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SIZE-SEGREGATED PM EMISSIONS FROM DIESEL WITH AFTER-TREATMENT AND FROM CNG-FUELED TRANSIT BUSES

Norman Kado, Alberto Ayala, and Robert Okamoto

California Environmental Protection Agency

Air Resources Board

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Overview

- **CARB's CNG and Diesel Transit Bus Emissions Comparative Study**
  - Investigators from CARB, UCD, UCONN, CAVTC
  - Funding by CARB, SCAQMD, So.Cal. Gas Co.
  - Contributions from BP
  - All late-model, in-use transit buses
  - Phase 1 = Diesel (DOC), Diesel (CRT), CNG (no aftertreament)
  - Phase 2 = CNG (no aftertreatment), CNG (OxiCat)

- **MOUDI Size Distributions**
  - Steady State (55mph) and Central Business District Cycle
  - Only for Phase 1 testing (no CNG with OxiCat results)

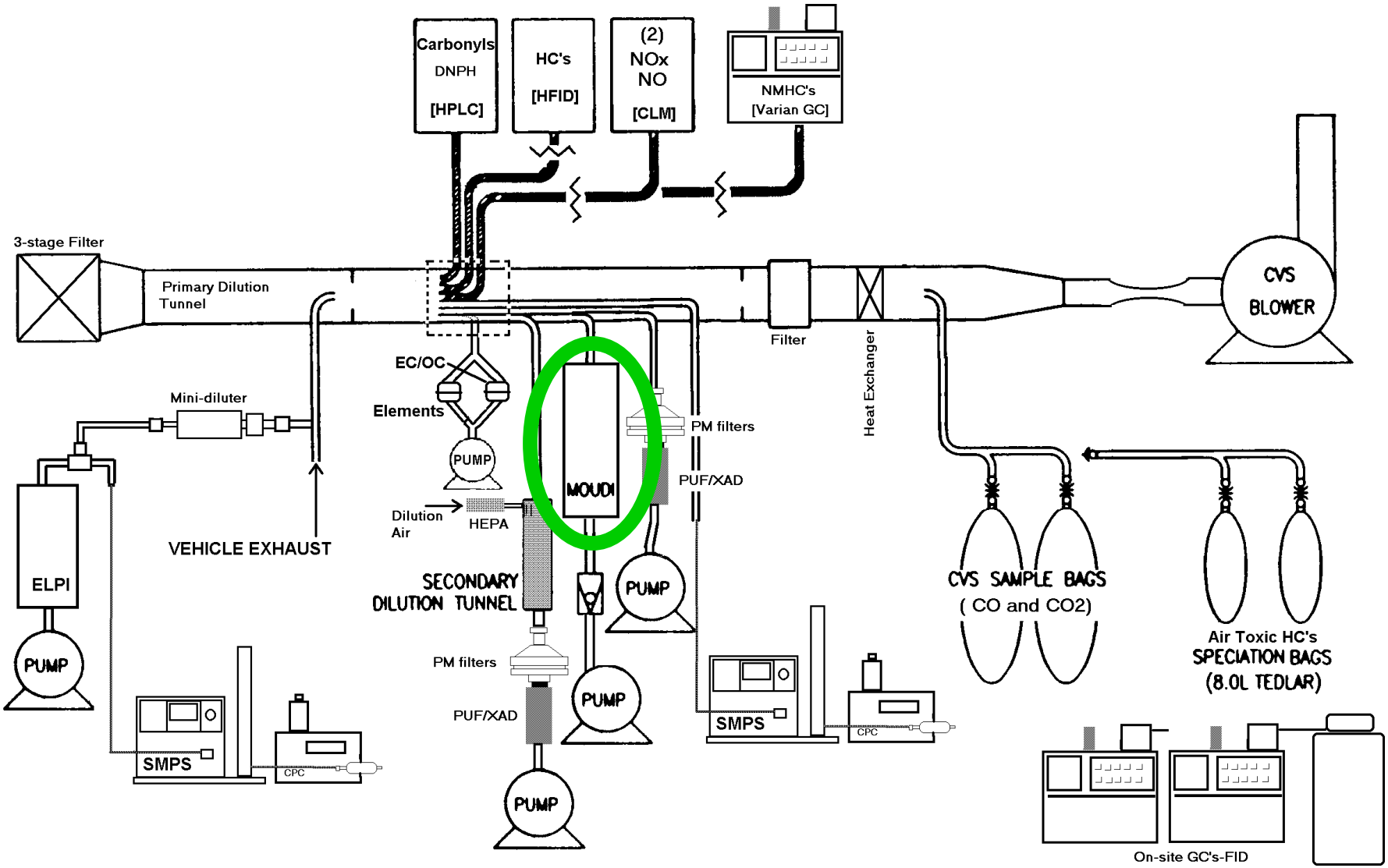
Motivation

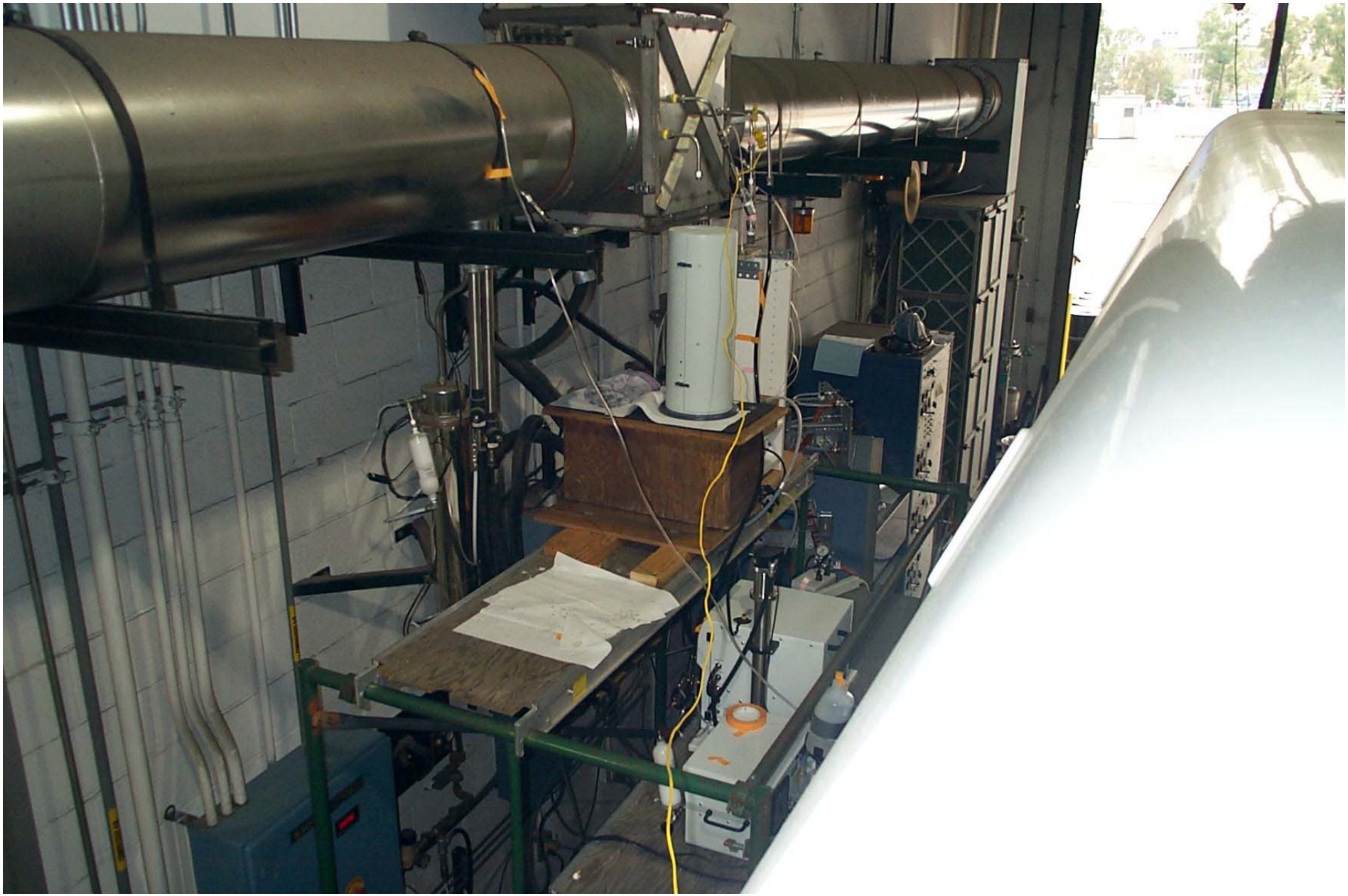
- Ultrafine (UF) particle health effects
- Diesel vehicle exhaust = toxic air contaminant
