PMP-IWG Web Conference on 1st Dec. 2021

Verifications of Direct Measurement Method for HD-PN Emissions at NTSEL

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Contents

1. Background

This April, Japan(JASIC) commented on the questions about direct PN measurement method.

(1)effect of sampling point

"Sampling close to the engine as to ensure an exhaust gas temperature of at least 343 K (70 °C) at the probe position."

- Replace "*close to the engine*" with "*representative to retention time in typical application*"
- Delete 70°C or replace with "*to avoid (or minimize) condensation*"
- Other suggestion:

Comment:

We cannot comment at this time as we lack knowledge on the matter, but we are considering verification tests.

(2) effect of pre-diluter (PND0)

- The dilution at the pre-diluter (PND0) is in a small degree like the dilution at a proportional flow system or the full dilution tunnel. Do you think that higher losses should be allowed for the pre-diluter (expressed as lower penetration and higher PCRF ratios) or any losses should be included in the VPR requirements?

Comment:

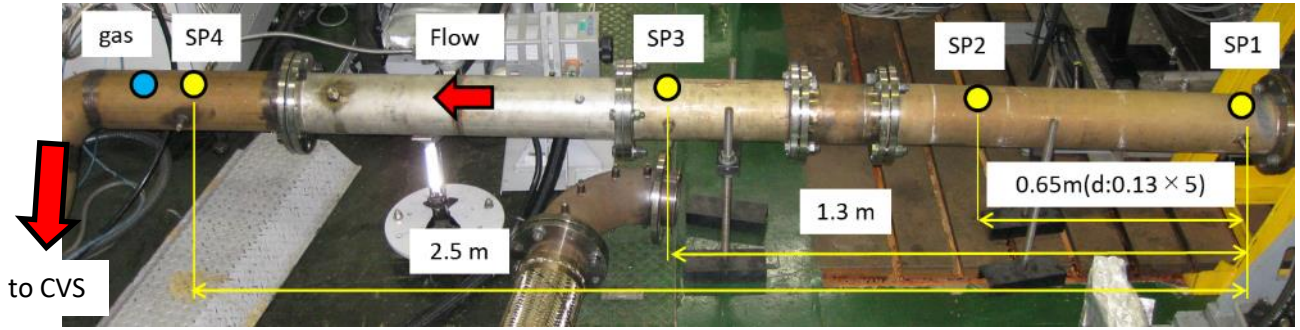
To make any comment, we need verification data, which requires further verification tests. Verification tests are being considered in Japan.

NTSEL conducted the verification tests for (1) & (2).

2. Experimental, Outline of Verification Tests

(1) effect of sampling point

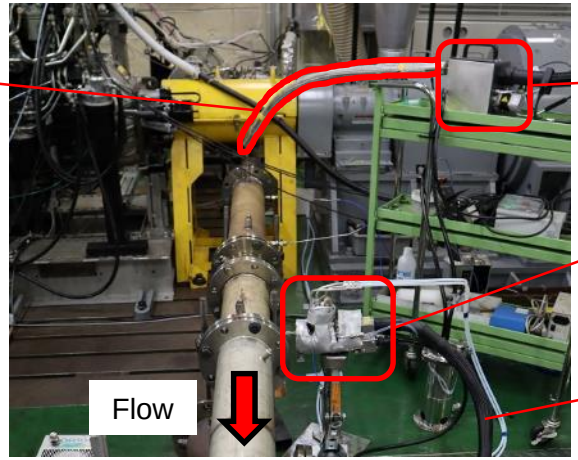
・Comparison of PN emissions at four different sampling points in below



2.3 m from outlet of aftertreatment system

(2) effect of pre-diluter (PND0)

・Comparison of direct PN emissions measured by SPCS (with PND0) and APC (without PND0)



Hot tube(150℃)

PND1 of APC

PND0 of SPCS

Hot tube(47℃)

2. Experimental

Tested Engine

Displacement	5193 cc
Cylinders	4
Aspiration	Turbocharged and Charge Air Cooled
Fuel	Diesel
Max Power	154 kW/2400 rpm
Max Torque	706Nm/1400-1600 rpm
Aftertreatment	DOC+DPF+SCR
Emissions	Post Post New Long Term (2018 Japan)

Test Procedure

1. Pre-conditioning
   - ・Regeneration during WHTC hot
   - ・Soak (1 night or weekends)
   - ・WHTC × 6 (cold × 1,hot × 5)
2. Soak (1 night)
3. WHDC (WHTC cold & hot)
4. WHSC

→return to 1.

Calculations of PN emissions

- ・Diluted PN emissions : Ave. PN conc. at dilution tunnel × Vmix ÷ THP
- ・Direct PN emissions : Σ（Exhaust gas flow rate × PN conc. at tailpipe）÷THP

Exhaust gas flow rate = Intake air flow + Fuel flow

Intake air flow: Laminar air flow meter (TSUKASA SOKKEN, LFE-350B)

Fuel flow： Volumetric fuel flow detector (ONO SOKKI, FP-2240HA)

