Characterization of the Physical and Chemical Properties of Diesel Aerosols in an Underground Mine Diesel Laboratory

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Specific Aims of the Study

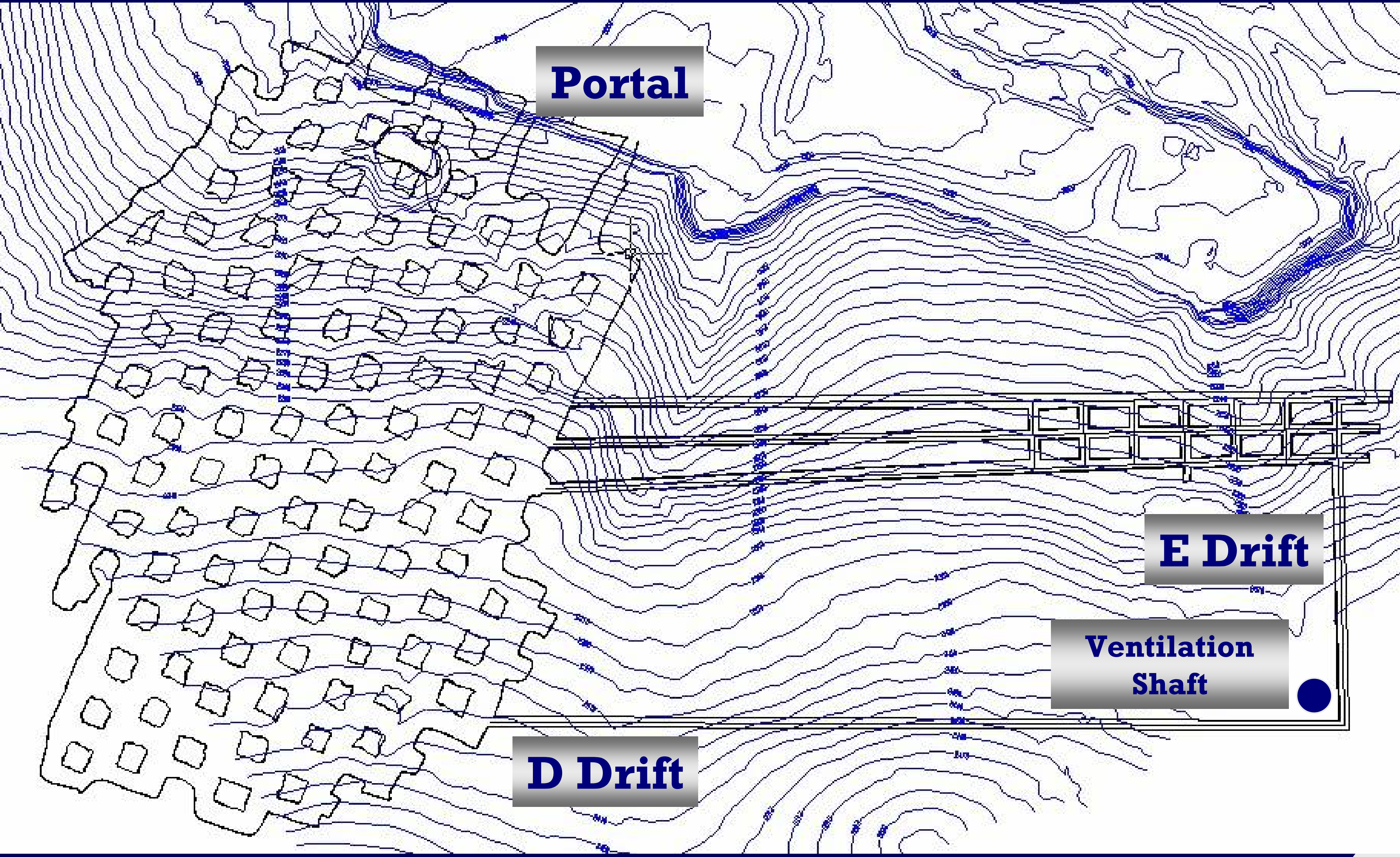
- Characterize nano and ultrafine aerosols emitted by heavy- and light-duty diesel engines.
- Study the effects of selected control technologies (diesel particulate filters, diesel catalytic converters, disposable filter elements, fuel formulations…) on concentrations of diesel aerosols in the workplace.

Methodology

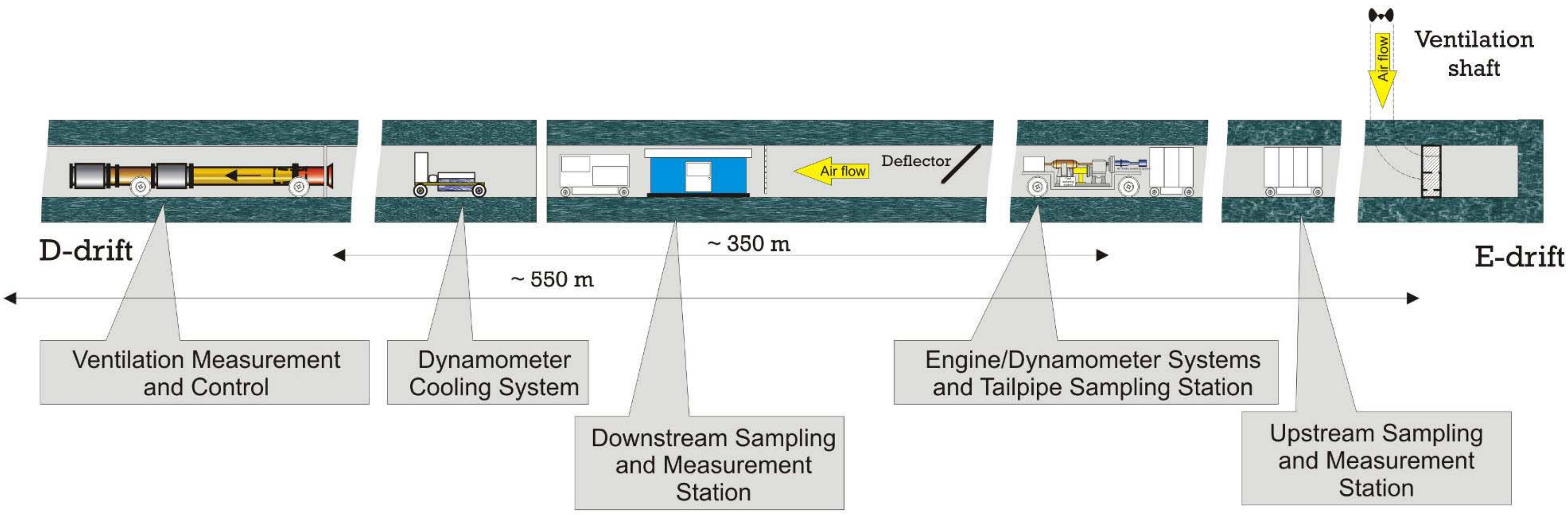
- Characterization of diesel aerosols in occupational setting:
  - NIOSH Mobile Engine Emissions Laboratory (MEEL) at Lake Lynn Laboratory (LLL)
  - Avoid laboratory uncertainties introduced with various simulations of processes
  - Bridge gap between inherently inaccurate field and unrealistic laboratory experiments

- This facility offers unique environment for field testing with laboratory accuracy.

NIOSH Lake Lynn Laboratory (LLL)



NIOSH Diesel Laboratory at LLL



Engine/Dynamometer Systems

- 150 kW eddy current dynamometer coupled to Isuzu C240 Engine
- Dynamometer and engine controls on board of the system remotely operated from downstream station
- Air intake, fuel and other engine and dynamometer operating parameters acquired by 32-channel data acquisition system on-board of the system

Measurement and Sampling Stations

- Downstream station
- Upstream station
- Tailpipe station
- Ventilation control and measurement system

Downstream Station

- Real-time concentrations of aerosols and selected gases:
  - SMPS
  - FMPS
  - ELPI
  - TEOM
  - NDIR
  - CLD…
- Filter sampling for gravimetric, chemical and genotoxicity analysis
- Ambient parameters

Instrumentation at Downstream Station

Upstream Station

- Real-time concentrations of aerosols and selected gases:
  - SMPS
  - TEOM
- Filter sampling for gravimetric and chemical analysis

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Tailpipe Station

- Concentrations of CO_2 ,CO, and HC
- Relevant engine, dynamometer, and ambient parameters

Ventilation Control and Measurement System

- 25,000 cfm Venturi meter
- Auxiliary fan
- Ventilation stopping
- Real-time flow-rate measurements
- Ambient parameters

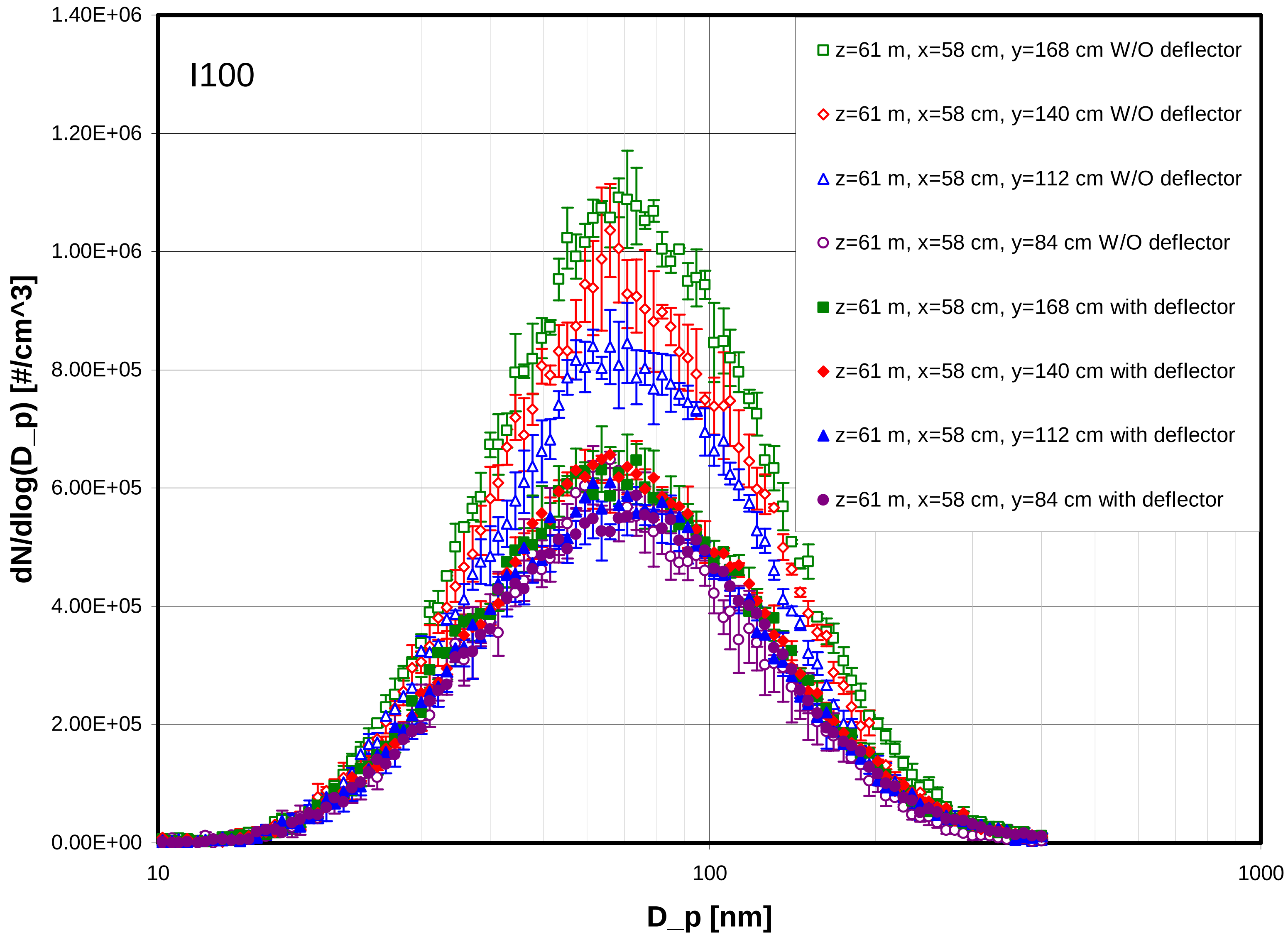
Ventilation Control and Measurement System

