This informal document is submitted by the Informal Working Group (IWG) Particle Measurement Programme to inform and update the GRPE of the work of the IWG on the amendment of UN GTR 15 Annexes 5, 6, 7 to:

- Modify the existing solid PN measurement methodology having a 50% cut-off size at 23 nm (SPN23) in order to allow the use of catalyzed volatile particle remover (VPR) and introduce minor improvements

- Include as a second option a solid PN measurement methodology with a 65% cut-off size at 10 nm (SPN10).

This is the consolidated document addressing the changes to the current methodology and the proposed changes for the second options to extend the particle size detection range to 10 nm.

In the text of the GTR referring to PN measurement, the "track change" function highlights the changes that apply to both the SPN23 and SPN10 procedures.

The SPN23 procedure is obtained by deleting the text sections identified by the labels "SPN10:".

The SPN10 procedure is obtained by deleting the text sections identified by the label "SPN23:".

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Text of the global technical regulation

Annex 5

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4.3.　　　PN measurement equipment (if applicable)

This regulation allows for 2 optional settings for the measurement of PN, differentiated by the particle electrical mobility diameter at which the PNC's detection efficiency is stated. The two values included are 23 nm and 10 nm.

While most of the paragraphs and sub-paragraphs are common to the two different settings and have to be applied for both 23 nm and 10 nm PN measurement, some contain two different options starting respectively with the markings "SPN23" and "SPN10".

Where such options exist, a Contracting Party wishing to apply the 23 nm value should select the requirements starting with the marking "SPN23" whereas a Contracting Party wishing to apply the 10 nm value should select the requirements starting with the marking "SPN10".

4.3.1.　　　Specification

4.3.1.1.　　　System overview

4.3.1.1.1.　　　The particle sampling system shall consist of a probe or sampling point extracting a sample from a homogenously mixed flow in a dilution system, a volatile particle remover (VPR) upstream of a particle number counter (PNC) and suitable transfer tubing. See Figure A5/14a or Figure A5/14b (as applicable).

4.3.1.1.2.　　　It is recommended that a particle size pre-classifier (PCF) (e.g. cyclone, impactor, etc.) be located prior to the inlet of the VPR. The PCF 50 per cent cut point particle diameter shall be between 2.5 μm and 10 μm at the volumetric flow rate selected for particle sampling. The PCF shall allow at least 99 per cent of the mass concentration of 1 μm particles entering the PCF to pass through the exit of the PCF at the volumetric flow rate selected for particle sampling.

A sample probe acting as an appropriate size-classification device, such as that shown in Figure A5/11, is an acceptable alternative to the use of a PCF.

4.3.1.2.　　　General requirements

4.3.1.2.1.　　　The particle sampling point shall be located within a dilution system. In the case that a double dilution system is used, the particle sampling point shall be located within the primary dilution system.

4.3.1.2.1.1. The sampling probe tip or PSP, and the PTT, together comprise the particle transfer system (PTS). The PTS conducts the sample from the dilution tunnel to the entrance of the VPR. The PTS shall meet the following conditions:

(a) The sampling probe shall be installed at least 10 tunnel diameters downstream of the exhaust gas inlet, facing upstream into the tunnel gas flow with its axis at the tip parallel to that of the dilution tunnel;

(b) The sampling probe shall be upstream of any conditioning device (e.g. heat exchanger);

(c) The sampling probe shall be positioned within the dilution tunnel so that the sample is taken from a homogeneous diluent/exhaust mixture.

4.3.1.2.1.2. Sample gas drawn through the PTS shall meet the following conditions:

(a) In the case that a full flow exhaust dilution system, is used it shall have a flow Reynolds number Re lower than 1,700;

(b) In the case that a double dilution system is used, it shall have a flow Reynolds number Re lower than 1,700 in the PTT i.e. downstream of the sampling probe or point;

(c) Shall have a residence time ≤ 3 seconds.

4.3.1.2.1.3. SPN23:

Any other sampling configuration for the PTS for which equivalent solid particle penetration at 30 nm can be demonstrated shall be considered acceptable.

SPN10:

Any other sampling configuration for the PTS for which equivalent solid particle penetration at 15 nm can be demonstrated shall be considered acceptable.

4.3.1.2.1.4. The outlet tube (OT), conducting the diluted sample from the VPR to the inlet of the PNC, shall have the following properties:

(a) An internal diameter ≥ 4mm;

(b) A sample gas flow residence time of ≤ 0.8 seconds.