THP: Total Horse Power

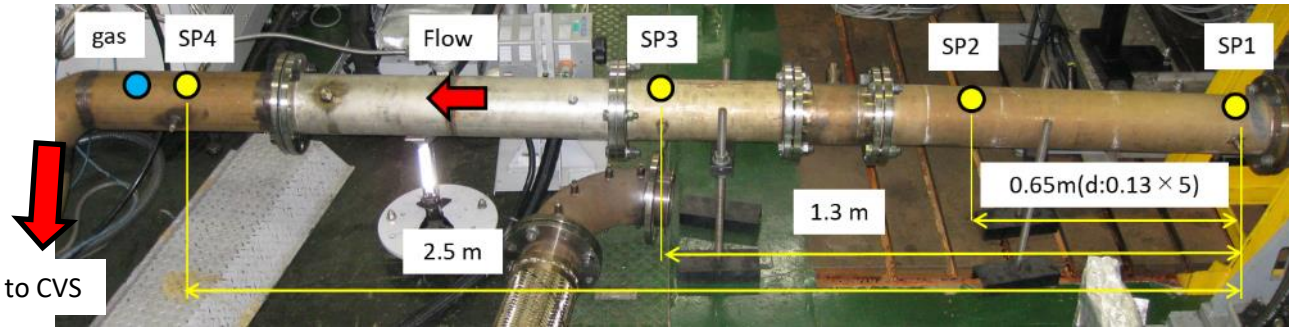
2. Experimental

PN analyzers

PN analyzer	SPCS2300	APC-CS (xApp 10)	APC-ET (xAPP)
Manufacturer	HORIBA	AVL	AVL
D50	23 nm	10 nm & 23 nm (external)	23 nm
VPR	ET	CS	ET
Sampling point	**Direct (PND0)**	**Direct (hot dilution)**	**Dilute**

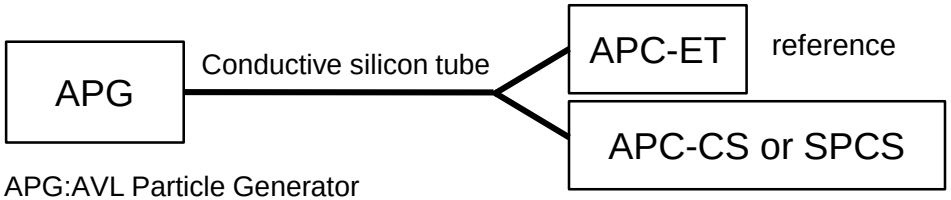
Layouts

Sampling point		SP1	SP2	SP3	SP4	Dilute
Layouts	1	APC-CS		SPCS		APC-ET
	2		APC-CS		SPCS	APC-ET
	3	SPCS		APC-CS		APC-ET
	4		SPCS		APC-CS	APC-ET

