The Number Concentration of Non-Volatile Particles
Design Study for an Instrument According to the PMP Recommendations

Markus Kasper
Matter Engineering, Wohlen, Switzerland

The increasing use of diesel particulate filters (DPF) as the most effective exhaust aftertreatment method to reduce particle emissions from internal combustion engines emphasizes the need for new particle measurement methods beyond gravimetric. Following a guideline of the Swiss EPA to extend particle measurement to particle size, number concentration and surface concentration, a group of European countries, joined by Japan, have initiated a large-scale investigation of particle metric and measurement methods, the "Particulate Measurement Programme" (PMP). Under the auspicies of the UNECE Group of Experts on Pollution and Energy (GRPE), PMP aims at finding a particle metric that is more sensitive to the toxicologically relavant submicron particles and that is to supplement, or even replace, gravimetric as future certification standard for particle emissions.
The particle metric and corresponding measurement system recommended after phase I and II of GRPE-PMP is the number concentration of non-volatile exhaust particles, to be measured with a combination of thermo-diluter and condensation nucleus counter (CNC). This paper presents a design study for an integrated instrument according to the PMP recommendations. Thermo-dilution as particle conditioning concept is explained and compared to alternative methods such as hot diluter and thermo-desorber. Particle number as preferred metric is discussed as well as the suggested instrument, CNC, and some of its challenges. Along with issues of principal and scientific interest, the measurement system must fulfill very practical usability criteria when used as certification instrument, such as robustness, ease of use, and moderate cost.

The Number Concentration of Non-Volatile Particles

Design Study for an Instrument According to the PMP Recommendations

Markus Kasper

Matter Engineering AG

7th ETH Conference on Combustion Generated Nanoparticles,
Zürich, August 19, 2003

GRPE-PMP Phase II Report

Recommendation to measure

the number concentration of

solid (non-volatile) particles

CVS + ThermoDiluter + CPC

Ref [1]

The Scope

- Why Number?
- CPC - Commonly Preferred Consensus?
- ThDil - No Nanodroplets Allowed
- NanoMet-C - All in One

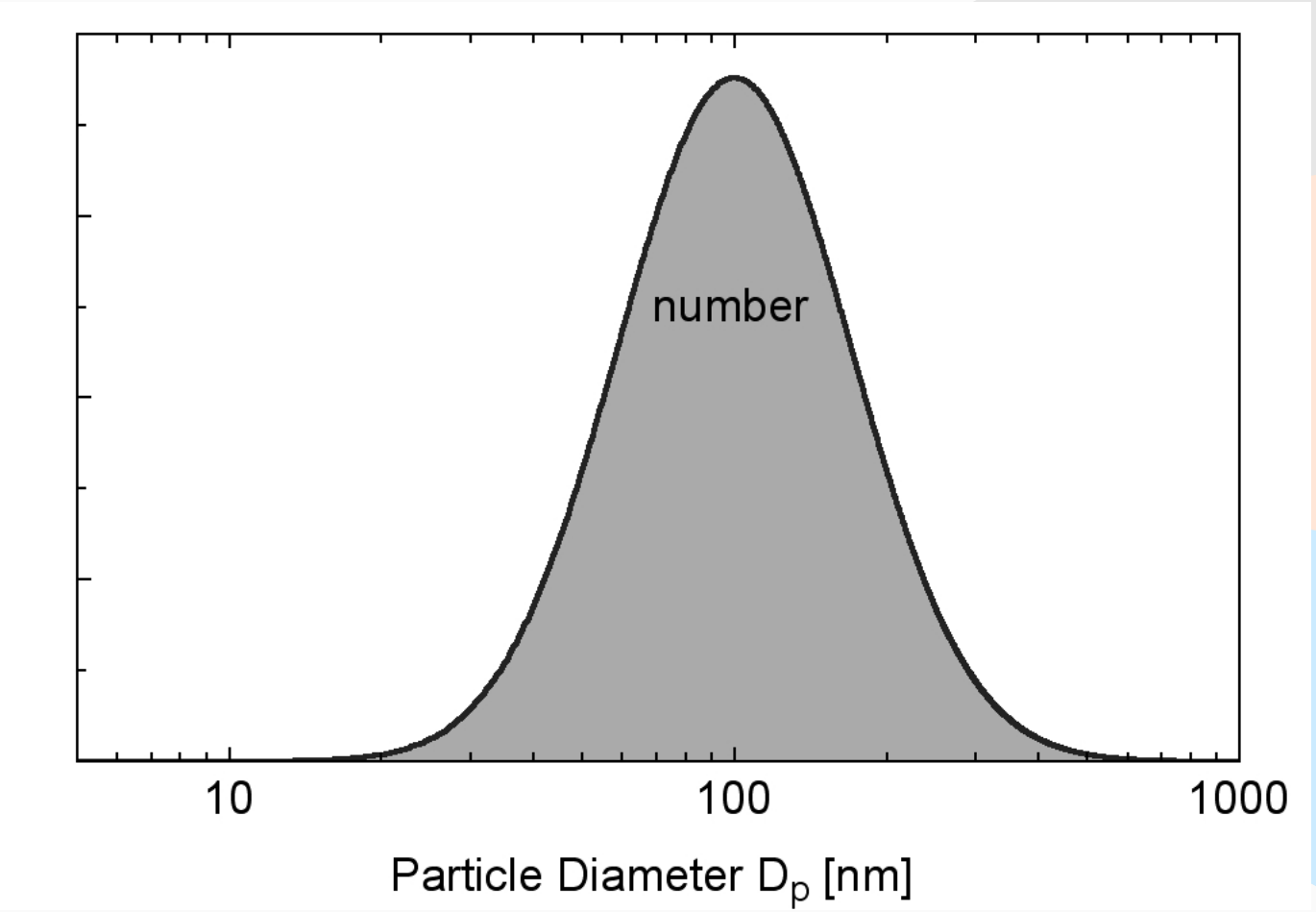
The Scope

- Why Number?
- CPC - Commonly Preferred Consensus?
- ThDil - No Nanodroplets Allowed
- NanoMet-C - All in One

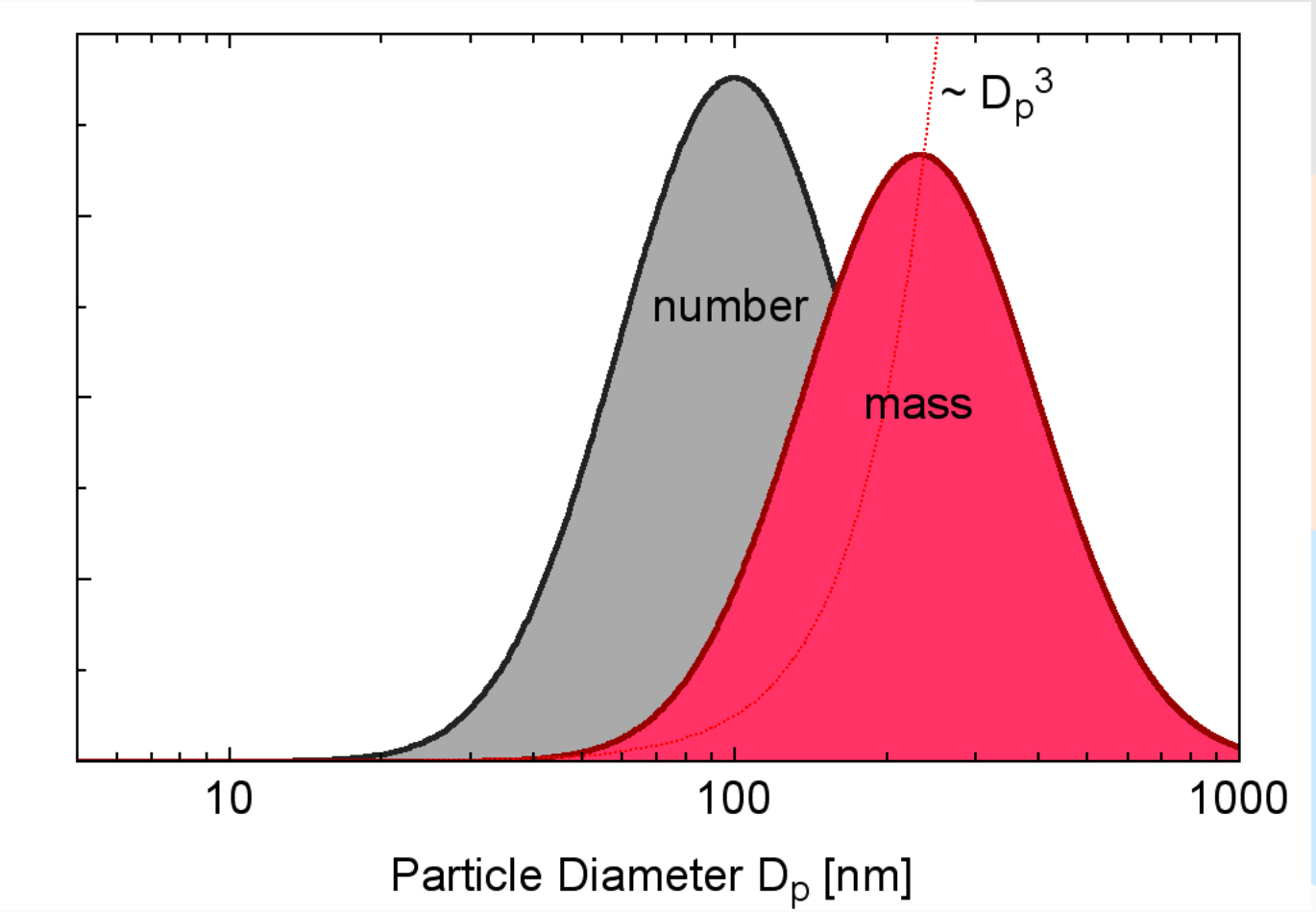
Available Particle Metrics

- mass (PM, EC)
- active surface
- total aerosol length
- number
- ?

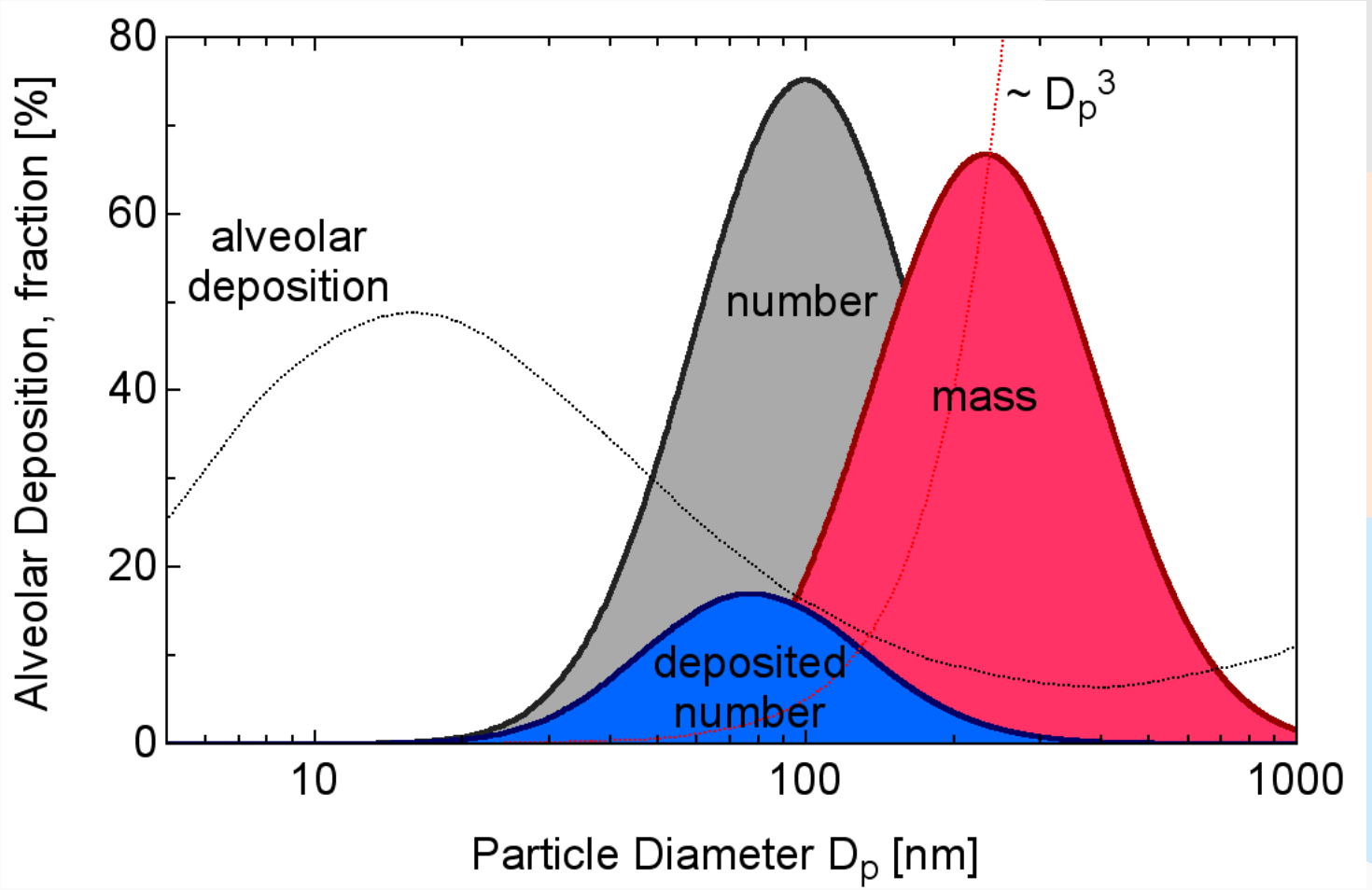
Why Prefer Number to Mass?