- Total air flow rate through D-drift was maintained constant:
  - 25,178.5 ± 265.4 kg/h
- This resulted in the following dilution ratios and ambient conditions:

Mode	Dilution Ratio
R50	148
R100	149
I50	186
I100	188

Mode	Air Temperature @ LFE	Air Temperature @ Downstream Station	Relative Humidity @ LFE	Relative Humidity @ Downstream Station
	° C	° C	%	%
Minimum	10.5	14.7	28.3	23.0
Maximum	18.7	22.3	81.5	70.7

Plume Propagation, Thermal Stratification and Forced Mixing



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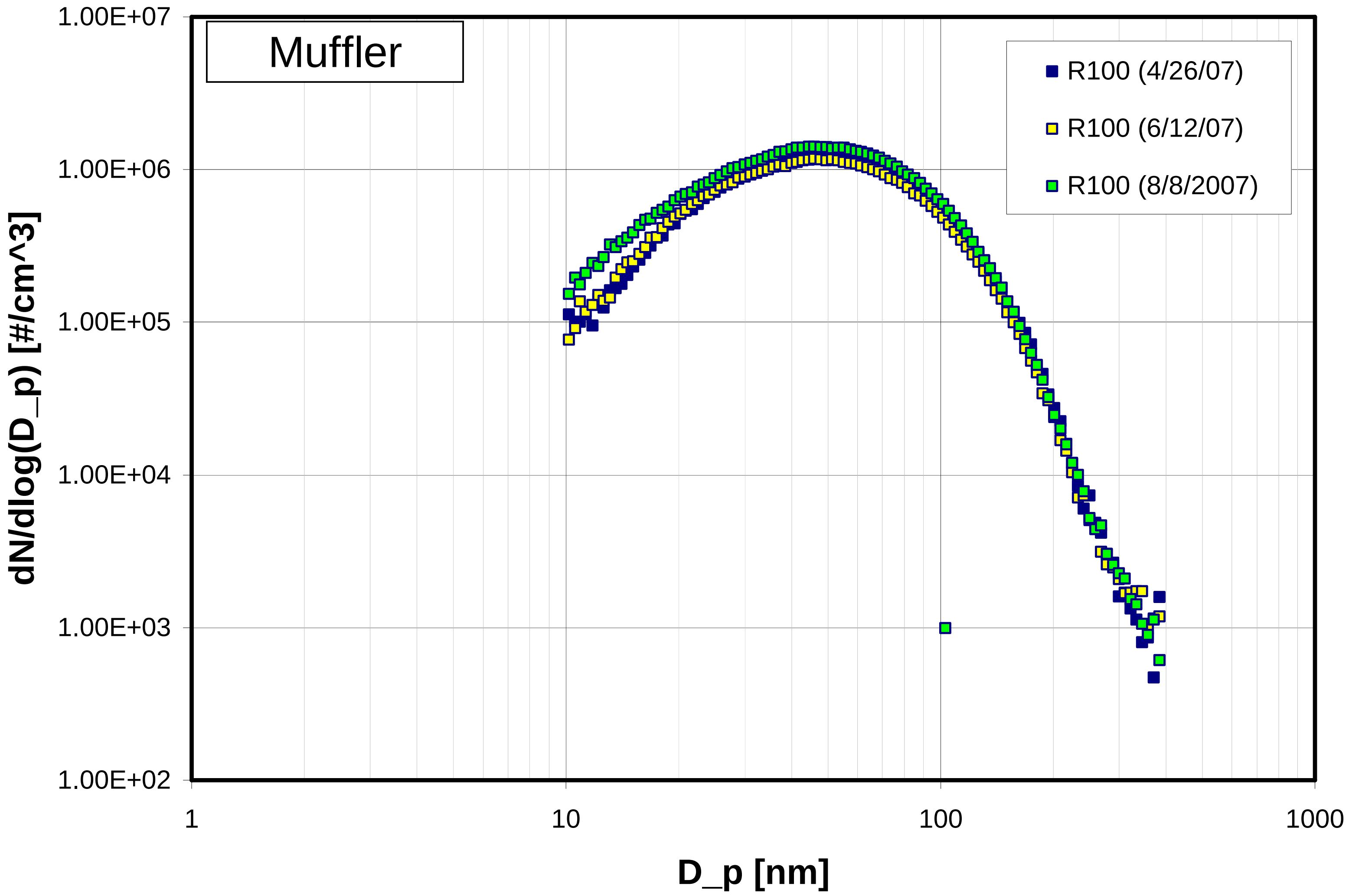
Repeatability



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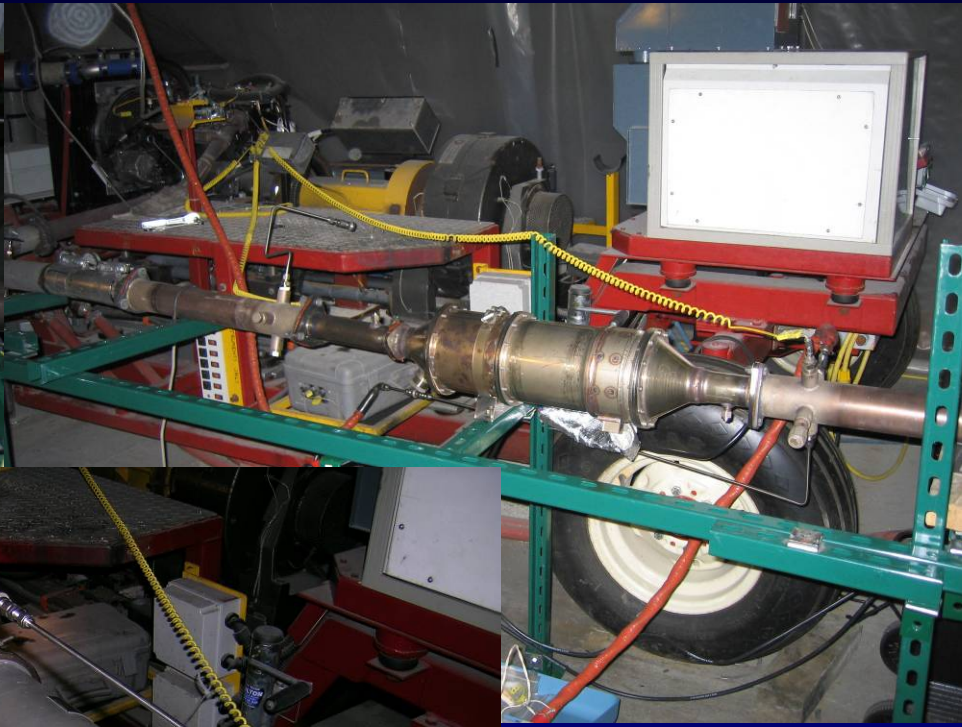
Control Technologies

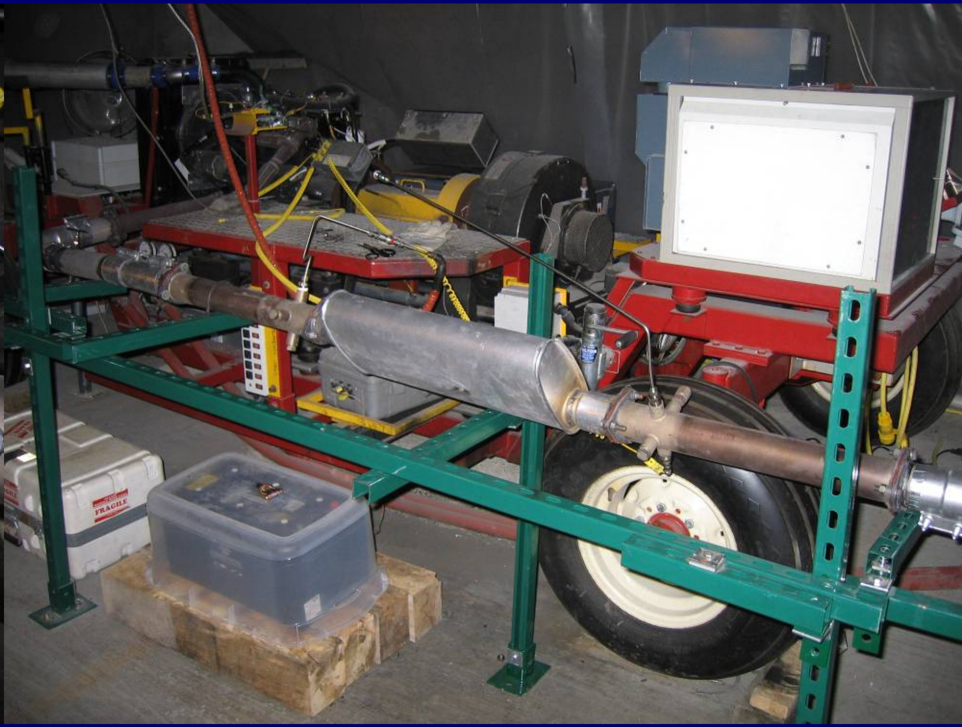
- Diesel particulate filter (DPF) systems
  - Cordierite element
  - SiC element
  - Sintered metal element
- Filtration systems with dry heat exchanger and high-temperature disposable filter elements (DFE)
  - New and laundered DFE from supplier #1
  - New DFE from supplier #2
- Diesel oxidation catalytic converter
- The baseline was established using standard muffler

Diesel Particulate Filter (DPF) Systems



High-Temperature Disposable Filter Elements (DFE) Integrated in the Filtration System with Dry Heat Exchanger

Diesel Oxidation Catalytic Converter and Muffler



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Test Modes

Mode	Description	Engine Speed	Torque	Power
		rpm	Nm	kW
R50	Rated speed 50% load	2950	55.6	17.2
R100	Rated speed 100% load	2950	111.2	34.3
I50	Intermediate speed 50% load	2100	69.1	14.9
I100	Intermediate speed 100% load	2100	136.9	30.6

Fuel

Test		Method	Result	Units
BTU, Net		ASTM D-240	43468	kJ/kg
Cetane Number		ASTM D-613	61.8	-
Density		ASTM D-4052	0.8038	gm/ml
Flash Point, PMCC		ASTM D-93A	62.2	°C
Hydrocarbon Type				
	Aromatics	ASTM D-1319	7.2	LV%
	Olefins	ASTM D-1319	1.1	LV%
	Saturates	ASTM D-1319	91.7	LV%
Oxygen Content			3.45	Wt. %
Sulfur Content		ASTM D-5453	11	mg/kg