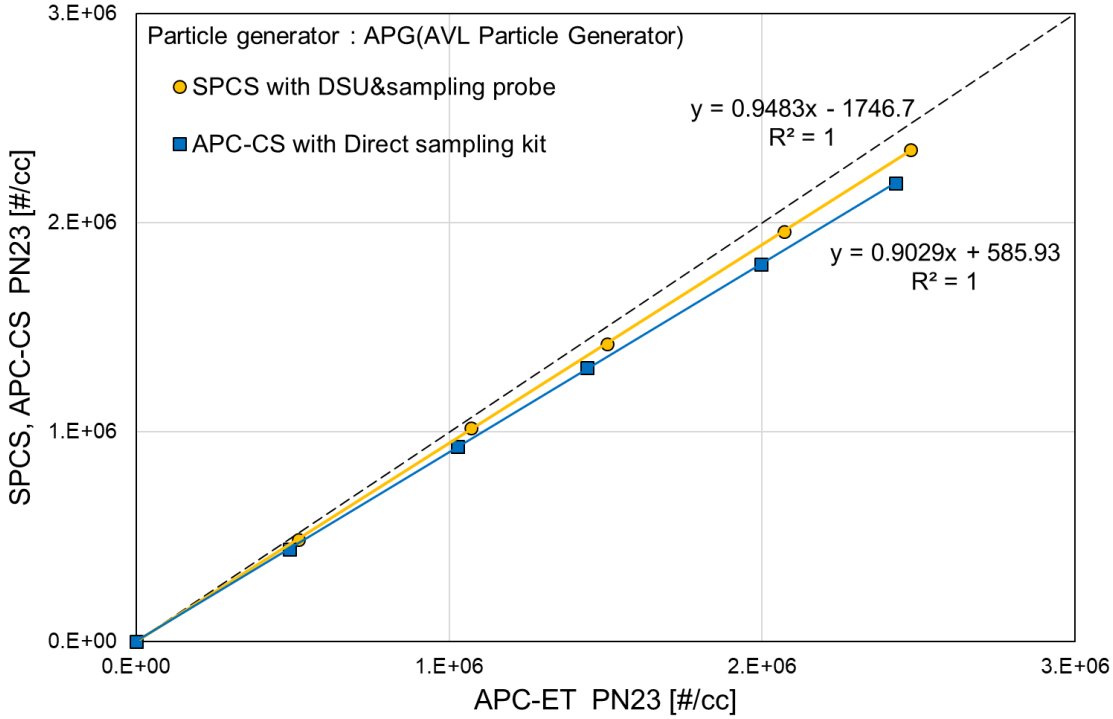


2.3 m from outlet of aftertreatment system

3. Results　Evaluation of linearity of each PN analyzer



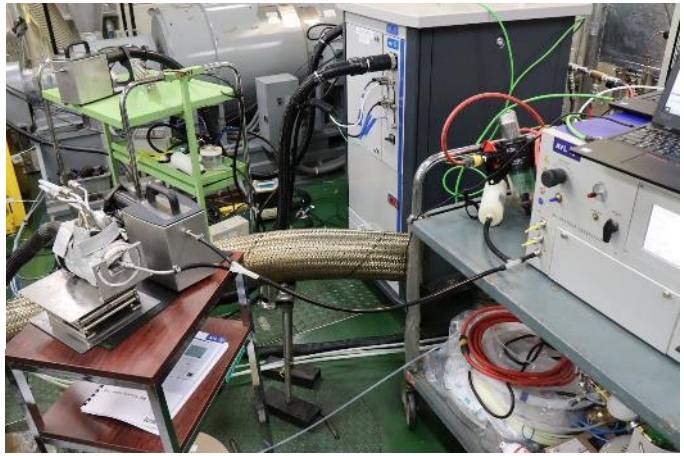
APG:AVL Particle Generator



SPCS: 5%
APC-CS: 10%
} lower than the reference (APC-ET)

APC-CS and SPCS were set-up for direct measurement as with actual testing condition.

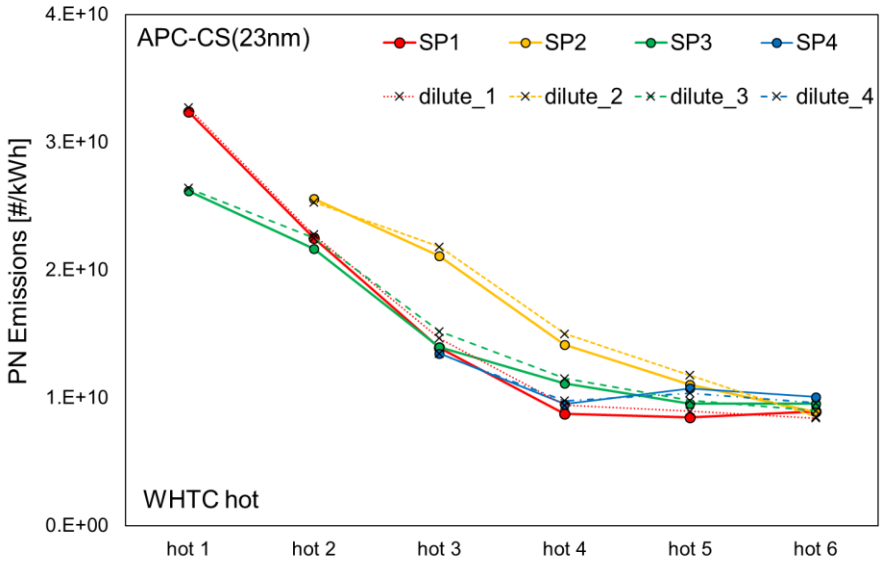
APC-CS vs APC-ET

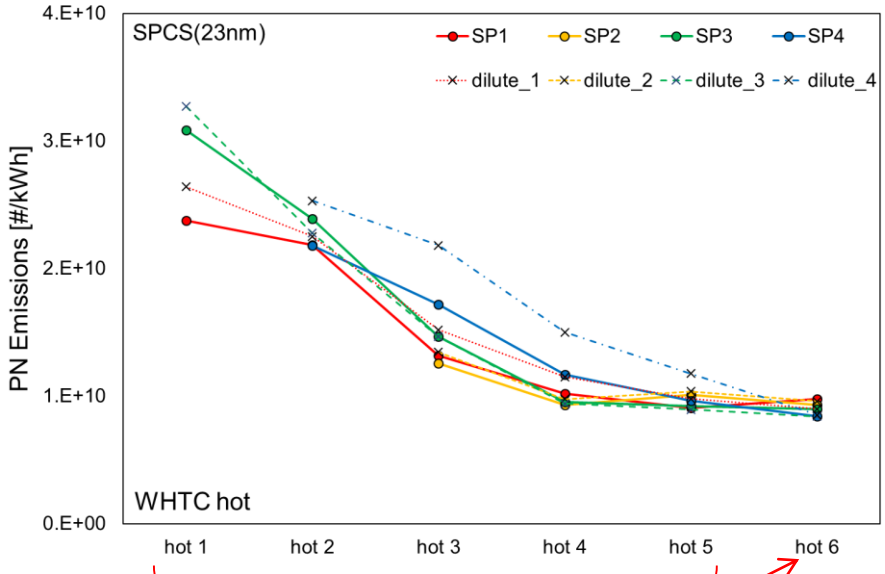


SPCS vs APC-ET

Following results contain the difference.(The values are not corrected.)

3. Results　WHTC-hot　PN emissions





Procedure：WHTC Regeneration→Soak → TC-cold → **hot 1-5** → Soak → cold → **hot 6**

Pre-conditioning　　WHDC test

Some conditions are no data, although the preconditioning was conducted.

Common results

- PN emissions decreased by repeating test cycle after DPF regeneration.
- PN emissions on WHDC test (hot6 in the graph) were stable due to the pre-conditioning.

