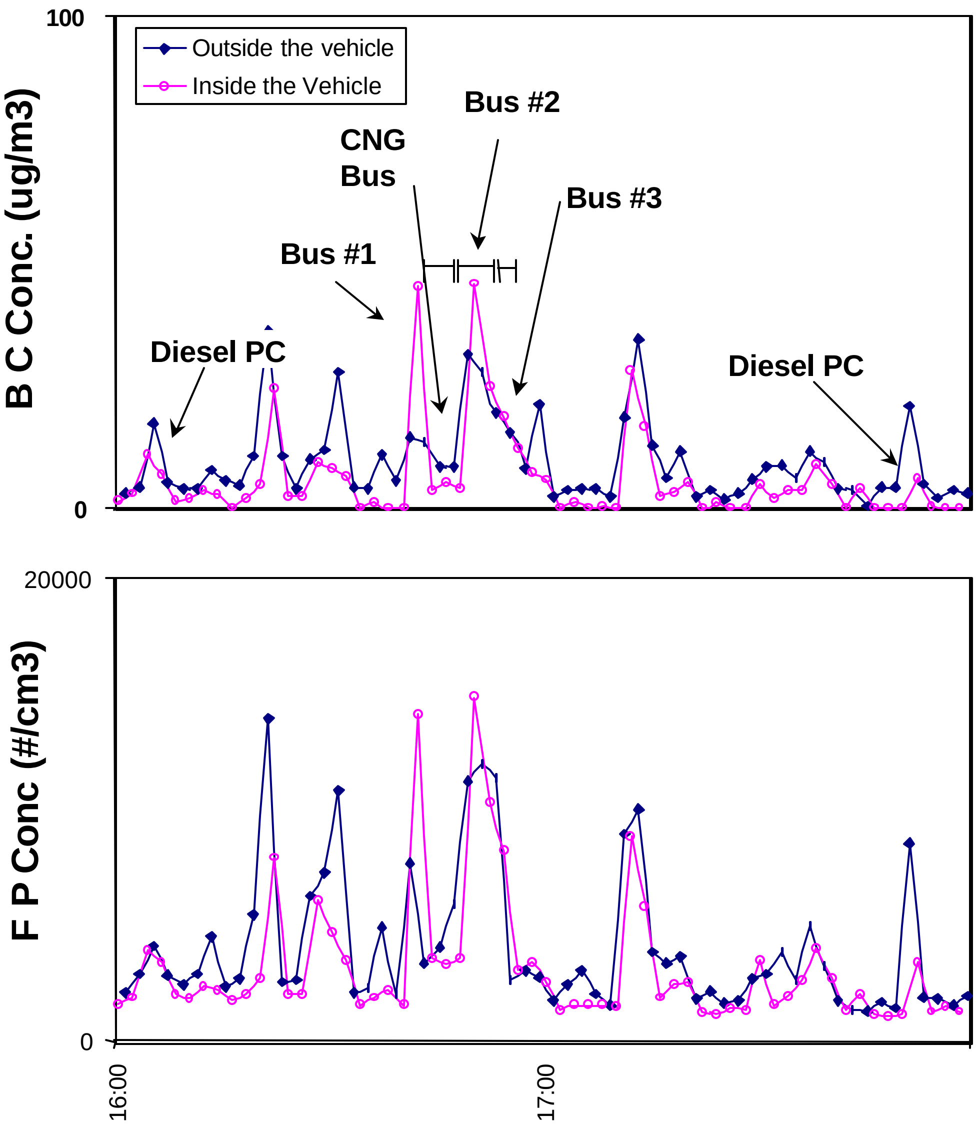
Field Study Overview

- Speciated VOCs, metals; real-Time CO, fine PM, and BC
- 29 two-hour runs: Sacramento (13), Los Angeles (16)
- Fall, 1997
- Freeway, arterial, carpool lanes
- Speed, following distance measured
- Congestion estimated
- Video taped
- Emphasis on following diesel-powered vehicles

