# Nano Aerosols in Underground Mines

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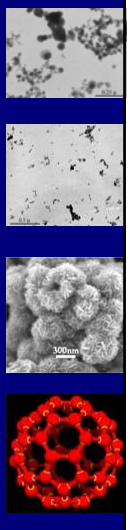
## Nanoparticles

- Particles with diameter smaller then 50 nm, length scale of approximately 1-100 nm…
- Normally occurring
  - Forest fires…
- Incidental anthropogenic
  - Diesel
  - Open flame heating
  - Welding fumes…
- Engineered nanoscale materials (nanotechnology)
  - Nanotubes
  - Nanosperes…
  - **Nanoparticle Information Library (NIL) @ http://www.cdc.gov/niosh/topics/nanotech/NIL.html**



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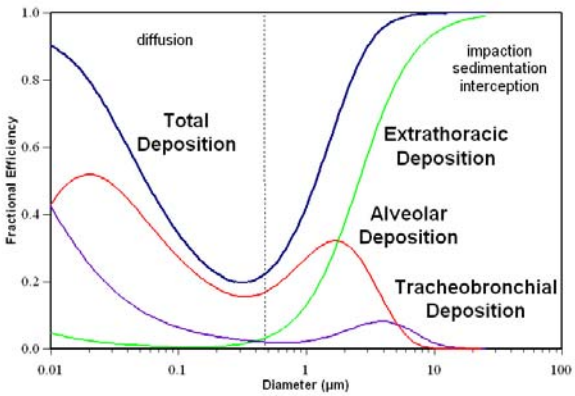
## Potential Health Hazard Associated with Exposure to Nanoparticles

- At nanoscale, materials begin to exhibit unique properties that affect physical, chemical and biological behavior.




**Particle Deposition in the Human Respiratory Tract as a Function of the Particle Diameter**

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## Potential Health Hazard Associated with Exposure to Nanoparticles

- Long-term exposure to combustion-related ultrafine particulate air pollution is an important environmental risk factor for cardiopulmonary and lung cancer mortality [Pope et al. 2002].
- Donaldson and Stone (2003) concluded that there is good toxicological evidence that ultrafine particles cause inflammation in the lungs even when composed of relatively low toxicity material
- There is growing evidence suggesting that particle number, surface area or size, or perhaps some associated structural properties may affect nanoparticle toxicity in comparison with larger respirable particles of the same composition [Donaldson et al. 2003].

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## Nanotechnology Safety and Health Research Program at National Institute for Occupational Safety and Health (NIOSH)

- In general, occupational health risks associated with exposure to nano and ultrafine aerosols are not yet clearly understood.
- NIOSH is focusing on answering the following questions that are essential to understanding occupational safety and health implications of exposure to nanoparticles:
  - How might workers be exposed to nanoparticles?
  - How do nanoparticles interact with the body's systems?
  - What effects might nanoparticles have on the body's systems?

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## Nanotechnology Safety and Health Research Program Critical Topics

- NIOSH has identified 10 critical topic areas to guide in addressing knowledge gaps, developing strategies, and providing recommendations:
  1. Toxicity
  2. Risk Assessment
  3. Epidemiology & Surveillance
  4. Controls
  5. Measurement Methods
  6. Exposure & Dose
  7. Safety
  8. Recommendations & Guidance
  9. Communication & Education
  10. Applications

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## Nanotechnology Safety and Health Research Program Projects

1. Generation and Characterization of Occupationally Relevant Airborne Nanoparticles – Bon-Ki Ku, Ph.D.
2. Pulmonary Toxicity of Carbon Nanotube Particles – Anna Shvedova, Ph.D. and Paul Baron, Ph.D.
3. Role of Carbon Nanotubes in Cardio-Pulmonary Inflammation and COPD Related Diseases – Michael Luster, Ph.D. and Petia Simeonova, Ph.D.
4. Particle Surface Area as a Dose Metric – Vincent Castranova, Ph.D.
5. Ultrafine Aerosols from Diesel-Powered Equipment – Aleksandar Bugarski, Ph.D.
6. Nanotechnology Safety and Health Research Coordination – Vincent Castranova, Ph.D.
7. Systemic Microvascular Dysfunction: Effect of Ultrafine vs. Fine Particles – Vincent Castranova, Ph.D.
8. Pulmonary Deposition and Translocation of Nanomaterials – Robert Mercer, Ph.D and James Antonini, Ph.D.
9. Dermal Effects of Nanoparticles – Anna Shvedova, Ph.D. and Min Ding, Ph.D.

