Heavy-Duty Diesel On-Road Emission Factor Research

D. Bruce Harris

Office of Research & Development

National Risk Management Research Laboratory

Air Pollution Prevention and Control Division

Research Triangle Park, NC

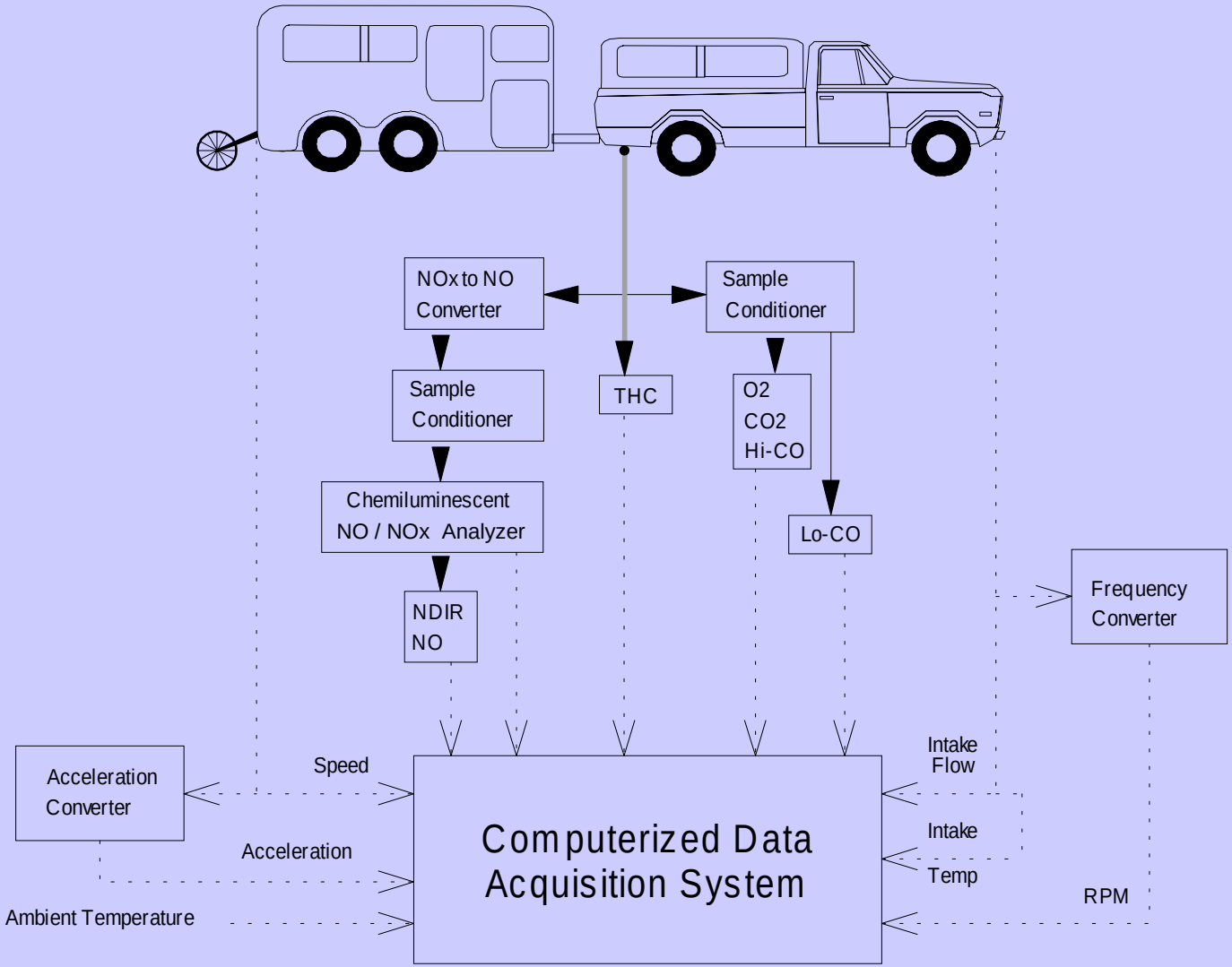
April 2001

Research & Development Objectives

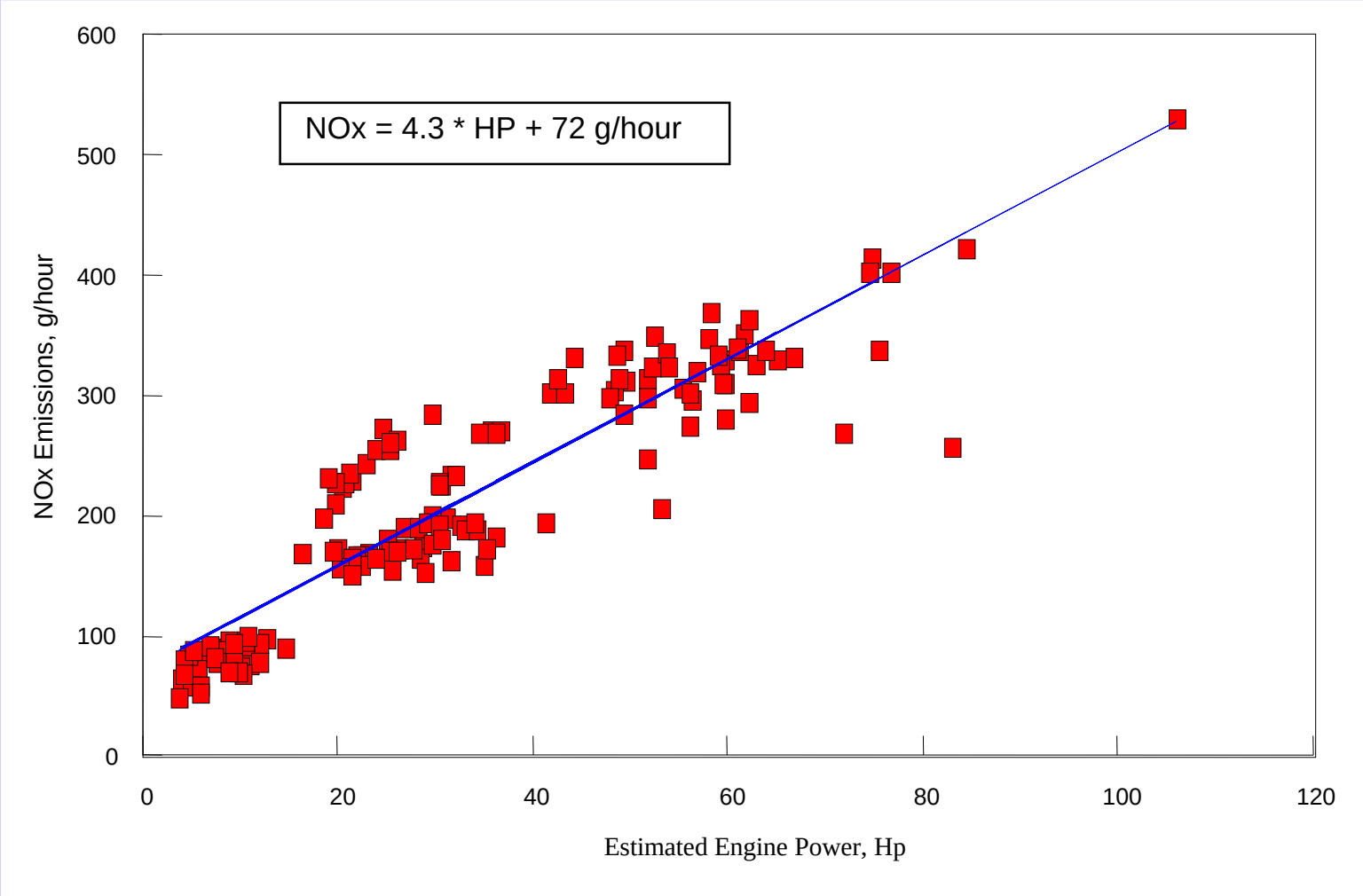
- Develop on-road testing facilities and methods with data comparable to dynos
- Collect on-road data that can be used to improve the emission factors for use in MOBILE
- Identify emissions trends that might be important to the development of a modal emissions model

