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Paper/Poster-Abstract Form

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Title: Comparison of different flue gas treatment sections in the abatement of ultrafine particles emitted by waste incinerators

Extended summary

In the waste field, incineration represents a favorable technique for reducing the volume of waste streams and recovering its energy content for the generation of electricity and district heating. The incineration sector has undergone rapid technological development over the last 10–15 years, due to specific legislation applied to industry that has obliged several European countries to reduce toxic emissions from municipal waste incinerators (MWI). Nevertheless, in Western countries there is a strong debate on the emission of ultrafine particles (UFPs) at the stack of waste-to-energy plants. Currently, as regards particle emission, only a mass-based threshold value need to be observed ("total dust", as stated in the EU Directive 2000/76), whereas fine and ultrafine particle emissions have not yet been fully characterized. Moreover, a key aspect to be investigated is the influence of the flue gas treatment section on the sub-micrometer particle emission.
The main aim of the paper is to deepen the knowledge about fabric filter influence on ultrafine particle emission levels, therefore, aerosol particle measurements were also extended at a section located before the fabric filter for two of the incinerators under examination.
To this purpose, experimental campaigns involving aerosol particle characterization were performed in four plants burning municipal waste. The exhaust treatment sections are different between the analyzed plants in terms of gas-acid (dry, semi-dry, wet process...), NO_x (Selective Non-Catalytic Reduction, SNCR, or Selective Catalytic Reduction, SCR), and dust reduction (fabric filter, electrostatic precipitator, cyclones). In Table 1 a summary of the main characteristics of the combustion and flue gas treatment sections of each plant is reported.

Table 1: Main characteristics of the combustion and flue gas treatment sections of the analyzed plants.

Plant	furnace and waste characteristics	Flue gas treatment section description
Plant A	Grate type: moving grate Type of waste fed: Refuse Derived Fuel (RDF)	semi-dry process made up of a SNCR, a spray absorber system (lime milk and powder activated carbons) and a fabric filter
Plant B	Grate type: moving grate Type of waste fed: Refuse Derived Fuel (RDF)	dry process made up of a SNCR, a spray absorber system (Sodium bicarbonate and powder activated carbons) and a fabric filter
Plant C	Grate type: roller-type grate Type of waste fed: Municipal solid waste (MSW)	wet process (wet scrubber) made up of a fabric filter and a SCR
Plant D	Grate type: moving grate Type of waste fed: Municipal solid waste (MSW)	double filtration approach: lime milk is added before the first fabric filter; sodium bicarbonate and activated carbon before the second fabric filter; SCR for NO_x reduction

In order to measure total particle number concentration and size distributions the following instruments were used: (i) a condensation Particle Counter CPC 3775 (TSI Inc.); (ii) a Scanning Mobility Particle Sizer spectrometer SMPS 3936 (TSI Inc.) made up of an Electrostatic Classifier EC 3080 (TSI Inc.) and a CPC 3775 (TSI Inc.); (iii) a Condensation Particle Counter CPC 5403 (Grimm); (iv) a scanning particle sizer spectrometer obtained by connecting an Electrostatic Classifier "Vienna"-Type DMA 55706 (Grimm) to the CPC 5403; (v) a thermo-dilution system (two-step dilution) made up of a Rotating Disk Thermodiluter (Model 379020, Matter Engineering AG) and a Thermal Conditioner (Model 379030, Matter Engineering AG) able to assured a correct aerosol sampling (Burtscher, 2005).
In Figure 1 particle number distributions measured through particle mobility spectrometers at the stack of the analyzed incineration plants are reported. The data represent the particle number distributions corresponding to the highest emissions of the plants. Plant A and C show an unimodal distribution with peak values in the range 60-100 nm, plant B and D show bimodal distributions with one of the peak in the nucleation range (about 10 nm). In particular, the Plant D show a minor peak at about 30 nm: no particles larger than 100 nm were emitted. This behavior could be assessed to the presence of the double filtration approach made up of two fabric filters.
In Figure 2 the comparison amongst particle number distributions measured (through SMPS 3936) at the stack and before the fabric filter of the Plant A and B is reported: total particle concentrations before and after filtration differ of five order of magnitude. It gives evidence of the important contribution in the sub-micrometer particle reduction of the fabric filter.

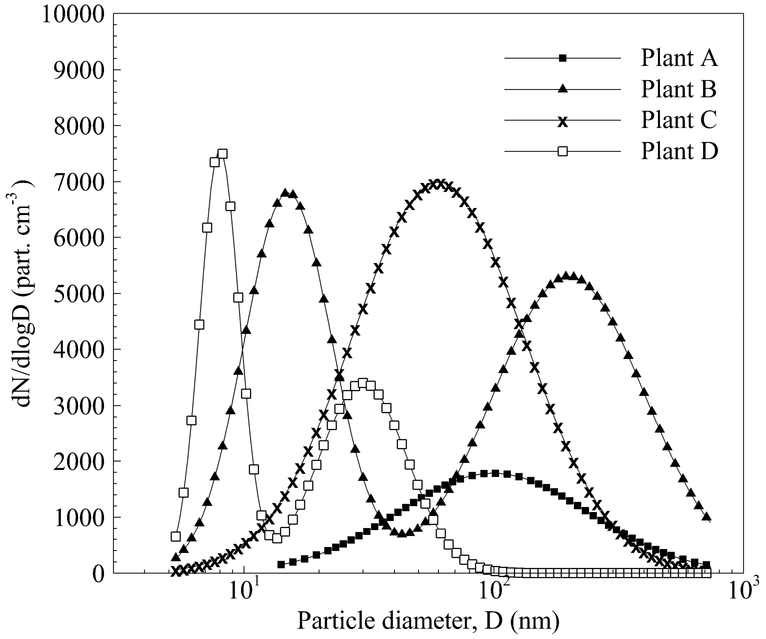

Figure 1: Particle number distributions measured through mobility particle sizers in the analyzed incineration plants.

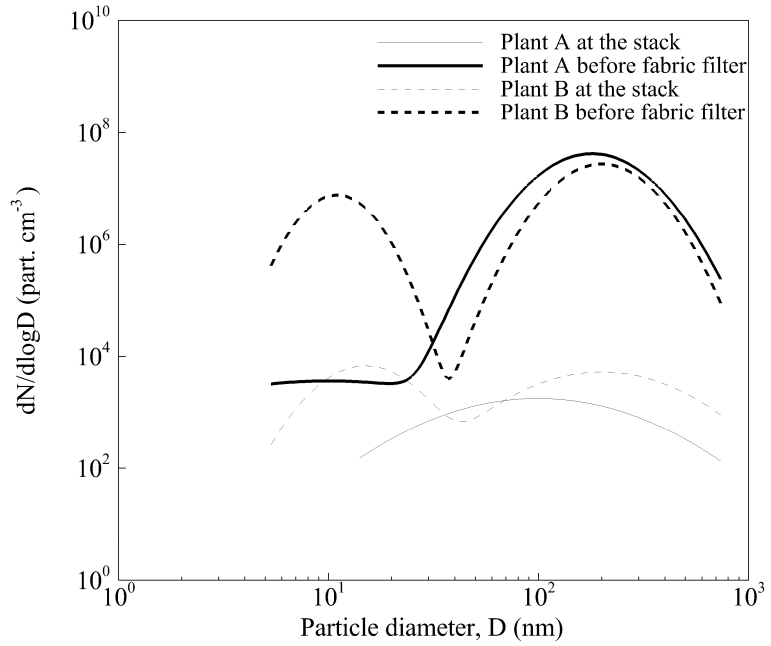

Figure 2: Particle number distributions measured through SMPS 3936 at the stack and before the fabric filter of the Plant A and B.

References

Burtscher, H., 2005. Physical characterization of particulate emissions from diesel engines: a review, Aerosol Science, 36, 896-932.

EU Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste.

Short CV: Luca Stabile earned the master degree in Mechanical Engineering at the University of Cassino, Italy, in 2006 and the Ph.D. degree in Civil Engineering from the same institution in 2011 with a dissertation on the aerosol measurement in several microenvironments. Currently he is assistant professor at the University of Cassino and his main research topic is the aerosol particle characterization. He is author of several papers published on national and international journals and presented to national and international congresses.

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Plant C	Grate type: roller-type grate Type of waste fed: Municipal solid waste (MSW)	wet process (wet scrubber) made up of a fabric filter and a SCR
Plant D	Grate type: moving grate Type of waste fed: Municipal solid waste (MSW)	double filtration approach: lime milk is added before the first fabric filter; sodium bicarbonate and activated carbon before the second fabric filter; SCR for NO_x reduction

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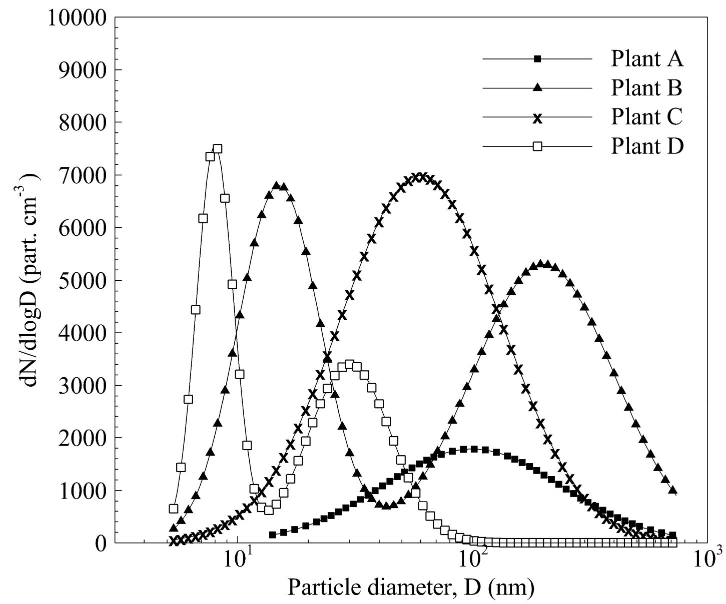

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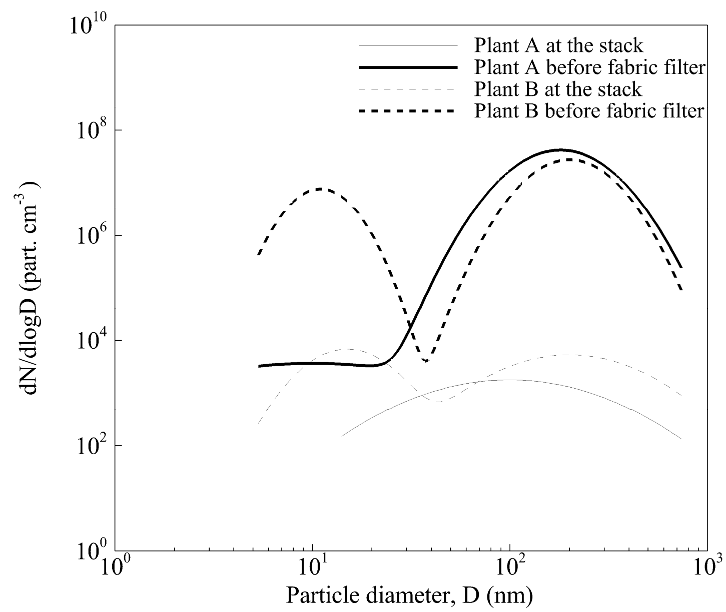

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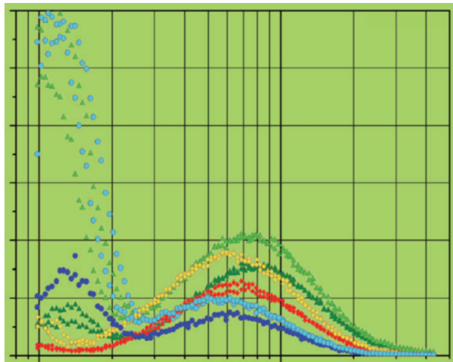

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www.nanoparticles.ethz.ch

COMPARISON OF DIFFERENT FLUE GAS TREATMENT SECTIONS IN THE ABATEMENT OF ULTRAFINE PARTICLES EMITTED BY WASTE INCINERATORS

