TA

Technische Anleitung
Technical Instruction
Instruction technique

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PTI by Particle Count PN at Low Idle

VERT recommended procedures and instruments

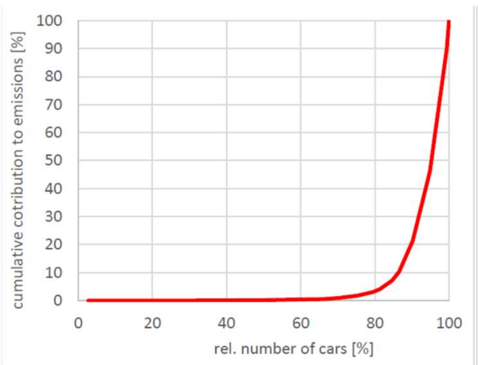
1. Why Periodic Technical Inspection (PTI) for On-road and Non-road Fleets Represents the Fastest Route to Clean Urban Air at Low Cost

To guarantee lifelong emission quality for the all-diesel powered vehicle/machine fleets a hierarchy of control steps are required:

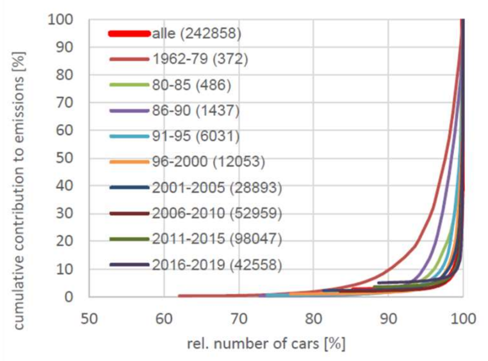
- Homologation guarantees that new vehicle generations comply with updated legislation;
- Conformity of production (COP) guarantees uniformity of the produced technology;
- In Service Conformity (ISC) supervises aging and systematic deteriorating effects;
- Surveillance Monitoring by EU-member states shall ensure impartial monitoring in future.

Today these four principles are respected for the on-road fleet, but they deal only with the systematic deterioration effects arising from the technology used and the established production quality. Further, COP and ISC are neglected worldwide for the non-road fleet, in spite of its high influence on urban air quality.

But what about random failures, maintenance negligence and intentional manipulation, which might have much stronger influence on urban air quality than well controlled systematic deteriorations? Recent vehicle emission history has clearly demonstrated [1] that these statistic and manipulative effects can increase emission levels by several orders of magnitude above limit values and are not necessarily detected by most modern on-board control since even OBD seems to be an easy target for software manipulation.



PN emission at low idle of 1000 diesel vehicles at Zürich 2018 with DPF [2]; 5% emit 80% of total PN



PN at light load of 500‘000 petrol vehicles in Mexico City [3] 2018; in some classes 3 % emit 90% of total PN

This risk of deterioration has become larger with introduction of emission control elements like DPF, DOC and SCR since these tools are expensive to replace giving rise to increased temptation for manipulation [16].

However, since these emission controls are so powerful, putting them on hold or disabling them with defeat devices has a tremendous influence on urban air quality and a small percentage of the fleet can offset overall emissions progress as clearly demonstrated by the “dirty tail” shown in the 2 diagrams above for Diesel and Petrol vehicles.

These statistics tell us, that a few vehicles, maybe 2-3% of the fleet – overaged, damaged, deteriorated or manipulated – are the dominant sources of pollution in a city. Repairing or scrapping such vehicles could reduce the PN pollution and other toxic contaminants in urban air immediately to a very high degree and at a low cost [14].

It is therefore necessary to identify these vehicles and this requires full fleet periodic technical inspection [4].

Why choose PN as the flagship metric for air pollution?

- because it dominates the health risk in urban air;
- because it is the most sensitive criterion, easy to control and monitor and quantify;
- because it characterizes the main emission source: the internal combustion engine.