On-Road Measurement of Heavy-Duty Diesel Vehicle Emissions

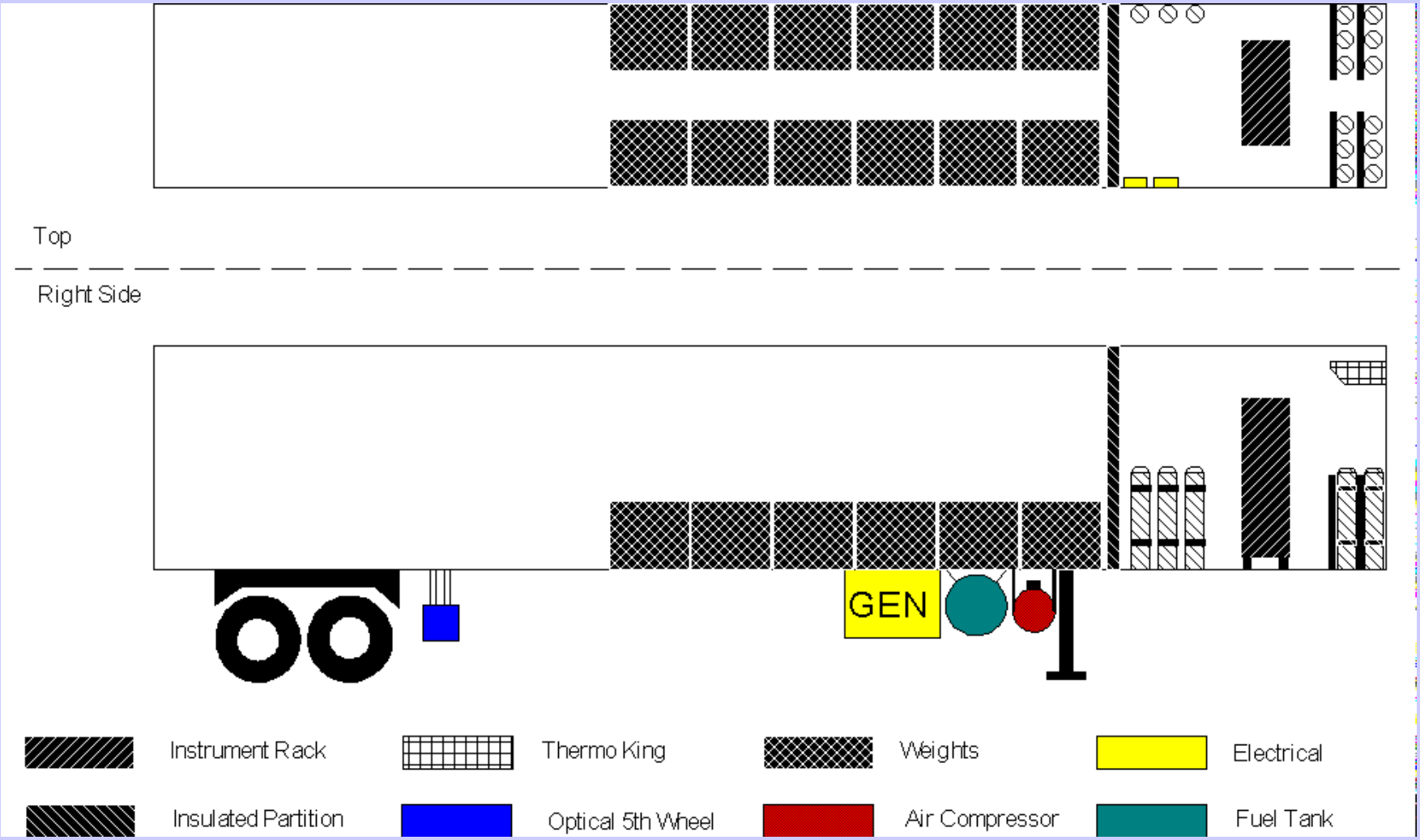
- Phase I -- Prototype Facility
  - Diesel pickup truck for subject vehicle
  - Focus on proof-of-concept testing
- Phase II -- Full-scale Facility
  - Develop test matrix
  - Conduct modal tests of:
    - mechanically injected vehicle
    - 1st generation electronic control vehicle - low power
    - 1st generation ECV - high power
    - 1st generation ECV - high power after rebuild
    - 2000 spec ECV - high power



