JCAP II
JAPAN CLEAN AIR PROGRAM

For better air quality,
further challenges of automobile and fuel

Investigation of Measurement Conditions of Ultrafine Particles Emitted by Automobiles

JCAP Unregulated Material Working Group

Yanagisawa, N Suzuki, A Ikeda, T Yamashita, T
Tanaka, S Iwakiri, Y Takahashi, K
Shoji, T Hosoya, M Sekimoto, M Nakajima, T

9th ETH Conference on Combustion Generated Nanoparticles, 2005

Contents of presentation

1. Outline of the study of unregulated material WG
2. Wind tunnel test results of size distribution measurement of ultrafine particles emitted into the atmosphere
3. Results of ultrafine particle measuring method that reproduces emission into the atmosphere
4. Summary of ultrafine particle measuring method
5. Future plan of unregulated material WG

Outline of Unregulated material WG of JCAP

What is JCAP (Japan Clean Air Program)?

- **Collaborative study** by **automobile** and **oil industries**
  - to find the best combination of automobile and fuel technologies to improve the air quality of Japan
  - to provide the government with rational technical data for policy making.
  - Supported by METI (the Ministry of Economy, Trade and Industry)
- JCAP I:1997 –2001 (Budget: Approx. 5.4 billion yen)
- **JCAP II: 2002 –2006** (Budget : Approx. 5.6 billion yen)
  - Determination of **future automobile/fuel technologies** toward **near Zero Emissions**
  - **Prediction of air quality improvement** through the introduction of novel emission reduction technologies

Objectives of Unregulated material WG

For **ultrafine particles** and **unregulated materials**
in automobile exhaust of which health effects are concerned,

(Step1) 2002-2004

To find appropriate **measuring methods**

(Step2) 2005-2006

To clarify the direction of **automobile and fuel technologies** development for zero emission

Outline of ultrafine particle study

Chase experiments

Wind tunnel tests

Size distributions of particles emitted into the atmosphere

Laboratory tests

Determination of measuring conditions

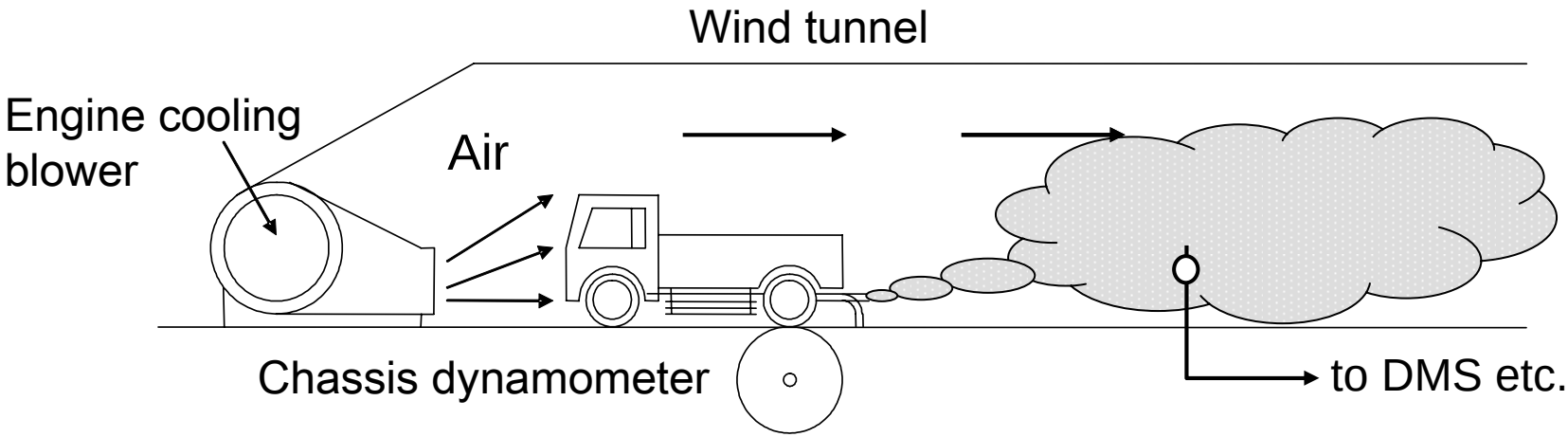
Laboratory test method that can reproduce size distributions of particles emitted into the atmosphere

Contents of presentation

1. Outline of the study of unregulated material WG
2. Wind tunnel test results of size distribution measurement of ultrafine particles emitted into the atmosphere
3. Results of ultrafine particle measuring method that reproduces emission into the atmosphere
4. Summary of ultrafine particle measuring method
5. Future plan of unregulated material WG

Wind tunnel tests - Emission into the atmosphere

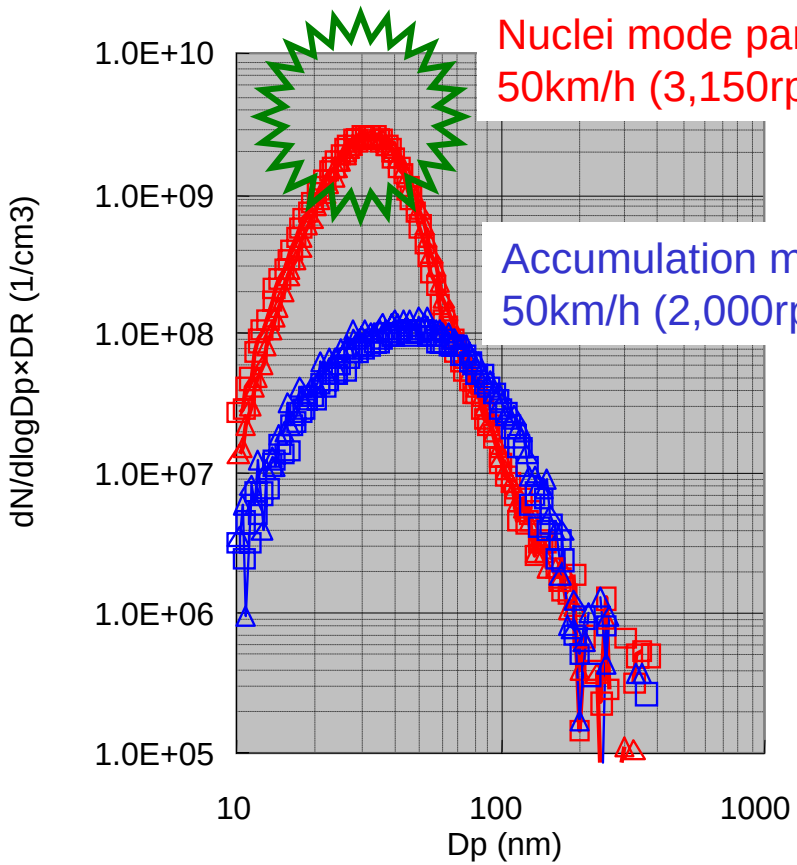
- **To reproduce ultrafine particles emitted into the atmosphere , wind tunnel tests on chassis dynamometer were conducted**



