

# Fundamentals of Counting Solid Particles using CPC Technology and its Application in Vehicle Emissions Testing

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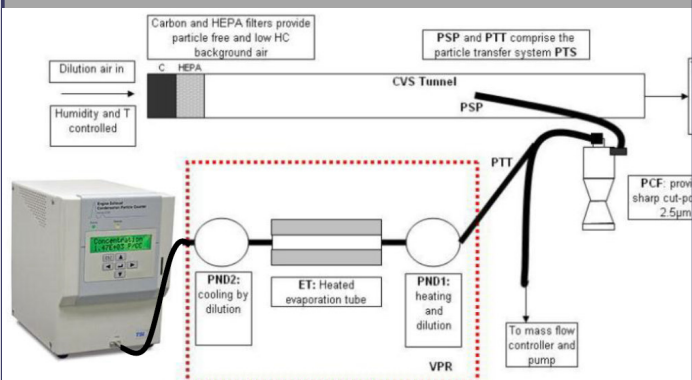


UNDERSTANDING, ACCELERATED

# Measuring particle number in exhaust emissions - CPCs

+ Used **>20 years** in engine emission testing

Type approval testing  
EURO 5b/6 – Reg. 83/49



Real Driving Emissions  
PN-PEMS



Source: [www.horiba.com](http://www.horiba.com)

