

Preliminary Results from Isolated Zone Testing of Diesel  
Emissions Control Technologies

Stillwater Nye Mine  
September 2004 Study

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## Acknowledgements

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- Dan Milton, Stillwater Nye Mine
- Carla Allen, Stillwater Nye Mine

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- ☀ Study was conducted under auspices of Metal/Nonmetal Diesel Partnership (NIOSH, NMA, USWA, MARG)

### Objectives of the study

- ☀ To measure the effects of selected diesel emissions control technologies on the concentrations and properties of aerosols and gases in mine air

*Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health*

### Methodology - List of the Tests

| Vehicle | Exhaust System                 | Fuel Formulation                                 |
|---------|--------------------------------|--|
| MU257   | Muffler                        | #1 Diesel  |
|         | Arvin Meritor (AM) with Pt DOC | #1 Diesel  |
|         | Arvin Meritor (AM) with Pd DOC | #1 Diesel  |
|         | Donaldson P604516              | #1 Diesel  |
|         | Filter Service                 | #1 Diesel  |
|         | Clean Air Power/ETG CPO        | #1 Diesel  |
| MU344   | Muffler                        | #1 Diesel  |
|         | Muffler                        | PuriNOx Cold-Weather                             |
|         | Muffler                        | PuriNOx Warm-Weather                             |
|         | Muffler                        | Soy Biodiesel 20% Blend with #1 Diesel           |
|         | Muffler                        | Soy Biodiesel 50% Blend with #1 Diesel           |
|         | DCL International DOC          | Soy Biodiesel 50% Blend with #1 Diesel           |
|         | Muffler                        | Yellow Grease Biodiesel 20% Blend with #1 Diesel |
|         | Muffler                        | Yellow Grease Biodiesel 50% Blend with #1 Diesel |
|         | Muffler                        | ULS (<15 ppm Sulfur) Diesel                      |
|         | DCL International DOC          | ULS (<15 ppm Sulfur) Diesel                      |

### Methodology – Vehicles/Engines Tested in the Study

| Vehicle | Vehicle Type   | Vehicle Make | Vehicle Model | Engine Make | Engine Model    | Engine Displacement | Engine Rating | Engine Type  |
|---------|----------------|--------------|---------------|-------------|-----------------|---------------------|---------------|--|
| Unit    | -              | -            | -             | -           | -               | [liters]            | [hp]          | -  |
| MU257   | Load Haul Dump | Wagner       | ST-2D         | Deutz       | BF4M 1013FC/MVS | 4.764               | 151           | Fully Electronic Controlled, Turbo Charged, Air to Air After Cooled. |
| MU344   | Load Haul Dump | Wagner       | ST-3.5        | Caterpillar | 3126B DITA AA   | 7.243               | 200           | Fully Electronic Controlled, Turbo Charged, Air to Air After Cooled. |

### Methodology – Tested DPF Systems

| DPF System                     | Media Type                          | Catalyst                | DOC   |
|--------------------------------|-------------------------------------|-------------------------|---|
| Arvin Meritor (AM) with Pt DOC | Ceramic, Cordierite                 | N/A                     | Metal Substrate Platinum Based Catalyst                 |
| Arvin Meritor (AM) with Pd DOC | Ceramic, Cordierite                 | N/A                     | Metal Substrate with Paladium Based Catalyst            |
| Donaldson P604516              | Disposable High Temperature         | N/A                     | N/A   |
| Filter Service                 | Disposable High Temperature         | N/A                     | N/A   |
| Clean Air Power/ETG CPO        | Deep Bed Fiber, Quartz Silica Fiber | Precious Metal Catalyst | Ceramic Monolith Substrate with Precious Metal Catalyst |

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### Tested DPF Systems Installed on MU257



### Methodology – Isolated Zone

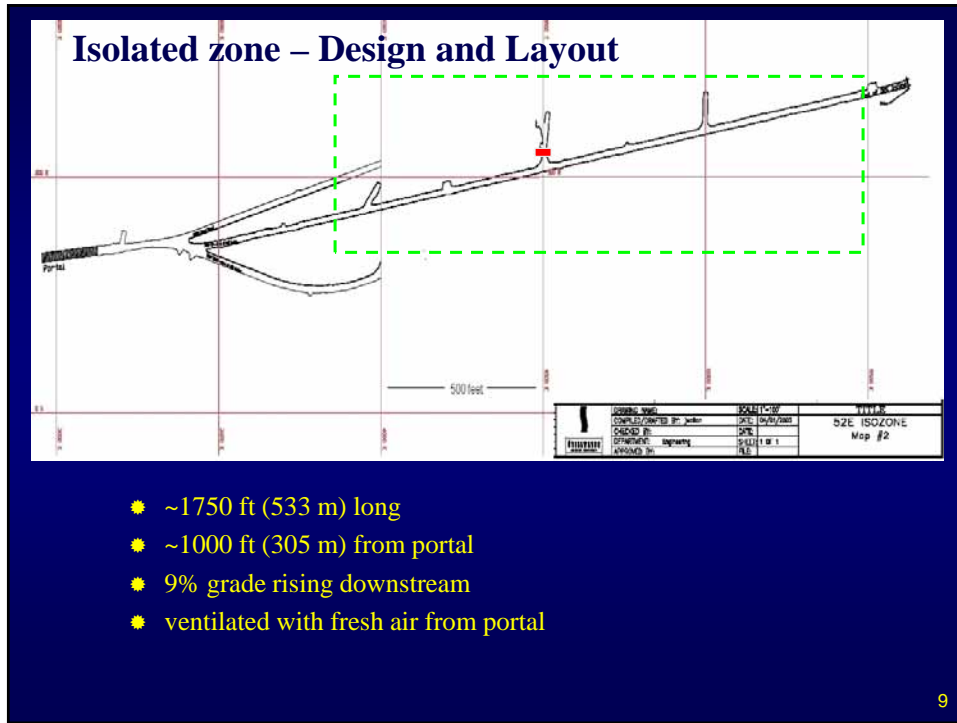
- ✱ The study was conducted in an isolated zone at Stillwater Nye mine:
  - Nye, Montana
  - Precious metals mine (palladium, platinum, gold, silver,...)
  - Vein mining
  - Large inventory of diesel-powered equipment (~ 400 units)
  - Relatively small and low-power equipment
  - Main portal at 5000 feet above sea level with production between 2900-7000 ft
  - Isolated zone between level 5000 and 5200
  
