

CITA Workshop Brussels 6.November 2019

**N-PTI**

# **New Particle Number Measurement for Vehicle Inspection**

*Result of an International Task Force  
a powerful, dedicated group  
2016-2019*

**Andreas Mayer/VERT**

G.Kadijk / TNO, L. Zuidgeesst/NL, H.Burtscher /FHNW, T.Lutz/ ETH, V.Hensel/VERT et al.

# Why Emission Aftertreatment?

Modern «electronic» Engines have improved efficiency ( $\text{CO}_2$ ) ,  
but Emissions PN and  $\text{NO}_x$  are still as high as before

Petrol engines are high emitters and were only cleaned by the **3WC**  
– John J. Mooney 1970 – still they emit high PN and the 3WC let PN  
pass – **GPF** is needed

Diesel engines need **DPF** to «eliminate» PM/PN-emissions from fuel,  
lubrication oil and wear.

Diesel Engines also need oxidation catalysis **DOC** to eliminate PAH,  
Nitro PAH and other highly toxic substances

Diesel engines need **DeNO<sub>x</sub>** to reduce  $\text{NO}_2$  and  $\text{NO}$  → SCR+

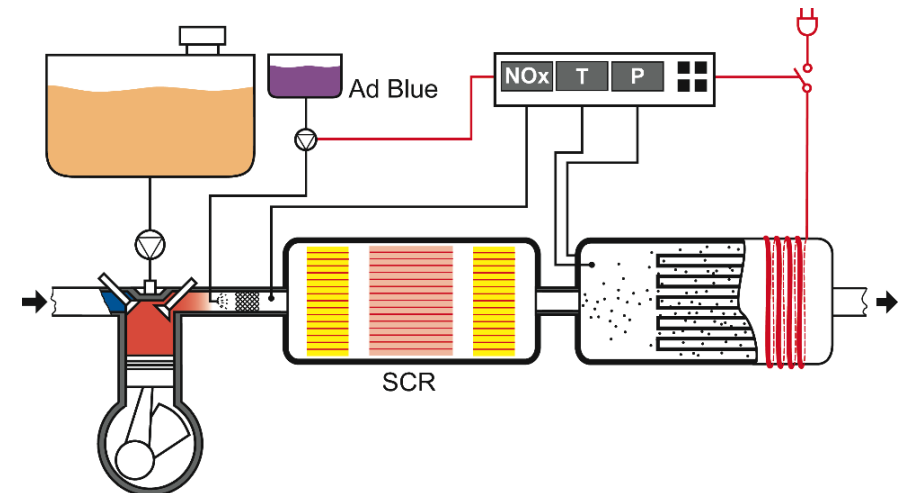
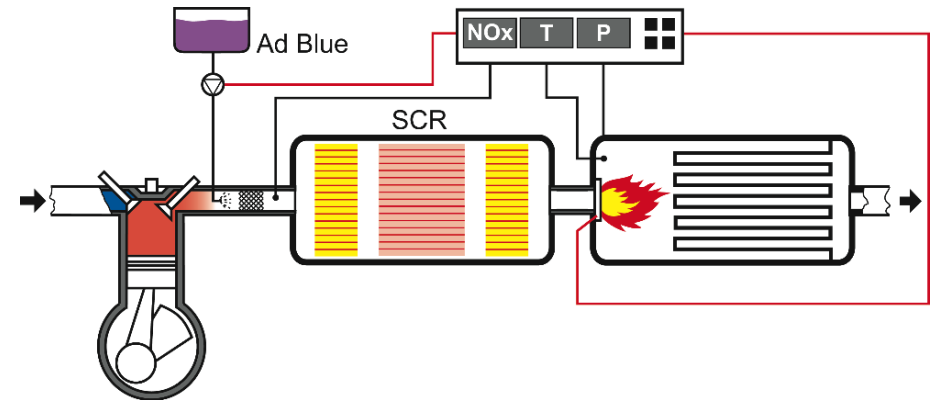
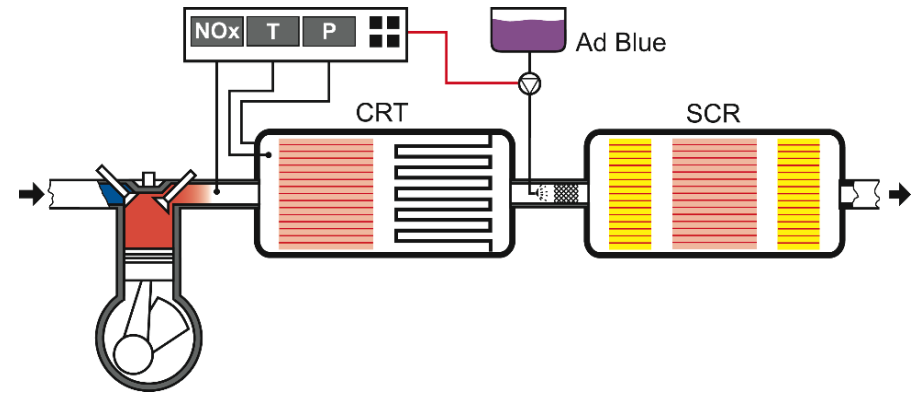
Modern Engines have ideally **de-coupled** functions:

- The Engine operates at best Performance for  $\text{CO}_2$
- Aftertreatment EAC detoxifies perfectly the Exhaust Gas

# Emission Control by aftertreatment is indispensable

- very efficient > 99%
- but no plug and play
- depend on operation profile
- risk of wear, aging and poisoning, pollution
- **risk of tampering with and manipulation by manufacturer and operator**

→ ***Control is required***

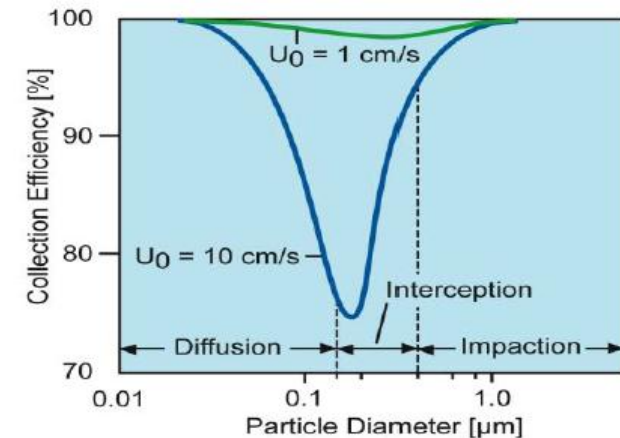
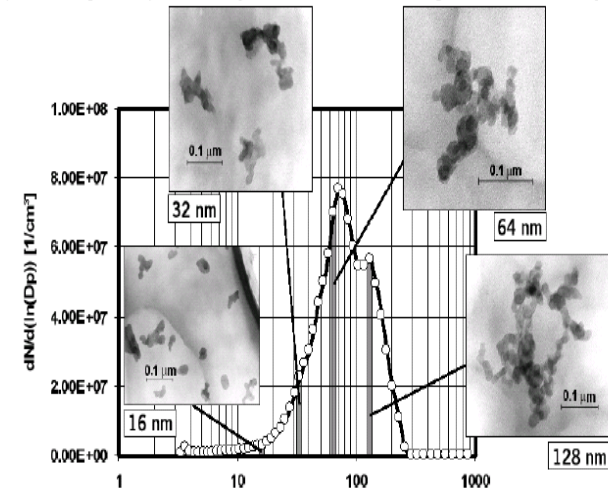
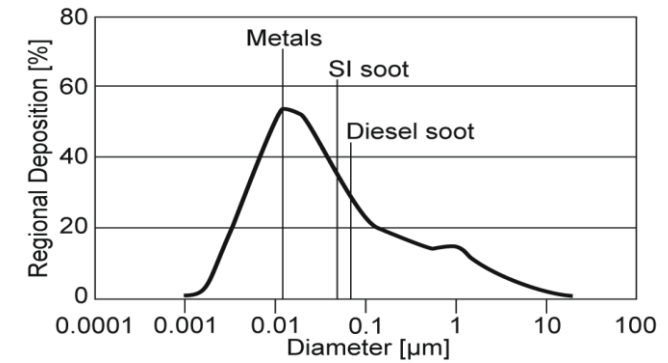


# Why Particle Number and Particle Size?

PN counting is the only method sensitive and accurate enough in the nanometer size range to control filter quality

We are confronted to a very strange coincidence:

*The most sensitive size range of the Lungs is the most intensive emission range of the Engines and the weakest size range of Filtration*



