Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
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Federal Institute of Metrology METAS

Standardisation of Particulate and Aerosol Measurements

Hanspeter Andres

Agenda

1. Particulates in Aerosols
2. Measures for Particulates in Aerosols
3. Traceability routes
4. International comparability
5. Roadmap

Particulates in Aerosols
Natural and artificial aerosols

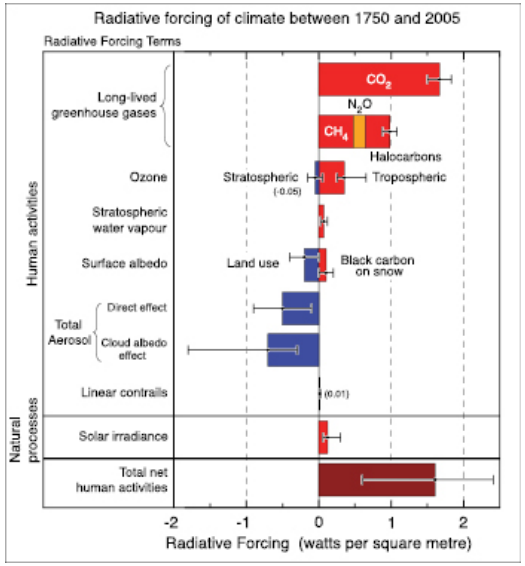
An aerosol is a colloid of fine solid particles or liquid droplets, in air or another gas (Hinds 1999).

- Natural aerosol: e.g. fog, volcanic ash, geyser steam
- Artificial aerosols: e.g. haze, air pollutants, smoke

Particulates in Aerosols public perception

Diesel exhaust fumes are 'major cancer risk' and as deadly as asbestos and mustard gas, says World Health Organisation

Dailymail 2012



Nature **409**, 671-672 (8 February 2001) | doi:10.1038/35055640

The dark side of aerosols

Meinrat O. Andreae

According to new modelling calculations, black carbon in the atmosphere exerts a large warming influence on global climate. Curbing emissions of this pollutant may be advisable both on climate and on human health grounds.

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Particulates in Aerosols
European Emission Standards

European emission standards for passenger cars (Category M*), g/km

Tier	Date	CO	THC	NMHC	NO_x	HC+NO_x	PM	PN [#/km]
Diesel								
Euro 1†	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	0.14 (0.18)	-
Euro 2	January 1996	1.0	-	-	-	0.7	0.08	-
Euro 3	January 2000	0.64	-	-	0.50	0.56	0.05	-
Euro 4	January 2005	0.50	-	-	0.25	0.30	0.025	-
Euro 5a	September 2009	0.50	-	-	0.180	0.230	0.005	-
Euro 5b	September 2011	0.50	-	-	0.180	0.230	0.005	6×10^{11}
Euro 6	September 2014	0.50	-	-	0.080	0.170	0.005	6×10^{11}
Petrol (Gasoline)								
Euro 1†	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	-	-
Euro 2	January 1996	2.2	-	-	-	0.5	-	-
Euro 3	January 2000	2.3	0.20	-	0.15	-	-	-
Euro 4	January 2005	1.0	0.10	-	0.08	-	-	-
Euro 5	September 2009	1.0	0.10	0.068	0.060	-	0.005**	-
Euro 6	September 2014	1.0	0.10	0.068	0.060	-	0.005**	6×10^{11}***

* Before Euro 5, passenger vehicles > 2500 kg were type approved as light commercial vehicles N_1-I

** Applies only to vehicles with direct injection engines

*** 6×10^{12}/km within first three years from Euro 6 effective dates

† Values in parentheses are conformity of production (COP) limits

Source (wikipedia)

Measures for Particulates in Aerosols
Various Measures

Chemical Measures:

- EC/OC/TC: elemental, organic and total carbon content
- PAHs: persistent aromatic hydrocarbon content
- Water content
- Anion, Cation and Metal content

Optical Measures:

- BC: black carbon content expressed as equivalent black carbon (EBC) or refractive black carbon (ERC)

Physical Measures:

- Particle number and charge concentration
- Particle sizes
- Particle mass concentration (e.g. PM_{10})

Measures for Particulates in Aerosols
Various Measures addressing different effects