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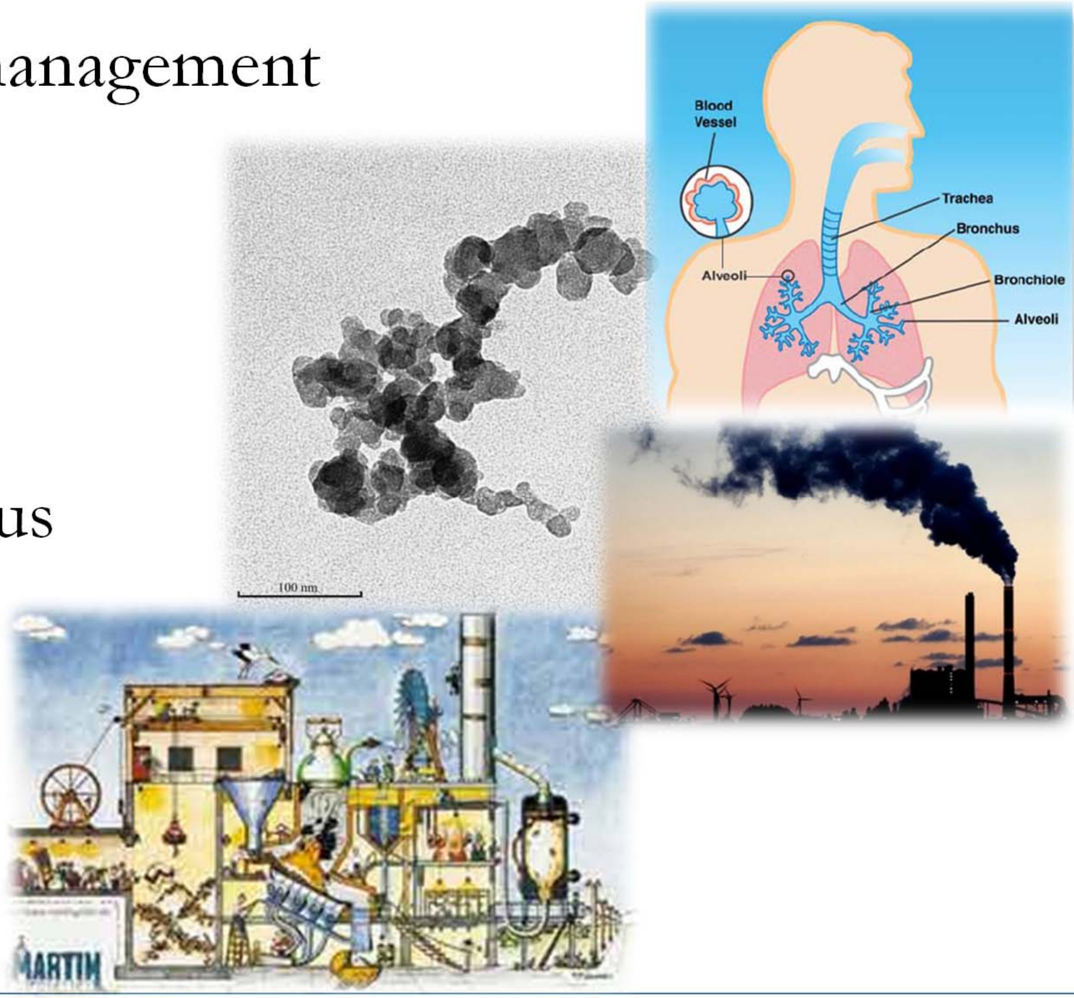
29th June, 2011 - ETH Zentrum, Zurich, Switzerland

OUTLINES

- Introduction: waste management
- Work's aim
- Plants' description
- Experimental apparatus
- Results
- Conclusions



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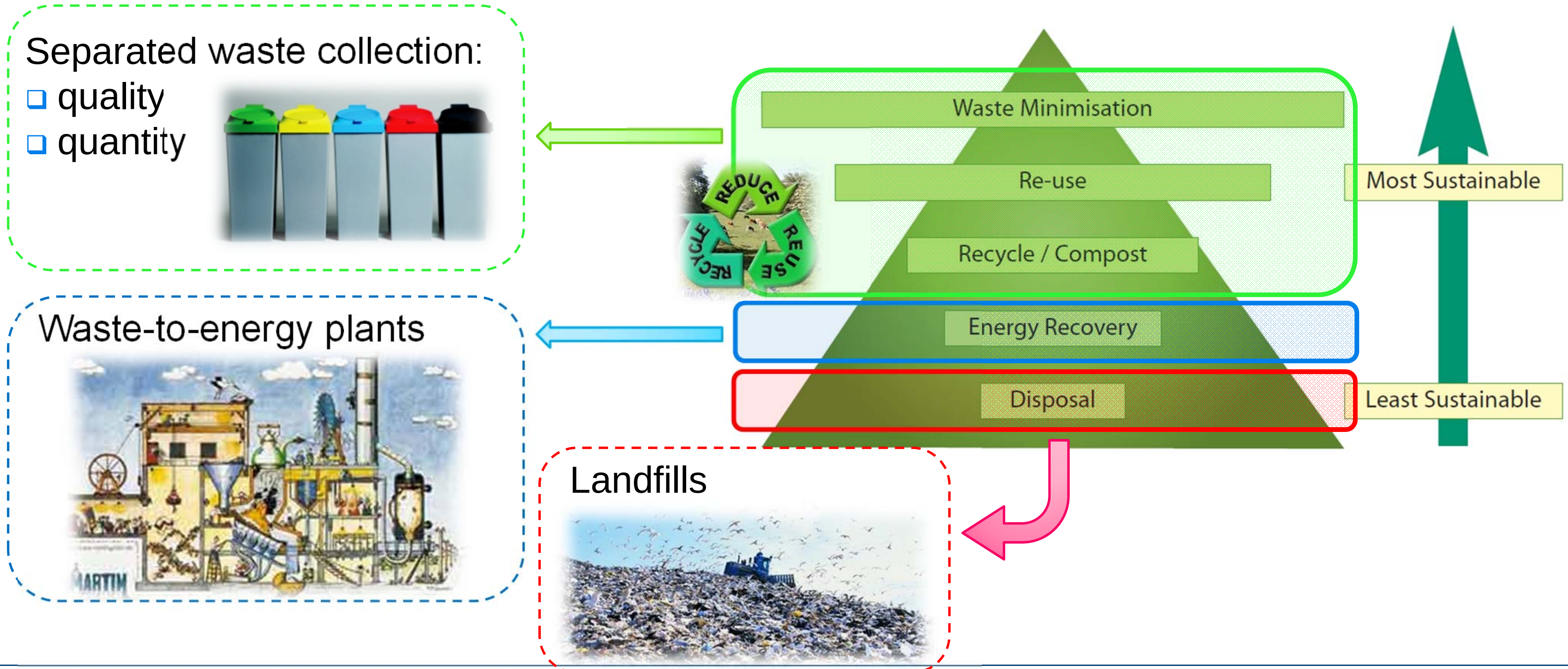
INTRODUCTION: waste management

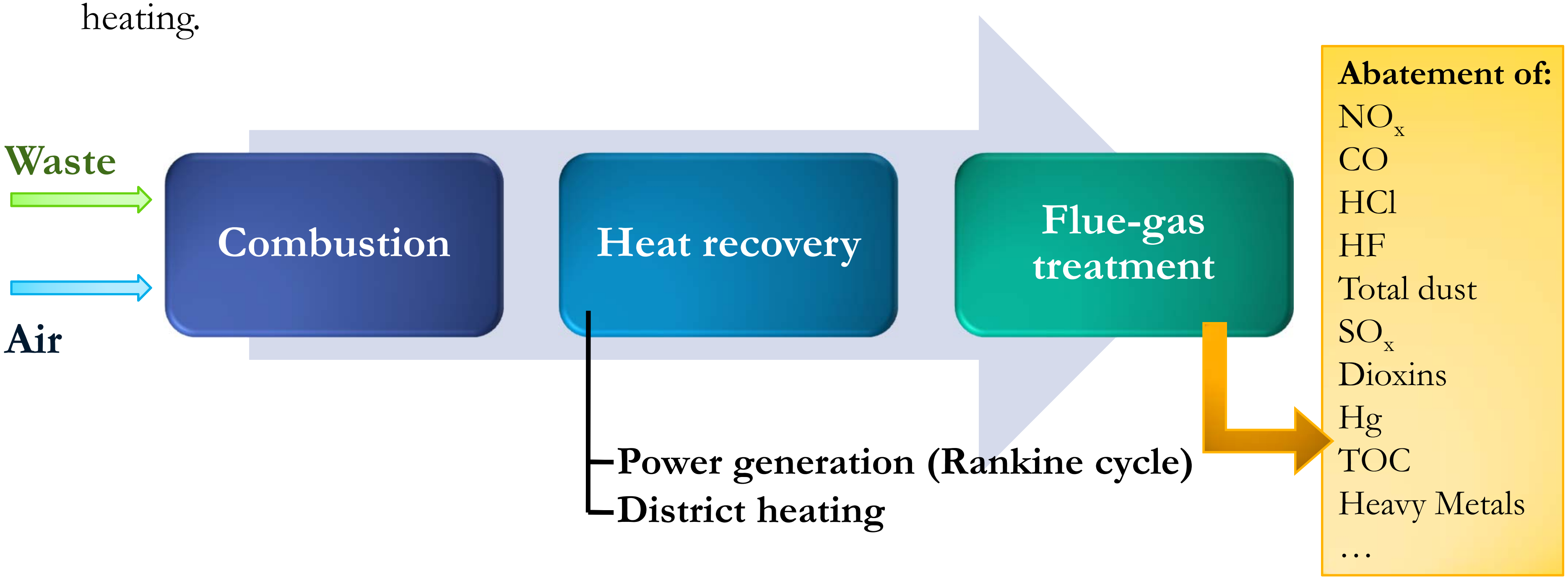
The waste hierarchy

- European Union's Waste Framework Directive of 1975 (Directive 75/442/EEC) introduced for the first time the waste hierarchy concept into European waste policy.
- In 2008, the EU parliament introduced a **new five-step waste hierarchy:** waste legislation Directive 2008/98/EC.



INTRODUCTION: incineration technique

- In the waste management, incineration represents a favorable technique for reducing the waste volume and recovering its energy content for generating electricity and district heating.



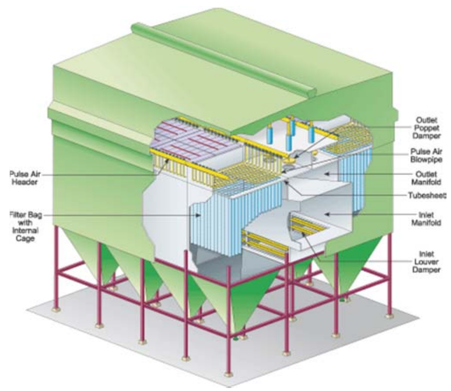
- The incinerators have undergone rapid technological development over the last 10–15 years, due to specific legislation applied to industry that obliged several European countries to reduce toxic emissions from municipal waste incinerators (MWIs).

WORK'S AIM

- A mass-based threshold limit value is currently required in the operation of such plants (Directive 2010/75/EU):
  - 10 mg m^{-3} on daily basis;
  - 30 mg m^{-3} on half-hour basis.
- In Western countries there is a strong debate on the emission of **ultrafine particles** at the stack of waste-to-energy plants with a diffuse social response like the Not In My Backyard (NIMBY).

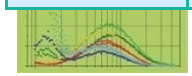
…a lack of understanding…

- Evaluation of UFPs emission in terms of particle distributions and total concentrations at the stack of four incinerators.
- Investigation of fabric filter influence on ultrafine particle emission levels through measurement campaign before the fabric filter.



EXPERIMENTAL ANALYSIS: plants' description

Plant	Furnace and Waste characteristics	Flue gas treatment section description
Plant A	Grate type: moving grate Type of waste fed: Refuse Derived Fuel (RDF)	▪Semi-dry process: spray absorber system (lime milk and powder activated carbons) ▪Selective Non-Catalytic Reduction (SNCR) Systems: urea ▪Fabric Filter
Plant B	Grate type: moving grate Type of waste fed: Refuse Derived Fuel (RDF)	▪Dry process: spray absorber system (Sodium bicarbonate and powder activated carbons) ▪Selective Non-Catalytic Reduction (SNCR) Systems: urea ▪Fabric Filter
Plant C	Grate type: roller-type grate Type of waste fed: Municipal solid waste (MSW)	▪Fabric Filter ▪Wet process: wet scrubber ▪Selective Catalytic Reduction (SCR) Systems: NH_3
Plant D	Grate type: moving grate Type of waste fed: Municipal solid waste (MSW)	double filtration approach: ▪Semi-dry process (lime milk) ▪first Fabric Filter ▪Dry process (sodium bicarbonate and activated carbon) ▪second Fabric Filter; ▪Selective Catalytic Reduction (SCR) Systems: NH_3
Biomass plant	Grate type: fluidized bed reactor Type of waste fed: biomass	▪Electrostatic precipitator (ESP) ▪Wet process: wet scrubber ▪Selective Catalytic Reduction (SCR) Systems: NH_3



EXPERIMENTAL ANALYSIS: methodology

- The experimental campaigns were carried out during the period 2007-2010.
- Measurements of total particle number concentrations and particle size distributions were performed **at the stack** of each selected plant.
- Measurements were carried out also at a section **before the fabric filter for Plant A and B.**
- Sufficiently stable operating conditions.

