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**REPORT ON INTERCOMPARISON OF PERSONAL SAMPLERS AND
MONITORS USING POLYDISPERSE COMPACT AND AGGLOMERATED
PARTICLES UNDER TEST STAND CONDITIONS**
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Abstract

This document describes the outcome of the tests carried out at the NanoTestCenter of the Institute for the Research on Hazardous Substances (IGF) in Dortmund, Germany and at IUTA in Duisburg using polydisperse particles to investigate the accuracy and comparability of personal monitors (miniDiSc/DiSCmini, Partector, NanoTracer) and samplers (NB2013, ESPnano, TP, PENS).

Keyword list

Personal monitors, personal samplers, polydisperse particles

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1. Introduction

The accuracy and comparability of different personal samplers and monitors were tested under well defined laboratory conditions by simultaneously challenging the instruments with polydisperse aerosols of different concentrations, sizes and morphologies.

Table 1-1 provides an overview of the type and number of instruments, as well as of the organizations that took part to the study and supplied the instruments. Altogether three identical miniature diffusion size classifiers (miniDiSC 1, miniDiSC 2 and DiSCmini), five Partector (Partector 1 to 5) and five nanoTracer (nanoTracer 1 to 5), as personal monitors, were included in the study. Three CEA

nanosampling devices (NB2013), one thermal precipitator (TP), one ESPnano and one Personal Nanoparticle Sampler (PENS), as personal samplers, were also tested. For technical specifications regarding the personal monitors and samplers involved in this study please refer to Deliverable 3.2.

Table 1-1 Overview of the type and number of personal monitors and samplers tested

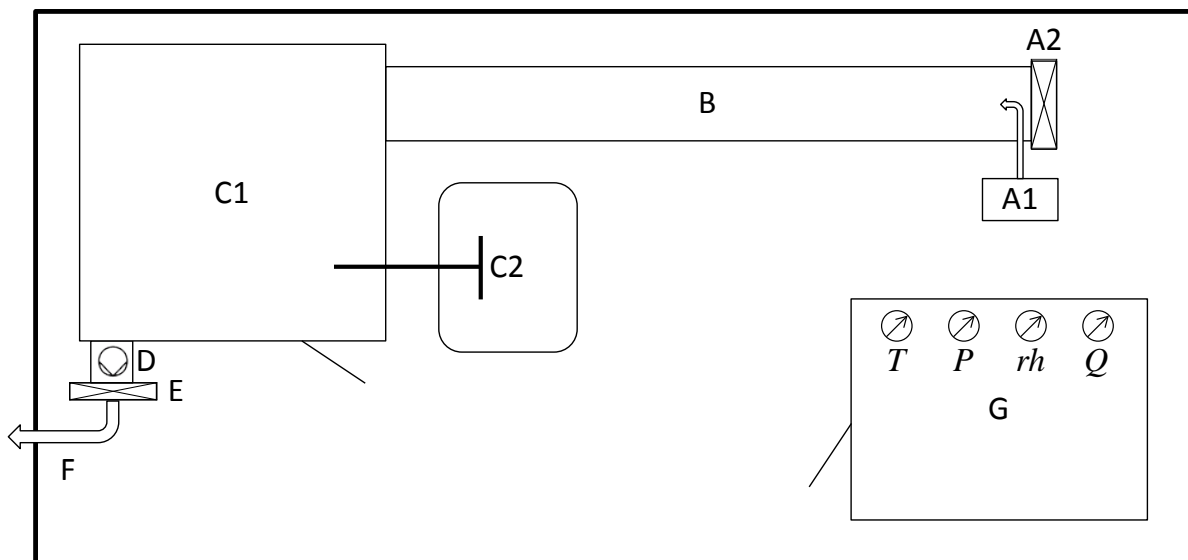
Organisation	Manufacturer & model no.	Instrument ID
Institut für Energie und Umwelttechnik (IUTA) e.V.	naneos	Partector 1 Partector 2 Partector 3
	Fachhochschule Nordwestschweiz	miniDiSC 1 miniDiSC 2
	Philips Aerasense	nanoTracer 3 nanotracer 4
	TSI, 3936	SMPS N-DMA
	TSI, 3550	NSAM
	TSI, 3776	UCPC
		PENS
	ESPnano	ESPnano
Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA)	Matter Aerosol	DISCmini TP
University of Applied Sciences and Arts Northwestern Switzerland (FHNW)	naneos	Partector 4 Partector 5
Institute for the Research on Hazardous Substances (IGF)	Philips Aerasense TSI, 3936 TSI, 3007	nanoTracer 5 SMPS L-DMA CPC
Atomic Energy Commission (CEA)	CEA	NB2013-v3.7 NB2013-v3.8 NB2013-v3.9
Huub Vroomen Arjan van der Vleuten	Philips Aerasense	nanoTracer 1 nanoTracer 2
Institute of Environmental Assessment and Water Research (IDAEA-CSIC)	TSI, 3910 Aethlabs	nanoScan microAeth

Additionally, two Scanning Mobility Particle Sizers, one operated with a nano DMA (SMPS N-DMA) and the other with a long DMA (SMPS L-DMA) and one nanoScan (TSI, model 3910) were used in the study to monitor the size distribution of the test aerosols. A stand-alone butanol Ultrafine Condensation Particle Counter (UCPC, TSI model 3776, size range 2.5 nm to several μm) and one hand-held Condensation Particle Counter (CPC, TSI model 3010, size range 10 nm to several μm) were employed to monitor the total particle number concentration and its stability. A Nanoparticle Surface Area Monitor (NSAM, TSI model 3550) was also involved in the study to measure the lung deposited surface area (LDSA) concentration.

2. Experimental set-up

The tests were conducted at the NanoTestCenter, a set-up based on an earlier test stand for the generation of diesel soot test particles (Dahmann, 1997), of the Institute for the Research on Hazardous Substances (IGF) in Dortmund, Germany. The NanoTestCenter (for a schematic of the set-up see Figure 2-1) has successfully been used for several intercomparison studies in the past (Asbach et al., 2009; Asbach et al., 2012; Dahmann et al. 2001, Kaminski et al. 2013). It consists of an approximately 20 m long wind tunnel with 70 cm diameter that feeds the aerosol into a closed mixing chamber with a volume of approximately 20 m³. The air flow through the chamber and the wind

tunnel is provided by a blower outside the mixing chamber. It was previously shown that the aerosol is homogeneously distributed throughout the mixing chamber, such that all instruments can be placed inside the chamber to sample the same aerosol. The concentration may only differ near the chamber walls (Asbach et al., 2012). The chamber is sufficiently large to simultaneously host dozens of instruments which then all sample the identical aerosol. Those instruments that require frequent attention or adjustment were placed outside the chamber and connected to a sampling train that withdraws aerosol from within the chamber. The sampling train is T-shaped and has connections for up to six instruments on each end of the T (see Figure 2-1).



- A1 Aerosol generation (atomizer, spark generator or flame generator), drying and neutralization
- A2 Optional ULPA background filter
- B Wind tunnel, approximately 20 m long, 0.7 m diameter
- C1 Measurement chamber, approximately 20 m³
- C2 T-shaped sampling train
- D Blower
- E Exhaust filter
- F Exhaust
- G Control room for flow rate Q , measurement of temperature T , pressure P and relative humidity rh in measurement chamber C1

Figure 2-1 Experimental set-up IGF - NanoTestCenter

The measurement facility is specifically designed for the comparison of aerosol measurement devices with well defined aerosols with a large range of particle sizes and morphologies. Four different types of aerosol generators were used: (1) a home-made atomizer to produce particles from a solution (Sodium Chloride, NaCl) or to produce small droplets of Di-Ethyl-Hexyl-Sebacate, DEHS, C₂₆H₅₀O₄); (2) a spark generator (Palas GFG3000) to produce agglomerated particles, namely carbon-aerosol (“soot”) from graphite electrodes; (3) a home-built flame generator to produce zinc oxide and NaCl particles (Monsé et al., 2013); and (4) a diesel engine (aspiration type, 2180 cm³, Mercedes Benz 220 D, 44 kW at 4200 rpm) to produce agglomerated diesel soot particles. The freshly produced particles were neutralized with an ⁸⁵Kr Neutralizer (TSI, model 3012A; 370 MBq initial activity) and in case of particles atomized from an aqueous suspension, additionally dried in a home-made coaxial silica gel dryer. While the atomizer is usually used to produce compact particles, i.e. cubic in case of NaCl and spherical in case of DEHS, the spark and flame generators produce very high concentra-

tions of small primary particles that quickly coagulate to form agglomerates or aggregates. The degree of agglomeration can best be controlled with the spark generator by the amount of dilution air that is introduced into the device.

After switching a particle generator on, it usually takes 5-10 minutes for the total concentration in the chamber to stabilize. The number concentration then remains constant for up to several hours with deviations of usually less than $\pm 5\%$. (Kaminski et al, 2013). Measurements were started approximately 15 minutes after a generator was switched on.

Table 2-1 Overview of the test aerosols used in the study

ID	Particle type	d_{modal} SMPS [nm]	Concentration [#/cm ³]	SD	Generator	Generator settings
1	NaCl	13	9400	1410	Burner	solution: 1 g/l; feed rate: 0.5 ml/min; dilution air: 625 m ³ /h
2	NaCl	12	78600	3000	Burner	solution: 1 g/l; feed rate: 5 ml/h; dilution air: 625 m ³ /h
3	NaCl	63	17500	3230	Atomizer	solution 54 g/l, 2 Bar, dilution air: 936 m ³ /h
4	NaCl	55	163000	6630	Atomizer	solution 54 g/l, 4 Bar, dilution air: 250 m ³ /h
5	DEHS	240	20800	280	Atomizer	1 Bar, dilution air: 2180 m ³ /h
6	DEHS	250	98600	2440	Atomizer	1 Bar, dilution air: 360 m ³ /h
7	Soot	53	15000	240	Spark	current: 14.6 mA; 5 lpm Ar, 17.5 lpm air, low energy; dilution air: 2880 m ³ /h
8	Soot	69	101600	1800	Spark	current: 14.6 mA; 5 lpm Ar, 17.5 lpm air, low energy; dilution air: 270 m ³ /h
9	Soot	85	11100	180	Spark	current: 14.6 mA; 5 lpm Ar, 5 lpm air, high energy; dilution air: 1800 m ³ /h
10	Soot	109	78700	2350	Spark	current: 14.6 mA; 5 lpm Ar, 5 lpm air, high energy; dilution air: 200 m ³ /h
11	Diesel soot bimodal	31+145	233000	7220	Diesel engine	engine settings: 800 rpm, dilution air: 3660 m ³ /h
12	Diesel soot	98	123900	8760	Diesel engine	engine settings: 1200 rpm, dilution air: 950 m ³ /h
13	NaCl bi-modal	26+57	168400	3720	Burner	solution: 5 g/l, feed rate: 30 ml/h, dilution air: 1027 m ³ /h
14	NaCl/DEHS bi/trimodal	24+53+141	292400	40450	Burner+Atomizer	burner see #13, atomizer: 3 Bar, DEHS:IPA 1:1
15	DEHS	202	42400	3130	Atomizer	settings see #14
16	NaCl bi-modal	26+53	108900	4090	Burner	settings see #13
17	ZnO	69	124900	4730	Burner	feed rate 40 ml/h; dilution air: 0.8 m/s

Tests were conducted with different unimodal test aerosols with modal diameters between 12 and 250 nm. Each of these size distributions were produced with two different concentration levels, one near the expected lower (around 10,000 #/cm³) and the other near the upper end (> 100,000 #/cm³) of the typical concentration range in workplaces. The particle concentrations were adjusted to different levels for each particle material by changing the dilution air flow rate in the wind tunnel. Tests

were also conducted with bimodal distributions, which can occur in real work places if the background forms one mode and particles from a specific source (e.g. leak in a nanoparticle production facility) form a second mode. Bimodal distributions included either two modes of solid particles (NaCl and soot) or a mixture of a solid and a liquid particle mode (NaCl and DEHS). The test aerosols are summarized in Table 2-1.

Normalized size distributions of the test aerosols, averaged over 30 minutes, measured either by SMPS L-DMA or by SMPS N-DMA are shown in Figure 2-2 to Figure 2-4. Symbols represent the measured data, error bars indicate the standard deviation of the measured concentrations in each size bin and lines are lognormal fitted data. As the dilution in the wind tunnel mainly affected the concentrations and had only a minor effect on the particle size distributions only the size distributions corresponding to the higher concentrations are represented in the figures.

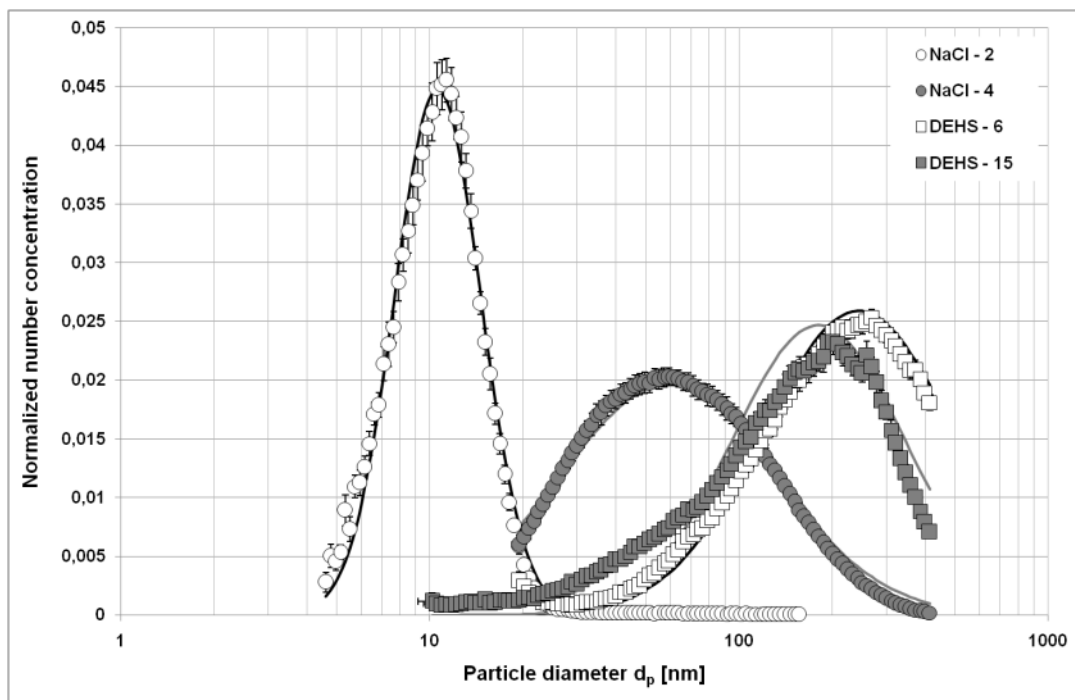


Figure 2-2 Normalized size distributions of test aerosols of spherical (DEHS) and cubic (NaCl) morphologies.

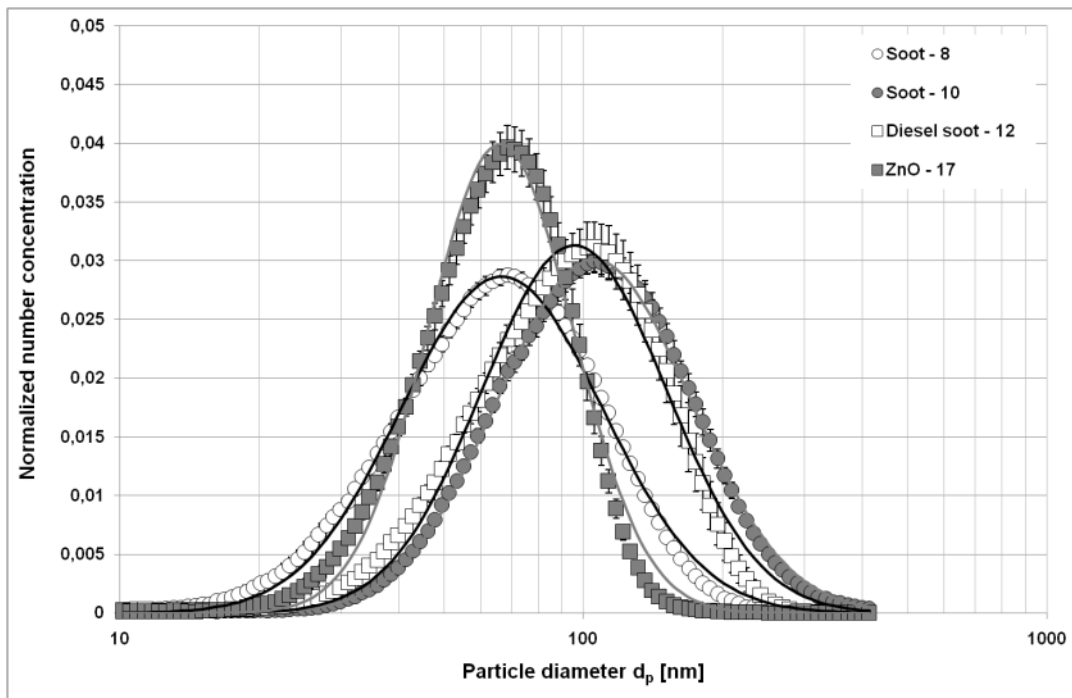


Figure 2-3 Normalized size distributions of the test aerosols with agglomerate morphologies.

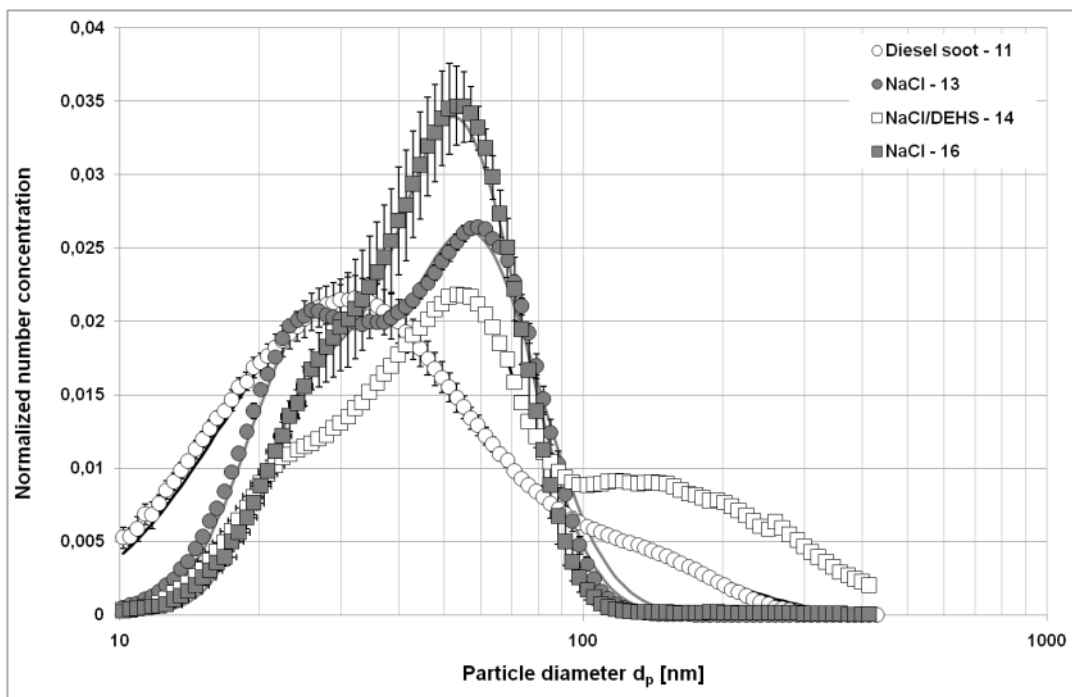


Figure 2-4 Normalized size distributions of the bimodal/trimodal test aerosols.