Chemical Measures:

- EC/OC/TC: elemental, organic and total carbon content
- PAHs: persistent aromatic hydrocarbon content
- Water content
- Anion, Cation and Metal content

Health

Optical Measures:

- BC: black carbon content expressed as equivalent black carbon (EBC) or refractive black carbon (ERC)

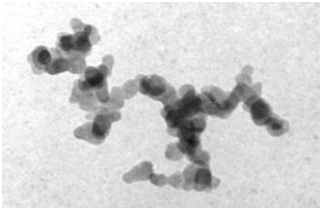
Climate change

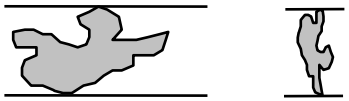
Physical Measures:

- Particle number and charge concentration
- Particle sizes
- Particle mass concentration (e.g. PM_{10})

Air pollution

Measures for Particulates in Aerosols
Particle sizes differ

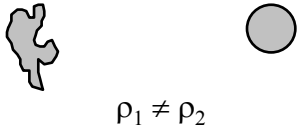




Geometric diameter:
Considering their vertical size, the two particles are approximately the same. e.g. microscopy

Aerodynamic diameter:
Considering the sedimentation velocity, the two particles are approximately the same. e.g. impactor

Optical diameter:
Considering the light scattering properties, the two particles are approximately the same. e.g. optical particle counter



Mobility diameter:
Considering the diffusion behavior, the two particles are approx. the same. e.g. diffusion battery, electronic mobility analyzer

Traceability routes
Chemical Measures

EC/OC/TC:

- EC/OC are method defined parameter,
- only TC traceable to SI
- Standardised thermo-optical reference method for EC/OC determination on quartz filters (EN 16909);
- EC/OC/TC agreement in the order of 10 % to 20 %;

PAHs, water, anions, cations and metals:

- SI traceability established
- specific issues with sampling for semi-volatile PAHs and water
- small sample quantities for chemical analysis
- specific SI-traceable matrix reference materials in development

Traceability routes
Optical Measures

Soot: product of incomplete combustion of fossil fuels / biomass linked to **adverse health effects and climate change**

Organic **C**arbon

Black **C**arbon (**E**lemental **C**arbon)

Measurements of BC (or EC) rely on the following methods:

Photo-acoustic, Extinction-Scatt.

EBC

Calibration and traceability for absorption with standard gases

Absorption (Filter-based)

EBC

Artifacts due to filter texture and loading

Absorption and incandescence

ERC

Direct calibration is difficult

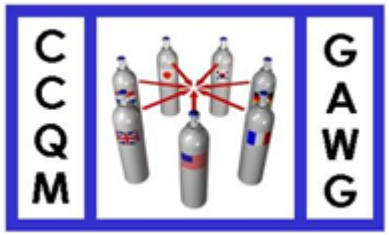
Thermo-optical analysis

EC

No consensus on the measurement protocol

Measurement results depend strongly on the method and instrument employed

Traceability routes
Black Carbon Roadmap



Traceability to SI for photo-acoustic, scattering and extinction

Metrological comparisons for photo-acoustic, scattering and extinction

Development of near-black non-volatile aerosol source

Characterisation of "near-black carbon" source using SI-traceable methods

Comparisons of EBC and ERC using "near-black carbon" source

Development of OC/EC (filter or powder) CRMs

Development of OC/EC CRMs incorporating "near black carbon"

Traceability to SI for all EBC and ERC either as absorption coefficient or via SI-traceable " ear-black carbon" CRM;

EC traceability to EC/OC CRMs incorporating "near-black carbon"