Prototype On-Road Test System



Diesel Pickup On-Road Emissions

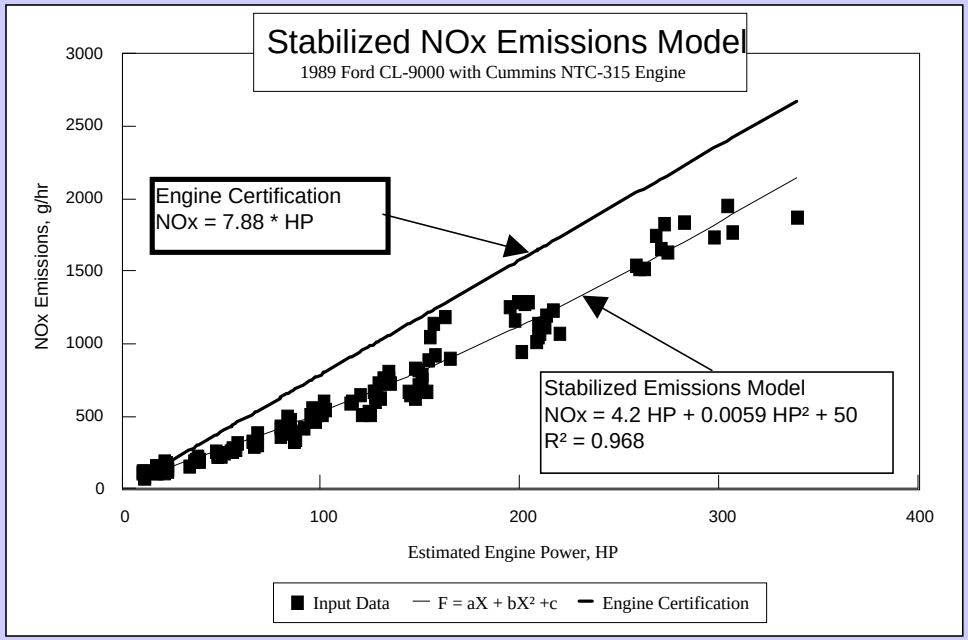


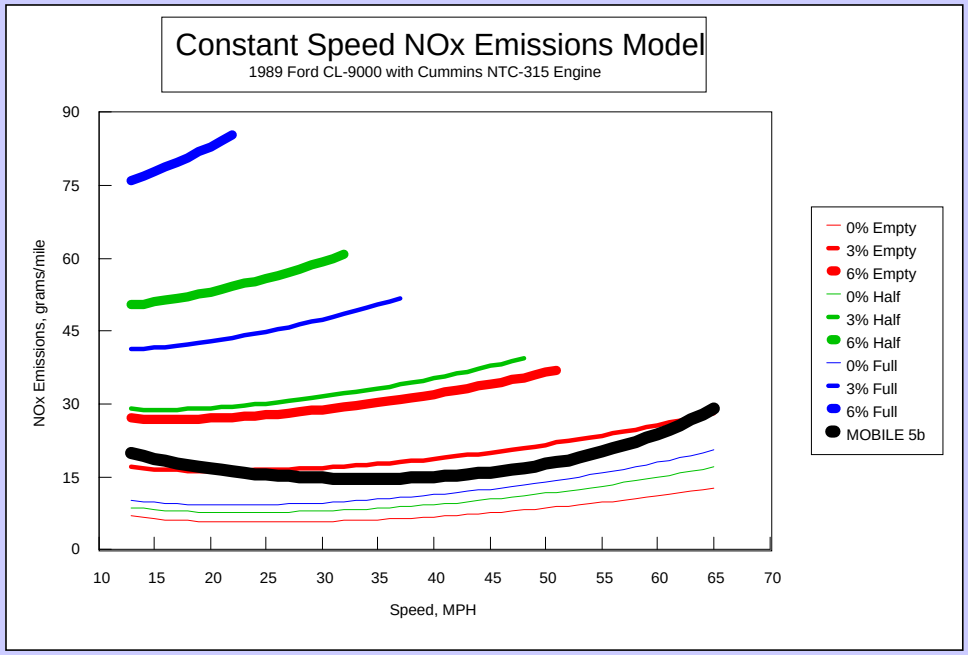
On-Road Emissions Characterization Laboratory