# Size Distribution must be respected

## Diesel

Sootpeak: 80 nm;  $10^6$  P/cc

Ashpeak: 10 nm;  $10^7$  P/cc

## Petrol

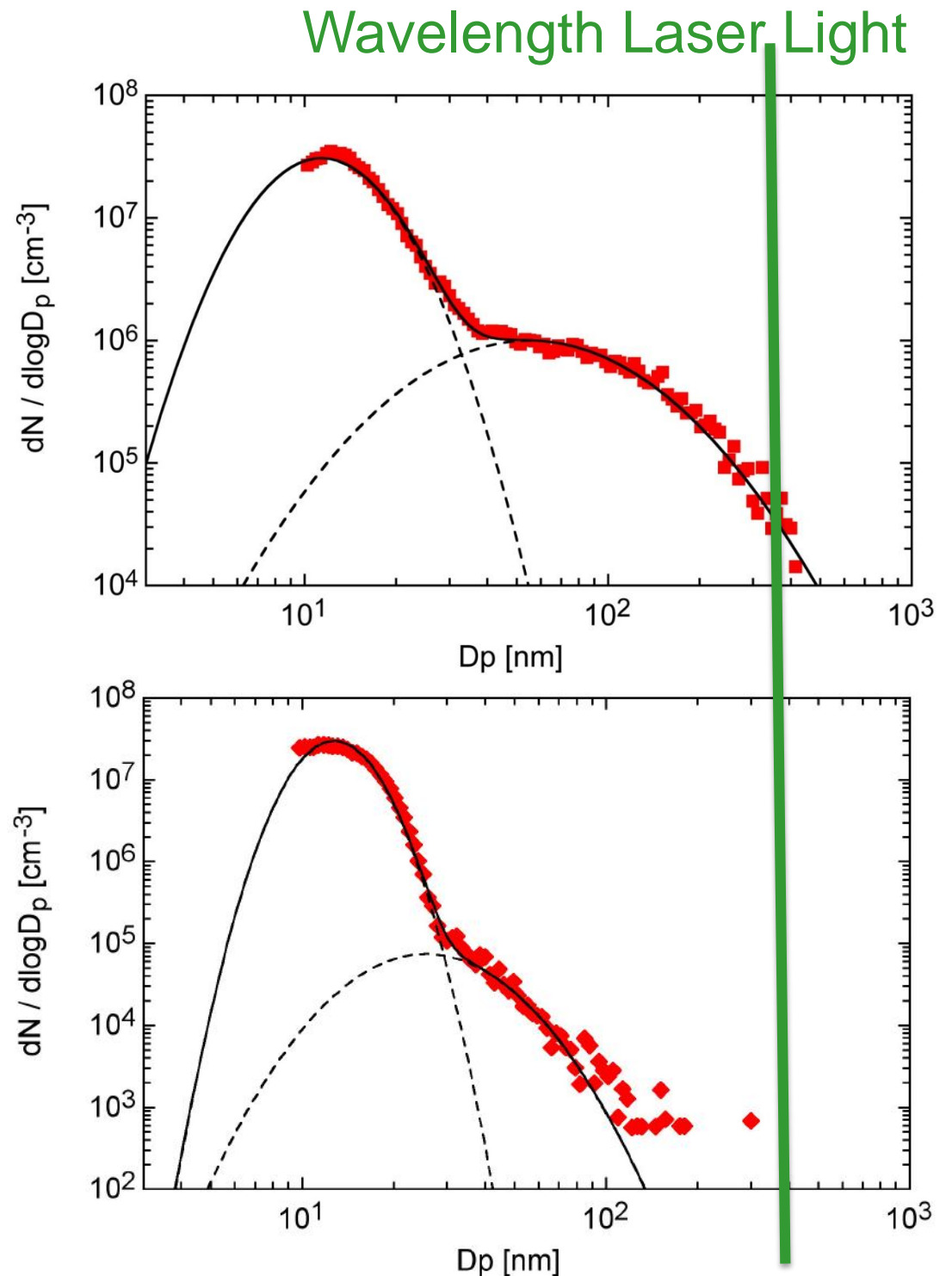
Sootpeak: 40 nm;  $10^5$  P/cc

Ashpeak: 10 nm;  $10^7$  P/cc

Leight absorption prop  $D^4$

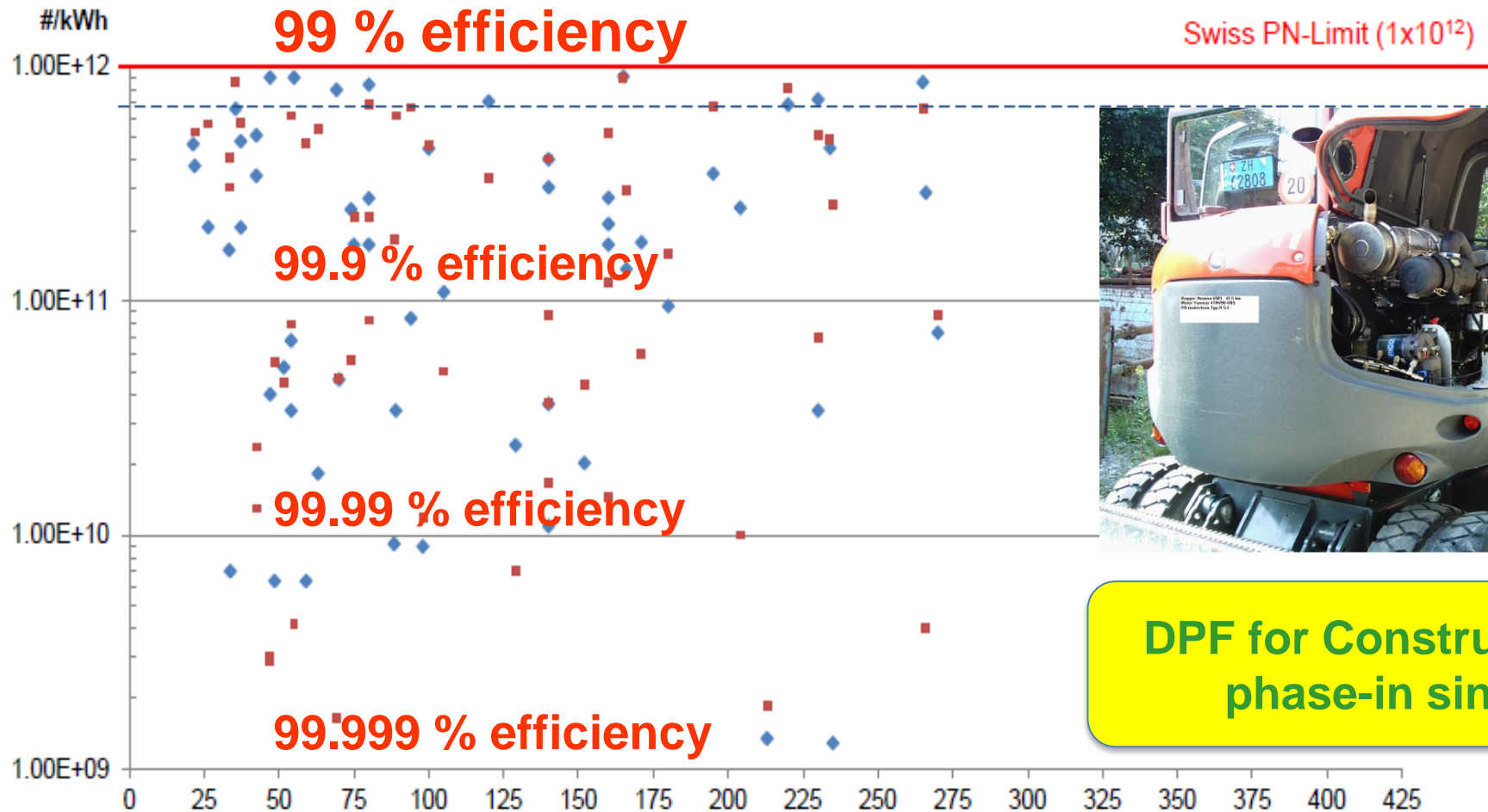
Leight dispersion prop.  $D^5$

Raleigh scattering prop  $D^6$





# PN-Test results



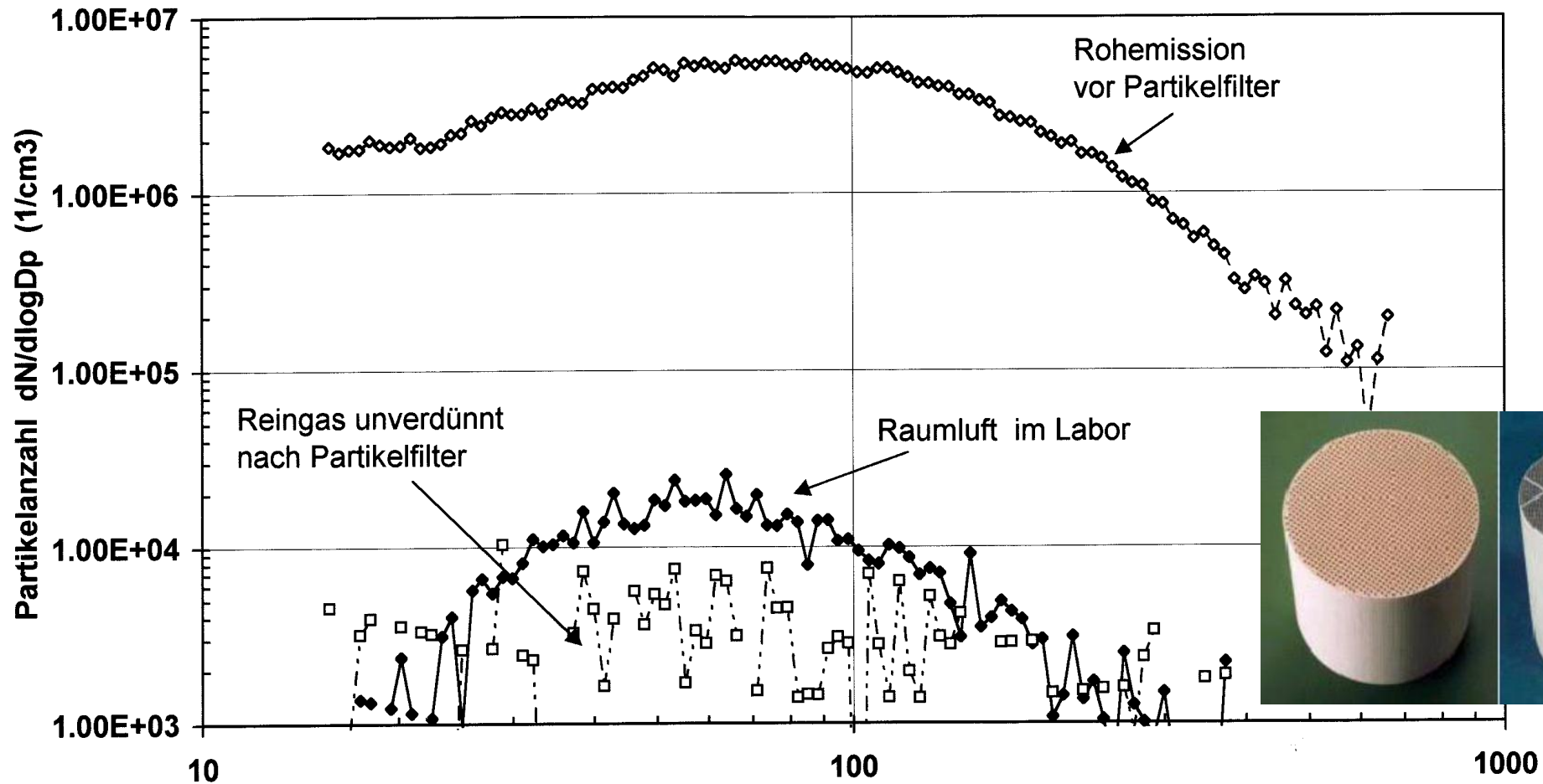
**DPF for Construction in CH  
phase-in since 1998**

Type approval of imported construction machines in stationary and transient cycle  
In function of engine power [kW]

DPF Technology permits limit strengthening by one order of magnitude

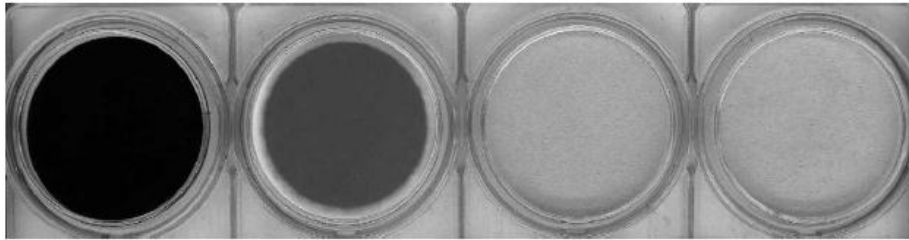


# Exhaust Gas cleaner than Ambient Air

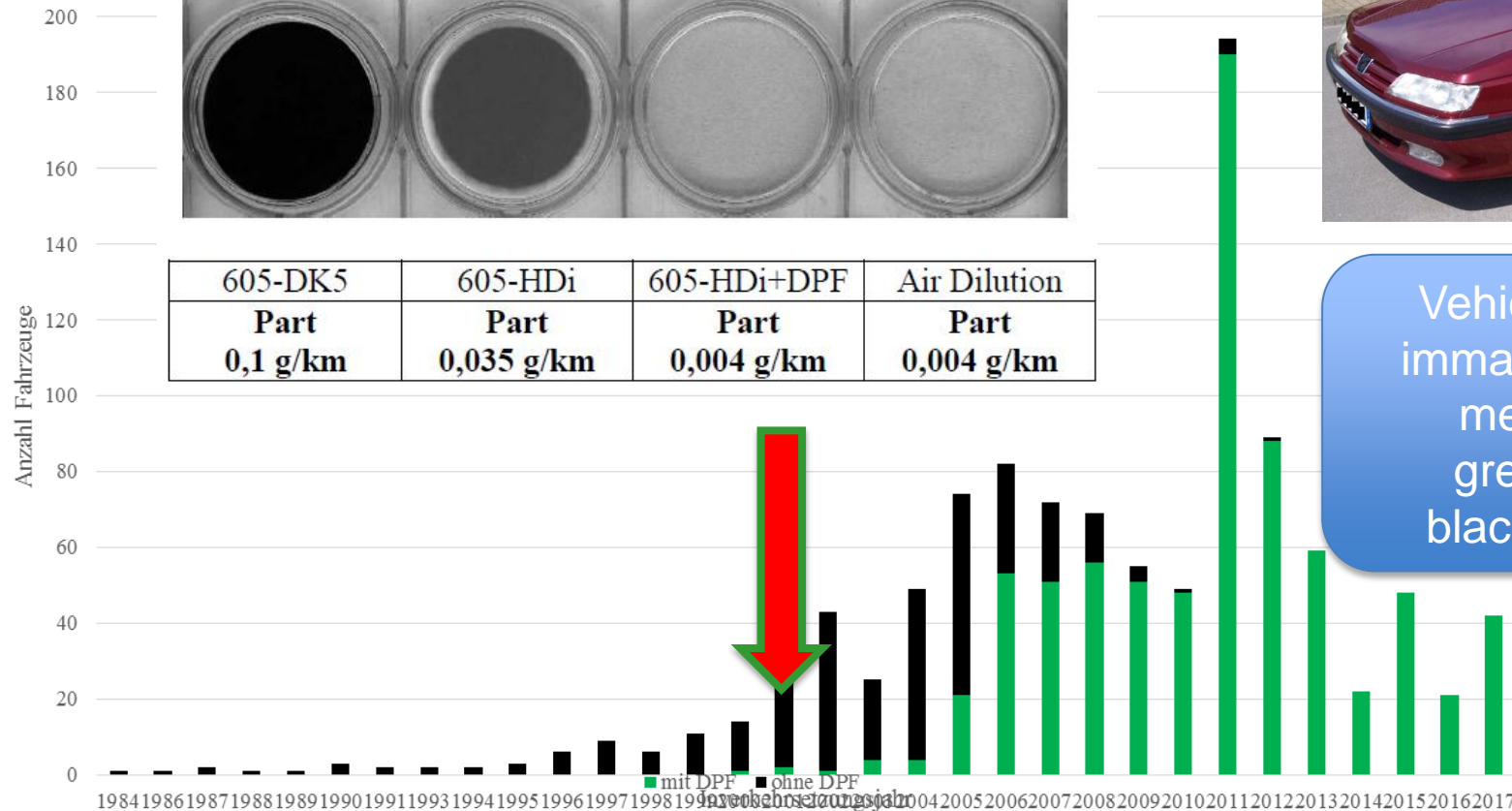


# Introduction of DPF in LDV started in Switzerland Y 2000

## Peugeot 605 FAP rollout May 2000



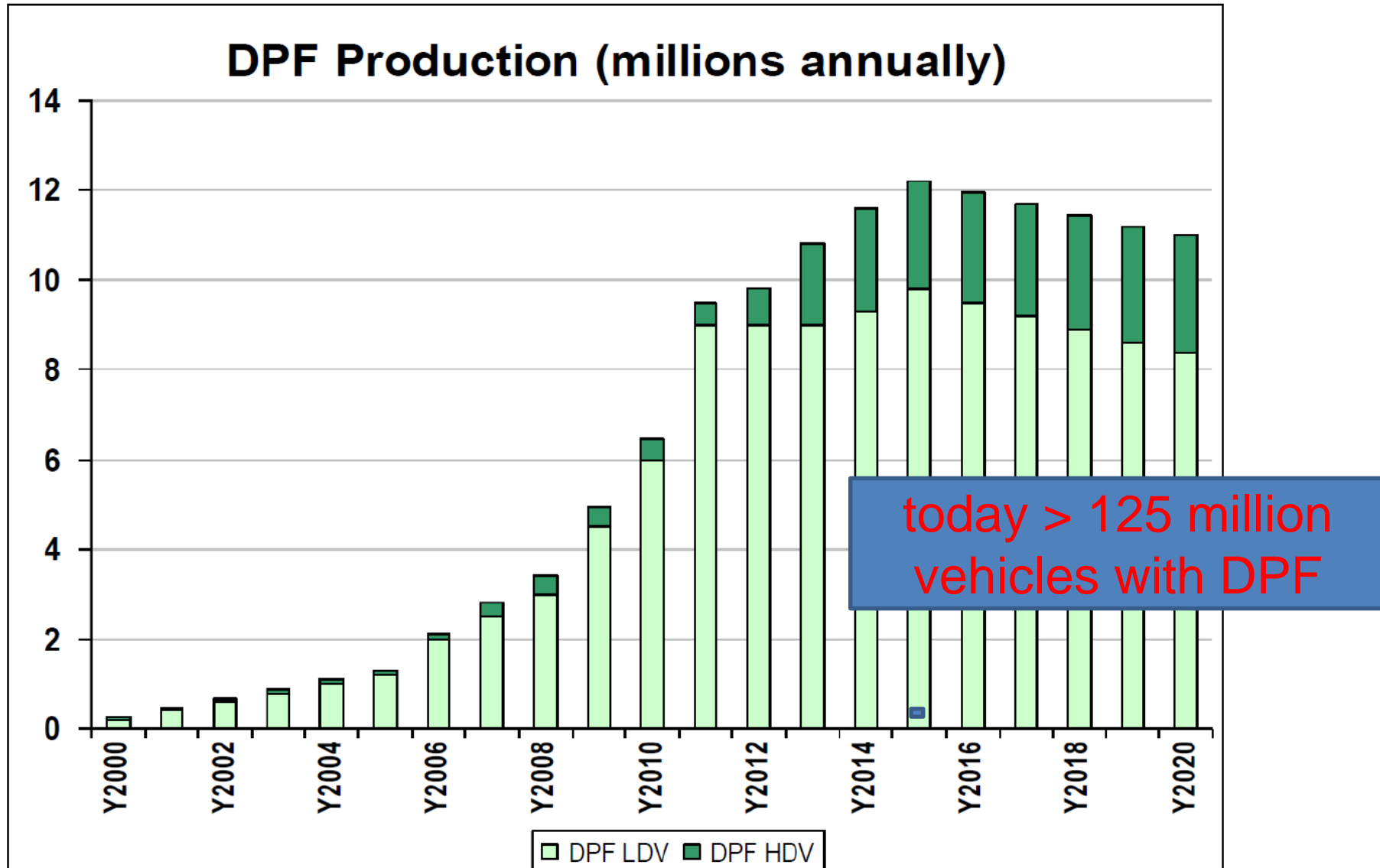
605-DK5	605-HDi	605-HDi+DPF	Air Dilution
Part 0,1 g/km	Part 0,035 g/km	Part 0,004 g/km	Part 0,004 g/km