- Transit buses = potentially significant sources of UF particle exposure in urban areas
- Evidence of UF particle emissions from CNG-fueled vehicle (Ref: 1999 World Truck Conf., WVU)
- HEI report (1996) that newer diesel engines emit lower mass, but higher particle number
- Need for assessing toxicity equivalency of “clean” engine options (e.g. clean diesel and CNG)
- Need for determining duty cycle effects on criteria and UF emissions

Project Scope

- Five cycles: Idle, SS (55mph), CBD, NYBC, UDDS
- Chassis dynamometer testing at CARB's Heavy-duty Emissions Laboratory
- Criteria Pollutants (NO_X, total PM, CO, Total HC's)
- Other Gases of Interest (NMHC, CO_2 and NO_2)
- Panel of Toxics:
  - 13 Carbonyl Compounds (Formaldehyde to Hexanal)
  - VOC's (1,3-Butadiene, BTEX)
  - 24 PAH's (Phase distribution from Benzo(g,h,i)perylene to Naphthalene)
- Inorganic elements and EC/OC
- Mutagenicity via Modified Ames Assay
- Size-segregated Ultrafine Mass (MOUDI) and Number Emissions (SMPS and ELPI)
- *http://www.arb.ca.gov/research/cng-diesel/cng-diesel.htm*

