Effects of Alternative Fuels on Concentrations of Nanometer and Ultrafine Particles in an Underground Mine

Aleksandar Bugarski, Steven Mischler, and George Schnakenberg
National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory,
626 Cochrans Mill Road, Pittsburgh PA 15236-0070, USA

Introduction

This study was organized as part of a larger effort to identify technically and economically feasible controls for the curtailment of diesel particulate matter (DPM) and gaseous emissions from existing and new diesel-powered vehicles used in underground mines. The objective of the tests, performed in an underground mine using an isolated zone testing methodology, was to determine the effects of selected emission control technologies, including reformulated and alternative fuels, on the ambient concentrations of particulate matter and gases emitted by diesel-powered mining equipment. The results of several earlier studies demonstrated the potential of reformulated diesel fuels, such as water-in-diesel fuel emulsions [Dunfee and Carlson 2001, House and Rosenblatt 1999], biodiesel blends [McDonald et al. 1997, Watts et al. 1998], and ultralow sulfur diesel, for controlling diesel particulate matter (DPM) emissions. This paper summarizes the results of the isolated zone tests and reports the effects of several selected reformulated fuels on the concentrations of nanometer and ultrafine particles, elemental carbon and total particulate matter in mine air.

Methodology

During this study two groups of tests were conducted in an isolated zone, a long underground mine entry ventilated by fresh air. Isolated zone tests were designed to be a compromise between the genuineness of in-situ measurements of concentrations and the repeatability and accuracy of the emission measurements obtained under research laboratory conditions. These tests allowed the operation of vehicles under conditions and over duty cycles that closely mimic actual production duty cycles in an area that was not contaminated by emissions from other vehicles as would occur in tests conducted in real production areas. In addition, artifacts usually generated under laboratory conditions while attempting to simulate real-life conditions and processes do not compromise the results of isolated zone tests.

The first group of tests evaluated the effects of alternative diesel fuel formulations, including two formulations of water-in-diesel-fuel emulsions, two types of blended biodiesel fuels, ultra low sulfur diesel fuel, and #1 diesel (see

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Table 1), on DPM and gaseous ambient concentrations. The properties of the selected fuel formulations are listed in Table 2. The second group of tests evaluated the effects of a hydrogen-fueled vehicle (see
Table 1).

Table 1. Test matrix

Vehicle	Exhaust System	Fuel Formulation
LHD powered by Caterpillar 3126B DITA AA	Muffler	#1 Diesel
	Muffler	PuriNOx cold-weather water-fuel emulsion
	Muffler	PuriNOx warm-weather water-fuel emulsion
	Muffler	20% soy biodiesel and 80% #1 diesel blend
	Muffler	50% soy biodiesel and 50% #1 diesel blend
	DCL International DOC	50% soy biodiesel and 50% #1 diesel blend
	Muffler	20% yellow grease biodiesel and 80% #1 diesel blend
	Muffler	50% yellow grease biodiesel and 50% #1 diesel blend
	Muffler	ULS (10 ppm sulfur) diesel
	DCL International DOC	ULS (10 ppm sulfur) diesel
Utility Truck ZEUS powered by Caterpillar 3304 modified to combust hydrogen	DOC	Hydrogen

A different vehicle was employed to serve as a test platform for each group of tests (see Table 3). A Wagner ST3.5 load-haul-dump (LHD), powered by a Caterpillar 3126B DITA AA and equipped with a standard muffler, was selected for the evaluation of reformulated diesel fuels. Included in this group were two tests in which a muffler was replaced with a standard diesel oxidation catalyst (DOC). This vehicle is a heavy-duty production machine and its engine is routinely heavily loaded in the course of its normal duty cycle. An auxiliary tank was integrated into the fueling system of the LHD vehicle to facilitate exchange of fuels and special precautions were taken to avoid cross contamination of the fuels from consecutive fuel tests. During the tests, the LHD was fueled at a fueling station located in a crosscut in the isolated zone approximately midway between the upstream and downstream sampling station, as shown in Figure 1 and Figure 2.

Table 2. Fuel formulation properties

Fuel Formulations			PuriNOx cold-weather	PuriNOx warm-weather	20% soy biodiesel	50% soy biodiesel	ULS fuel
Properties	**Method**	**Units**					
Aromatics	ASTM D1319	vol %	22.4	23.7	-	-	26.4
Olefins	ASTM D1319	vol %	2.3	2.4	-	-	1.2
Saturates	ASTM D1319	vol %	75.3	73.9	-	-	72.4
Density @ 16 °C	ASTM D4052	g/ml	0.853	0.866	0.836	0.854	0.850
Sulfur Content	ASTM D2622	ppm	300	279	205	129	4
Oxygen	By diff.	% wt.	7.8	15.3	4.4	7.4	1.3
Heat of Combustion	ASTM D240	BTU/ lb	17003	15905	18075	17553	18433
Flash Point	ASTM D93	°C	47	-	68	70	64

For the second group of tests, the vehicle selected was the zero emissions utility solution (ZEUS), an EIMCO 975 articulated utility vehicle powered by a water-cooled Caterpillar 3304 diesel engine that was modified to burn hydrogen. As a hydrogen internal combustion engine, it has spark plugs with individual coils and an engine-driven magneto to provide spark and timing. The hydrogen gas is injected into the cylinders through a parallel port system, much the same as is done for an engine converted to run on natural gas or liquid petroleum. A more detailed description of the ZEUS vehicle including descriptions of the power train, hydrogen storage, and safety systems is available in Woodward and Varley [2004]. The ZEUS vehicle was fueled outside of the mine portal. The basic specifications for the vehicles and engines are given in Table 3.

The LHD vehicle and ZEUS utility truck were operated in the isolated zone over a reproducible and representative duty cycle, as shown in Figure 1 and Figure 2, respectively. In the meanwhile, DPM and gas concentrations were measured at fixed locations upstream and downstream of the operating vehicle. Scanning Mobility Particle Sizers (SMPS) from TSI Inc. were used to measure size distribution and count concentrations of aerosols. Concentrations of elemental carbon (EC) were determined by performing NIOSH Analytical Method 5040 on the samples collected using a high volume (HV) sampling method. Concentrations of total particulate matter (TPM), with an aerodynamic diameter below 800 nm (D_{50}<800nm), in the mine air were determined using gravimetric analysis and with TEOM Series 1400a ambient particulate monitors from Rupprecht & Patashnick.

Table 3. Specifications for test vehicles

Vehicle	Vehicle Type	Vehicle Make	Vehicle Model	Engine Make	Engine Model	Engine Displ.	Engine Rating	Engine Type
Unit	-	-	-	-	-	liters	hp	-
LHD	Load Haul Dump	Wagner	ST-3.5	Cater-pillar	3126B DITA AA	7.243	200	Fully Electronic Controlled, Turbo Charged, Air to Air After Cooled.
ZEUS	Utility truck	Eimco	975	Cater pillar	3304	6.964	100	After Market Turbo, Air to Water After Cooled, Spark Fired w/Magneto.

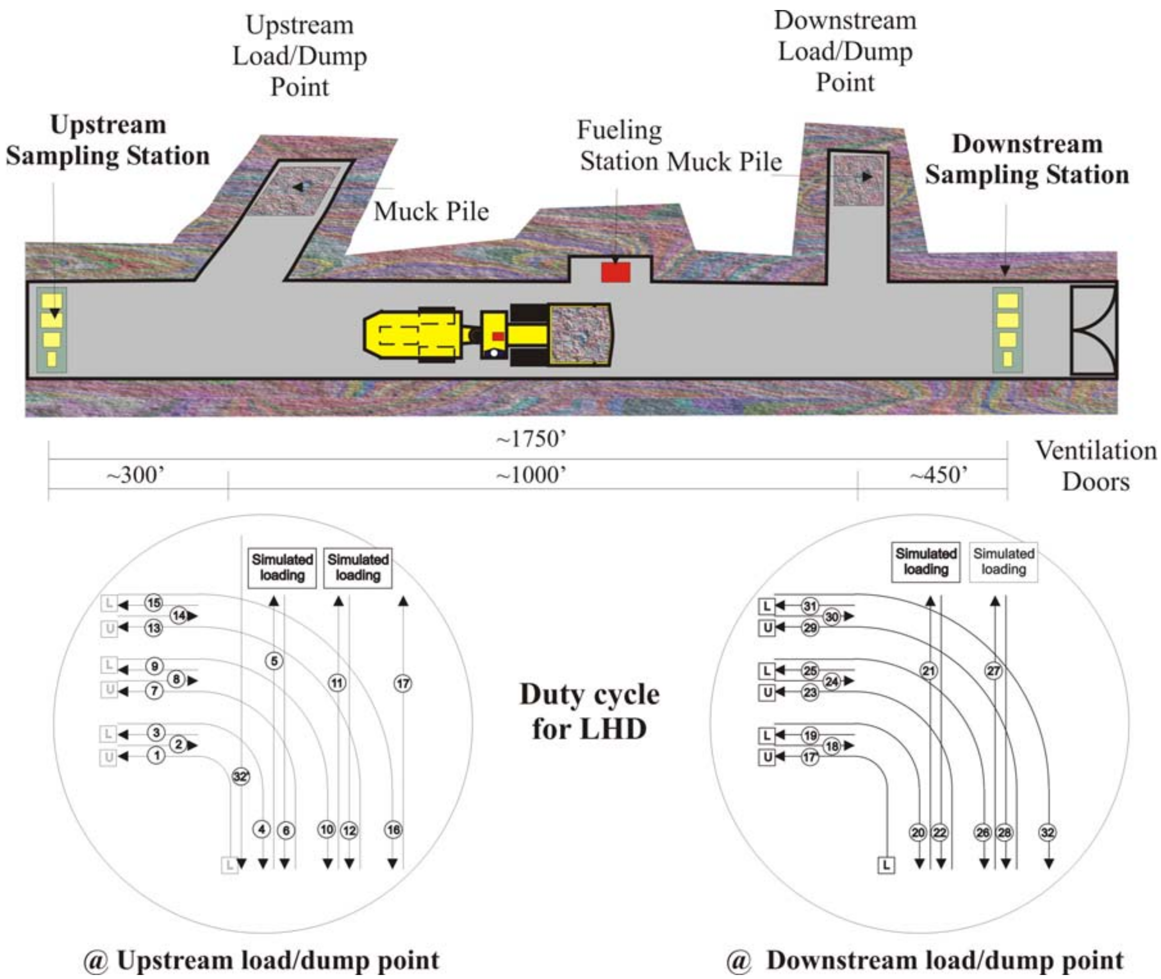


Figure 1. Design and layout of isolated zone and duty cycle for LHD vehicle

The isolated zone was ventilated with fresh air from the portal located approximately 300 meters from the zone. Air velocities were measured continuously during the tests in the approximate center of the drift at the downstream and upstream sampling stations using Anemosonic UA6 digital ultrasonic anemometers from Airflow Developments Limited. Ventilation rate was calculated as a product of measured air velocity and drift cross-sectional area. An average ventilation rate (VR) of approximately 19.0 m^3/s was maintained for all tests. This relatively high amount of air was assumed to provide a relatively stable air flow and good mixing of the vehicle emissions. All of the distributions presented in the results section were standardized for differences in the VR for each test by adjusting them to 19.28 m^3/s, the average VR maintained during the baseline test.

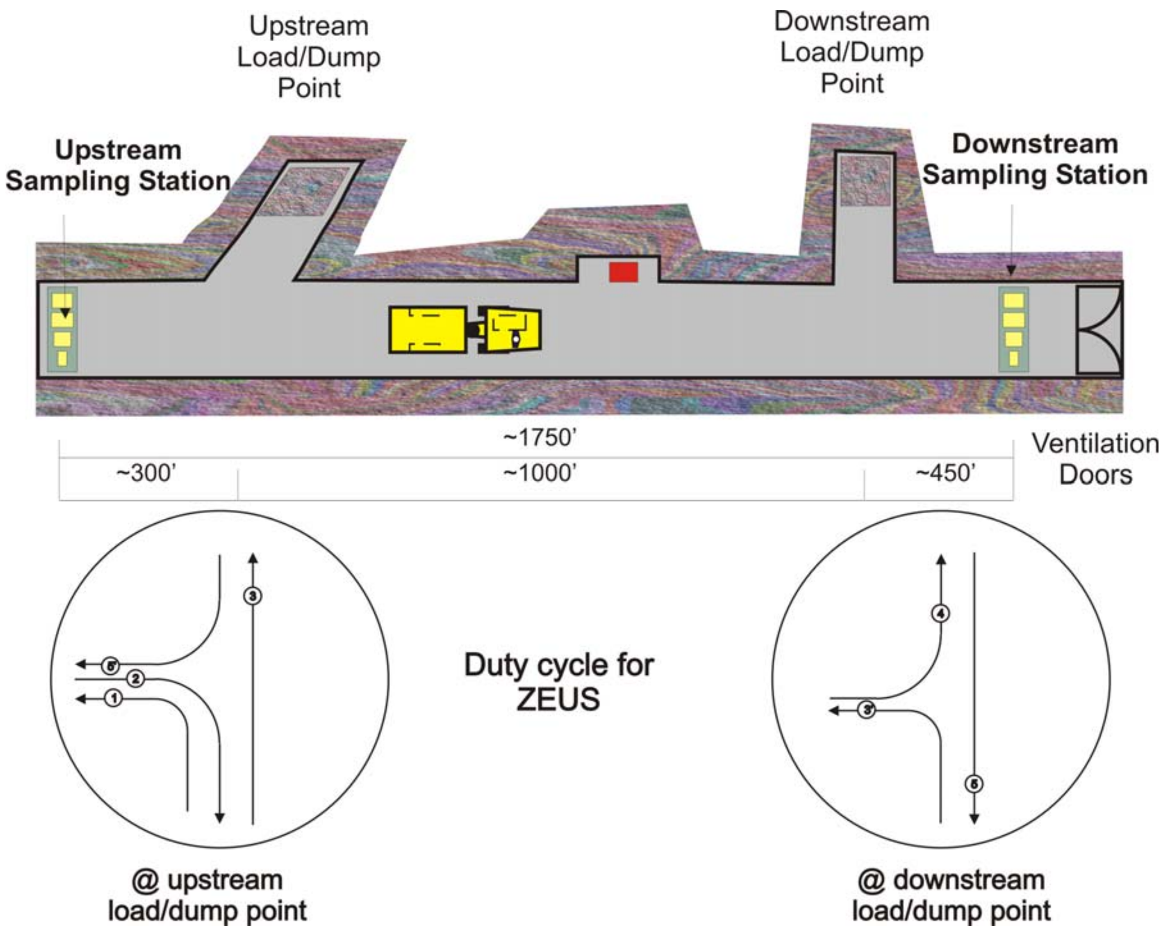


Figure 2. Design and layout of isolated zone and duty cycle for ZEUS utility truck

The net contributions of the vehicle's emissions to the ambient aerosol concentrations were obtained by subtracting concentrations measured at the upstream sampling station from those measured at the downstream station. Each aerosol number concentration presented is the ventilation rate-adjusted average of several measurements performed during a test. The presented concentrations of EC and total carbon (TC) represent the average concentration over the duration of each test. The relative effects of the tested fuel formulations are expressed as the difference between the net contributions calculated during the fuel tests and the net contribution calculated in the baseline case (#1 diesel). More details on the methodology used in this study are available elsewhere [Bugarski et al. 2005].