4.3.1.2.1.5. SPN23:

Any other sampling configuration for the OT for which equivalent solid particle penetration at 30 nm can be demonstrated shall be considered acceptable.

SPN10:

Any other sampling configuration for the OT for which equivalent solid particle penetration at 15 nm can be demonstrated shall be considered acceptable

4.3.1.2.2. The VPR shall include devices for sample dilution and for volatile particle removal.

4.3.1.2.3. All parts of the dilution system and the sampling system from the exhaust pipe up to the PNC, which are in contact with raw and diluted exhaust gas, shall be made of electrically conductive materials, shall be electrically grounded to

prevent electrostatic effects and designed to minimize deposition of the particles.

4.3.1.2.4.   The particle sampling system shall incorporate good aerosol sampling practice that includes the avoidance of sharp bends and abrupt changes in cross-section, the use of smooth internal surfaces and the minimization of the length of the sampling line. Gradual changes in the cross-section are permitted.

4.3.1.3.   Specific requirements

4.3.1.3.1.   The particle sample shall not pass through a pump before passing through the PNC.

4.3.1.3.2.   A sample pre-classifier is recommended.

4.3.1.3.3.   The sample preconditioning unit shall:

   (a)   Be capable of diluting the sample in one or more stages to achieve a particle number concentration below the upper threshold of the single particle count mode of the PNC;

   (b)   Have a gas temperature at the inlet to the PNC below the maximum allowed inlet temperature specified by the PNC manufacturer;

   (c)   Include an initial heated dilution stage that outputs a sample at a temperature of $\geq 150\ °C$ and $\leq 350\ °C \pm 10\ °C$, and dilutes by a factor of at least 10;

   (d)   Control heated stages to constant nominal operating temperatures, within the range $\geq 150\ °C$ and $\leq 400\ °C \pm 10\ °C$;

   (e)   Provide an indication of whether or not heated stages are at their correct operating temperatures;

   (f)   d Achieve a solid particle penetration efficiency of at least 70 per cent for particles of 100 nm electrical mobility diameter;

   (g)   SPN23:

   Achieve a particle concentration reduction factor $f_r(d_i)$ for particles of 30 nm and 50 nm electrical mobility diameters that is no more than 30 per cent and 20 per cent respectively higher, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole;

   The particle concentration reduction factor at each particle size $f_r(d_i)$ shall be calculated using the following equation:

$$f_r(d_i) = \frac{N_{in}(d_i)}{N_{out}(d_i)}$$

   where:

   $N_{in}(d_i)$ is the upstream particle number concentration for particles of diameter d_i;

   $N_{out}(d_i)$ is the downstream particle number concentration for particles of diameter d_i;

   d_i is the particle electrical mobility diameter (30, 50 or 100 nm).

   $N_{in}(d_i)$ and $N_{out}(d_i)$ shall be corrected to the same conditions.

The arithmetic average particle concentration reduction factor at a given dilution setting $\overline{f_r}$ shall be calculated using the following equation:

$$\overline{f_r} = \frac{f_r(30\text{ nm}) + f_r(50\text{ nm}) + f_r(100\text{ nm})}{3}$$

It is recommended that the VPR is calibrated and validated as a complete unit;

SPN10:

Achieve a particle concentration reduction factor $f_r(d_i)$ for particles of 15 nm, 30 nm and 50 nm electrical mobility diameters that is no more than 100 per cent, 30 per cent and 20 per cent respectively higher, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole;

The particle concentration reduction factor at each particle size $f_r(d_i)$ shall be calculated using the following equation:

$$f_r(d_i) = \frac{N_{in}(d_i)}{N_{out}(d_i)}$$

where:

$N_{in}(d_i)$ is the upstream particle number concentration for particles of diameter d_i;

$N_{out}(d_i)$ is the downstream particle number concentration for particles of diameter d_i;

d_i is the particle electrical mobility diameter.

$N_{in}(d_i)$ and $N_{out}(d_i)$ shall be corrected to the same conditions.

The arithmetic average particle concentration reduction factor at a given dilution setting $\overline{f_r}$ shall be calculated using the following equation:

$$\overline{f_r} = \frac{f_r(30\text{ nm}) + f_r(50\text{ nm}) + f_r(100\text{ nm})}{3}$$

It is recommended that the VPR is calibrated and validated as a complete unit;

(h) Be designed according to good engineering practice to ensure particle concentration reduction factors are stable across a test;

(i) SPN23:

Achieve more than 99.0 per cent vaporization of 30 nm tetracontane $(CH_3(CH_2)_{38}CH_3)$ particles, with an inlet concentration of $\geq 10{,}000$ per cm³, by means of heating and reduction of partial pressures of the tetracontane.

