Real-World Measurements of Diesel Particulate Matter

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Contributors/Support

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- Sponsor:
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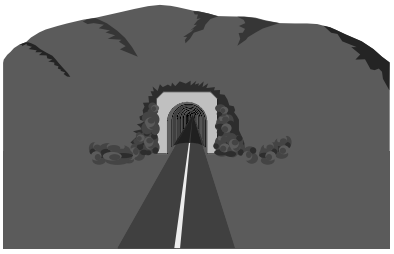


Motivation

- Studies have identified a link between fine particle emissions and human health impacts.
- ☛ Diesels are a significant source of fine particles.
- HEI plans to begin epidemiological studies in 2000 to provide dose-response data on the relationship between human cancer risk and long-term exposure to diesel emissions.
- ☛ Prior to commencing the year 2000 studies, there is a need to characterize ambient diesel emissions.
- ☛ There is also a need to link current diesel emissions with those obtained in previous studies.

Objectives

- Obtain chemically speciated diesel profiles for use in source apportionment studies.
- Determine the chemical species present in real-world diesel emissions.
- Measure particle number and chemically speciated size-segregated particle distributions.
- Confirm the results of recent dynamometer studies of diesel emissions.
- Determine how much improvement there has been in the diesel exhaust particulate mass emission rates.
- Measure particulates from light-duty gasoline vehicles.

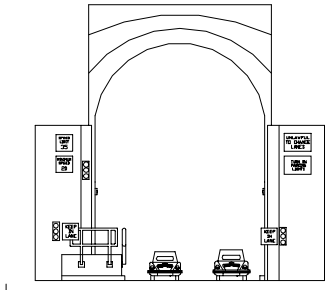
Why Perform Measurements in Tunnels?

- Provides a measure of real-world emissions - Engine and chassis dynamometer tests don't accurately "capture" the in-use fleet.
- Cost - Can evaluate emissions from thousands of vehicles.
- Examples of issues we can address:
  - Impact of improved technology and fleet turnover on emissions;
  - Highway versus urban fleet emissions;
  - Differences between countries;
  - Impact of reformulated fuels on emissions;
  - Emissions factor model performance.

Caveats

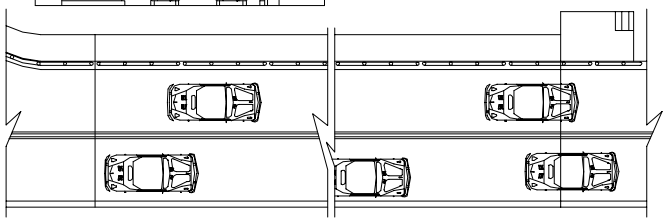
- "Snapshot" real-world driving.
- Limited range of vehicle speeds and accelerations.
- Hot-stabilized operating mode.