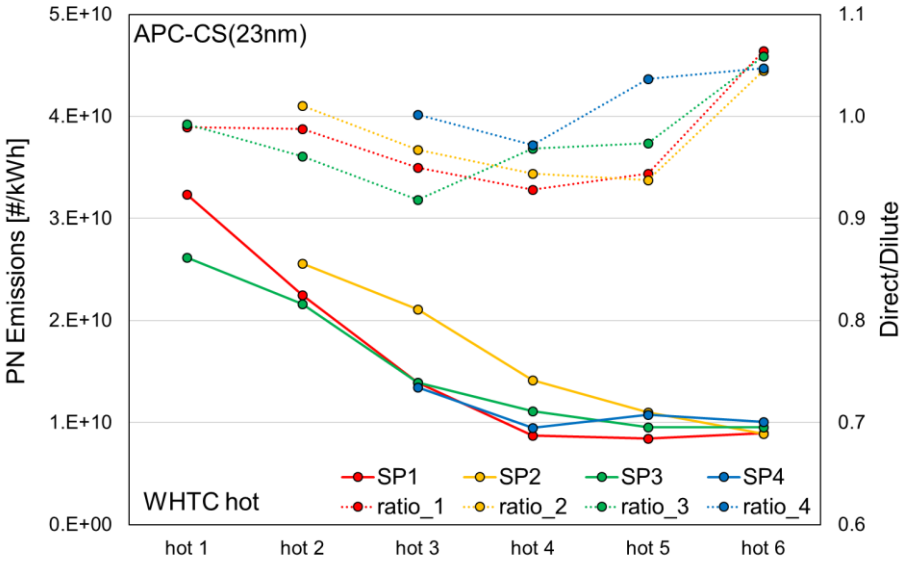
APC-CS

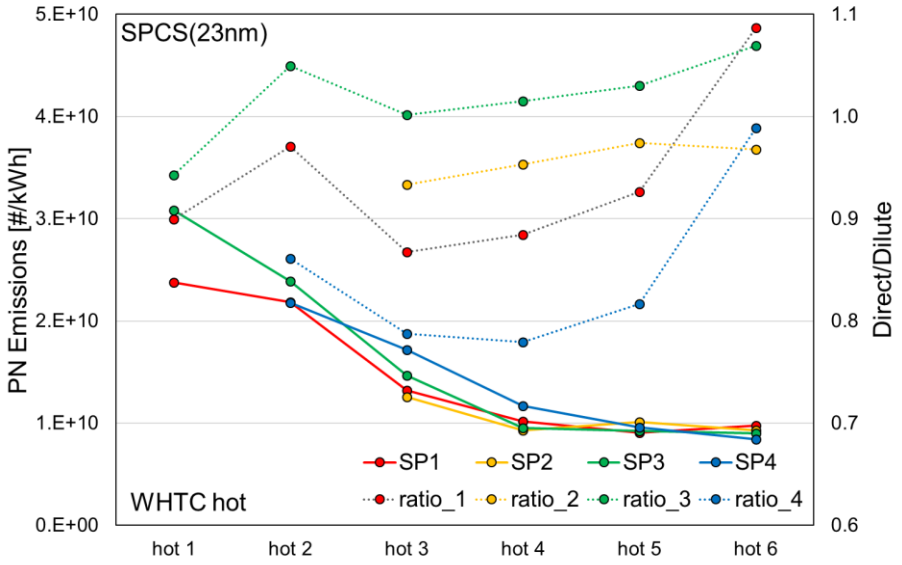
- PN emissions of APC-CS(direct) corresponded with that of APC-ET(dilute) well.

SPCS

- PN emissions of SPCS(direct) corresponded with that of APC-ET(dilute) roughly.

3. Results　WHTC-hot　Direct/Dilute ratio





Common　result

・Direct/Dilute ratios tended to change during the pre-conditioning.

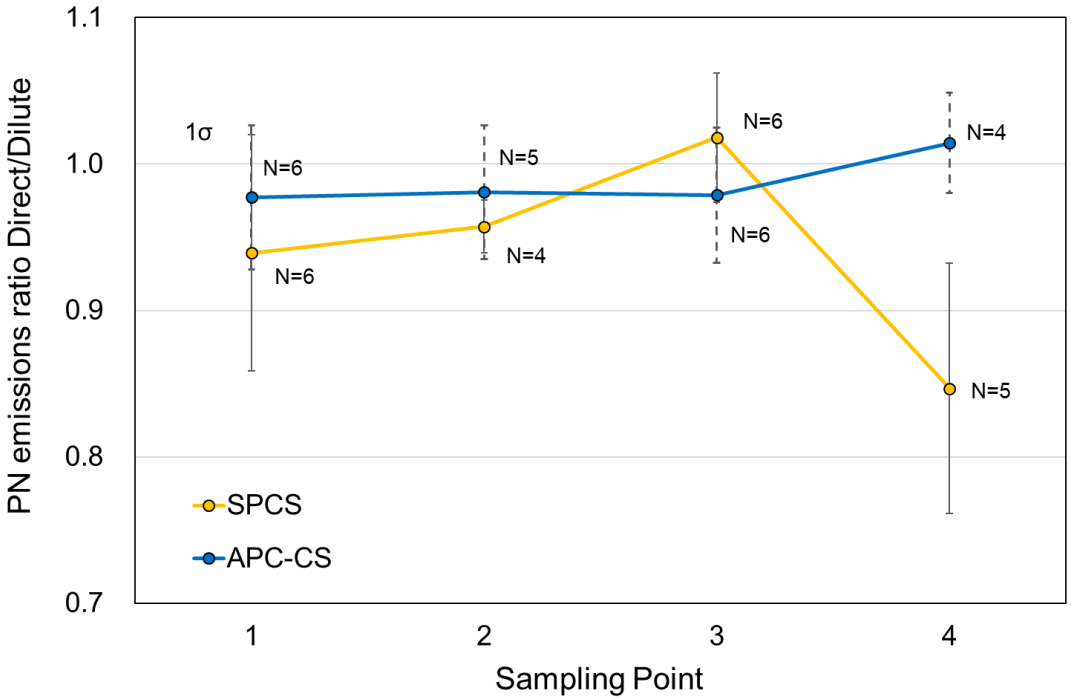
APC-CS

・Direct/Dilute ratios of "hot 6" were almost same at any sampling points.
→The effect of sampling point is negligible in this verification.

