Submitted by the IWG PMP

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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 and 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 evaporation device in volatile particle remover (VPR) and introduce minor improvements
- Include as a second alternative option a solid PN measurement methodology with a 65% cut-off size at 10 nm (SPN10).

This is an explanatory note accompanying the consolidated document addressing the changes to the current methodology and the proposed changes for the second alternative option to extend the particle size detection range to 10 nm particles (GRPE-81-10).

Purpose and summary of the modifications

This proposed amendment to GTR 15 aims mainly at introducing as an alternative option a solid particle number measurement procedure with a cut-off size of approximately 10 nm (SPN10) differing in this from the existing procedure which has a 50% cut-off size at 23 nm (SPN23).

This amendment stems from the evidence that specific technologies like PFI and CNG engines may exhibit, in some cases, particle emissions close to the existing emission limit and at the same time a significantly high fraction of sub-23 nm particles. In view of a possible extension of the particle number limit to all combustion engines, the European Commission and other Contracting Parties had expressed the interest in a test procedure with a lower cut-off size in order to improve the control of particle emissions whatever the average size of the particles emitted. The PMP IWG concluded that it would be extremely challenging to develop a reliable particle counting methodology with a d50 below 10 nm while a 65% cut-off size at 10 nm would be achievable by properly adapting the existing methodology.

For this reason the PMP IWG has worked to identify the necessary changes which would allow an increase to the size range of the particles counted, whilst maintaining an appropriate level of repeatability/reproducibility, and at the same time trying to reduce as much as possible the impact on the testing burden and the measuring equipment required. The new proposed procedure has been assessed by means of an inter-laboratory exercise that has involved several laboratories located in Europe and Asia. This exercise has shown that the variability level of SPN10 results is at the same level as the SPN23 values.

Since a few Contracting Parties have asked to maintain the existing methodology with the 50% cut-off size at 23 nm in the GTR15, in agreement with the GRPE Secretariat, it is proposed to keep the existing methodology with some modifications and introduce the new procedure with the cut-off size at about 10 nm as an additional option. Both the changes to the existing methodology and the changes to extend the particle size detection range to 10 nm are summarized and explained in the table 1.

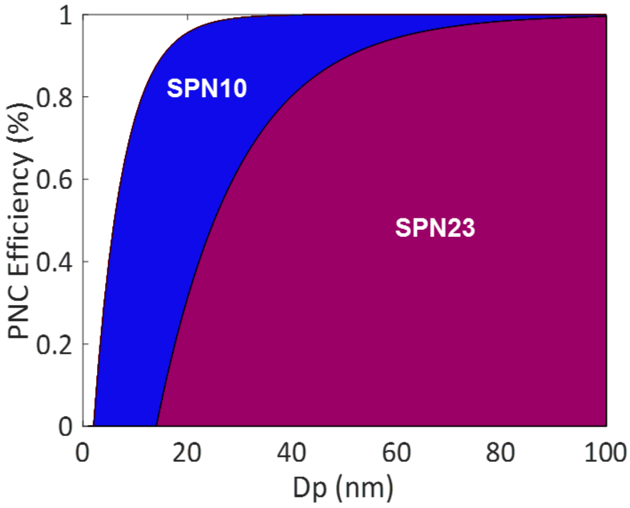
One of the more debated points in the PMP IWG concerned the volatile particle remover and more specifically whether for SPN10 this should be based on a catalytic stripper or whether also the usual evaporation tube should be allowed. The results of the validation exercise have not provided clear evidence that one solution is definitely better than the other, but there is large consensus among the experts that the catalytic stripper minimizes the risk of artefacts due to too low dilution ratios. Moreover, losses are more critical for particles below 23 nm and if not properly measured and modelled, allowing both systems could result in an increased variability among instruments based on different sample treatment approaches. For these reasons it has been decided to allow only the use of the catalytic stripper for SPN 10. However, in order to maintain the possibility of using sampling systems designed for SPN10 also for SPN23 measurement, the IWG proposes to modify also the existing procedure by removing the restriction that the sampling system parts shall not react with the exhaust gas components. In this way a sampling system with a catalytic stripper fitted with a condensation particle counter with the proper calibration can be used for the SPN23 measurement. As supported by several experimental data, the different losses between catalytic stripper and evaporation tube become important only below 23 nm and therefore, allowing the use of both devices for SPN23, should not result in an increased variability of the measurements.