**http://www.cdc.gov/niosh/topics/nanotech/default.html**

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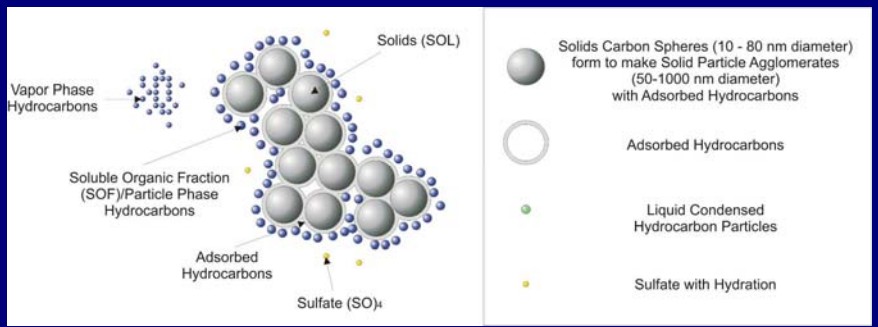
## Ultrafine Aerosols from Diesel-Powered Equipment

- Diesel powered vehicles are major source of nano and ultrafine (N&UF) particles in workplace.
- Physical and chemical properties of the aerosols emitted by diesel powered equipment are significantly changing with a number of engine parameters and with the implementation of various emissions control technologies.

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## Diesel in Underground Mines

- Miners in U.S. metal and nonmetal underground mines are exposed to elemental carbon (EC) concentrations as high as 3300 µg/m$^3$ [Cash and Baughman 2005].
- Current U.S. regulations limiting exposure of metal and nonmetal underground miners to DPM are based on feasibility of implementation of control technologies rather than established health effects of DPM.
- Strong push toward improving existing and introducing new diesel emissions control strategies and technologies.

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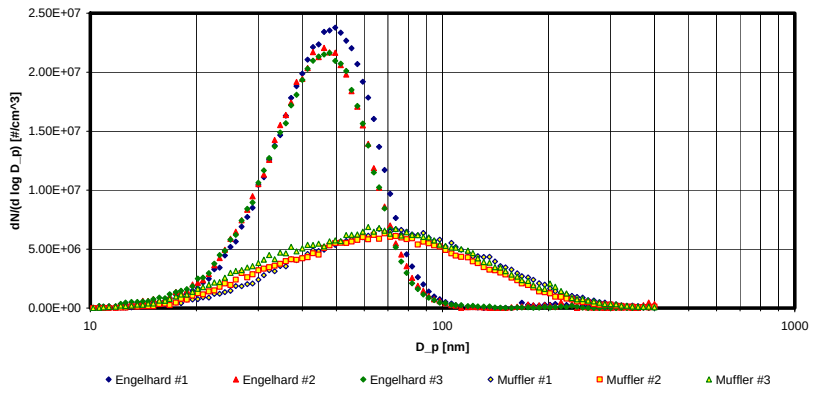
## Stillwater 2003
## Effects of DPF 1 on size distribution of aerosols

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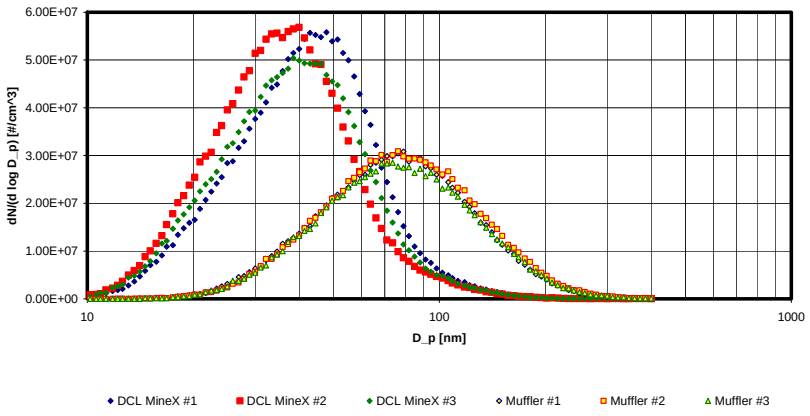
## Stillwater 2003
## Effects of DPF 2 on size distribution of aerosols