SPCS

・Direct/Dilute ratios varied widely at each sampling point.
However, the sampling points might not be the main cause since the distance from the outlet of after-treatment system cannot explain the results. Continue to investigate the cause.

3. Results　WHTC-hot　Averaged Direct/Dilute ratio



Effect of pre-diluter (PND0)

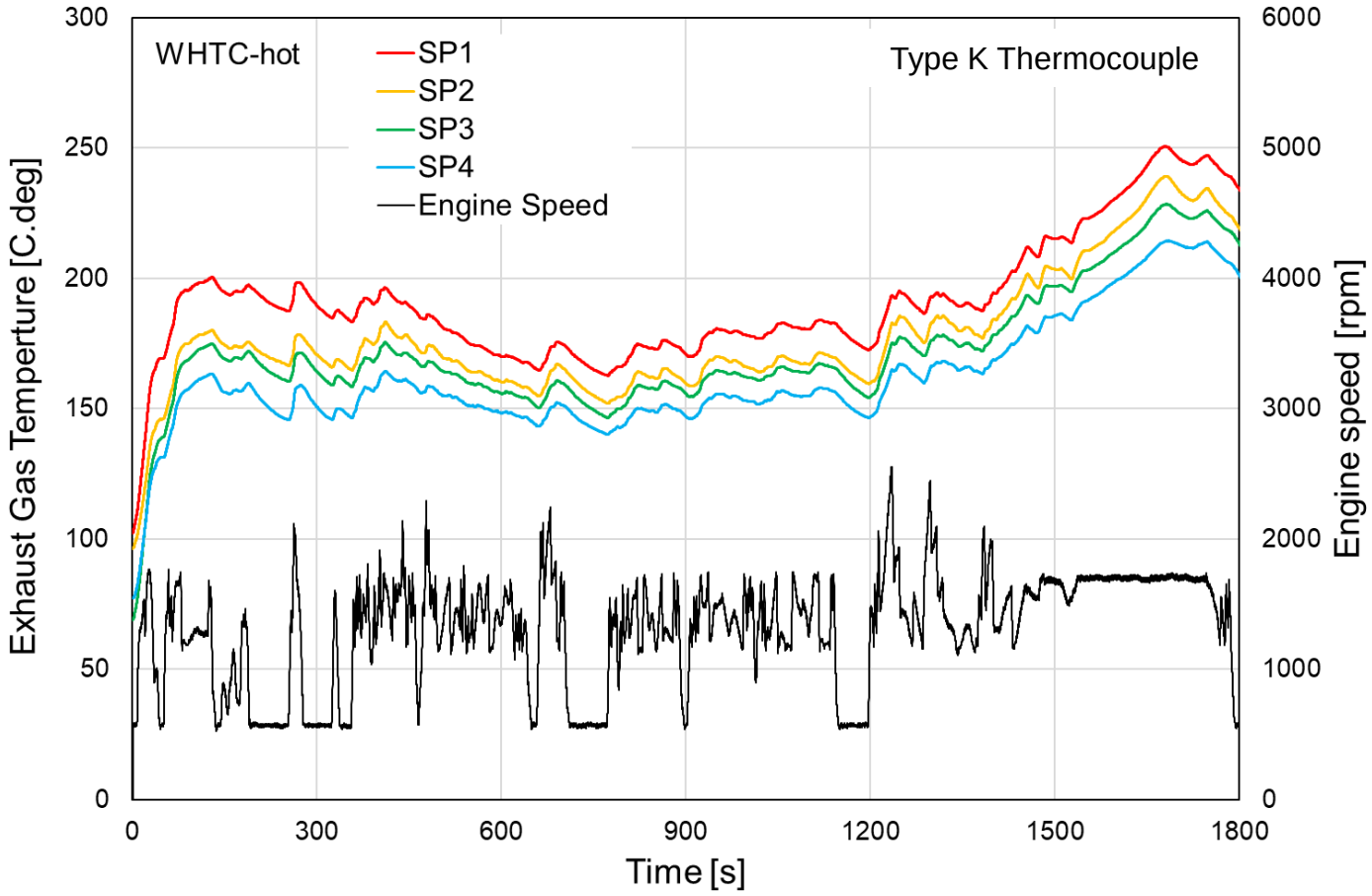
・Direct/Dilute ratios of APC-CS ≦ **1**　(except SP4)

Considering particle loss in the transfer tube to dilution tunnel, the direct/dilute ratio should be above 1.
Therefore, the results of APC-CS is slightly underestimated as well as the evaluation of linearity with APG.
The possibility of slight particle loss in the hot tube.

