

## Continuous Monitoring of UFP Across 11 European Cities: First Results from the Net4Cities Project

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Ultrafine particles (UFPs; <100 nm) represent a significant environmental health challenge, particularly within the transport sector. Traditional mass-based metrics used to monitor particulate matter emissions (PM<sub>10</sub>, PM<sub>2.5</sub>) poorly capture the impact of UFPs, which contribute only negligibly to mass but dominate in number and need to be addressed. Recent updates to the EU air quality directive (Directive (EU) 2024/2881) have placed an emphasis on ultrafine particle (UFP) measurements, particularly within the newly defined supersites. These supersites are mandated to perform total UFP particle number concentration (PNC) measurements using condensation particle counters (CPC). While PNC has long been the primary metric for quantifying UFP exposure, Lung Deposited Surface Area (LDSA) has emerged as a valuable complementary for a more nuanced health risk assessment. LDSA specifically quantifies the total active surface area of particles that deposit in the alveolar regions of the lung<sup>1</sup>. In the Horizon Europe Net4Cities project, a major aim is to enhance air and noise pollution monitoring infrastructure across 11 European cities to support Zero Pollution Action Plans and the EU Green Deal objectives, including through the measurement of UFPs. To address this new legislative requirement for the monitoring of UFPs, the Net4Cities project has adopted a dual-approach through the measurement of PNC using Airmodus CPCs and the measurement of LDSA using naneos diffusion-charging LDSA monitors. In the 11 partner cities, new UFP monitoring networks have been established at traffic, airport, and port monitoring sites, leading to the installation of 24 CPCs and 33 LDSA monitors. In this work we present preliminary results of these extensive measurements of PNC and LDSA across Europe. We also perform initial comparisons of the two metrics and identify linkages with local meteorology and transport emissions sources. Our preliminary results confirm a high degree of spatiotemporal heterogeneity in concentrations, a characteristic previously identified in smaller-scale studies, and demonstrate that these fluctuations are strongly coupled with local human activity across all site types.

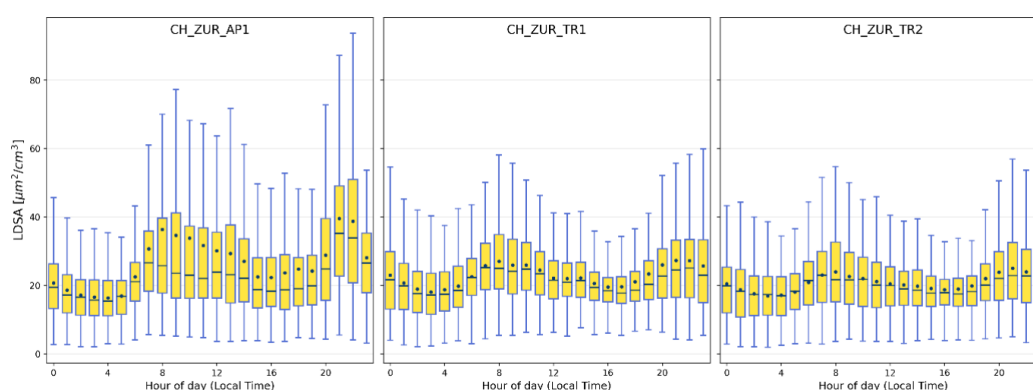


Figure 1: Box-and-whisker plots of hourly mean LDSA concentrations at three selected sites (one airport, two traffic hubs) in a representative partner city, measured from March 28th to November 20th, 2025.

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**Experimental evaluation of nucleation phenomena in an oxidation flow reactor (DOFR™)**P. Juuti<sup>1</sup>, M. Nikka<sup>1</sup>, J. Haapanen<sup>1</sup>, A. Arffman<sup>1</sup><sup>1</sup>Dekati Ltd., Kangasala, 36240, Finland

Oxidation flow reactors (OFR), such as Dekati® Oxidation Flow Reactor (DOFR™) are aerosol conditioning units designed to simulate atmospheric aging and especially used in studying secondary aerosol formation. DOFR design is similar to previously published OFR TSAR (Tampere University Secondary Aerosol Reactor, Simonen et al. [1]). Utilizing high concentrations of OH-radicals and UVC (254 nm) radiation, days-long oxidation processes can be achieved within minutes. The oxidation of volatile vapors, present in the measured aerosol, can make them condensable within the OFR chamber, leading to growth of existing particles or to nucleation of new particles. Whether nucleation takes place depends on the overall process parameters, but more interestingly here, on the ratio between condensable vapor and seed particles of the measured aerosol. So, at the output of the OFR, the condensed particulate mass can end up in its own distribution mode and/or growing the existing seed particle mode. Similar phenomena in which background aerosol influences new particle formation may also happen in real ambient conditions affecting, e.g., pollution formation processes.

In our experiments we varied the ratio between condensable vapor and seed particles around the point where nucleation takes place. Soot seed particles were generated using a Miniature Inverted Soot Generator (MISG). An eDiluter™ Pro along with a catalytic stripper were used to condition and to adjust the concentration of the soot seed particles. As a condensable vapor precursor, toluene,  $\alpha$ -pinene, and mixture of their vapor was introduced from a temperature-controlled flow saturator continuously and in pulses with a syringe. The prepared aerosol was then atmospherically aged with a DOFR™ using stable humidity and ozone concentration. The aged aerosol from the DOFR™ was measured with an ELPI®+ and an SMPS. The oxidation age was estimated by using a CO gas tracer, and the aging controlled by varying the UVC radiation intensity in the oxidation chamber.

The point where nucleation occurs was found for both stable and pulsed vapor cases. Results for the pulsed vapor case with four different injection intervals are shown in Figure 1. Measurements were performed to cover cases where practically only nucleation or coated soot particles were present, as well as the case where both modes are present. Clear differences were observed between ELPI®+ and SMPS distributions as the soot seed particles started to grow from the condensing vapor, indicating the change in effective density of the measured particles. Additionally, the DOFR™ response time for a pulsed vapor source was determined by comparing an input of a near point source of vapor to an output of a broadened particle size distribution.

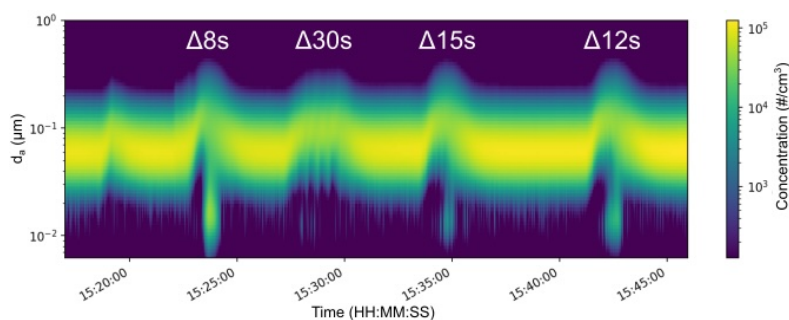


Figure 1: Vapor injection series with varying injection interval

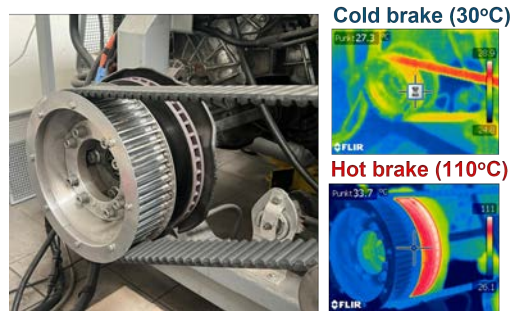
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## Particle number emissions from brakes of passenger cars

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This article presents the current legal framework and upcoming regulations related to particulate matter emissions resulting from the wear of automotive brake components. Brake dust emissions are a recurring topic in scientific literature due to their detrimental impact on both the environment and human health. Brake dust has been shown to exhibit carcinogenic properties similar to those of exhaust-derived particulate matter. This issue also affects electric vehicles, which are often heavier than internal combustion engine vehicles. When regenerative braking is underutilized, the increased vehicle mass may result in elevated brake dust emissions. Consequently, forthcoming regulations such as Euro 7 will mandate the assessment and limitation of such emissions for both conventional and electric vehicles.