Previous results of chase experiments(1) – Actual emissions into the atmosphere

- **In usual steady state driving, nuclei mode particles are hardly generated.**

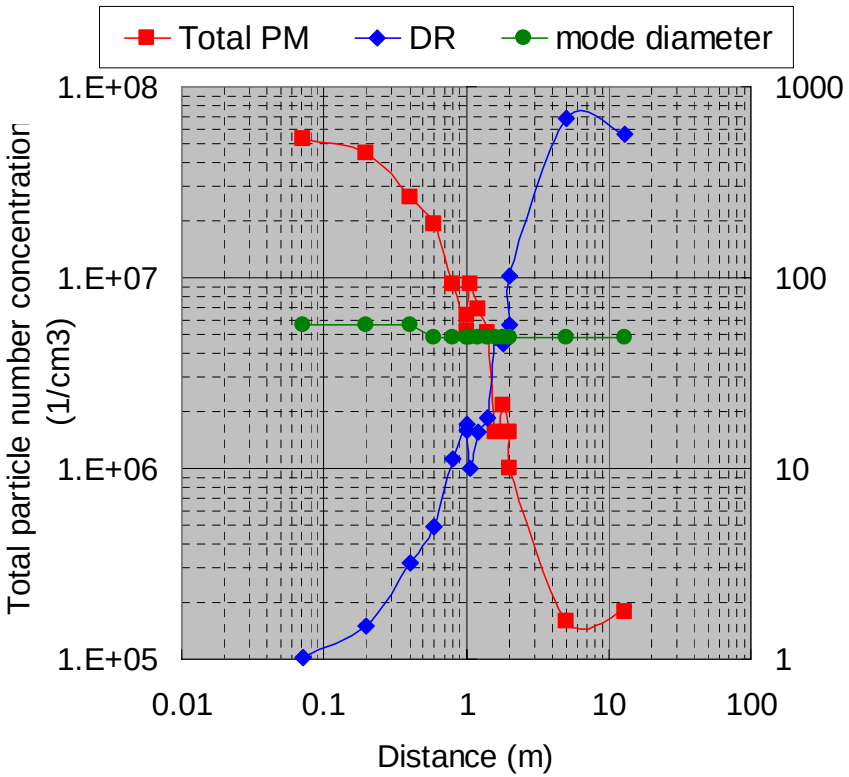
- **Nuclei mode particles** are generated in an extreme condition
  - high engine speed / low load – nanoparticles derived from organic carbon

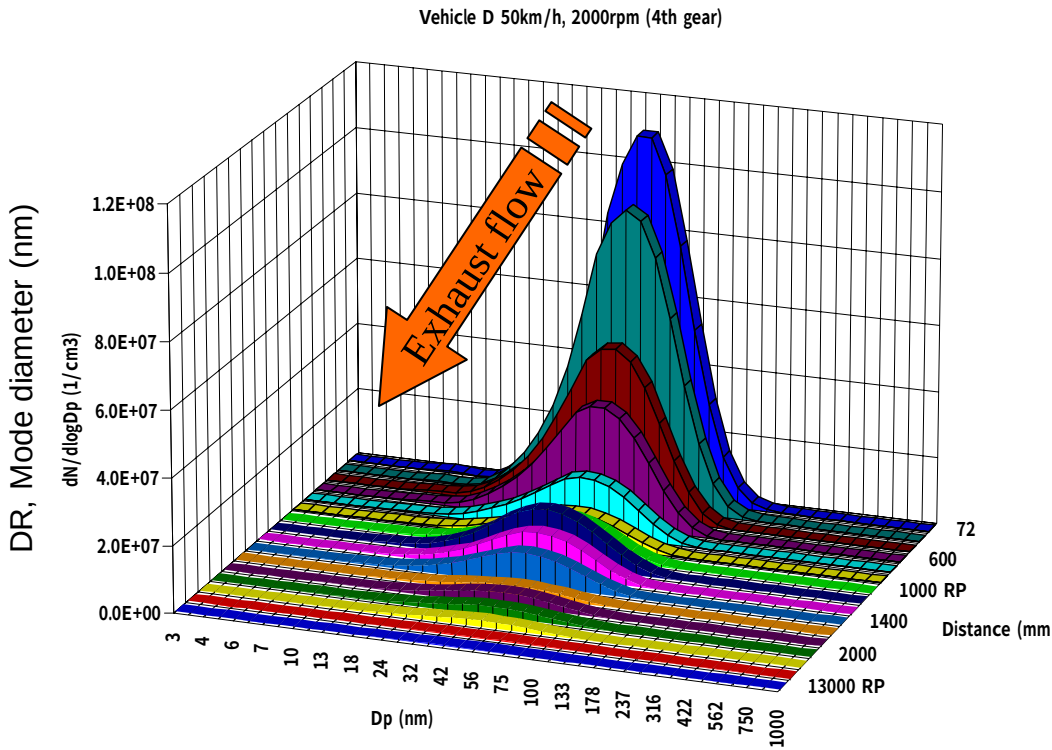


HD Diesel (4.3L DI, No after treatment)
Diesel fuel (Sulfur 50ppm)

Wind tunnel test – accumulation mode particles (1)

- Dilution process of stable accumulation mode particles
  - HD Diesel (4.3L DI, No after treatment), Diesel fuel (Sulfur 50ppm)
  - 50km/h (2,000rpm at 4th gear)