Examples of Real-Time Data

Los Angeles Arterial Roads

Run #27



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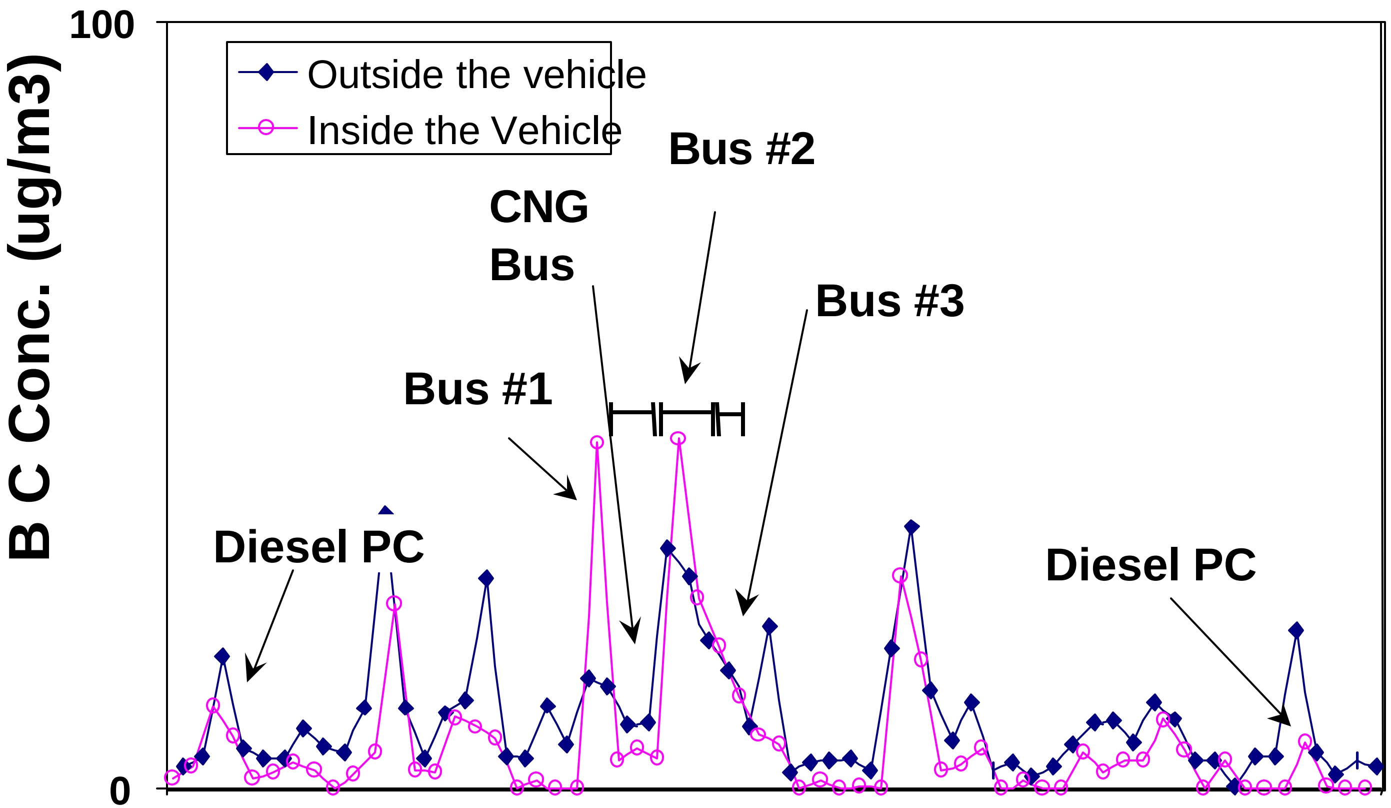


Preliminary Analysis

- **Very close association between peak concentrations and vehicles followed with fast response time**
- **Concentrations appeared significant**
- **Atypical driving apparent**

Study Goals

- Adjust in-vehicle concentrations for non-realistic driving, apply to other regions of the state
- Add in-vehicle exposures to previous assessments of exposure
- Characterize uncertainty, including previous exposure assessment

Methods: Video Tape Analysis

1. Analyzed video tapes for:
   - Types of vehicles followed
   - Visible emissions
   - Exhaust location, axle number
   - Road type, number...
2. Assigned video observation variables to measured 60-second averages

Statistical Treatments*

3. Performed statistical analyses to find most appropriate BC concen-tration groupings

- **Multiple regressions**
  - **Type of vehicle followed, visible smoke, exhaust height most important**
- **Longer averaging times**
  - **Reduced autocorrelation**
  - **Reduced bias due to long following times**

*thanks to L. Larsen, J. Austen, H. Tran

Deriving Distributions

4. Created in-vehicle DPM distributions

- PC/no target, low-exhaust diesel bus, alt-fuel diesel bus, other 2-axle, 3 to 5-axle
  - Linkable to other traffic measures

- Sacramento and LA separate

- Theoretical best fit of log-normal distribution.