Vehicles of different  
immatriculation years  
measured 2017  
green: with DPF  
black: without DPF

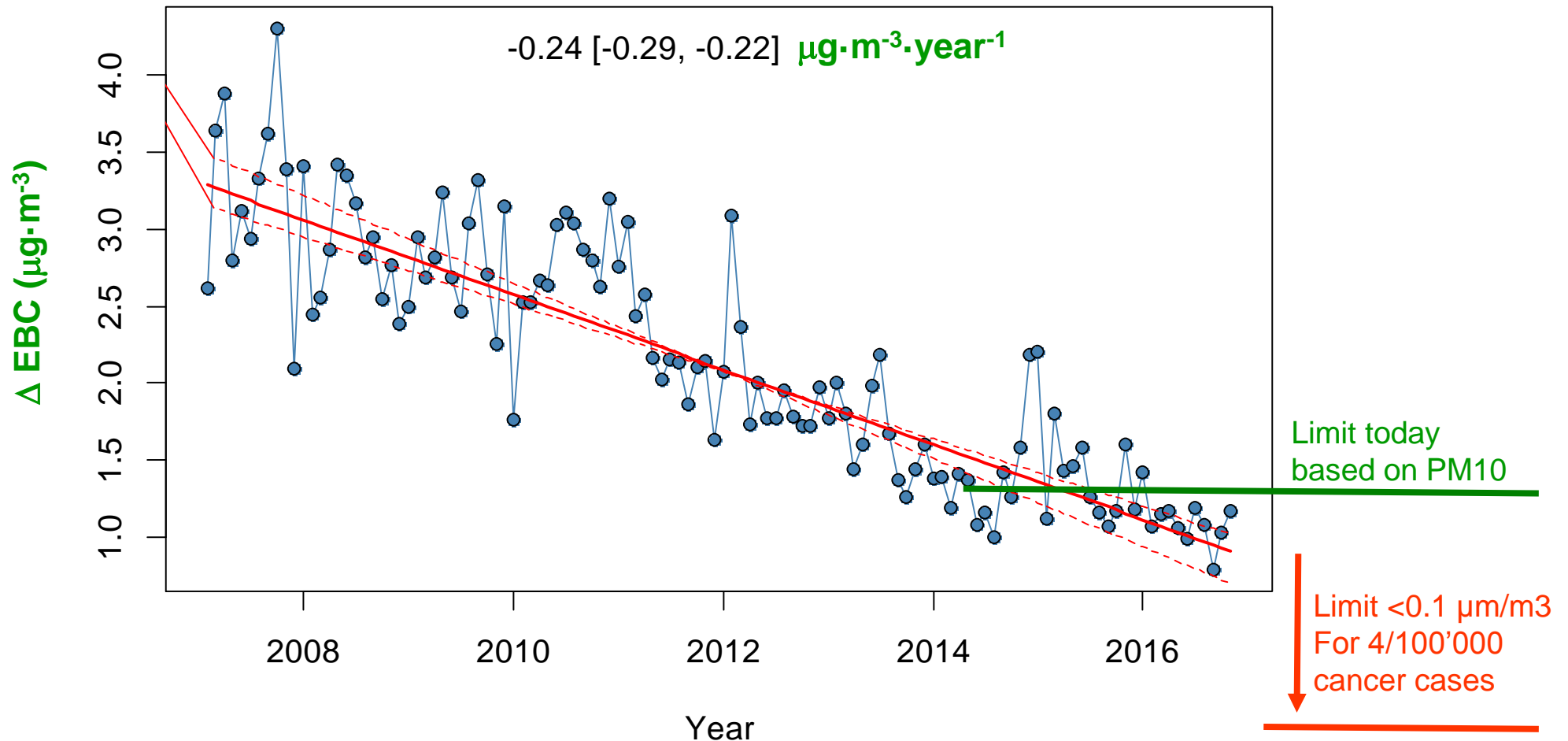


# DPF-Installations in Europe



# and the Result: Cleaning the Air by DPF in Switzerland

Monitoring BC at the motorway crossing Härkingen

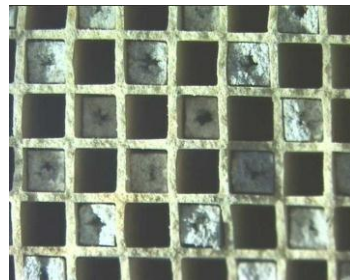
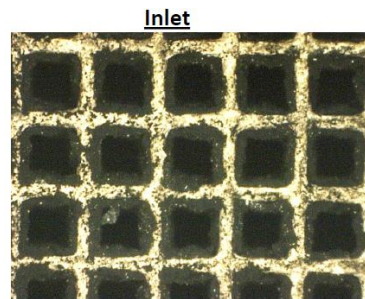


*with Emission Aftertreatment EAS  
we have reached*

**Orders of Magnitude  
of Emission Reduction  
to improve public health**

*but at the same time we are facing  
a high risk for Emission Stability  
due to serious flaws in Legislation  
Implementation and Enforcement*

# and this is what we are finding – why?



because they want to avoid cost  
for proper repair or cleaning



# Biggest Mistake of EU-Policy:

***Control „delegated“ to OBD***

**invited car makers to fraudulent hard- and software**

## Quality Control ideal

- **Type Approval**
- **COP** Conformity of Production
- **IUC** In Use Compliance
- **PTI** Periodic Techn. Inspection

## EU Quality Control

- **Type Approval**
- **COP**
- **IUC not implemented**
- **PTI abandoned (CH:2012)**

Based on EU 2014/45 for all vehicles with OBD

**Control for Public Health must be independent**

Montesquieu: De l'esprit des lois 1748 → la séparation des pouvoirs

# VERT at Expert Hearing Bundestag 5 PUA Berlin 22. Sept. 2016 on Dieselgate

→ **This must be reversed and Emission PTI must become EU-Regulation**  
and here is our recommendation to the German government 9/2016

## Beitrag zur Sachverständigenanhörung des 5.PUA (18/8273, 8932)

zur Frage erhöhter Schadstoffemissionen und Verbräuche von Fahrzeugmotoren durch Manipulation der elektronischen Motorsteuerung durch Hersteller und Betreiber, ungeeigneter Emissionsmessung, unzureichender Gesetzgebung und mangelhaften Vollzugs am 22.9.2016 in Berlin, Paul-Löbe-Haus, Sitzungssaal E 700

Deutscher Bundestag  
5. Untersuchungsausschuss  
der 18. Wahlperiode

Ausschussdrucksache  
18(31)38

## Emissionsstabilität von Fahrzeugmotoren

Der einzig sichere Weg zur Emissionsstabilität bestverfügbarer Abgastechnologie ist die flächendeckende unabhängige periodische Kontrolle nach einem neuen Testprotokoll

→ **Germany Road Authority reacted immediately by re-activation of AU January 2017**



# Swiss Ordinance for PN-PTI for offroad machines with DPF 2012

**Ordinance of the FDJP  
on Exhaust Gas Analysers  
(VAMV)**

Amendment of 22nd august 2012

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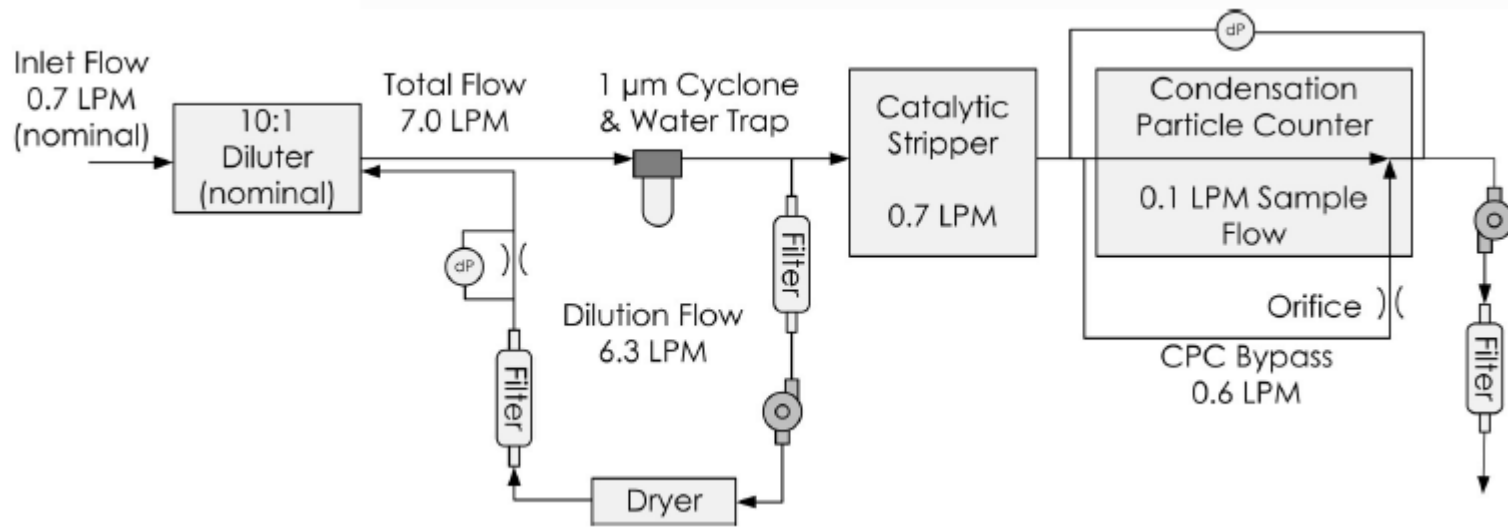
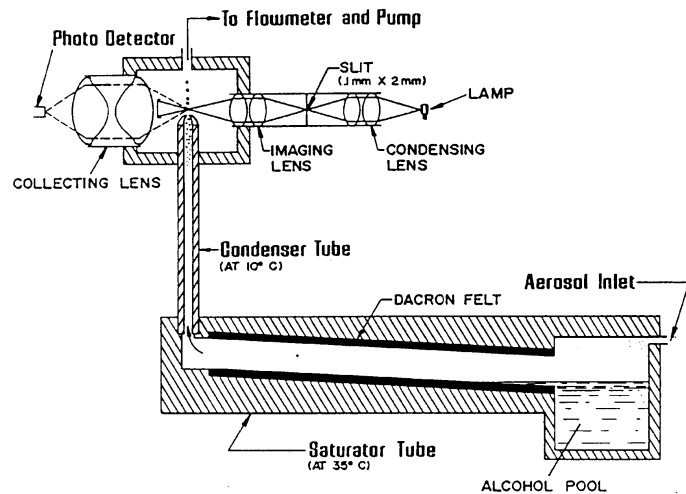
*The Federal Department of Justice and Police  
hereby decrees:*

## **B Measurement requirements**

### **1 Measurement range**

- 1.1 The measurement range for the nanoparticle number concentration is at least between  $5 \times 10^4 \text{ cm}^{-3}$  and  $5 \times 10^6 \text{ cm}^{-3}$ .
- 1.2 In case of measured values outside the measurement range, the measuring instrument must indicate whether the measured value lies below or above the measurement range. If no categorisation is possible, then no value should be displayed.
- 1.3 The particle number concentration of each measurement must be indicated at the ambient conditions.

