The Outline of JCAP II Research Activities

Yoshiaki Shibata
(JCAP Promotion Dept., Petroleum Energy Center)

Key word: Environment, Emission, Diesel Engine Particulate / Japan Clean Air Program

1. Introduction

Japanese automobile emission regulation is one of the stringent emission regulations in the world, however, the air quality standard has not been attained in some urban areas such as roadside of arterial roads in metropolitan area, and thus, further effort at reducing automobile emissions has been required. Japan Petroleum Energy Center has worked on a program "Development of automobile and fuel technologies for better air quality" called Japan Clean Air Program (JCAP) since 1997, a research program subsidized by the Ministry of Economy, Trade and Industry with the cooperation of Petroleum Association of Japan (PAJ) and Japan Automobile Manufacturers Association (JAMA). Research in the effect of automobile and fuel technologies on automobile emissions has been carried out to develop rationally attainable environmental load reduction technologies and also to find medium-to-long term direction of the technologies.[1)]

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 and *to provide* the government with rational technical data for policy making.
- Supported by Petroleum Energy Center, a subsidy of METI *METI: Ministry of Economy, Trade and Industry*
- **JCAP I** :1997 – 2001 (Budget: Approx. 5.4 billion yen, Numbers of staffs: over 100 members)
- **JCAP II**: 2002 – 2006 (Budget : Approx. 5.6 billion yen, Numbers of staffs: about 130 members)

Fig.1 JCAP (Japan Clean Air Program) definition

Under JCAP II, research on following subjects has been carried out: comprehension of effect of engine/fuel properties and oil properties on emissions, effect of fuel on ultrafine particles, comprehensive evaluation of fuel properties and CO2 emission, urban and roadside air quality simulation study.

Table 2 JCAP II Research Subject

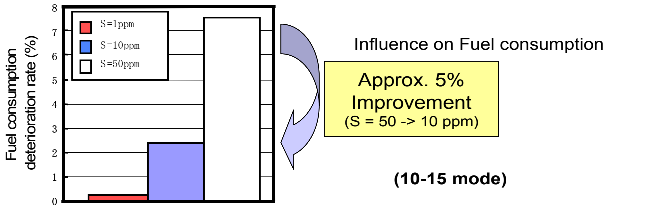
Working Group Name	Study subjects
Gasoline WG	-Fuel property influence on automobile exhaust emissions -Sulfur content influence on emissions and fuel consumption -Optimum octane number in view of total CO2 emission
Diesel WG	-Exhaust emissions and CO2 emission reduction potential with high diesel technologies and the ideal fuels
Oil WG	-Oil property influence (Ash, P, S) on after-treatment devices (DPF, DeNox catalysts, etc.)
Unregulated Material WG	-Fine particle measurement methods -Fuel and lubricant property influence on fine particles -Actual conditions of trace unregulated air pollutants
CO2 Emission Study WG	-Octane number and CO2 emission from vehicle and refineries -Low sulfur content in fuel and CO2 emission inventory from vehicles and refineries
Air Quality Model Group	-Development of next generation traffic flow model, emission inventory model, high-accurate roadside air quality model -Integration of air quality models with variable scale

2. Research Activity Outline

2.1 Gasoline WG Research Activity Outline

Gasoline WG carries out research on the effect of emission reduction technology (DI engine + NOx storage reduction catalyst, etc.) and fuel properties (sulfur content, aromatics, T90) on emissions especially for DI engine.

Fuel sulfur content reduction from 50 to 10ppm reduces the amount of fuel used for sulfur poisoning recovery of lean NOx catalyst system, which is resulted in improvement in 10·15 mode fuel consumption by approx. 5%.



Difference in fuel consumption deterioration due to catalyst sulfur poisoning recovery control

Fig.2 Effect of Gasoline Sulfur Content

2.1 Diesel WG Research Activity Outline

Diesel WG carries out research on the effect of fuel properties (sulfur content, aromatics, T90) on emissions in the case of advanced exhaust emission reduction technology (NOx adsorption reduction type catalyst, Urea-SCR, Continuous Regeneration type DPF).

Research results which are obtained so far are;

1) Effect of fuel sulfur content on fuel consumption in the case of NOx adsorption reduction type catalyst: change of sulfur poisoning recovery control frequency due to sulfur content reduction from 50 to 10ppm improves fuel consumption by approx. 4%.
2) Effect of fuel sulfur content on catalyst NOx adsorption in the case of Diesel Particulate and NOx reduction system (DPNR): sulfur removal is made for the three test fuels with sulfur content alone varied, when sulfur consumption level is provided as same, the degree of effect in descending order is 50ppm > 10ppm > 0ppm.

2.2 Oil WG Research Activity Outline

Oil WG carries out research on the effect of oil formulation on aftertreatment devices such as Continuous Regeneration type DPF (CR-DPF), NOx adsorption reduction type catalyst, etc.

For CR-DPF, the amount of engine oil ash and clogging with additive-derived metals varied by additive type and formulation are evaluated. For NOx adsorption reduction type catalyst, the effect of phosphorus and sulfur content in engine oil is evaluated.

Research results on the effect of oil ash on CR-DPF[2)] are:

1) Oil sulfated ash is reduced, ash deposit on DPF decreases and increase in pressure drop is also lessened. Main component of ash deposited on DPF is $CaSO_4$.
2) Oil ash tends to deposit on downstream side of DPF more than upstream side, and to deposit mainly on filter surface, that is, less invasion of DPF wall is observed.

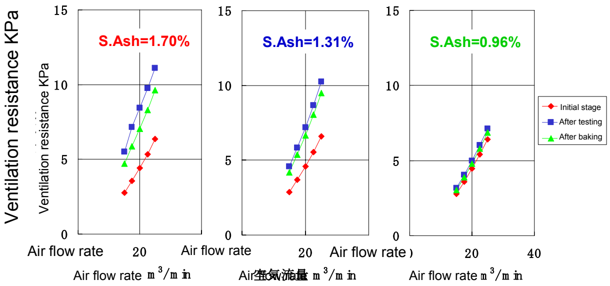


Fig.3 Oil ash and ventilation resistance of CR-DPF

2.3 Unregulated Material WG Research Outline

Unregulated Material WG carries out research on the effect of advanced engine and fuel technologies on ultrafine particles through comparison in measurement method for fine particles and unregulated materials.

Since standard calibration method of fine particle measurement instruments has not been established, Unregulated Material WG did a cross-check on fine particle measurement instruments such as ELPI, SMPS, etc. in cooperation with domestic research institutes extensively to evaluate accuracy and reproducibility of the instruments.

Particle size is almost coincided, however, particle number concentrations are varied by instruments. Difference in hard/software of instruments makes a wide difference in particle number concentrations.

Meanwhile, research on the reality of fine particle emission through chasing experiment and simple wind tunnel test, etc. has been carried out for evaluation of the reality of fine particles in automobile exhaust emissions. Chasing experiment is a test in which fine particles emitted from the foregoing test vehicle on test course are measured by the chasing monitoring vehicle. Simple wind tunnel test is a test in which test vehicle on chassis dynamometer is covered with simple wind tunnel and evaluation of fine particle emission is made.

In fine particle size distribution, (sulfate-derived?) nuclei mode particle formation tends to restrain because of sulfur content reduction in fuel. And emission aftertreatment device (CRT) and low sulfur fuel have a possibility of reduction in fine particle emission.


Fig.4 Chasing Experiment

2.4 Air Quality Model WG Research Activity Outline

Succeeded to JCAP I study results, Air Quality Model WG carries out research aiming to “supply high accurate data and advanced tool so as to help neutral and effective environmental policy-making based on data”.

Keywords of Air Quality Model research activity are:

1) Real World: Emission inventory under actual conditions
2) High accuracy: Contribution of background concentration - Multi-scale model,
3) Roadside: Concentration distribution in intersections - Inhabitants, pedestrians, drivers, etc.
4) Nanoparticle: Tailpipe out emission

Nanoparticle model having a close relationship with diesel engines and roadside air quality observation is outlined.

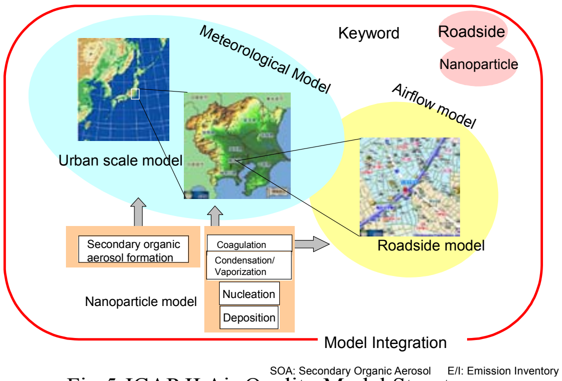


Fig.5 JCAP II Air Quality Model Structure

2.5 Roadside Observation

Nanoparticle roadside observation has been made to gather input data into Nanoparticle model and its verification data at roadside in Tokyo metropolitan area to clarify relationship between traffic conditions and particle size distribution in the air. Monitoring points are selected based on correlation analysis of Tokyo Metropolis traffic data in traffic census, in which traffic volume affecting traffic conditions considerably, heavy-duty vehicle mixing ratio, and field survey result at the top and low ranking points of average vehicle speed during rush hours were taken into consideration. Ultrafine particulate matter number concentrations by particle size and meteorological data have been measured using Scanning Mobility Particle Sizer (SMPS) at the 13 monitoring points.

Particle number concentration distribution at monitoring points was classified into 4 types in terms of distribution shape. Number concentration peak is observed around 30nm of particle size at points with high passenger car mixing ratio, while around 18nm at points with high heavy-duty vehicle mixing ratio.

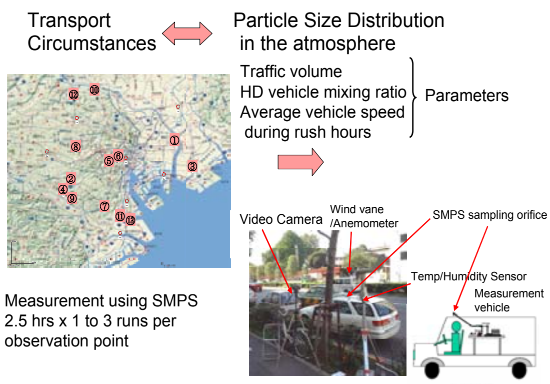


Fig.6 Roadside Observation Outline

3. Postscript

Interim report on JCAP II is scheduled to issue at the end of FY 2004, and every WG will pursue research for producing good results expected at the termination of JCAP II.