NRMM - SR 941.242/  
Swiss ships SR 747.201.3



Aircraft emissions SAE E-31

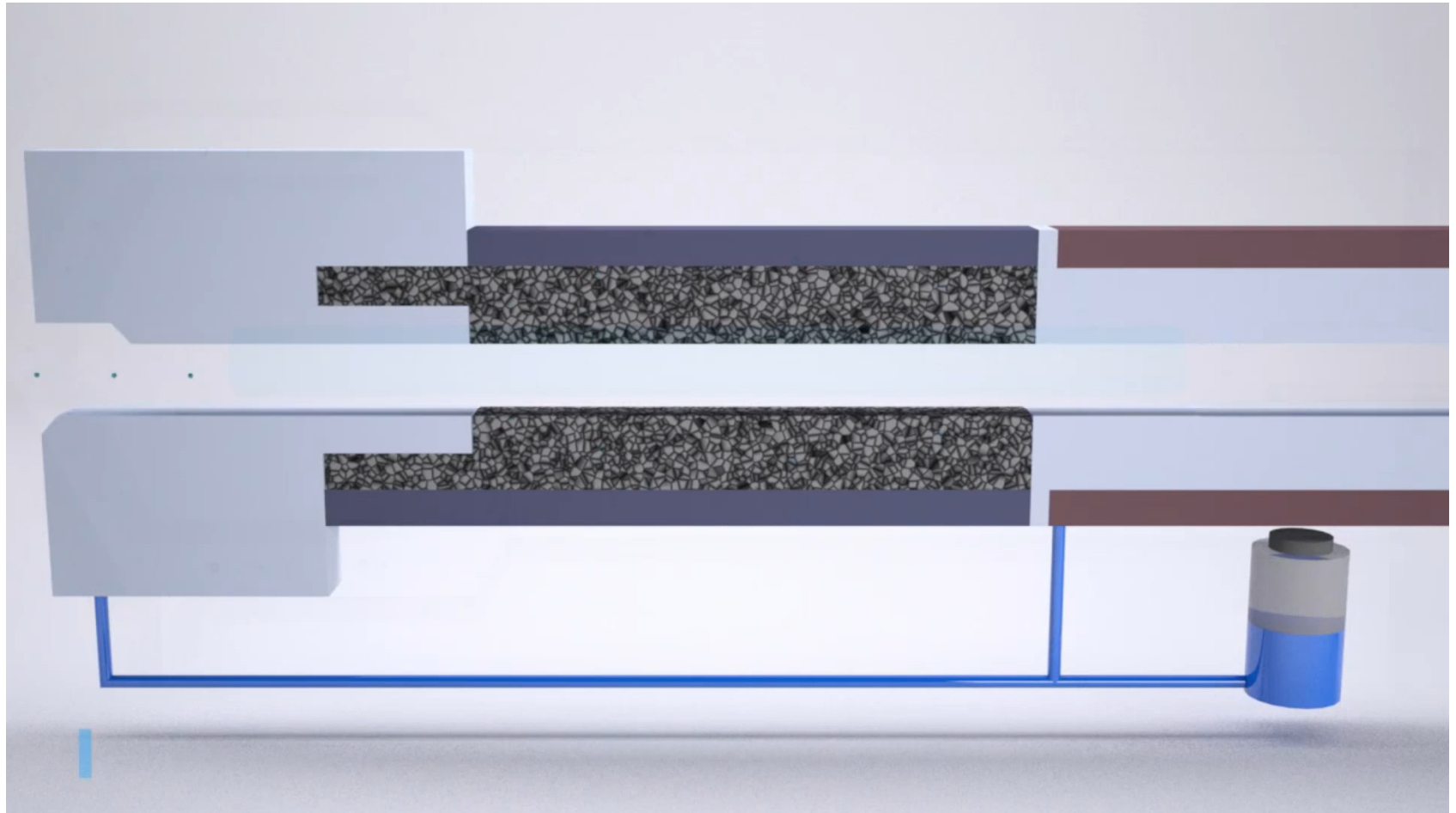


Solid PN >10nm

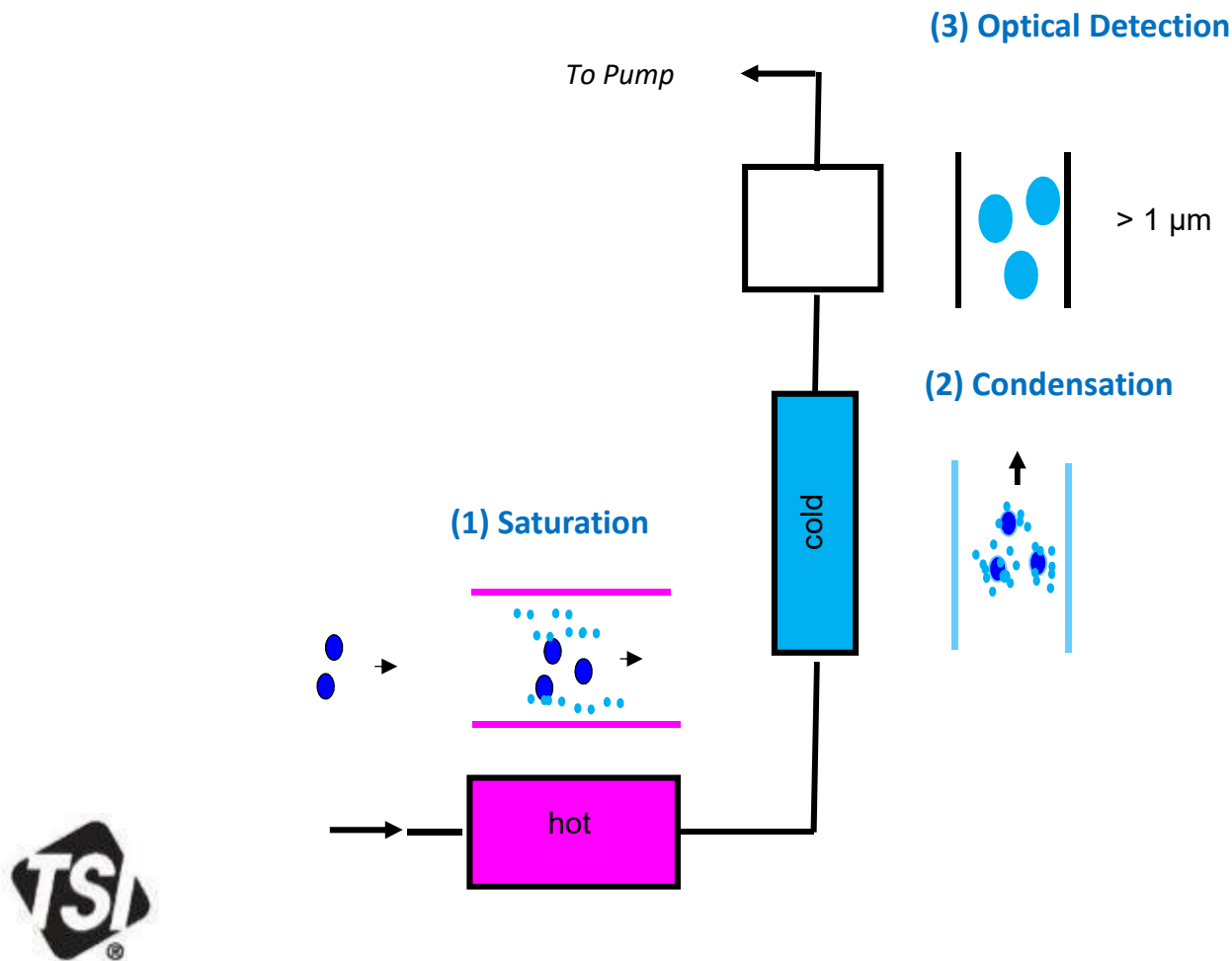
- + Suitable for Diesel, gasoline, and heavy duty emissions
- + Reliable and traceable results



