

John McAughey
Colin Dickens, David Booker
AEATechnology
Aerosol Science Centre/Harwell

Evaluation of Instruments for Vehicle Emission Particle Sizing

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Colin Dickens, David Booker
Aerosol Science Centre
AEA Technology



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DOT/DOE/SMMT Instrument Evaluation - Objectives

- ◆ Re-Design Sampling Arrangement
- ◆ Test QCM with Charge Equilibration
- ◆ Assess ELPI
- ◆ Assess Accuracy of SMPS Reported Concentrations
- ◆ Evaluate TEOM for Real-Time Measurements
- ◆ Evaluate Anderson MkIII



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DOT/DOE/SMMT Instrument Evaluation - Project Structure

- ◆ Stage I
 - Sample Column Design
 - ELPI/SMPS Calibration
- ◆ Stage II
 - Steady-State Evaluation
- ◆ Stage III
 - Transient Evaluation

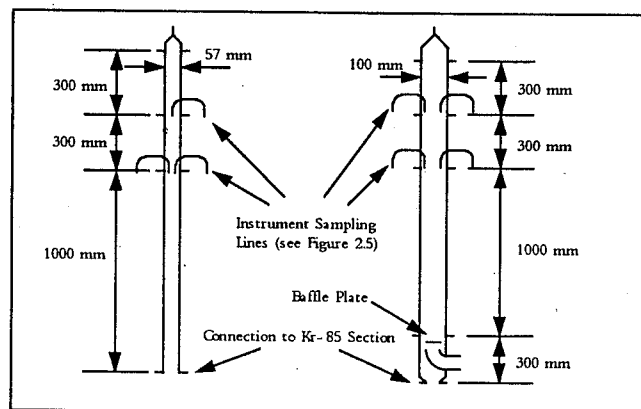
DOT/DOE/SMMT Instrument Evaluation - Test Instruments

- ◆ SMPS
- ◆ QCM
- ◆ ELPI
- ◆ TEOM
- ◆ Anderson MkIII

DOT/DOE/SMMT Instrument Evaluation - Sample Column

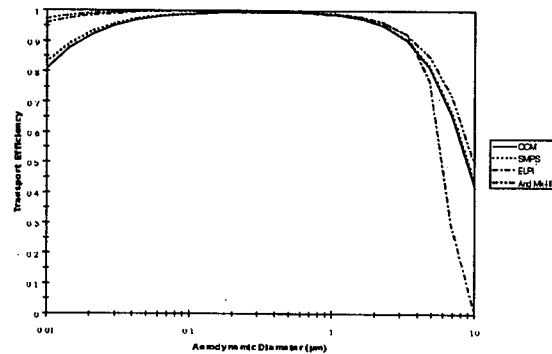
- ✦ Minimise Sampling Loss
- ✦ Allow Charge Equilibration
- ✦ Use Regulated Sample Probe (Without Chinese Hat)
- ✦ Instrument Sample Probes to Match Instrument Inlets
- ✦ Allow Further Dilution

DOT/DOE/SMMT Instrument Evaluation - Sample Column

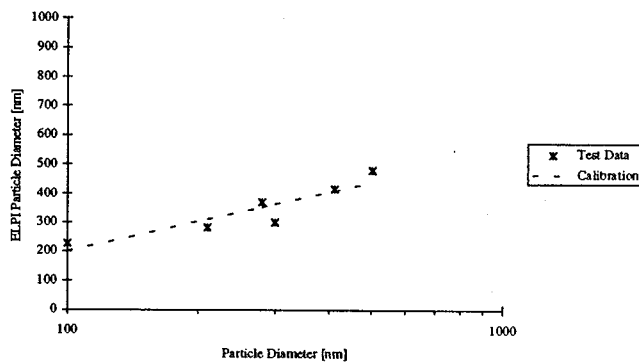


DOT/DOE/SMMT Instrument Evaluation - Sample Column

Total Transport Efficiency for each Instrument



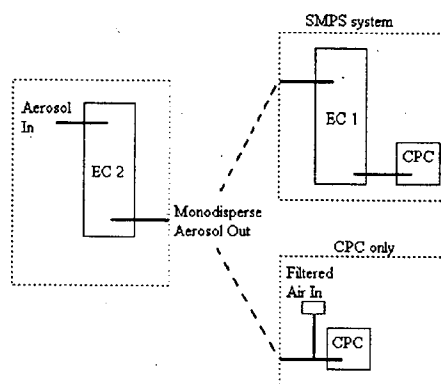
DOT/DOE/SMMT Instrument Evaluation - ELPI Calibration



DOT/DOE/SMMT Instrument Evaluation - ELPI Calibration

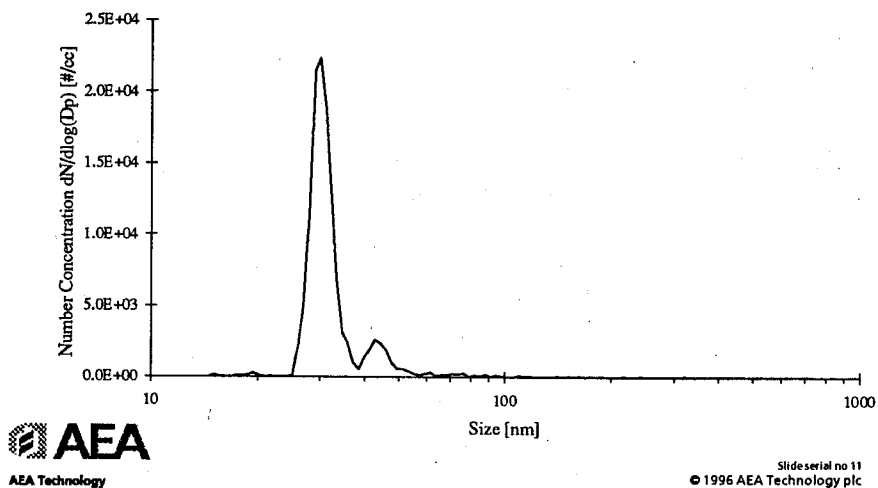
- Mass mode calibration close to manufacturers calibration
- Number mode calibration does not agree with mass mode calibration. Small particles ($\sim 100\text{nm}$) land on higher stages