Technical reports, presentation materials, and latest research activities of JCAP are appeared on the following JCAP homepage: http://www.pecj.or.jp/jcap/index-jcap.htm

References

1) Y Shibata et al. : ” Results of JCAP I Studies and Outline of JCAP II Program”、SAE 2003-01-1902
2) S. Nemoto et al. :“Impact of Oil-derived Ash on

PEC-2001JC-26　タイヤ磨耗粉等の微小粒子に関する沿道大気観測報告書、平成14年3月

Continuous Regeneration-type Diesel Particulate Filter",
SAE 2004-01-1887

JCAP II
JAPAN CLEAN AIR PROGRAM

Further Challenge in Automobile and Fuel Technologies for Better Air Quality

The Outline of JCAP II Research Activities

Yoshiaki Shibata

JCAP Promotion Dept.
Japan Petroleum Energy Center

August 16, 2004
8th ETH-Conference

Content

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 and *to provide* the government with rational technical data for policy making.
- Supported by Petroleum Energy Center, a subsidy of METI *METI: Ministry of Economy, Trade and Industry*
- **JCAP I** :1997 – 2001 (Budget: Approx. 5.4 billion yen, Numbers of staffs: over 100 members)
- **JCAP II**: 2002 – 2006 (Budget : Approx. 5.6 billion yen, Numbers of staffs: about 130 members

JCAP II Study Subject Outline

(1) Automobile and Fuel Technology Study

- Evaluate high technology for gasoline/diesel vehicles aiming at near Zero Emissions and fuel/oil properties
- Evaluate emissions and CO_2 reduction potential
- Examine fine particle measurement method and evaluate high technology through high measurement methods

Key Word: Zero Emissions, CO_2 reduction, Octane Number of Gasoline, Bio fuel, Nanoparticle, Oil properties (Ash, P,S)

(2) Air Quality Model Study

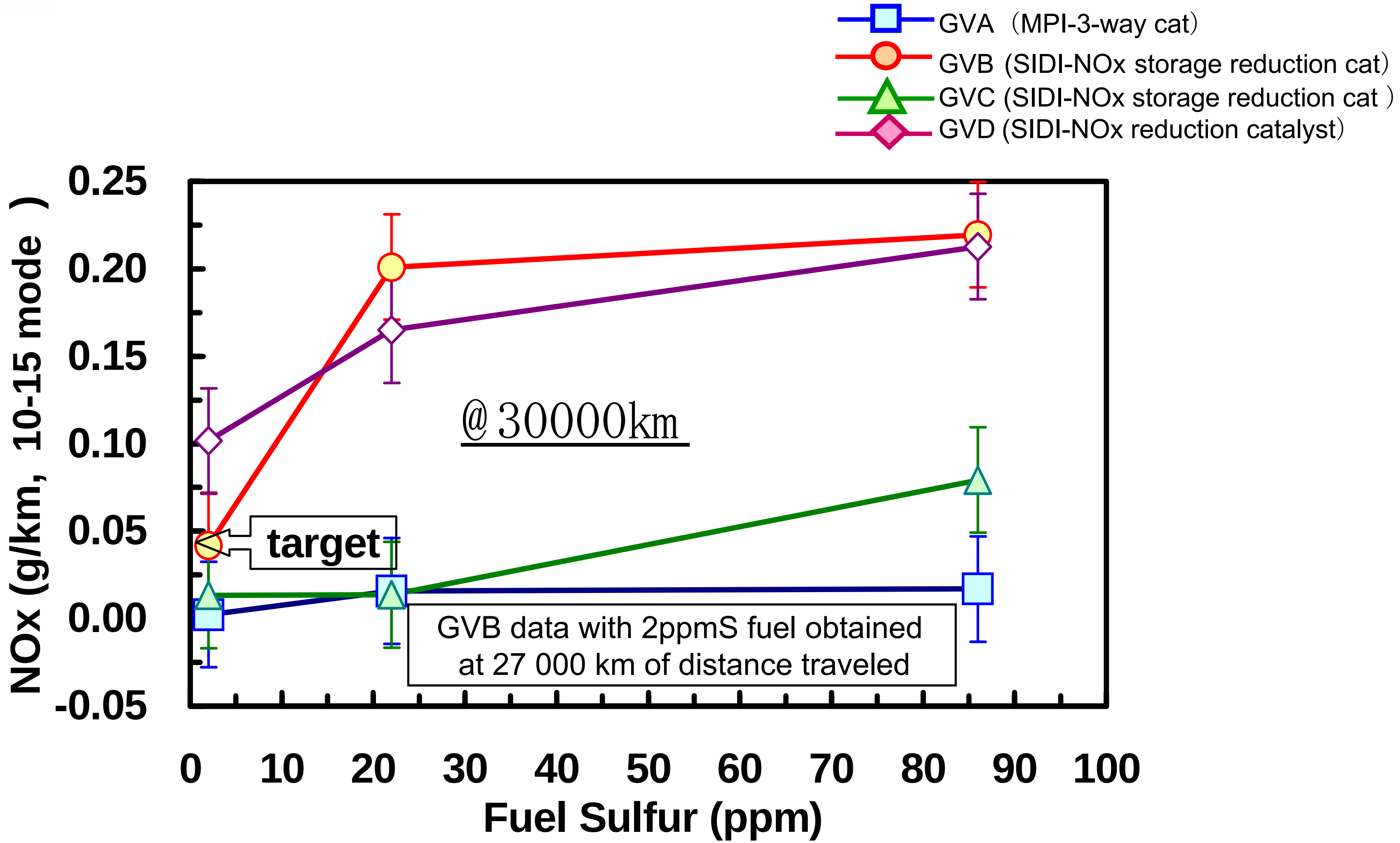
- Build Real-world Emission Inventory Simulation Model
- Build Integrated Air Quality Model of Urban Air Quality Model and Roadside Air Quality Model
- Evaluate Integrated Air Quality Model and Case Study

Key Word: Real world, High accurate model, Roadside, Nanoparticle

Working Group study subject

Working Group Name	Study subjects
Gasoline WG	-Fuel property influence on automobile exhaust emissions -Sulfur content influence on emissions and fuel consumption -Optimum octane number in view of total CO_2 emission
Diesel WG	-Exhaust emissions and CO_2 emission reduction potential with high diesel technologies and the ideal fuels
Oil WG	-Oil property influence (Ash, P, S) on after-treatment devices (DPF, DeNox catalysts, etc.)
Unregulated Material WG	-Fine particle measurement methods -Fuel and lubricant property influence on fine particles -Actual conditions of trace unregulated air pollutants
CO_2 Emission Study WG	-Octane number and CO_2 emission from vehicle and refineries -Low sulfur content in fuel and CO_2 emission inventory from vehicles and refineries
Air Quality Model Group	-Development of next generation traffic flow model, emission inventory model, high-accurate roadside air quality model -Integration of air quality models with variable scale

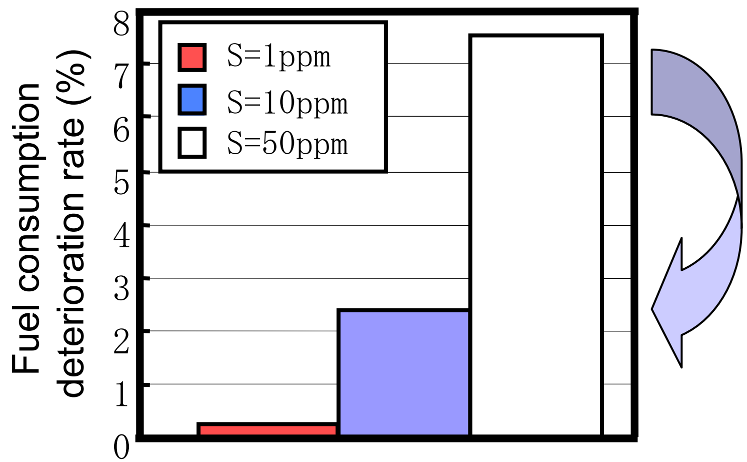
Sulfur Effect on NOx Emissions



-Although no sulfur effect is shown in any test vehicles at 0 km, the effect is evident in SIDI vehicle at 30,000 km of distance traveled.

Effect of Sulfur on Fuel Economy

Gasoline Engine with NSR Catalyst



Effect on Fuel consumption

Approx. 5% Improvement
(S = 50 -> 10 ppm)

(10-15 mode)