Methodology - Calculation of Emission Factors

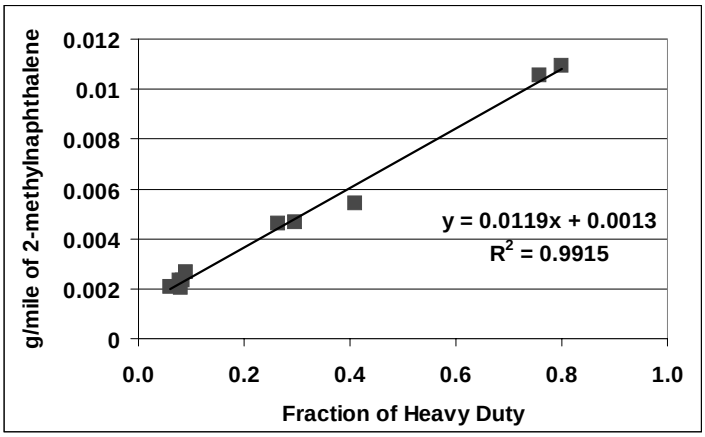


$$M = \sum_i (C_{out}V_{out})_i - \sum_j (C_{in}V_{in})_j$$

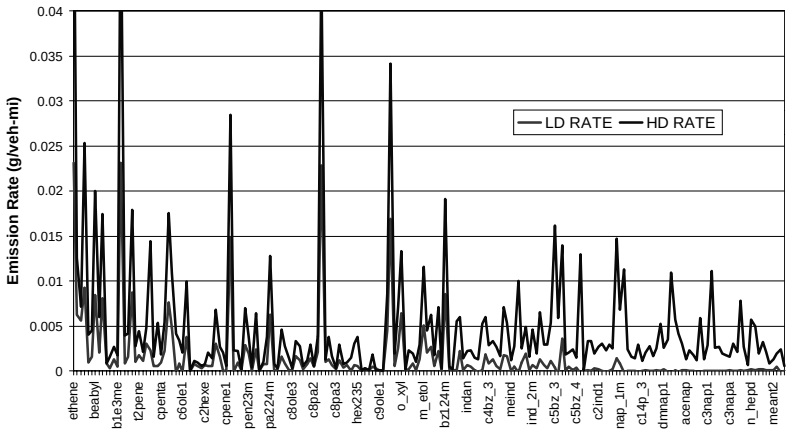
$$E = M / (NL)$$



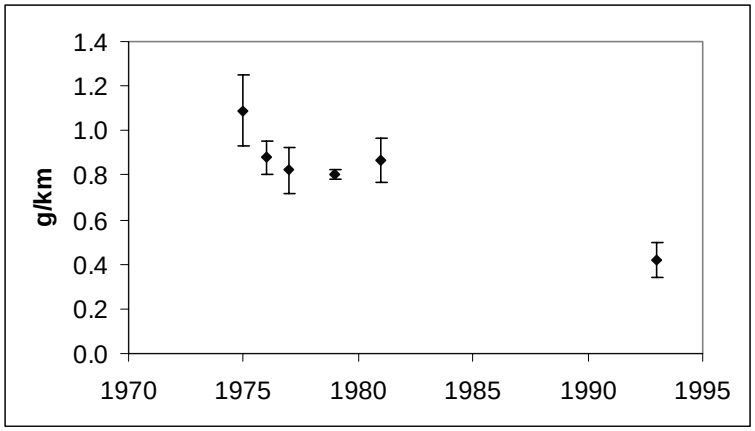
Separation of LD and HD Emissions



LD/HD Speciated Emissions



Trend in HDD Particle Emission Rates



1992 Emission Rates

	Light-duty	Heavy-duty
CO_2 g/mi	232 ± 12	1596 ± 39
CO g/mi	4.89 ± 0.49	6.03 ± 1.61
NMHC g/mi	0.29 ± 0.06	0.68 ± 0.20
NO g/mi as NO_2	0.41 ± 0.23	18.27 ± 0.76
NO_x g/mi as NO_2	0.39 ± 0.26	19.46 ± 0.85
Miles/gallon	37.0 ± 1.8	5.71 ± 0.14

Tuscarora Tunnel Description

- Located on the Pennsylvania Turnpike, I-76
- Two bores
- Two lanes/bore
- 1623 m (5325 ft) long
- +0.3% grade
- Ventilated entirely by the traffic piston effect
- Average residence time of air within the tunnel was 5±1 minutes

Fleet Operating Conditions

- The nearest interchange is very lightly used.
- The Sideling Hill service plaza (22 km to the west) is heavily used.
- Effectively the minimum trip length before reaching the tunnel is 15 minutes.
- Trips longer than 50 minutes before reaching the tunnel constitute some 75% of all trips.
- Cold-start and hot-start operations are inconsequential and most vehicles entering the tunnel are operating in a steady-state cruise mode.