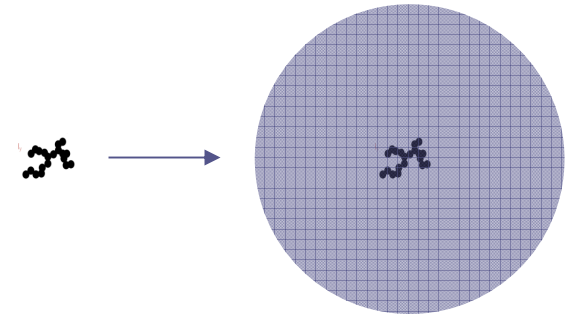
# Condensation Particle Counter Working Principle



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## + Working Fluid – Isopropanol

- Coats or encapsulates all ultrafine/nano particles
- Grows the soot particles into much bigger droplets
- All droplets are about the same size ( $\sim 3 \mu\text{m}$ )
- $3 \mu\text{m}$  droplets follow the laminar flow ( $< 100 \text{ nm}$  particles have a high diffusion coefficient)

-> Minimizes contamination

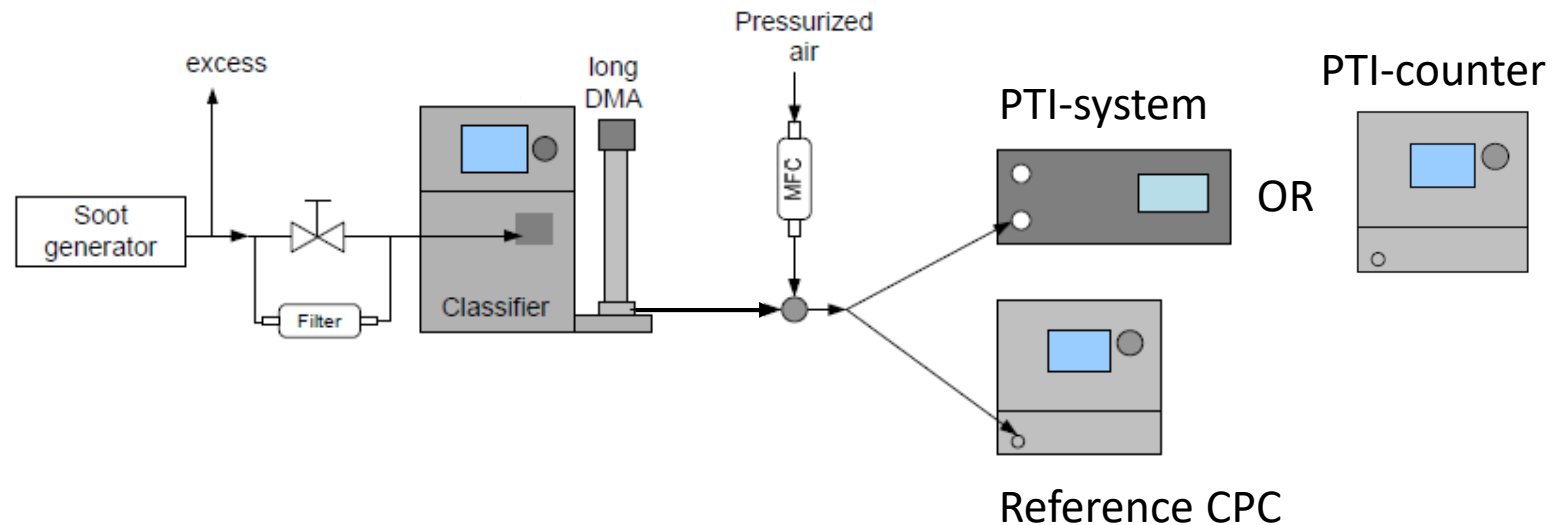
-> CPCs are maintenance free ( $\geq 1$  year)