・Direct/Dilute ratios of SPCS were uneven.

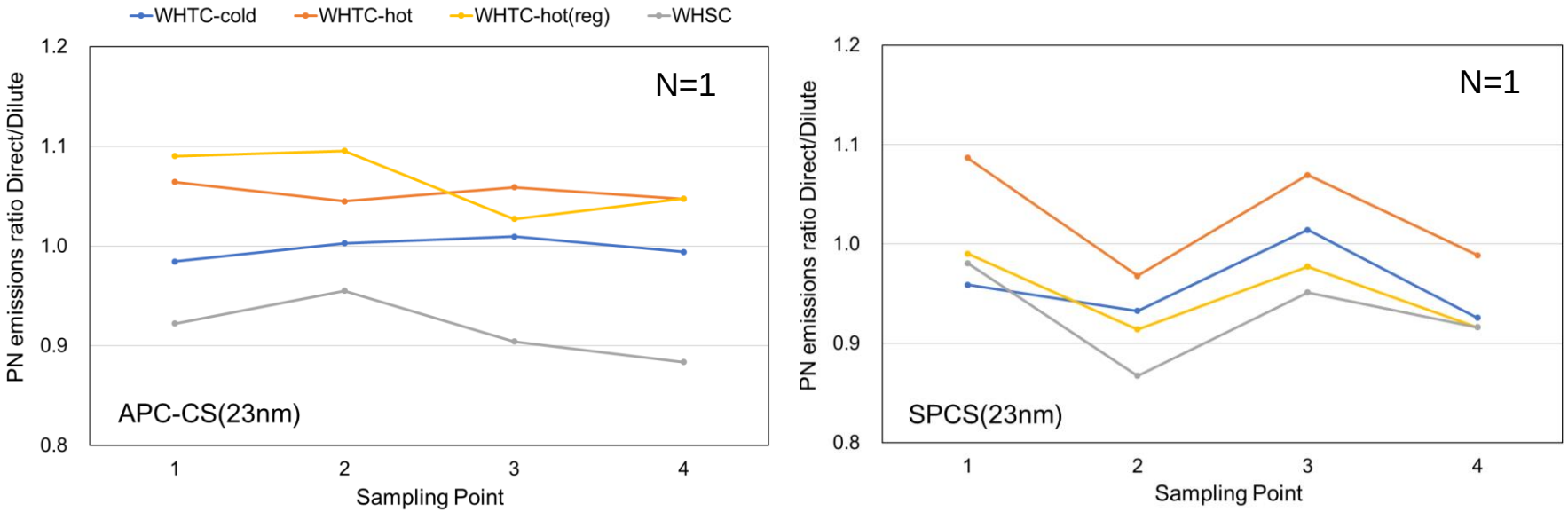
As mentioned previously, the distance from the outlet of after-treatment system cannot explain the results.
The possibility that PND0 brings higher dispersion of dilution factor.

3. Results, Appendix Temperature of exhaust gas at each sampling point



・The maximum temperature was about 210 to 250℃.
・There was no condensation, since the temperature was above 100℃ during the test cycle.

3. Results　　Effect of test cycle



Procedure: WHTC × 6 & soak → **WHTC-cold → WHTC-hot → WHSC → WHTC-hot (regeneration)**

Effect of sampling point in the same test cycle

APC-CS: Difference of Direct/Dilute ratio was about 3-8%.

→Effect of sampling point is almost negligible regardless of the test cycle.

SPCS: Difference of Direct/Dilute ratios was about 10-15%.

Effect of test cycle at the same sampling point

APC-CS: Difference of Direct/Dilute ratio was about 15%.

Direct/Dilute ratio: WHSC < WHTC-cold < WHTC-hot ≦ WHTC-hot regeneration

SPCS: Difference of Direct/Dilute ratio was about 10%.

Direct/Dilute ratio: WHSC < WHTC-hot regeneration < WHTC-cold < WHTC-hot

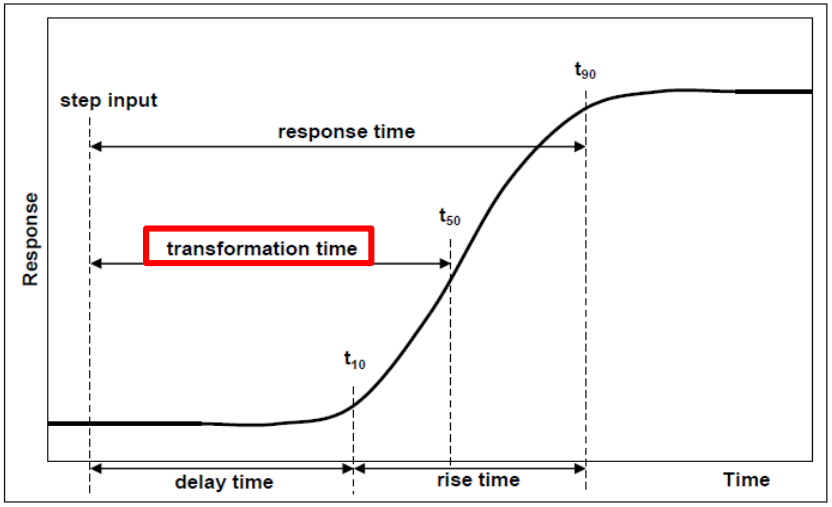
The cause of difference in test cycles is under investigation, e.g. particle size, temp. & time alignment.