DOT/DOE/SMMT Instrument Evaluation - SMPS Calibration



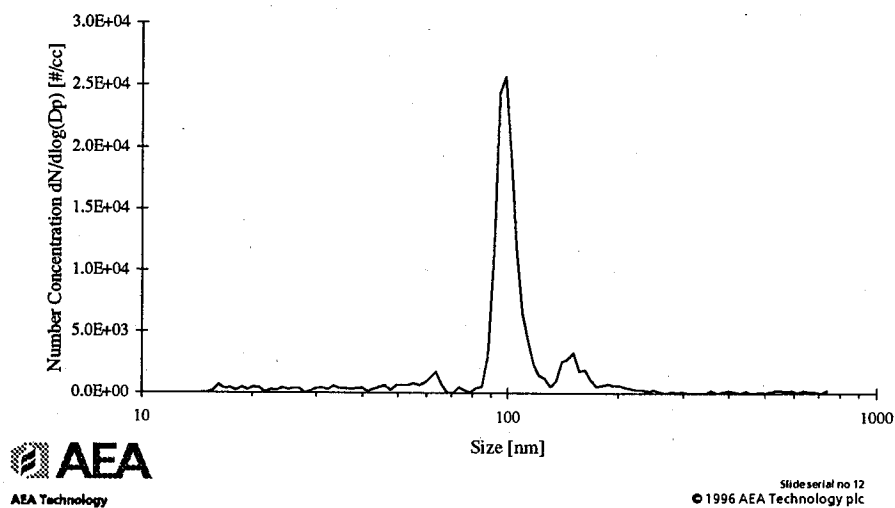
DOT/DOE/SMMT Instrument Evaluation - SMPS Calibration

30nm Diesel Particles

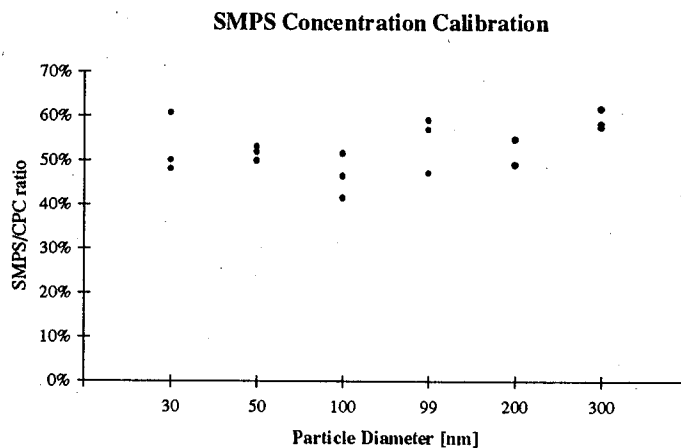


DOT/DOE/SMMT Instrument Evaluation - SMPS Calibration

100nm Polystyrene Particles



DOT/DOE/SMMT Instrument Evaluation - SMPS Calibration



DOT/DOE/SMMT Instrument Evaluation - SMPS Calibration

- ◆ SMPS Size Calibration Excellent
- ◆ Reported Concentration Systematically Lower than 'True' Concentration by a Factor of 2
- ◆ Size Selection for Transient Tests Very Good

DOT/DOE/SMMT Instrument Evaluation - Steady-State

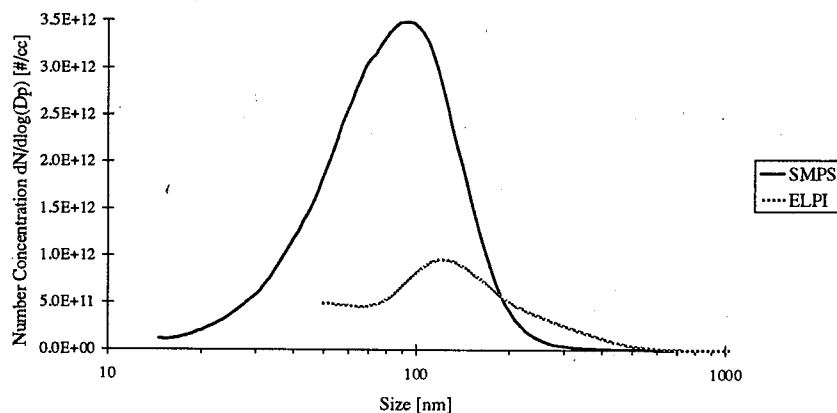
- ◆ Performed on Light-Duty CVS Tunnel
- ◆ 8.5 Kw Diesel Twin-Cylinder Engine
- ◆ Sampling Column
- ◆ Number Distributions
 - SMPS, ELPI
- ◆ Mass Distributions
 - ELPI, QCM, TEOM, Anderson MkIII
 - SMPS (Volume)



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DOT/DOE/SMMT Instrument Evaluation - Number Mode