Test Strategy

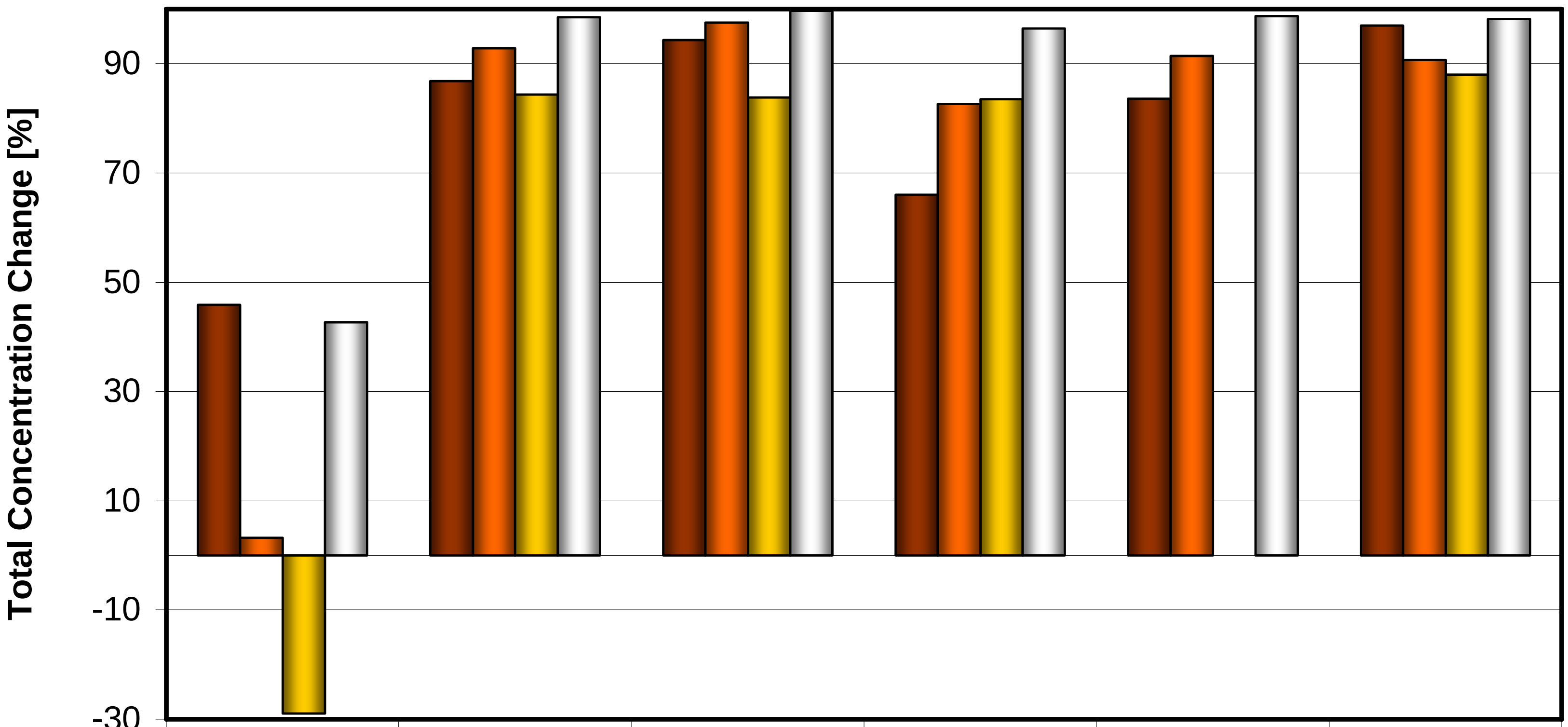
- Typical test takes approximately 3 hours
  - The test starts after selected steady-state engine operating conditions are achieved
  - The first hour of the test is used to achieve steady-state conditions in complete system
  - The measurements start at the beginning of the second hour.
  - The results obtained by averaging data from the last hour of the test are reported.

- Selected tests involving DFEs were extended to 5 or 12 hours. The aforementioned approach is also used for measurement and data processing for these tests.

Results

Effects of Control Technologies on Total Mass Concentrations of Aerosols in Mine Air

Effectiveness in Reducing Total Mass of Particles Calculated Using TEOM Data



	Cordierite DOC	Cordierite DPF	SiC DPF	Sintered Metal DPF	DFE #1	LDFE
R50	45.90	86.78	94.33	66.01	83.59	97.03
R100	3.27	92.86	97.49	82.64	91.40	90.69
I50	-28.98	84.34	83.83	83.53		88.04
I100	42.66	98.46	99.67	96.41	98.71	98.17

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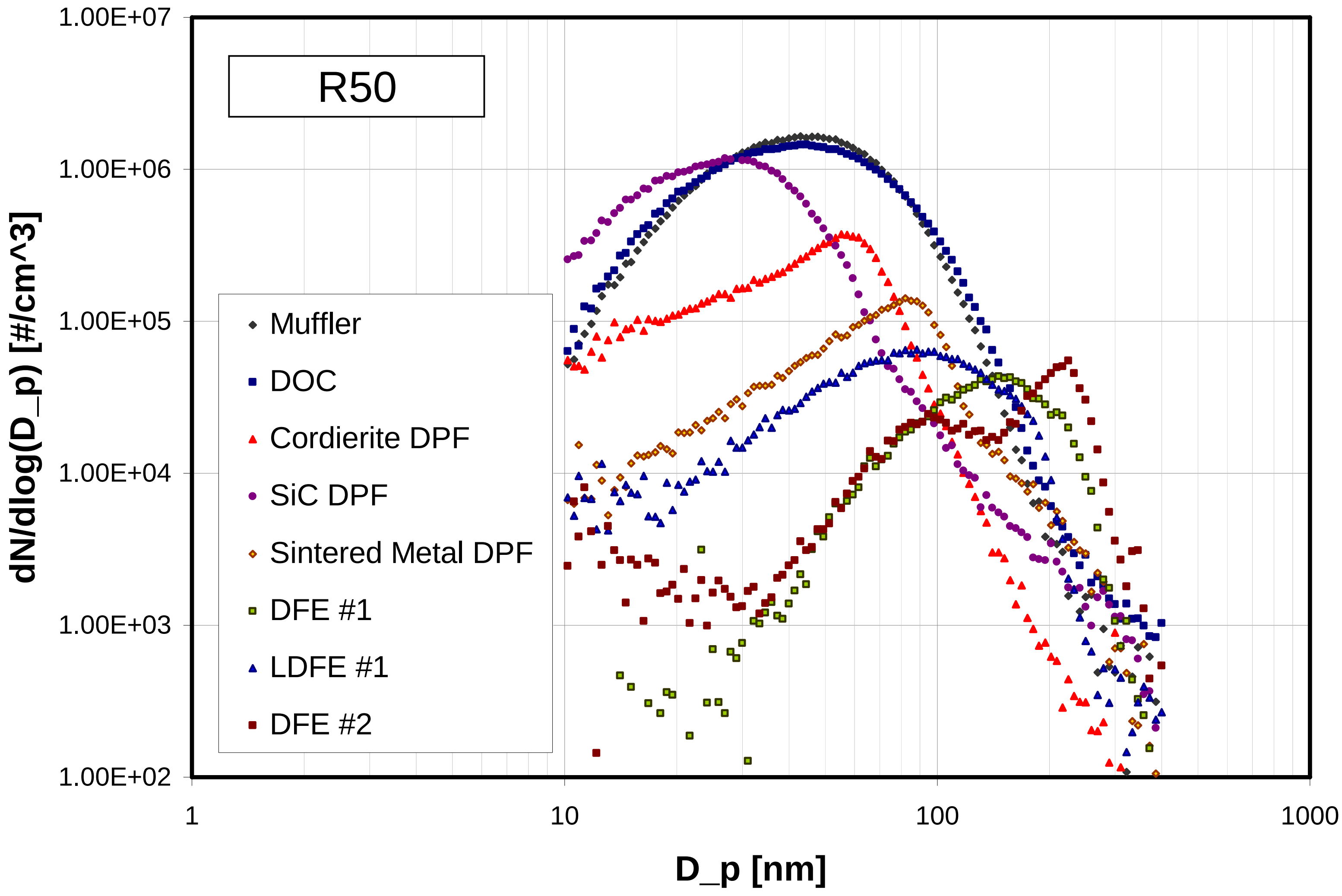
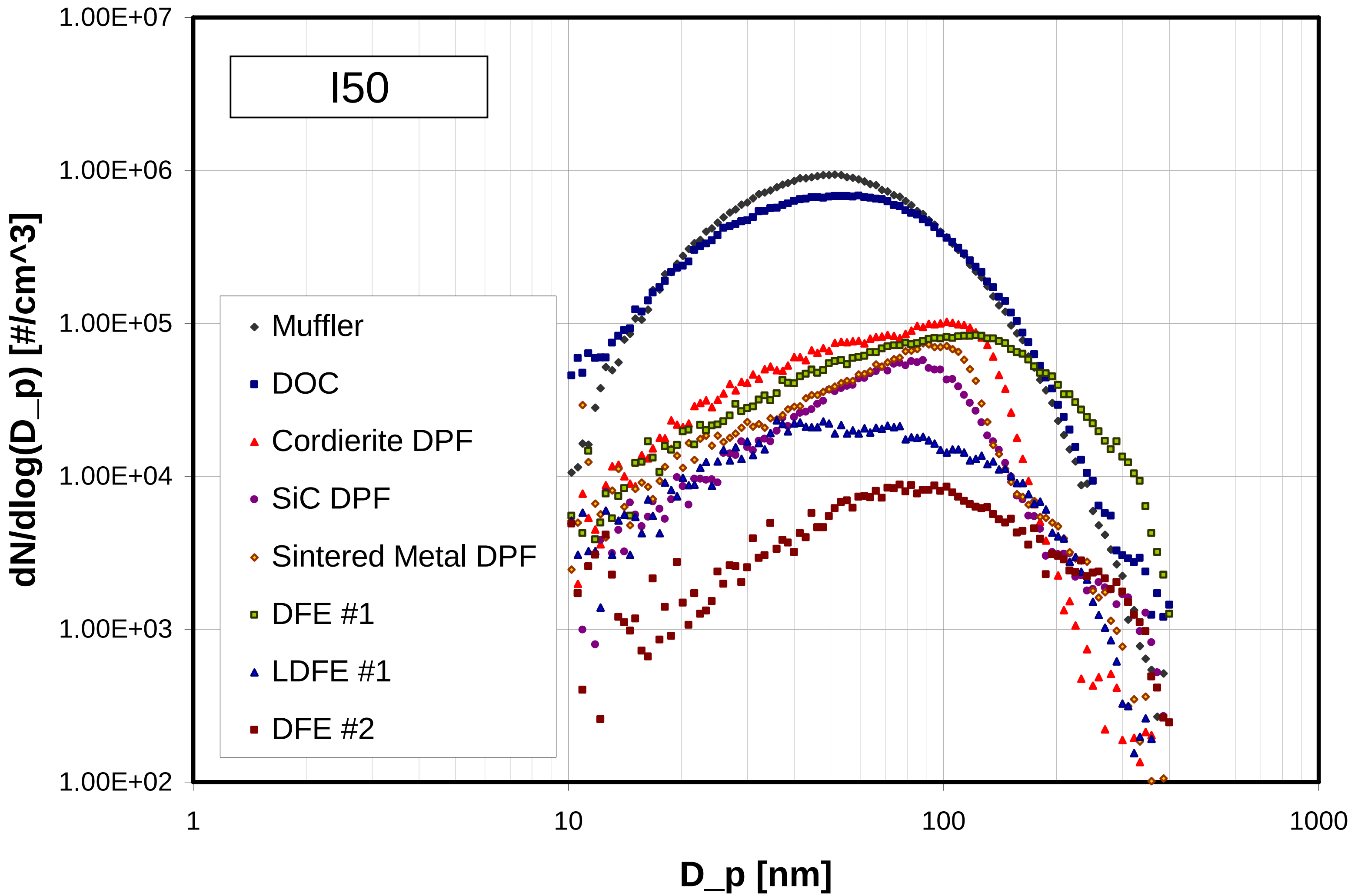
Results