Comparisons of EBC, ERC and EC using ambient and existing sources

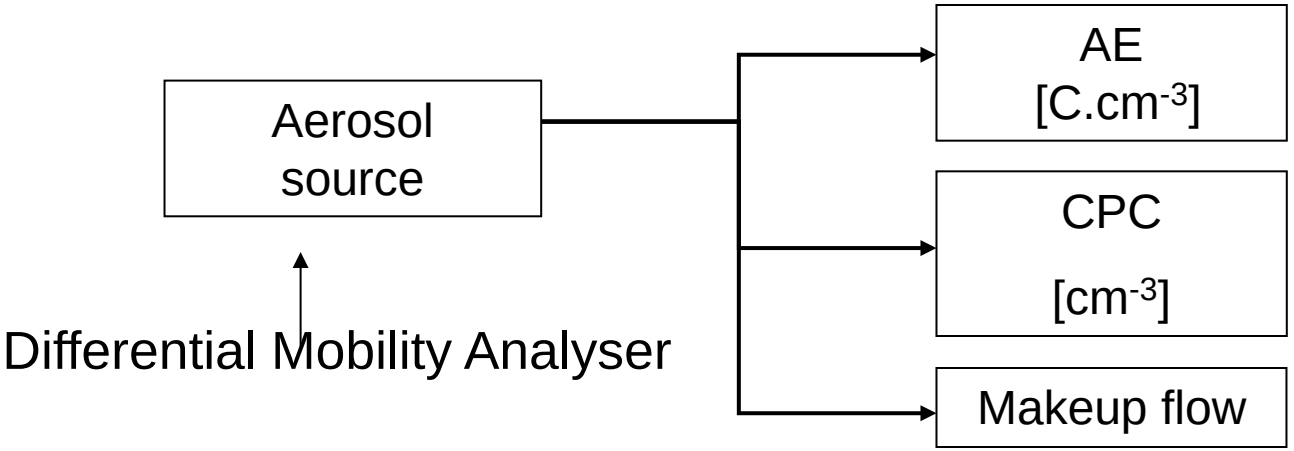
present

future

Traceability routes
Physical Measures

Particle number and charge concentration:

- Most mature field of particle metrology
- ISO 27891:2015 defines calibration procedure for condensation particle counters (CPCs); most direct traceability to SI via Aerosol Electrometers (AEs)



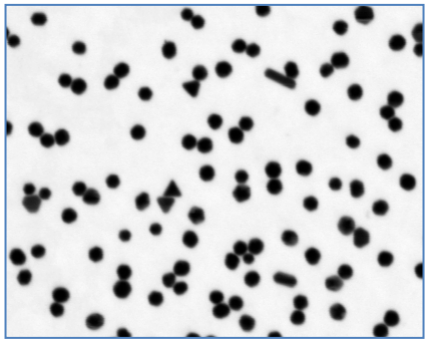
- issues with number counting of particles > 500 nm

Traceability routes
Physical Measures

Particle size:

- different metrics: aerodynamic, electrical mobility, geometric

Project PartEmission



TSEM image,
Au 30 nm particles

Nominal diameter	20 nm	30 nm	40 nm
TSEM mean diam	21.0 ± 1.9 nm	29.8 ± 2.0 nm	44.5 ± 2.2 nm
TSEM mode diam	20.4 nm	29.3 nm	42.9 nm
DMA mode diam	24.0 ± 0.4 nm	33.8 ± 0.6 nm	44.6 ± 1.0 nm
Factor DMA/TSEM	**1.18**	**1.15**	**1.04**

- issues with sizing below 10 nm and at 2.5 and 5 μm (not Europe):

Traceability routes
Physical Measures

Particle mass concentration:

- Most important particle measure
- Traceability to SI straightforward
- Issues with semi-volatiles and water content
- Controlled artificial aerosol lacking

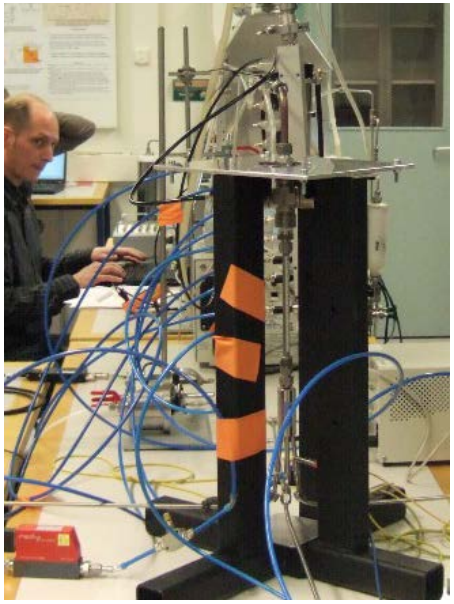
Light scattering

Beta-absorption

TEOM (Tapered Element Oscillating Microbalance)