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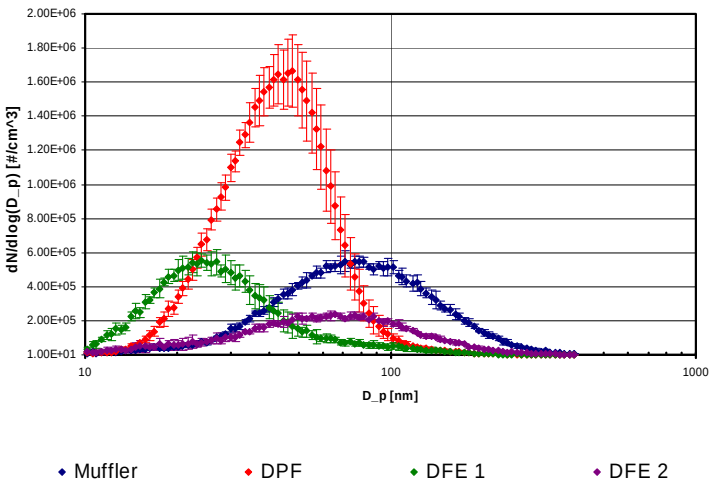
## Stillwater 2004
## Effects of DPF and DFEs on size distribution of aerosols

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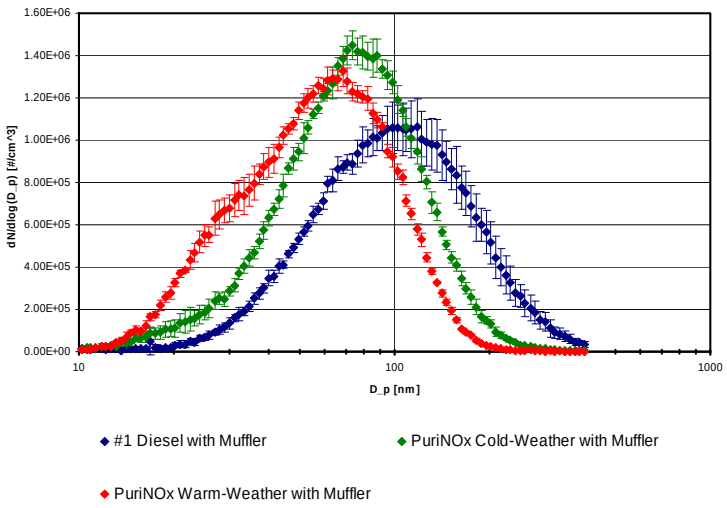
## Stillwater 2004
## Effects of water-in-diesel-fuel emulsions on size distribution of aerosols in mine air

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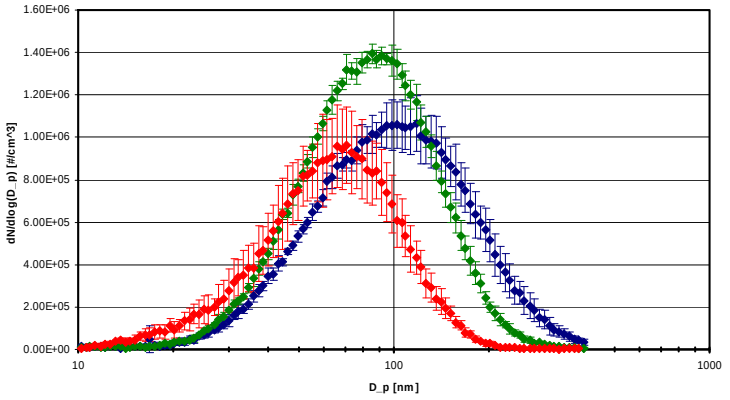
## Stillwater 2004
## Effects of yellow grease biodiesel blends on size distribution of aerosols