SPN10:

Achieve more than 99.9 per cent vaporization of tetracontane $(CH_3(CH_2)_{38}CH_3)$ particles with count median diameter > 50 nm and

mass > 1 mg/m^3, by means of heating and reduction of partial pressures of the tetracontane.

4.3.1.3.3.1 The solid particle penetration $P_r(d_i)$ at a particle size, d_i, shall be calculated using the following equation:

$$P_r(d_i) = DF \cdot N_{out}(d_i)/N_{in}(d_i)$$

Where

$N_{in}(d_i)$ is the upstream particle number concentration for particles of diameter d_i;

$N_{out}(d_i)$ is the downstream particle number concentration for particles of diameter d_i;

d_i is the particle electrical mobility diameter

DF   is the dilution factor between measurement positions of $N_{in}(d_i)$ and $N_{out}(d_i)$ determined either with trace gases, or flow measurements.

4.3.1.3.4. The PNC shall:

(a) Operate under full flow operating conditions;

(b) Have a counting accuracy of ± 10 per cent across the range 1 per cm³ to the upper threshold of the single particle count mode of the PNC against a suitable traceable standard. At concentrations below 100 per cm³, measurements averaged over extended sampling periods may be required to demonstrate the accuracy of the PNC with a high degree of statistical confidence;

(c) Have a resolution of at least 0.1 particles per cm³ at concentrations below 100 per cm³;

(d)

Operate under single counting mode only and have a linear response to particle number concentrations within the instrument's specified measurement range;

(e) Have a data reporting frequency equal to or greater than a frequency of 0.5 Hz;

(f) Have a t_{90} response time over the measured concentration range of less than 5 seconds;

(g)

Introduce a correction with an internal calibration factor as determined in paragraph 5.7.1.3. of this annex.

(h) Have counting efficiencies at the different particle sizes as specified in Table A5/2a or Table A5/2b (as applicable).

(i) SPN23:

The PNC calibration factor from the linearity calibration against a traceable reference shall be applied to determine PNC counting

efficiency. The counting efficiency shall be reported including the calibration factor from linearity calibration against a traceable reference.

SPN10:

The PNC calibration material shall be 4cSt polyalphaolefin (Emery oil) or soot-like particles (e.g. flame generated soot or graphite particles). The PNC calibration factor from the linearity calibration against a traceable reference shall be applied to determine PNC counting efficiency. The counting efficiency shall be reported including the calibration factor from linearity calibration against a traceable reference.

(j) If the PNC applies some other working liquid besides n-butyl alcohol or isopropyl alcohol, the counting efficiency of the PNC shall be demonstrated with 4cSt polyalphaolefin and soot-like particles.

SPN23:
Table A5/2a
PNC counting efficiency

Nominal particle electrical mobility diameter (nm)	PNC counting efficiency (per cent)
23	50 ±12
41	> 90

SPN10:
Table A5/2b
PNC counting efficiency

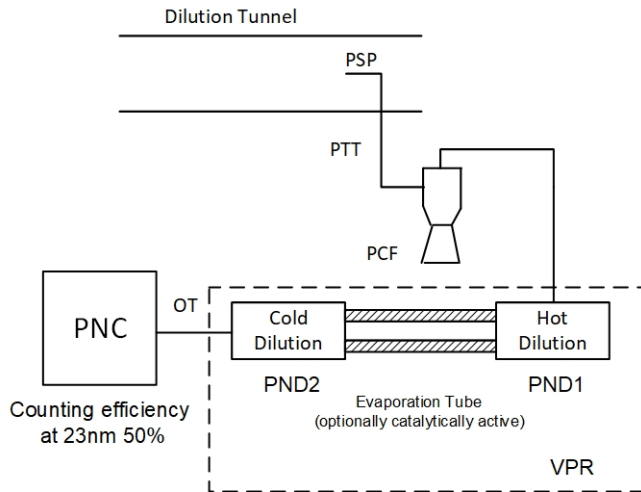| Nominal particle electrical mobility diameter (nm)	PNC counting efficiency (per cent)
10	65 ±15
15	> 90

4.3.1.3.5. If the PNC makes use of a working liquid, it shall be replaced at the frequency specified by the instrument manufacturer.

