Future Challenges in Automobile and Fuel Technologies For a Better Environment

Diesel WG Report

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JCAP Diesel WG
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Objectives

1. To research diesel engine technologies and fuel technologies for automobile emission reduction and determine the mid-to-long term direction in these technology areas.

-Target: The assumption is the new long term regulation
-Measurement item: Regulated components and non-regulated components

2. Provide data required for improvement of Atmospheric model simulation accuracy

Schedule

Evaluation of countermeasures for vehicles in use

FY	97	98	99	00	01
STEP I					
STEP II					

-Evaluation of existing technologies
-Existing-Model fuel

-Evaluation of future technologies
-Future fuel

Contents of This Report

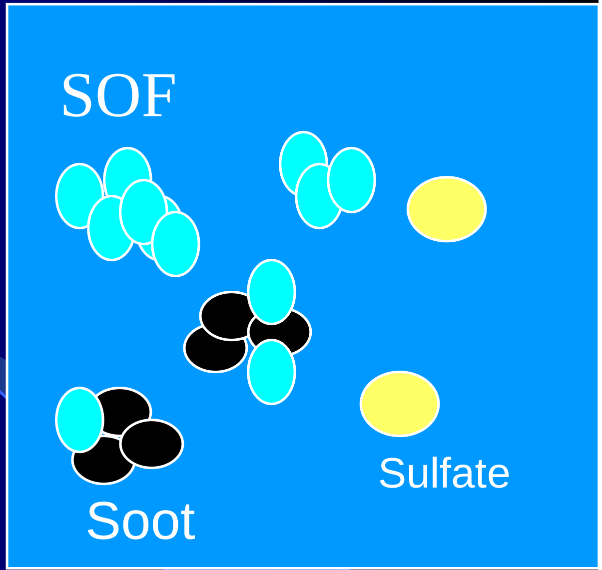
3. Evaluation result of countermeasures for vehicles in use

FY	97	98	99	00	01
STEP I					
STEP II					

1. Achievements in STEP I

2. Plan for Step II

What is PM



- **PM （Particulate Matter）**
  Minute Particles in diesel exhaust
  Visible Black smoke (soot, dry soot)
  Invisible Other combustion products
  (including sulfur-based sulfates contained in fuel)
  The components that can be dissolved in organic solvents are called Soluble Organic Fraction.

SOF: Soluble Organic Fraction

1. Achievements in STEP I

Study Contents in STEP I

(1) Vehicle・ Engine

- 9 vehicles and 11 engines from passenger cars to heavy duty trucks were evaluated.
  - ・Complied with 1989/short term/long term regulations.
  - ・Besides high pressure injection and EGR, high-performance oxidation catalyst and DPF were also evaluated.

(2) Fuel

- 13 types of fuels with different sulfur levels, distillation characteristics and aromatic series contents were evaluated.

・ Sulfur	0 - 500 ppm
・ Distillation characteristics (90 % distillation point)	Max. level in the market - ultra light quality
・ Aromatic series contents	Max. level in the market – 0 %

Achievements in STEP I (1)

Reduction effect of regulated components by high-performance oxidation catalyst

- For HC and CO, this latest catalyst technology can exhibit remarkable reduction effect.
- The PM amount increases due to sulfate generation from sulfur contents

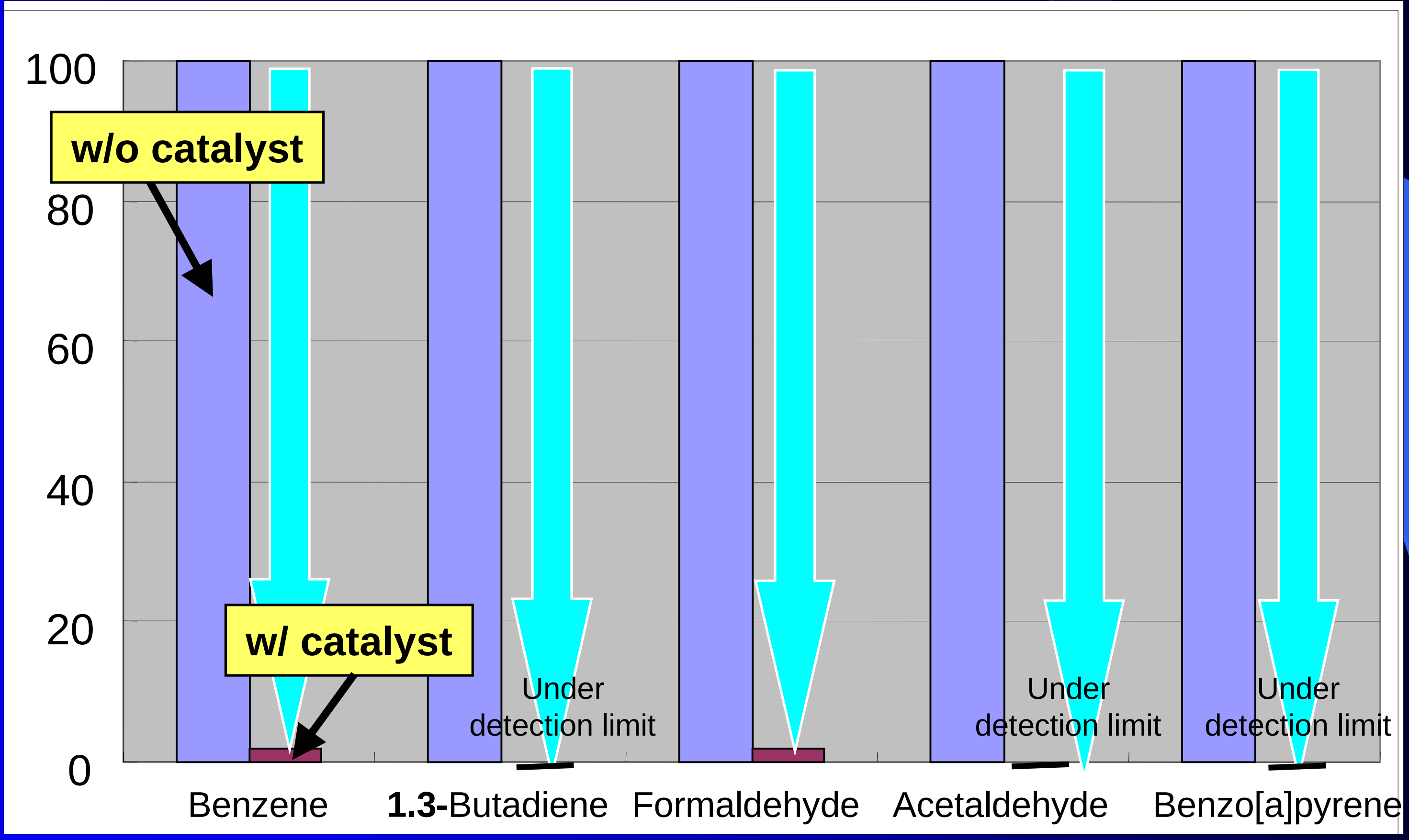
	Emission reduction rate (Dummy catalyst base)			
	PM	NOx	HC	CO
diesel fuel S 0.04 %	−25	−14	96	100
diesel fuel S 0.00 %	15	1	96	100

Results of 10/15 mode tests.Minus (-) in the table indicates increase.

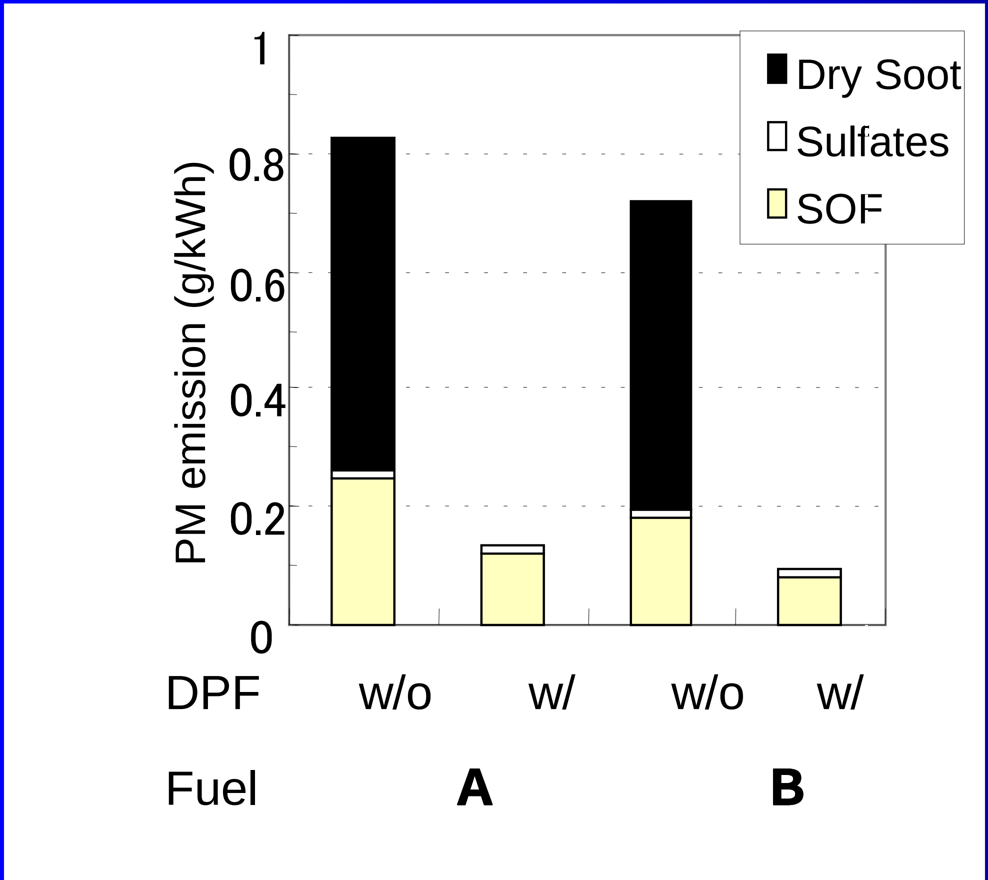
Achievements in STEP I (2)

