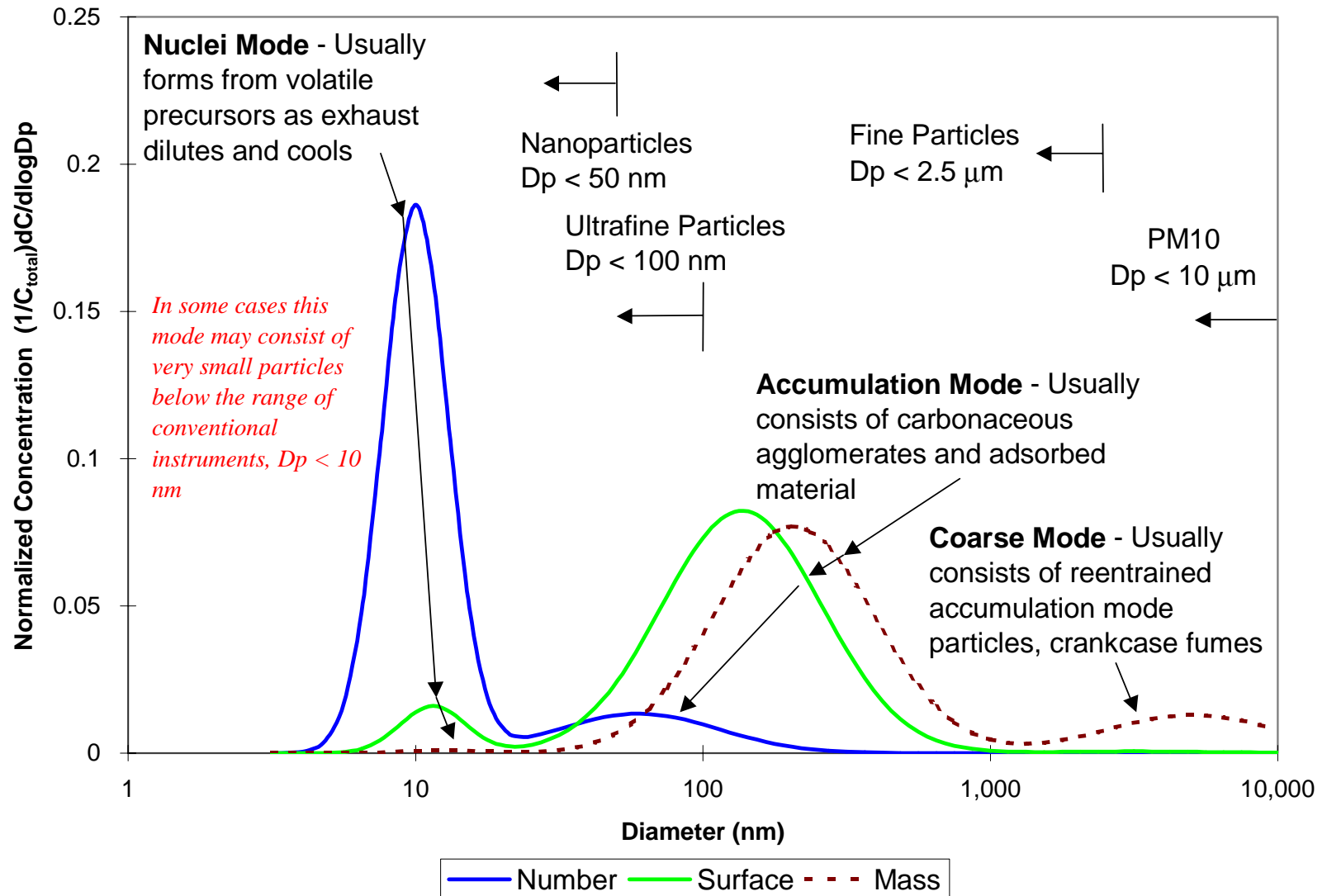

Sampling and Dilution Issues

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Typical Engine Exhaust Particle Size Distributions, Number, Surface Area, and Mass Weightings Are Shown



