# Particles Emission from a HD diesel vehicle with urea SCR Catalyst

**Yuichi GOTO, Hajime ISHII, Hisakazu SUZUI, Terunao KAWAI**
**Environment Research Department**
**National Traffic Safety and Environment Laboratory**

## 1. Preface

To meet with the Japanese new long-term exhaust regulation (2005), one solution of reduction technique for diesel vehicle's NOx is urea SCR (Selective Catalytic Reduction). Before SCR catalyst urea water is added and urea water is formed into ammonia by hydrolysis; thereby NOx is reduced at SCR with ammonia as reductant. Also, at SCR outlet, post oxidation catalyst oxidizes and reduces surplus ammonia. Pre oxidation catalyst converts from NO to $NO_2$, oxidizes and reduces HC and CO. Moreover, this catalyst increases the exhaust gas temperature to light-off temperature of SCR catalyst.

NOx reduction by Urea SCR system is one different way from other storage reduction measures using catalyst (NSR, NOx Storage Reduction). In this paper only Urea SCR (without DPF) system is focused on. PM reduction is done by improving engine parts, such as improving the high-pressure fuel injection. Therefore, although this achieved value less than the new long-term regulation value (<0.027g/kWh) by adding urea SCR system, the particle emission behavior is not clear from the viewpoint of particle number.

For a vehicle with Urea SCR system achieving level for new long-term regulation; emission behavior of particulate matter from the standard particle number is examined by using EEPS that can measure excessive particle behavior.

## 2. A Test Vehicle and Test Device

Mass weight of test vehicle is 25t, with the emission amount of 9.2Ｌ. Urea SCR system is installed at the vehicle. JIS No. 2 light oil was used with sulfur contents of 24ppm. Test urea water used was equivalent of DIN standard. The vehicle is installed on chassis. Steady and transient driving mode were performed. Because the particle concentration in the exhaust gas is high, the sampling gas was diluted 8 times by Dekati diluter. The particle size distributions of the exhaust gas were measured by EEPS (Engine Exhaust Particle Sizer, TSI3090). Simultaneously, the engine speed and vehicle speed were measured. Particle measurement was done at about 2 meters back of the tailpipe after Urea SCR system passed at flow.

## 3. Test Condition

For each conditions, such as steady driving mode condition (60, 80km/h), quasi-steady driving mode condition (Japanese D13 mode) and transient driving mode condition (JE05 mode, FTP mode), tests were done and Urea SCR system's particle size distribution behaviors at transient condition were measured.

## 4. Results and Observation

### 4.1 Particle Size Distribution on Idling

The particle size distribution on idling has two peaks of less than 6nm and about 70nm. Small peak of particle size is the peak of nuclei mode, which is formed nuclei mode particle when hydrocarbon were condensed.

### 4.2 Steady and Quasi-Steady Test（D13）

In particle size distribution under steady driving mode（60, 80km/h）condition, the particle concentration become high under acceleration condition before entering steady driving condition from 0km/ to 60km/h and from 60km/h to 80km/h. However, especially, under the last deceleration, particle concentration becomes very high. Normally at deceleration, fuel is not injected into combustion chamber to cut down on fuel to improve fuel economy. At deceleration, particle is not generated due to combustion.

It is known well that, condensed particles from lubrication oil vapor and from high boiling hydrocarbon vapor absorbed on the wall of the exhaust pipe are observed as nuclei particles from conventional diesel engine without Urea SCR system. Nano particle size as nuclei mode particles is less than 50nm and it differs from particles size as agglomeration particles observed with this test in the vicinity of 70nm. Therefore, particles observed at deceleration are not particles derived from combustion but are likely to be particle generating through exhaust system or Urea SCR system.

In the particle size distribution under Japanese D13 mode driving, similar condensed particles equivalent to particle size/area emitted particle can be recognized.

### 4.3 Transient Mode Test（JE05, FTP）

In the particle size distribution under JE05 mode driving condition, during acceleration, the number concentration of agglomeration mode particle is more than $10^6$ number/cc. Generally particle number concentration in the atmosphere is at the rate of $10^4$ number/cc. Comparing to ambient concentration, high number of particle concentration is shown. For vehicles with DPF（CRT™）using cordierite filter, exhaust particle concentration is less than $10^5$ numbers/cc. Vehicles with only urea SCR system fulfilled PM regulation on mass base but a number of particle concentration emitted at high peak, compared to vehicles with DPF. Also, during deceleration, substantial amount of particles are emitted as agglomeration mode particles. Usually at deceleration fuel is cut, so this means no particle generation from combustion. Particles, formed by condensation from lubrication vapor and high boiling point hydrocarbon desorption from exhaust system, seems to be particle of less than 50nm and differ from agglomeration mode particle of particle range (70nm). In the case of re-emission of particles attached to the exhaust system, particle numbers are thought to be few with large size particle. Considering the above, agglomeration mode particles are assumed to be particles generated from urea SCR system, and its generation process needs to be clear in the future.

For urea SCR system, $NH_3$ is generated by hydrolyzing urea and used as a reductant. From $SO_x$ generated by oxidization of sulfur in fuel oxidizes, particles of ammonium sulfate may are generated. Also, from $NH_3$ and combustion product $NO_x$, generation of ammonium nitrate particle may be possible. Generally speaking, $NH_3$ in the atmosphere is closely linked to generation of particles. Particle generated by $NH_3$ in the exhaust system need to be investigated in the future.

In the particle size distribution in FTP mode driving condition, particle emission behavior is similar to JE05 mode.

**5. Summaries and Future Outlook**

(1) From the vehicle with only Urea SCR system complying with Japanese long term PM regulation (<0.027 g/kWh), during acceleration and deceleration, agglomeration mode particle is emitted at high peak particle number concentration compared to usual DPF.