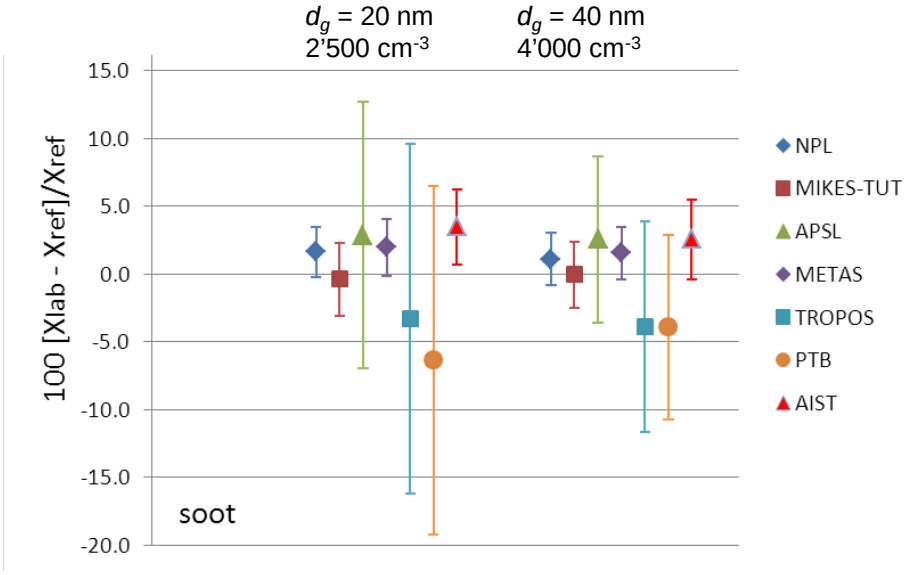
International comparability particle charge concentration EURAMET 1244 - I

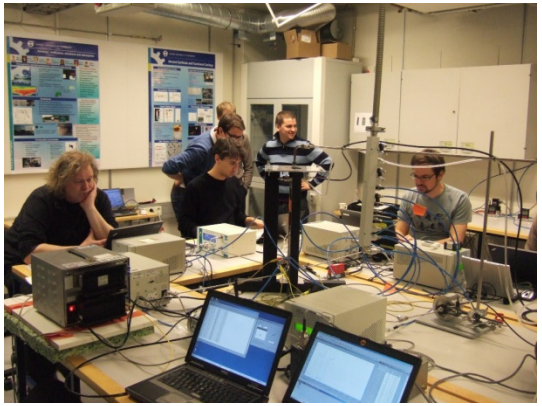
- EURAMET 1244 compared measurements of airborne charge concentration (in $fC \cdot cm^{-3}$).
- The comparison was based on measurements of a common aerosol source and was hosted by METAS in Finland on 18-22 March 2013.
- aerosol sources:
  SCAR (single charge aerosol reference)
  Multiple charge soot generator
- Particle sizes from 6 nm to 200 nm.
- Concentration range from 0.15 $fC \cdot cm^{-3}$ - 3 $fC \cdot cm^{-3}$ (equivalent to around 1,000 particles cm^{-3} to 20,000 particles cm^{-3})



International comparability particle charge concentration EURAMET 1244 - II

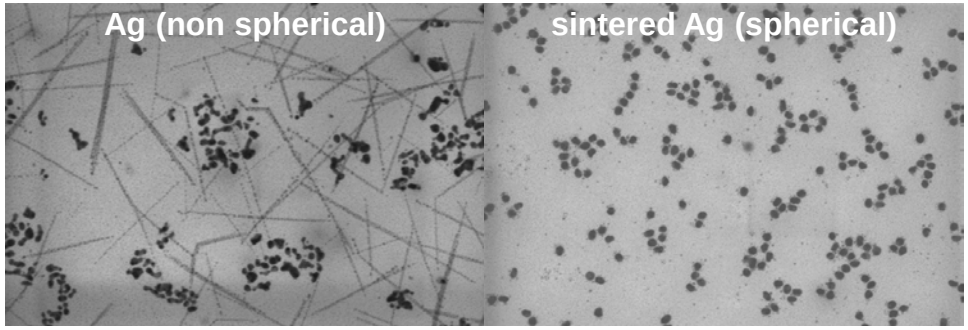
- Participants generally agree within 2 % in the size range 20 nm to 100 nm and number concentrations above 5000 cm^{-3} for singly charged synthetic particles.
- JRC results were 10% to 30% lower than the other participants' results; most probably due to commercial instrument design.
- Larger deviations result at lower particle sizes and particle concentrations and soot particles.





