The Result of Japan's Round Robin Engine Test: Measurement of PM and PN

3/30/2009

PMP Informal Meeting

National Traffic Safety and Environmental Laboratory
Japan Automobile Research Institute

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- Round Robin Test Results
- Understanding the Factors Affecting the Measurement Results
- Summary

Outline and Objective

- Japan's round robin test, the measurement of PN and PM using HD engines, was conducted at two laboratories (NTSEL and JARI).
- The round robin test in Japan had the following two objectives:
  - To perform testing according to Validation Exercise at NTSEL and JARI and supply data to PMP;
  - To study the optimum measurement method as the PN-measurement method and filter-weight method and provide data that will help determine the measurement procedures.

Specifications of Test Engine and Fuel

- Test Engine

Engine Model	HINO J08E-TP
Configuration	Inline 6cyl, w/I.C.,T.C.
Bore X Stroke	112 X 130
Displacement	7.684 L
Compression ratio	18.0
Injection System	Common Rail (Max 1600bar)
Emission Reduction Device	DPF w/Cat., Cooled EGR
Performance	177kW / 2700rpm
Emission	2005JP, nearly EURO V

- Test Fuel

  In conformity with RF-06-03

Specifications of Full and Partial Tunnels

		NTSEL (Lab. A)	JARI (Lab. B)
Full Tunnel	1st Tunnel Diameter	457 mm	605 mm
	CVS Flow	50 m^3/min	60 m^3/min
	2nd Tunnel Diameter	83 mm	83 mm
	PM Sample Flow Rate	67 L/min	68 L/min
	Dilution Air Flow Rate	50 L/min	15 L/min
Partial Tunnel	Tunnel Diameter	29.4 mm	29.4 mm
	PM Sample Flow Rate	67 L/min	68 L/min
	Split Ratio of Exhaust Flow	1/700	1/1000
PM Sample	Filter Material	TX47Φ	TX47Φ
	Temperature	47±5°C	47±5°C

Particle Number Counting System

- 2 Horiba systems and 1 Matter system were used. One of the Horiba systems was used by both laboratories as common system.

System	Maker	Model No.	PND1 dilution ratio setting	PND2 dilution ratio setting	Tested by
SPCS1	Horiba	MEXA-1000SPCS	**10**	**15**	NTSEL (Full) JARI (Full/Partial)
SPCS2	Horiba	MEXA-1000SPCS	**20**	**15**	NTSEL (Partial)
Matter	Matter	MD19+ASET15	**22**	**10**	JARI (Full/Partial)

- NTSEL

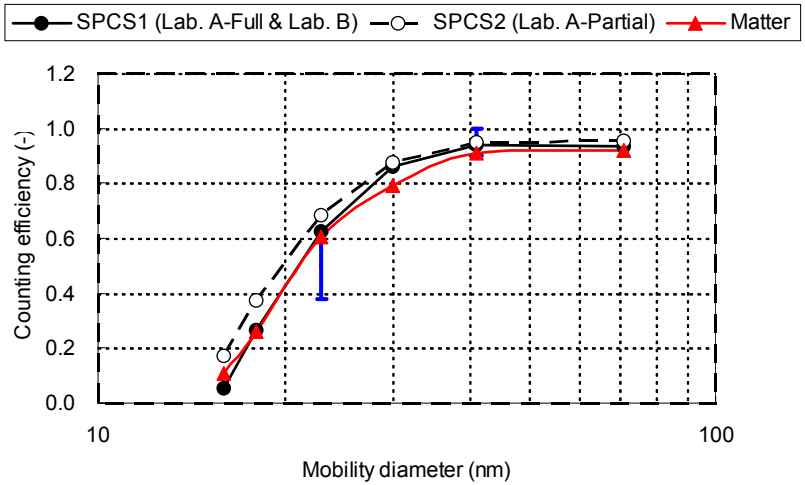
  Conducted simultaneous measurement with full and partial tunnels in the same test using 2 SPCSs.

- JARI

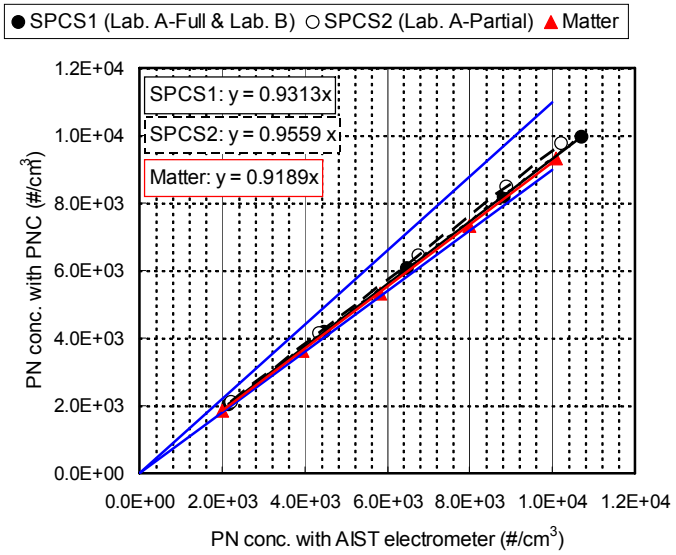
  Conducted measurement at the same sampling point using 1 SPCS and 1 Matter. Measurement with full tunnel and that with partial tunnel were performed in separate tests.

PNCS Data to Calculate Emission

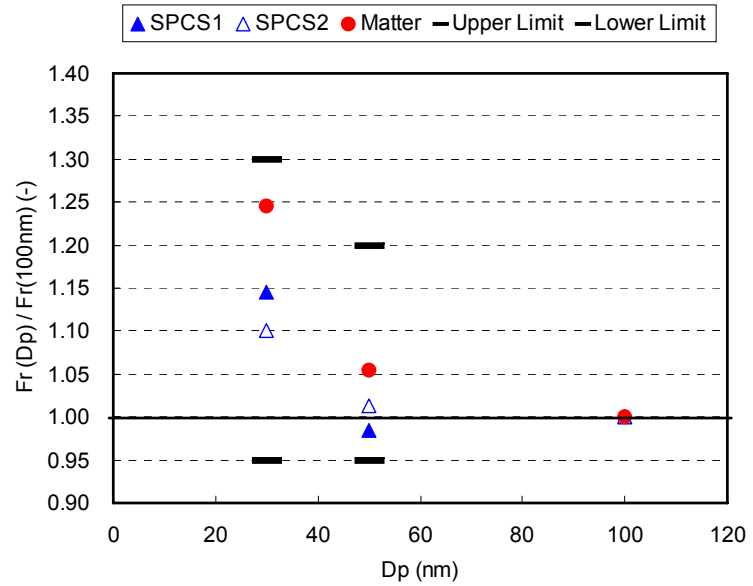
PNC cut-off point



Linearity check against electrometer



PCRF regulation



- No problem with PNC provisions (cut-off point, correlation with reference meter).
- As to PCRF, all systems were within the specified range; however, Fr(50nm)/Fr(100nm) ratio was below 1 in one system. Possibly problematic.

Daily Schedule of the Round Robin Test

	Mon.	Tue. - Fri.	Remarks
0	Each lab's own test for study	IFV	
1		**BG**	
2		**C_WHTC#1~8**	
3		10 min soak	
4		**H_WHTC#1~8**	
5		CP	
6		**WHSC#1~8**	
7	Rated 20 min.	Rated 20 min.	
8	**Engine stop 10 min.**	**Engine stop 10 min.**	
9	Preliminary JE05	Preliminary JE05	
10	Engine stop 10 min.	Engine stop 10 min.	
11	**Full JE05 test**	**Full JE05 test**	
12		15 min.	
13		BG	

Tunnel blank (TB) measurement:

Sampling time: 30 min.
Measurement timing: At start and completion of daily test

IFV:	Instrument Functional Verification (Daily check of PNCS, etc.)
CP:	Continuous Protocol (Idle 6 min. ⇒ WHSC mode9 10 min. ⇒ Engine stop 5 min.)
PC:	Power Curve (Not to be recorded; To be checked at rated operation before JE05 test; rated output only)
SMP:	Stabilization Mode Protocol (JE05 test to be defined as SMP)

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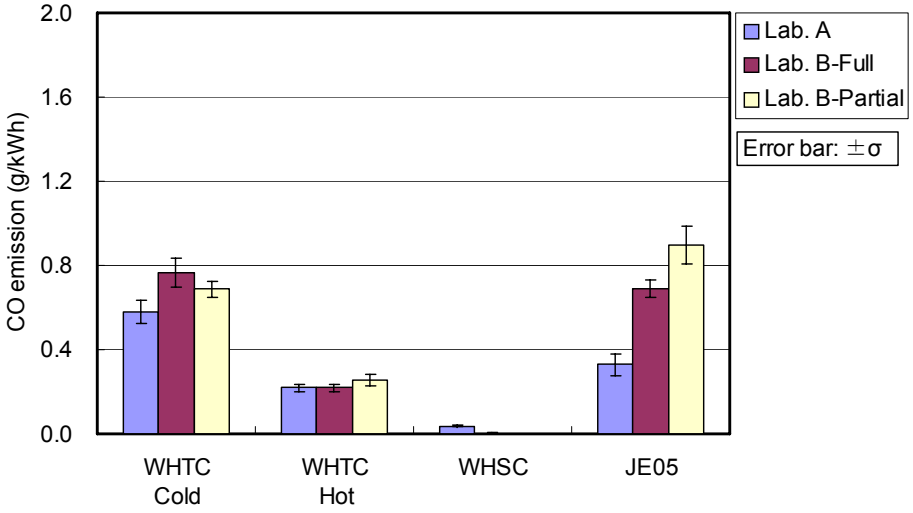
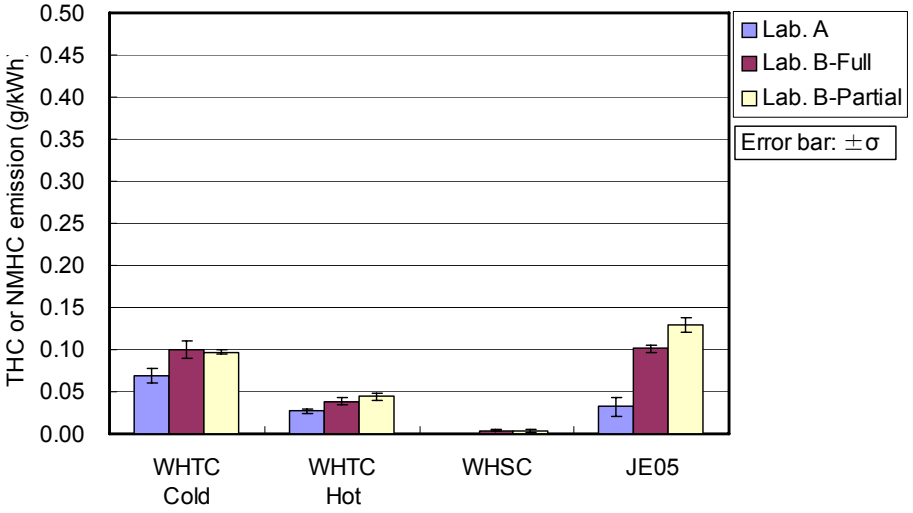
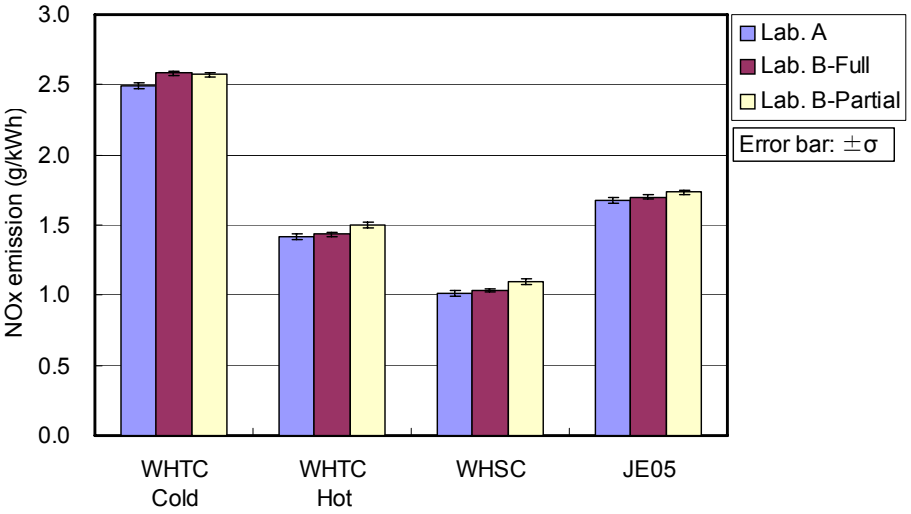
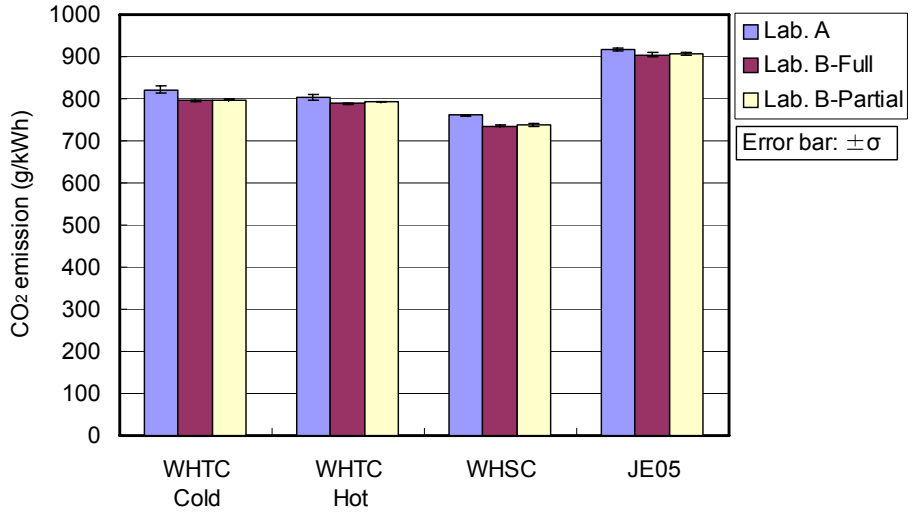
Gaseous Emission