(2) In the decreasing mode from constant speed condition or transient condition, high concentration agglomeration mode particles were emitted. These particles are estimated to derive from not combustion but exhaust system including urea SCR system, because of particles emission in the decreasing mode. These particles have possibility to consist of ammonium compounds.

As emission behavior that differs from the conventional particle behavior can be particularly seen in Urea SCR System, detailed research including particle generation mechanism will be necessary in the future.

# Particles Emission from a HD diesel vehicle with urea SCR Catalyst

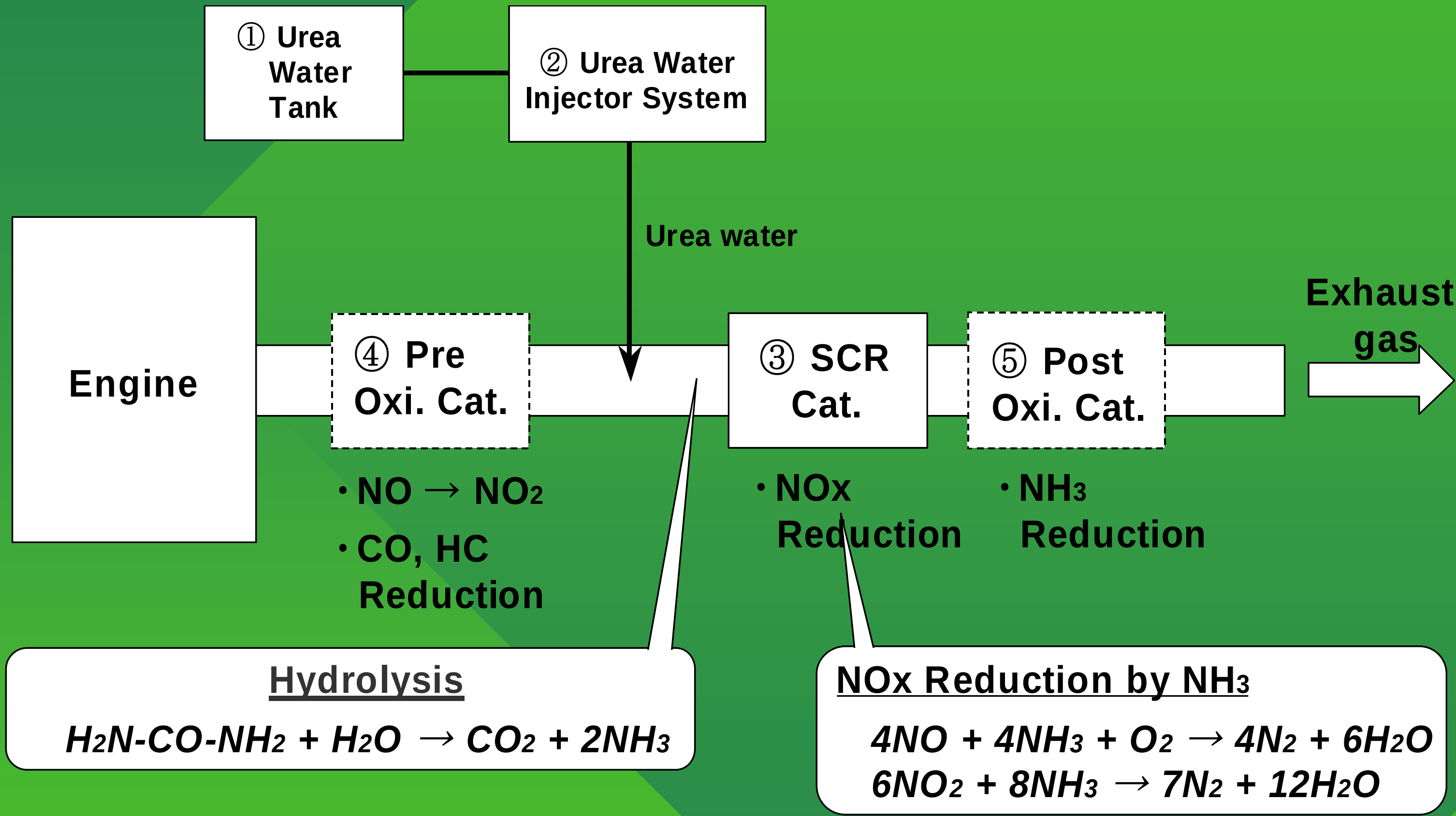

**Yuichi GOTO**

**Hajime ISHII, Hisakazu SUZUI, Terunao KAWAI**
**Environment Research Department**
**National Traffic Safety and Environment Laboratory**