3. Results, Appendix　Time alignment

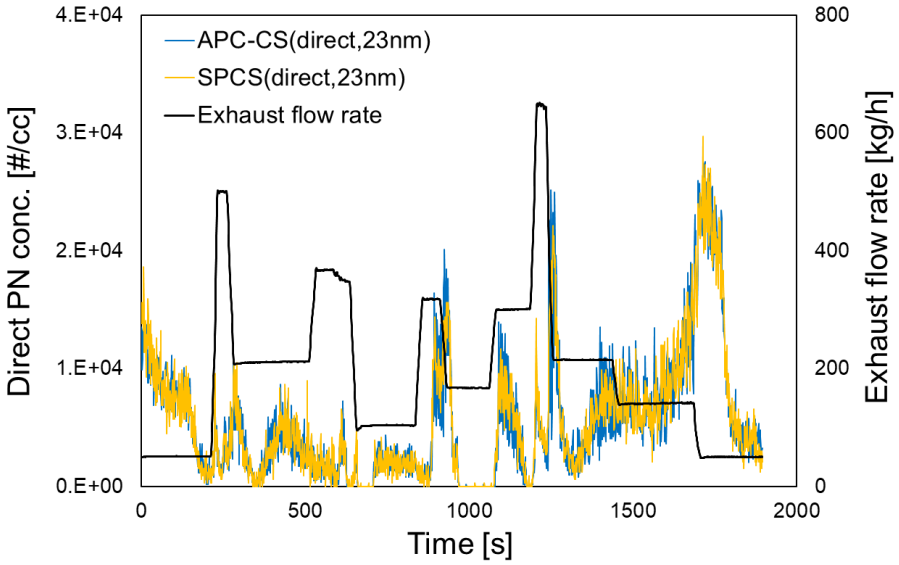
According to the proposal of Consolidated Resolution

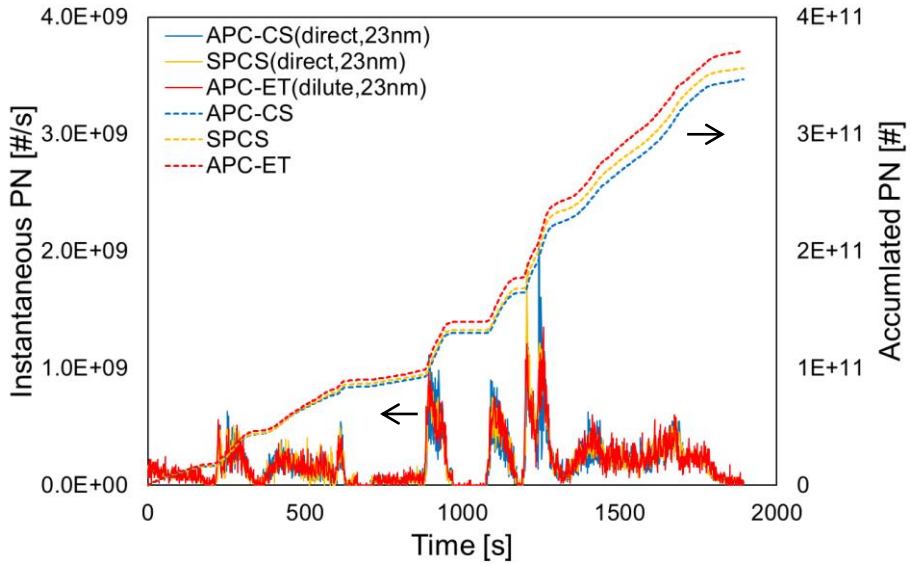
10.4.1.Time alignment

For direct tailpipe sampling with fixed initial dilution ratio the particle number signal shall be time aligned with the exhaust flow signal using the respective **transformation times**. The transformation time of the particle number sampling shall be determined according to paragraph A.8.1.3.7 of Appendix 8 to this annex.