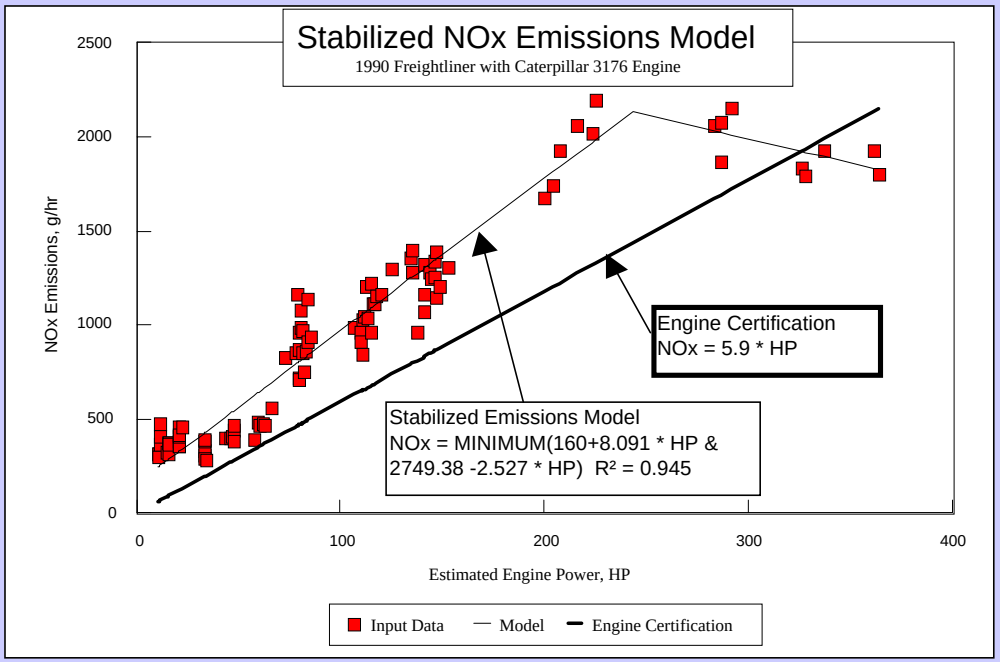
General Test Matrix

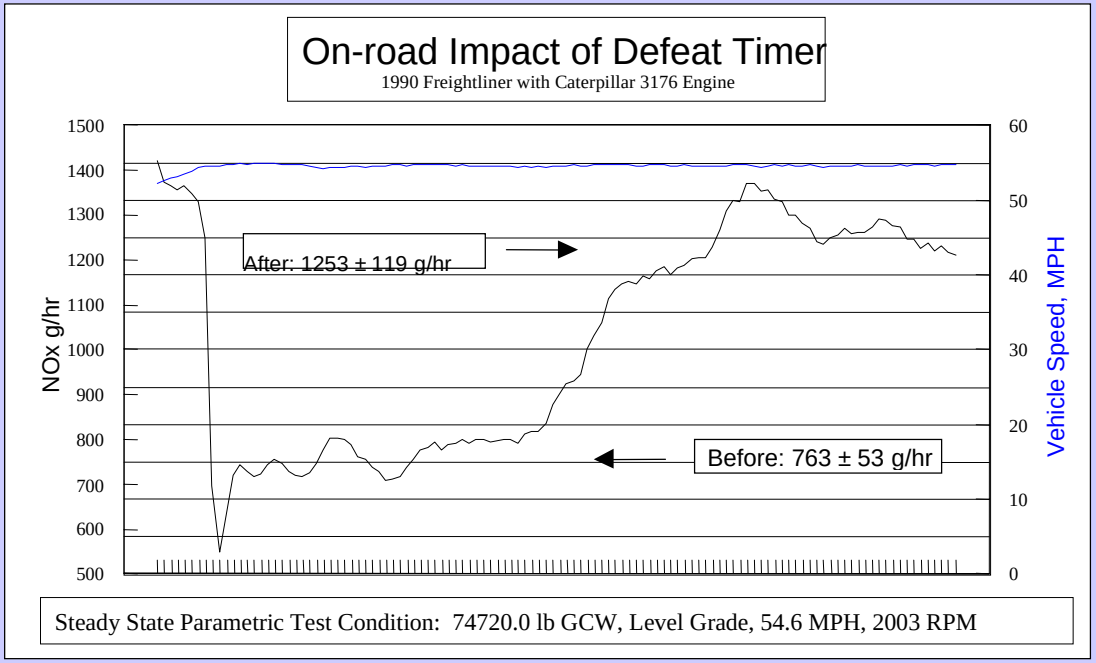
Speed	Slow	15 mph	(constant speed)
	Medium	35 mph	(constant speed)
	Fast	55 mph	(constant speed)
Acceleration 0 to 55 MPH	Normal	Shift gears when engine speed reaches governed rpm	
	Short Shift	From 80% governed, advance to higher rpm shift with each gear	
Grade	Level	0%	U.S. 70 near New Bern, NC
	Moderate	3.1%	I-26 near Hendersonville
	Steep	6%	I-26 near Hendersonville
Downhill	Steep	6%	Load variation only
Load (GCW)	Light	Empty Trailer	(25,000 - 30,000 lb GCW)
	Medium	½ Max Cargo Load	(up to 55,000 lb GCW)
	Heavy	Max Cargo Load	(up to 80,000 lb GCW)

(3 Speeds + 2 Accelerations)•(3 Grades • 3 Loads) + Downhill = 46 Triplicate Tests Maximum


Stabilized NOx Emissions Model
1989 Ford CL-9000 with Cummins NTC-315 Engine
Engine Certification
NOx = 7.88 * HP
Stabilized Emissions Model
NOx = 4.2 HP + 0.0059 HP² + 50
R² = 0.968
NOx Emissions, g/hr
Estimated Engine Power, HP
Input Data
F = aX + bX² +c
Engine Certification


Constant Speed NOx Emissions Model
1989 Ford CL-9000 with Cummins NTC-315 Engine
NOx Emissions, grams/mile
Speed, MPH
0% Empty
3% Empty
6% Empty
0% Half
3% Half
6% Half
0% Full
3% Full
6% Full
MOBILE 5b


Stabilized NOx Emissions Model
1990 Freightliner with Caterpillar 3176 Engine
NOx Emissions, g/hr
2500
2000
1500
1000
500
0
0
100
200
300
400
Estimated Engine Power, HP
Engine Certification
NOx = 5.9 * HP
Stabilized Emissions Model
NOx = MINIMUM(160+8.091 * HP &
2749.38 -2.527 * HP) R² = 0.945
Input Data
Model
Engine Certification


On-road Impact of Defeat Timer
1990 Freightliner with Caterpillar 3176 Engine
NOx g/hr
1500
1400
1300
1200
1100
1000
900
800
700
600
500
Vehicle Speed, MPH
60
50
40
30
20
10
0
After: 1253 ± 119 g/hr
Before: 763 ± 53 g/hr
Steady State Parametric Test Condition: 74720.0 lb GCW, Level Grade, 54.6 MPH, 2003 RPM