High-performance oxidation catalyst effects for reducing 5 non-regulated components

Remarkable reduction of 5 non-regulated components is also made possible by the catalyst.



Achievements in STEP I (3)
PM Reduction Effect by DPF



Large PM reduction. In particular, the dry soot reduction effect is significant.

DPF
(Diesel Particulate Filter)

Cordierite honeycomb DPF w/o catalyst was used.

STEP I Summary (1)

1. PM reduction

- DPF exhibits remarkable PM reduction effects.
  The combination of high-performance oxidation catalyst and low-sulfur diesel fuel is expected to significantly reduce dry soot, SOF, HC, CO, as well as non-regulated components.

-The effect on PM reduction resulting from diesel fuel characteristics(90% distillation temperature (T90), aromatic series content and sulfur level)was evident.
  However, the effectiveness varies considerably depending on vehicle and engine technologies.

STEP I Summary (2)

2. NOx reduction

-The fuel effect on NOx is less than that for HC, CO, and PM. For reducing NOx, engine technologies will be the main solution.

3. Reduction of non-regulated components

-The catalyst exhibits a considerable effect on the non-regulated components. Fuels have very little effect. However, more data should be collected to validate the measurement accuracy.

2. Plan for STEP II

Study Contents in STEP II

(1)Vehicle・Engine

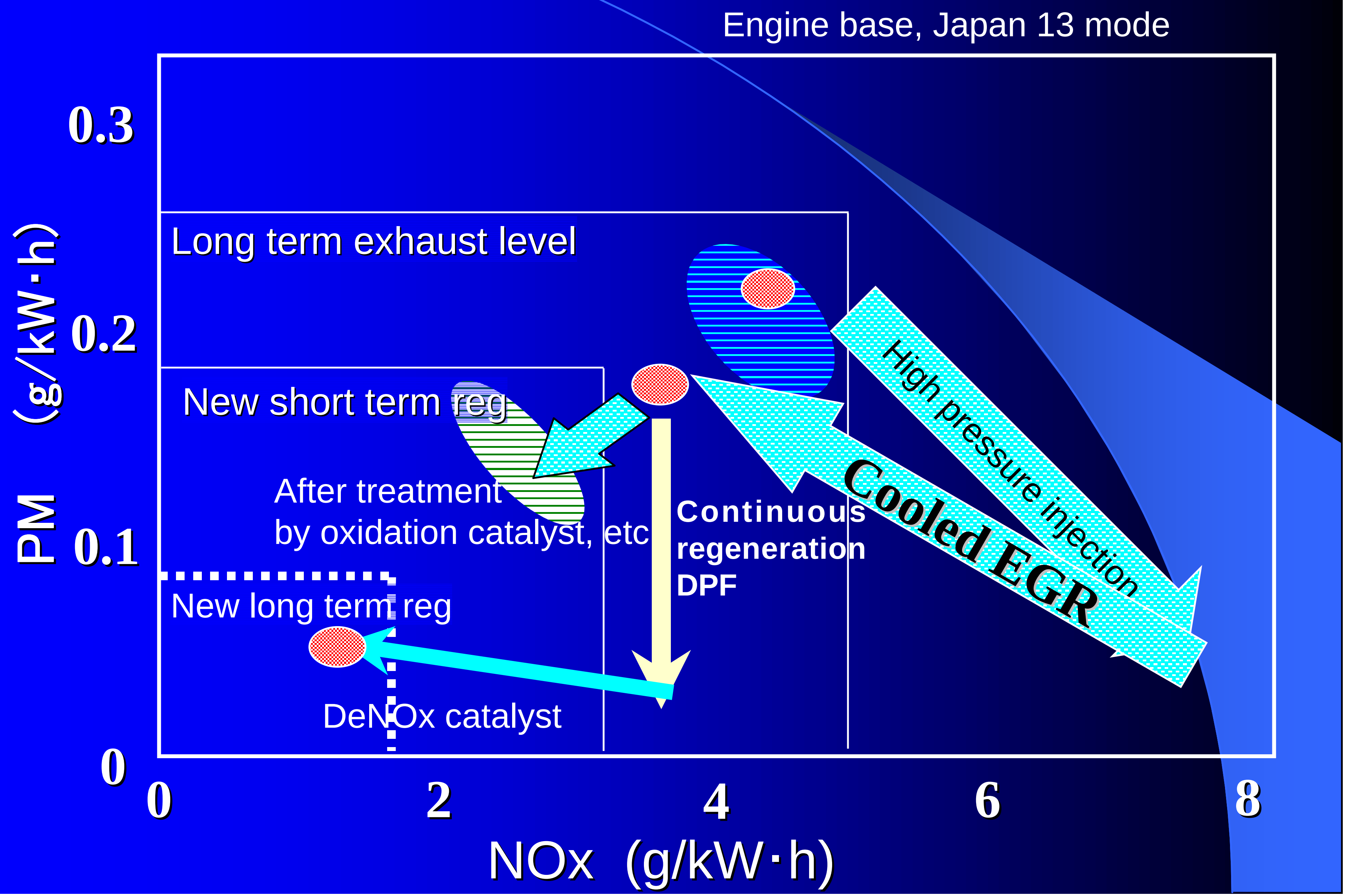
- 10 vehicles (4 models) and 6 engines (3 models) ranging from passenger cars to heavy duty trucks are to be evaluated
  - Target - the new long term regulation
  - Evaluate comprehensive systems consisting of DeNOx catalyst, continuous regeneration DPF, high pressure injection and cooled EGR

(2)Fuel

- 8 types of fuels with different sulfur levels and distillation characteristics as well as 2 oxidized types to be evaluated.

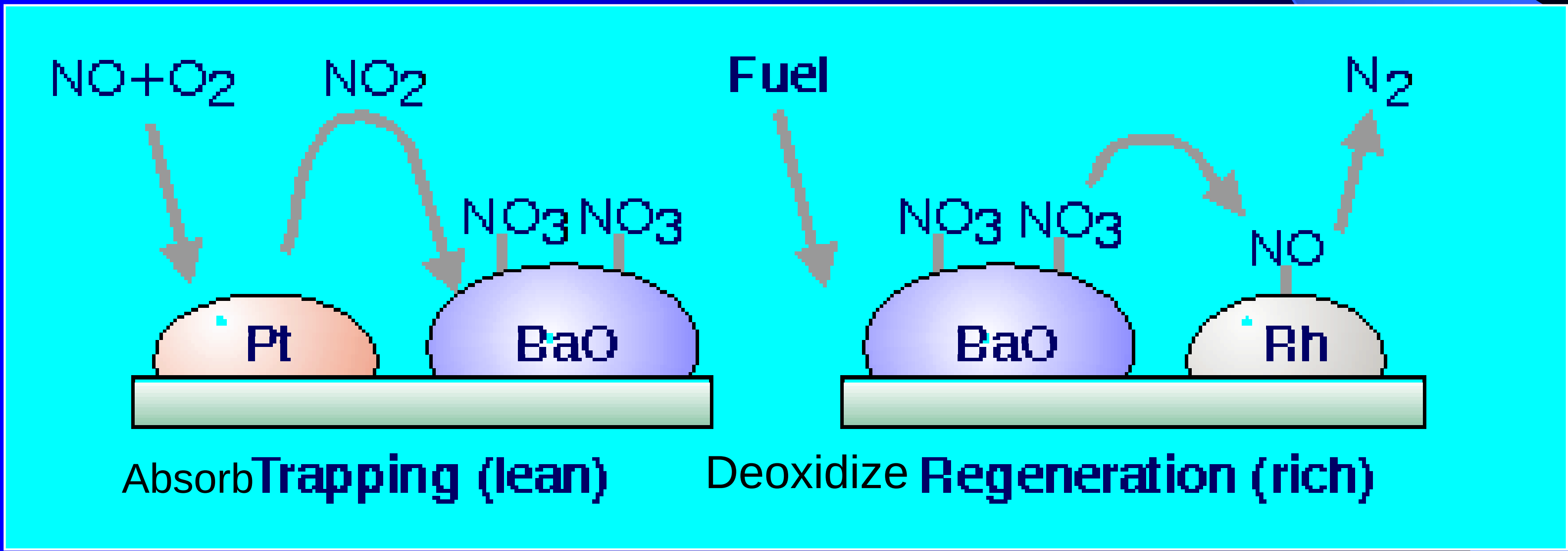
• Sulfur	10 - 500 ppm
• Distillation characteristics (90% distillation point)	Average level in the market - ultra light quality
• Oxidized basis	2 types containing 10% blend (some vehicles)

