The Traceable Calibration of Condensation Particle Counters

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Why calibrate CPCs?

- Condensation particle counters (CPCs) have been used to measure number concentration of ultrafine particles for almost 30 years
  - As part of scanning mobility particle sizer (SMPS™) to measure size distributions as well
- Currently new regulations involving particle number concentration measurements are discussed
- Hence, calibration of CPCs using a traceable method to ensure proper performance is required
  - Method to calibrate smallest particle size detection limit, counting efficiency & concentration linearity

Calibration:[2)]

The set of operations that establish, under specific conditions, the ***relationship between values for quantities*** indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards.

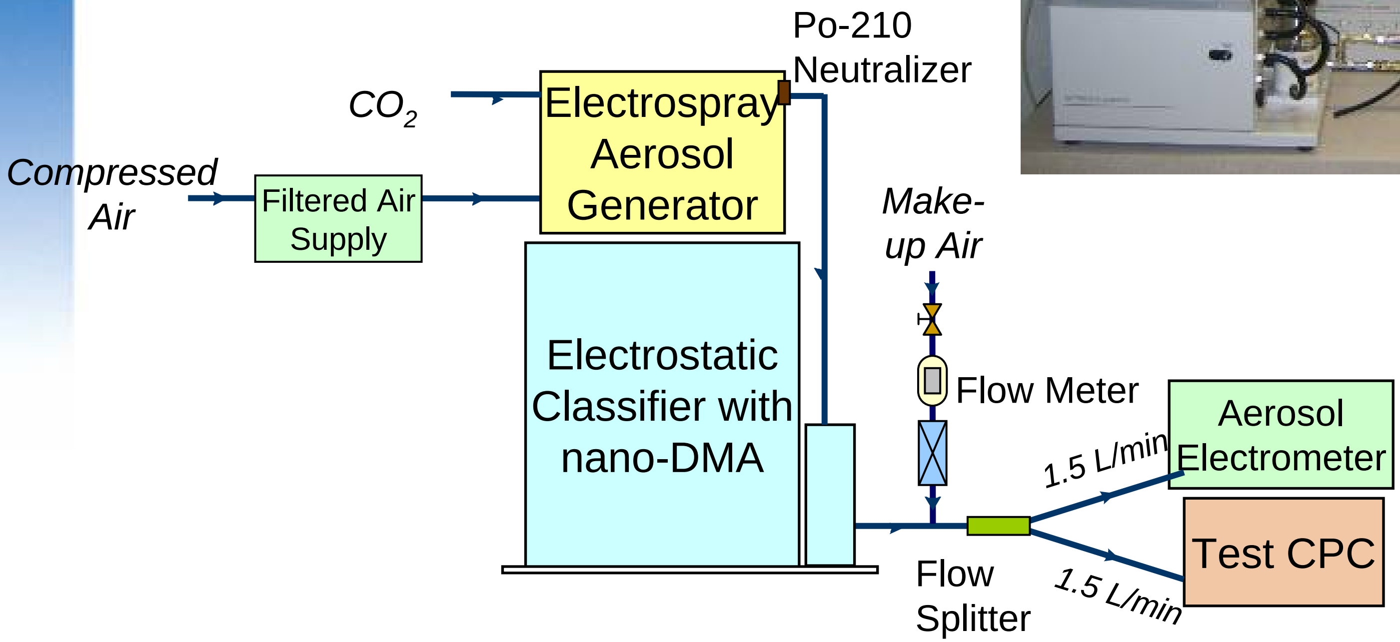
[2)] International Vocabulary of Basic and General Terms in Metrology, 2nd ed., BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML, International Organization for Standardization (ISO), 1993 (VIM), 6.11

Calibration Method

The calibration method at TSI follows the well-known ‘primary absolute calibration’ method first described by leading aerosol scientists B. Liu and D. Pui in 1974 [3)]

[3)] Liu, B.Y.H. and D.Y.H. Pui [1974]. A Submicron Aerosol Standard and the Primary Absolute Calibration of the Condensation Nucleus Counter. *J. Coll. Int. Sci.*, Vol. 47, pp. 155–171

Calibration Setup



- Electrospray AG generates (emery oil) particles
- DMA selects singly-charged, monodisperse particles of known size
- Monodisperse aerosol mixes with filtered air & splits equally into aerosol electrometer and CPC
- Counting efficiency: ratio CPC / electrometer readings