4.3.1.3.6. Where not held at a known constant level at the point at which PNC flow rate is controlled, the pressure and/or temperature at the PNC inlet shall be measured for the purposes of correcting particle number concentration measurements to standard conditions. The standard conditions are 101.325 kPa pressure and 0°C temperature.

4.3.1.3.7. The sum of the residence time of the PTS, VPR and OT plus the t_{90} response time of the PNC shall be no greater than 20 seconds.

4.3.1.4. Recommended system description

The following paragraph contains the recommended practice for measurement of PN. However, systems meeting the performance specifications in

paragraphs 4.3.1.2. and 4.3.1.3. of this annex are acceptable. See Figure A5/14a or Figure A5/14b (as applicable)
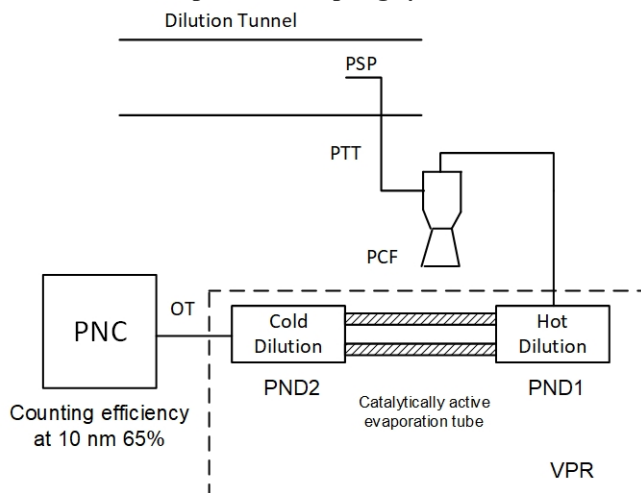
SPN 23:
Figure A5/14a
A recommended particle sampling system

SPN10:
Figure A5/14b
A recommended particle sampling system

4.3.1.4.1.   Sampling system description

4.3.1.4.1.1.   The particle sampling system shall consist of a sampling probe tip or particle sampling point in the dilution system, a PTT, a PCF, and a VPR, upstream of the PNC unit.

4.3.1.4.1.2.   The VPR shall include devices for sample dilution (particle number diluters: PND_1 and PND_2) and particle evaporation (evaporation tube, ET).

4.3.1.4.1.3.   SPN23:

The evaporation tube, ET, may be catalytically active.

SPN10:

The evaporation tube, ET, shall be catalytically active.

4.3.1.4.1.4.   The sampling probe or sampling point for the test gas flow shall be arranged within the dilution tunnel so that a representative sample gas flow is taken from a homogeneous diluent/exhaust mixture.

5.   Calibration intervals and procedures

5.1.   Calibration intervals

All instruments in Table A5/3 shall be calibrated at/after major maintenance intervals.

Table A5/3
Instrument calibration intervals

Instrument checks	Interval	Criterion
Gas analyser linearization (calibration)	Every 6 months	±2 per cent of reading
Mid-span	Every 6 months	±2 per cent
CO NDIR: CO_2/H_2O interference	Monthly	-1 to 3 ppm
NO_x converter check	Monthly	> 95 per cent
CH_4 cutter check	Yearly	98 per cent of ethane
FID CH_4 response	Yearly	See paragraph 5.4.3. of this annex.
FID air/fuel flow	At major maintenance	According to the instrument manufacturer.
NO/NO_2 NDUV: H_2O, HC interference	At major maintenance	According to the instrument manufacturer.
Laser infrared spectrometers (modulated high resolution narrow band infrared analysers): interference check	Yearly	According to the instrument manufacturer.
QCL	Yearly	According to the instrument manufacturer.
GC methods	See paragraph 7.2. of this annex.	See paragraph 7.2. of this annex.
LC methods	Yearly	According to the instrument manufacturer.
Photoacoustics	Yearly	According to the instrument manufacturer.
FTIR: linearity verification	Within 370 days before testing	See paragraph 7.1. of this annex.
Microgram balance linearity	Yearly	See paragraph 4.2.2.2. of this annex.
PNC (particle number counter)	See paragraph 5.7.1.1. of this annex	See paragraph 5.7.1.3. of this annex.
VPR (volatile particle remover)	See paragraph 5.7.2.1. of this annex.	See paragraph 5.7.2. of this annex.