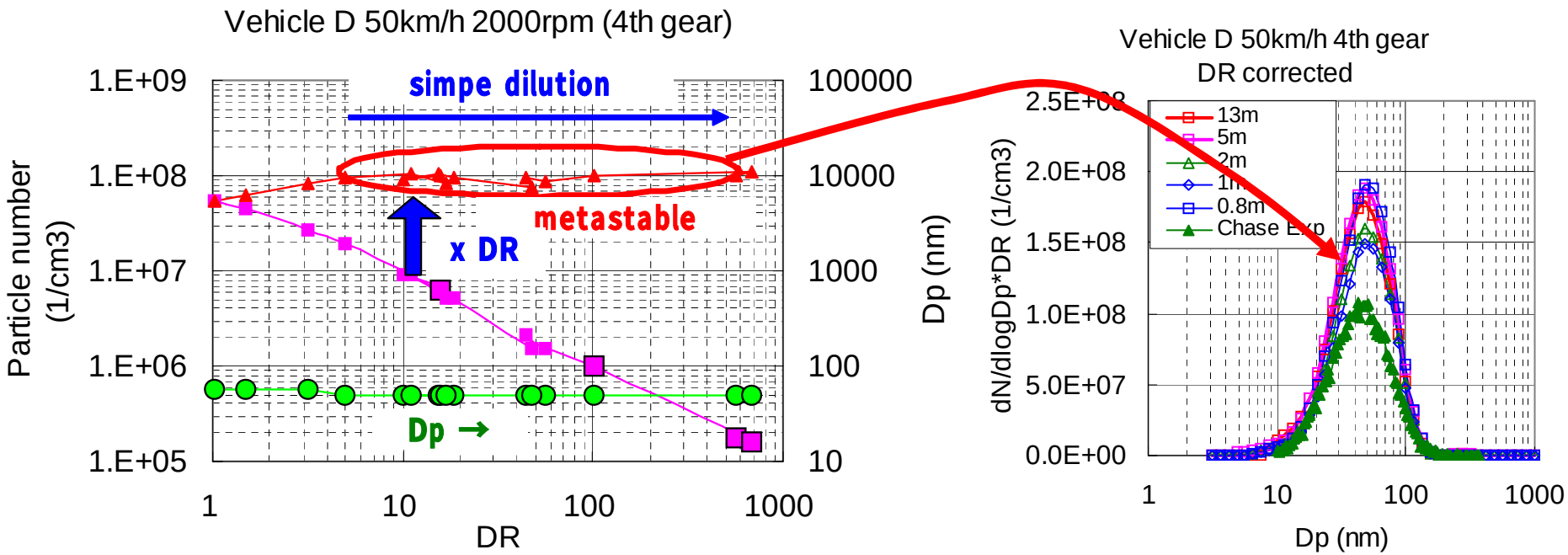




- Particle number concentrations decreased with distance monotonously.
  Profile of particle size distribution was not changed significantly.

Wind tunnel test – accumulation mode particles (2)

- **Particle size distribution corrected with dilution ratio of stable accumulation mode particles**
  - HD Diesel (DI, No after treatment), Diesel fuel (Sulfur 50ppm) Condition:50km/h (2,000rpm at 4th gear)