The authors conducted a series of braking scenarios on a specialized test bench, measuring dust emission parameters and determining the mass loss of brake pads after each test. The scenarios varied in terms of simulated initial vehicle speed, brake pedal force (including emergency braking conditions), and pre-established braking protocols. The study included measurements of particulate matter concentration and particle number across various size ranges. The AVL Micro Soot Sensor was used for particulate matter concentration measurements, while a TSI Engine Exhaust Particle Sizer (EEPS) spectrometer was employed to measure particle number and size distribution (covering diameters from 6 nm to 600 nm). The results enabled a qualitative comparison of particulate emissions and an analysis of particle size distribution across different braking conditions. The next phase of the study will evaluate the particle size under similar operating conditions but using various types of friction linings.

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## Emission of particulate matter during braking of a rail vehicle on a test stand

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This study addresses the problem of particulate matter emissions released into the atmosphere during the braking process of a rail vehicle tested on a laboratory stand. The experimental tests were designed to replicate real operating conditions. The angular velocities to which the flywheel mass of the test stand was accelerated corresponded to linear vehicle speeds of 160 km/h and 200 km/h. The mass that had to be decelerated by the braking system was 6700 kg.

An EEPS 3090 mass spectrometer was used to measure the particle size distribution and mass of particulate matter generated as a result of friction between the brake pad and the brake disc of the rail vehicle. After each braking cycle, the brake pads were removed from the test stand, weighed, and reinstalled in their original positions.

Figure 1 presents the number concentration of particulate matter emitted in the immediate vicinity of the brake pads for braking speeds of 160 km/h and 200 km/h. The maximum instantaneous particle number concentrations reached  $1.62 \times 10^6$  #/cm<sup>3</sup> and  $4.01 \times 10^6$  #/cm<sup>3</sup>, respectively. In addition, particle size distributions were determined. For the lower braking speed, the highest particle concentrations were observed in the diameter ranges of 19.1–39.2 nm. For the braking speed of 200 km/h, the highest concentrations occurred in the particle diameter range of 16.5–52.3 nm.

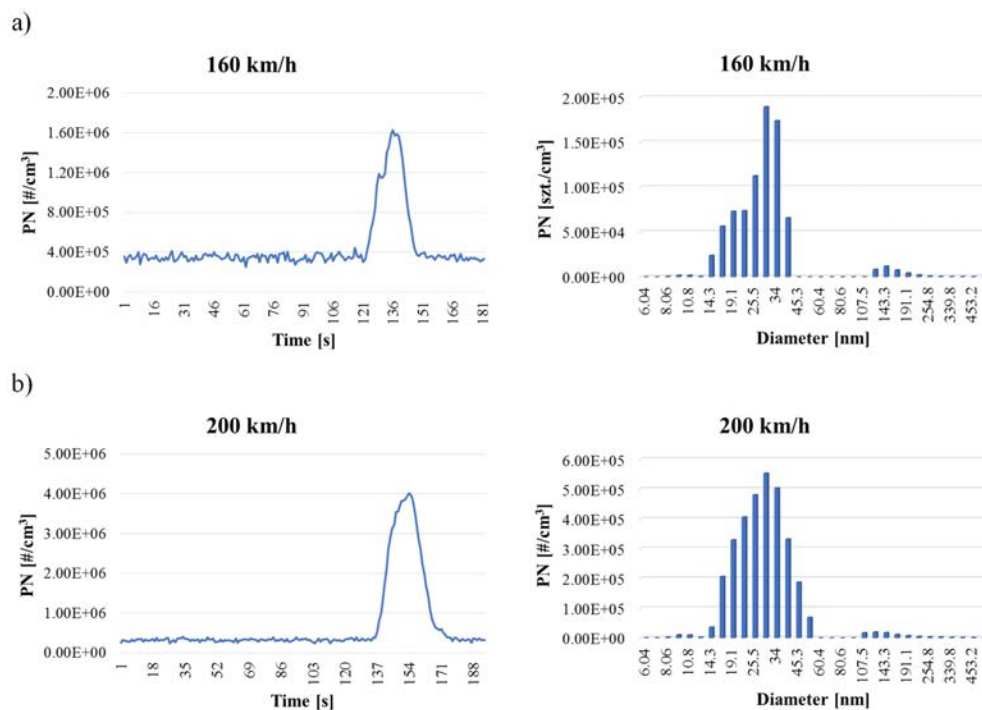


Figure 1. Particle number concentration during the braking process with size distributions for braking speeds a) 160 km/h and b) 200 km/h

Using the spectrometer data, the mass loss of the analyzed samples was determined. For the braking speed of 160 km/h, the mass loss amounted to 187.8 µg, while for 200 km/h it reached 345.6 µg. Measurements of the total mass of the brake pads using a precision balance showed that the overall pad wear during the tests corresponded to 5 g and 11 g for the respective braking speeds.

**On-road tire-wear particle emissions from a light-duty vehicle**

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The topic of non-exhaust emissions has received increased attention over recent years due to the continuous reduction of combustion-generated (tailpipe) emissions from mobile sources and their relevance to air quality and health. Current emission regulatory efforts are focusing on reducing particulate non-exhaust emissions that originate from the wear of brakes and tires. Tire-wear particles are small particles abraded from tires during driving due to friction with the road surface and can contribute to ambient ultrafine particle emissions, as well as to PM<sub>2.5</sub> and PM<sub>10</sub> emissions. This study used a novel sampling system to assess tire-wear real-time particle number, particle size distributions, and gravimetric PM<sub>2.5</sub> and PM<sub>10</sub> mass from a light-duty truck during on-road driving. . Tire-wear testing was performed on six different tires from five different manufacturers over multiple routes representing urban and highway driving, and concrete and asphalt road pavement. The temperature of the tires was monitored with an IR camera. In addition to the real-time particle measurements, particle morphology for PM<sub>2.5</sub> and PM<sub>10</sub> was performed by employing a scanning electron microscopy (SEM) with Energy Dispersive X-ray (EDX). Trace elements and metals were analyzed with an X-ray fluorescence (XRF) method, according to US EPA IO-3.3. PM emission samples were also chemically characterized for organic rubber compounds, including N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD), 6PPD-quinone, diphenylguanidine, 1,3-diphenylurea, 1H-benzotriazole, 2-minobenzothiazole, and many more.