3. Study of personal monitors with polydisperse particles

The results are presented as bar charts of the averages of the number concentration, lung deposited surface area concentration and mean particle size, respectively, for each test aerosol. The bars are grouped and coloured according to the instrument type, i.e. red for CPC, green for electrical mobility spectrometers (SMPS with long and nano-DMA and nanoScan), blue for minidisc/DiSCmini, grey for nanoTracer, orange for Partector and pink for NSAM. In addition, the bar which can be considered as the reference for this test aerosol (depending on particle size, concentration and metric) is represented with a thick black frame. Results are discussed only for the personal monitors in comparison with the reference. Data from CPC 3007 and nanoScan are shown for information only, as both are no personal monitors, but handheld instruments.

The LDSA concentrations from the SMPSs and nanoScan were calculated assuming spherical particles. Although it is known for agglomerated particles (test aerosol numbers 7, 8, 9, 10, 11, 12 and 17) that this assumption does not meet the true particle morphology, there is currently no feasible way of calculating a better estimate for the LDSA concentration. The assumption of spherical particles was, however, shown to introduce only small errors (Fissan et al., 2012) and was hence considered to be justified here.

It should be noted that it was found that miniDiSC 1 more or less consistently produced higher concentrations than the other two identical instruments (miniDiSC 2 and DiSCmini). Furthermore it was detected that nanoTracers 1 and 2 showed consistently higher concentrations than nanoTracers 3 to 5. It was checked whether the discrepancies were caused by spatial inhomogeneities in the measurement chamber, which can however be excluded. Partector 3 was found to draw a too low flow rate, resulting in too low concentrations to be reported back.

Test Aerosol 1

Test aerosol 1 is a burner generated sodium chloride aerosol with a modal diameter around 13 nm and an average number concentration of 9,400 1/cm³. The aerosol also showed a secondary peak from the particle background in the room, which is insignificant for the number concentration, but since the modal diameter of the secondary peak is around 90 nm, it does affect the LDSA concentration and the mean particle size determined by the diffusion charger instruments. Hence the SMPS with long DMA was chosen as reference for the LDSA concentration and mean particle size. It can be seen from Figure 3-1(a) that all miniDiSCs/DiSCmini and nanoTracer underestimate the number concentration by factors between 3 and 7. This is because the number concentration is dominated by the very small particles, which are too small for these instruments. The LDSA concentration (see Figure 3-1(b)) is overestimated by all instruments, however the deviations are much smaller than for the number concentration. Leaving aside nanoTracer 1 and 2 the instrument responses were too high by factors of between 1.06 and 1.69. nanoTracers 1 and 2 were found to be always over-reporting and were hence considered as malfunctioning. Their results are still reported here for the sake of completeness. The mean particle size reported by all instruments is close to the ones provided by the reference SMPS and differed within a range from -30% to +15%.

Test Aerosol 2

Test aerosol 2 is a burner generated sodium chloride aerosol with a modal diameter around 12 nm and an average number concentration of 78,600 1/cm³. The secondary peak around 90 nm, which affected particularly the LDSA concentration and mean particle size in the case of test aerosol 1, was also present here. However, compared with the concentration of the primary peak around 12 nm,

the secondary peak only had a small contribution to the total LDSA concentration and only caused a minor shift in the mean particle size.

It can be seen from Figure 3-2(a) that the number concentrations delivered by the miniDiSCs/DiSCmini deviated only by at most 15%, whereas the nanoTracer concentrations were all by a factor of around 2 too low. At the same time the mean particle size reported by miniDiSCs/DiSCmini were all very close to the actual mean size (12 nm), whereas the mean size provided by the nanoTracers were by a factor of approximately 2 too large. It should, however, be noted that the nanoTracer is specified only for particles >20 nm and was hence used outside of its specifications. It should furthermore be noted that the size distribution of test aerosols 1 and 2 are rather unlikely to be found in real workplace environments. Figure 3-2(b) shows that the LDSA concentration from miniDiSCs and nanoTracers were all by a factor between 1.65 and 2.33 too high. The Partectors agreed a little better, but were still by factors between 1.23 and 1.79 too high. The overestimation of LDSA concentrations for such small particles agrees well with the findings obtained with monodisperse particles (see deliverable D3.2) where it was found that all instruments showed too high LDSA concentrations for 10 nm particles.

Test Aerosol 3

Test aerosol 3 is an atomizer generated sodium chloride aerosol with a modal diameter around 63 nm and an average number concentration of 17,500 1/cm³. The comparative results of all monitors are shown in Figure 3-3. It can be seen in Figure 3-3(a) that the number concentrations provided by the DiSCmini and nanoTracer 4 are close to the reference value (deviation only approximately 10%), whereas the other instruments show too high concentrations, by a factor of up to 1.8 in case of nanoTracer 1.

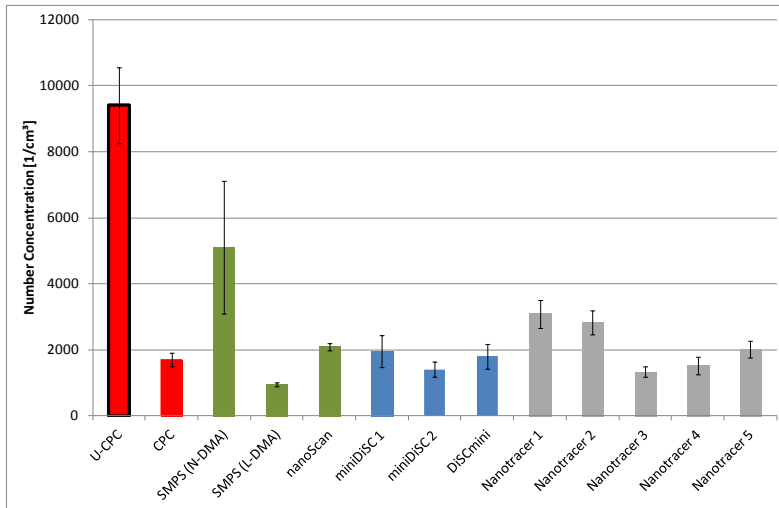
The agreement of the lung deposited surface area concentration is much better for all instruments, with deviation all within a margin of $\pm 20\%$, except for nanoTracers 1 and 2 which showed a deviation of around +30%. On average, the Partectors showed the lowest deviations (around $\pm 10\%$) for the LDSA concentrations. The deviations of the reported mean particle sizes from the reference values were also much lower than for the number concentration and within $\pm 15\%$, except for nanoTracer 3 (+28%).

Test Aerosol 4

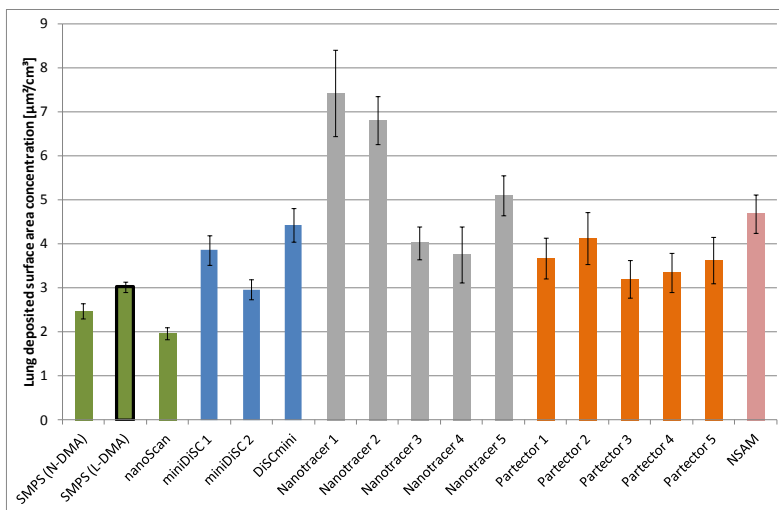
Test aerosol 4 is an atomizer generated sodium chloride aerosol with a modal diameter around 55 nm and an average number concentration of 163,000 1/cm³. The comparative results of all monitors are shown in Figure 3-4. It can be seen in Figure 3-4(a) that the number concentrations provided by all personal monitors are too high by factors between 1.28 (nanoTracer 3 and 4) and 2.06 (miniDiSC 1). Again the agreement for the LDSA concentration with deviations all within $\pm 20\%$, except for nanoTracers 1 and 2 which showed a deviation of around +30%. In terms of the mean particle size, miniDiSC 1 and 2 as well as nanoTracer 3 showed deviations on the order of 30%, whereas all other instruments agreed very well with the reference value.

The comparability with test aerosol 4 is very comparable with those using test aerosol 3. The test aerosols 3 and 4 were generally quite similar, except for an approximately tenfold higher concentration in case of test aerosol 4. This shows that the monitors do deliver repeatable results, which are not affected by the absolute concentrations.

(a)



(b)



(c)

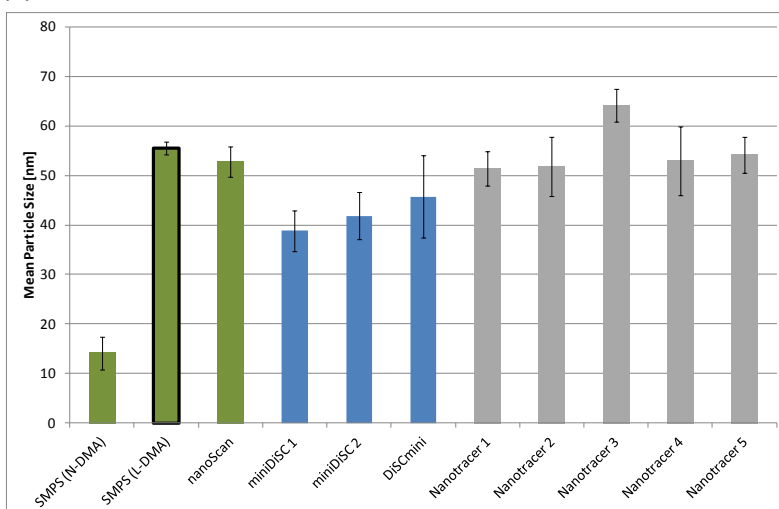
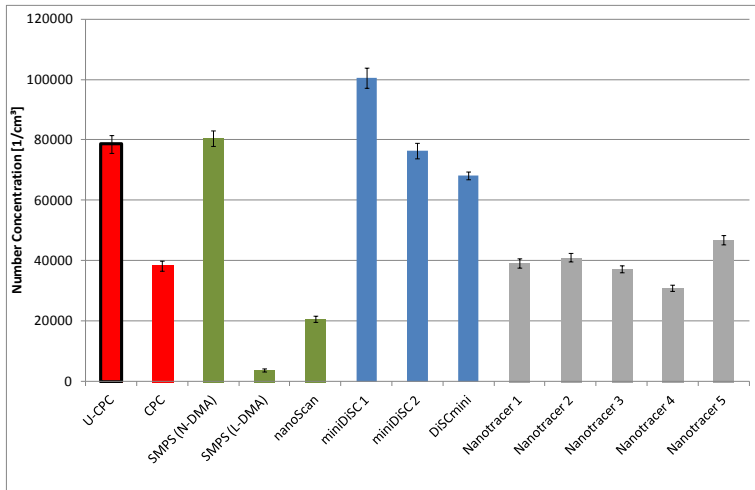
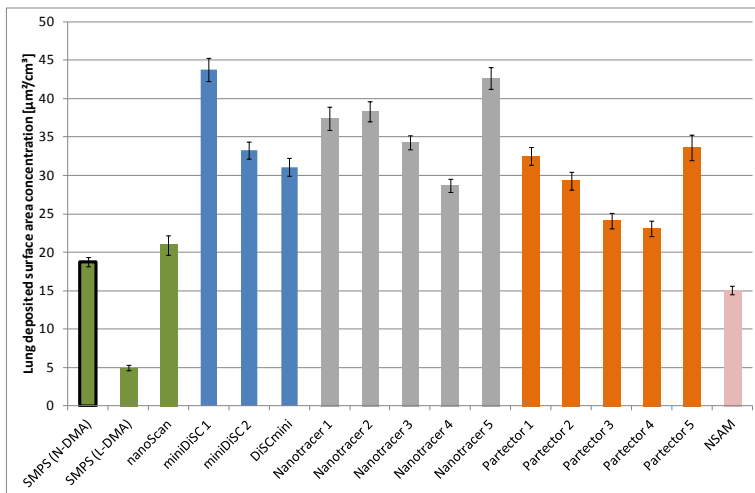


Figure 3-1 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 1 (burner generated NaCl) with 13 nm modal diameter and a number concentration of 9,400 1/cm³

(a)



(b)



(c)

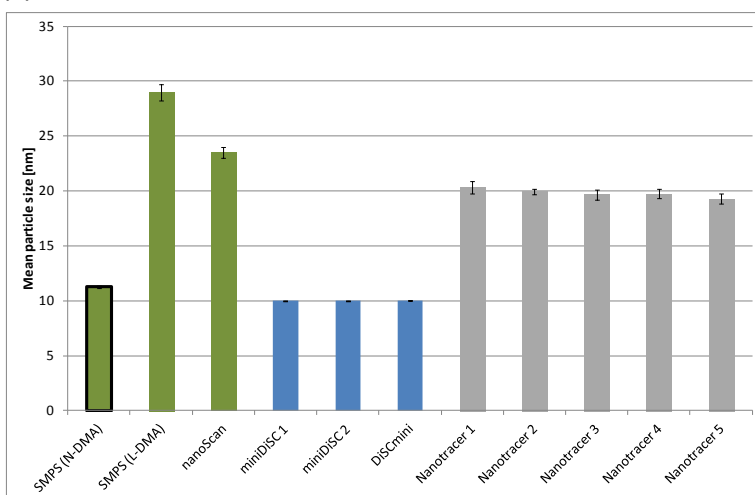
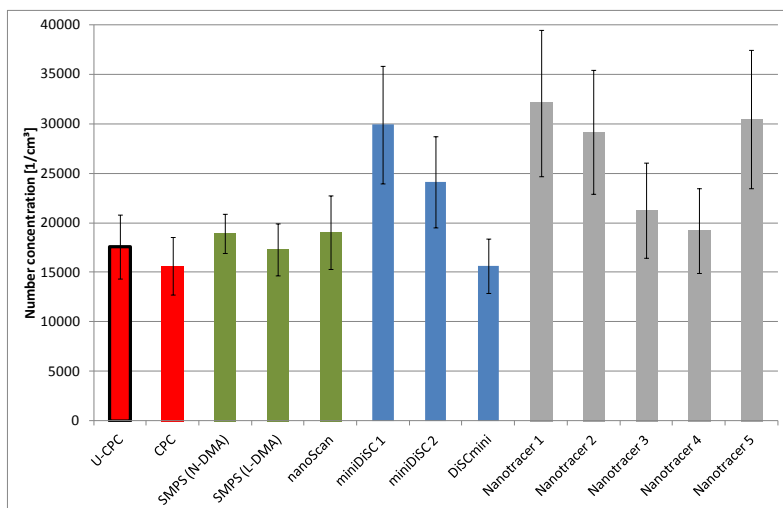
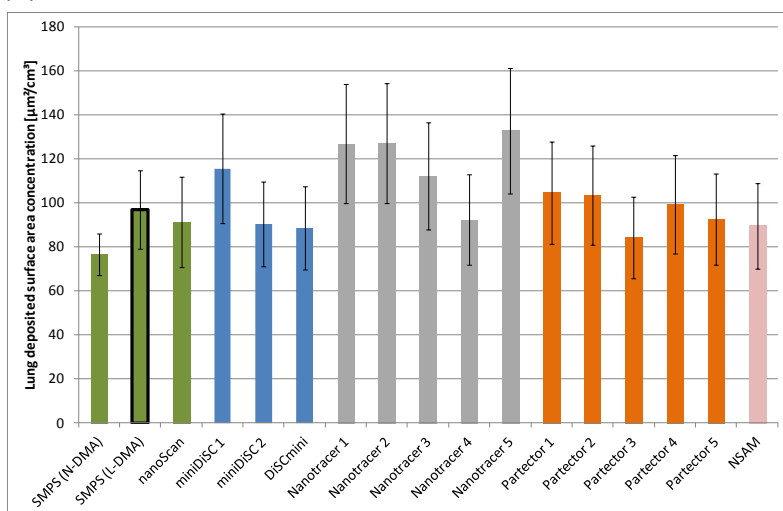


Figure 3-2 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 2 (burner generated NaCl) with 12 nm modal diameter and a number concentration of 78,600 1/cm³

(a)



(b)



(c)