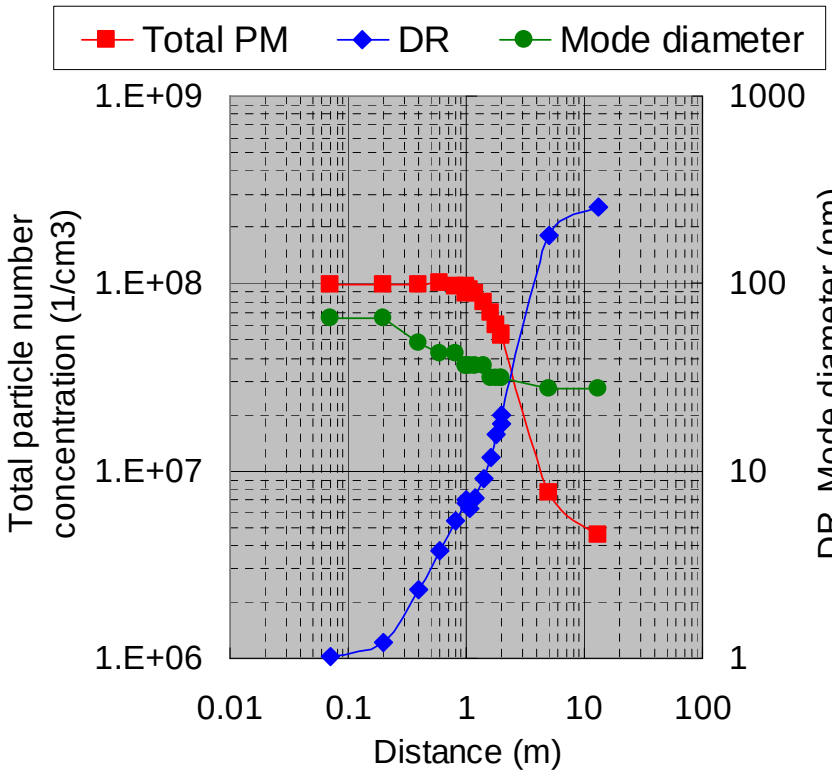


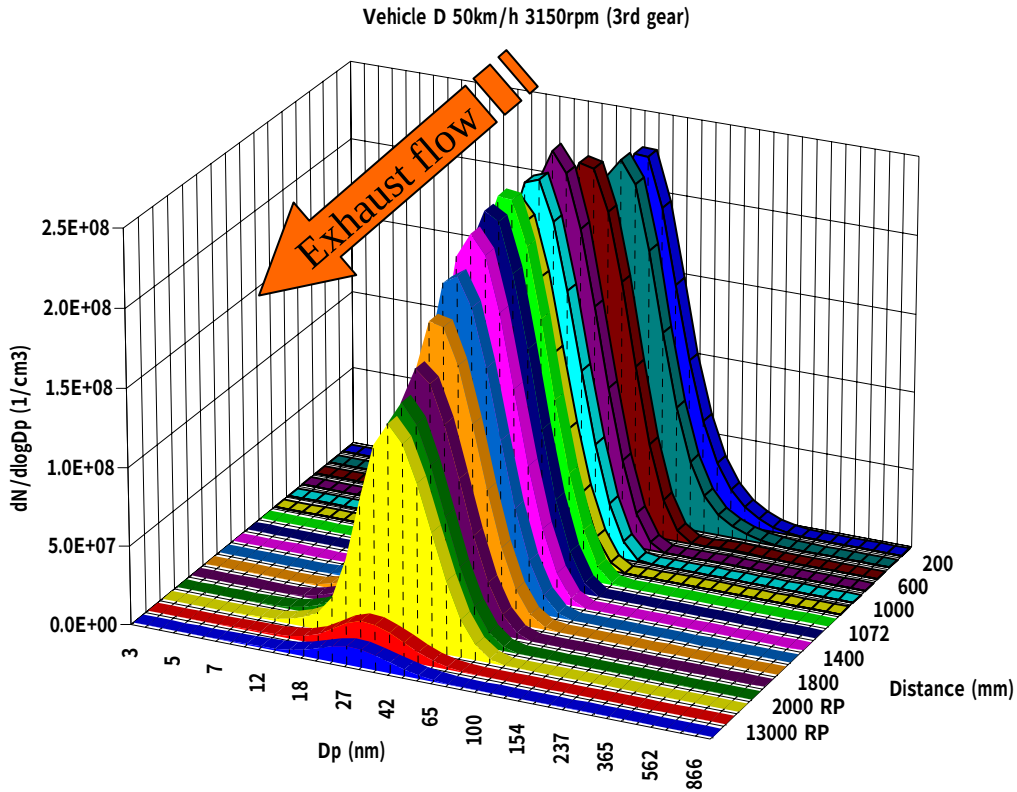
Particle size distribution corrected with dilution ratio are **metastable** at **DR (dilution ratio) >= 5 .**

⇒**Distribution to be reproduced in the laboratory.**

Wind tunnel test – Nuclei mode particle(1)

- Dilution process of unstable nuclei mode particles was observed.
  - HD Diesel (DI, No after treatment) , Diesel fuel (Sulfur 50ppm) 50km/hr(3,150rpm at 3rd gear)

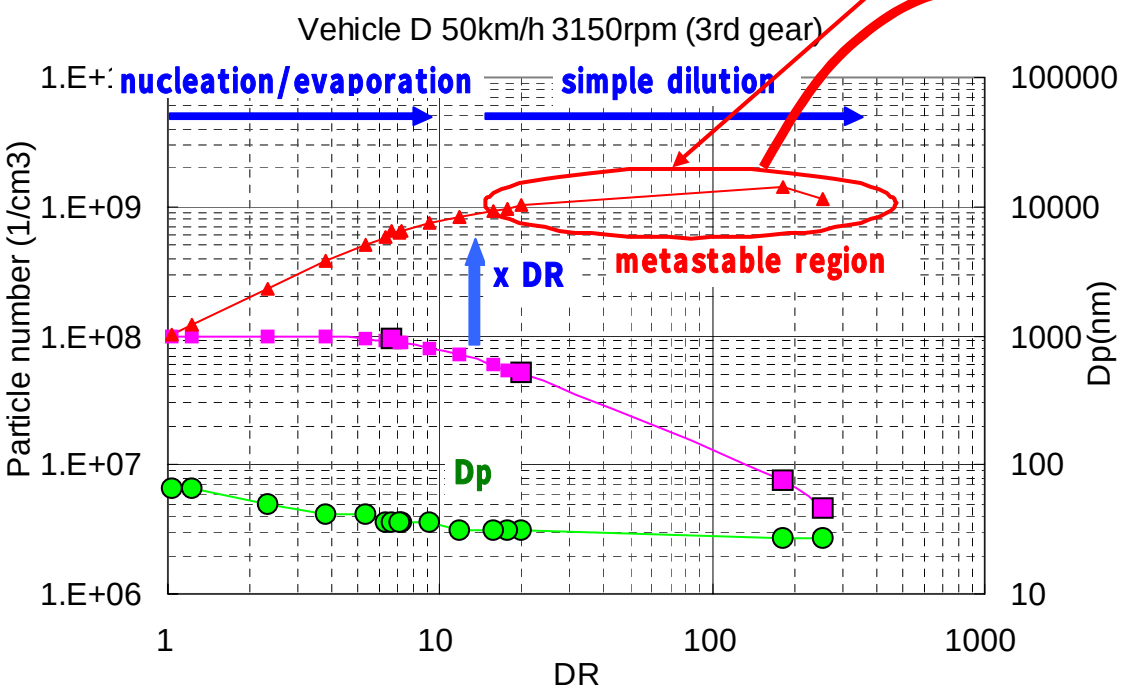


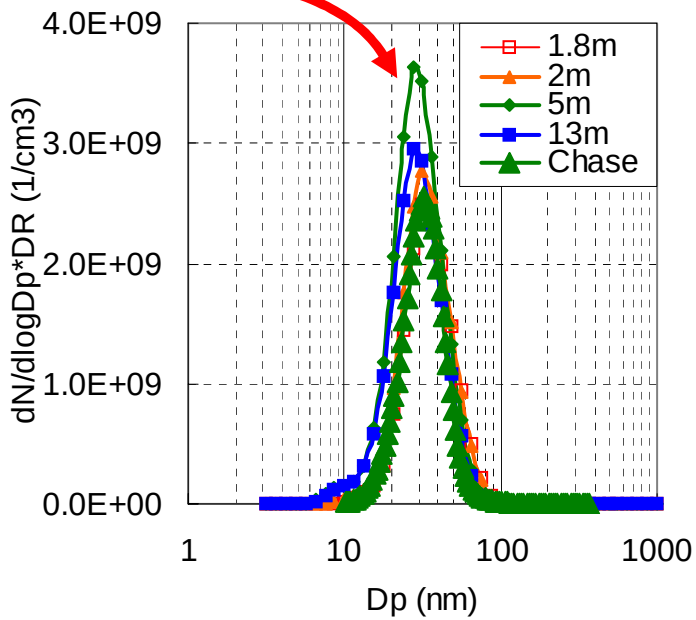


- Particle number concentrations decreased with distance >1m.