**Brake-wear particle emissions measurement and characterization during on-road vehicle testing**

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Brake-wear particulate emissions were assessed during on-road driving with a light-duty vehicle over different routes in the South Coast Air Basin of California. The test routes included a mix of driving conditions, such as highway and urban driving, frequent stop-and-go events, and deceleration events. A novel sampling system was designed to fully enclosed the brake rotor and caliper. The measurement principle was based on the CVS technique in which the airflow rate through the system is held constant. Filtered air was directed into the enclosure and an outlet for the suspended particles was drawn into the onboard sampling tunnel. Emission measurements from multiple brake pads included gravimetric mass for PM<sub>2.5</sub> and PM<sub>10</sub>. PM<sub>2.5</sub> and PM<sub>10</sub> filters were analyzed for metals and trace elements using the X-ray fluorescence (XRF) method, according to EPA IO-3.3. Real-time PM<sub>2.5</sub> emissions were measured with a TSI DustTrak DRX Aerosol Monitor 8534. Total particle number and particle size distribution were made with a Dekati high-resolution ELPI+. In addition to the emission measurements, several thermocouples were used to monitor temperature changes across the brake disc. The results of this study will be discussed as a function of brake disc temperature, driving operating conditions, and brake energy.

## Mitigating The Environmental Release of Metal Wear Particles through Sustainable Lubricant

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Metal wear particles are produced as a result of wear processes and may accumulate in grease-lubricated railway components, including axle bearings and wheel–rail interface lubrication systems [1]. These particles may be released into the environment during leakage and disposal, contributing to soil and water contamination. Particles in grease have been shown to promote surface damage and wear progression in lubricated contacts [2], and wheel–rail interactions also produce airborne wear particles that can contribute to environmental contamination [3].

This study presents a sustainable lubricant strategy aimed at mitigating the environmental release of metal wear particles through source reduction via lubricant formulation. A bio-based grease formulated using palm oil was developed and evaluated against a conventional mineral-based grease. Tribological performance was assessed under boundary contact conditions using a tribometer, focusing on friction behavior, wear response, and wear particle generation. The sustainable grease exhibited significantly lower friction coefficients and reduced wear compared to the conventional mineral grease, indicating improved lubricating efficiency and surface protection.

Wear particle analysis revealed a substantially lower concentration of metal wear particles in the formulated grease, demonstrating effective suppression of particle generation at the tribological interface. Biodegradability was evaluated using Fourier transform infrared spectroscopy (FTIR) and gas chromatography (GC), which showed accelerated chemical degradation of the palm oil–based grease relative to the mineral counterpart. The combination of reduced metal wear particle formation and enhanced biodegradability highlights the potential of the proposed sustainable lubricant to minimize the environmental impact associated with grease waste. This work demonstrates that sustainable lubricant formulation offers a viable pathway for controlling metal wear particles while improving environmental compatibility in heavy-duty machinery applications.

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**Measurement of emission factors for brake and tire wear particles from actual vehicles driving on real roads**

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Road traffic emissions have long been considered a major cause of air pollution, and accordingly, they have been strictly managed through emission regulations. As a result, exhaust gas emission has decreased significantly. However, due to the increase in the number and weight of vehicles, non-exhaust emissions (NEE) generated by friction between tires and road surfaces or between brake pads and discs are continuously rising. Since Brake Wear Particles (BWP) and Tire Wear Particles (TWP) are major sources of non-exhaust emissions, they are scheduled to be subject to regulation under Euro 7 standards starting in 2026. Regenerative braking is an effective strategy for responding to these regulations on brake wear particle emissions. Although UN GTR No. 24, the Euro 7 BWP emission measurement protocol, specifies the method for measuring BWP emissions from vehicles equipped with regenerative braking, in practice, BWP emissions from regenerative braking vehicles are not measured directly but are estimated indirectly through the friction braking ratio. Furthermore, while there are numerous research papers on tire wear used in electric vehicles, there are no standard studies regarding particulate matter emissions based on PM10 standards. In this study, a method was developed to measure BWP and TRWP (tire road wear particle) emissions when actual vehicles are driven on real roads. Utilizing this method, BWP and TRWP emissions were measured for internal combustion engine vehicles (ICEVs), hybrid vehicles (HEVs), and pure electric vehicles (PEVs) in real road environments (urban, suburban, and highway). Simultaneously, friction braking energy was measured to analyze the proportional relationship between the regenerative braking ratio and BWP emissions. To measure the non-exhaust emissions of the vehicles, dilution flow rates around the brakes and tires were calculated using tracer gas (NO) experiments, and data post-processing was performed using a special algorithm to eliminate the influence of external particles. As a result, it was confirmed that BWP emissions decreased proportionally as the regenerative braking ratio increased. Furthermore, BWP emissions were highest in the order of urban, suburban, and highway, and the regenerative braking ratios followed the same order. TRWP emissions were highest in electric vehicles, and the emission factor itself was found to be lower than that of BWP.

## INDOAIROTOX: Project Overview and Experimental Design for Indoor Ultrafine Particles—Sources, Dynamics, and Toxicity

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Inhalation exposure to particulate matter (PM) is known to cause adverse impacts on human health. Much of this exposure is incurred indoors, where people spend the majority of their time. Existing research on air quality and health impacts of PM typically focus on atmospheric fine and coarse particles (PM<sub>2.5</sub> and PM<sub>10</sub>, respectively). More recent studies have shifted their focus to ultrafine particles (UFPs), with diameters less than 100 nm.<sup>1</sup> Relative to larger particles, UFPs pose concerns for human health due to their small size and high surface area-to-mass ratio.<sup>2</sup> This facilitates the transport of particle-bound chemicals deep into the respiratory system. Despite the potential for increased adverse health effects from exposure to UFPs relative to larger particles, studies of UFPs of indoor origin remain sparse.

Indoor UFP sources typically fall into three categories: combustion, volatilization/nucleation/condensation (VNC), and oxidation. Various studies have characterized the number concentration of indoor UFPs emitted by different indoor activities such as cooking, heating, and human occupancy.<sup>3-4</sup> However, the composition of UFPs, their dynamics, and the health impacts resulting from exposure to UFP from different sources remains unclear. In this work, indoor UFP sources, dynamics, and toxicity will be systematically investigated using a multidisciplinary approach. A state-of-the-science environmental chamber for controlled UFP generation and transformation experiments will be used, in combination with advanced chemical characterization techniques (PTR-ToF-MS, EESI-MS), and a lung-tissue exposure chamber. This presentation focuses on the project overview and highlights of the experimental design.

Indoor UFP sources of interest include cooking (for different diets, and by different methods), heating, and ozone interactions with emissions from cleaning, human occupants, and personal care products. It is hypothesized that different sources will generate chemically distinct particle populations, producing varying toxicological effects. The impacts of various environmental conditions and building operational settings on UFP formation, dynamics, and lifetime will also be investigated. This unique approach will enable a mechanistic understanding of UFP behavior and toxicity. Findings from this project will improve our understanding of UFP composition, how UFPs from various indoor sources interact with human lung tissues, and inform the design and optimization of building ventilation and air purification systems to minimize indoor UFP exposure.

This study is supported by the Swiss National Science Foundation (CR00-5-239851).