Effects of Control Technologies on Size Distribution of Aerosols in Mine Air

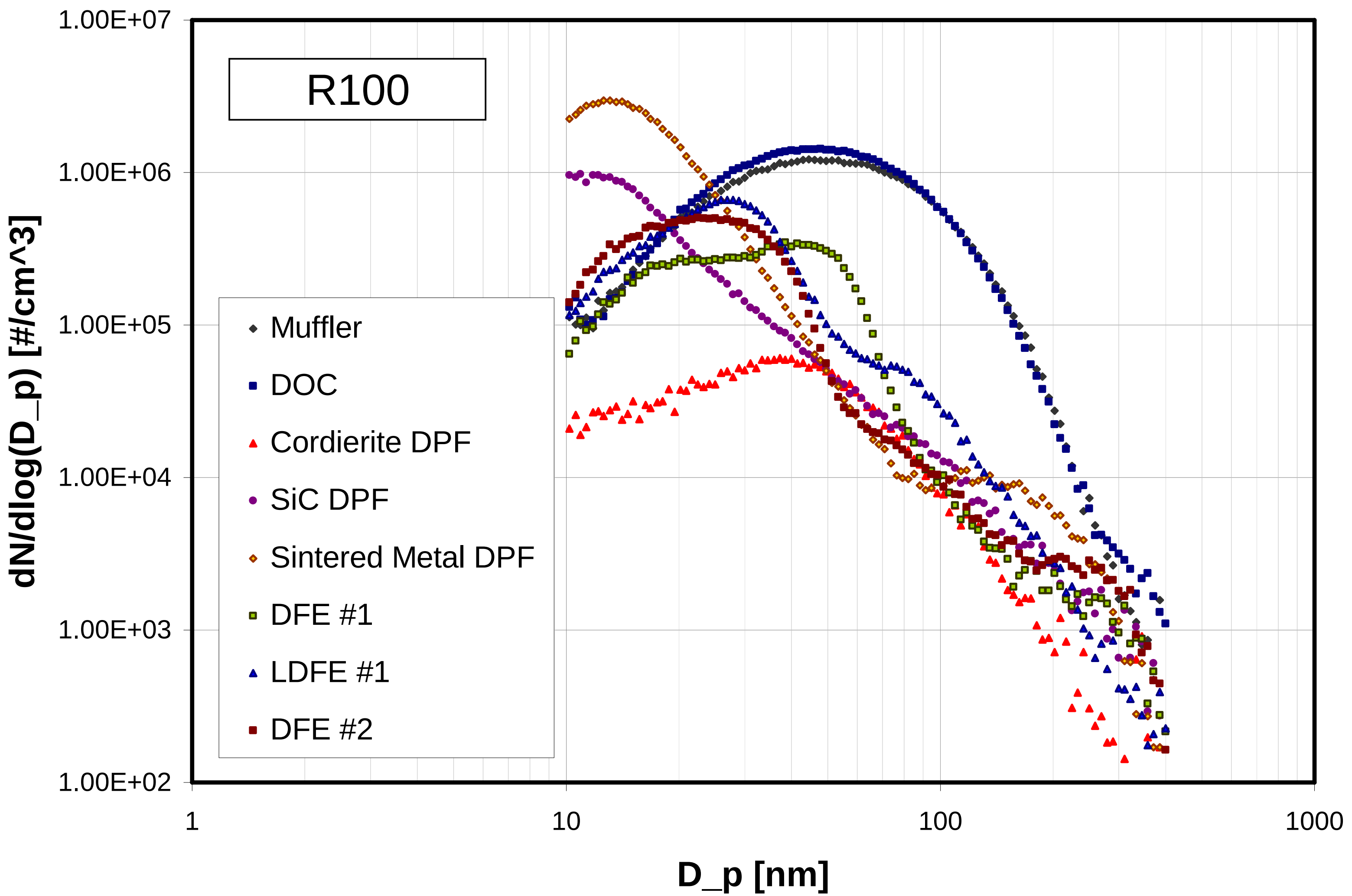
Size Distribution of Aerosols Measured at Downstream Station Using SMPS: R50



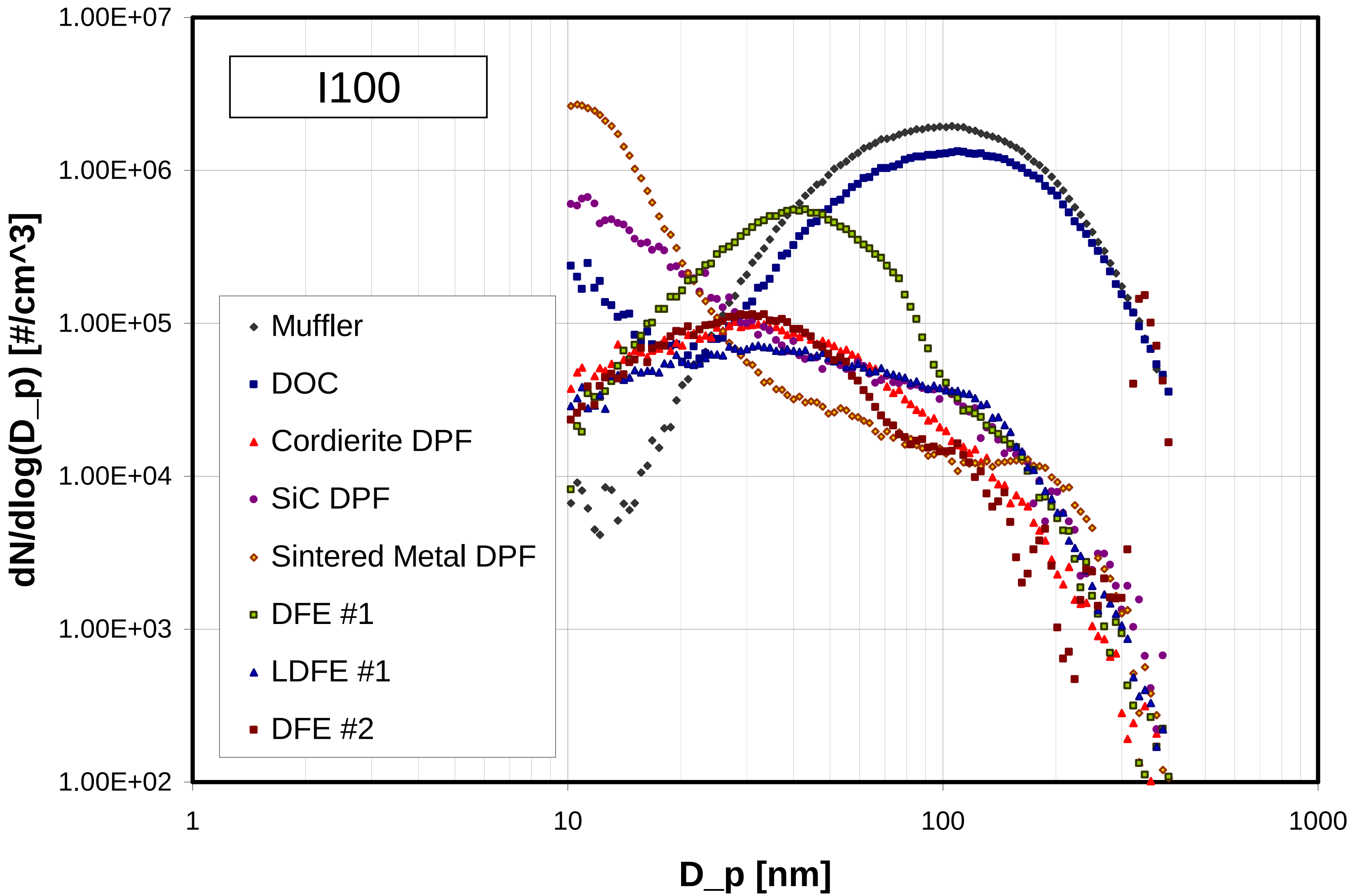
Size Distribution of Aerosols Measured at Downstream Station Using SMPS: I50



Size Distribution of Aerosols Measured at Downstream Station Using SMPS: R100



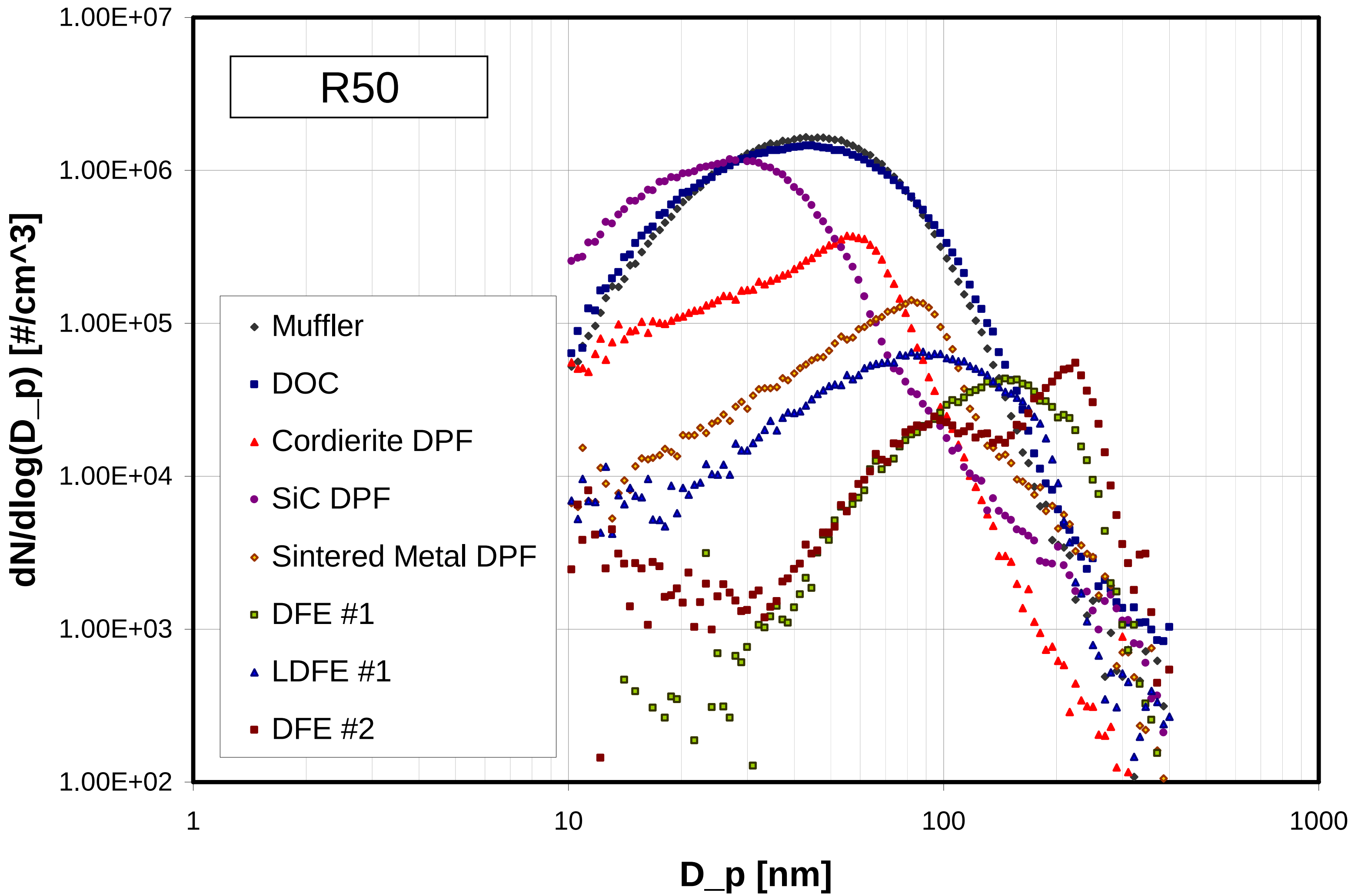
Size Distribution of Aerosols Measured at Downstream Station Using SMPS: I100