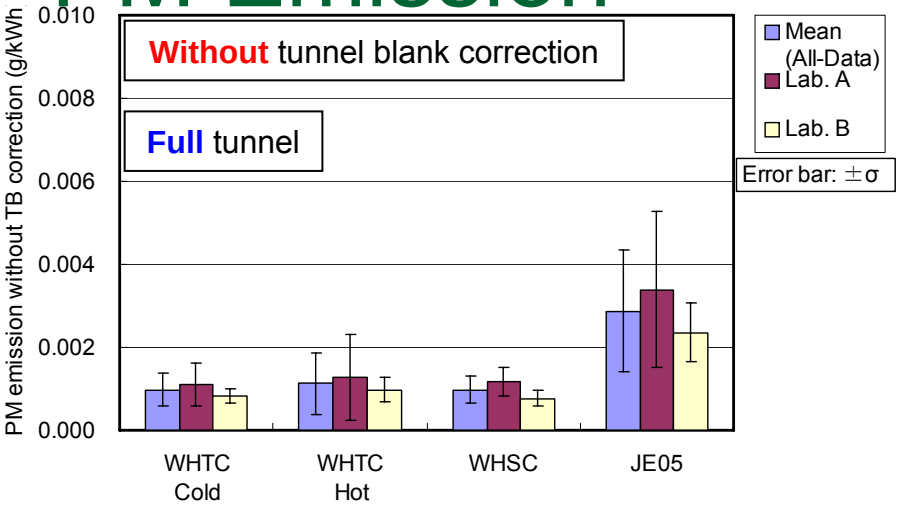


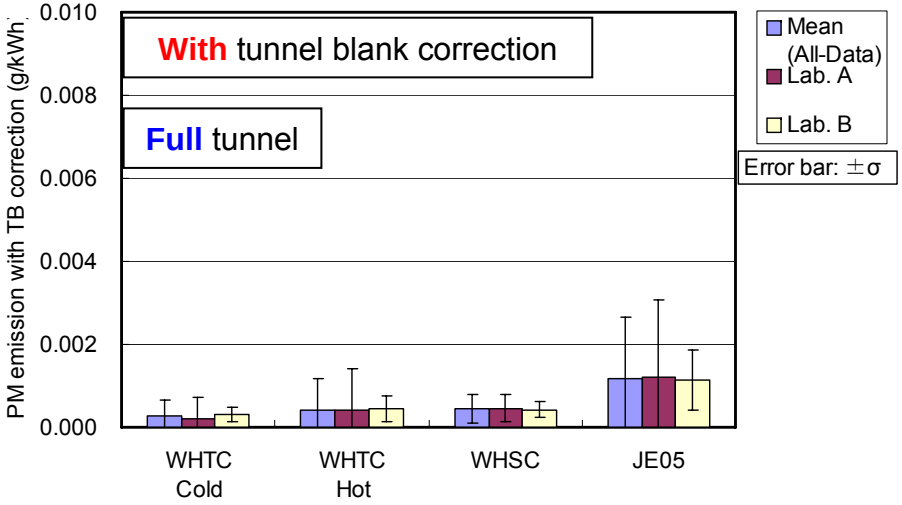


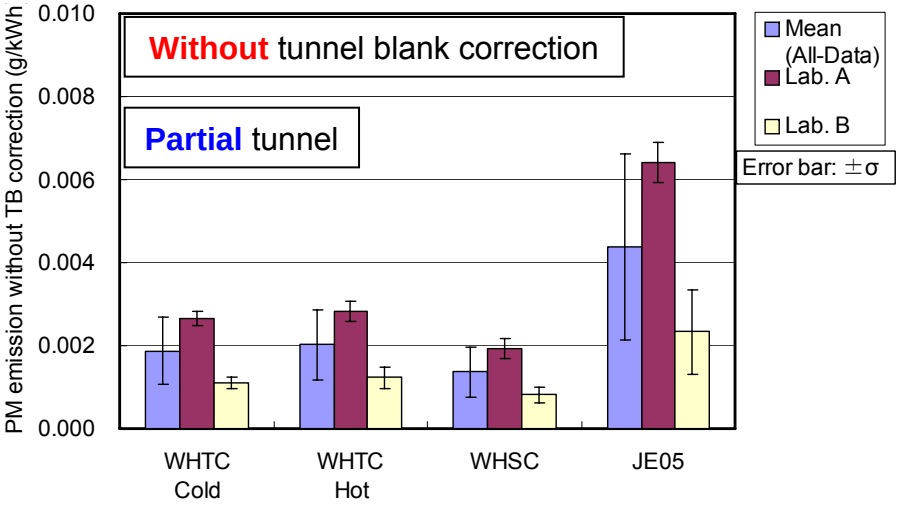


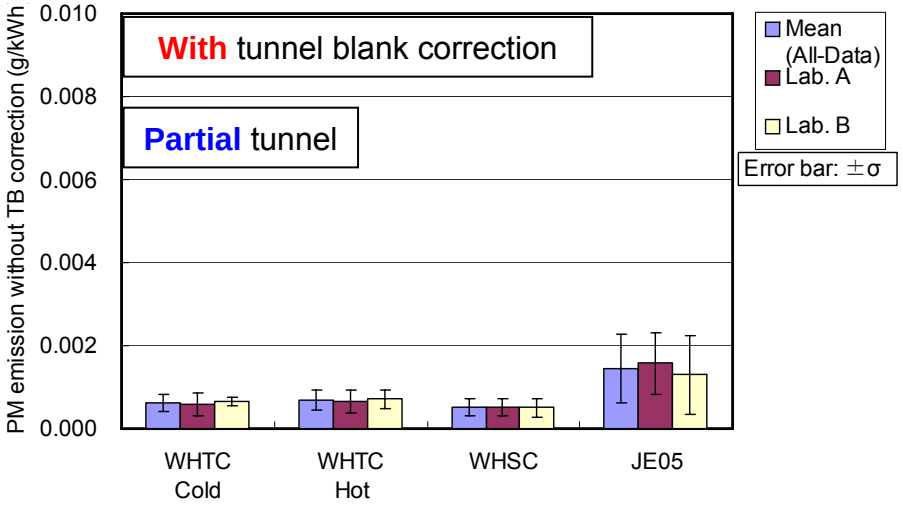
* CO & HC: Slight differences in the result among labs in some modes; good repeatability.
* NOx & CO_2: Almost the same results among labs; good repeatability.

PM Emission





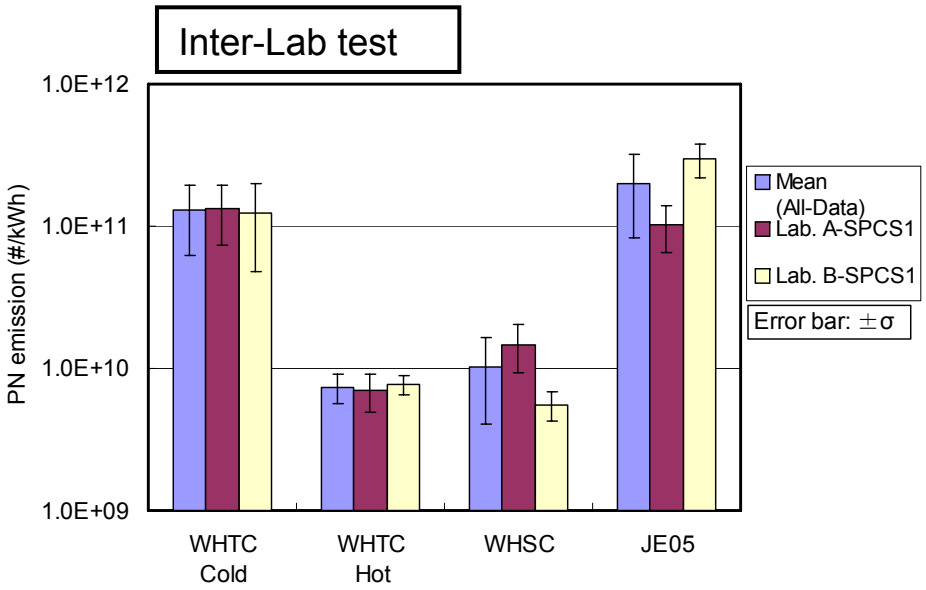


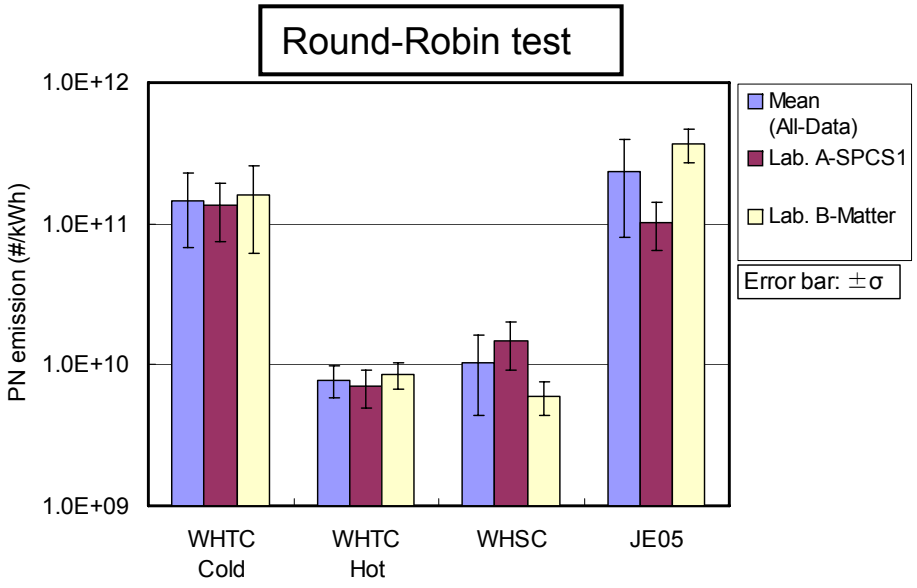


Before TB correction, emission levels of Lab. A were significantly higher than the others; After TB correction, emission levels of Lab. A and Lab. B *became almost the same.*

PM emission: JE05 > WHTC-Hot ≈ WHTC-Cold ≈ WHSC

PN (Number) Emission -Full Tunnel-





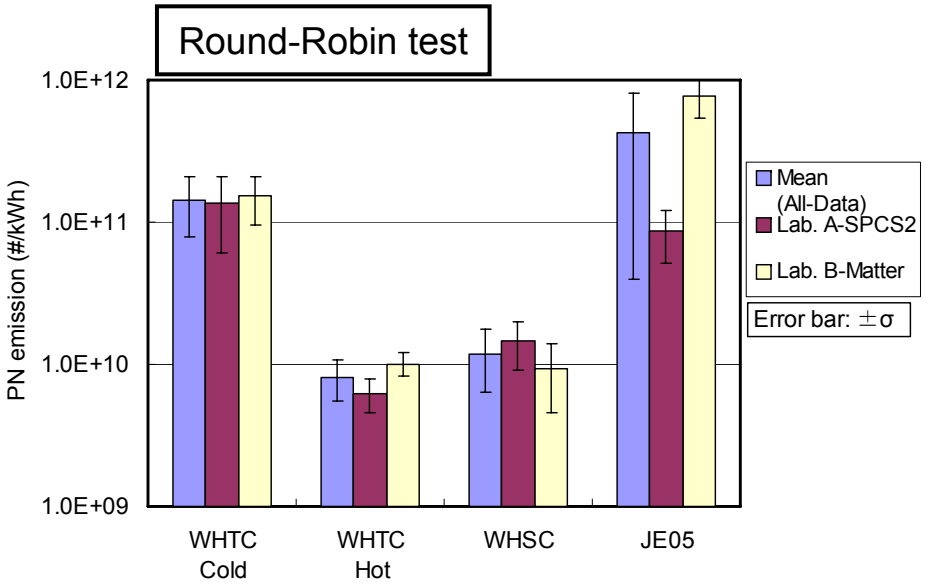
Full tunnel:

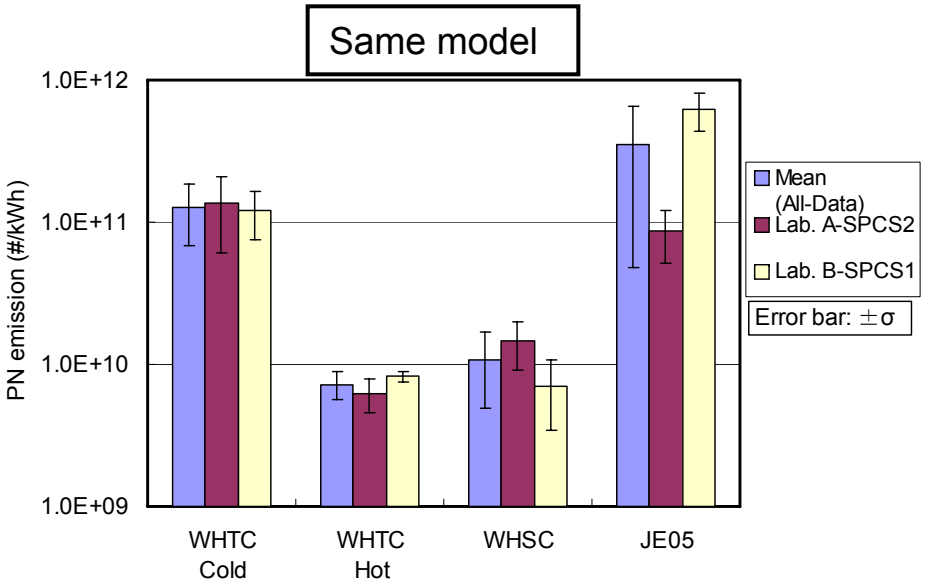
** The emission levels in WHTC-C/H of Lab. A and Lab. B were almost the same.*

** The emission level in WHSC of Lab. A and that in JE05 of Lab. B were about 3 times higher, respectively.*

Also, even when the same PNCS was used, the result differed between labs.