Objectives Accomplished

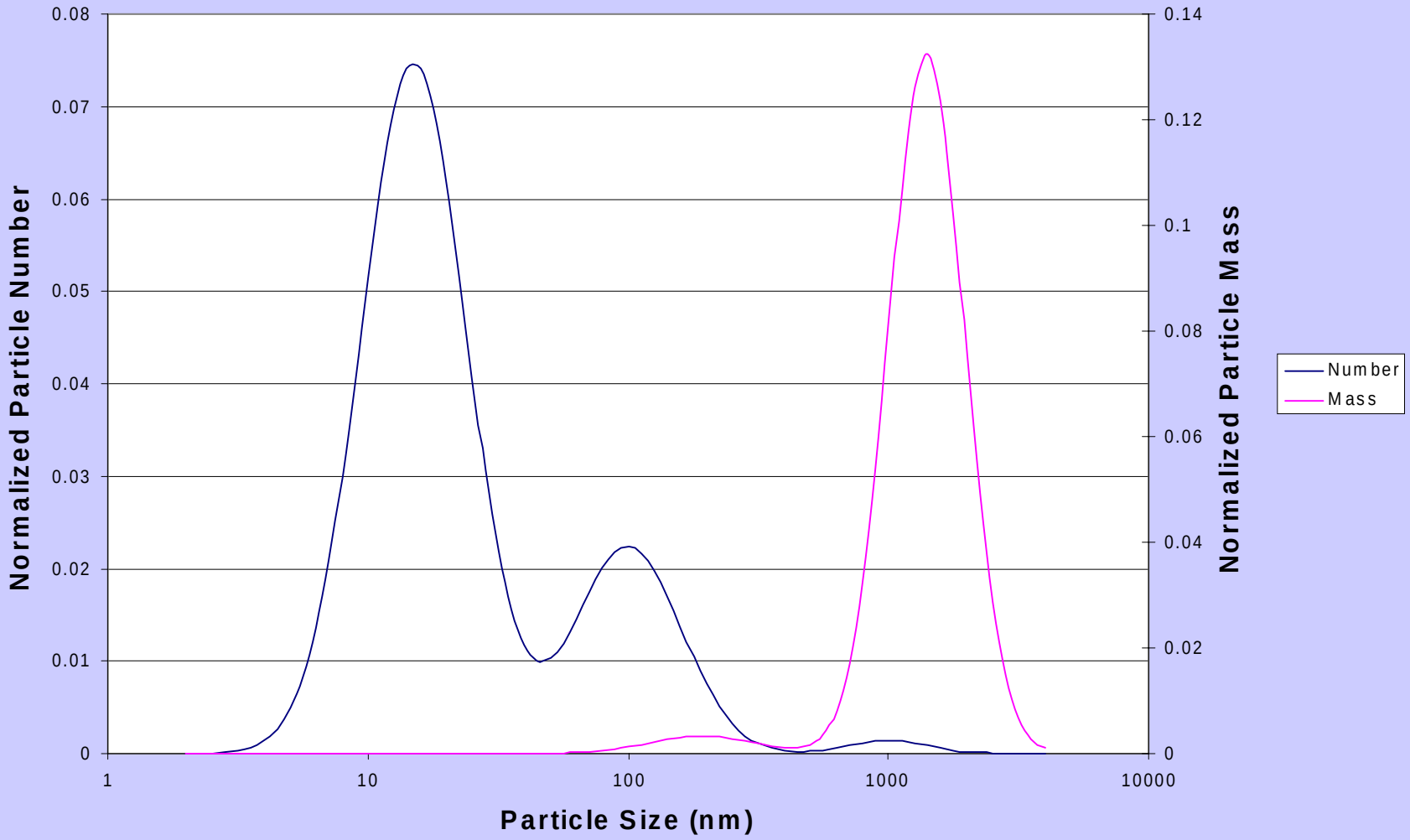
- Designed and built two on-road testing facilities (Phase I and Phase II)
- Collected on-road data and used the data to examine the MOBILE correction factors
- Identified emissions trends that might be important to the development of a modal emissions model