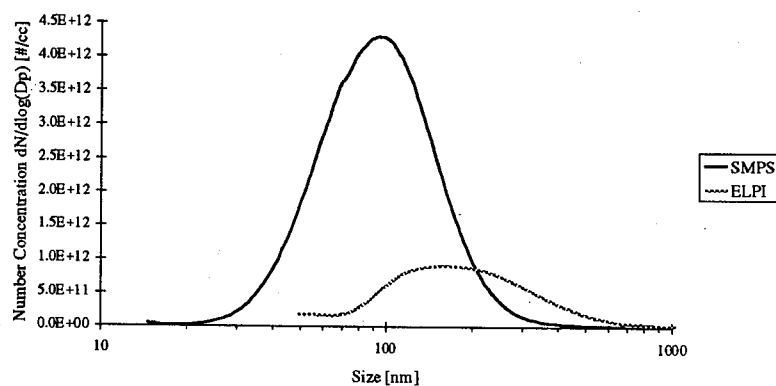
0load-2



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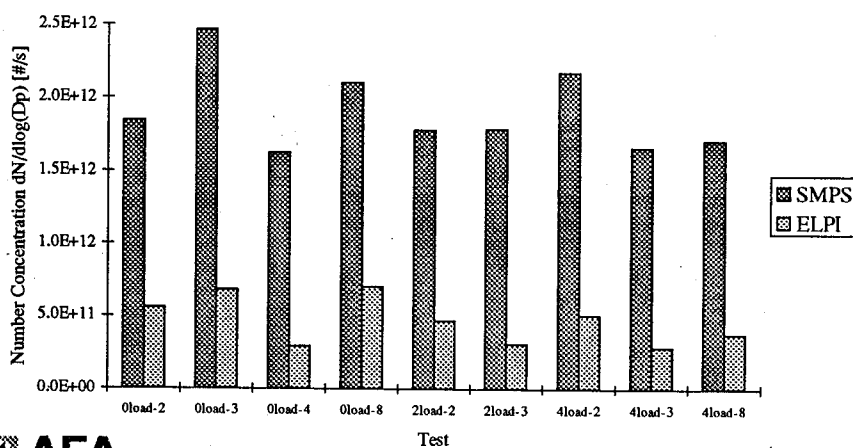
DOT/DOE/SMMT Instrument Evaluation - Number Mode

4load-2



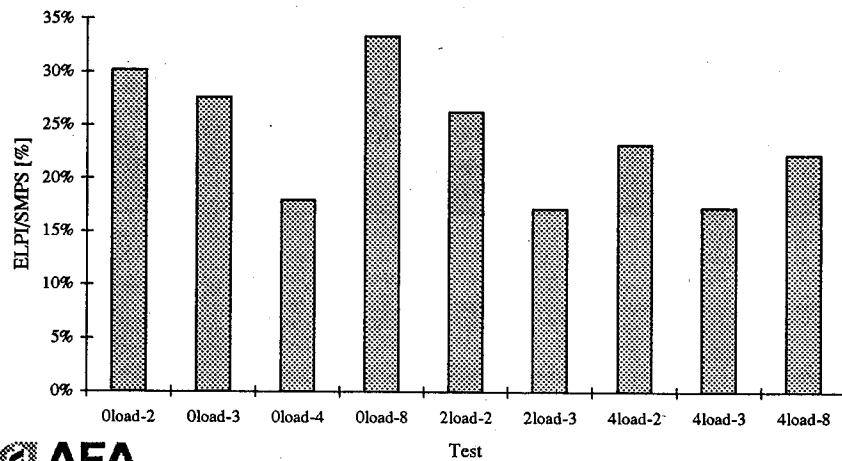
DOT/DOE/SMMT Instrument Evaluation - Number Mode

Total Particle Flux



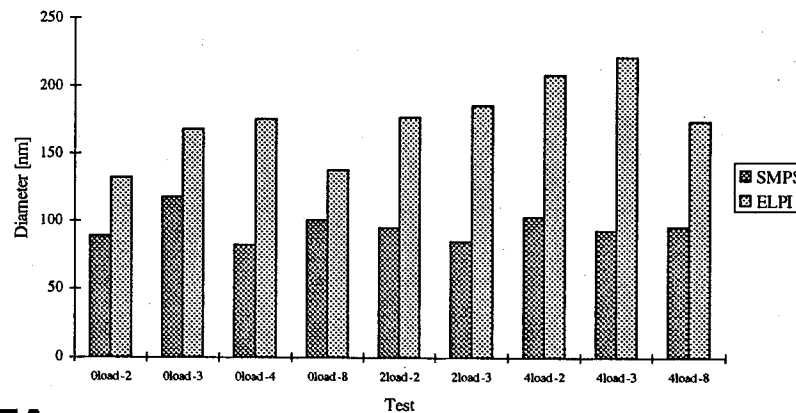
DOT/DOE/SMMT Instrument Evaluation - Number Mode

ELPI to SMPS Total Particle Flux Ratio



DOT/DOE/SMMT Instrument Evaluation - Number Mode

Mean Particle Diameter



DOT/DOE/SMMT Instrument Evaluation - Number Mode

- ✦ Correlation Between SMPS and ELPI
Number Distribution Shape
- ✦ ELPI Number Concentration
24% $\pm$ 6% of SMPS Value
- ✦ ELPI reports higher particle size than
SMPS