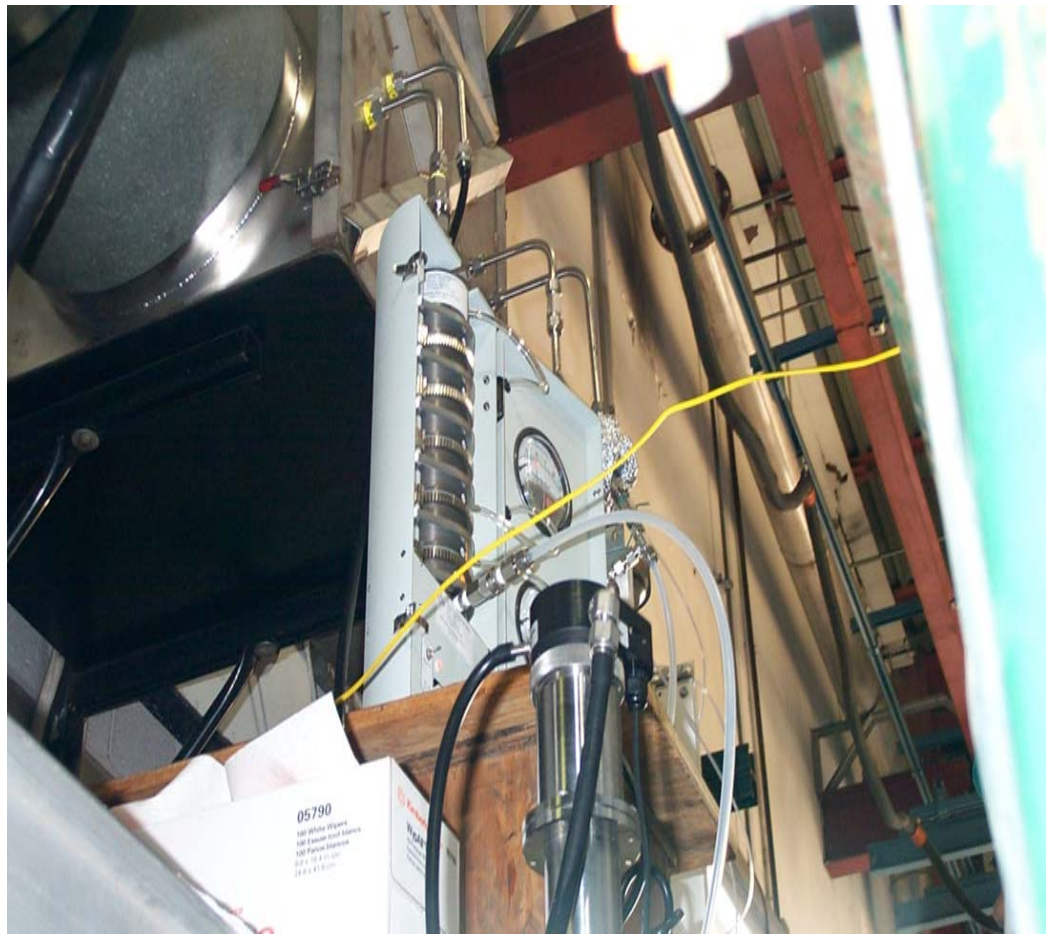
CVS Dilution Tunnel Setup





Micro-Orifice Uniform Deposit Impactor

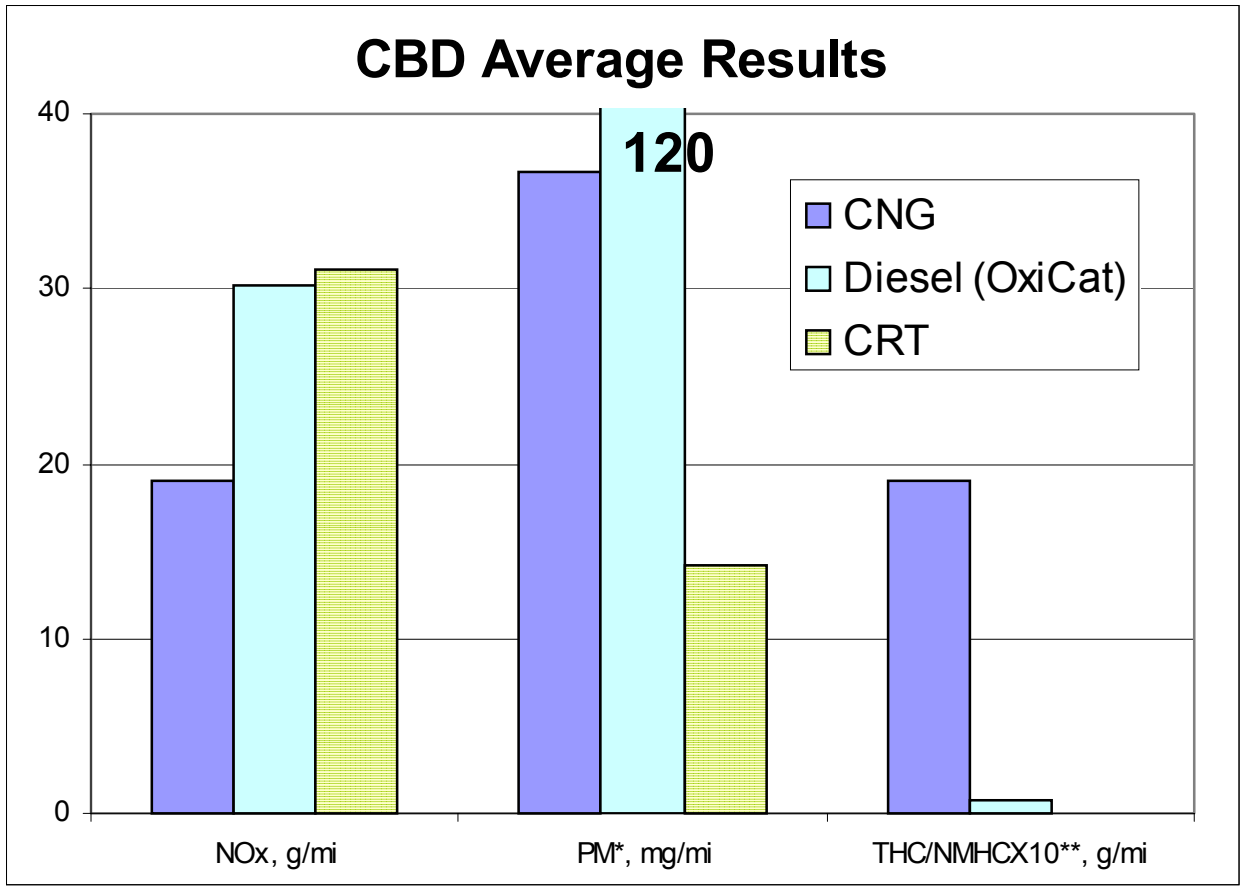
- 10-stage rotating MOUDI
- Not all 10 stages used due to time/resource constraints
- Collection from CVS tunnel
- Teflon substrates, no grease
- Composite samples collected over multiple cycles. Sampling time varied
- Tunnel blanks
- DR from CO2 measurements
- dM/dlog(Dp), µg/m3
- QA/QC protocol in place for sample collection