Table A5/4
Constant volume sampler (CVS) calibration intervals

CVS	Interval	Criterion
CVS flow	After overhaul	±2 per cent
Temperature sensor	Yearly	±1 °C
Pressure sensor	Yearly	±0.4 kPa
Injection check	Weekly	±2 per cent

Table A5/5
Environmental data calibration intervals

Climate	Interval	Criterion
Temperature	Yearly	±1 °C
Moisture dew	Yearly	±5 per cent RH
Ambient pressure	Yearly	±0.4 kPa
Cooling fan	After overhaul	According to paragraph 1.1.1. of this annex.

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5.7.   Calibration and validation of the particle sampling system (if applicable)

SPN23: Examples of calibration/validation methods are available at: http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/pmpFCP.html.

SPN10:

[Reserved]

5.7.1.   Calibration of the PNC

5.7.1.1.   The responsible authority shall ensure the existence of a calibration certificate for the PNC demonstrating compliance with a traceable standard within a 13-month period prior to the emissions test. Between calibrations either the counting efficiency of the PNC shall be monitored for deterioration or the PNC wick shall be routinely changed every 6 months if recommended by the instrument manufacturer. See Figures A5/16 and A5/17. PNC counting efficiency may be monitored against a reference PNC or against at least two other measurement PNCs. If the PNC reports particle number concentrations within ±10 per cent of the arithmetic average of the concentrations from the reference PNC, or a group of two or more PNCs, the PNC shall subsequently be considered stable, otherwise maintenance of the PNC is required. Where the PNC is monitored against two or more other measurement PNCs, it is permitted to use a reference vehicle running sequentially in different test cells each with its own PNC.

Figure A5/16
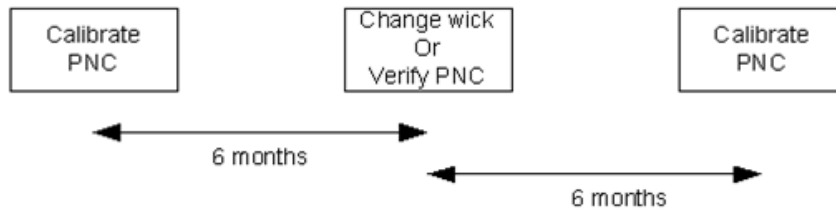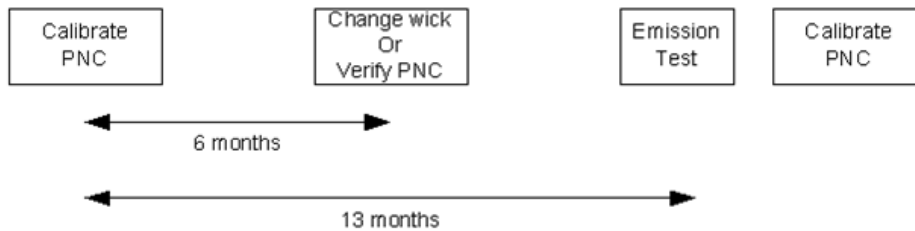**Nominal PNC annual sequence**

Calibrate PNC | Change wick Or Verify PNC | Calibrate PNC

6 months

6 months

Figure A5/17
Extended PNC annual sequence (in the case that a full PNC calibration is delayed)

Calibrate PNC | Change wick Or Verify PNC | Emission Test | Calibrate PNC

6 months

13 months

5.7.1.2.   The PNC shall also be recalibrated and a new calibration certificate issued following any major maintenance.

5.7.1.3.   Calibration shall be undertaken according to ISO 27891:2015 and shall be traceable to a national or international standard by comparing the response of the PNC under calibration with that of:

(a)   A calibrated aerosol electrometer when simultaneously sampling electrostatically classified calibration particles; or

(b)

SPN23:

A second full flow PNC with counting efficiency above 90 per cent for 23 nm equivalent electrical mobility diameter particles that has been calibrated by the method described above. The second PNC counting efficiency shall be taken into account in the calibration.

SPN10:

A second full flow PNC with counting efficiency above 90 per cent for 10 nm equivalent electrical mobility diameter particles that has been calibrated by the method described above. The second PNC counting efficiency shall be taken into account in the calibration.

5.7.1.3.1.   For the requirements of paragraphs 5.7.1.3.(a) and 5.7.1.3.(b), calibration shall be undertaken using at least six standard concentrations across the PNC's measurement range. These standard concentrations shall be as uniformly spaced as possible between the standard concentration of 2,000 particles per cm³ or below and the maximum of the PNC's range in single particle count mode.