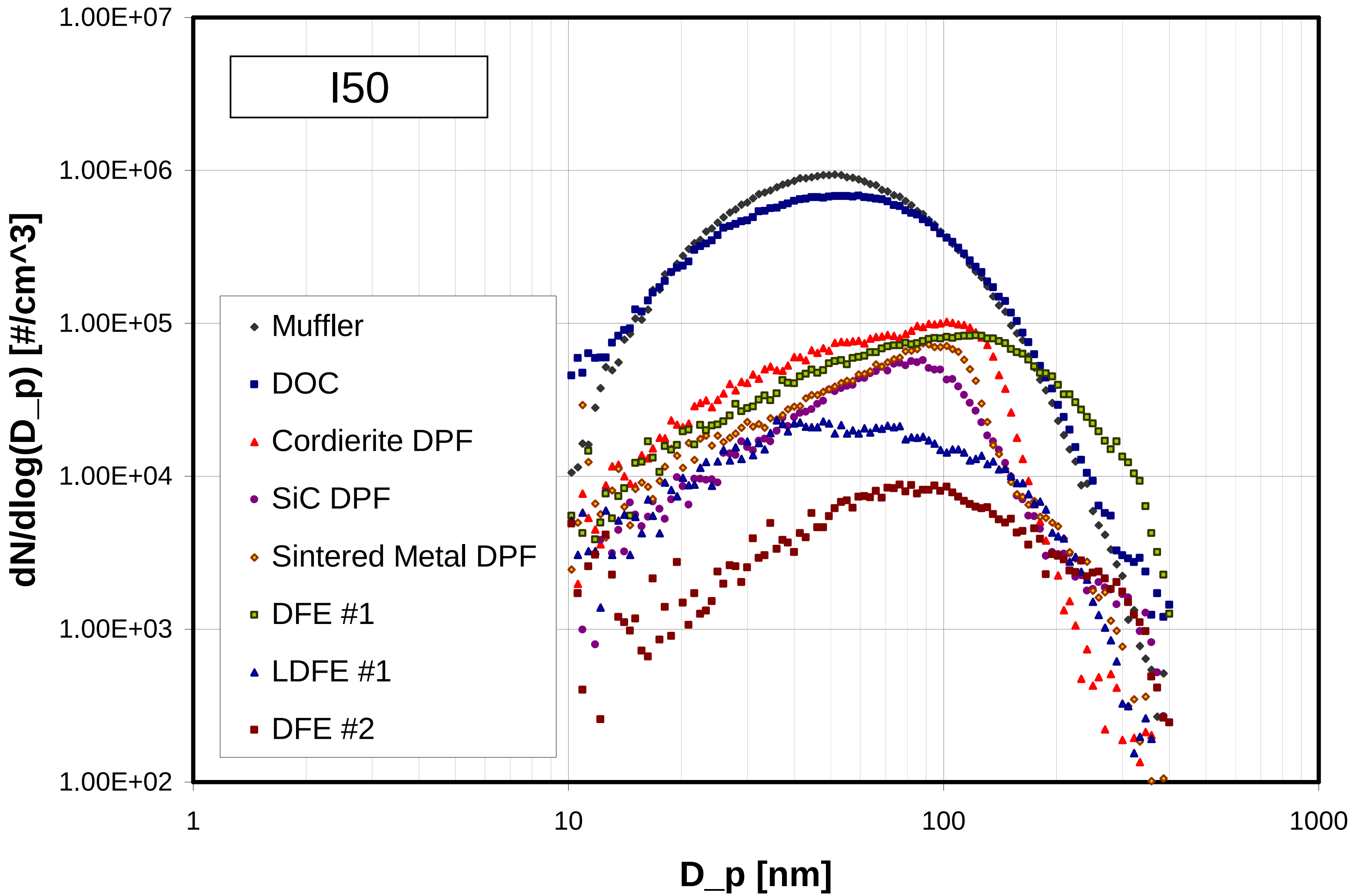
Results Indicate Strong Relationship between Size Distributions and Exhaust Temperatures

Mode	DPFs, DOC, Muffler		DFEs	
	Exhaust Temperature at Inlet of Device	Temperature at Outlet from Device	Exhaust Temperature at Inlet of Device	Temperature at Outlet from Device
	°C	°C	°C	°C
R50	**306**	**258**	**200**	**154**
R100	**529**	**436**	**329**	**242**
I50	**254**	**216**	**160**	**125**
I100	**485**	**402**	**313**	**234**

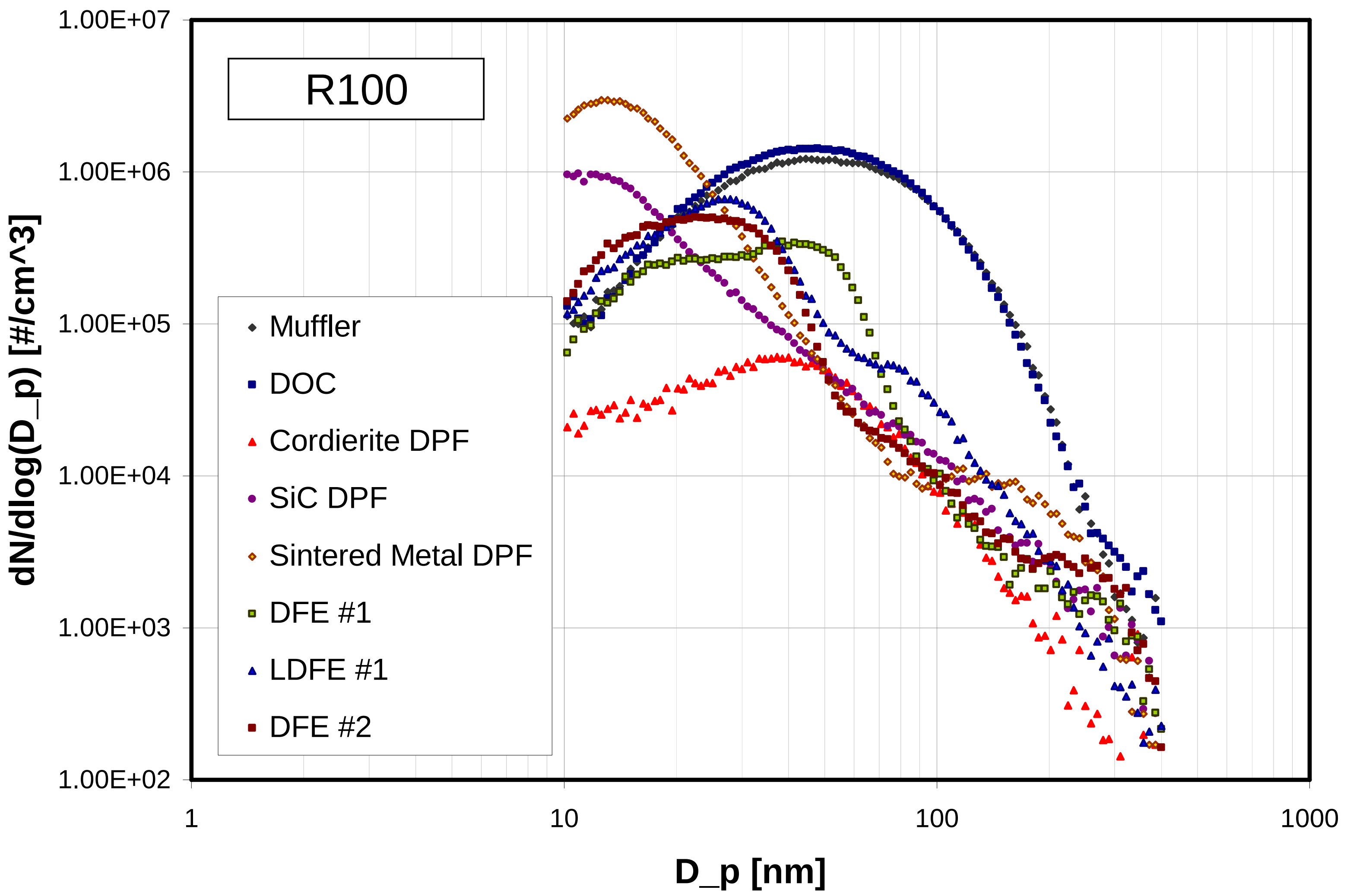
Size Distribution of Aerosols Measured at Downstream Station Using SMPS: R50



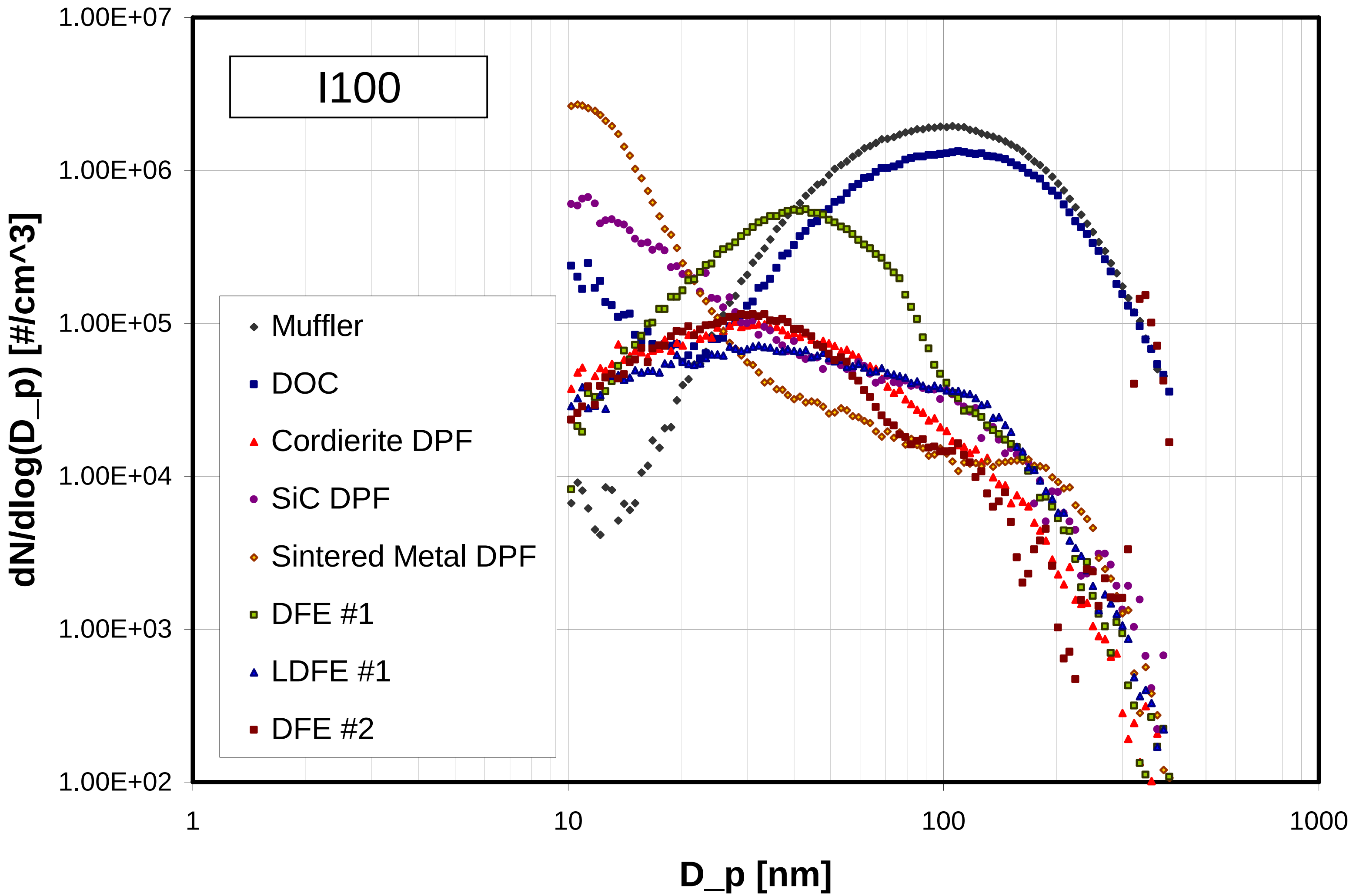
Size Distribution of Aerosols Measured at Downstream Station Using SMPS: I50