2. PN Dominates the Health Risk in Urban Air

Health risk of the toxic contaminants in urban air is continuously evaluated by epidemiology:

WHO region	Year	Population ($\times 10^6$)	Mortality attributable to air pollution (deaths $\times 10^3$)						
			$PM_{2.5}$					O_3	Total
			ALRI < 5 yr	IHD ≥ 30 yr	CEV ≥ 30 yr	COPD ≥ 30 yr	LC ≥ 30 yr	COPD ≥ 30 yr	
Africa	2010	809	90	55	77	11	2	2	237
	2050	1,807	158	185	262	38	5	12	660
Americas	2010	930	0	44	8	4	7	5	68
	2050	1,191	0	75	15	7	11	11	119
Eastern Mediterranean	2010	602	56	115	86	12	5	12	286
	2050	1,021	66	321	246	37	13	40	723
Europe	2010	867	1	239	95	13	27	6	381
	2050	886	1	307	156	18	37	11	530
Southeast Asia	2010	1,762	64	327	250	124	15	82	862
	2050	2,332	104	865	807	419	48	227	2,470
Western Pacific	2010	1,812	19	299	794	209	107	35	1,463
	2050	1,861	16	413	1,120	309	155	57	2,070
World	2010	6,783	230	1,079	1,311	374	161	142	3,297
	2050	9,098	346	2,166	2,604	828	270	358	6,572

Contribution of outdoor air pollution sources to premature mortality, updated 2018 [5]
Particulate matter PM2.5 is responsible for >90 % of total mortality attributable to air pollution, mainly by cardiovascular (IHC), cerebrovascular (CEV) disease and lung cancer (LC).

PM2.5 is a mix of all solid and volatile particles with undefined chemical composition, but within this mix, the most dangerous part are solid carcinogenic particles in the size range of 10-500 nm since they can penetrate the alveoli membranes and translocate into the bloodstream. These particles are generated by combustion and the main source in urban air are internal combustion engines. The total mass PM [mg/m^3, mg/kWh] of these tiny particles is extremely low and often below detection limits in modern engines, but the number concentration, a digital definition PN [1/cm^3, 1/kWh] is high and can be measured very precisely even in exceptionally clean engines at low idle conditions.

3. PN is the Most Sensitive Criterion for Emission-Deterioration of ICE

Experience tells us that internal combustion engines (ICE) burning carbon-based fuel and using carbon-based lubricants are forming ultrafine particles (soot) whether they use a diesel- or an otto-cycle, whether they are running four strokes or two strokes, whether they are supercharged or naturally aspirated, whether they are equipped with emission control devices or not, whether they use electronic direct injection or indirect aspiration through a carburettor. No other ICE combustion parameter applies in such a uniform way to detect the beginning of deterioration or damage and nothing else is so sensitive as to indicate this moment earlier than the digital particle number counting method.

In some cases, we may also detect increasing concentrations of gaseous pollutants like NOx, HC, CO or noise or exhaust colour or exhaust odour or vibration but not in such a uniform way and with far less sensitivity.

Just a few examples, which deserve more research to understand the causality in detail:

- Injection problems → PN
- Turbocharger problem →PN
- Valve leakage → PN
- Altitude compensation problem → PN
- Fuel problems → PN
- EGR-problems → PN
- DPF-problem → PN
- Piston, liner or ring wear → PN
- Lube oil quality or filtration → PN
- DOC and SCR-problems → PN

Even more impressive is the enormous spread of particle concentration in these cases:

- a diesel engine with a good DPF will show PN emissions below 1000 $1/cm^{3,}$ but in case of filter matrix damage [16] this number might increase to 10'000'000 $1/cm^3$ and this spread of four orders of magnitude can be detected quite precisely with reliable and cost-effective instruments. While in case of particle filter damage, the effect is easy to understand, in many other more complex cases, detection is just as obvious.
- a good petrol engine, even without a GPF, may have PN emissions below 1000 $1/cm^3$, but some of these engines [3], even equipped with a TWC, may emit as much as 100'000'000 $1/cm^3$.