Fleet Characteristics (1992 Experiment)

- $0.06 < F_{HD} < 0.80$
- Depending on the period, 73 to 99% of the HD vehicles were diesel (average weight ~27 metric tons)
- LD average speed was 59.4 ± 5.6 mi/hr
- HD average speed was 54.0 ± 2.8 mi/hr

Sampling Setup

- Propeller anemometers and SF_6 dilution for air flow measurements
- Tedlar bag sampler for $CO/CO_2/THC/NO/NO_x/SF_6$
- Tenax sampler for SVOCs (C_8 to C_{20} hydrocarbons)
- TIGF/PUF/XAD sampler for PAHs
- DRUM sampler for size-fractioned (0.07-0.24; 0.24-0.34; 0.34-0.56; 0.56-0.75; 0.75-1.15; 1.15-2.5; 2.5-5.0; and 5.0-10.0 μm aerodynamic diameter) particle mass and speciation
- IMPROVE sampler for $PM_{2.5}$ for mass and chemical speciation
- Scanning mobility analyzer/CN counter
- Dust Track for PM_{10} mass
- Video camera for vehicle counts and classification
- Radar gun for vehicle speed

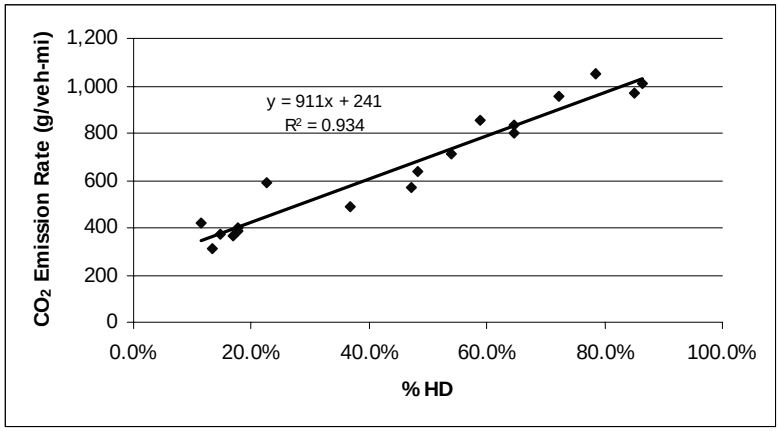
Additional Measurements and Support

- Ammonia/ammonium emission rates and LD model year estimates (CRC)
- Carbonyl emission rates (Grosjean)
- USEPA (Harris et al.) and West Virginia University (Clark and Nine) provided instrumented HDD vehicles