Why Prefer Number to Mass?

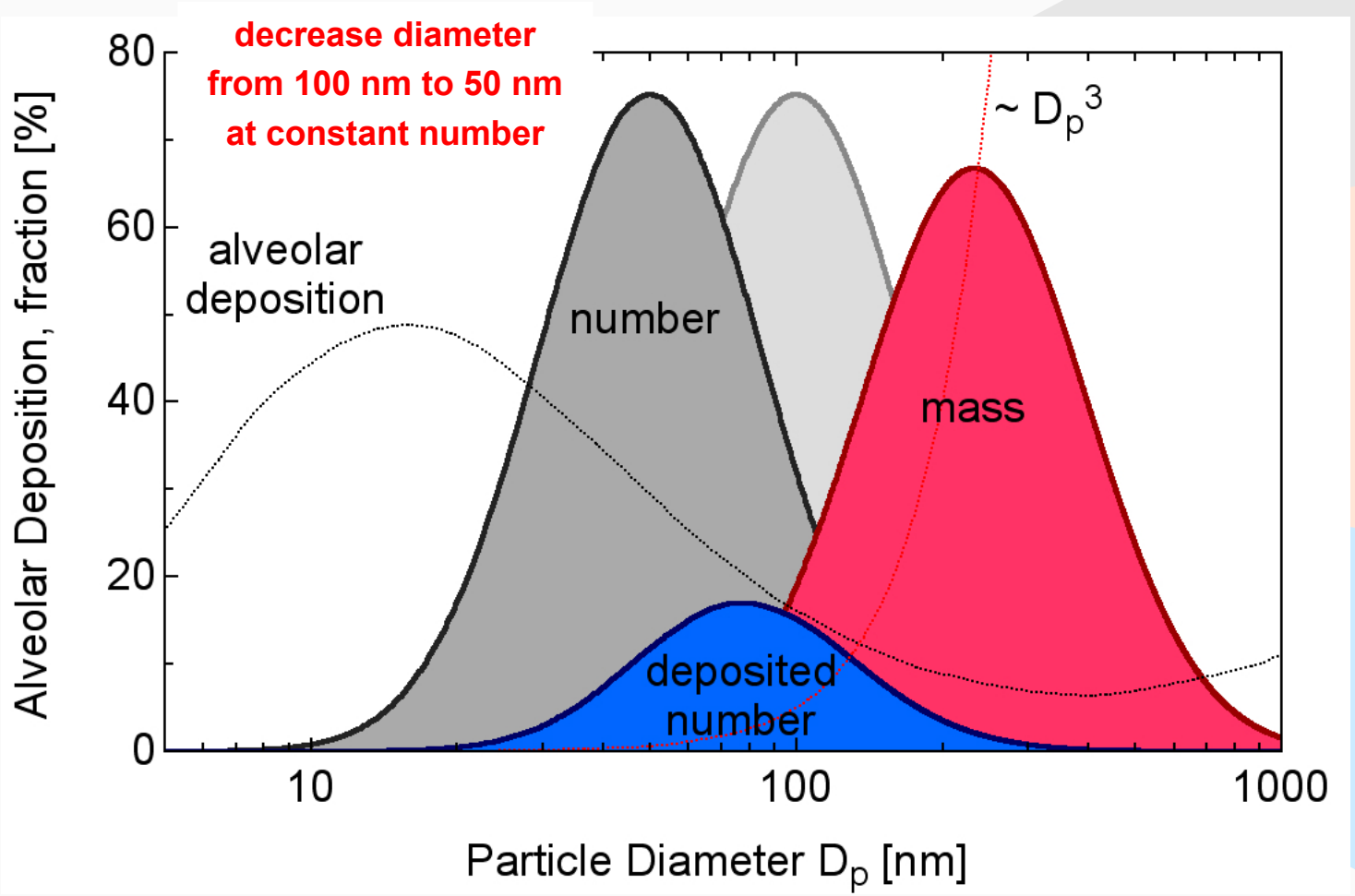


Why Prefer Number to Mass?

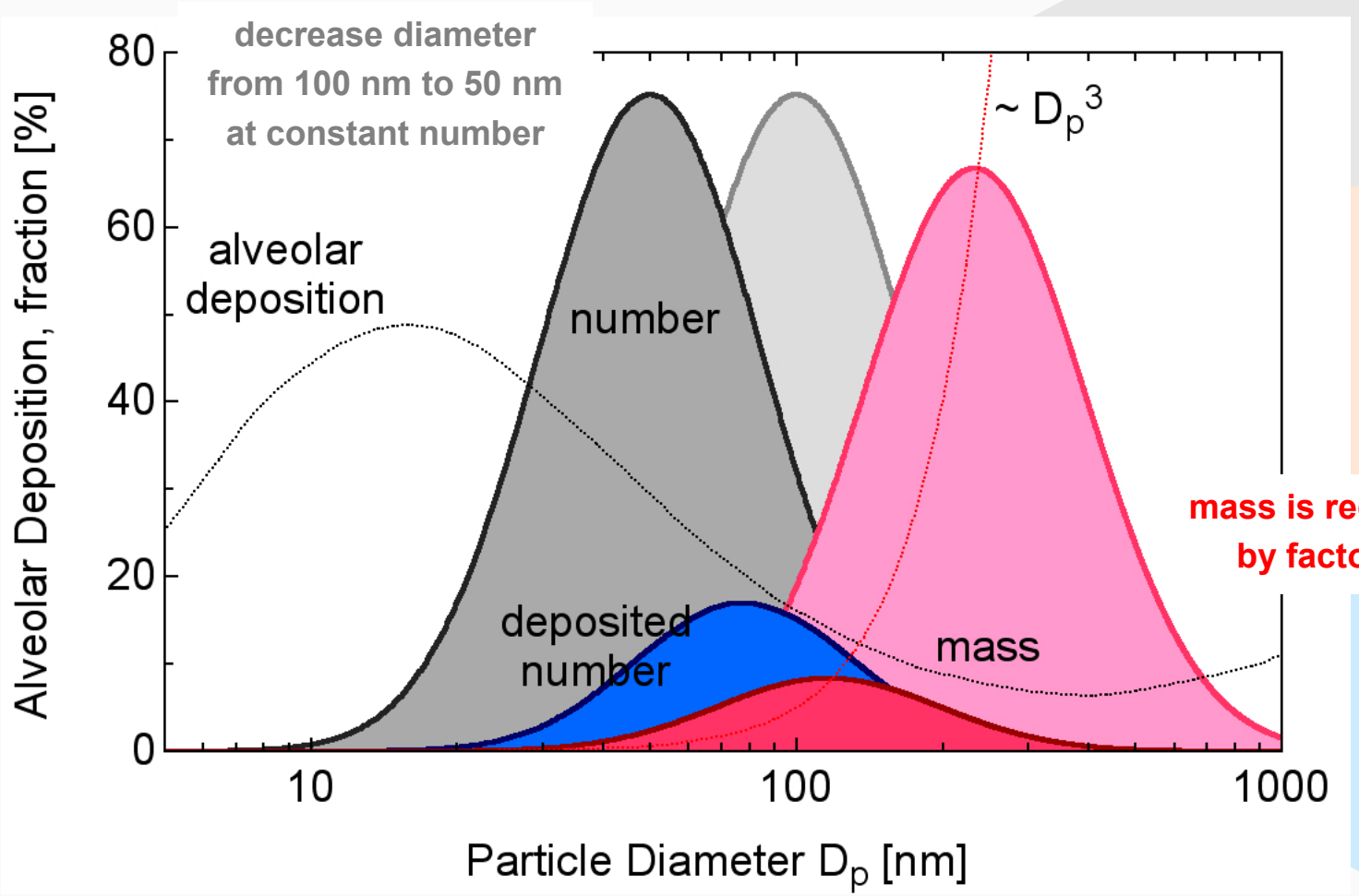


Ref [2]

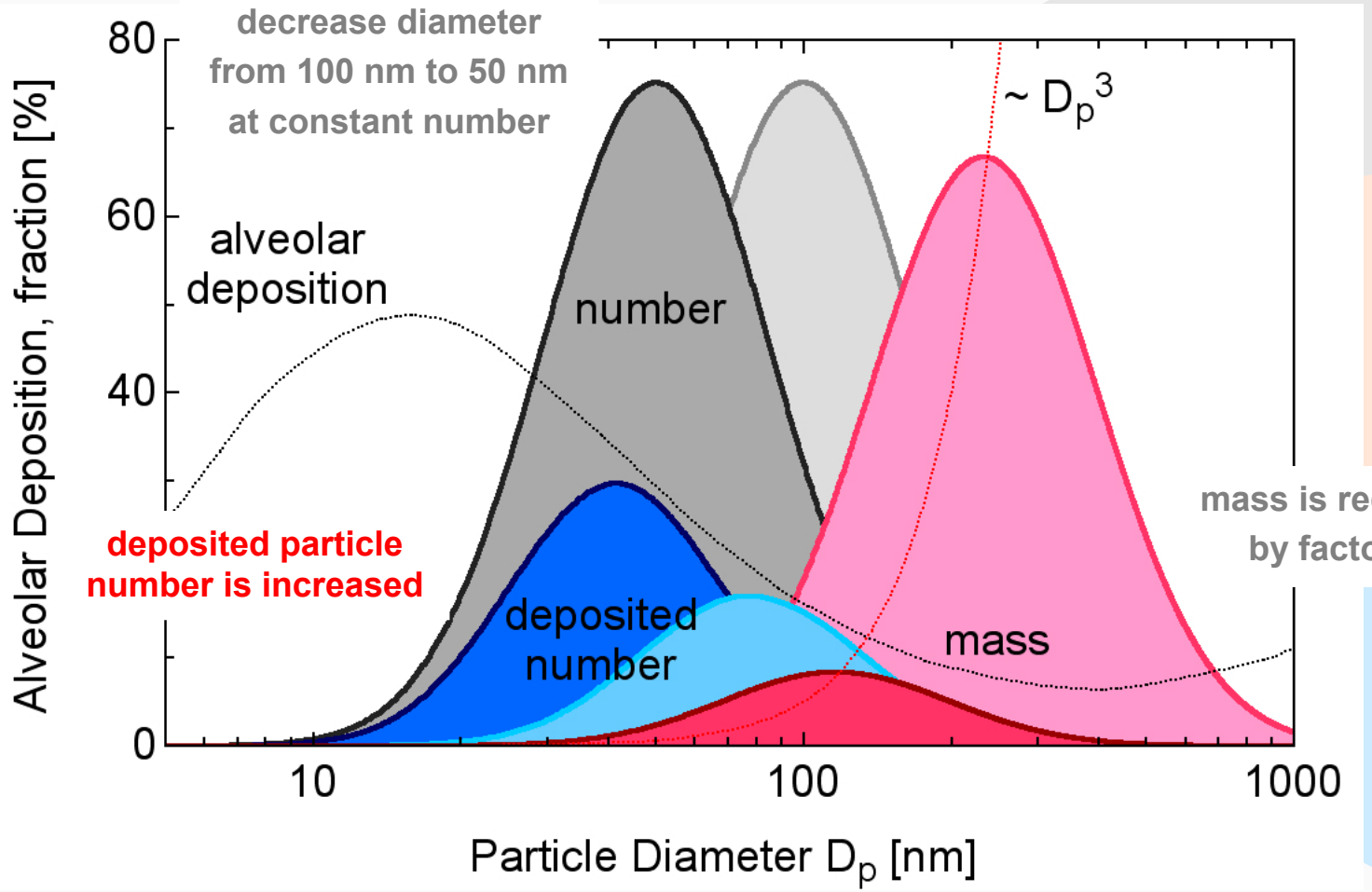
Why Prefer Number to Mass?