Wind tunnel test – Nuclei mode particle(2)

- Particle size distribution corrected with dilution ratio was approximately constant in high dilution ratio region.
  - HD Diesel (DI, No after treatment) , Diesel fuel (Sulfur 50ppm) 50km/h (3150rpm 3rd gear)

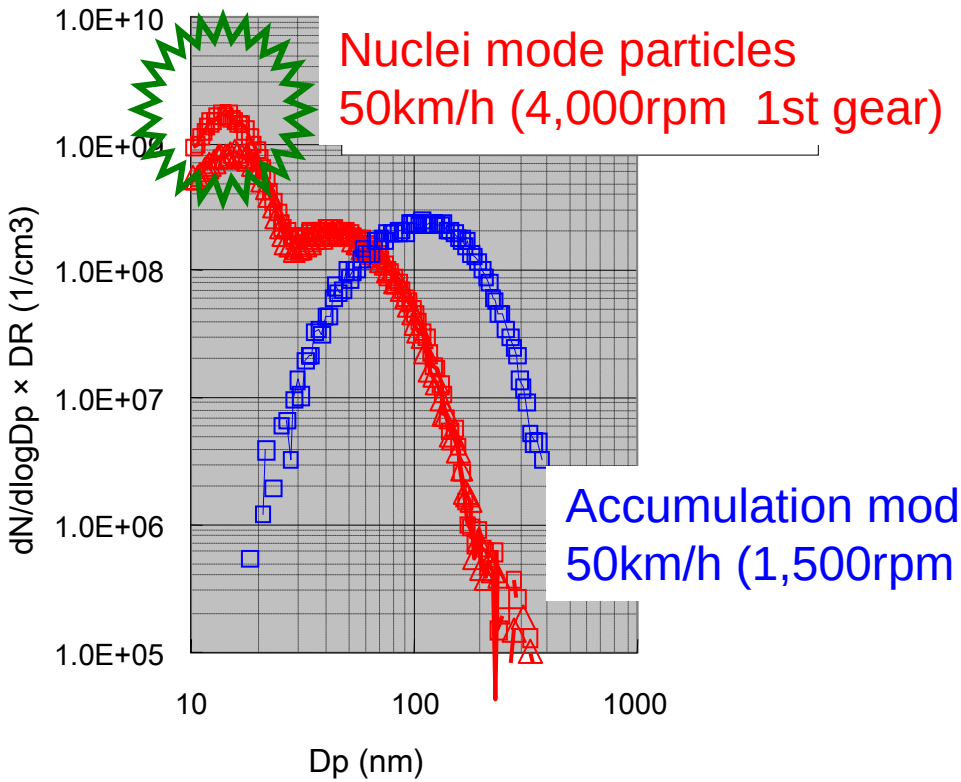




Particle size distribution was approximately unchanged at >2m behind the tail pipe (DR >18).

Previous results of chase experiments (2)

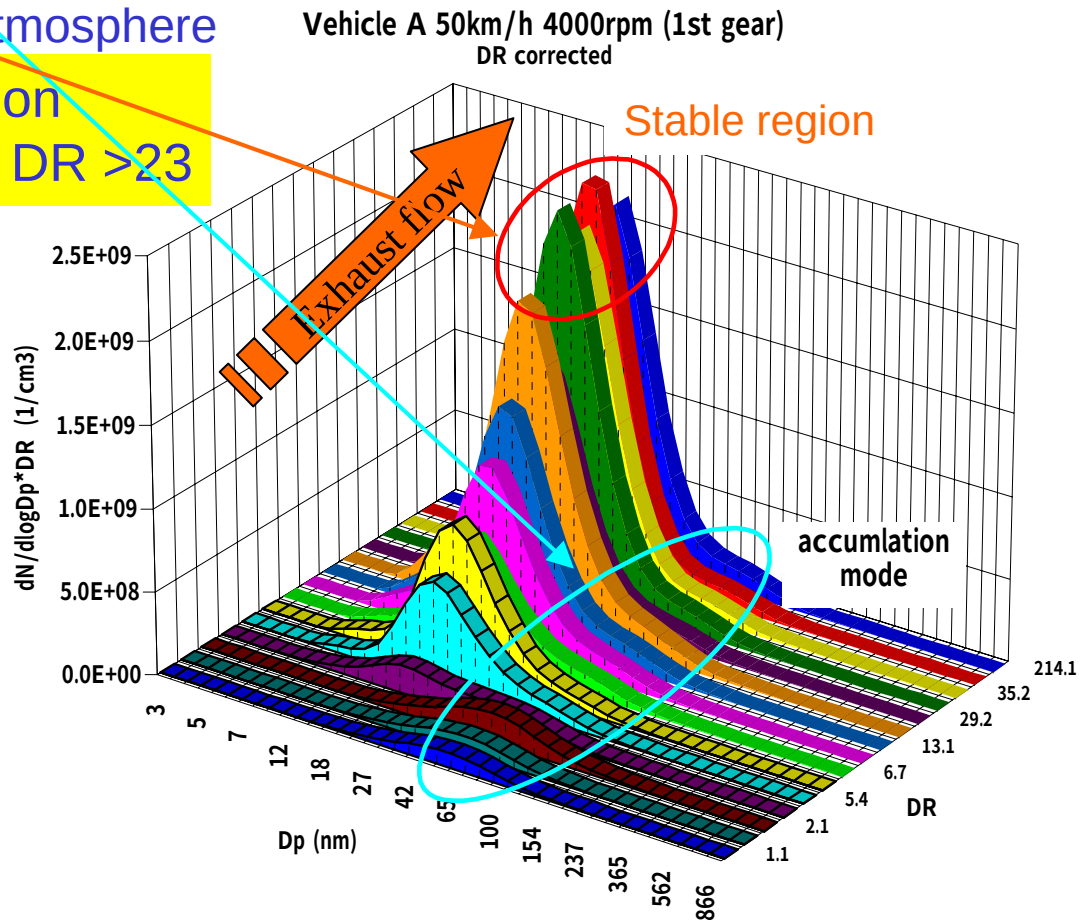
- In usual steady state driving,
  nuclei mode particles are hardly generated.
- Nuclei mode particles are generated in another extreme condition
  - **•Oxidation catalyst, high exhaust temperature and fuel with high sulfur content**
    - **– nanoparticles derived from sulfate**