# NPET / TSI – first METAS-certified PTI instrument for Swiss construction machines



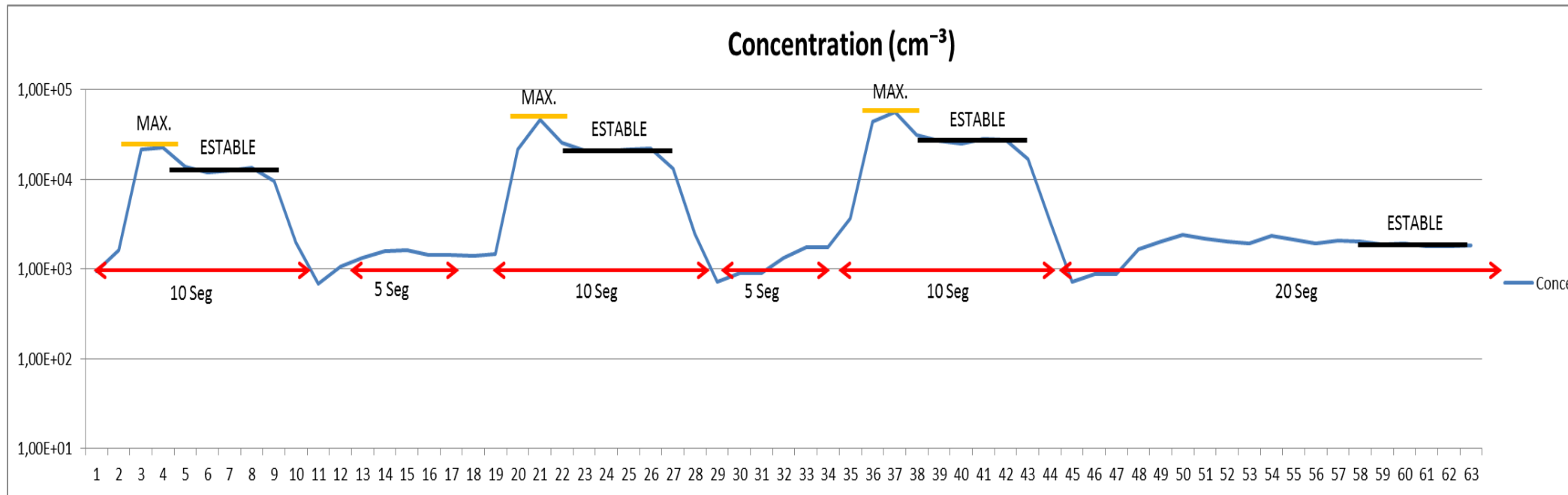
# Start 2015 with VERT- SANTIAGO

## Measurement Protocol Roadside

### Opacity and PN at exhaust exit

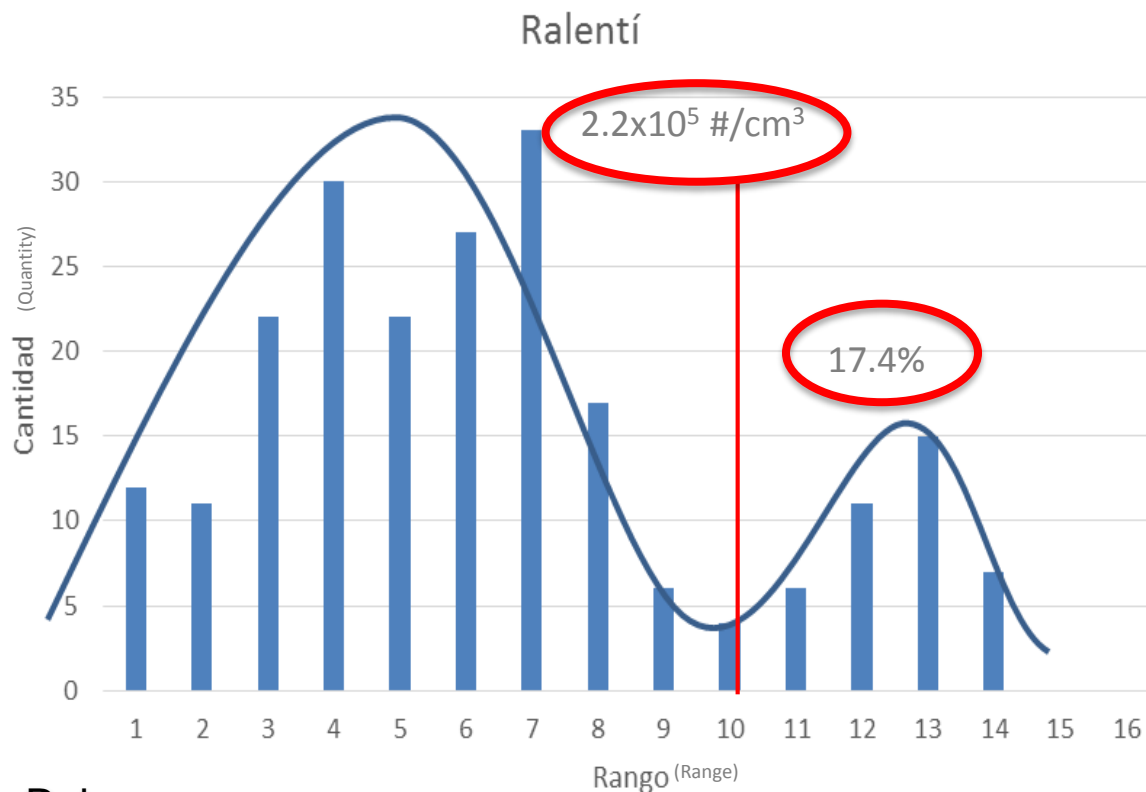
### during free acceleration, high idle and low idle

### 2015 - 400 vehicles



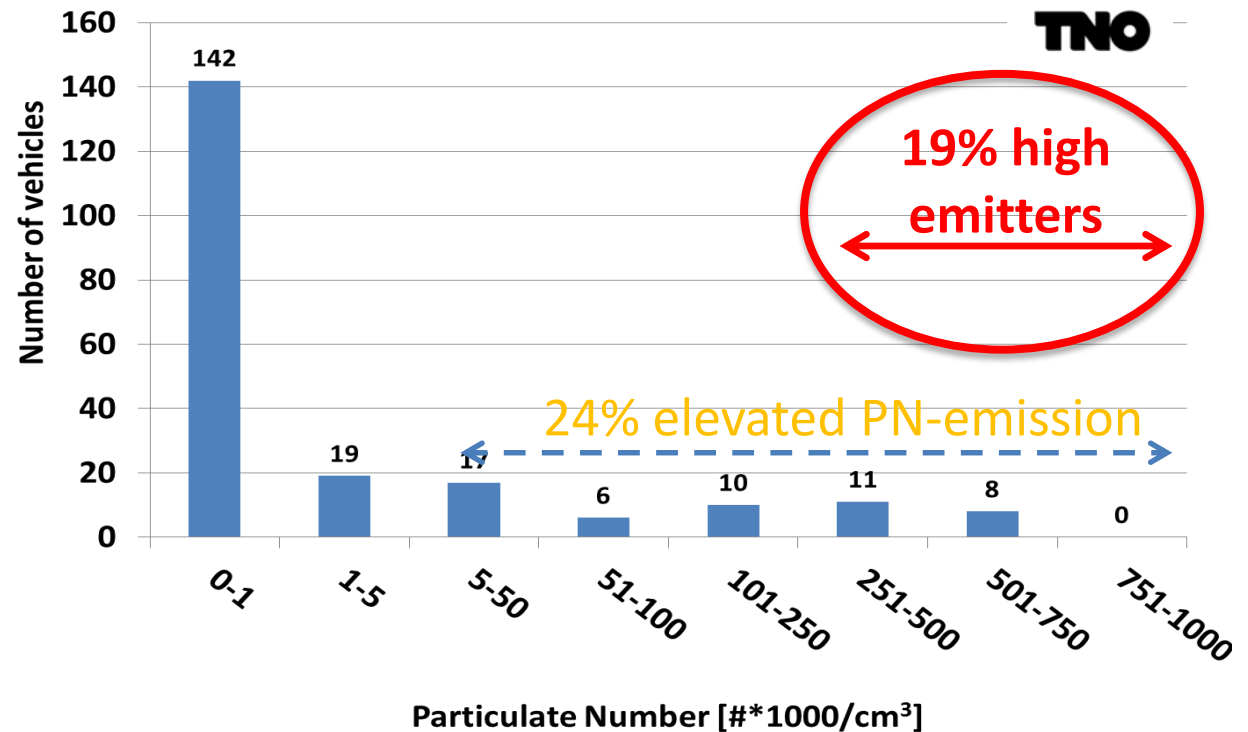
# VERT in Santiago de Chile 2015

Quality Control of 400 DPF buses retrofitted 8 years ago  
stopped by police at roadside  
PN measurement by TSI NPET



Range	≥	<	N	Condition
1	1,00E+02	2,20E+02	12	Normal
2	2,20E+02	4,70E+02	11	Normal
3	4,70E+02	1,00E+03	22	Normal
4	1,00E+03	2,20E+03	30	Normal
5	2,20E+03	4,70E+03	22	Normal
6	4,70E+03	1,00E+04	27	Normal
7	1,00E+04	2,20E+04	33	Normal
8	2,20E+04	4,70E+04	17	Normal
9	4,70E+04	1,00E+05	6	Normal
10	1,00E+05	2,20E+05	4	Indifferent
11	2,20E+05	4,70E+05	6	Abnormal
12	4,70E+05	1,00E+06	11	Abnormal
13	1,00E+06	2,20E+06	15	Abnormal
14	2,20E+06	4,70E+06	7	Abnormal
15	4,70E+06	1,00E+07	0	Abnormal
16	1,00E+07	2,20E+07	0	Abnormal
TOTAL			223	

# PN EMISSIONS @ low idle speed 2016

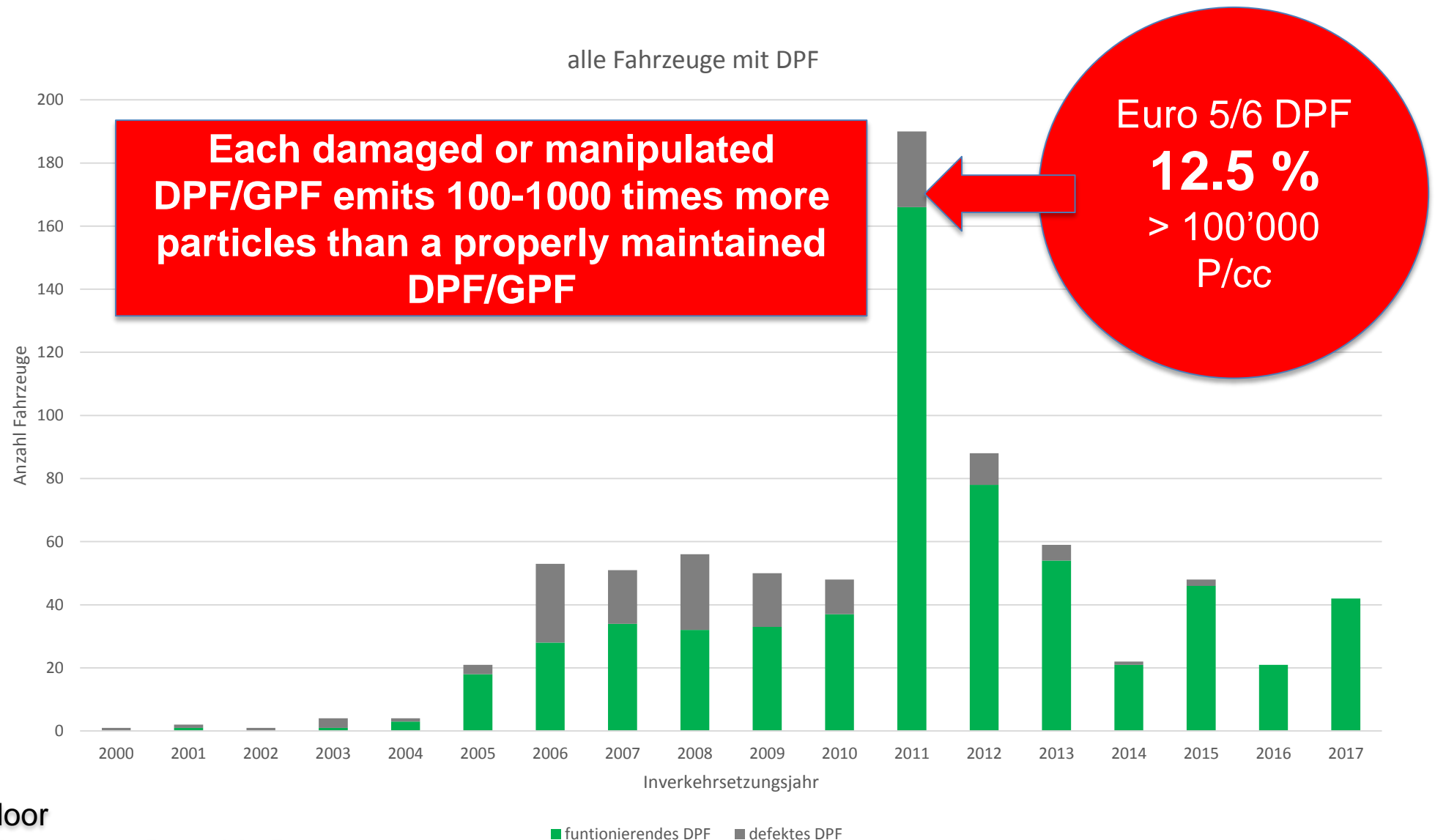


161 vehicles (76%) have a PN emission of  $< 5000 \# / \text{cm}^3$ .

52 vehicles (24%) have an elevated PN emission of  $> 5000 \# / \text{cm}^3$ .

**10% of the vehicles have a PN emission of  $> 250.000 \# / \text{cm}^3$ .**

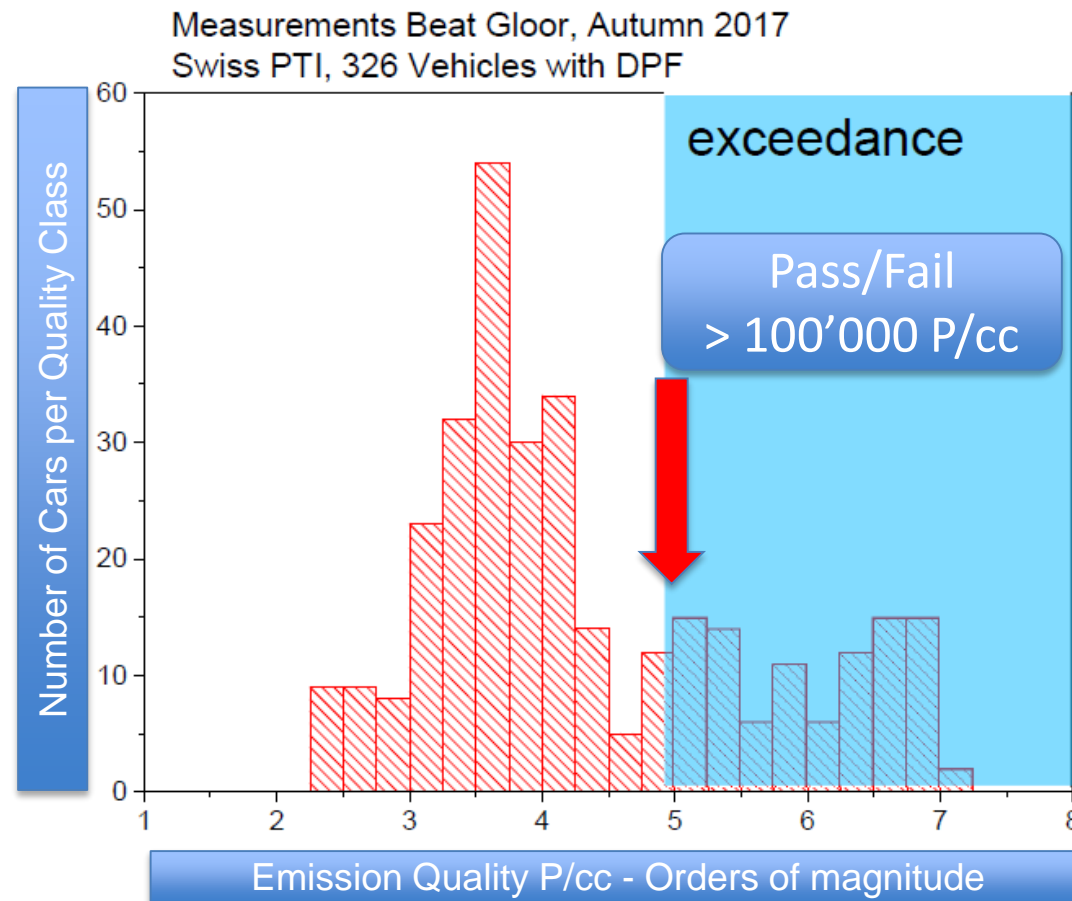
# DPF Failure Statistics in Switzerland 2017