Test Buses

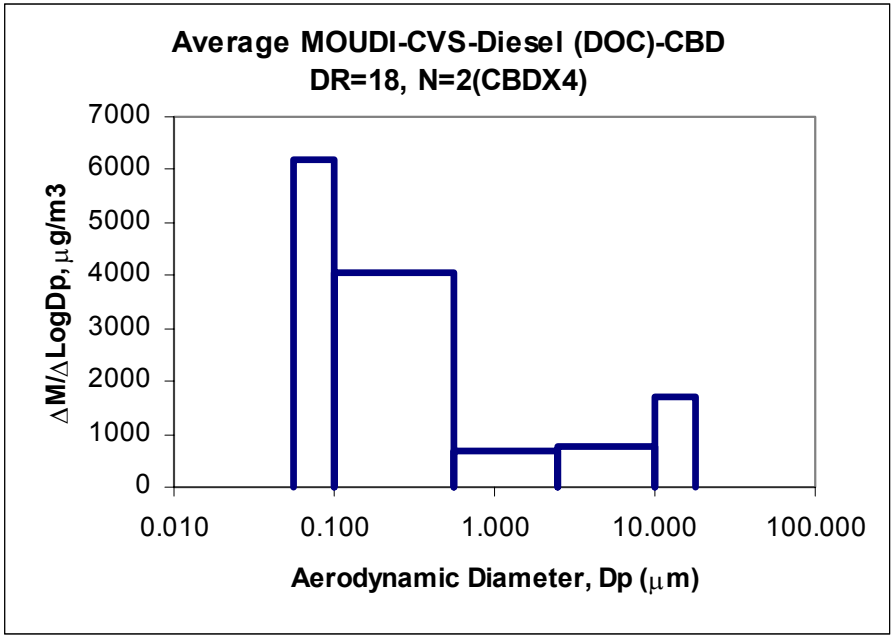
	Model Year	Engine Make	After-treatment	Fuel
Diesel	1998	DDC-S50 8.5L/4 cyl	DOC DPF(CRT™)	ECD-1 15 ppm S
CNG	2000	DDC-S50G 8.5L/4 cyl	none	Ref. Stat.

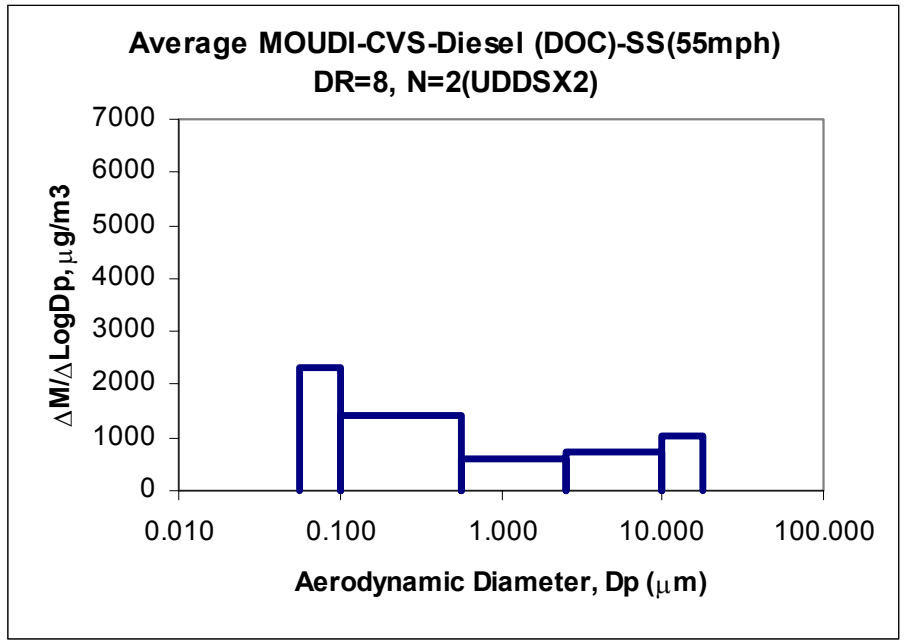
NO_X, PM, and HC Emissions-CBD



Reference: Ayala, A., N.Y. Kado, R.A. Okamoto, B.A. Holmen, P.A. Kuzmicky, R. Kobayashi, and K.E. Stiglitz, "Diesel and CNG Heavy-duty Transit Bus Emissions over Multiple Driving Schedules: Regulated Pollutants and Project Overview," *SAE Transactions Journal of Fuels and Lubricants,* **2002**, pp. 735-747.