Our target is to guarantee lifelong emission quality. Hence, we need to detect all non-compliant on-road or in-use vehicles/machines as soon as possible since they are members of the "dirty tail" and must be rejected, flagged for repair or scrapped. And as this VERT standard demonstrates: This decision can be taken in less than 3 minutes in a PTI test centre or by mobile enforcement.

Why PN and not opacity?

- PN is 1000 times more sensitive than opacity and more precise in the quantification;
- PN detects all particles, not only black soot, but also highly toxic ash particles;
- PN can work at low idle speed;
- PN is physically clearly defined;
- PN as a digital value is much easier to handle by mobile enforcement.

4. Testing Procedures

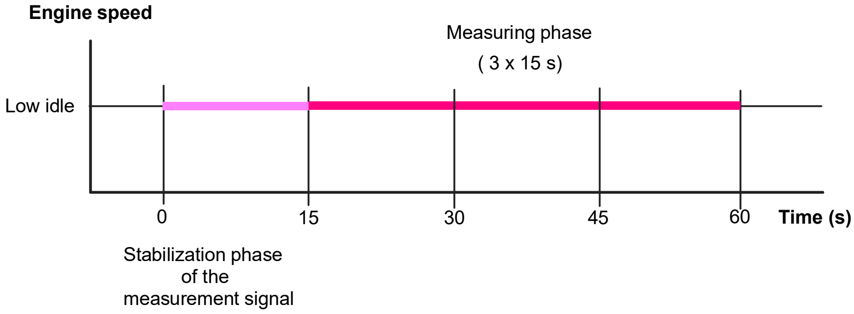
The testing procedure consist of the famous triangle of testing protocol, instrument specification and fail/pass limit values and might be different for different engine or vehicles classes

4.1 Diesel Engines

Various studies, [4, 9,10,17], have shown that measuring the particle number concentration at low idle correlates to the particle emission during the legal homologation test cycle and provides sufficient reliability to determine the filtration quality of the DPF. This simple method allows the detection of even small filter failures due to cracks of the ceramic substrate or leakage in the housing, as well as the larger ones caused by manipulation of the DPF system. This test can be performed within one to three minutes (one for early pass and three after conditioning for definite fail) with cost effective portable instruments. Therefore, after extensive testing of LDV, HDV and non-road vehicles and reviewing published proposals (see References and Appendix) VERT recommends the following ***testing protocol***.

The PTI particle emission test shall consist of measuring the number concentration of solid particles in the size range of 23-200 nm. The engine is started and the sampling line of the PN tester is inserted at least 0.3 meters into the middle of the exhaust pipe or one of the exhaust pipes in such a way to ensure that a representative sample is taken while the engine is idling. After the stabilization phase of the activated tester of 15 seconds, the measurement takes place three times for 15 seconds uninterrupted periods at low idle. The decisive value for the fail/pass assessment is the mean value of the three individual measurement phases.

Source: G.Kadijk, TNO, 2017



The particulate measurement can be performed regardless of the operating state (cold/warm, EGR valve open/closed) of the engine since a diesel engine with a faultless filter usually emits significantly less than 3'000 1/cm^3 at low idle, i.e. much less than what is set as the limit for passing the test (see section 5). There is therefore no need to condition the engine before the test procedure.

In the case the limit value is exceeded, the test can be repeated one time with the engine warmed up (conditioned) and EGR valve closed. The latter is achieved by idling for a few minutes (taxi mode) or by means of the OBD tester [6, 7, 8].

4.2 Gasoline Engines

As early tests indicate, vehicles with gasoline engines can be tested in the same way as diesel engines, but it is recommended to perform the test at a higher engine speed, e.g.: 2000 rpm. However, there is still limited information available regarding the influence of the coolant temperature on the test result, the influence of the higher humidity due to lower excess air and the applicability of the new PTI-PN-instruments, which were primarily developed for Diesel engines.

4.3. Nonroad Machines, Mobile or Stationary

Some of these diesel-powered machines might not have a governor-controlled low idle speed. In this case, any repeatable engine speed can be selected for this test using the lowest possible load.