# CPC - Traceable calibration

## ISO 27891

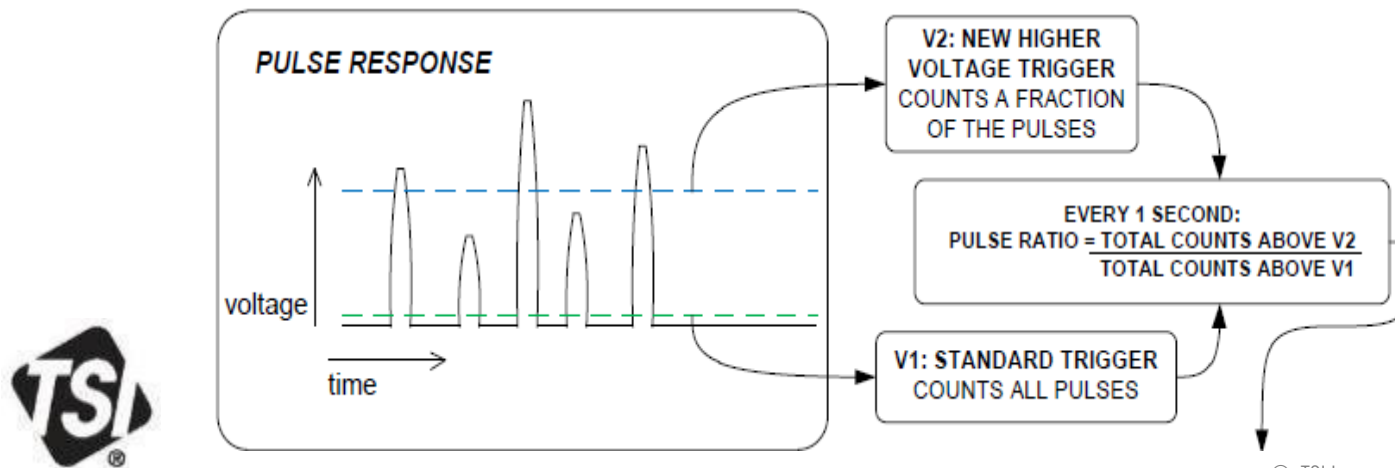
+ Calibration setup\* already in use:



(\*) Adapted from JRC Technical Report 2018, Real Driving Emissions (RDE) B. Giechaskiel