PN (Number) Emission -Partial Tunnel-





Partial tunnel:

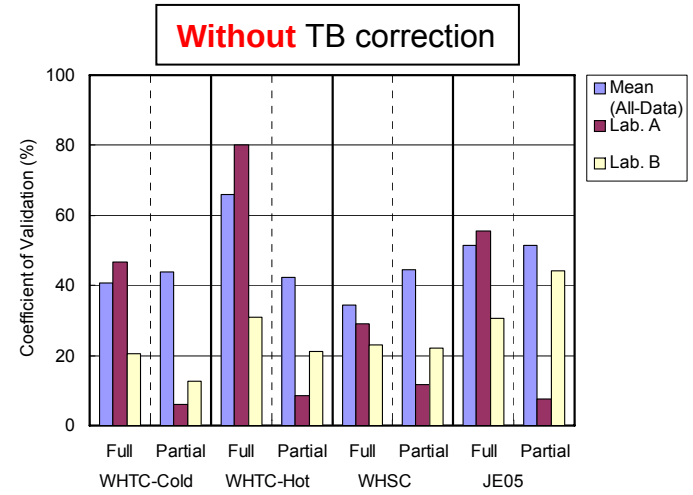
* *The emission levels of Lab. A and Lab. B were the same as the full tunnel, except for JE05.*

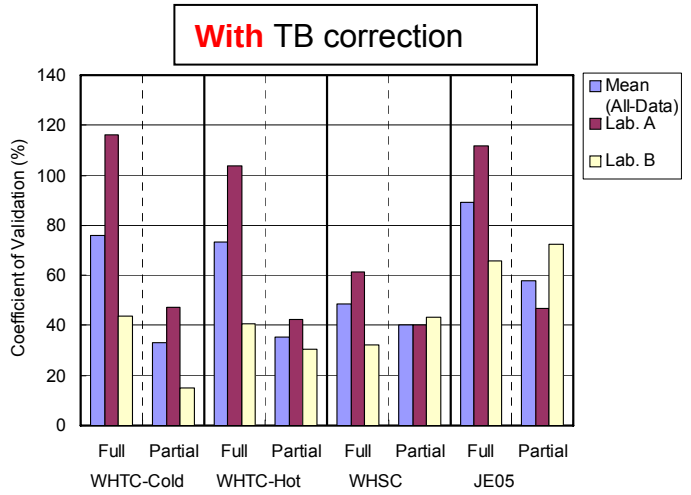
* *The emission level in JE05 of Lab. B was about double the level in the full tunnel.*

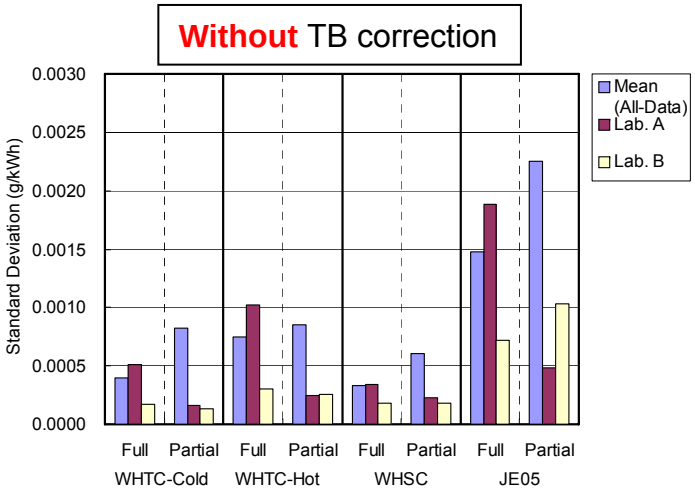
Also, even when the same-model PNCS was used, the result differed between labs.

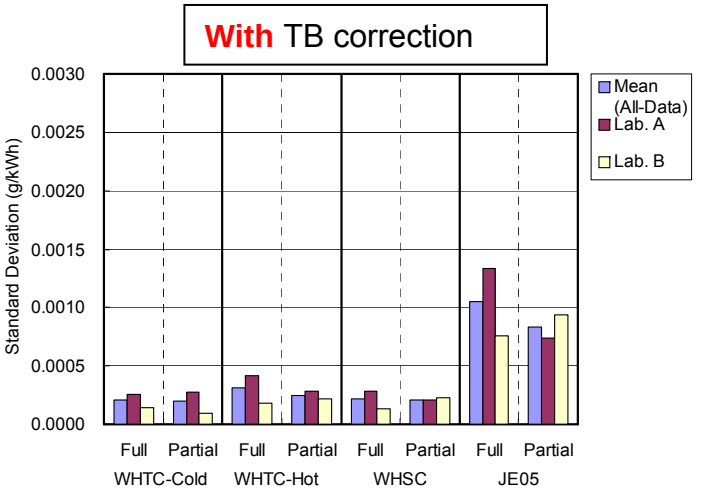
PN emission: JE05 > WHTC-Cold > WHTC-Hot ≈ WHSC
The emission-level order of WHTC-Cold differed between PM and PN.

Comparison of COV for PM





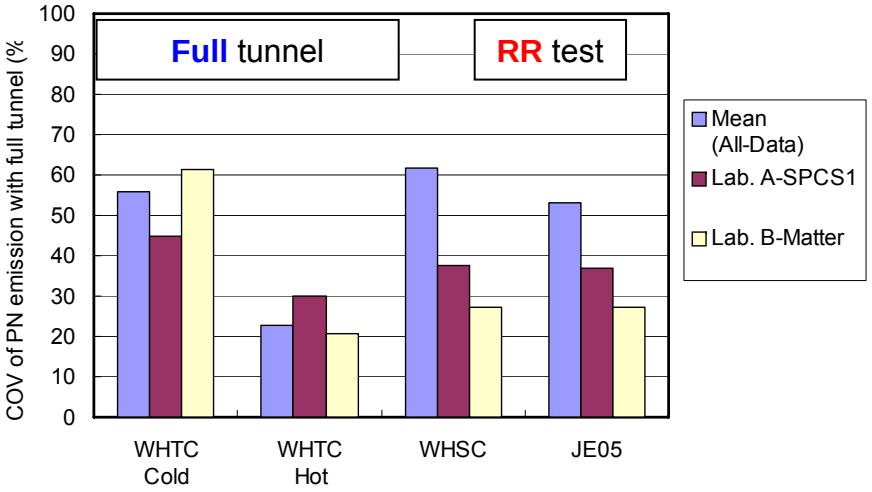


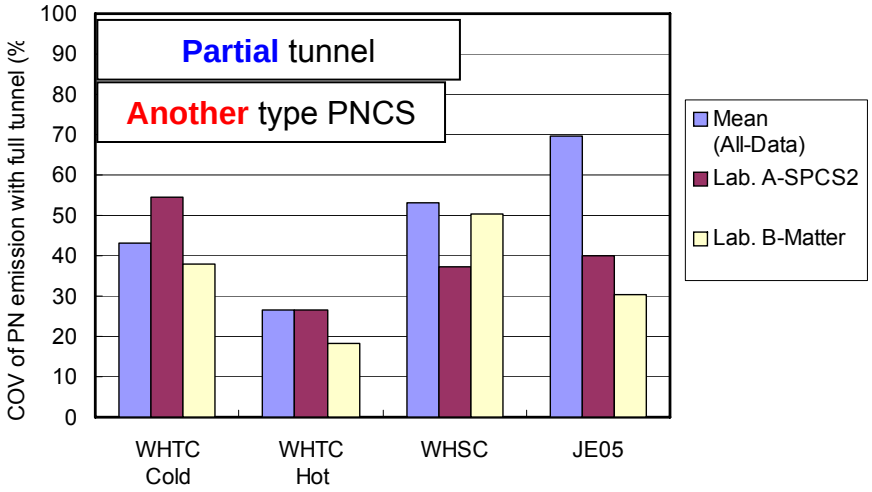


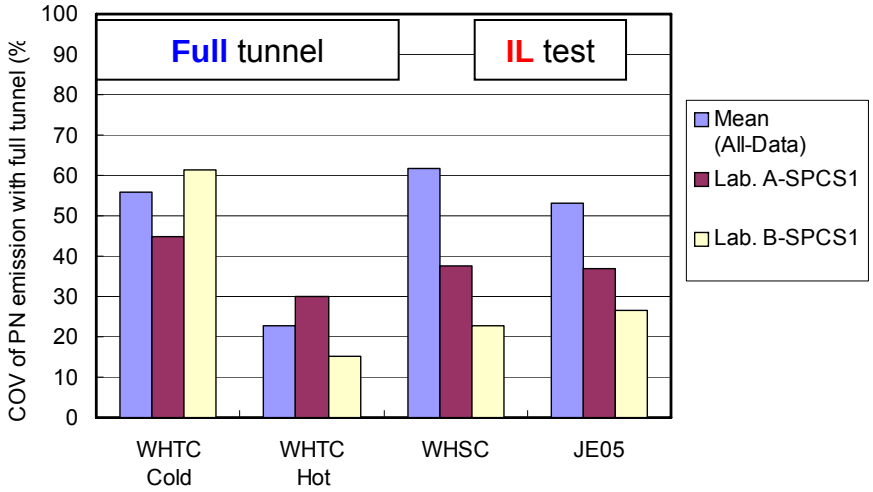
TB correction on PM lowered *emission levels, causing COV to be higher.*

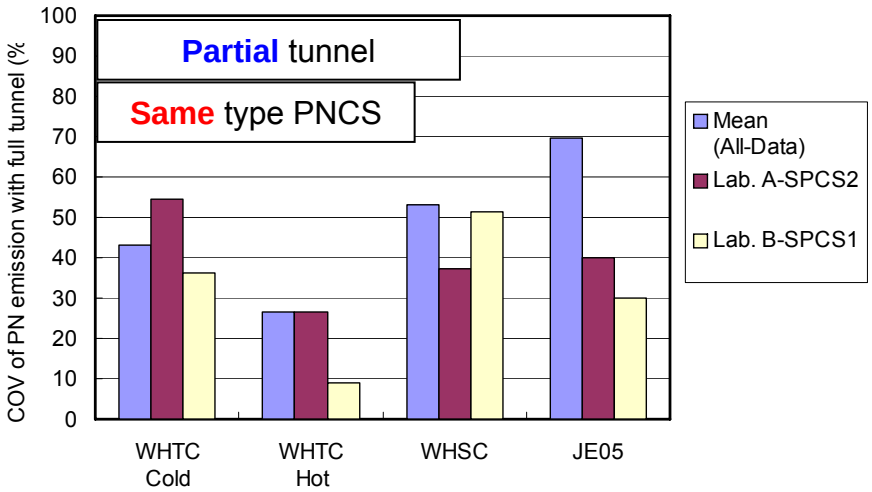
However, TB correction reduced the standard deviation (g/kWh), *resulting in smaller variations.*

Comparison of COV for PN









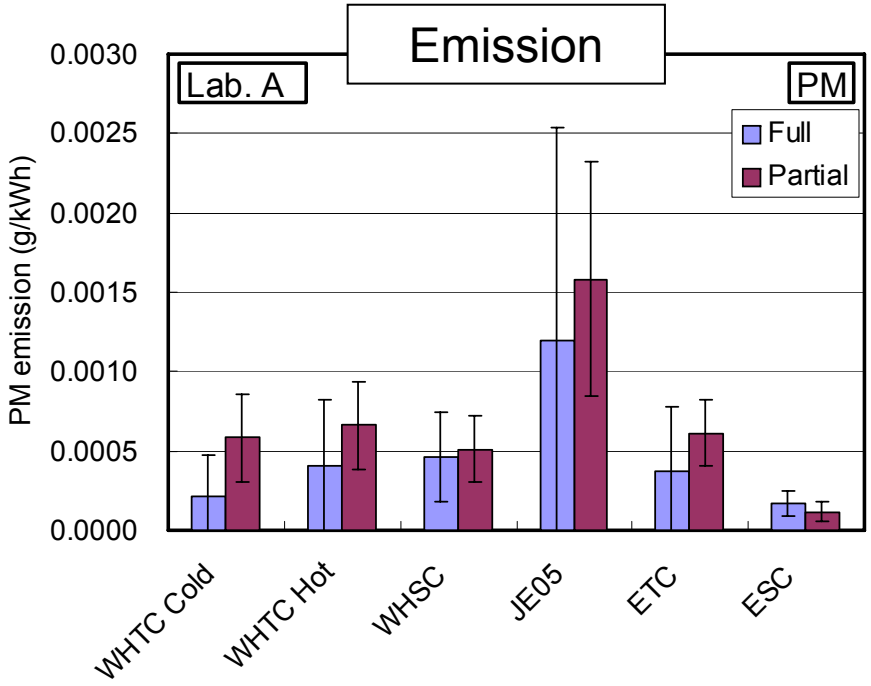
COV for PN:

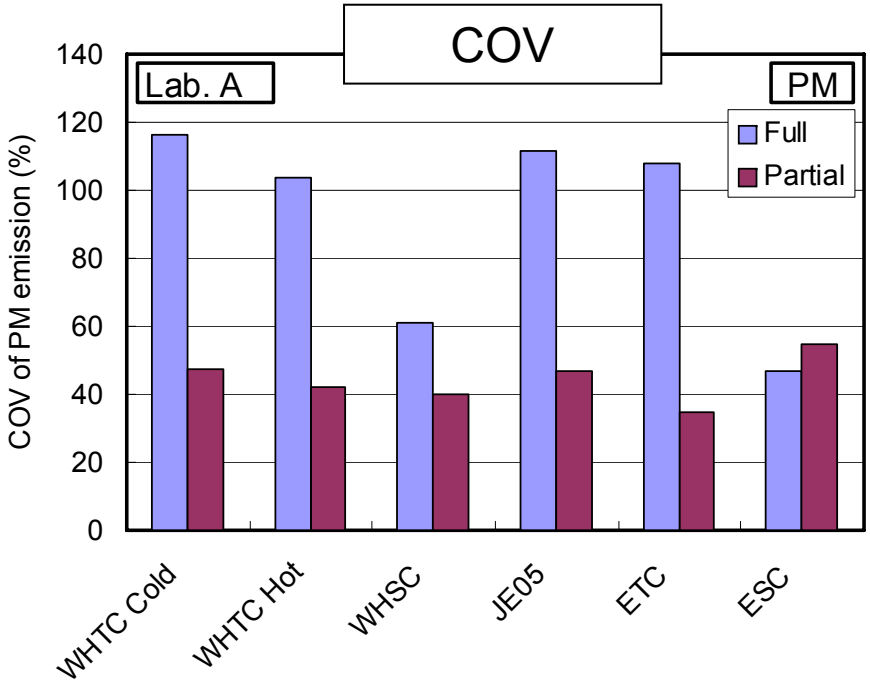
** No large difference between full tunnel and micro tunnel dilutions; around the same level.*