# Introduction

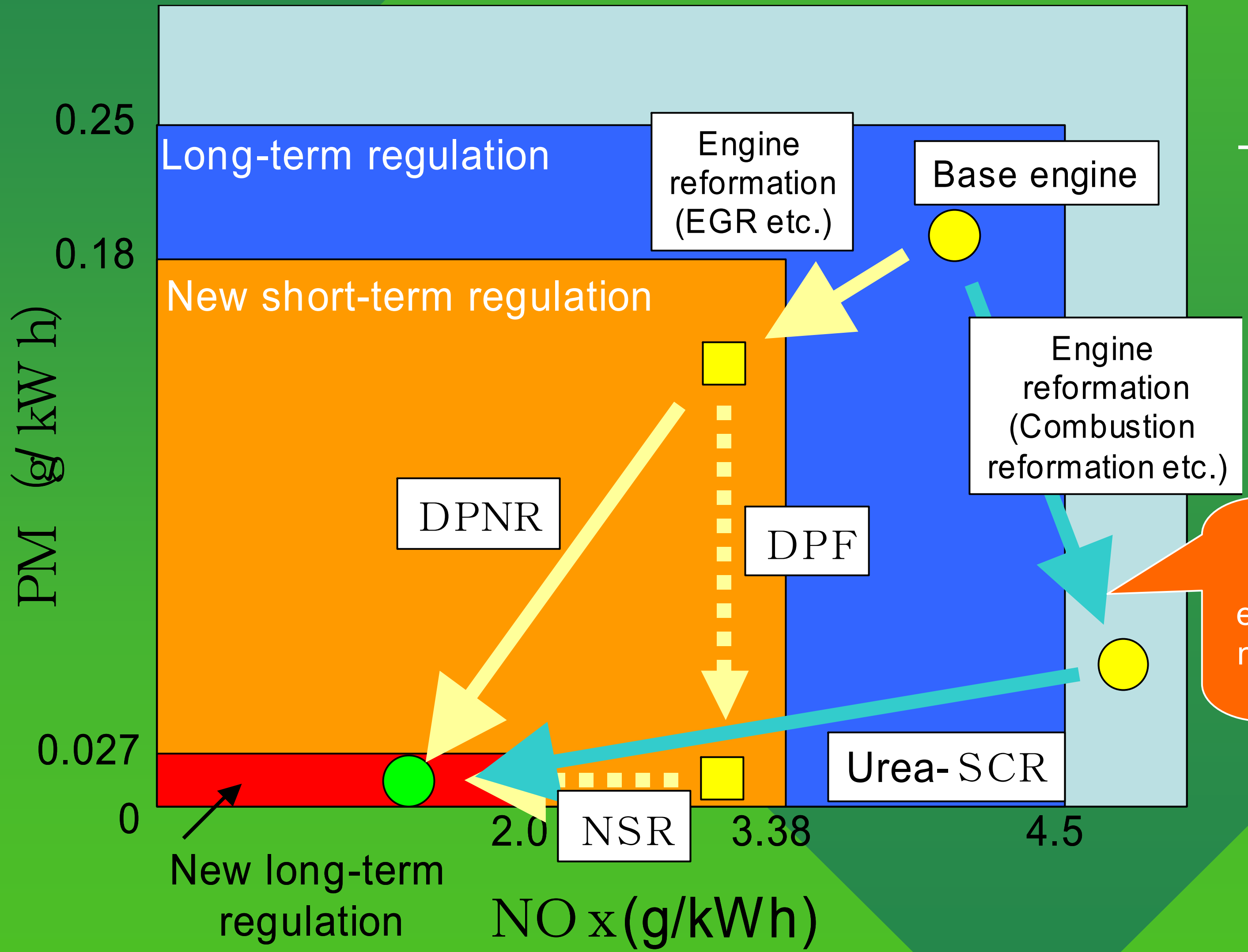
- One solution of NOx reduction for HD diesel vehicles is Urea SCR (Selective Catalytic Reduction) system.
- In near future the number of vehicle with Urea SCR system will increase.
- But the behavior of particle number emission from Urea SCR system is not clear. It is important to investigate the behavior at this time.
- Vehicle with only Urea SCR system ( without DPF) complying with Japanese new long-term regulation was tested.
- Particle number emission behavior of this type vehicle was examined by using EEPS.

# Example of Urea-SCR System




- Urea water is converted to ammonia by hydrolysis. NOx is reduced by using ammonia as reductant in SCR catalyst.
- At SCR outlet, oxidation catalyst oxidizes and reduces surplus ammonia.
- Pre oxidation catalyst converts from NO to NO2、and oxidizes and reduces HC, CO. Pre oxidation catalyst also increases exhaust gas temperature to light-off temperature.

# Concepts of Countermeasures for Reduction of Diesel Exhaust Emissions




Two approaches of NOx and PM reduction

In this approach, particle number emission behavior is not clear because of no DPF

# Conditions

# Specification of Test Diesel Vehicle and Engine

| | |
|---|---|
| VW (kg) | (8, 740) |
| GVW (kg) | (24, 850) |
| Engine diplacement (L) | 9.203 |
| Engine system | 4 cycle・6 cylinder・TI |
| Bore×Stroke (mm) | Φ125.0×125.0 |
| Fuel supply system | Common rail |
| Fuel | Diesel oil |
| Emission reduction system | Urea-SCR |