Scenario for Emission Reduction



Absorption DeNox Catalyst

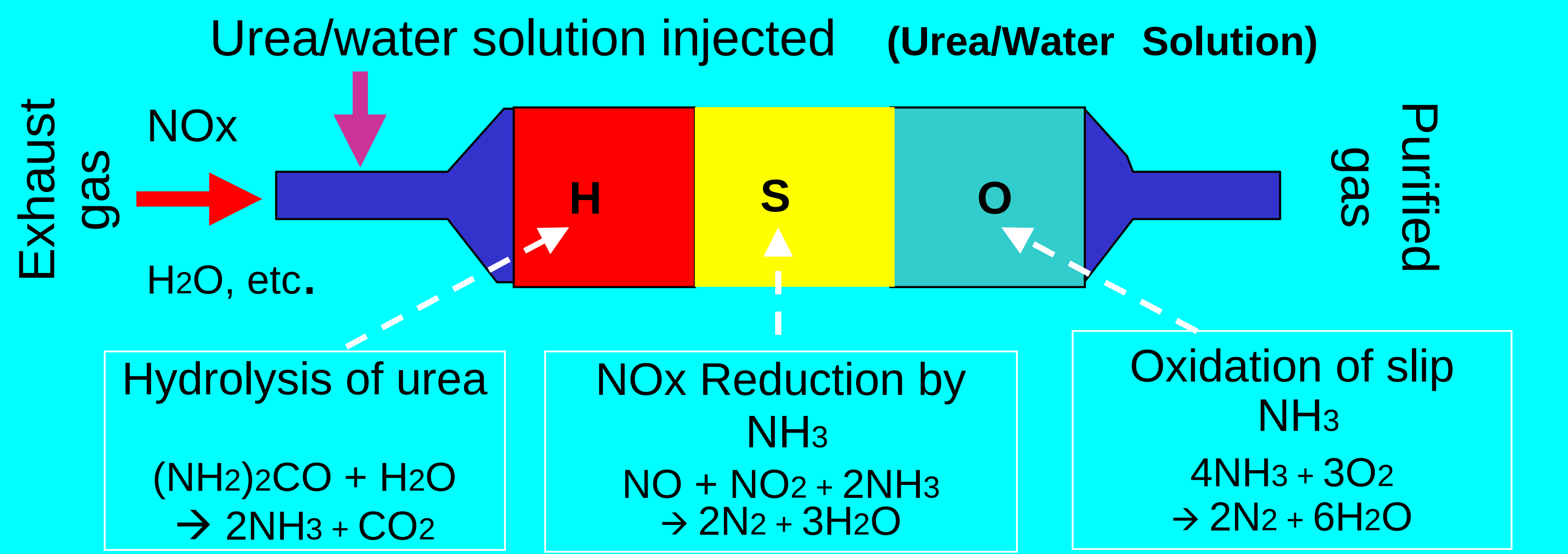
- Three-way catalyst containing NOx absorber.
- Absorbs NOx and deoxidizes it periodically.
- Remarkably higher NOx reduction rate than conventional technologies.
- Sulfur poisoning(Sulfate storage) on NOx Absorber.



Prototype Vehicle with Absorption DeNox Catalyst

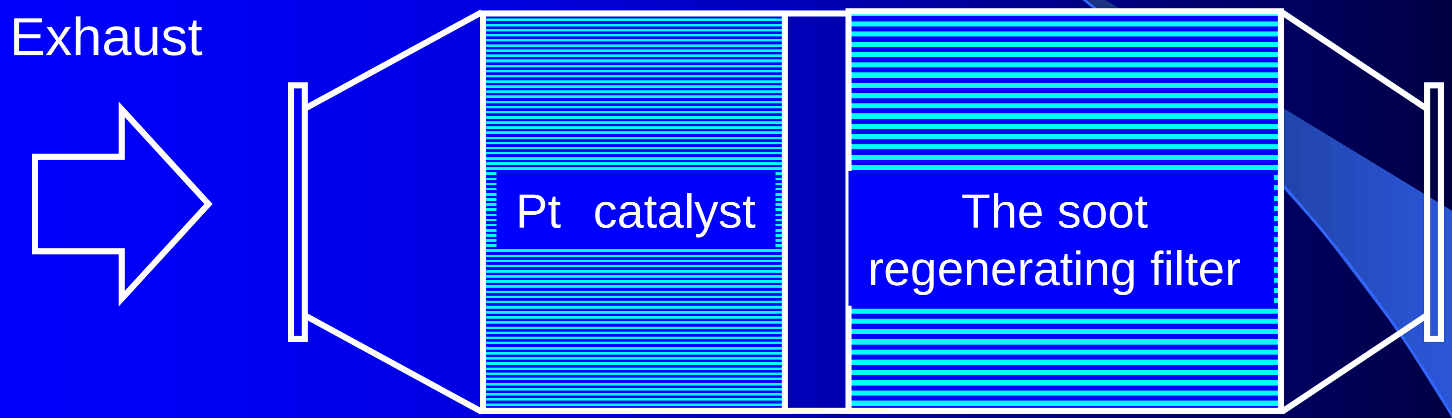
Urea Selective Catalytic Reduction

- A system that creates ammonia, a reducing agent, by spraying urea in the exhaust pipe and purifying NOx in the catalyst.
- Ammonia not reacted must be eliminated.
- Urea must be added periodically.



Concept Chart of SCR (Selective Catalytic Reduction)

Continuous Regeneration DPF (1)
(Example: CRT ™ by Johnson Matthey Co.)



$2NO + O_2 \rightarrow 2NO_2$

$C + 2NO_2 \rightarrow CO_2 + 2NO$
$C + O_2 \rightarrow CO_2$

Convert NO in the exhaust to NO_2 at the catalyst located upstream.
Collect soot in the filter downstream and oxidize it with NO_2.
→ PM regeneration is affected by NOx/PM ratio.

Continuous Regeneration DPF (2)

- SO_2 generated from sulfur in the fuel prevents the NO-to-NO_2 reaction and causes plugging in the filter and back pressure increase.
- The soot regenerating filter can work at low temperature (from 260 Deg. Celsius).
- The low regeneration temperature provides to higher reliability.
- The fuel economy deterioration is low due to less back pressure increase. Not only PM but also CO, HC and five non-regulated components can be reduced by the catalyst function.

Progress

Evaluation result of countermeasures for vehicles in use

FY	97	98	99	00	01
STEP I					
STEP II					

-Evaluation of existing technologies
-Existing-Model fuel

-Evaluation of future technologies
-Future fuel

3. Evaluation Results of Countermeasures for Vehicles in Use

Purpose of Evaluation

To obtain technical data on the effects and issues anticipated from DPF installation to diesel vehicles in use.

Background of Evaluation of PM Reduction Technologies for Vehicles in Use

(1) From the beginning of this year, public awareness of diesel PM has increased from the court ruling in the Amagasaki pollution case and the Tokyo Metropolitan Government 's proposal of mandatory DPF installation.

(2) Nonetheless, many of the vehicles in use today that meet past regulations continue to emit high PM. This is an urgent problem that need to be solved.

(3) To address the above problem, JCAP added the evaluation of PM reduction technologies for vehicles in use.