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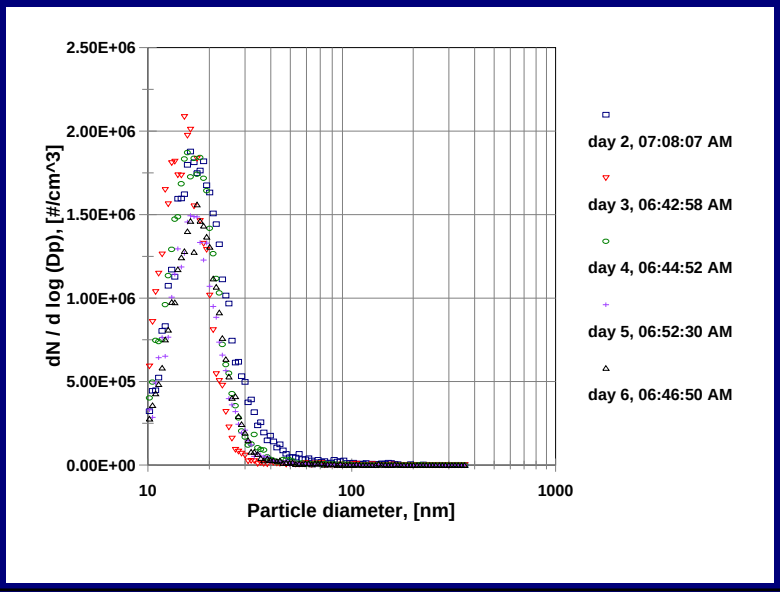
## Noranda BM&S 2001
## Other sources of nano aerosols in underground mines

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## Ultrafine Aerosols from Diesel-Powered Equipment
## Specific Aims

- Characterize physical, chemical, and toxicological properties of nano and ultrafine aerosols emitted by heavy- and light-duty diesel engines
- Study the effects of selected control technologies (diesel particulate filters, diesel catalytic converters, fuel formulations) on concentrations of diesel aerosols in work place.
- Determine the effects of aging and dispersion processes on aerosols emitted by diesel engines.
- Investigate the need for establishing a new metric for monitoring occupational exposure to diesel aerosols.
- Evaluate currently available instrumentation and develop new methods for monitoring worker exposure to diesel aerosols, using size distribution, number, surface area as a metric.

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## Methodology

- Characterization of DPM in occupational setting:
  - NIOSH Engine Emissions Laboratory (EEL) at Lake Lynn Laboratory (LLL)
    - Avoid laboratory uncertainties introduced with various simulations of processes
    - Bridge gap between inherently inaccurate field and unrealistic laboratory experiments
- LLL offer unique environment for field testing with laboratory accuracy.

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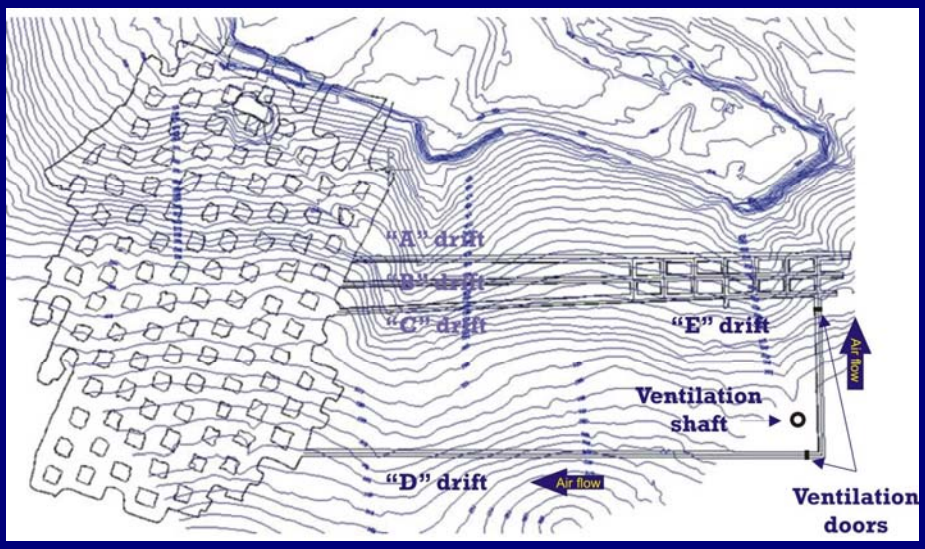
## NIOSH Lake Lynn Laboratory (LLL)