Calibration Details

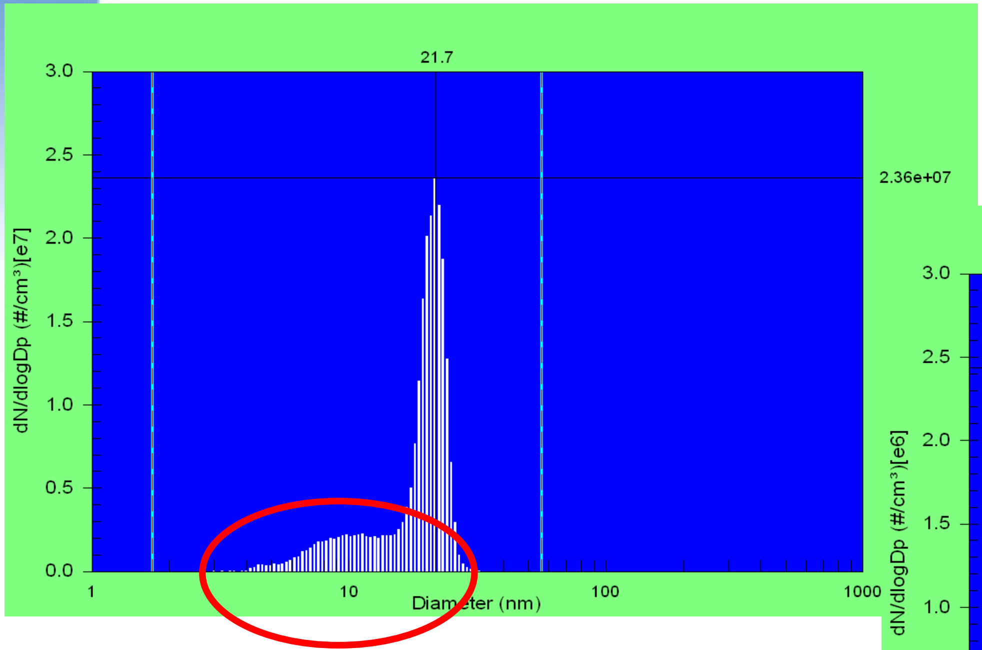
- This presentation discusses calibration results for standard TSI model 3010 and 3010D (PMP) CPCs.
  - Smallest particle size detection limit & Counting efficiency
  - Concentration linearity
  - CPC intercomparison

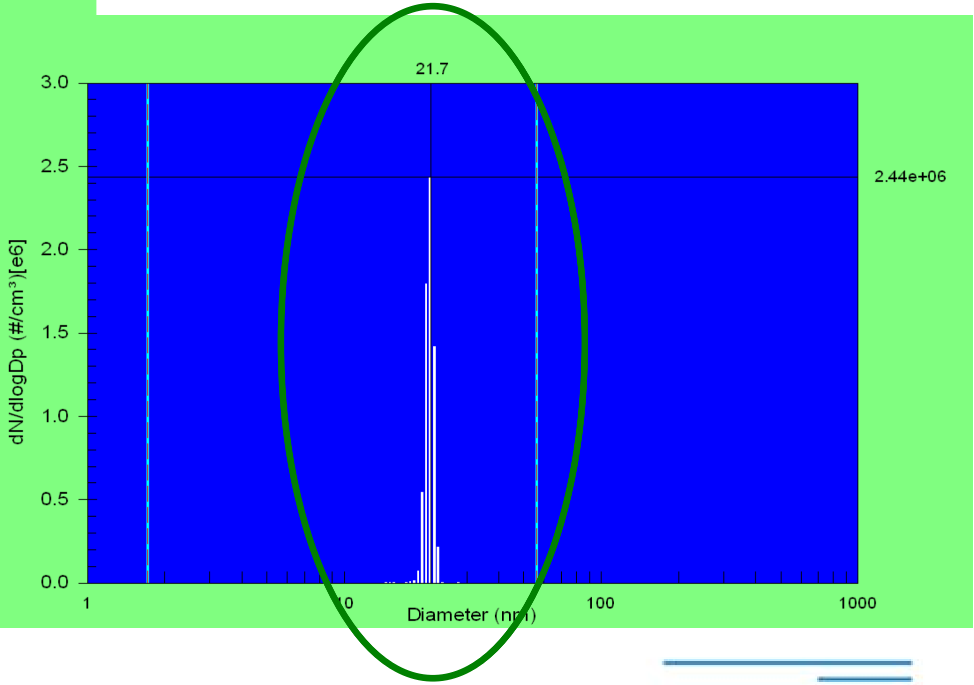
- **Traceability of the CPC calibration method depends on:**
  - The ability of generating singly-charged, monodisperse particles of known size
  - The ability of measuring particle concentration accurately using a reference aerosol detector

Monodispersity of Particles

Step 1: Particles generated by electrospray (22 nm, GSD = 1.46)

Step 2: Particles generated by electrospray <u>and selected by DMA</u> (22 nm, GSD = 1.04)





Electrospray-generated, DMA-selected particles:

50 nm: GSD = 1.04

90 nm: GSD = 1.11

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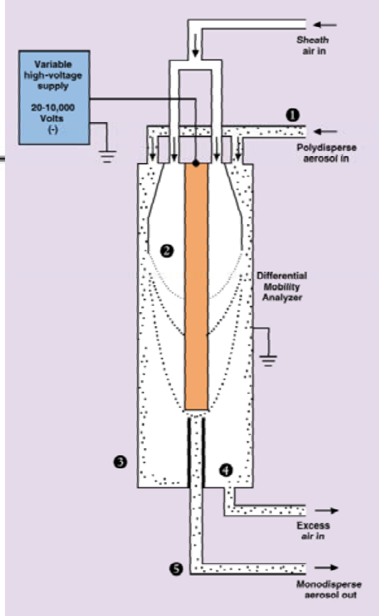
Traceability – DMA



In a cylindrical DMA, Z_p of selected particles is

$$Z_p = \frac{[q_t - 1/2(q_p + q_m)]\ln(r_2/r_1)}{2\pi VL}$$

- Flow rates ($q_t=q_s+q_p$) – NIST traceable flow meters
  - Sheath flow rate (q_s)
  - Polydisperse/Monodisperse aerosol flow rate ($q_p = q_m$)
- Geometric parameters – NIST traceable bore gage, micrometer, and caliper
  - r_1 / r_2 = inner / outer electrode radius
  - L = characteristic length between aerosol inlet/outlet slits
- Voltage on center electrode (V) – calibrated with NIST traceable kilovolt divider