California Driving Patterns

5. Characterized California driving in terms of these DPM distributions
   - Typical diesel following frequency
     - Reduced frequency bias
   - VMT per road mile as measure of congestion
   - Speed differences
6. Realistic driving represented by distribution weighting factors

Uncertainty Analysis

7. Estimated uncertainties in DPM distributions and weightings

8. Estimated uncertainties in original exposure assessment

9. Propagated uncertainty through all calculations

Exposure Calculations

10. Calculated exposures with CPIEM

- Original results duplicated
- New in-vehicle distributions and weighting factors added
- Sensitivity runs used to reduce number of uncertainty runs
- Uncertainty runs conducted

Results:
Influence of Vehicle Followed

Type of diesel vehicle followed was strong predictor of BC concentrations

Explained 73% of BC variability in LA, 34% in Sacramento

BC Concentrations by Vehicle (LA)

No target or PC	4.8 µg/m³
Tractor trailer	11
Diesel PC	18
Delivery truck, low exh	23
MTA bus, low exhaust	64

Effect of Exhaust Height

By vehicle and exhaust height (LA):

Tractor-trailer with container	11 µg/m³
Delivery truck, high exh.	14
Delivery truck, low exh.	23
MTA bus, high exhaust	18
MTA bus, low exhaust	64

Effect of Visible Smoke

- Explained 44% of BC variability in LA and 25% in Sacramento
- By category (LA):

Opaque, dense plume	210 $\mu g/m^3$
Visible during acceleration	32
Continuously visible	22
Slightly visible	12
Not visible	12
No diesel followed	4.8

Gear Shift

Continuous

Dense Plume

Variables of Lesser Importance

- Moderately important variables
  - Run number
  - Road type (Sacramento)
- Little association
  - Driver estimates of congestion
  - Speed
  - Following distance
  - Freeway number
  - Air exchange rate
  - Time of day

In-Vehicle Exposures

- **Study measurements biased high for LA; Sacramento not biased**
  - **LA field study averaged 33 µg/m³ DPM while realistic modeling calculated 12 µg/m³**
- **Largest contributor to in-vehicle DPM exposure was driving time in areas of high congestion while <u>not</u> behind diesel vehicles**