Results and Discussion

Effects of reformulated diesel fuels

The average size distributions of aerosols measured at the downstream and upstream sampling stations during the reformulated fuel tests are shown in Figure 3. The results of the statistical analyses performed on those data, including average geometric mean diameters (GMD), geometric standard deviations (GSD), and ventilation-adjusted average total particulate number concentrations are summarized in Table 4. The results of SMPS size distribution measurements performed at the downstream and upstream sampling stations during the tests with ten different fuel formulations are presented in Figure 3 and Table 4, and these show that the background number concentrations of aerosols entering the isolated zone during the tests were relatively low when compared to the downstream concentrations.

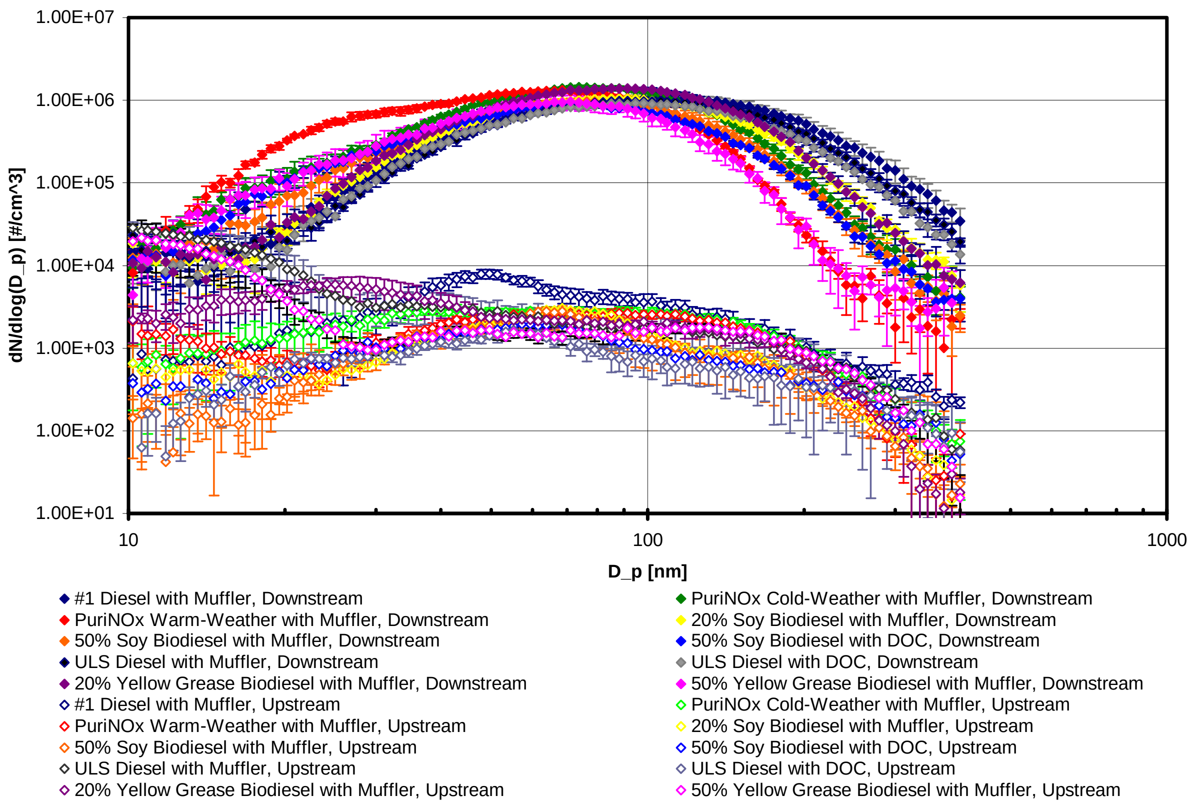


Figure 3. Size distribution of aerosols measured at downstream and upstream sampling station during reformulated diesel fuel tests

Table 4. Effects of fuel formulations on geometric mean and total number concentrations of aerosols

Test	Downstream			Upstream			Net Contribution	
	Average GM	Average GSD	Normal. Average Number	Average GM	Average GSD	Normal. Average Number	Normal. Average Number	Change
	nm	-	$\#/cm^3$	Nm	-	$\#/cm^3$	$\#/cm^3$	%
#1 Diesel / Muffler	95.1	1.76	4.29E+07	57.3	1.92	2.64E+05	4.27E+07	0.0
PuriNOx Cold-Weather / Muffler	68.4	1.69	4.89E+07	59.4	2.07	1.73E+05	4.87E+07	14.2
PuriNOx Warm-Weather / Muffler	54.9	1.72	4.98E+07	59.0	2.26	1.45E+05	4.97E+07	16.4
20% Soy Biodiesel Blend / Muffler	80.6	1.67	3.77E+07	59.1	1.98	1.00E+05	3.76E+07	-12.0
50% Soy Biodiesel Blend / Muffler	70.3	1.68	3.40E+07	61.8	1.81	9.02E+04	3.39E+07	-20.5
50% Soy Biodiesel Blend / DOC	67.0	1.73	3.20E+07	56.9	1.99	8.17E+04	3.19E+07	-25.3
20% YG Biodiesel Blend / Muffler	81.0	1.63	4.73E+07	35.3	2.14	2.49E+05	4.70E+07	10.3
50% YG Biodiesel Blend / Muffler	61.4	1.67	3.17E+07	26.8	2.35	3.66E+05	3.13E+07	-26.6
ULS Diesel / Muffler	93.0	1.73	3.77E+07	21.1	2.07	5.58E+05	3.72E+07	-12.8
ULS Diesel / DOC	89.3	1.71	3.45E+07	55.4	2.03	6.53E+04	3.44E+07	-19.4

The individual effects of the tested formulations are shown in Figure 4 thru 7. The relative changes in concentrations of EC and TPM with D_{50} < 800 nm with respect to the baseline case are summarized in Figure 8.

Effects of Water-Fuel Emulsions

The SMPS measurements (see Figure 4) show that using the cold weather and warm weather water-fuel emulsion formulations caused a 14.2% and 16.4% increase, respectively, in total aerosol number concentration over the baseline case (see Table 4). The same water-fuel emulsion formulation reduced concentrations of EC by about 70% and TPM by 45% and 46% as determined by gravimetric analysis and TEOM measurements, respectively. The warm weather water-fuel emulsion formulation reduced EC by about 85%, gravimetric TPM by 58 %, and TEOM TPM by 66%.

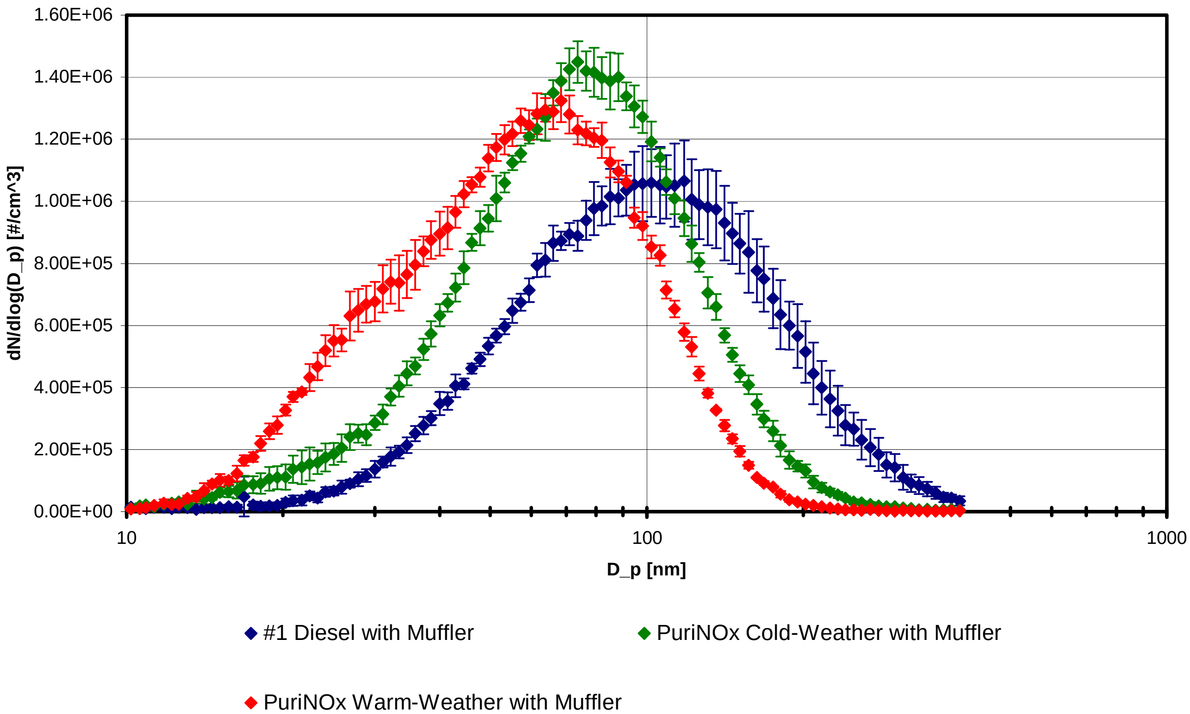


Figure 4. Effects of water-in-diesel-fuel emulsions on size distribution of aerosols in mine air

Effects of Biodiesel Blends

The four tested biodiesel fuel blends were 20% and 50% blends of neat soy biodiesel and 20% and 50% blends of neat yellow grease (YG) biodiesel with #1 diesel fuel. The SMPS results shown in Figure 5 and Figure 6 indicate that the total aerosol number concentrations for the 20% and 50% soy blend were reduced by 12.0% and 20.5% respectively, yet the 20% YG blend increased the SMPS concentration by 10.3% while the 50% YG blend reduced the aerosol number concentration by 26.6%. Use of the DOC with the 50% soy blend reduced the number concentration by 25.3% compared to the baseline. The carbon measurement results show EC reductions of 49% and 66% for 20% and 50% soy biodiesel blends, respectively (see Figure 8). The 20% and 50% YG blends showed slightly less pronounced reductions of 33% and 56% respectively. The 20% YG blend reduced the gravimetric TPM concentration by 32% whereas the 50% YG blend reduced the gravimetric TPM concentration by 48%. Replacing the muffler with a diesel oxidation catalyst (DOC) further reduced the gravimetric TPM concentration of the 50% YG blend to 60%. The results of the TEOM analysis show similar reductions in TPM.

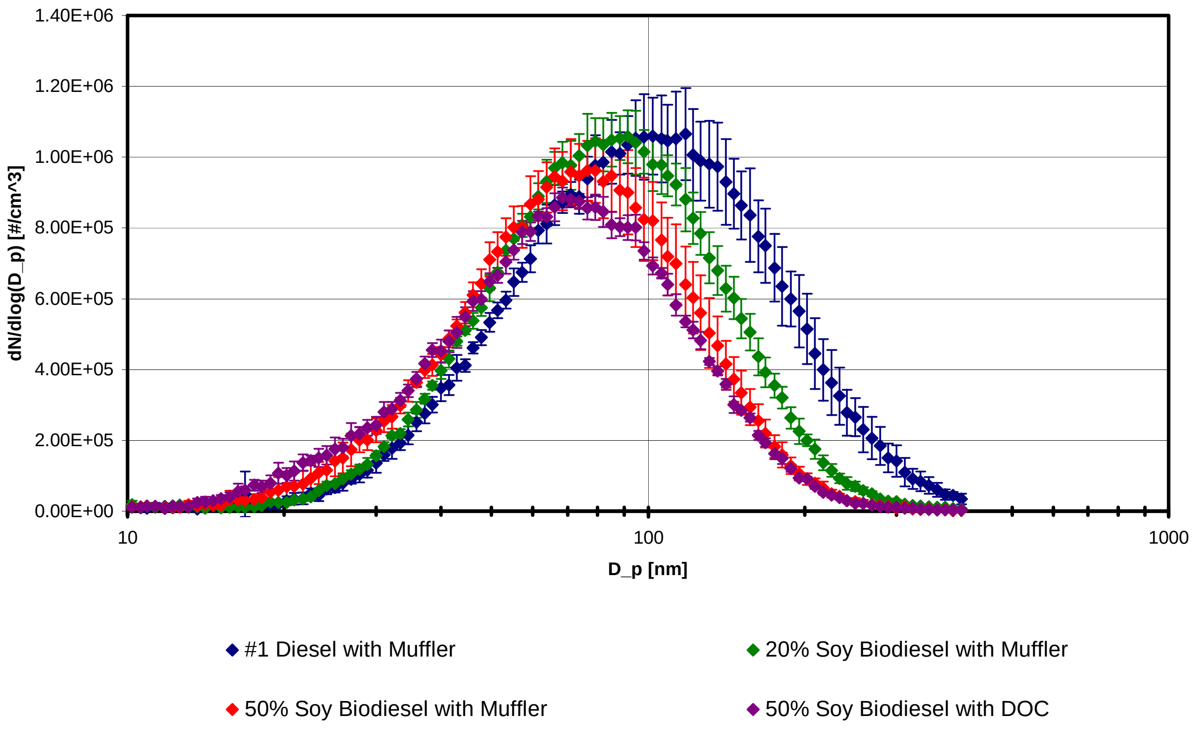


Figure 5. Effects of soy biodiesel blends on size distribution of aerosols in mine air