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**Particle pollution from ovens in Danish kitchens**

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**Background:** In developed countries, people spend a large proportion of their lives at home, where smoke from ovens contributes significantly to indoor particle pollution, thereby increasing the risk of cardiovascular diseases, blood clots, lung diseases, cancer, etc. Good kitchen habits and the correct use of efficient cooker hoods or ventilation reduce pollution and the connected risk of morbidity. However, a YouGov survey conducted for Bolius in December 2024 showed that just 12 percent of Danes switch on the cooker hood when using their oven. At the same time, there is a fast rise in the sale of ovens built into kitchen cabinets outside the range of the cooker hood. **Purpose:** The purpose of this study was to perform detailed investigations of particle pollution from cooking food in six traditional ovens under cooker hoods and six ovens built into kitchen cabinets (not under hoods) in Danish kitchens. **Methods:** Particles (PN and PM<sub>2.5</sub>) were measured with calibrated P-Traks and DustTraks from TSI in 12 Danish kitchens. Before measurements, ovens were cleaned and the efficiency of the cooker hoods were tested. No other pollution sources were active during the measurements. A reproducible standard frying setup preparing two pieces of bacon in the oven was used under the following three test conditions: a) not using the hood, b) using the hood at the highest level, c) using ventilation (through draught versus open kitchen window). **Results:** For ovens placed under cooker hoods, efficient hoods and ventilation with through draught are roughly equally effective at removing PN pollution, while the hoods are more effective than ventilation with just the kitchen window open. Efficient hoods are better than ventilation at removing PM<sub>2.5</sub>. For ovens not placed under kitchen hoods (ovens built into kitchen cabinets), ventilation can be the most efficient method for removing both PN and PM<sub>2.5</sub>. Frying two pieces of bacon under standard conditions in an oven without the use of a cooker hood or ventilation can contribute more than 20 times as much to the pollution with PN and PM<sub>2.5</sub> in the kitchen as the local traffic contributes to the pollution on the most polluted street in Copenhagen during rush hours. This is because most diesel cars have particulate filters and pollution from traffic is diluted in a large volume of air, while the smoke from the oven is concentrated in the kitchen if no hood or ventilation is in use. Significantly higher pollution levels would be expected when the oven, baking trays etc. are not cleaned properly, and more than two pieces of bacon are cooked. The pollution spreads to the rest of the home if the kitchen door is left open. **Conclusion:** This study confirms that pollution from using ovens without using cooker hoods or ventilation will expose Danes to high levels of PN and PM<sub>2.5</sub> pollution. Exposure can be reduced significantly if using an efficient cooker hood (especially for ovens placed under a cooker hood) or ventilating during cooking. Through draught is generally more efficient in removing particle pollution than just an open kitchen window. **Perspectives:** There is an urgent need for much more information on the importance of using an efficient cooker hood, or at least ventilation, when cooking in ovens, in order to prevent health damaging pollution in Danish homes. The Danish Building Code should include specific requirements to improve public health by reducing particle pollution from cooking. Finally, requirements are needed to ensure that key pollution sources, such as ovens, are placed under effective hoods when installing new kitchens and when changing ownership of homes. **Acknowledgement:** This study is funded by the philanthropic organisation Realdania.

**Distinguishing Total and Solid Particle Emissions from Household and Office Devices using a Catalytic Stripper**

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People spend most of their time indoors, where they are exposed to a very complex mixture of aerosol. Their size and chemical composition depends on various factors, e.g. the room, furniture, and activity of the people and can range from ultra-fine particles (UFPs) to coarse mode aerosol. Especially household appliances which produce heat, such as toasters, hair driers [4], and also printers [3], are prone to generate a large number of particles. Most of the UFPs produced are semi-volatile organic compounds (SVOCs) [4], but, e.g., a toaster can be seen as a hot wire generator, which also produces solid (metal) particles.

A catalytic stripper (CS) is commonly used to separate the volatile and semi-volatile fraction of the aerosol from the solid aerosol part [5]. It has the advantage over a normal thermal denuder that the volatile substances get catalytically transformed and cannot condense again into particles after the treatment. The CS has successfully been used in many Particle Measurement Programme (PMP) compliant studies [1, 2, 5], however not in many indoor aerosol studies, where this simple distinction between volatile and solid particles might also be an important factor for health and mitigation strategies.

Here we present various studies on household and office devices, where we used a CS to determine the amount and size of solid and semi-volatile particles. One example is the printer, which has important implications for home and work place air quality. For example, a laser printer was placed in a box with particle-free air supply. The solid and total particle number concentration was monitored with two condensation particle counters (CPCs) with or without a CS, respectively. The printer produced already particles before the actual printing process started with concentrations going beyond  $10^5/\text{cm}^3$ . About 97% of the particles are from SVOCs. Another example is the toaster, where about 98% of the particles were solid.

These examples demonstrates the simplicity of distinguishing between solid and volatile particles using the CS, which is also possible for other indoor aerosol sources. This information could help to develop new mitigation strategies and foster future particle emission regulations for household and office devices.

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### Comparative analysis of particulate matter emissions from 3D printing and the internal combustion engine

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The aim of the study was to compare particulate matter emissions in terms of both concentration and number during the operation of a 3D printer and a motor vehicle. The research objects included a desktop 3D printer with a closed chamber and no filtration system, as well as a passenger car equipped with a spark-ignition engine. For comparison purposes, the printing process of a carabiner using black ABS filament was analyzed, while the vehicle was driven under real operating conditions on urban and suburban roads. The highest intensity of particulate matter emissions during the 3D printing process occurred at the raft printing stage and at the initial phase of the actual printing. In the case of passenger car operation, particulate emissions were strongly dependent on driving conditions, with the highest values recorded during rapid vehicle acceleration. When comparing both research objects, it can be assumed that, in quantitative terms, the number-based particulate matter emissions generated during a 1 km drive in a modern passenger car are equivalent to those produced by four 3D printers operating continuously for one hour.

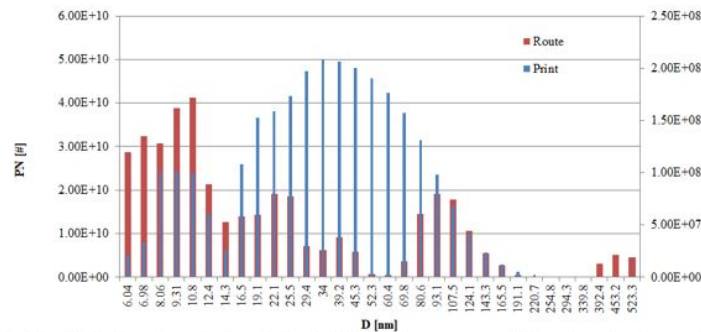


Figure 1. Total particulate matter emissions during the 3D printing process and internal combustion engine operation.