Operating conditions during experimental analysis

Parameter	Plant 1		Plant 2		Plant 3		Plant 4	
	Mean Value	Standard deviation (%)	Mean Value	Standard deviation (%)	Mean Value	Standard deviation (%)	Mean Value	Standard deviation (%)
Normalized flow rate ($m^3 h^{-1}$)	98.3×10^3	1.7%	75.8×10^3	1.2%	120.0×10^3	2.6%	100.0×10^3	1.6%
Stack temperature (°C)	135	3.0%	154	1.1%	150	3.0%	135	2.4%
Combustion chamber temperature (°C)	991	1.0%	1209	0.9%	1000	1.0%	980	1.1%
Relative humidity (%)	15.3	6.5%	14.9	6.7%	15	7.3%	13	8.5%
O_2 in dry flue gas (%)	10.7	2.8%	8.7	1.1%	13	1.5%	10.5	2.9%
SO_2 ($mg\ m^{-3}$)	8.2	14.6%	5.1	15.7%	5	15.6%	0.5	0.0%
NO_x ($mg\ m^{-3}$)	115.0	7.5%	174.8	10.6%	50	11.2%	60.3	11.3%
CO ($mg\ m^{-3}$)	5.2	32.7%	5.5	98.2%	10	27.6%	30.1	29.9%
Total dust ($mg\ m^{-3}$)	0.68	16.2%	1	0.0%	2	34.5%	0.9	27.8%
HCl ($mg\ m^{-3}$)	4.3	7.0%	6.6	16.7%	<1	-	1.1	27.3%

EXPERIMENTAL APPARATUS

- **Total particle number concentration measurement**
  - Condensation Particle Counter CPC 3775 (TSI Inc.) able to measure particle total number concentration down to 4 nm in diameter;
  - Condensation Particle Counter CPC 5403 (Grimm) able to measure particle total number concentration down to 4.5 nm in diameter.

Condensation Particle Counter CPC *3775 TSI*

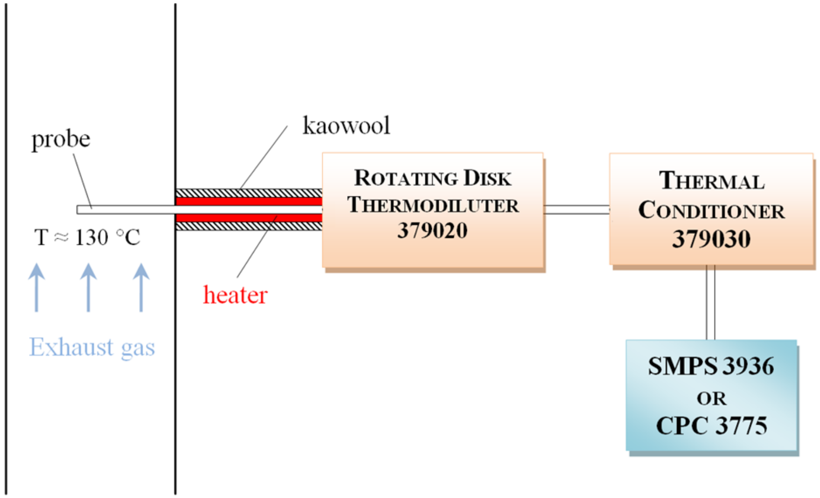
- **Particle size distribution measurement**
  - a Scanning Mobility Particle Sizer spectrometer SMPS 3936 (TSI Inc.) made up of an Electrostatic Classifier EC 3080 (TSI Inc.), used to classify the sampled particles in different channel according to their size, and a CPC 3775 (TSI Inc.);
  - an Electrostatic Classifier "Vienna"-Type DMA 55706 (Grimm) able to classify particles in the range 5.5-350 nm coupled with the CPC 5403 in a scanning mobility particle sizer configuration.

Electrostatic Classifier EC *3080 TSI*

- **Sampling and thermo-dilution systems**
  - Heated sampling lines and thermo-dilution systems were used to ensure proper sample conditioning during the measurements.

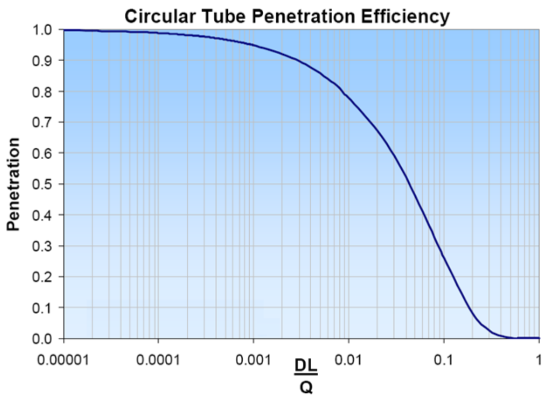
EXPERIMENTAL APPARATUS: sampling line

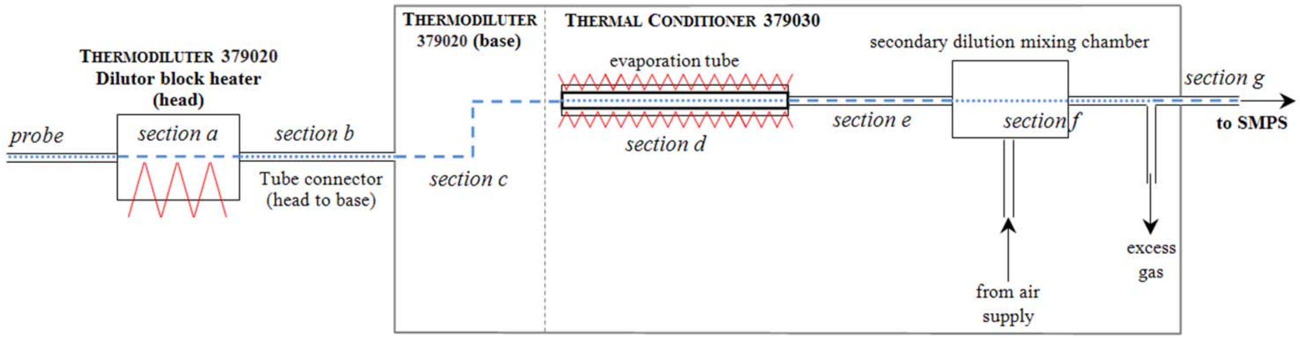
- **Diffusion losses correction**



The path experienced by the aerosol before entering in the measurement devices is quite long, a diffusion loss correction was applied to estimate the particle losses onto the inner surface of the connecting tubes.

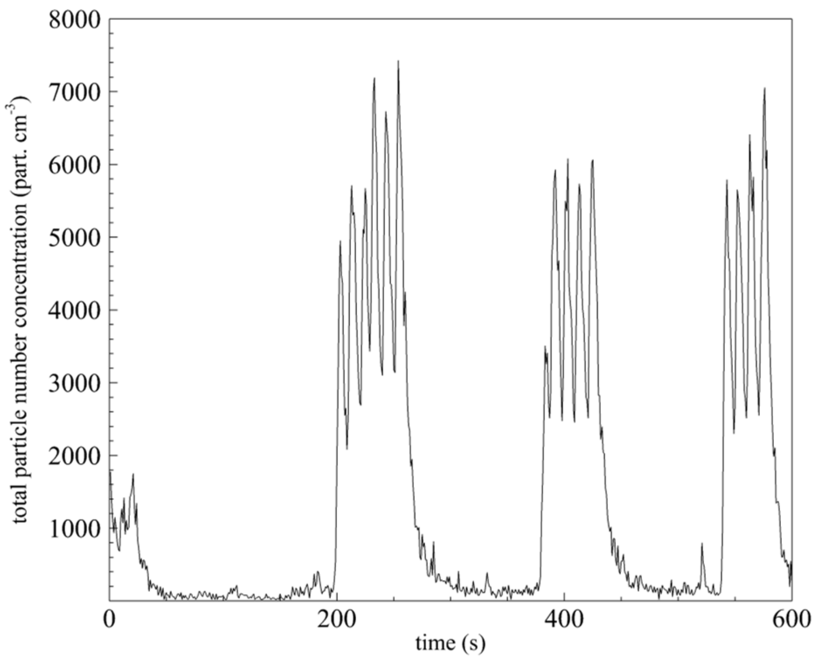
Section	from	to	Residence time (s)	Reynolds number
Probe	Probe inlet	Rotating disk (RD) inlet	0.8	424
a	RD inlet	Tube connector to the RD base (RD head)	0.2	533
b	RD head	RD base	1.8	531
c	RD base	Evaporation tube inlet	0.3	514
d	Evaporation tube inlet	Secondary dilution chamber inlet	0.4	111
e	Secondary dilution chamber inlet	Flow splitter (excess air)	0.4	463
f	Flow splitter	Thermal conditioner exit	0.5	335
g	Thermal conditioner exit	SMPS inlet	0.3	406
		Total residence time	**4.8**	



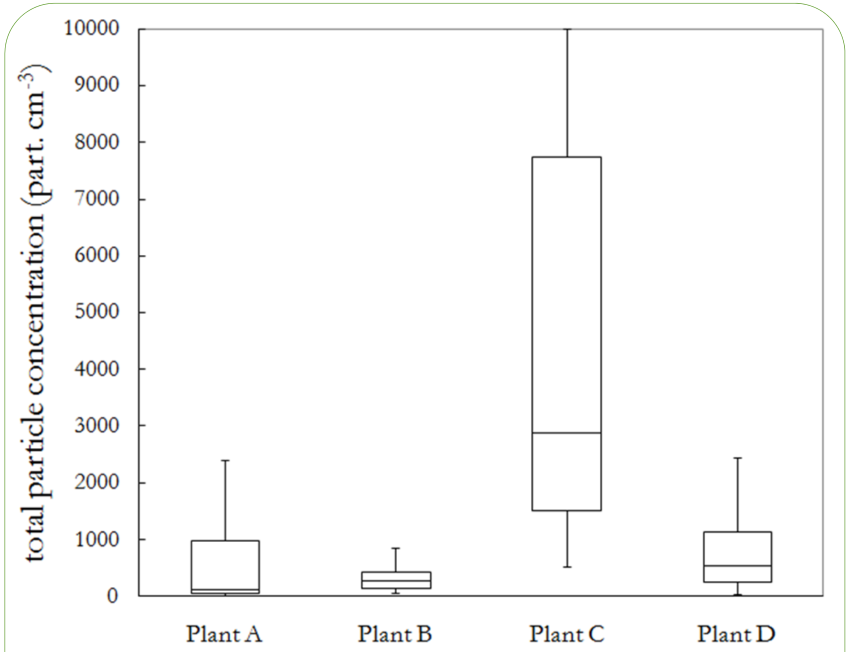


RESULTS: concentrations at the stack

- Average total particle number concentration **at the stack**: $0.4\times10^3 - 6.0\times10^3$ part. cm^{-3}
- Maximum total particle number concentration **at the stack**: 1.0×10^4 part. cm^{-3}



Example of a 10-minute total particle number concentration measurement through CPC3775 at the stack of the Plant B