Diesel Engine with NSR Catalyst

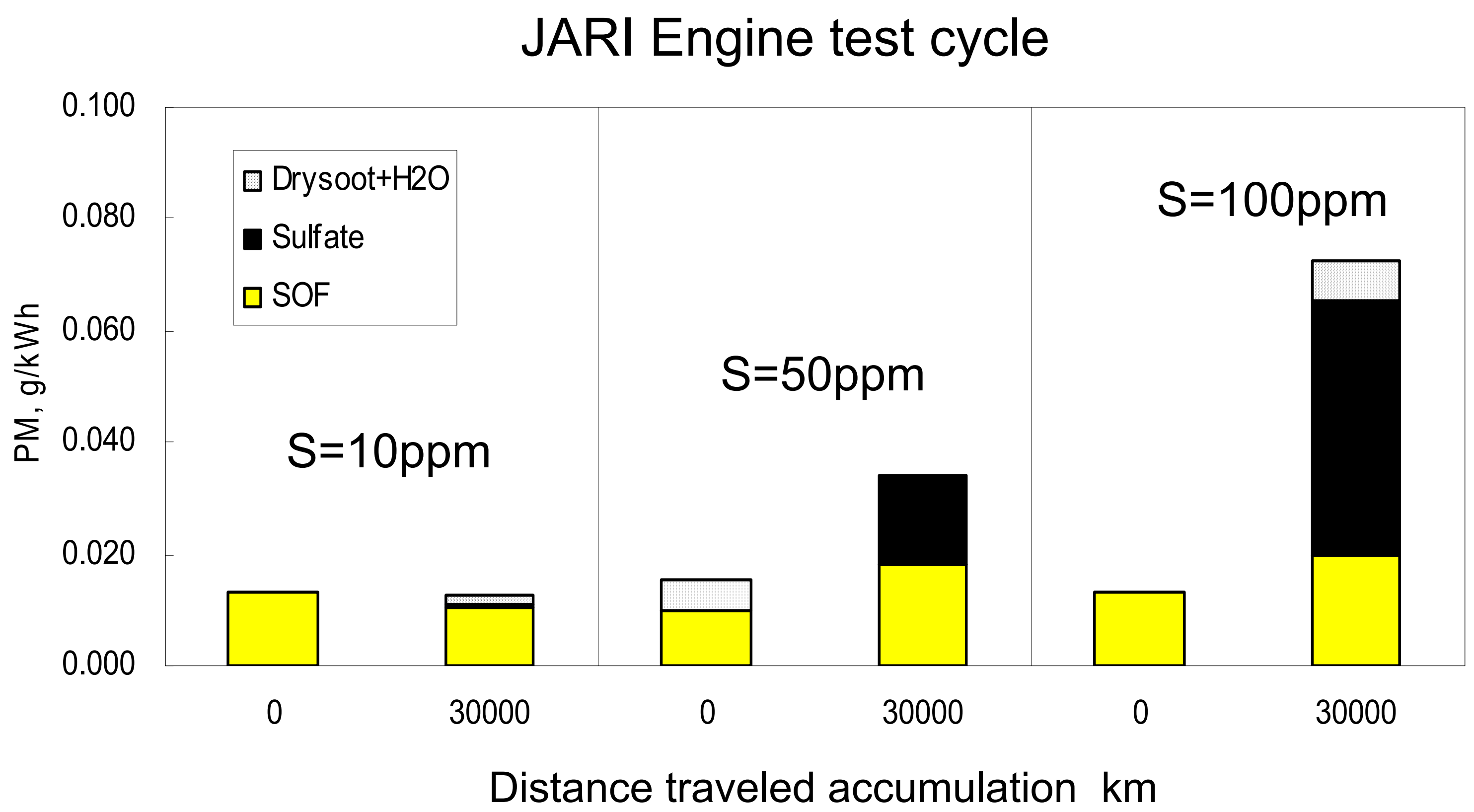
S=50ppm Fuel consumption: 6.62km/L

S=10ppm Fuel consumption: 6.88km/L

3.9% Improvement

(Corrected 11 laps)

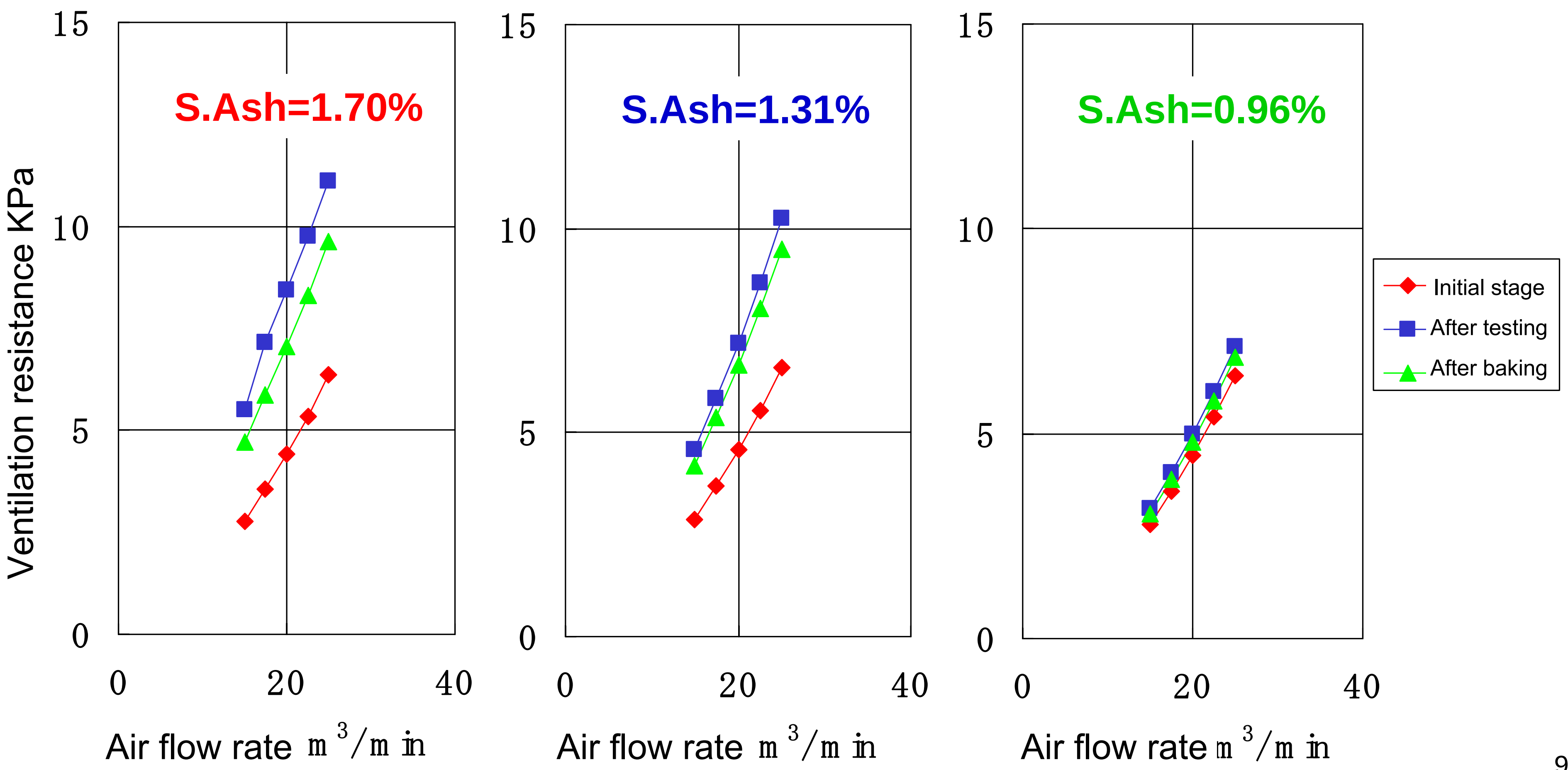
Effect of Sulfur on DPF



Emissions from Diesel Vehicle

Pressure Drop Change in CR-DPF

- **Pressure drop of DPF after 600 hr driving test has been measured.**
  - **Ventilation resistance increases as sulfated ash in oil increases at every air flow rate.**
  - **In case of Sulfated Ash = 1.70%, ventilation resistance increase after baking, it suggested amount of residual soot was large.**



Microscopic Examination

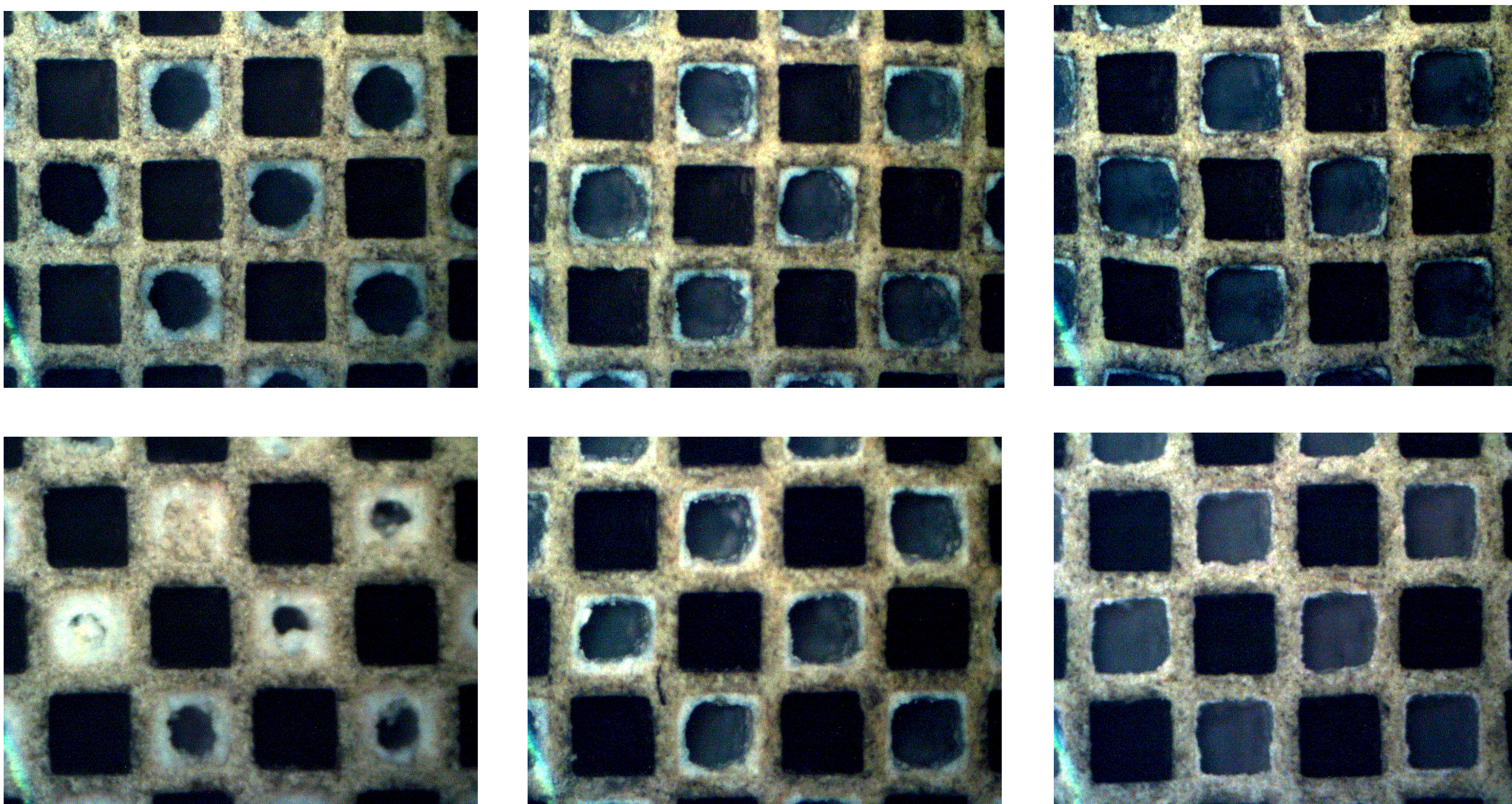
(Center part of DPF, before Reverse Air Blow)