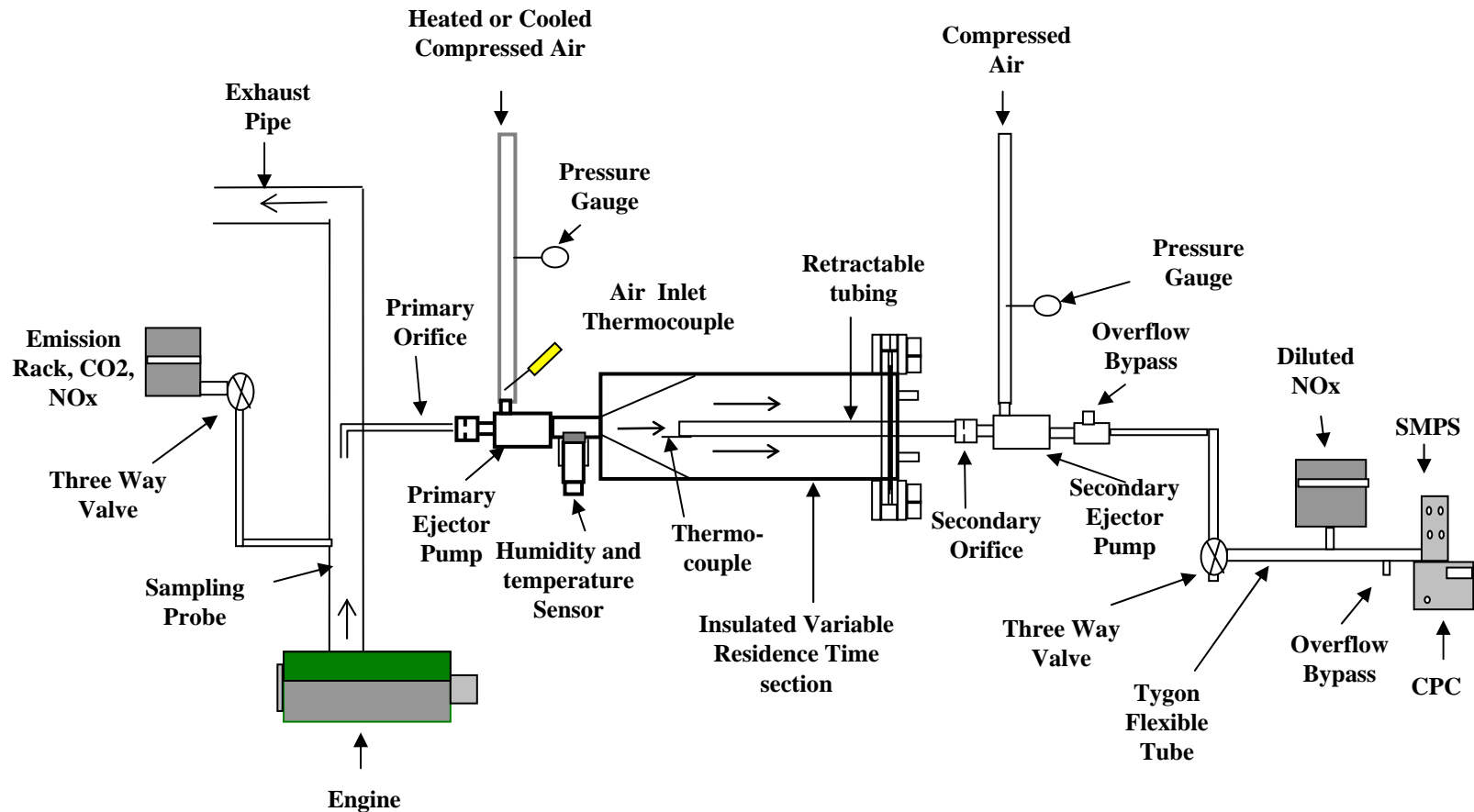
Sampling and Dilution Issues

- Homogeneous processes sensitive to correct simulation of atmospheric dilution
 - Gas to particle conversion
 - Nucleation - homogeneous formation of new particles
 - Condensation/Absorption - transfer of gas molecules into liquid droplets
 - Adsorption - forming a layer of molecules on solid particles
 - Coagulation - particle to particle collisions
- Heterogeneous
 - Loss of particles to walls of sampling and dilution system
 - Loss of particle precursors to walls of sampling and dilution system
 - Storage and release of particle precursors on walls of sampling and dilution system

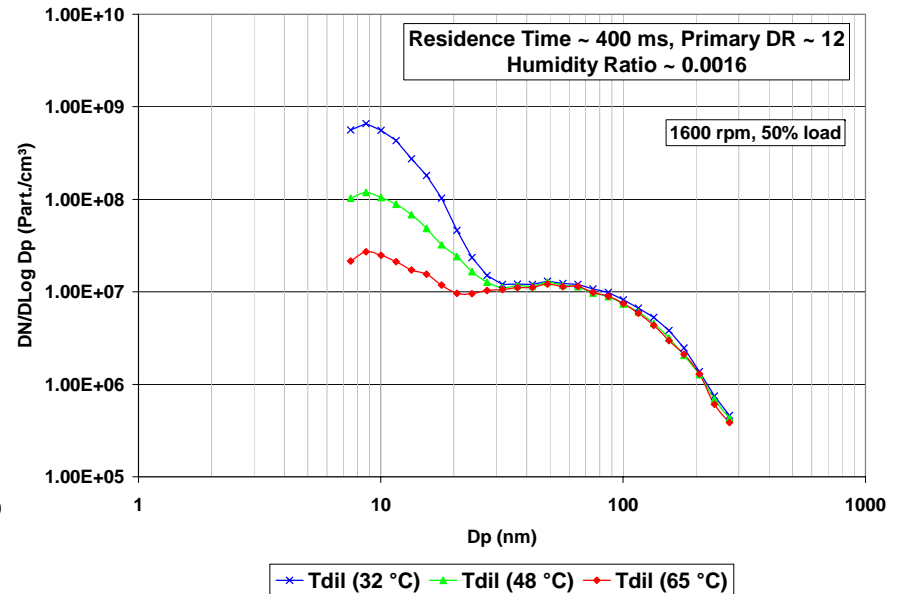
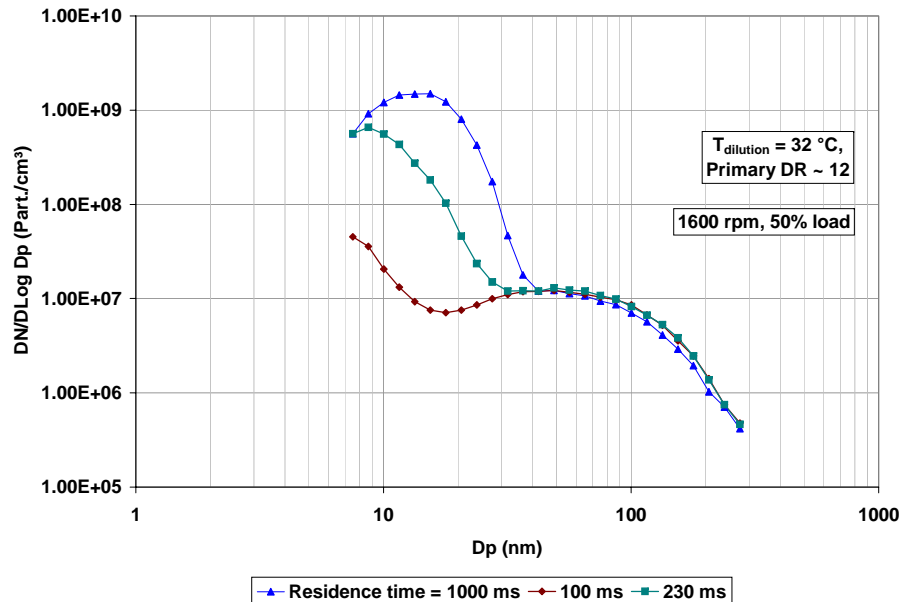
Significant Gas to Particle Conversion Takes Place as the Exhaust Dilutes and Cools