Table 1: Main changes to SPN23 and changes/additions for SPN10

Subject	**GTR 15, Annex 5 – Original requirements**	**Proposed changes for SPN23**	**Proposed changes for SPN10**	**Reasoning**
PNC efficiency	50±12 % @ 23 nm, >90% @ 41nm	None	65±15 % @ 10 nm, >90% @ 15nm	Typical PNC-efficiency, well tested in the field.
Maximum VPR-loss requirement	@ 30nm 30% and @ 50 nm 20% higher than @ 100 nm	None	Addition @15 nm 100 % higher than at 100 nm	No additional requirement below 15 nm since generation of particles < 15 nm challenging, uncertainties high
Polydisperse validation of VPR	a polydisperse 50 nm aerosol may be used for validation	None	Removed	Uncertainties @ 15 nm or below high → test serves no purpose
VPR validation	> 99.0 % vaporization of 30 nm tetracontane particles, with an inlet concentration of ≥ 10,000 per cm³ **(Monodisperse)**	None	> 99.9 % removal efficiency of tetracontane particles with count median diameter > 50 nm and mass > 1 mg/m3. **(Polydisperse)**	Secure the functioning of VPR also for PNC with 65±15 % @ 10 nm, >90% @ 15nm
Volatile Particle Remover (VPR)	All parts (of SPN-system) -- shall not react with exhaust gas components	-- VPR may be catalyzed (both heated evaporation tube and catalytic stripper allowed)	- the VPR shall be catalyzed (use of catalytic stripper only)	Minimize the risk of artefacts for SPN10. Comparability of PNC10 and PNC23 and possibility of using new sampling systems with CS also for SPN23 by fitting a PNC with a D50 @ 23 nm.

A specific technical issue stemmed from the concern that to certify a vehicle for two different regions applying different PN limits (i.e. PN10 and PN23) either two different instruments or double testing might be required. This would lead in any case to increased testing costs and burden. Both those situations might be avoided if a test performed using the SPN 10 measurement procedure could also cover the SPN23 nm test.

In principle measuring SPN10 should result in higher PN values and therefore if the PN23 limit is met it can be concluded that the same limit would be more easily met when using the SPN23 procedure (see picture below). The PMP IWG believes that this option is acceptable if any party would like to implement it.



As explained above, the proposed amendment does not just contain a second option for SPN10 measurement, but also includes a number of corrections/improvements to the existing and the proposed methodology. The following table describes in detail only the changes to the existing, SPN23 methodology. When in the "New text" column the marking "SPN23" does not appear, the changes also apply to the SPN10 procedure.

Annex 5	**Original text**	**New text**	**Justification**
4.3. PN measurement equipment (if applicable)	None	This regulation allows for two 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	The text explains how to read the annex in the context of having common text, SPN10 specific text and SP23 specific text- as introduced by the new and the amended test procedure.

Annex 5	Original text	New text	Justification
		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".	
4.3.1.2.3.	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 designed to minimize deposition of the particles. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.	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.	This change allows the use of a catalytic stripper in the sampling system used for SPN23 measurement
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 and a gas temperature below 35 °C at the inlet to the PNC;	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;	Permits the use of systems that can control the inlet temperature
4.3.1.3.3.	The sample preconditioning unit shall: (e) Be designed to achieve a solid particle penetration efficiency of at least 70 per cent for particles of 100 nm electrical mobility diameter;	The sample preconditioning unit shall: (f) Achieve a solid particle penetration efficiency of at least 70 per cent for particles of 100 nm electrical mobility diameter;	Only editorial change
4.3.1.3.3.	The sample preconditioning unit shall: (h) Also achieve more than 99.0 per cent vaporization of 30 nm tetracontane (CH3(CH2)38CH3) particles, with an inlet concentration of ≥ 10,000 per cm³, by means of heating and reduction of partial pressures of the tetracontane.	The sample preconditioning unit shall: (h) SPN23: Achieve more than 99.0 per cent vaporization of 30 nm tetracontane (CH3(CH2)38CH3) particles, with an inlet concentration of ≥ 10,000 per cm³, by means of heating and reduction of partial pressures of the tetracontane.	Only editorial change
New 4.3.1.3.3.1	None	The solid particle penetration $P_r(d_i)$ at a particle size, d_i, shall be calculated using the following equation:	Definition of penetration. It was not defined

Annex 5	Original text	New text	Justification
		$P_r(d_i) = DF \cdot N_{out}(d_i)/N_{in}(d_i)$ 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: (d) Have a linear response to particle number concentrations over the full measurement range in single particle count mode;	The PNC shall: (d) Operate under single counting mode only and have a linear response to particle number concentrations within the instrument's specified measurement range;	Clarification of the already existing requirement of single counting mode
4.3.1.3.4.	The PNC shall: (g) Incorporate a coincidence correction function up to a maximum 10 per cent correction, and may make use of an internal calibration factor as determined in paragraph 5.7.1.3. of this annex but shall not make use of any other algorithm to correct for or define the counting efficiency;	The PNC shall: (g) Introduce a correction with an internal calibration factor as determined in paragraph 5.7.1.3.	The coincidence correction is outdated. New counters have more sophisticated algorithms
4.3.1.3.4.	None	The PNC shall: (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 the linearity calibration against a traceable reference.	Clarification that the calibration factor has to be applied when checking the efficiencies at the cut-off curve sizes
4.3.1.3.4.	None	The PNC shall: (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	To confirm that PNC working fluid does not behave differently with soot particles, i.e. soot is somewhat hydrophobic and PNCs applying