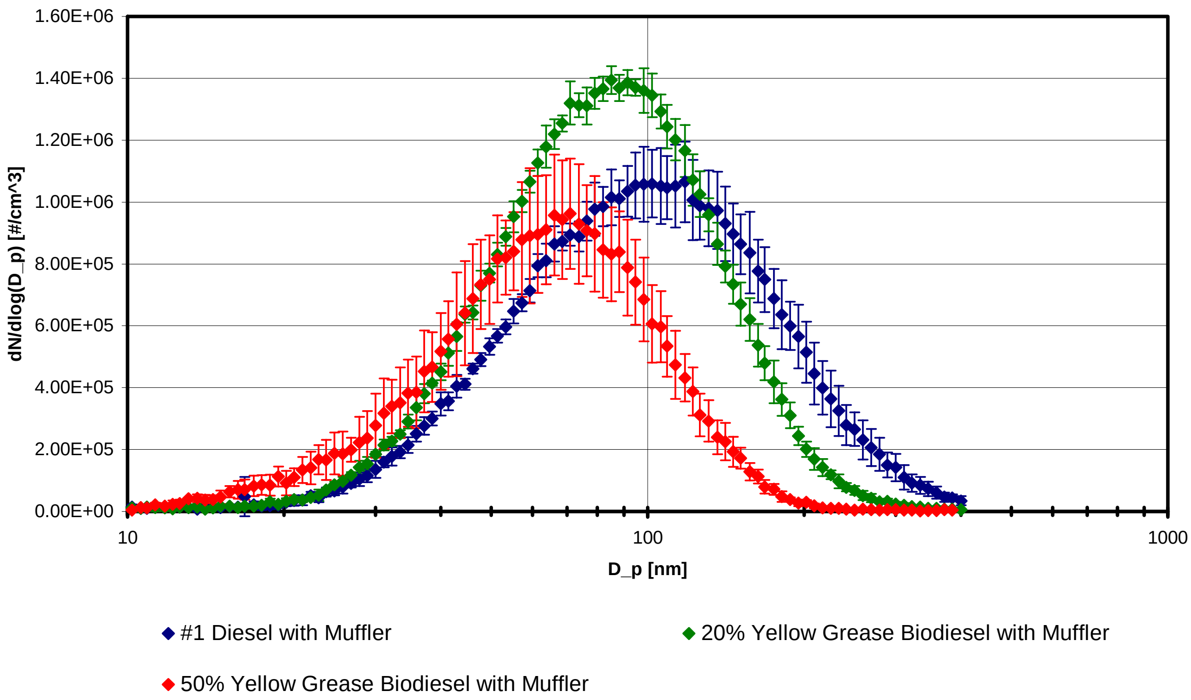


Figure 6. Effects of yellow grease biodiesel blends on size distribution of aerosols in mine air

Effects of Ultra Low Sulfur Fuel

The effects of ultra-low sulfur diesel (ULS) fuel on the size distribution of aerosols in mine air are shown in Figure 7. SMPS results show a 12.8% lower aerosol number concentration for the ULS fuel then for #1 diesel. Using a DOC caused a further reduction in the number concentration. EC and TPM concentrations were unaffected by using ULS fuel in place of #1 diesel whereas the sulfate concentrations decreased from 5.5 μg/m^3 to 0.3 μg/m^3. Using a DOC with ULS fuel increased the sulfate concentration to 0.8 μg/m^3.

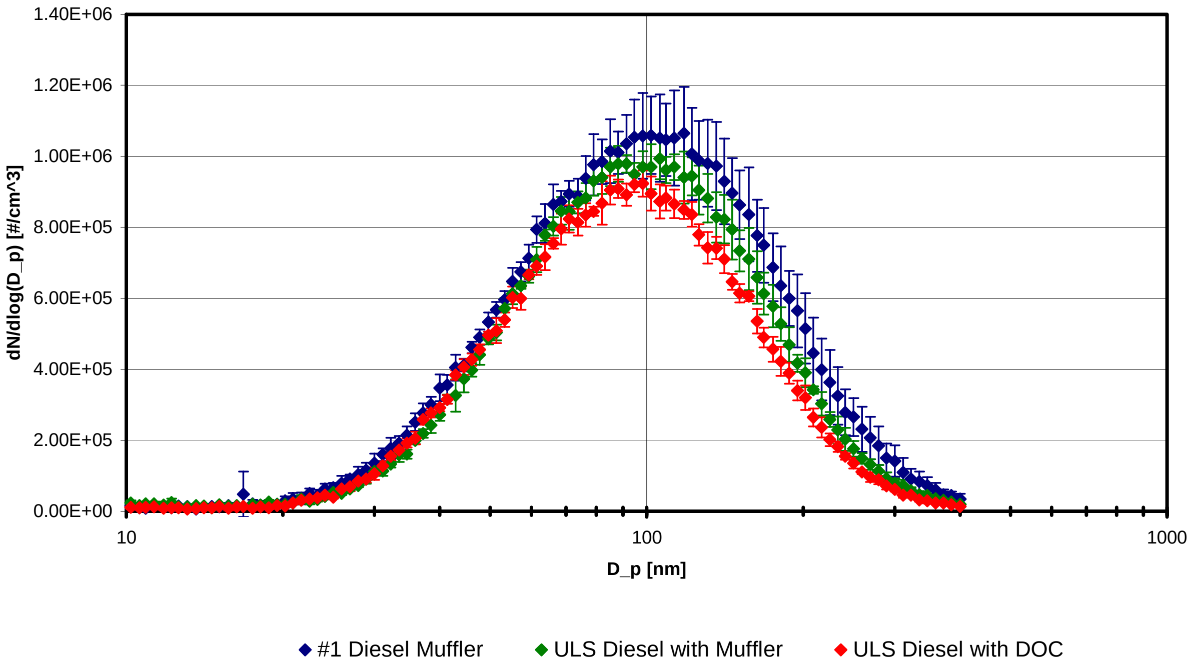
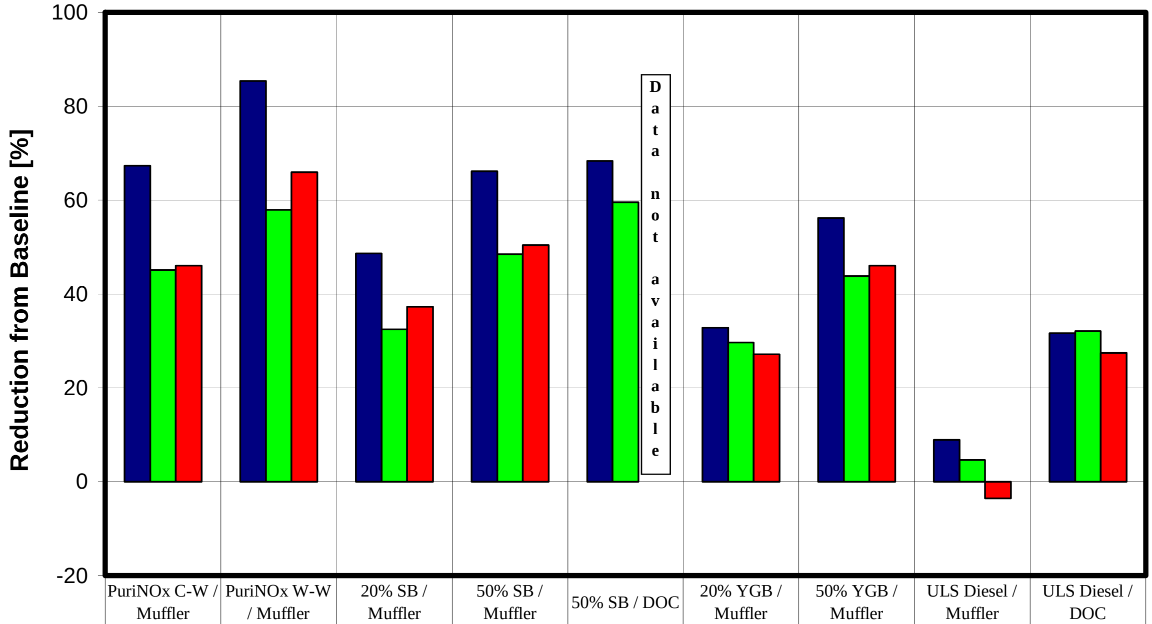


Figure 7. Effects of ultralow sulfur fuel (10 ppm S) on size distribution of aerosols in mine air



	PuriNOx C-W / Muffler	PuriNOx W-W / Muffler	20% SB / Muffler	50% SB / Muffler	50% SB / DOC	20% YGB / Muffler	50% YGB / Muffler	ULS Diesel / Muffler	ULS Diesel / DOC
EC HV	67	85	49	66	68	33	56	9	32
TPM GRAV	45	58	32	48	60	30	44	5	32
TPM TEOM	46	66	37	50		27	46	-3	27

Figure 8. Effects of fuel formulations on mass concentrations of elemental carbon and total particulate matter with D_{50} < 800 nm

Effects of Hydrogen-fueled Vehicle

The results of size selective measurements performed at the downstream and upstream sampling stations during the ZEUS test are shown in Figure 9.

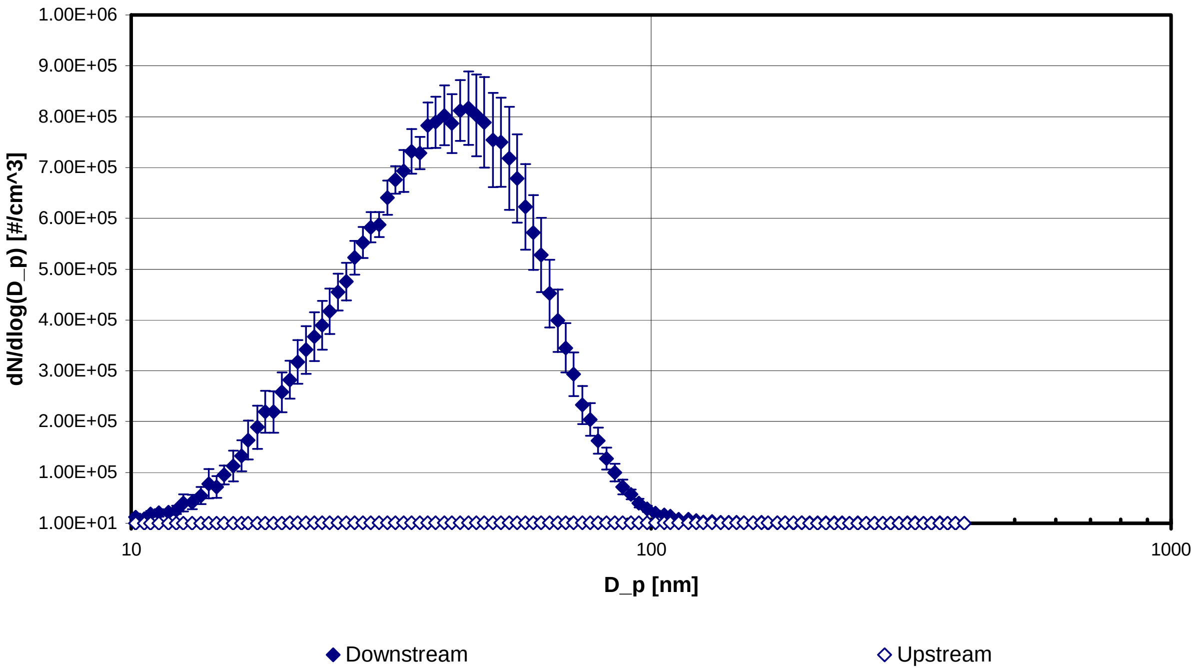


Figure 9. Size distribution of aerosols measured at downstream and upstream sampling station during ZEUS test

The size distribution measurements show that, compared to the diesel results, ZEUS decreased the number of larger (>80 nm) particles, but increased the concentrations of nanometer aerosols in mine air. The average concentrations of EC and TPM (gravimetric and TEOM) at the downstream station during the test are summarized in Table 5.

Table 5. Average concentrations of elemental carbon (EC), gravimetric and TEOM determined total particulate matter (TPM) (Ventilation rate = 21.17 m3/s)

Test	Average Contributions to Concentrations		
	EC NIOSH 5040	TPM Gravimetric Analysis	TPM TEOM
	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$
ZEUS	1.8	29.7	24.8

The concentrations of TPM were found to be higher than the concentrations of EC, which were almost undetectable. This confirms that the ZEUS emitted little, if any, EC and may suggest that ZEUS's contribution to TPM is potentially from semivolatile organic carbon and solid non-carbonaceous material such as ash.

Concluding Remarks

Substantial reductions in EC and TPM mass concentrations from the baseline case (#1 diesel) were observed when the test diesel-powered vehicle was fueled with water-fuel emulsions and biodiesel blends. When those alternative fuels were used, the aerosol number distributions were characterized, in general, with smaller median diameters and comparable peak concentrations. When water-fuel emulsions were used, the total number concentration of aerosols was found to be on average 15% higher than in the baseline case. The total number of aerosols was found to be lower in most cases when biodiesel blends were used. The ultralow sulfur diesel and #1 diesel fuel were found to result in relatively comparable concentrations of EC and TPM and size distributions of aerosols.

The mass concentrations of EC at the downstream sampling station were practically undetectable for the ZEUS hydrogen fueled vehicle. The gravimetric analysis and TEOM measurements showed that corresponding mass concentrations of TPM were found to be substantially higher than those of EC. In addition, size distribution measurements showed an increase in the number of nanometer aerosols in mine air downstream of ZEUS. These results taken together indicate the presence of organic carbon aerosols and/or self nucleated nanoparticles of ash. Further research is underway to clarify this.

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By
Aleksandar Bugarski, Steven Mischler
and George Schnakenberg
NIOSH Pittsburgh Research Laboratory

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Introduction

- On June 6, 2005 U.S. Mine Safety and Health Administration promulgated final rule limiting concentrations of diesel particulate matter to which underground metal/nonmetal miners can be exposed:
  - Interim limit is set at 308 μg/m^3 of elemental carbon (EC)
  - Final limit is currently set at 160 μg/m^3 of total carbon (TC)
  - Compliance established by personal exposure sampling
  - Samples analyzed using NIOSH 5040 method
- A number of challenges associated with implementation of diesel particulate filter systems
- Previous laboratory and field studies showed that alternative fuels such as biodiesel blends and water-fuel emulsions are viable methods for controlling diesel emissions
  - Limited data on the effects of those fuels on
    - EC emissions and
    - size distribution of diesel aerosols

Objectives of the study

- To determine the effects of selected emission control technologies on the ambient concentrations of particulate matter emitted by underground diesel-powered mining equipment.