LD **Diesel (3.0L DI with DOC)**
Diesel fuel (**Sulfur 500ppm**)

Wind tunnel test – Nuclei mode particle(3)

- Accumulation mode particles
  - Nearly unchanged after initial dilution
- Nuclei mode particles
  - Formed during dilution of exhaust in the atmosphere
- Particle size distribution is relatively stable at DR >23
  - Vehicle LD Diesel (DI with DOC), Fuel S 500ppm
  - 50km/h (1st gear)

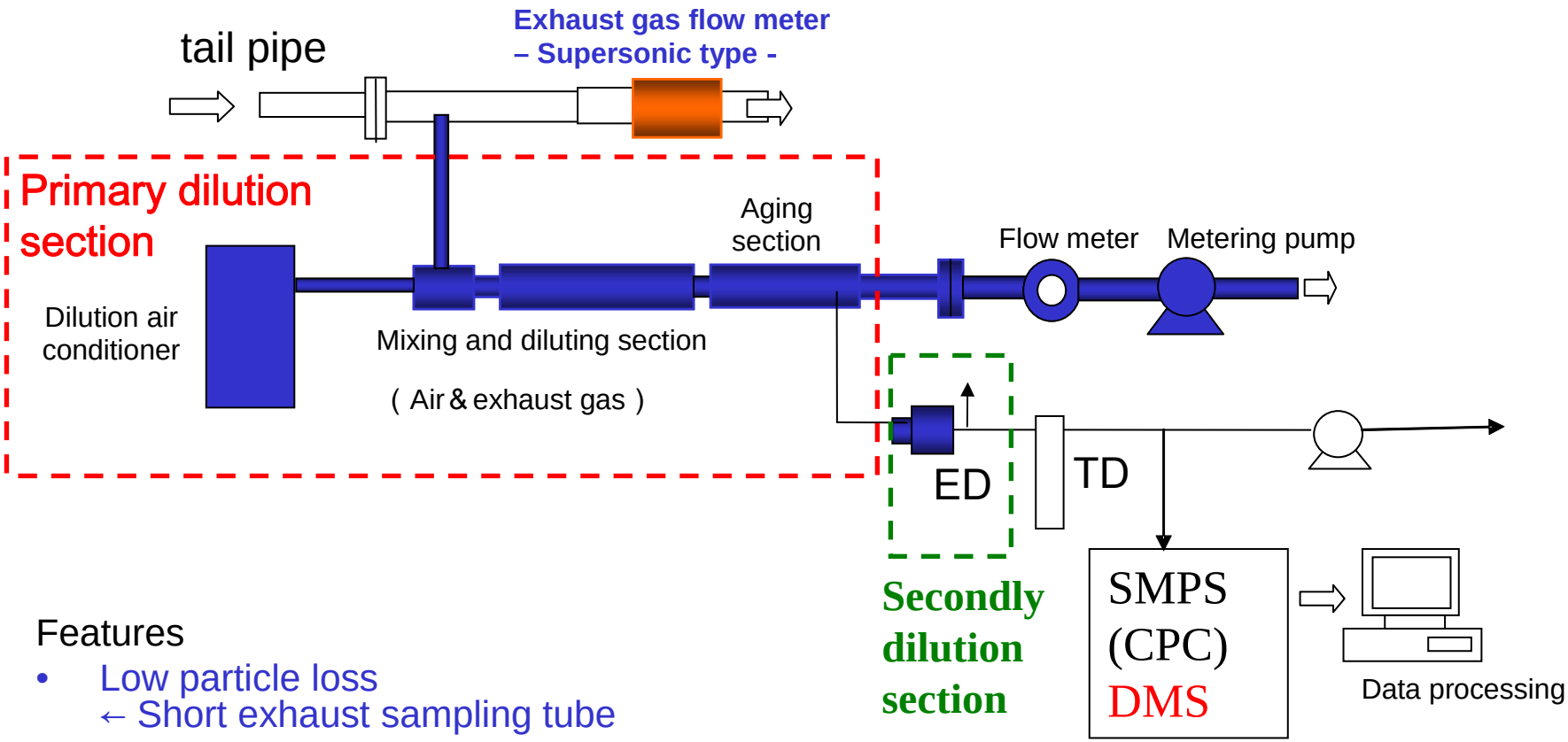


Contents of presentation

1. Outline of the study of unregulated material WG
2. Wind tunnel test results of size distribution measurement of ultrafine particles emitted into the atmosphere
3. Results of ultrafine particle measuring method that reproduces emission into the atmosphere
4. Summary of ultrafine particle measuring method
5. Future plan of unregulated material WG

Ultrafine particle measuring system

Ultrafine particle measuring system using PPFDII

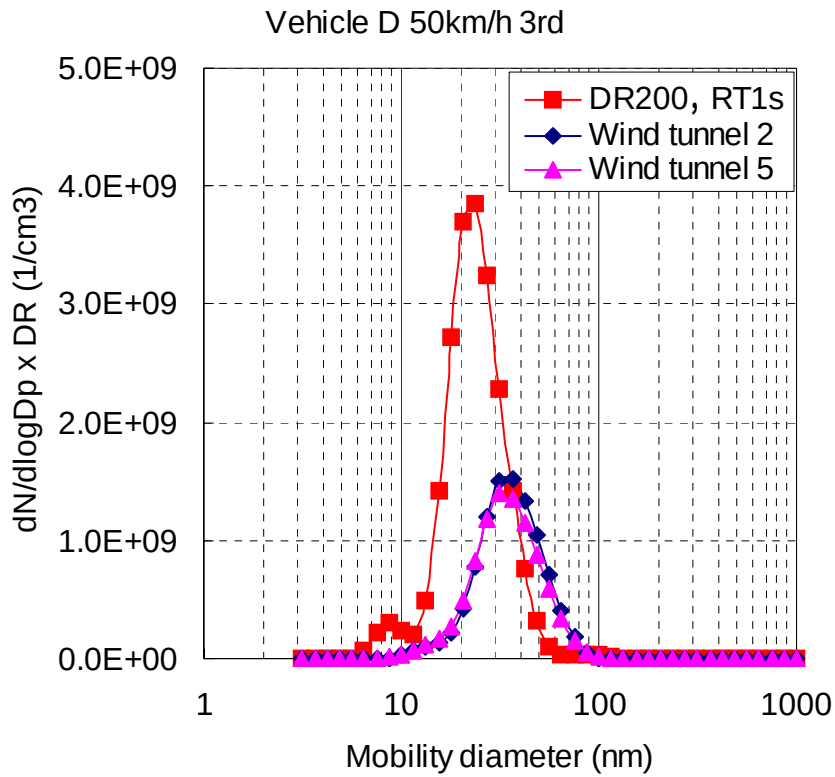


Features

- Low particle loss
  ← Short exhaust sampling tube
- Dilution air with temperature and humidity controlled
- Dilution ratio control capable of transient test
  - Constant dilution ratio or Constant split ratio