Engines Used for Test

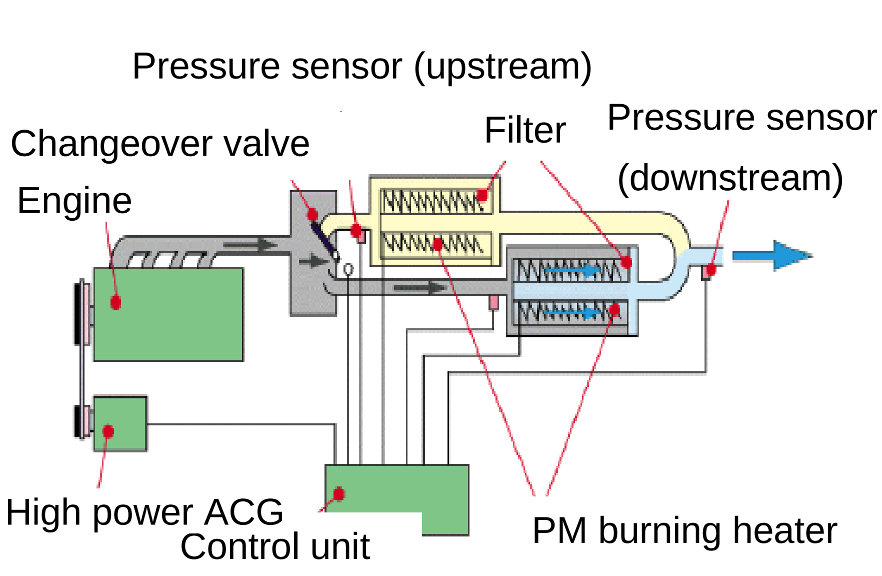
Engine type	1989 reg. compliant engine	1994 short term reg. compliant engine	1999 long term reg. compliant engine
Displacement	11149 cc	9203 cc	6925 cc
Power	166 kW	162 kW	175 kW
Torque	764 Nm	569 Nm	667 Nm
Feature	w/o turbocharger	w/o turbocharger	w/ inter-cooler turbocharger electronic control

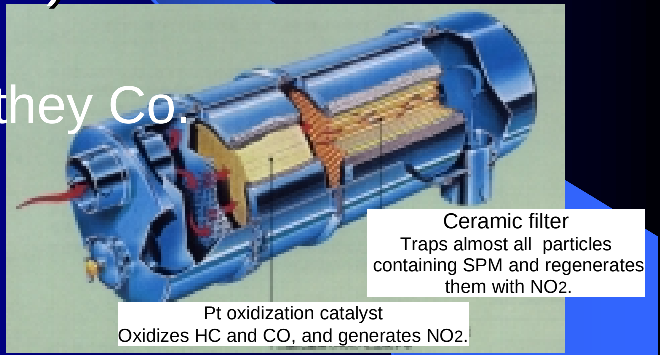
Fuel Used for Test

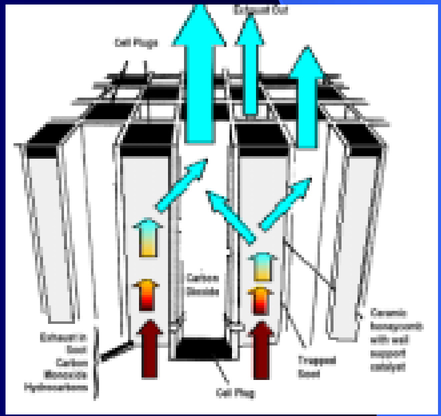
	Existing diesel fuel	Low sulfur diesel fuel
Sulfur level	443 ppm	46 ppm
Cetane number	57	59
90% distillation temperature	325 °C	334 °C
Density	0.832	0.831

DPF Used for JCAP Test

Alternate regeneration (Heat and burn by heater)	Continuous regeneration
Alternate regeneration DPF made by Isuzu	CRT™ (CRT) made by Johnson Matthey Co.
	DPX™(CSF) made by Engelhard Co.

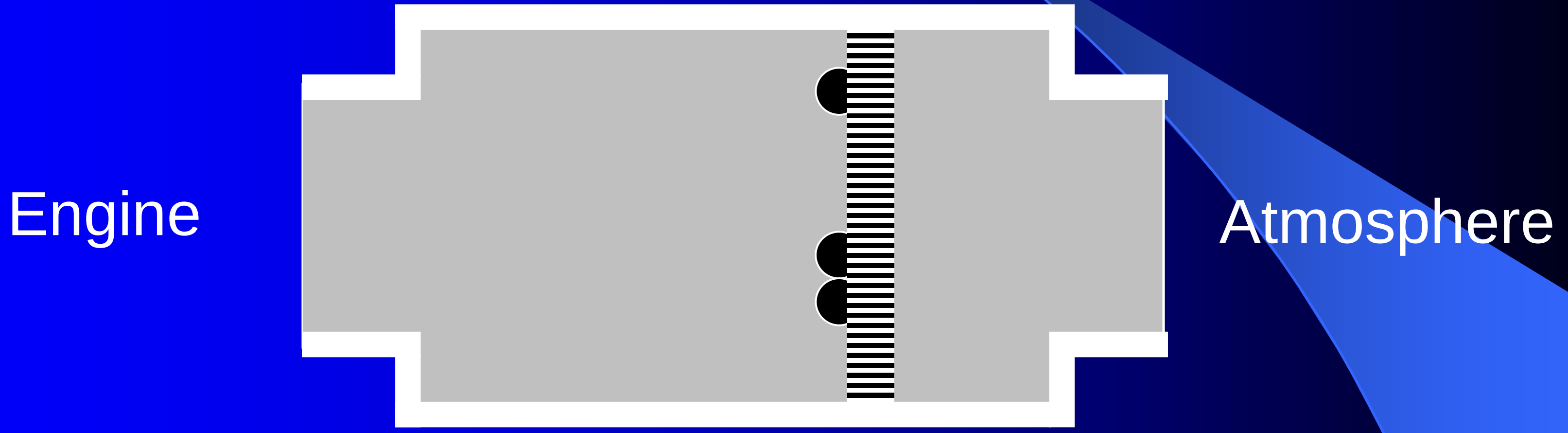






Evaluation of DPF

The following three points are key for DPF evaluation.



① To what degree is it able to reduce PM dispersing in the air? Reduction effect

② How efficiently is it able to remove PM? → Regeneration performance

③ How long is it able to maintain the above performances → *Fleet test*

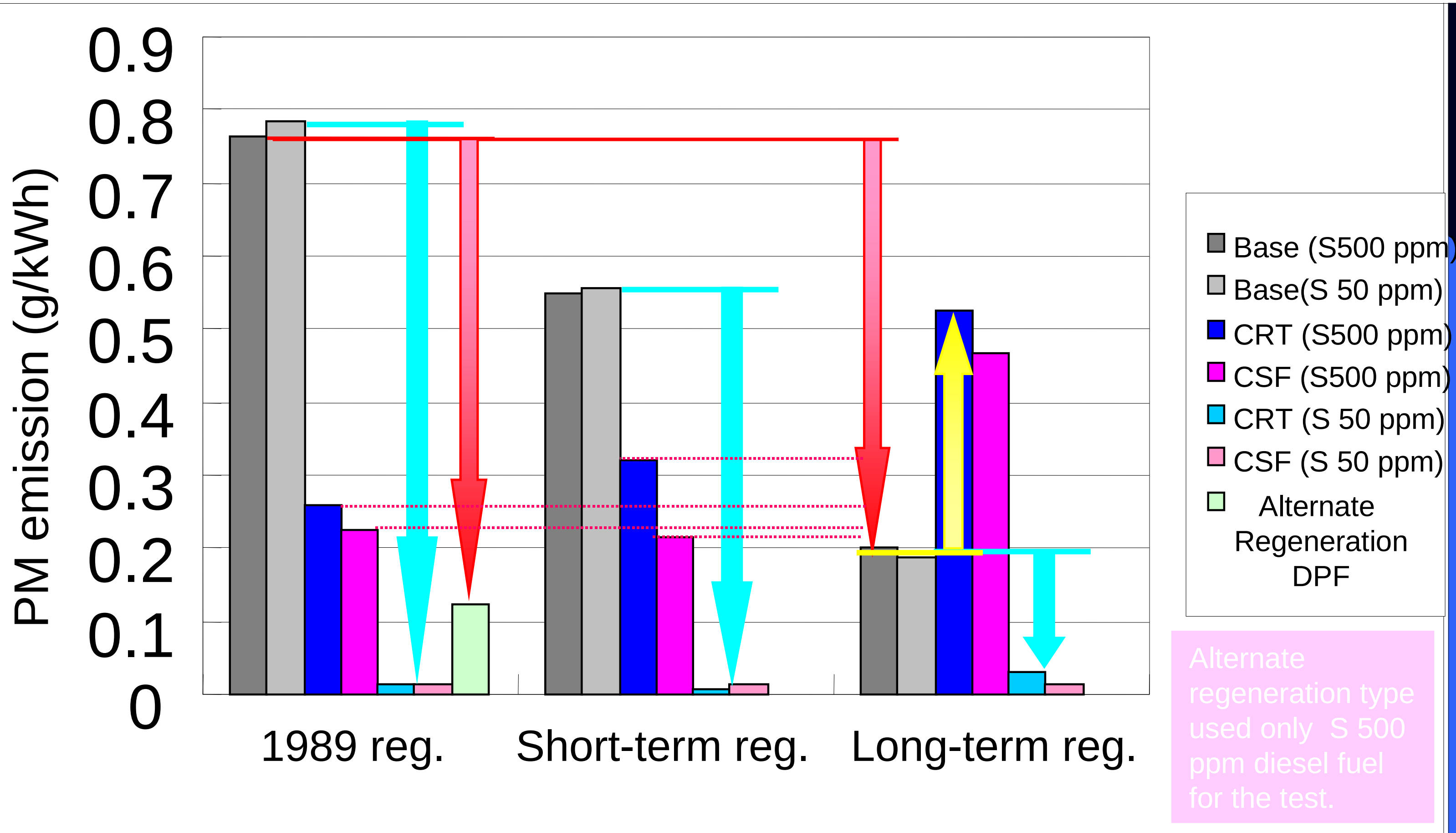
First Point
PM Reduction Effect

Comparison of PM Reduction Effect

(a) When 50 ppm diesel fuel was used, CRT and CSF showed remarkable reduction effect exceeding 95% in 1989 and short-term regulation/ compliant engines.