5.7.1.3.2.   For the requirements of paragraphs 5.7.1.3.(a) and 5.7.1.3.(b), the selected points shall include a nominal zero concentration point produced by attaching HEPA filters of at least Class H13 of EN 1822:2008, or equivalent performance, to the inlet of each instrument. The gradient from a linear least squares regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the

PNC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (r) of the two data sets and shall be equal to or greater than 0.97. In calculating both the gradient and r^2, the linear regression shall be forced through the origin (zero concentration on both instruments). The calibration factor shall be between 0.9 and 1.1 or otherwise the PNC shall be rejected. Each concentration measured with the PNC under calibration, shall be within ±5 per cent of the measured reference concentration multiplied with the gradient, with the exception of the zero point, otherwise the PNC under calibration shall be rejected.

5.7.1.4.   SPN23:

Calibration shall also include a check, according to the requirements of paragraph 4.3.1.3.4.(h) of this annex, on the PNC's detection efficiency with particles of 23 nm electrical mobility diameter. A check of the counting efficiency with 41 nm particles is not required.

SPN10:

Calibration shall also include a check, according to the requirements of paragraph 4.3.1.3.4.(h) of this annex, on the PNC's detection efficiency with particles of nominally 10 nm electrical mobility diameter. A check of the counting efficiency with particles of 15 nm electrical mobility diameter is not required.

5.7.2.   Calibration/validation of the VPR

5.7.2.1.   SPN23:

Calibration of the VPR's particle concentration reduction factors across its full range of dilution settings, at the instrument's fixed nominal operating temperatures, shall be required when the unit is new and following any major maintenance. The periodic validation requirement for the VPR's particle concentration reduction factor is limited to a check at a single setting, typical of that used for measurement on particulate filter-equipped vehicles. The responsible authority shall ensure the existence of a calibration or validation certificate for the VPR within a 6-month period prior to the emissions test. If the VPR incorporates temperature monitoring alarms, a 13-month validation interval is permitted.

It is recommended that the VPR is calibrated and validated as a complete unit.

The VPR shall be characterised for particle concentration reduction factor with solid particles of 30, 50 and 100 nm electrical mobility diameter. Particle concentration reduction factors $f_r(d)$ for particles of 30 nm and 50 nm electrical mobility diameters shall be no more than 30 per cent and 20 per cent higher respectively, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter. For the purposes of validation, the arithmetic average of the particle concentration reduction factor calculated for particles of 30 nm, 50 nm and 100 nm electrical mobility diameters shall be within ±10 per cent of the arithmetic average particle concentration reduction factor $\overline{f_r}$ determined during the latest complete calibration of the VPR.

SPN10:

Calibration of the VPR's particle concentration reduction factors across its full range of dilution settings, at the instrument's fixed nominal operating

temperatures, shall be required when the unit is new and following any major maintenance. The periodic validation requirement for the VPR's particle concentration reduction factor is limited to a check at a single setting, typical of that used for measurement on particulate filter-equipped vehicles. The responsible authority shall ensure the existence of a calibration or validation certificate for the VPR within a 6-month period prior to the emissions test. If the VPR incorporates temperature monitoring alarms, a 13-month validation interval is permitted.

It is recommended that the VPR is calibrated and validated as a complete unit.

The VPR shall be characterised for particle concentration reduction factor with solid particles of 15, 30, 50 and 100 nm electrical mobility diameter. Particle concentration reduction factors $f_r(d)$ for particles of 15 nm, 30 nm and 50 nm electrical mobility diameters shall be no more than 100 per cent, 30 per cent and 20 per cent higher respectively, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter. For the purposes of validation, the arithmetic average of the particle concentration reduction factor calculated for particles of 30 nm, 50 nm and 100 nm electrical mobility diameters shall be within ±10 per cent of the arithmetic average particle concentration reduction factor $\overline{f_r}$ determined during the latest complete calibration of the VPR.

5.7.2.2. SPN23:

The test aerosol for these measurements shall be solid particles of 30, 50 and 100 nm electrical mobility diameter and a minimum concentration of 5,000 particles per cm³ at the VPR inlet. As an option, a polydisperse aerosol with an electrical mobility median diameter of 50 nm may be used for validation. The test aerosol shall be thermally stable at the VPR operating temperatures. Particle number concentrations shall be measured upstream and downstream of the components.

The particle concentration reduction factor for each monodisperse particle size, $f_r(d_i)$, shall be calculated using the following equation:

$$f_r(d_i) = \frac{N_{in}(d_i)}{N_{out}(d_i)}$$

where:

$N_{in}(d_i)$ is the upstream particle number concentration for particles of diameter d_i;

$N_{out}(d_i)$ is the downstream particle number concentration for particles of diameter d_i;

d_i is the particle electrical mobility diameter (30, 50 or 100 nm).