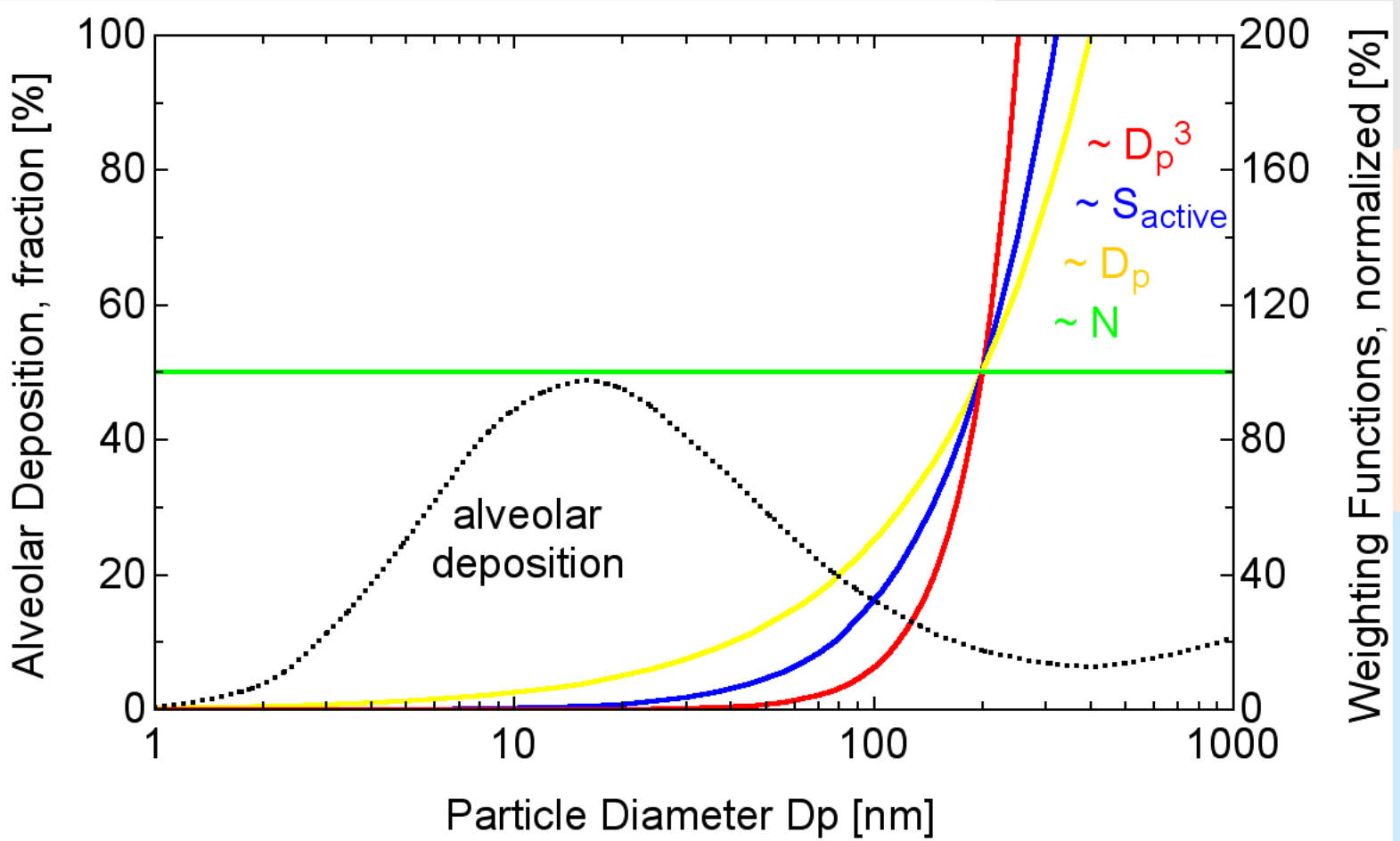
Why Prefer Number to Mass?



Why Prefer Number to Mass?



Weighting Functions: Vol, S_{act}, D_p, N



Ref [2]

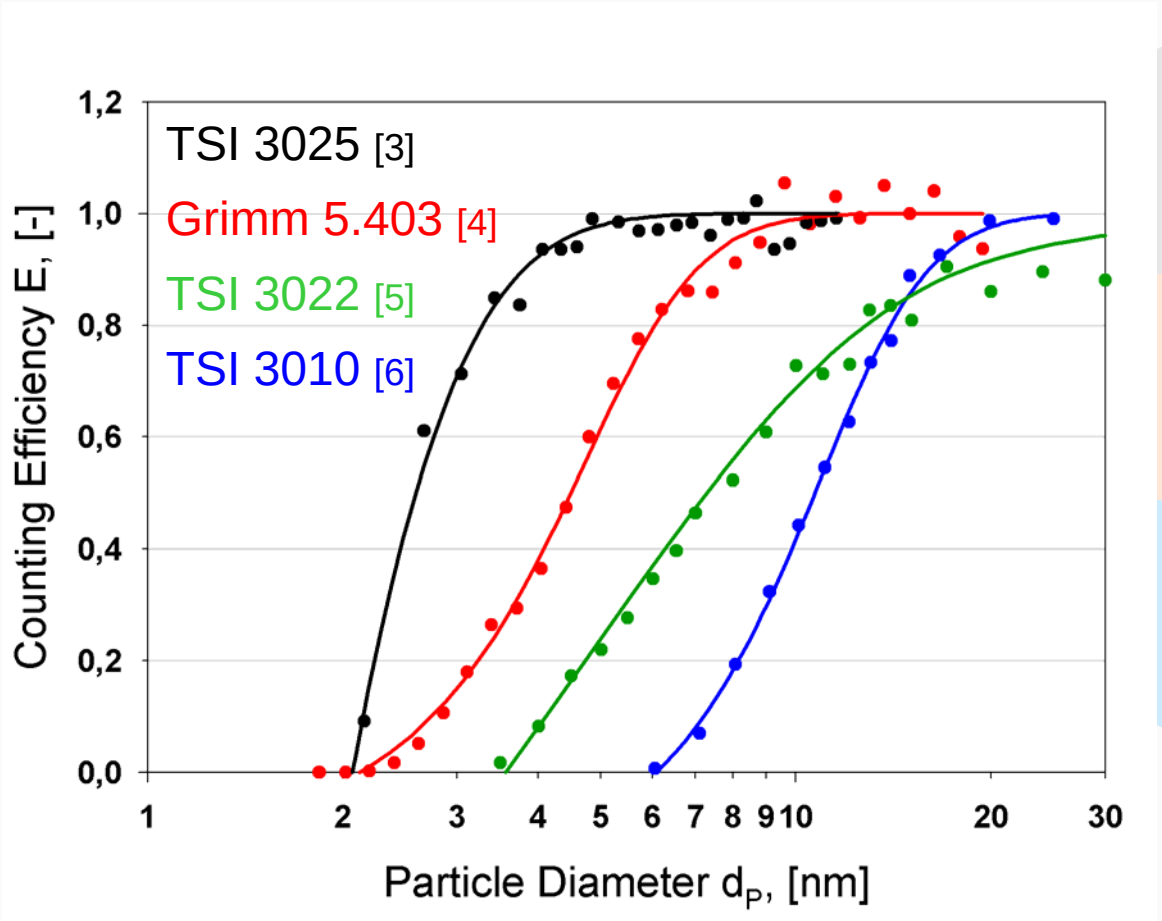
The Scope

- Why Number?
- CPC - Commonly Preferred Consensus?
- ThDil - No Nanodroplets Allowed
- NanoMet-C - All in One

Instruments to Measure “Number”

- CPC (Condensation Particle Counter)
- DMS, SMPS, ELPI, EDB – integrated
- ...

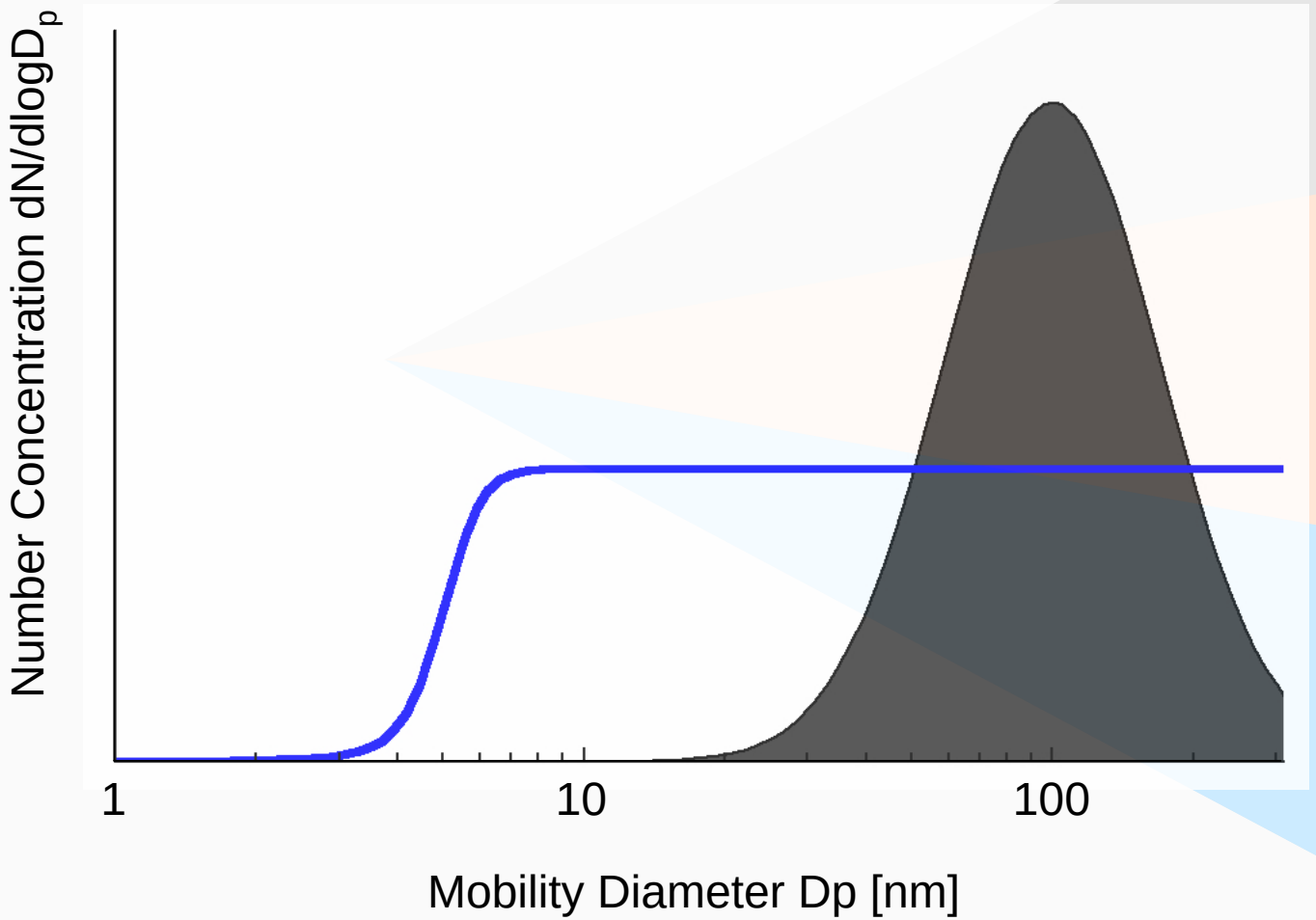
CPC Effective Count Rate



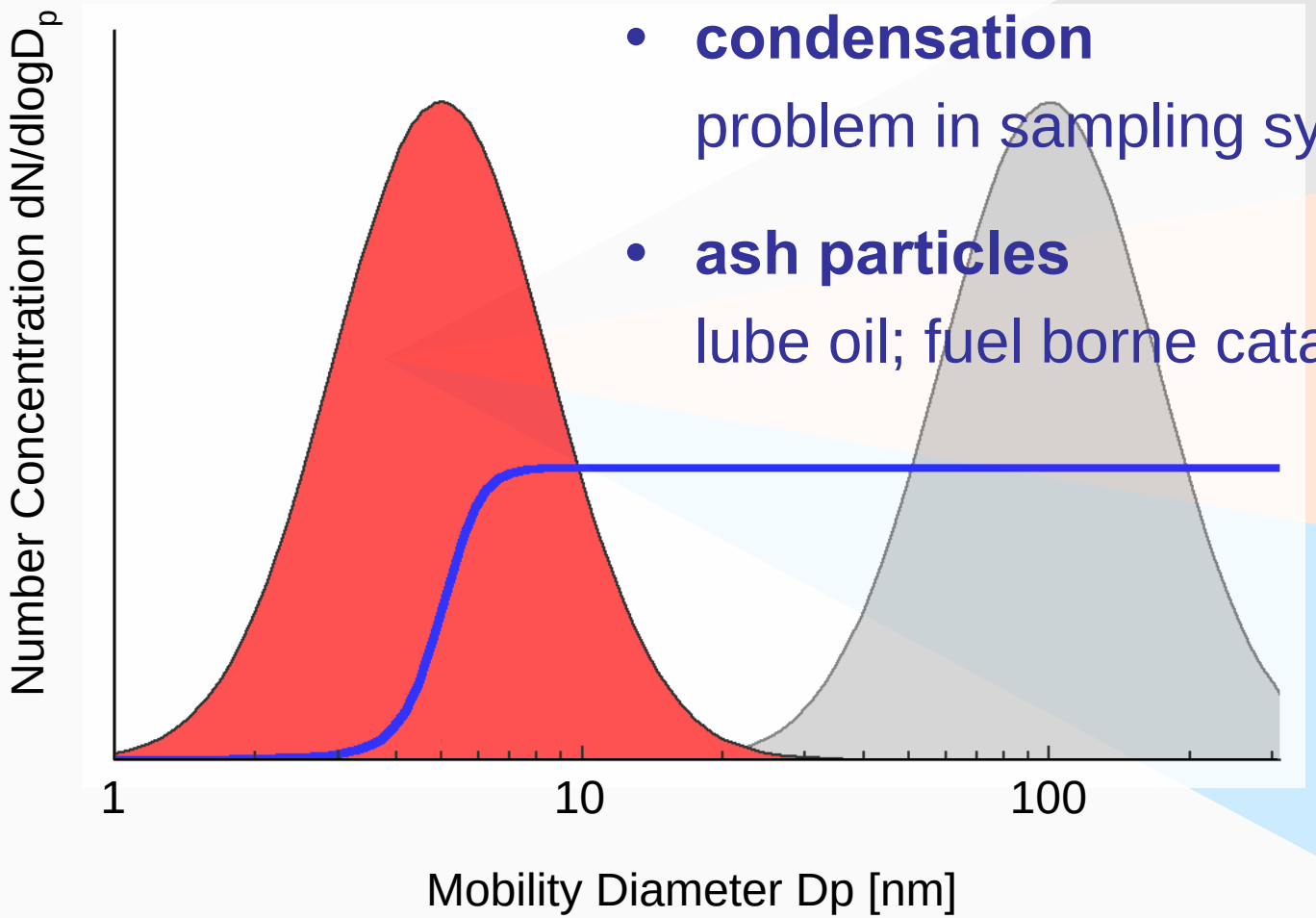
- **cut-off at low diameters**
- **due to working principle of CPC**