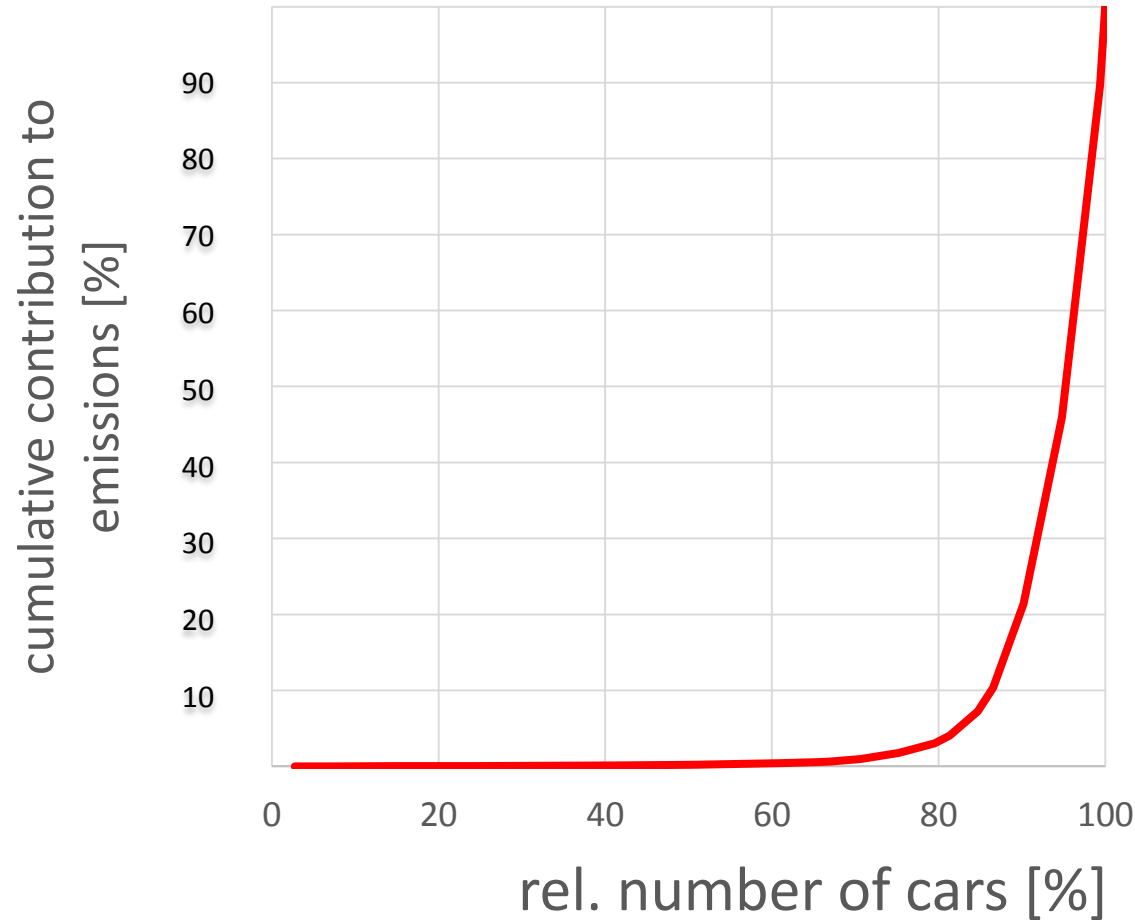
# Failure Statistics Euro 5 in Switzerland

## Zürich / PKW



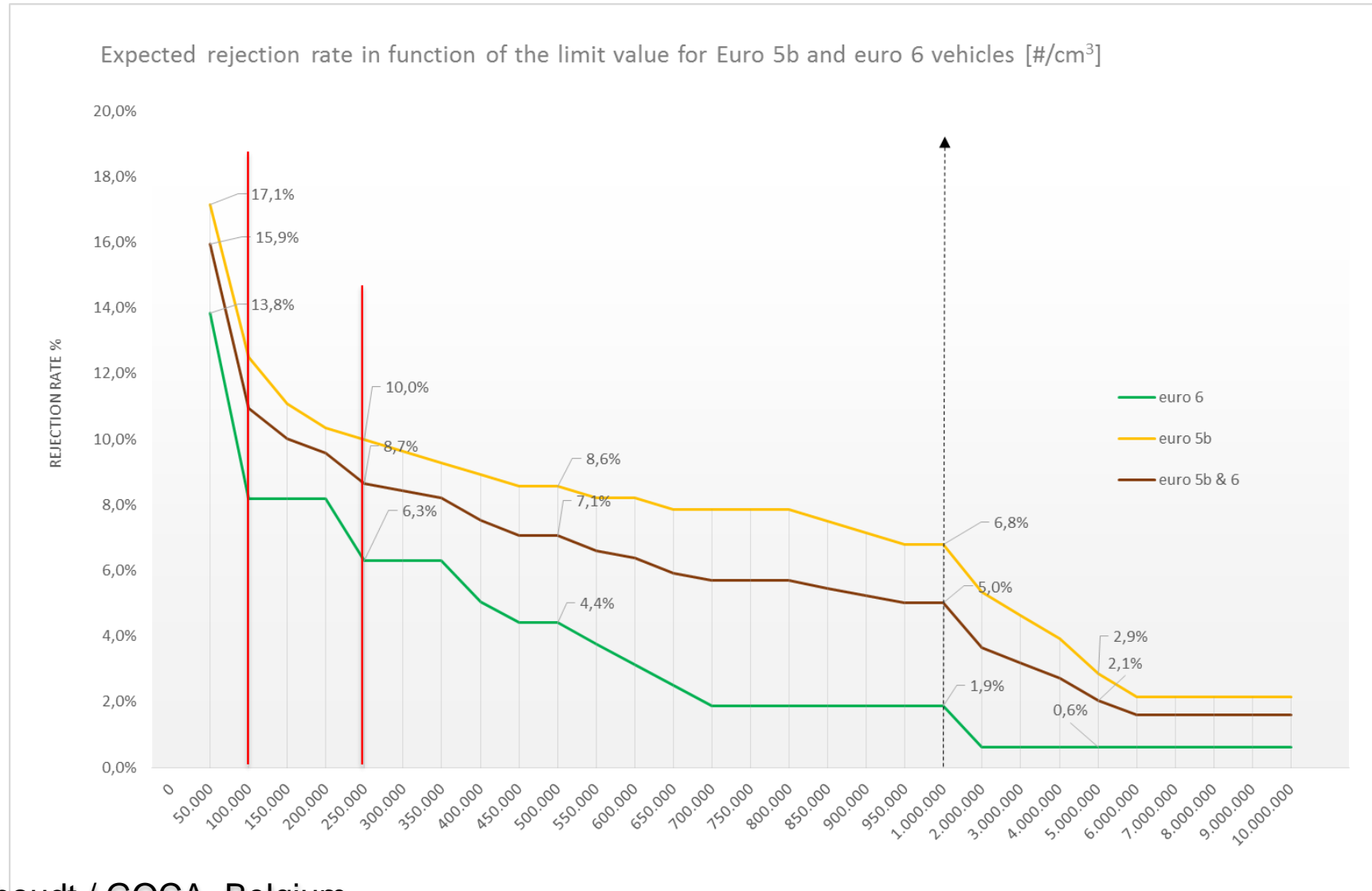
**Correcting Failures with PN > 100'000 P/cc  
improves fleet average emission by factor >10**

# Cumulative Contribution of High Emitters to Fleet Emission



# GOCA: Expected rejection rate

## in function of the limit value for Euro 5b and 6

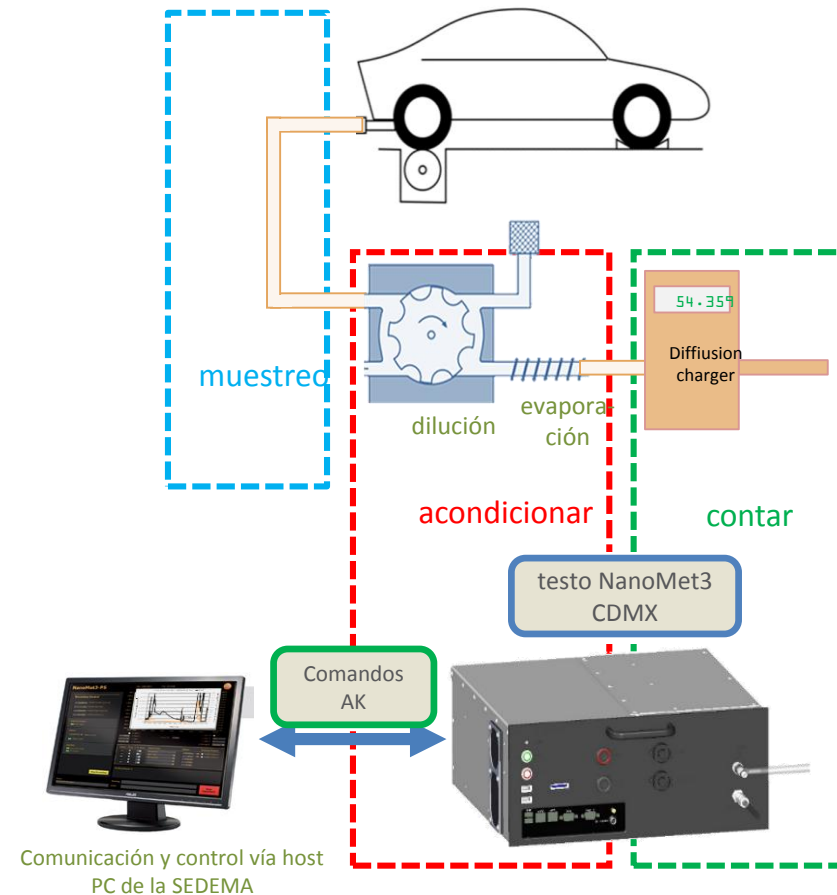


# MÉXICO CDMX 2019

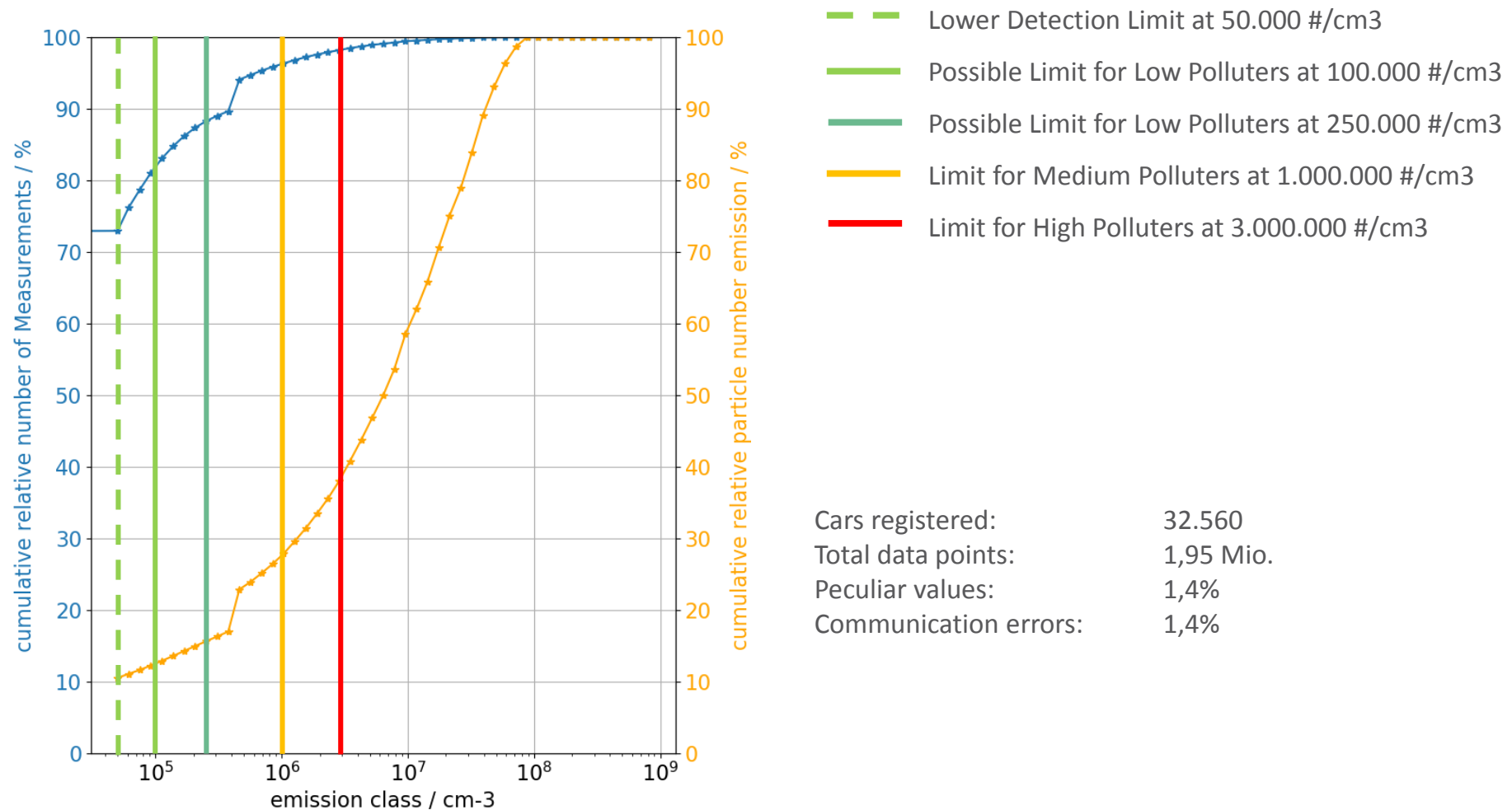
## Medición de los números de partículas PN en todos 55 verificacentros



Integración de la medición de las nanopartículas al procedimiento existente de la medición de los gases.