(b) When the only 500 ppm diesel fuel data was compared, the alternate regeneration type had the highest reduction effect. Also, the long-term regulations compliant vehicles without DPF showed lower PM emission than the 1989 and short-term standard compliant vehicles with DPF.

(c) The long-term standard compliant engine used in this test showed increase in PM both by CRT & CSF when 500 ppm diesel fuel was used.



Summary of PM Reduction Effect

Sulfur in fuel (ppm)	DPF		Steady drive (D13 mode) Test engine: 1989 & short-term reg.	Steady drive (D13 mode) Test engine: Long-term reg.	Urban drive (JARI transient test cycle) Test engine: short-term reg.
50	CRT		More than 95 %	84 %	98 %
	CSF			93 %	97 %
500	CRT		40 – 70 %	Increase	-
	CSF				97 %
500	Alternate regeneration	A	80 %	–	–
		B		–	–

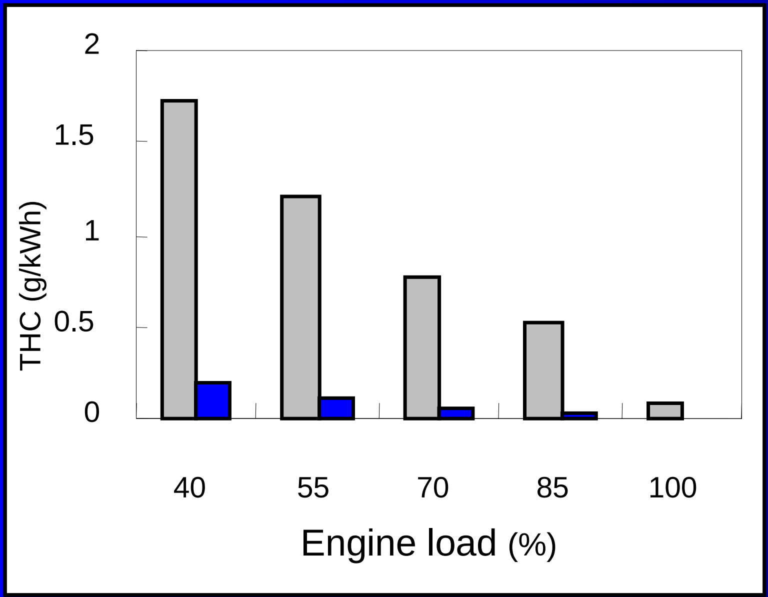
A; Cordierite honeycomb + heater (tested in JCAP STEP I)
B; SiC fiber + heater

Reduction Effect Other Than PM

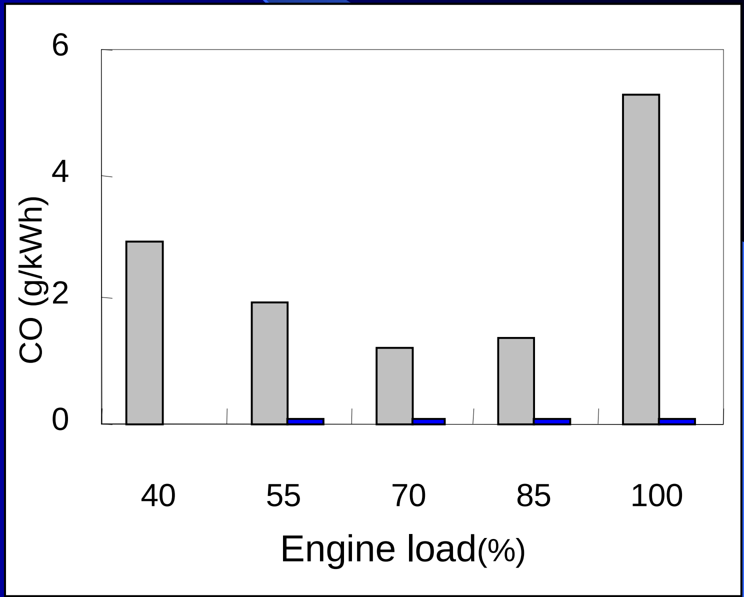
The reduction effect for HC and CO is also remarkable.

CRT inlet
CRT outlet

HC



CO



RPM point equivalent to 80% of max. power

1989 regulations compliant engine
Fuel 2D-04 (50 ppm)

Summary of PM Reduction Effect

1.Alternate regeneration DPF

-Exhibits high level of PM reduction effect.

2.Continuous regeneration DPF

(1) In case of fuel with 50 ppm sulfur

-Exhibits extremely high level of PM reduction effect.

(2) In case of fuel with 500 ppm sulfur

-Exhibits only poor PM reduction effect.

Conversely, PM emission increases in the long-term regulations compliant engines.

(3) Also has high reduction effect on HC and CO.

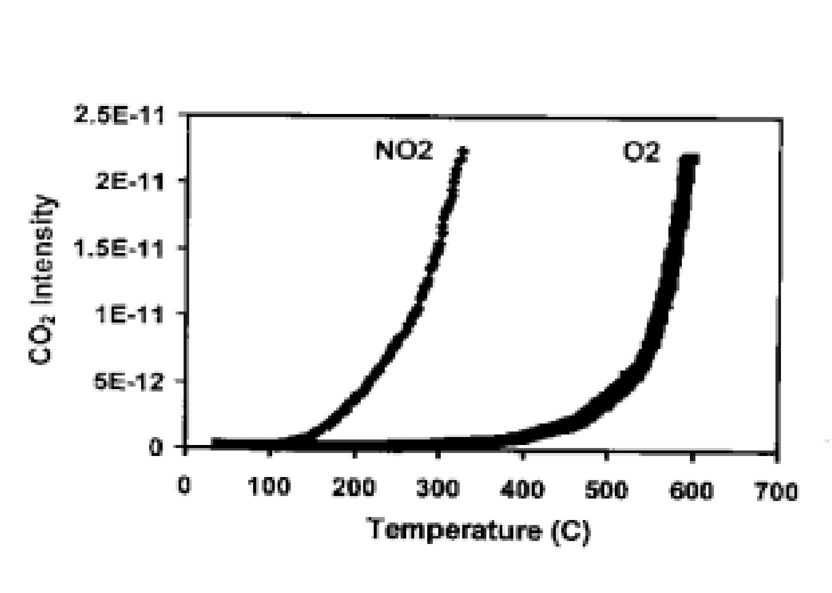
Second Point
Regeneration Performance

Study with Continuous Regeneration Type

Factors Affecting CRT Regeneration

1. Temperature

The regeneration of CRT by NO_2 Combustion can occur at lower temperature than oxygen but requires at least 260 °C.