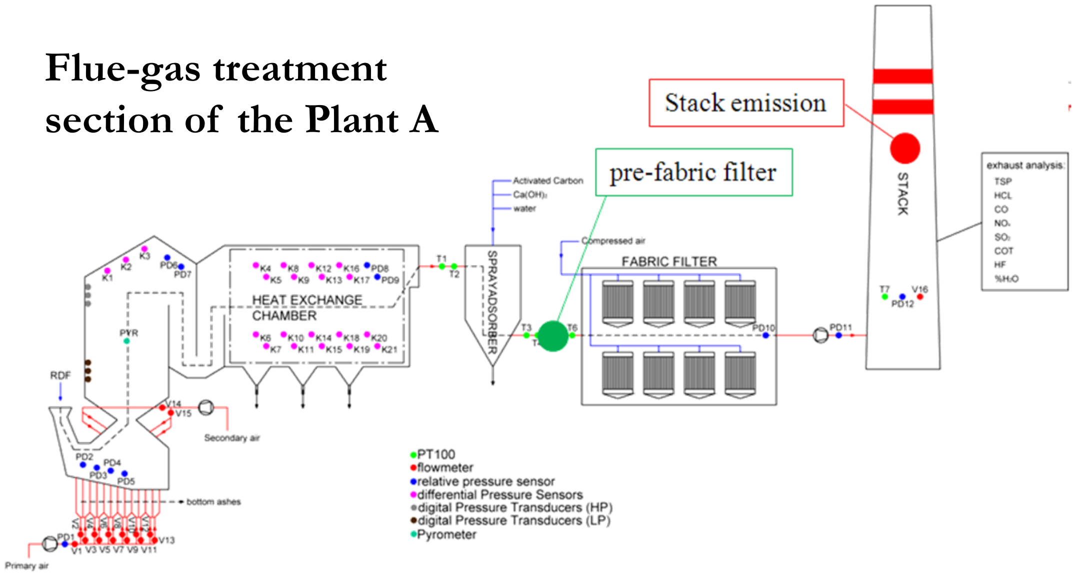
Statistics of total particle concentrations measured through particle counters at the stack of the analyzed incineration plants: min, max, median, 1st quartile, 3rd quartile values

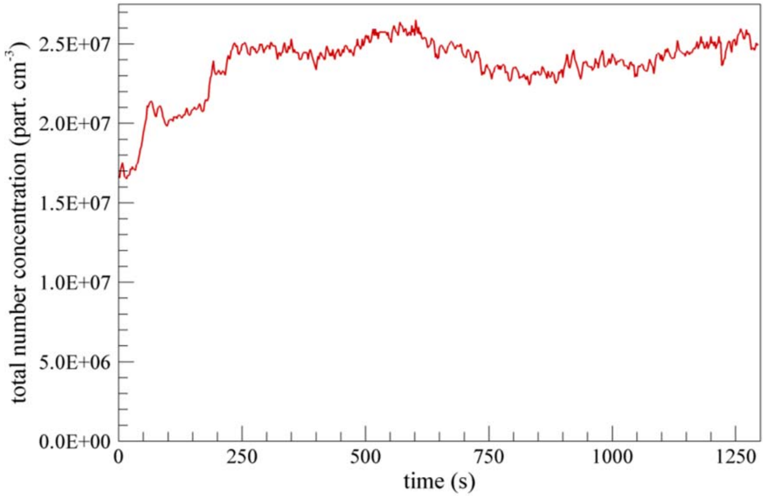
- At the stack of the Plant burning biomass (**filtration trough ESP**): 3.0×10^5 part. cm^{-3}.

RESULTS: concentrations pre-fabric filter

- Average total particle number concentrations before the fabric filter:
  - $2.4\times10^{7} \pm 0.2\times10^{7}$ part. cm^{-3} at Plant A;
  - $1.4\times10^{7} \pm 0.1\times10^{7}$ part. cm^{-3} at Plant B.
  - nearly steady-state conditions during the measurement periods: the large deviation of the data at the stack can only be due to the fabric filter cleaning operations…

Flue-gas treatment section of the Plant A

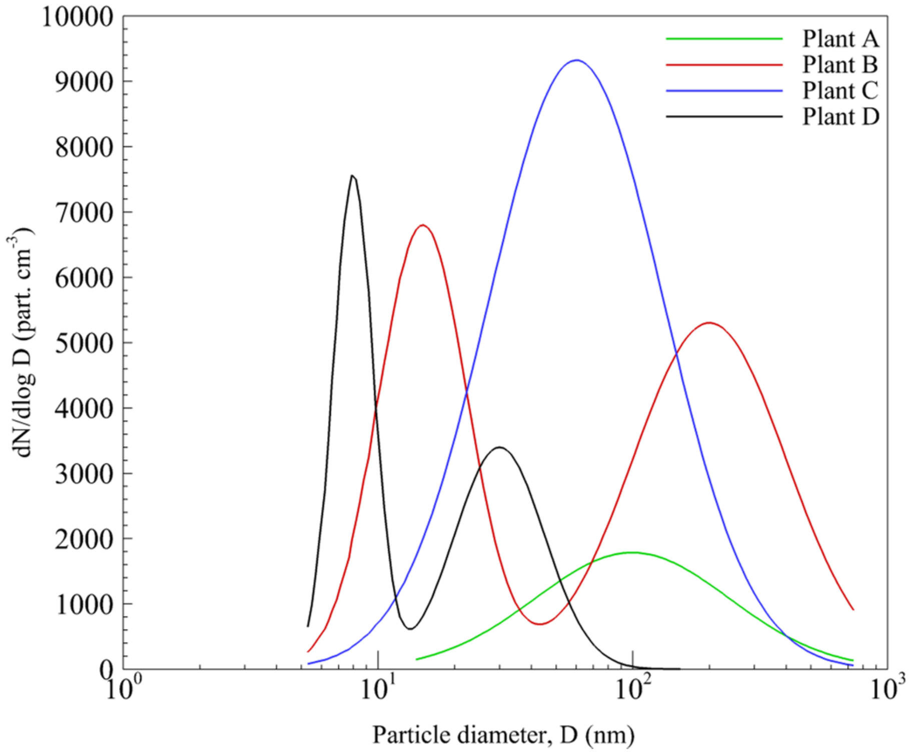




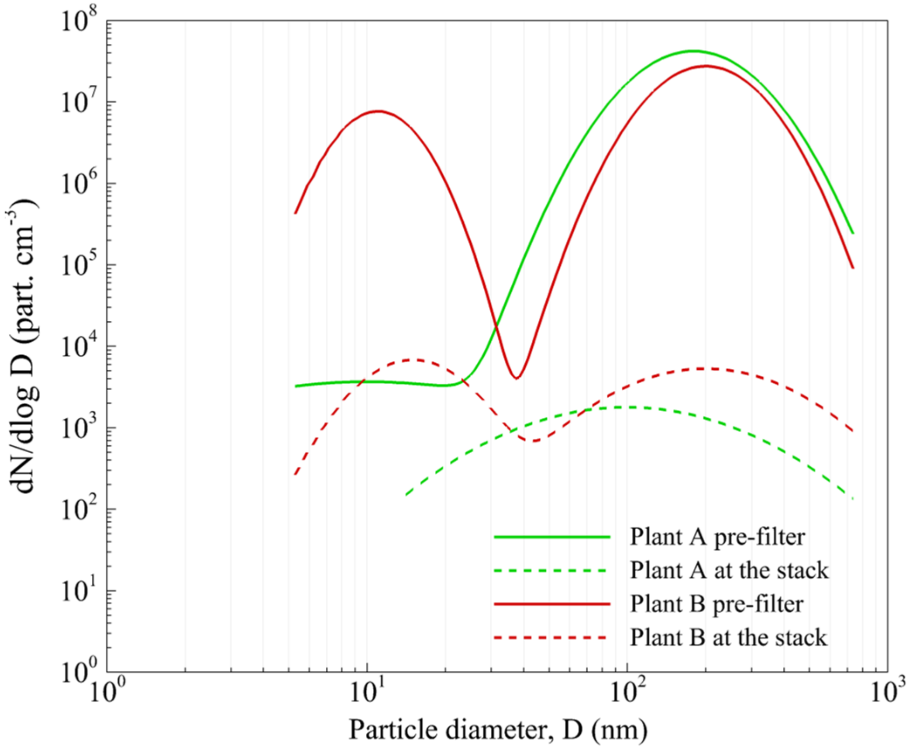
Example of a 10-minute total particle number concentration measurement through CPC3775 **before the fabric-filter** of the Plant B

RESULTS: particle number distributions

- Maximum number distribution at the stack:
  - Plant D show no particles larger than 100 nm: it could be due to the presence of two **fabric filters**…



- Comparison amongst distribution measured at the stack and before the fabric-filter:
  - filtration efficiency of both the fabric filters (in terms of UFPs) is higher than 99.99%!!!



Elemental analysis: particle collection

- At the stack of the **Plant B**, particles were collected through a Nanometer Aerosol Sampler (NAS 3089 TSI Inc.) according to several imposed diameters (50, 100, 150 and 200 nm):
  - an **elemental analysis** of particles collected at the stack was carried out for the different size-selected filters by means of a nuclear techniques, i.e. **Instrumental Neutron Activation Analysis** (INAA) in collaboration with ISPESL (Rome, Italy).

*The choice of involving a **nuclear methodology** was necessary because of both the very light filter dimension and the lowest amount of material deposited onto it. In fact, the INAA does not need any chemical pre-treatment of the samples.*

20 elements were determined: Al, As, Cd, Ce, Co, Cr, Cs, Eu, Fe, Hg, Na, Ni, Sb, Sc, Sm, Ta, Th, V, Yb, Zn

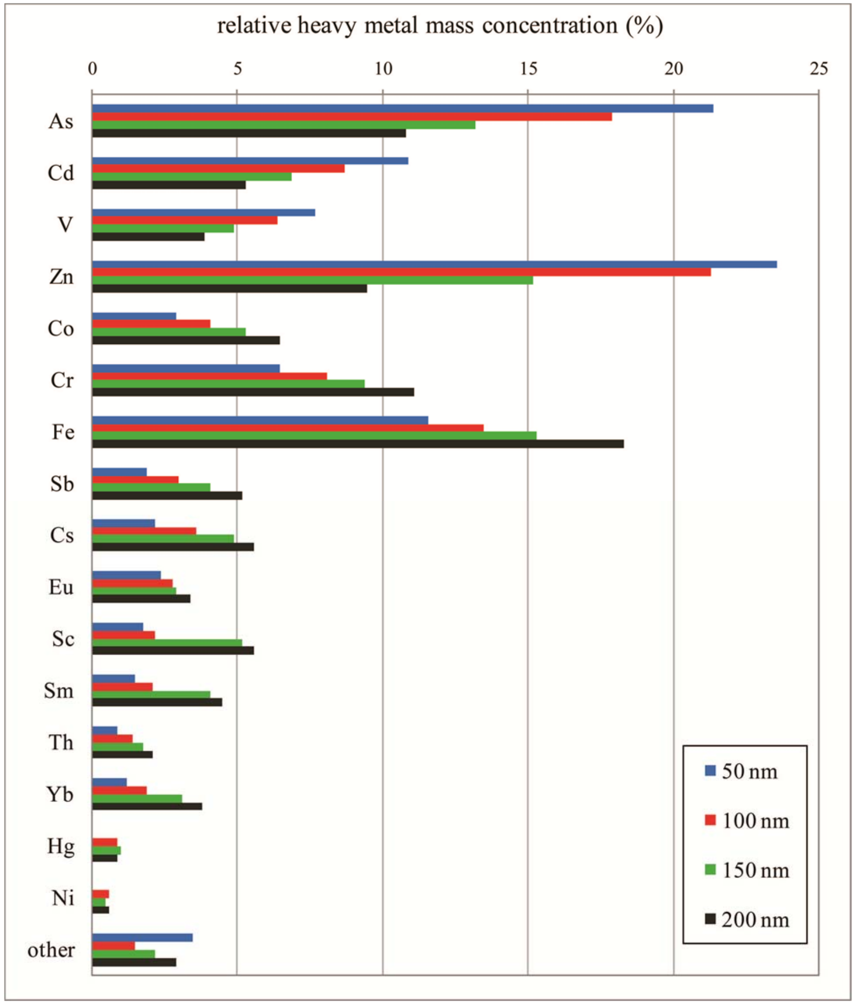
Nanometer Aerosol Sampler *3089 TSI*

RESULTS: heavy metal concentrations

- The boiling point effect:
  - **As, Cd, V and Zn** decreases their contribution to the total mass concentration as the particle diameter increases (from 50 to 200 nm)

    (boiling temperature lower than 1200 °C, except for V)
  - **Co, Cr, Fe, Sb, Cs, Sc, Sm, Th, Eu and Yb** increase their contribution to the total amount with the increasing of the particle size.