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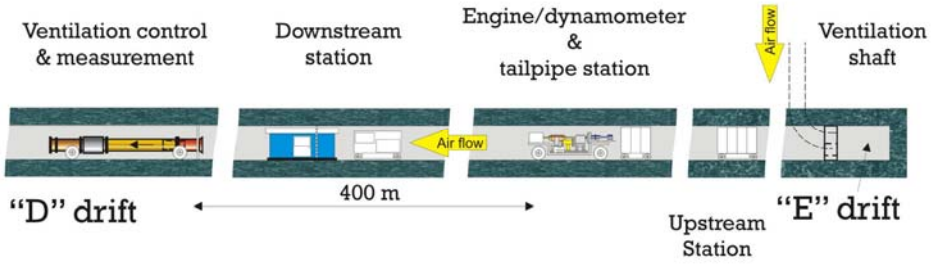
## NIOSH Engine Emissions Laboratory at Lake Lynn Laboratory

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## Control Technologies

- Old vs. modern engines
  - Mechanically controlled naturally aspirated engine (Isuzu C240) used in light-duty applications.
  - Electronically controlled turbocharged engine (MB OM904) used in heavy-duty applications.
- Various aftertreatment devices
  - Diesel particulate filters
  - Disposable filter elements
  - Diesel oxidation catalytic converters…
- Reformulated fuels
  - Biodiesel
  - Additives…

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## Sampling and Measurement Methodology and Instrumentation

- State-of-the-art instrumentation and methods for physical and chemical characterization of aerosol:
  - SMPSs;
  - FMPS;
  - ELPI
  - NSAM;
  - TEOMs…

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## Sampling and Measurement Methodology and Instrumentation

- State-of-the-art instrumentation and methods for measurement of gases:
  - HFID for HC analysis;
  - Chemiluminescence for NO and $NO_2$;
  - NDIR for CO and $CO_2$;
  - Photoacoustics for CO, $CO_2$, and $SO_2$
  - GC/MS for speciation of semi-volatile and volatile hydrocarbons;
  - FTIR

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## Sampling and Measurement Methodology and Instrumentation

- In-vitro genotoxicity
  - Development of surfactant-based airborne nanoparticle sampler for evaluating the toxicity of diesel aerosols
  - Analysis performed by NIOSH-HELD –Molecular Biophysics Team primarily Dr. Shi Xiao-Chun under supervision from Dr. William Wallace:
    - bacterial gene mutation assays
    - mammalian cell chromosomal and DNA damage assays
  - Shi XC, Keane M, Ong T, Harrison J, Gautam M, Bugarski A, Wallace W. In vitro mutagenic and DNA and chromosomal damage activity by surfactant dispersion or solvent extract of a reference diesel exhaust particulate material. 12th Diesel Engine-Efficiency and Emissions Research (DEER), August 20-24, 2006.

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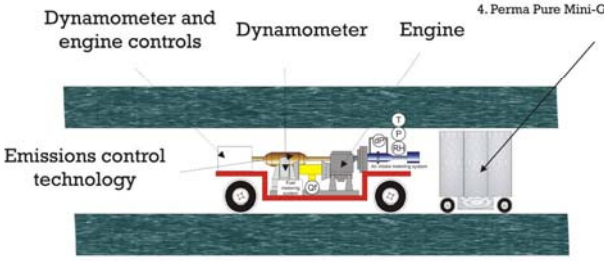
## Engine/Dynamometer Systems and Tailpipe Sampling Station

TAILPIPE EMISSIONS CART

1. California Analytical Model 602 NDIR CO and $CO_2$ analyzer
2. ECOM Model KL Portable Emissions Analyzer ($CO, O_2, NO, NO_2$)
3. Horiba Instruments Automated Gas Divider Model SGD-A104
4. Perma Pure Mini-GASS Gas Analysis Sampling System Model MG-1220

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## 150 kW Dynamometer Coupled to Isuzu C240 Engine

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## 400 kW Dynamometer Coupled to Mercedes Benz OM904 Engine

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## Tailpipe Sampling Station

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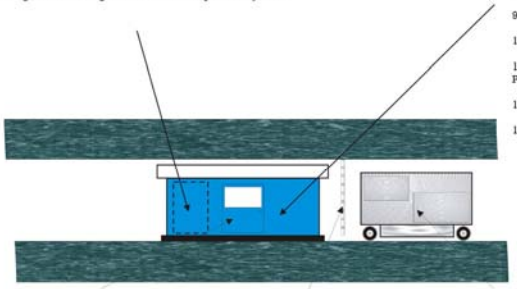
## Downstream Sampling and Measurement Station