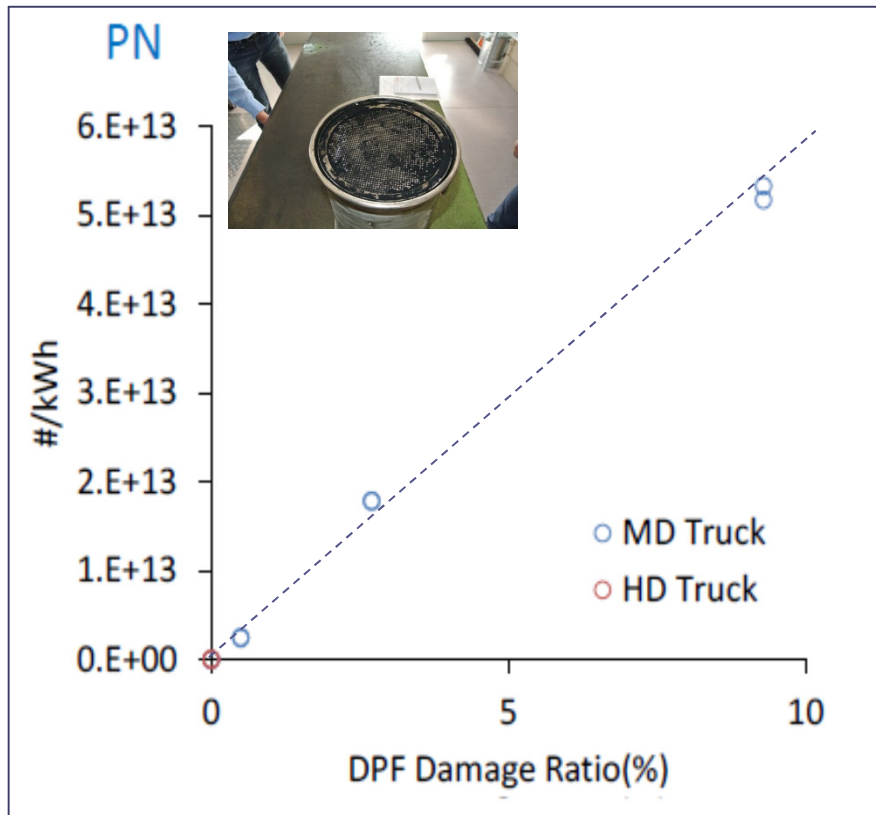
# Condensation Particle Counter Working Principle

- + Every single particle is counted by detecting its light scatter when illuminated by laser → **pulse**
- + As droplets are all of similar size, the pulses are all similar as well
- + Monitoring the **pulse height** is a real time diagnostic tool to verify the proper operation



# Condensation Particle Counter

## High performance



- + DPFs can fail in the field (1.5-2% /year)
- + Partial failures can be detected & subsequently repaired
  - Decision by owner
  - Potential to save cost
  - Additional business for shops

Increasing number of holes

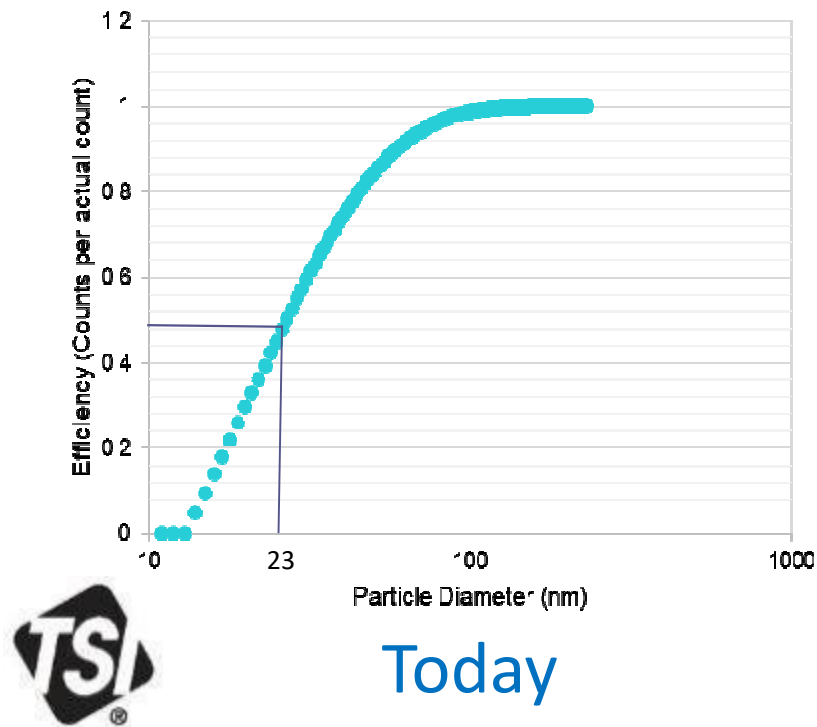


Measurement of **solid** particle number concentration, Yamada, ETH-2015  
“Detect Small Failures (increasing number of holes) in DPFs at Low Idle - linear”