Aerosol Electrometer

$$N = \frac{V}{e \cdot R \cdot n_p \cdot q_e}$$

where:

N = particle number concentration

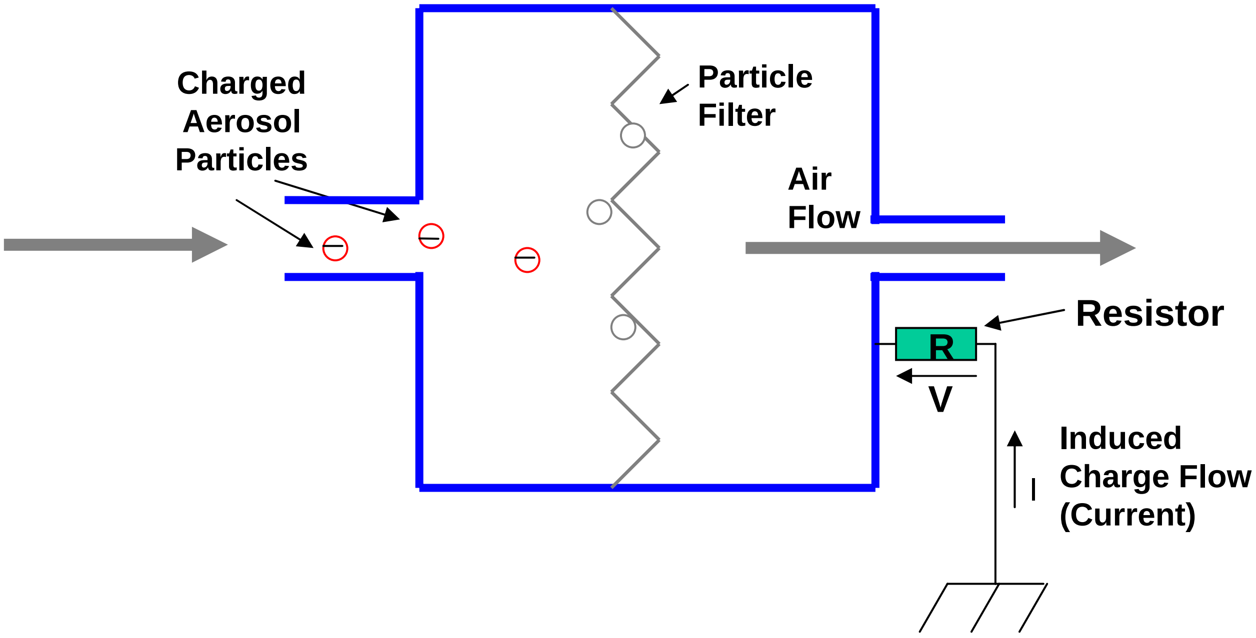
V = electrometer voltage reading (IR)