- The emphasis was given to the effects of reformulated diesel fuels and hydrogen on the
  - concentrations of nanometer and ultrafine aerosols
  - concentrations of elemental carbon
  - concentrations of total particulate matter determined by
    - gravimetric analysis
    - tapered element oscillating microbalance (TEOM) measurements

Methodology

A series of tests was conducted in the isolated zone, a long mine entry ventilated by fresh air, to evaluate the effects of various types of reformulated diesel fuels and hydrogen

Table 1. Test matrix

Vehicle	Exhaust System	Fuel Formulation
LHD powered by Caterpillar 3126B DITA AA	Muffler	#1 diesel
	Muffler	cold-weather water-in-diesel fuel emulsion
	Muffler	warm-weather water-in-diesel fuel emulsion
	Muffler	20% soy biodiesel and 80% #1 diesel blend
	Muffler	50% soy biodiesel and 50% #1 diesel blend
	DOC	50% soy biodiesel and 50% #1 diesel blend
	Muffler	20% yellow grease biodiesel and 80% #1 diesel blend
	Muffler	50% yellow grease biodiesel and 50% #1 diesel blend
	Muffler	ULS (10 ppm sulfur) diesel
	DOC	ULS (10 ppm sulfur) diesel
Utility truck (ZEUS) powered by Caterpillar 3304 modified to combust hydrogen	DOC	hydrogen

Fuel Properties

Table 2. Fuel properties

Fuel Formulations			Water-in-diesel fuel emulsion – cold-weather (86% #2 diesel fuel, 10% water, 2% methanol, and 2% of the proprietary emulsifying agent)	Water-in-diesel fuel emulsion- warm weather (77% #2 diesel fuel, 20% water, and 3% proprietary emulsifying agent)	20% soy biodiesel and 80% #1 diesel blend	50% soy biodiesel and 50% #1 diesel blend	ULS fuel
Properties	Method	Units					
Aromatics	ASTM D1319	vol %	22.4	23.7	-	-	26.4
Olefins	ASTM D1319	vol %	2.3	2.4	-	-	1.2
Saturates	ASTM D1319	vol %	75.3	73.9	-	-	72.4
Density @ 16 °C	ASTM D4052	g/ml	0.853	0.866	0.836	0.854	0.850
Sulfur Content	ASTM D2622	ppm	300	279	205	129	4
Oxygen	By diff.	% wt.	7.8	15.3	4.4	7.4	1.3
Heat of Combustion	ASTM D240	BTU/ lb	17003	15905	18075	17553	18433
Flash Point	ASTM D93	°C	47	-	68	70	64

Figure 1. Fuel samples

Test Vehicles

Figure 3. Specifications for test vehicles

Vehicle	Vehicle Type	Vehicle Make	Vehicle Model	Engine Make	Engine Model	Engine Displace.	Engine Rating	Engine Type
Unit	-	-	-	-	-	[liters]	[hp]	-
LHD	Load Haul Dump	Wagner	ST-3.5	Caterpillar	3126B DITA AA	7.243	200	Fully Electronic Controlled, Turbo Charged, Air to Air After Cooled.
ZEUS	Utility truck	Eimco	975	Caterpillar	3304	6.964	100 (estimated)	Naturally Aspirated, After Market Turbo, Air to Water After Cooler, Spark Fired w/Magneto.

Figure 2. LHD

Figure 3. LHD engine

Figure 4. ZEUS

Figure 5. ZEUS exhaust

Isolated Zone Testing

- Rational 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

Isolated zone – Concept and Layout

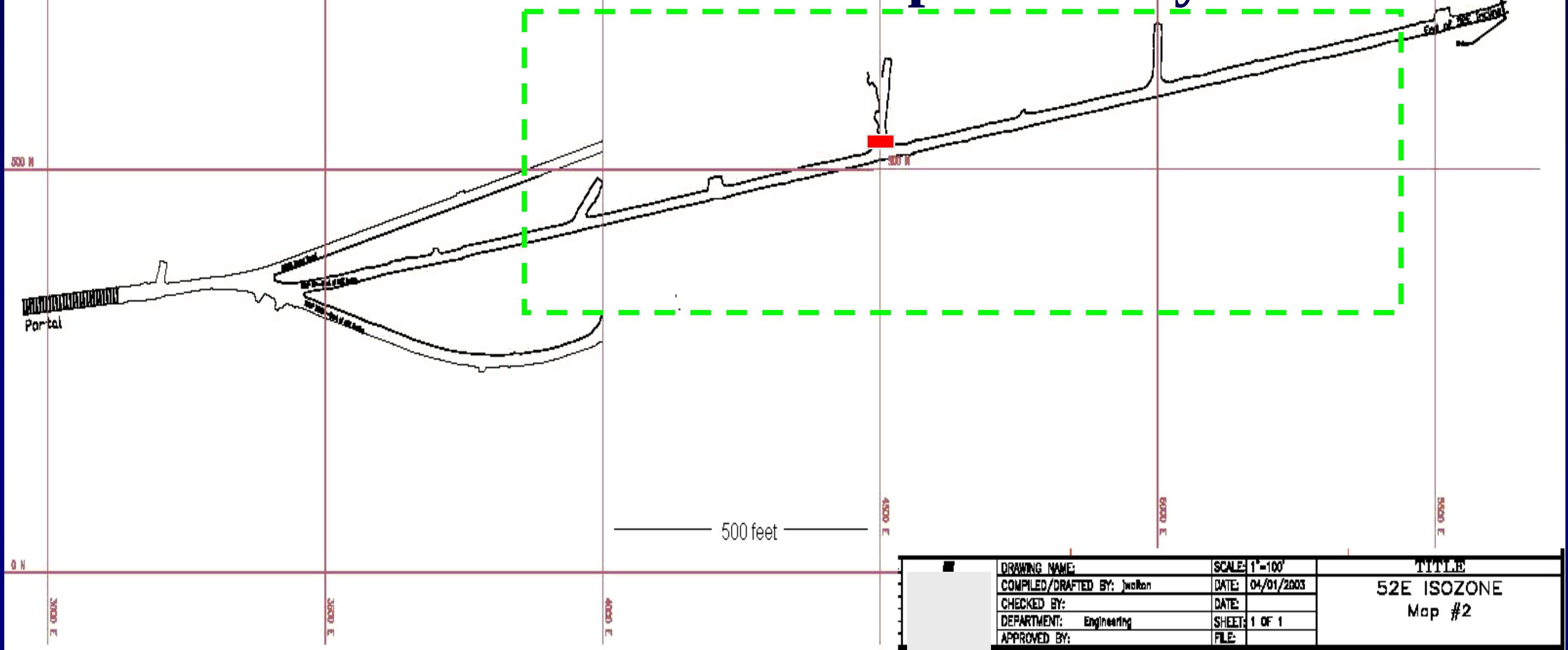


Figure 6. Isolated zone

- Approximately 600 meters long drift between levels 5000 and 5200
- The test zone ventilated from the portal situated at 1500 meters above see level
- Isolated zone
- The average cross-sectional dimensions approximately 3.6 m by 2.7 m.
- The ramp has a 9% rise towards the downstream end

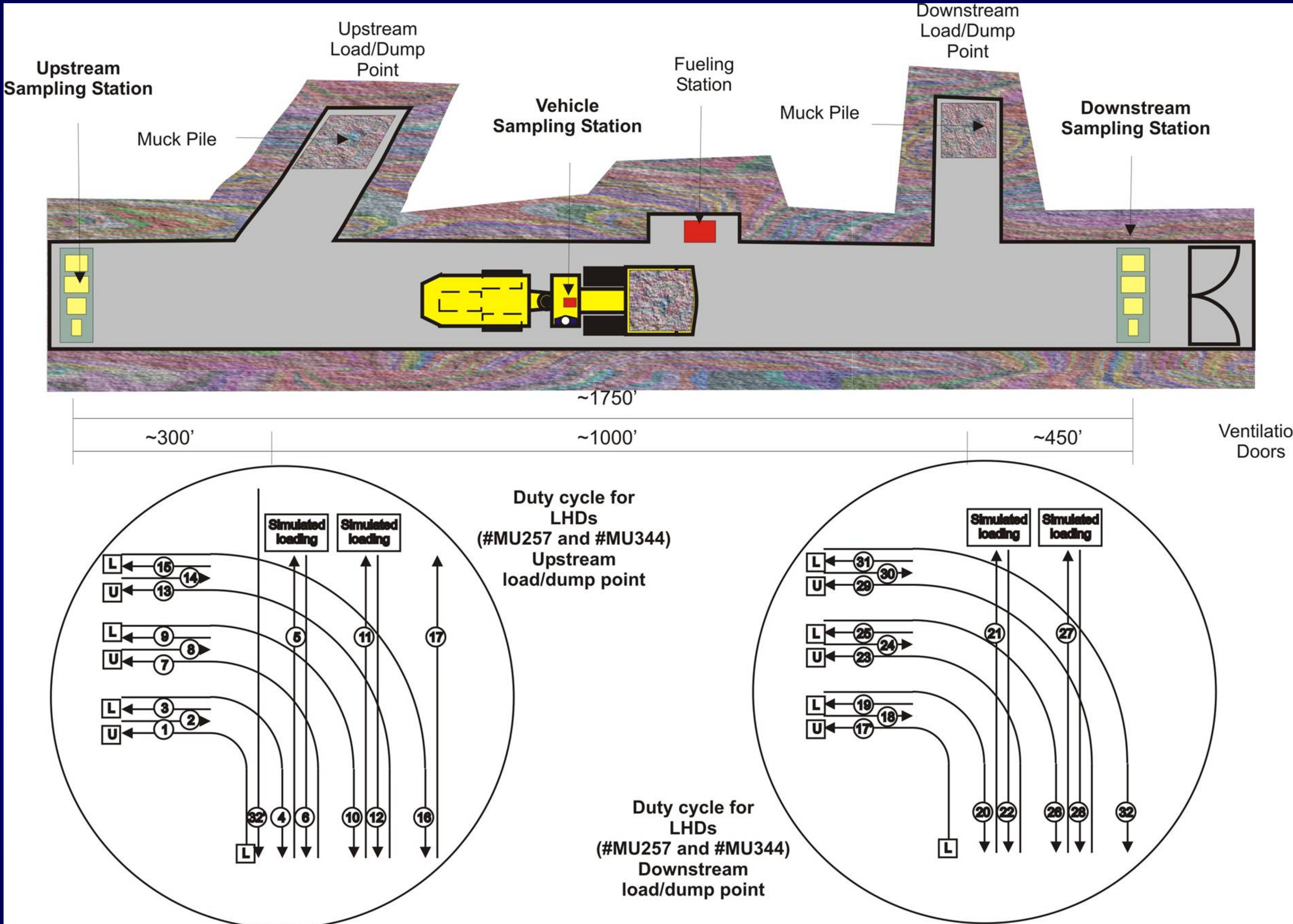


Figure 7. Design and layout of isolated zone and LHD duty cycle

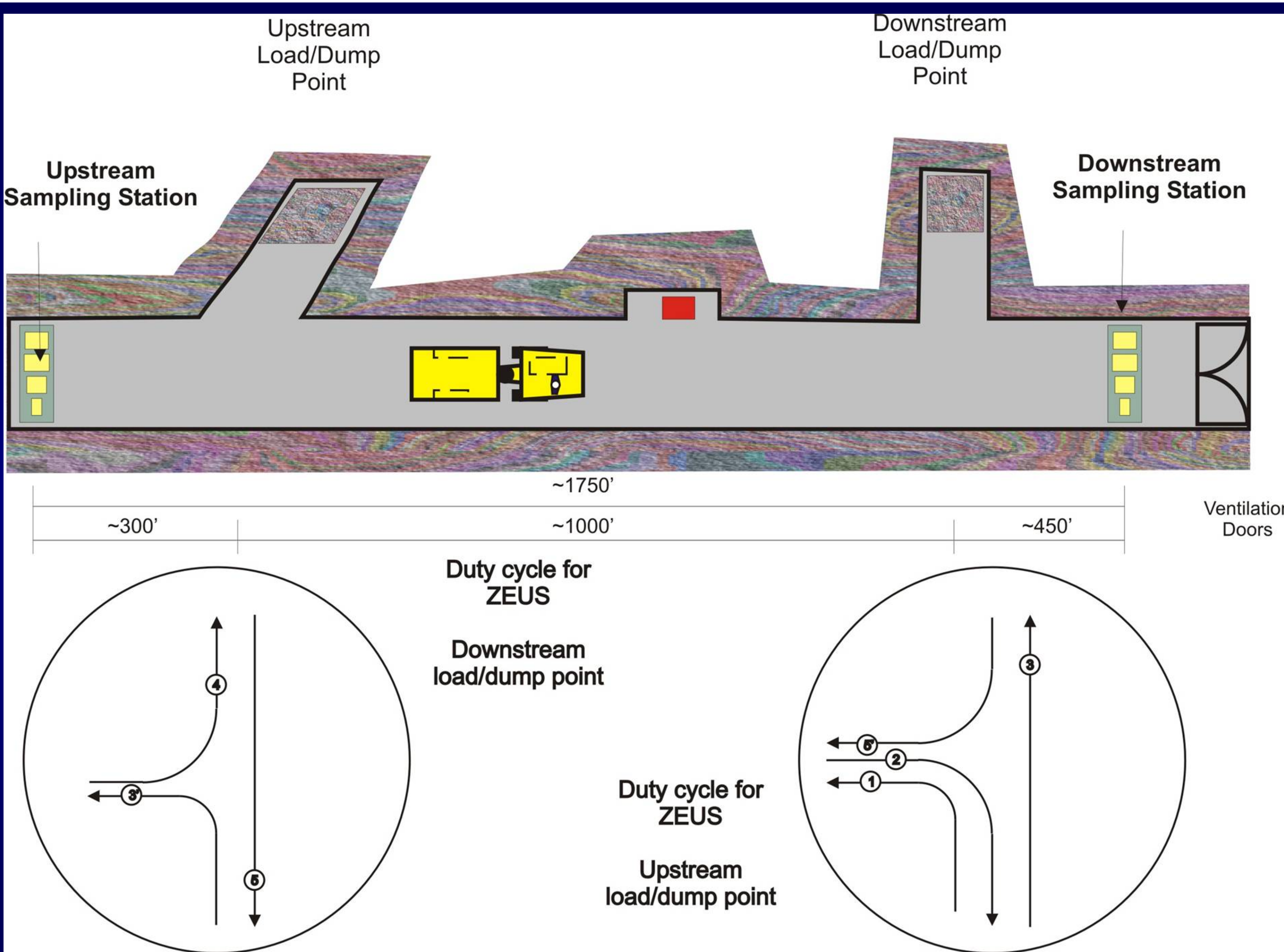


Figure 8. Design and layout of isolated zone and duty cycle for ZEUS

Sampling Strategy Used in Isolated Zone Tests

- Two sampling locations:
  - Downstream sampling station, ~ 137 m downstream of the upstream load/dump point
  - Upstream sampling station, ~ 91 m upstream of the upstream load/dump point
- In general, net contribution from the vehicles were obtained by subtracting upstream from downstream concentrations.