Results for Diesel (DOC) Baseline





Ratio After filter/Total MOUDI PM=16%

Ratio PM2.5/Total MOUDI PM=87%

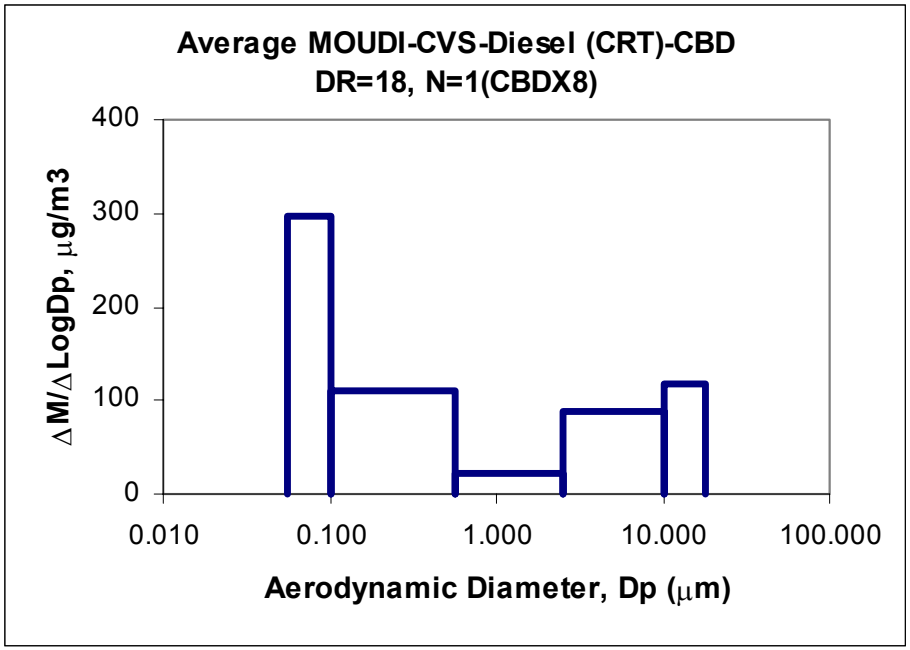
Ratio After filter/Total MOUDI PM=13%

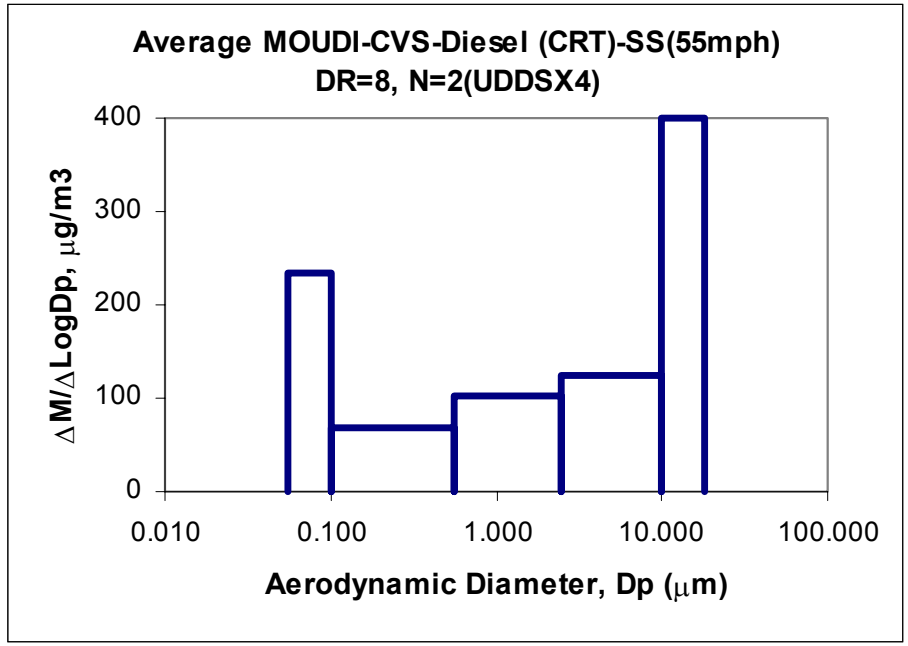
Ratio PM2.5/Total MOUDI PM=78%

Monomodal size distribution for baseline diesel

Transit cycle UF conc. >> Steady state cruise

Results for Diesel with CRT™





Ratio After filter/Total MOUDI PM=21%

Ratio PM2.5/Total MOUDI PM=74%

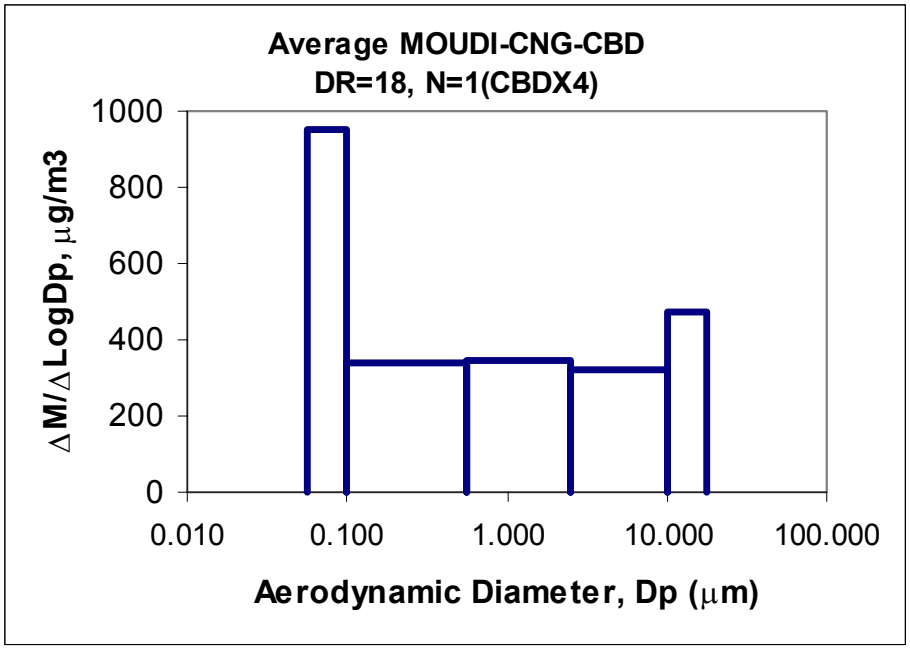
Ratio After filter/Total MOUDI PM=9%

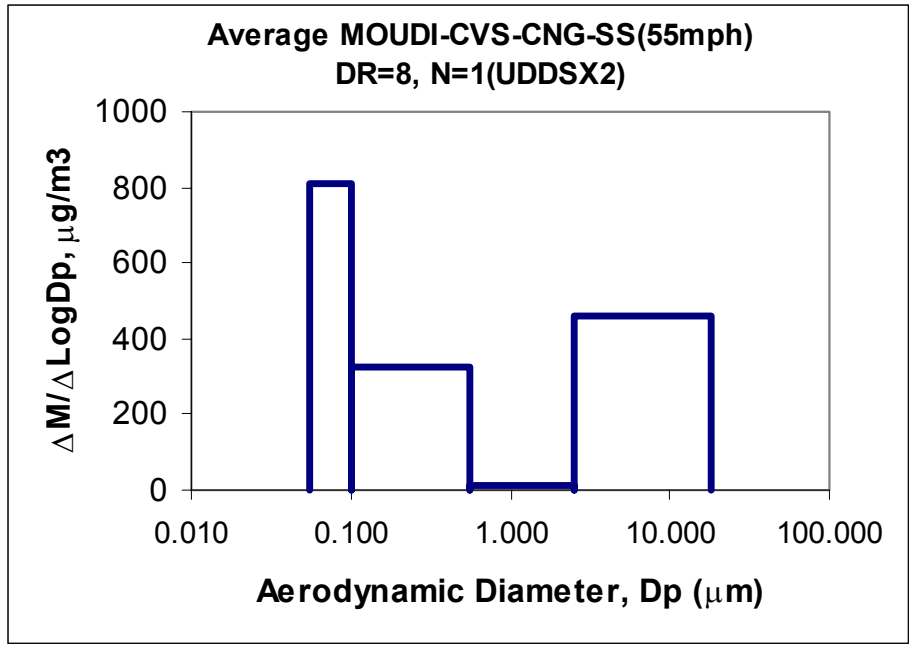
Ratio PM2.5/Total MOUDI PM=55%

Diesel CRT conc. << Diesel Baseline

Unlike Diesel Baseline, cycle effect for Diesel (CRT) not discernable

Results for CNG (no aftertreament)