    (boiling temperature higher than 1200 °C, except for Cs)



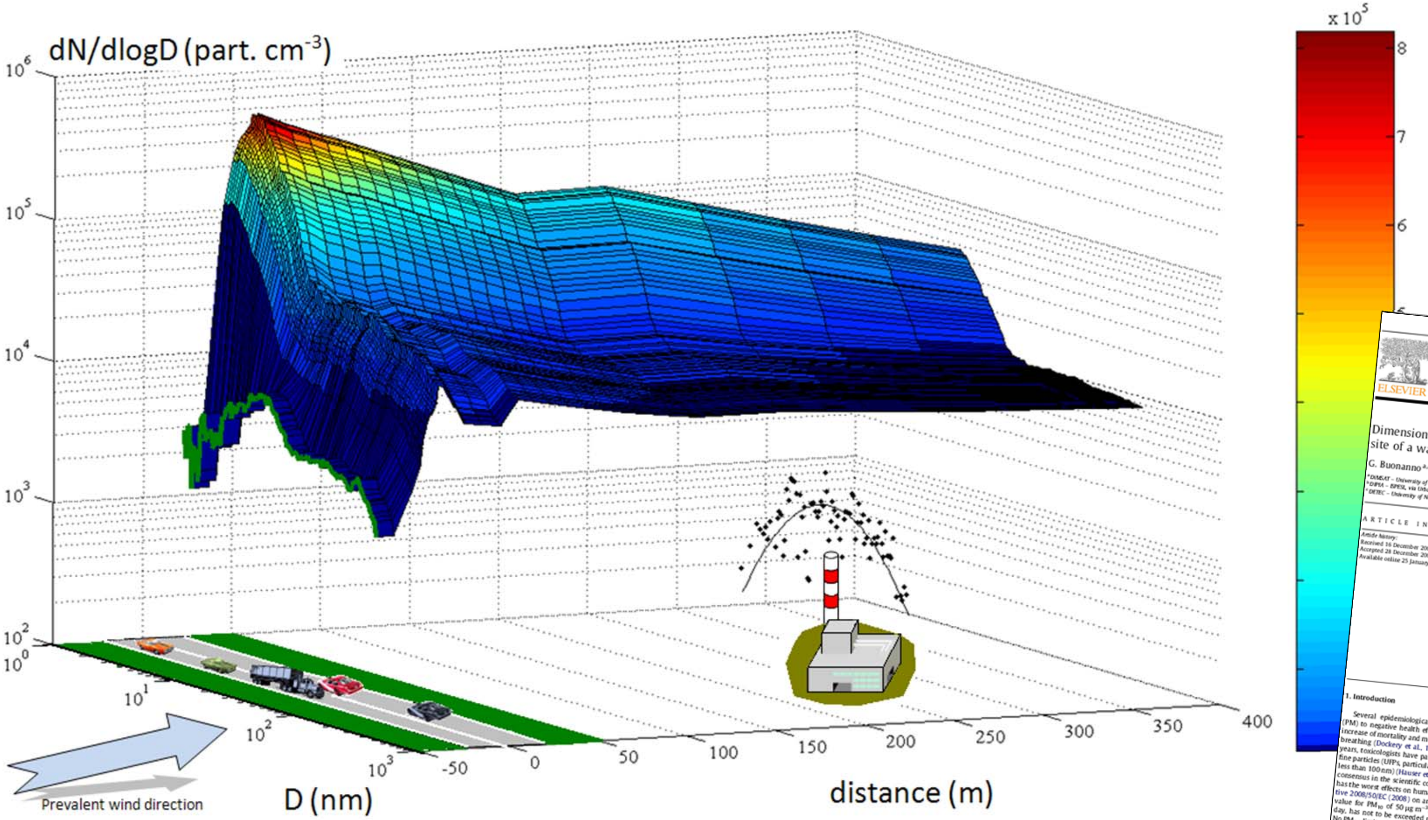
- A probable pathway:

reaction of elemental metal to form metal oxide (a substance with a significantly higher vapor pressure).

- o elements showing a lower boiling point evaporate in a complete way;
- o metals having higher boiling temperature tend to remain in the solid phase and highly contribute to the mass of larger particles (200 nm).

RESULTS: linear and point sources

- Incinerator (Plant B) *vs.* Major Italian highway (A1)…

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Dimensional and chemical characterization of particles at a downwind receptor site of a waste-to-energy plant

G. Buonanno, L. Stabile, P. Avino, R. Vanoli

ARTICLE INFO

ABSTRACT

1. Introduction

CONCLUSIONS

The analysis of the results of these measurement campaigns leads to the following conclusions:

- UFP concentrations at the stack are lower than 1×10^{4} part. cm^{-3};
- removal efficiency of the fabric filters is greater than 99.99%;
- in regard to heavy metal concentrations, elements with a boiling temperature lower than 1200 °C decrease their contribution to the total fraction with the increasing of the diameter (from 50 nm to 200 nm), whereas element with a boiling temperature greater than 1200°C increase their contribution to the total amount with the increasing of the particle size;
- **UFP emissions from incinerators are significantly lower than other anthropogenic activities.**

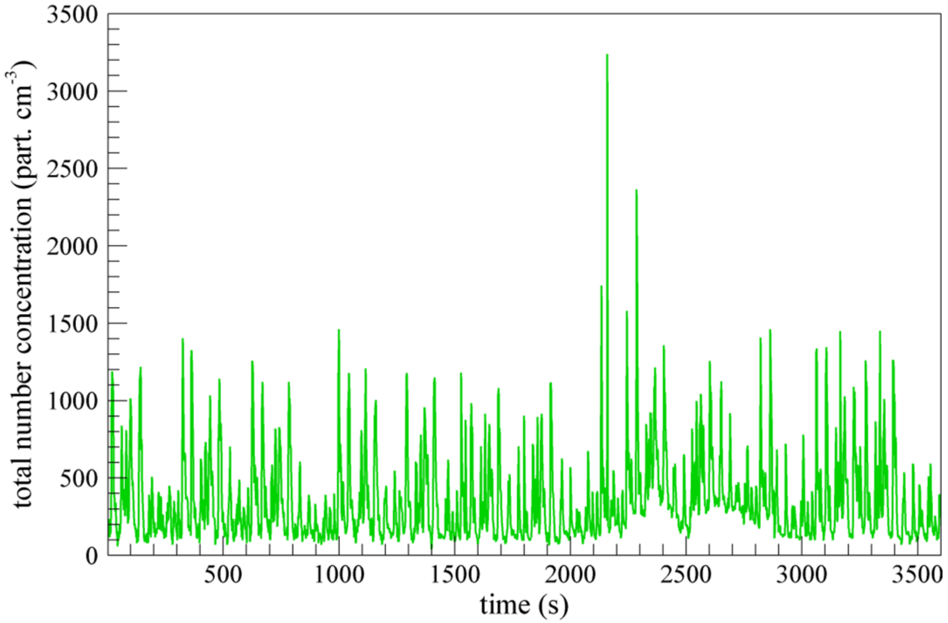
Thank you for your attention

Extra slides…

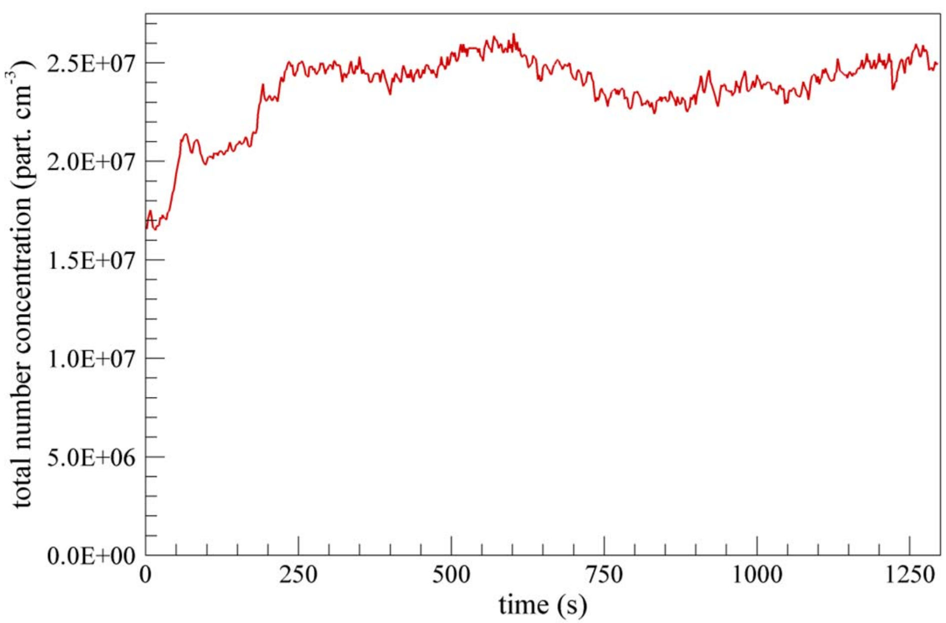
RESULTS: number concentrations

PLANT B

- Total particle number concentration **at the stack**: 1×10^2 - 1×10^3 part. cm^{-3}
- Total particle number concentration **before the fabric filter**: 2.0×10^7 part. cm^{-3}



Total number concentration trend measured at the stack through a CPC 3775



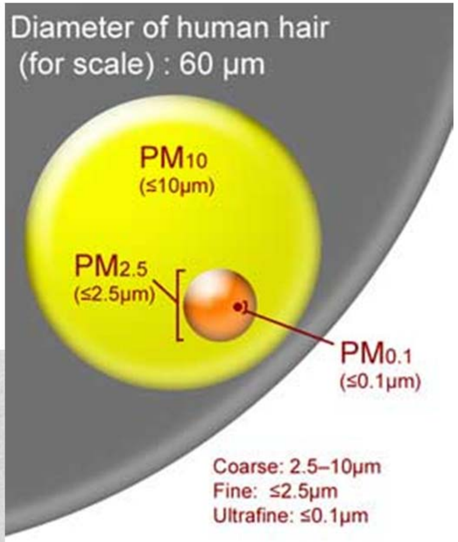
Total number concentration trend measured before of the aerosol entrance in the fabric filter through a CPC 3775

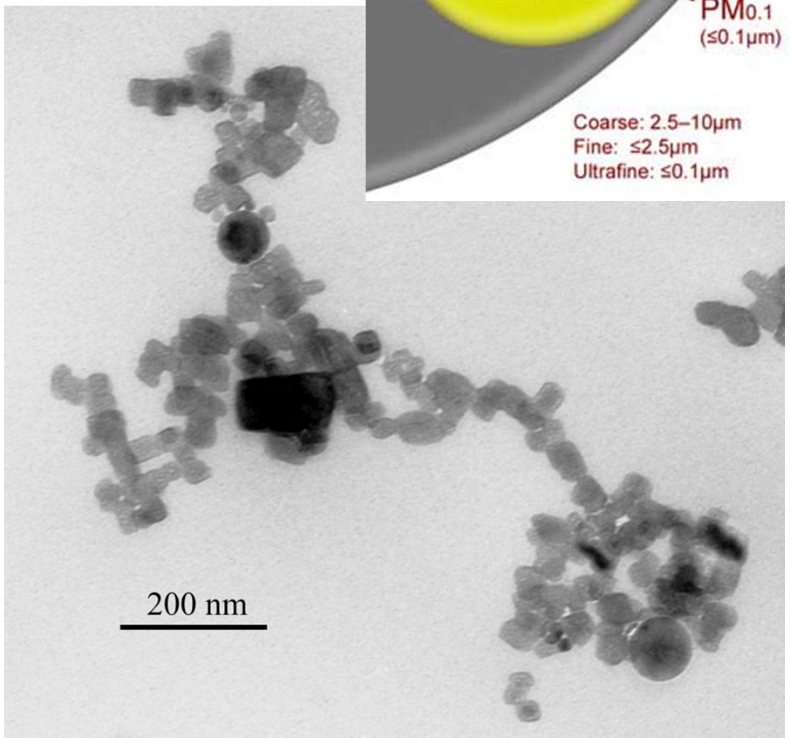
INTRODUCTION: definitions

- Atmospheric Aerosol

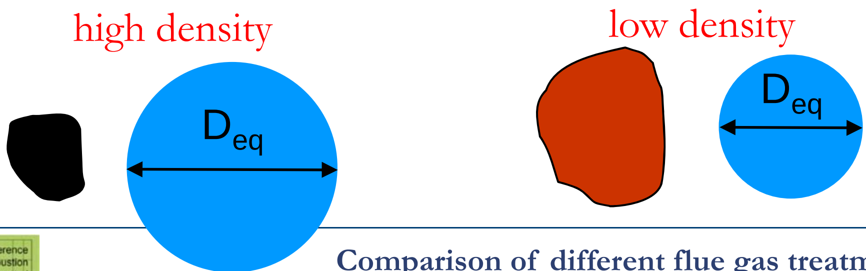
  is a metastable suspension of solid or liquid particles in a gas (e.g. air).