Comparison of wind tunnel and PPFDll test results (1)

- **Comparison of size distributions of nuclei mode particles in steady state condition**



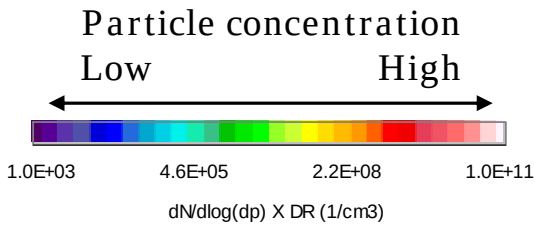
Vehicle: Diesel (DI, No after treatment)
Fuel: Diesel fuel (Sulfur 50ppm)
Condition:50km/h (3,150rpm 3rd gear)

	Wind tunnel	PPFDll
Mode diameter (nm)	32	23
total particle concentration (cm^{-3})	0.8×10^9	1.0×10^9

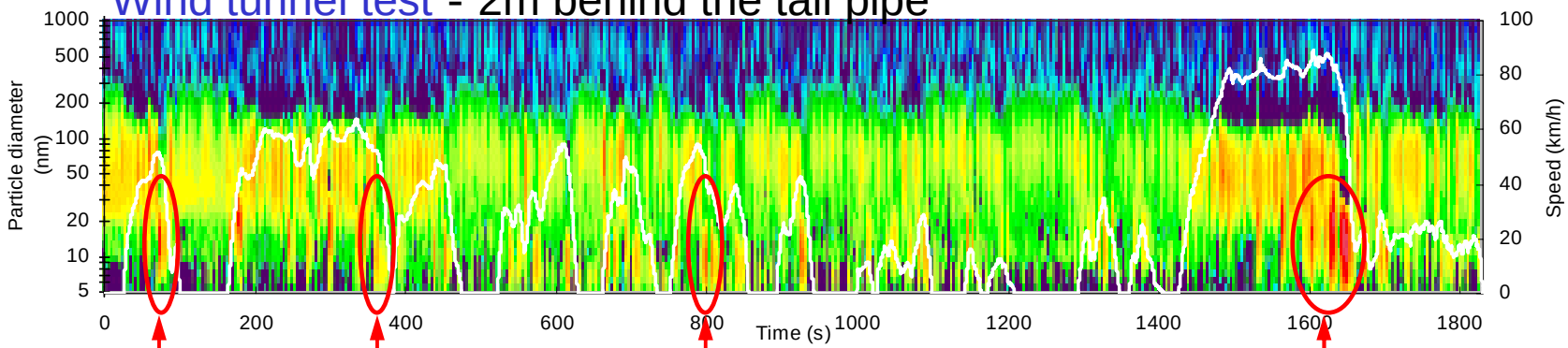
Comparison of wind tunnel and PPFDIItest results (2)

- **Transient tests (JE05 mode)**
  Nuclei mode particle formation during deceleration was reproduced.

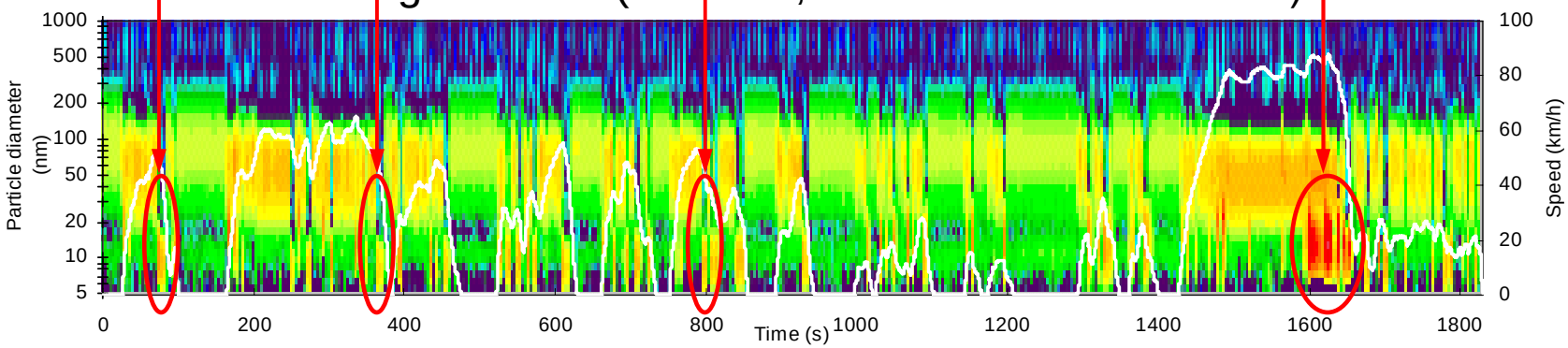
Vehicle: Diesel (DI, No after treatment)
Fuel: Diesel fuel (Sulfur 50ppm)



Wind tunnel test - 2m behind the tail pipe



PPFDII - 2 stage dilution (DR: 200, Residence time RT: 1s)