GAS BENCH

1. Eco Physics Model CLD 700 AL Chemiluminescence NO/NO2 analyzer
2. California Analytical Model 300 HFID Heated Flame Ionization Detector
3. INNOVA Model 1312 Photoacoustic Multi-gas Monitor for CO, CO2, SO2
4. Two Horiba Instruments (STEC Inc.)Model SGD-A10 Automated Gas Divider
5. Perma Pure Zero-Air Generator (18 liter)
6. Balston H2-150 Hydrogen Generator
7. M&C Model PSS-10 Portable Gas Conditioning System
8. Agilent Technologies 34970A Data Acquisition System

AEROSOL BENCH

1. TSI Model 3080 Electrostatic Classifier
2. TSI Model 3025 A Condensation Particle Counter
3. TSI Model 3776 Condensation Particle Counter
4. TSI Model 3091 Fast Mobility Particle Sizer
5. TSI Model 3550 Nanoparticle Surface Area Monitor
6. Dekati Model DAS 3100 Electric Low Pressure Impactor
7. Topas Model TDD 590 Thermo Diffusion Denuder
8. TSI Model 3089 Nanometer Aerosol Sampler
9. Varian Saturn 2200 GC/MS with 3800 GC
10. EcoChem Analytics PAS 2000 Real Time PAH Monitor
11. Matter Engineering Diffusion Charging Particle Sensor Model LQ1-DC
12. Filter Sampling System
13. Genotoxicity Sampling System



Instrumentation Hut

Sampling Grid

FTIR Cart with Perkin Elmer Spectrum GX FTIR

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## Downstream Sampling and Measurement Station

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## Upstream Sampling and Measurement Station

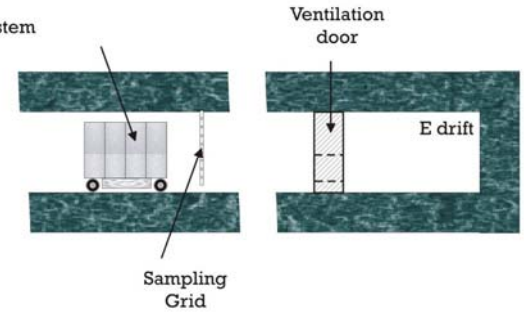
UPSTREAM SAMPLING CART

1. Rupprecht & Patashnick TEOM Series 1400a Ambient Particulate Monitor

2. TSI Model 3080 Electrostatic Classifier

3. TSI Model 3010 Condensation Particle Counter

4. Filter Sampling System

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## Upstream Sampling and Measurement Station

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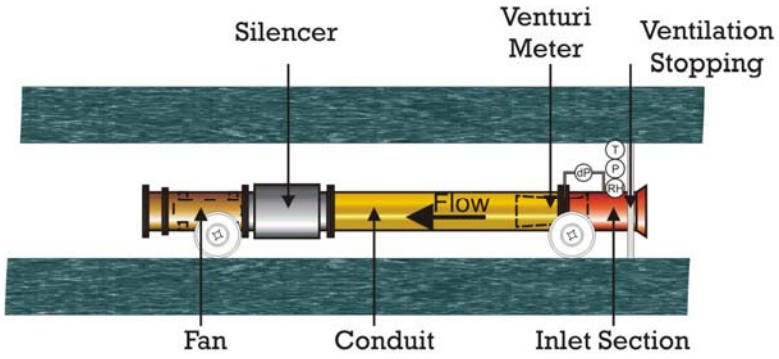
## Ventilation Measurement and Control

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## Ventilation Control and Measurement System

- Flow measurement
  - 25,000 cfm Venturi meter from Primary Flow Signal Inc.
- Auxiliary fan
- Ventilation stopping.

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## Summary of the Expected Outputs

- Detailed profile of nano and ultrafine aerosols emitted by diesel engines in term of:
  - mass;
  - number;
  - surface area;
  - size resolved chemical composition;
  - In vitro genotoxicity

  for various types of engines, fuel formulations, and exhaust aftertreatment devices.
- Improve understanding of the effects diesel aerosols have on the workers health.
- The comprehensive evaluation of the aerosol instrumentation for monitoring workers exposure to nano and ultrafine aerosols.

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## Summary of the Expected Outputs

- Reduce workers exposure to DPM aerosols through:
  - better assessment of worker exposure
  - better selection of control technologies and strategies
  - better exposure monitoring

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