- Current engines
 - More than 90% of the particle number may form through homogeneous nucleation of nanoparticles
 - From 5 to more than 50% of the particle mass may form through adsorption, absorption, and nucleation
- Future engines with filters
 - Nearly 100% of the particle number may form through homogeneous nucleation of nanoparticles
 - Much of the particle mass may form through adsorption, absorption, and nucleation
 - Sampling issues that apply to only to number on current engines will apply to mass on filter equipped ones
- These processes are *extremely* sensitive to sampling and dilution conditions

Studies of Diesel Nanoparticle Formation Using a Variable Residence Time Dilution System

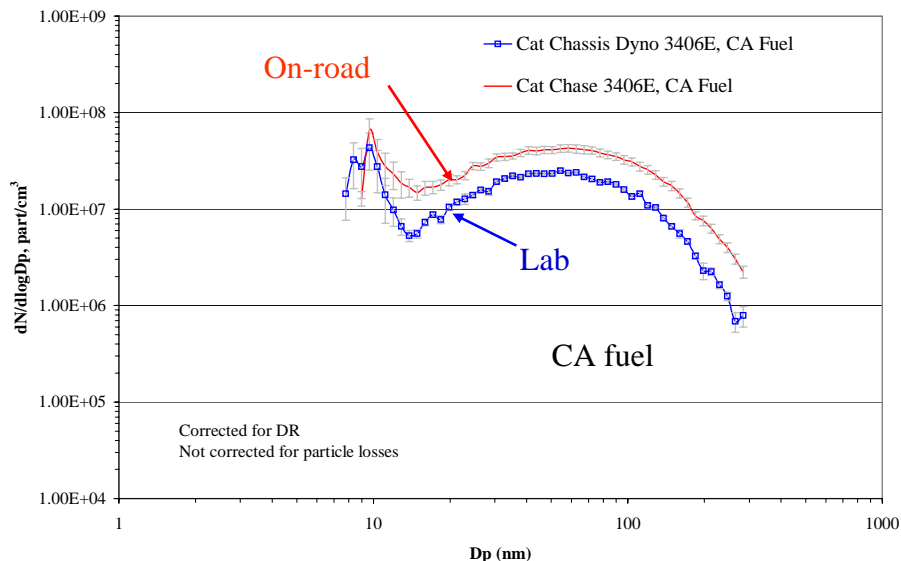
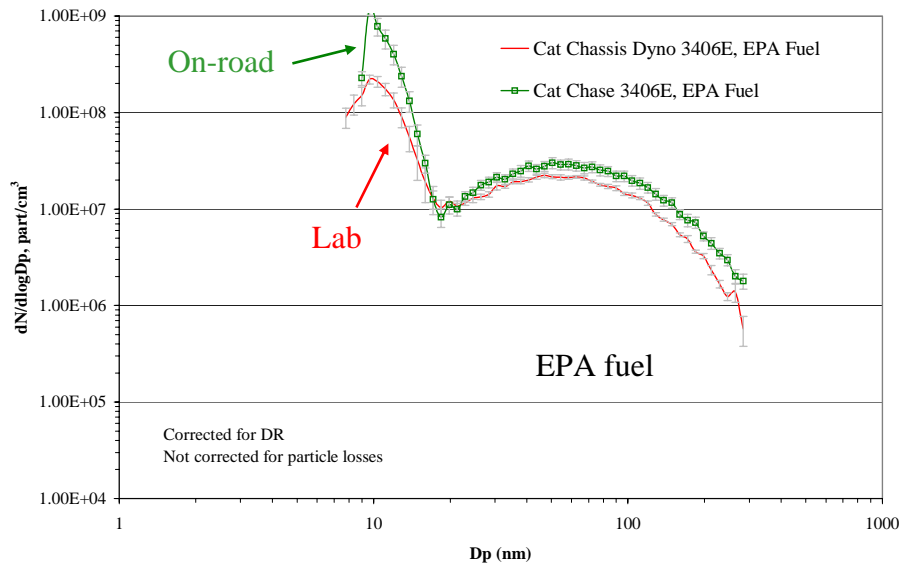


Nuclei mode formation is extremely sensitive to sampling conditions



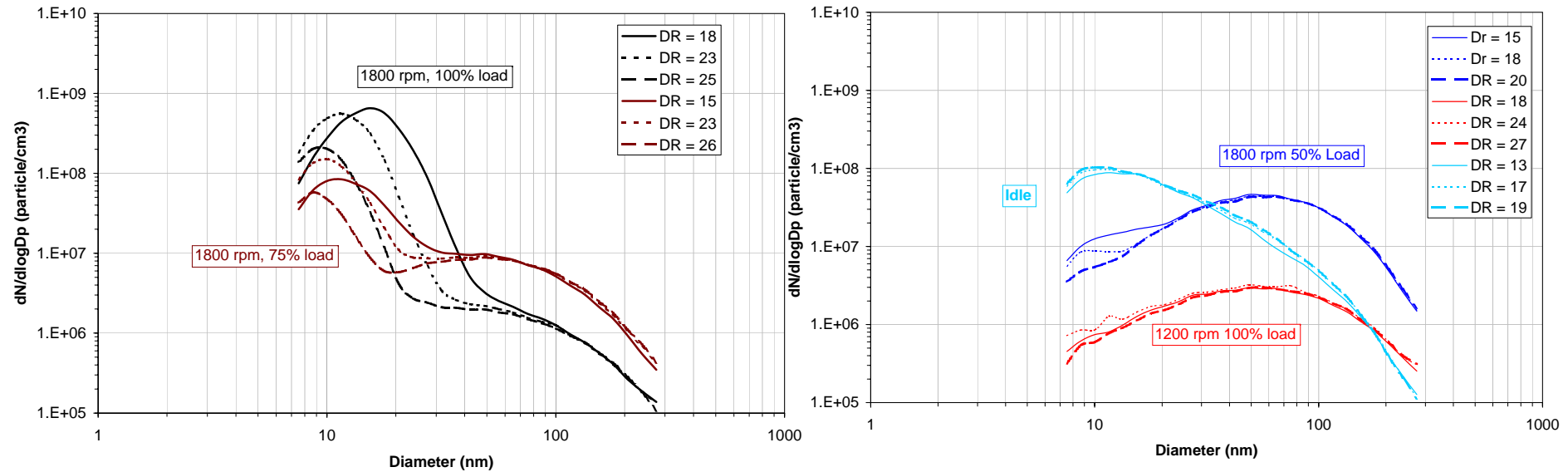
- Medium-duty Diesel engine running at medium speed and load
- Increasing residence time in the primary dilution chamber from 230 ms to 1 s increases the size of the nuclei mode by two orders of magnitude
- Decreasing the temperature in the primary dilution chamber from 66 to 32 °C increases the size of the nuclei mode by about one and one half orders of magnitude
- Concerns about sampling and dilution led to the CRC E-43 program