- **Clogging tends to arise at downstream side more than upstream.**
- **Deposit increases as sulfated ash in oil increases.**

S. Ash=1. 70% | S. Ash=1. 31% | S. Ash=0. 96%

Upstream side

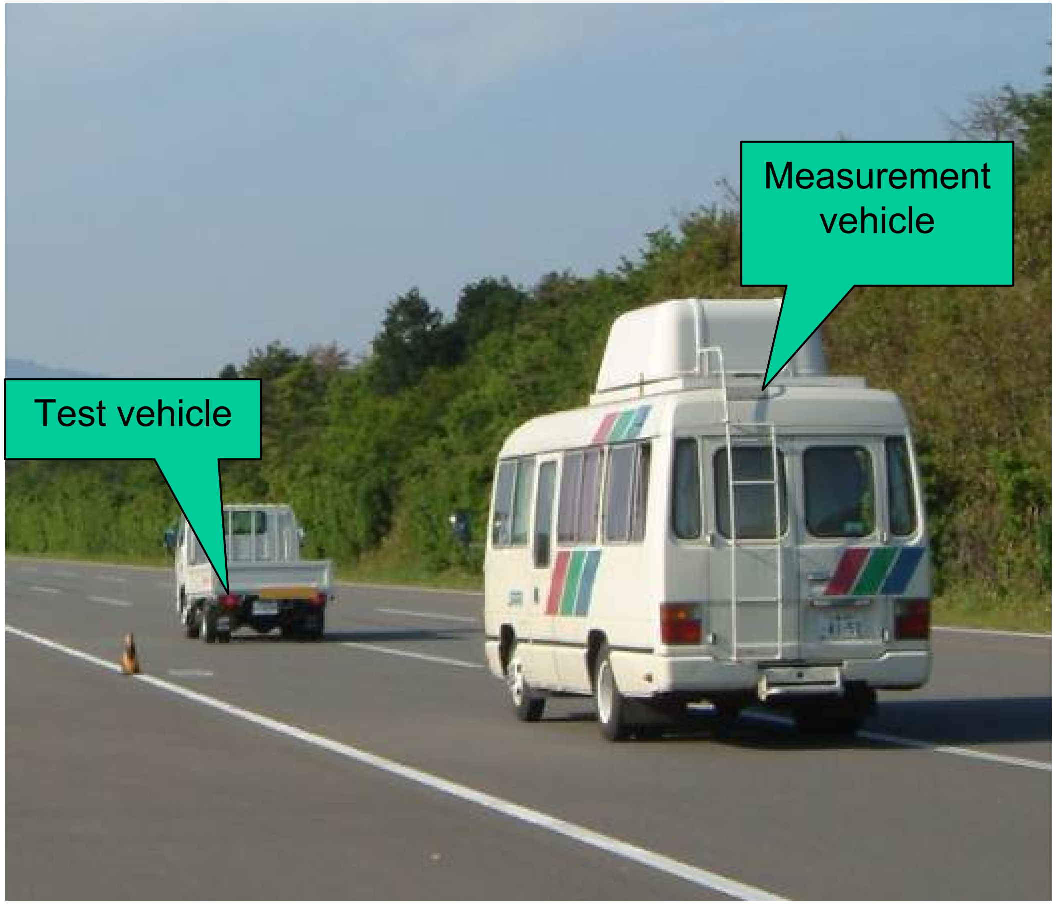
Downstream side



Fine Particles Emission into the Atmosphere

(Chasing Experiment)

- Measurement of fine particles emitted during actual driving
  - Fine particles from the preceding test vehicle were measured by the chasing measurement vehicle on JARI test course



Chasing Experiment Results —Comparison by vehicle type

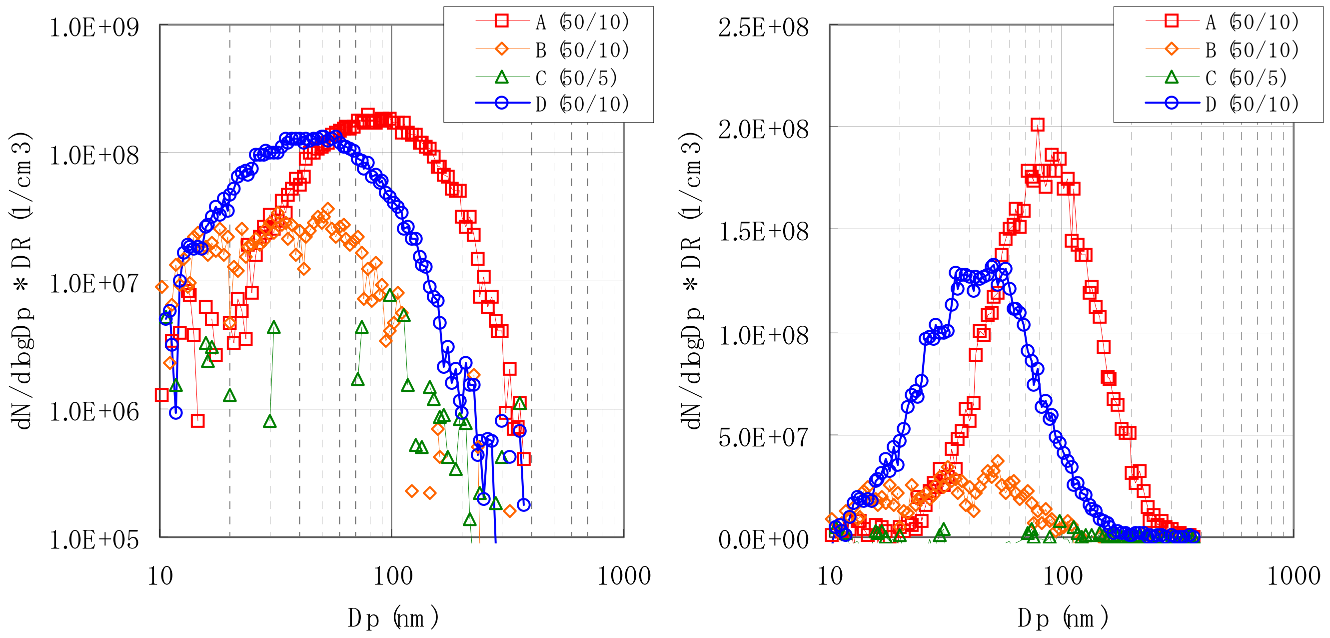
- Particle size distribution comparison
  (after dilution ratio correction)

  -Particle Number concentration:

  A(DI with DOC), D(DI) > B(SIDI) >> C (DI with DPF) ~ BG

  -Mode particle diameter:

  A (DI with DOC) > D (DI), B (SIDI)



Effect of Sulfur Content in Fuel

-Vehicle D Chasing experiment : Comparison between 50ppm and 500ppm

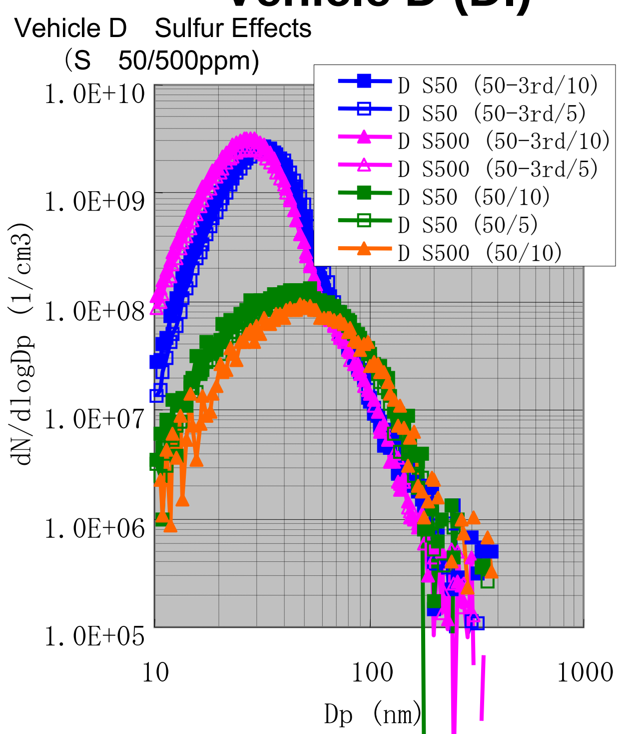
- Effect on accumulation mode and nuclei mode particles is not so great.

-Vehicle A Chassis dynamometer test: Comparison between 50ppm and 500ppm

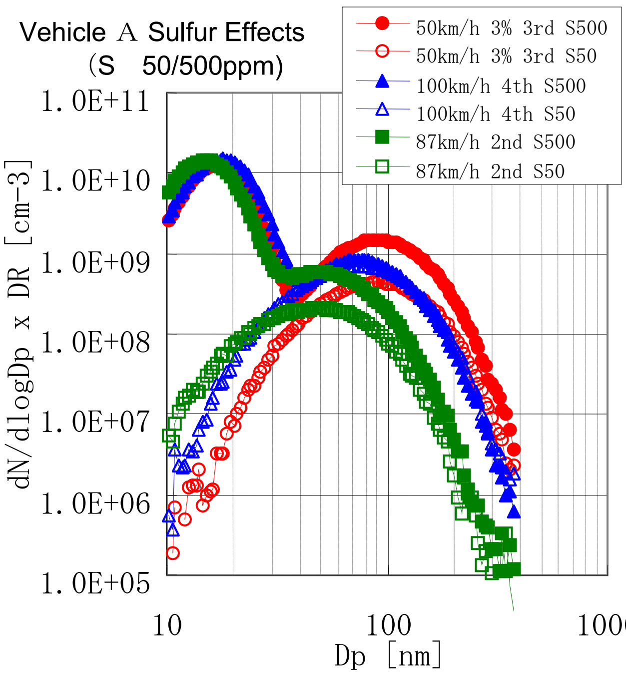
- Nuclei mode particle formation tends to be restrained with sulfur reduction.