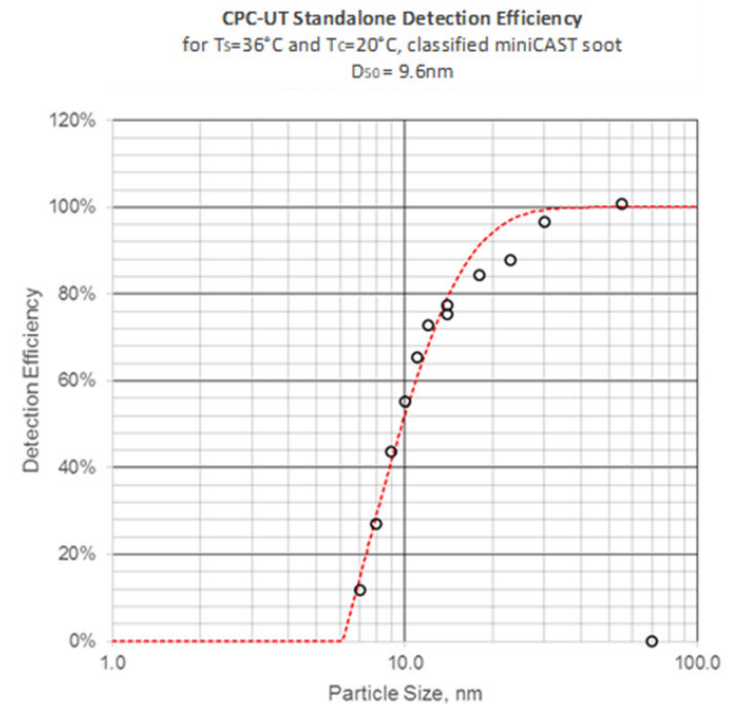


# Condensation Particle Counter Technology – future ready

- + The same CPC can be adjusted to measure 10 nm particles instead of starting at 23 nm



Today



Future requirement?

# What we blow out when we floor the throttle

Empa researchers studied exhaust emissions from seven gasoline cars and one diesel, six of which were built between 2012 and 2016. Alarming substances came to light in the gas chromatograph, a fine, analytical instrument. As the dynamometer revealed, most of these substances are produced when the vehicle accelerates.

## Soot particles

The nanoparticles, which initially have a diameter of 15 to 20 nanometers (millionths of a millimeter), congregate to form larger particles measuring 80 to 100 nanometers, and penetrate the alveoli of the lung (The lungs can only remove particles that are larger than 200 nanometers). Chemical pollutants accumulate on the surface of the soot particles, which transport them into the lungs and thus into the bloodstream – like a Trojan horse.

→ Euro 6 permits 6 trillion particles / km for direct-injection gasoline cars and 600 billion particles / km for diesel vehicles. For gasoline cars with intake manifold injection, there are no emission limits at all.

## Carbon monoxide (CO)

The gas is poisonous as it binds to hemoglobin and thus interferes with oxygen transport in the blood. CO poisoning is fatal within a short period of time. In January, six teenagers died in Germany using a gasoline power generator in a summerhouse.

→ Euro 6 permits 1,000 mg CO / km for gasoline cars and 500 mg / km for diesel.

## Nitric oxides (NO and NO<sub>2</sub>)

In air NO rapidly oxidizes to form NO<sub>2</sub>, a poisonous gas with a pungent odor that irritates the throat and dissolves readily in water to form nitric acid. Above 21 degrees Celsius, it transforms into N<sub>2</sub>O<sub>4</sub>, a corrosive and highly oxidizing gas.

→ Euro 6 permits 60 mg NO + NO<sub>2</sub> / km for gasoline cars and 80 mg / km for diesel.

## Formaldehyde (CH<sub>2</sub>O)

Formaldehyde can cause allergies and skin, respiratory tract or eye irritations. In concentrations of 30ml/m<sup>3</sup> and above, it can be life-threatening. In case of chronic exposure, it is carcinogenic and affects the memory, ability to concentrate and sleep.