e = unit charge, 1.602 x 10^{-19} C

R = resistance of resistor

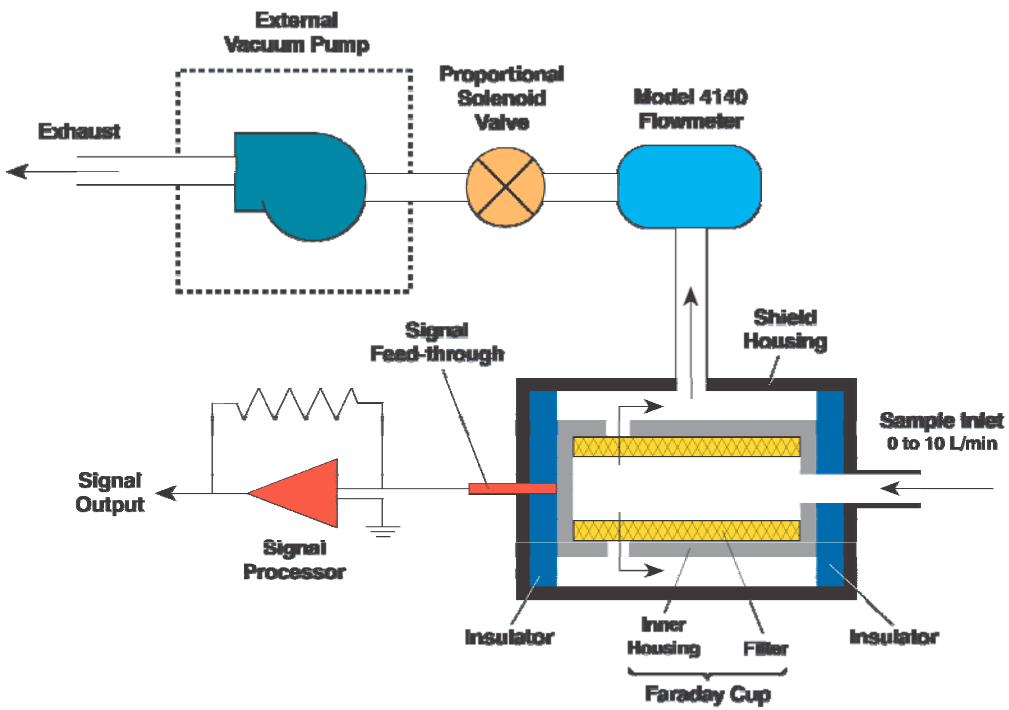
n_p = number of charges per particle

q_e = air flow rate

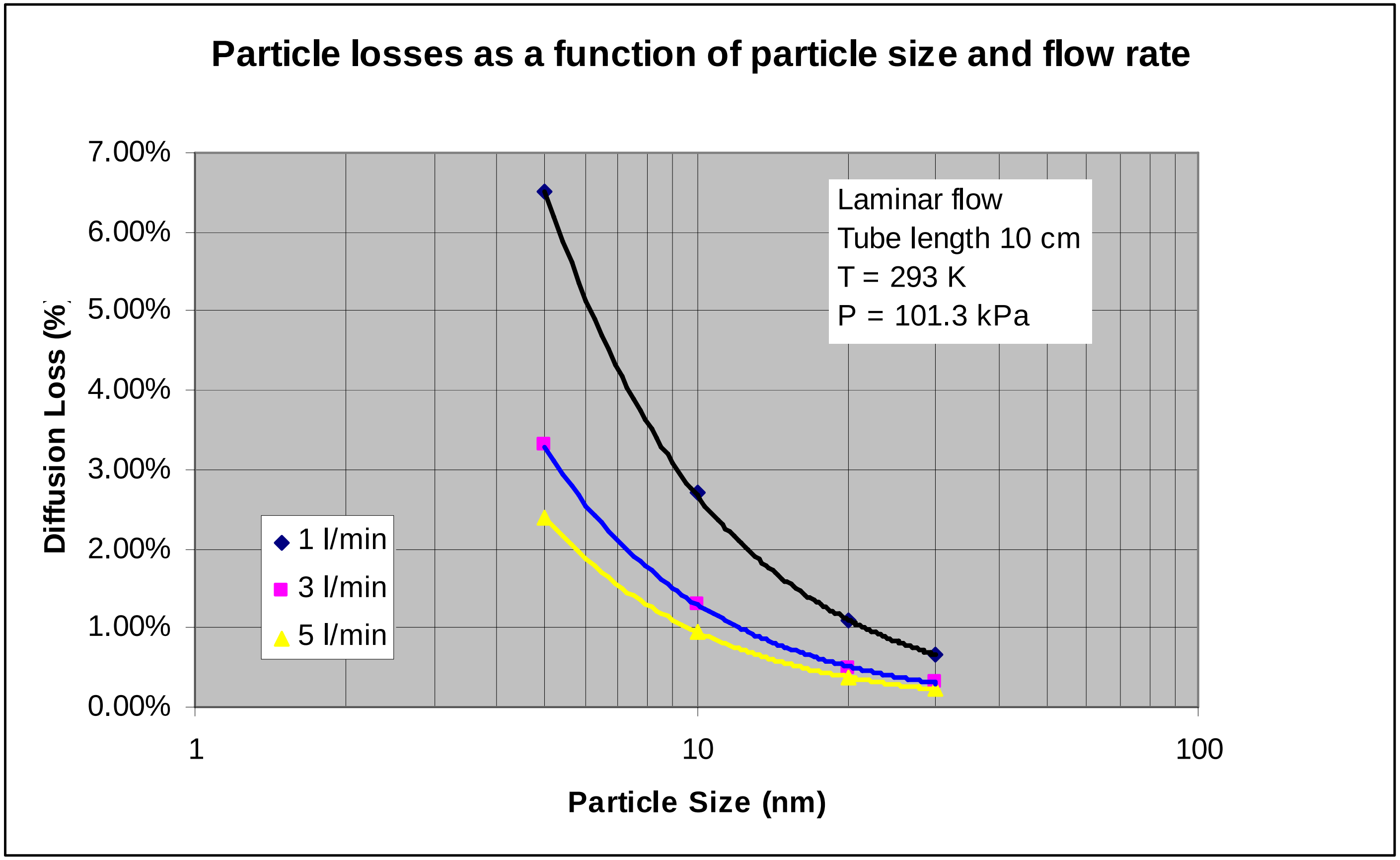


Traceability – Aerosol Electrometer

- Unit charge (e) – is a constant (1.602×10^{-19} C)
- Resistor (R) – 1% precision, measured by manufacturer using NIST traceable standard
- Particle charge (n_p) – verified to be unity (1.0) by SMPS
- Flow rate (q_e) – NIST traceable flow meter



Aerosol Electrometer Inlet Losses



Inlet tubing to the Faraday cage must be kept as short as possible or losses must be quantified and corrected.

Smallest Particle Size & Counting Efficiency

- Depending on CPC model, 10 – 14 particle sizes below 100 nm used for counting efficiency curve
- Particle concentration < 10^4 P/cm^3
- CPCs 3010, 3010D (or other models) can be tested simultaneously
  - Model 3776 is tested one by one due to low concentration at their smallest particle sizes
- To eliminate need for diffusion loss correction
  - Equal tube lengths from flow splitter to electrometer & CPCs
  - Equal flow rates for electrometer & CPCs
- CPC concentrations corrected for coincidence