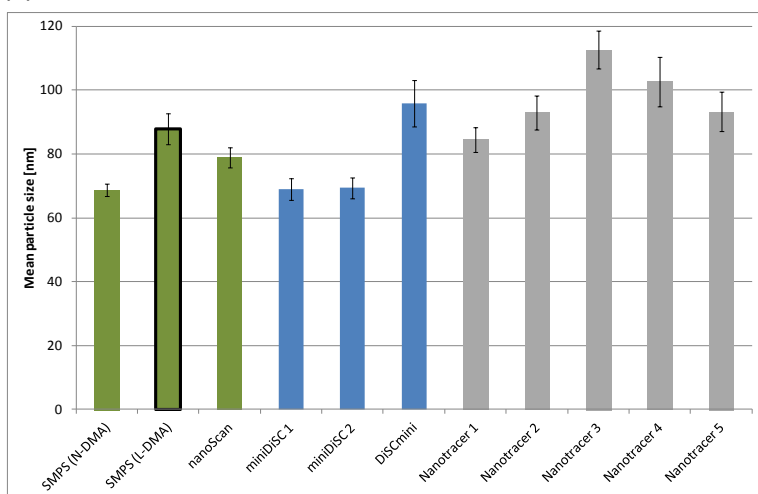
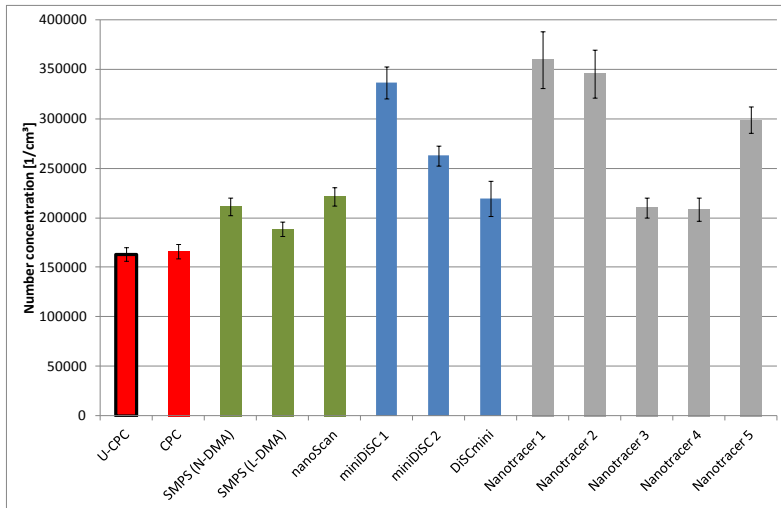
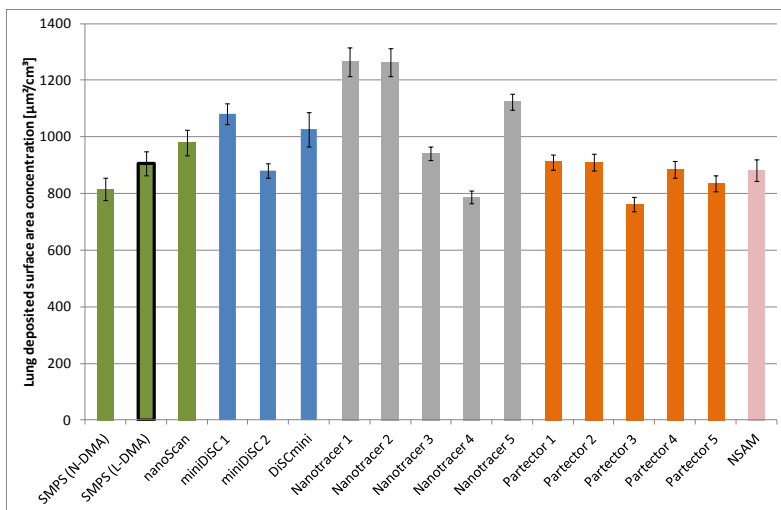


Figure 3-3 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 3 (atomizer generated NaCl) with 63 nm modal diameter and a number concentration of 17,500 1/cm³

(a)



(b)



(c)

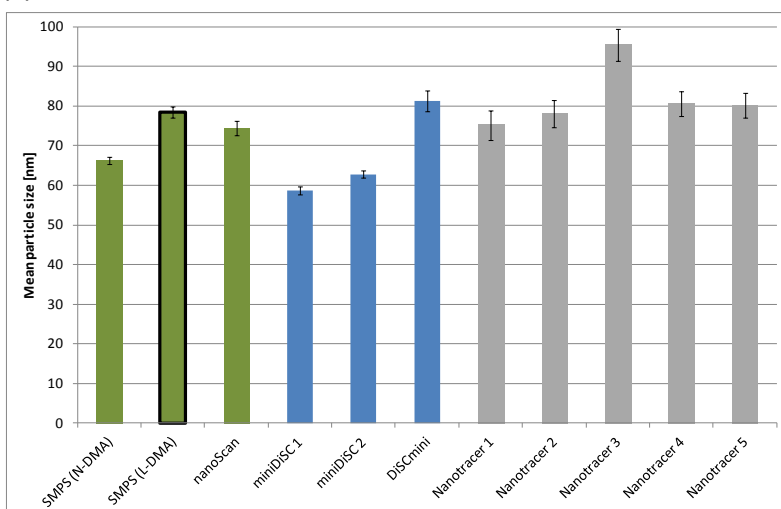
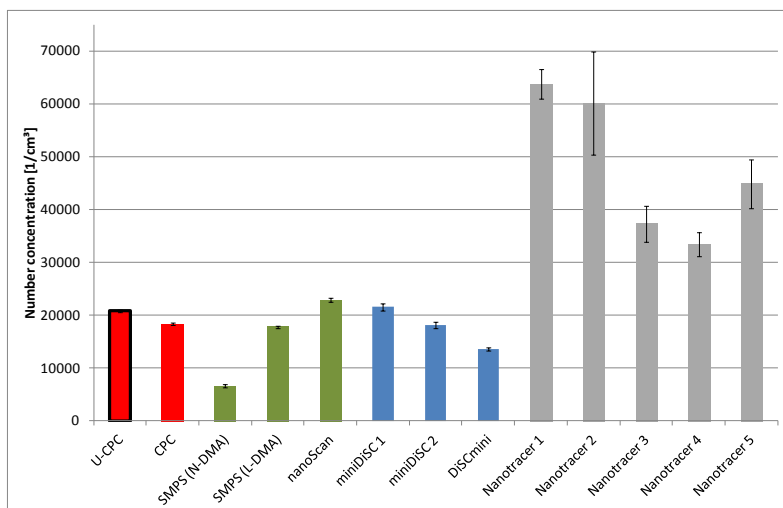
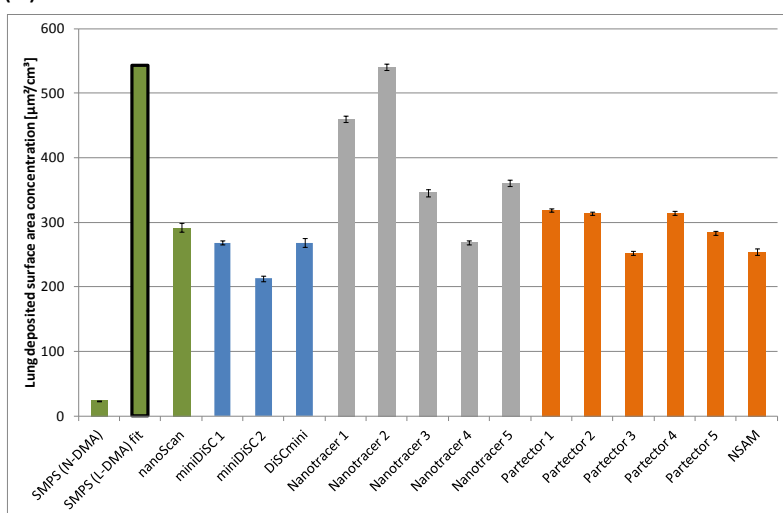


Figure 3-4 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 4 (atomizer generated NaCl) with 55 nm modal diameter and a number concentration of 163,000 1/cm³

(a)



(b)



(c)

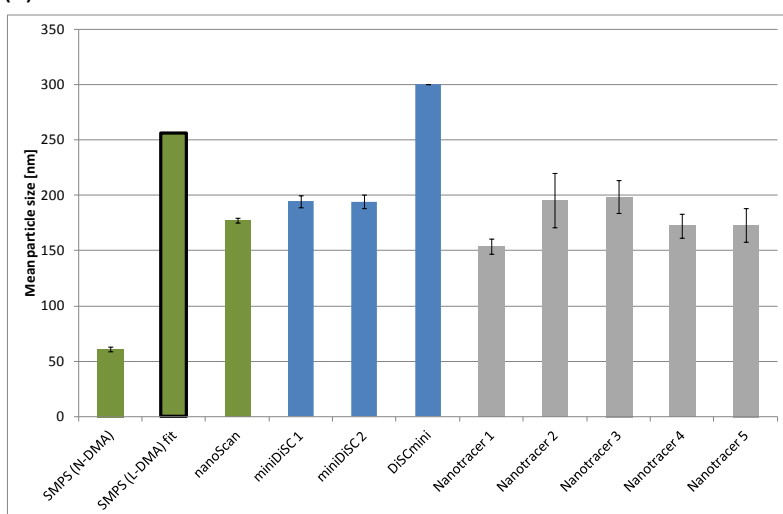


Figure 3-5 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 5 (atomizer generated DEHS) with 240 nm modal diameter and a number concentration of 20,800 1/cm³

Test Aerosol 5

Test aerosol 5 is an atomizer generated DEHS aerosol with a modal diameter around 240 nm and an average number concentration of 20,800 1/cm³. The comparative results of all monitors are shown in Figure 3-5. The SMPS with long DMA was set to measure from approximately 20 nm to 415 nm. Since the mode of the size distribution was at around 240 nm with a geometric standard deviation around 2, the SMPS size range did not cover the full range of the size distribution and hence missed the upper part of the size distribution. The measured distribution was therefore fitted to a lognormal size distribution and extrapolated to 1 µm. When converted to LDSA size distribution, still a large fraction of the size distribution was missing. It is known from the study with monodisperse particles that none of the instruments in the test is able to measure the LDSA concentration or mean particle size of such large particle correctly. Therefore only particle sizes up to 700 nm were taken into account for the determination of the LDSA concentration and mean particle size, since the miniDiSC and DiSCmini use a pre-separator that excludes all particles >700 nm from the measurement.

It can be seen that both LDSA concentration and the mean particle size are both underestimated by all monitors, except for the DiSCmini that showed a somewhat larger particle size. While the number concentration of miniDiSC 1 and 2 agreed well with the one from the reference CPC, the DiSCmini showed a noticeable deviation of 35%. All nanoTracers showed too high concentrations by a factor between 1.6 and 3.1. Similar results have been reported in the past for the nanoTracer by Asbach et al. (2012) and Kaminski et al. (2013). It was found that the nanoTracer seems to overestimate particle number concentrations if the modal diameter is beyond the specifications of the instruments. The nanoTracer is specified for modal diameters between 20 and 120 nm, whereas the modal diameter of test aerosol 5 was around 240 nm.

Test Aerosol 6

Test aerosol 6 is an atomizer generated DEHS aerosol with a modal diameter around 250 nm and an average number concentration of 98,600 1/cm³. The comparative results of all monitors are shown in Figure 3-6. As in the measurements for test aerosol 5, the SMPS with long DMA was set to measure from approximately 20 nm to 415 nm. Since the mode of the size distribution was at around 240 nm with a geometric standard deviation around 2, the SMPS size range did not cover the full range of the size distribution and hence missed the upper part of the size distribution. To overcome this problem, the measured number size distribution curve was fitted to a lognormal distribution as described above and the curve extrapolated up to 1 µm. The LDSA concentration in Figure 3-6 b is shown only for particles <700 nm, because the miniDiSC/DiSCmini uses a preseparator to remove all particles larger than this size. The reference value for the mean particle size was calculated from the extrapolated size distribution, however also up to 700 nm. Figure 3-6 b shows that all monitors provide too low LDSA concentrations. This is in good agreement with the findings with monodisperse particles. The same holds true for the determination of the mean particle size, where also all instrument (except for DiSCmini) show too low values. It should however be noted that the particle sizes were mostly beyond the specified size range of the nanoTracer and at least the upper branch of the size distribution was outside the specifications of the miniDiSC/DiSCmini.

While the number concentration of the miniDiSCs and DiSCmini agreed to within ±25% with the one from the reference CPC, all nanoTracers showed too high number concentrations by a factor between 1.6 and 3.3. This agrees well with the findings with test aerosol 5. Test aerosols 5 and 6 share very similar size distributions but with different concentrations. Similar results have been reported in the past for the nanoTracer by Asbach et al. (2012) and Kaminski et al. (2013). It was found that

the nanoTracer seems to overestimate particle number concentrations if the modal diameter is beyond the specifications of the instruments. The nanoTracer is specified for modal diameters between 20 and 120 nm, whereas the modal diameter of test aerosol 5 was around 240 nm. The good general agreement between the results with test aerosols 5 and 6 shows the good repeatability of the instruments.

Test Aerosol 7

Test aerosol 7 is a spark generated carbon agglomerate aerosol with a modal diameter around 53 nm and an average number concentration of 15,000 1/cm³. The test aerosol was chosen to investigate the potential effect agglomerates particles may have on the response of the personal monitors. The comparative results of all monitors are shown in Figure 3-7.

Figure 3-7(a) shows that all personal instruments deliver too high number concentrations. While nanoTracer 3 and 4 deviate by only 3%, the deviation of the other nanoTracers is between 32% and 100%. The deviations of the miniDiSCs and DiSCmini were not consistent with 32%, 65% and 94%, respectively.

As in the previous cases, the agreement of the lung deposited surface area concentration with the reference from the SMPS with long DMA was much better. All instruments agreed within a range of $\pm 25\%$. Except for Partector 3, which -as mentioned above- had a too low flow rate, all Partectors even agreed to within $\pm 4\%$ with the reference value.

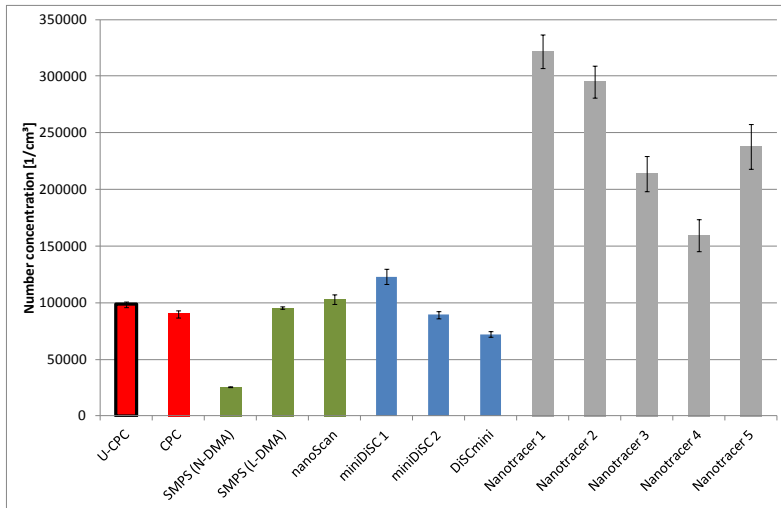
The mean particle size provided by the personal monitors agreed to with $\pm 20\%$ with the reference value. It should be noted that the reference value from the SMPS is the mean electrical mobility diameter, i.e. an equivalent diameter.

Test Aerosol 8

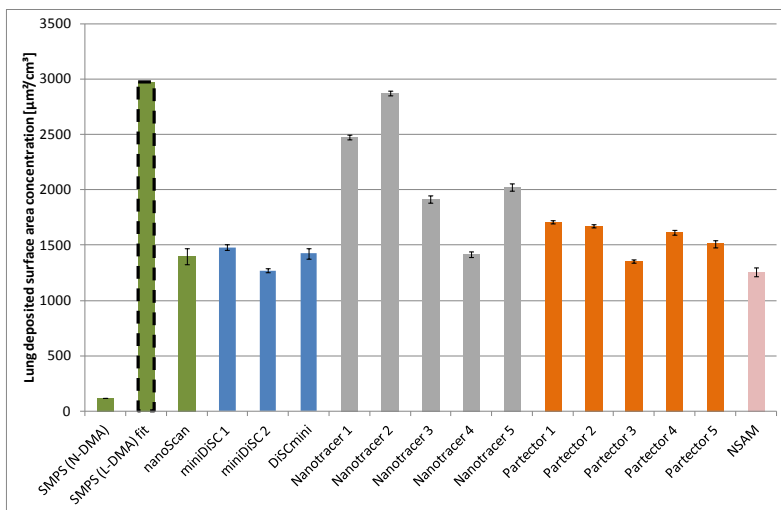
Test aerosol 8 is a spark generated carbon agglomerate aerosol with a modal diameter around 69 nm and an average number concentration of 101,600 1/cm³. The test aerosol is similar to the previous one and was chosen to investigate the potential effect agglomerated particles may have on the response of the personal monitors. The comparative results of all monitors are shown in Figure 3-8.

Similarly to the results with the previous test aerosol, the number concentrations, reported by all monitors were too high. Only nanoTracer 4 provided a good estimate with only 9% deviation. All other nanoTracers deviated between 50% and 108% and miniDiSC/DiSCmini between 32% and 115%. To the contrary, the LDSA concentrations again agreed rather well with each other and – leaving aside the instruments known as faulty- to within $\pm 15\%$. The agreement of the reported mean particle sizes was within $\pm 20\%$.