The CRC E-43 Program compared size distributions measured in the laboratory with those measured on-road



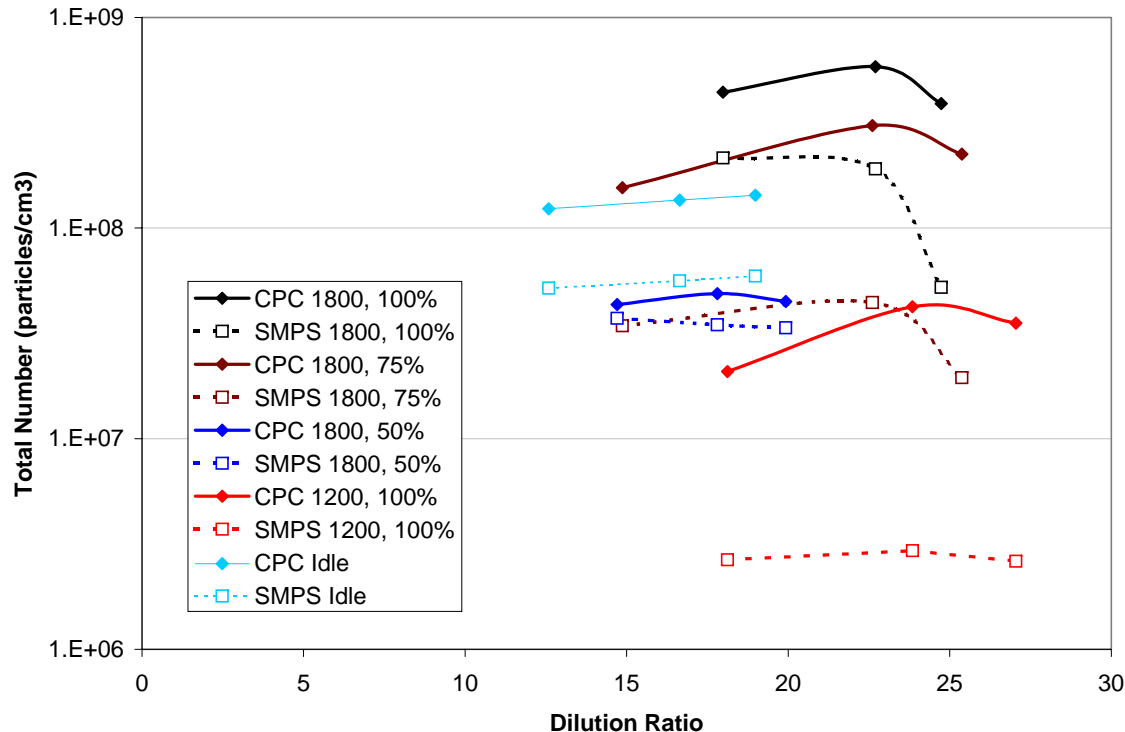
- Results shown are composite of loaded and unloaded highway cruise for a modern heavy-duty Diesel engine with full electronic engine management
- A two-stage, porous tube / ejector dilutor could simulate on-road nuclei mode formation for composite, summertime highway conditions
- The relative sizes of the two modes are more significant than the absolute levels – due to uncertainty in on-road dilution ratios
- In general the CA fuel produced a smaller nuclei mode than EPA fuel
- These results show that it is possible to simulate carefully defined on-road conditions
- At present, it is unclear which on-road conditions should be simulated. There are many variables including
 - Temperature
 - Previous operating history
 - Road speed
 - Exhaust system design
 - Others

Measurements made with a modern heavy-duty engine show dilution sensitivity depends on operating condition