Size Distribution of Aerosols Measured at Downstream Station Using SMPS: R100



Size Distribution of Aerosols Measured at Downstream Station Using SMPS: I100



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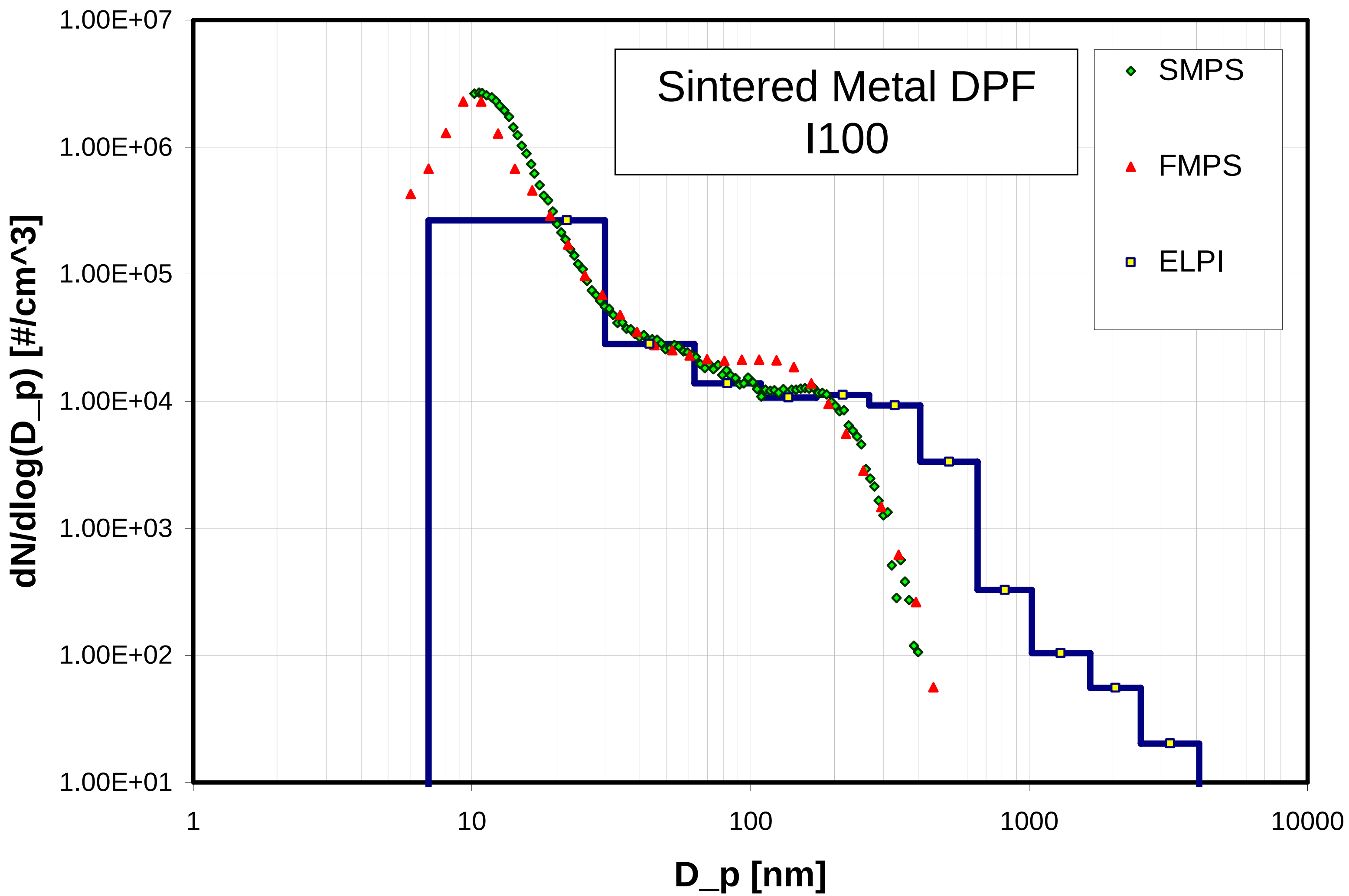
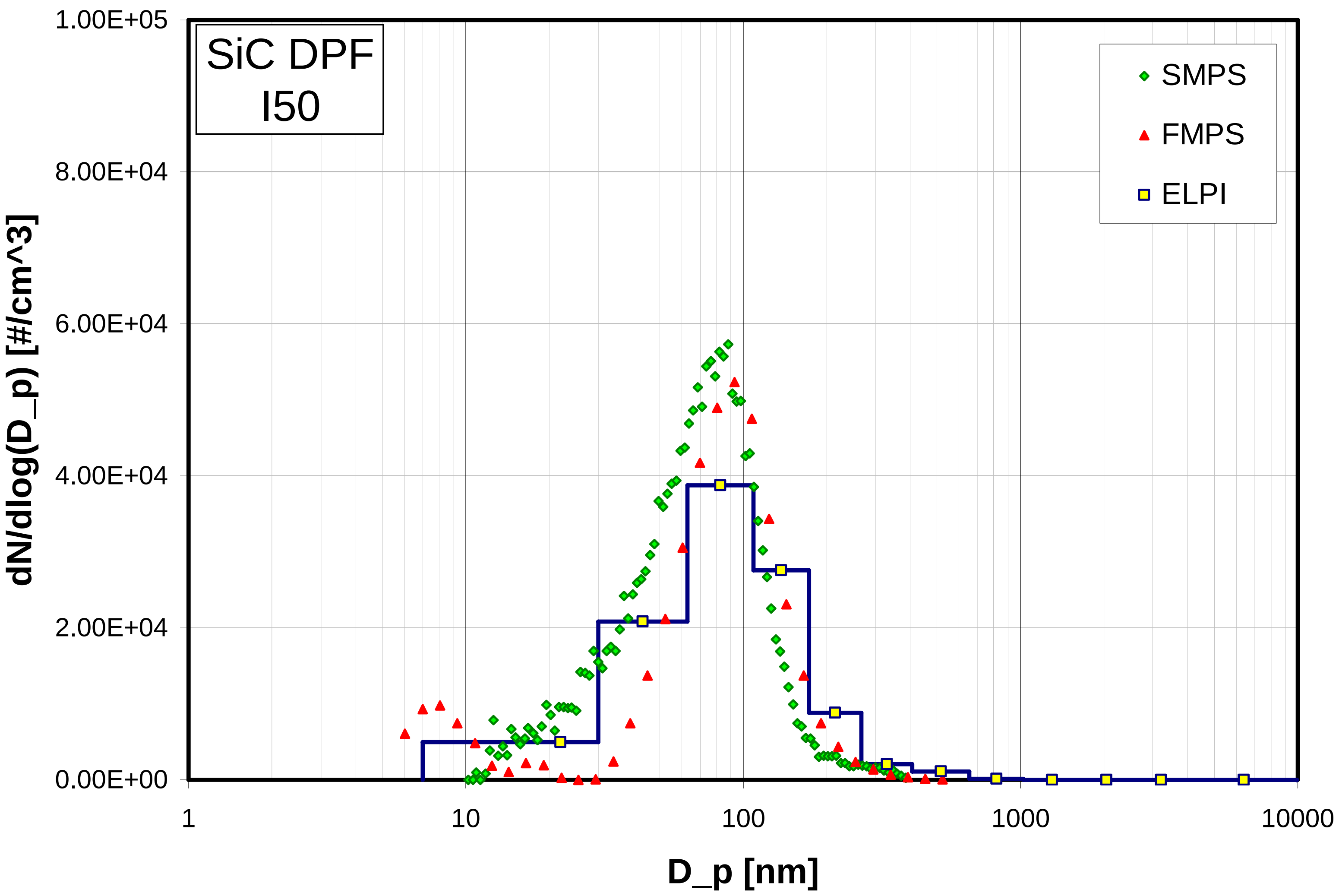
Correlation Between Results SMPS, FMPS and ELPI Measurements: Sintered Metal DPF, I100