- ✱ Tests were conducted in a two-week period in September 2004

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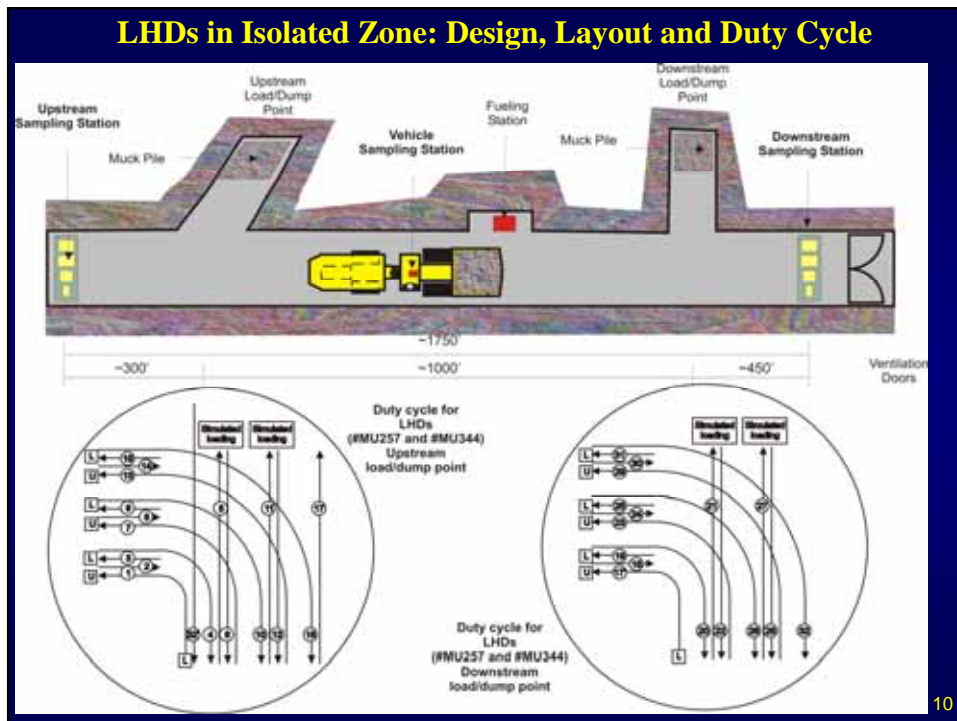
### Rationale Behind Isolated Zone Testing

- ✱ Direct in-situ assessment of the effects of control technologies on quality of ambient air in occupational environment
  
- ✱ Vehicles operated over a simulated transient production cycle
  
- ✱ Interaction between vehicle, engine, and control technology
  
- ✱ Complements results of laboratory evaluations

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### Sampling Strategy Used in IsoZone Tests

- \* Three sampling locations:
  - Downstream sampling station, ~ 450 ft (137 m) downstream of the upstream load/dump point
  - Upstream sampling station, ~ 300 ft (91 m) upstream of the upstream load/dump point
  - Vehicle sampling station, ~ 6 ft (1.8 m) from the operator
  
- \* Contribution from the vehicles obtained by subtracting upstream from downstream concentrations.

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### Sampling and Instrumentation at Downstream Sampling Station

- \* DPM samples for
  - Carbon analysis using NIOSH 5040 (High Volume)
  - Carbon analysis using NIOSH 5040 (SKC Diesel Samplers, only for fuel tests)
  - Gravimetric analysis
  - Sulfates analysis
  - PAH analysis
- \* Size distribution and number concentration using SMPS (EC 3080 and CPC 3025)
- \* Mass concentration of DPM using TEOM 1400a
- \* Concentrations of PAH and EC using PAS 2000
- \* Concentration of CO and CO<sub>2</sub> using INNOVA 1312
- \* Concentration of CO, NO and NO<sub>2</sub> using iTX Multigas Monitor
- \* Concentration of CO<sub>2</sub> using RKI Eagle monitor
- \* Vent rate and ambient temperature using Ultrasonic Anemometer

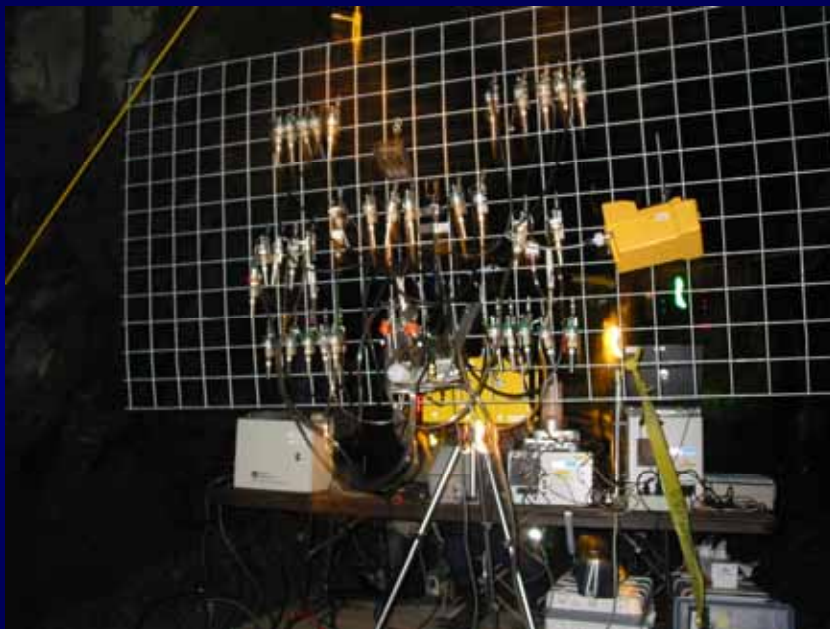
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### Instrumentation at Downstream Sampling Station



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### Sampling Grid at Downstream Sampling Station



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### Sampling and Instrumentation at Upstream Sampling Station

- DPM samples for
  - Carbon analysis using NIOSH 5040 (High Volume)
  - Carbon analysis using NIOSH 5040 (SKC Diesel Samplers, only for fuel tests)
  - Sulfates analysis
  - PAH analysis
- Size distribution and number concentration using SMPS (EC 3080 and CPC 3010)
- Mass concentration of DPM using TEOM 1400a
- Concentration of CO, NO and NO<sub>2</sub> using iTX Multigas Monitor
- Concentration of CO<sub>2</sub> using RKI Eagle monitor
- Vent rate and ambient temperature using Ultrasonic Anemometer

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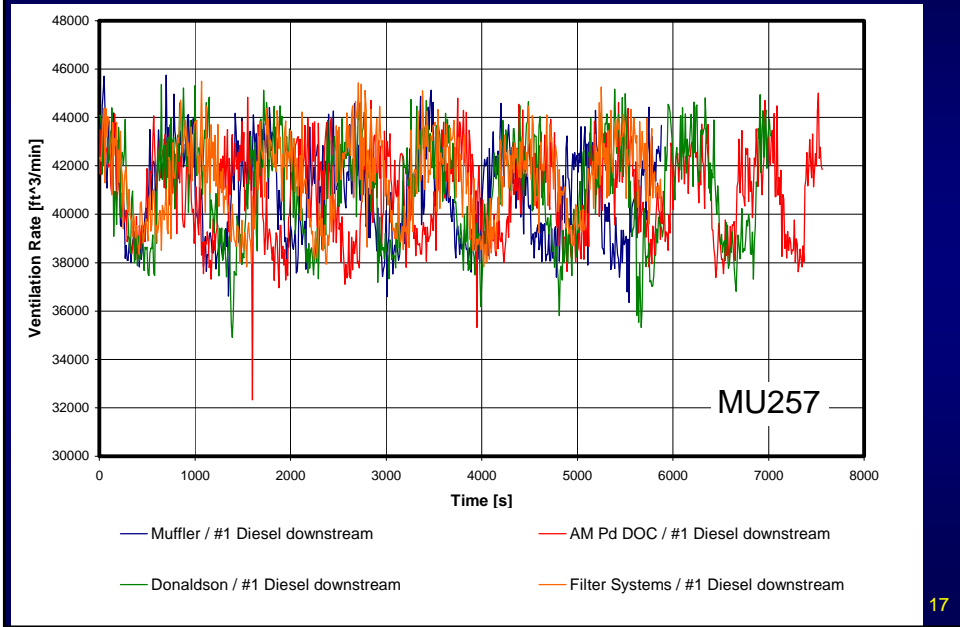
### Sampling and Instrumentation at Vehicle Sampling Station