Ratio After filter/Total MOUDI PM=12%

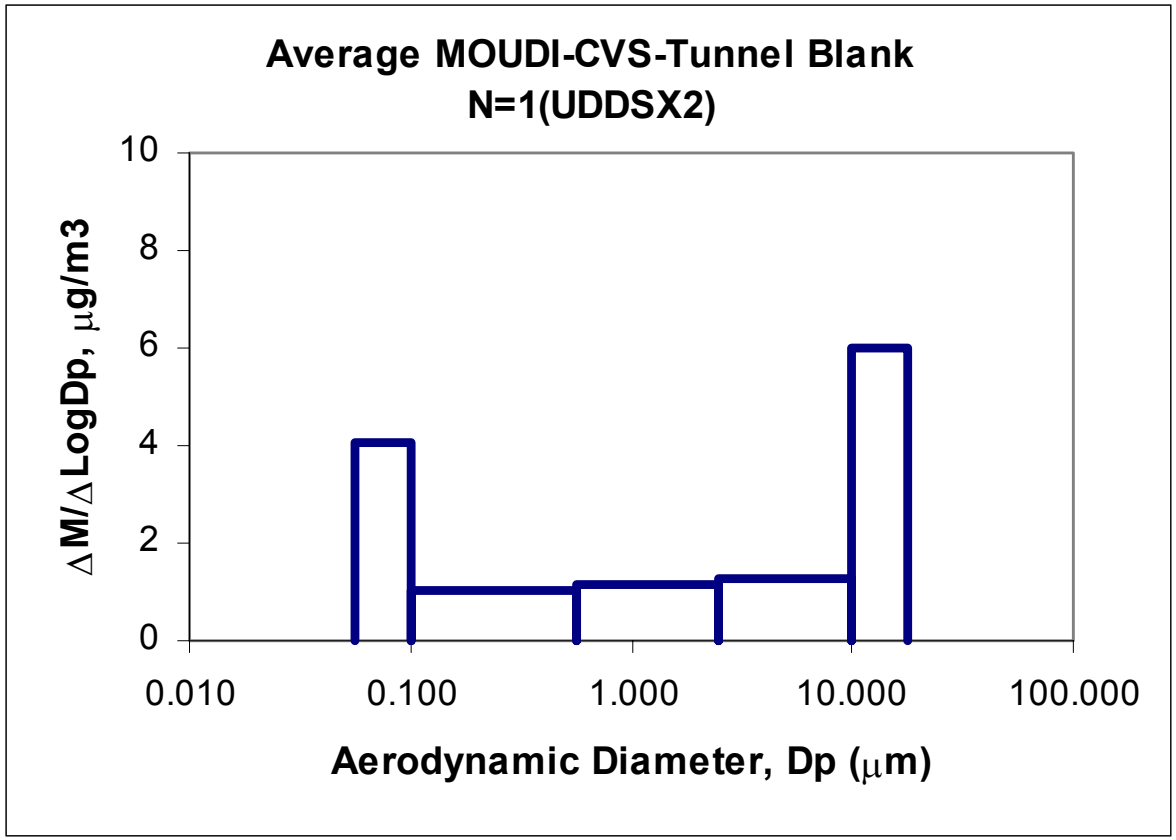
Ratio PM2.5/Total MOUDI PM=73%

Ratio After filter/Total MOUDI PM=35%

Ratio PM2.5/Total MOUDI PM=70%

CNG UF conc. > Diesel (CRT) UF conc.