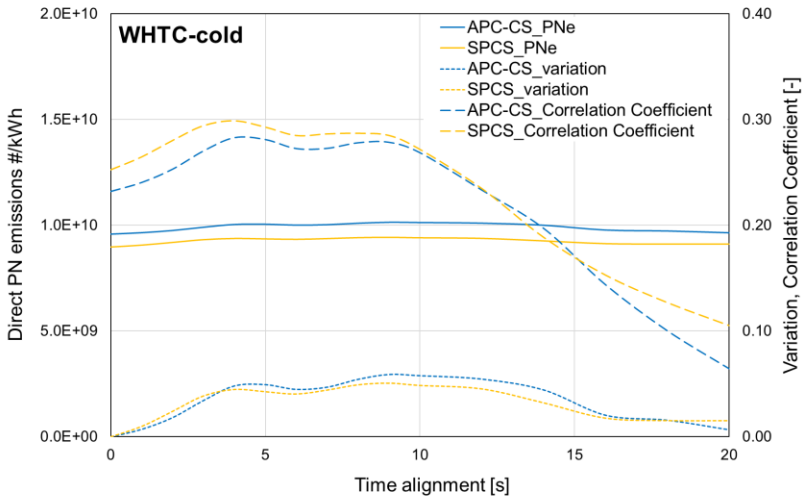


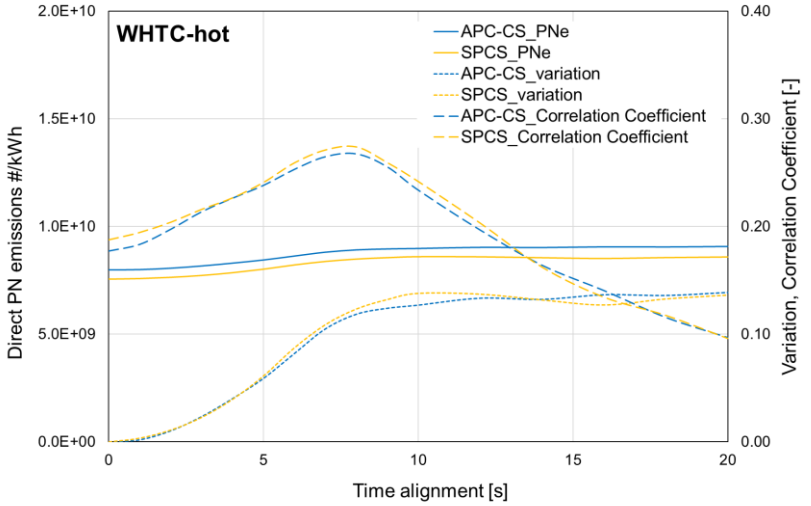
Transformation time
APC-CS: 4.7 s, SPCS: 3.7 s

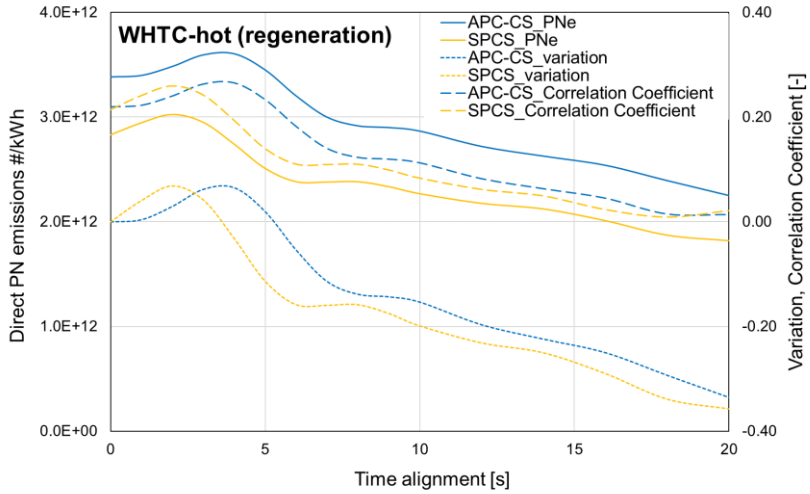


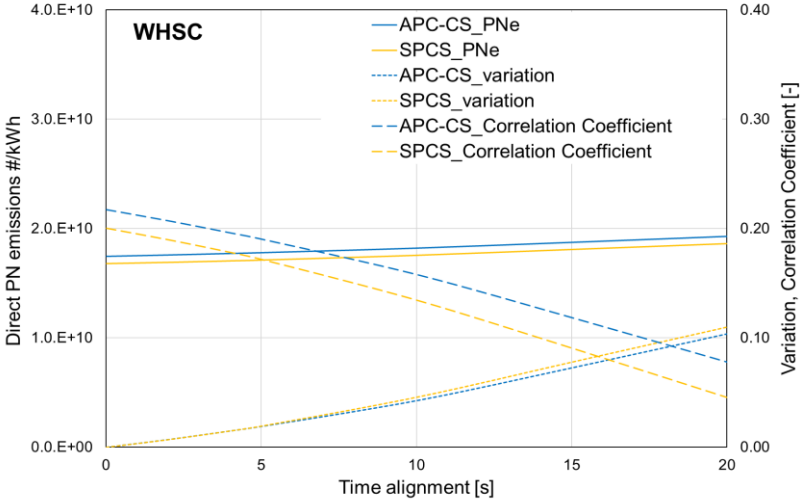


3. Results, Appendix　Impact of time alignment on each test cycle









Variation = PNe(ta = t) / PNe(ta = 0) - 1　ta: time alignment [s]
Correlation Coefficient: between Direct PN conc. and Exhaust flow rate

4. Conclusion

To verify the effects of **(1) sampling point** and **(2) pre-diluter (PND0)** on the direct PN measurement, NTSEL conducted verification tests and compared the direct PN emissions evaluated at different sampling points by APC-CS(without PND0) and SPCS(with PND0).

(1) Effect of sampling point

- According to the results of APC-CS,
  the effect of sampling point is negligible regardless of the test cycle in this verification.
- The results of SPCS were different in each sampling point. However, the distance from the outlet of aftertreatment system cannot explain the difference. Continue to investigate the cause.

(2) Effect of pre-diluter (PND0)

- Evaluation of Linearity with APG
  APC-CS : 10% **lower** than the reference (APC-ET)
  SPCS : 5% **lower** than the reference

- Results of repetition of WHTC-hot
  APC-CS(direct): tended to be **slightly lower** than APC-ET(dilute)
  SPCS(direct): PN emissions against the APC-ET(dilute) were **uneven**.

  - APC-CS：Possibility of slight particle loss in the hot tube
  - SPCS：Possibility that PND0 brings higher dispersion of PCRF

Thank you for your kind attention.