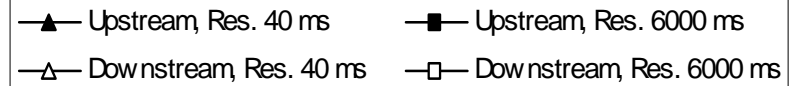
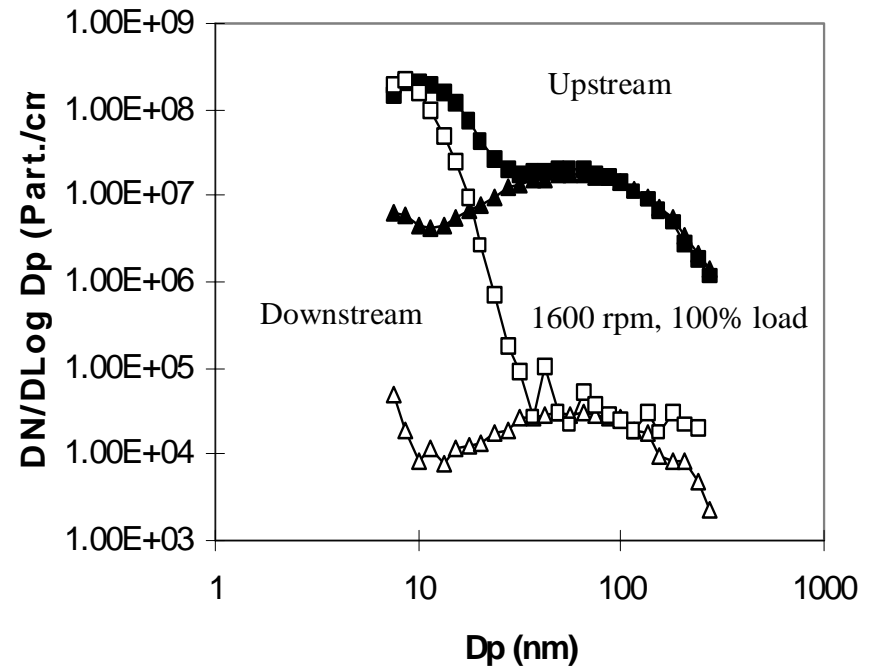
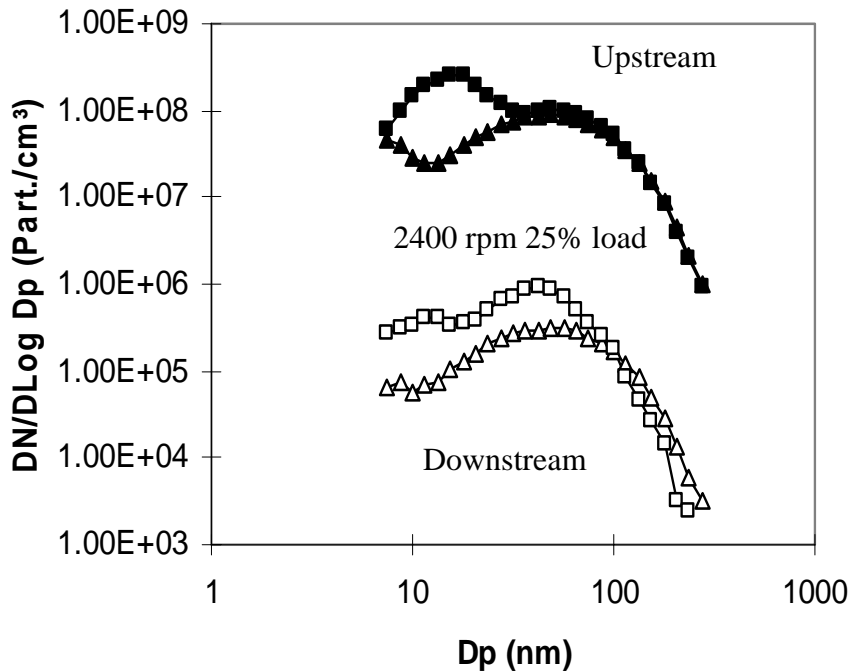
- Ongoing EMA program
- Two-stage dilution system with variable first stage dilution ratio
- Dilution air temperature 20 C
- High speed, high load conditions show significant changes in nuclei mode with modest changes in dilution ratio
- How do we determine sensitivity?

Dilution sensitivity may be determined by swinging through dilution range at constant operating condition



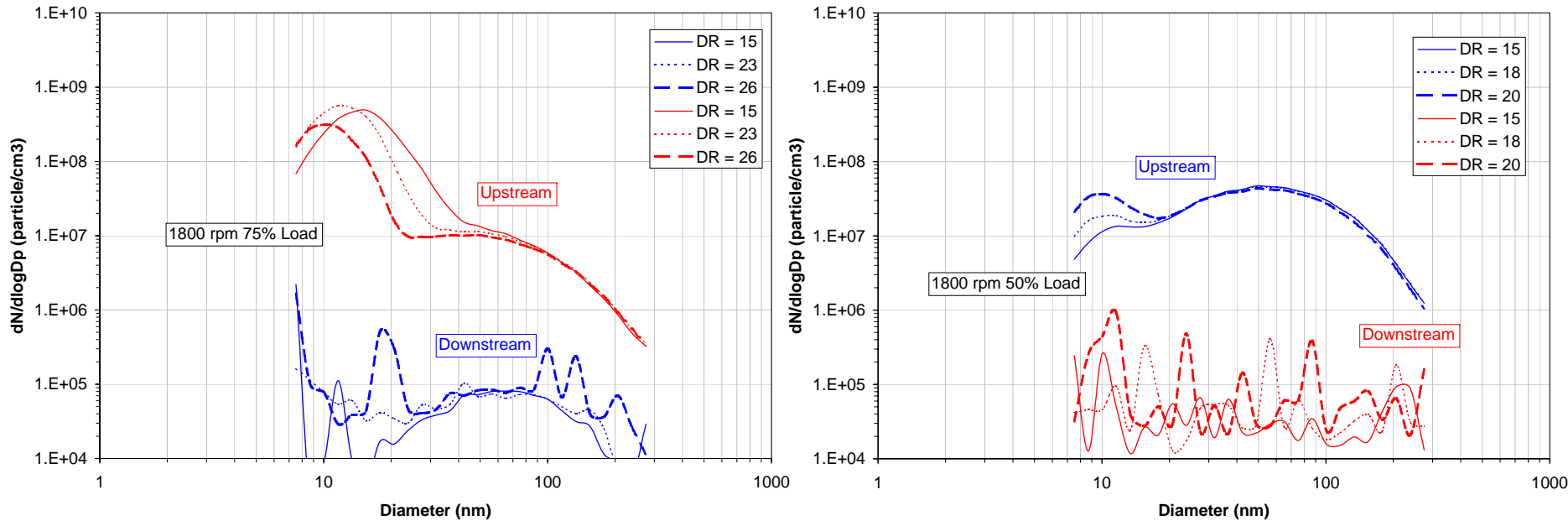
- Total SMPS number concentration ($D_p > 8$ nm) for the 5 operating modes shown in the previous slide are shown here
- Also shown is the total CPC number concentration ($D_p > 3$ nm)
- Some engine conditions are much more sensitive to dilution than others
- Note that CPC number may be an order of magnitude or more higher than SMPS – even in cases where SMPS suggests no nuclei mode

How do dilution conditions influence trap equipped engines?