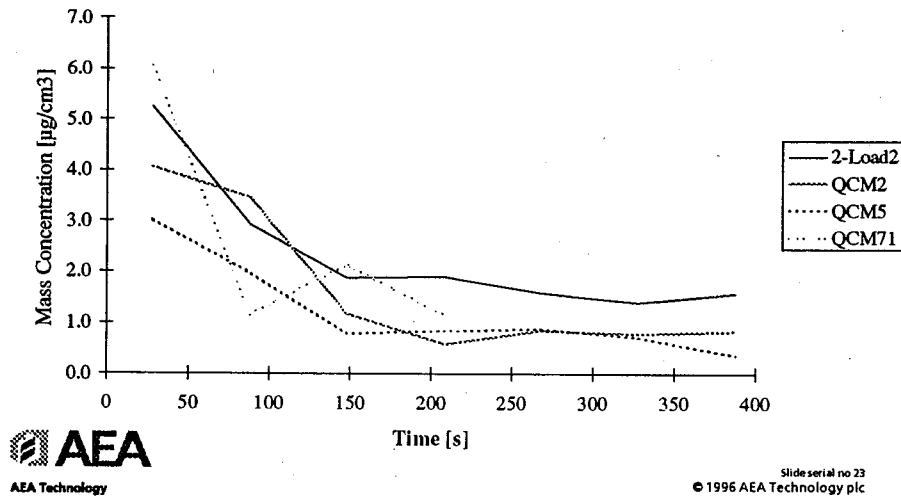
DOT/DOE/SMMT Instrument Evaluation - QCM

QCM Total Mass

Test	Charge Equilibration	QCM/Average of ELPI, TEOM, Anderson
0load-6	No	11%
2load-6	No	2%
0load-7	Yes	13%
4load-9	Yes	9%
4load-a	Yes	3%
0load-a	Yes	13%
0load-b	Yes	11%

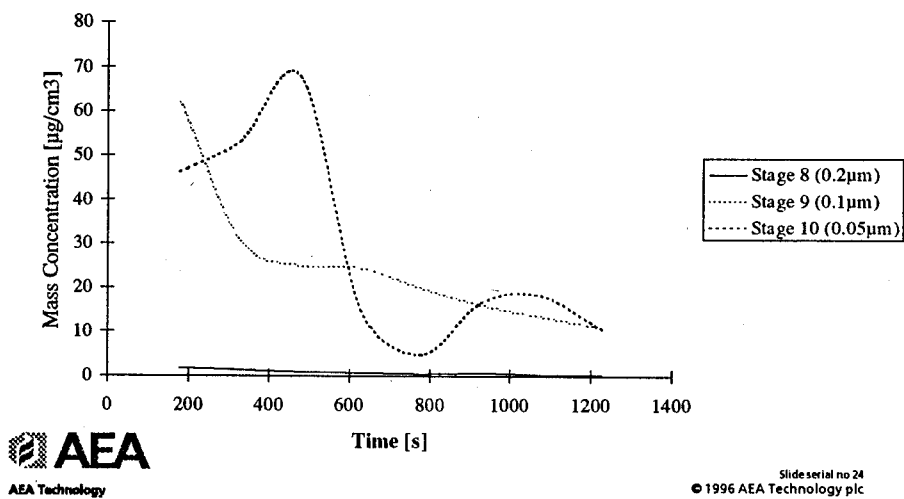
DOT/DOE/SMMT Instrument Evaluation - QCM

QCM Time Response to Steady State



DOT/DOE/SMMT Instrument Evaluation - QCM

QCM Stage Mass Concentration

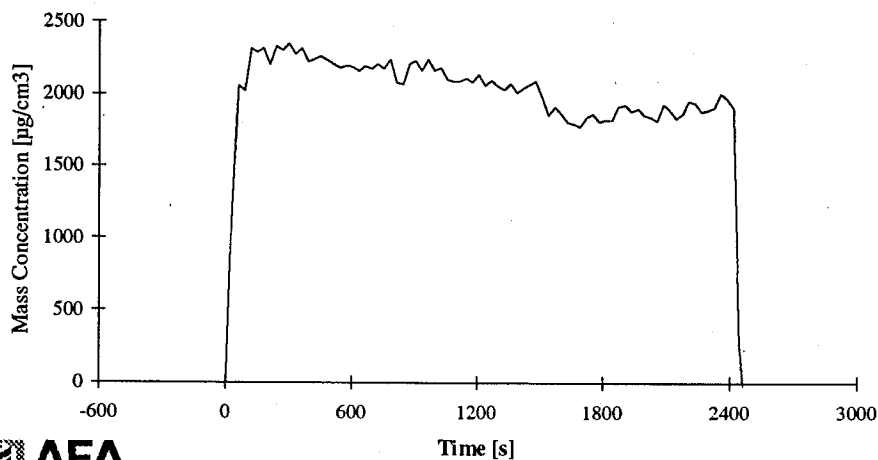


DOT/DOE/SMMT Instrument Evaluation - QCM

- ◆ QCM Unaffected by Charge Equilibration
- ◆ QCM Reported Mass Concentrations Low
- ◆ Loss of Stage Collection Efficiency Against Time (Loading)
- ◆ QCM Unsuitable for Vehicle Emissions

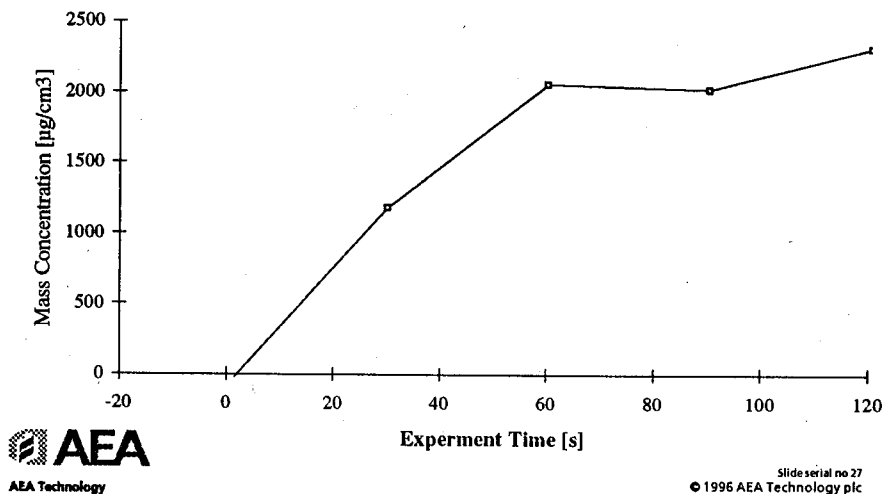
DOT/DOE/SMMT Instrument Evaluation - TEOM