Like Diesel (CRT), cycle effect for CNG not discernable

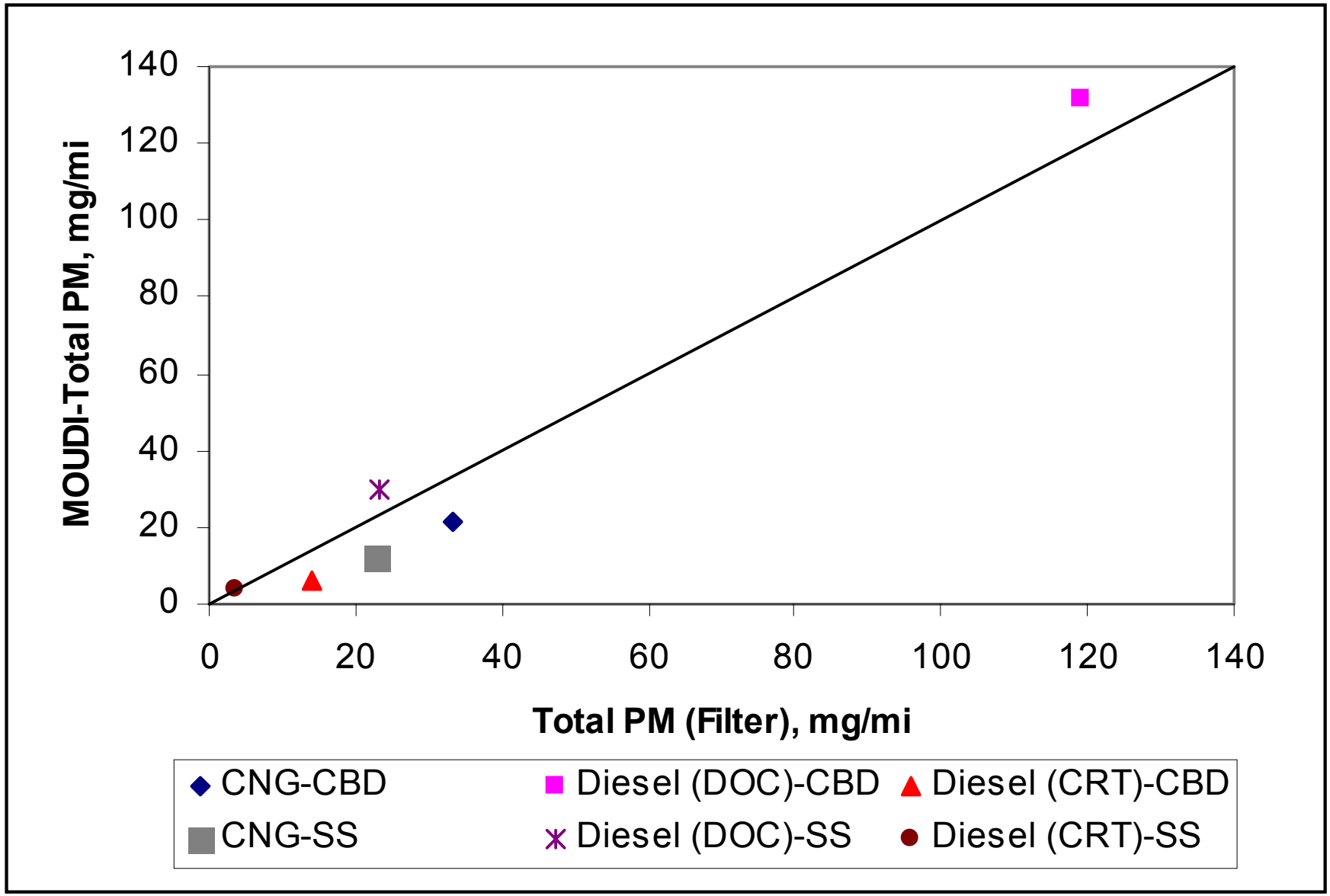


Ratio After filter/Total PM=17%

Ratio PM2.5/Total PM=61%

MOUDI tunnel blank conc. <<< bus emissions

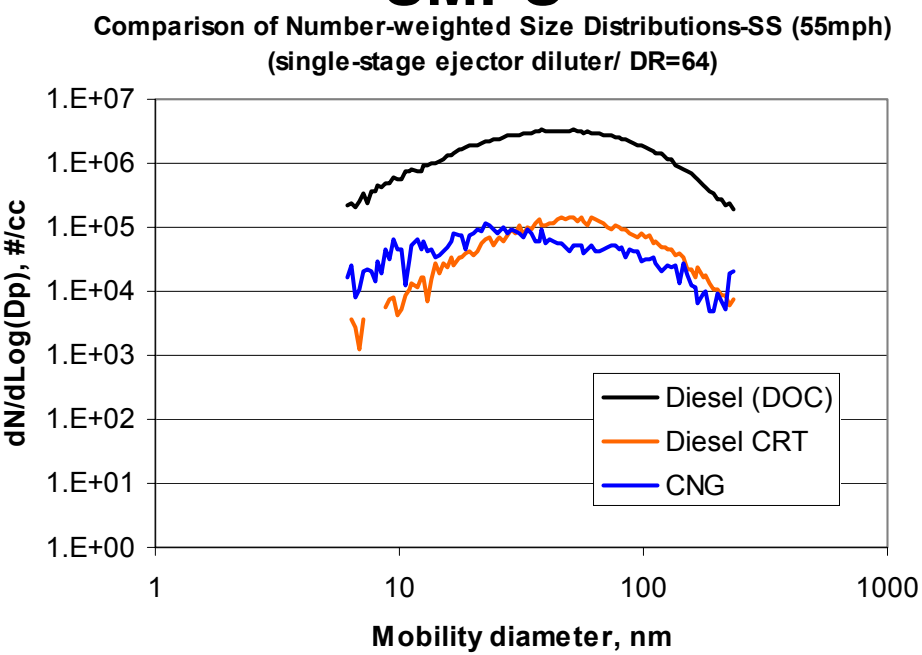
Comparison of CFR Filter Method and MOUDI



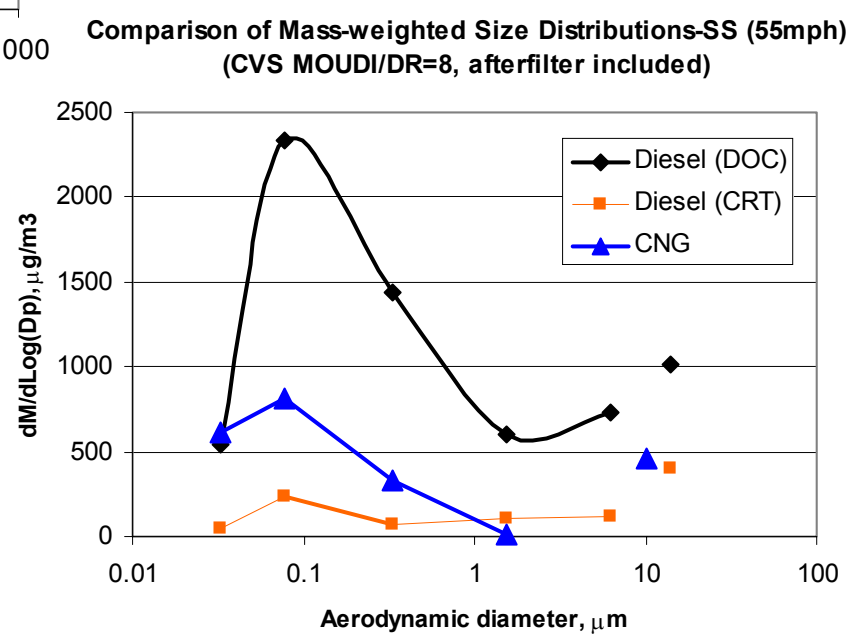
Comparison of MOUDI and SMPS* Size Distributions

(Afterfilter mass included)