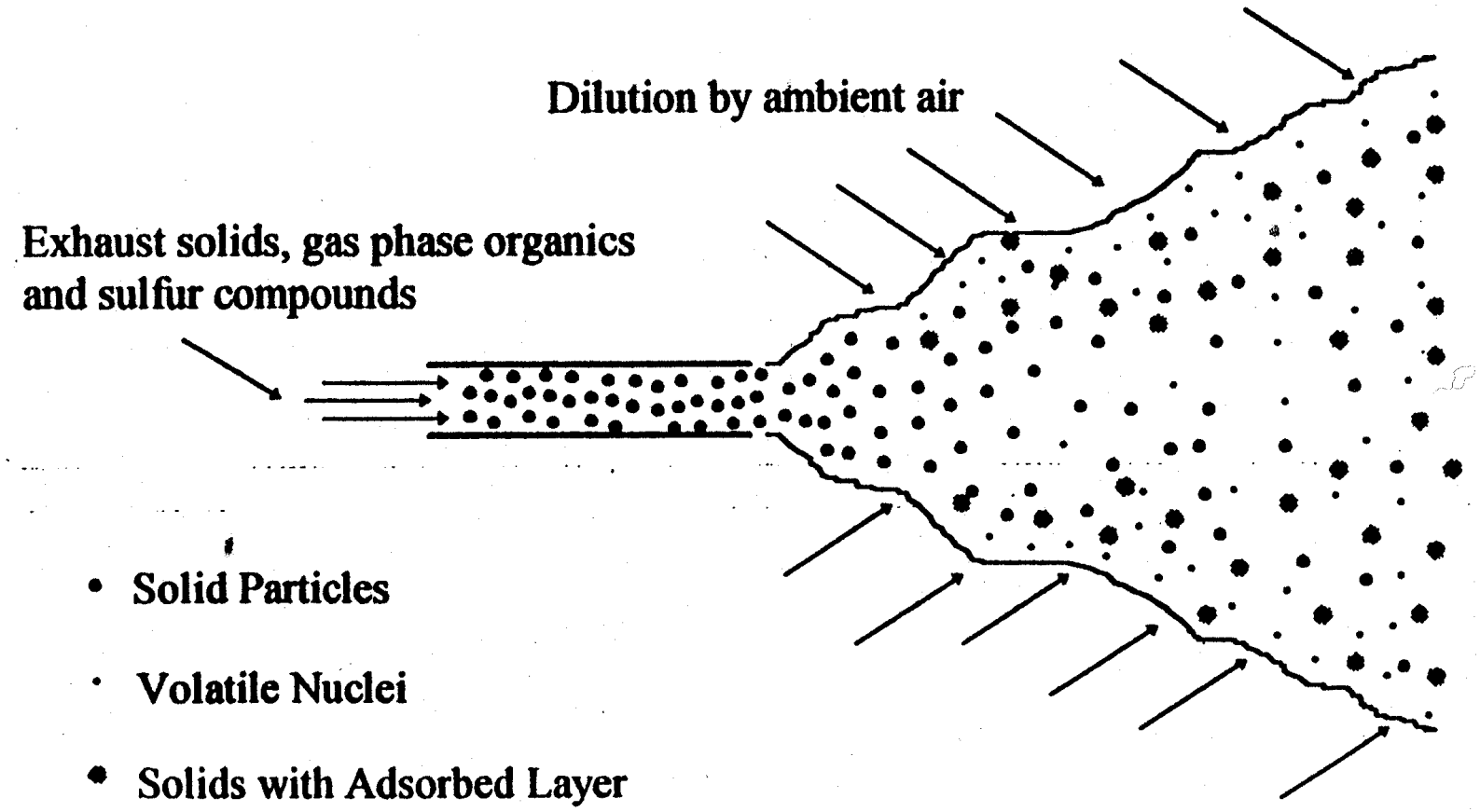
Heavy-Duty Diesel On-Road Test Facility

On-Road Diesel Emissions Program: Fine PM Objectives

- Develop Capability to Measure Fine PM Emissions from an On-Road Vehicle
- Characterize Fine PM Emissions from Heavy-Duty Diesel Trucks
  - Assess “typical” emissions and variability
  - Identify patterns and trends

Mass vs. Number Distributions of Diesel PM




Dilution by ambient air
Exhaust solids, gas phase organics and sulfur compounds
Solid Particles
Volatile Nuclei
Solids with Adsorbed Layer