* COV was 20%-70%; *almost the same level as PM without TB correction.*

NTSEL data

PM Emission in ETC and ESC Modes

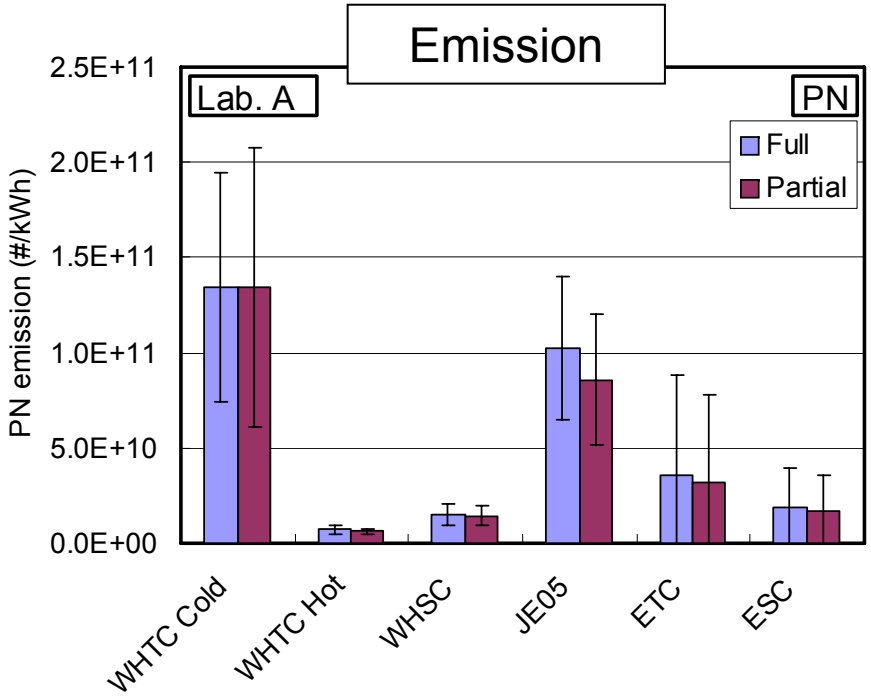


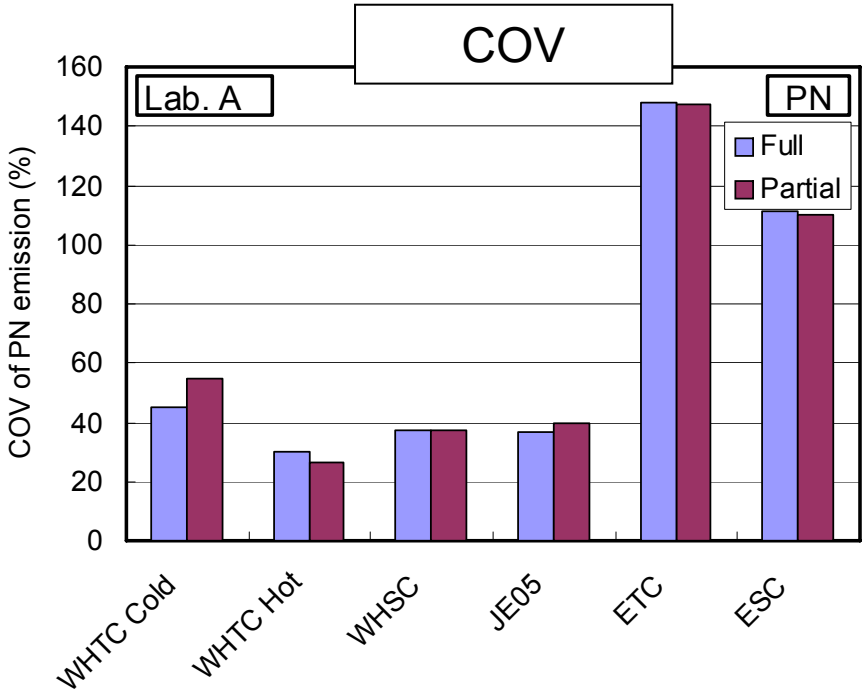


- No unique tendency in the emission level and COV was observed in either ETC or ESC.

NTSEL data

PN Emission in ETC and ESC Modes

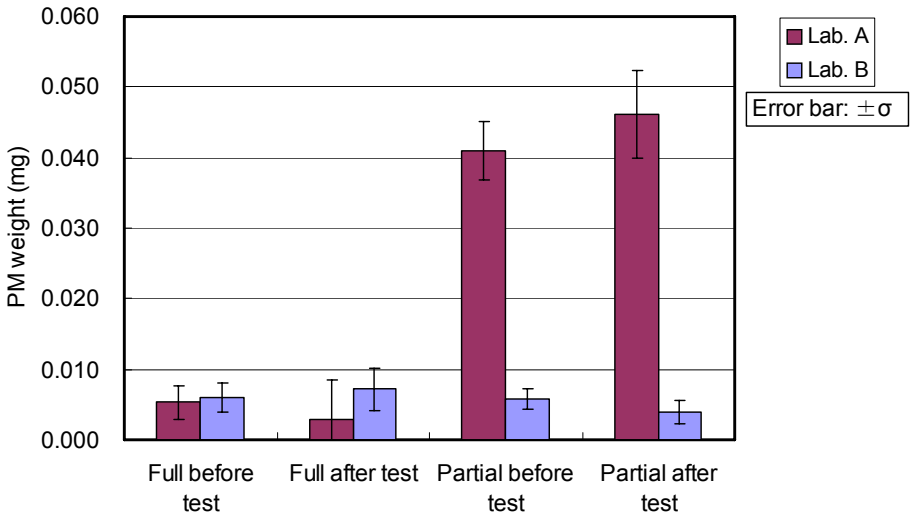




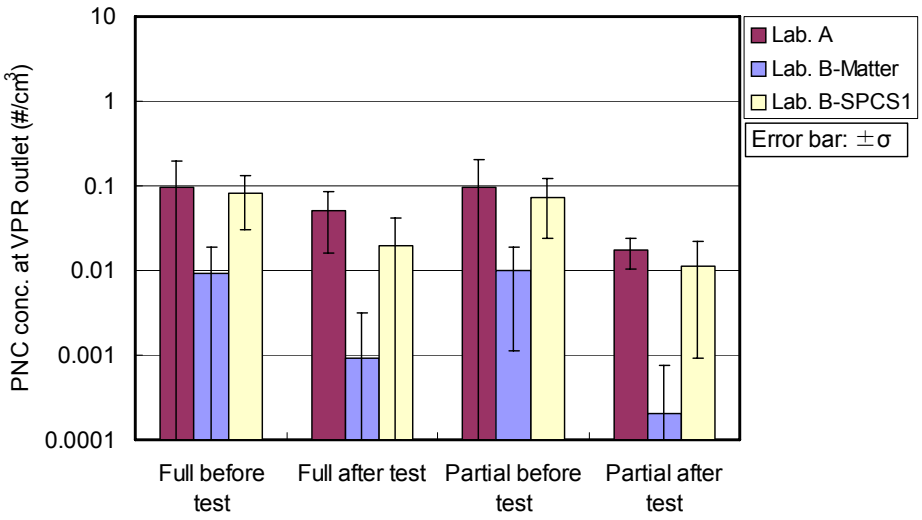
- Correlation of PN and PM was good in both ETC and ESC, similarly to WHTC Hot, etc.
- COV were relatively high in ETC and ESC, which is presumed to have been caused by the conditions being not uniform due to the simple preconditioning procedures.

Effect of Tunnel Blank - Measured values -

Amount of PM trapped (mg/30min)



Average PN (#/cc/30min)



PM:

TB levels of PM were high with test of the partial tunnel of Lab. A.

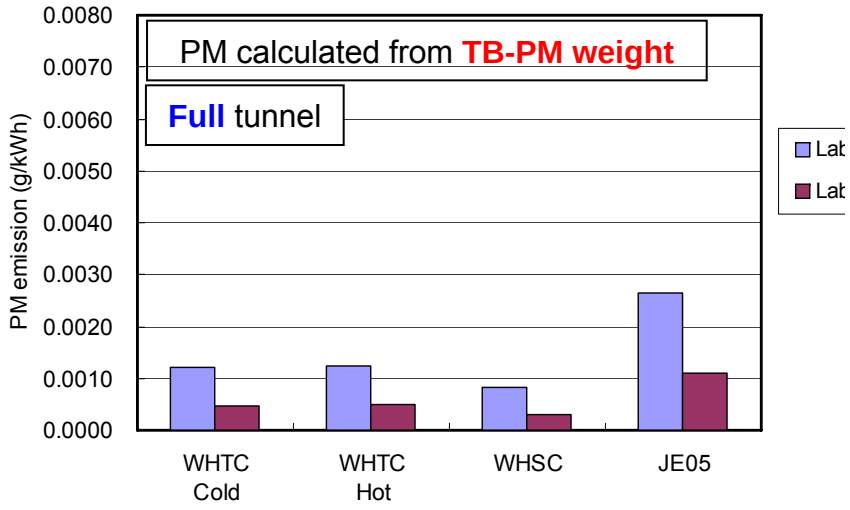
PN:

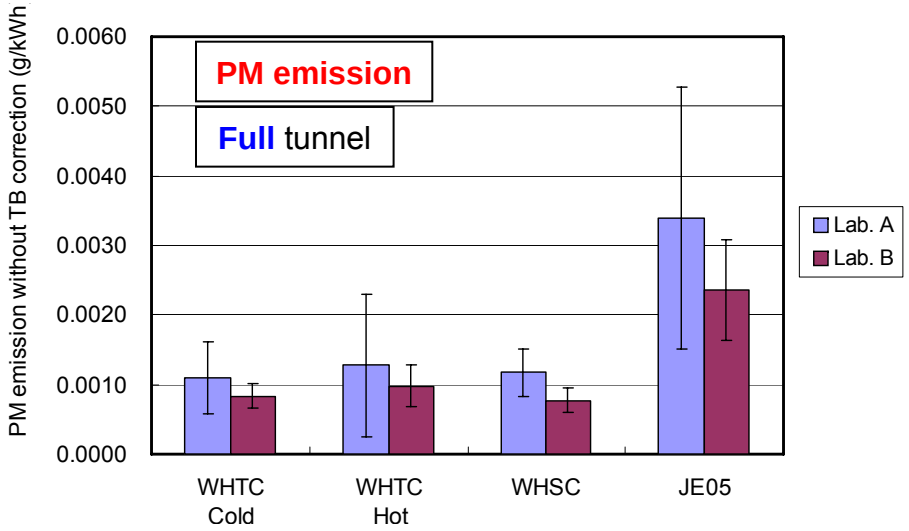
TB levels were higher with SPCS system than Matter system in this research.

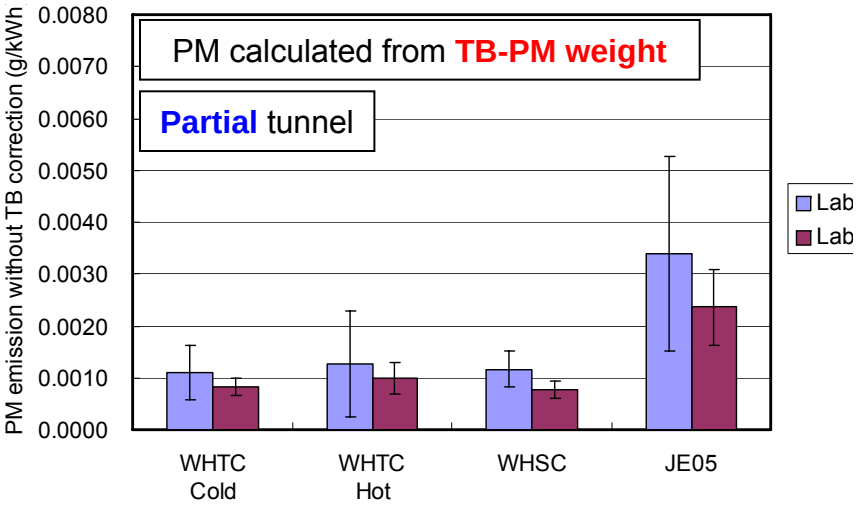
TB levels of the same-model system were around the same level in any laboratory.

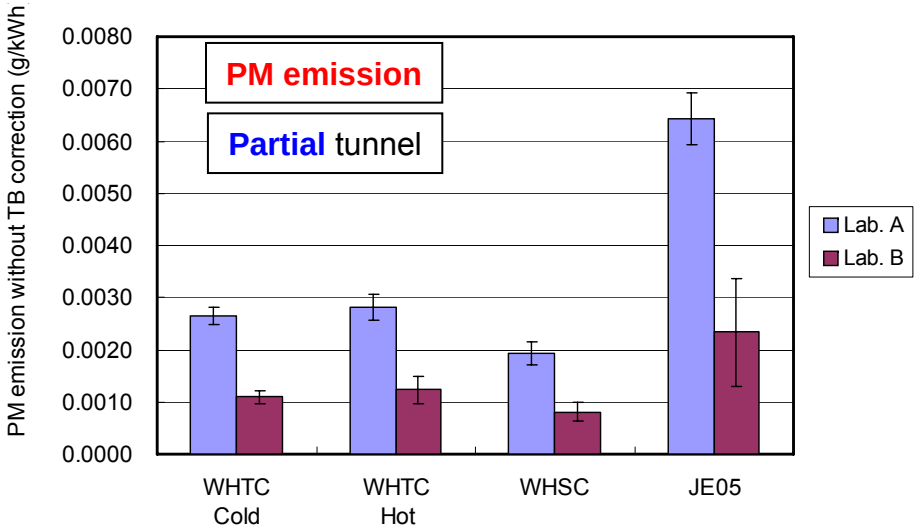
⇒ Presumably due to the noise from CPC and differences in the dilution method.

Effect of Tunnel Blank - Converted to mode emission -







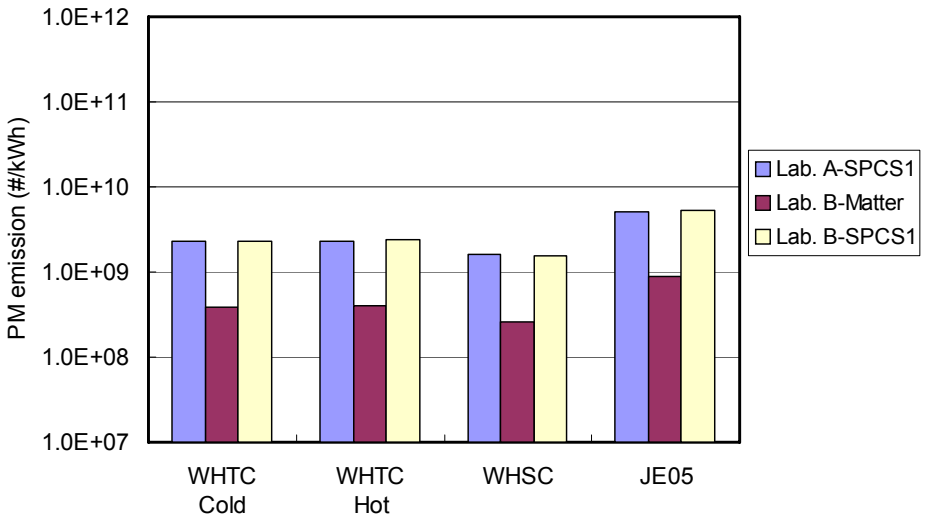


TB levels of PM were high with the partial tunnel of Lab. A, and its contribution to the emission was also high.