Ref [3, 4, 5, 6]

CPC Effective Count Rate



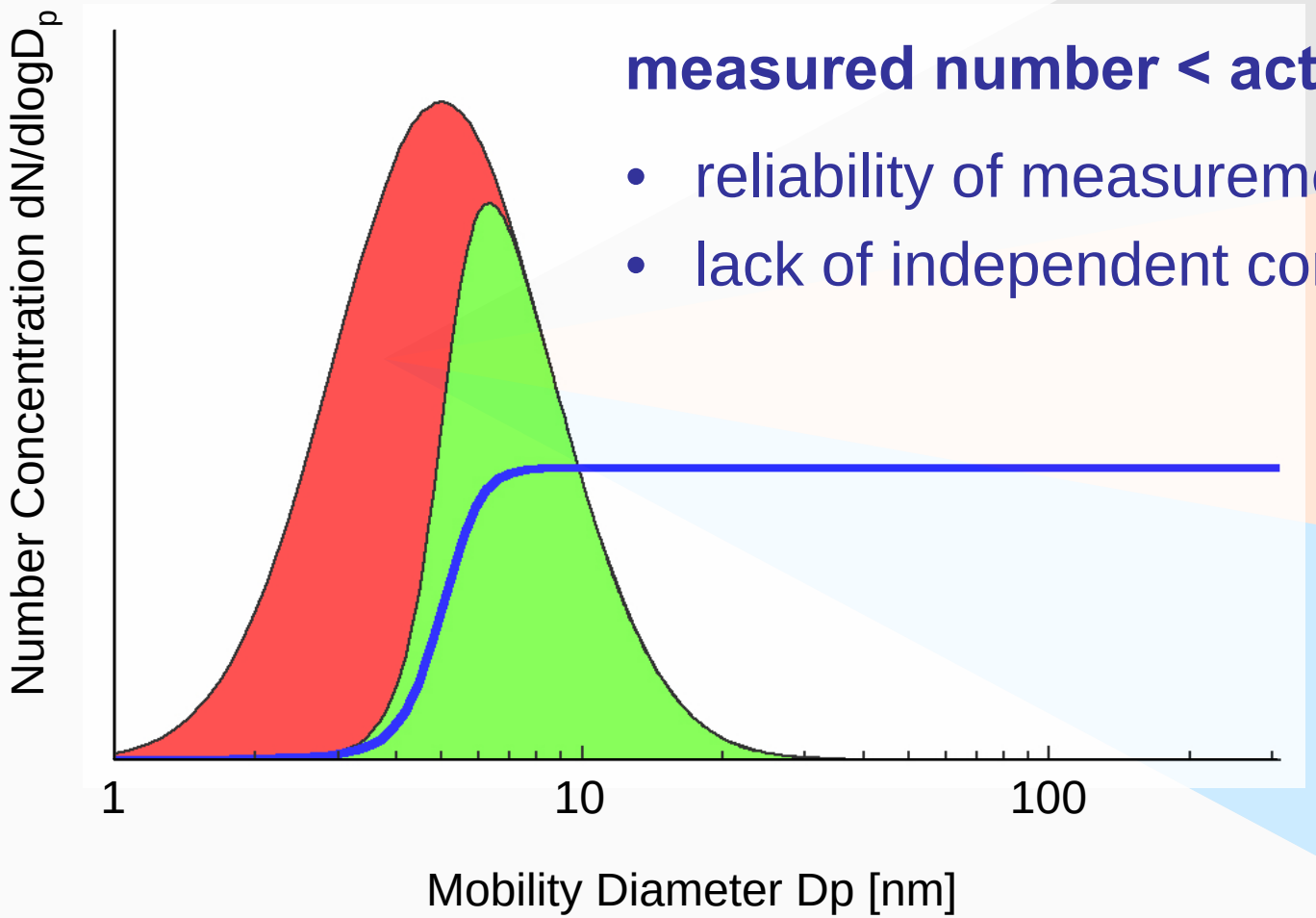
CPC Effective Count Rate



- **condensation**
  problem in sampling system
- **ash particles**
  lube oil; fuel borne catalysts

Ref [7]