# Specification of Test Diesel Fuel

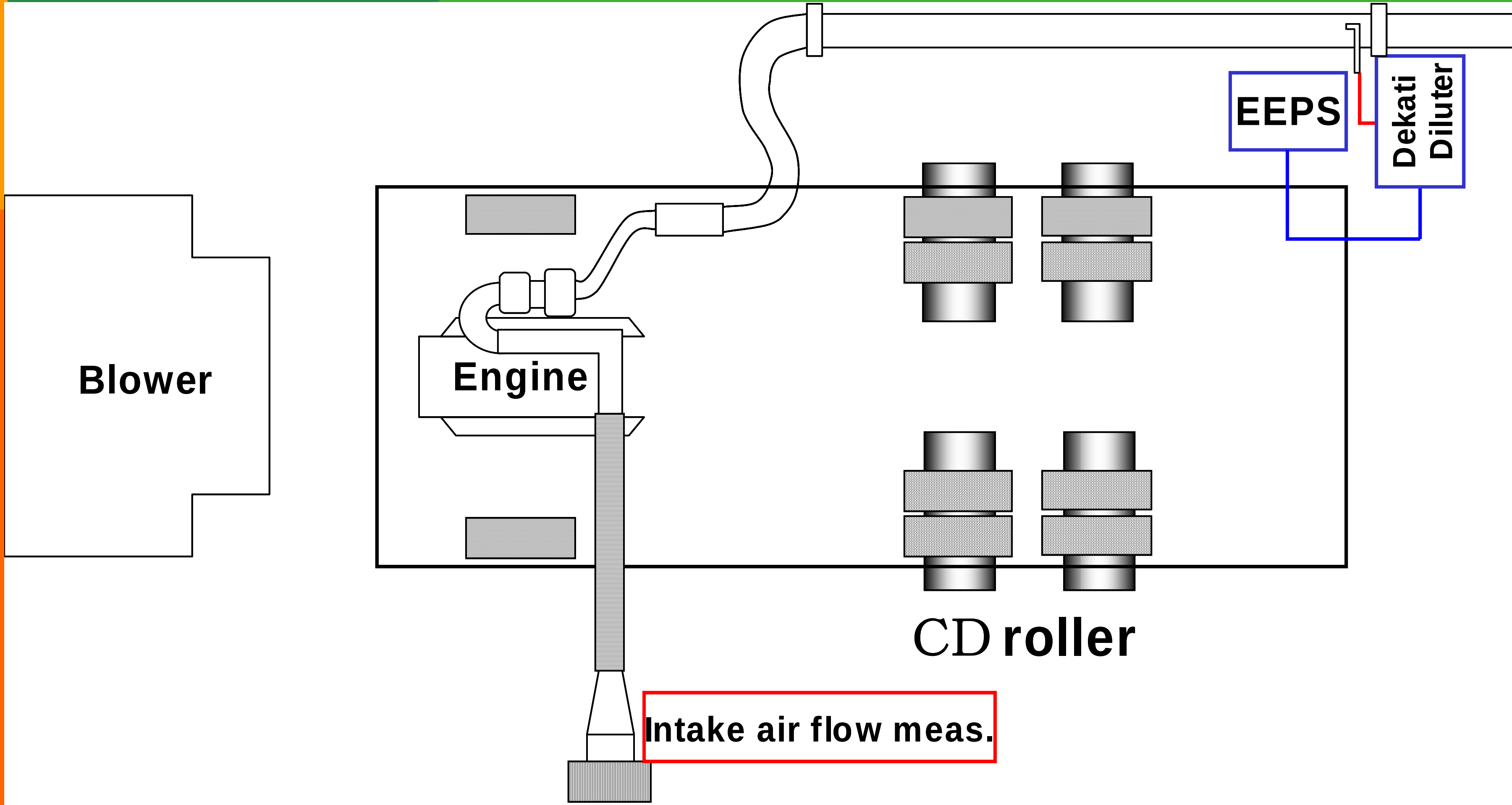
| Item | Unit | Value |
|---|---|---|
| Cetane Index (JISK2280) | | 59.4 |
| Density 15℃ | g/cm3 | 0.8261 |
| Sulfur Contents | mass % | 0.0024 |

# Specification of Test Urea Water (DIN)

| Item | Unit | DIN |
|---|---|---|
| Concentration | % | 32.5± 0.5 |
| pH-value (10%HS-solution) | | 10 > |
| Density (20℃) | kg/L | 1.085 ~ 1.095 |
| Refractive index at 20℃ | | 1.3821 ~ 1.3835 |
| Alkalinity as NH3 | % | 0.1 > |
| Carbonate as CO2 | % | 0.1 > |
| Biuret | % | 0.3 > |
| Formaldehyde | wt-ppm | 10 > |
| Insolubles | wt-ppm | 10 > |
| Phosphoric (PO4) | wt-ppm | 0.2 > |
| Ca | wt-ppm | 0.5 > |
| Fe | wt-ppm | 0.5 > |
| Cu | wt-ppm | 0.2 > |
| Zn | wt-ppm | 0.2 > |
| Cr | wt-ppm | 0.2 > |
| Ni | wt-ppm | 0.2 > |
| Mg | wt-ppm | 0.5 > |
| Na | wt-ppm | 0.5 > |
| K | wt-ppm | 0.5 > |

Test urea water is equivalent of DIN standard.