2. NOx/PM ratio

In quantitative terms;

NOx/PM ratio > 8

Recommendation:

NOx/PM ratio > 24

Oxidation of NO_2

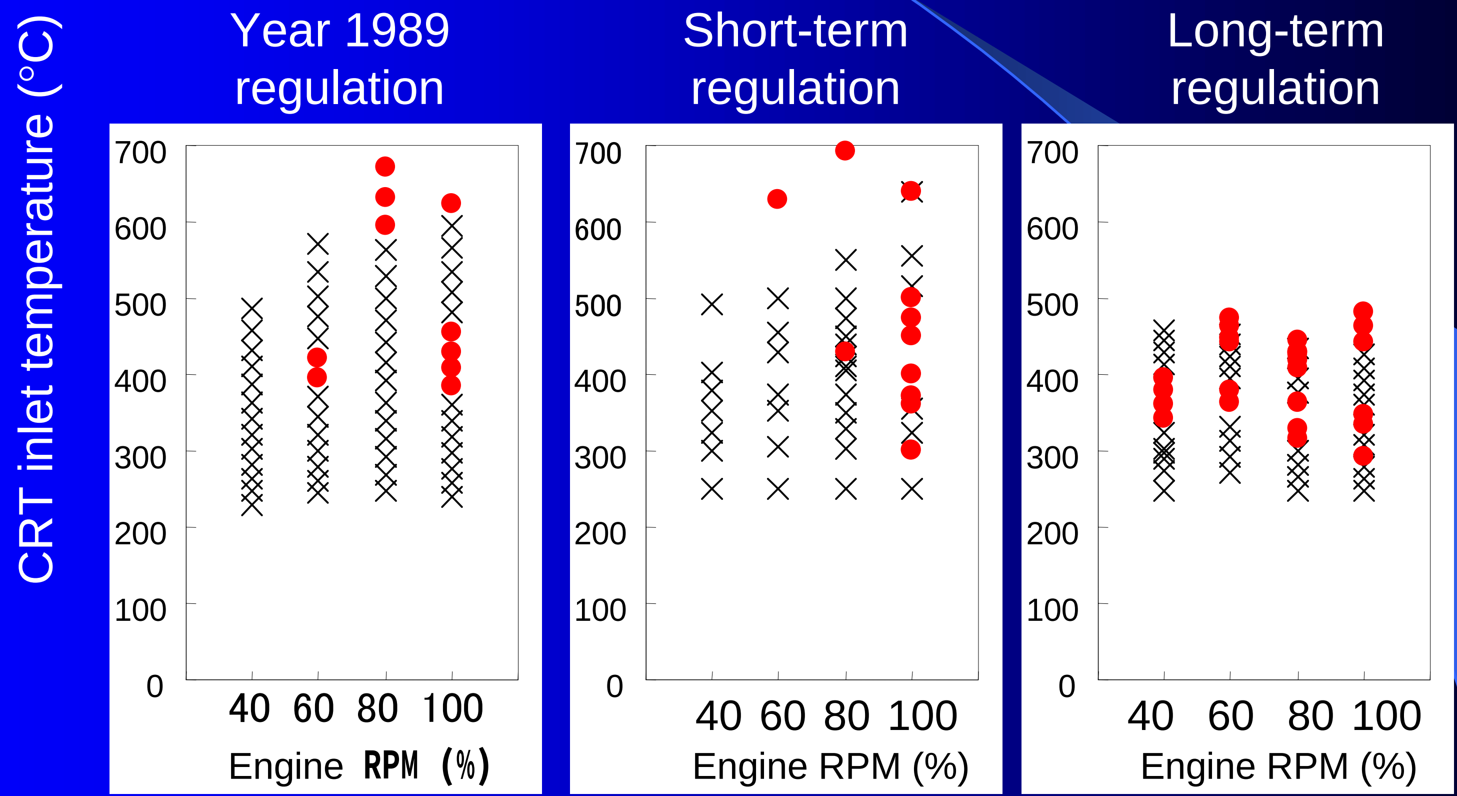
$C + 2NO_2 \rightarrow CO_2 + 2NO$

NO_2 generation

$2NO + O_2 \rightleftarrows 2NO_2$

CRT Regeneration Temperature Range

(Sulfur level 50 ppm)

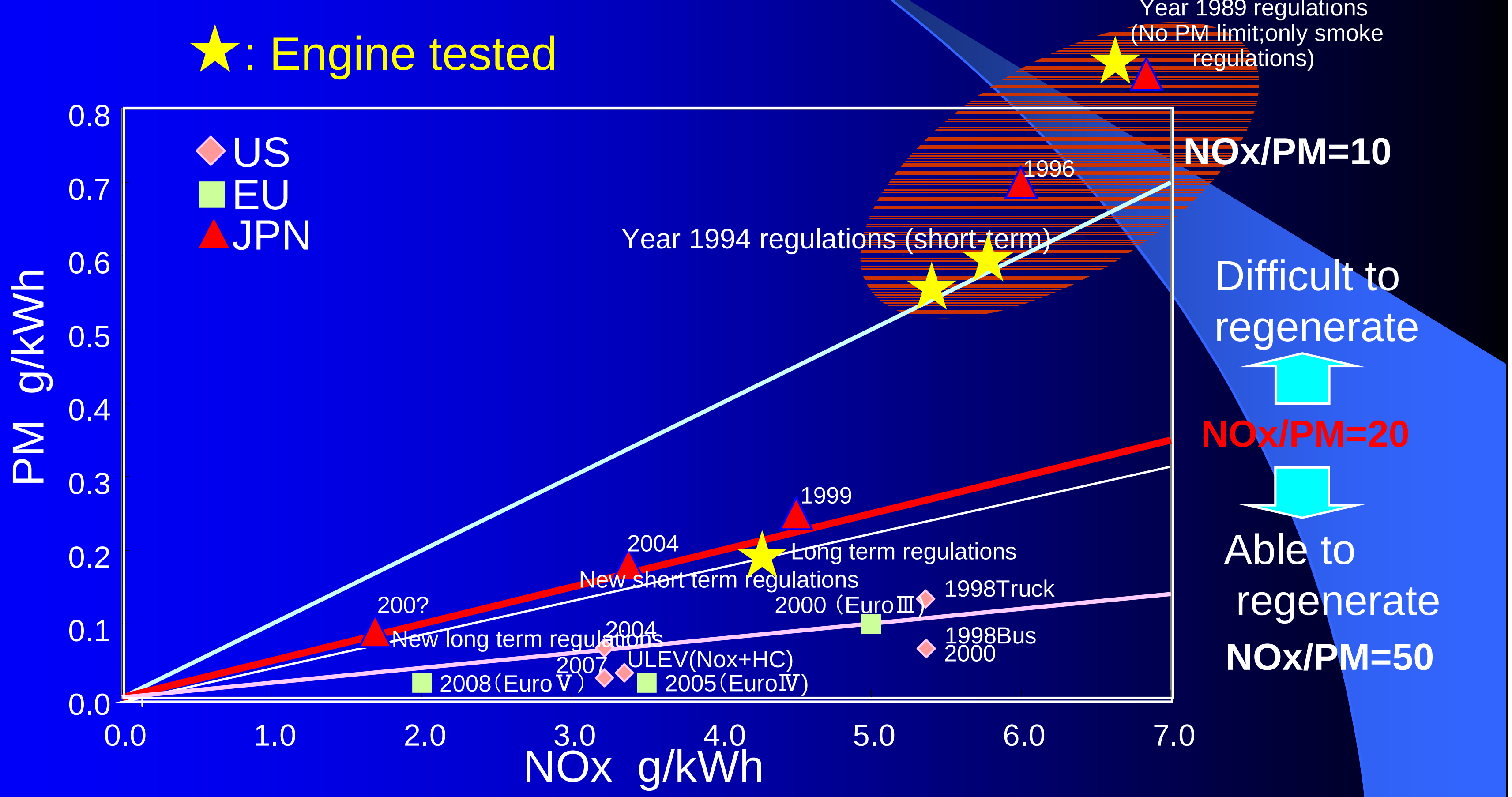


●: Regenerated (Differential pressure before and after DPF decreased or made no change.)

X: Not regenerated (Differential pressure before and after DPF increased.)

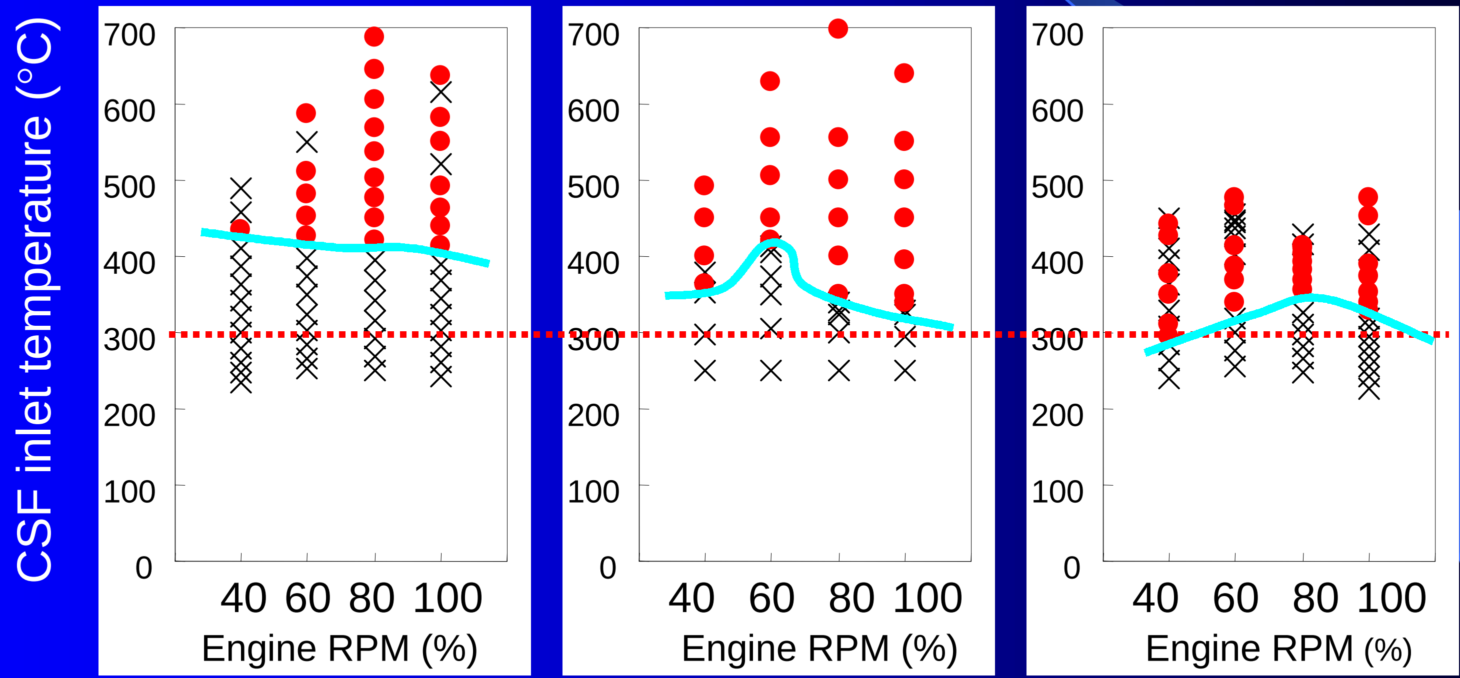
CRT Regeneration Conditions and NOx/PM ratio