5. Pass/Fail-Criteria

Criteria to discriminate between ‘pass’ and ‘fail’ must fulfil a number of conditions:

- promote best available technology;
- cannot be more stringent than valid legal limit values defined for test cycles; [9]
- must cover bands of maximum permissible errors of the instruments;
- must cover the differences between unconditioned and thermally conditioned engine;
- must cover the influence of EGR;

In conclusion, this moves rejection limit values to rather high levels but simplifies the test procedure.
In future, these limit values should be lowered by increments as soon as experience allows the adoption of the VERT best available technology principle [10].

The following table gives estimates based on VERT experience on:
- PN levels observed at idle which we expect when the engine & aftertreatment are working well,
- which levels we expect to see when we are exposed to failures or manipulation
- which PN limits we recommend flagging an engine for maintenance.

Numbers are particle count per cm^3	Well maintained	Technical failure or manipulation	**Needs maintenance**	Comments
Diesel LDV + HDV with DPF	3’000	>1’000’000	**50’000**	Measured at low idle
Diesel LDV Without DPF	100’000	>1’000’000	**250’000**	Measured at low idle
Petrol PFI LDV with GPF	3’000	>1’000’000	**50’000**	Measured at elevated idle
Petrol DI LDV With GPF	5’000	>10’000’000	**50’000**	Measured at elevated idle
Petrol DI LDV without GPF	100’000	>10’000’000	**250’000**	Measured at elevated idle
Non-road & Construction Diesel / DPF	1’000	10’000’000	**50’000**	Measured at low idle
Non-road incl. handheld Petrol 4S & 2S	?	?	**?**	No experimental data available yet
Stationary Diesel with DPF	3’000	10’000’000	**50’000**	at low load at any reproducible speed

For diesel engines, this table clearly demonstrates the high filtration quality of modern particle filters under all operating conditions including low idle and it also shows the exceedingly high level of raw emissions. These numbers are supported by large fleet testing campaigns in reference [2] and Swiss non-road experience. Given the excellent measurement capability of available instrument technology, a rejection limit value of 100’000 1/cm^3 may seems high, but we also have to consider Euro 6 legal limit values and statistical variation in order to simplify the testing protocol [10]. The values for flagging maintenance must be lower, where we recommend a number concentration of 50’000 1/cm^3.

For petrol engines our experience is currently more limited and review of ongoing large VERT trials in 2021 might lead to corrections. However, available experience [3], clearly demonstrates that these petrol fleets have very pronounced “dirty tails”, where the application of a simple PTI using PN measurement could immediately improve the average fleet quality and, with this, the air pollution in metropolitan areas.

For small engines, including 4S and 2S handheld engines, we also have a challenge to improve emissions, but there is no experimental data available which would allow the introduction of a similar PTI procedure. There is a need for research.

6. VERT PN-PTI Recommendation

Performance requirements of PN measurement instruments have already been defined by several metrology institutions and in some countries [6, 11, 12]. The columns in the table in Annex show existing definitions and requirements. VERT has organised these into classes that can be certified. The lower the number the more stringent the requirements typically are. Classes 0 and 00 are shown for information and represent the expected requirements for post EURO VI/6 and the requirements for PMP, respectively. Class 1 on next page shows the recommended requirements that VERT sees for leading the way into a less polluted future.

This classification will help stakeholders to define or select measurement instruments which are suitable for the current and future air quality improvement goals. The aim is to achieve uniform PN-PTI regulations across Europe or even globally with sufficient flexibility in selecting appropriate limit values and corresponding instrument classes while regulatory text could be harmonized and adopted by the majority.

VERT also encourages EU-member states to promote mutual recognition of certification tests conducted by individual National Meteorological Institutes so that instruments certified against lower instrument classes are accepted in markets and applications which require the same or less stringent limit values.