International comparability particle number concentration EURAMET 1282 - 1

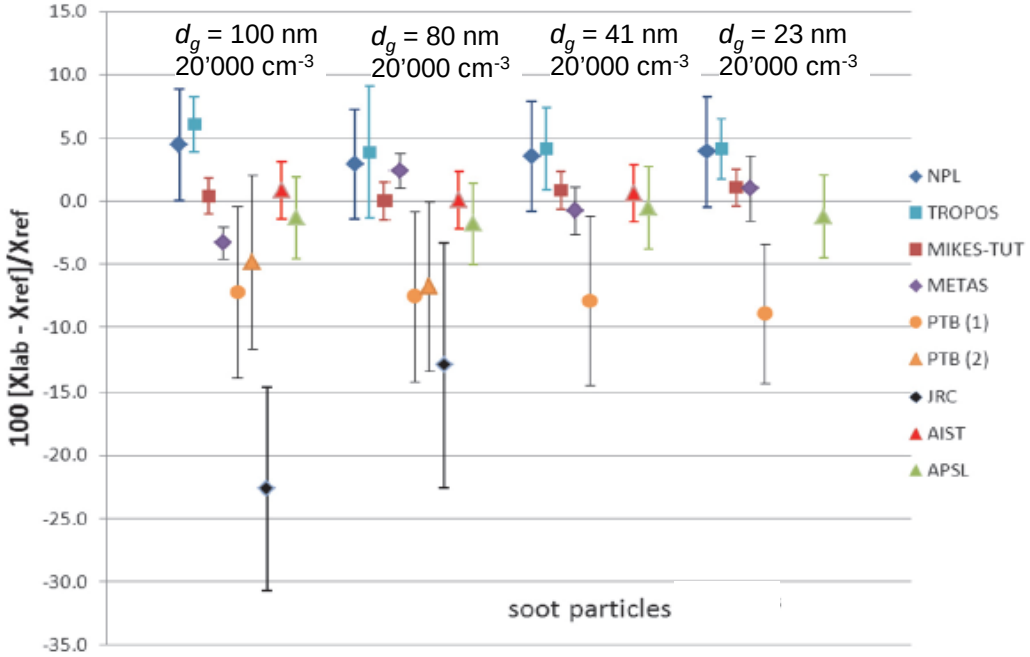
- EURAMET 1282 compared measurements of particle number concentration (in cm^{-3}).
- The comparison was based on measurements of a common aerosol source and was hosted TROPOS in Leipzig on 14-18 October 2013.
- aerosol sources:
  sintered silver
  silver
  soot



- Particle sizes from 6 nm to 100 nm.
- Concentration range 100 particles cm^{-3} to 20'000 particles cm^{-3}

International comparability particle number concentration EURAMET 1282 - 2

- Results show that the agreement of participants is less good than in the AE comparison. Agreement to ±10% between reference laboratories is currently achieved.
- Increased uncertainties down the traceability chain from primary AE → reference CPC (ISO/DIS 27891).