(a)



(b)



(c)

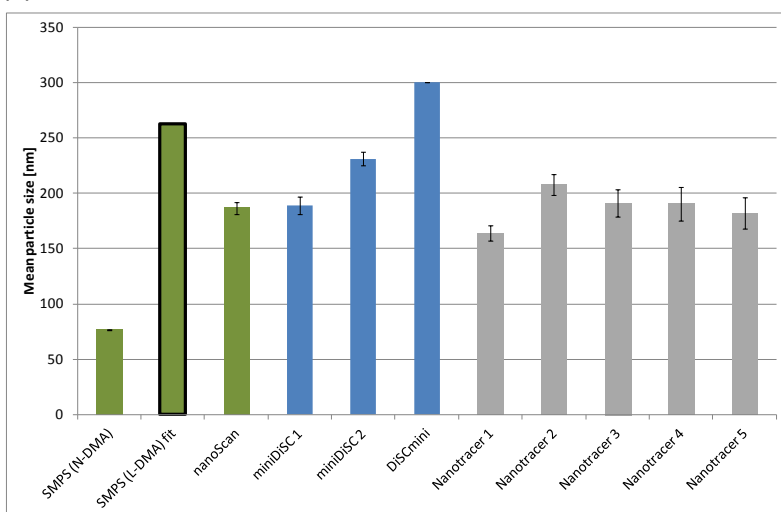


Figure 3-6 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 6 (atomizer generated DEHS) with 250 nm modal diameter and a number concentration of 98,600 1/cm³

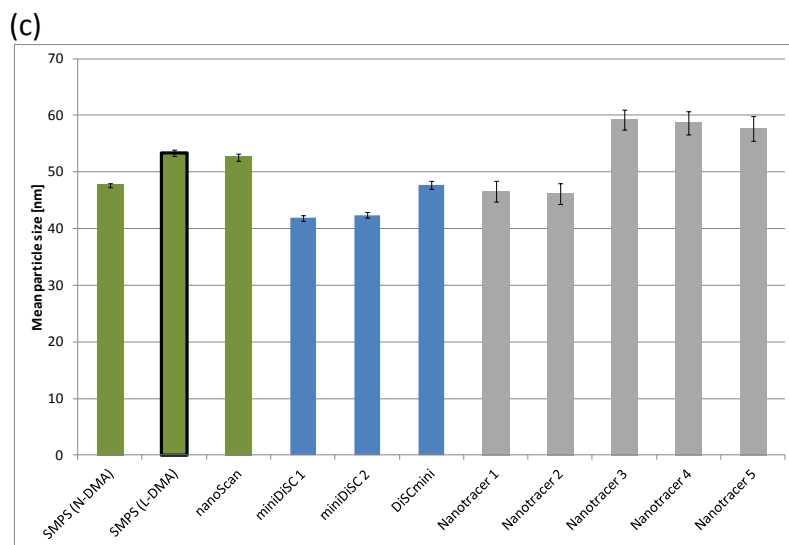
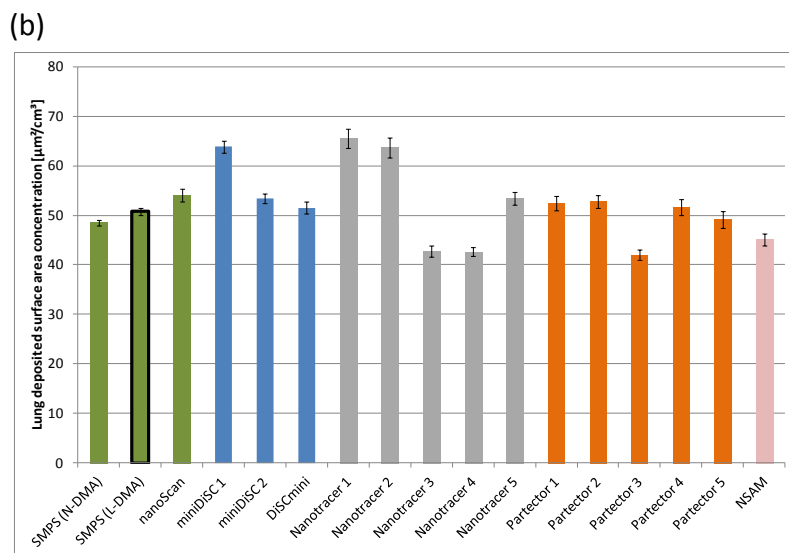
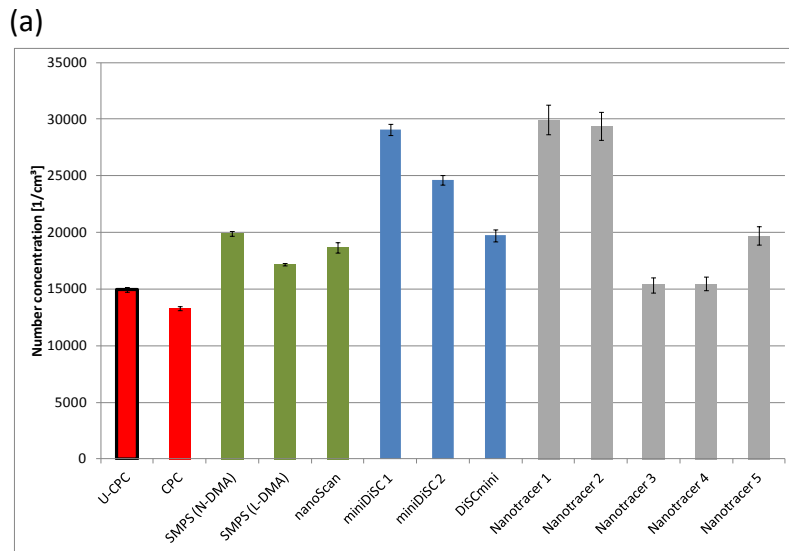
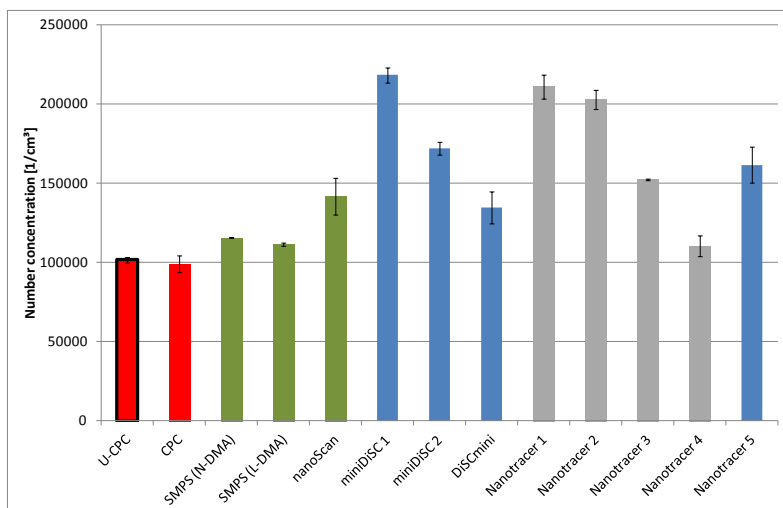
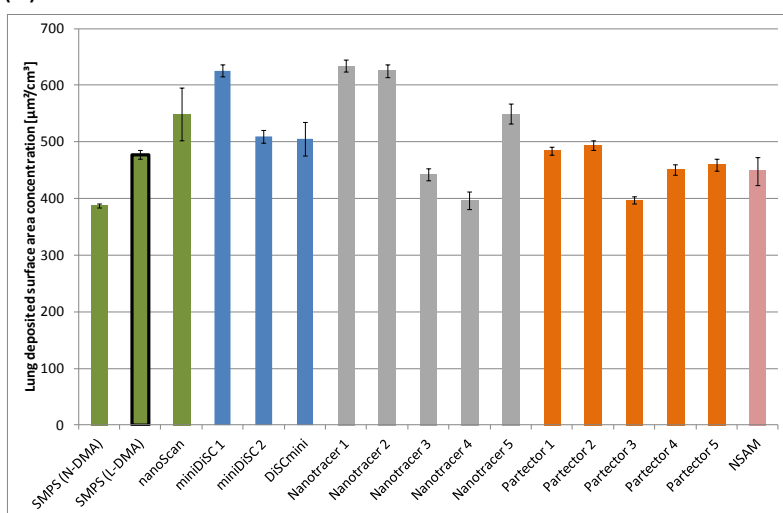


Figure 3-7 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 7 (spark generated carbon) with 53 nm modal diameter and a number concentration of 15,000 1/cm³

(a)



(b)



(c)

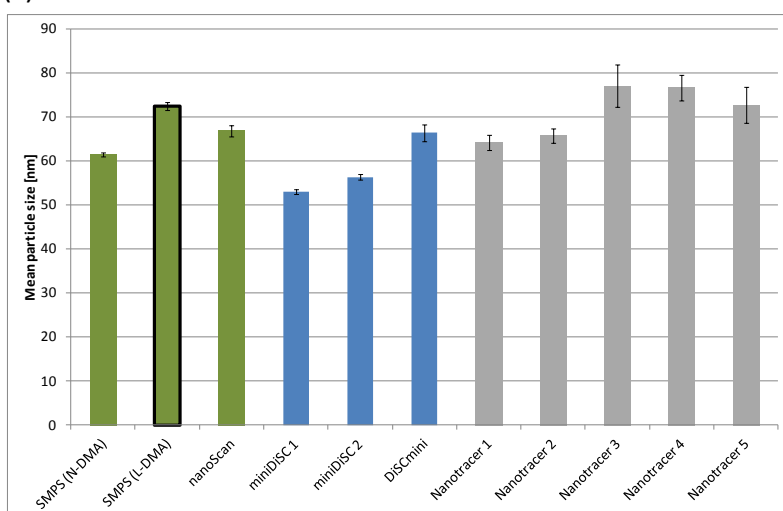
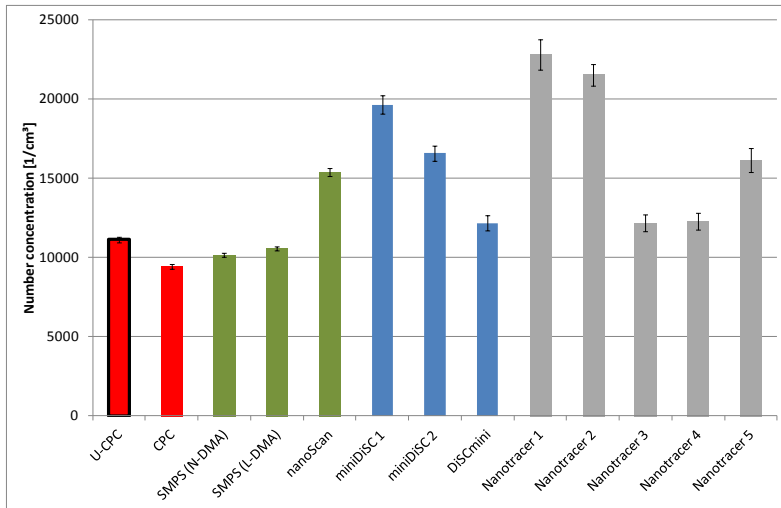
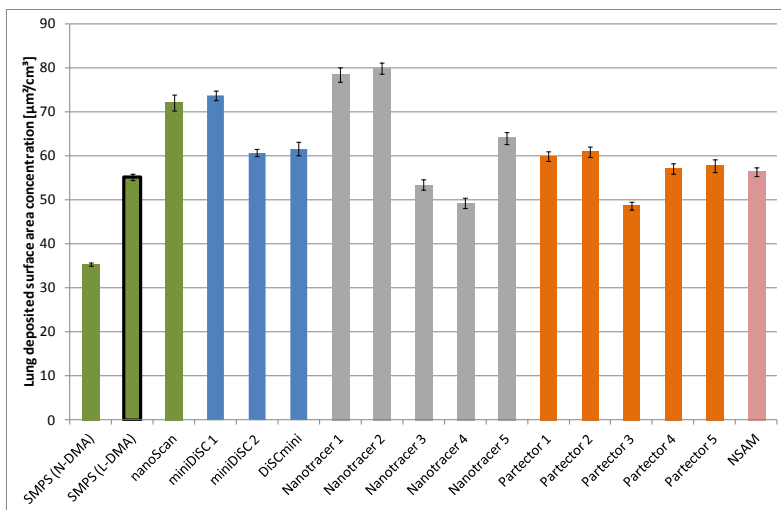


Figure 3-8 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 8 (spark generated carbon) with 69 nm modal diameter and a number concentration of 101,600 1/cm³

(a)



(b)



(c)

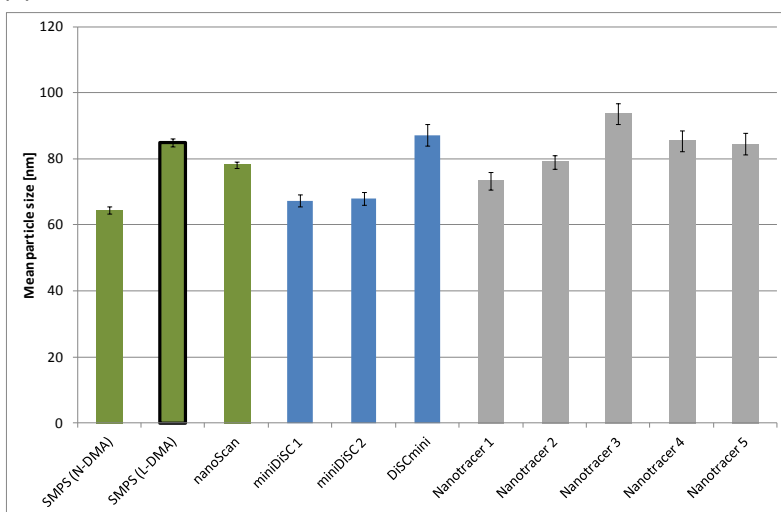


Figure 3-9 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 9 (spark generated carbon) with 85 nm modal diameter and a number concentration of 11,100 1/cm³

Test Aerosol 9

Test aerosol 9 is a spark generated carbon agglomerate aerosol with a modal diameter around 85 nm and an average number concentration of 11,100 1/cm³. The particles are similar to the ones in test aerosols 7 and 8, but slightly larger. The comparative results are shown in Figure 3-9.

As with the previous aerosols, the number concentrations, delivered by the personal monitors were all too high. The deviations are also very comparable with the previous cases, i.e. approximately 10% for nanoTracer 3 and 4 and DiSCmini and between 45% and 105% for all other instruments. Again, the agreement of LDSA concentrations among all non-faulty instruments was very good and within $\pm 10\%$. The agreement of the instruments responses concerning mean particle size agreed within $\pm 20\%$.

Test Aerosol 10

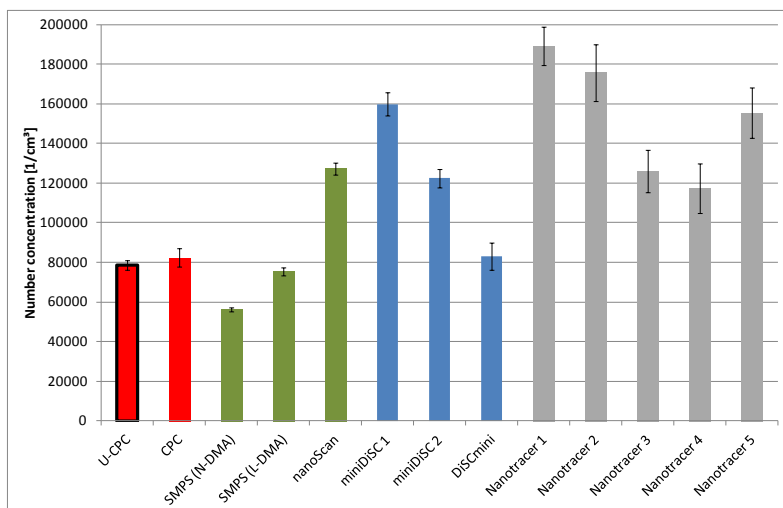
Test aerosol 10 is a spark generated carbon agglomerate aerosol with a modal diameter around 109 nm and an average number concentration of 78,700 1/cm³. The particles are similar to the ones in test aerosols 7 to 9, but slightly larger. The comparative results are shown in Figure 3-10.

The patterns of the bar graphs are very similar to those for test aerosols 7 to 9. Also for test aerosol 10, the number concentrations measured with all instruments are between 6% and 97% too high. Interestingly, nanoTracers 3 and 4, which both showed much better agreement in case of test aerosols 7 to 9 now deviate by 49% and 60%. It is assumed that this deviation is caused more by the particle size than the particle morphology, because it was shown with test aerosols 4 and 5 that large deviations of the reported number concentrations may occur in case of large particles, whereas the agreement for smaller agglomerated particles (especially test aerosols 7 and 8) was rather good.

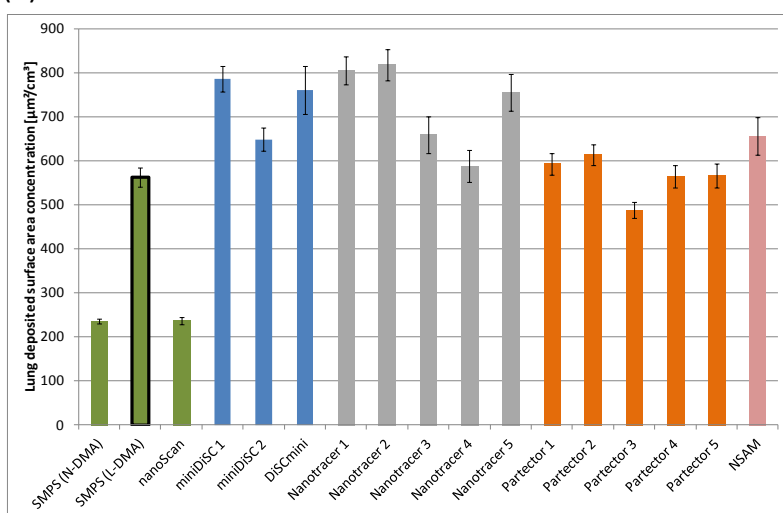
Similarly to the previous test aerosols, the agreement of the measured LDSA concentrations was rather good and within $\pm 30\%$. A similar overall agreement was found for the mean particle size.

The similarities in the patterns in Figure 3-7(a), Figure 3-8(a), Figure 3-9(a) and Figure 3-10(a) in comparison to the other aerosols show that the observed deviations are systematic and likely caused by the particle morphology.

(a)



(b)



(c)

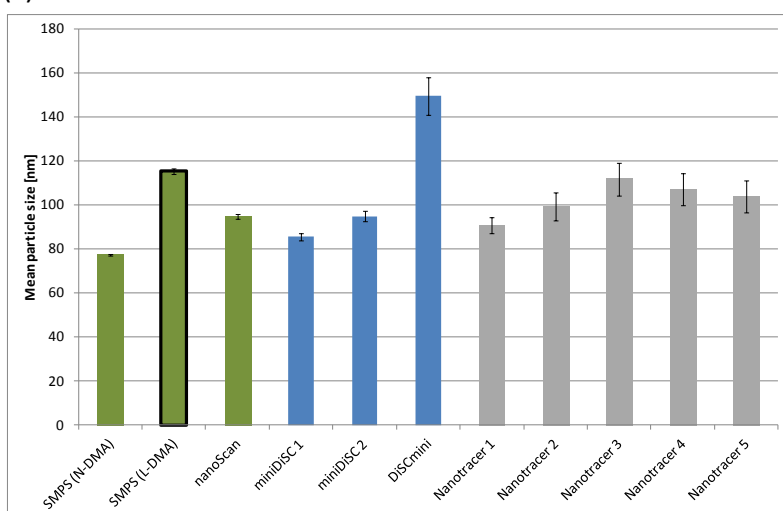


Figure 3-10 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 10 (spark generated carbon) with 109 nm modal diameter and a number concentration of 78,700 1/cm³

Test Aerosol 11

Test aerosol 11 is a diesel soot aerosol, generated with a passenger car diesel engine. Diesel soot is known to consist of agglomerated carbon particles, covered with a variety of components, such as volatile organic compounds (VOCs). The test aerosol was chosen, because it is a common challenge aerosol in real workplaces, where diesel or other engines are in operation. With the engine setting used in this experimental run, the size distribution exhibits a bimodal distribution with the first mode at 31 nm and the second mode at 145 nm. The total number concentration was 233,000 1/cm³. The comparative results are shown in Figure 3-11.

The patterns in the bar charts are again very similar to the previous graphs, likely due to the agglomerated nature of the test particles. The bimodal shape of the distribution did not seem to negatively affect the agreement between the instruments. In fact, the agreement for the number concentration was better compared with the previous cases. The non-faulty devices deviated from the reference by a margin between -18% and +39%, compared with deviations of sometimes >100% for the “clean” carbon agglomerates. It is assumed that this lower deviation is a morphology effect, because diesel soot particles tend to be more fluffy particles, whereas the spark generated carbon particles form rather chain-like agglomerates. In addition, the VOC layer on the diesel soot particles may make them appear more compact in the airborne state and hence the charging efficiency is close to that of spheres.