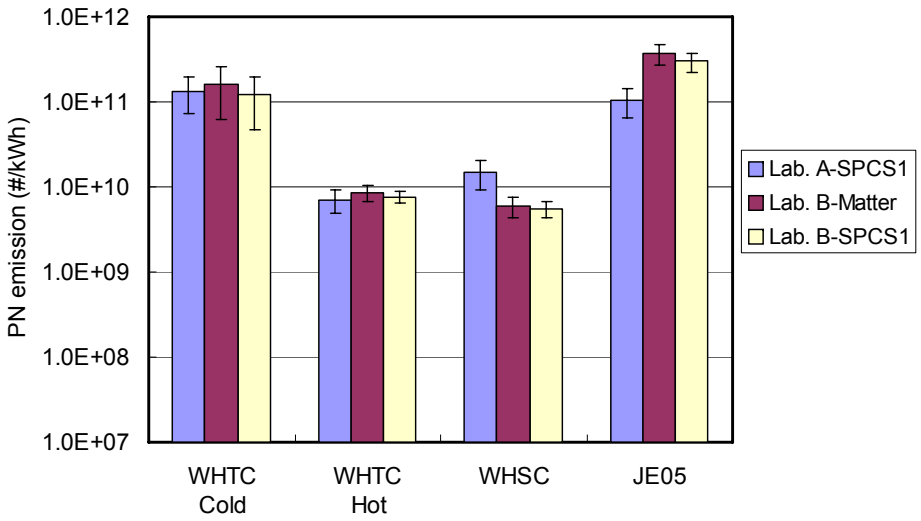
Effect of Tunnel Blank - Converted to mode emission -

PN

Emission calculated from TB conc.



Emission



Since the effect of TB is affected by Vmix and power output of engine, the level of effect differs among modes.

* With Matter, TB contribution was about 1/100 to 1/1000; low effect on emissions.

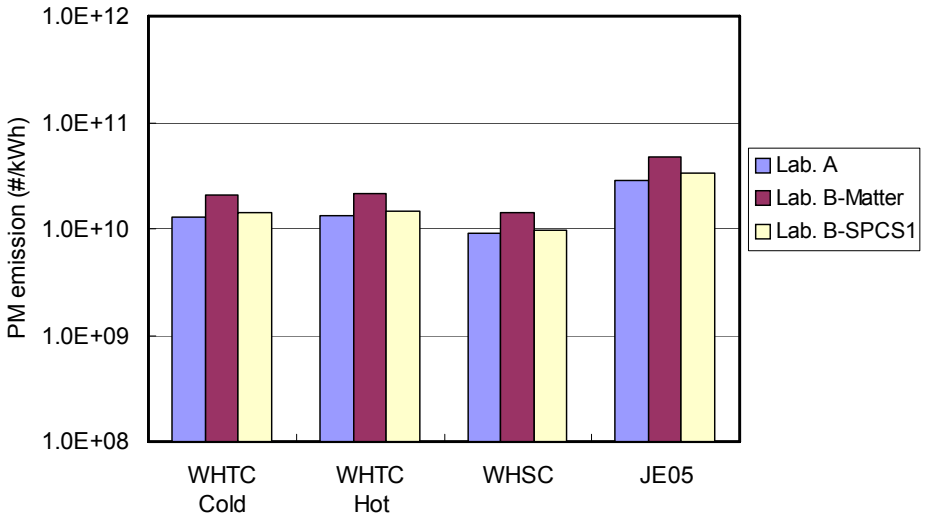
* With SPCS, TB contribution was about 1/10 to 1/100; effect on some modes.

* The difference in the level of effect between Matter and SPCS is possibly due to the difference in the dilution method and the CPC noise level.

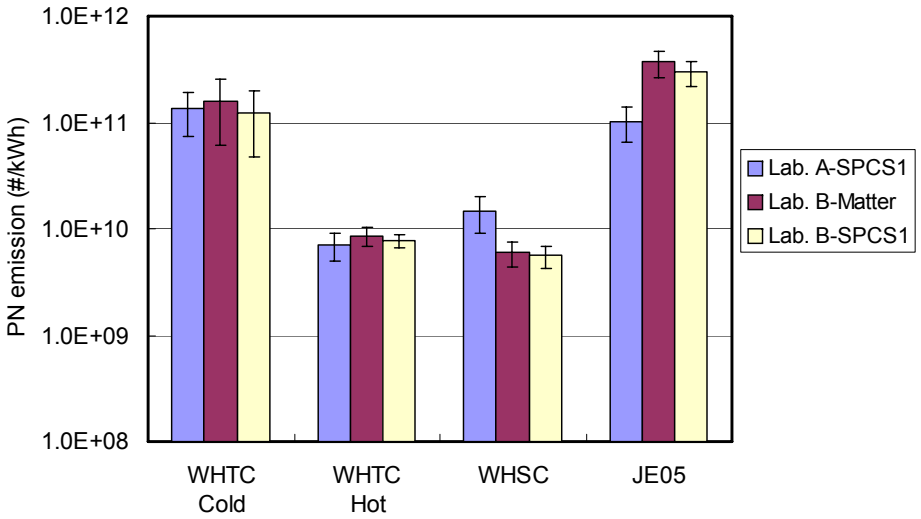
Impact of PN Tolerance on PN Emission

Regarding check procedure of R83 on pre-measurement (0.5 particle/cm^3 or less when equipped with HEPA filter), the level of effect of this being measured as TB was calculated using the measured Vmix and power output.

Emission calculated from Tolerance



Emission



Since the set dilution ratio was higher in Matter than SPCS, the level of effect was also higher in Matter.

Since the equipment specifications differed for each lab, the level of effect also differed for each test condition.

When the number of particles within the limit, 0.5 particle/cm^3, was kept being measured, the calculated levels were the same as or exceeded the measured PN emission levels in some modes (WHTC-Hot, WHSC).

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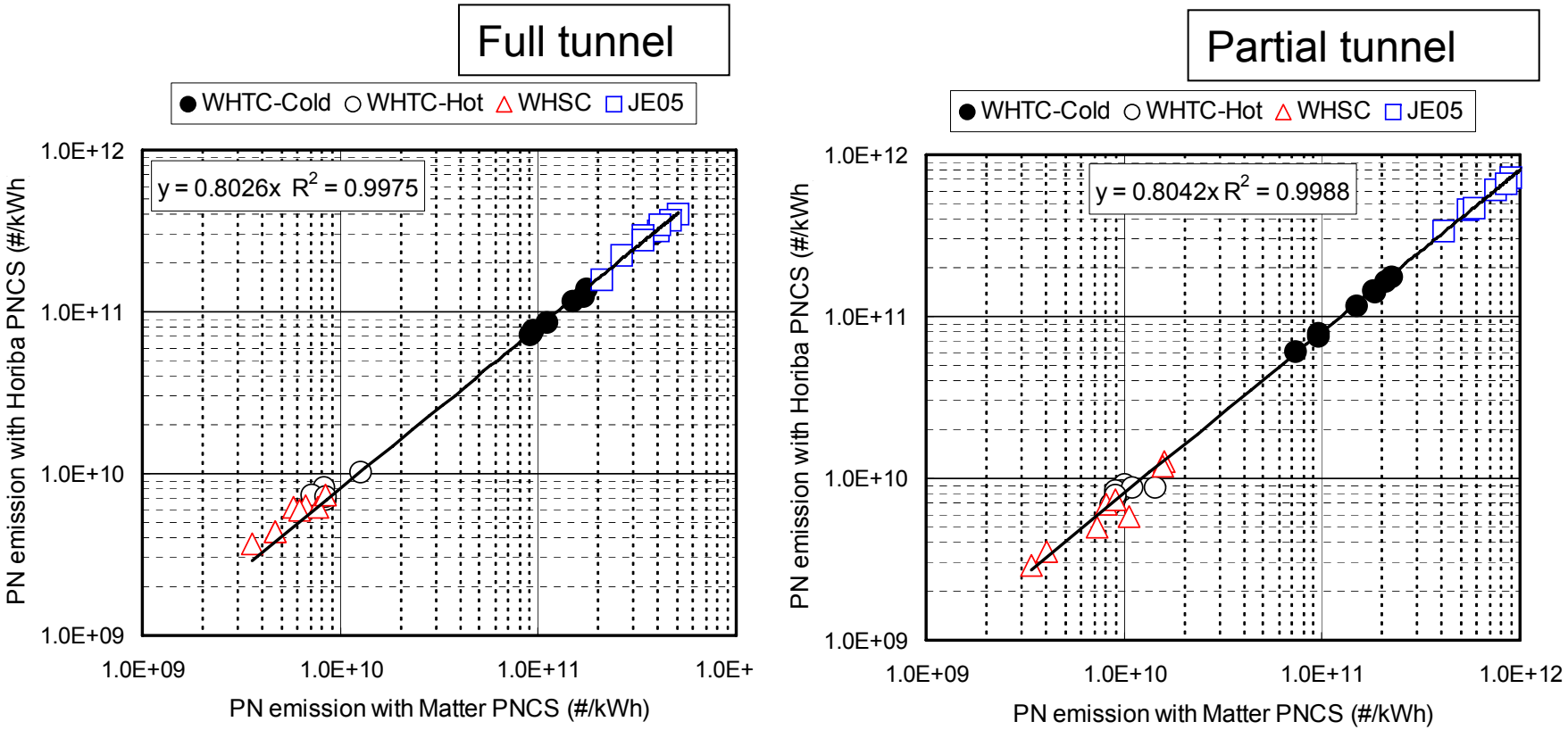
  - Sensitiveness of the Methods: PM & PN
  - Effect of Filter Material on PM Emission
- Summary

Correlation of SPCS-1 and Matter

JARI data



Correlation of the two PNCSs was very good (coefficient of determination $R^2 > 0.99$).

However, the linear approximation slopes had the value of about 0.8, which means the emissions measured by SPCS-1 were lower than those by Matter by about 20%.

JARI data

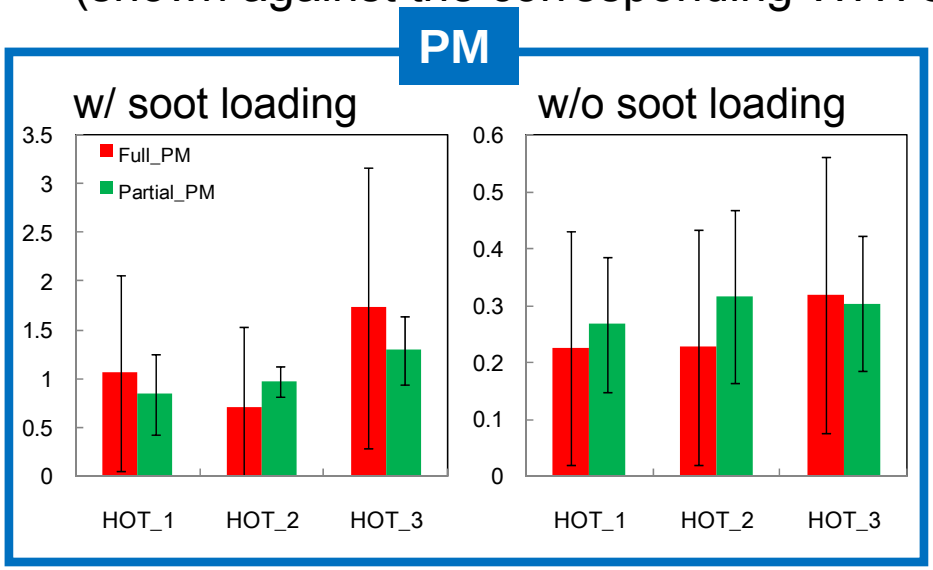
Possible Factors for the Differences in the Results

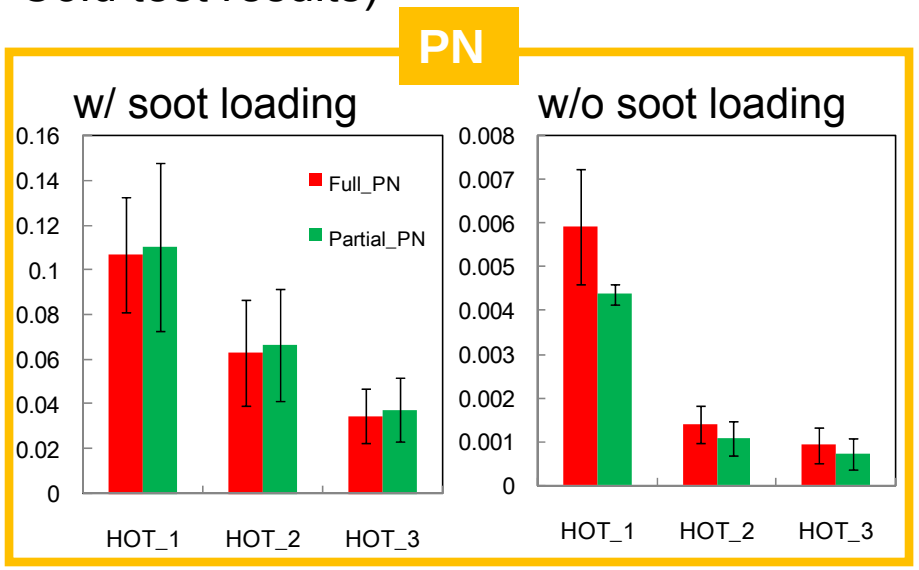
- Differences in the correction method between two systems
  - Matter (JARI's method)
    - Particle type: NaCl particles produced by vaporization and condensation method
    - Concentration: About 8000–10000 particles/cm3
  - SPCS (Horiba's method)
    - Particle type: NaCl particles produced with atomizer
    - Concentration: Varies depending on the particle size
- Other factors
  - Dilution method
  - CPC measurement sensitivity
  - …..
- Fr calibration was performed on both systems according to the R83 regulations; however, there was a difference of 20% or more in their measurement results.
  Hence, the above factors need to be studied/discussed.
- Since the possibility of the differences in the calibration method affecting the results cannot be denied, more detailed calibration procedures should be specified.