International comparability internationally agreed measurement capabilities

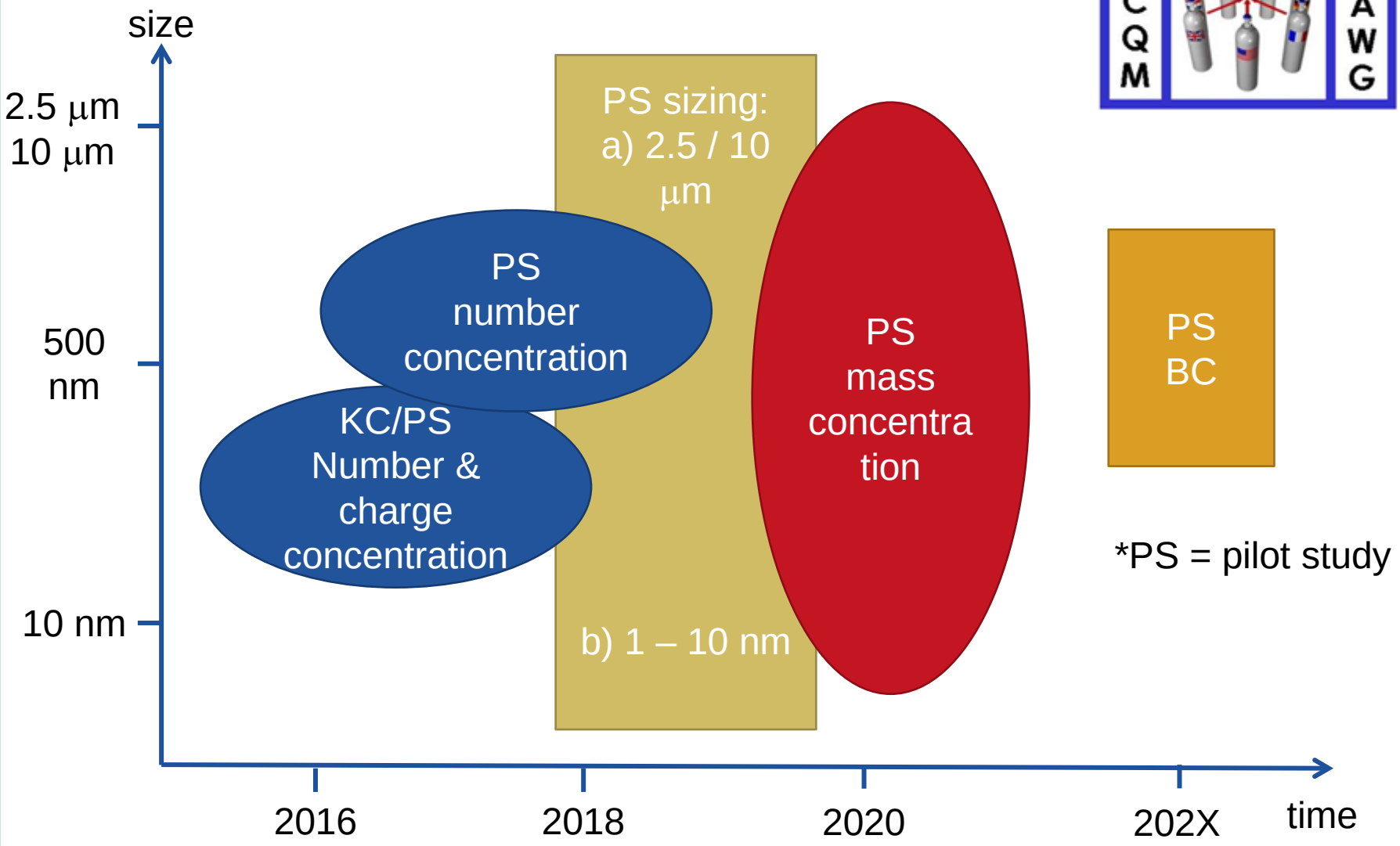
- Agreed CMCs of NPL, METAS and PTB on particle number and charge concentration.

- Extract from KCDB for METAS:

Measurement Service Sub-Category	Matrix	Measurand		Dissemination Range of Measurement Capability			Range of Expanded Uncertainties as Disseminated				Mechanism(s) for Measurement Service Delivery	Comments
		Analyte or Component	Quantity	From	To	Unit	From	To	Unit	Is the expanded uncertainty a		
Other (particulates)	air	airborne particles	Number concentration	100	20000	cm^{-3}	3	5	%	Yes	Calibration	Soot particle size: 23 nm to 500 nm. Approved on 08 July 2015
Other (particulates)	air	airborne particles	Charge concentration	1	3	$fC\ cm^{-3}$	2	2	%	Yes	Calibration	Soot particle size: 20 nm to 500 nm

- Proposed KC in this area (NPL, PTB at TROPOS)

Roadmap
planed particle comparison



*PS = pilot study

Thank you very much for your attention