- DPM samples for
  - Carbon analysis using NIOSH 5040 (SKC Diesel Samplers, only for fuel tests)
- Concentration of CO, NO and NO<sub>2</sub> using iTX Multigas Monitor
- Concentration of CO<sub>2</sub> using RKI Eagle monitor

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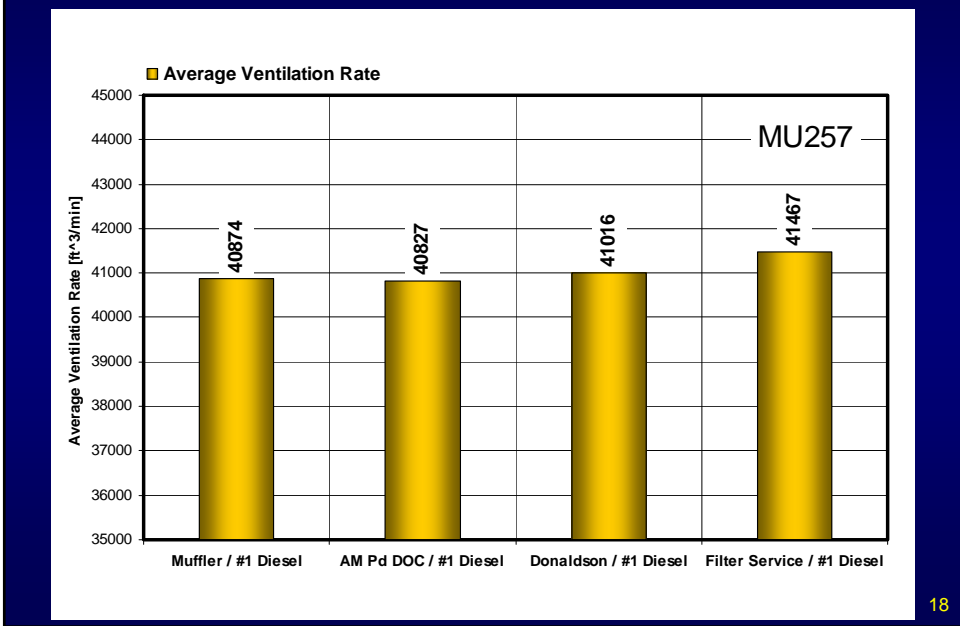


### Ventilation Rates, Test Involving MU257



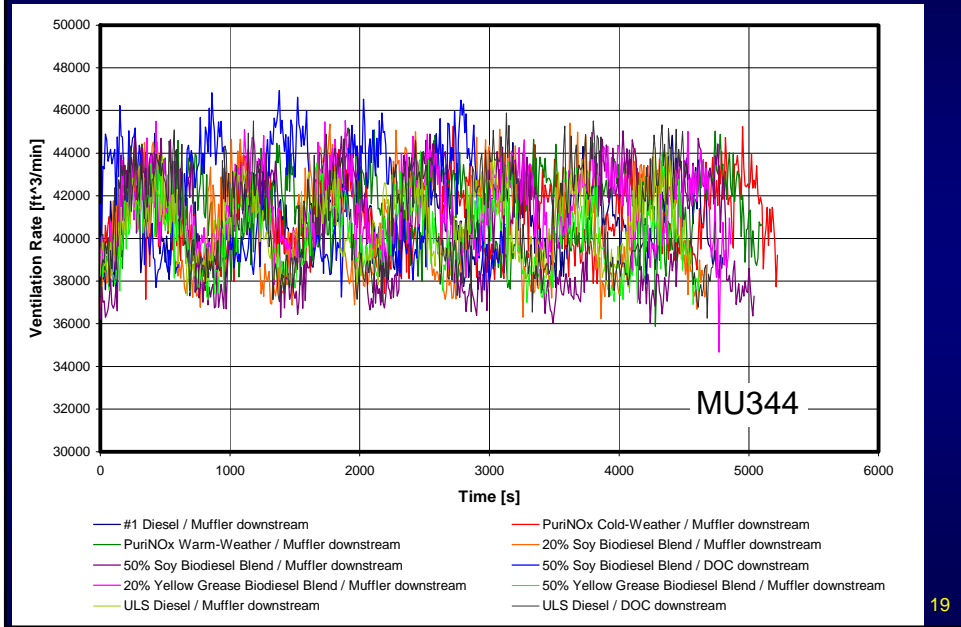
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### Average Ventilation Rates, Test Involving MU257



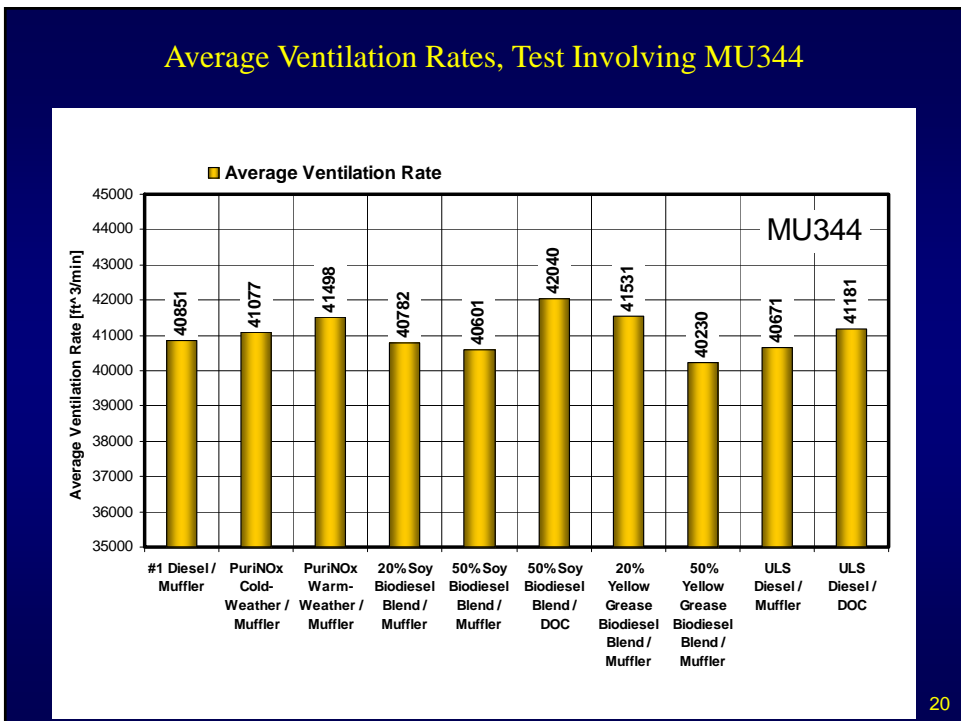
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### Ventilation Rates, Test Involving MU344