# Contribución de las clases de emisiones de coches a la polución total de la flota



**It is not only about Failures  
of Diesel Particle Filters**

**but**

**the much larger problem of**

**High Emitters**

**w/wo Filters, Diesel and Gasoline**

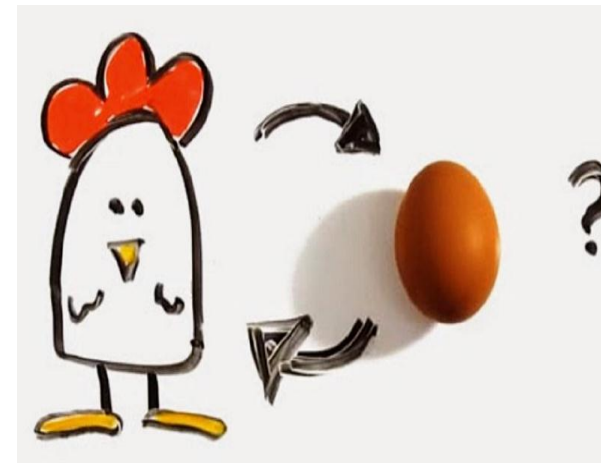
**which can be detected by the sensitive PN-method  
and maintaining them may clean the air fast at low cost**



# NPTI – Task Force

Kick off by VERT and TNO 23.11.2016

*NL, CH, DE, BE, EU ... FR, GB, ES*



**The Netherlands:** G.Kadijk , L.Zuidgeest, P.Kok, H.Peeters-Weem, H.Bussink

**Switzerland:** Th.Lutz, H.Burtscher, V.Hensel, A.Mayer / VERT

**Germany:** S.Limbeck/BAST; V.Ebert/PTB; D.Saar/DUH

**Belgium:** P.Buekenhoudt, B.Veldeman, Ph.de Meyer / GOCA

**EU-JRC:** R.Suarez-Bertoa

**TSI:** J.Spielvogel

**AVL:** K.Schulte, W.Lukesch

**SENSORS:** O.Franken, D.Booker, J.Morril

**TESTO:** M.Stratmann, M.Schumann, M.van Dam

**DEKATI:** M.Moisio

**PREMIERDiagnostics:** R. Wilce

**HJS:** Ph.Schulte

**MAHA:** D.Mohr

**EGEA:** G.Petelet

**TEN:** Marc de Goede

# Concept

for a very efficient and cost effective 100% in-use periodic emission control for DPF equipped vehicles

- **PN-Test at low idle**
- PN with DPF;  $< 10^3$
- PN with failure  $> 10^6$
- Pass/Fail: 100'000 1/cc

**This Test is more than Pass/Fail**

It supplies **quantitative diagnostic** information for the **functionality** of each emission control component and the engine as well and permits **preventive repair and maintenance**.



# Two years 10 meetings Instrument Specification



Paul Kok | Innovation Engineer|  
D +31 786332340 | [www.nmi.nl](http://www.nmi.nl)  
NMI Certin B.V. | Hugo de Grootplein –  
NL-3314 EG Dordrecht

## Particulate Number Counter

INTERNATIONAL

RECOMMENDATION

Draft 2018-03-08 (E)

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Instruments for measuring vehicle  
exhaust particulate number emissions

- **For engines running idle**

Part 1: Metrological and technical requirements  
Part 2: Metrological controls and performance tests



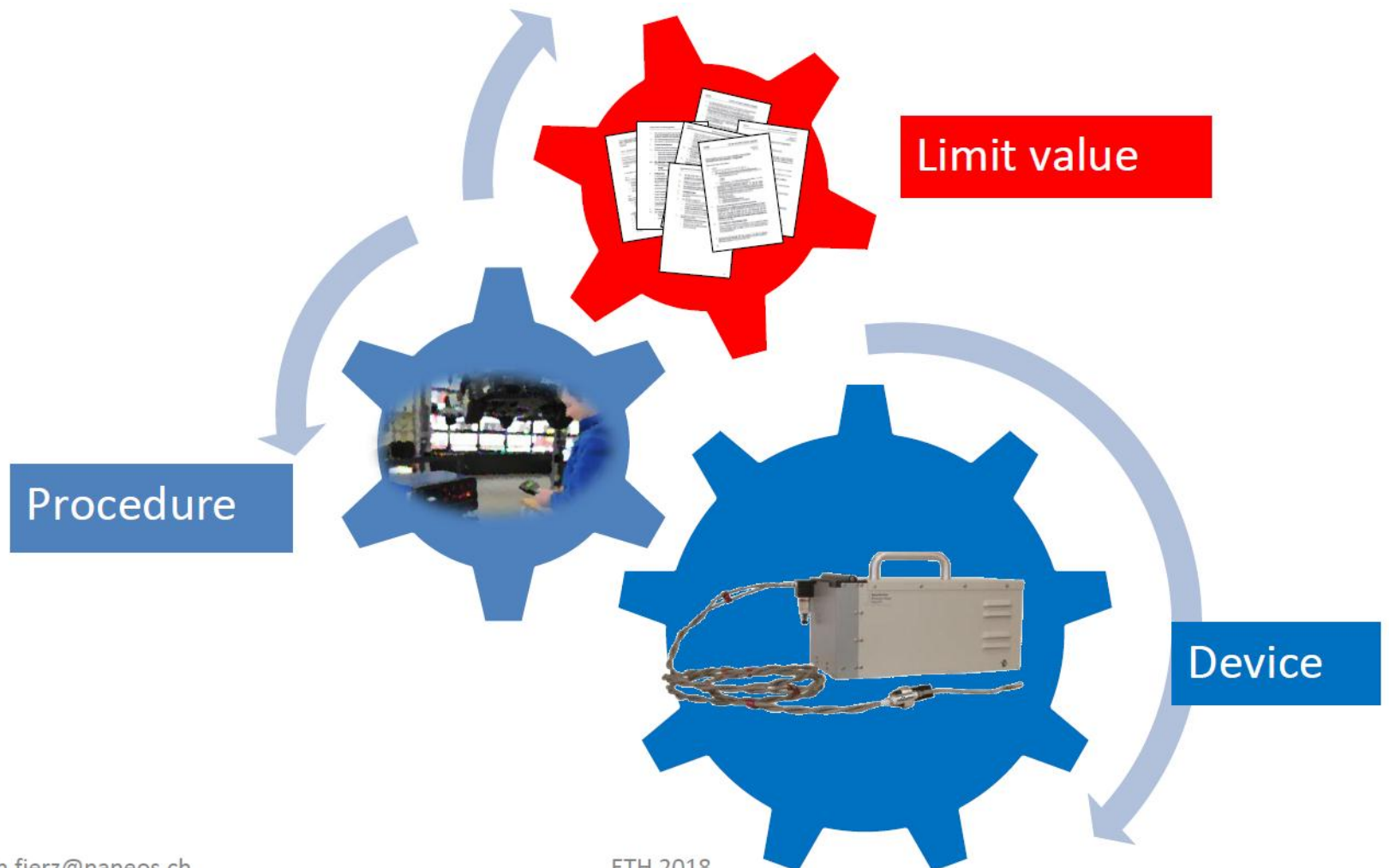
Organisation Internationale de Métrologie Légale

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International Organization of Legal Metrology

*Aufgrund des Europäischen Prinzips der “mutual recognition” kann das von allen Mitgliedsstaaten der EU (+CH) übernommen werden*

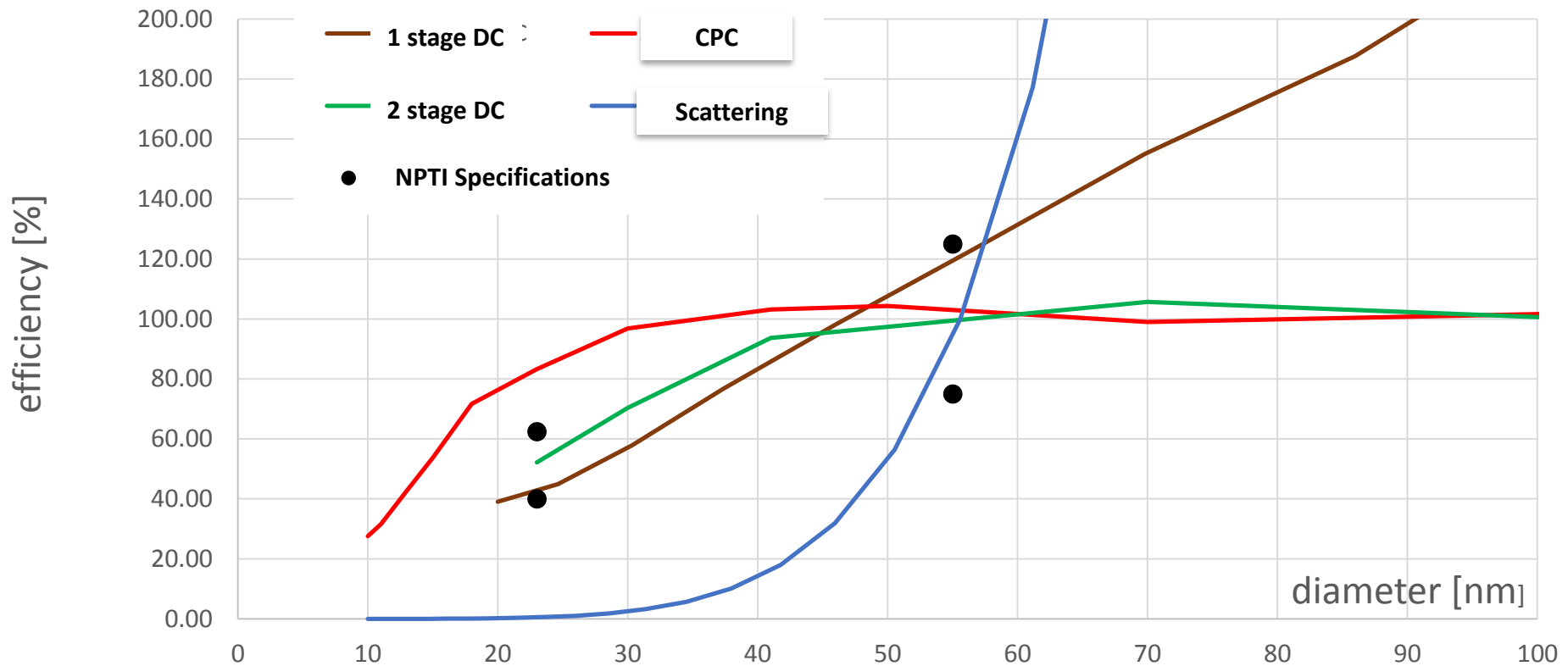
# New PTI is a package with 3 elements



# Specifications NPTI

- The PTI test has case to be short (< 2 min) and simple
- applicable for road checks, in workshops and in the roadworthiness test centers.
- The NPTI working group has elaborated specifications for such a device.
  - Efficiency 100%  $\pm$ 25% at 55nm
  - Efficiency 50%  $\pm$ 25% at 23nm
  - Volatile removal in Tetracontane test: >90% for 30nm particles with a number concentration  $<10^5\text{cm}^{-3}$

***Light Scattering must be excluded***  
*size characteristic (Raleigh scattering)  $D^6$*   
*by far too steep  $\rightarrow$  small particles are invisible*

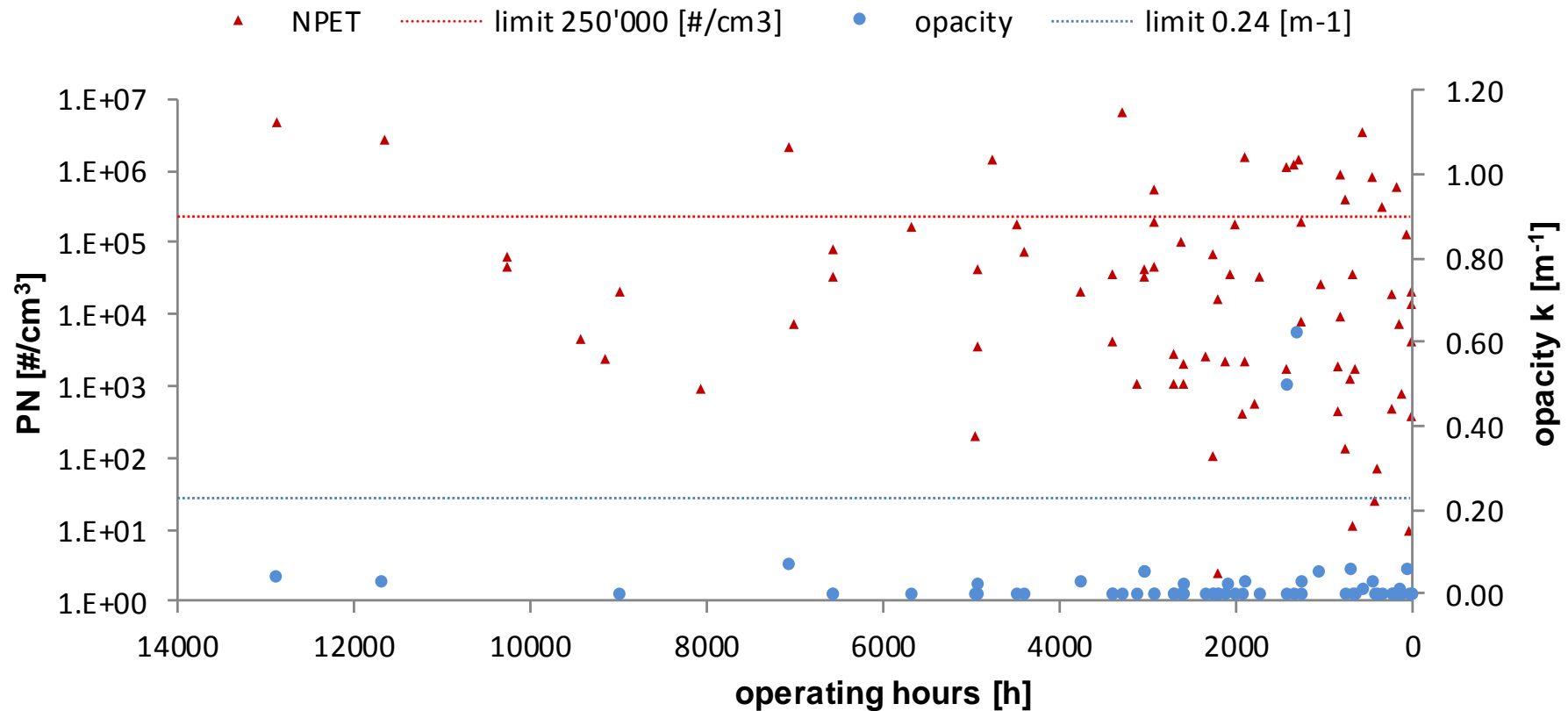




# Opacity measurement must be excluded

→ too insensitive → small particles invisible

107 machines 2016 Switzerland AFHB 2016



# CPC Instruments by TSI et al. for NPTI

## NANOPARTICLE EMISSION TESTER FOR PERIODIC INSPECTION

PORTABLE, FAST, PASS-FAIL RESULTS

Due to:

- + Only certified instrument at this time
  - METAS certification to stringent requirements of Swiss Regulation SR 941.242 (2014) for NRMM
- + Measurement of **solid** particle number concentration only
- + Link to type approval test results



The PTI-PN tester is a light-weight, battery powered, mobile solution for garage shops, service stations and technical inspection facilities to test for nanoparticle emission levels of vehicles. Sampling emissions straight from the tailpipe with a pass/fail result in less than one minute, this tester is perfect for easy diesel or gasoline Particle Filter Testing (DPF or GPF).