NTSEL data

Sensitiveness of the Methods

The results of the WHTC Hot tests repeated after WHTC Cold tests on that day (shown against the corresponding WHTC Cold test results)





* PM: Mode ratio (Hot/Cold) of the PM weight was constant, with or without soot loading.

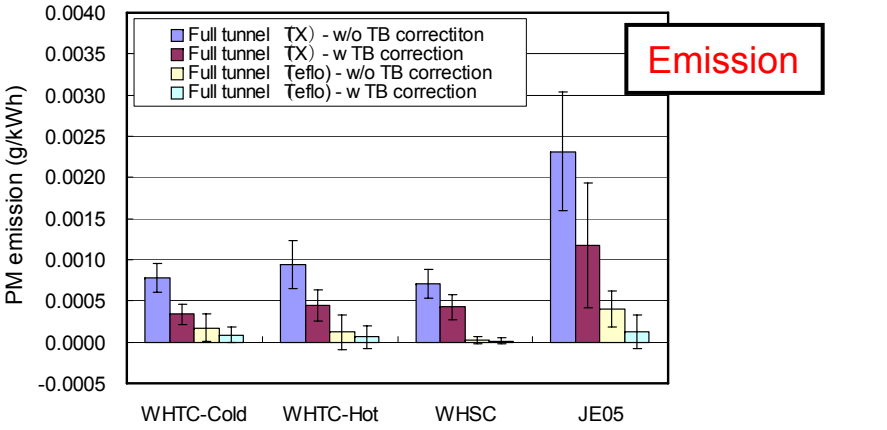
* PN: Ratio (Hot/Cold) of the PN count was decreased by repetition, with or without soot loading.

* It is possible that DPF and other conditions cause experimental errors.

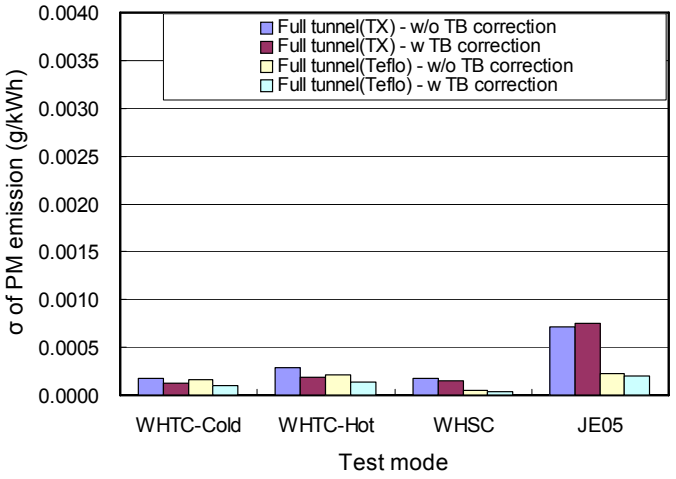
To improve the repeatability of PN measurement, more strict test procedures are necessary.

JARI data

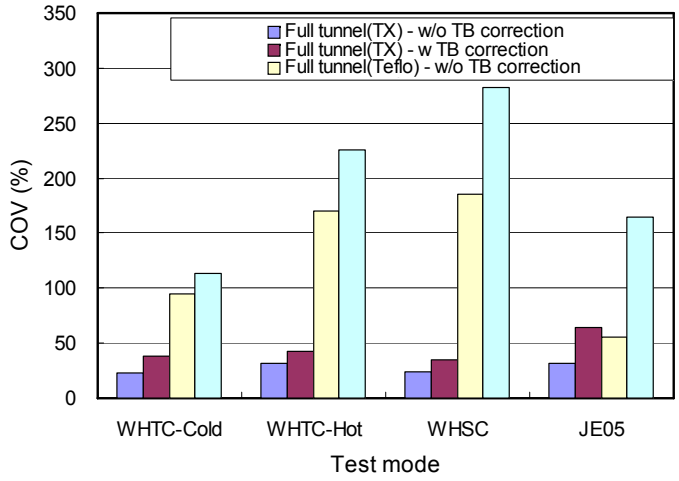
Effect of Filter Material on PM Emission



Emission



Standard deviation



COV

* Since the effect of gas adsorption is small on Teflo filters, even the non-TB-corrected PM emissions measured with Teflo were lower than the TB-corrected emissions measured with TX40.
* Change of filter from TX to Teflo lowered PM emission levels, causing COV to be higher.
* However, the use of Teflo made variations (standard deviation in g/kWh) smaller, resulting in the emissions around the same level as TB-corrected TX-filter emissions (WHTC-Cold & Hot) or smaller (WHSC & JE05).

Conclusion 1: Results of Repeated Tests

- PM:
  - Before TB correction, emission levels of the partial tunnel tended to be higher than the full tunnel, but TB correction reduced the difference between partial and full tunnels as well as the difference between labs.
  - TB correction lowered the emission levels, causing the apparent COV to be higher. However, it made the standard deviation (variations) smaller.
- PN:
  - Comparison between labs: The PN emission levels in WHTC-Cold and Hot were the same between labs, but there were about 2- to 7-fold differences in WHSC and JE05.
  - Comparison between full and partial tunnels: In Lab. A, the emission levels were the same between full and partial tunnels, but in Lab. B, the partial tunnel emissions were double the full tunnel emissions in JE05. It is important to investigate the factors affecting the results, such as the differences in the dilution ratio, test environment, etc. among labs.
- COV:
  - The PM COV and PN COV were mostly around the same level.
  - *However, for PN, since the measurement results are largely affected by engine factors such as deposition conditions of DPF, more detailed test procedures are necessary.*
- Correlation of PM and PN emissions:
  - In the emissions from engines equipped with DPF, correlation of PM and PN emissions was small.
- TB correction:
  - PM: The correction reduced the difference among labs.
  - PN: Depending on the equipment specs. (CVS flow rate) or test mode (power output), calculation errors that exceed the levels of measured emissions from engines are possible to generate.
  - Based on the current technologies, it is necessary to give sufficient consideration to the lower limit that is measurable.

Conclusion 2: Factors Affecting the Results of PN Measurement

- While the correlation of the two PNCSs used in this test was good, a difference of about 20% in the sensitivity was observed between SPCS and Matter.
- The difference in the sensitivity of PNC can be corrected using the sufficient correction scheme that is currently available. However, the VPR PCRF correction method varies among manufacturers.
- To minimize differences in the measurement results, it is necessary to prescribe more detailed provisions on those items that would affect the measurement results, such as the correction method.
- PN emissions in the repeated tests decreased continuously. Therefore, it is necessary to establish detailed test procedures for PN measurement by giving sufficient consideration to the loading conditions of DPF.

Tasks for Particle Number Measurement

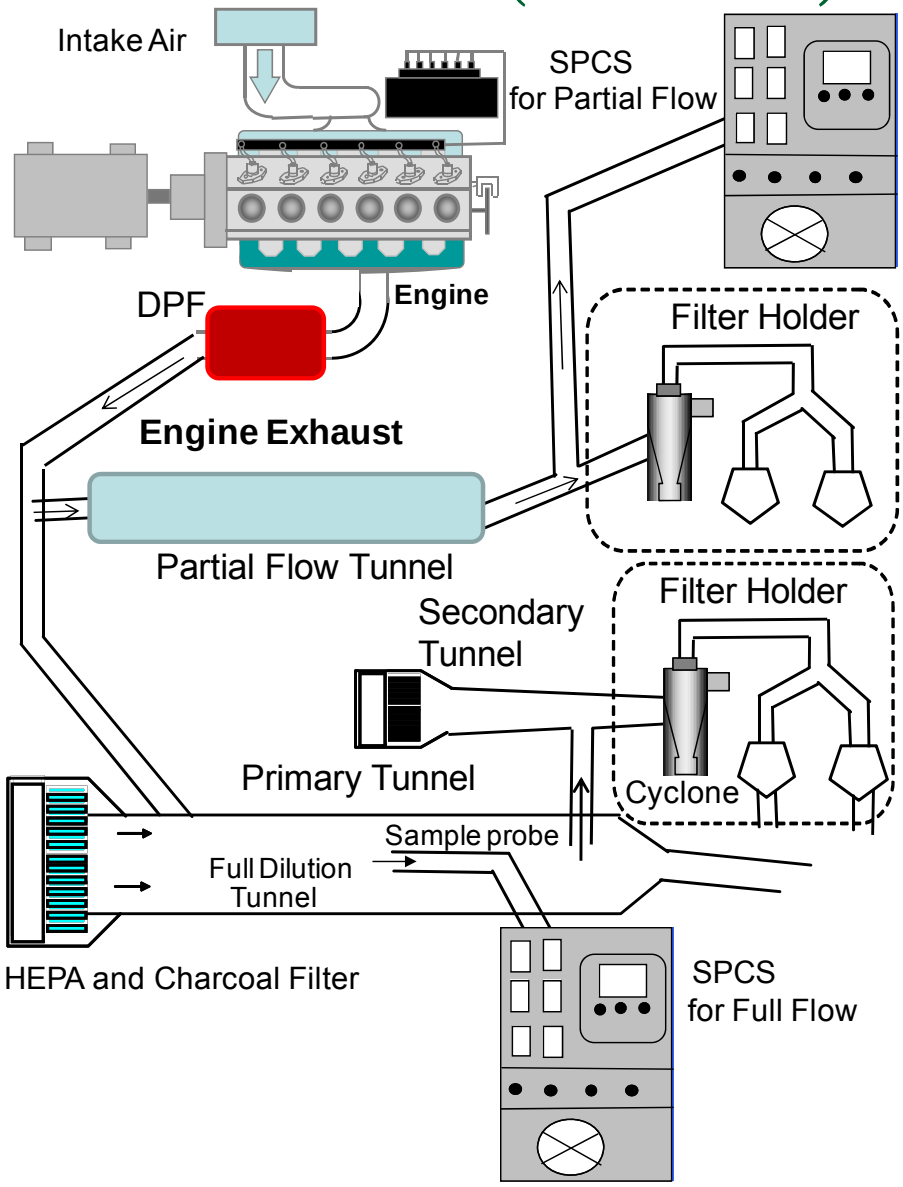
- To measure PN with good reproducibility, it is necessary to establish strict test procedures including the preconditioning conditions, etc.
- TB correction on PM is an effective method for mitigating differences among labs and/or systems.
- Depending on the equipment differences or test mode, it is possible that tunnel blank/system blank-level particle concentrations will contribute to the PN emissions.

  ⇒Sufficient consideration should be given to the lower limit for measurement.
- In drafting the provisions on the PN calibration method, it is desirable to make modifications to the details:
  - PCRF correction and its allowable range
  - Strict regulations on particle species and concentration, etc. for calibration particles

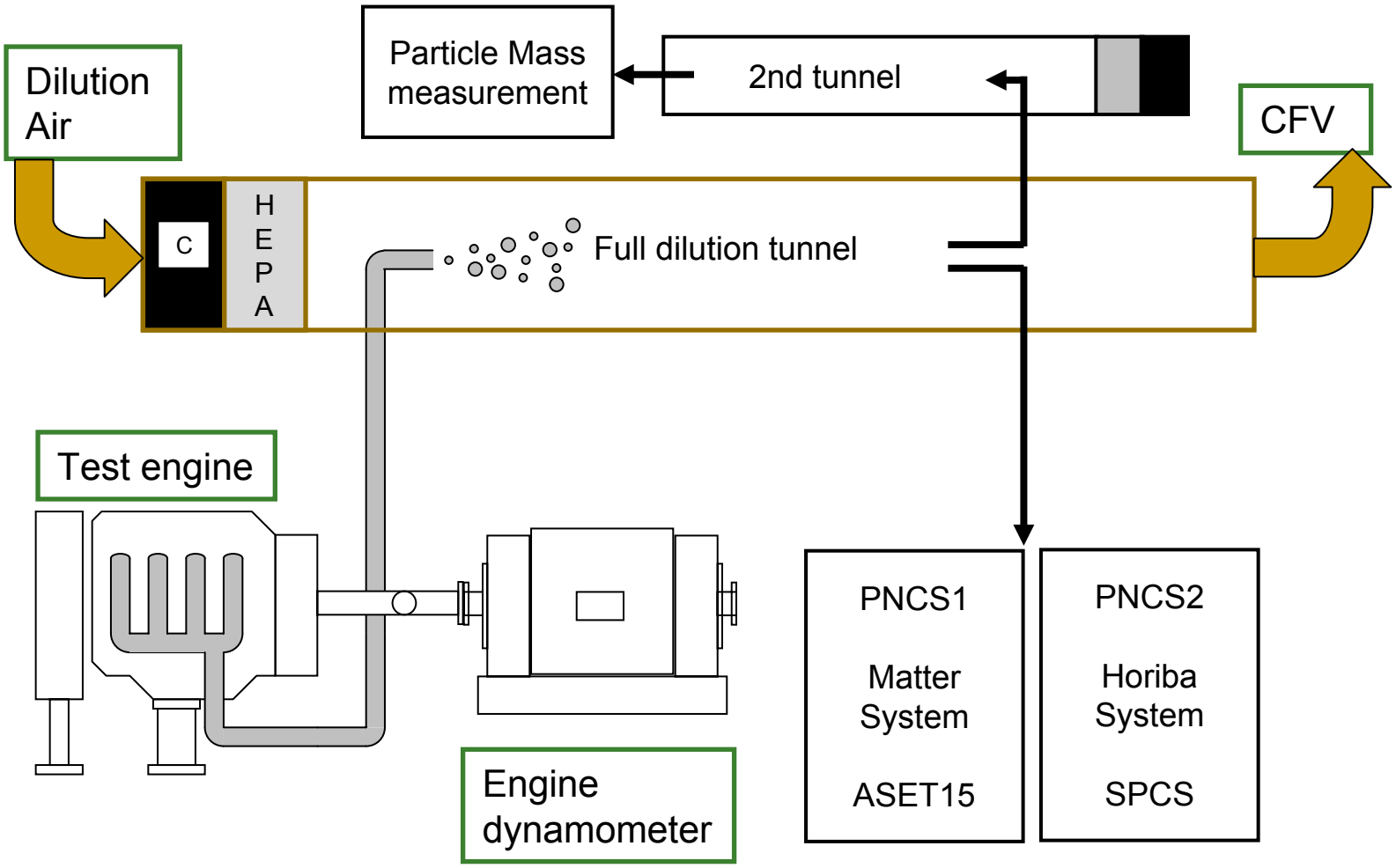
Appendix

- Test System Diagram
- Correlation of PN and PN emission
- Effect of Dilution Ratio in PNCS
- Effect of Introducing-Hose Temperature
- Effect of Introducing-Pipe Length
- Effect of Micro Tunnel Sampling Position