VERT recommendation for PTI-PN instruments for Diesel

Regulation	VERT (1) Recommended 2021
Limit Value	50‘000 1/cm³
Fast Pass	30‘000 1/cm³
Fuels	all carbon- based
Vehicle Classes	all vehicles with ICE
Test Type	low idle
Test Duration	3 x 15 s sampling
PN-Range	3’000 ÷ 1’000’000 1/cm³
Max. Permissible Errors	
Error at Type approval	25% / 5‘000 1/cm³
Error at Annual Calibration	50% / 10‘000 1/cm³
Particle Sizes	23 ÷ 200 nm
Counting Efficiency	
at 10 nm	-
at 23 nm	0.2 ÷ 0.6
at 50 nm	0.6 ÷ 1.3
at 80 nm	0.7 ÷ 1.3
at 200 nm	< 2
VPR-Efficiency (Tetracontan >5’000**)**	> 0.95
General Daily Checks:	
Zero PN	yes
Ambient PN	yes
Humidity	no
Drift	No
Additional Requirements	
Vehicle and Workshop Test see 7.	yes
Calibration	annual
Shock & Vibration	M2
IP class	open location

7. VERT Approval Procedure and Certification for PTI Instruments

VERT offers to approve all instruments which fulfil the criteria outlined in chapter 6 of this TA-24/21.
In order to obtain VERT certification and be listed in the respective category in the VERT filter list the instrument manufacturer has to provide the test data which he has received during a type-approval process performed by one of the VERT accredited metrology laboratories.

In addition, VERT might ask for demonstration of practical experience in typical garage environments on vehicles and for proof of repeated calibration cycles.

This approval procedure should not take longer than 3 month and must be repeated every 5 years with documentation on failure statistics and technical modifications compared to the first VERT approval.

8. First Steps of NPTI Introduction

- PN-measurement for non-road PTI regulation in Switzerland 2012; [7, 11]
- NPTI regulation for diesel vehicles in the Netherlands January 2021; [6, 12]
- NPTI regulation for diesel vehicles in Belgium March 2021;
- EU 2014/45 Announcement of the Commission 2.Oct. 2020 to include PTI by PN; [15]
- PN PTI regulation in Germany announced Jan.2017 to be introduced January 1. 2023; [18]
- PN PTI regulation announced in the legislation of Chile 2019, EU-notified;
- PN PTI regulation announced in the legislation of Columbia 2019.

9. Concluding Remarks

VERT's commitment is to the application of best available technology for emission mitigation of internal combustion engines. VERT supports the development of cleaner engines, the improvement of after-treatment with respect to PN, NOx, HC, CO, CO2 and secondary emissions and on-board emission control technology. Based on the last two decade's experience with these systems VERT emphasizes the worldwide need for PTI with particular focus on controlling PN emissions at low idle speed.

Our final goal is clean air in urban environments. With the implementation of proper PTI using the principles outlined in this VERT-TA-024/21, the in-service fleet can be cleaned of high emitters at low cost and we are not aware of any other available method that can clean urban air as quickly and efficiently.

Cleaning nanoparticles from the air not only reduces PM 2.5, the pollutant most affecting our health in the air we breathe and the second most important substance affecting global warming after CO_2, but also effectively reduces secondary organic aerosols and haze caused by condensation in the presence of ultrafine particles providing condensation cores [13].

10. Abbreviations

$1/cm^3$	Particle concentration: particles per cubic centimeter
2S / 4S	Two stroke, four stroke Internal combustion engines
CE	Counting efficiency
CEV	Cerebrovascular disease
CH	Confoederatio Helvetica = Switzerland
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Conformity of production
DI	Direct injection
DOC	Diesel oxidation catalyst
DPF	Diesel particle filter
EGR	Exhaust gas recirculation
EMI	Electromagnetic interference
GPF	Gasoline particle filter
HC	Hydrocarbons
HDV	Heavy duty vehicle
ICE	Internal combustion engines
IHC	Ischaemic heat disease
ISC	In service conformity
LC	Lung cancer
LDV	Light duty vehicle
nm	Nanometer = 10^{-9}m
NMI	Netherlands Metrology Institute
NOx	Nitrogen oxides NO+ NO_2
NRMM	Nonroad Mobile Machines (e.g construction)
OBD	On board diagnosis
PFI	Port fuel injection
PMP	Particle measurement program
PTB	Physikalisch-Technische Bundesanstalt
PM2.5	Particulate matter below 2.5 micrometer
PN	Particle number concentration; particle count
PTI	Periodic technical inspection
RDE	Real driving emission
RH	Relative Humidity
R^2	Error square
SCR	Selective catalytic reaction / reactor
TBD	to be determined
TWC	Three-way catalyst
VAMV	Swiss ordinance on exhaust gas analysers
VERT	Verification of emission reduction technology; Association VERT
VPR	Volatile particle remover