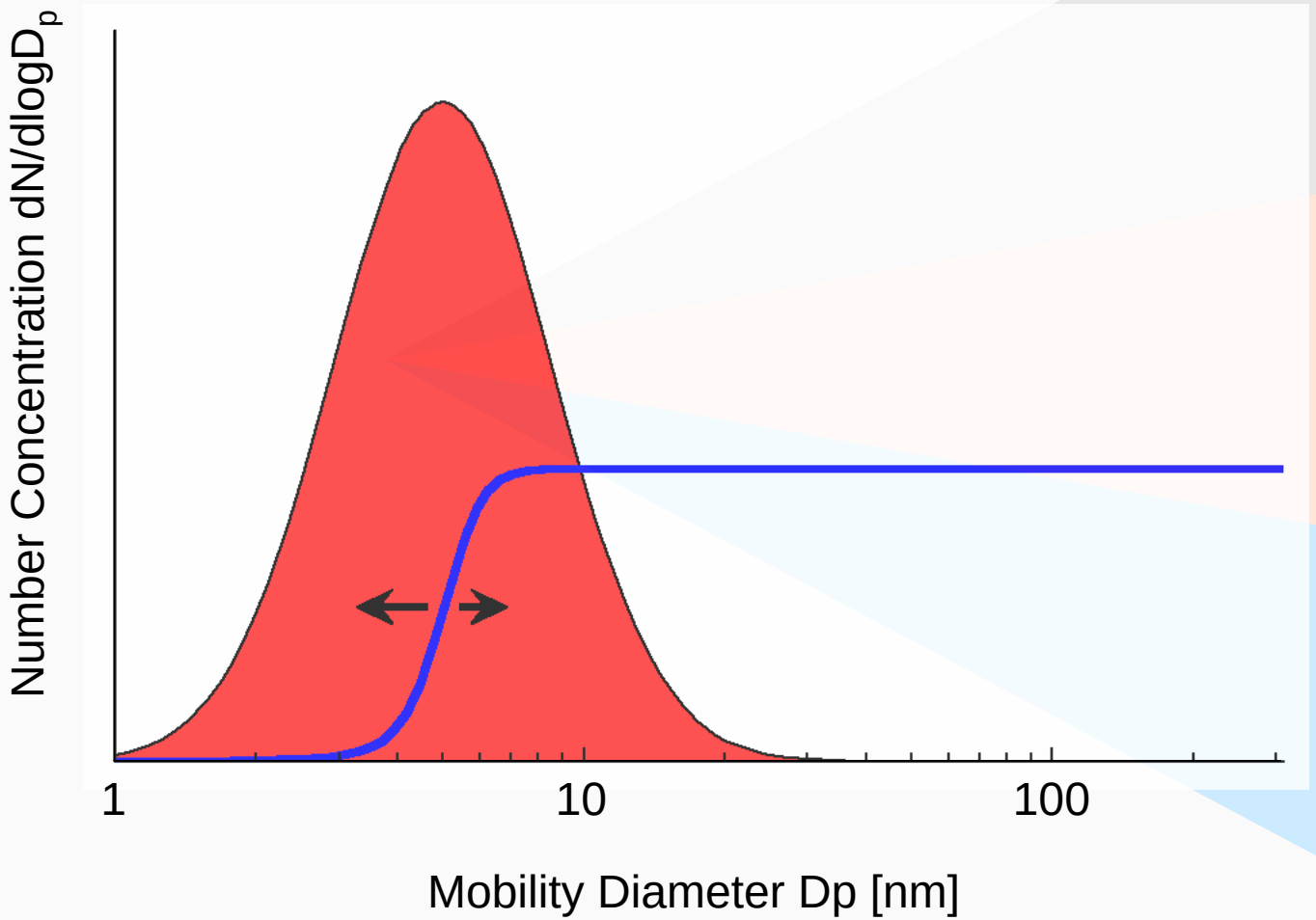
CPC Effective Count Rate



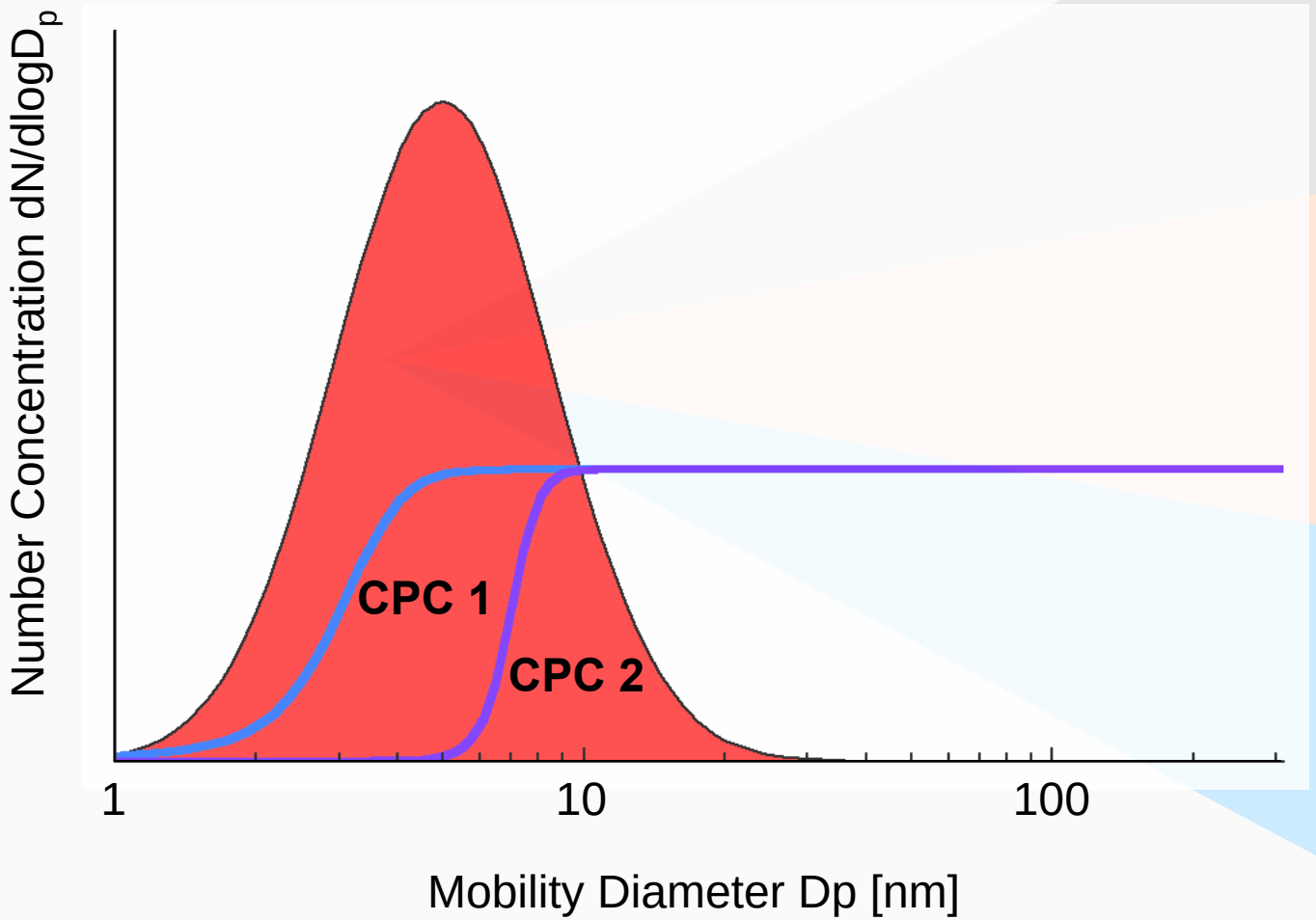
measured number < actual number

- reliability of measurement?
- lack of independent control

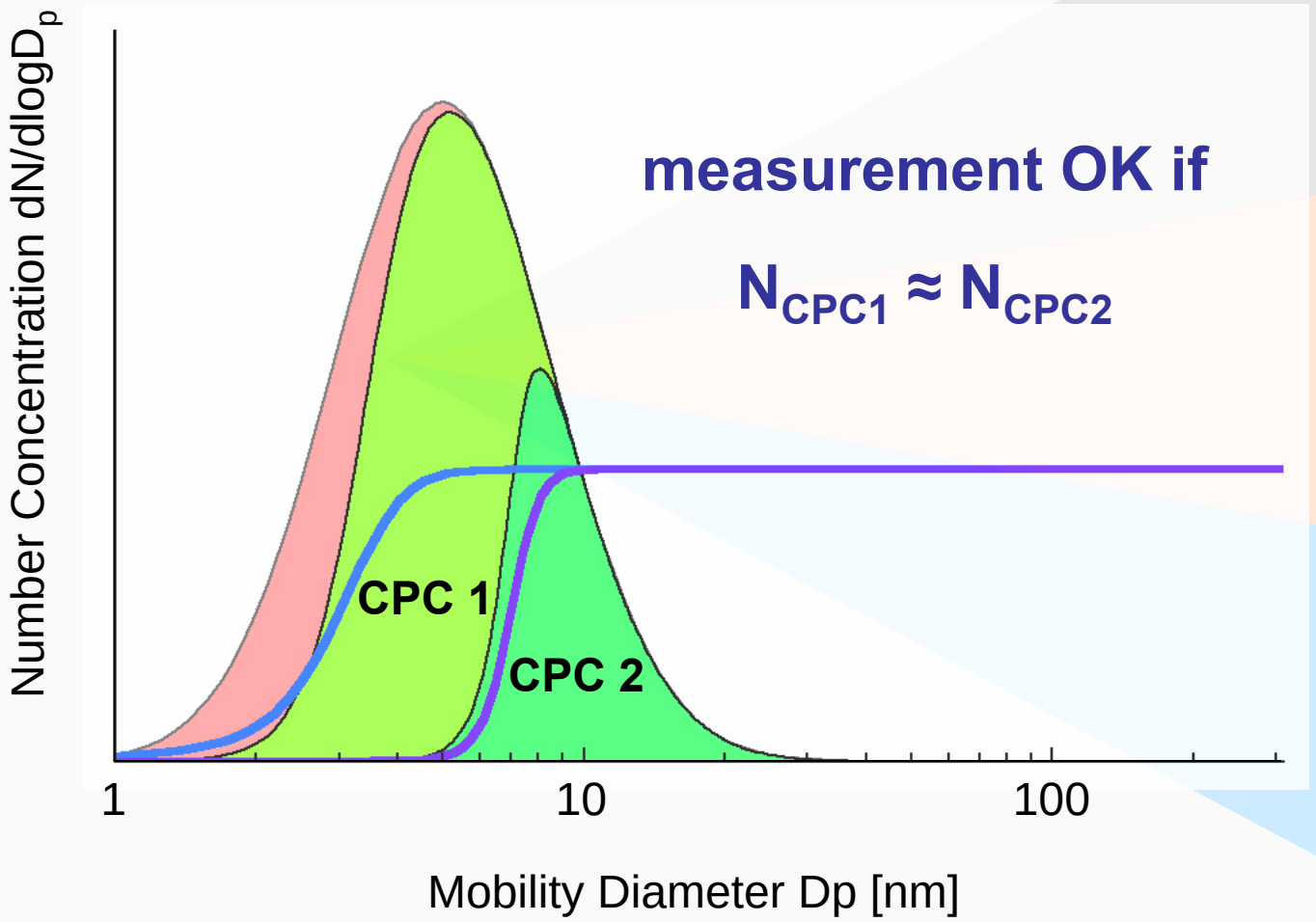
CPC Effective Count Rate



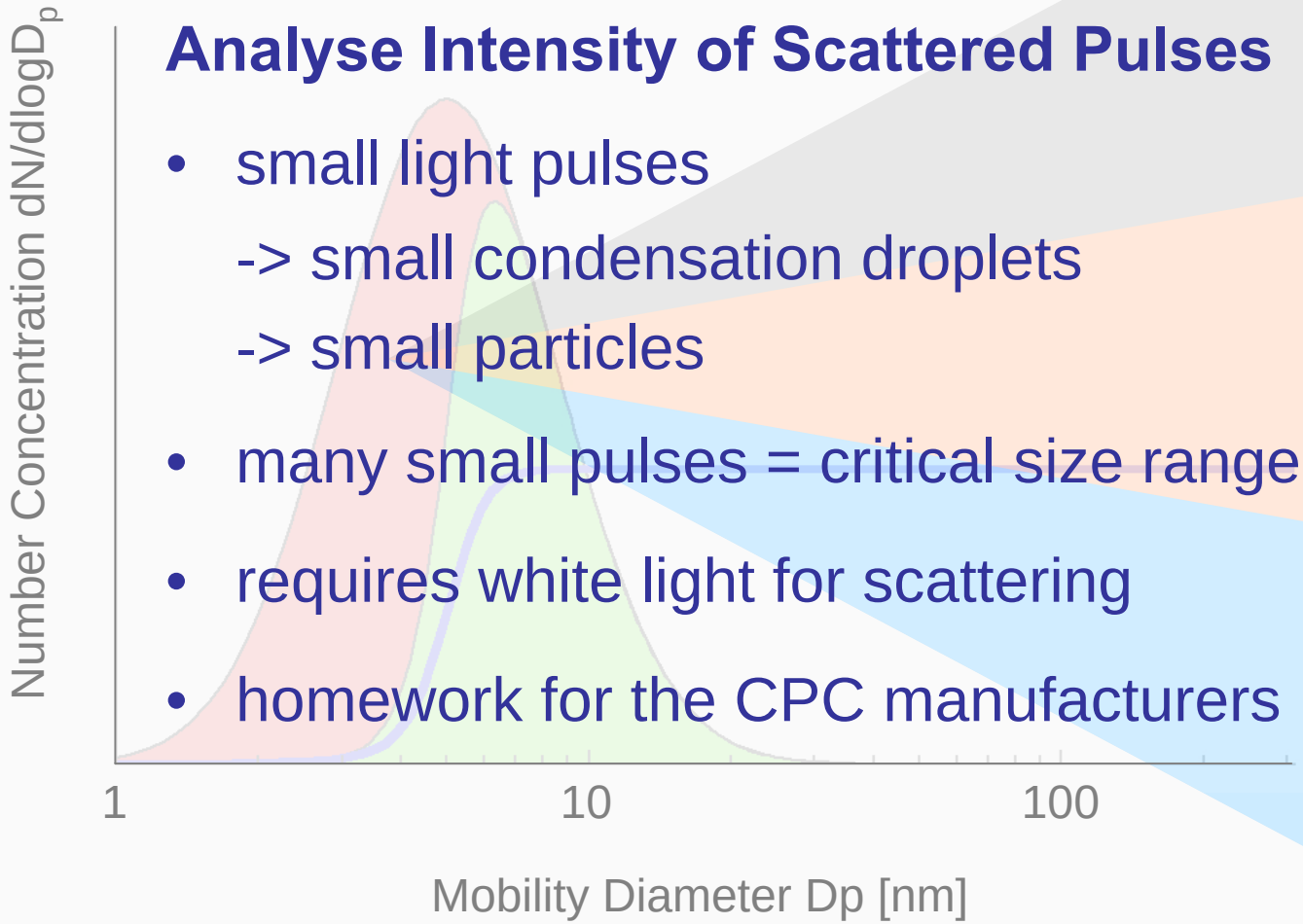
CPC Effective Count Rate



CPC Effective Count Rate



CPC Effective Count Rate



Analyse Intensity of Scattered Pulses

- small light pulses
  -> small condensation droplets
  -> small particles
- many small pulses = critical size range
- requires white light for scattering
- homework for the CPC manufacturers

The Scope

- Why Number?
- CPC - Commonly Preferred Consensus?
- ThDil - No Nanodroplets Allowed
- NanoMet-C - All in One

Why Separate Volatiles from Solids?

solid particles (soot, ash)

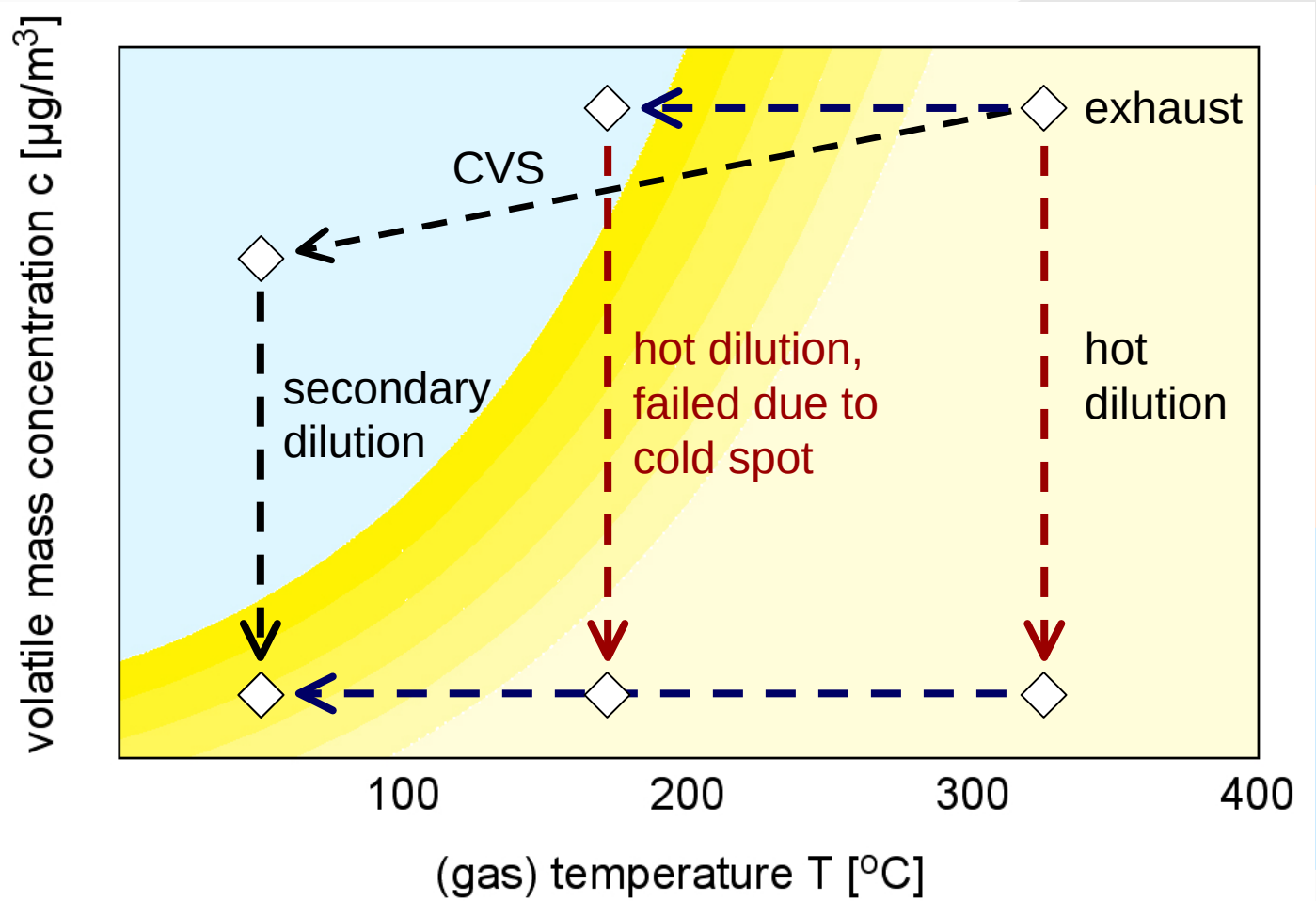
- insoluble
- health effect by “existence”
- limit number concentration

volatile droplets (sulfate, HC, water)

- soluble
- health effect by toxic components
- limit substance specific mass concentration

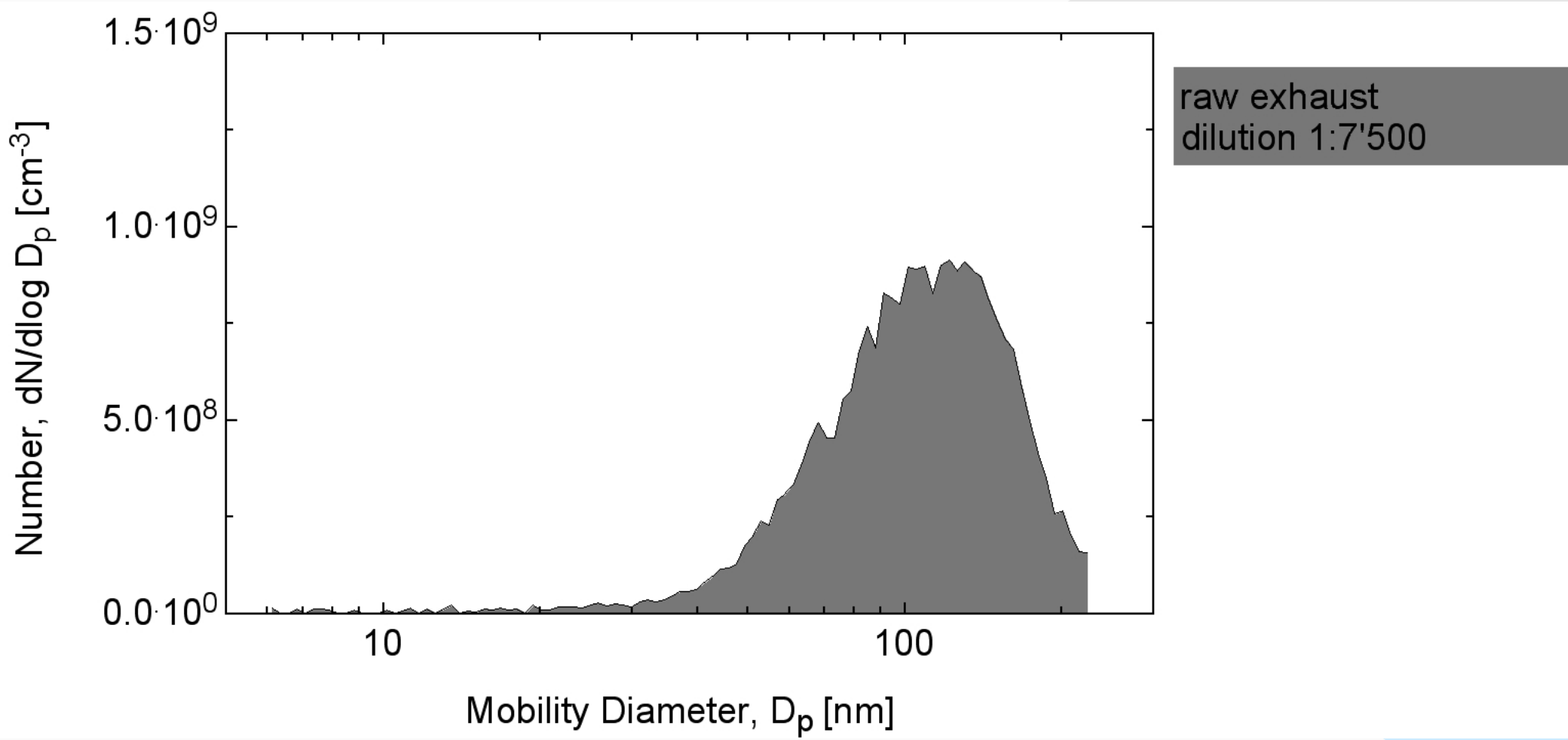
Ref [8]