$N_{in}(d_i)$ and $N_{out}(d_i)$ shall be corrected to the same conditions.

The arithmetic average particle concentration reduction factor $\overline{f_r}$ at a given dilution setting shall be calculated using the following equation:

$$\overline{f_r} = \frac{f_r(30nm) + f_r(50nm) + f_r(100nm)}{3}$$

Where a polydisperse 50 nm aerosol is used for validation, the arithmetic average particle concentration reduction factor $\overline{f_v}$ at the dilution setting used for validation shall be calculated using the following equation:

$$\bar{f}_v = \frac{N_{in}}{N_{out}}$$

where:

N_{in} is the upstream particle number concentration;

N_{out} is the downstream particle number concentration.

SPN10:

The test aerosol for these measurements shall be solid particles of 30, 50 and 100 nm electrical mobility diameter and a minimum concentration of 5,000 particles per cm³ and a minimum concentration of 3,000 particles per cm³ of 15 nm electrical mobility diameter at the VPR inlet. The test aerosol shall be thermally stable at the VPR operating temperatures. Particle number concentrations shall be measured upstream and downstream of the components.

The particle concentration reduction factor for each monodisperse particle size, $f_r(d_i)$, shall be calculated using the following equation:

$$f_r(d_i) = \frac{N_{in}(d_i)}{N_{out}(d_i)}$$

where:

$N_{in}(d_i)$ is the upstream particle number concentration for particles of diameter d_i;

$N_{out}(d_i)$ is the downstream particle number concentration for particles of diameter d_i;

d_i is the particle electrical mobility diameter.

$N_{in}(d_i)$ and $N_{out}(d_i)$ shall be corrected to the same conditions.

The arithmetic average particle concentration reduction factor $\bar{f}_r$ at a given dilution setting shall be calculated using the following equation:

$$\bar{f}_r = \frac{f_r(30nm) + f_r(50nm) + f_r(100nm)}{3}$$

5.7.2.3.   SPN23:

The VPR shall demonstrate greater than 99.0 per cent removal of tetracontane ($CH_3(CH_2)_{38}CH_3$) particles of at least 30 nm electrical mobility diameter with an inlet concentration $\geq$ 10,000 per cm³ when operated at its minimum dilution setting and manufacturer's recommended operating temperature.

SPN10:

The VPR shall demonstrate greater than 99.9 per cent removal efficiency of Tetracontane ($CH_3(CH_2)_{38}CH_3$) particles with count median diameter > 50 nm and mass > 1 mg/m³.

5.7.2.4   The instrument manufacturer shall provide the maintenance or replacement interval that ensures that the removal efficiency of the VPR does not drop

below the technical requirements. If such information is not provided, the volatile removal efficiency shall be checked yearly for each instrument.

5.7.2.5   The instrument manufacturer shall prove the solid particle penetration $P_r(d_i)$ by testing one unit for each PN-system model. A PN-system model here covers all PN-systems with the same hardware, i.e. same geometry, conduit materials, flows and temperature profiles in the aerosol path. $P_r(d_i)$ at a particle size, d_i, shall be calculated using the following equation:

$$P_r(d_i) = DF \cdot N_{out}(d_i)/N_{in}(d_i)$$

Where

$N_{in}(d_i)$ is the upstream particle number concentration for particles of diameter d_i;

$N_{out}(d_i)$ is the downstream particle number concentration for particles of diameter d_i;

d_i is the particle electrical mobility diameter

DF   is the dilution factor between measurement positions of $N_{in}(d_i)$ and $N_{out}(d_i)$ determined either with trace gases, or flow measurements.

5.7.3.   PN measurement system check procedures

On a monthly basis, the flow into the PNC shall have a measured value within 5 per cent of the PNC nominal flow rate when checked with a calibrated flow meter. Here the term 'nominal flow rate' refers to the flow rate stated in the most recent calibration for the PNC by the instrument manufacturer.