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### Average Ventilation Rates, Test Involving MU344



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## Results and Discussion

| Vehicle | Exhaust System                 | Fuel Formulation                                 | Comments                    |
|---------|--------------------------------|--|-----------------------------|
| MU257   | Muffler                        | #1 Diesel  | Successful                  |
|         | Arvin Meritor (AM) with Pt DOC | #1 Diesel  | Test prematurely terminated |
|         | Arvin Meritor (AM) with Pd DOC | #1 Diesel  | Successful                  |
|         | Donaldson P604516              | #1 Diesel  | Successful                  |
|         | Filter Systems                 | #1 Diesel  | Successful                  |
|         | Clean Air Power/ETG CPO        | #1 Diesel  | Test prematurely terminated |
| MU344   | Muffler                        | #1 Diesel  | Successful                  |
|         | Muffler                        | PuriNOx Cold-Weather                             | Successful                  |
|         | Muffler                        | PuriNOx Warm-Weather                             | Successful                  |
|         | Muffler                        | Soy Biodiesel 20% Blend with #1 Diesel           | Successful                  |
|         | Muffler                        | Soy Biodiesel 50% Blend with #1 Diesel           | Successful                  |
|         | DCL International DOC          | Soy Biodiesel 50% Blend with #1 Diesel           | Successful                  |
|         | Muffler                        | Yellow Grease Biodiesel 20% Blend with #1 Diesel | Successful                  |
|         | Muffler                        | Yellow Grease Biodiesel 50% Blend with #1 Diesel | Successful                  |
|         | Muffler                        | ULS (<15 ppm Sulfur) Diesel                      | Successful                  |
|         | DCL International DOC          | ULS (<15 ppm Sulfur) Diesel                      | Successful                  |

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## Results and Discussion

- Effects of selected DPF systems (tests involving MU257) on:
  - total mass of particles under 800 nm
  - mass concentrations of total particulate matter under 800 nm
  - number concentrations and size distribution of aerosols between 10 and 392 nm
  - Concentrations of NO<sub>2</sub>
  
- Effects of different fuel formulations (tests involving MU344) on:
  - total mass of particles under 800 nm
  - mass concentrations of total particulate matter under 800 nm
  - number concentrations and size distribution of aerosols between 10 and 392 nm

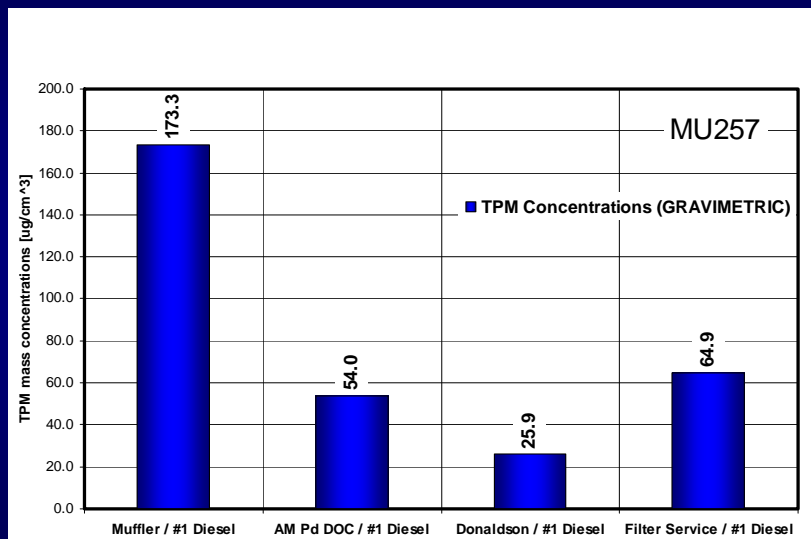
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### Effects of selected DPF systems



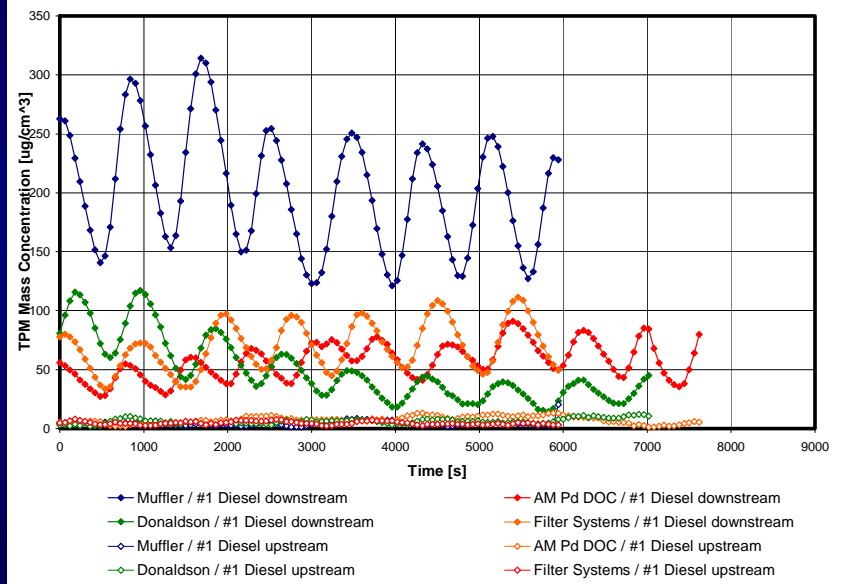
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### Effects of Selected DPF Systems on Total Mass of Particulate Matter under 800 nm Measured Gravimetrically



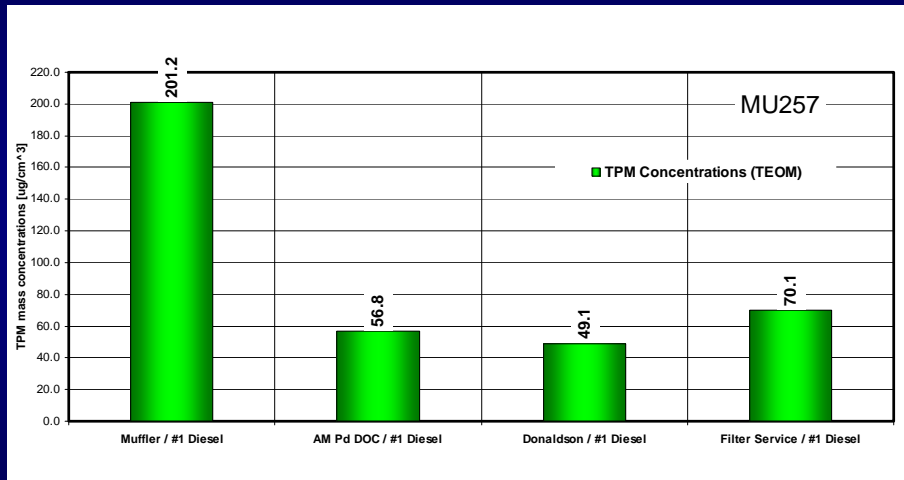
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Effects of Selected DPF Systems on Mass Concentrations of Total Particulate Matter under 800 nm measured in Real Time by TEOM 1400a