→ Euro 6 does not specify any limits.

## Benzene (C<sub>6</sub>H<sub>6</sub>)

Its breakdown in the body produces toxins that can trigger cell mutations (cancer). Its long-term intake can harm the inner organs and bone marrow, which causes anemia. In humans and animals, benzene accumulates in the brain, bone marrow and fatty tissue.

→ Euro 6 does not specify any limits.

## Dinitropyrene (C<sub>16</sub>H<sub>10</sub>N<sub>2</sub>O<sub>4</sub>)

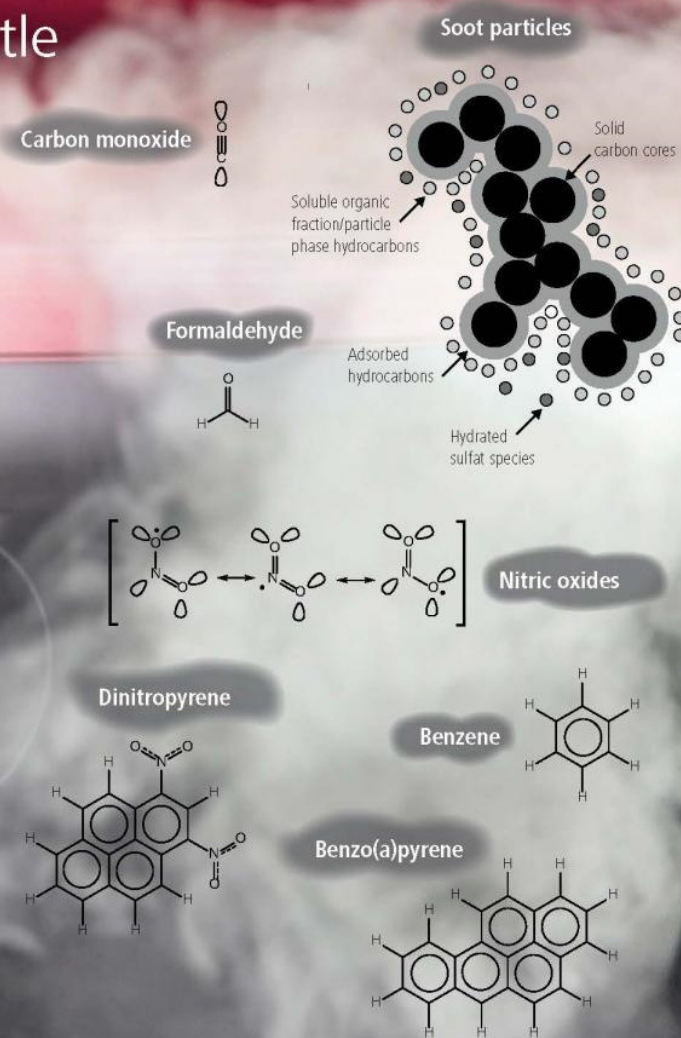
Dinitropyrene is produced in the hot exhaust tract in diesel engines through the reaction between pyrene and NO<sub>2</sub>. 1,3-, 1,6- and 1,8-dinitropyrenes are particularly mutagenic and trigger malignant tumors in many organs in various lab animals.

→ Euro 6 does not specify any limits.