11. References

[1] Koch-Gröber, H. Das Diesel Dilemma – Verantwortungen und Perspektiven; ZfU 1/2020 41-66

[2] Gloor B, AWEL: Survey about functional efficiency of DPF PTI in Zurich, VERT-Forum 2018

[3] Dominguez C., Cureño I. / GESPA, Mexico; Measurement of Particle number (PN) emissions in Mexico City's vehicles inspection process; VERT Web Conference High Polluters 10. November 2020; www.vert-certification.eu

[4] Kadijk, G., TNO: New Periodic Technical Inspection: Concept for DPF Proven and Ready to Introduce, 22.ETH-NPC 2018

[5] Lelieveld et al.; The contribution of outdoor air pollution sources to premature mortality; Nature 17.Sept.2015

[6] NL PN Instrument Specification published 28.06.2019 by the Metrological Institute of the Netherland NMI "particle number counter: instruments for measuring vehicle exhaust particulate number emissions"

[7] Luftreinhaltung auf Baustellen – Baurichtlinie Luft, Stand 10.Februar 2015, BAFU, Switzerland

[8] Reinoso, A.: Santiago de Chile Experience with Respect to Inspection and Maintenance Using Particle Number Measurements, ETH-NPC 2017

[9] Giesachskiel B, Suarez R. et al /EU-JRC: Comparison of Laboratory and On–Road Type Approval Cycles with Idling Emissions. Implication of Periodical Technical Inspection (PTI); Sensors 2020, 20,5790

[10] Burtscher H., Lutz Th., Mayer A. / VERT; NPTI: A new periodic technical inspection for particle emissions of vehicles, ECST-D-19-00019

[11] VAMV: Ordinance of the FDJP on Exhaust Gas Analysers; Amendment 22.August 2012, Bern; SR 941.210

[12] Staatscourant van het Koninkrijk der Nederlanden; 22.11.2019 „Regeling von de Minister voor Milieu en Wonen van 21. November 2019, Nr. IENW/BSK-2019/202498, tot wijziging van de Regeling voertuigen om comtrole van roetfilters met een deeltjesteller mogelijk to maken en een aantal overige techische wijzigingen door to voeren.

[13] Seippenbusch M., Kasper G. /KTI; Temporal Evolution of Nanoparticle Aerosols in Workplace Exposure; Occ.Hygiene, pp.1-10 June 2008

[14] Beinschub M., Schriefl M./AVL-DiTEST, Bergmann A. / Uni Graz: Particle number measurement within periodic technical inspections: A first quantitative assessment of the influence of size distributions and the fleet emission reduction; Atmospheric Environment 8/2020

[15] EN E-004320/2020; EU-Parlamentary Question on "effectiveness of periodic vehicles roadworthiness tests for the detection of soot filter tempering", 22.July 2020 and Answer of the Commission, 2.October 2020.