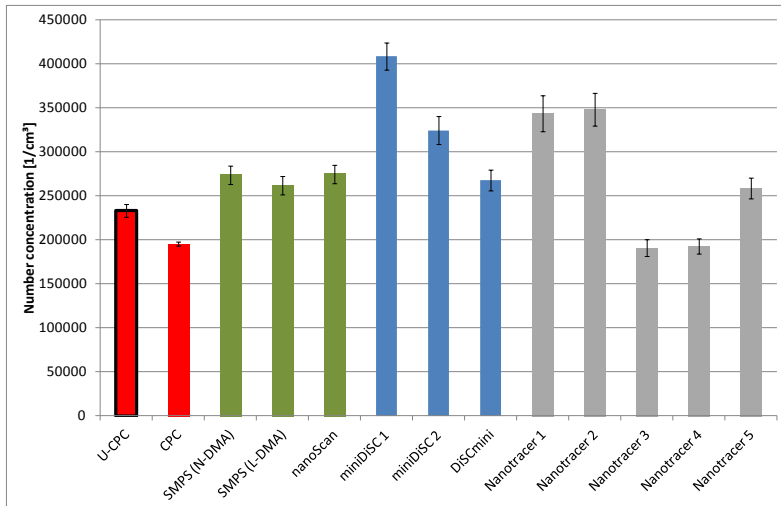
Similarly to the pure carbon agglomerates, the agreement among the instruments for LDSA concentration was mostly around $\pm 15\%$ and $\pm 25\%$ for the mean particle size.

Test Aerosol 12

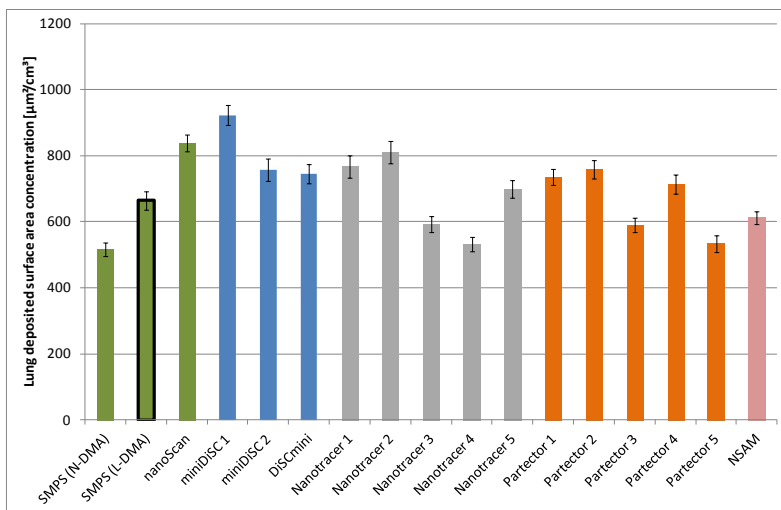
Test aerosol 12 is also a diesel soot aerosol, generated with a passenger car diesel engine. With the engine setting used in this experimental run, the size distribution exhibits a single mode only at 98 nm. The total number concentration was 123,900 1/cm³. The comparative results are shown in Figure 3-12.

Again the patterns are very similar as with test aerosol 11 and the deviations for the number concentrations are almost identical with those measured with test aerosol 11, i.e. between -14% and +39%. This shows that the bimodal distribution in case of test aerosol 11 indeed did have no effect on the instruments' comparability. While the LDSA concentrations in the previous case were rather a little higher, they are here rather a little bit below the reference value. miniDiSCs 2 and 3 showed deviations of only 0.5% and 3.5% (miniDiSC 1: 25%). The deviations of the nanoTracers were mostly within $\pm 20\%$. The Partectors all slightly underestimated the LDSA concentrations between, however only by a few percent.

(a)



(b)



(c)

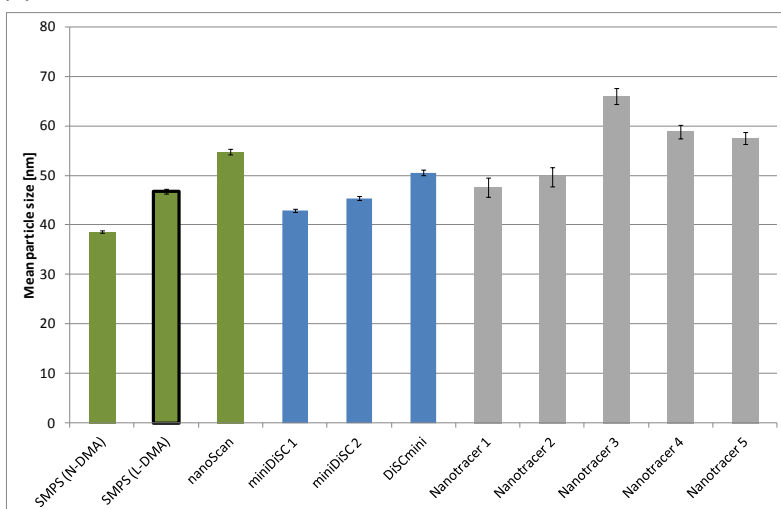
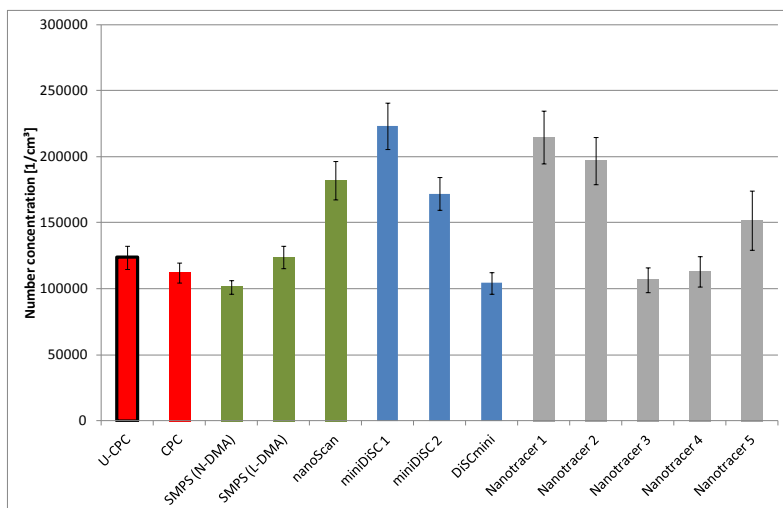
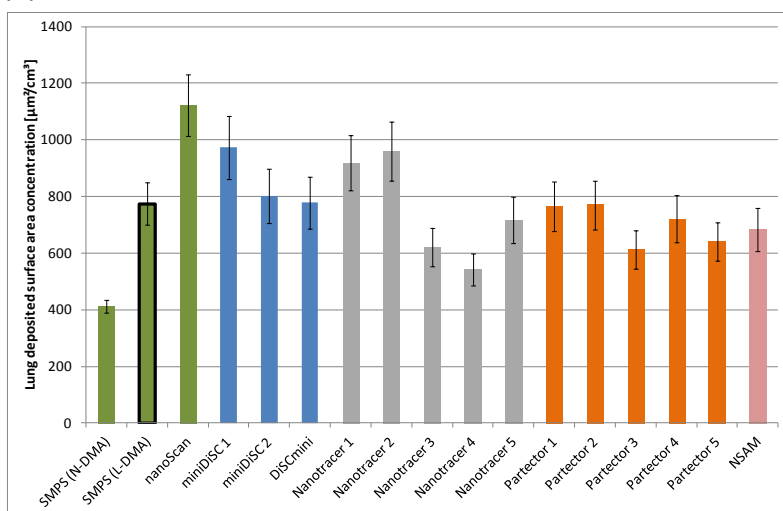


Figure 3-11 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 11 (diesel soot); bimodal distribution with peaks at 31 nm and 145 nm and a number concentration of 233,000 1/cm³

(a)



(b)



(c)

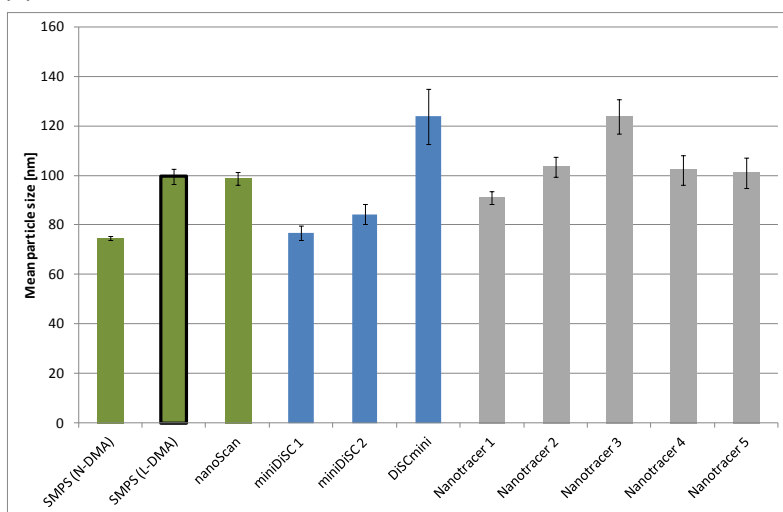
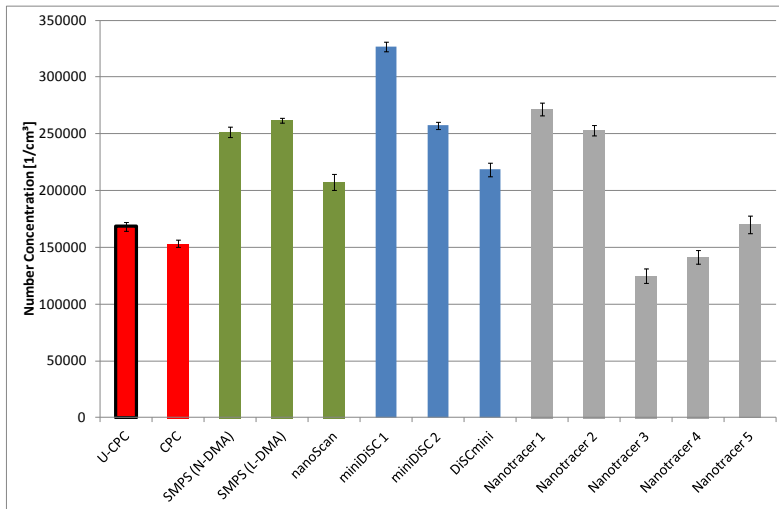
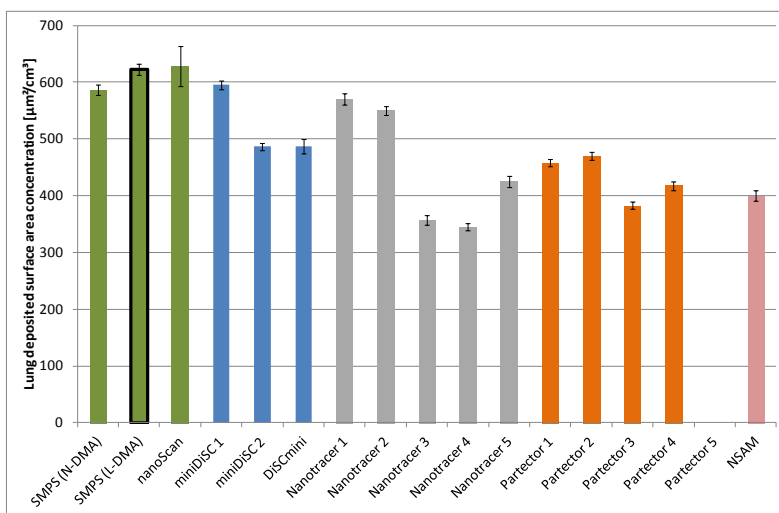


Figure 3-12 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 12 (diesel soot) with a modal diameter of 98 nm and a number concentration of 123,900 1/cm³

(a)



(b)



(c)

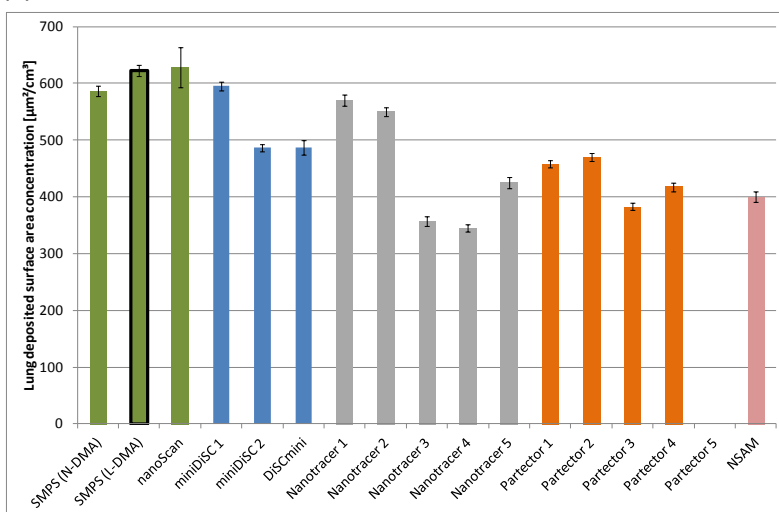


Figure 3-13 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 13 (NaCl) with a bimodal distribution with first mode at 26 nm, second mode at 57 nm and a number concentration of 168,400 1/cm³

Test Aerosol 13

Test aerosol 13 is a sodium chloride aerosol, generated with the diffusion burner. With the generator settings used, the size distribution exhibits a bimodal distribution with the first peak at 26 nm and the second peak at 57 nm. The total number concentration was 168,400 1/cm³. The comparative results are shown in Figure 3-13.

With this test aerosol, the miniDiSCs and DiSCmini provided too high concentrations (+53% and +30% for miniDiSC 2 and DiSCmini, respectively). The number concentration of nanoTracer 5 agreed very well with the reference value (deviation of 1%), whereas the number concentrations from nanoTracer 3 and 4 were 16% and 26%, respectively, too low. The deviations of miniDiSC 1 and nanoTracers 1 and 2 were higher than the ones explained above.

For test aerosol 13, all results from the monitors for the LDSA concentration were lower than the reference data from SMPS with long DMA. MiniDiSC 2 and DiSCmini results were both 22% lower. The results from nanoTracer 3 to 5 were between 32% to 42% and the Partector data between 24% and 39% too low. Interestingly, the results from miniDiSC 1 and nanoTracer 1 and 2, i.e. the instruments which were considered to be faulty, agreed better with deviations of 4% (miniDiSC 1) and 8% and 12% in case of nanoTracer 1 and 2, respectively.

The results for the mean particle size of miniDiSC 2 and DiSCmini are 17% and 9% too low (miniDiSC 1: -21%), whereas the results from nanoTracers 3 to 5 are 15 to 35% too high. nanoTracers 3 to 5 delivered very accurate size information (-1% and +3% deviation, respectively).

Test Aerosol 14

Test aerosol 14 is combination of the bimodal sodium chloride test aerosol 13 and a DEHS aerosol. The test aerosol was generated with a combination of the diffusion burner (NaCl) with an atomizer (DEHS). The size distribution was trimodal with the first and second peak from NaCl at 24 nm and 53 nm and the third peak at 141 nm. The size distribution was rather unstable and therefore the results presented here are rather vague and will be omitted from the planned publication. Although the size range exceeded the SMPS size range as in several earlier cases, it was not fitted to a combination of lognormal distributions, due to the uncertainty in the size distribution.

The total number concentration was 292,400 1/cm³. The third mode of the size distribution was at around 141 nm with a geometric standard deviation around 2 and therefore –as mentioned- at least partially beyond the SMPS size range. As a result, LDSA concentration and the mean particle size are both underrepresented by the SMPS and therefore a good reference value can only be given for the number concentration, measured by the CPC. The comparability of the mean particle size and LDSA concentration are hence not further discussed here.

The comparative results are shown in Figure 3-14. The results for the comparability of the number concentrations are rather diverse. miniDiSC 2 and DiSCmini deviated by +44% and -12%, respectively. The nanoTracers all showed too high concentrations. nanoTracer 3 and 4 by 16% and 13%, respectively and nanoTracer 5 by 48%. The fact that all nanoTracer number concentrations are too high may be caused by the large size of the third peak of the particles. The same effect was observed with pure DEHS particles with test aerosols 5 and 6. However, for test aerosol 14, the DEHS was diluted and consequently the particle size was smaller, resulting in significantly lower deviations from the reference value. It should be noted that the modal diameter of the third peak was still beyond the specifications of the nanotracers.