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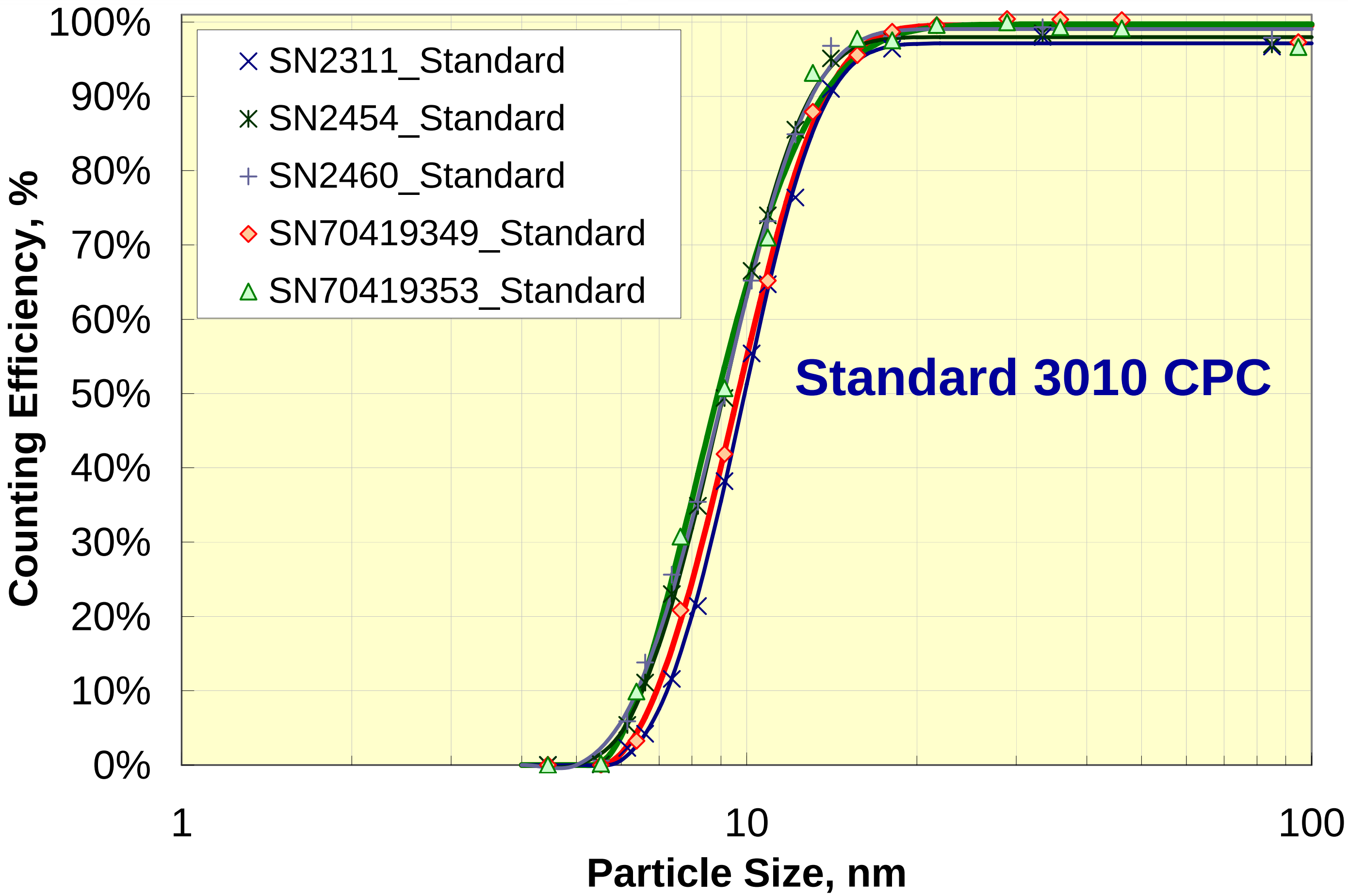
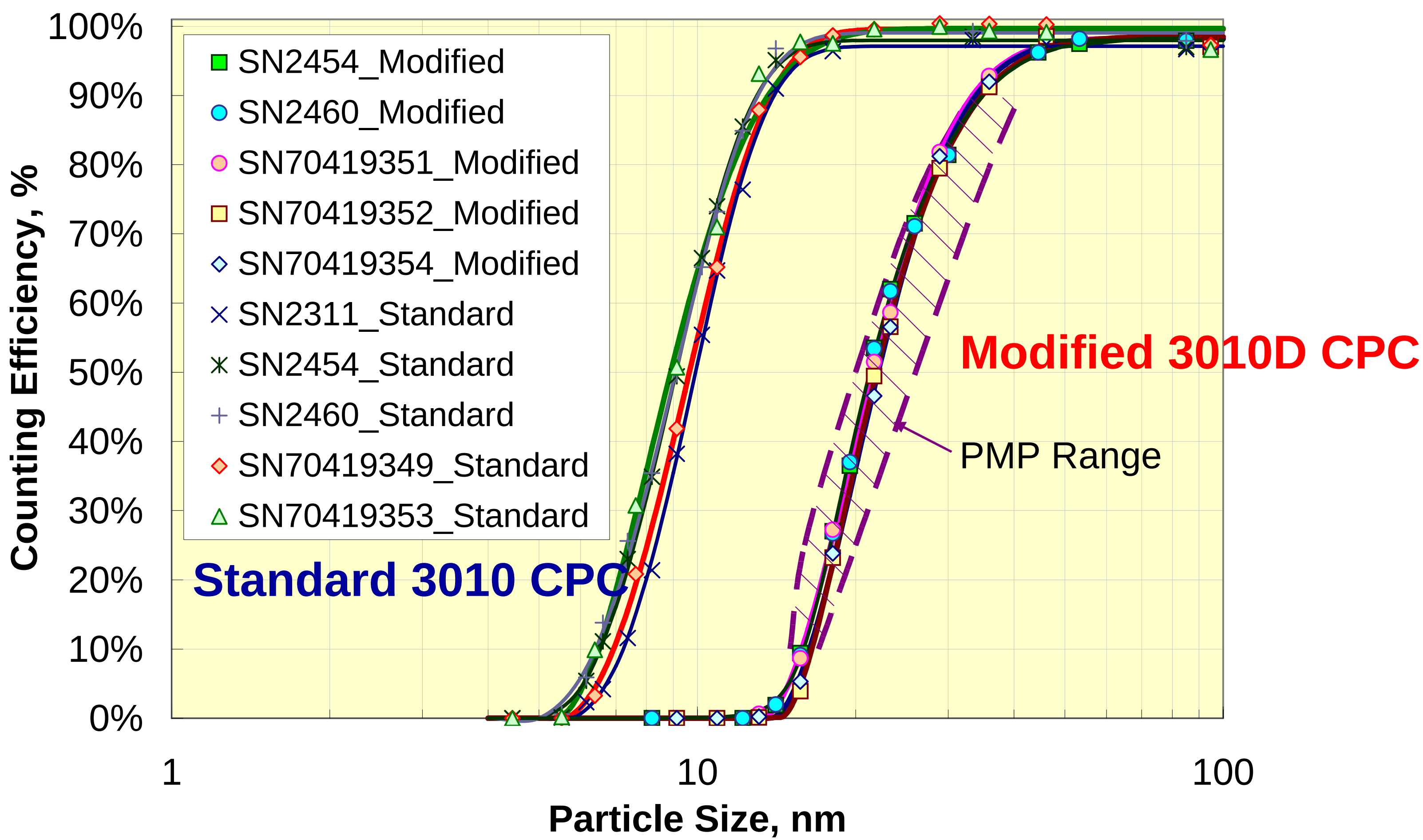
Results: Counting Efficiency of 3010



