Continuous, Long Term Monitoring of Ultrafine Particles (UFP) in Urban Air

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Leapfrogging Opportunities for Air Quality Improvement
Xi'an, Shaanxi Province, China
Outline

- What are Ultra-fine Particles (UFP)?
- Why Monitor UFP?
- European Regulatory Activity
- Ways to Measure Ultra-fine Particles
  - Total Concentration
  - Size Distribution
- Instrumentation
What are Ultra-Fine Particles?

1. US EPA definition: Particles with a diameter <100nm
2. UFPs occur in massive numbers in urban air but essentially have no measurable mass
3. Most common source in urban environment is vehicle exhaust
Why Monitor UFP?

1. Potential Health Effects
   - 2008 UCLA Study: How UFP in Air Pollution May Cause Heart Disease
   - 2004 Oberdörster Study: Evidence of UFP Accumulation in Brain

2. Increased Exposure to Ultra-fines
   - Ultrafine Particles in Classrooms: Studied UFP in 3 elementary classrooms in Brisbane, Australia: Numerous occasions where UFP levels were significantly higher than outdoor air.
   - Ultrafine Particles in Tunnels: Measured UFP concentration levels outside a vehicle traveling through the M5 East tunnel in Sydney, Australia: at times the levels are up to 1000 times higher than in urban ambient conditions.
   - Ultrafine Particles Near Airports: Measured range of air pollutants near Santa Monica Airport: Found that emissions of (UFP) were significantly elevated, up to 10 times higher at a downwind about 100 yards and 2.5 times higher at distance of about 600 yards.

3. Air Quality Effects
   - Ultra-fine particles from combustion sources are frequently hygroscopic
   - At high relative humidity, condensing water enlarges UFPs to a size that is efficient at scattering light and interferes with visibility.
   - UFPs are primarily responsible for urban smog
UFP: Mass or Number?

Traditional mass based measurements like PM$_{10}$ and PM$_{2.5}$ severely underestimate contribution of UFPs.

1. **Euro 5/6:** First regulation to restrict the number (not mass) of UFP in light duty diesel vehicle emissions.

2. Clean Air Commission of VDI/DIN* is preparing German national guidelines for particle number concentration and size distribution measurements in air quality monitoring networks.

3. CEN/TC** 264/WG 32 is working on technical recommendations for number concentration and size distribution measurement of UFP in air quality monitoring.

4. Clean Air for Europe (CAFE)
   - Thematic Strategy on Air Pollution
   - Program to improve data quality for advanced environmental monitoring, including UFP number concentration and size distribution.

5. UFIPOLNET† project initiated to develop an affordable, low maintenance monitor for UFP number and size.

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* VDI is the Association of German Engineers; DIN is the German Institute for Standardization  
** CEN is the European Committee for Standardization; TC is an Independent Technical Committee for air quality control  
† UFIPOLNET: UltraFIne Particle Size Distributions In Air POLIution Monitoring NETworks
How to Measure Ultra-Fine Particles

1: Condensation Particle Counter
2: Scanning Mobility Particle Sizer
3: Ultra Fine Particle Monitor

Total Number Concentration

Condensation Technique Used to Count Ultra-Fine Particles

- Standard method used by government agencies (NIOSH, EPA, etc.) and air quality measurement experts to measure UFP concentrations.
- Single particle counting: particles are counted individually, significantly increasing concentration accuracy.
UFP Particle Number (PN) Concentration

**EPC™ Environmental Particle Counter™**

- 7 nanometer detection
- Up to $10^6$ particles/cm$^3$ – single particle counting
- Data acquisition via USB flash drive, software or ASCII commands
- Sampling intervals down to 1 second
- Low maintenance

Data from US EPA Roadside Study Site – Las Vegas, NV
UFP Size Distributions

- Developed by UFIPOLNET team
- Designed for 24/7 Air Quality monitoring
- Continuous particle size and concentration measurements
- Standardized measurement method
- Extensive field validation
- No working fluids; no radioactive source

Specifications

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<th>20 nm to ~800nm</th>
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<tr>
<td>6 size channels</td>
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<td>Concentration up to (10^6) particles/cm(^3)</td>
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<td>15 minute data sets</td>
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<td>Data Interfaces: Ethernet, RS-232, USB</td>
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UFIPOLNET Design Criteria

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<th>Affordable price/low cost of ownership</th>
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<td>Low cost of ownership</td>
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<td>Easy integration into monitoring systems</td>
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<td>Manageable data sets</td>
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<td>Reliable, sensitive and accurate data</td>
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UFIPOLNET - Project

- UFIPOLNET Technical Final Report is public on the UFIPOLNET web site www.ufipolnet.eu
UFP Monitor Principle

- **Inlet**
- **Unipolar Charger**
- **Electrostatic Classifier**
- **Aerosol Electrometer**

**Sample the particles**

**Charge the particles**

**Classify into size fractions**

**Quantify the concentration**

**Average Weekday Concentrations of UFP, NOx and Soot in Dresden, Germany, 1/24 – 3/19/2007**

Gerwig, H. *et al.*, “UFIPOLNET: Concentration of Particle Number Distributions at 4 Stations in Europe, Poster Presentation, Particle and Photo-oxidants in Europe, Sep 25-27, 2007, Prague, Czech Republic
Typical Field Setup

- Roof PM$_{10}$ Inlet
- PM$_{1}$ Cyclone
- Flow Splitter
- 16.7 L/min
- Filtered Air
- 11.7 L/min
- Valve
- Nafion Dryer
- 5 L/min
- Pump
- Exhaust
3031 Flow Schematic

Charge the Particles

Select Particles by Size

Measure the Concentration
Validation: Co-Located Instruments

Comparison of two UFP Monitors for six size classes

Correlations:
\( r^2: 0.94 - 0.98 \)
Slope: 0.90 – 1.04

Field Evaluation at 4 locations in Europe

- The 12 months of continuous operation
  - Demonstrate data availability of the devices
  - Determine optimal maintenance scheme
  - Correlation analysis with other measured contaminants

- All four prototype units achieved data availability >90%

- No reliability problems reported during entire period (>12 months)
Diurnal Variations

Field Measurements of UFP Size Distributions

- **Beijing Olympics**: Researchers from Cornell University used a 3031 to monitor UFP in Beijing during August 2008 Olympic Games.
- **USEPA**: Las Vegas Roadside Study – Designed to Evaluate UFP in the Near-Roadway Environment
- **Delaware Department of Natural Resources and Environmental Control**: New Air Quality Project to Monitor Nanoparticles [http://www.awm.delaware.gov/Pages/AirQuality.aspx](http://www.awm.delaware.gov/Pages/AirQuality.aspx)
- **Other Agencies**
  - Ontario Ministry of Environment & Department of the Environment
  - Environmental Protection Agency Air Sciences: Queensland, Australia
Thank You for your Attention