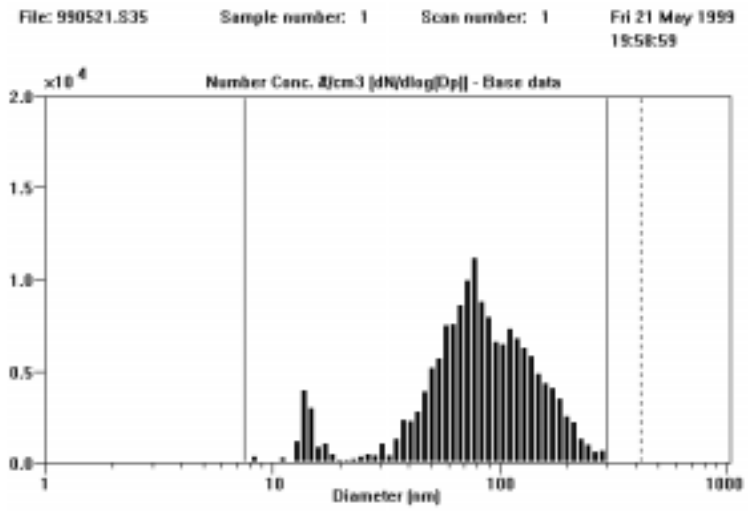
1999 Experimental Periods

Run	Date	Day	Start	End	# LD	# HD (Class 4-6)	# HD (Class 7- 8)	Total Vehicles	Fraction HD (4-8)	Avg. LD Model Year	Avg. Spd. (mph)
1	18-May	Tue	1200	1300	334	24	171	529	36.9%	1994.1	54.9
2	18-May	Tue	2000	2100	177	11	197	385	54.0%	1994.6	54.8
3	18-May	Tue	2200	2300	104	10	179	293	64.5%	1993.5	57.0
4	19-May	Wed	0000	0100	31	4	171	206	85.0%	1993.5	54.9
5	19-May	Wed	0200	0300	26	10	156	192	86.5%	1991.1	55.1
6	19-May	Wed	1900	2000	240	14	200	454	47.1%	1994.8	57.7
7	19-May	Wed	2100	2200	148	20	191	359	58.8%	1994.3	54.4
8	19-May	Wed	2300	0000	70	4	178	252	72.2%	1993.6	53.6
9	20-May	Thur	0100	0200	43	6	152	201	78.6%	1994.3	55.0
10	20-May	Thur	1600	1700	505	23	202	730	30.8%	1994.8	53.2
11	21-May	Fri	0500	0600	88	9	151	248	64.5%	1993.7	58.1
12	21-May	Fri	0700	0800	208	27	167	402	48.3%	1994.9	57.5
13	21-May	Fri	900	1000	366	17	90	473	22.6%	1994.7	53.8
14	21-May	Fri	1700	1800	706	16	92	814	13.3%	1994.7	56.9
15	22-May	Sat	1100	1200	490	11	53	554	11.6%	1995.0	57.0
16	22-May	Sat	1300	1400	444	15	80	539	17.6%	1994.5	56.5
17	22-May	Sat	1500	1600	406	12	70	488	16.8%	1994.6	57.0
18	22-May	Sat	1700	1800	377	14	51	442	14.7%	1994.2	59.5
19	23-May	Sun	1000	1100	435	14	80	529	17.8%	1994.3	58.1
20	23-May	Sun	1200	1400	1400	29	252	1681	15.7%	1992.6	61.7

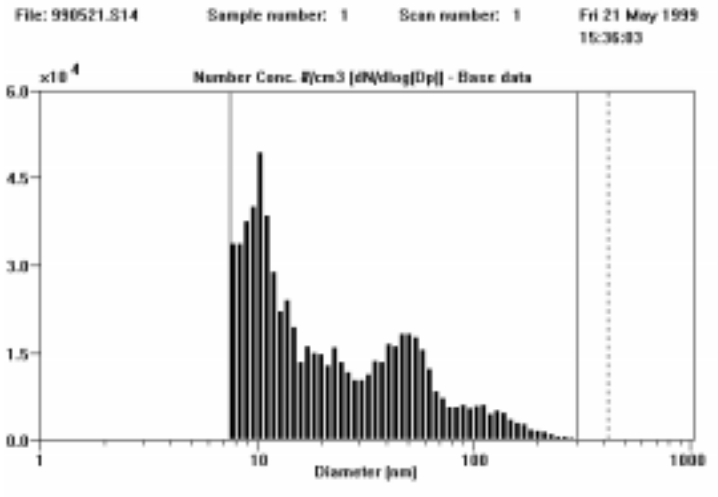
Preliminary 1999 CO_2 Emission Rate



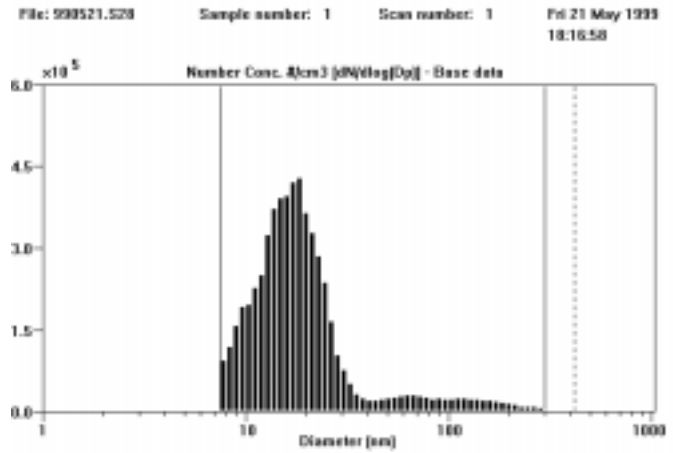
Particle Size Distribution in Background Air