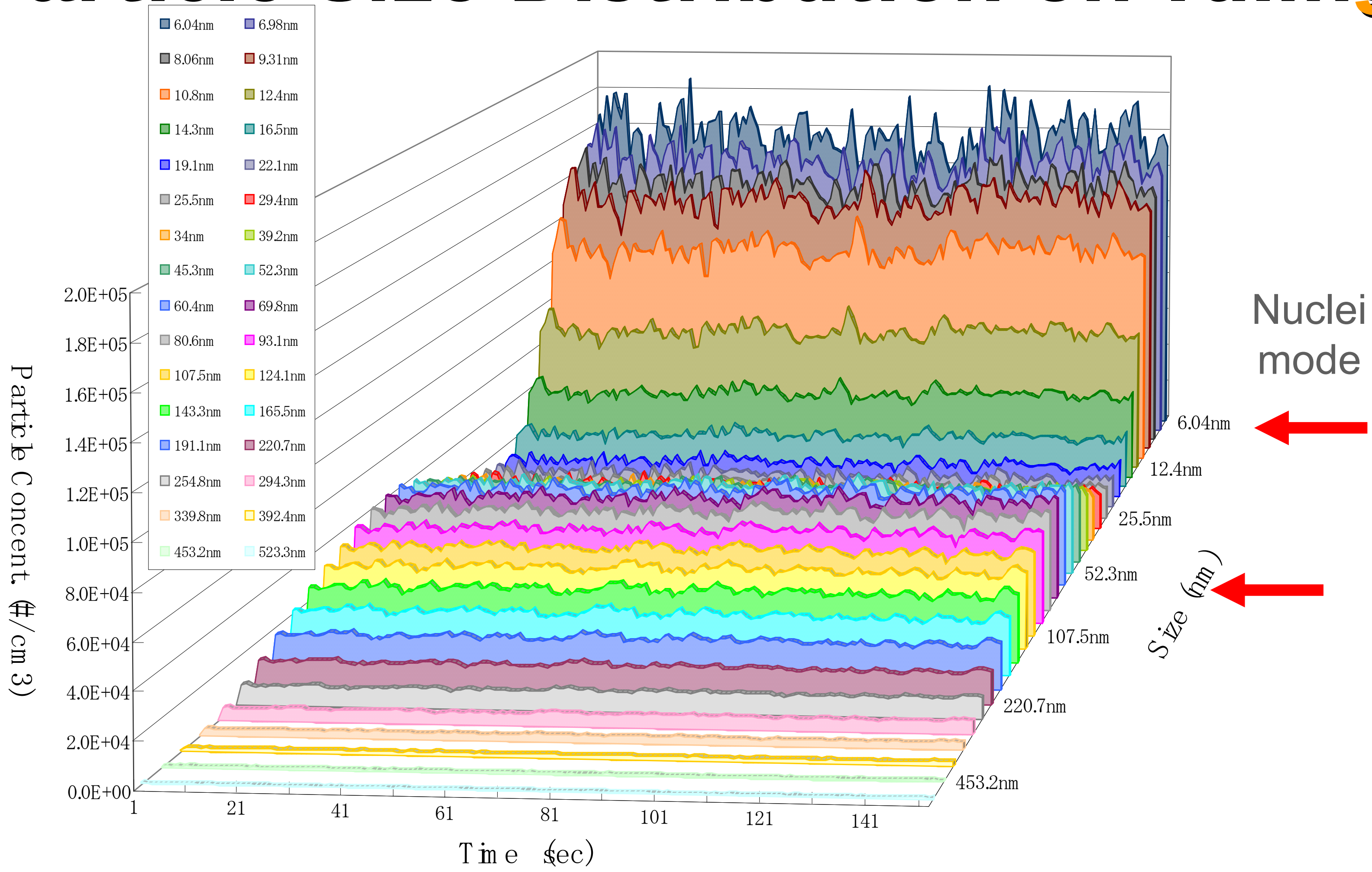
# Configuration of Test system




After sample gas was diluted 8 times by Dekati diluter, particle size distribution was measured by EEPS.

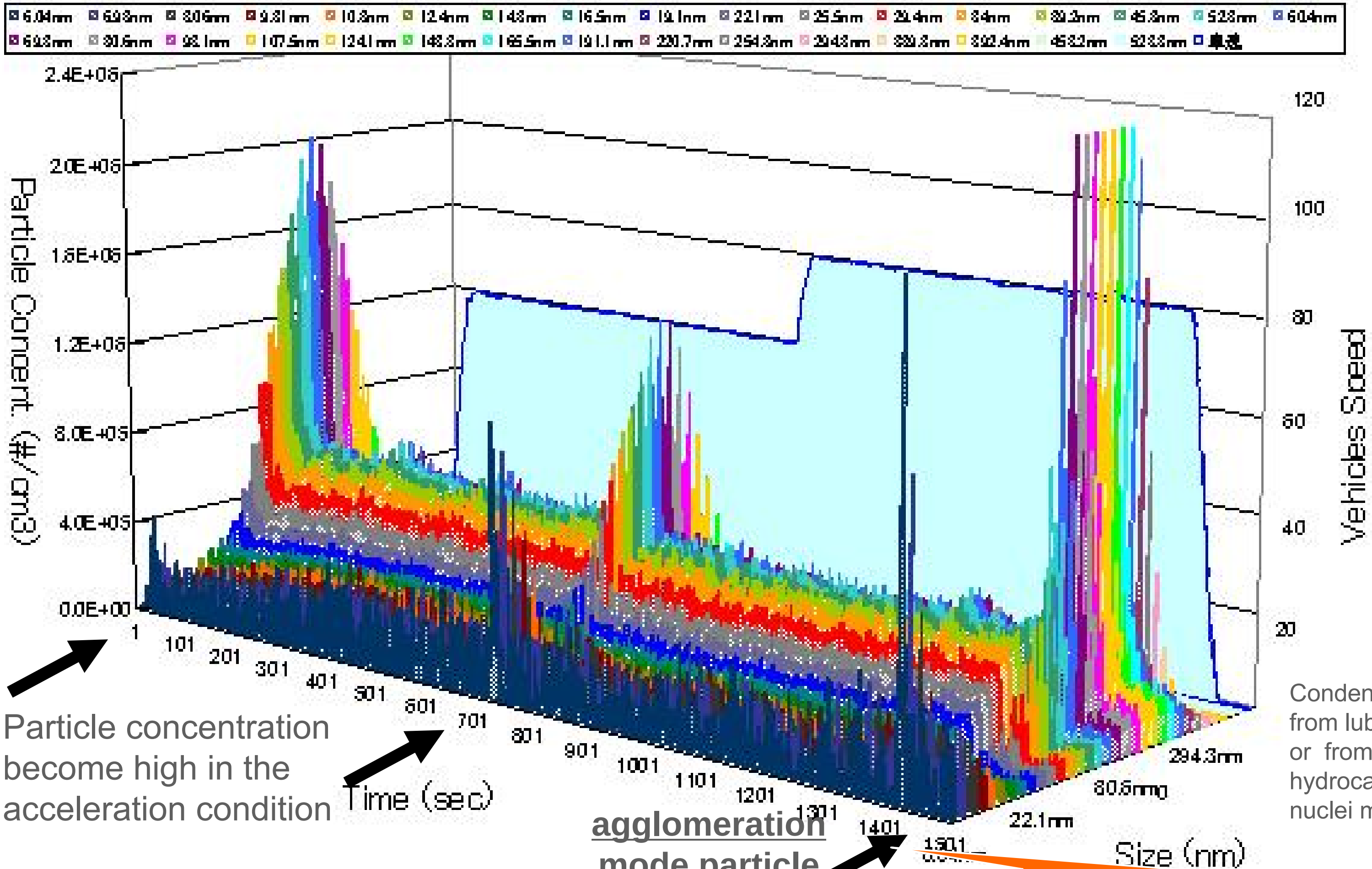
# Results

# Particle Size Distribution on Idling




This has two peaks of about 6nm and 70nm.