From Vapor to Droplet to Vapor

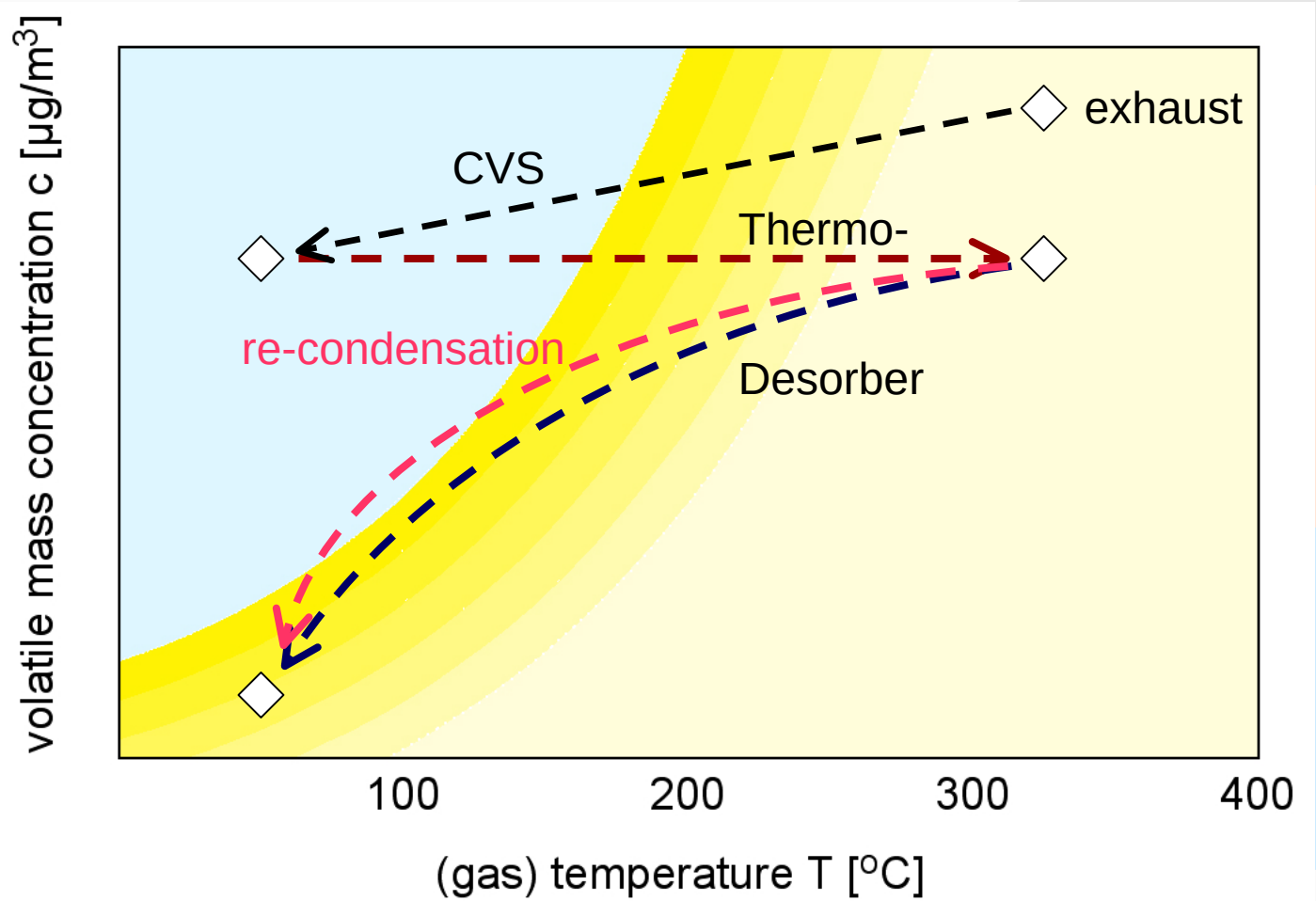


Ref [2]

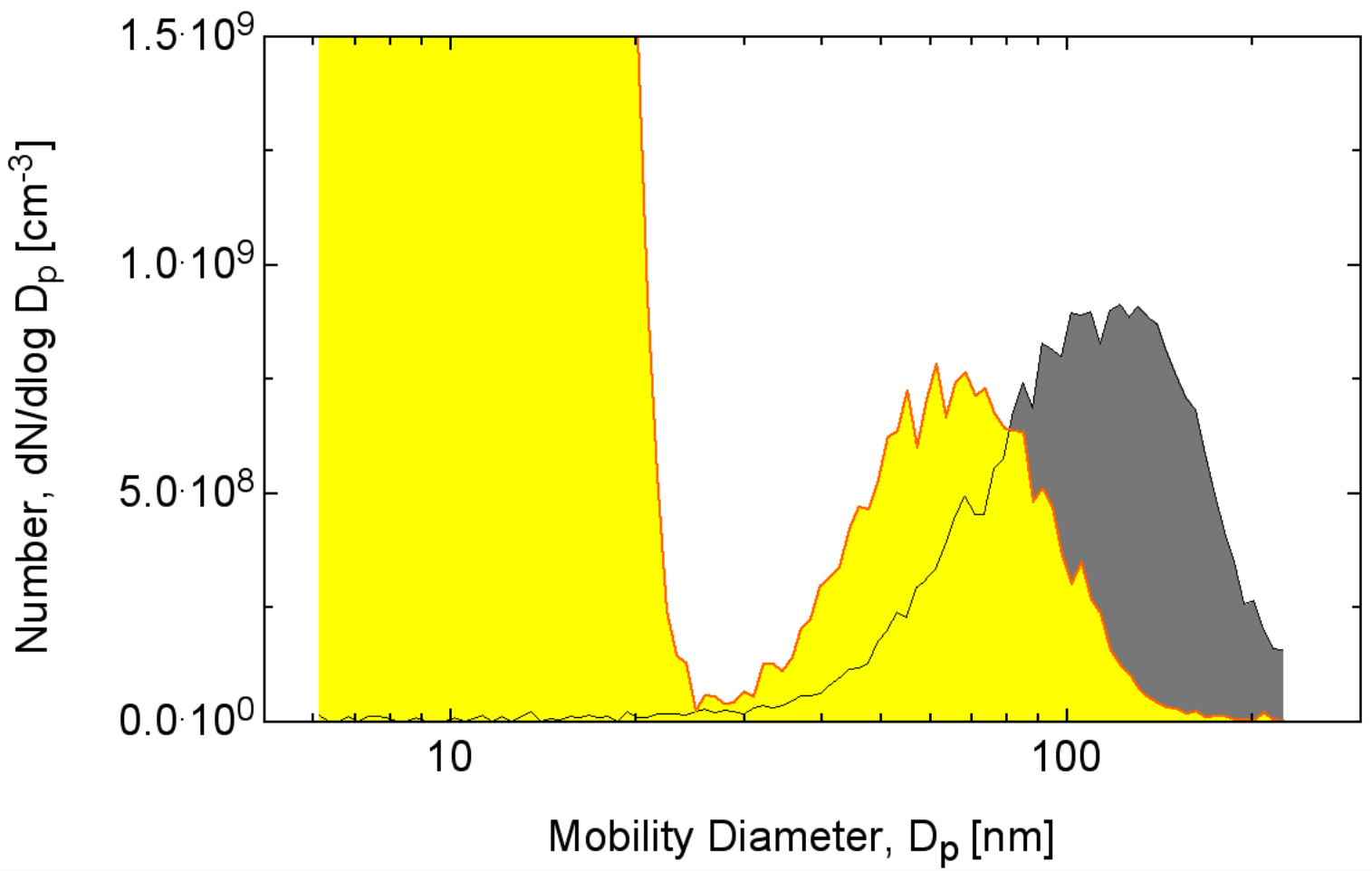
Results: Exhaust from a 2-Stroke Scooter



From Vapor to Droplet to Vapor



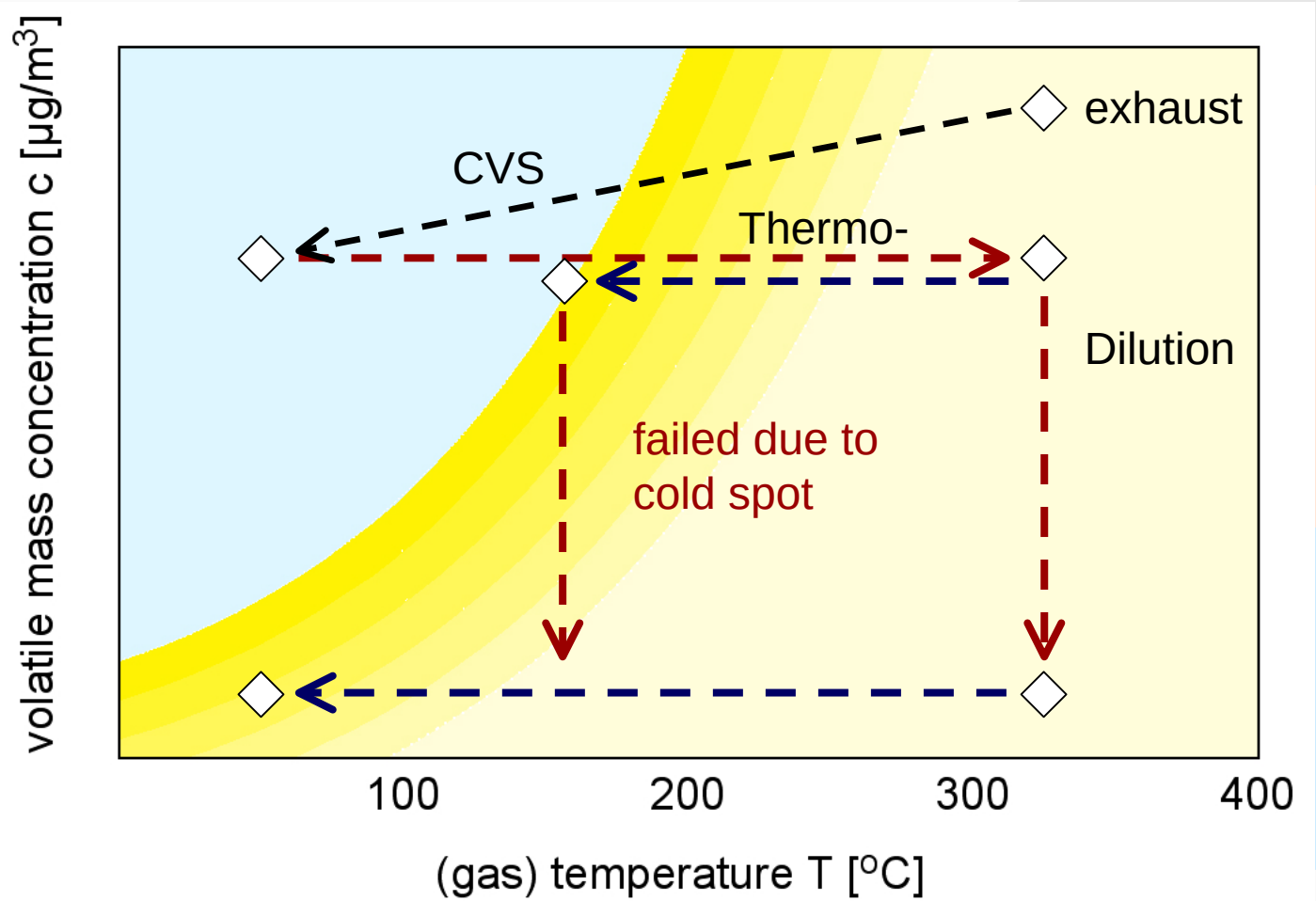
Results: Exhaust from a 2-Stroke Scooter