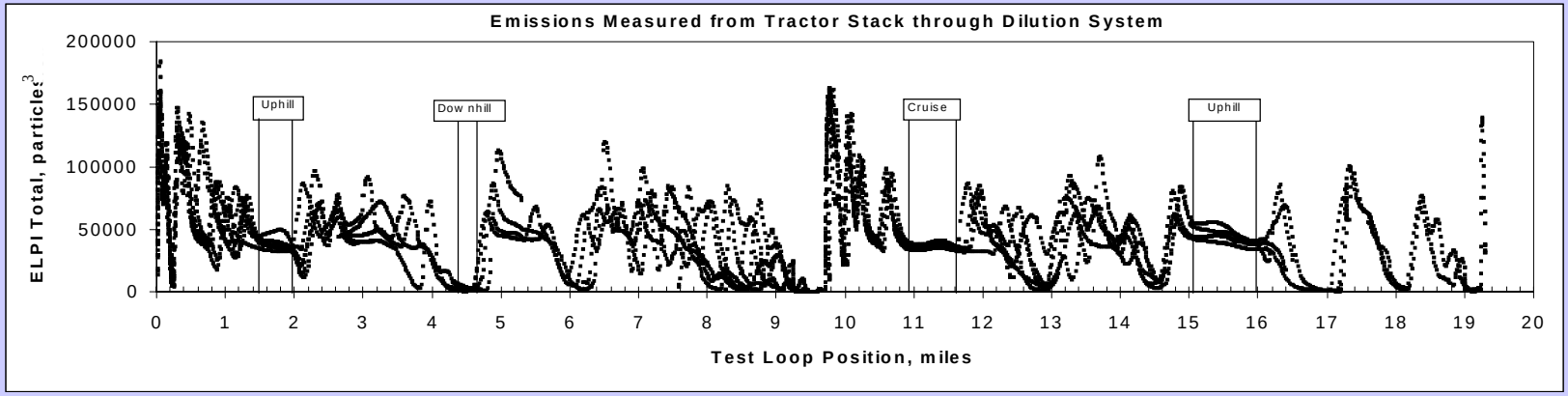
Important Facts About Diesel Fine PM

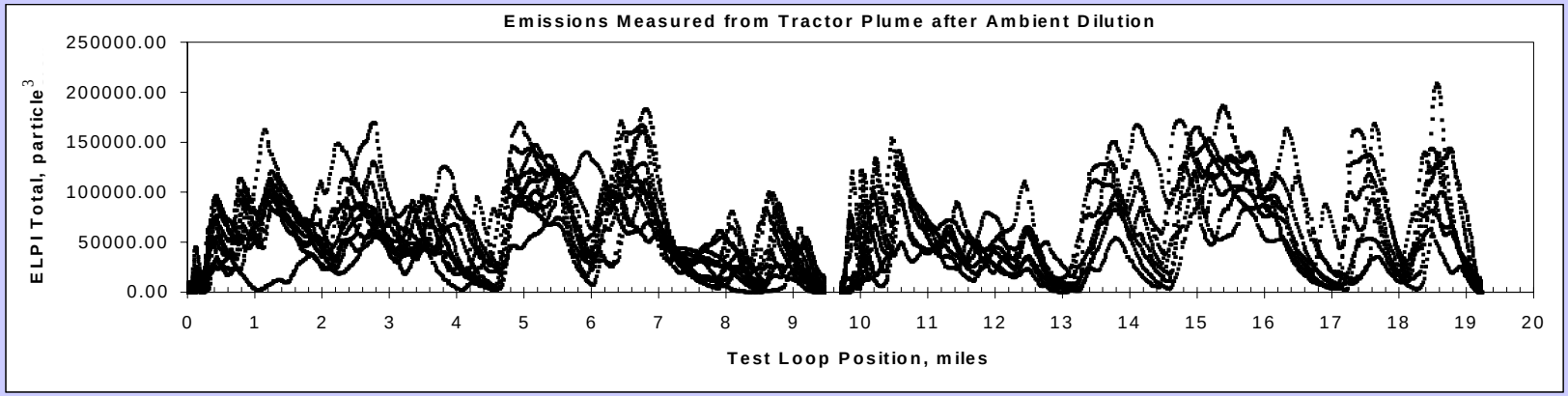
- Diesel PM is in a state of flux between dilution ratios of 5:1 and 50:1
- Dilution schedules fundamentally affect PM size distributions
- No standard dilution method mimics plume dilution

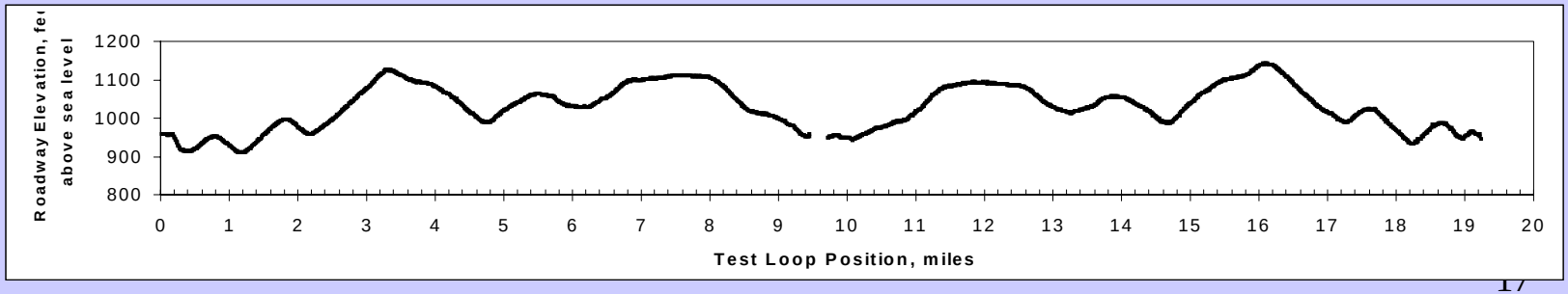
Testing Prototype Dilution System

- Prototype Dilution Versus Ambient Plume
- Tests Conducted During DRI's 1999 Tuscarora Tunnel Study
  - With only one ELPI, successive nights were compared
  - Data were collected continuously both nights
  - Comparison data were selected from roadway segments where emissions were repeatable
- Results of Prototype System Test
  - Truck exhaust plume was successfully captured and measured at 11m back
  - At this distance, plume dilution was ~250:1
  - Our prototype dilution system favored nucleation more than ambient dilution did