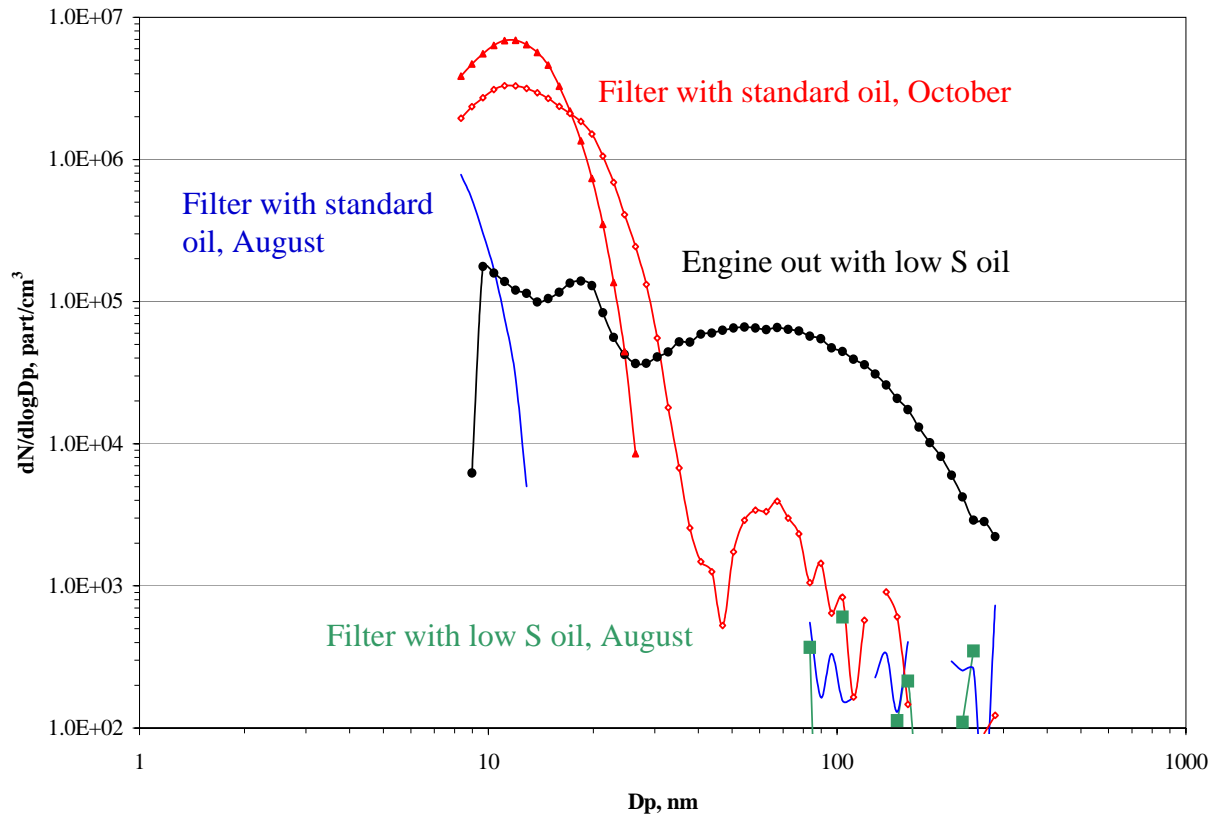
- Early work with medium-duty engine and uncatalyzed filter showed some dilution sensitivity
- In some cases nuclei mode particles formed downstream of the filter

Measurements made with a modern heavy-duty engine with catalyzed exhaust filter



- These data preliminary, part of an ongoing EMA program
- A very low S (< 1 ppm) used in these tests
- Little evidence of nuclei mode downstream of filter
- Number concentrations reduced by well over 99%
- No clear dilution sensitivity downstream