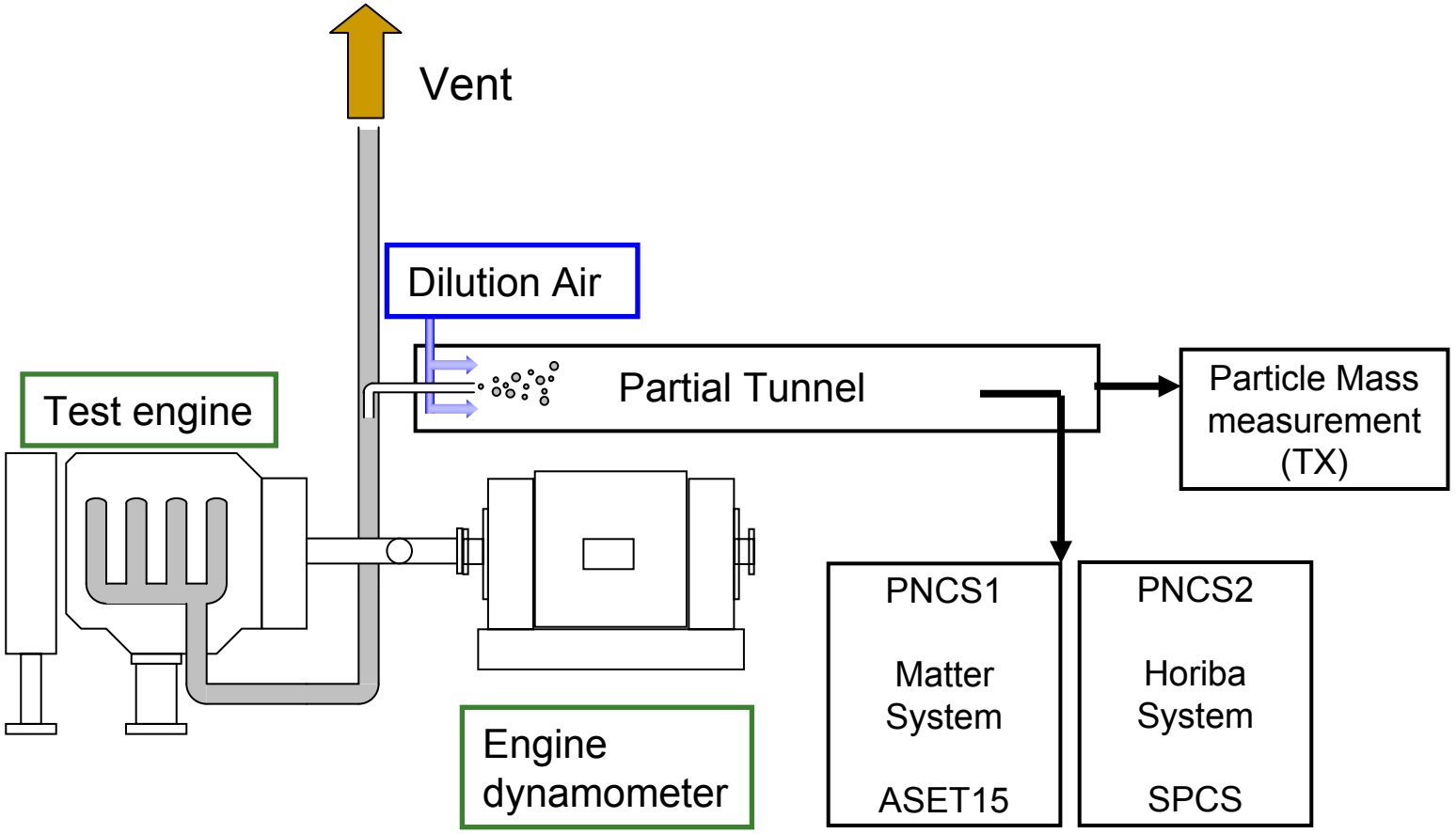
Test System Overview (NTSEL)



Test System Overview (JARI Full Tunnel)

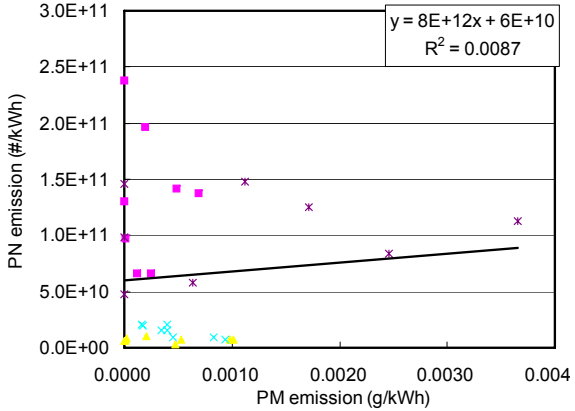


Test System Overview (JARI Micro Tunnel)

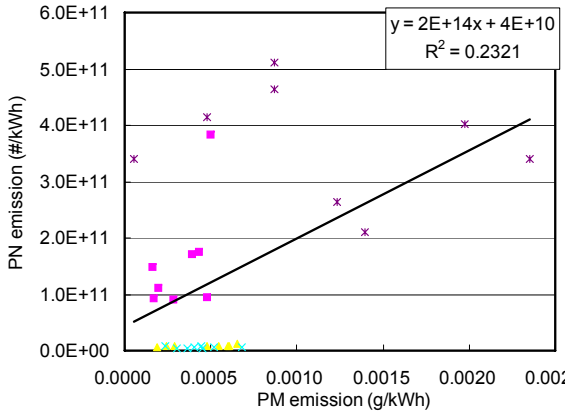


Correlation of PM and PN emission

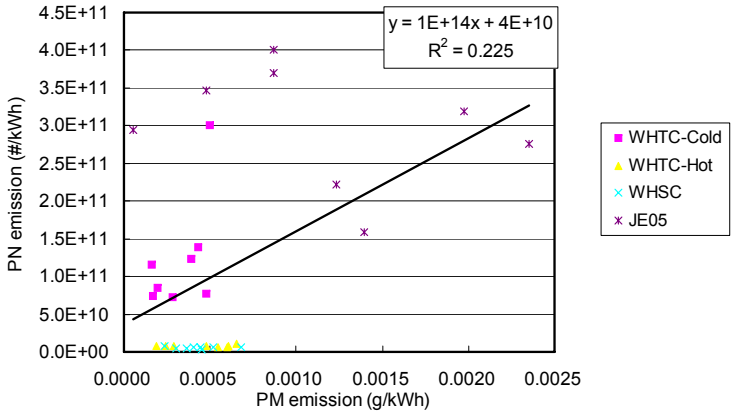
Full tunnel –Lab. A **SPCS1**



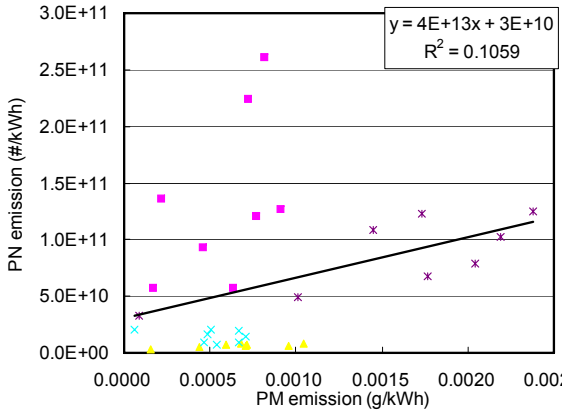
Full tunnel –Lab. B **Matter**



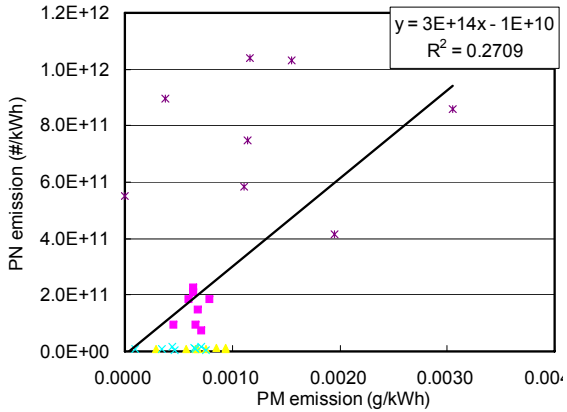
Full tunnel –Lab. B **SPCS1**



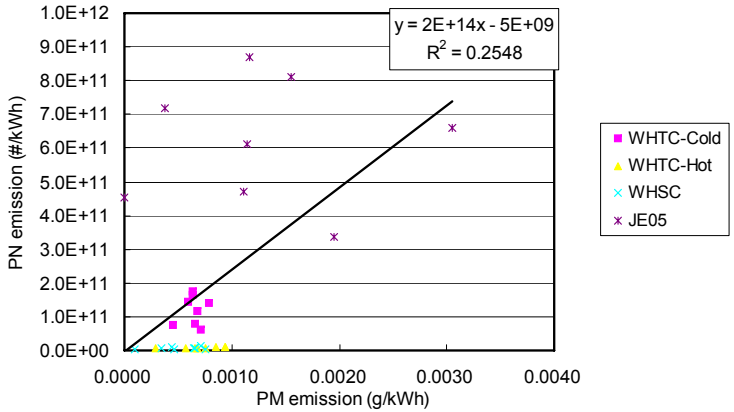
Partial tunnel –Lab. A **SPCS2**



Partial tunnel –Lab. B **Matter**



Partial tunnel –Lab. B **SPCS1**



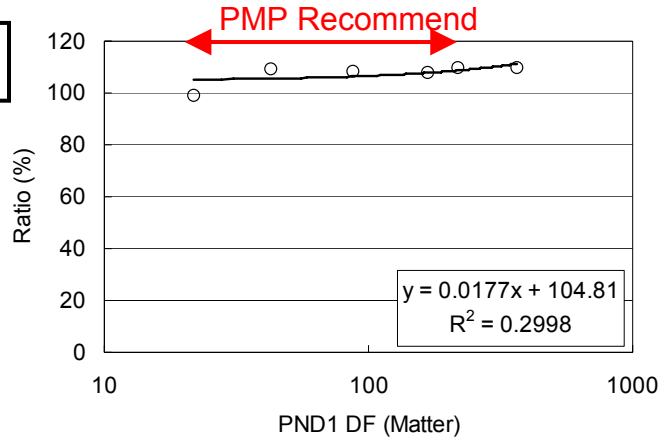
Correlation of PM and PN was low at the emission levels of DPF-equipped engines.

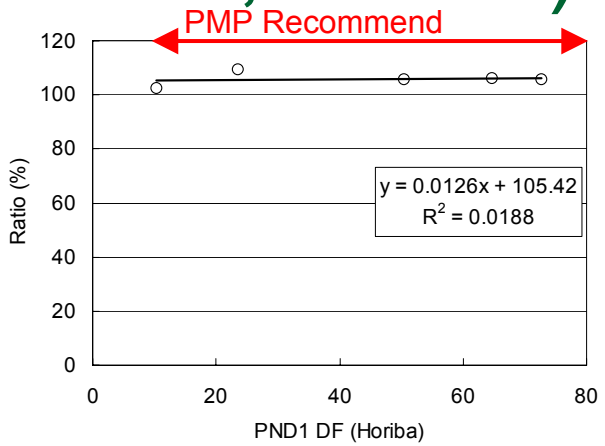
Relationship between PM and PN emissions was likely to differ among modes.

JARI data

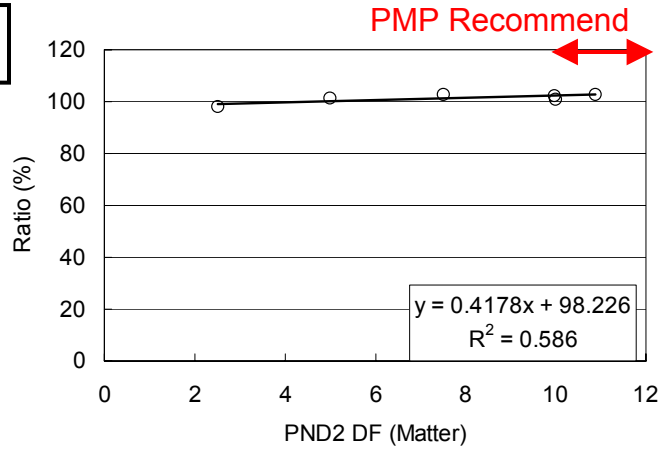
Effect of Dilution Ratio (PND1, PND2)

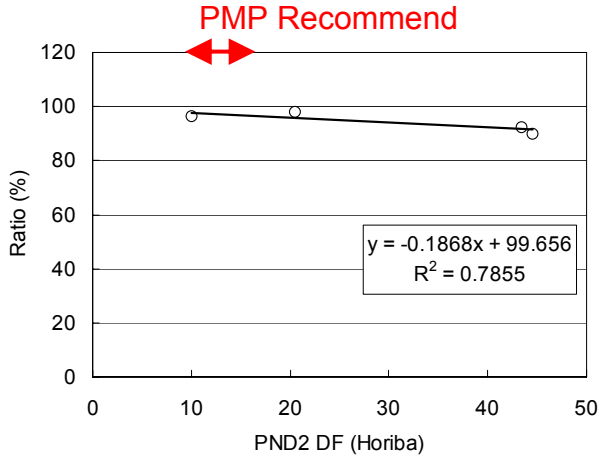
PND1





PND2



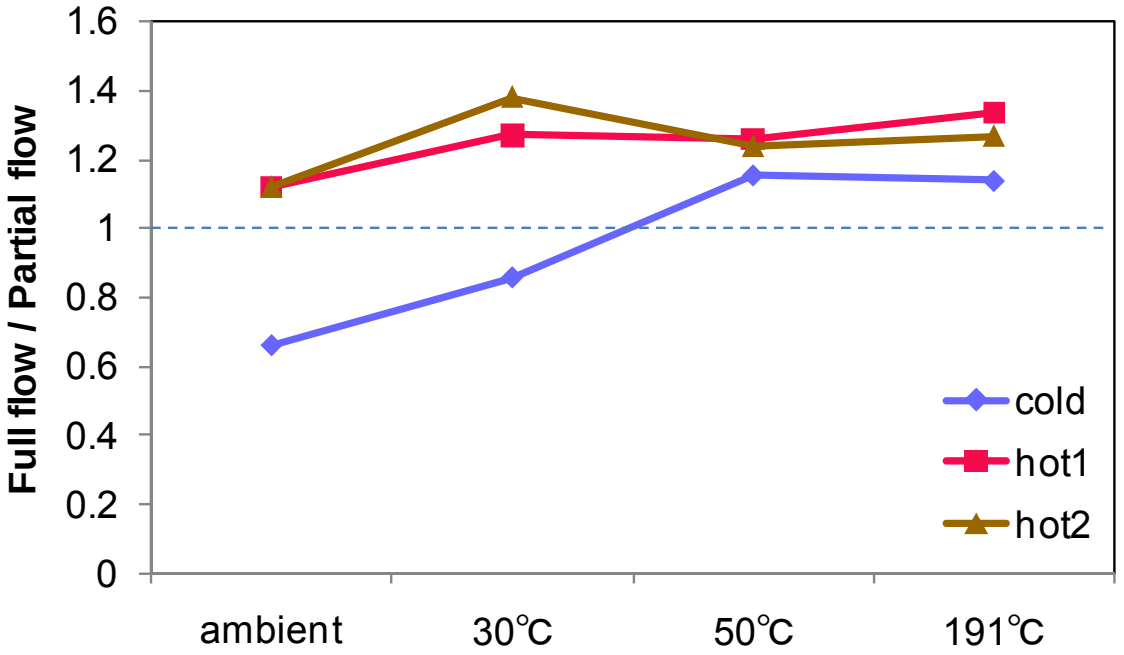


- In PND1, it was indicated that changes in the dilution ratio might affect the measurement results slightly.
- In PND2, the effect on the measurement results was small in the dilution ratio range under PMP Recommend.