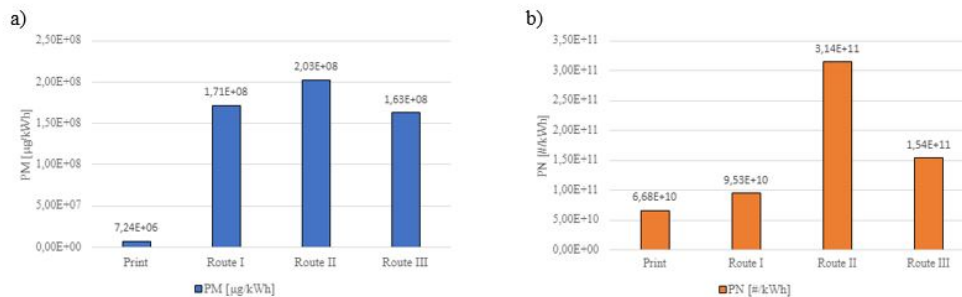


Figure 2. (a) Mass distribution of emissions relative to process energy consumption; (b) Number-based distribution of particulate emissions relative to process energy consumption

A tendency toward increased concentrations of particulate matter in poorly ventilated indoor environments without additional air filtration poses a significant health risk. Given the growing popularity of desktop 3D printers among home users, further research is recommended. Future studies should include a wider range of materials used in additive manufacturing and assess the influence of environmental conditions—such as air humidity and filament properties—on the health risks associated with individual use of 3D printers.

## Particle Number Concentration and Size Distribution in the Cabin of a Light Aircraft during Real-World Flight Operations

R. Jasiński<sup>1</sup>

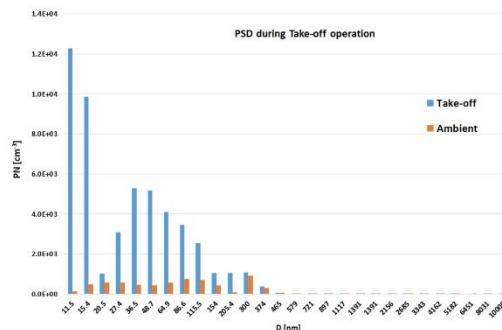
<sup>1</sup>Poznan University of Technology, Institute of Powertrains and Aviation

People spend a significant portion of their time in enclosed environments, including vehicle cabins, where exposure to airborne particulate matter may pose health risks. While indoor particle concentrations have been extensively studied in buildings and ground vehicles, data for small aircraft cabins remain scarce. This study investigates particle number concentration and size distribution inside the cabin of a light aircraft (Cessna) under real operational conditions.

Measurements were conducted during several dozen flight hours using a portable aerosol spectrometer, covering a wide range of flight phases and maneuvers, including taxiing, take-off, climb, cruise, descent, and landing, as well as selected dynamic maneuvers. Particle number concentrations and size distributions in the submicron and ultrafine particle ranges were continuously recorded and analyzed in relation to flight phase, engine operating conditions, cabin ventilation settings, and aircraft dynamics.

The results reveal pronounced variability in particle concentrations depending on flight phase, with elevated levels observed during ground operations and specific in-flight maneuvers. Changes in particle size distributions suggest differing source contributions, including infiltration of outdoor air, engine-related emissions, and resuspension processes induced by aircraft motion and airflow patterns within the cabin. The findings highlight the influence of ventilation effectiveness and operational parameters on passenger and pilot exposure.

This study provides one of the few comprehensive datasets on particulate matter in small aircraft cabins and contributes to a better understanding of indoor air quality in aviation environments. The results may support the development of targeted mitigation strategies, including improved ventilation and filtration solutions, to reduce particle exposure in general aviation.



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**Industrial Waste Derived Filtration Systems for Mitigating Indoor TVOC Exposure from Household Cooking**A. Lawrence<sup>1</sup><sup>1</sup>Department of Chemistry, Isabella Thoburn College, Lucknow, India

Indoor air pollution from biomass based cooking remains a major public health concern in rural households, where women experience disproportionately high exposure to total volatile organic compounds (TVOCs). This study investigates the performance of a cascaded industrial waste derived filtration system designed to sequentially remove TVOCs emitted during typical household cooking. The system integrates three low-cost, sustainable layers i.e. a coconut husk mat (macro-porous), fly ash based porous pellets (meso-porous), and electrospun nanofiber mats (nano-porous). Laboratory experiments were conducted using a glass exposure chamber linked to a traditional mud chulha, and parallel onsite trials were performed in rural households. TVOC concentrations before and after filtration were measured using a BR-SMART VOC analyzer to determine removal efficiency, adsorption capacity, kinetic constant (k), and temporal decay behaviour. Five composition coconut husk, fly ash pellets, nanofiber mat, fly ash + nanofiber, and the full tri-layer system were evaluated. Laboratory removal efficiencies ranked as follows: tri-layer (83.51%), fly ash + nanofiber (80.73%), nanofiber (59.0%), fly ash pellets (48.90%), and coconut husk (34.01%). Onsite measurements showed similar stratification with slightly lower values (78.12%, 73.40%, 46.8%, 41.2%, and 26.8%, respectively), reflecting environmental variability. Response Surface Methodology (RSM), contour plots, and wireframe decay curves demonstrated that adsorbent mass, initial concentration, pore structure, and adsorbed mass strongly influence removal dynamics. Pearson correlation analysis identified the kinetic constant k as the dominant driver of TVOC reduction under both laboratory and field conditions ( $r \approx 0.95$ ), whereas adsorption capacity exhibited weak correlation due to short exposure duration. The cascaded multilayer design exhibited synergistic behaviour by coupling macro-, meso-, and nano-scale adsorption mechanisms, enhancing mass transfer, surface interactions, and breakthrough resistance. The findings confirm that combining natural biomass materials with industrial waste derived adsorbents and engineered nanofibers provides an effective, adaptable, and economically viable solution for reducing women's indoor exposure to hazardous VOCs in biomass-dependent rural communities.

## Healthy Indoor Air - Nanoparticles from Laser Printers

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Toner are mixtures of polymers, magnetised metal oxides, and chemical additives. Printer emitted particles (PEPs) are released in the indoor air. Billions of ultrafine particles by printing only one page, accumulating in rooms, even in low doses but over prolonged periods. They penetrate biological barriers and reach multiple organs, including the brain. Sizes of toner particles (<0,8 µm) are comparable with diesel soot (1 µm).

Data from independent and official measurements underscore the magnitude of exposure with ultrafine particles, accumulating in the indoor air:

· German Environment Agency: ~250 billion particles in 10 minutes ([Blue Angel Eco Label 2025](#)) · TÜV testing (2014): approx. 900 billion particles in 10 minutes of printing · Harvard system (2015): 1.3 million particles/cm<sup>3</sup> — while inflammation can begin at 20,000–30,000 particles/cm<sup>3</sup>

Indoor air quality remains an underregulated and underestimated health concern. While public attention often focuses on outdoor pollution, indoor environments may expose individuals to comparable or even higher levels of ultrafine particles (UFPs). The International voluntary foundation nano-Control, founded 2008 by affected individuals, was established to address this gap. The mission of [nano-Control](#) — healthy indoor air we can rely on — emerged directly from lived experiences of people often suffering serious health impacts from long-term exposure to emissions from toner-based laser printers and copiers. We support science, collect available information and support affected people by providing relevant information.

The presented poster will inform about physics of the laser printers nanoaerosols, about the methods to measure it, some research experiences, possibilities of prevention and efforts to address the problem at the legal-administrative level. [nano-Control, International Foundation](#) is advocating for stricter regulations to protect public health indoors.