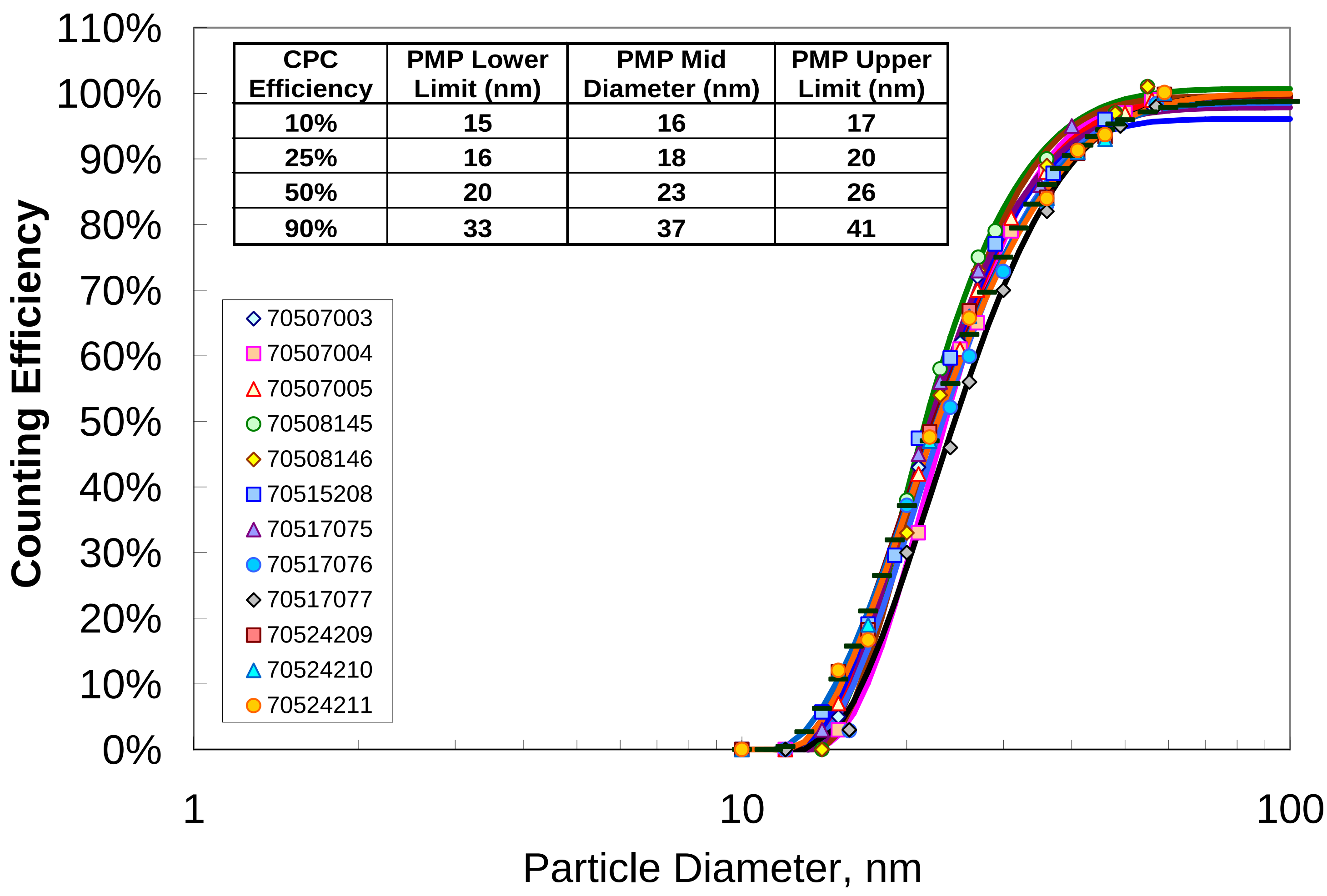
	SN2311_S	SN2454_S	SN2460_S	SN70419349_S	SN70419353_S	Size Range
D10, nm	7.2	6.5	6.4	6.9	6.5	6.8 ± 0.4
D25, nm	8.3	7.6	7.5	8.0	7.4	7.9 ± 0.5
D50, nm	9.9	9.1	9.1	9.7	8.9	9.4 ± 0.5
D75, nm	11.9	11.0	11.0	11.7	11.1	11.4 ± 0.4
D90, nm	14.0	13.0	13.0	13.8	13.6	13.5 ± 0.5

