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Federal Institute of Metrology METAS

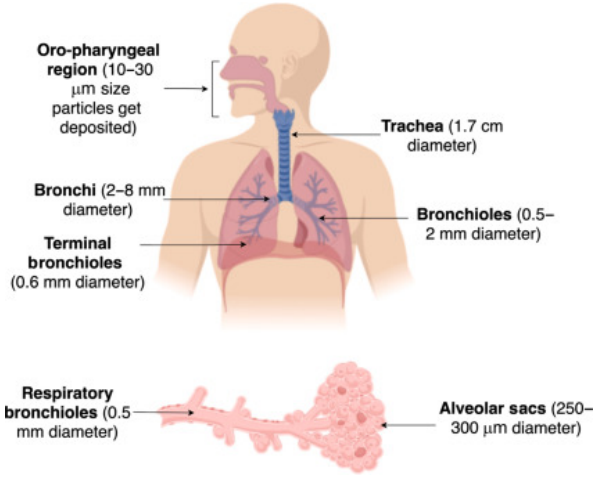
Counting particles in air

Konstantina Vasilatou

CCU/CCQM workshop 29/03/2023

Airborne particles

Particle deposition in the respiratory system



K. Thakur at al. in Targeting Chronic Inflammatory Lung Diseases Using Advanced Drug Delivery Systems, 2020

Particle counting is essential for

- **Emission control**
(e.g. vehicle type-approval, periodic technical inspection of diesel vehicle exhaust in Europe, inspection of ship emissions in Switzerland)

- **Clean room operation**
(e.g. biotechnology and pharma sector, semiconductor manufacturing, operating rooms in hospitals)

- **Bioaerosol monitoring networks**
(allergenic pollen and fungal spores, plant pathogens, invasive species)

- **Research** (e.g. atmospheric or health-related studies)

- Counting of particles in air covered within the technical activities of the CCQM GAWG
- Measurements are reported in terms of particle number concentration (typically as cm^{-3} or m^{-3} but sometimes also as $\#/cm^3$)
- Target values for PN concentration emitted by diesel vehicles legislated in several European countries
- Discussions on whether to include target values for the PN concentration of ultrafine particles in the European Ambient Air Quality Directive 2008/50/EC

Types of commercial particle counters

A. Traditional instruments

Optical particle counters
Aerosol spectrometers
Aerodynamic particle sizers
Condensation particle counters
Diffusion chargers

→ Single particle counting
No particle identification

→ Total (undifferentiated) particle number concentration

B. Hybrid instruments

Optical particle counters
coupled with holography/microscopy
and/or UV-LIF detection
and machine learning

→ Single particle counting
Particle identification and classification

→ Number concentration of different particle types

(Total) number concentration of sub-micrometre particles

CCQM-K150 intercomparison (Draft B, to be published)

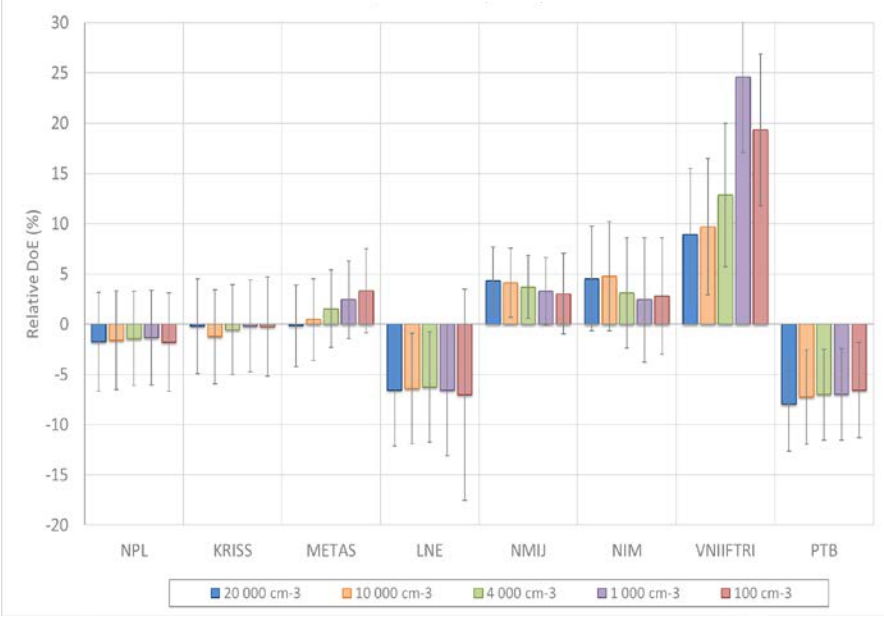


Figure: Condensation Particle Counter comparison results for 40 nm aerosol particles.

Primary standard:
Commercial or custom-made Aerosol Faraday Cup Electrometer (FCAE); measures electric current

Secondary standard:
Condensation particle counter (CPC) calibrated against FCAE according to ISO 27891 standard

SI traceability

↑

Standard of electric current (voltage and resistance)
Standard of gas flow rate

↑

FCAE

Test particles: singly-charged, size-classified → ↑ ← Corrections for multiply charged particles, diffusion losses, flow splitter bias etc.