The NOx/PM ratio level defined in the Japanese diesel emission regulations up to the present is too low to cause CRT regeneration.



Diesel Regulations Criteria Comparison Between US/EU/JPN

CSF Regeneration Temperature Range
(Sulfur level 50 ppm)



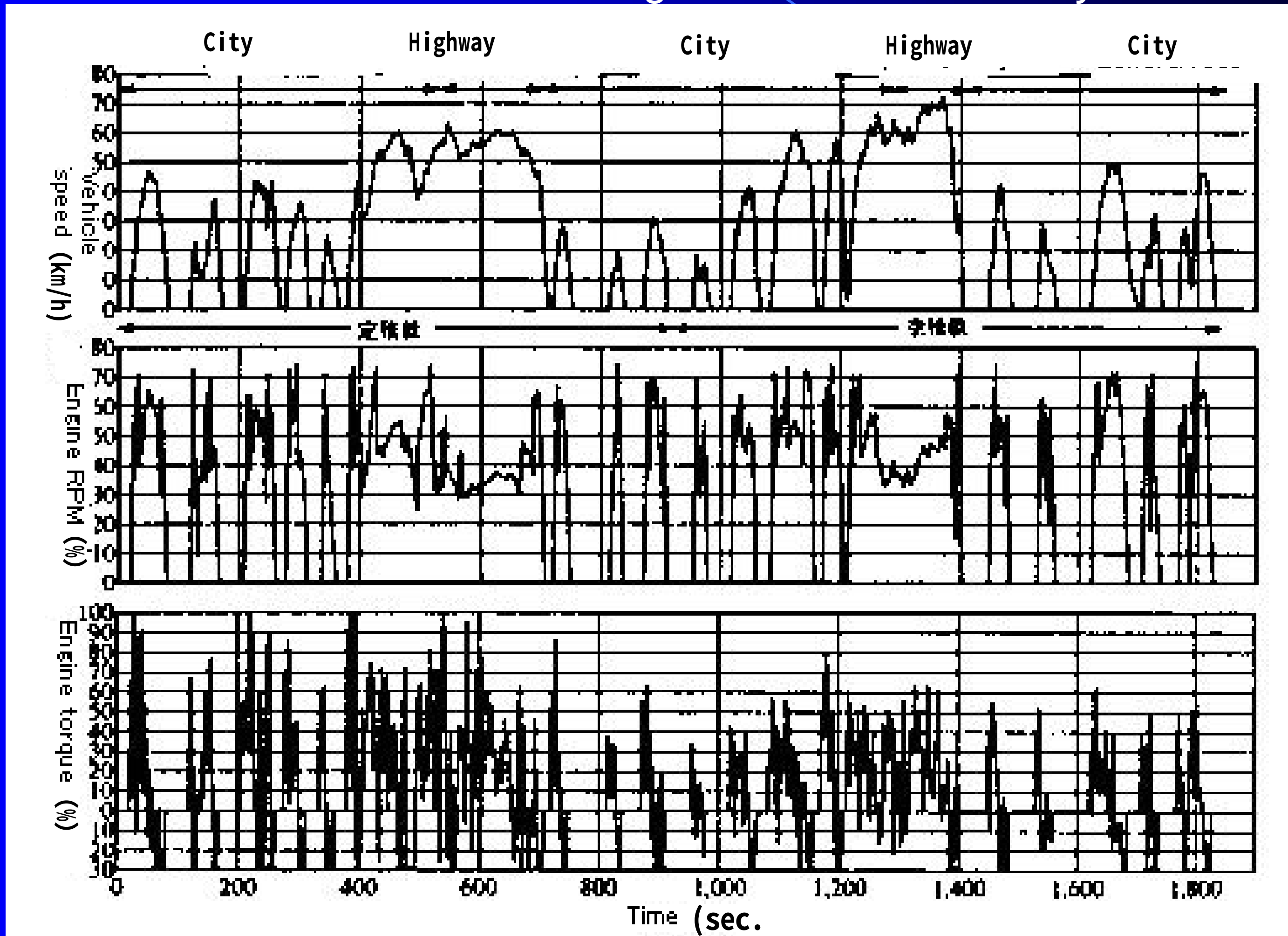
●: Regenerated (Differential pressure before and after DPF decreased or made no change.)

X: Not regenerated (Differential pressure before and after DPF increased.)

Actual Status of Exhaust Temperature

Studied through JARI engine test cycle

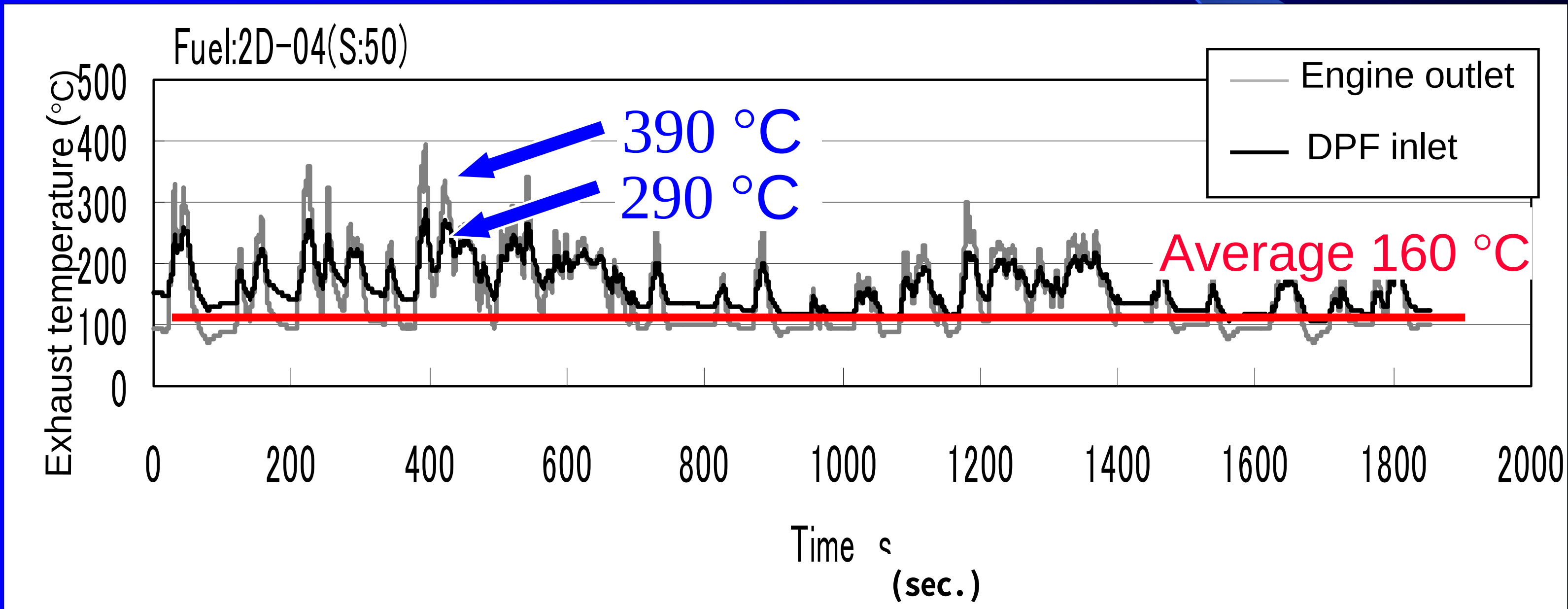
Transient mode simulating a urban drive in Tokyo area