Evolving from original nanoparticle sensors and sensors for compliance testing, TSI's PTI-PN tester enables the measurement of particle number emissions accurately and reliably. TSI's tester provides touch screen guidance for the technician through the test cycle, step-by-step, ensuring measurements are taken correctly. The test cycle requires the vehicle's engine to be warmed up and in idle conditions and the ambient air measurement precedes the tailpipe emission test. A total of four measurements are taken, each last five seconds where the average of the engine emission test is compared to a pass/fail threshold setting. In addition to the test cycle, manual measurements can be enabled for diagnostic or research purposes.

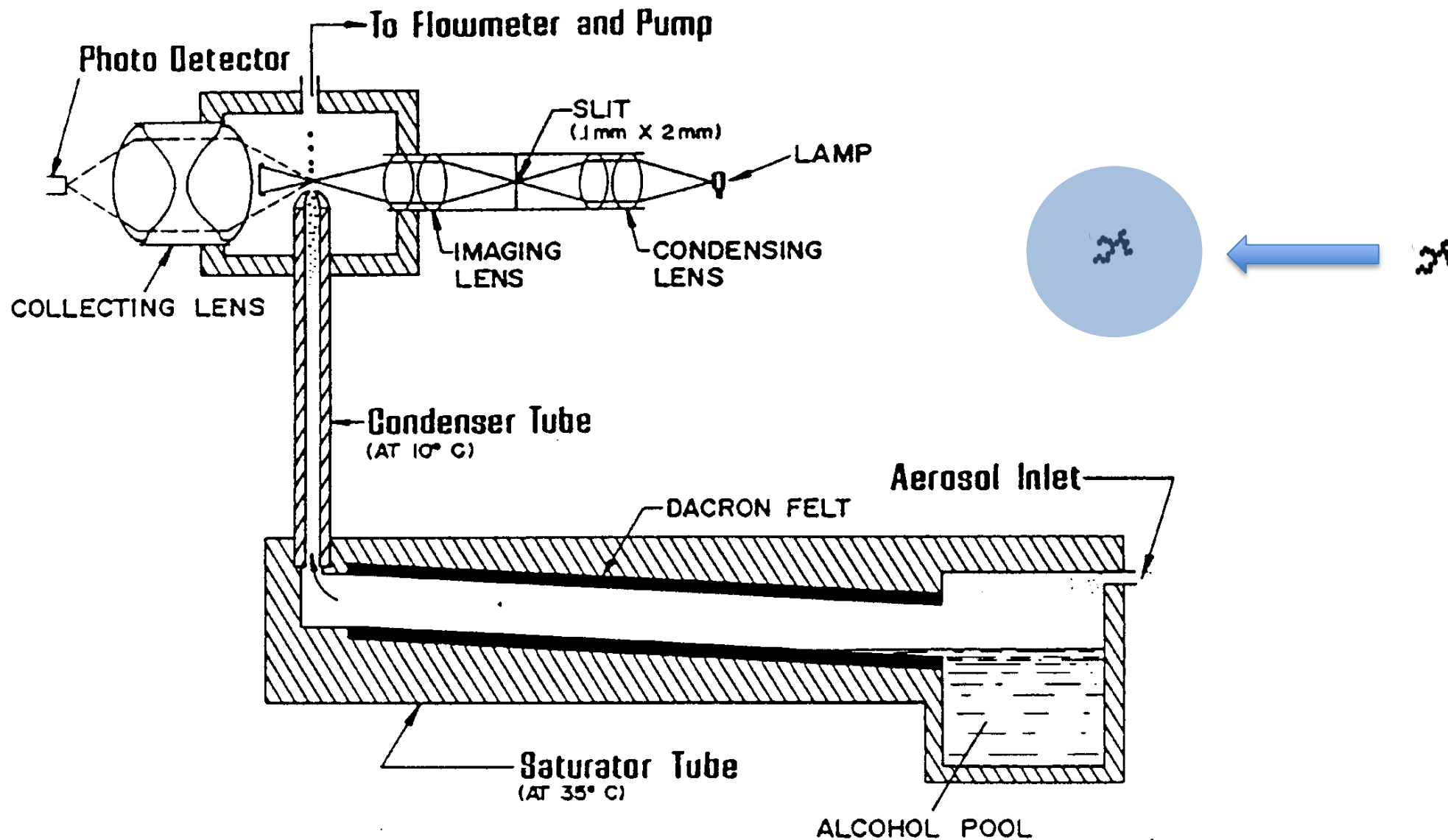
### Features and Benefits

- Light-weight, battery powered mobile tester
- Easy Diesel or Gasoline Filter Testing (DPF, GPF)
- Sample straight from the tailpipe with included probe
- Pass/fail result in less than a minute
- Results backed up in internal memory
- Test Cycle and Manual measurement mode

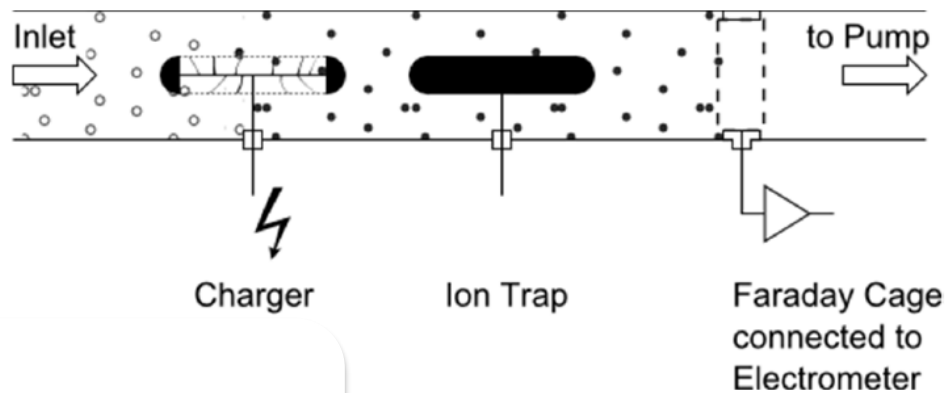
Sampling	Ambient Air			Tailpipe Emission										
PN Measurement														
Time (seconds)				0	5	10	15	20	25	30	35	40	45	50

The time sequence of a pre-defined test cycle in 5-second intervals. Nanoparticles in ambient air are sampled as reference point, before the sampling probe is attached to the tailpipe. These measurements are recorded at the tailpipe and averaged, and the pass or fail result is based on comparing the average to a defined limit value.

# CPC = Condensation Particle Counter

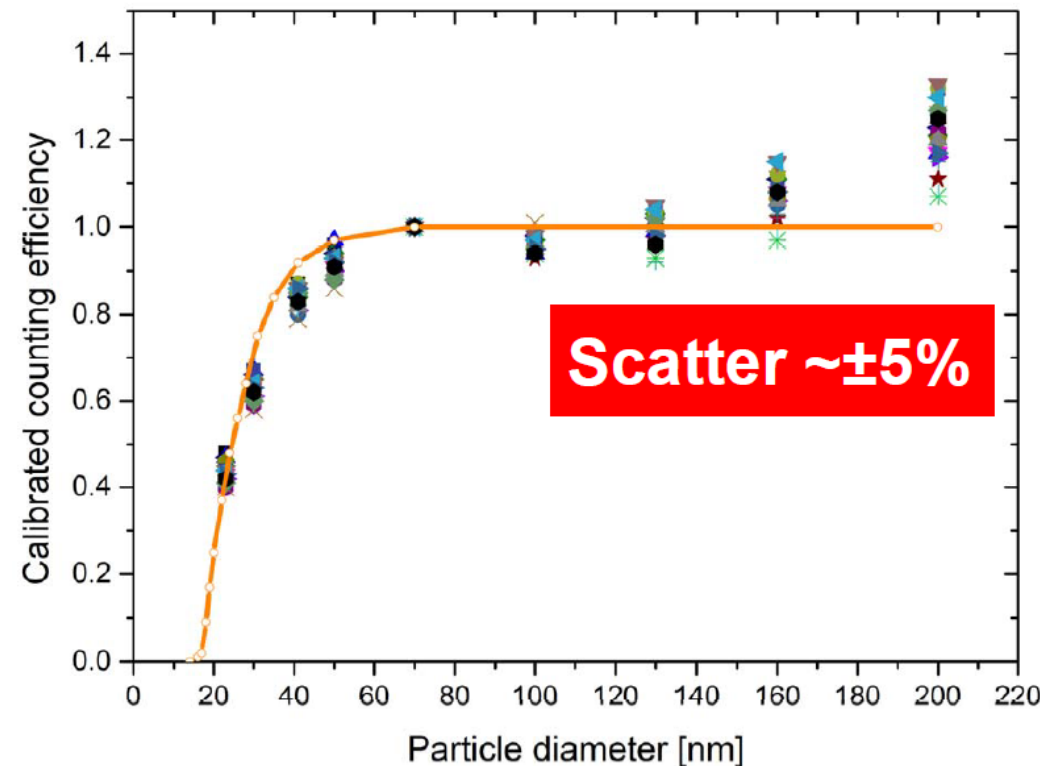


# DC-Instruments by NANEOS et al. for NPTI

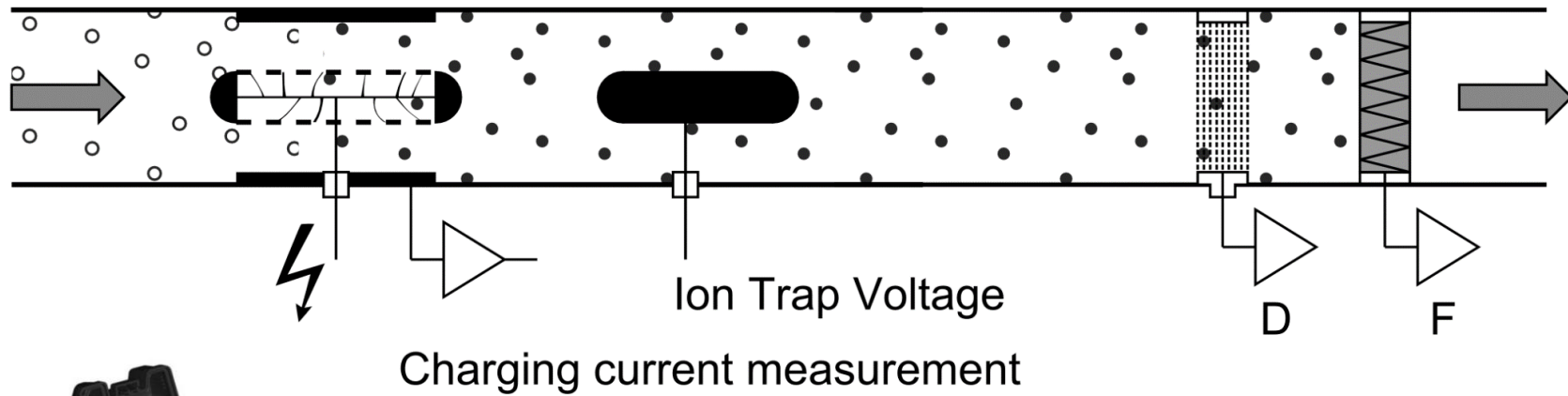


## Sensors for NPTI

- Inlet heating: up to 190 °C.
- Sensor heating: up to 80 °C
- For diesel used: 45 °C
- Bluetooth



# Diffusion Charging by TESTO, Naneos and others





# Suppliers of PN testers for NPTI:

- TSI
- Testo
- Naneos
- Sensors
- AVL
- Dekati

12 companies  
develop these new instrument  
so we will see a strong competition