CPC

State of the art

CMCs available in the range 100 cm^{-3} - 20'000 cm^{-3}

New CMC claims submitted for extended range 1 cm^{-3} – 60'000 cm^{-3} *

Relative expanded uncertainties (95 % confidence level) down to 2-3 %

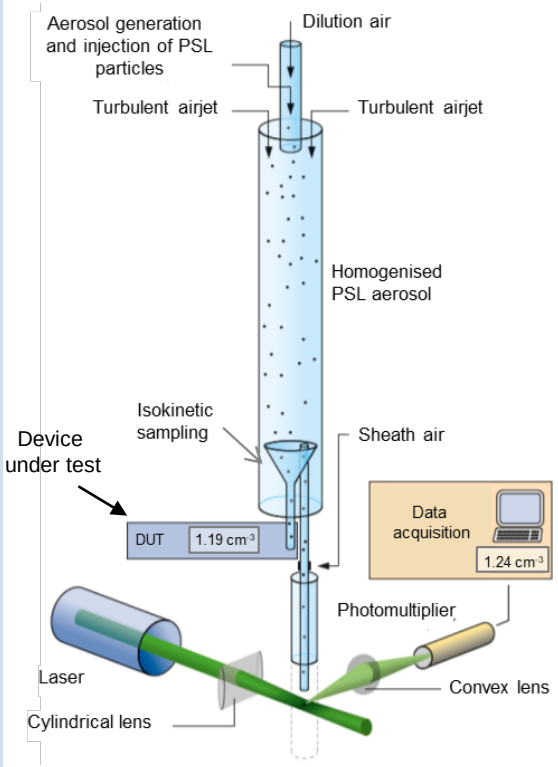
Typical particle size (mobility diameter): 23 nm – 200 nm

Validation of CPC calibration procedures through intercomparisons is necessary for identifying possible systematic errors when converting electric current to particle number

* H. Sakurai, Y. Murashima, K. Iida, C. Wälchli, K. Auderset and K. Vasilatou, Traceable methods for calibrating particle counters at concentrations down to 1 cm^{-3}, *Metrologia,* in review

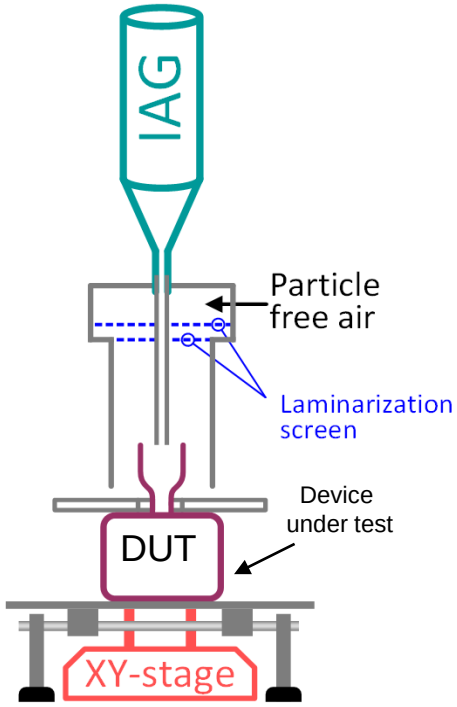
(Total) number concentration of micrometre-sized particles

METAS (DFM)



Horender et al. *Rev. Sci. Instrum.* **90**, 075111 (2019)

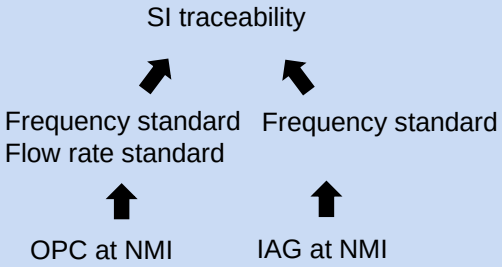
NMIJ (NIM)



Iida et al., *Aerosol Science & Technology* **48**,789–802 (2014)
Iida and Sakurai, *Aerosol Science & Technology* **52**, 1156 (2018)

Primary standards for particle counting

Custom-made optical particle counter (METAS)
Modified commercial OPC (DFM)
Inkjet Aerosol Generator (NMIJ, NIM)



Validation through intercomparisons is essential for identifying possible systematic errors related to particle sampling

Vasilatou et al., *Metrologia* **57**, 025005 (2020)
Vasilatou et al., *Journal of Aerosol Science* **157**, 105818 (2021)
Vasilatou et al., *Aerosol Science & Technology* **57**, 24–34 (2022)

Relevant documentary standards:
ISO 21501-1 & ISO 21501-4

State of the art

Traceable measurement of number concentration in the range 0.01 cm^{-3} – 800 cm^{-3}
Relative expanded uncertainties (95 % confidence level) of 2-9 %, CMCs available
Particle diameter range: 100 nm – 15 µm