Results: Counting Efficiency of 3010D



	SN2454_M	SN2460_M	SN70419351_M	SN70419354_M	SN70419352_M	Size Range	PMP Range
D10, nm	15.9	16.2	15.8	16.4	16.5	16.1 ± 0.4	16 ± 1
D25, nm	17.9	18.2	17.9	18.5	18.4	18.2 ± 0.3	18 ± 2
D50, nm	21.3	21.6	21.5	22.1	21.9	21.7 ± 0.4	23 ± 3
D90, nm	34.9	35.3	33.4	33.9	34.8	34.3 ± 1.0	37 ± 4

Counting Efficiency 3010D



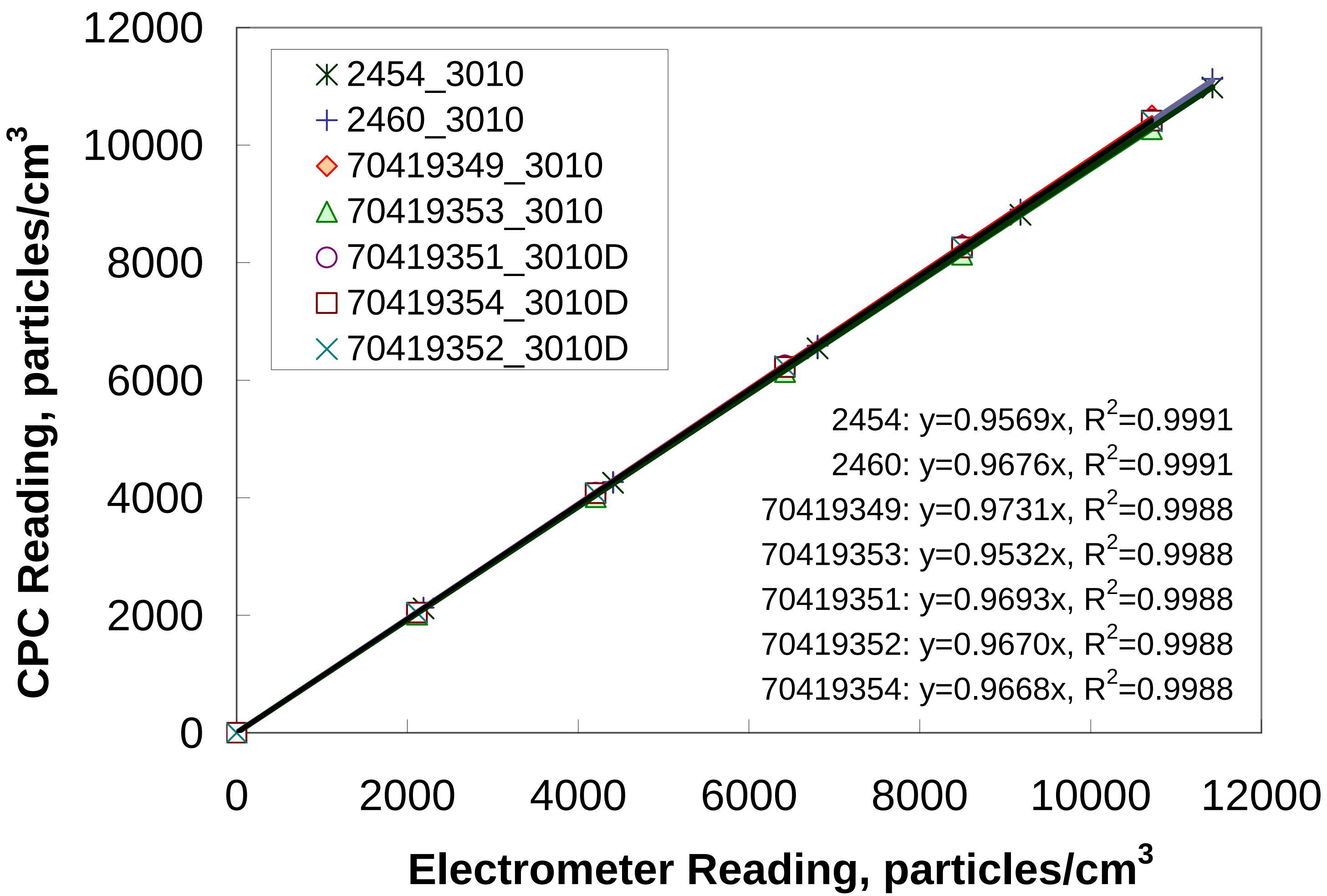
CPC Efficiency	PMP Lower Limit (nm)	PMP Mid Diameter (nm)	PMP Upper Limit (nm)
10%	15	16	17
25%	16	18	20
50%	20	23	26
90%	33	37	41

Counting Efficiency Results for Twelve 3010D Production CPCs.