[16] Bémer et al, / INRS; Performance of a Diesel Particle Filter Damaged by Drilling Holes in the Filter Walls to simulate Internal Micro-Cracks; ECST(2020) 6

[17] Giechaskiel B., et al, JRC,Ispra: Assessment of 10 nm Particle Number (PN) Portable Emissions Measurement Systems (PEMS) for Future Regulations; ESC 2020-06-15

[18] PTB-Anforderungen an Messgrössen im öffentlichen Verkehr und Partikelzähler; Draft 03.05.2021

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The VERT Association publishes on its web site information on the topic of particle filter retrofitting. The site also has a comprehensive database of already retrofitted vehicles and machines. The VERT Filter List documents the certified filter systems and their manufacturer: www.VERT-certification.eu

The PDF version of this publication can be downloaded at www.VERT-certification.eu

Annex: Classification of PTI instruments

Regulation	**Switzerland (4)** VAMV [11]	**Netherlands (3)** BSK-2019/202498 [12]	**Germany (2)** PTB-A [18]	**VERT (1) Global** Recommended 2021	**Post Euro 6 EU (0)** 2014/45 update [17]	**EU-PMP (00)** Equivalent PTI test [9]
Limit Value	250'000 1/cm³	1'000'000 1/cm³	250'000 1/cm³	50'000 1/cm³	50'000 1/cm³	n/a
Fast Pass	-	-	50'000 1/cm³	30'000 1/cm³	-	
Fuels	Diesel	Diesel	Diesel	all carbon- based	all carbon based	all carbon based
Vehicle Classes	NRMM w. DPF	Euro (4) + 5 + 6	Euro 6 / VI	all vehicles with ICE	Euro 6/VI	Euro 6/VI + 7/VII
Test Type	high idle	low idle	low idle	low idle	low idle	TBD
Test Duration	3 x 5 s sampling	15 s sampling	3 x 35 s sampling	3 x 15 s sampling	TBD	approx. 5 min
PN-Range	50'000 ÷ 5'000'000 1/cm³	5'000 ÷ 5'000'000 1/cm³	5'000 ÷ 500'000 1/cm³	3'000 ÷ 1'500'000 1/cm³	0 ÷ 500'000 1/cm³	0 ÷ 500'000 1/cm³
Max. Permissible Errors						
Error at Type approval	-	25% / 25'000 1/cm³	25% / 5'000 1/cm³	25% / 5'000 1/cm³	25% / 2'000 1/cm³	10% / 1'000 1/cm³
Error at Annual Calibration	-	25% / 25'000 1/cm³	75%/ 10'000 1/cm³	50% /10'000 1/cm³	<50% / 5'000 1/cm³	(0.2-0.5)
Particle Sizes	23 ÷ 300 nm	23 ÷ 200 nm	23 ÷ 200 nm	23 ÷ 200 nm	10 ÷ 200 nm	(10) 23 ÷ 200 nm
Counting Efficiency Not all size classes mentioned See references						
at 10 nm	-	-	-	-	0.2 ÷ 0.5	
at 23 nm	<0.5	0.2 ÷ 0.6	0.2 ÷ 0.6	0.2 ÷ 0.6	-	(0.55 ÷ 0.85) 0.38 ÷ 0.62
at 50 nm	-	0.6 ÷ 1.3	0.6 ÷ 1.3	0.6 ÷ 1.3	0.85 ÷ 1.15	(0.9 ÷ 1.1) 0.75 ÷ 1.05
at 80 nm	0.7 ÷ 1.3	0.7 ÷ 1.3	-	0.7 ÷ 1.3	0.85 ÷ 1.15	0.9 ÷ 1.1
at 200 nm	<3	-	0.5 ÷ 2.0	< 2	0.85 ÷ 1.15	0.9 ÷ 1.1
VPR-Efficiency (Tetracont. >5'000**)**	> 0.95	> 0.95	> 0.90	> 0.95	> 0.98	> 0.99
General Daily Checks:						
Zero PN	-	✓	✓	✓	✓	✓
Ambient PN	-	-	optional	✓	✓	✓
Sample RH measurement	-	-	-	-	✓	✓
Drift	-	✓	-	-	✓	✓
Additional Requirements						
Vehicle and Workshop Test see 7.				✓		
Shock & Vibration	M2	M2 /M3 (portable)	M2/M3 (portable)	M2	M2/M3 (portable)	M2
IP class	open location	open location	IP 54	open location	IP 54	TBD