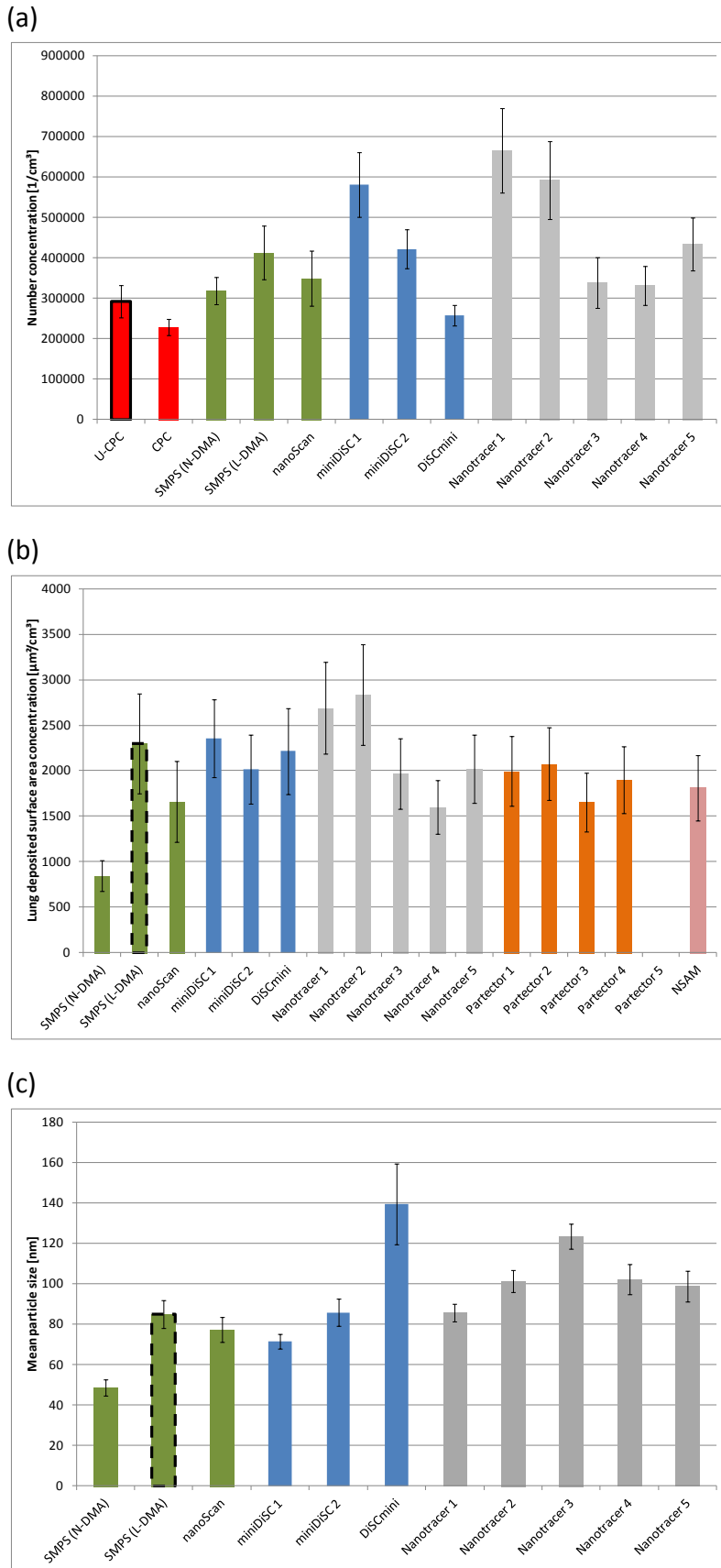
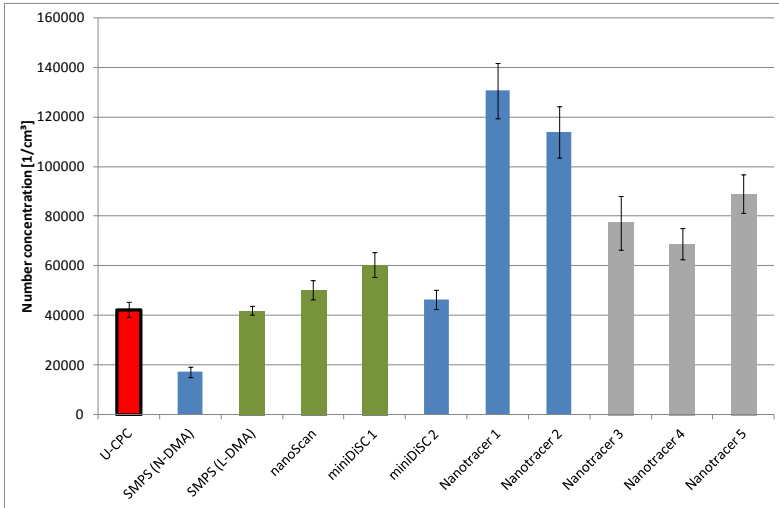
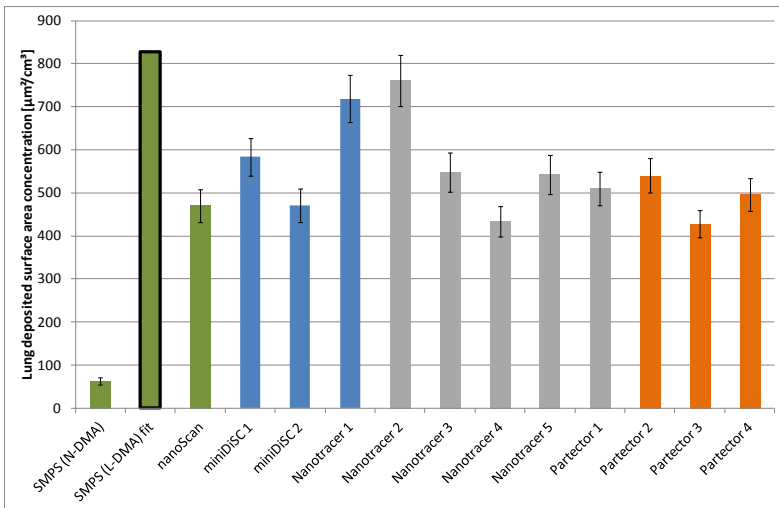


Figure 3-14 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 14 (NaCl and DEHS) with a trimodal distribution with first mode at 24 nm, second mode at 53 nm, third mode at 141 nm and a number concentration of 292,400 1/cm³

(a)



(b)



(c)

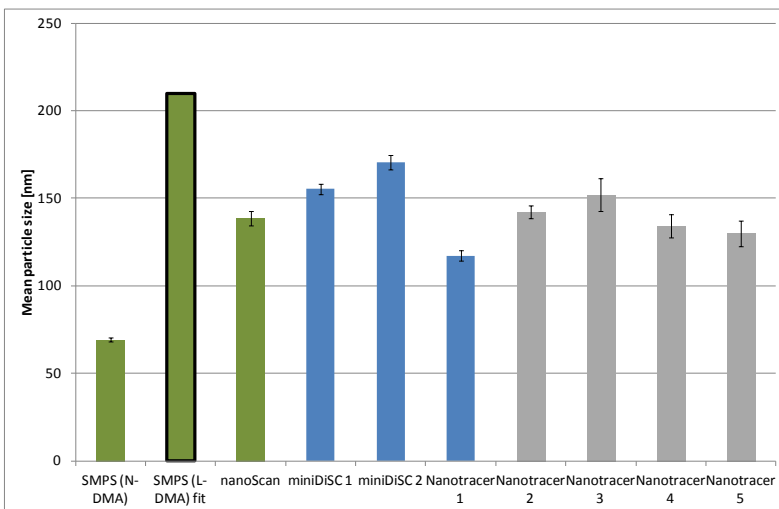
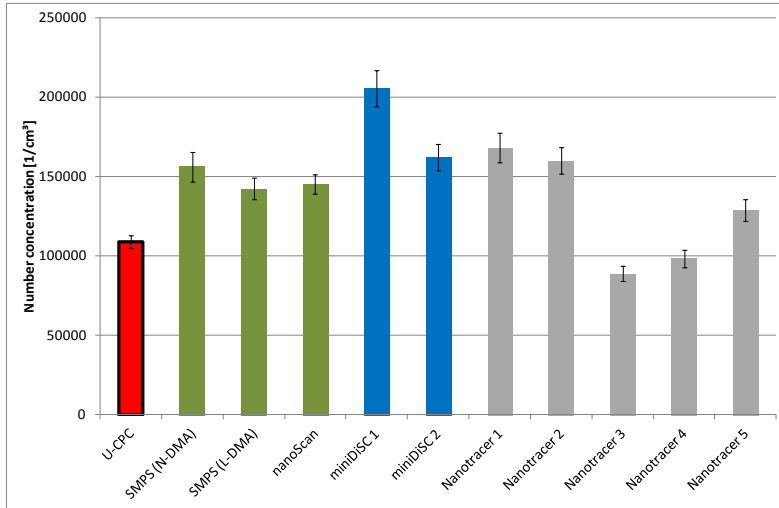
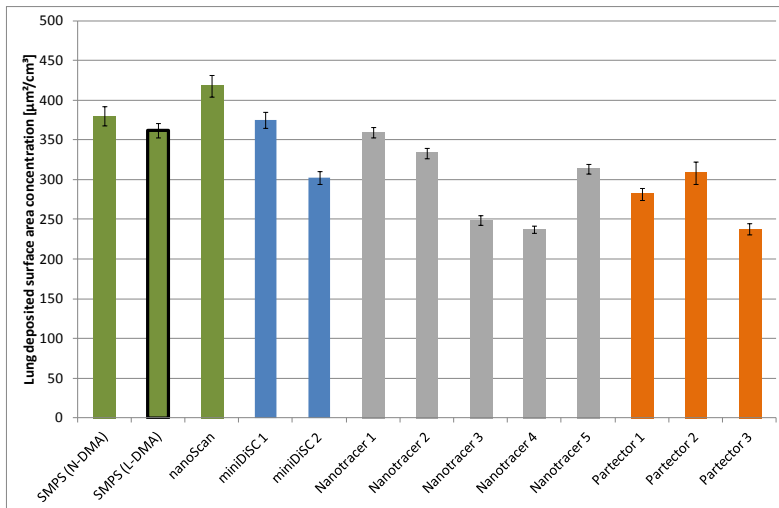


Figure 3-15 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 15 (DEHS) with a modal diameter of 202 nm and a number concentration of 42,400 1/cm³

(a)



(b)



(c)

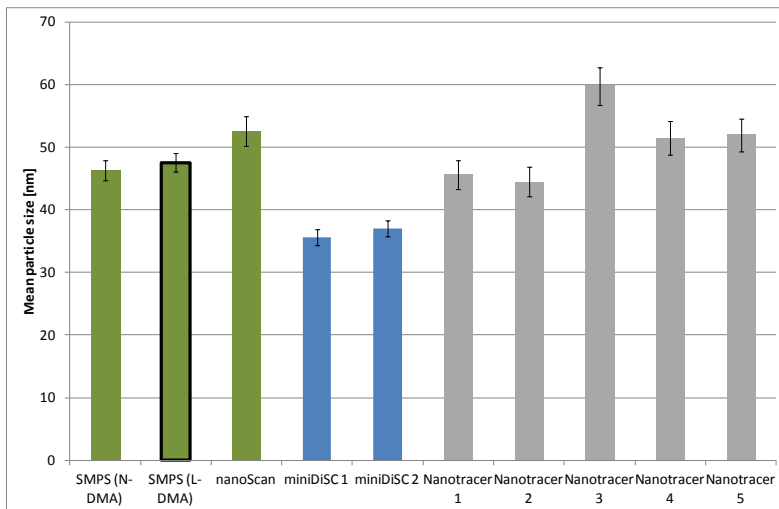


Figure 3-16 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 16 (NaCl) with a bimodal distribution with modal diameters of 26 nm and 53 nm and a number concentration of 108,900 1/cm³

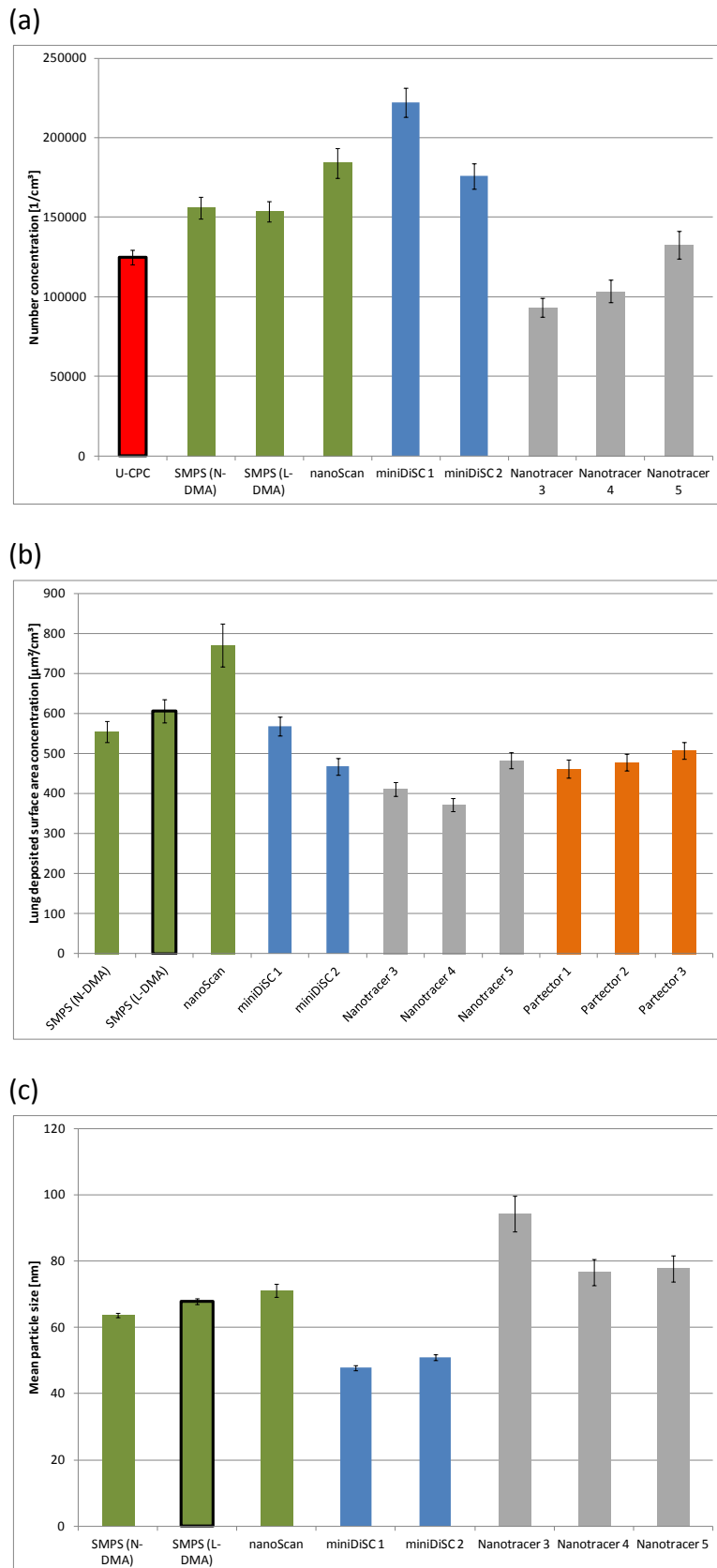


Figure 3-17 Number concentration (a), lung deposited surface area concentration (b) and mean particle size (c) for test aerosol 17 (ZnO) with a modal diameters of 69 nm and a number concentration of 124,900 1/cm³

Test Aerosol 15

Test aerosol 15 is a DEHS aerosol, generated with the atomizer from DEHS diluted 1:1 with isopropyl alcohol. The size distribution shows a mode at 202 nm and a total number concentration of 42,400 1/cm³. Since the mode of the size distribution was at around 202 nm with a geometric standard deviation around 2, the SMPS size range did not cover the full range of the size distribution. The number size distribution was therefore fitted to a lognormal distribution and the curve extrapolated to 1 µm. The LDSA concentration and mean particle size in Figure 3-15 were calculated from this extrapolated curve, however, only up to 700 nm because it is the cut-off size of the preseparator used by the miniDiSC/DiSCmini. None of the other instruments uses a pre-separator, but it is known that the working principle of these instruments fails to deliver accurate results above this size. Figure 3-15 shows that all instruments deliver both too low LDSA concentrations and too low mean particle sizes. This is most likely caused by the fact that a large portion of the particle size distribution is beyond the specified size ranges of the instruments.

The number concentration of DiSCmini 2 deviated by +10% from the reference value (minidiSC 1 by +43%). All nanoTracers showed significantly too high concentrations, by factors between 1.6 and 3. This is likely caused by the same reason as discussed above for test aerosols 5, 6 and 14, i.e. the too large particle sizes for this type of instruments.

Test Aerosol 16

Test aerosol 16 is an NaCl aerosol, generated with the diffusion burner. Test aerosol 16 is a repetition of test aerosol 13. Since the results are very comparable with the previous ones, they are not further discussed here.

Test Aerosol 17

Test aerosol 17 contains agglomerated ZnO particles, generated with the diffusion burner. This test aerosol was mainly generated to test the personal sampler NB2013. Therefore several partners had already left and the number of personal samplers was lower than during all previous measurements. The modal diameter of this size distribution is 69 nm with a total number concentration of 124,900 1/cm³. The comparative results are shown in Figure 3-17.

For this test aerosol, the number concentration delivered by miniDiSC 2 was approximately 41% higher than the reference value from the U-CPC. The nanoTracers 3 and 4 results were 25% and 17%, respectively, too low, whereas the nanoTracer 5 results deviated only by 6%. The LDSA concentration from miniDiSC 2 was 23 % too low. The LDSA concentrations from the nanoTracers were between 20% and 39% too low. LDSA concentrations delivered by the Partectors were between 16% and 24% below the reference value. The mean particle size delivered by miniDiSC 2 was 25% below and the ones from the nanoTracers between 13% and 39% above the reference value.

Conclusions

The results delivered by the different instruments are rather diverse and difficult to interpret. It was clearly shown that the nanoTracers delivered significantly too high number concentrations in the presence of large particle, which are beyond the specifications. A general dependence of all instruments' responses on particle morphology could not be observed. It is, however, apparent that the lung deposited surface area concentrations, delivered by the instruments seem to be more accurate than the number concentrations. Also the mean particle size was typically rather accurate. Deviations of the LDSA concentration and mean particle size were typically well within a margin of ±30%, whereas the deviations for the number concentrations were often higher.

4. Sampling and analysis with the NB2013 samplers

The polydisperse aerosols generated during the round-robin tests performed at IGF in February 2014 were sampled with three NB2013 samplers. The NaCl and ZnO aerosols were collected on polycarbonate filters, which were then analysed by X-ray fluorescence spectroscopy yielding the elemental composition of the collected material and their average concentration in air. The carbon-based aerosols (soot and diesel soot) were collected on freshly fired quartz filters. The amount of elemental carbon (“black” carbon) on the filters was measured in a thermal-optical analyser (Lab OC-EC Aerosol Analyzer from Sunset Laboratory).

The NB2013 samplers provide a time integrated measure of the exposure. Whenever the aerosols were generated under changing conditions (*e.g.* changes in number concentration), the quantification of the particles on the filters yields a single integrated result for both low and high aerosol concentrations, as shown in Table 0-1. The NB2013 was operated at $0.6 \text{ L}\cdot\text{min}^{-1} \pm 5\%$. A description of the NB2013 and its impaction stage is detailed in Deliverable 3.2 “Report on sampling efficiencies of personal samplers and personal monitors using monodisperse particles”. The description of the X-ray fluorescence spectrometry (instrumentation, calibration curves, etc.) is also detailed in deliverable 3.2.

Test aerosols 1 & 2: polydispersed NaCl (mean 10 nm)

The particle number size distribution obtained when running the NaCl flame generator at low and high concentrations is shown in Figure 4-1. The SMPS was equipped with a Nano DMA classifier column. The total number concentration was simultaneously monitored by a CPC (Figure 4-2) over the course of the sampling. The NB2013 samplers were exposed to the dilute NaCl aerosol for about 45 min and then to the concentrated aerosol for 1h 30min.