TEOM Mass Concentration



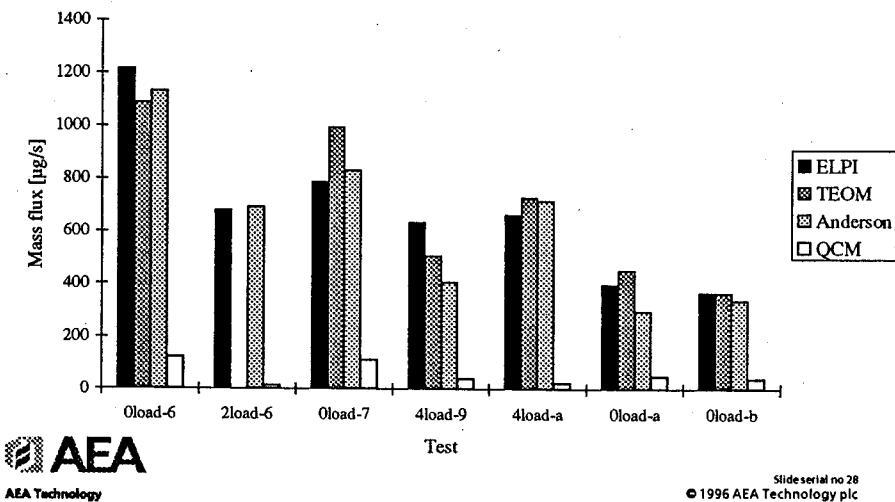
DOT/DOE/SMMT Instrument Evaluation - TEOM

TEOM Mass Concentration



DOT/DOE/SMMT Instrument Evaluation - Mass Flux

Mass Flux Measurements



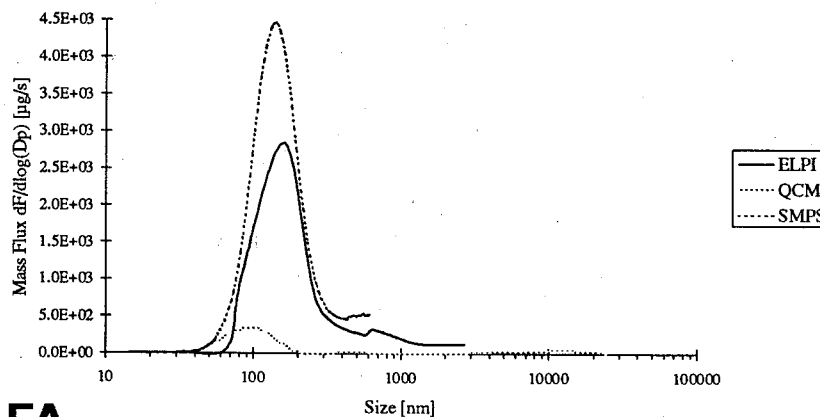
DOT/DOE/SMMT Instrument Evaluation - Mass Distribution

Mass Mean Particle Diameter

Test	Mass Mean Particle Diameter [nm]		
	SMPS (volume)	ELPI	QCM
0load-6	172	215	96
2load-6	202	278	114
0load-7	177	210	80
4load-9	255	311	288
4load-a	247	360	100
0load-a	151	189	85
0load-b	147	184	94

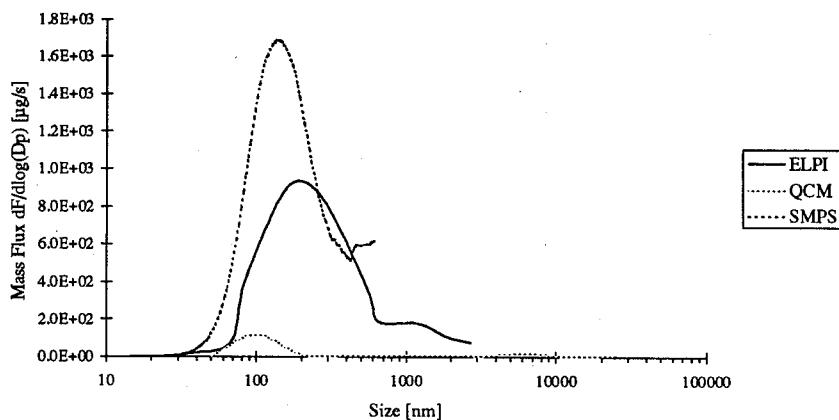
DOT/DOE/SMMT Instrument Evaluation - Mass Distribution

0load-6



DOT/DOE/SMMT Instrument Evaluation - Mass Distribution

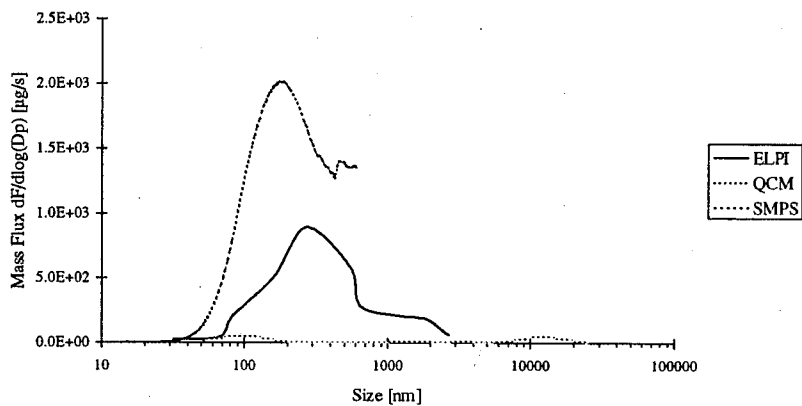
2load-6



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DOT/DOE/SMMT Instrument Evaluation - Mass Distribution