Annex 6

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2.1.3.2.	Background particle number determination (if applicable)
2.1.3.2.1.	Where the Contracting Party permits subtraction of either dilution air or dilution tunnel background particle number from emissions measurements and a manufacturer requests a background correction, these background levels shall be determined as follows:
2.1.3.2.1.1.	The background value may be either calculated or measured. The maximum permissible background correction shall be related to the maximum allowable leak rate of the particle number measurement system (0.5 particles per cm³) scaled from the particle concentration reduction factor, PCRF, and the CVS flow rate used in the actual test;
2.1.3.2.1.2.	Either the Contracting Party or the manufacturer may request that actual background measurements are used instead of calculated ones.
2.1.3.2.1.3.	Where subtraction of the background contribution gives a negative result, the PN result shall be considered to be zero.
2.1.3.2.2.	The dilution air background particle number level shall be determined by sampling filtered dilution air. This shall be drawn from a point immediately downstream of the dilution air filters into the PN measurement system. Background levels in particles per cm³ shall be determined as a rolling arithmetic average of least 14 measurements with at least one measurement per week.
2.1.3.2.3.	The dilution tunnel background particle number level shall be determined by sampling filtered dilution air. This shall be drawn from the same point as the PN sample. Where secondary dilution is used for the test the secondary dilution system shall be active for the purposes of background measurement. One measurement may be performed on the day of test, either prior to or after the test using the actual PCRF and the CVS flow rate utilised during the test.

...

2.11.	PN sampling (if applicable)
2.11.1.	The steps described in paragraphs 2.11.1.1. to 2.11.1.2. inclusive of this annex shall be taken prior to each test:
2.11.1.1.	The particle specific dilution system and measurement equipment shall be started and made ready for sampling;
2.11.1.2.	The correct function of the PNC and VPR elements of the particle sampling system shall be confirmed according to the procedures listed in paragraphs 2.11.1.2.1. to 2.11.1.2.4. inclusive of this annex.
2.11.1.2.1.	A leak check, using a filter of appropriate performance attached to the inlet of the entire PN measurement system, VPR and PNC, shall report a measured concentration of less than 0.5 particles per cm³.
2.11.1.2.2.	

Each day, a zero check on the PNC, using a filter of appropriate performance at the PNC inlet, shall report a concentration of ≤ 0.2 particles per cm³. Upon removal of the filter, the PNC shall show an increase in measured concentration and a return to ≤ 0.2 particles per cm³ on replacement of the filter. The PNC shall not report any error.

2.11.1.2.3.   It shall be confirmed that the measurement system indicates that the evaporation tube, where featured in the system, has reached its correct operating temperature.

2.11.1.2.4.   It shall be confirmed that the measurement system indicates that the diluter PND_1 has reached its correct operating temperature.

Annex 7

4.   Determination of PN (if applicable)

PN shall be calculated using the following equation:

$$PN = \frac{V \times k \times \left(\overline{C_s} \times \overline{f_r} - C_b \times \overline{f_{rb}} \right) \times 10^3}{d}$$

where:

PN   is the particle number emission, particles per kilometre;

V   is the volume of the diluted exhaust gas in litres per test (after primary dilution only in the case of double dilution) and corrected to standard conditions (273.15 K (0 °C) and 101.325 kPa);

k   is a calibration factor to correct the PNC measurements to the level of the reference instrument where this is not applied internally within the PNC. Where the calibration factor is applied internally within the PNC, the calibration factor shall be 1;

$\overline{C_s}$ is the corrected particle number concentration from the diluted exhaust gas expressed as the arithmetic average number of particles per cubic centimetre from the emissions test including the full duration of the drive cycle. If the volumetric mean concentration results $\overline{C}$ from the PNC are not measured at standard conditions (273.15 K (0 °C) and 101.325 kPa), the concentrations shall be corrected to those conditions $\overline{C_s}$;

C_b is either the dilution air or the dilution tunnel background particle number concentration, as permitted by the responsible authority, in particles per cubic centimetre, corrected to standard conditions (273.15 K (0 °C) and 101.325 kPa);

$\overline{f_r}$ is the mean particle concentration reduction factor of the VPR at the dilution setting used for the test;

$\overline{f_{rb}}$ is the mean particle concentration reduction factor of the VPR at the dilution setting used for the background measurement;

d   is the distance driven corresponding to the applicable test cycle, km.

$\overline{C}$ shall be calculated using the following equation:

$$\overline{C} = \frac{\sum_{i=1}^{n} C_i}{n}$$

where:

C_i is a discrete measurement of particle number concentration in the diluted gas exhaust from the PNC; particles per cm³;

n   is the total number of discrete particle number concentration measurements made during the applicable test cycle and shall be calculated using the following equation:

$$n = t \times f$$

where:

t   is the time duration of the applicable test cycle, s;

f   is the data logging frequency of the particle counter, Hz.