# Particle Size Distribution in Constant Speed Condition(60, 80km/h)




Particle concentration become high in the acceleration condition

**agglomeration mode particle**

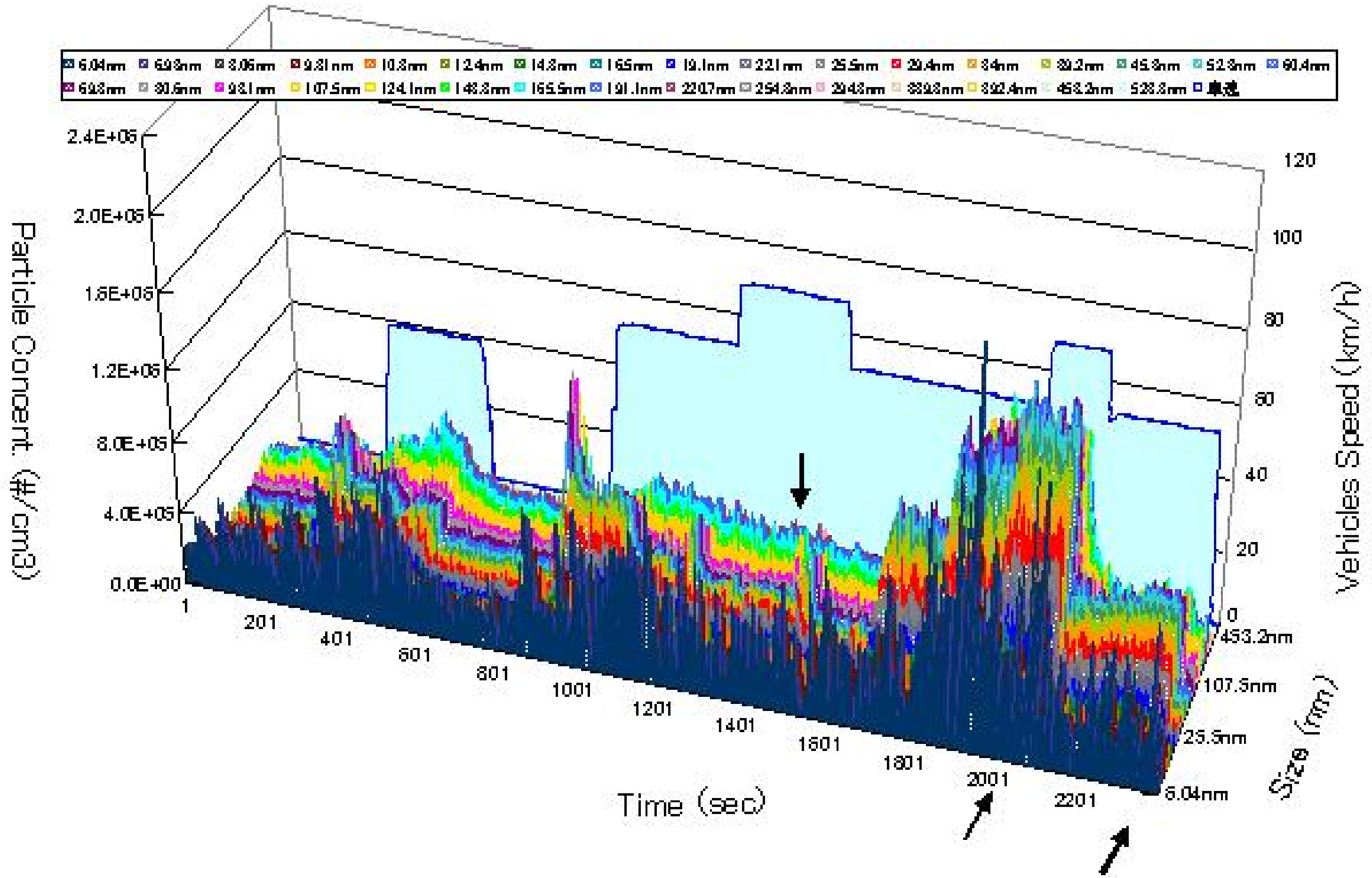
Condensation particles from lubrication oil vapor or from high boiling hydrocarbon vapor are nuclei mode

At deceleration, particles are not generated by combustion.

●Normally at deceleration, fuel is not injected into combustion chamber to cut down on fuel to improve fuel economy