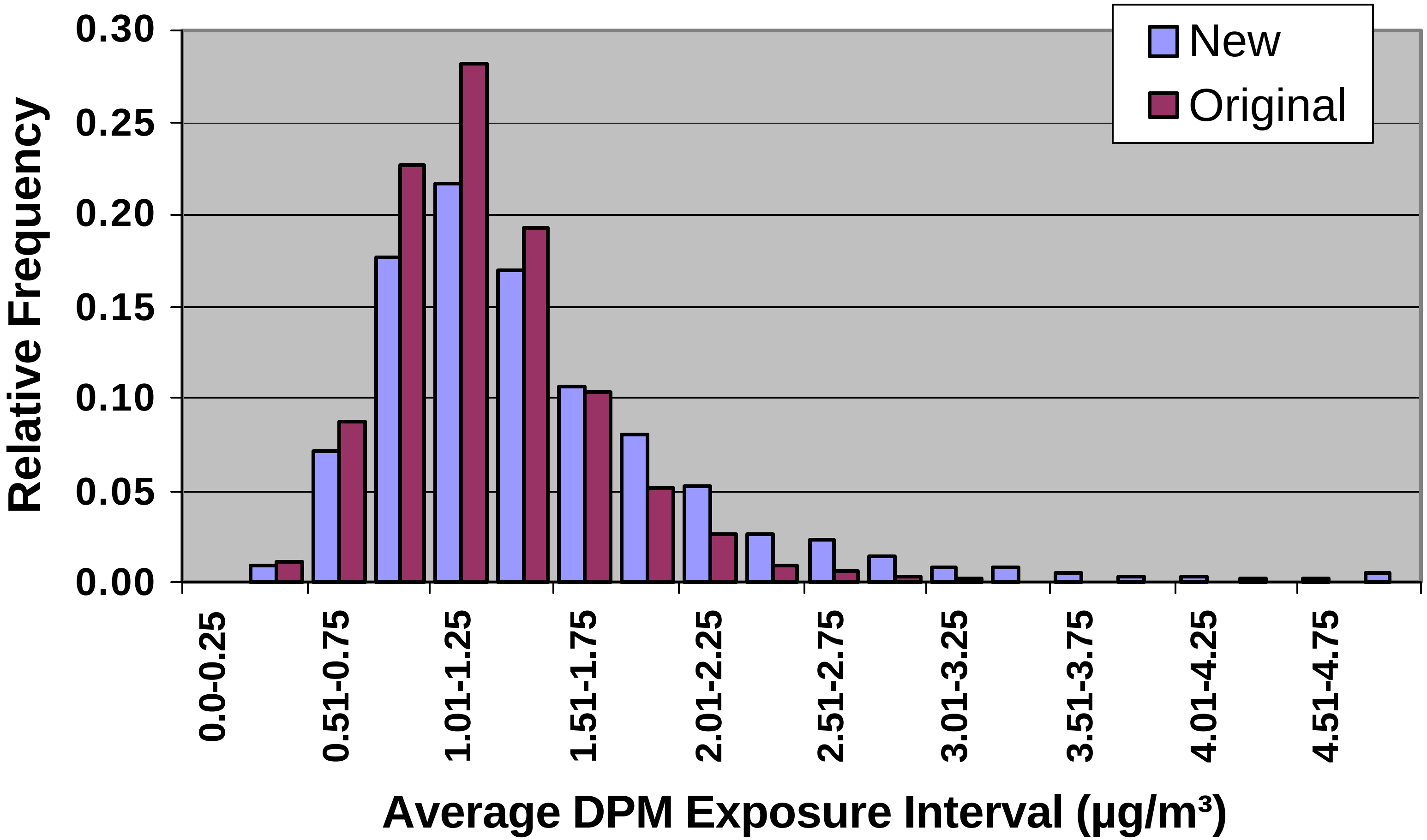
Overall Exposures

- **Average 24-hour DPM exposures increased about 30%**
- **In-vehicle exposures contributed about one-third of exposures while comprising 6% of people's day**
- **Largest overall contributor to DPM exposure was time spent at home**