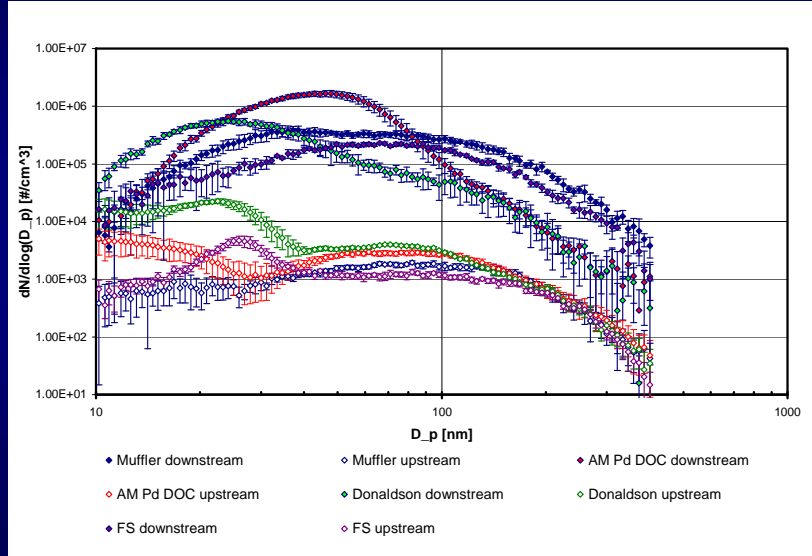
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Effects of Selected DPF Systems on Mass Concentrations of Total Particulate Matter under 800 nm measured by TEOM 1400a



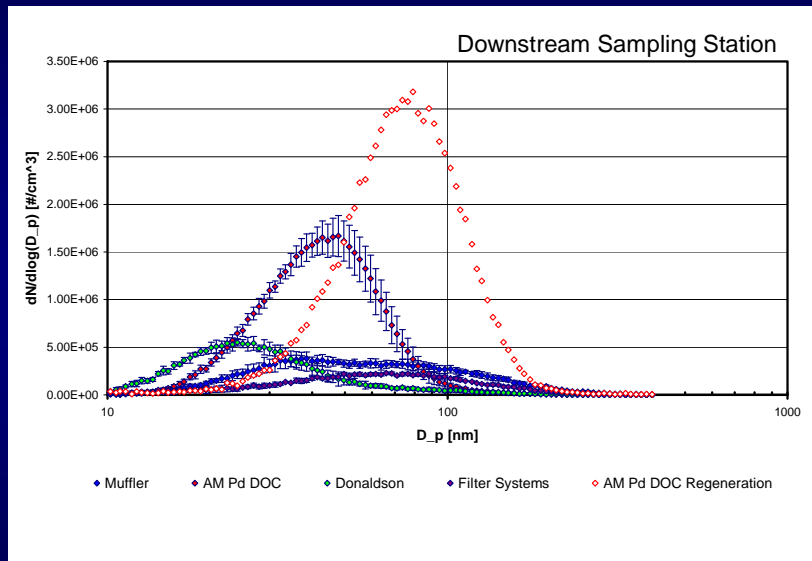
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Effects of Selected DPF Systems on Number Concentrations and Size Distribution of Aerosols between 10 and 392 nm



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Effects of DPF Systems on Size Distribution of Particulate Matter

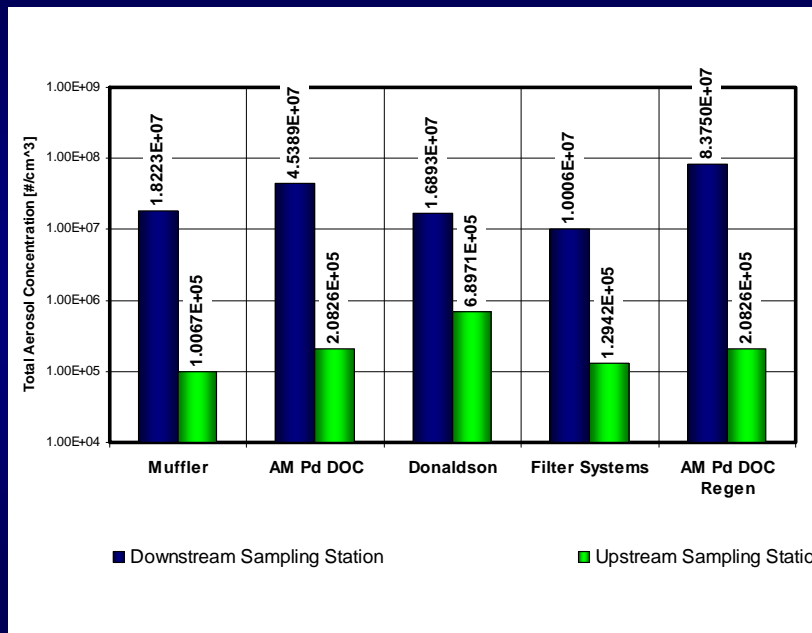


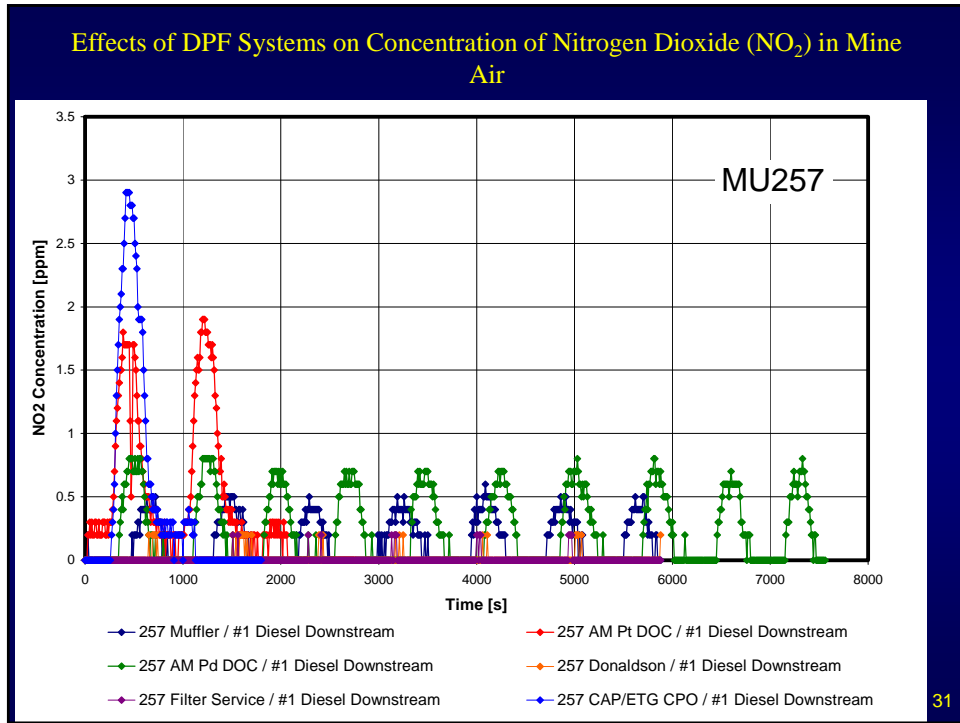
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Effects of DPF Systems on Total Number of Aerosols in Mine Air

| MU257                              | Downstream            |                | Upstream              |                | Percent Change |
|------------------------------------|-----------------------|----------------|-----------------------|----------------|----------------|
| Test Type                          | Average Concentration | 95% Confidence | Average Concentration | 95% Confidence |                |
| Muffler / #1 Diesel                | 1.8223E+07            | 1.0676E+06     | 1.0067E+05            | 1.4708E+04     | N/A            |
| AM Pd DOC / #1 Diesel              | 4.5389E+07            | 3.4852E+06     | 2.0826E+05            | 4.8224E+04     | 149.3          |
| Donaldson / #1 Diesel              | 1.6893E+07            | 1.7871E+06     | 6.8971E+05            | 1.2319E+05     | -10.6          |
| Filter Systems / #1 Diesel         | 1.0006E+07            | 9.0520E+05     | 1.2942E+05            | 1.1535E+04     | -45.5          |
| AM Pd DOC Regeneration / #1 Diesel | 8.3750E+07            | N/A            | 2.0826E+05            | N/A            | 361.0          |