Analysis results suggest that principal chemical component of nuclei mode particle for Vehicle A is sulfate, that for Vehicle D is other species (hydrocarbon?).

Vehicle D (DI)

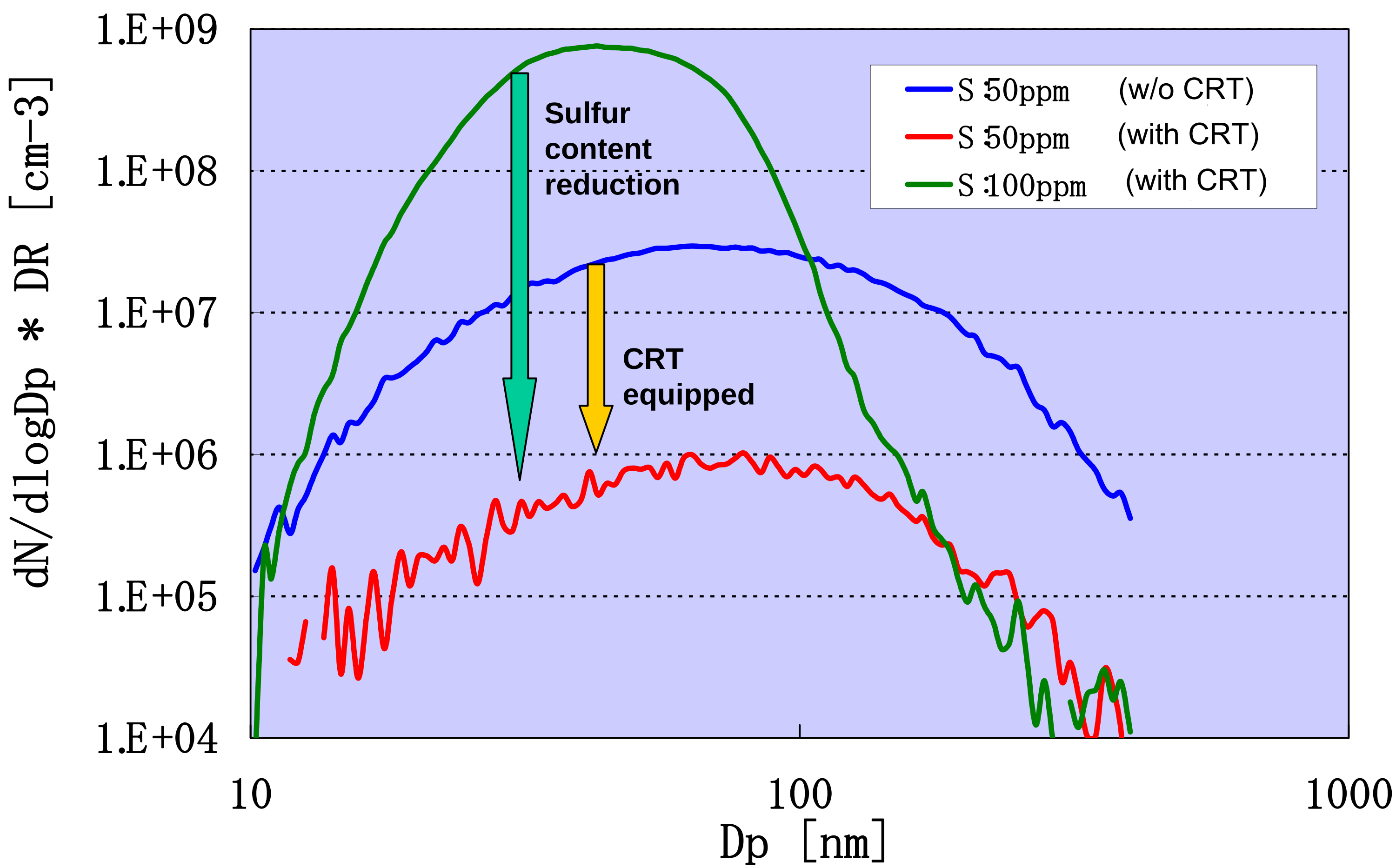


Vehicle A (DI with DOC)



Diesel Engine Bench Test Results

Combination of aftertreatment device and low sulfur fuel has a possibility of reduction of fine particles emitted from diesel engine.



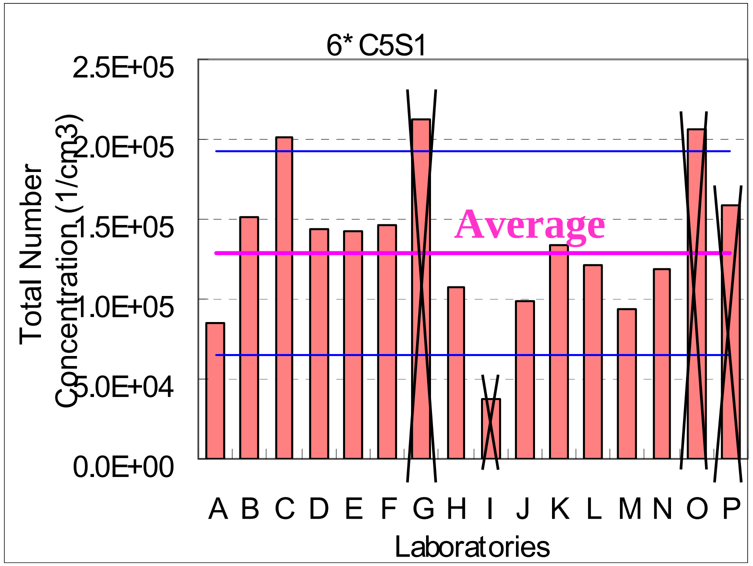
※Same dilution rate and same driving conditions

SMPS Crosscheck Results

- Among all SMPS, particle diameter almost coincides, however, particle number concentration largely differs.
  - Variation of Hardware and Software of instrument type makes a large difference in particle number concentration.
  - **Comparison should be made on instruments with same specifications**

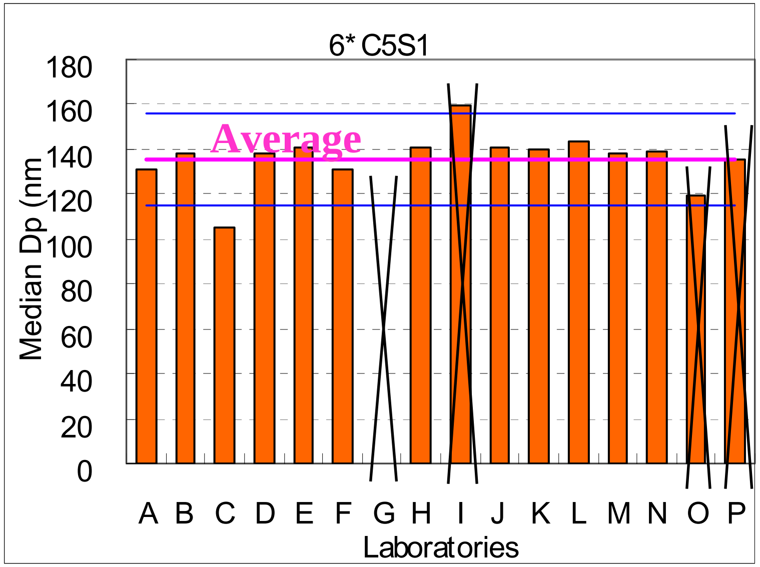
Particle number concentration COV

All devices 35%⇒ Instruments with same spec 25%



Particle size COV

All devices 9%⇒ Instruments with same spec 8%



Summary of Study Results to Date

- Particle size distribution of fine particles from automobile

  Fine particles emission into the atmosphere (Chasing experiment)

  - Repeatability is almost good.
  - Fine particle emissions from the largest: DI, SIDI, DI vehicle with DPF.
  - Nuclei mode particle tends to restrain because of sulfur reduction.
  - Nuclei mode particle formation under stead speed driving are limited.

- Chasing experiment reproduction in chassis dynamometer
  - Exhaust emissions diffluence dilution system (PPFD) is needed to improve.

- Automobile and fuel technologies effect on fine particle

  Study through Diesel engine bench test

  - Aftertreatment device (CRT) and low sulfur fuel has a possibility of reduction of fine particles emitted from diesel engine.

- Fine particle measurement instrument calibration method

  Crosscheck test on various instruments at the same particle emission source

  - For comparison of SMPS and ELPI, make and specifications of the instrument should be unified.