Instrumentation and Sampling at Downstream Sampling Station

- Size distribution and number concentration were measured using SMPS (Electrostatic Classifier Model 3080 and CPC Model 3025)
- DPM samples were collected for
  - Carbon analysis using NIOSH 5040 (High Volume)
  - Carbon analysis using NIOSH 5040 (SKC Diesel Samplers, only for fuel tests)
  - Gravimetric analysis
- Mass concentration of DPM was measured using R&P TEOM 1400a
- Vent rate and ambient temperature were measured using Ultrasonic Anemometer
- Concentrations of CO, NO, and NO_2 were measured using Industrial Scientific iTX portable monitors

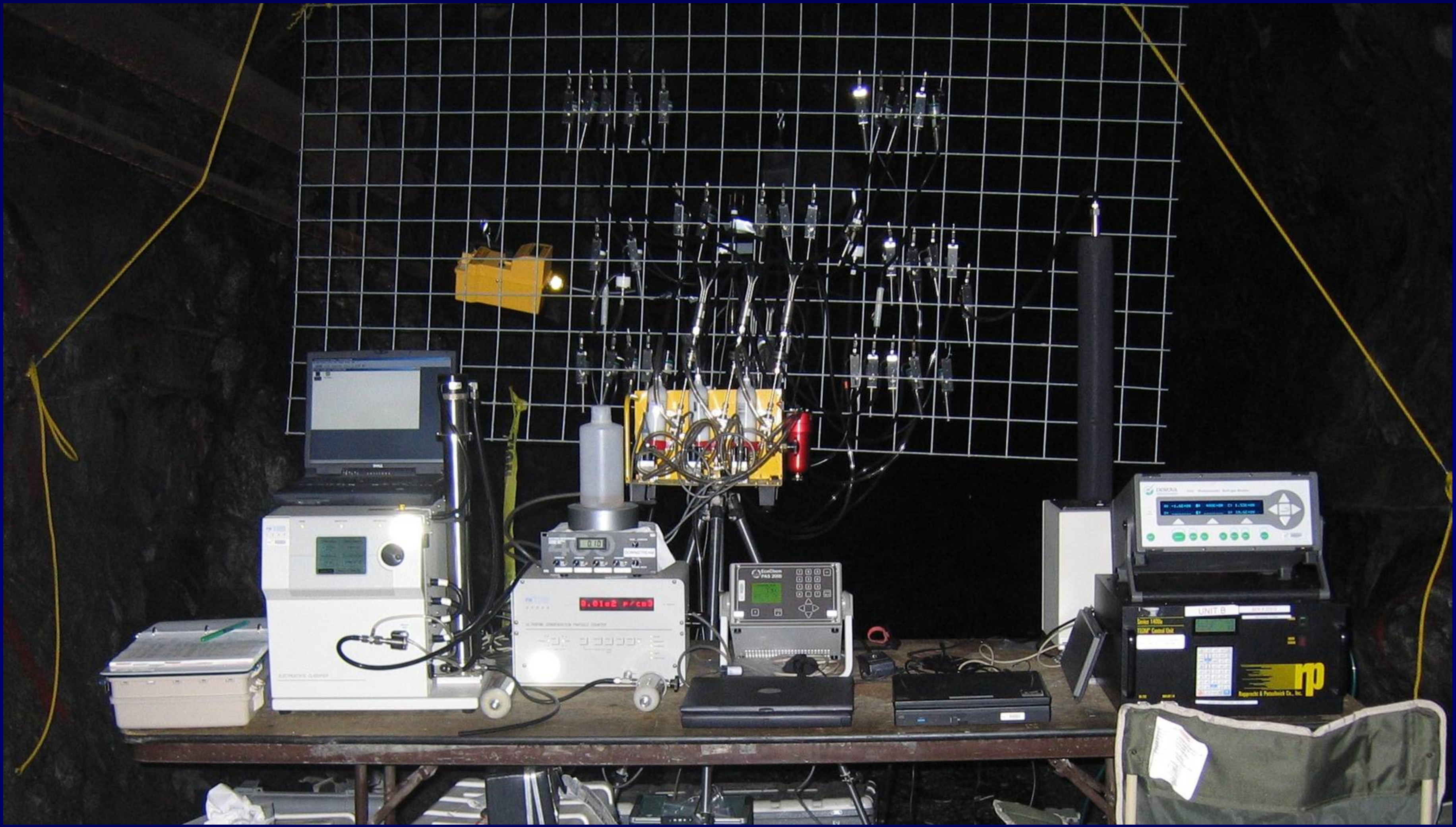


Figure 9. Downstream sampling station

Instrumentation and Sampling at Upstream Sampling Station

- Size distribution and number concentration was measured using SMPS (EC 3080 and CPC 3010)
- DPM samples were collected for
  - Carbon analysis using NIOSH 5040 (High Volume)
  - Carbon analysis using NIOSH 5040 (SKC Diesel Samplers, only for fuel tests)
- Mass concentration of DPM was measured using R&P TEOM 1400a
- Vent rate and ambient temperature were measured using Ultrasonic Anemometer
- Concentrations of CO, NO, and NO_2 were measured using Industrial Scientific iTX portable monitors

Figure 10. Instrumentation at upstream sampling station

Ventilation

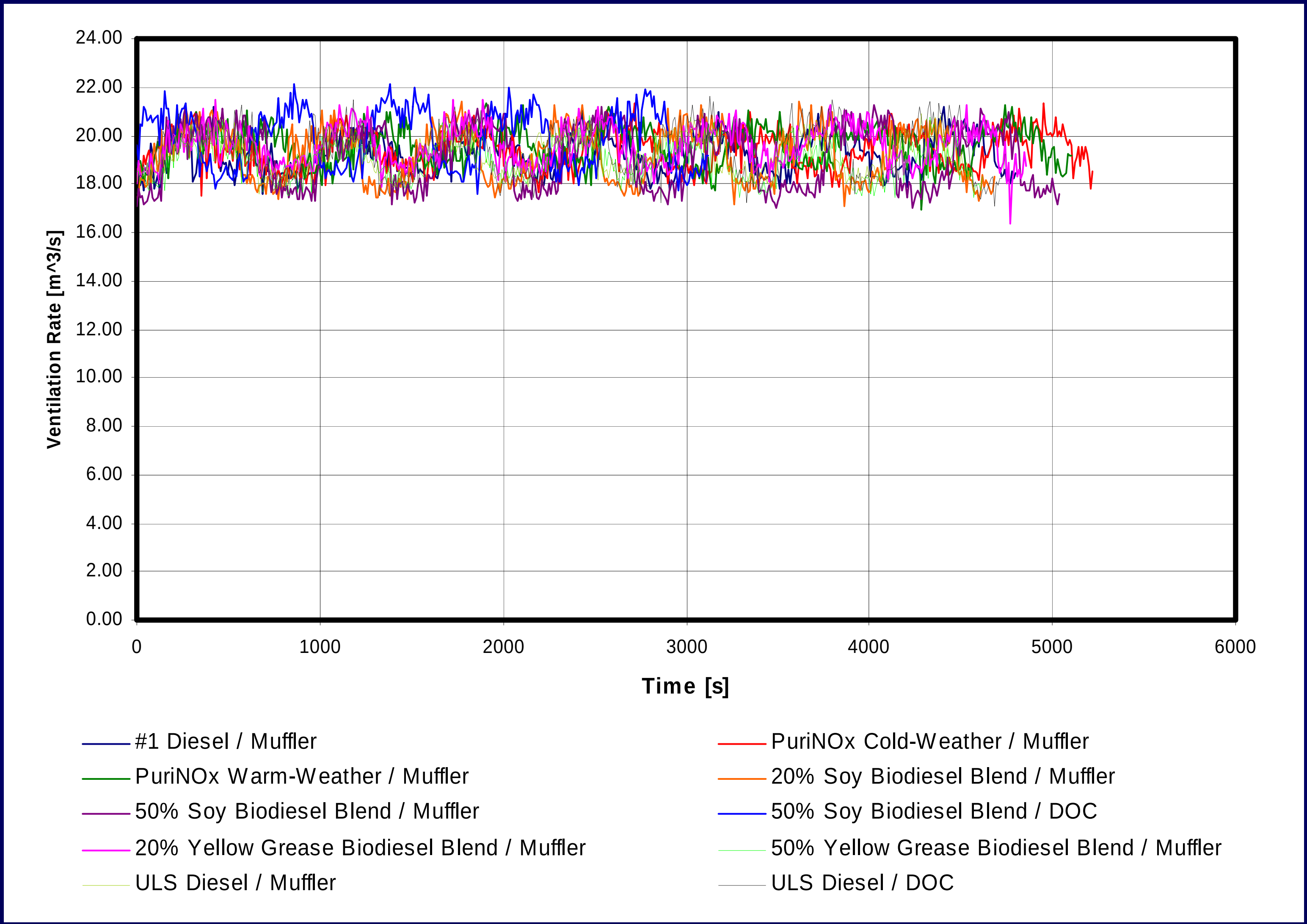


Figure 11. Ventilation rates, reformulated fuels tests

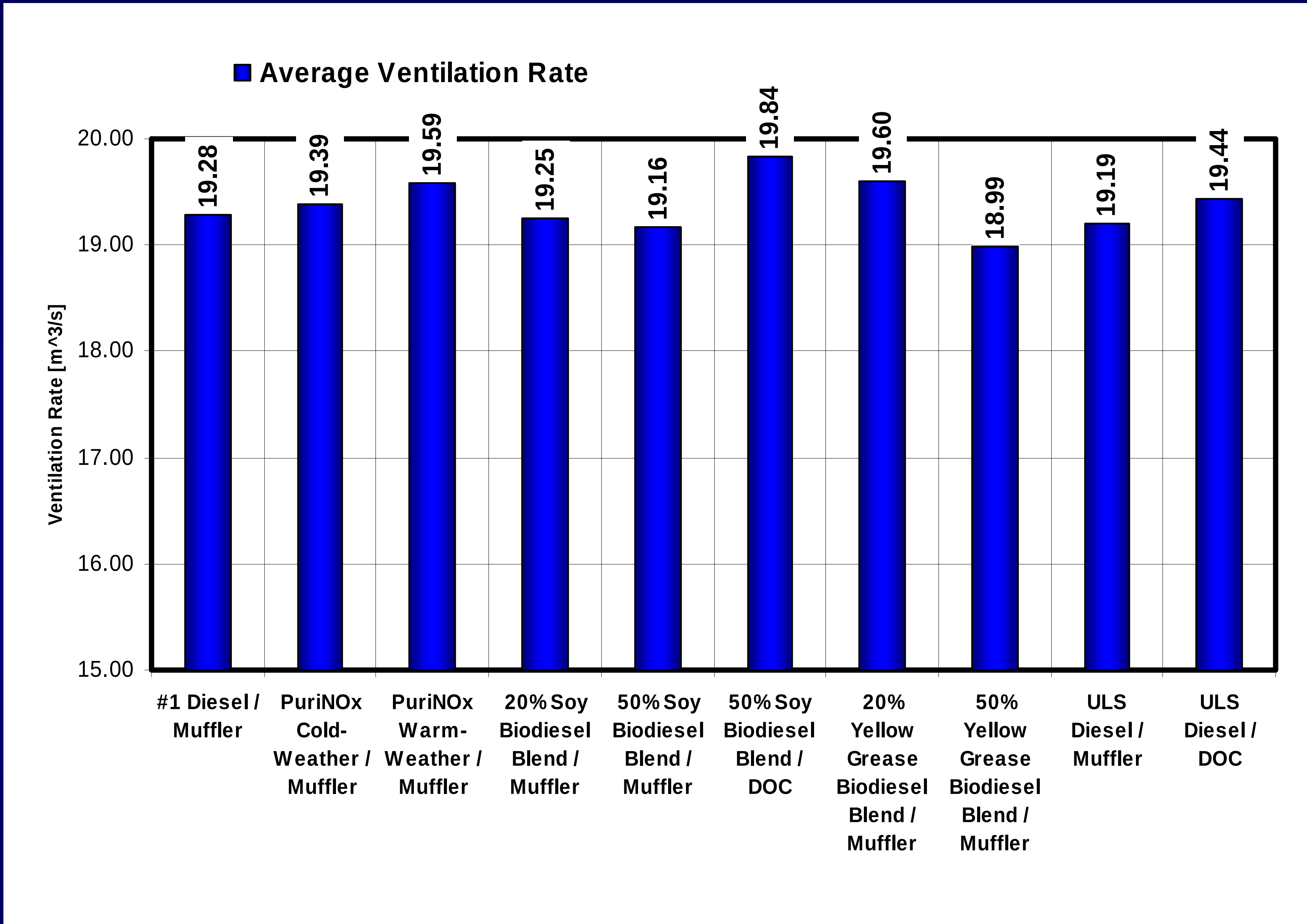


Figure 12. Average ventilation rates, reformulated fuels tests

Results and Discussion

- Effects of reformulated diesel fuels and hydrogen on:
  - number concentrations and size distribution of aerosols between 10 and 392 nm
  - total mass of particles and elemental carbon under 800 nm
  - mass concentrations of total particulate matter under 800 nm

Figure 13. Fueling station for reformulated fuels

Figure 14. Hydrogen fueling station

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

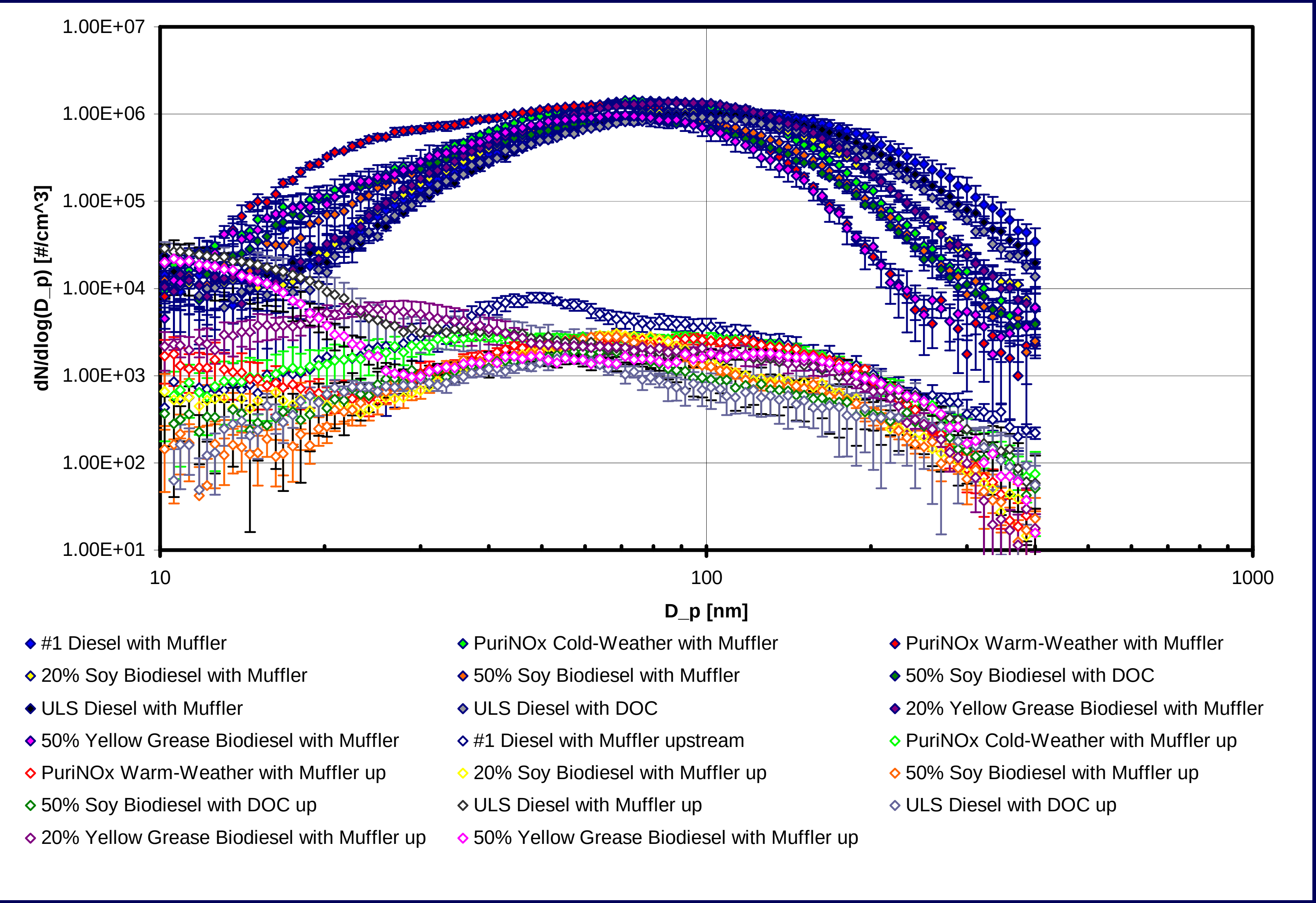


Figure 15. Size distribution of aerosols measured at downstream and upstream sampling station during LHD tests