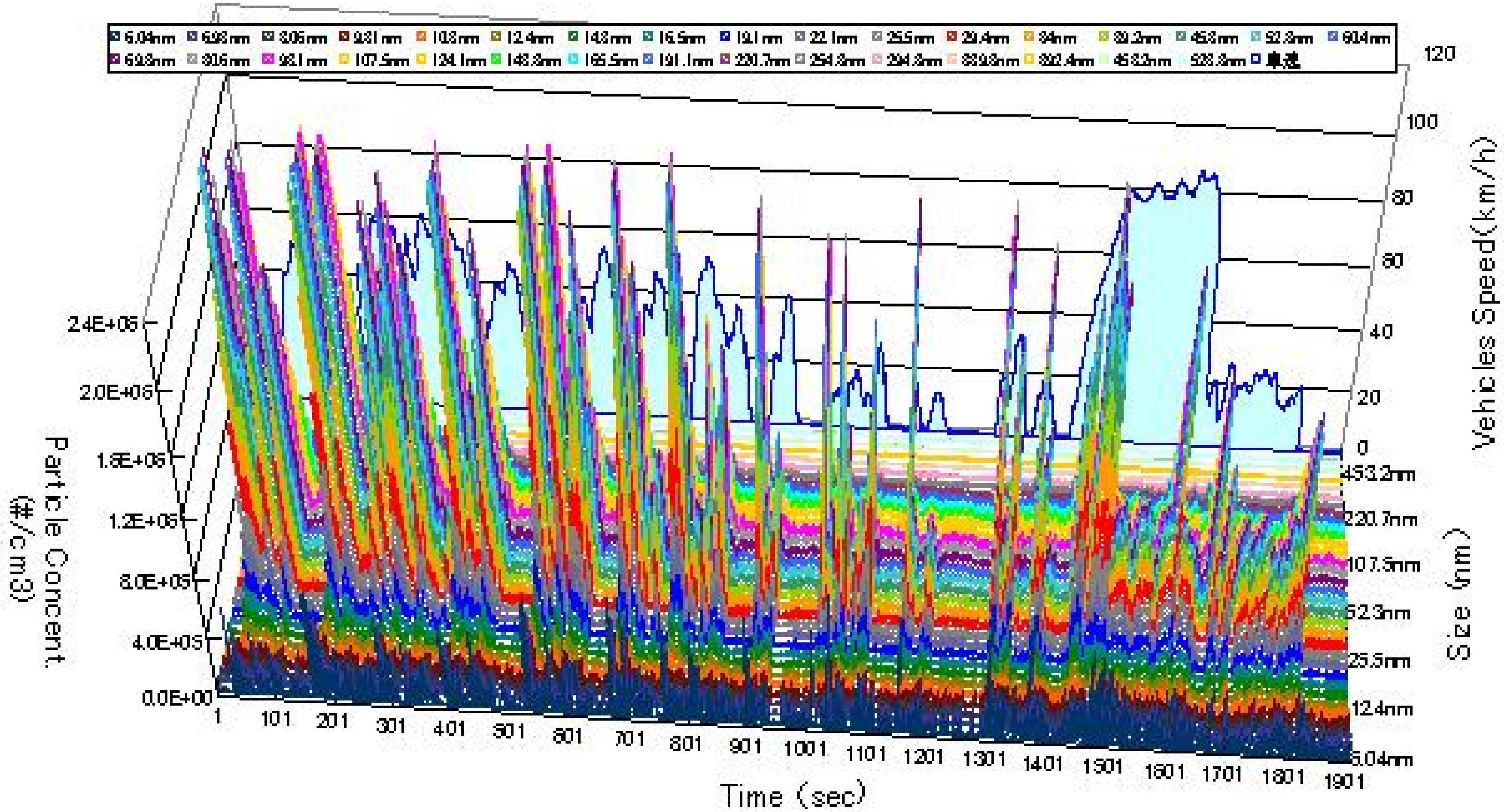
●Particles at deceleration are likely to be particles generating through exhaust system or Urea SCR system

# Particle Size Distribution in Japanese D13 Mode Driving Condition




In Japanese D13 mode condition also similar particles were emitted, too.

# Particle Size Distribution in Japanese <u>JE05 Mode</u> Driving Condition (1)



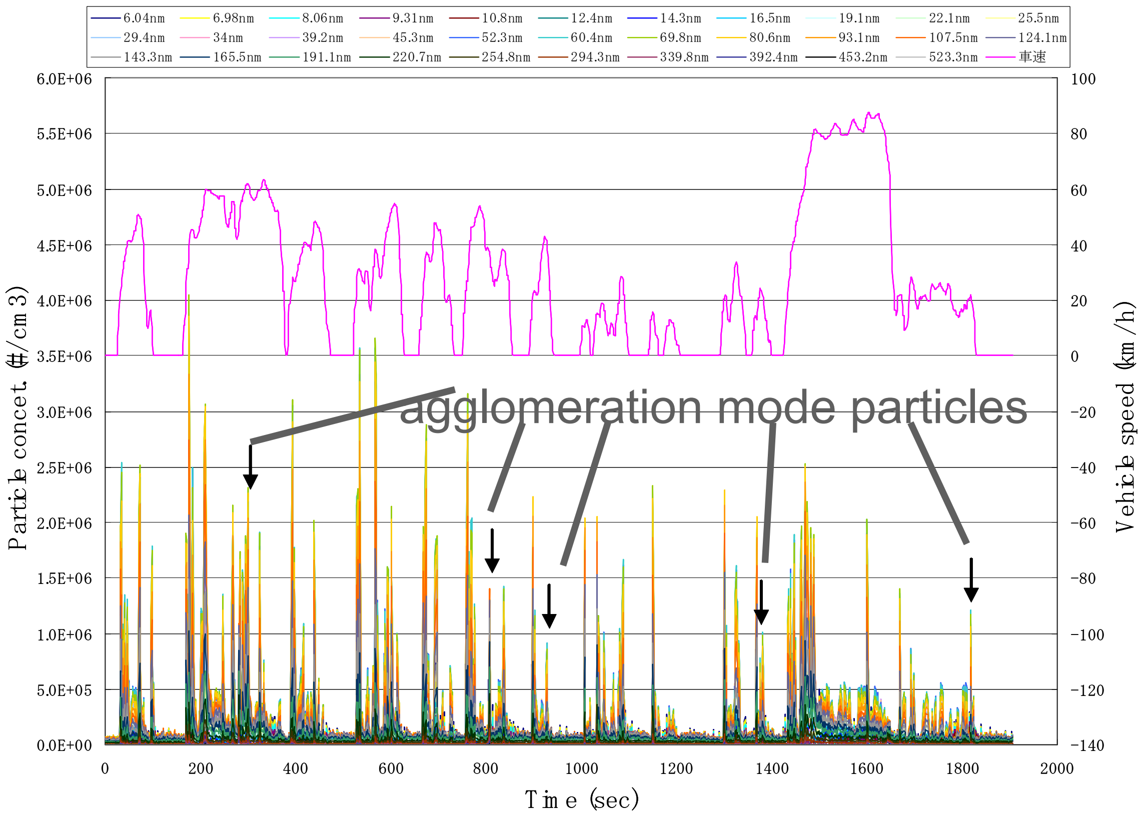

●During acceleration, agglomeration mode particle is more than $10^{6}$ number/cc are emitted.

●Generally speaking, particle number concentration in the atmosphere is about $10^4$ number/cc. Particle number concentration in this case was higher than ambient particle number concentration.