Annex 5	Original text	New text	Justification
		polyalphaolefin and soot-like particles.	water as working fluid should be avoided
Table A5/2a PNC counting efficiency	23±1 41±1	23 41	Reference to “nominal” particle size
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	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.	Standard conditions defined to avoid ambiguity.
4.3.1.4.1.3.	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.	Becomes 4.3.1.4.1.4 and a new provision is inserted in 4.3.1.4.1.3	Change on indexing
New 4.3.1.4.1.3	None	SPN23: The evaporation tube, ET, may be catalytically active.	Clarification that catalytically active evaporation tube is permitted
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. 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	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	This is obsolete for some instrument on the market as they have an integrated quality check option (e.g. pulse-height determination)

Annex 5	Original text	New text	Justification
	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	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	
5.7.1.3	Calibration shall be traceable to a national or international standard calibration method by comparing the response of the PNC under calibration with that of:	Calibration shall be undertaken according to ISO 27891:2015 and traceable to a national or international standard by comparing the response of the PNC under calibration with that of:	Requirement that PNC calibration should follow the recently released ISO 27891:2015.
5.7.1.3	(b) A second PNC that has been directly calibrated by the method described above.	(b) SPN23: A second full flow PNC with counting efficiency above 90 per cent for 23 nm equivalent electrical mobility diameter particle s that has been calibrated by the method described above. The second PNC counting efficiency shall be taken into account in the calibration.	Requirement that facilitates the PNC calibration with a reference PNC different to that required in ISO 27891:2015.
5.7.1.3.1	For the requirements of paragraph 5.7.1.3.(a), calibration shall be undertaken using at least six standard concentrations spaced as uniformly as possible across the PNC's measurement range.	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.	Paragaphs 5.7.1.3.1 and 5.7.1.3.2 combined together and clarified
5.7.1.3.2	For the requirements of paragraph 5.7.1.3.(b), calibration shall be undertaken using at least six standard concentrations across the PNC's measurement range. At least 3 points shall be at concentrations below 1,000 per cm³, the remaining concentrations shall be linearly spaced between 1,000 per cm³ and the maximum of the PNC's	Deleted	Paragaphs 5.7.1.3.1 and 5.7.1.3.2 combined together and clarified

Annex 5	Original text	New text	Justification
	range in single particle count mode.		
Old 5.7.1.3.3 becomes new 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. With no calibration factor applied to the PNC under calibration, measured concentrations shall be within ±10 per cent of the standard concentration for each concentration, with the exception of the zero point, otherwise the PNC under calibration shall be rejected. 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 r2, the linear regression shall be forced through the origin (zero concentration on both instruments).	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 r2, 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 concentrations multiplied with the gradient, with the exception of the zero point, otherwise the PNC under calibration shall be rejected..	Stricter requirement for the linearity (instead of +/-10%, reduced to +/-5%) from the slope. Additionally, linearity is no more compared on absolute, measured reference concentrations, but on forecasted reference concentration.
5.7.2.1.	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	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	"Primary calibration" replaced "with latest complete calibration". Primary is ambiguous and unrealistic if interpreted as the first calibration of the instrument.

Annex 5	Original text	New text	Justification
	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 shall be within ±10 per cent of the arithmetic average particle concentration reduction factor $\overline{f_r}$ determined during the primary calibration of the VPR.	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 primary calibration of the VPR.	
New 5.7.2.4	None	The instrument manufacturer must 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 has to be checked yearly for each instrument.	Require the instrument manufacturer to recommend the maintenance interval to ensure proper functioning of the VPR
New 5.7.2.5	None	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.	Definition of penetration. It was not defined.

Annex 5	Original text	New text	Justification
		same geometry, conduit materials, flows and temperature profiles in the aerosol path. 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.	
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.	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.	Clarification of what nominal flow rate means.
Annex 6			
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 to at least 100 particles per cm³ when sampling ambient air and a return to ≤ 0.2 particles per cm³ on replacement of the filter.	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.	The 100 particles/cm3 was removed because it was a random number that does not confirm the proper operation of the PNC and sometime too restrictive for low-ambient backgrounds
Annex 7			
4. Determination of PN (if applicable)	C_b is either the dilution air or the dilution tunnel background particle number concentration, as permitted by the responsible authority, in	C_b is either the dilution air or the dilution tunnel background particle number concentration, as permitted by the responsible authority, in particles	Coincidence correction eliminated

Annex 5	Original text	New text	Justification
	particles per cubic centimetre, corrected for coincidence and to standard conditions (273.15 K (0 °C) and 101.325 kPa);	per cubic centimetre, corrected to standard conditions (273.15 K (0 °C) and 101.325 kPa);	
	C_i is a discrete measurement of particle number concentration in the diluted gas exhaust from the PNC; particles per cm^3 and corrected for coincidence;	C_i is a discrete measurement of particle number concentration in the diluted gas exhaust from the PNC; particles per cm^3;	Coincidence correction eliminated