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## Nonwoven polyester fabric hybrid with conducting nanowire and photocatalytic nanoparticle for dual-functional indoor air filtration

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In light of the substantial threat to public health and quality of life, air pollution has been ranked as the 2nd leading global risk factor for death and disability, according to the World Health Organization and the State of Global Air report [1,2]. This cruel reality has prompted authorities, researchers, and individuals with strong ambition to tackle this global issue. Among these, particulate matter (PMs) can penetrate deep into the lungs and enter the bloodstream, and it also seriously affects Earth's climate. Indoor volatile organic compounds (VOCs), such as formaldehyde, can be emitted from furnishings and decorating materials. And, microorganisms, including COVID-19, can easily adhere to PMs in the air. Hence, it is high time to consider how we can protect human health and address PMs and VOCs more efficiently and economically. While a variety of porous and fibrous filters based on mechanical filtration mechanisms have been reported for indoor air quality control, deeper capture of PMs by these filters can cause excessive pressure drop and an unfavorable clogging effect, leading to a low dust-holding capacity, a short service life, and heavy energy consumption [3]. Therefore, deep insight into the augmentative materials and feasible fabrication systems would be very helpful in the quest for highly efficient, sustainable, and affordable air pollution control.

Here, we report a dual-functional electrostatic air filter on the basis of household nonwoven polyester fabric hybrid with conducting nanowire and photocatalytic nanoparticle for indoor air quality improvement—showcasing a remarkable PM removal efficiency of up to 99.5% and a high quality factor of  $0.42 \text{ Pa}^{-1}$  without sacrificing its air permeability under a hazardous smoke environment. The Dust Holding Capacity test reveals that our filters could operate for a longer service life (25–60 times higher than those of commercial HEPA filters). The washable, reusable filter also maintains good removal efficiency after five cleaning cycles. Further, with the aid of the surface-decorated titanium dioxide nanoparticles, the same fabric network can effectively degrade gaseous formaldehyde under UV irradiation. To sum up, we anticipate that this strategy may pave the way toward the development of indoor air control and public healthcare.

[1] WHO Global Air Quality Guidelines: Particulate matters (PM<sub>2.5</sub> and PM<sub>10</sub>), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, World Health Organization, Geneva, 2021. License: CC BY-NC-SA 3.0 IGO.

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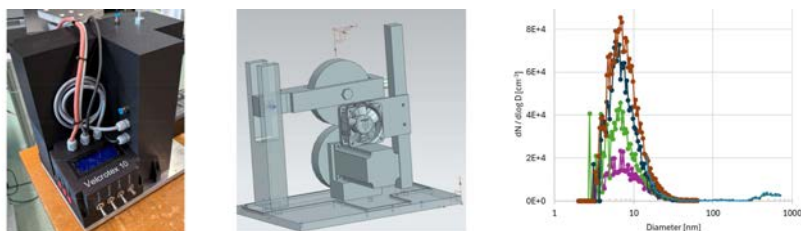
[3] H. Liu, C. Cao, J. Huang, Z. Chen, G. Chen and Y. Lai, Progress on particulate matter filtration technology: basic concepts, advanced materials, and performances, *Nanoscale*, 2020, 20, 1–9.

## Unexpected Ultrafine Particle Emissions from Disengagement of Hook-and-Loop Fasteners

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Recent observations have revealed that the mechanical disengagement of synthetic hook-and-loop (Velcro) fasteners can lead to the emission of substantial numbers of ultrafine aerosol particles with diameters well below 100 nm. Such particle sizes are typically associated with high-temperature combustion, gas-phase nucleation, or condensation processes rather than macroscopic mechanical actions, making this phenomenon both unexpected and scientifically intriguing. In this work, we present a systematic experimental investigation of nanoparticle formation during cyclic opening of commercial polyamide-based hook-and-loop fasteners. A dedicated automated test apparatus (“Velcrotex 10”) was developed to ensure reproducible and well-defined operating conditions. The device enables continuous disengagement at controlled velocities, adjustable normal forces, regulated gas atmospheres, and the optional introduction of liquid organic additives. The particle generation chamber was designed to be compact, electrically conductive, and largely free of parasitic particle sources. Aerosol number size distributions were measured using two Scanning Mobility Particle Sizers (SMPS), complemented by optical absorption measurements with an Aethalometer to assess the presence of light-absorbing carbonaceous material.



Left: External view of the 'Velcrotex 10' with control unit. Centre: Sketch of the interior layout of the generation chamber showing the unrolling cylinders fitted with Velcro fasteners. Right: Typical measured particle size distribution when pure nitrogen was fed into the generation chamber and the rotating Velcro fasteners were lightly moistened with JetA1 fuel (kerosene).

The experiments confirm that purely mechanical operation of hook-and-loop fasteners can reproducibly generate high concentrations of ultrafine particles with modal diameters typically around 5-20 nm. Particle emission rates depend strongly on operating parameters such as peeling velocity and accumulated wear of the fastener. Long-duration experiments reveal a pronounced decrease in particle output with increasing mechanical degradation, while the characteristic size distribution remains comparatively stable. Introducing reactive organic liquids or nonpolar additives significantly alters both particle number concentration and size distribution. Polar solvents tend to suppress nanoparticle formation, likely due to plasticization or increased electrical conductivity of the polymer surfaces, whereas nonpolar additives can shift the distribution toward larger particle sizes. Measurements conducted under oxygen-depleted conditions indicate that classical combustion processes are unlikely to be responsible for particle formation. Instead, the results point toward a combination of mechanochemical polymer fragmentation, release of volatile and semi-volatile organic compounds, and subsequent nucleation or condensation as plausible formation pathways.

These findings demonstrate that common fastening materials can act as efficient and controllable sources of ultrafine particles under mechanical stress. Beyond raising questions regarding indoor air quality and occupational exposure, this phenomenon may offer new opportunities for low-cost nanoparticle generation and calibration sources in the sub-20 nm size range. Future work will focus on chemical and morphological characterization of the emitted particles and on distinguishing between solid abrasion particles and condensed organic aerosols.

## A new instrument to examine the oxidizing properties of polluted air in both the gas and particle phases (GP-OOPAAI)

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The complexity of the air's composition makes it difficult to identify which compounds are most harmful. To assess the influence of atmospheric composition on human health, the oxidative potential (OP) represents a key metric, as it reflects the capacity of particulate matter to generate reactive oxygen species (ROS), which play a central role in oxidative stress and related biological responses in the human body. An imbalance between ROS or other exogenous oxidants and antioxidants leads to oxidative stress, which contributes to the development of various diseases. OP has recently been proposed as a new parameter to be measured at air monitoring stations across Europe in the new European Air Quality Directive. Numerous studies have focused on OP generated by particulate matter (PM), which has been proven to have significant impacts on human health [1]. However, gaseous pollutants in the air — such as NO<sub>x</sub>, SO<sub>x</sub>, O<sub>3</sub>, and reactive organic gaseous compounds — also contribute substantially to the production of ROS [2]. To better understand the combined oxidative impact of both phases, it is necessary to develop analytical instruments capable of measuring the oxidative potential of gases and particles simultaneously and with high time resolution to capture the highly dynamic changes in atmospheric composition. Over the past two decades, several antioxidants have been used for OP measurements, the most common being DCFH, DTT, and AA (ascorbic acid). Among these, AA is often preferred because it is a naturally occurring antioxidant in the human lung, making it particularly relevant for representing real biological oxidation processes. Recent developments have enabled online measurements of the oxidative potential of the particulate phase as characterized with AA in ambient air with a time resolution of a few minutes [3].