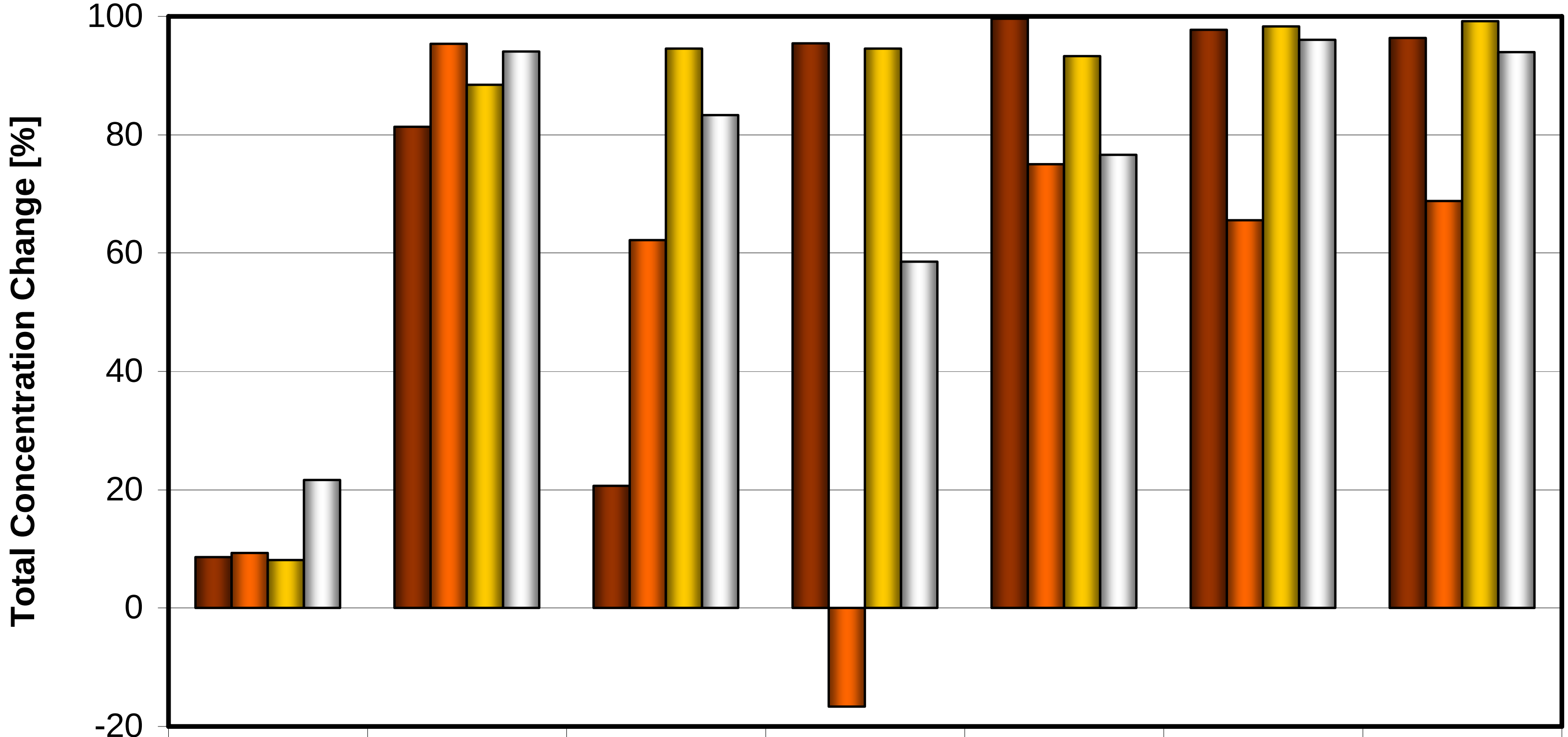
Correlation Between Results SMPS, FMPS and ELPI Measurements: SiC DPF, I50



Results

Effects of Control Technologies on Total Concentrations of Aerosols by Number in Mine Air

Effectiveness in Reducing Total Number of Particles Calculated Using SMPS Data



	Cordierite DOC	Cordierite DPF	SiC DPF	Sintered Metal DPF	DFE #1	LDFE	DFE #2
R50	8.6	81.3	20.6	95.4	99.6	97.8	96.3
R100	9.3	95.3	62.2	-16.7	75.0	65.6	68.8
I50	8.2	88.5	94.6	94.5	93.3	98.3	99.2
I100	21.6	94.0	83.3	58.6	76.6	96.1	94.0

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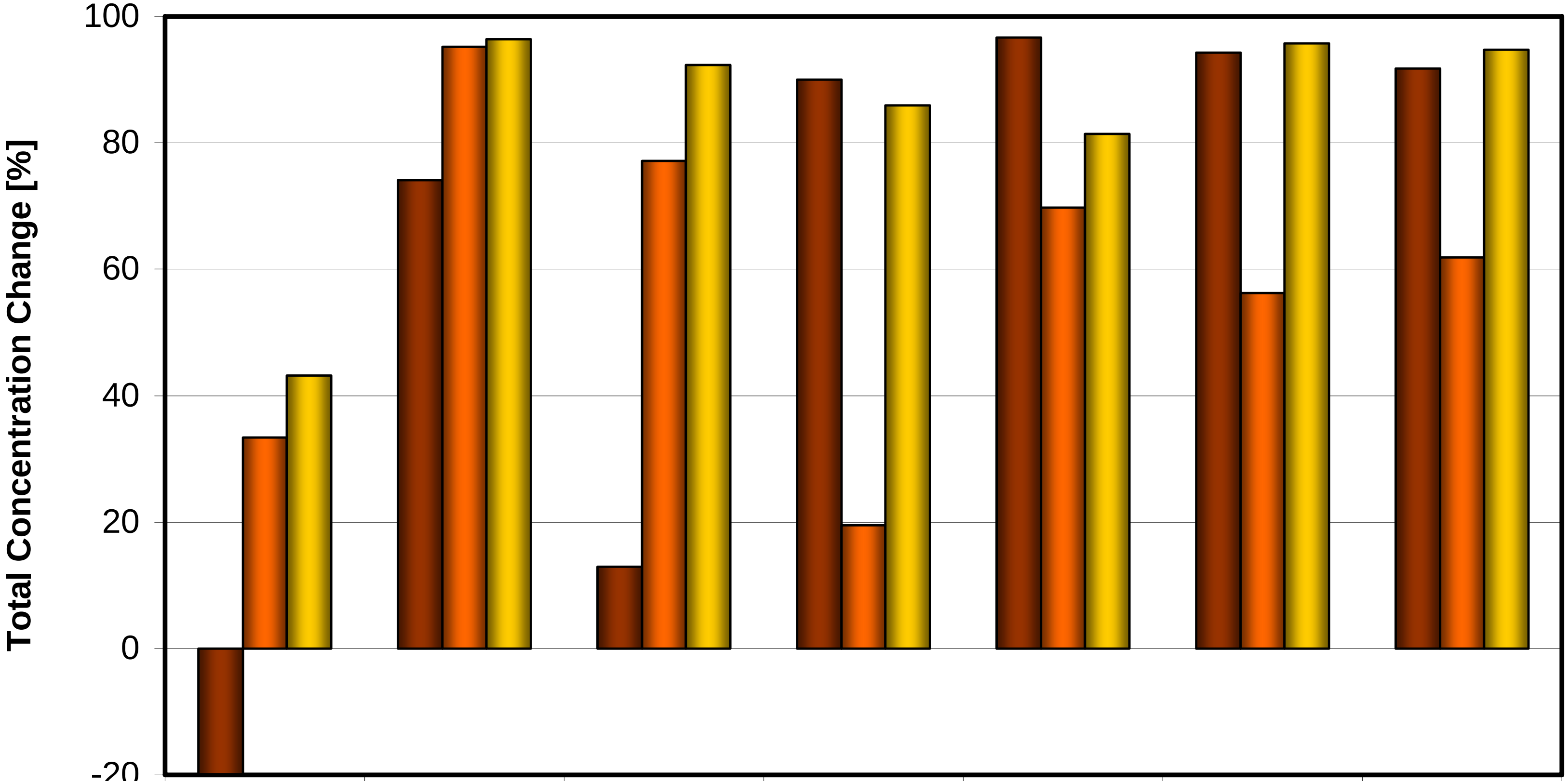
Effectiveness in Reducing Total Number of Particles Calculated Using ELPI Data



	Cordierite DOC	Cordierite DPF	SiC DPF	Sintered Metal DPF	DFE #1	LDFE	DFE #2
R50	-19.9	74.1	12.9	90.0	96.6	94.2	91.7
R100	33.4	95.2	77.1	19.5	69.8	56.3	61.9
I100	43.2	96.3	92.3	86.0	81.4	95.8	94.8

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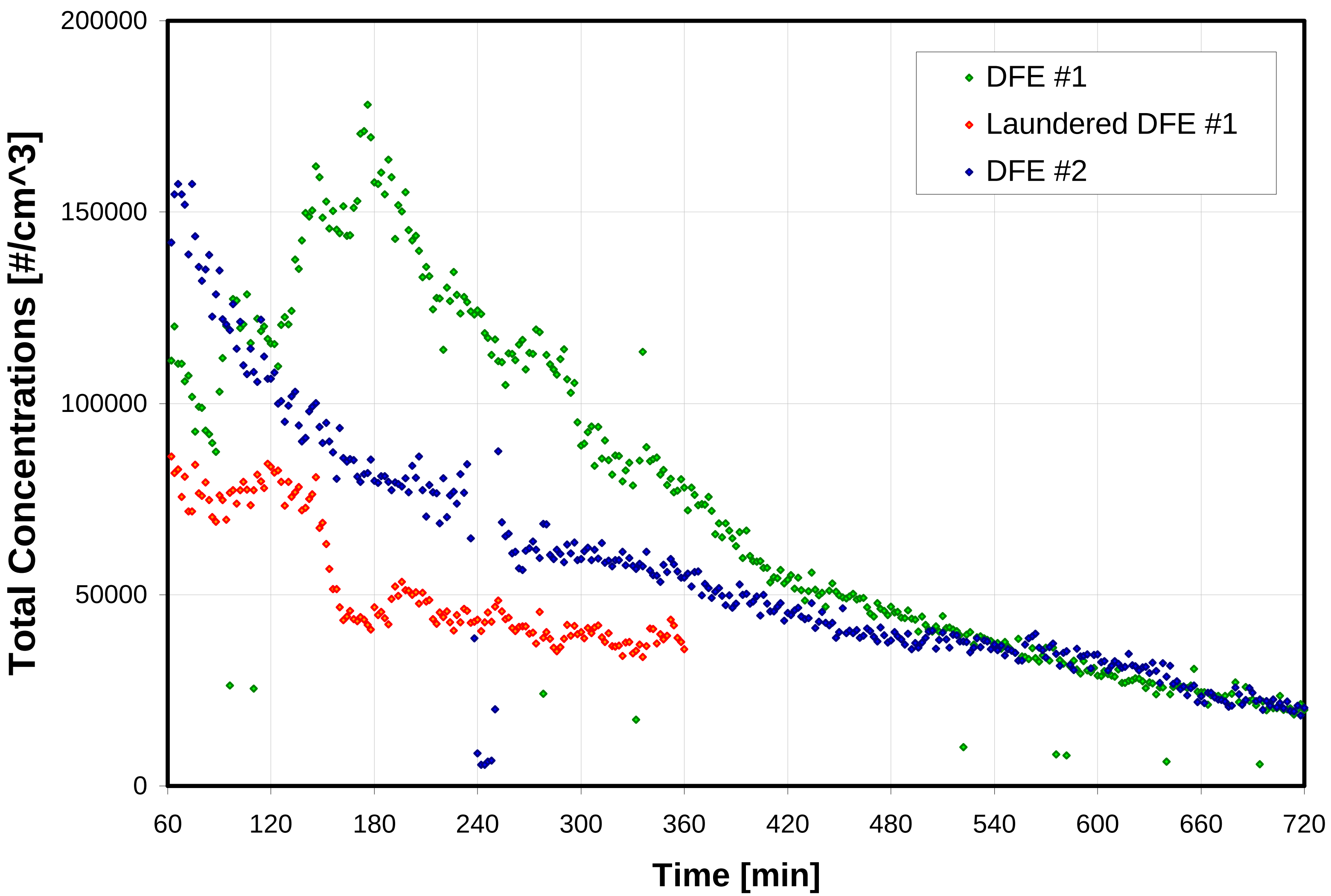
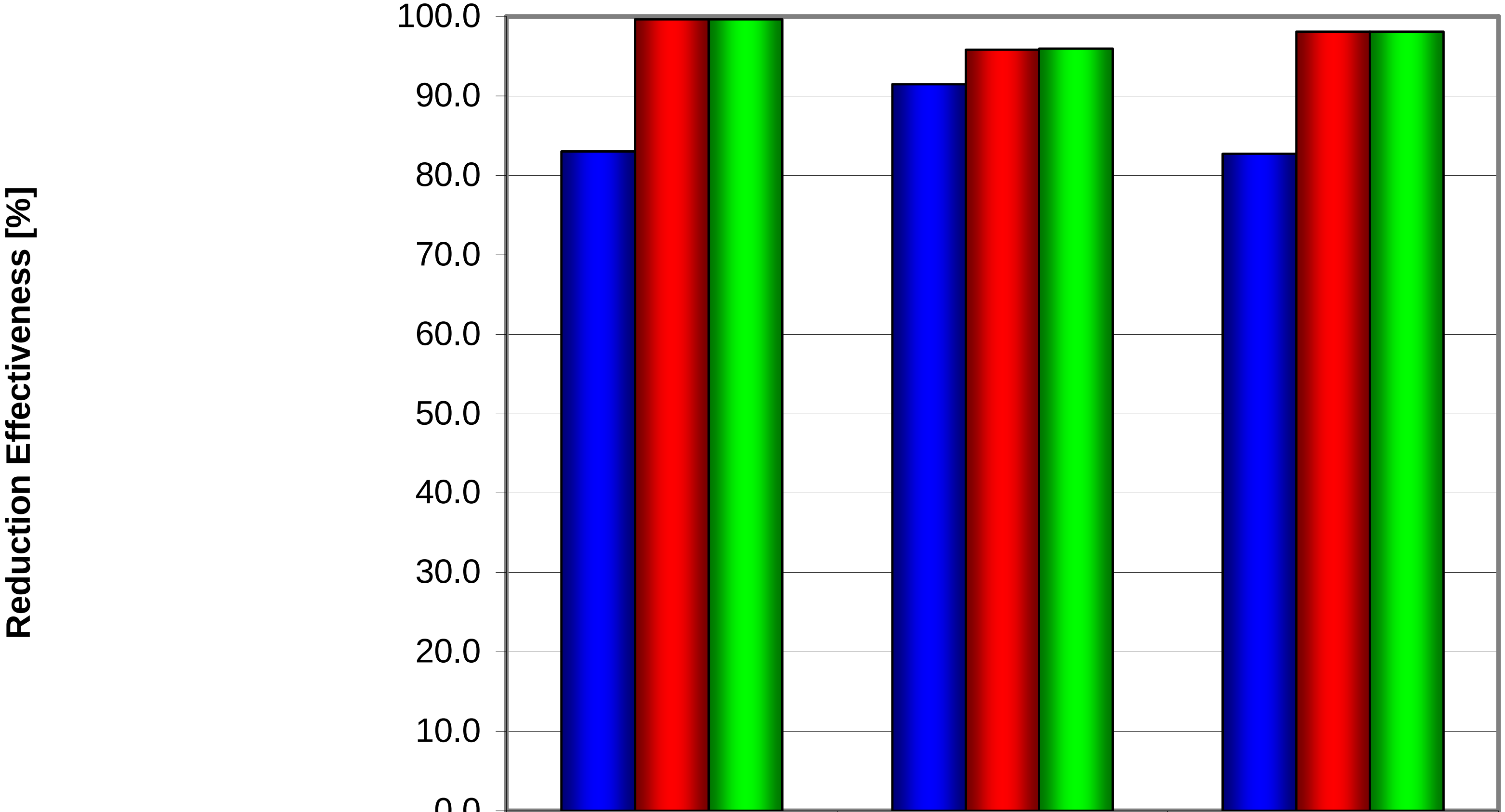
Total Aerosol Concentrations by Number During Long Tests of "Fresh" DFEs, R50