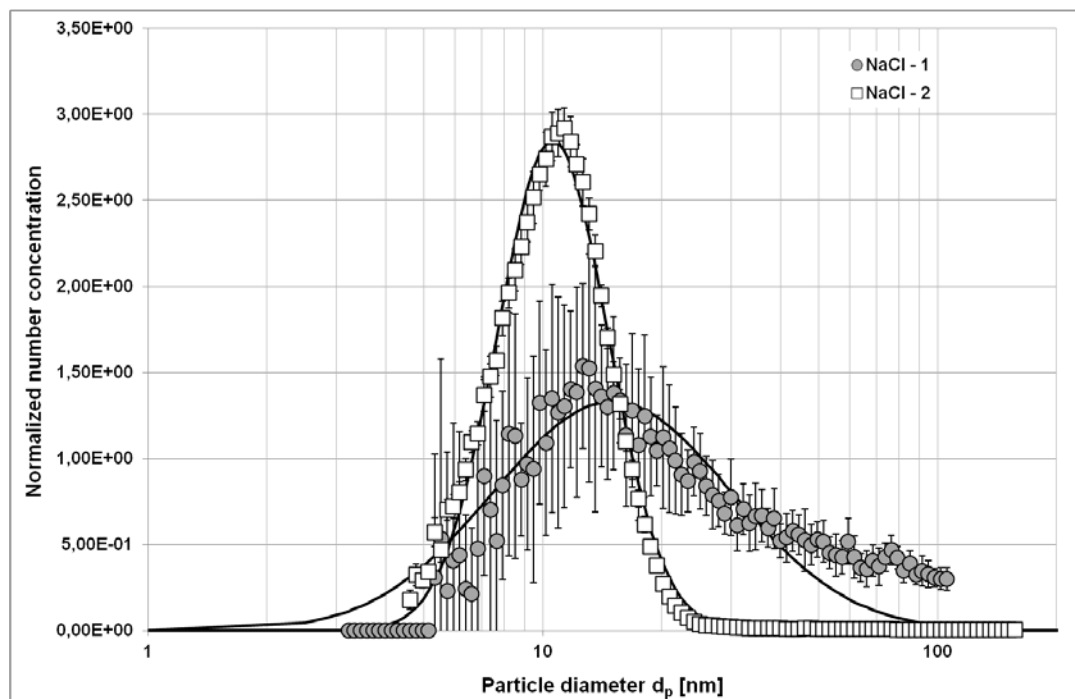


Figure 4-1 Normalized size distribution of the polydisperse 10-nm NaCl aerosol at low (ca. 10 000 #/cm³) and high (ca. 80 000 #/cm³) concentrations.

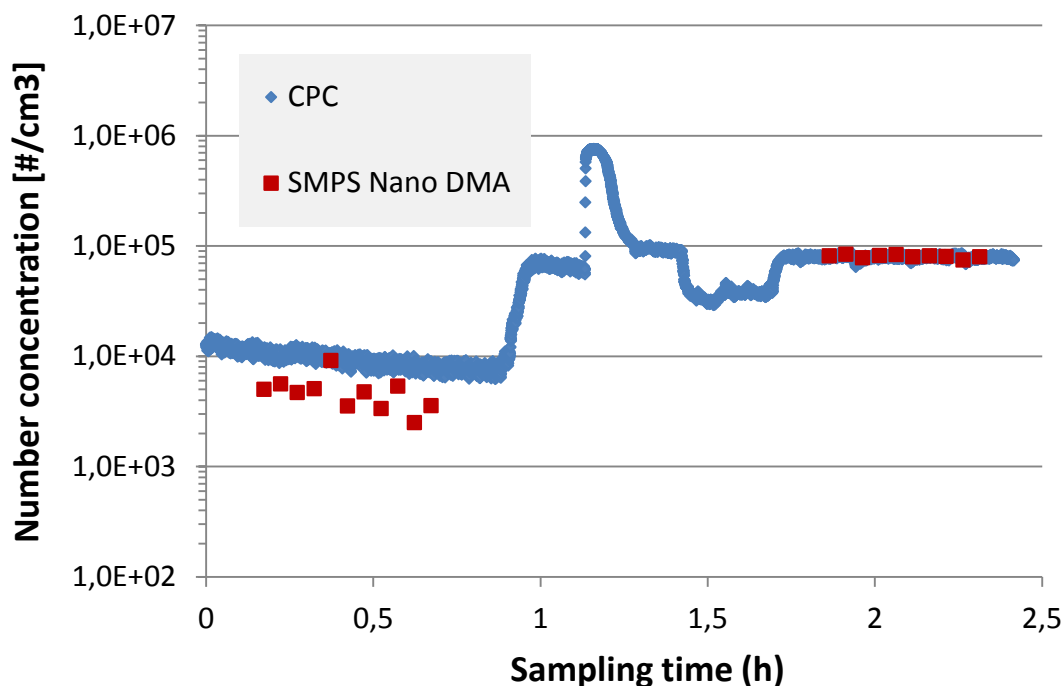


Figure 4-2 Number concentration of the 10 nm polydisperse NaCl aerosol during the sampling.

The quantity of NaCl collected from the 10 nm aerosol was estimated from the analysis of the filters by XRF (Cl element) and ICP-MS (Na element after filter digestion) and from the aerosol monitors. Results are shown in Table 4-1. The discrepancy between the two NB2013 samplers can be ascribed to the low amount of sodium on the filters, which is close to the detection limit of the XRF technique. The CPC and SMPS results are however in good agreement.

The CPC monitors recorded large variations in number concentration from 1h10 to 1h40 of sampling, as shown in Figure 4-2. These fluctuations do not correspond to NaCl particles and were not accounted for in the mass calculation from the CPC data to avoid an overestimation (the number concentration was assumed to be stable around 10^5 particles/cm³). The results are shown in Table 4-1. The XRF measurements and the mass estimated from the monitors are in good agreement.

Table 4-1 Mass of NaCl deposited on the filters after removing the burst in concentration seen in Figure 4-2, estimated from the SMPS measurements ($m_{SMPS}(NaCl)$), from the CPC measurements ($m_{CPC}(NaCl)$) and measured by XRF spectroscopy ($m_{exp}(NaCl)$)

Filter	$m_{exp}(NaCl)$ (ng) (*)	$m_{SMPS}(NaCl)$ (ng) (**)	$m_{CPC}(NaCl)$ (ng) (***)
F01-v3.7	5.9	11.1	5.9
F02-v3.8	9.2	11.5	6.1

(*) experimental from XRF (Cl element) and ICP-MS measurements (Na element)

(**) calculated from SMPS data assuming a density of 2.165 g/cm³ and a spherical shape.

(***) calculated from CPC data with a number concentration equal to the average value of the aerosol during the sampling. Outlier points around the burst in concentration were not considered (from 10:40 to 11:10, corresponding to sampling times from 1h10 to 1h40 in Figure 4-2).

The NaCl particles could not be found by SEM and EDX analysis (Figure 4-3). Some large particles (around 200 nm in diameter) were present, identified as ZnO by EDX, as well as micron-sized particles containing small amounts of Na.

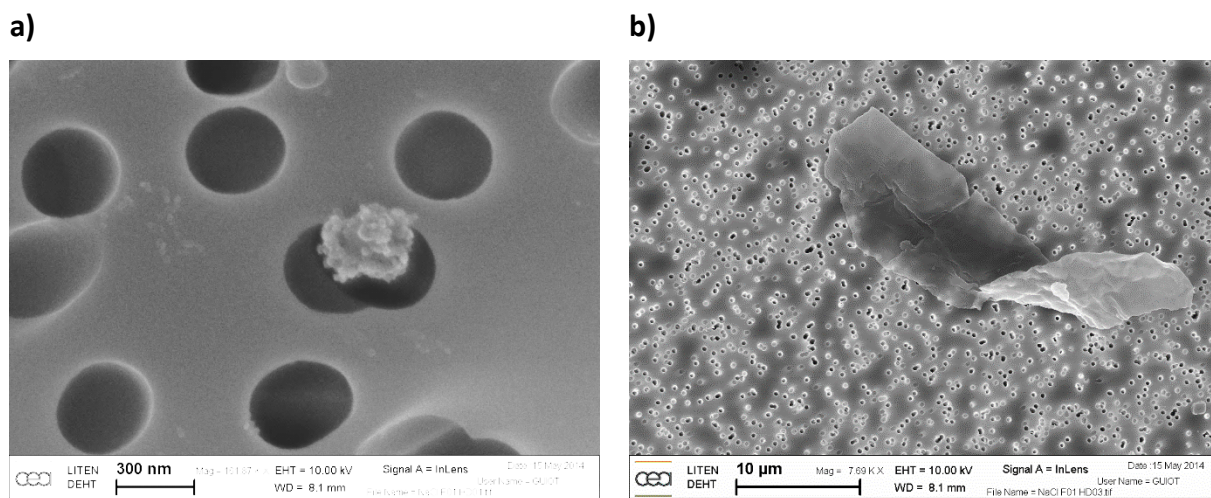


Figure 4-3 SEM images of the polycarbonate filter (F01) sampled from the 10-nm NaCl aerosol.

Test aerosols 3 & 4: polydispersed NaCl (mean 80 nm)

The particle number size distribution of the NaCl aerosol generated by the atomizer at low and high concentrations is shown in Figure 4-4. The number concentration of particles in the aerosol varied a lot during the sampling, as shown in Figure 4-5 particularly during the transition from test aerosol 3 to 4. The mass of NaCl collected on the filter was evaluated by XRF spectrometry (Cl element) and ICP-MS (Na element after filter digestion in HNO₃).

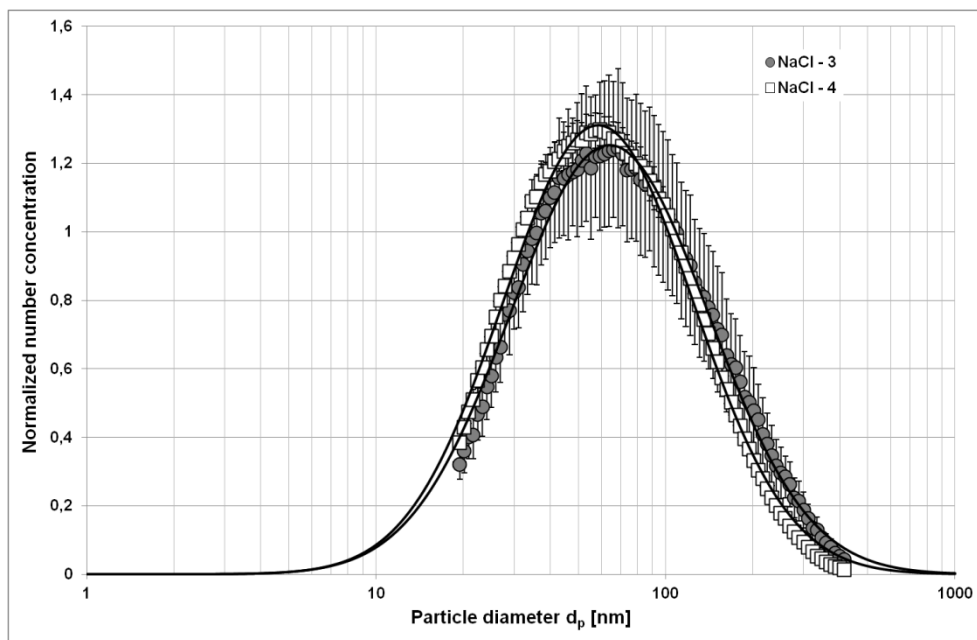


Figure 4-4 Normalized size distribution of the polydisperse 80-nm NaCl aerosol at low (ca. 20 000 #/cm³) and high (ca. 160 000 #/cm³) concentrations

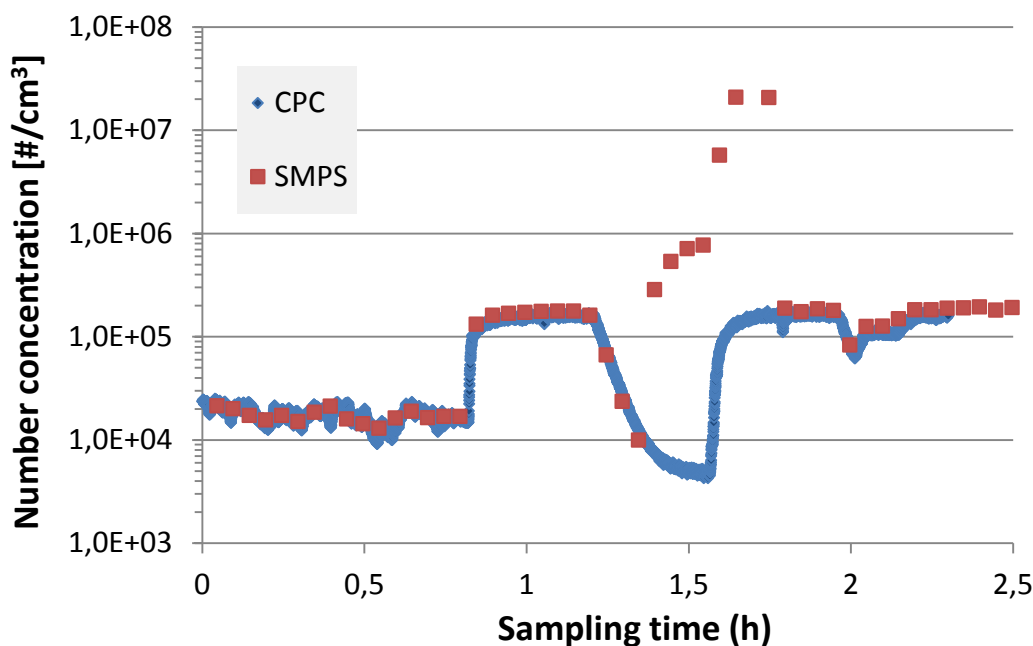


Figure 4-5 Number concentration of the 80-nm polydisperse NaCl aerosol recorded by the CPC and the SMPS during the sampling

Table 4-2 Mass of NaCl deposited on the filters, estimated from the SMPS measurements ($m_{SMPS}(NaCl)$), from the CPC measurements ($m_{CPC}(NaCl)$) and measured by XRF spectroscopy ($m_{exp}(NaCl)$)

Filter	$m_{exp}(NaCl)$ (μg) (*)	$m_{SMPS}(NaCl)$ (μg) (**)	$m_{CPC}(NaCl)$ (μg) (***)
F04-v3.7	21.0	15.2	4.1
F05-v3.8	20.8	16.3	4.4

(*) experimental from XRF (Cl element) and ICP-MS measurements (Na element)

(**) calculated from SMPS data assuming a density of 2.165 g/cm³ and spherical shape. Outlier points (from 14:00 to 14:21, corresponding to sampling times from 1h25 to 1h45) detected by comparison of the total number concentration of the SMPS with the CPC values were removed.

(***) calculated from CPC data with a number concentration equal to the average value of the aerosol during the whole sampling time.

The XRF measurements and the SMPS mass estimation are in good agreement. The CPC underestimates the mass of NaCl because the size distribution is broad and dissymmetric (Figure 4-4).

The NaCl particles are faceted with spherical and rectangular morphologies, as shown on the SEM images (Figure 4-6). Although the sizes range from tens of nm up to the μm , the particles are dense which supports the use of the bulk NaCl density for the mass calculations.

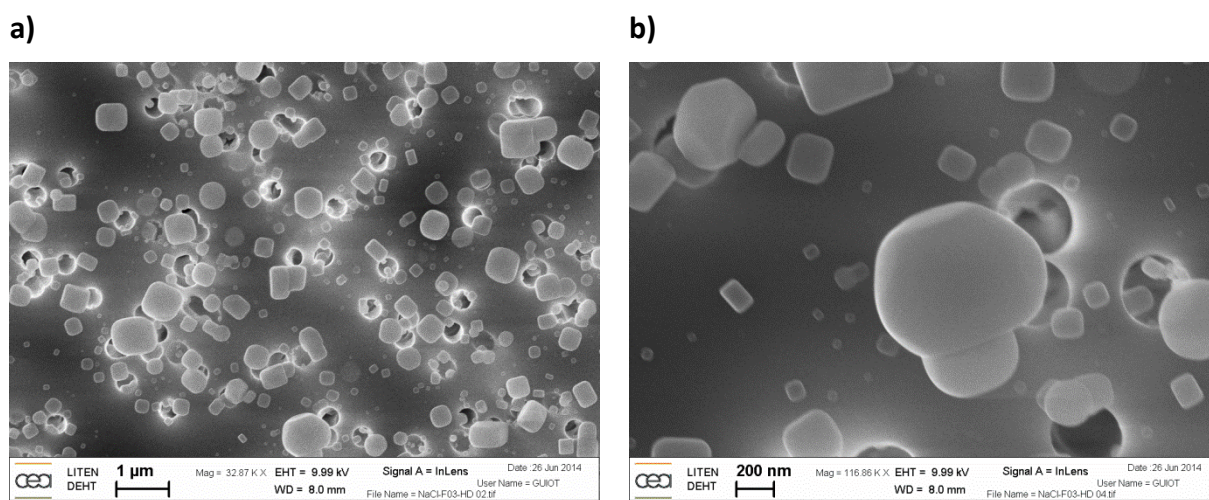


Figure 4-6 SEM images of particles (F03) sampled from the 80-nm NaCl aerosol.

Test aerosols 7-10: Spark-generated soot

Two aerosols of soot particles were produced using a spark generator operated at low and high spark energy in order to vary the average particle size. The number size distribution of the aerosols is shown in Figure 2-3.

Three samplers NB2013 were used, two were equipped with pre-fired quartz filters for thermal optical analysis and one with a polycarbonate membrane for SEM imaging.

The SEM images of the soot particles sampled from the aerosols (Figure 4-7 a-b) on polycarbonate filter show that the spark generator produces spherical primary soot particles of 20 nm which form loosely-packed agglomerates. The size of the agglomerates is much larger than the 50 nm measured by the SMPS, which suggests that on the one hand the equivalent electrical mobility diameter measure with the SMPS does not represent the geometric particle size. On the other hand additional agglomeration occurred on the filter. The soot particles produced at high energy (100 nm) consist in agglomerates of both small (20 nm) and bigger (80-100 nm) primary soot particles, as shown in Figure 4-7 c-d.

The NB2013 samplers used for quantification were equipped with quartz filters. The mass of carbon deposited on the filters was measured by submitting the filters to heat in an inert and then an oxidizing gas flow (Figure 4-8). A flame ionization detector quantifies the carbon evolving from the filters. The carbon detected during the inert stage corresponds to organic compounds, while elemental carbon (soot) is detected in the oxidizing stage.