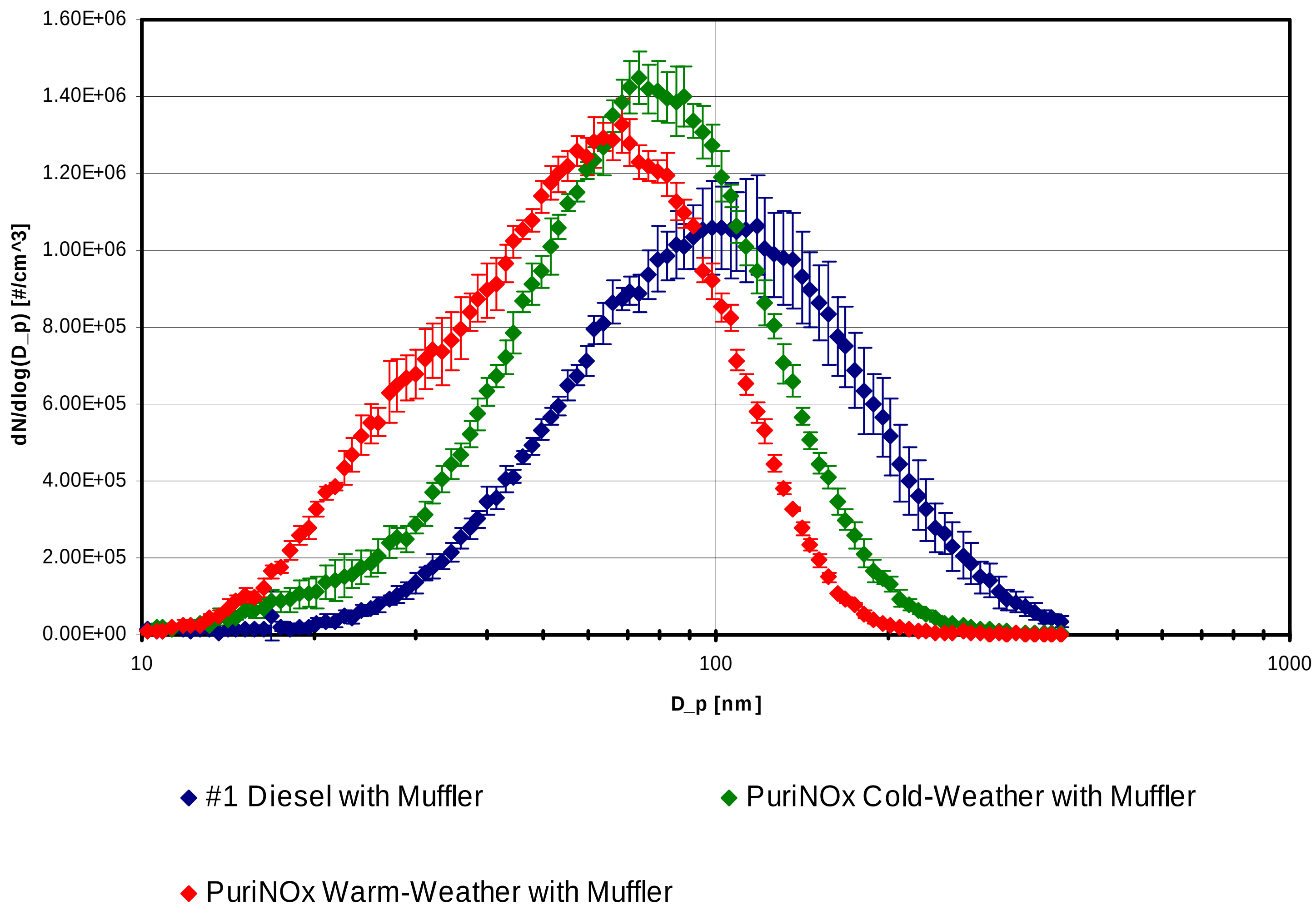
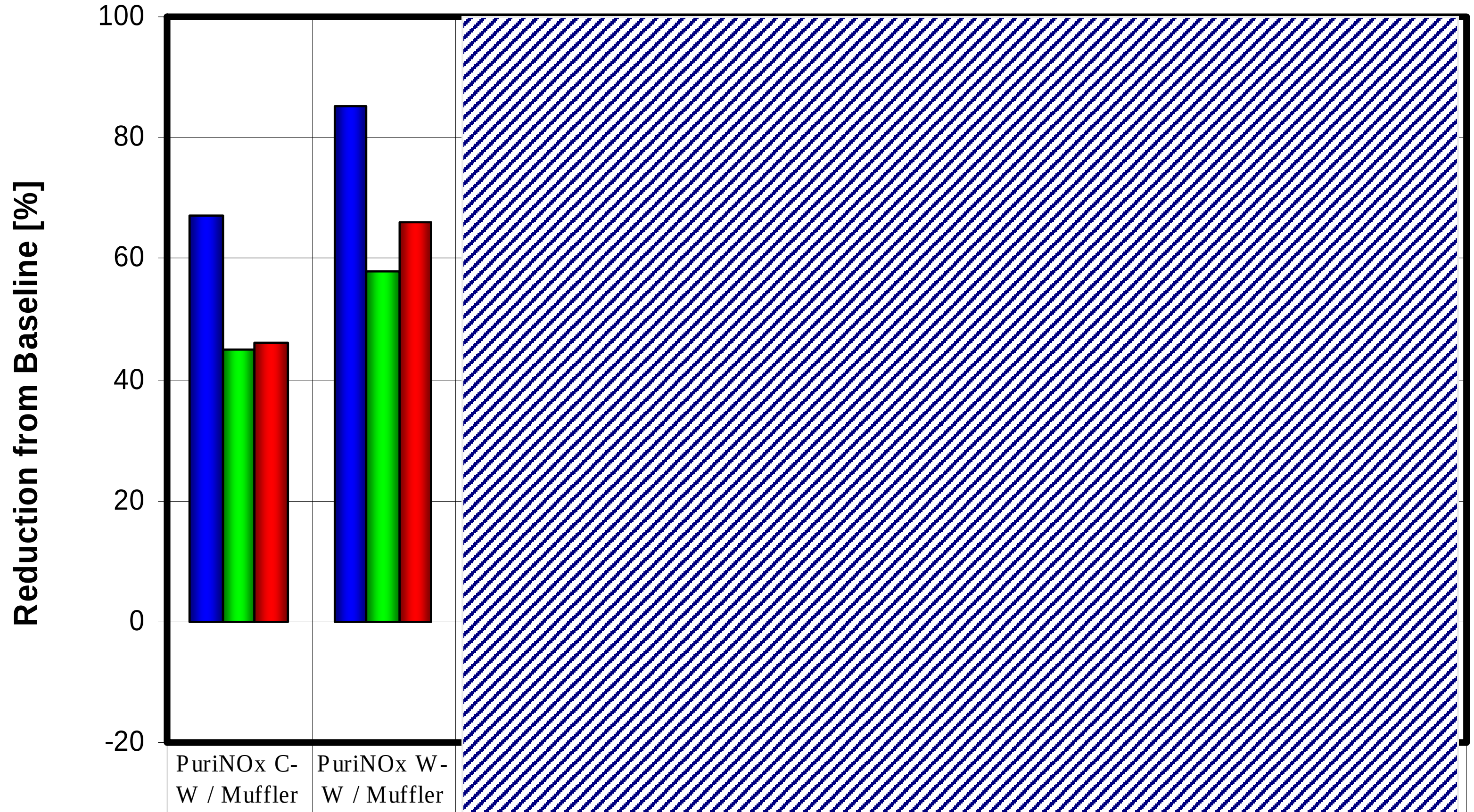


Figure 16. Effects of water-in-diesel-fuel emulsions on size distribution of aerosols in mine air



	PuriNOx C-W / Muffler	PuriNOx W-W / Muffler
EC HV	67	85
TPM GRAV	45	58
TPM TEOM	46	66

Figure 20. Effects of fuel formulations on concentrations of elemental carbon and total particulate matter with D_{50} < 800 nm

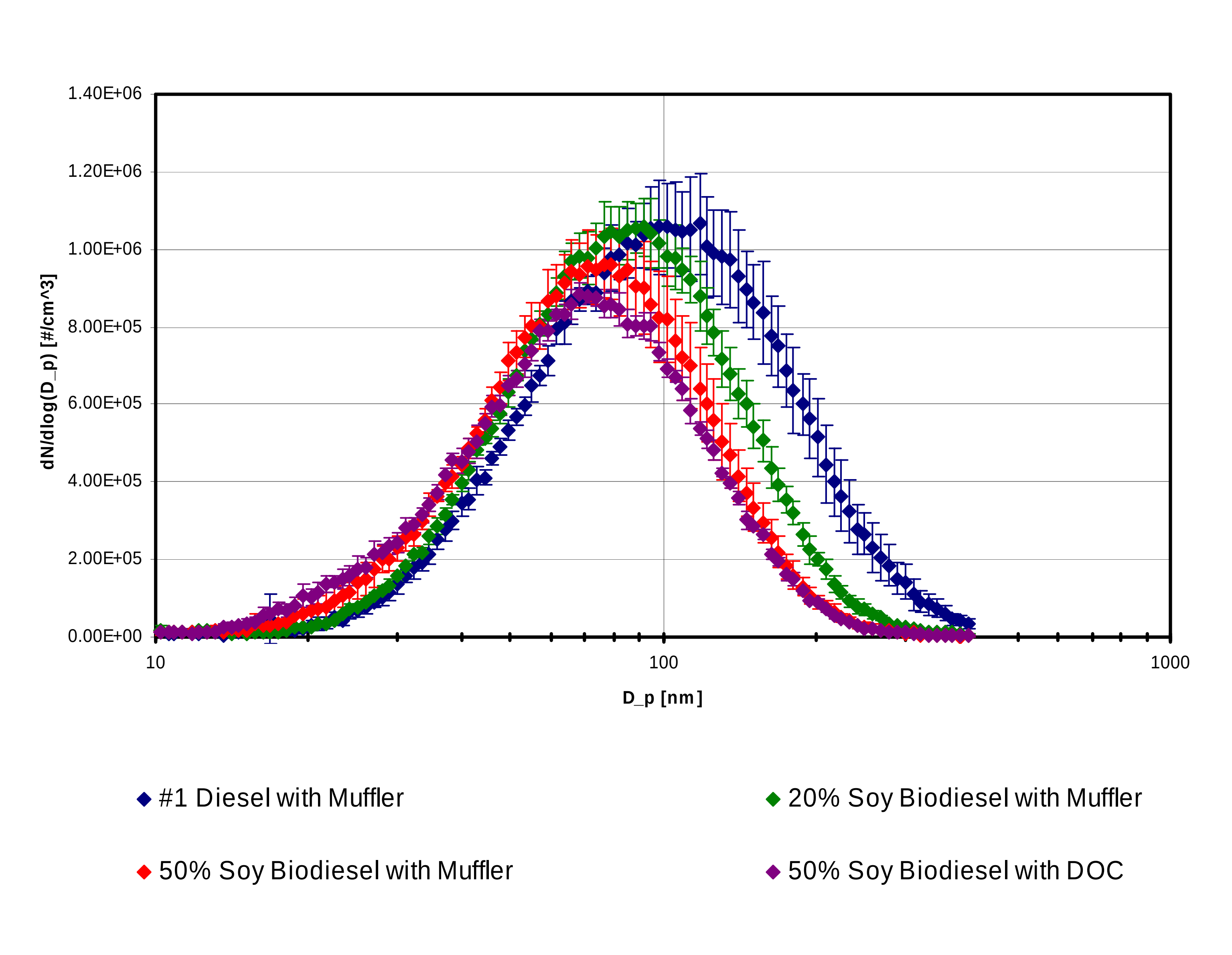
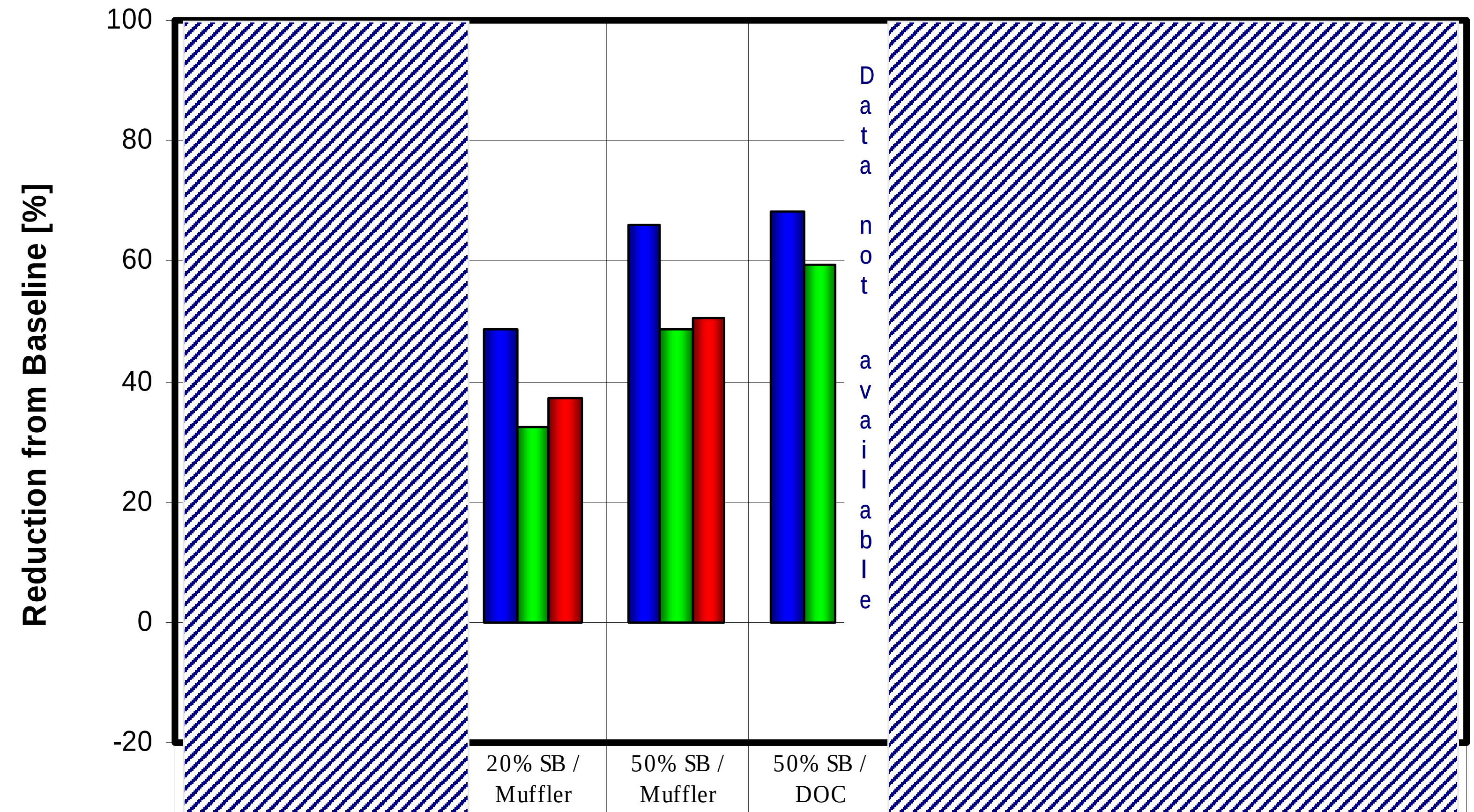