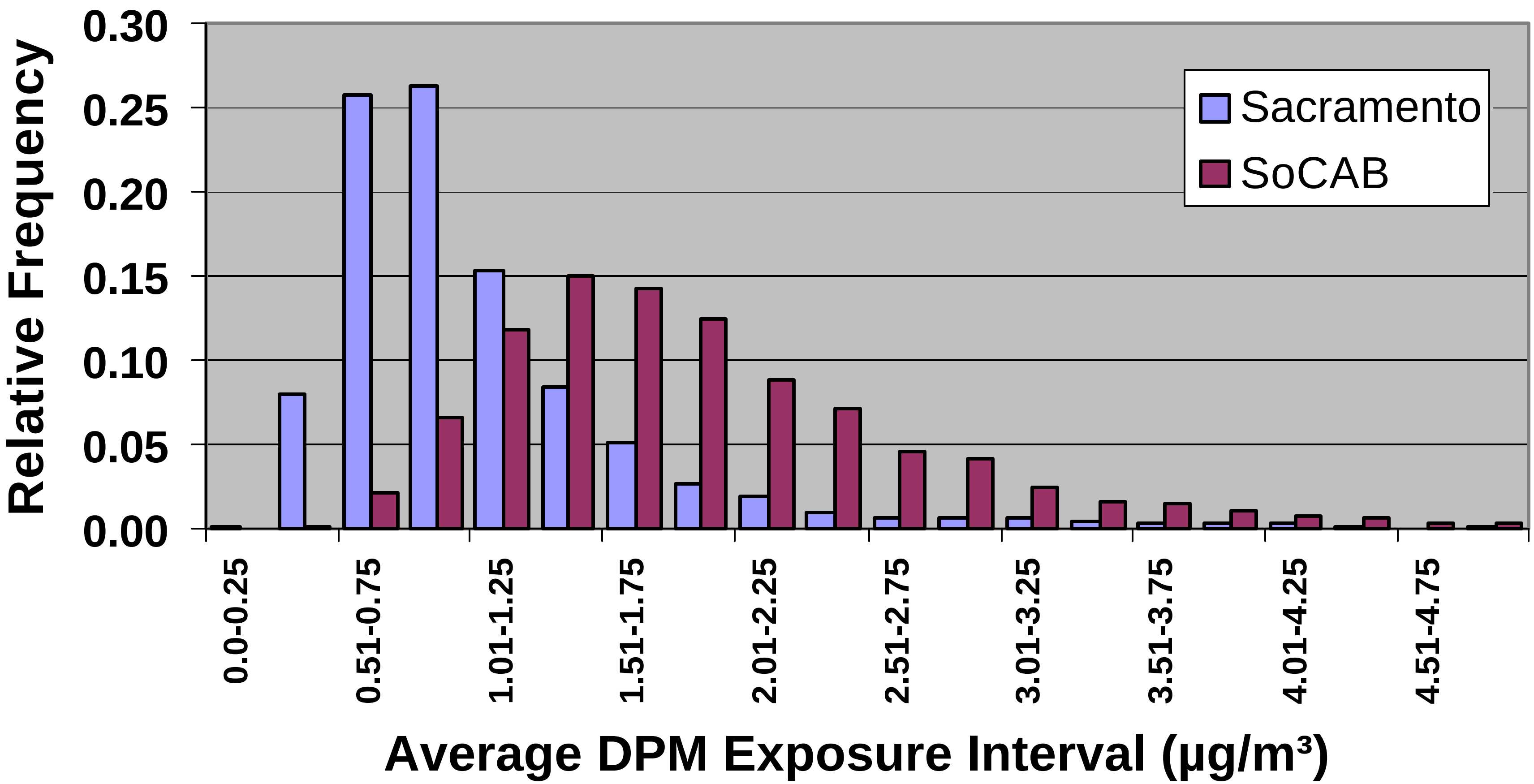
24-Hour DPM Averages,

	Year 2000 ($\mu g/m^3$) CA	LA
Avg Amb. Conc.	1.8 ± 0.66	2.4 ± 0.92
Avg 24-Hr Exposure	1.7 ± 1.6	2.2 ± 2.3
Avg In-Veh Exposure	8.3 ± 25	12 ± 36