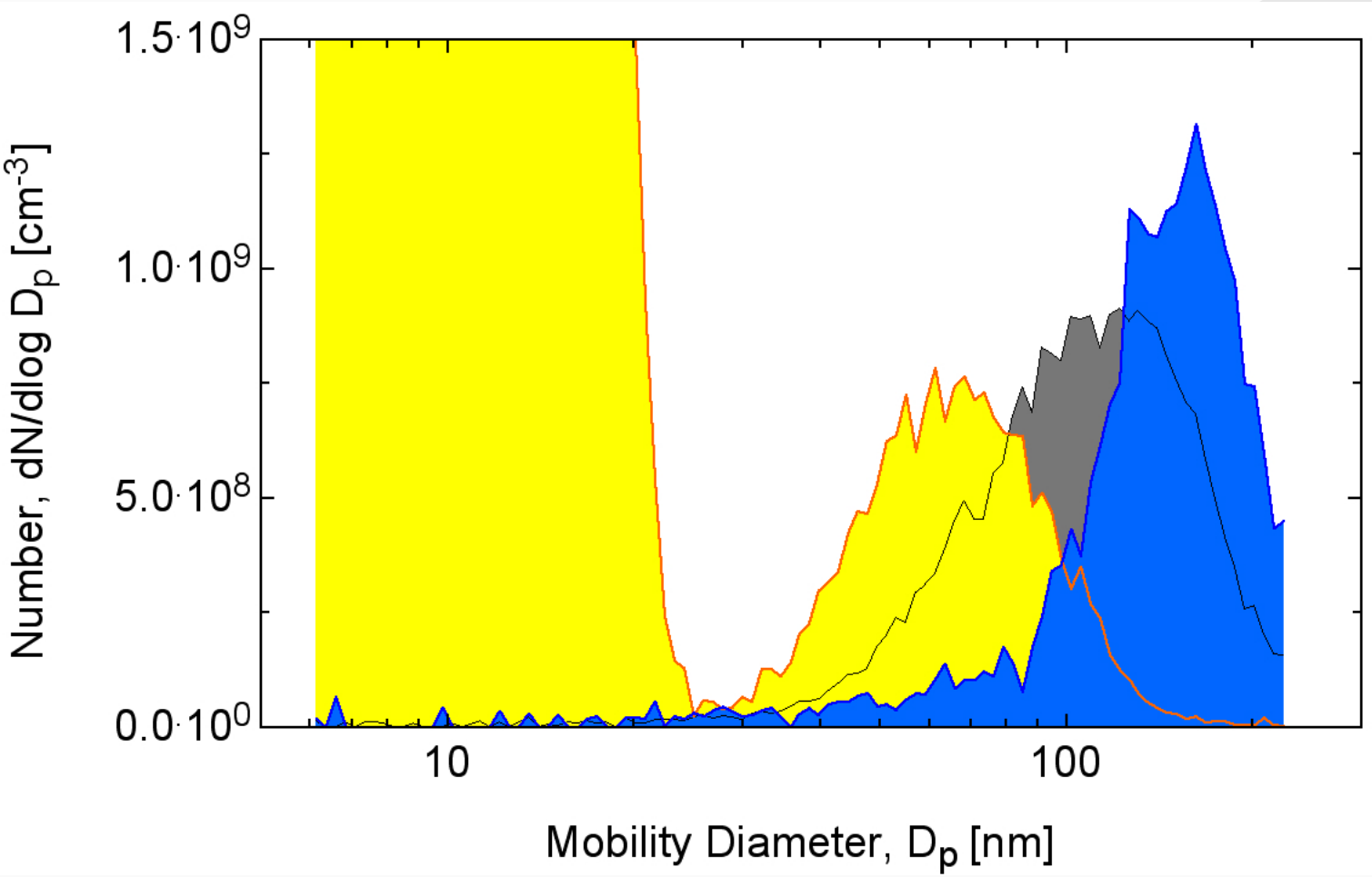
raw exhaust
dilution 1:7'500

ThermoDesorber
after diluter (1:7'500)

From Vapor to Droplet to Vapor



Results: Exhaust from a 2-Stroke Scooter

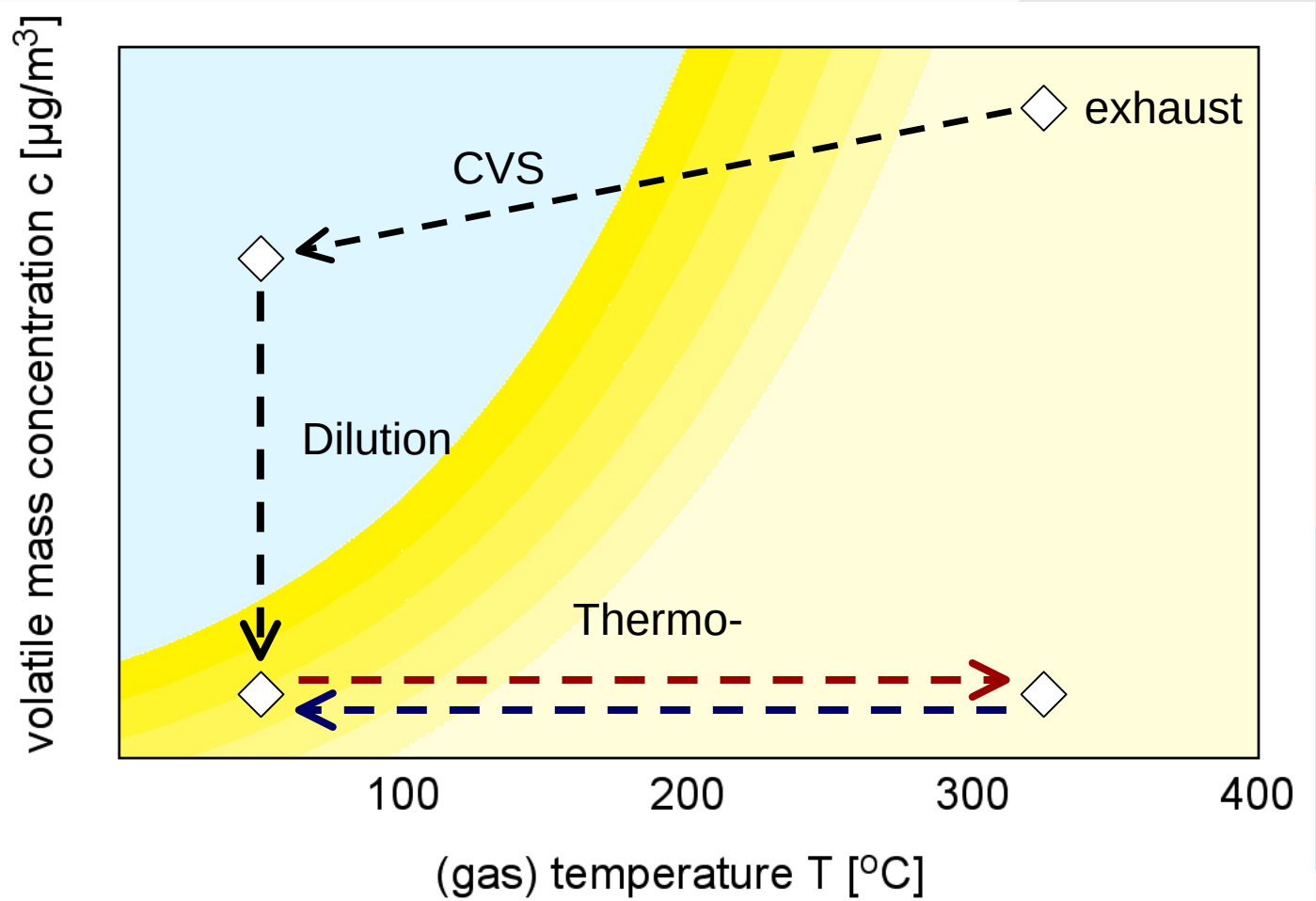


raw exhaust
dilution 1:7'500

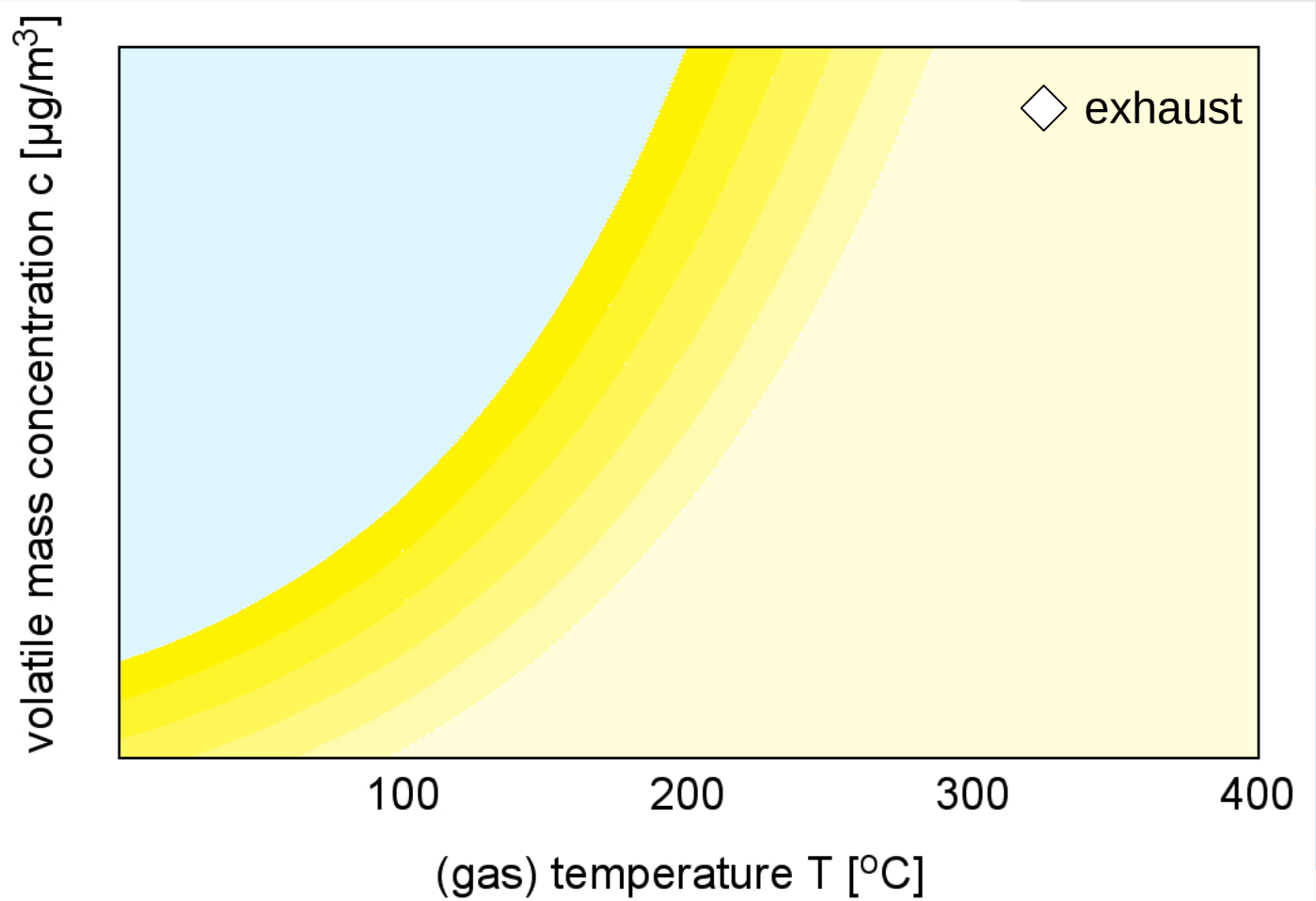
ThermoDesorber
after diluter (1:7'500)

ThermoConditioner
before diluter (1:15'000)