Figure 17. Effects of soy biodiesel blends on size distribution of aerosols in mine air



	20% SB / Muffler	50% SB / Muffler	50% SB / DOC
EC HV	49	66	68
TPM GRAV	32	48	60
TPM TEOM	37	50	

Figure 20. Effects of fuel formulations on concentrations of elemental carbon and total particulate matter with D_{50} < 800 nm

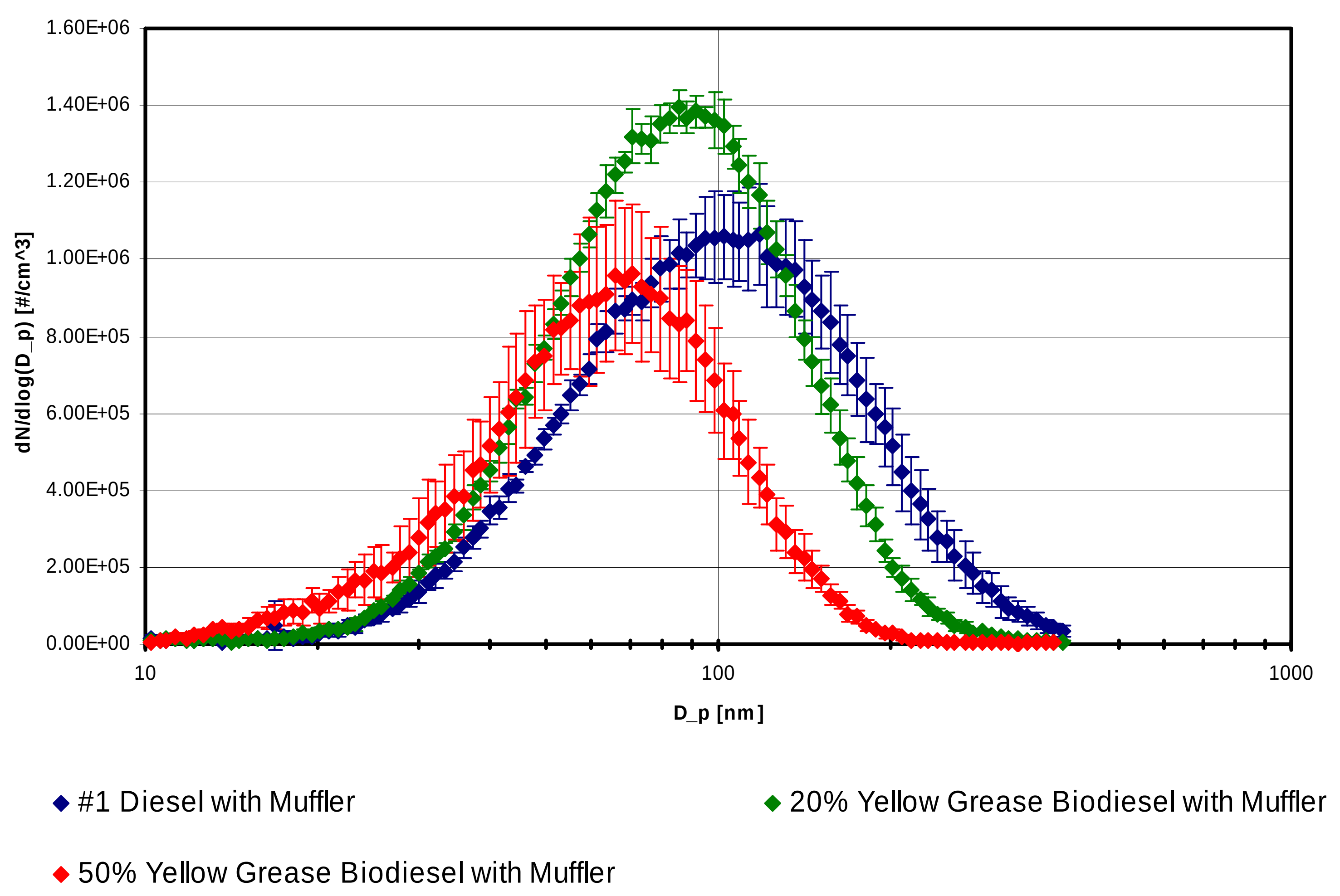
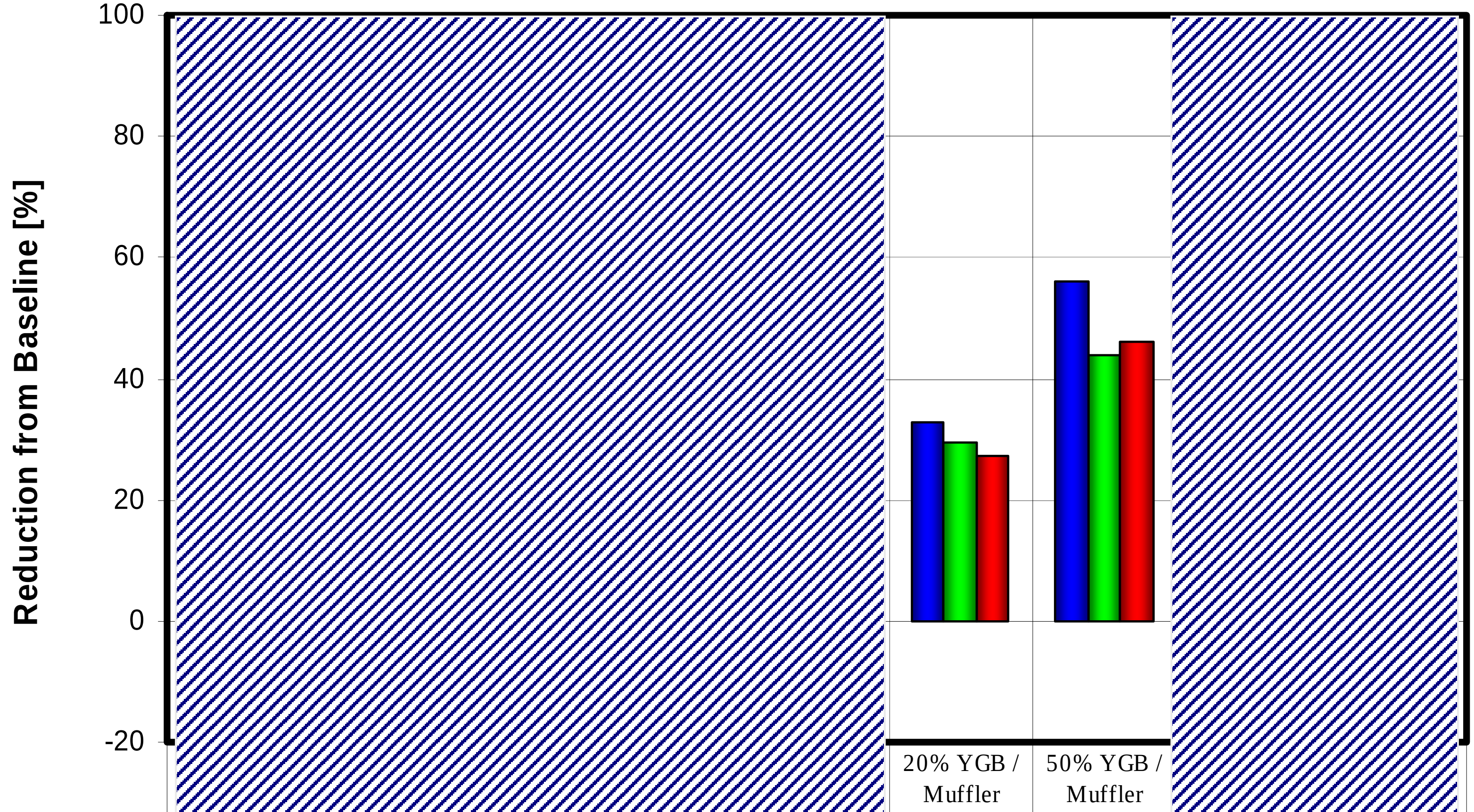


Figure 18. Effects of yellow grease biodiesel blends on size distribution of aerosols in mine air



	20% YGB / Muffler	50% YGB / Muffler
EC HV	33	56
TPM GRAV	30	44
TPM TEOM	27	46

Figure 20. Effects of fuel formulations on concentrations of elemental carbon and total particulate matter with D_{50} < 800 nm

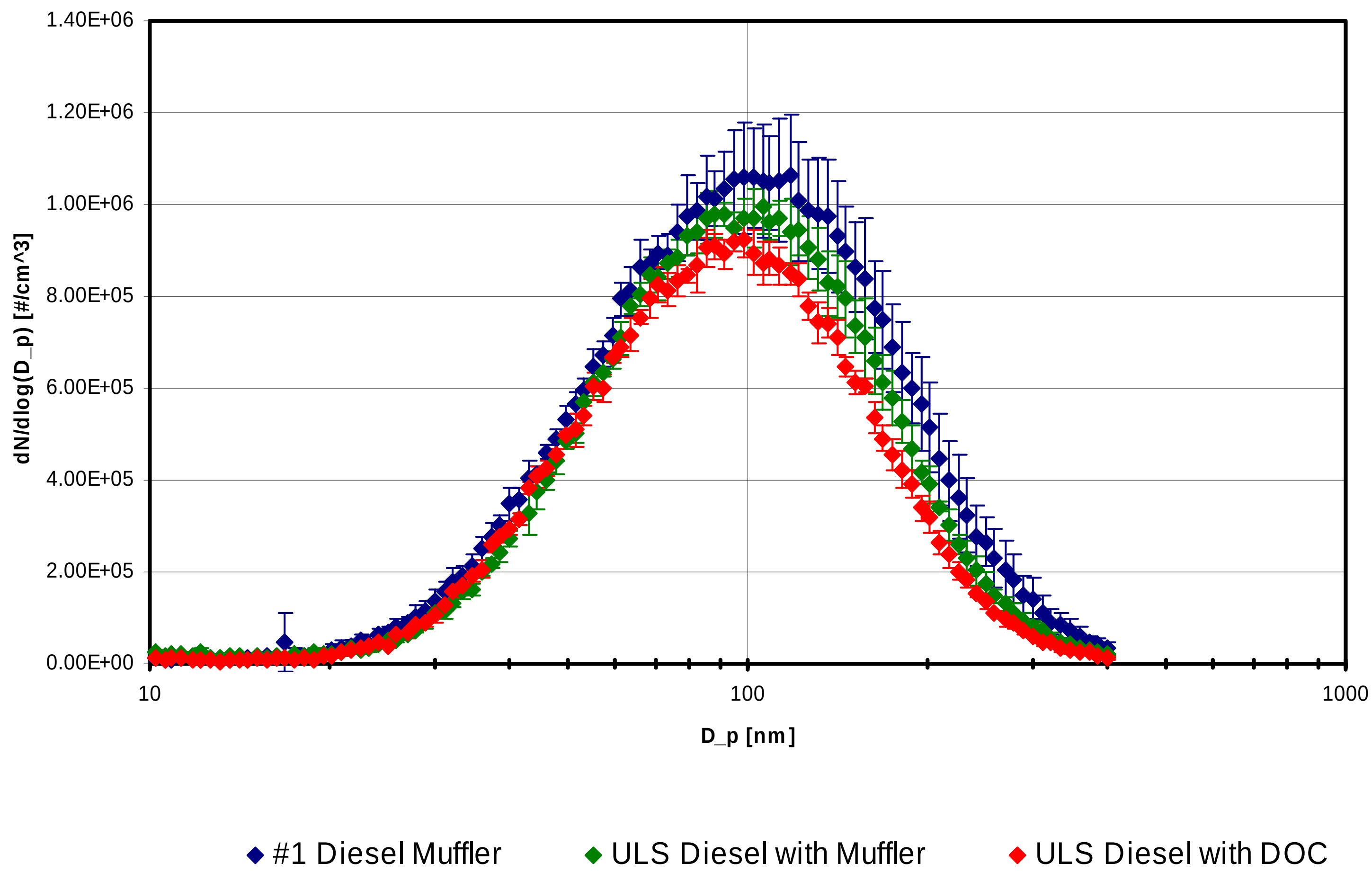
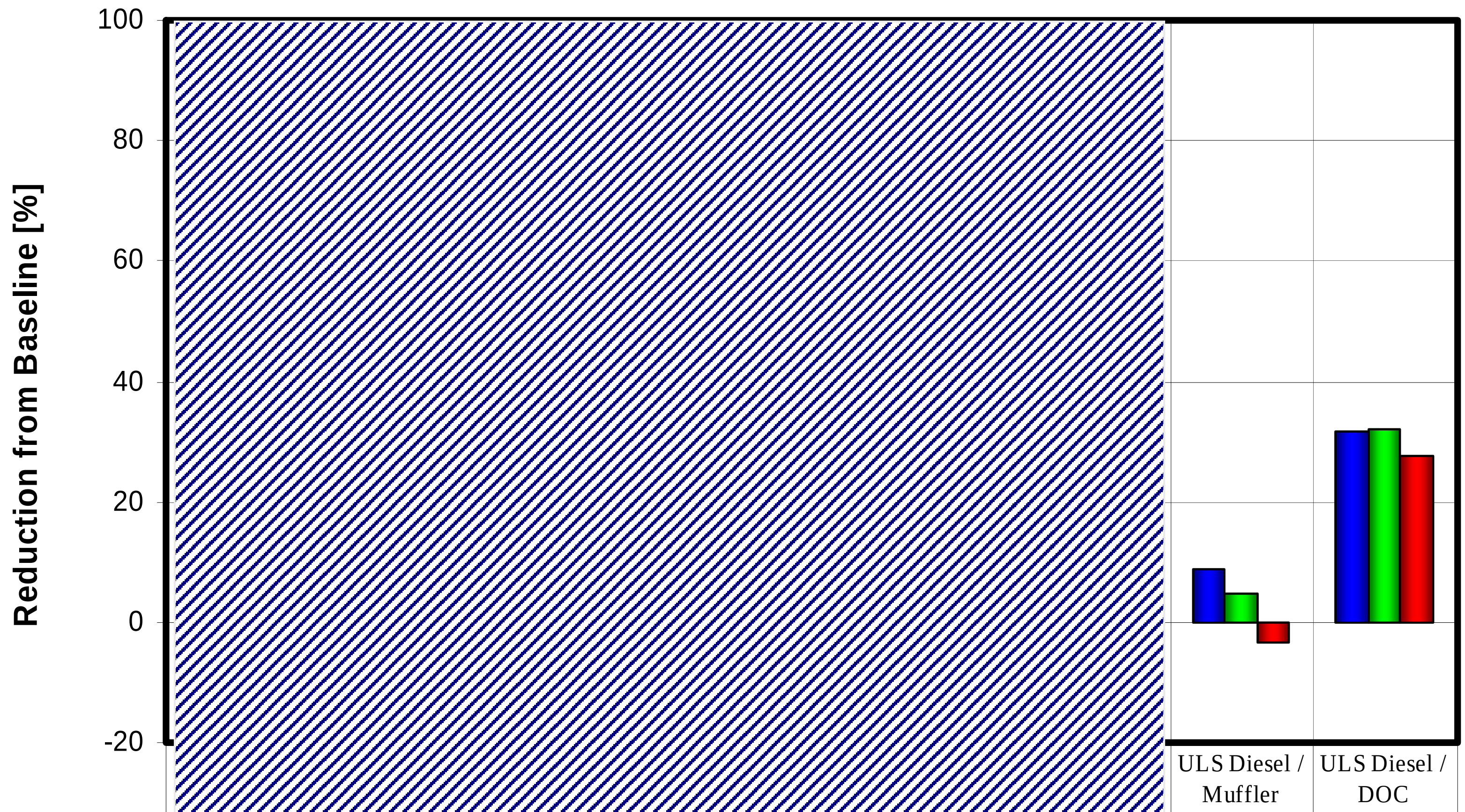