- Classification by size
  - PM_{10} — $D_{eq} < 10\ \mu m$
  - Coarse Particles ($PM_{2.5-10}$) — $2.5\ \mu m < D_{eq} < 10\ \mu m$
  - Fine Particles ($PM_{2.5}$) — $D_{eq} < 2.5\ \mu m$
  - Ultrafine particles (UFPs) — $D_{eq} < 0.1\ \mu m$ (100 nm)
  - Nanoparticles — $D_{eq} < 0.050\ \mu m$ (50 nm)

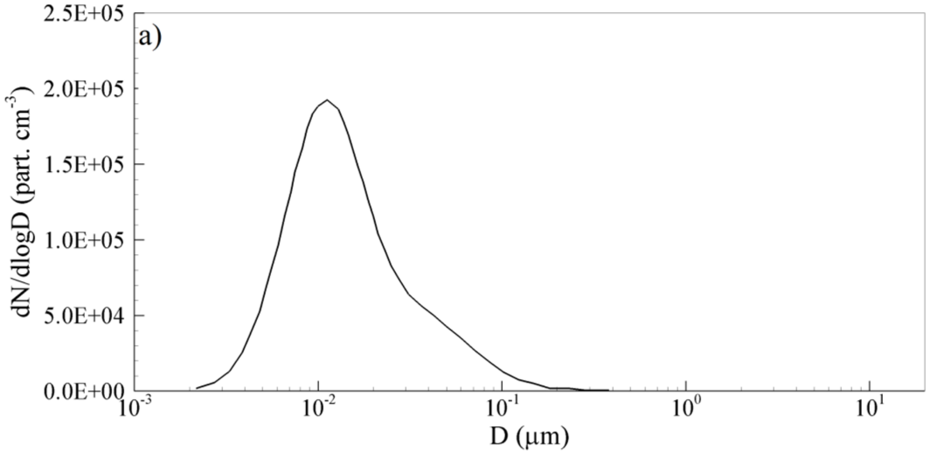




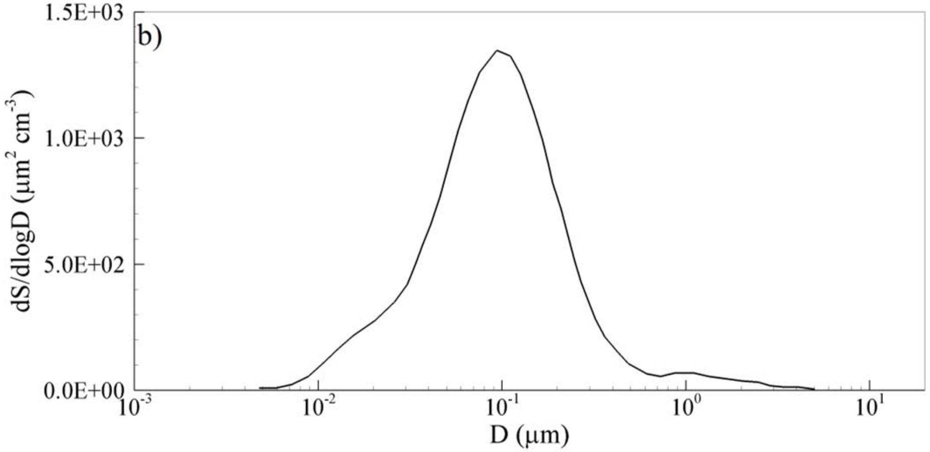
- Aerodynamic equivalent diameter

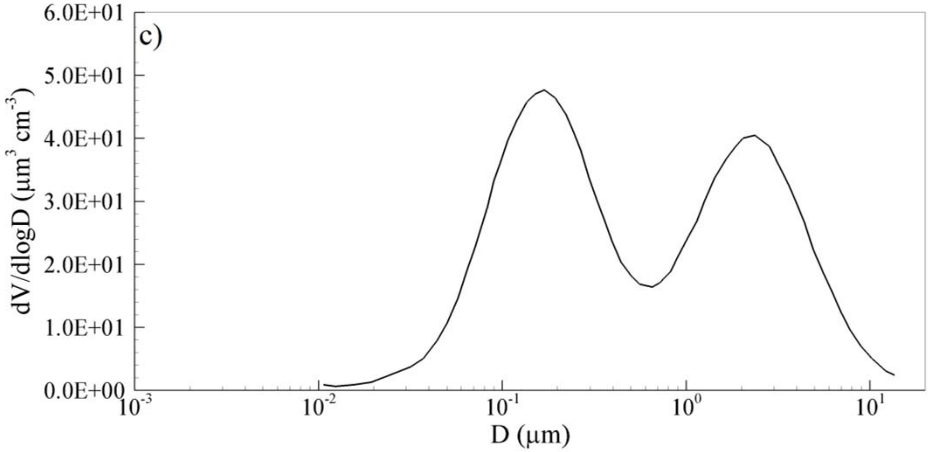


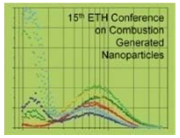
INTRODUCTION: distributions



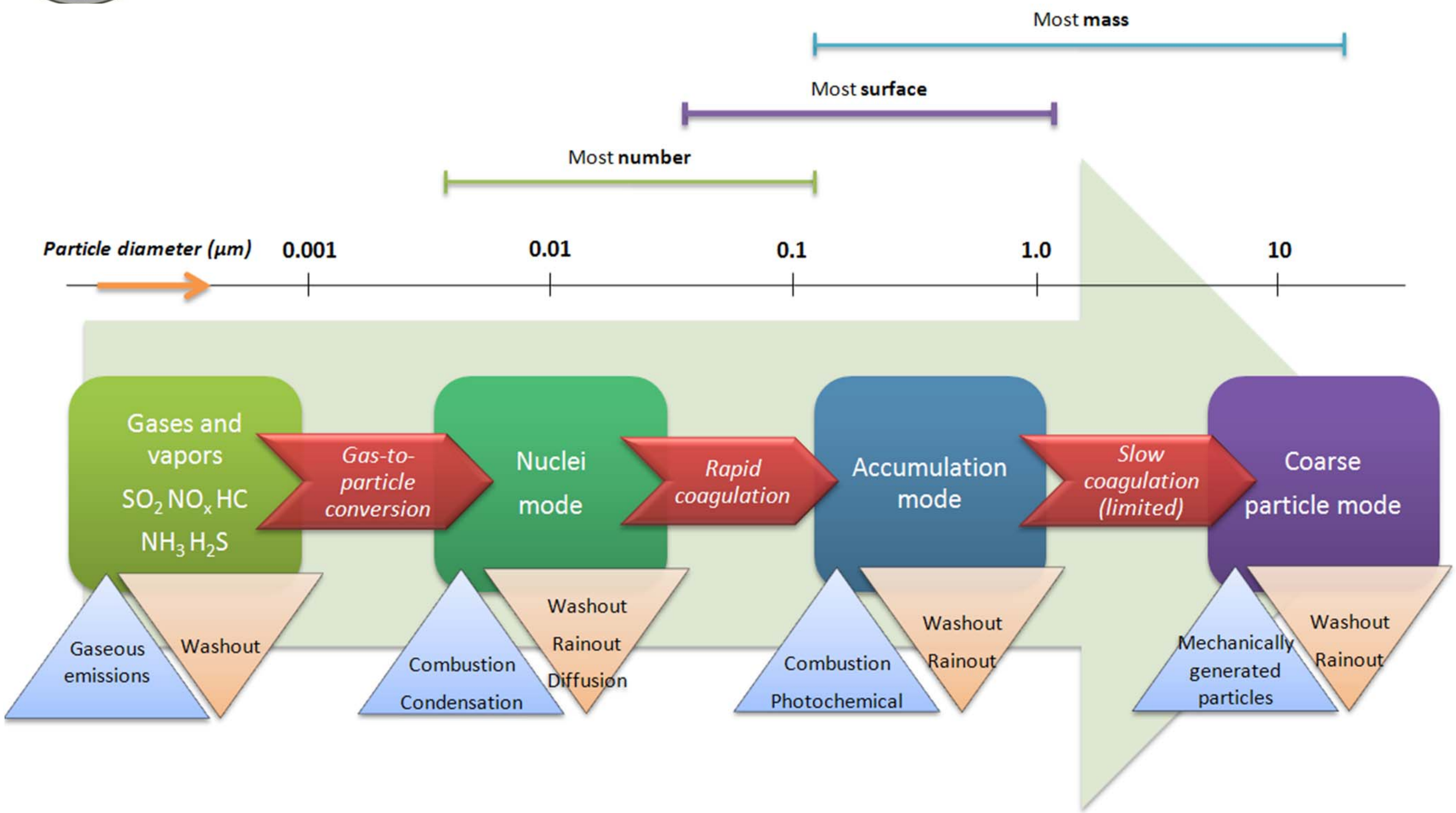
Number (a), Surface Area (b) and Volume (c) distributions of an urban aerosol (*Seinfeld and Pandis, 2006*).







INTRODUCTION: aerosol thermodynamics

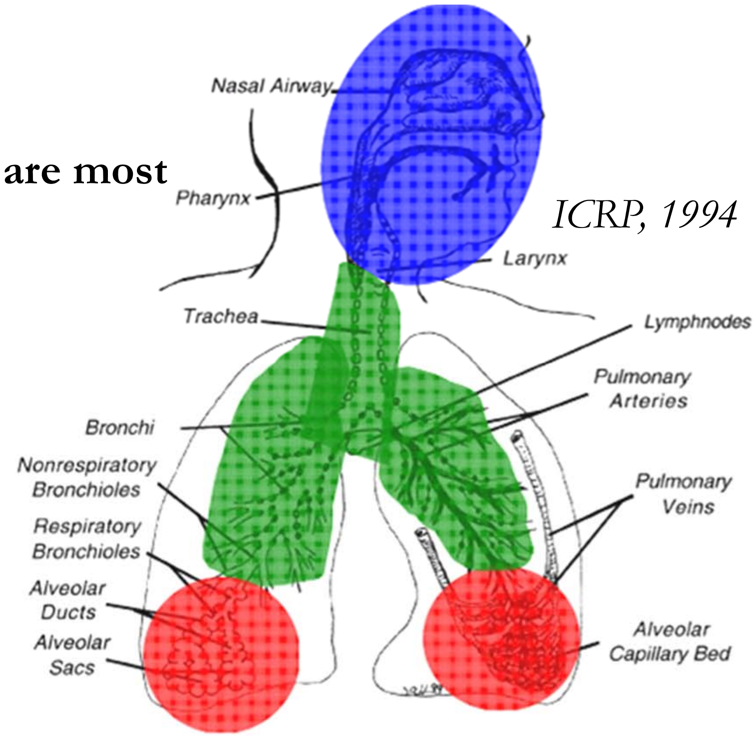


INTRODUCTION: health effects

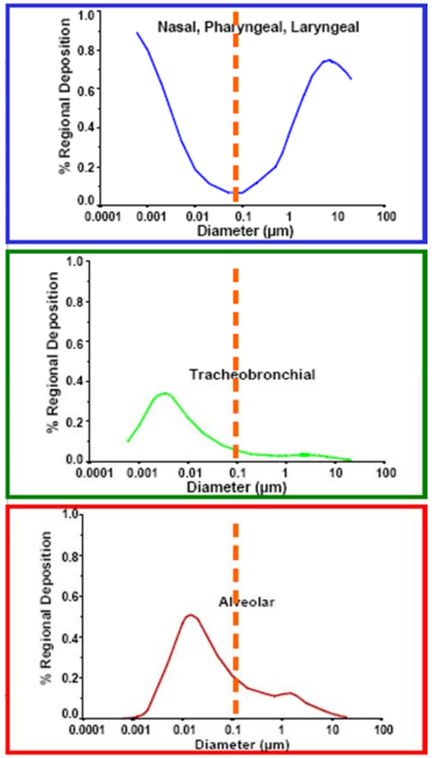
- A number of epidemiological studies were carried out in order to link particulate matter (PM) with negative health effects (cardiovascular and breathing problems…)
  - *Dockery, D.W., Pope, C.A., Xu, X., Spengler, J.D., Ware, J.H., Ferris, B.G., Speizer, F.E. (1993). Mortality Risks of Air Pollution: A Prospective Cohort Study, New England J. Medicine, 329, 1753 - 1759.*
  - *Pope, C.A. (2000). What do Epidemiologic Findings Tell us About Health Effects of Environmental Aerosols? J. Aerosol Med. 13:335 - 354.*
  - …

- **What types or sizes of particles are most responsible for health effects?**
  - PM concentrations: PM_{10} – $PM_{2.5}$
  - Number concentration: UFP
  - Surface area concentration
  - Assumption rate

  …
  - Carbonaceous nuclei *(black carbon)*
  - Volatile Organic carbon *(VOC)*



ICRP, 1994



EXPERIMENTAL APPARATUS: APS

- **Aerodynamic Particle Sizer - APS** *3321 TSI*

  Measurement range: 0.5 – 20 μm

  “sizing” technique: *time-of-flight*

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Uncertainty Budget of the SMPS–APS System in the Measurement of PM_1, $PM_{2.5}$, and PM_{10}

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The effects of particulate matter on environment and public health have been widely studied in recent years. In spite of the presence of numerous studies about this topic there is no agreement on the relative importance of the particles' size and origin with respect to health effects among researchers. Nevertheless, air quality standards are moving, as the epidemiological attention, towards greater focus on the smaller particles. The most reliable method used in measuring particulate matter (PM) is the gravimetric method since it directly measures PM concentration, guaranteeing an effective traceability to international standards. This technique, however, neglects the possibility to correlate short term intraday atmospheric parameter variations that can influence ambient particle concentration and size distribution as well as human activity patterns. Besides, a continuous method to determine PM concentrations through the measurement of the number size distribution is the system constituted by a Scanning Mobility Particle Sizer (SMPS) and an Aerodynamic Particle Sizer (APS). In this article, the evaluation of the uncertainty budget in measuring PM through the SMPS–APS system, as well as a metrological comparison with the gravimetric reference method in order to analyze the compatibility, was carried out and applied with reference to an experimental campaign developed in a rural site. This choice allowed to assume the hypothesis of spherical particle morphology. The average PM_{10}, $PM_{2.5}$, and PM_1 uncertainties obtained for the SMPS–APS system are equal to 27%, 29%, and 31%, respectively. Here the principle influence parameter is the particle density that has to be directly measured with low uncertainty in order to reduce the PM uncertainty.