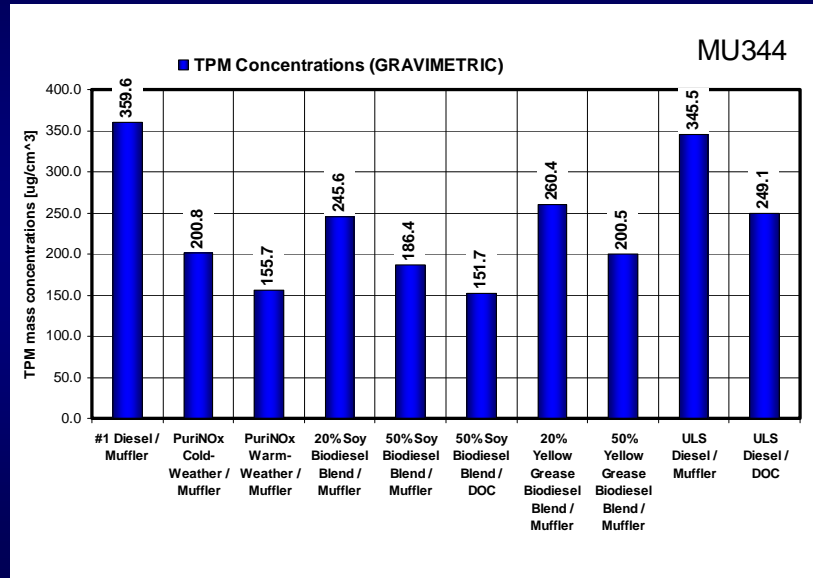
Effects of DPF Systems on Total Number of Aerosols in Mine Air





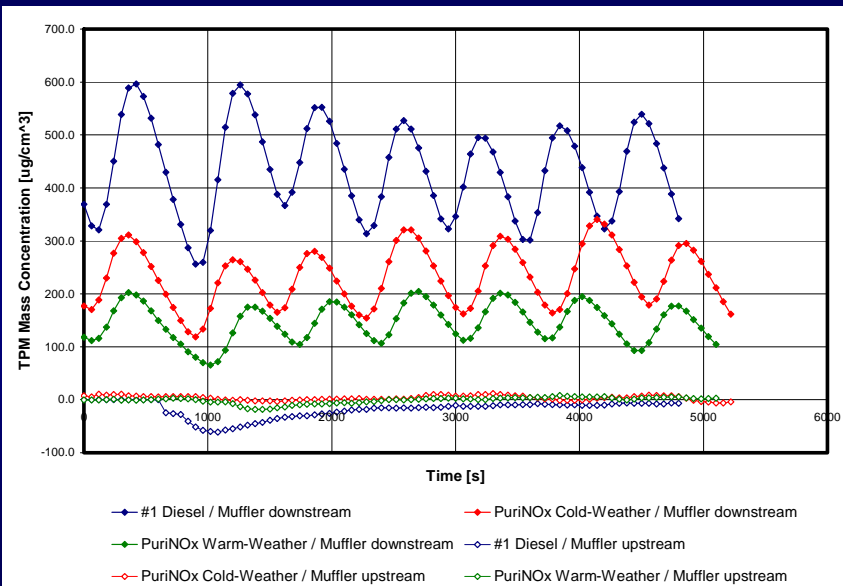


Effects of Fuel Formulations on Total Mass of Particulate Matter under 800 nm Measured Gravimetrically



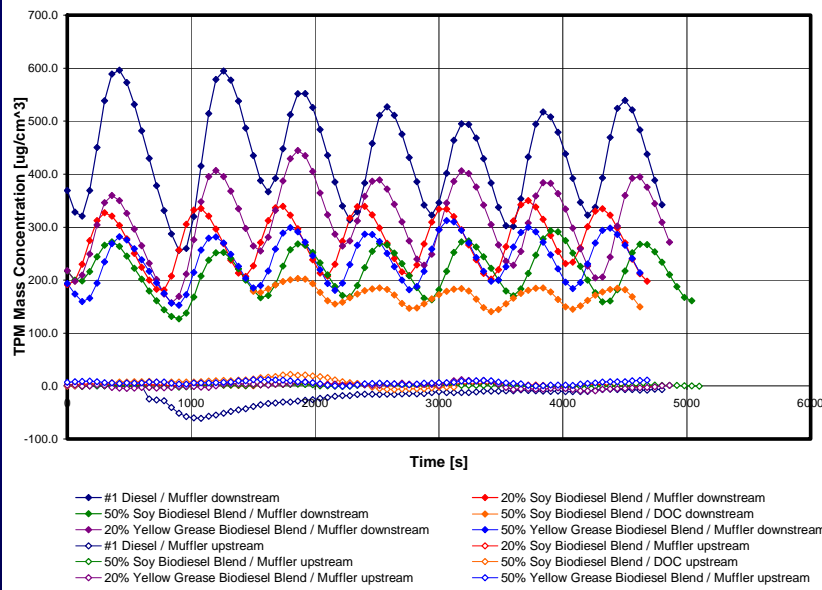
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Effects of Fuel Formulations on Mass Concentrations of Total Particulate Matter under 800 nm Measured in Real Time by TEOM 1400a



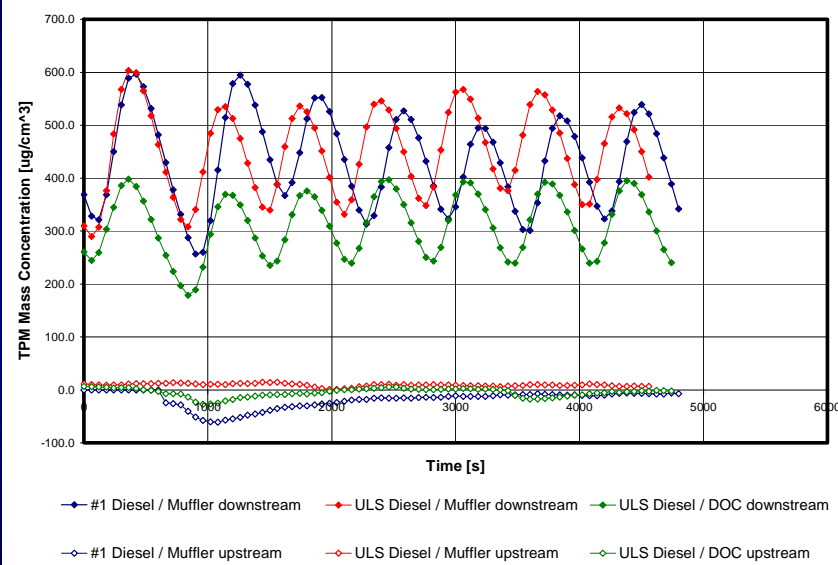
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Effects of Fuel Formulations on Mass Concentrations of Total Particulate Matter under 800 nm Measured in Real Time by TEOM 1400a