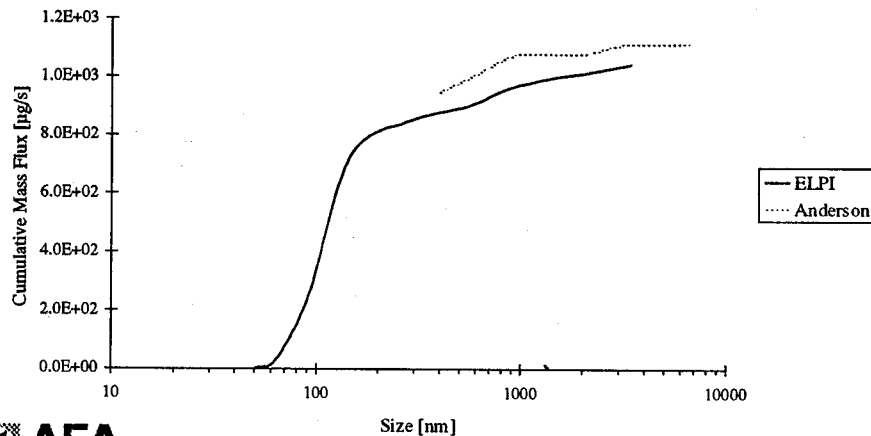
4load-a



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DOT/DOE/SMMT Instrument Evaluation - Mass Distribution

0load-6

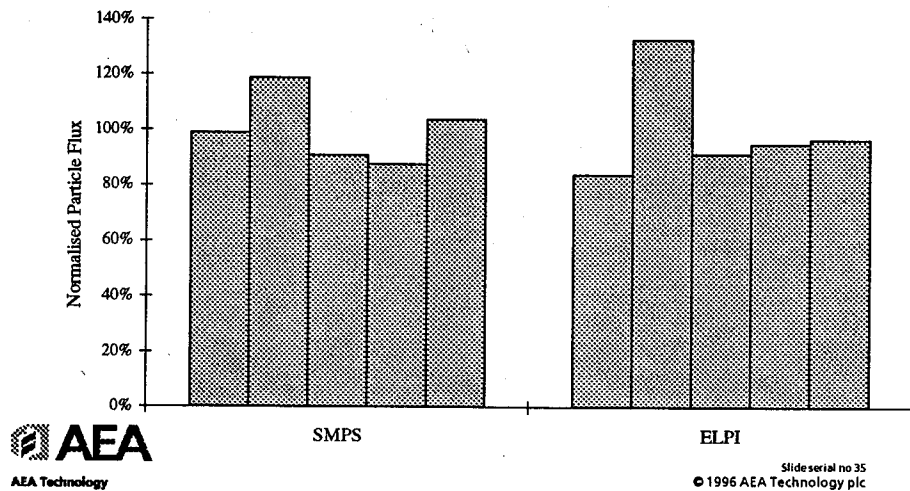


DOT/DOE/SMMT Instrument Evaluation - Drive Cycle

- ◆ Light & Medium Duty
 - ECE/EUDC
 - Transit Van, Montego, Vectra
- ◆ Heavy Duty
 - FIGE
 - Eagle II
 - RF73, City Diesel

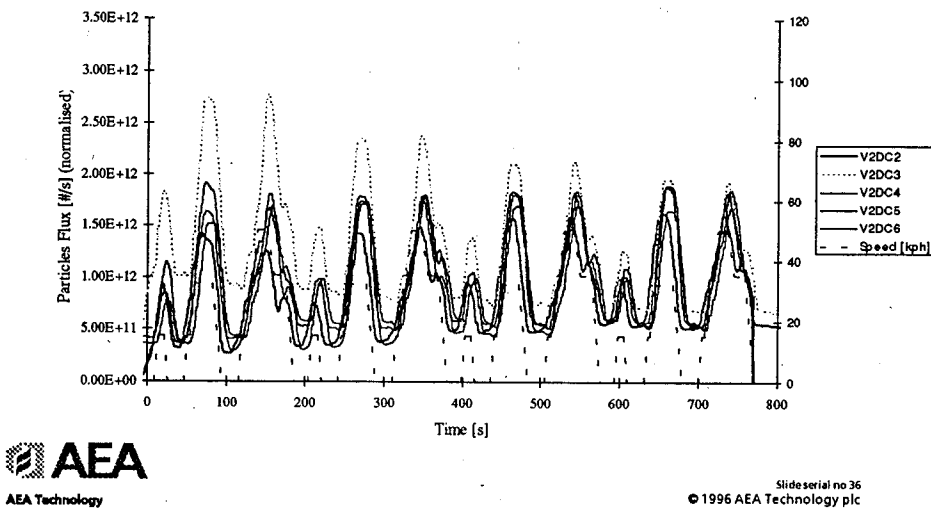
DOT/DOE/SMMT Instrument Evaluation - Number Mode

Normalised Particle Flux - V2 (ECE)