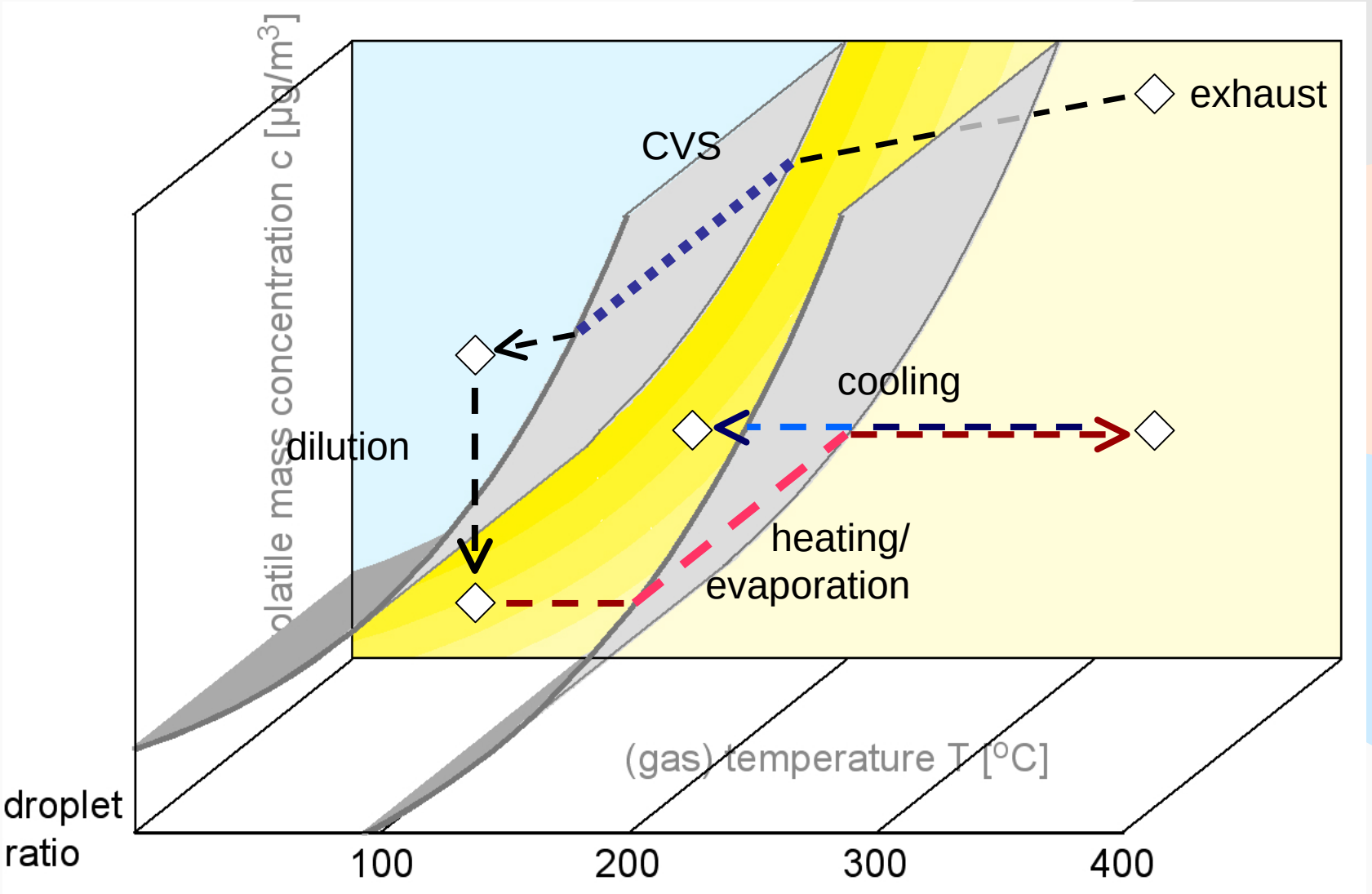
From Vapor to Droplet to Vapor



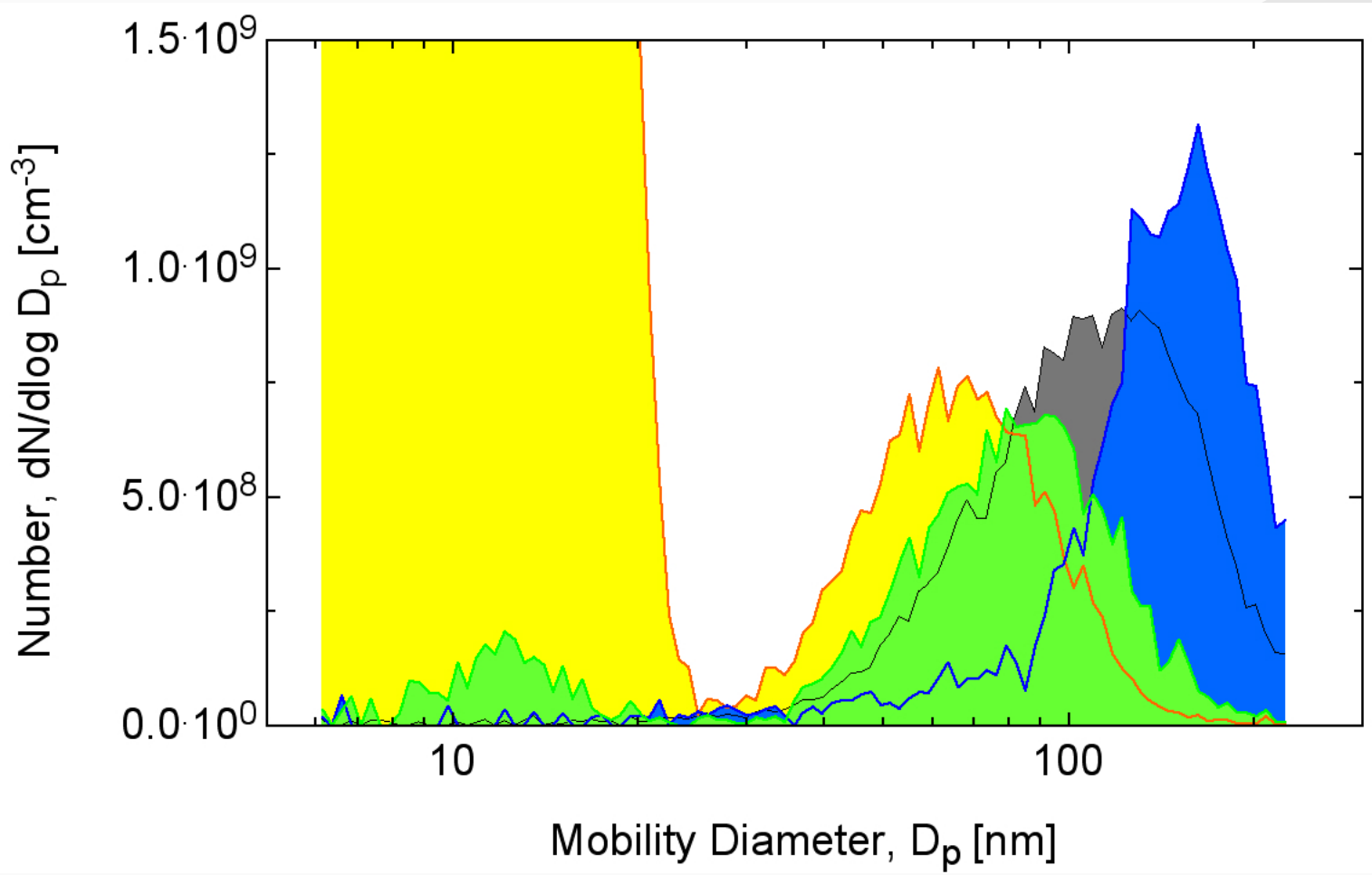
From Vapor to Droplet to Vapor



From Vapor to Droplet to Vapor



Results: Exhaust from a 2-Stroke Scooter



raw exhaust
dilution 1:7'500

ThermoDesorber
after diluter (1:7'500)

ThermoConditioner
before diluter (1:15'000)

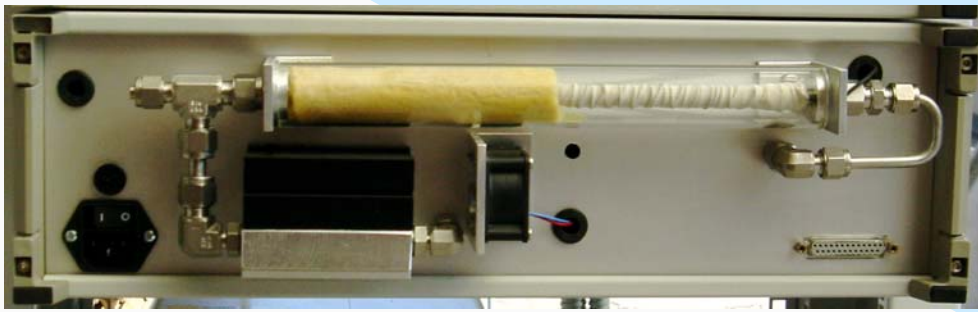
ThermoConditioner
after diluter (1:15'000)

The Scope

- Why Number?
- CPC - Commonly Preferred Consensus?
- ThDil - No Nanodroplets Allowed
- NanoMet-C - All in One

All in One: NanoMet-C

- (CVS)
- rotary diluter
- thermal conditioner
- CPC
- stand-alone DAQ unit



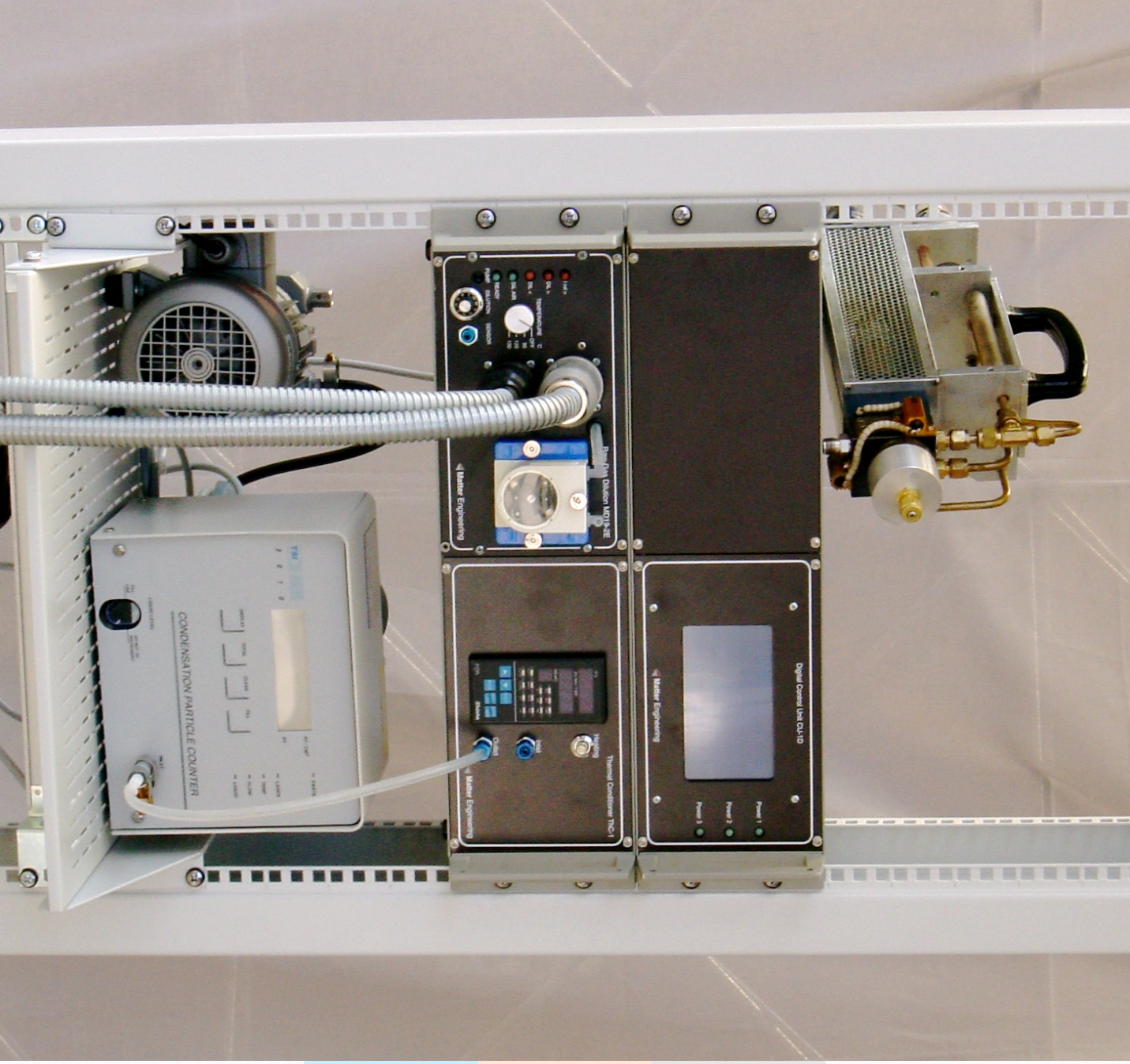
Conclusions

- PMP recommendation can be fulfilled, instrument likely to work
- number criterion maps health effects
- use ThermoDiluter, not ThermoDenuder

Conclusions / Still Unclear

- PMP recommendation can be fulfilled, instrument likely to work
- number criterion maps health effects
- use ThermoDiluter, not ThermoDenuder

- CPC counting efficiency?
- (size dependent) transfer function of ThDil?
- maybe use some size discrimination?



1-800-MY-NANOMET-C

Acknowledgments

Matter Engineering

Thomas Mosimann

Michael Riner

ISS, University of Applied Sciences Aargau

Martin Fierz

References

[1] Dunne, J.M. (2003) GRPE Particle Measurement Programme (PMP). Government Sponsored Work Programmes: Progress Report, 46th GRPE, 19-23 May 2003, agenda item 2, Informal document No. 16 (http://www.unece.org/trans/doc/2003/wp29grpe/%20TRANS-WP29-GRPE-specinf01e.pdf)

[2] Hinds, W.C. (1999) Aerosol Technology, 2nd ed., J. Wiley & Sons New York

[3] Kesten, J., Reineking, A., Porstendörfer, J. (1991) Calibration of a TSI Model 3025 Ultrafine Condensation Particle Counter, Aerosol Science and Technology **15**, 107-111

[4] Heim, M., Reischl, G.P. (2002) Performance of a New Commercial Electrical Mobility Spectrometer, 6th ETH Conference on Nanoparticle Measurement, Buwal 2002

[5] Quant, F.R., Caldow, R., Sem, G.J., Addison, T.J. (1992) Performance of Condensation Particle Counters with Three Continuous-Fow Designs, Journal of Aerosol Science **23**, Suppl. 1, 405-408

[6] Mertes, S., Schröder, F., Wiedensohler, A. (1995) The Particle Detection Efficiency Curve of the TSI 3010 CPC as a Function of the Temperature Difference Between Saturator and Condensor, Aerosol Science and Technology 23, 257-261

[7] Mayer, A., Ulrich, A., Czerwinski, J., Matter, U., Wyser, M. (2003) Retention of Fuel Borne Catalyst Particles by Diesel Particle Filter Systems, SAE 2003-01-0287, SAE Technical Paper Series

[8] Ultrafeine (Aerosol)-Teilchen und deren Agglomerate und Aggregate. In: BIA-Arbeitsmappe Messung von Gefahrstoffen. 21.Lfg. X/1998. Ed.: BIA (Berufsgenossenschaftliches Institut für Arbeitssicherheit), Sankt Augustin, Germany