In this study, a new instrument is being developed to measure online the oxidative potential of both the gas and particle phases of ambient air, using a Metrohm AeRosol Sampler (MARS) and ascorbic acid (AA). The objective is to develop an analytical method capable of estimating the oxidizing properties of polluted air in both phases. Air is sampled using the MARS system, where an ascorbic acid (AA) aqueous solution is constantly pumped through a wetted wall annular denuder. This setup enables the transfer of reactive gaseous molecules into the liquid phase, where they react with AA to form dehydroascorbic acid (DHA). Particles are not retained in the denuder but are collected separately in a PILS unit behind the denuder in an AA solution. The concentration of DHA (indicating the amount of AA oxidized by gases and particles) are then separately mixed with o-phenylenediamine (OPDA). DHA reacts with OPDA to form 2,3-dihydroxyfluorene (DFQ), a fluorescent compound. Finally, by measuring the fluorescence intensity of DFQ, the oxidative potential of the air sample can be quantified in the gas and particle phase. Flow characteristics of the AA solution in the denuder and the reaction efficiency of the AA towards NO<sub>2</sub>, O<sub>3</sub>, and gaseous peroxides are being determined to characterize the response of oxidizing gases in relation to the overall OP of a polluted atmosphere.

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## Comparing effects of freshly generated brake wear particles with particles collected on Teflon filters in an advanced in vitro lung model

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Non-exhaust emissions have gained increasing attention in light of the upcoming Euro 7 regulation for vehicles, which defines maximum particulate matter (PM) emission factors for tire and brake wear.  $PM \leq 2.5 \mu m$  (PM2.5) is of special interest since it can enter, deposit and accumulate deep in the lungs where it can lead to inflammatory reactions. To analyze brake dust more in depth, a custom-built brake dyno was used to generate brake wear emissions [1]. Chemical analysis of the brake dust revealed highly metallic content with  $> 50\%$  of PM2.5 emitted as iron and other heavy metals in varying concentrations depending on the brake pad used. Particles from low-metallic brake pads were produced under real-world conditions and directly exposed to lung cells, as well as collected in parallel on Teflon filters. Direct exposure to a 3D lung cell model composed of bronchial epithelial cells (Calu-3), endothelial cells (EA.hy926), and macrophages (THP-1) resulted in a dose-dependent increase of cytotoxicity, and other endpoints are currently being analyzed. In this study, we extracted the particles collected on Teflon filters to compare the effects of direct particle exposure. Total particle mass that was extracted from the filters was determined by means of a Quartz Christal Microbalance. Scanning Electron Microscopy was used to compare the morphology of filter-extracted particles with the freshly generated particles and the morphology of the particles was similar. Preliminary 24-hour exposure experiments under quasi-ALI conditions to extracted brake wear particles indicate dose-dependent cytotoxic effects (LDH release). Particles may potentially cause disturbed membrane integrity (TEER), as well as release of inflammatory cytokines (IL-8).

The effects of direct brake wear particle exposures with particles collected on Teflon filters will be compared, including a particle deposition calculation.

### Acknowledgements:

- Low-C from the European Union's Horizon 2024 research and innovative program under grant agreement No 101192913
- ULTRHAs from the European Union's Horizon 2020 research and innovative program under grant agreement No 955390
- Adolphe Merkle Foundation

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**Assessment of aircraft engine exhaust toxicity using an on-site air–liquid interface cell exposure system**

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High levels of particulate matter and gaseous air pollutants originating from aircraft engine emissions are often detected in and around busy airports, raising concerns about potential health impacts on airport personnel and surrounding communities. The aim of this study is to study the potential health impacts of inhalation exposure to aircraft engine exhaust on the lung cell cultures. The VITROCELL<sup>®</sup> AirTox Monitor was used, allowing continuous exposure of lung cells under the air-liquid interface (ALI) conditions to whole aircraft engine exhaust. We first optimized the exposure procedure using human lung epithelial A549 cells grown for 4 days on permeable inserts. Complete cell handling, including transportation from the cell-culture laboratory to the on-site laboratory, as well as a 2-hour exposure to synthetic air (50 mL/min flow rate, 37°C, 85% relative humidity), did not induce cytotoxicity, and cells maintained intact, confluent monolayers. These results validate the use of synthetic air as a suitable control for engine-exhaust toxicity assessments. To assess aircraft engine exhaust toxicity, A549 cells were exposed to non-diluted and 10-times diluted exhaust for 2 hours, with each exposure comprising 30 minutes of engine exhaust during active aircraft engine testing followed by 90 minutes of filtered room air. Transmission electron microscopy (TEM) confirmed particle deposition on TEM grids placed on the inserts. Mass deposition of ~ 330 ng/cm<sup>2</sup> was measured by the quartz crystal microbalance (QCM) installed in the AirTox Monitor following non-diluted exhaust exposure. Lactate dehydrogenase (LDH) release increased nearly threefold under non-diluted engine exhaust relative to air controls, whereas no change was observed under 10-times diluted conditions, indicating cytotoxicity only at higher (non-diluted) exposure levels. Consistently, cell morphology analysis showed extensive detachment and loss of adhesion following non-diluted exhaust exposure, while cells exposed to diluted exhaust remained intact and comparable to the incubator and synthetic-air controls. Future studies will focus on repeated exposures across a wider range of dilution factors (*e.g.*, 2-10 times) to refine exposure parameters and establish dose–response relationships. Further biological assays will also be performed to achieve a more comprehensive characterization of toxicological effects, including inflammation and oxidative stress, induced by aircraft engine exhaust.

*This study was supported by the Federal Office of Civil Aviation and the Adolphe Merkle Foundation.*

## Nanoparticle-Forming Precursors & Associated Health Risks Across Urban Micro-Environments in eastern Indian urban area

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### Abstract

Exposure to fine and ultrafine particles is a major driver of urban health risks, particularly in rapidly industrializing regions of India. This study investigates pollutant characteristics and associated health impacts across diverse micro-environments (institutional, residential, traffic, and industrial) in the Bhilai–Durg region during winter (December 2024–January 2025). High-resolution measurements of VOCs, BTEX, inorganic gases, and PM<sub>2.5</sub> were conducted using FTIR-based analyzers and sensor networks. Results show strong spatial variability, with PM<sub>2.5</sub> concentrations (57–170 µg/m<sup>3</sup>) and reactive VOCs peaking in traffic and industrial corridors. Elevated levels of aromatics (toluene, xylenes) indicate enhanced secondary organic aerosol formation, contributing to nanoparticle burden. Health risk assessment reveals benzene-driven lifetime cancer risks exceeding acceptable limits across all sites. Coupled with trajectory analysis, the findings highlight combined local and regional influences on exposure. This work provides critical evidence linking emission sources to nanoparticle-forming precursors and associated health risks, supporting targeted mitigation strategies in emerging urban-industrial environments.