Aim of JCAP II Air Quality Modeling Study

Succeed to JCAP I study results

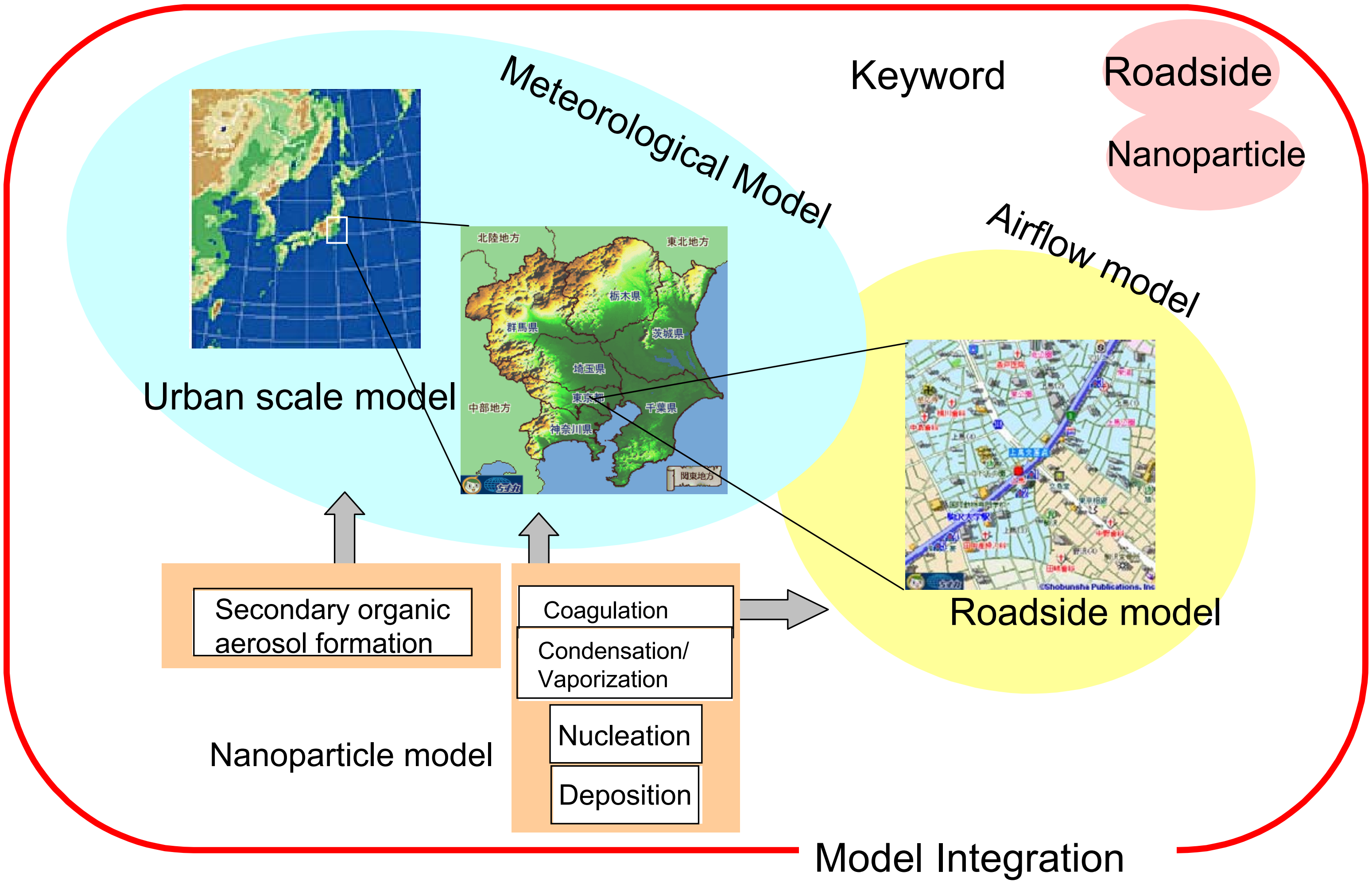
For predict the effect of air quality improvement measures such as automobile exhaust emission reduction and so on

[Supply high accurate data and advanced tool so as to help neutral and effective environmental policy making based on data]

Aim

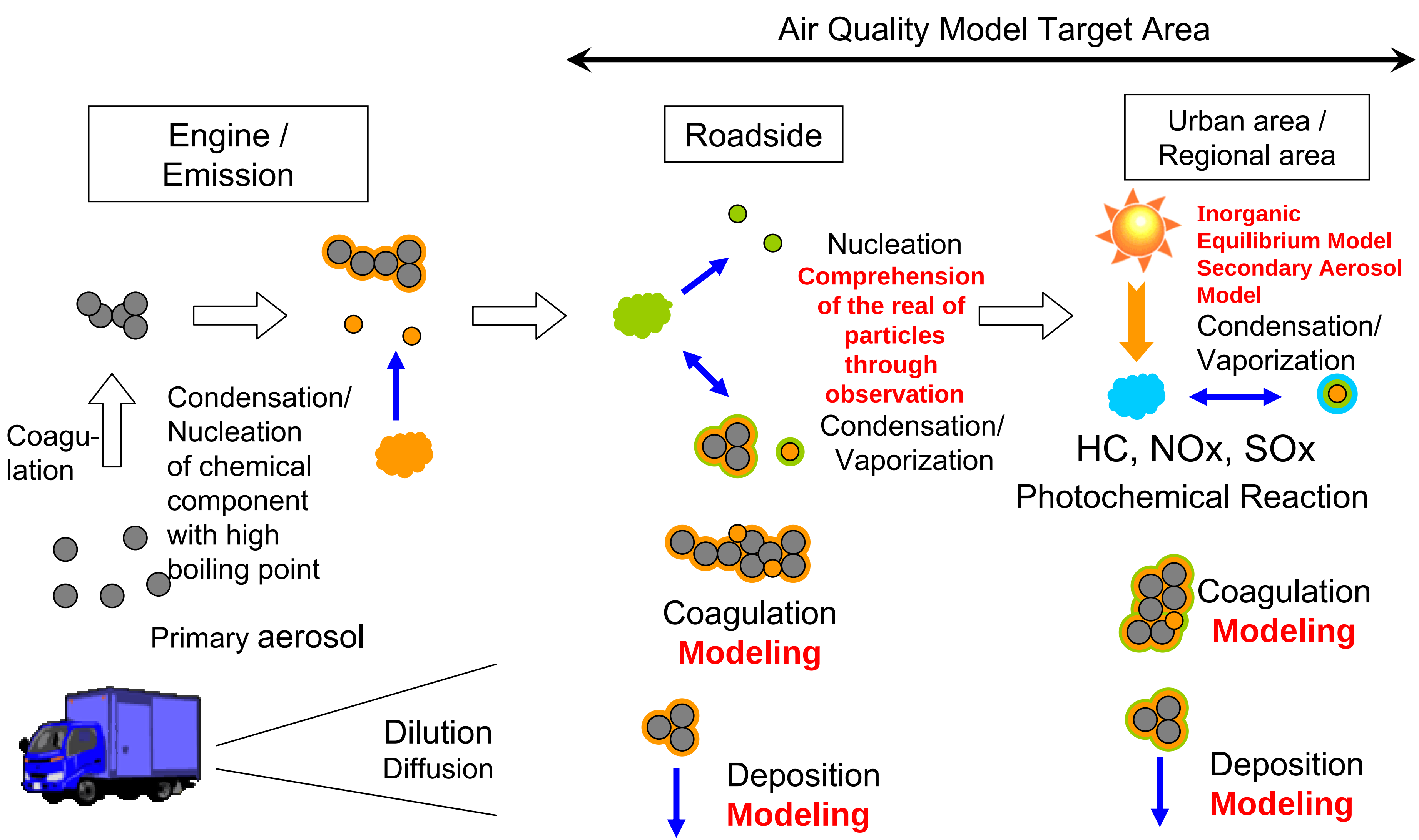
- **Real World** Emission inventory simulation under actual driving conditions
- **High accuracy** Contribution of background concentration – Multi-scale model, Emission inventory simulation and verification
- **Roadside** Concentration distribution in the vicinity of intersections - inhabitants, pedestrians, drivers, etc.
- **Nanoparticle** Tailpipe out emission ⇒ Kinetic behavior

JCAP II Air Quality Model Structure

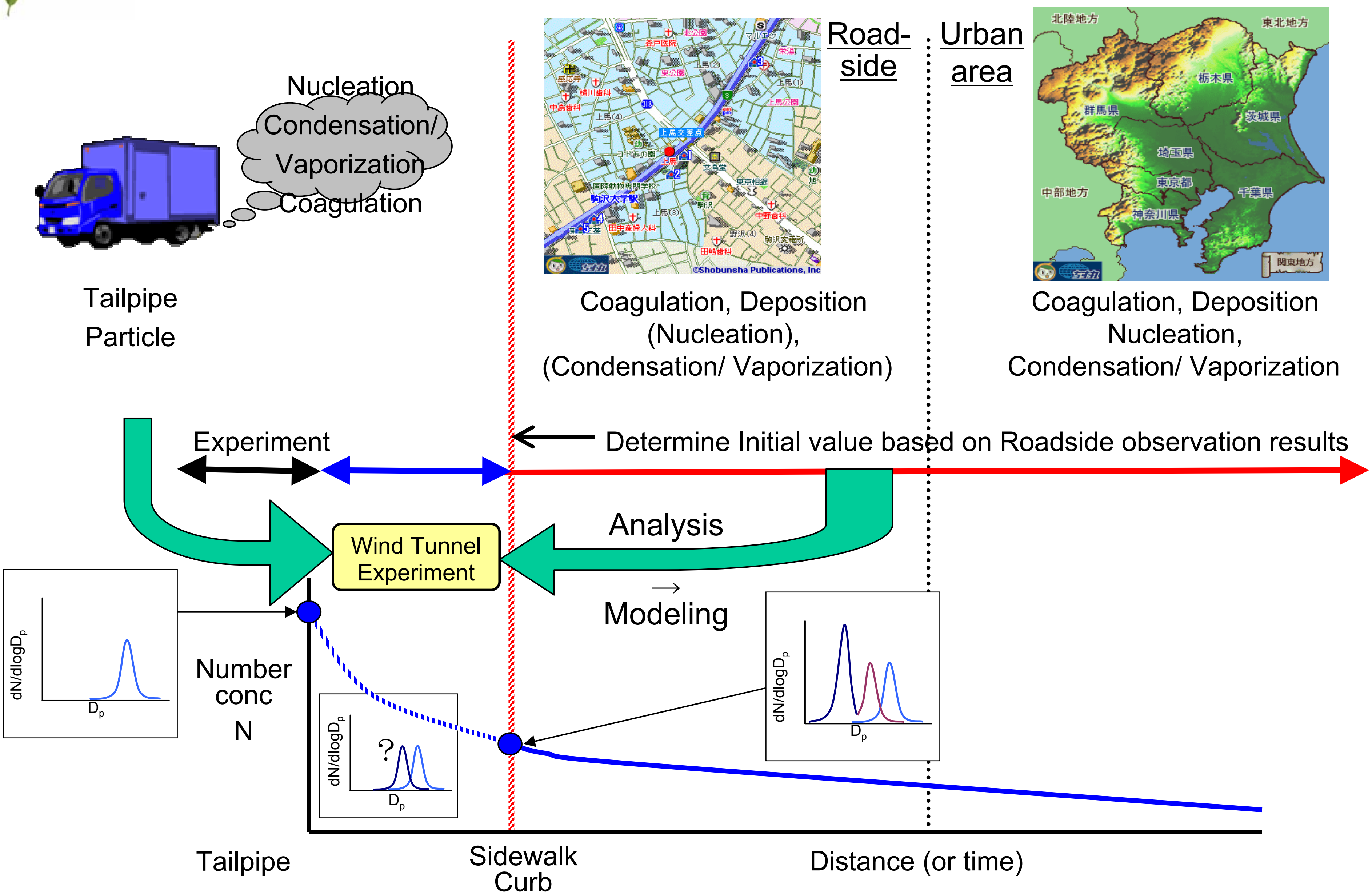


Nanoparticle Model

Nanoparticle in automobile exhaust emissions –
Behavior in the atmosphere (Image)