Average vehicle speed: 26 km/h, 1 cycle: approx. 31 minutes

Exhaust Temperature Measurements

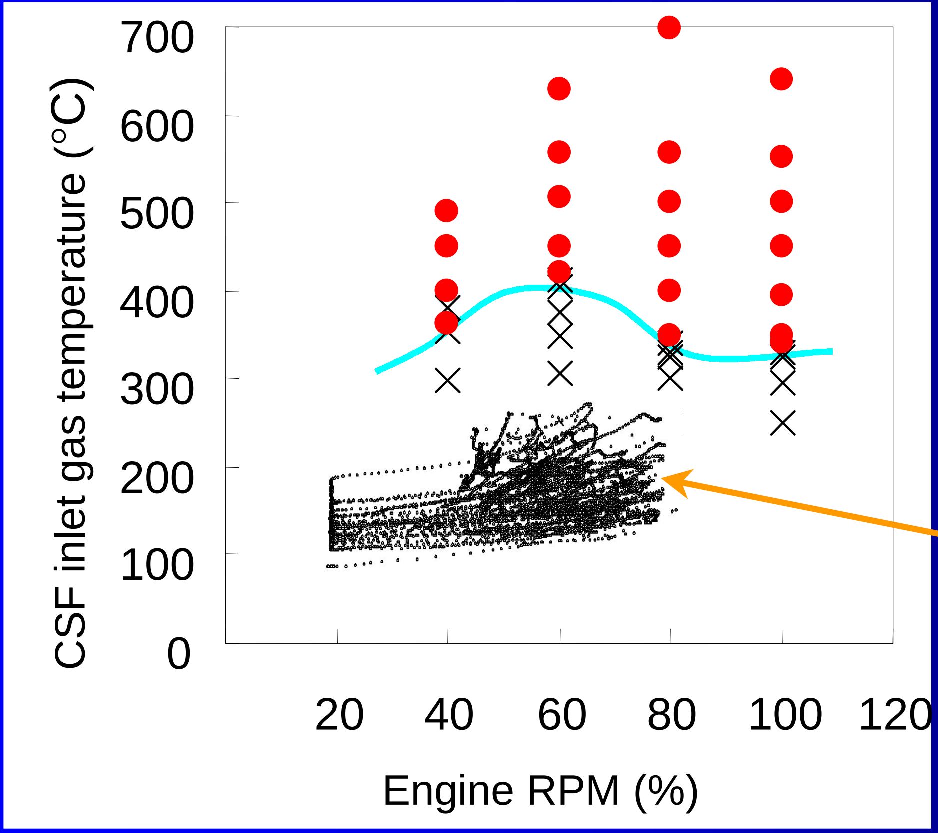
DPF inlet Average 160 °C （290 °C max.）
（Engine outlet 390 °C max.）



JARI engine test cycle
Short-term regulations compliant engine

Does the exhaust temperature reaches a level that causes CSF to regenerate during urban driving conditions ?

In typical urban driving, the exhaust temperature does not reach the regeneration threshold.



●: Regenerated

(Differential pressure before and after CSF decreased or made no change.)

X: Not regenerated

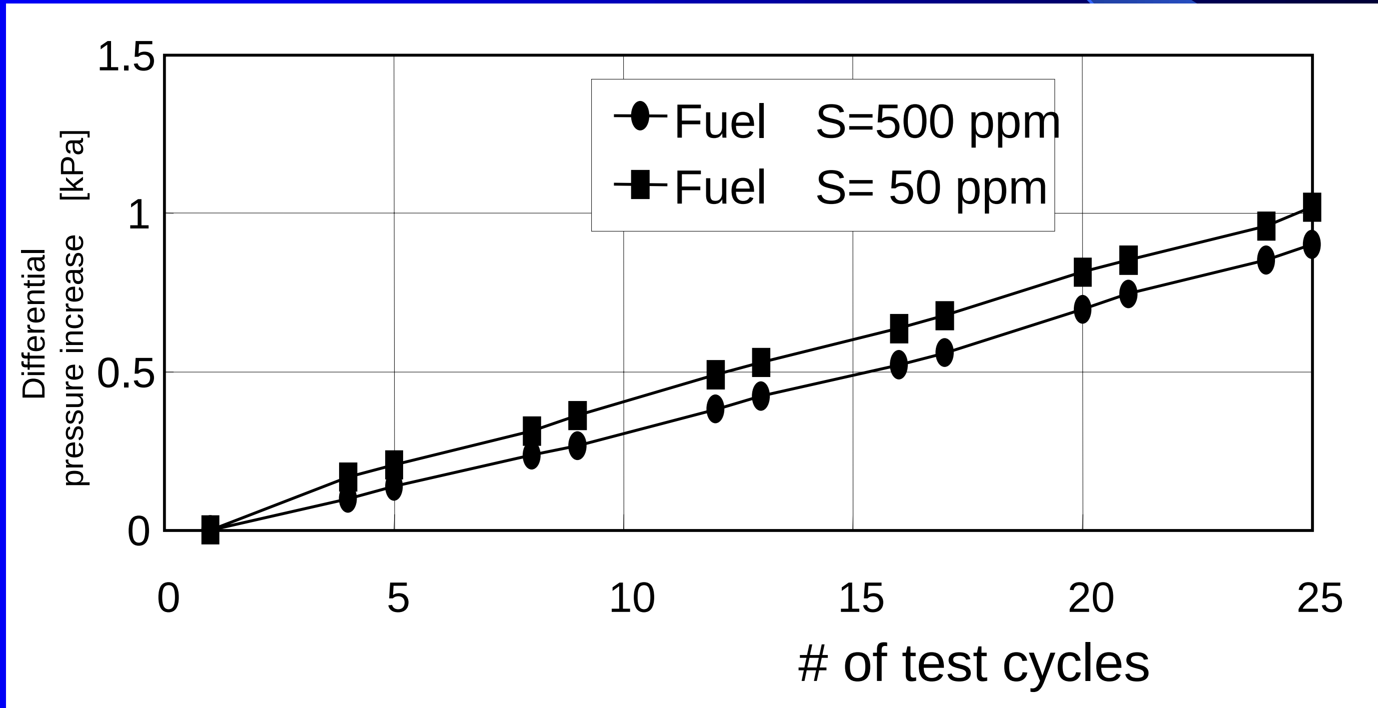
(Differential pressure before and after CSF increased.)

CSF inlet temperature during JARI engine test cycle drive

JARI engine test cycle
Short-term reg. compliant engine

When the exhaust temperature does not reach the regeneration threshold, does PM accumulate in CSF?

Result of engine test equivalent to 300 km drive
→ The differential pressure before and after CSF continuously increases (indicates PM accumulation)



JARI engine test cycle
Short-term regulations compliant engine + CSF

Summary of CRT Regeneration Performance

(1) On 1989 and short-term reg. engines, regeneration is observed in some mid-to-high speed RPM ranges.

(2) On long-term reg. engines, regeneration zone is wider than 1989 and short-term reg. engines.

(3) On short-term reg. engines, no regeneration is observed in repeated JARI engine test cycles.

Summary of Regeneration Performance

	Engine	CRT	CSF
Regeneration observed	Year 1989 reg. engine	-Regeneration observed in some mid-to-high speed RPM ranges	-Regeneration observed in all ranges at exhaust temperature of 400°C or higher
	Short-term reg. engine		-Regeneration zone in high RPM expanded on engines complying with 1989 reg. or above.
	Long-term reg. engine	-Regeneration zone wider than 1989 reg. and short-term reg.	-Regeneration zone expanded further than short-term reg. engine
Urban drive mode	Short-term reg. engine	-No regeneration observed in repeated JARI engine test cycles	

Summary of CSF Regeneration Performance

(1) In 1989 reg. engines, regeneration is observed in all ranges at exhaust temperature of 400°C or higher.

(2) In short-term reg. engines, regeneration zone stretches further at high RPM than 1989 reg. engines.

(3) In long-term reg. engines, regeneration zone is expanded further than short-term reg. engines.

(4) In short-term reg. engines, no regeneration is observed in repeated JARI engine test cycles.

General Summary

1. Fuel requirements

- - Low sulfur diesel fuel is needed to enhance CRT/CSF performance.

2. Applicability to vehicles in use

- There are a few opportunities for application under typical driving conditions in Tokyo urban areas.
- Some opportunities can be found in vehicles that run under conditions where exhaust temperature is likely to increase.
- CRT is considered difficult to apply to vehicles released before the short-term regulations were introduced because they have small NOx/PM ratios.

3. Generalization

- The technologies studied here can apply to vehicles in use if combined with new engine technologies, though opportunities are limited.

END