Figure 19. Effects of ultralow sulfur fuel (10 ppm S) on size distribution of aerosols in mine air



	ULS Diesel / Muffler	ULS Diesel / DOC
EC HV	9	32
TPM GRAV	5	32
TPM TEOM	-3	27

Figure 20. Effects of fuel formulations on concentrations of elemental carbon and total particulate matter with D_{50} < 800 nm

Table 4. Effects of Fuel Formulations on Total Number of Aerosols ($10\ nm < D_{50} < 392\ nm$) in Mine Air

LHD	Downstream			Upstream			Net Contribution	
	Average GM	Average GSD	Normal. Average Number	Average GM	Average GSD	Normal. Average Number	Normal. Average Number	Change (Increase)
	nm	-	$\#/cm^3$	nm	-	$\#/cm^3$	$\#/cm^3$	%
#1 Diesel / Muffler	95.1	1.76	4.29E+07	57.3	1.92	2.64E+05	4.27E+07	0.0
PuriNOx Cold-Weather / Muffler	68.4	1.69	4.89E+07	59.4	2.07	1.73E+05	4.87E+07	14.2
PuriNOx Warm-Weather / Muffler	54.9	1.72	4.98E+07	59.0	2.26	1.45E+05	4.97E+07	16.4
20% Soy Biodiesel Blend / Muffler	80.6	1.67	3.77E+07	59.1	1.98	1.00E+05	3.76E+07	-12.0
50% Soy Biodiesel Blend / Muffler	70.3	1.68	3.40E+07	61.8	1.81	9.02E+04	3.39E+07	-20.5
50% Soy Biodiesel Blend / DOC	67.0	1.73	3.20E+07	56.9	1.99	8.17E+04	3.19E+07	-25.3
20% YG Biodiesel Blend / Muffler	81.0	1.63	4.73E+07	35.3	2.14	2.49E+05	4.70E+07	10.3
50% YG Biodiesel Blend / Muffler	61.4	1.67	3.17E+07	26.8	2.35	3.66E+05	3.13E+07	-26.6
ULS Diesel / Muffler	93.0	1.73	3.77E+07	21.1	2.07	5.58E+05	3.72E+07	-12.8
ULS Diesel / DOC	89.3	1.71	3.45E+07	55.4	2.03	6.53E+04	3.44E+07	-19.4

Effects of Hydrogen Fueled Vehicle on Size Distribution of Aerosols in Mine Air

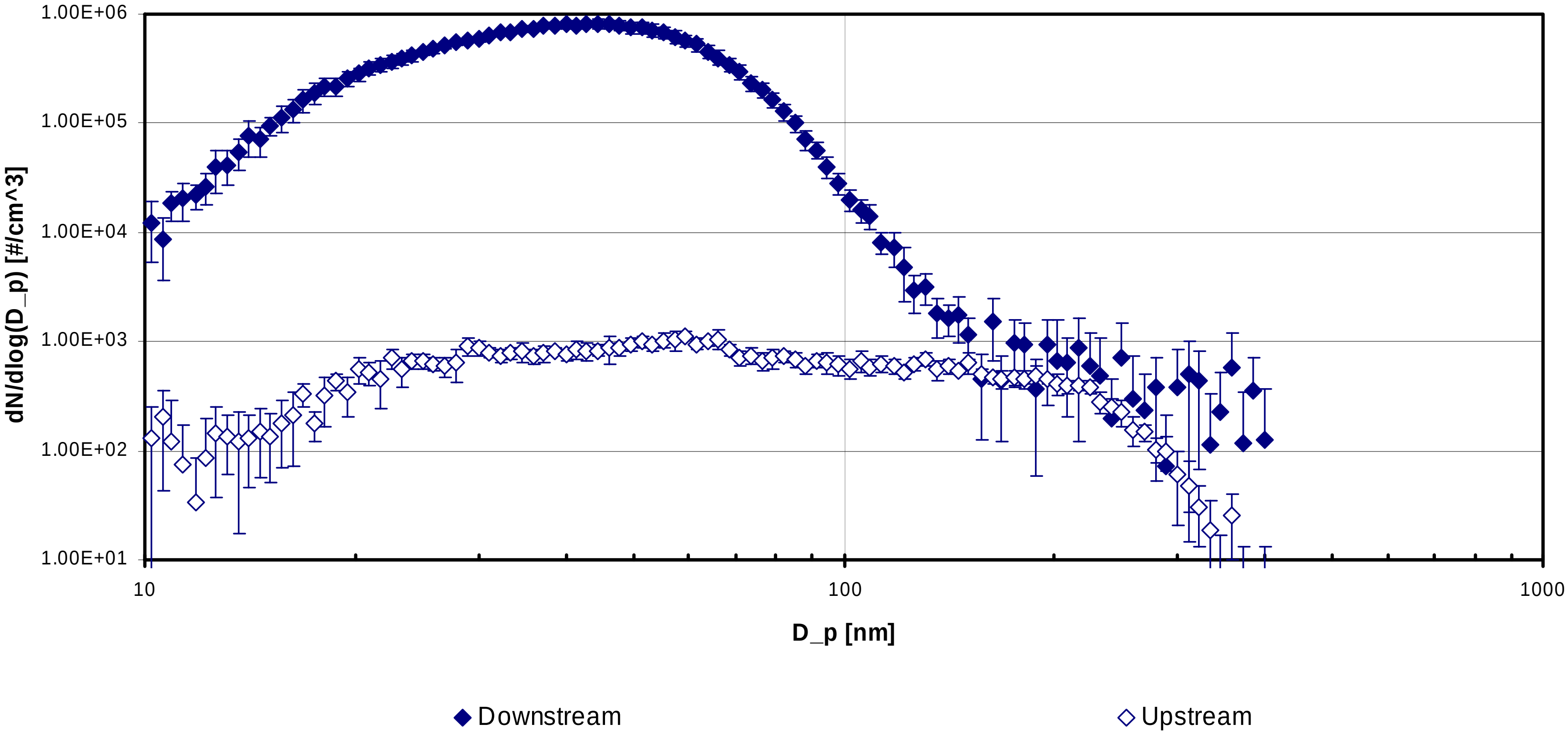


Figure 22. Size distribution of aerosols measured at downstream and upstream sampling station during ZEUS test

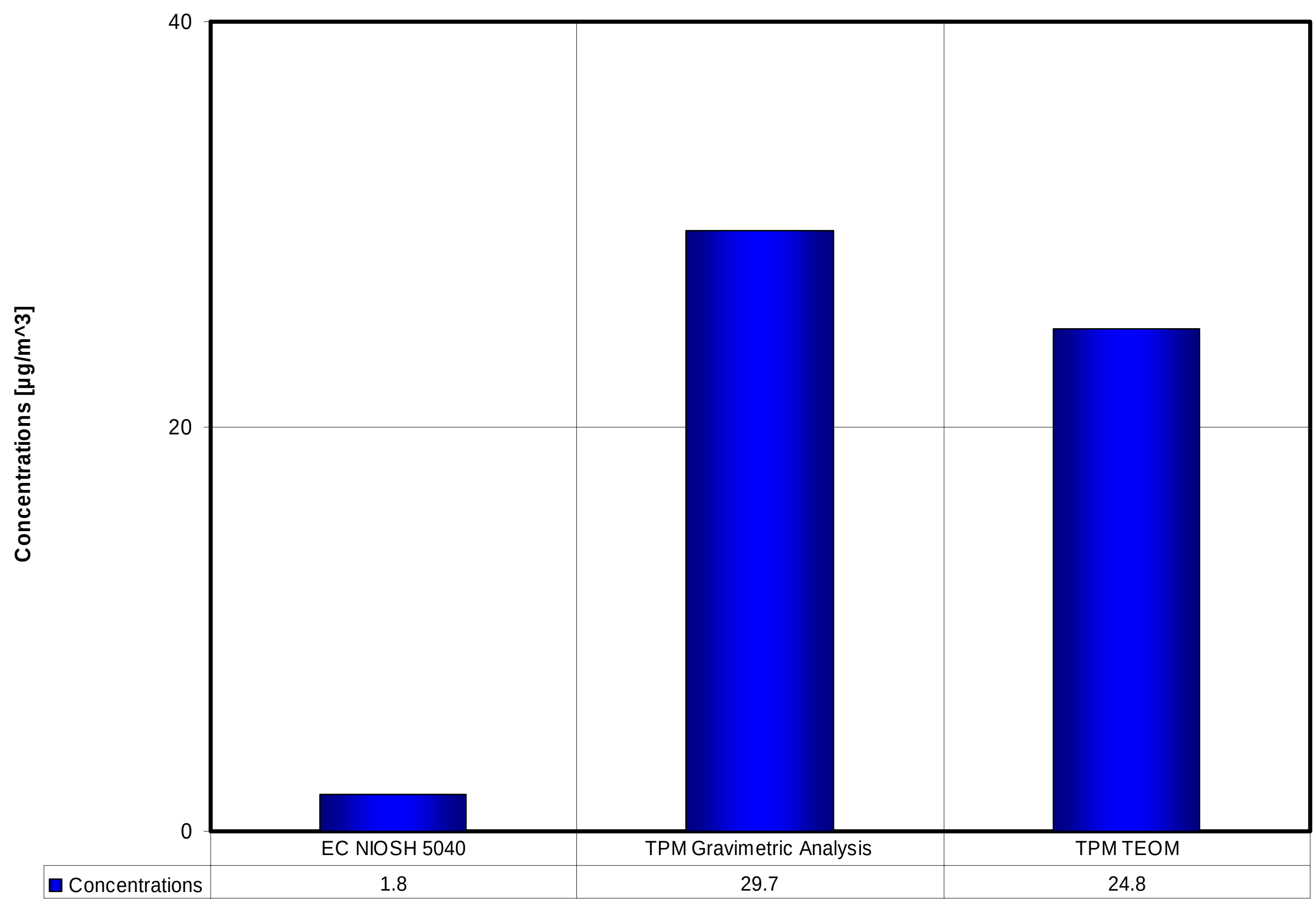


Figure 23. Effects of hydrogen fueled vehicle on concentrations of elemental carbon and total particulate matter with D_{50} < 800 nm

Concluding Remarks

- Substantial reductions in EC and DPM mass concentrations from baseline case (#1 diesel) were observed when test vehicle was fueled with water-fuel emulsions and biodiesel blends
- When those fuels were used the aerosol distributions in mine air were characterized in general with smaller D_{50}
- When water-fuel emulsions were used total number of aerosols was found to be 15% higher than in the baseline case
- The total number of aerosols was found to be lower in the most cases when biodiesel blends were used
- The ultralow sulfur diesel was found to have comparable effects on EC, DPM and size distribution of aerosols as #1 diesel fuel

Concluding Remarks (2)

- EC concentrations were practically undetectable when hydrogen fueled vehicle ZEUS was tested in the isolated zone
- The corresponding mass concentrations of DPM were found to be substantially higher
- Size distribution measurements showed presence of relatively large number of nanometer aerosols in mine air downstream of ZEUS
- The hypothesis is that those particles are generated through incomplete combustion of lubricating oil

Questions???

Aleksandar Bugarski,
NIOSH PRL,
phone: 412.386.5912
e-mail: ABugarski@cdc.gov