●On the other hand, particle number concentration of vehicles with DPF（CRT™） is less than $10^5$ number/cc.

●This vehicle with only Urea SCR system complies with Japanese new long term PM regulation, but particle number concentration was high, compared to vehicles with DPF.

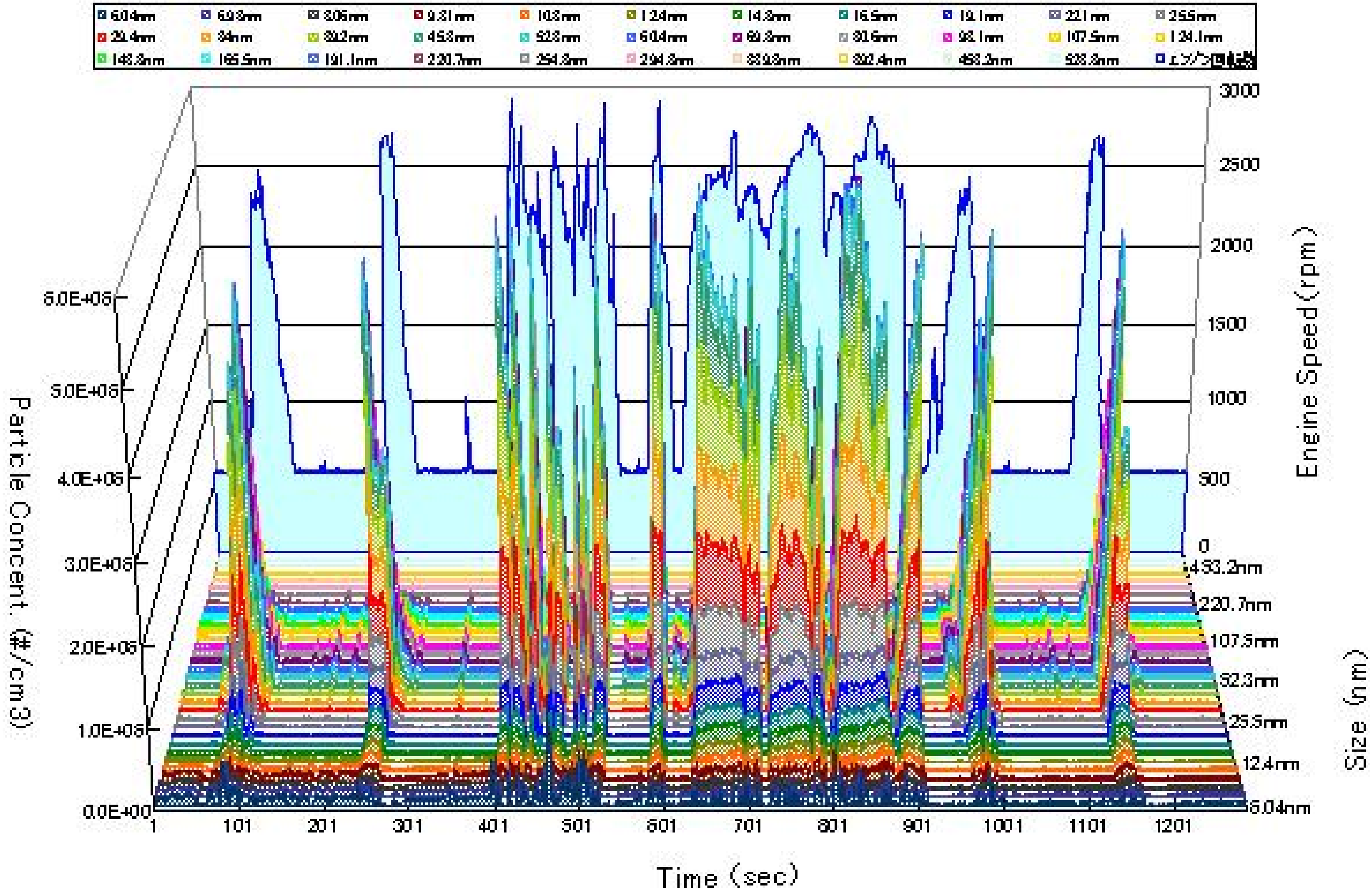
# Particle Size Distribution in Japanese JE05 Mode Driving Condtion(2)




- Agglomeration mode particle shown by arrows may be particles generated from Urea SCR system.
- In Urea SCR system, $NH_3$ is generated by hydrolyzing urea and used as a reductant.
- From $NH_3$ and SOx generated by oxidization of sulfur in fuel, there is possibility that particles of **ammonium sulfate** are generated.
- Also, from $NH_3$ and combustion product NOx, generation of **ammonium nitrate** particle is possible.

- Generally speaking, $NH_3$ in the atmosphere is closely linked to generation of particles.
- Particle generation by $NH_3$ in the exhaust system should be clarified.

# Particle Size Distribution in FTP Mode Driving Condition (1)




In FTP mode condition also the situation of particle number emission is the same as JE05 mode condition.

# Particle Size Distribution in FTP Mode Driving Condtion(2)


●The number concentration of agglomeration mode particles shown by arrow increases during deceleration. There is also possibility of particles generating from Urea SCR system.

# Conclusions

(1) From the vehicle with only Urea SCR system complying with Japanese long term PM regulation (<0.027 g/kWh), during acceleration and deceleration, agglomeration mode particle is emitted at high peak particle number concentration compared to usual DPF.

(2) In the decreasing mode from constant speed condition or transient condition, high concentration agglomeration mode particles were emitted. These particles are estimated to derive from not combustion but exhaust system including urea SCR system, because of particles emission in the decreasing mode. These particles have possibility to consist of ammonium compounds.

As emission behavior which differs from the conventional particle behavior can be particularly seen in Urea SCR System, detailed research including particle generation mechanism will be necessary in the future.