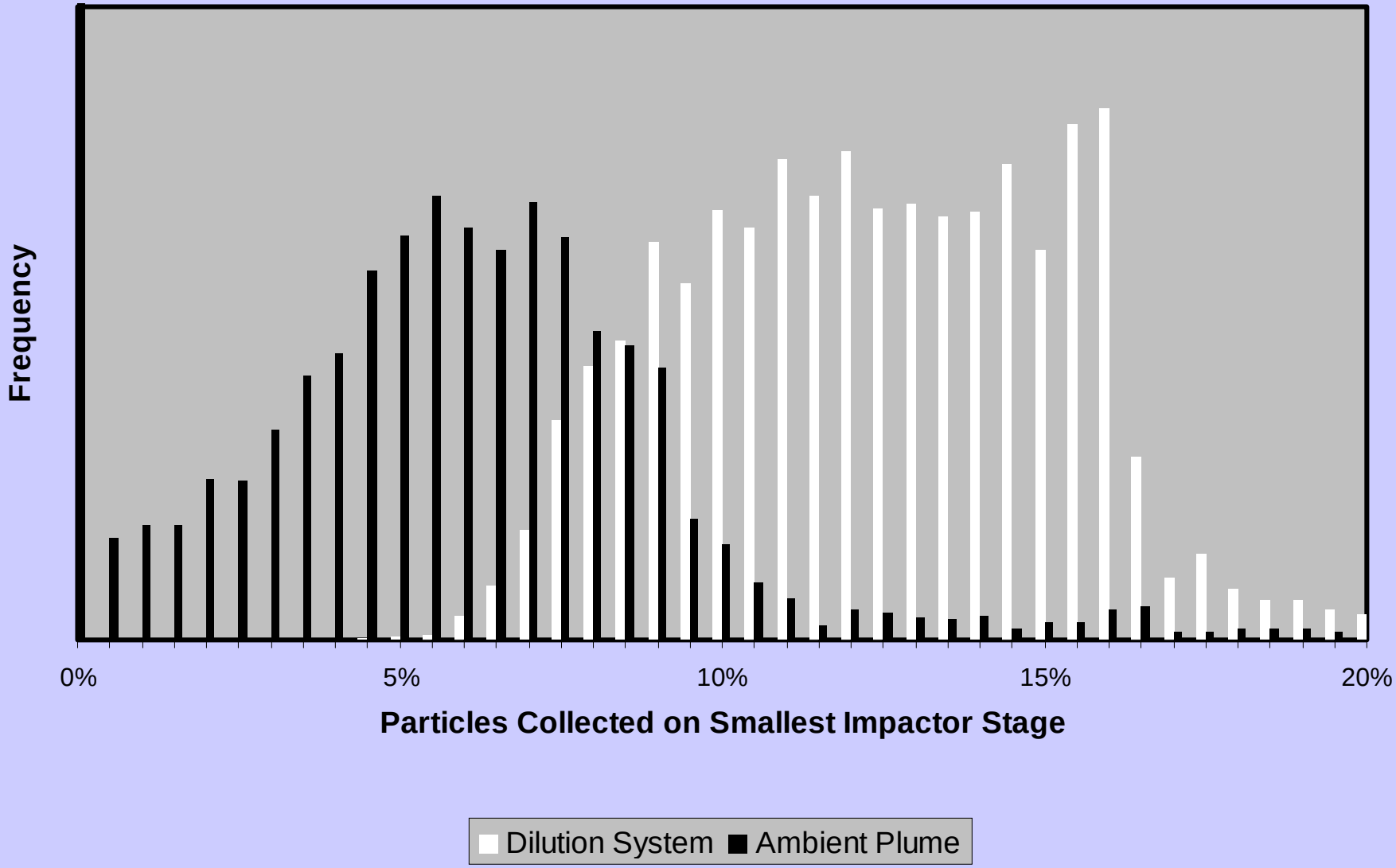
Sampling Locations



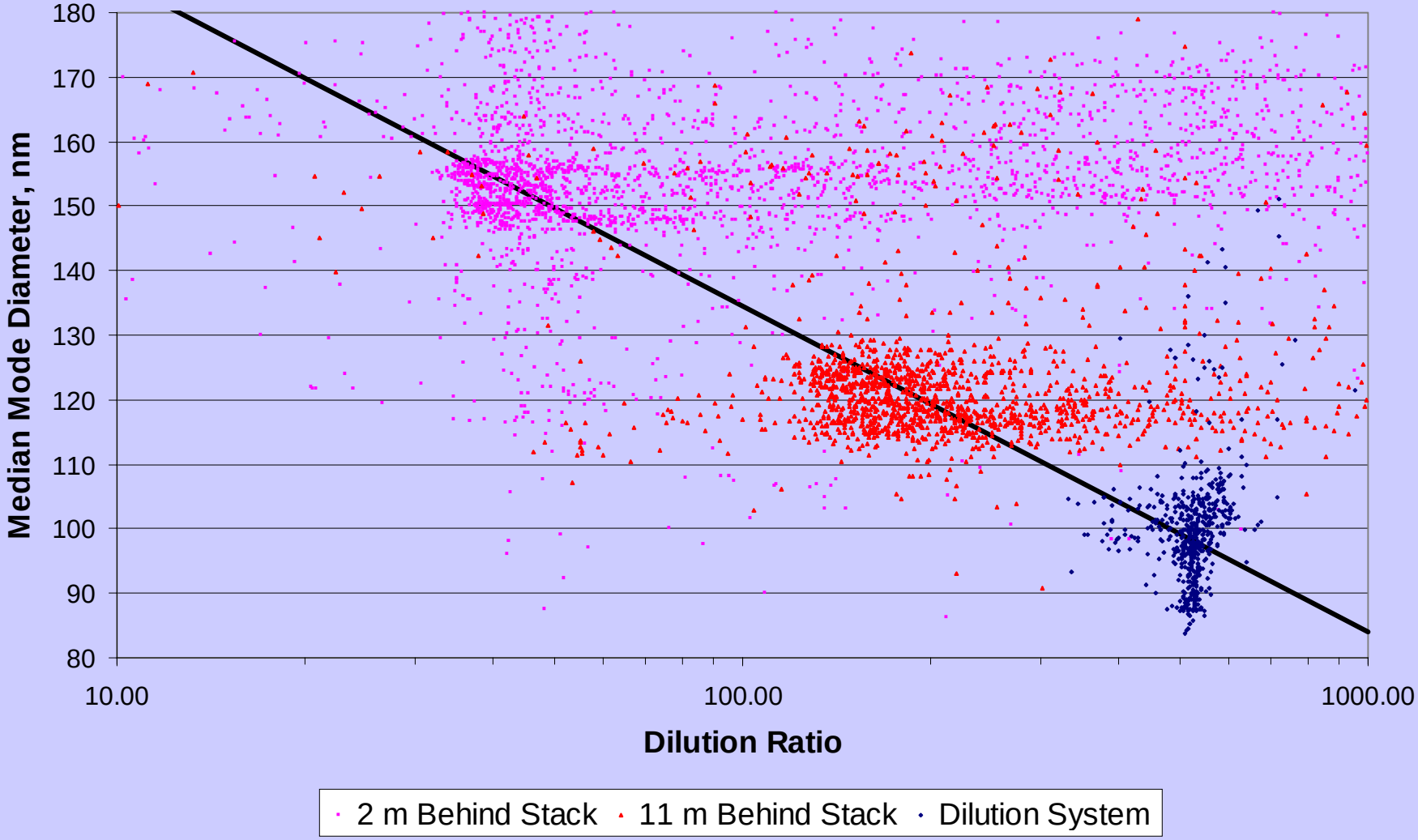




Comparison of Last Stage Proportions



Variation of Accumulation with Dilution



Future Program Goals

- Fully characterize the PM emissions plume from the EPA truck with respect to particle mass loading, size distribution (10 µm to 10 nm), chemical signature (including dioxins), and parametric effects.
- Develop a predictive tool(s) which relates emissions to key vehicle operating parameters such as torque, power demand, grade, and load.
- Design a normalization technique whereby the limited data collected from the EPA truck can be applied to larger vehicle populations.
- Devise a suitable dilution sampling methodology for use with a chassis dynamometer system which emulates the characteristics of the “real world” plume produced by heavy-duty diesel trucks.

Future Medium-Duty Program

- Support NHEERL exposure study
- On-road emissions characterization
- Support MEASURE-RTP via route-specific data
- Near-road plume characterization