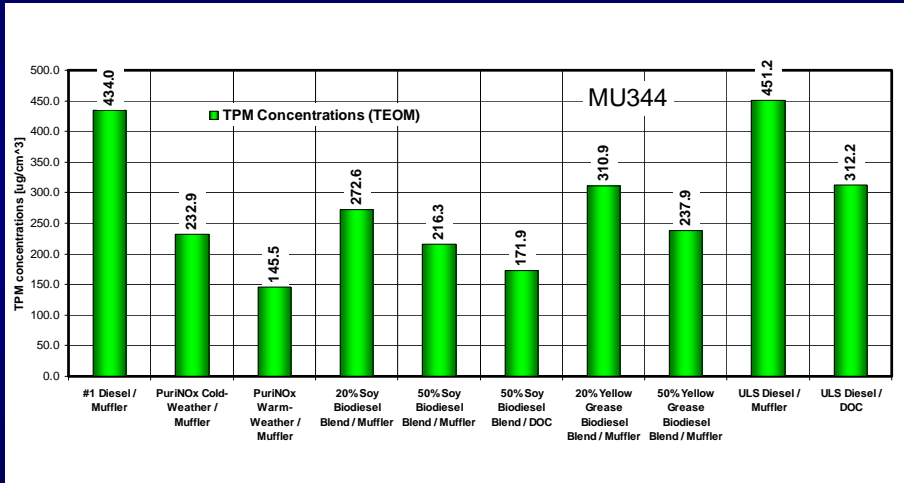
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Effects of Fuel Formulations on Mass Concentrations of Total Particulate Matter under 800 nm Measured in Real Time by TEOM 1400a



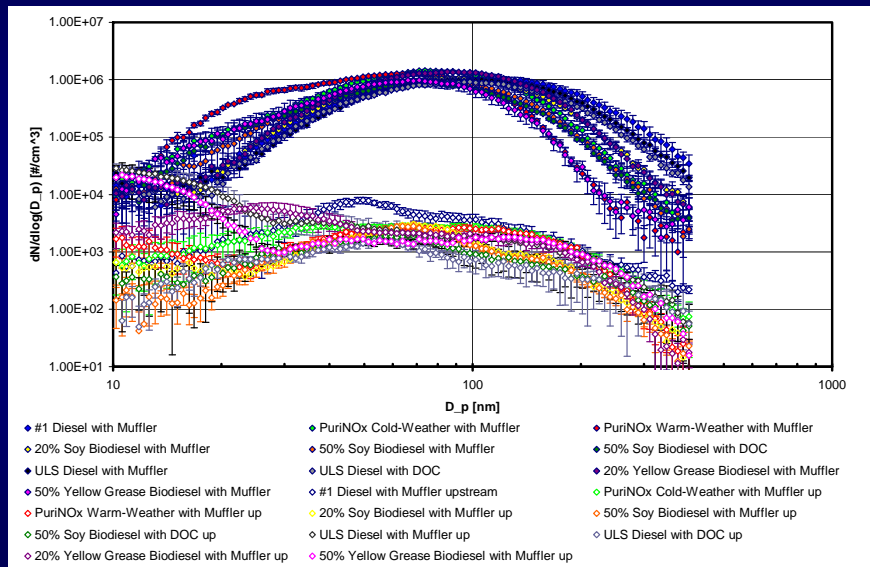
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Effects of Fuel Formulations on Mass Concentrations of Total Particulate Matter under 800 nm Measured by TEOM 1400a



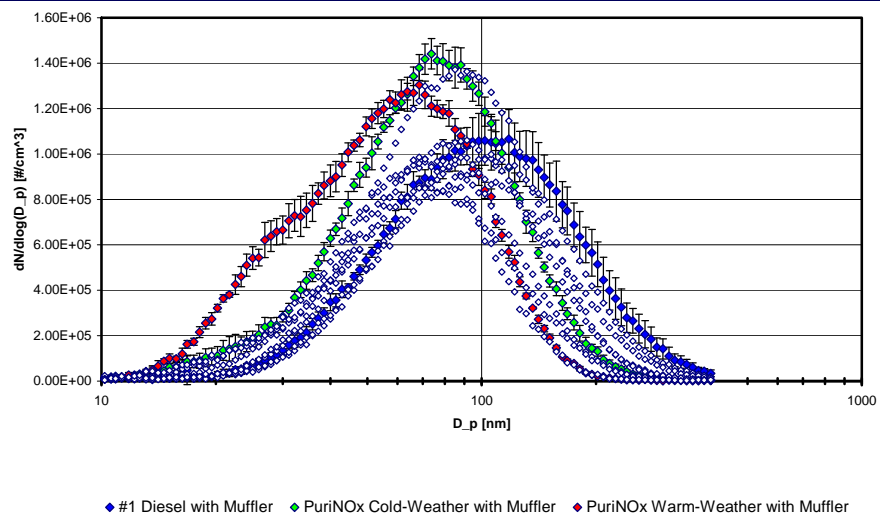
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Effects of Fuel Formulations on Number Concentrations and Size Distribution of Aerosols between 10 and 392 nm in Mine Air



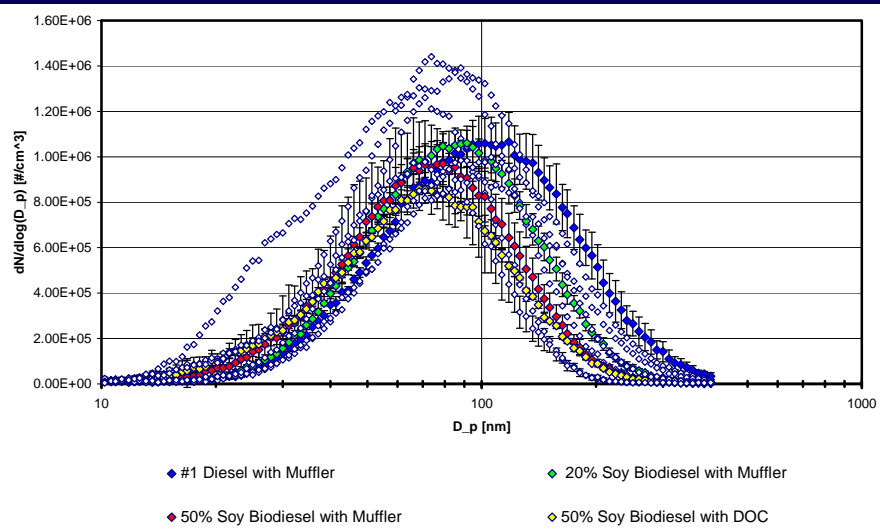
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Effects of PuriNOx Emulsions on Size Distribution of Aerosols in Mine Air