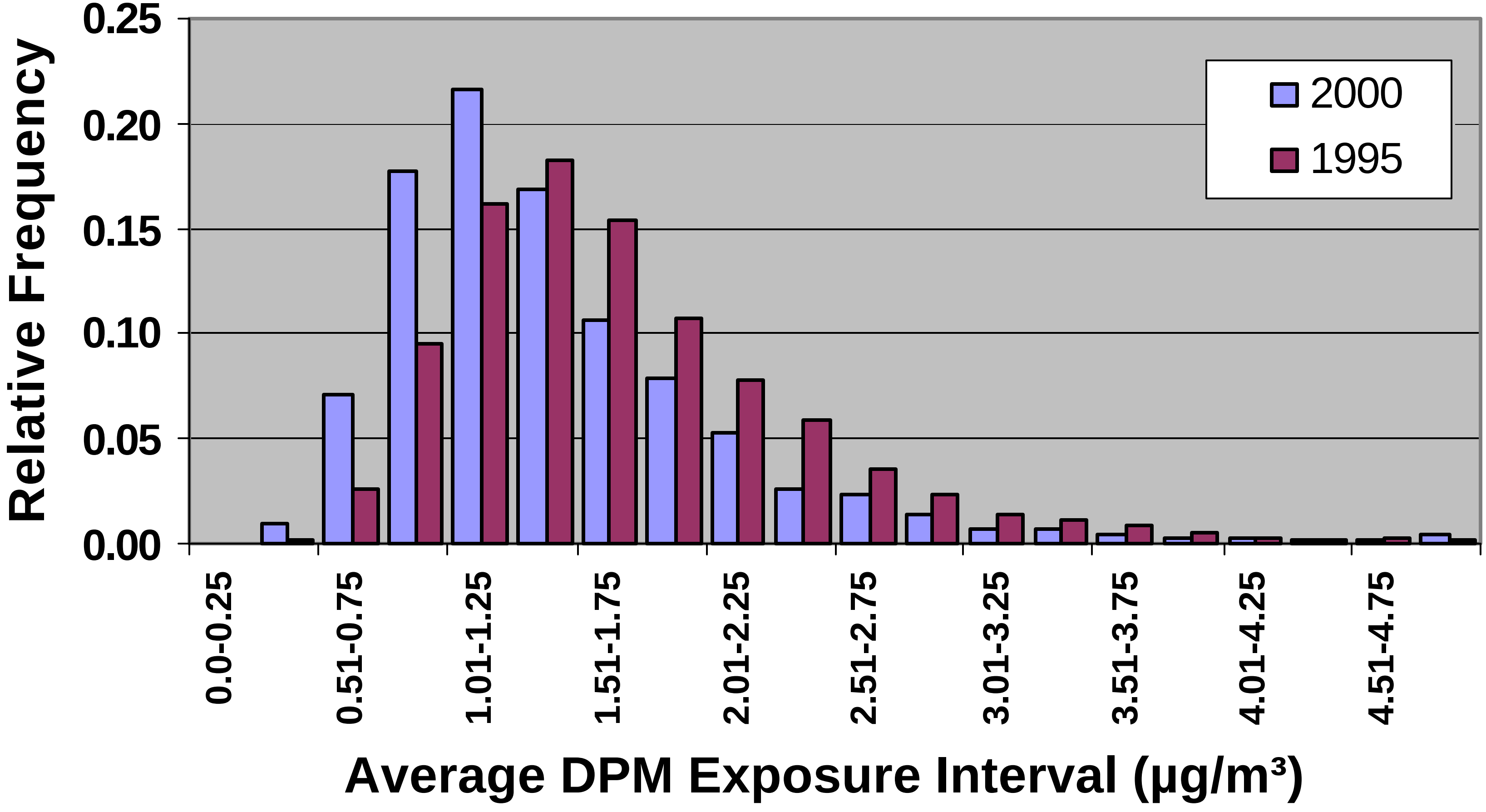
Statewide 24-Hr DPM Exposures, New vs. Original Assessment, 2000



24-Hr DPM Exposures, Sacramento vs. SoCAB, 2000



Statewide 24-Hr DPM Exposures, 1995 versus 2000



Results of Uncertainty Analysis

- Motor vehicle fraction of ambient PM from CMB ± 20 to 40%
- EMFAC diesel fraction uncertainty estimated to be at least ± 50%
- Ambient air DPM ± 50%
- Indoor DPM conc. ± 54%
- Overall DPM exposures ± 54%
- In-vehicle DPM exposures ± 16%

Implications of Uncertainty Analysis

- EMFAC-estimated DPM fraction of motor vehicle PM dominated uncertainty in
  - ambient air DPM concentrations
  - indoor DPM concentrations
  - overall exposure uncertainty
- Largest contributor to overall DPM exposure uncertainty by location was residential microenvironment

Policy Implications: On-Road Emissions

- On-road DPM emissions contribute three times as much exposure on an equal mass basis compared to off-road
  - Equal exposure from on-road and off-road
  - Off-road DPM 3/4 of total DPM emissions
- Vehicle characteristics can affect exposures
- Visible emissions a good indicator of strong source of DPM exposure

Policy Implications: Overall DPM Exposures

- In-vehicle time most important route of exposure on a per-time basis
  - Even more true for pollutants found in fresh vehicle exhaust, especially if short-lived
- Most overall DPM exposure still occurs at home
  - Proximity of homes to diesel vehicle traffic not taken into account

Recommendations for Future In-Vehicle Studies

- **Design to be representative, not "range-finding"**
  - **Use statistics to determine ranges**
- **Roadway concentrations more important to characterize than direct diesel influences**
  - **Runs can be shorter, so can include more geographic coverage in a city, other cities**
  - **Include more seasons**
  - **To save cost, measure fewer pollutants but add ultrafine number concentrations**

The End