Recent on-road tests of particle filtration device on heavy-duty truck

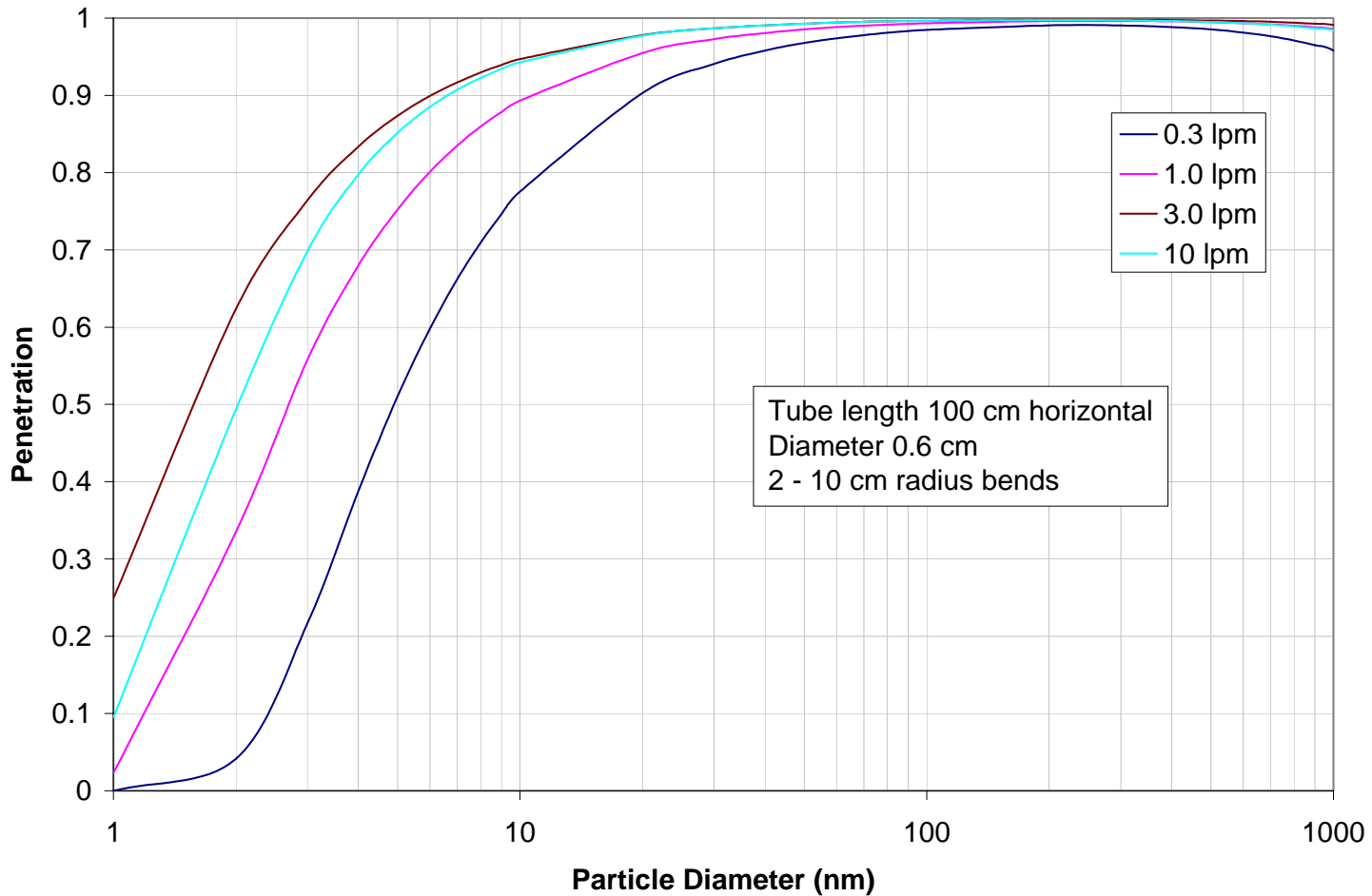


- Preliminary results part of an ongoing program
- All tests done with BP-15 fuel
- So far we can't duplicate nuclei mode formation in lab using same aftertreatment fuel and oil

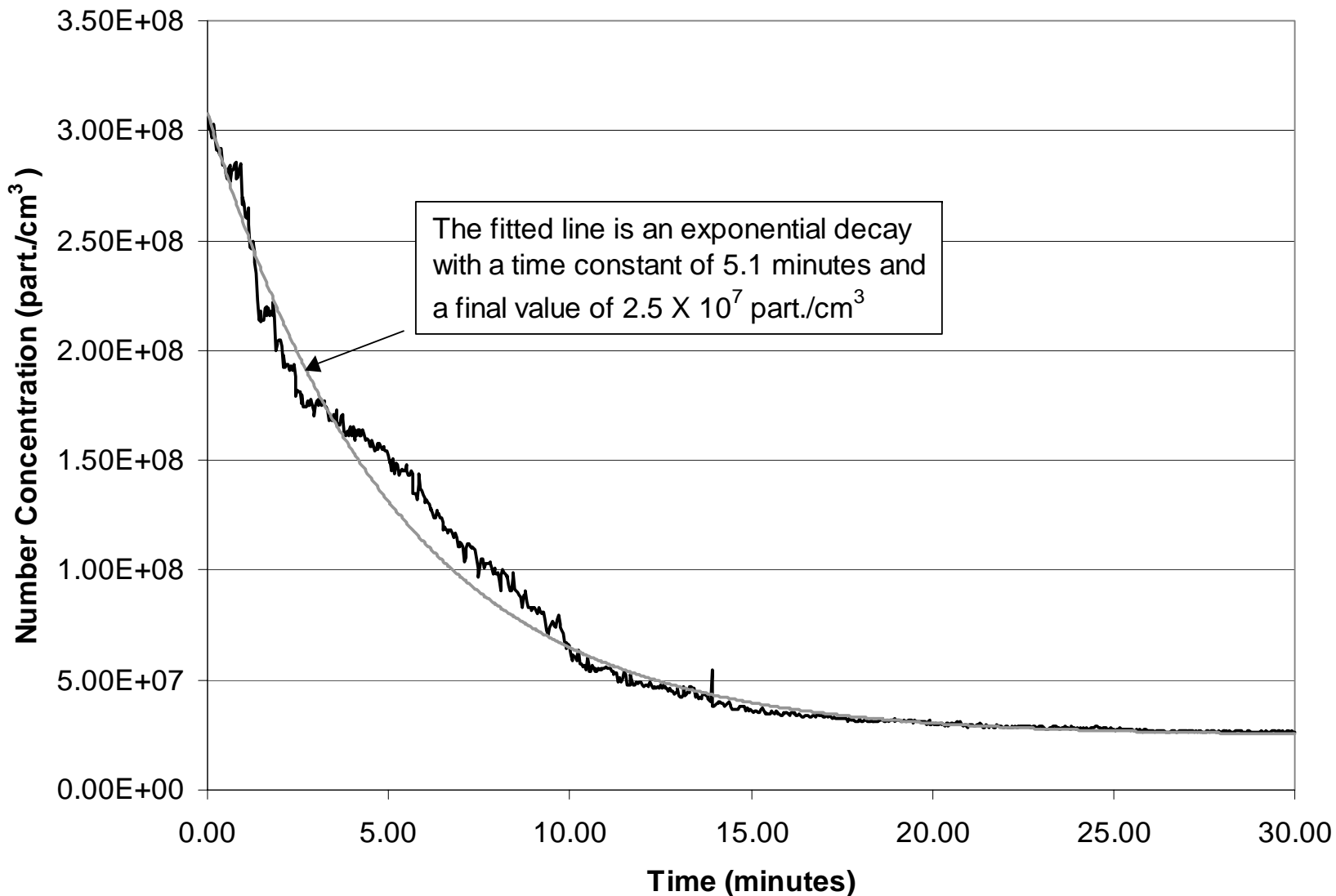
Wall influences

- Particle losses in sampling lines
- Storage and release of volatile particle precursors
 - Stored on exhaust system and transfer line surfaces
 - Stored on dilution and sampling system surfaces
 - Released from inappropriate materials in sampling system (elastomers)