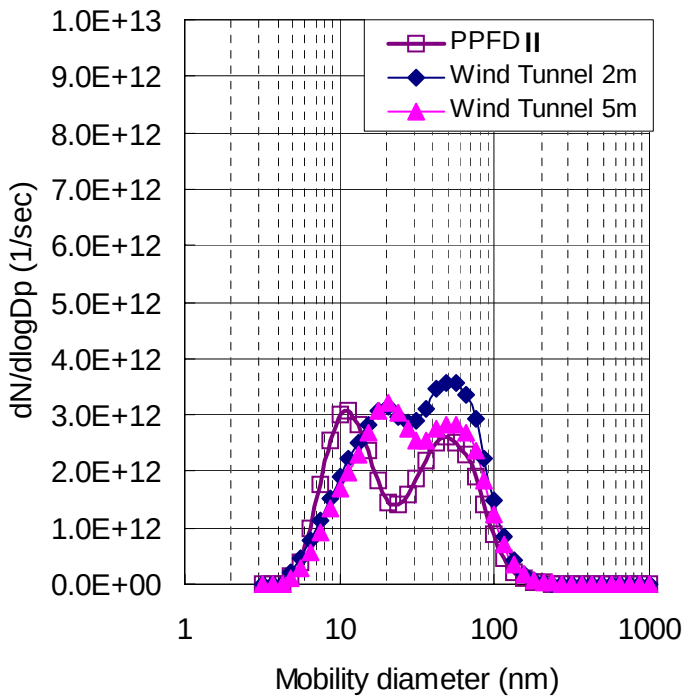
4.4 Comparison of wind tunnel and PPFDIItest results (3)

- Average particle size distributions of JE05 mode tests

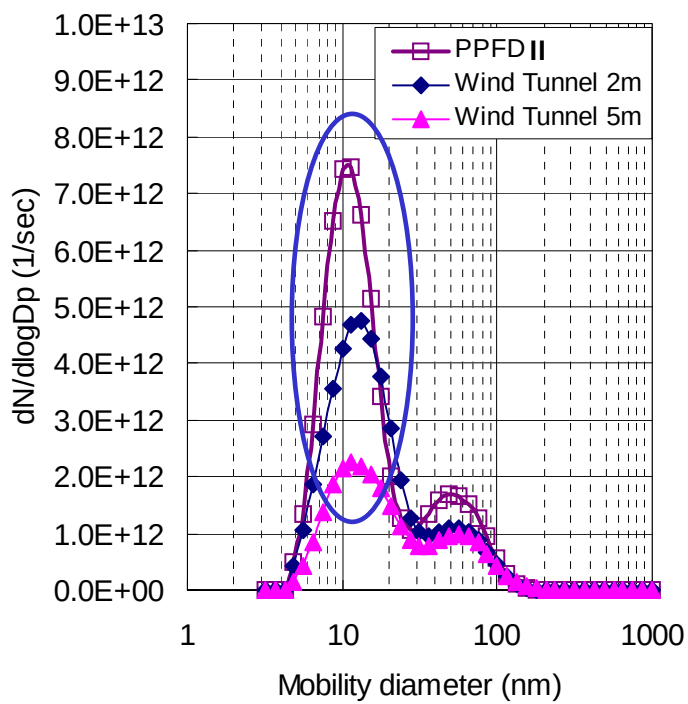
Concentration of mode average particle size distribution approximately coincided.
Large contribution of nuclei mode particles on average particle size distribution in deceleration was also reproduced.

Vehicle: Diesel (DI, No after treatment) Fuel: Diesel fuel (Sulfur 50ppm)
Wind tunnel test - 2m and 5 m behind the exhaust tube axis
PPFDII - secondary dilution(DR 200 , RT 1s)

Mode average



Average during deceleration



Contents of presentation

1. Outline of the study of unregulated material WG
2. Wind tunnel test results of size distribution measurement of ultrafine particles emitted into the atmosphere
3. Results of ultrafine particle measuring method that reproduces emission into the atmosphere
4. Summary of ultrafine particle measuring method
5. Future plan of unregulated material WG

Summary of study on ultrafine particle measuring method

Metastable particle size distribution of ultrafine particles after emitted into the atmosphere was confirmed.

⇒**Particle size distribution to be reproduced in the laboratory**

- Dilution status of ultrafine particles in metastable state

	Dilution ratio
nuclei mode particles	approx. 20 or higher
accumulation mode particles	approx. 5 or higher

Laboratory measuring method that can approximately reproduce metastable particle size distribution of ultrafine particles emitted into the atmosphere was established.

⇒ **Dilution condition of sampling system (PPFDII) was determined.**

- Dilution conditions

Primary dilution ratio	15 – 25
Residence time (sec)	1 - 2

Future plan of JCAP II Unregulated material WG

- **To clarify the direction of automobile and fuel technologies that enable the reduction of ultrafine particles.**

  - **Verification of accuracy of measuring method**
    - **Instruments correlation test for fast particle sizing (ex. DMS, EEPS)**

  - **Matrix test to assess the influences of automobile and fuel technologies on ultrafine particle emission**

  - **Measurement of emission factor of ultrafine particles for air quality modeling**

Ultrafine particle study of Unregulated material WG

Thank you for kind attention.

JCAP II Unregulated Material WG

Yanagisawa, N	ISUZU Advanced Eng. Center, Ltd.	Ikeda, T	COSMO OIL Co., Ltd.
Yamashita, T	Toyota Motor Corp.	Tanaka, S	COSMO OIL Co., Ltd.
Iwakiri, Y	Nissan Motor Co., Ltd.	Takahashi, K	Idemitsu Kosan Co., Ltd.
Shoji, T	Mitsubishi Fuso Truck and Bus Corp.	Suzuki, A	JOMO Technical Research Center, Ltd
Hosoya, M	Hino Motors, Ltd.	Sekimoto, M	ATRI
Nakajima, T	JARI		

Summary of the wind tunnel test results

- **At steady state driving condition**
  - **Particle size distributions in metastable region**
    - At several meters or more behind the tail pipe,
      the particle size distributions were confirmed to be relatively stable.
  - Dilution status in metastable region
    - Formation and growth of nuclei mode particles were found to be completed at approx. DR20
      and no significant change was observed during further dilution.

→**Reference size distribution data**
to reproduce emission into the atmosphere were obtained.

- **At transient driving condition**
  - Particle formation in transient driving was observed.
    - Formation of ultrafine particles mainly during deceleration was confirmed.
    - Qualitative data of ultrafine particle formation were obtained.