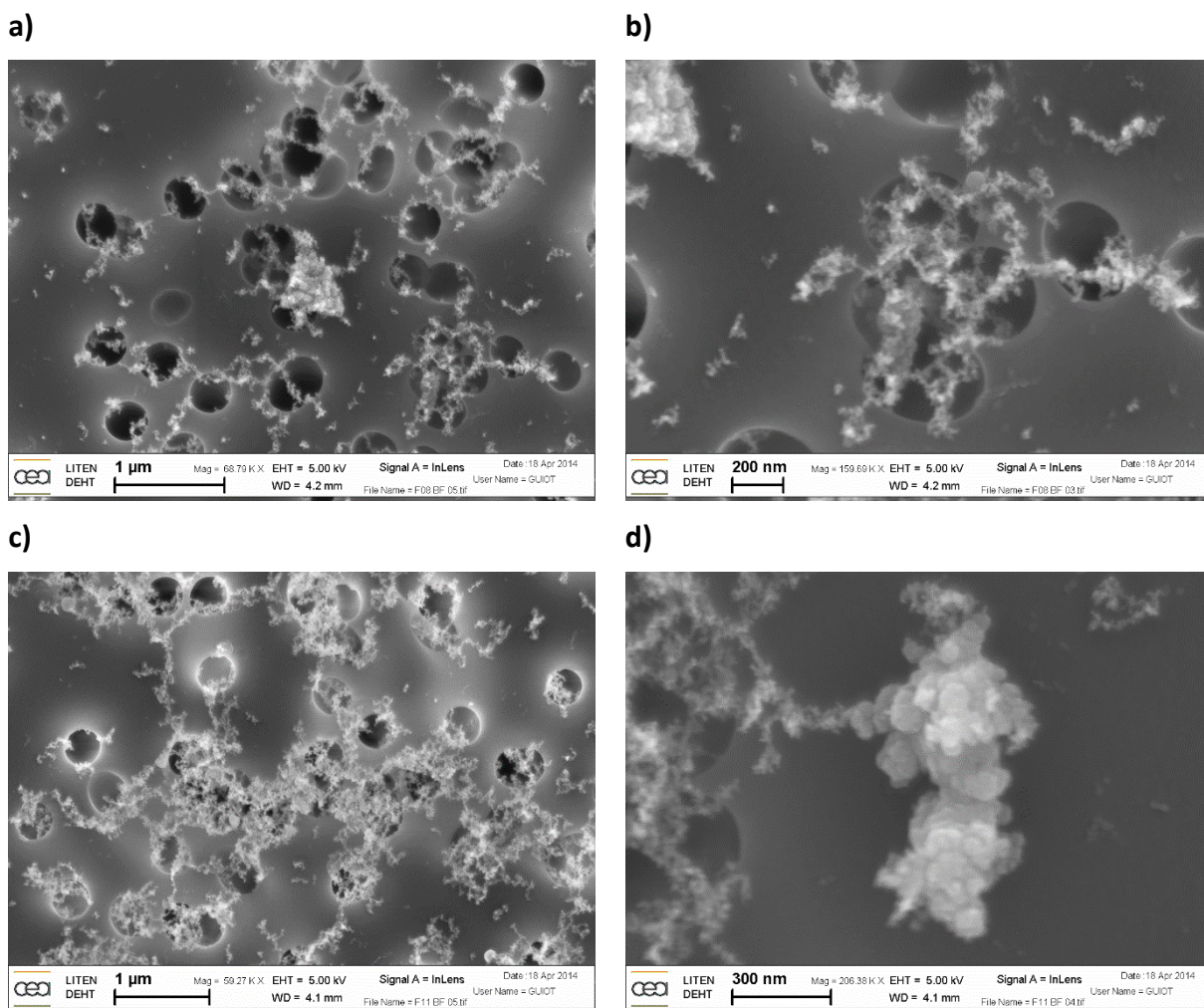


Figure 4-7 SEM images of the spark-generated soot particles; mean electrical mobility diameter 50 nm (a-b), mean electrical mobility diameter 100 nm (c-d).

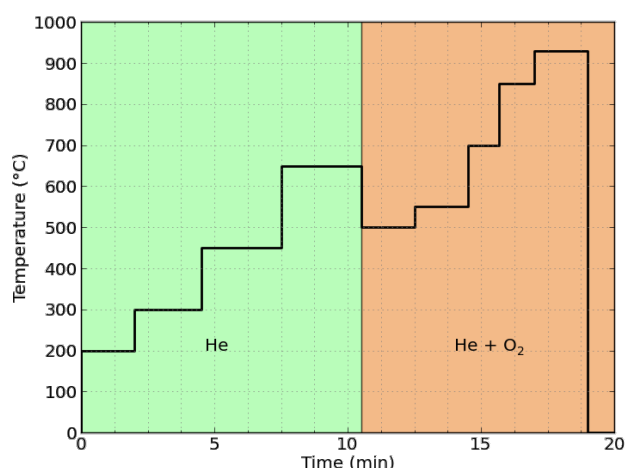


Figure 4-8 Protocol used to analyze the quartz filters. (modified EUSAAR2 protocol)

The mass of elemental carbon (m_{EC}) measured by thermal analysis of the quartz filters and by SMPS monitoring is shown in Table 4-3. Both methods yield masses in the same order of magnitude. However the mass m_{EC} detected on the filters exposed to the larger soot particles is not larger than the

mass detected with smaller soot particles, as would be expected from the SMPS results. During the analysis of the filters, we observed an unusually large amount of organic carbon, around 5 times larger than the amount of soot. The quartz filters were held in place within the sampling cassette by a few drops of organic binder. Although the parts of the filters that have been in contact with the binder have been trimmed before thermal analysis, some organic solvent from the binder may have been drawn into the filter by capillary action or vapor sorption. This organic contamination has probably degraded the accuracy of the soot quantification by thermal analysis.

Table 4-3 Mass of elemental carbon (soot) deposited on the filters from the spark-generated aerosols, measured by thermal analysis (m_{EC}) and estimated from the SMPS monitoring (m_{SMPS}).

Sampler	Soot 50 nm		Soot 100 nm	
	M_{EC} (μg) (*)	m_{SMPS} (μg) (**)	M_{EC} (μg) (*)	m_{SMPS} (μg) (**)
NB2013-v3.7	1.4	1.7	1.0	5.1
NB2013-v3.8	1.0	1.8	1.3	5.5

(*) experimental results from thermal-optical analysis

(**) calculated value assuming spherical shape with a density of 1 g/cm^3 ¹

Test aerosols 11-12: Diesel soot

Two aerosols of soot particles were produced using diesel engines. One aerosol has a monomodal distribution centered at 100 nm (see Figure 2-3), while the other aerosol is bimodal with populations of particles centered at 30 and 150 nm (see Figure 2-4). The SEM images of the diesel soot particles (Figure 4-9) show that the soot particles are composed of spherical primary particles around 30 nm in diameter, which are mainly found as agglomerates for the 100-nm aerosol, while they are present both as single primary particles and as agglomerates for the bimodal aerosol.

The comparison of the thermal analysis and the SMPS monitoring is presented in Table 4-4. Both methods are again yielding masses in the same order of magnitude. Once again, the organic contamination from the binder used to mount the filters reduces the accuracy of the thermal analysis, making it difficult to extract reliable information from the results. This is particularly evident for the filter yielding $5.6 \mu\text{g}$ of soot, which was clearly an outlier compared to all the soot filters which were produced during the round-robin tests.

¹ Maricq, M. M.; Xu, N.: *J. Aerosol Sci.* 35 (2004) 1251–1274.

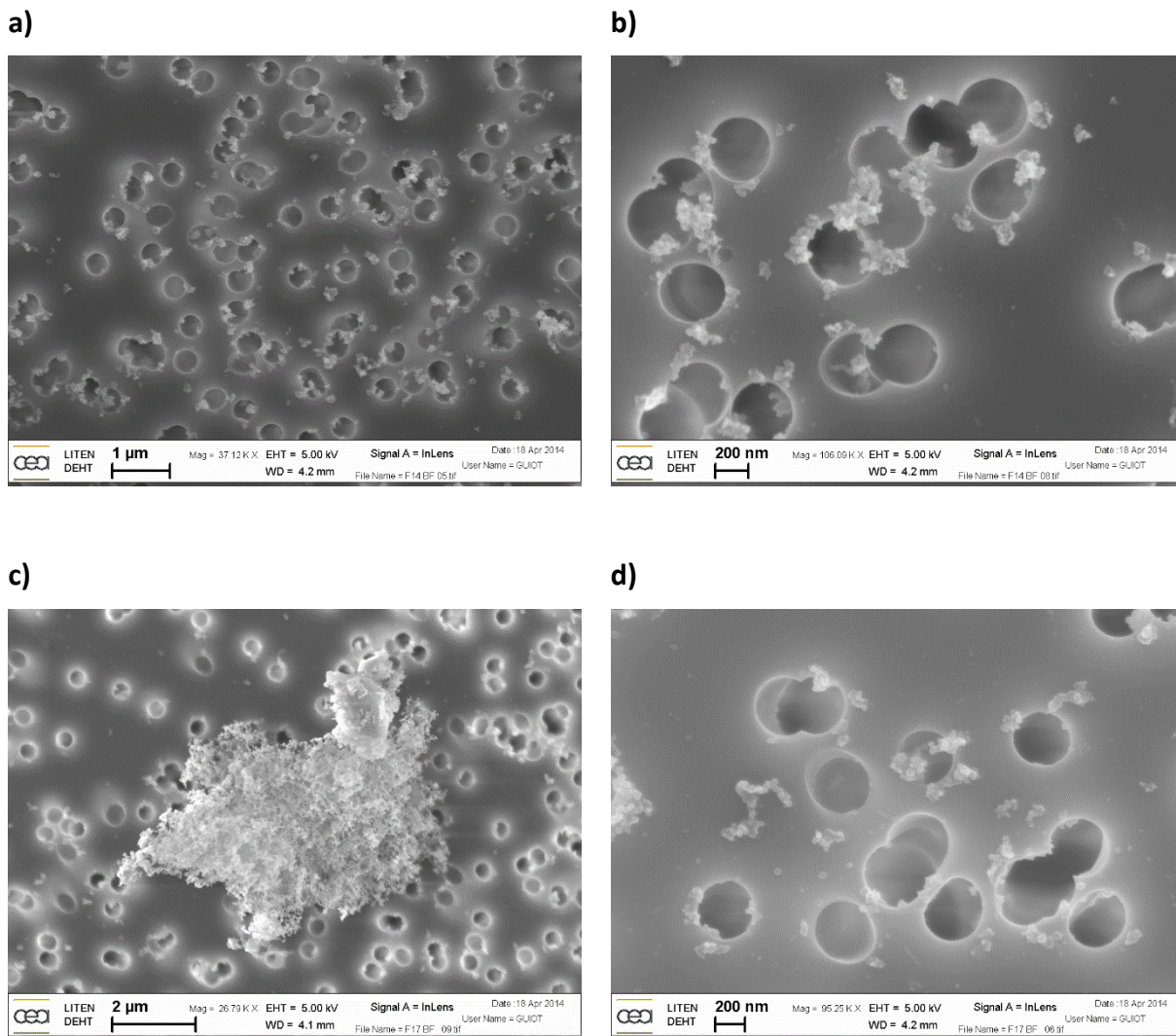


Figure 4-9 SEM images of the diesel soot particles; mean electrical mobility diameter 100 nm (a-b), expected bimodal distribution 30 and 150 nm (c-d).

Table 4-4 Mass of elemental carbon (diesel soot) deposited on the filters from the spark-generated aerosols, measured by thermal analysis (m_{EC}) and estimated from the SMPS monitoring (m_{SMPS}).

Sampler	Diesel 100 nm		Diesel 30 + 150 nm	
	m_{EC} (μg) (*)	m_{SMPS} (μg) (**)	m_{EC} (μg) (*)	m_{SMPS} (μg) (**)
NB2013-v3.7	1.4	3.0	2.2	2.6
NB2013-v3.8	1.3	3.1	5.6	2.9

(*) experimental results from thermal-optical analysis

(**) calculated value assuming a spherical shape with a density of 1 g/cm^3

Test aerosol 17: ZnO 70 nm polydisperse

A polydisperse aerosol of ZnO particles was generated by reacting a zinc acetate solution in a flame. The size distribution of the aerosol is centered at 70 nm, as shown in Figure 2-4. The concentration of the aerosol was kept at 130,000 particles per cm³, as indicated by the CPC monitoring in Figure 4-10.

The SEM image shows that the burner generates agglomerates composed of primary particles around 30 nm in diameter (Figure 4-11). Some large faceted particles have also been observed.

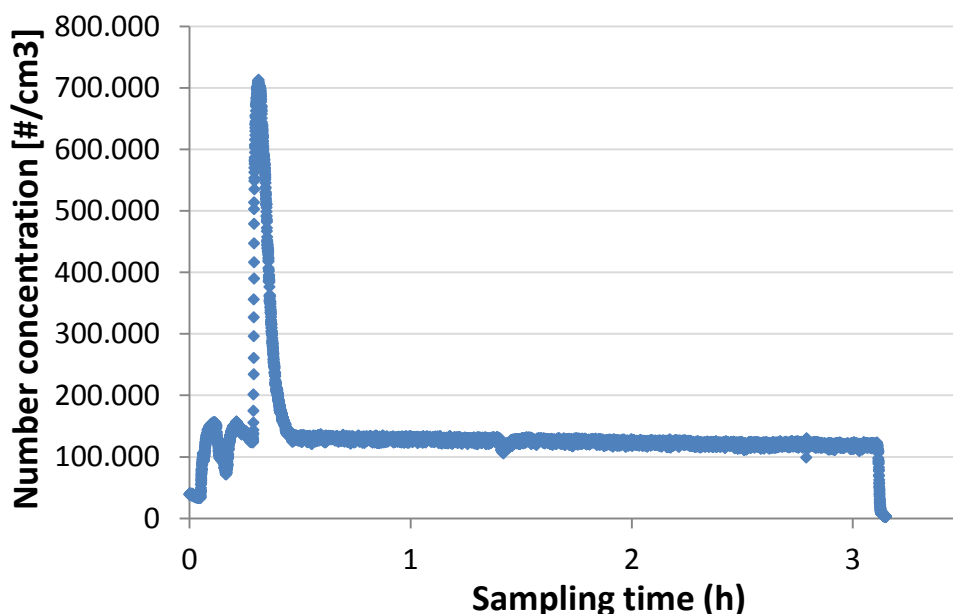


Figure 4-10 Number concentration of the polydisperse ZnO aerosol during the sampling

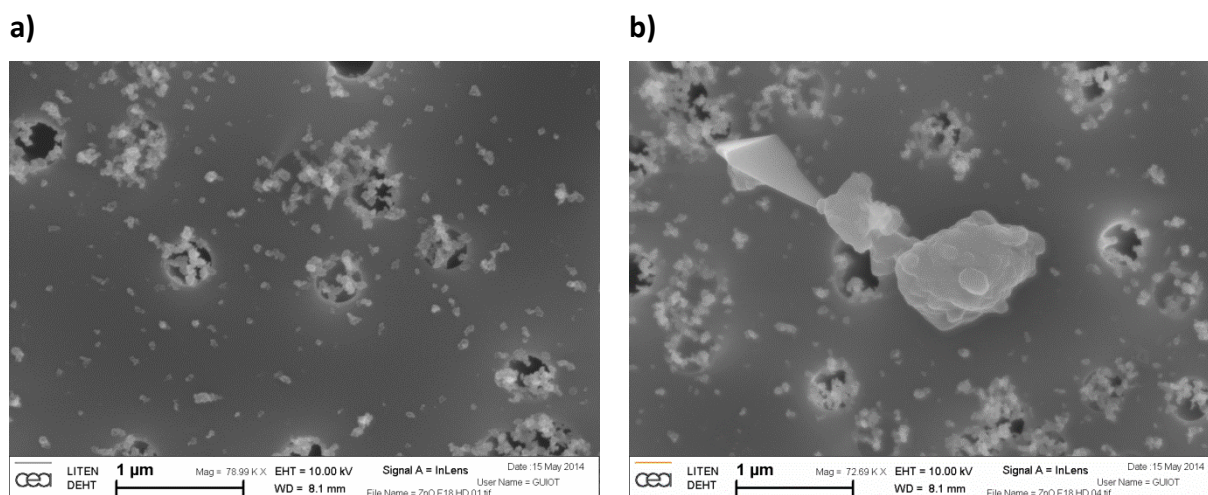


Figure 4-11 SEM image of the ZnO particles

The XRF results and the estimations from the monitors (CPC and SMPS) are in very good agreement as can be withdrawn from Table 4-5. The CPC results however slightly overestimate the mass of ZnO. A deviation was expected since the CPC calculation is not suitable for polydisperse aerosols with a dissymmetric size distribution.

Table 4-5 Concentration of the ZnO polydisperse aerosol calculated from the SMPS monitoring ($m_{\text{SMPS}}(\text{ZnO})$), from the CPC measurements ($m_{\text{CPC}}(\text{ZnO})$) and by XRF spectroscopy ($m_{\text{XRF}}(\text{ZnO})$)

Filter	$m_{\text{XRF}}(\text{ZnO})$ (μg) (*)	$m_{\text{SMPS}}(\text{ZnO})$ (μg) (**)	$m_{\text{CPC}}(\text{ZnO})$ (μg) (***)
F19-v3.7	3.2	2.4	3.3
F20-v3.8	3.6	2.5	3.3
F21-v3.9	3.9	2.6	3.6

(*) experimental from XRF measurements

(**) calculated from SMPS data assuming a spherical shape with a density of 1.2 g/cm^3

(***) calculated from CPC data with a concentration number equal to the average value of the aerosol during the whole sampling time.

Conclusions

The performance of the NB2013 sampler has been compared to state-of-the-art monitors on several polydisperse aerosol samples. The NaCl samples were very challenging to analyze with the sampler. Indeed, the sampling of the 10-nm aerosol results in very small masses, which are difficult to detect using XRF spectroscopy. Moreover, some contamination by ZnO particles and unidentified micron-sized particles was observed. Nevertheless the masses measured by XRF on the filters and estimated from the monitors data are of the same order of magnitude.

The soot particles generated by spark generator and by diesel engines have been successfully collected by the sampler on quartz filters. The mass of elemental carbon deposited on the filters has been determined by thermal-optical analysis. The low mass of elemental carbon on the filter, combined with contamination by organic compounds when mounting the filters, made it difficult to draw reliable conclusions on the results obtained. Nevertheless a proof-of-concept has been obtained and the results were in good agreement with the aerosol monitors. New ways to mount the filters will be investigated to increase the performance of the sampler for carbon-based aerosols.

Finally, very good agreement between the sampler and the monitors was obtained for polydisperse ZnO aerosols. The ZnO concentration was high enough to provide an accurate analysis on the filters by XRF spectroscopy.

5. Annex

Table 0-1 Sampling protocol

ID	Particle type	NB2013 sampling time	Filters (*)
1	NaCl	9:30 - 11:55	F01 (PC)
2	NaCl		F02 (PC)
3	NaCl	12:37 - 14:55	F03 (PC)
4	NaCl		F04 (PC)
5	DEHS	---	---
6	DEHS		---
7	Soot	9:40 - 12:01	F06 (PC+Q)
8	Soot		F07 (PC+Q) F08 (PC)
9	Soot	12:25-14:46	F09 (PC+Q)
10	Soot		F10 (PC+Q) F11 (PC)
11	Diesel soot bimodal	16:22-17:17	F15 (PC+Q) F16 (PC+Q) F17 (PC)
12	Diesel soot	15:10-16:04	F12 (PC+Q) F13 (PC+Q) F14 (PC)
13	NaCl bimodal	---	---
14	NaCl/DEHS bi/trimodal	---	---
15	DEHS	---	---
16	NaCl bimodal	---	---
17	ZnO	10:05 - 13:12	F19 (PC) F20 (PC) F21 (PC)

(*) PC : polycarbonate filter; PC+Q : polycarbonate filter + quartz filter