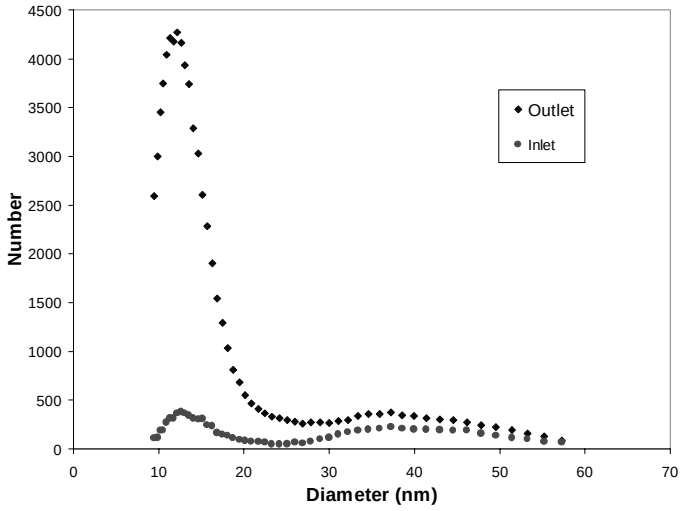
Particle Size Distribution at Tunnel Inlet



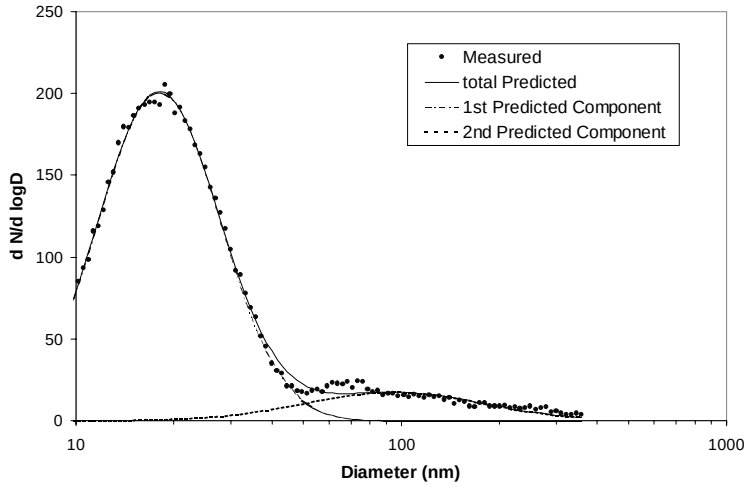
Particle Size Distribution at Tunnel Outlet



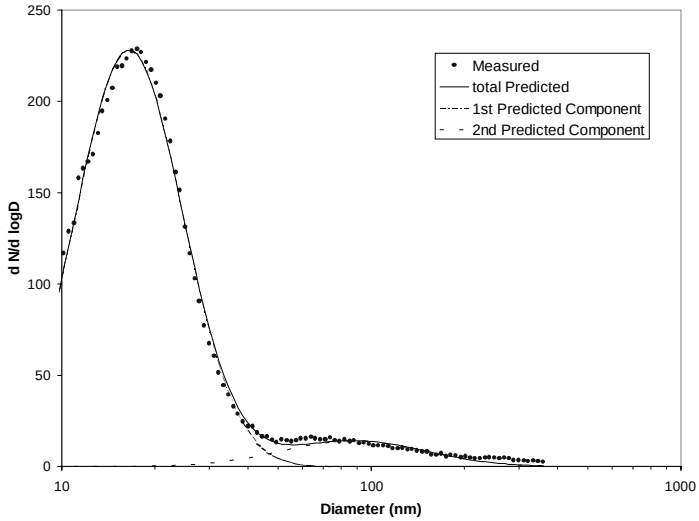
Outlet vs Inlet Particle Number Counts (13% HDD)