Effectiveness of DFEs in Reducing Total Number of Particles Calculated Using SMPS Data, R50: Number vs. Range



	DFE #1	Laundered DFE #1	DFE #2
Lowest 20-Minute Average	83.0	91.4	82.7
60-Minute Average	99.6	95.8	98.1
Highest 20-Minute Average	99.6	96.0	98.1

Mode

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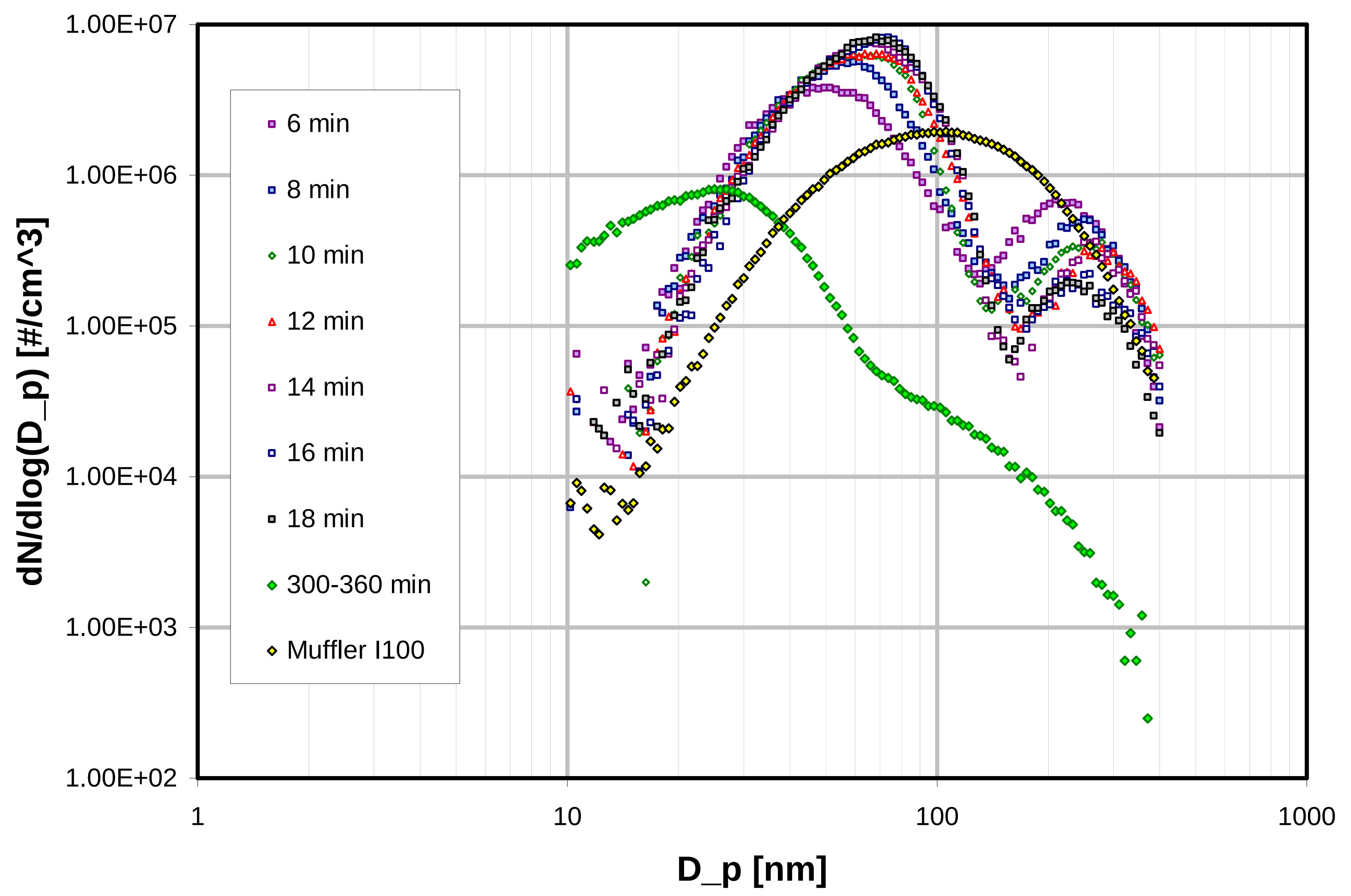
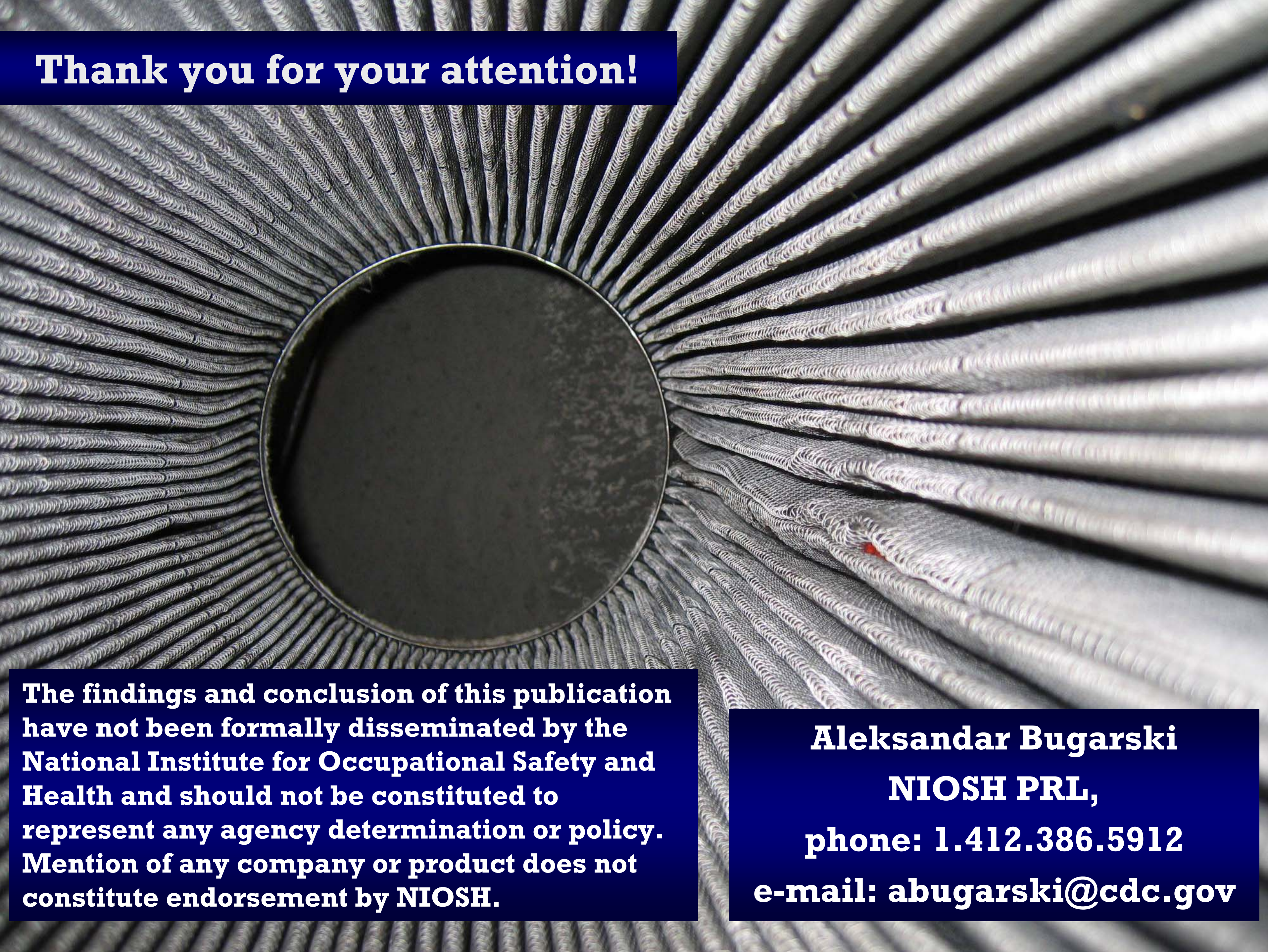
Size Distribution of Aerosols Measured at Downstream Station within the 20 minutes from the start of operating "Fresh" DFE at I100 Conditions





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