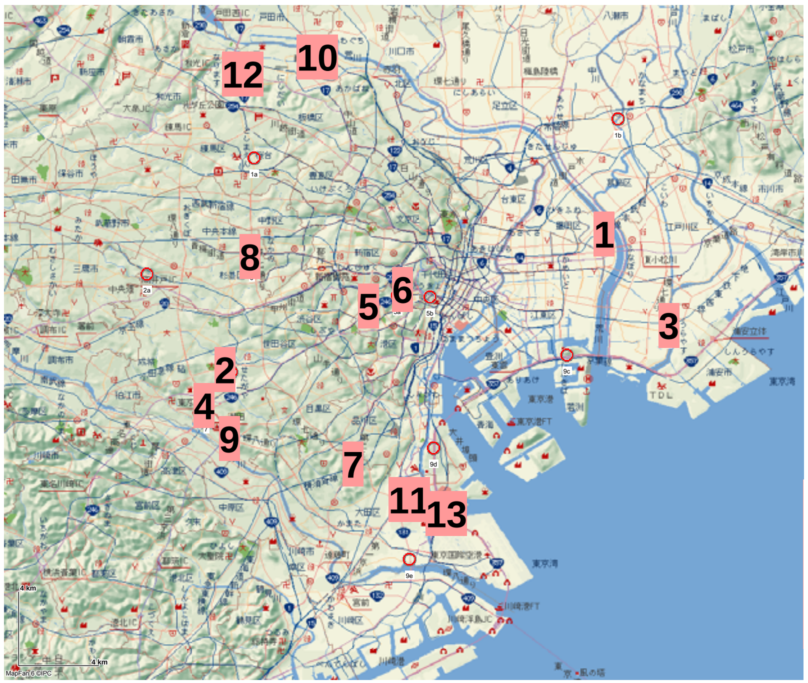


Roadside Observation Outline



Roadside Observation Results - Example 1 -

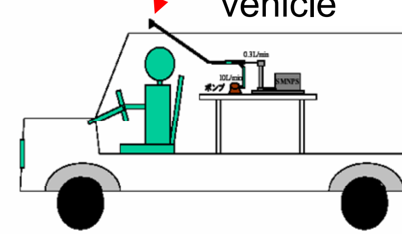
Transport Circumstances ⟷ Particle Size Distribution in the atmosphere



Traffic volume
HD vehicle mixing ratio
Average vehicle speed during rush hours

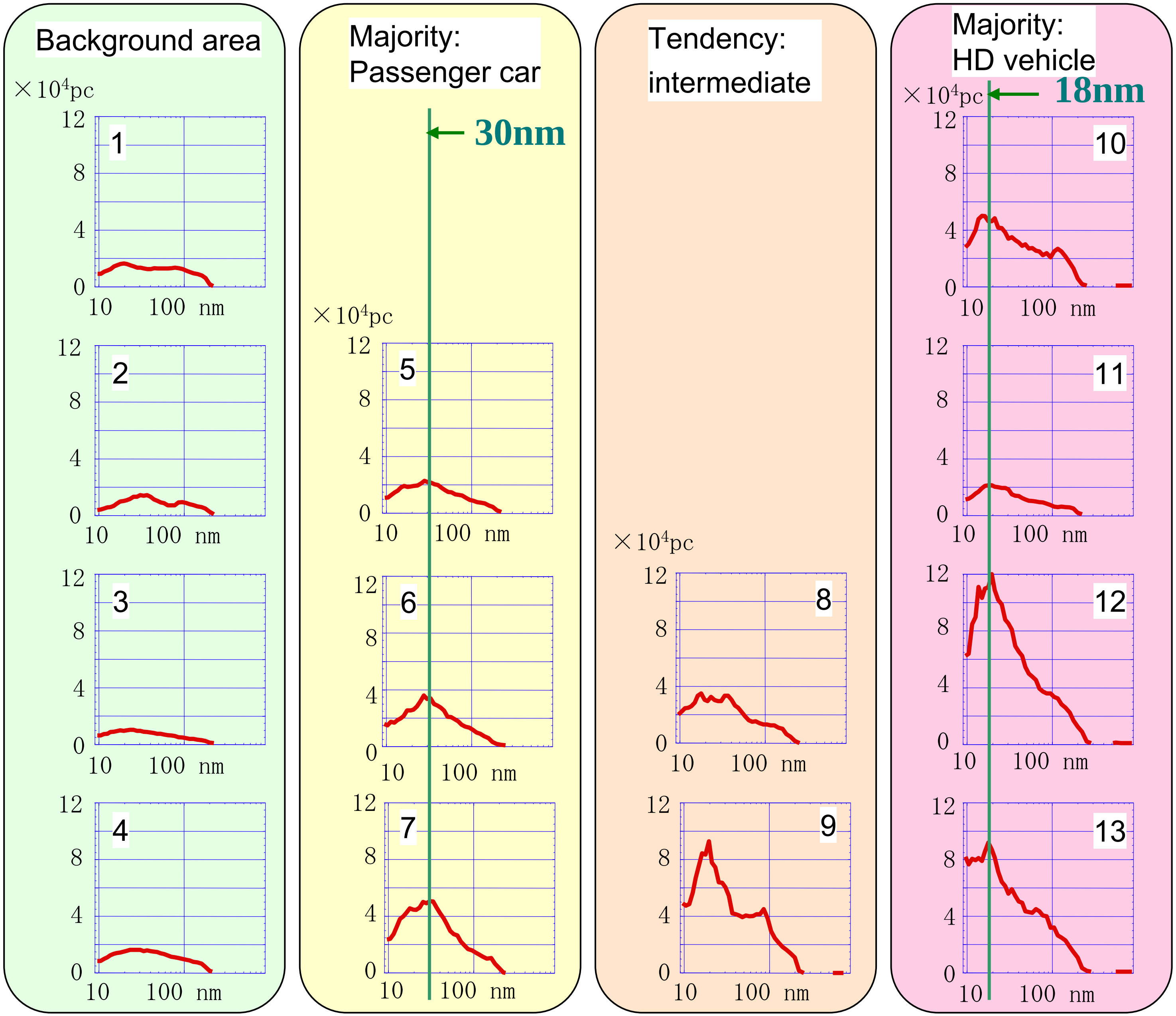
} Parameters

→ 13 observation points are selected in Tokyo Metropolitan area



Measurement using SMPS
2.5 hrs x 1 to 3 runs per observation point

Roadside Observation Results – Example 2



Roadside Observation – Winter 2004

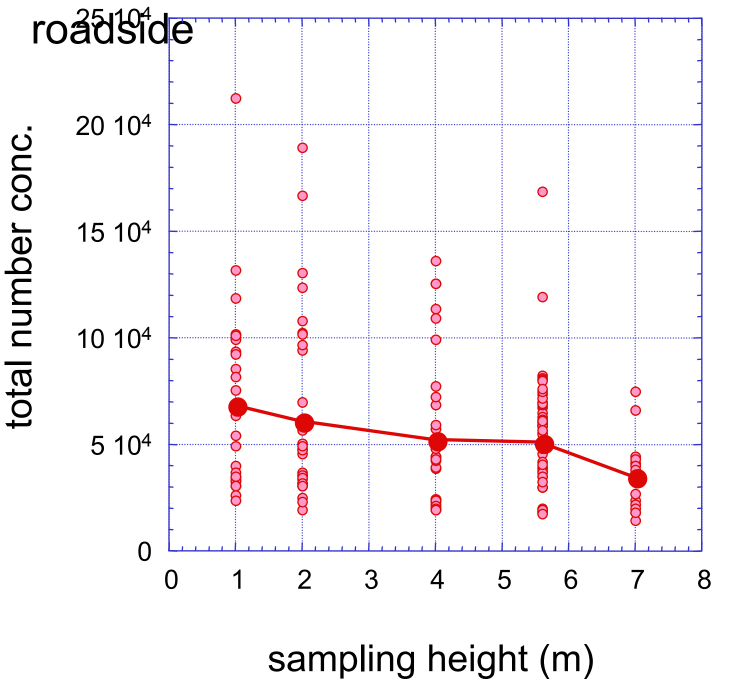
Roadside Observation Results – Example 3

Observation purpose:

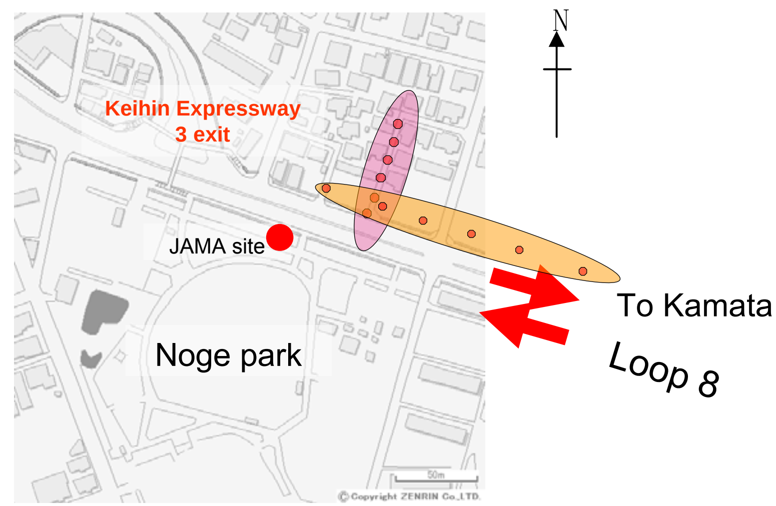
Set roadside boundary conditions for Nanoparticle Model establishment