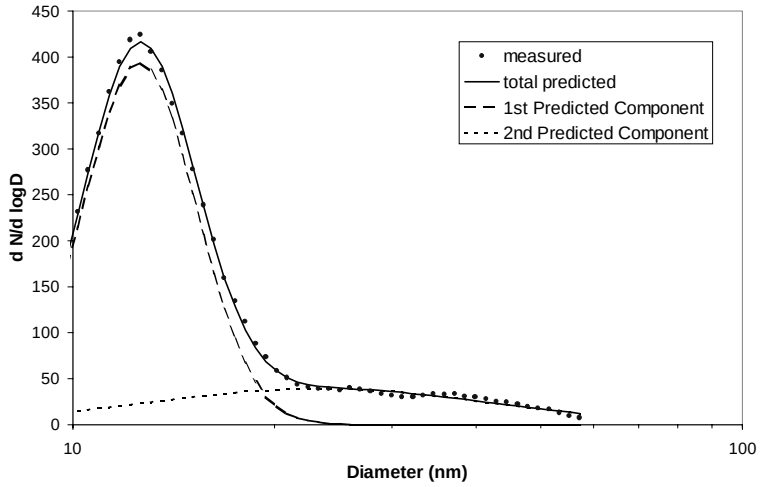
Particle Size Distribution - 78% HDD



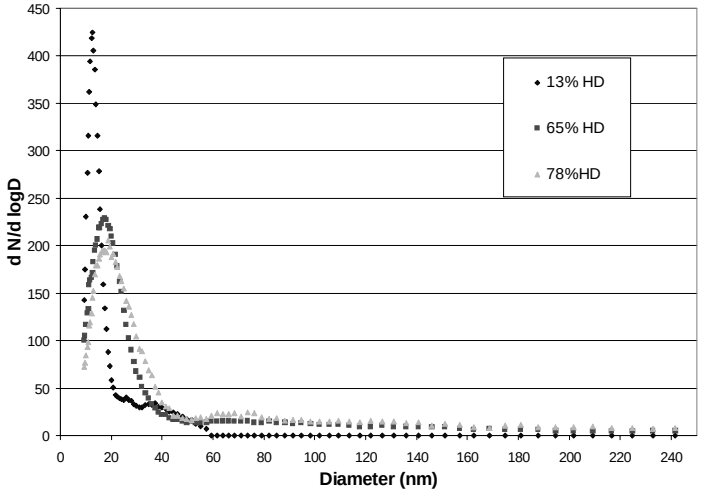
Particle Size Distribution - 65% HDD



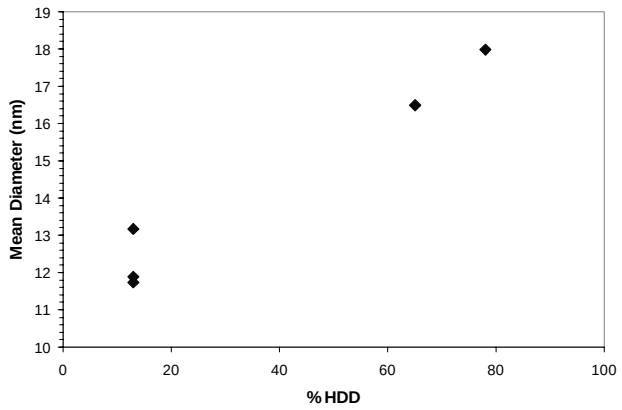
Particle Size Distribution - 13% HDD



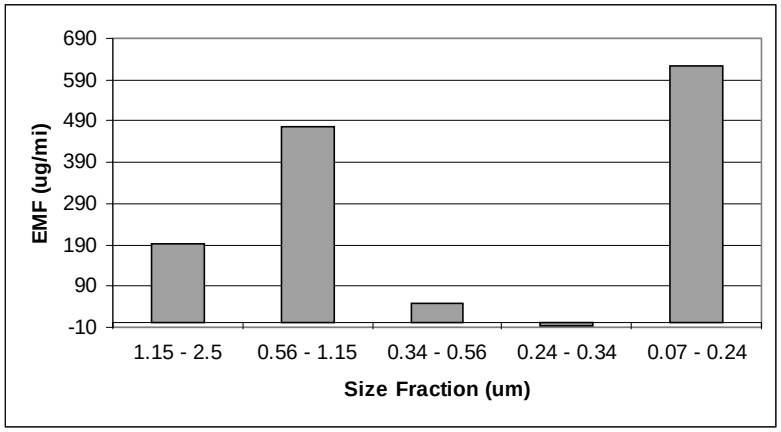
Particle Size Distribution vs. Fraction HDD