1. INTRODUCTION

Exposure of the population to ambient particulate matter (PM) received increased attention as a consequence of epidemiological studies which demonstrated relationships between ambient particle concentrations and significant health effects (Dockery et al. 1993; Pope 2000). The considerable interest in PM health effects was a guideline not only for the regulatory authorities but also for the air quality management community

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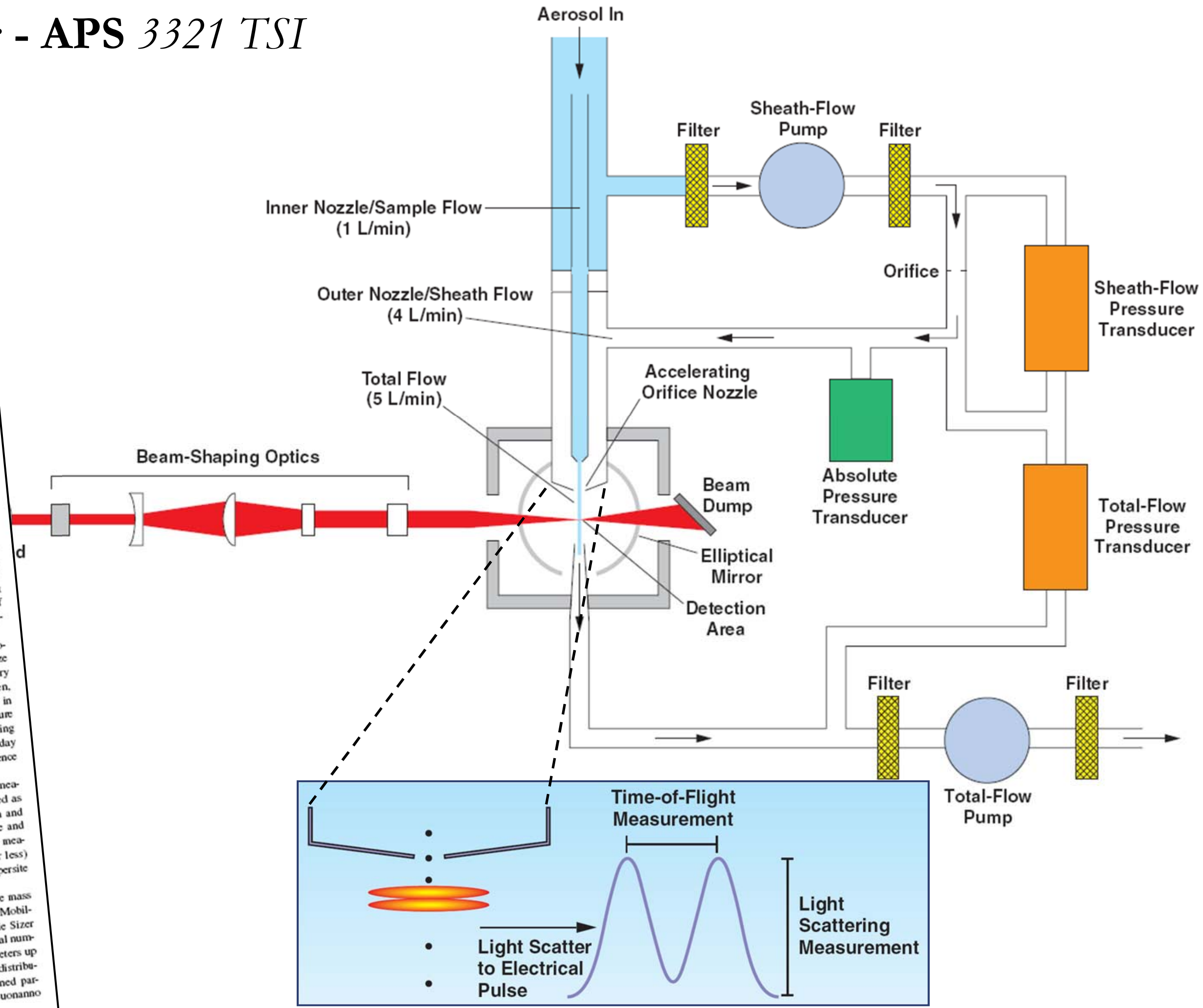
for the definition of new threshold air quality standards which are in movement towards the smaller particles as the epidemiological attention. Current air quality standards only regulate the mass of particulate matter with aerodynamic diameter less than 10 μm (PM_{10}) and 2.5 μm ($PM_{2.5}$) (US-EPA 40 CFR 1997; EN 12341 2001; EN 14907 2005). In particular, the U.S. Environmental Protection Agency (U.S. EPA) and the European Environmental Agency (EEA) assume as reference method the gravimetric analysis of particle filters collected over a period of 24 h. The gravimetric method is a time-integrated measurement based on field sampling and consequent laboratory analysis of particle mass, assuring the traceability to the International System (McMurry 2000).

Nevertheless, sources, meteorology, and atmospheric processes influencing ambient particle concentration and its size distribution, as well individual human activity patterns, vary in time scales that are practically shorter than 12–24 h. Then, the necessity to develop monitors of particle concentrations in shorter time intervals is very important to improve exposure assessment to ambient particles. In fact, the daily averaging times used in current networks tend to smooth out the intraday variability limiting our comprehension of the main influence parameters in PM accumulation in air.

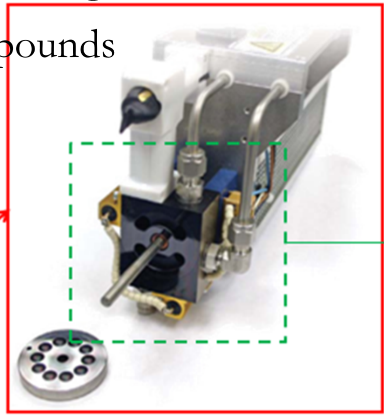
Over the last 6–8 years, significant advances in the measurement of PM chemical and physical properties resulted as an outcome of EPA's PM Supersites Program (Solomon and Sioutas 2008). In particular, Chow et al. (2008) describe and evaluate integrated and continuous and semicontinuous measurements (with a typical time resolution of an hour or less) for particle mass and chemical composition from the Supersite Program.

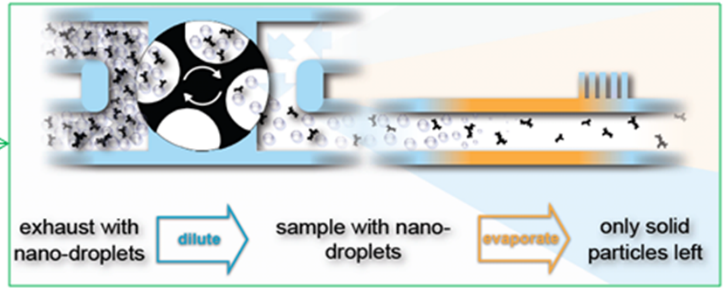
A continuous indirect method to estimate the particle mass concentration is the system constituted by the Scanning Mobility Particle Sizer (SMPS) and the Aerodynamic Particle Sizer (APS). It measures the number size distribution and total number concentration over a wide range (from few nanometers up to 20 μm) and it is also able to estimate the mass distribution and its total concentration, after having determined particle density (Sioutas et al. 1999; Fine et al. 2004; Buonanno et al. 2009).

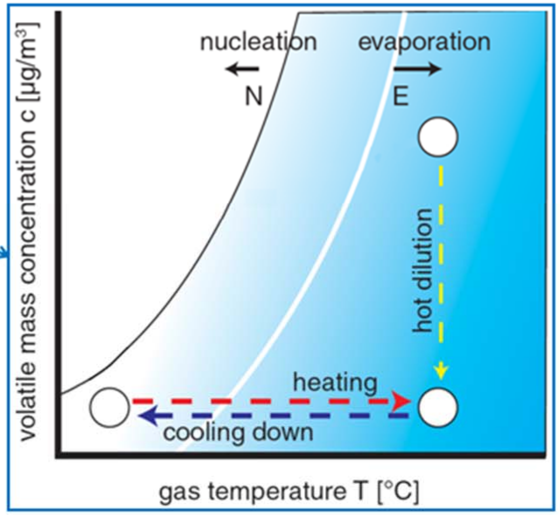


EXPERIMENTAL APPARATUS: RDTD

- **Rotating Disk Thermodiluter & Thermal Conditioner** *(Matter Engineering)*
  - Thermal conditioning of the exhaust gases
  - Evaporation of the volatile compounds







Thermodilution system prevents:

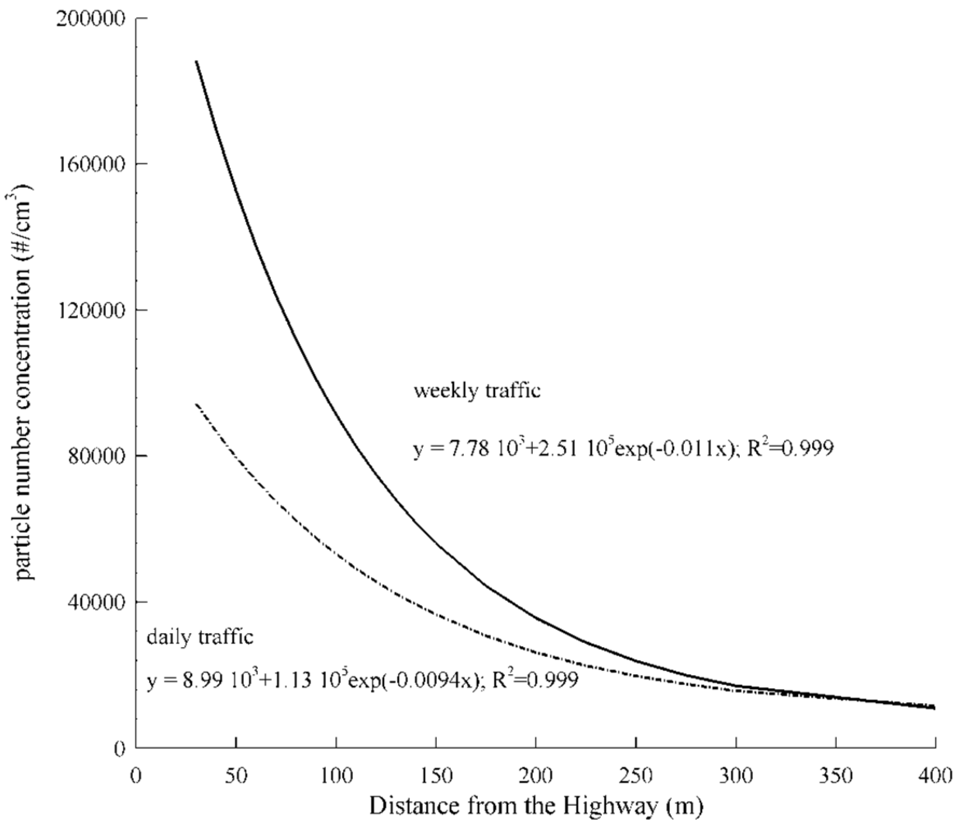
- Homogeneous and heterogeneous Nucleation
- Coagulation