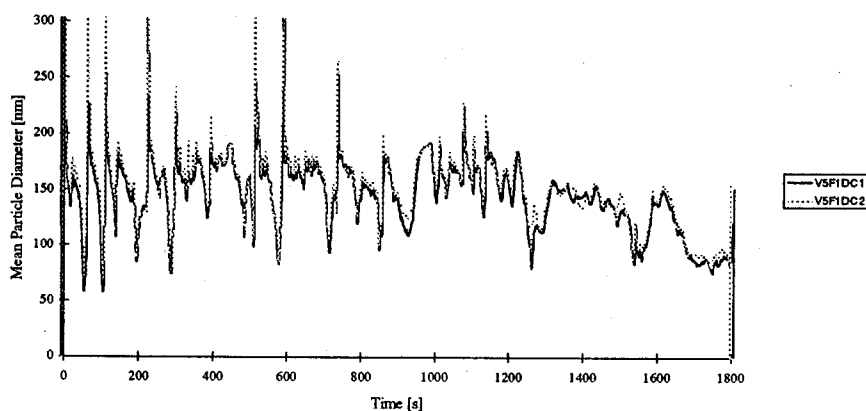
DOT/DOE/SMMT Instrument Evaluation - Number Mode

Vehicle 2



DOT/DOE/SMMT Instrument Evaluation - Number Mode

Vehicle 5 Fuel 1

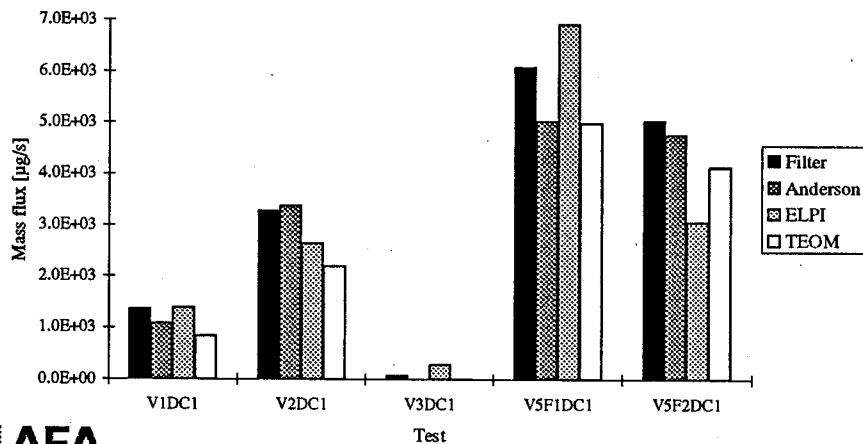


DOT/DOE/SMMT Instrument Evaluation - Number Mode

- ✦ ELPI repeatability as good as SMPS repeatability
- ✦ Time resolution good enough for drive cycle detail

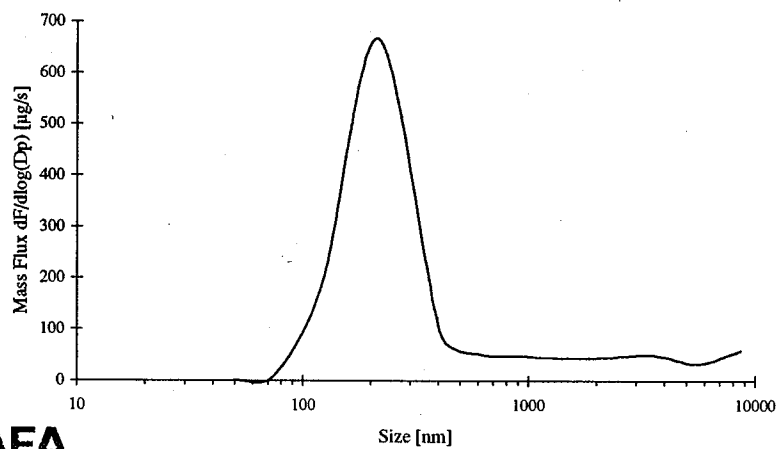
DOT/DOE/SMMT Instrument Evaluation - Mass Mode

Mass Flux Measurements Over Drive Cycles



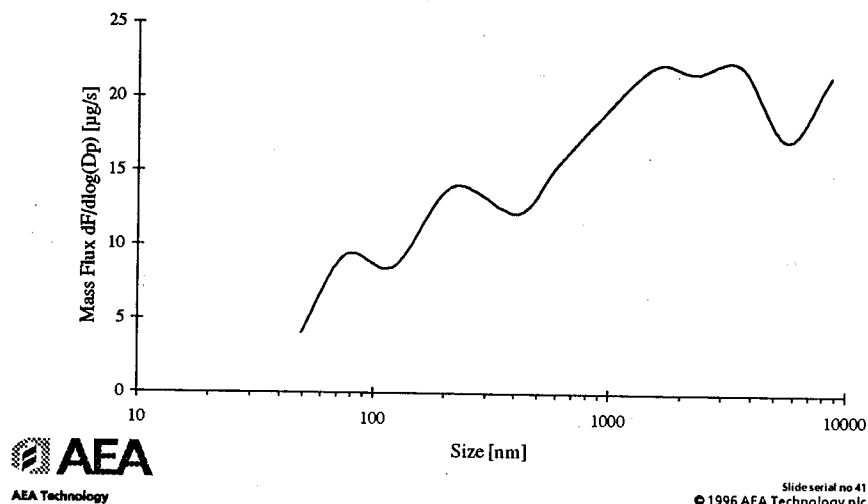
DOT/DOE/SMMT Instrument Evaluation - Mass Mode