# Volatiles must be removed

**Soot Particles**

**Ash Particles**

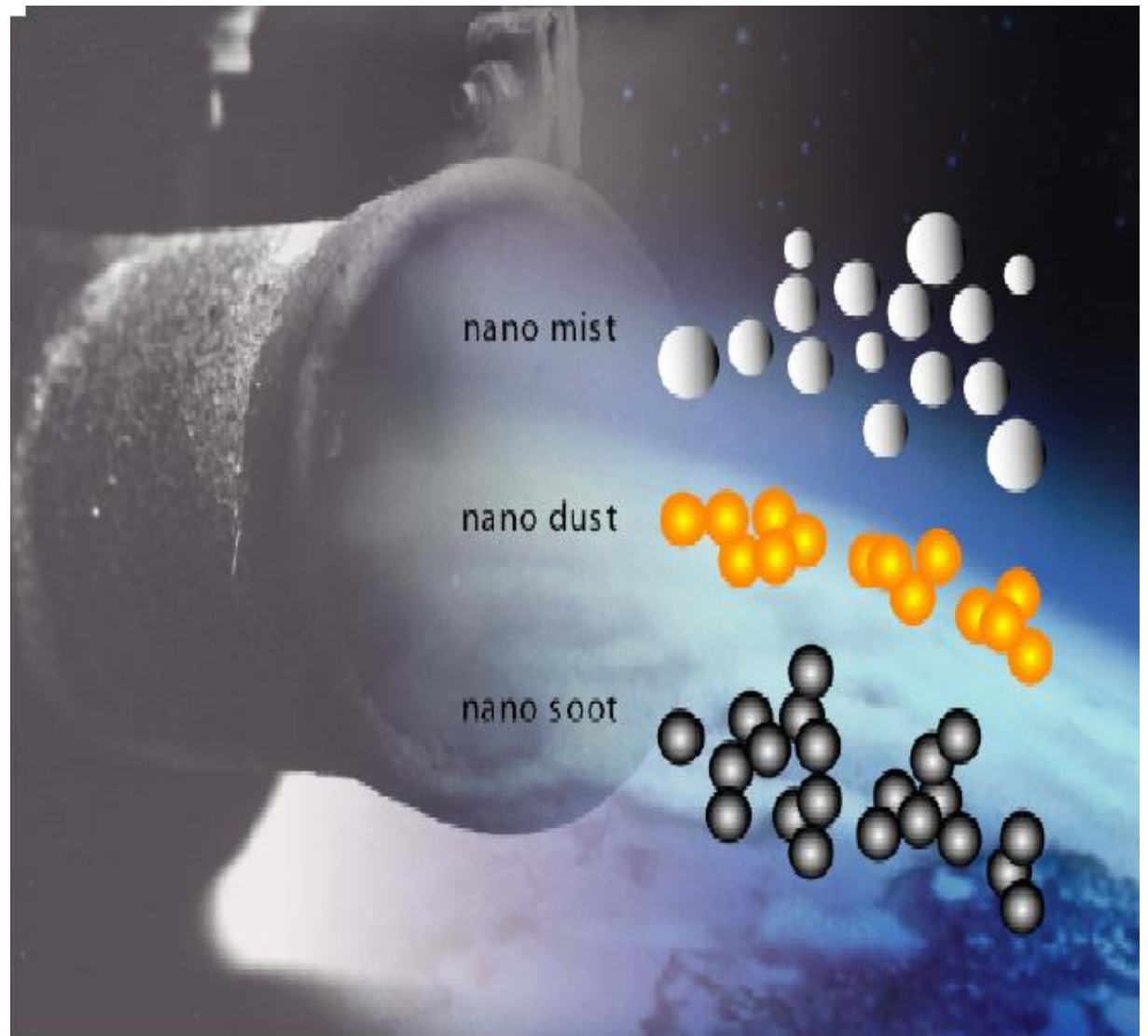
**Liquid Droplets**

- HC
- H<sub>2</sub>O
- H<sub>2</sub>SO<sub>4</sub>

**Gases:**

CO, HC, NO<sub>x</sub>

PAH, Nitro-PAH



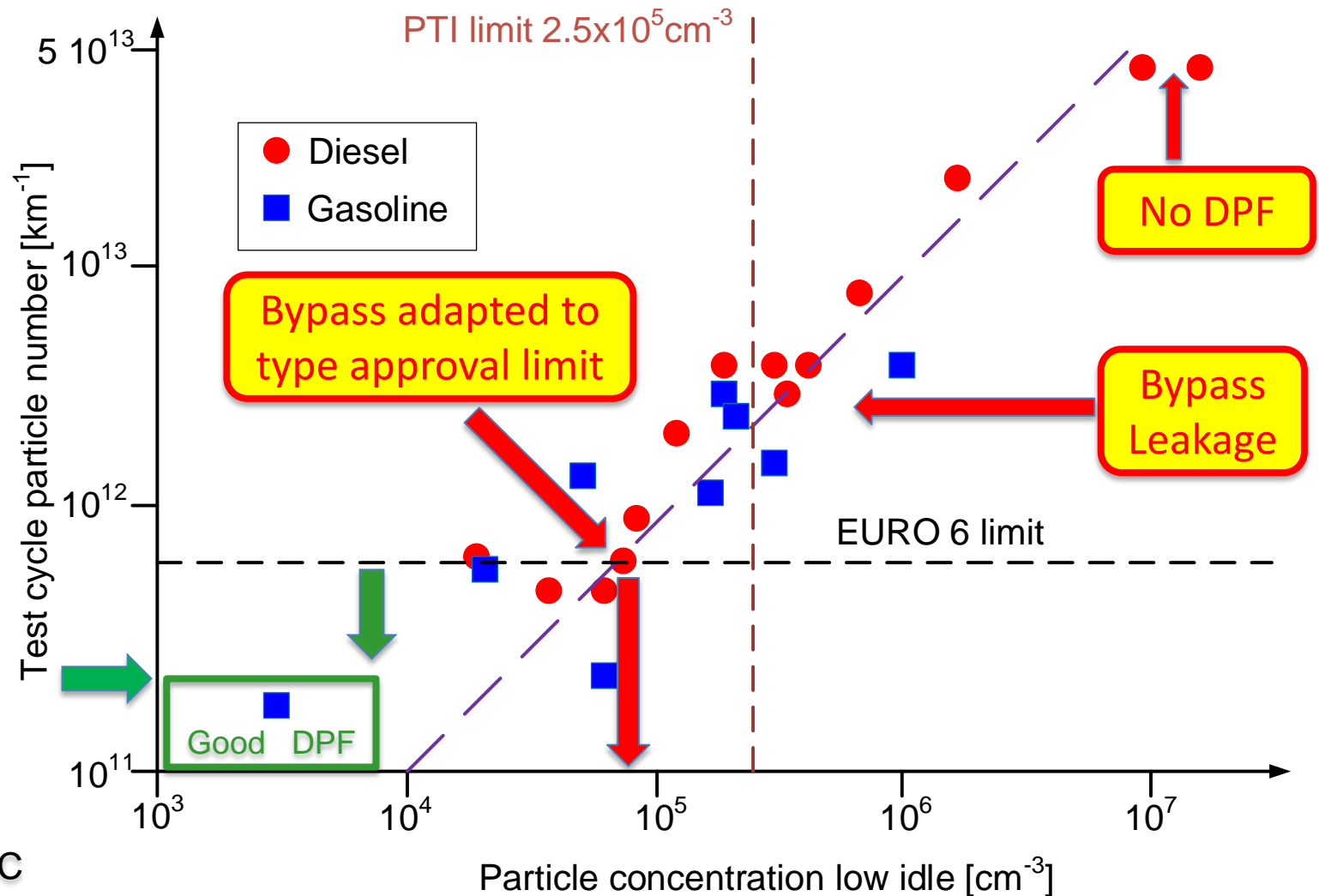


# How to respect Contingency:

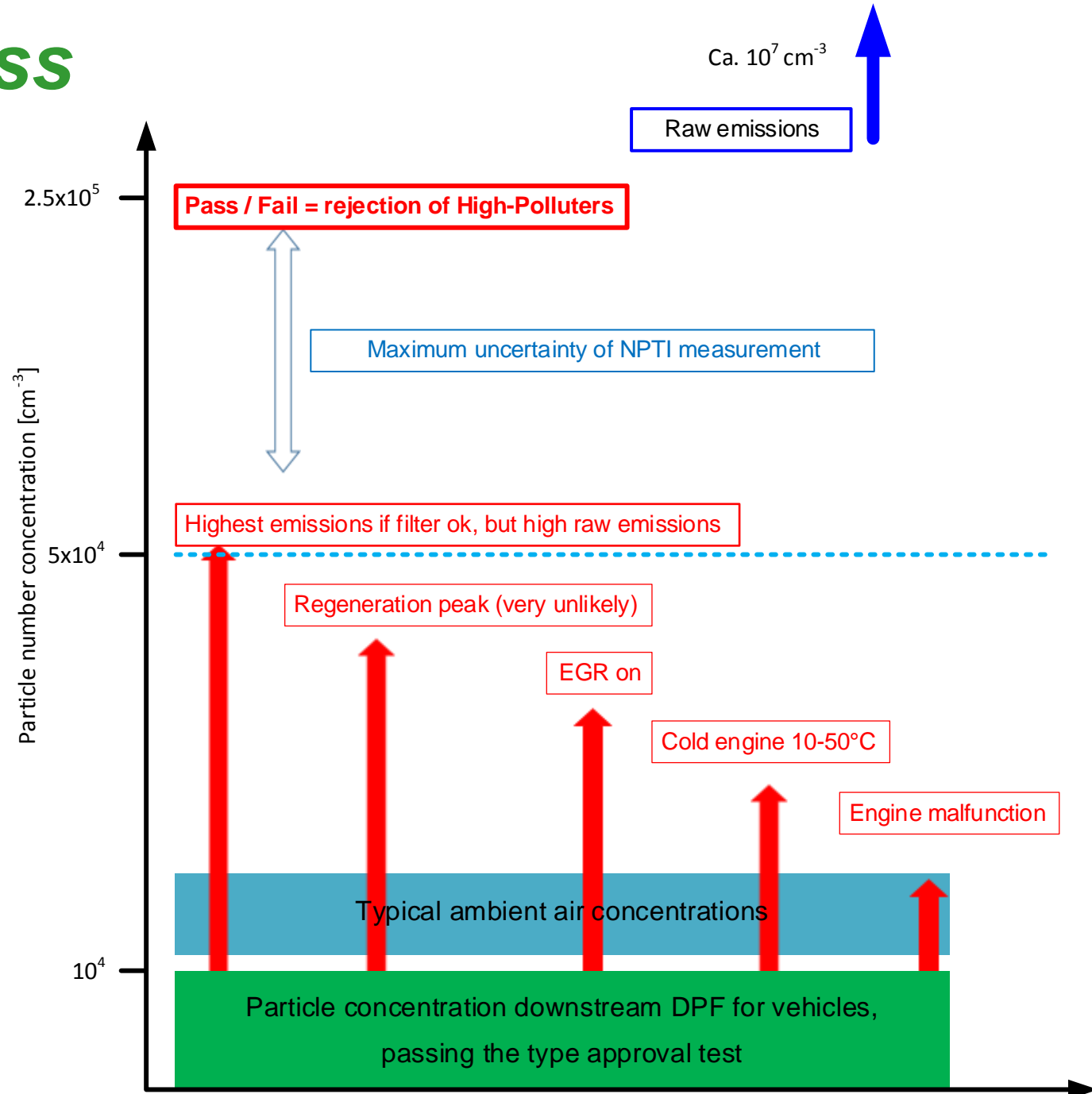
## PTI can not be stricter than Type Approval

PTI- Test ( PN at low idle	failed	prediction of short test wrong test limit	prediction of short test correct correct
	passed	prediction of short test correct certification	short test limit prediction of short test wrong
		passed	failed
		Type Approval (test cycle)	

# Good Correlation of type approval test cycle and NPTI low idle test with good/bad DPF to determine Pass/Fail Criterion



# *How define a pass fail criterion respecting all disturbance factors in a simple test*



# NPTI Mission for DPF is accomplished

- Netherlands will introduce NPTI in 2019, Belgium follows with the already Swiss-METAS certified instrument TSI NPET
- Germany has re-started AU in Jan. 2017, includes PN 2021
- Switzerland will follow as soon as instruments are available
- Spain and UK are in on a similar roadmap
- Six Instrument manufacturers will provide test samples 2019
- JRC performs instrument validation and reports to EU
- Instrument certification by NMI or METAS from fall 2019

**Repair Cost? → Liability of the manufacturers for emission stability within a period of 160'000 km (2005/78/EG)**



# and what about legal Implementation?

## Phased introduction of a particle test for DPFs in the Netherlands

Louis Zuidgeest

14 March 2019

VERT-Forum

*Ministry of Infrastructure and Water management*

Belgium and Germany + ?? will follow soon

# NPTI-Legislation in Germany

- Änderung der Richtlinie für die Durchführung der Untersuchung der Abgase von Kraftfahrzeugen nach Nummer 6.8.2 der Anlage VIIIa Straßenverkehrs-Zulassungs-Ordnung (StVZO) (AU- Richtlinie)
- Muster eines Nachweises über die Durchführung der AU nach Anlage VIII StVZO

Bonn, den 20. September 2017  
LA 27/7355.2/2

VkBl. Amtlicher Teil

853

- |       |  |
|-------|--|
| 3.    | Nummer 1.3 wird wie folgt gefasst:   |
| „1.3  | Inkrafttreten der Änderungen zu dieser Richtlinie  |
| 1.3.1 | Ab dem 01.01.2018 ist die Funktionsprüfung Abgas verpflichtend für alle AU-pflichtigen Kraftfahrzeuge durchzuführen. |
| 1.3.2 | Ab dem 01.01.2019 gelten die angepassten Sollwerte für alle Kraftfahrzeuge ab Emissionsklasse Euro 6/VI.             |
| 1.3.3 | Ab dem 01.01.2021 wird ein Verfahren zur Messung der Partikelanzahl bei Kompressionszündungsmotoren eingeführt.“     |



# Considerations of Periodical Technical Inspection of Vehicles with deNO<sub>x</sub> Systems

Jan Czerwinski, Pierre Comte, and Danilo Engelmann University of Applied Sciences Biel-Bienne

Andreas Mayer TTM

Thomas Lutz ETH

Volker Hensel Aurigna Consulting GmbH

**Citation:** Czerwinski, J., Comte, P., Engelmann, D., Mayer, A. et al., "Considerations of Periodical Technical Inspection of Vehicles with deNO<sub>x</sub> Systems," SAE Technical Paper 2019-01-0744, 2019, doi:10.4271/2019-01-0744.

## Abstract

An independent periodical technical inspection (PTI)<sup>2)</sup> of vehicles is proposed in the last time as a better prevention against increased emissions of the fleet.

Several projects focused on the Diesel vehicles (HD & LD) and on the functionality of the exhaust aftertreatment systems as a key element for lowering emissions of a vehicle or machine.

The present paper summarizes the results obtained on 3 modern passenger cars Euro 6b (with EGR, DOC, DPF & SCR) during load jumps, representing the heat-up or cool-down behaviour of the exhaust system.

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## A New Periodic Technical Inspection for Particle Emissions of Vehicles

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### Abstract

Meanwhile, a high fraction of vehicles, driven by diesel engines, is equipped with very efficient particle filters in Europe. The filters have been enforced by the particle number limit for type approval testing. If the filter works properly, the emissions are very low. However, a small fraction of vehicles having broken or manipulated particle filters and therefore very high emissions can dominate the average fleet emissions of vehicles. The on-board diagnostic systems do not detect most of these filter defects. In several studies, failure rates in the order of some percent up to 20% have been observed. Therefore, identifying these high polluters is urgently needed. An option to achieve this is a periodical technical inspection. Gasoline engines may also have very high particle emissions, if there is a malfunction. Nevertheless, as a first step, the focus of current work is on diesel engines. Some data for gasoline engines will be presented, but the suggested test procedure has only been verified for diesel engines. For these, it has been shown that a test measurement can be done at low idle, which allows a fast and cheap procedure. Requirements for the test instrumentation are specified and a test procedure is suggested. A limit value is proposed which on the one hand is higher than requirements in type approval, but low enough to detect high polluters. The method suggested can be applied to passenger vehicles, as well as to heavy-duty engines and off-road applications.

**Keywords** Diesel particle filter · Filter efficiency · Emission measurement · Periodical exhaust test · PTI · DPF failure analysis · Emission control manipulation · High polluters





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