RESULTS: heavy metal concentrations

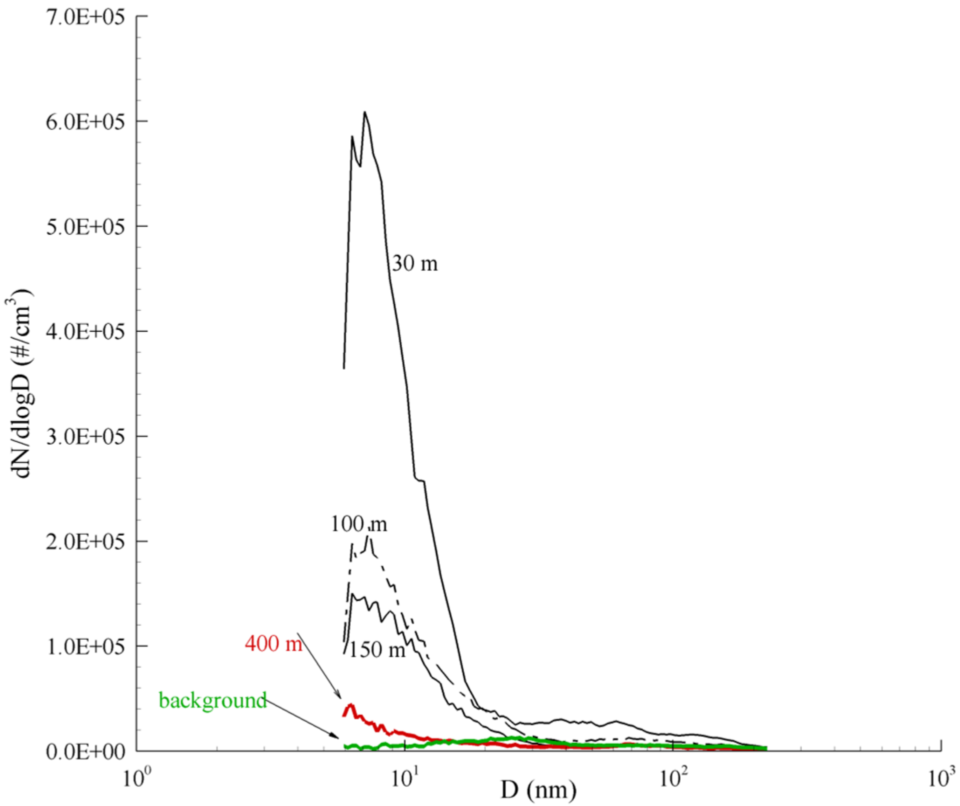
Element	Particle size				Boiling Point (°C)
	50 nm	100 nm	150 nm	200 nm	
Hg	-	0.9	1	0.9	357
As	21.4	17.9	13.2	10.8	603
Cs	2.2	3.6	4.9	5.6	671
Cd	10.9	8.7	6.9	5.3	765
Zn	23.6	21.3	15.2	9.5	907
Yb	1.2	1.9	3.1	3.8	1194
Sb	1.9	3	4.1	5.2	1587
Eu	2.4	2.8	2.9	3.4	1597
Sm	1.5	2.1	4.1	4.5	1791
Cr	6.5	8.1	9.4	11.1	2672
Ni	-	0.6	0.5	0.6	2732
Fe	11.6	13.5	15.3	18.3	2750
Sc	1.8	2.2	5.2	5.6	2831
Co	2.9	4.1	5.3	6.5	2870
V	7.7	6.4	4.9	3.9	3409
Th	0.9	1.4	1.8	2.1	4788

HIGHWAY EMISSION

Total particle number decay

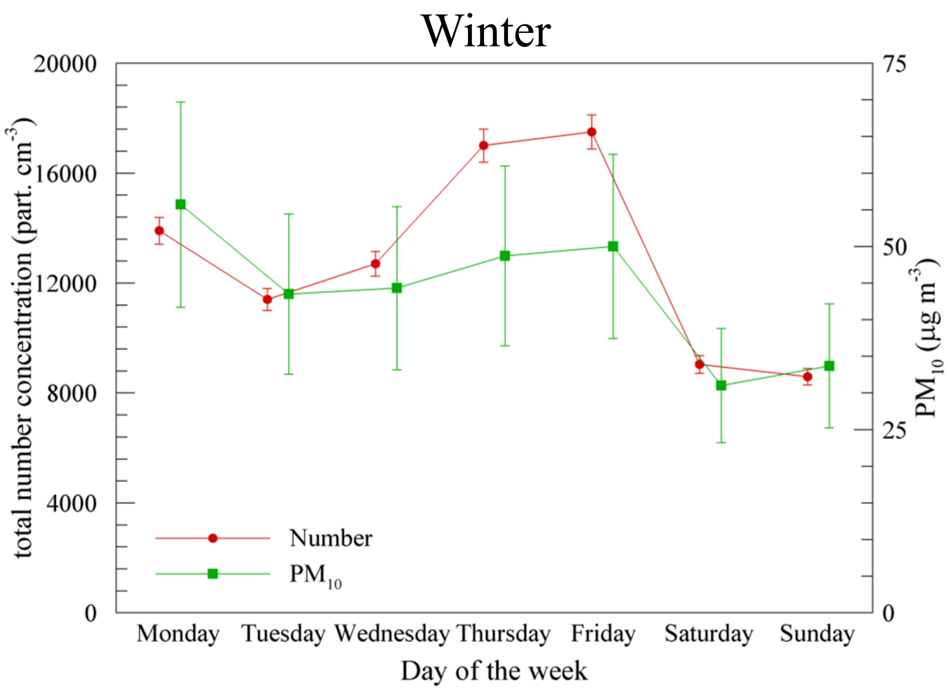


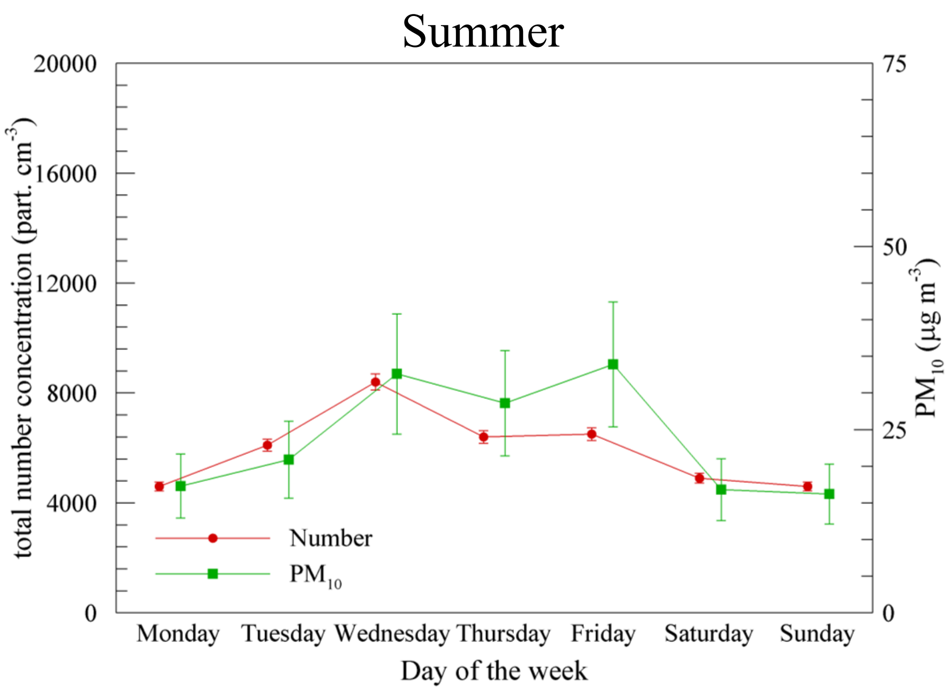
Distribution spatial evolution



DOWNWIND RECEPTOR SITE

- Daily trend: PM_{10} and Number concentration

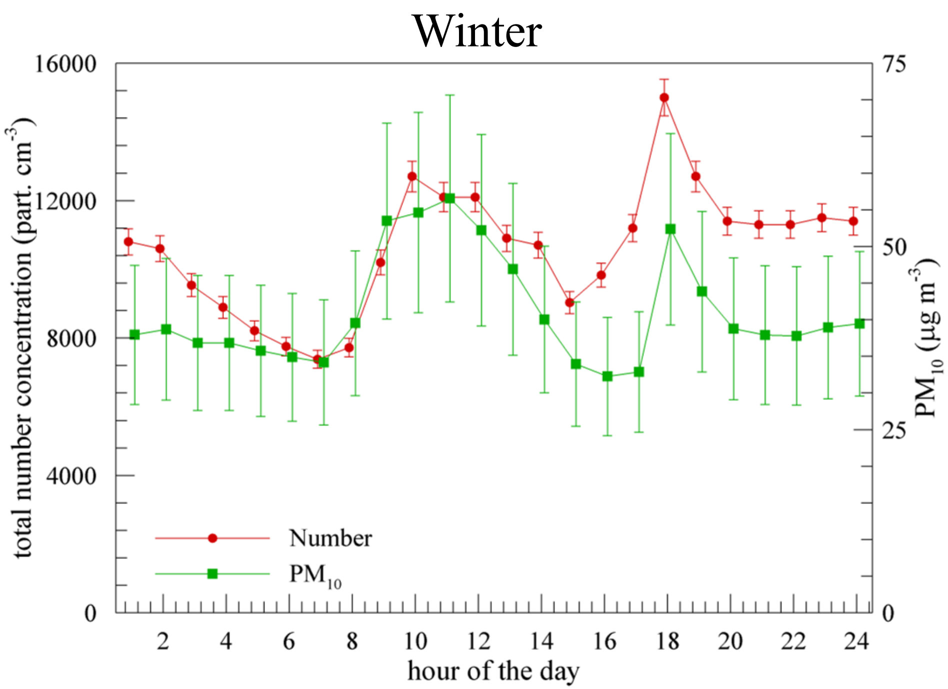


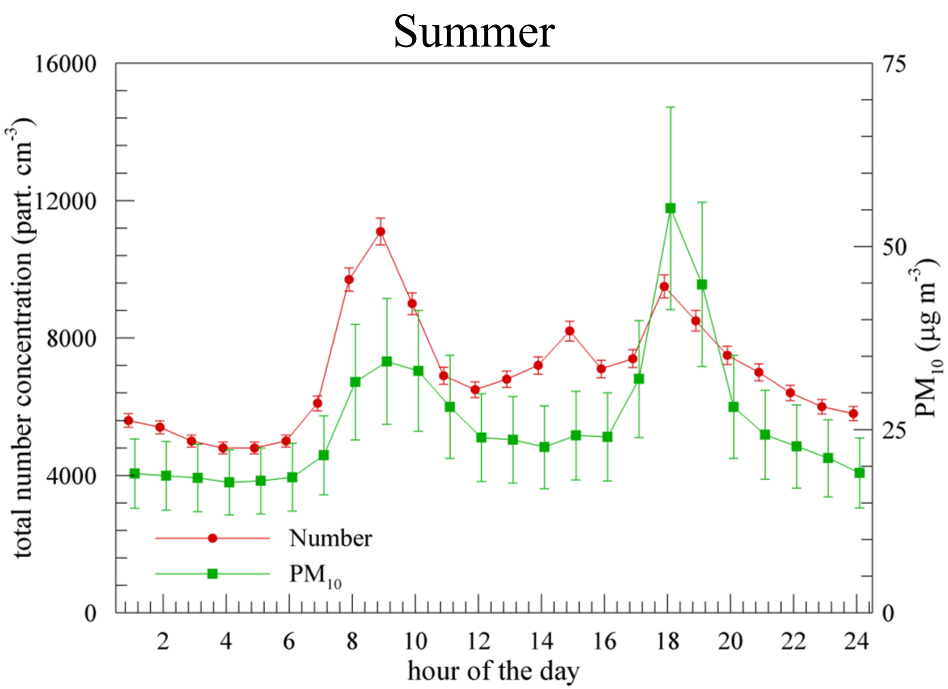


- Periodic behaviour: A1 influence

DOWNWIND RECEPTOR SITE

- Hourly trend: PM_{10} and Number concentration





- fresh particles early in the afternoon: SOA?