Vehicle 1



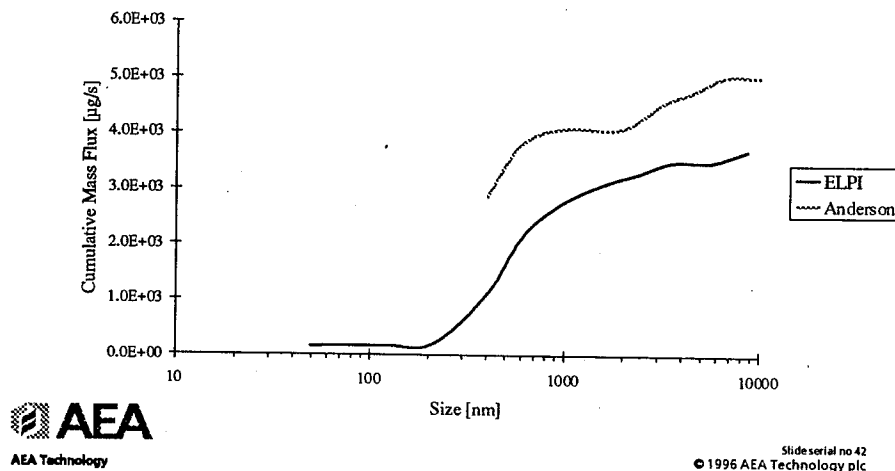
DOT/DOE/SMMT Instrument Evaluation - Mass Mode

Vehicle 3



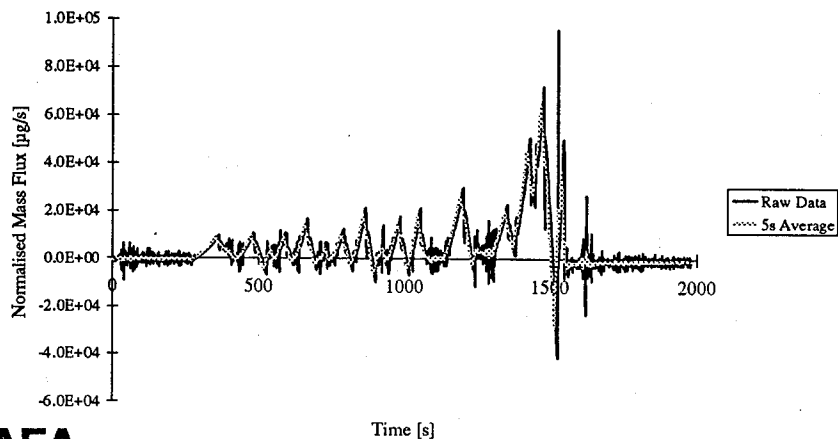
DOT/DOE/SMMT Instrument Evaluation - Mass Mode

Vehicle 5 - Fuel 1



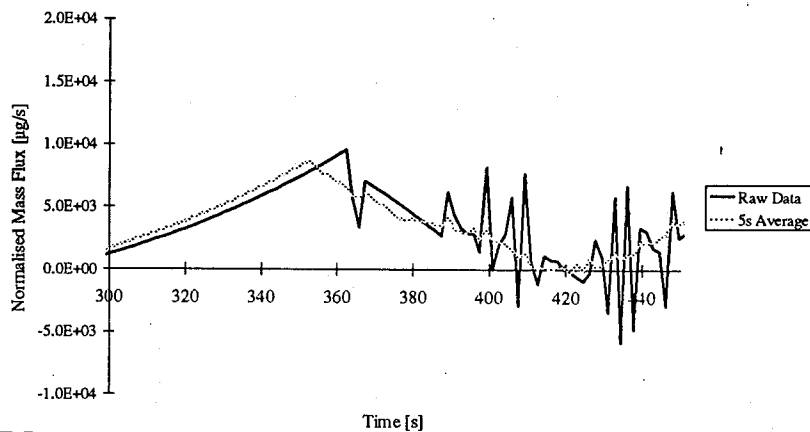
DOT/DOE/SMMT Instrument Evaluation - Mass Mode

Team Smoothing Over Drive Cycle



DOT/DOE/SMMT Instrument Evaluation - Mass Mode

Team Smoothing Over Drive Cycle



DOT/DOE/SMMT Instrument Evaluation - QCM

- Under Performs by 90% in Terms of Total Mass
- Problem not Charge Related
- Distribution Biased to Smaller Particles (Compared to ELPI/SMPS)
- Bad Coupling of Particles to Stages

DOT/DOE/SMMT Instrument Evaluation - ELPI (mass mode)

- Manufacturer's Calibration Needs Adjustment
- Reasonable Mass Flux Measurement
- Measures Cumulative Mass Distribution over Drive Cycle with Good Size Resolution.
- Not Real Time

DOT/DOE/SMMT Instrument Evaluation - ELPI (number)

- ◆ Real-time Particle Size Distributions
- ◆ Good Repeatability over Drive Cycles and Steady States
- ◆ Stage Sizes in Number Mode Differ from Mass Mode Calibration
- ◆ Possible Max Concentration Problem
- ◆ Needs Further Calibration

DOT/DOE/SMMT Instrument Evaluation - SMPS

- ◆ Excellent Size Resolution and Range for Steady State Tests.
- ◆ Concentration Out by Factor of 2
- ◆ Proven for Particle Emissions
- ◆ Restricted to Single Size over Drive Cycles

DOT/DOE/SMMT Instrument Evaluation - TEOM

- ◆ Measures Total Mass Concentration in Real-time
- ◆ Unstable Signal, Needs Smoothing

DOT/DOE/SMMT Instrument Evaluation - Anderson

- ◆ Cumulative Mass Size Distribution
- ◆ Resolution Only Good above 400nm
- ◆ Cheap Method for Checking for Large Particles

DOT/DOE/SMMT Instrument Evaluation - Sampling

- Sampling Column Needed for Multiple Instrument Sampling
- Large Particle Seen, so Good Sampling for Mass Mode Measurements Required

DOT/DOE/SMMT Instrument Evaluation Recommendations

- Number - Steady State
 - SMPS, ELPI?
- Number - Drive Cycle
 - ELPI? or SMPS
- Mass
 - ELPI (or Equivalent), Anderson MkIII?