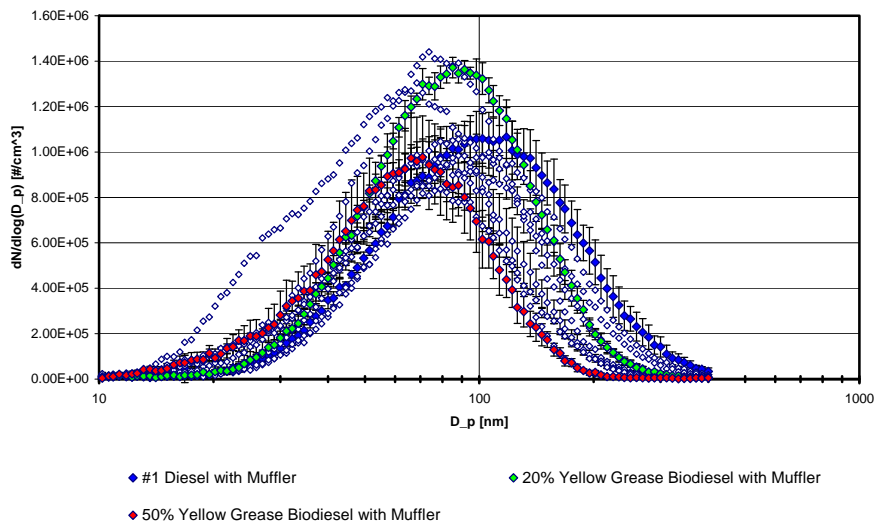
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Effects of Soy Biodiesel Blends on Size Distribution of Aerosols in Mine Air



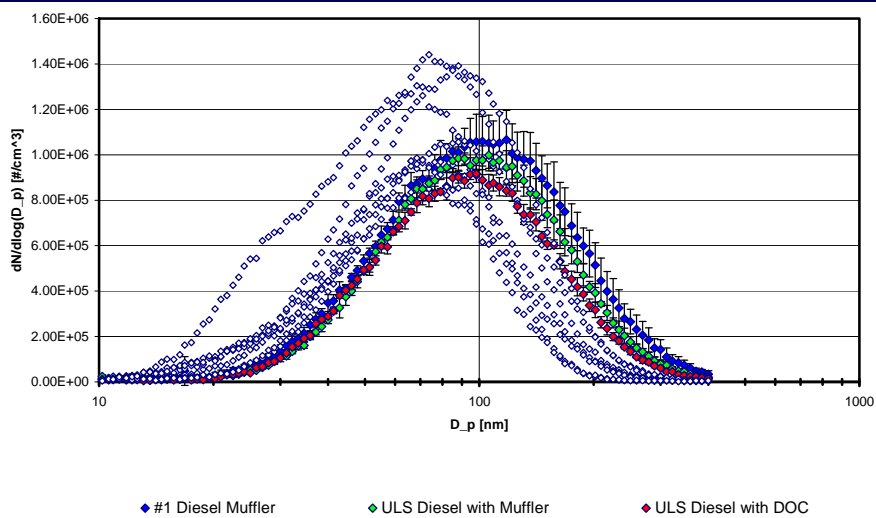
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Effects of Yellow Grease Biodiesel Blends on Size Distribution of Aerosols in Mine Air



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Effects of Ultralow Sulfur Fuel (<15ppm S) on Size Distribution of Aerosols in Mine Air



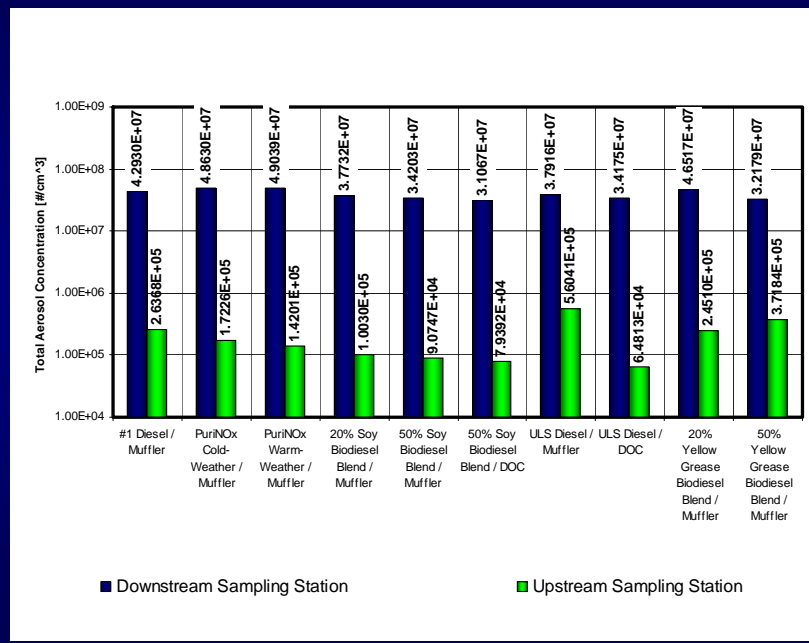
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Effects of Fuel Formulations on Total Number of Aerosols in Mine Air

| MU344<br>Test Type                          | Downstream            |                | Upstream              |                | Percent Change |
|---|-----------------------|----------------|-----------------------|----------------|----------------|
|   | Average Concentration | 95% Confidence | Average Concentration | 95% Confidence |                |
| #1 Diesel / Muffler                         | 4.2930E+07            | 3.5390E+06     | 2.6368E+05            | 9.9961E+04     | N/A            |
| PuriNOx Cold-Weather / Muffler              | 4.8630E+07            | 1.6194E+06     | 1.7226E+05            | 2.6813E+04     | 13.6           |
| PuriNOx Warm-Weather / Muffler              | 4.9039E+07            | 1.6481E+06     | 1.4201E+05            | 1.3852E+04     | 14.6           |
| 20% Soy Biodiesel Blend / Muffler           | 3.7732E+07            | 2.1423E+06     | 1.0030E+05            | 6.0767E+03     | -11.8          |
| 50% Soy Biodiesel Blend / Muffler           | 3.4203E+07            | 2.8664E+06     | 9.0747E+04            | 1.9543E+03     | -20.0          |
| 50% Soy Biodiesel Blend / DOC               | 3.1067E+07            | 8.1747E+05     | 7.9392E+04            | 1.4288E+04     | -27.4          |
| ULS Diesel / Muffler                        | 3.7916E+07            | 1.5042E+06     | 5.6041E+05            | 1.0890E+05     | -12.4          |
| ULS Diesel / DOC                            | 3.4175E+07            | 1.0851E+06     | 6.4813E+04            | 1.1751E+04     | -20.1          |
| 20% Yellow Grease Biodiesel Blend / Muffler | 4.6517E+07            | 2.0266E+06     | 2.4510E+05            | 1.5758E+04     | 8.5            |
| 50% Yellow Grease Biodiesel Blend / Muffler | 3.2179E+07            | 6.2428E+06     | 3.7184E+05            | 1.4555E+05     | -25.5          |

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Effects of Fuel Formulations on Total Number of DOC of Aerosols in Mine Air



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**Questions???**

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