Summary of part A

A. Traditional instruments

Optical particle counters
Aerosol spectrometers
Aerodynamic particle sizers
Condensation particle counters
Diffusion chargers

→ Single particle counting
No particle identification

→ Traceability of **total** PN concentration ✓

(challenges at PNC <0.05 cm^{-3} or >100'000 cm^{-3} and for particle diameters >15 µm)

Hybrid instruments (micrometre-sized particles)

- Hybrid instruments (i.e. coupled to machine learning) for bioaerosol monitoring

Rapid-E (Plair, Switzerland)
Elastic light scattering
UV-LIF
Machine learning

Poleno (Swisens, Switzerland)
Elastic light scattering
Holography
UV-LIF
Machine learning

BAA500 (Helmut Hund, Germany)
Microscopy
Machine learning

Aerotape (Oberon, France)
Microscopy
Machine learning

PS-400 (Pollen Sense, USA)
Microscopy
Machine learning

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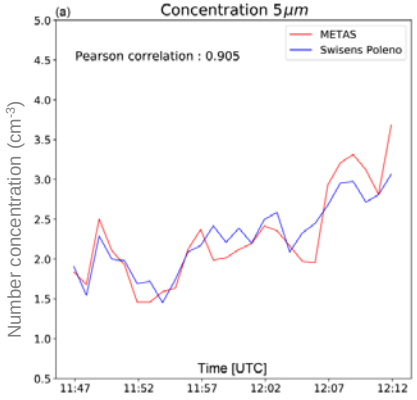
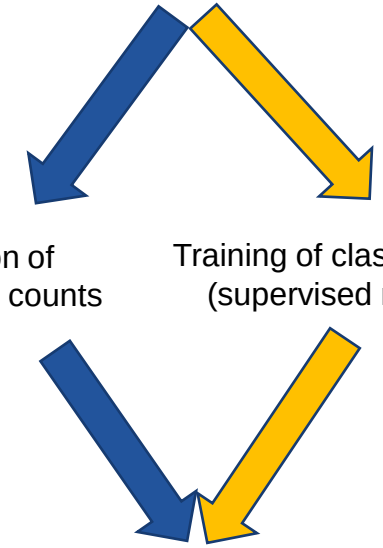
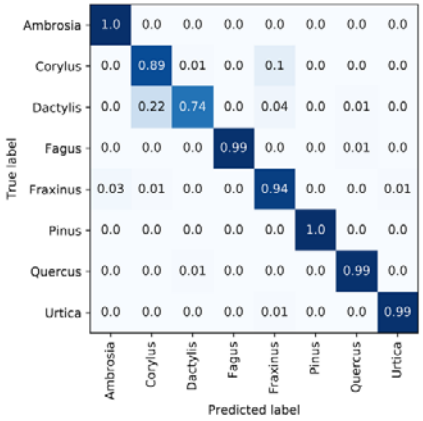




Calibration of total particle counts

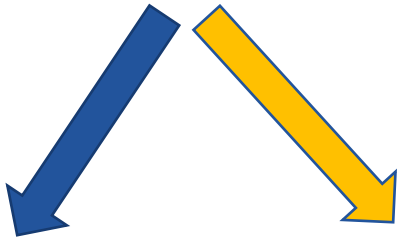
Training of classification algorithms (supervised machine learning)

Number concentration of different particle types



B. Hybrid instruments (micrometre-sized particles)

Hybrid instrument



Calibration of total particle counts (see slide 5)

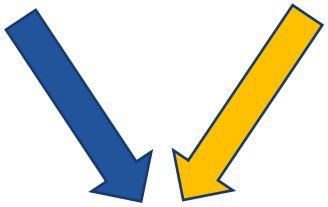
Challenges
Particle sizes >15 µm
Number concentrations <0.5 cm^{-3}
Need for more realistic test aerosols

Lieberherr et al., *Atm. Meas. Techn.* **14**, 7693–7706 (2021)

Training of classification algorithms with well-defined aerosols (supervised machine learning)

Challenges
Limited to a small (but growing) number of particle types
Quantification of uncertainties related to particle classification

Sauvageat et al., *Atm. Meas. Techn.* **13**, 1539–1550 (2020)
Sauliene et al., *Atm. Meas. Techn* **12**, 3435–3452 (2019)
Erb et al., *Aerobiologia*, 10.1007/s10453-023-09780-z (2023)



Particle number concentration of different particle types

Challenges
How do we combine and report uncertainties?
How do we estimate uncertainties of field measurements?

Commercial particle counters

A. Traditional instruments

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→ Single particle counting
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→ Traceability of **total** particle number concentration ✓

(challenges at PNC <0.05 cm^{-3} or >100'000 cm^{-3} and particle sizes >15 µm)

B. Hybrid instruments

Optical particle counters
coupled with holography/microscopy
and/or UV-LIF detection
and machine learning

→ Single particle counting
Particle identification and classification

→ Potential for full SI-traceability: number concentration of different particle classes !

Collaboration between aerosol and data scientists needed!

Thank you very much for your attention