- **Concentration Linearity**
- Setup for concentration linearity response [4)]
  - 50 nm particles chosen for ~100% counting efficiency for CPC
  - Six to ten concentrations levels, depending on CPC model
    - Higher concentrations reduced by dilution bridge
  - Equally spaced from 0 - 10^4 P/cm^3 (CPC 3010) and 2,000 to 300,000 P/cm^3 (UCPC 3776) respectively
  - Reference instrument
    - Aerosol Electrometer 3068A (for 3776 only for validation)
      - From April 2006 new aerosol electrometer model 3068B

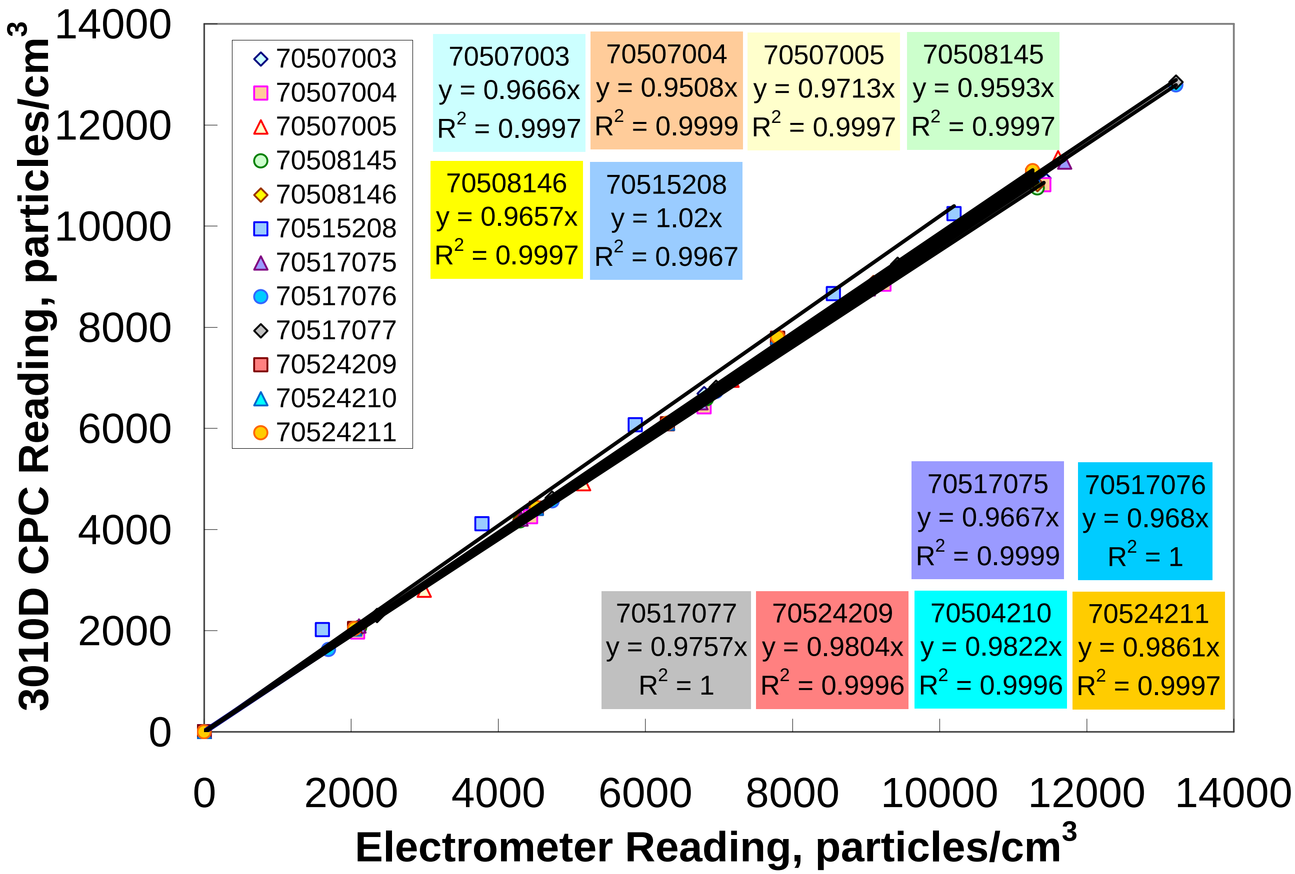
[4)] Liu, W., B.L. Osmondson, O.F. Bischof and G.J. Sem (2005). Calibration of Condensation Particle Counters. *SAE Paper* No. 2005-01-0189.

Linearity Response of 3010 & 3010D



Slope = 0.953 to 0.973
R^2 > 0.9988

Linearity of 3010D (Production)



Linearity Response of Twelve 3010D Production CPCs.

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