NTSEL data

Effect of Introducing-Hose Temperature

Effect of introducing-hose heating on the particle loss



Comments:

* In WHTC-Cold mode, the PN (full flow/partial flow) decreased when the sample-introducing-hose temperature was 50°C or below.

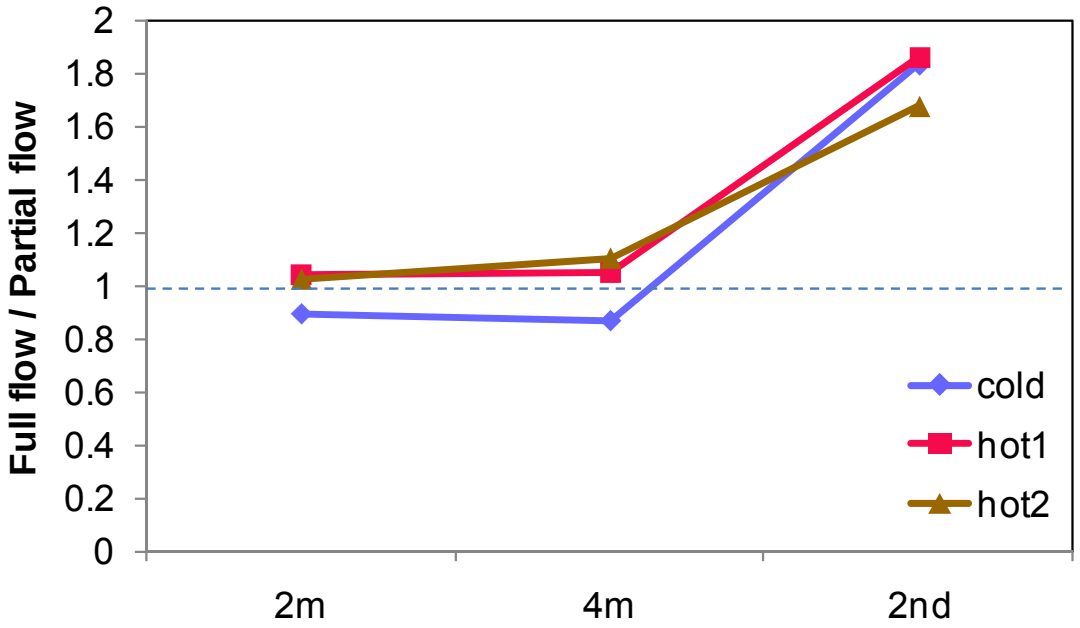
* No effect of temperature was observed in the repeated tests in WHTC-Hot mode.

Conclusion: If the hot hose is used, there will be no effect on the particle loss.

NTSEL data

Effect of Introducing-Pipe Length

Differences in the particle loss depending on the introducing-pipe length and sampling position



Comments:

* In WHTC-Cold mode, the PN decreased by 10% compared to the Hot mode.

* In WHTC-Hot mode, no effect of exhaust pipe length was observed.

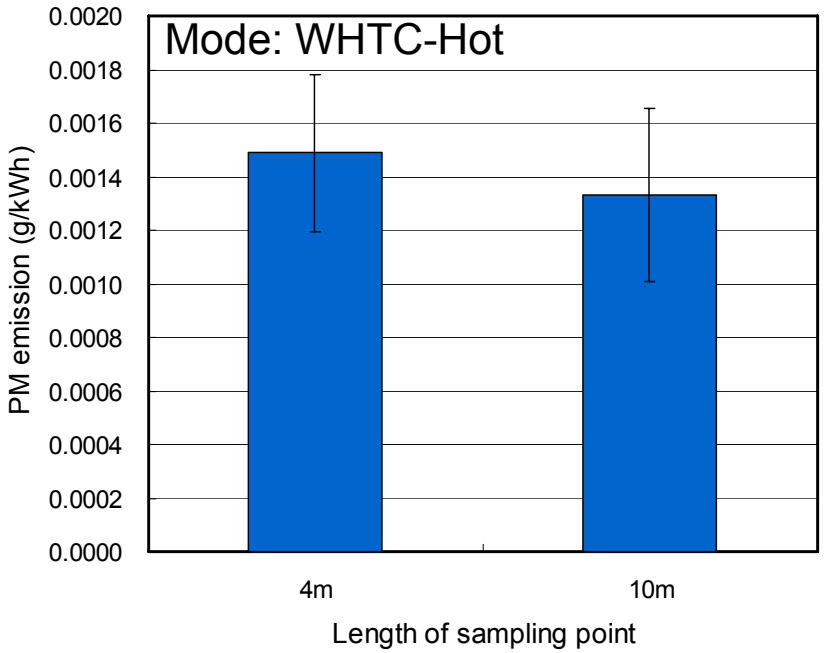
* When sample was taken from the 2nd tunnel, the PN (full flow/partial flow) increased (cause unknown).

Conclusion: No effect of exhaust pipe length was confirmed.

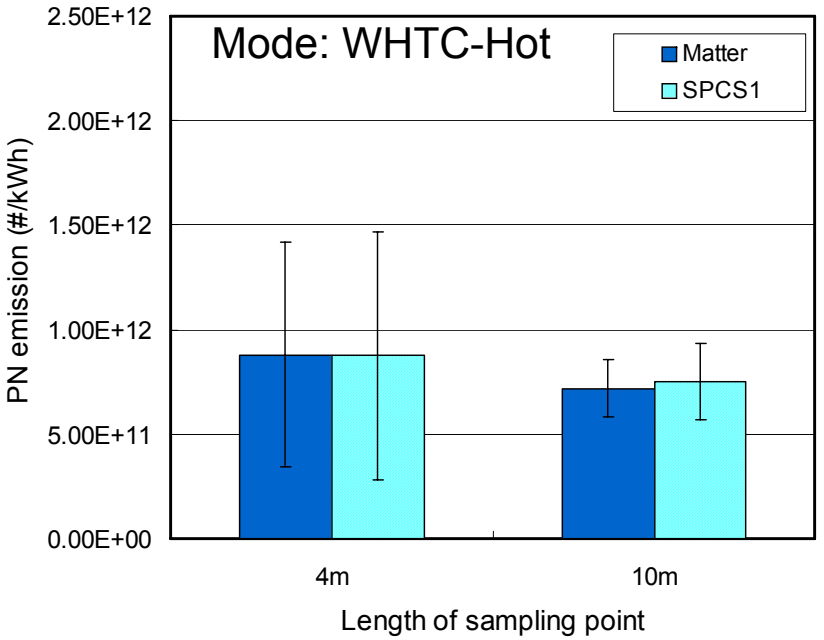
JARI data

Effect of PT Sampling Position

PM (*Mass*) emission



PN (*Number*) emission

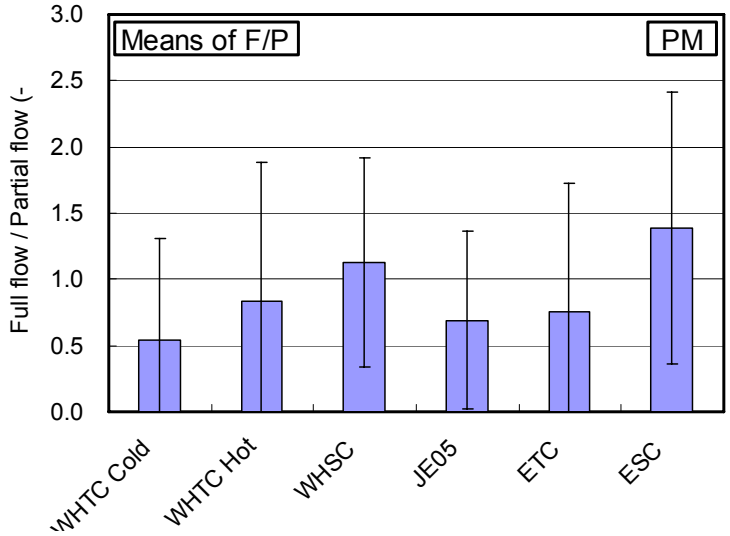


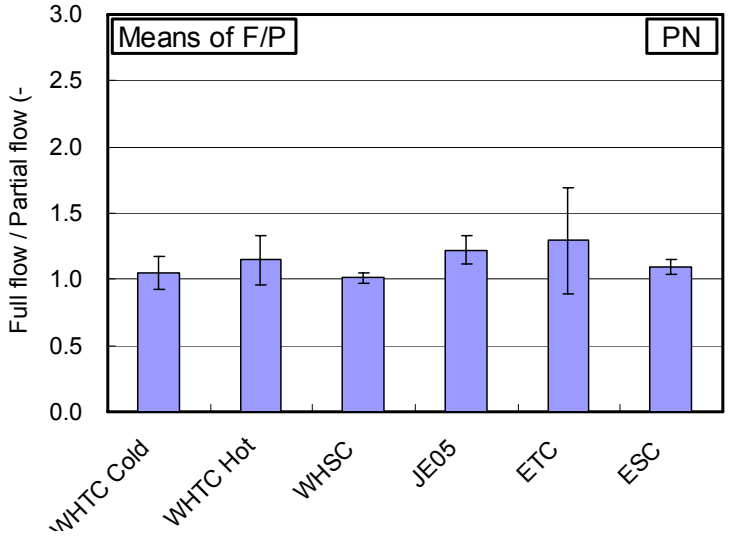
* The average of the measurement results indicated that sampling position changes tended to decrease particle emissions for both PM and PN.

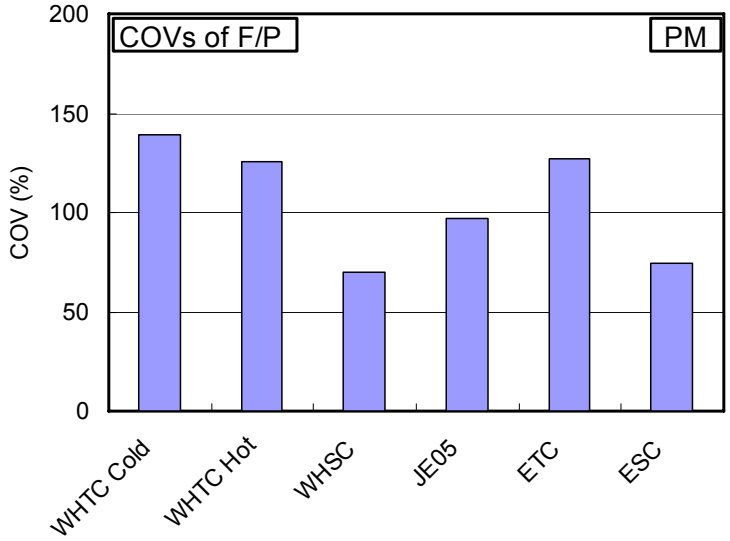
* However, there were relatively large variations in the results; hence, statistically speaking, it can be judged that there is little effect of the exhaust pipe length on the PM and PN emission levels.

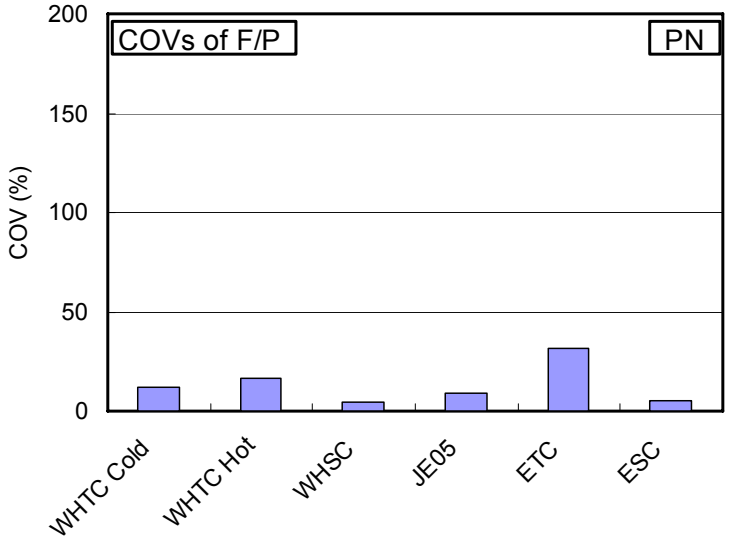
NTSEL data

Full/Partial Ratio and PM & PN Emissions









* Full/Partial COV was improved for PN; therefore, the variations observed in the PN measurements are presumed to have been caused by variations in the engine exhaust.