SMPS*



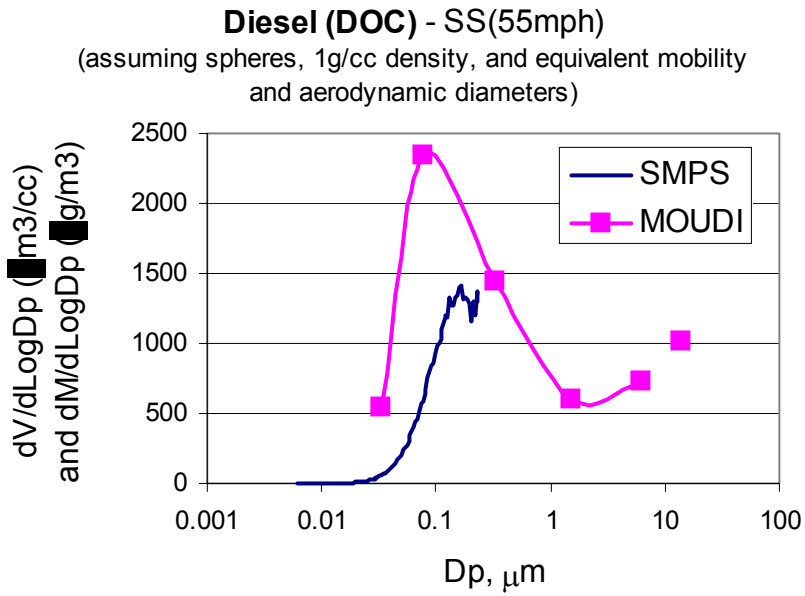
MOUDI

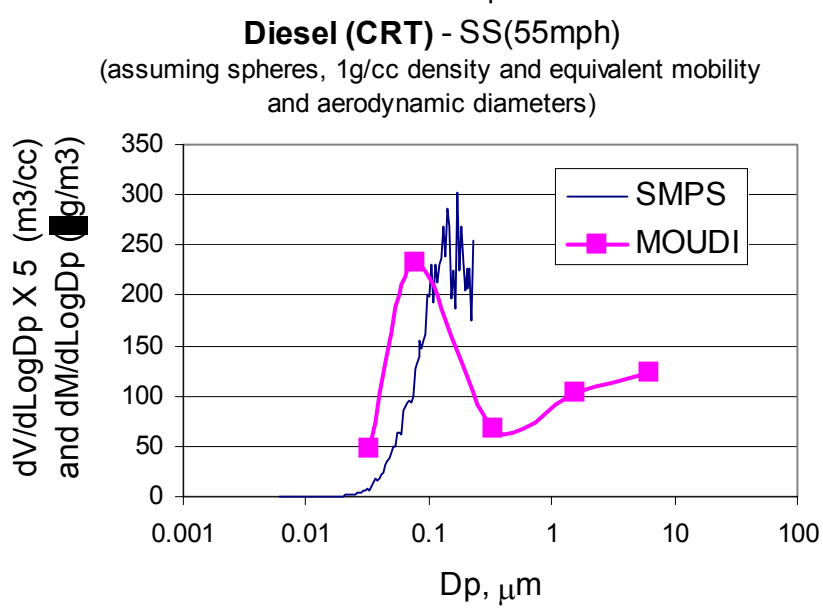


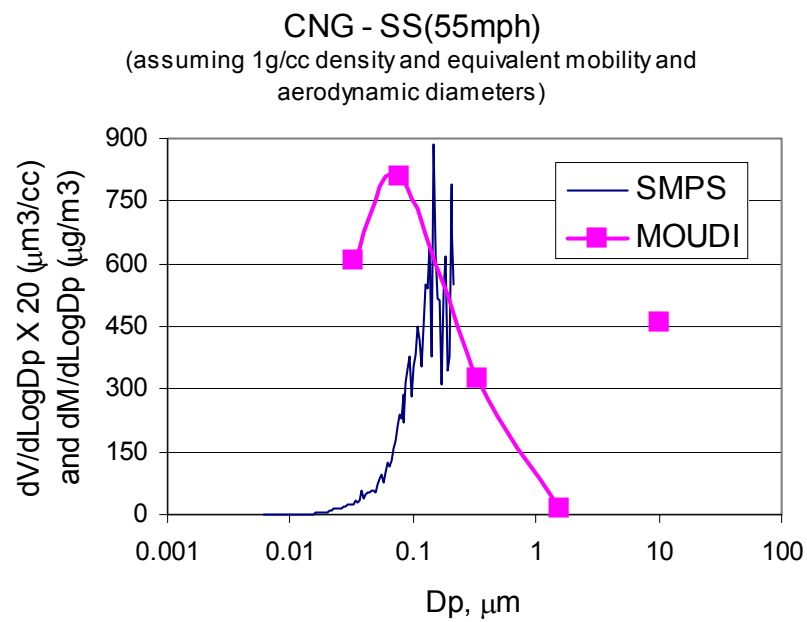
Same trend, but…

* ***Reference***: Holmen, B.A. and A. Ayala, "Ultrafine PM Emissions from Natural Gas, Oxidation-Catalyst Diesel and Particle-Trap Diesel Heavy-Duty Transit Buses," *Environmental Science and Technology*, **2002**, 36, 23, pp. 5041-5050.

MOUDI and SMPS* Comparison (Cont'd)







Different scale for Diesel (CRT) and CNG dV/dLog(Dp)

* ***Reference***: Holmen, B.A. and A. Ayala, "Ultrafine PM Emissions from Natural Gas, Oxidation-Catalyst Diesel and Particle-Trap Diesel Heavy-Duty Transit Buses," *Environmental Science and Technology*, **2002**, 36, 23, pp. 5041-5050.

Summary

- CNG and Diesel (CRT) reduced mass conc. by 10+ X compared to Diesel (DOC)
- Diesel (CRT) mass conc. < CNG mass conc.
- Cycles effects were evident for Diesel (DOC) where transient cycle conc. > steady state conc.
- Tunnel blank mass conc. <<< emission sample mass conc.
  - But temp. effects on TB vs. cycle need to be addressed
- Ratios of PM2.5/Total MOUDI PM ranged from 55% to 87%
- Ratios of after-filter PM/Total MOUDI PM ranged from 9% to 35%

Summary (Cont'd)

- Good agreement between Total PM (CFR filter method) and total MOUDI mass
- Reasonable agreement of SMPS and MOUDI for Diesel (DOC) over SS (55mph)
- However, bounce and artifacts may explain discrepancy in Diesel (CRT) and CNG SMPS and MOUDI comparison
- Trend in emission reduction for bus type is same
- Thus, for "clean" vehicles, approach based on sampling from CVS may lack sufficient resolution