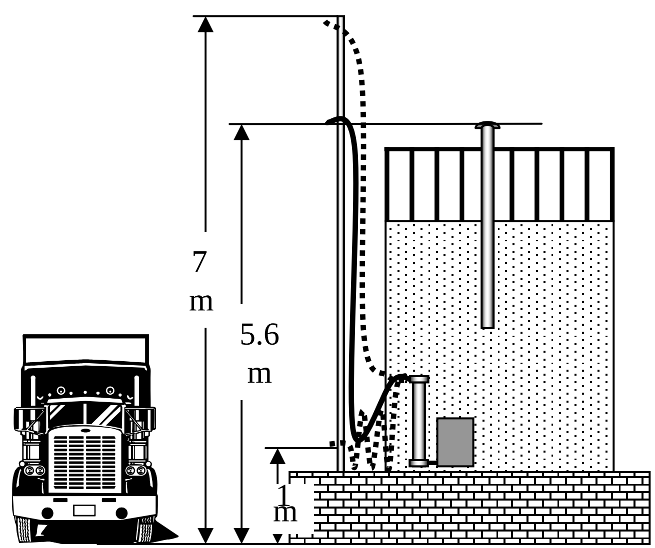
Observation parameters:

1. Vertical profile measurement at 1, 2, 4, 5.6 and 7m in altitude
2. Change in number concentration distribution from intersection along the arterial road
3. Measurement of decay by distance from roadside



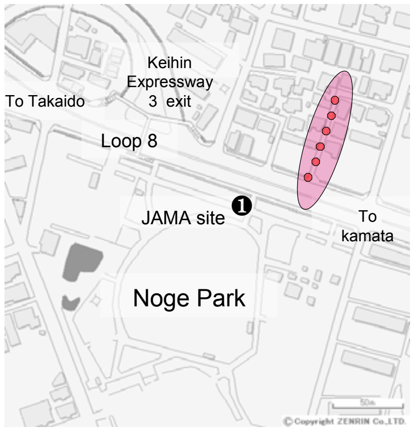
Number Concentration Vertical Profile

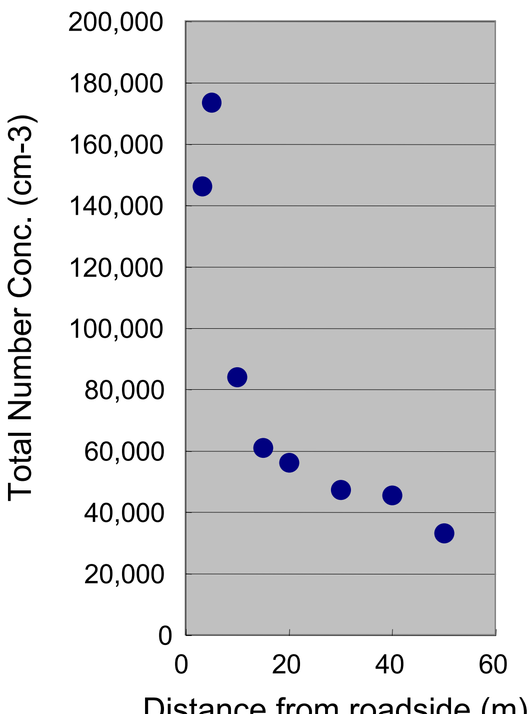




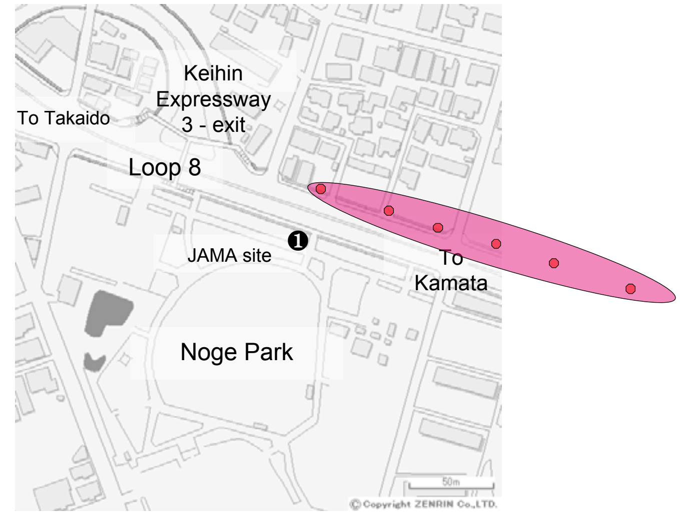
Roadside Observation Results – Example 4

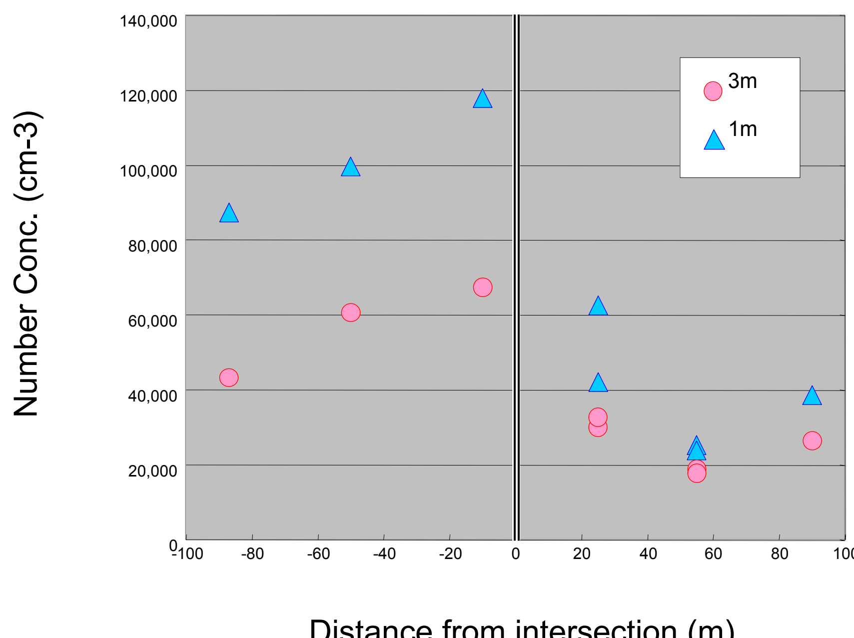
Decay by distance at Roadside



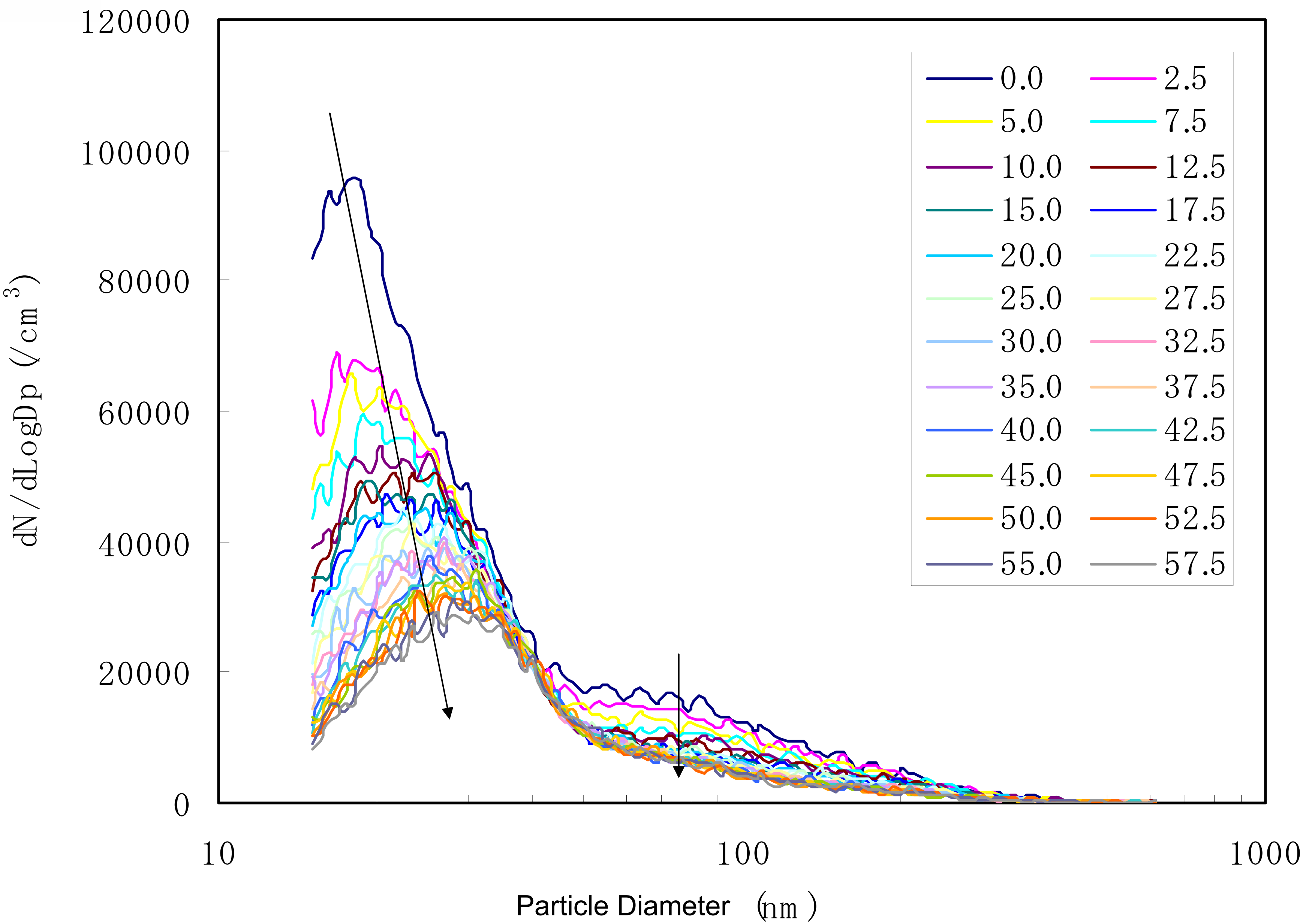


Change in distance from intersection





Particle Size Distribution Hourly Change in Chamber Experiment



JCAP II conference is planned to hold in June 2005.

Details shall be announced on our Website.

http://www.pecj.or.jp/jcap/index-jcap.htm

Thank you for your kind attention !