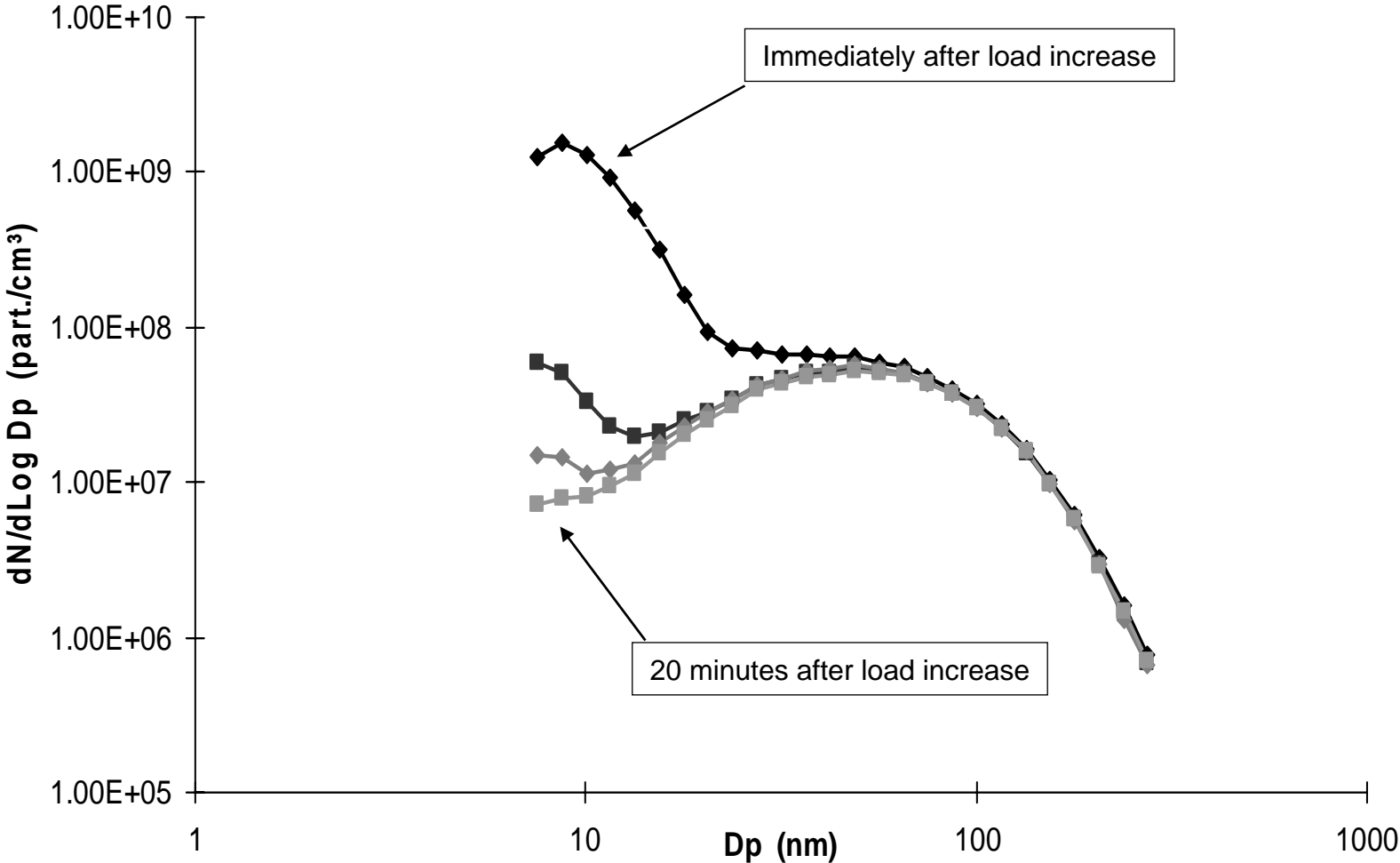
Normal sampling lines can have large particle losses



Storage and Release - Number Concentration Measured with CPC after Transition from Idle to Full Power



Particle Size Distributions Measured with SMPS during Transition from Idle to Full Power. Measured at 5-6 Minute Intervals



Dilution recommendations

- Precondition engine and sampling system
- Sampling should take place at the end of a realistic vehicle exhaust system,
- The exhaust transfer line should be designed for low heat and mass transfer
- The primary dilution ratio should be at least 5-10:1, but not greater than 30
 - The EU Particulates program recommended 12:1 with 32 C air
 - Current EMA tests show stable results in 15:1 to 25:1 range
 - Dilution sensitivity tests should be done
- The residence time in the primary dilution system should be 1-3 s
- Sampling lines should have short residence times to minimize particle losses – which should be measured

Dilution recommendations

- Secondary dilution should be used to raise the overall dilution ratio to >200 to freeze coagulation and growth
 - Lower overall ratios may be sufficient with trap equipped engines
- The dilution air temperature should be 20° - 35° C
 - Depends upon dilution ratio
- Dilution air should be absolute filtered and charcoal scrubbed
- Dilution air should be dry or precisely humidity controlled
- More validation of these needed for clean engines
- If you want to punt – do what the Europeans are doing and introduce thermal dilution to get rid of volatile particles

Acknowledgements

- We have had help from many collaborators
 - In the Center for Diesel Research
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