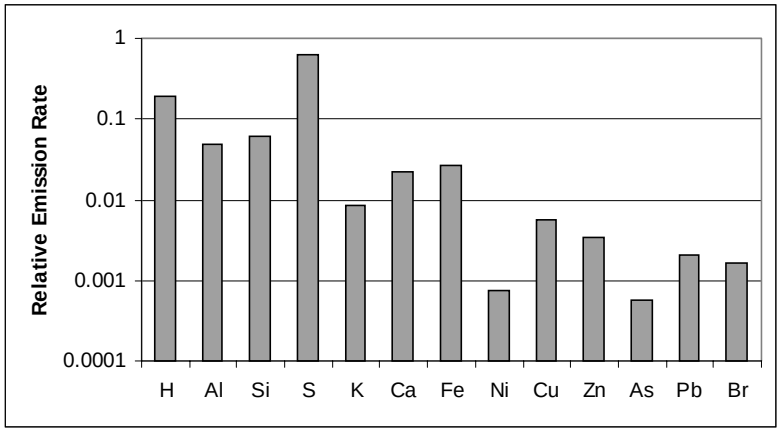
Variation in Average Particle Size with HDD Fraction



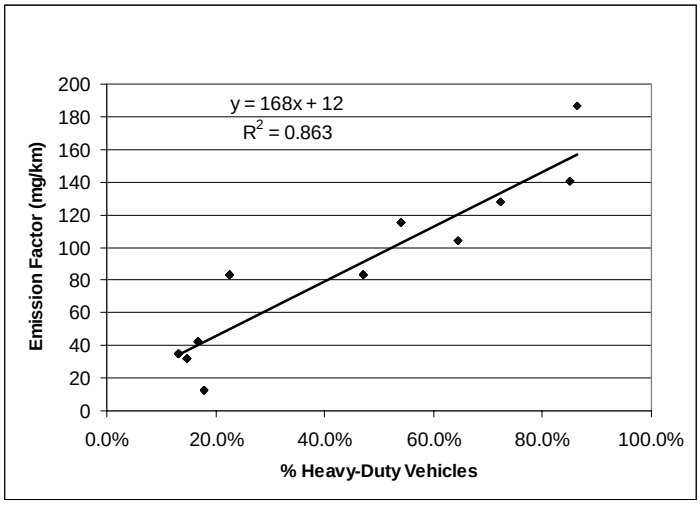
Avg. Iron Emission Rate vs. Size Fraction - All Runs



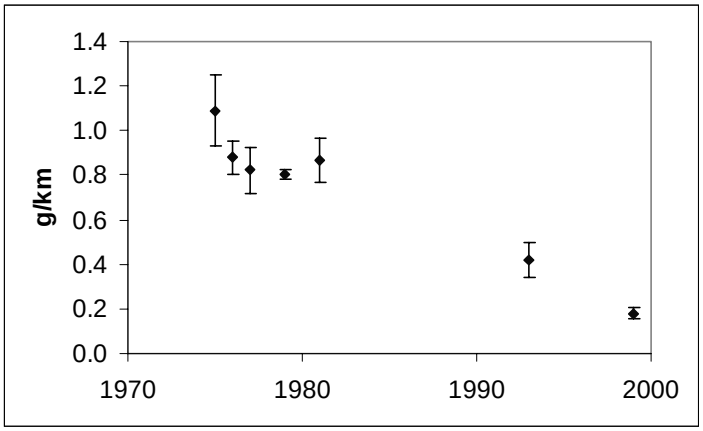
Relative Emissions for D<0.07 um (All Runs, 32.5% HDD)



Preliminary HD and LD PM_{10} Tailpipe Emissions



Updated Trend in HDD Particle Emission Rates



Summary

- Obtained measurements over a wide range of LD and HD fractions.
- HD PM mass emission rates have decreased significantly over a 25 year period.
- LD PM emissions cannot be ignored.
- LD and HD vehicles emit significant numbers of ultrafine particles and these particles are preserved.
- Chemical analyses just completed.
- Data analysis is currently being performed.