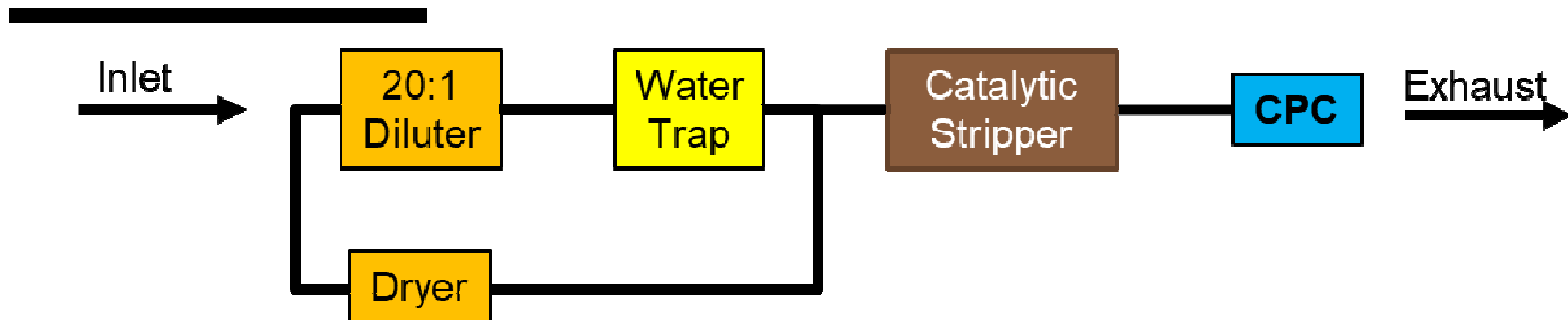
## Benzo(a)pyrene (C<sub>20</sub>H<sub>12</sub>)

Benzo(a)pyren is one of the longest known carcinogenic substances. It is found in cigarette smoke and causes lung cancer. Benzo(a)pyrene is converted chemically in the body. The metabolic product reacts with DNA, which can prevent cell division or cause mutations.

→ Euro 6 does not specify any limits.



# CPC is a component of the measurement system

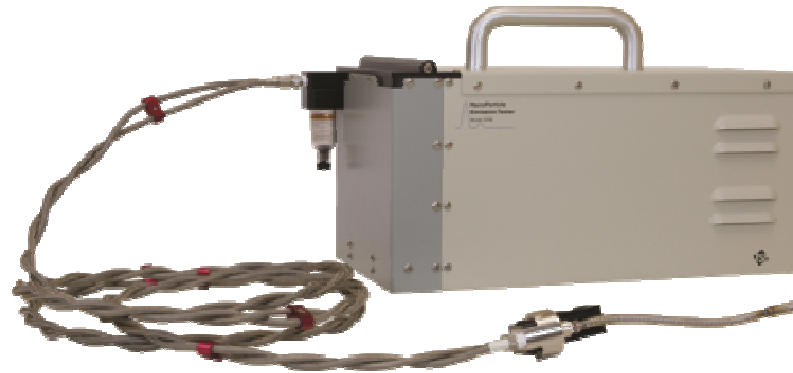


- + Tailpipe exhaust contains solid particles & **volatile** components
  - Need for removing volatiles to avoid condensation
- + Tailpipe exhaust contains high **humidity**
  - Need for drying to avoid condensation – water
- + Tailpipe exhaust can contain a high number of particles
  - Need for dilution



# Already existing instruments

+ NPET – Nanoparticle Emission Tester (TSI 3795)



+ Only **certified** instrument at this time

- METAS certification to stringent requirements of Swiss Regulation SR 941.242 (2014) for NRMM

+ The Netherlands



DPF tests can be done with the TSI NPET“



# Already existing instruments (CPC based)

## + TSI APET (Automotive Particle Emission Tester)

- Laminar flow CPC (Isopropanol)
- Tank for prolonged use (in docking station)
- Accuracy  $\pm 15\%$  absolute
- No zero drift



## + Sensors APA (Automotive Particle Analyzer)

- Mixing CPC (Isopropanol)
- Tank for prolonged use
- Accuracy  $\pm 15\%$  absolute
- No zero drift





# Summary Thank you for your attention!

## Using CPCs in Vehicle Emission Testing

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- + Used already for >20 years in regulatory testing
- + Direct measurement of particles
  - Traceable calibration according to ISO 27891
  - Comparable & defensible results, e.g. from PTI-station to PTI-station
- + CPCs are maintenance free ( $\geq 1$  year)
  - Have been optimized for robustness, e.g. flipping over
  - Infrequent fluid refill, e.g. annually
- + CPCs are built to last - Ready for future changes
  - Addition of gasoline cars
  - Lowering the sensitivity to 10 nm (from 23 nm)