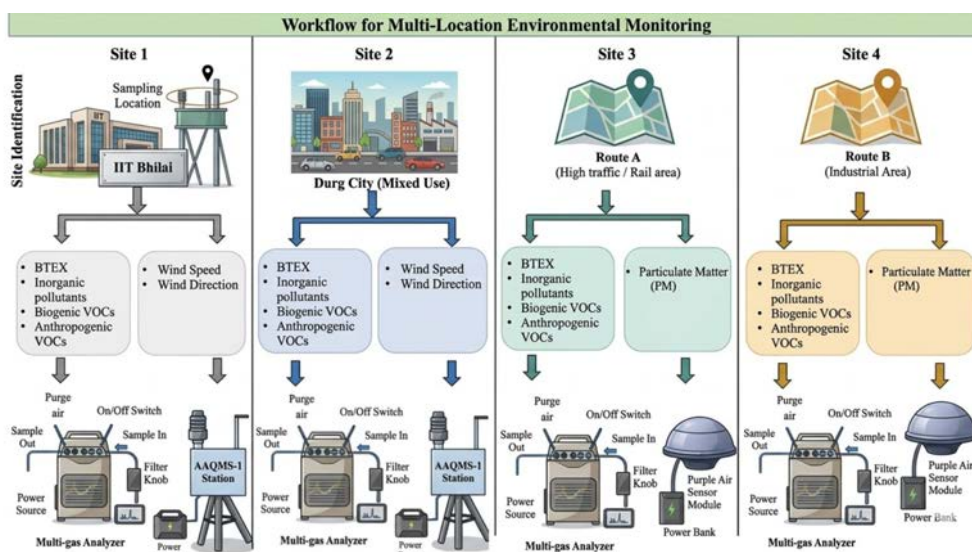


Fig. 1. Schematic representation of the sampling workflow across different micro-environments

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**Thermally stable and spherical silver particles as transfer standard for the calibration of particle number counters**

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Particle number concentration is one of the key physical parameters targeted by several vehicular emissions regulations [3, 4, 5, 6], and ambient air quality guidelines [1, 2]. Different calibration aerosols, such as solid soot, emery oil, and silver particles, are used to calibrate particle number counters in terms of counting efficiency and linearity. However, this leads to a lack of comparability of the results. For calibration facilities it is crucial to have a stable and well-characterized aerosol source that produces solid, inert, insoluble, and thermally stable spherical particles. Silver particles generally satisfy all of these requirements. PTB and Catalytic Instruments are working closely together to optimize the Silver Particle Generator (SPG) to fulfil a broad spectrum of calibration protocols, e.g., for ambient and automotive specifications. The goal is to establish a calibration aerosol that could serve as transfer standard across different communities.

Since October 2025, several tests have been performed at PTB to investigate the long-term stability and day-to-day variability of the SPG. At one operating point the Geometric Mean Diameter (GMD) (at 6 nm) exhibits an apparent long-term stability of approximately 0.5 nm over two months. During this time, fluctuations in particle size were observed to correlate with variations in ambient pressure. In addition, the SPG settings will be optimized to fulfil the CEN-CPC calibration protocol for linearity and counting efficiency testing. An initial CPC calibration test was performed by varying the SPG temperature, demonstrating good stability, a straightforward setup, and minimal time effort. The smooth operation of the SPG is the ability for controlling the heater temperature in precise 1°C steps that allows a stable production of narrow size distributions of spherical silver particles but also enables the ability to shift these distributions.

With this project we will demonstrate the feasibility of producing spherical silver particles beyond 100 nm in diameter. This provides the basis to establish a harmonized calibration standard across different communities. Next to the improvements of the SPG performance, a PTB-developed dilution unit and a coagulation chamber will be optimized to guarantee spherical silver particles at high concentrations even beyond 100 nm.

The project has received funding from PTB's TransMet (Transfer of Metrological Technology) programme, with the objective of fostering the research capabilities and competitive edge of small and medium-sized enterprises (SMEs) in Germany.

[1] Directive (EU) 2024/2881 of the European Parliament and of the Council of 23 October 2024 on ambient air quality and cleaner air for Europe, [2] EN 16976 (2024) Ambient air - Determination of the particle number concentration of atmospheric aerosol; German version, [3] UN Regulation No 168 (2024/211) – Uniform provisions concerning the approval of light duty passenger and commercial vehicles with regards to real driving emissions (RDE), [4] Directive (EU) 2024/2881 of the European Parliament and of the Council of 23 October 2024 on ambient air quality and cleaner air for Europe, [5] Nr. 133 Richtlinie zur Kalibrierung von Abgasmessgeräten, die für die Untersuchung der Abgase von Kraftfahrzeugen nach Nummer 6.8.2 der Anlage VIIIa StVZO eingesetzt werden („AU Geräte Kalibrierrichtlinie“), Absatz 3.2.5. Fassung vom Mai 2021,

[6] PTB-Anforderungen 12.16 „Partikelzähler“ (05/2021). Physikalisch-Technische Bundesanstalt, Braunschweig und Berlin. DOI: <https://doi.org/10.7795/510.20210623>

## Traceable Calibration of MPSS in Fast-Scan Mode: Recommendations for Particle Number Size Measurement at Urban Traffic Hot Spots

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Ultra fine particles (UFPs), owing to their documented health impacts and the Euro 7 revision (lowered particle-size threshold from 23 nm to 10 nm), have emerged as pollutants of primary concern. Consequently, to better represent real-world emissions there is a growing emphasis on measuring solid and total (solid + volatile) UFPs by establishing the monitoring networks strategically located near transport-related emission hotspots. Currently, the UFPs are monitored in Europe as part of particle number and size distribution (PNSD) measurements over the range 10-800 nm by using a mobility particle size spectrometer (MPSS). The associated quality assurance procedures are standardized by CEN/TS 17434:2020, which prescribes validation of a calibrated MPSS (to be deployed for the field measurements) against a reference MPSS (measuring PNSD) and CPC (measuring Particle Number i.e.,  $PN_{CPC}$ ) over this full scan range using ambient aerosol. However, this wide scan range is not ideal for measurements at urban traffic sites where the PNSDs typically peaks around 50-70 nm with negligible number above 300 nm. Specifically, the long scan time required for full-range measurements leads to degraded temporal resolution limiting detection of transient events such as passing of high-emitter vehicles. Moreover, the calibration using ambient aerosol may not represent traffic-related emission characteristics adequately.

To address these gaps, this study put forward an evolved calibration and validation procedure specifically designed for the PNSDs measurements at urban traffic sites. For validation and compliance with the existing norms, the performance of a candidate MPSS (the reference MPSS at PTB) is evaluated as per this modified procedure. The MPSS is evaluated under fast-scan mode (1 minute scan time and scan range 10-300 nm) using the lab generated solid/total soot PNSDs with varying operating points (Geometric Mean Diameters  $\sim$  30-90 nm and  $PN_{CPC}$ : 10,000 – 90,000  $cm^{-3}$ ). Moreover, a comparatively traceable and flexible uncertainty budget scheme (incorporating uncertainty dependency on the parameters of test aerosol) is proposed based on existing literature and the experimental observations.

The repeated long-term DMA calibrations results confirmed that the mobility diameters measurements by reference MPSS are reproducible to be within  $\pm 3$  % of the certified PSL diameters. Moreover, the cumulative PN measured by the reference MPSS ( $PN_{MPSS}$ ) remained within  $\pm 5$ % of the  $PN_{CPC}$  measured by a parallelly running reference CPC. The uncertainty limits of the reference MPSS for particle number (PN) per size bin at a nominal PNSD ( $PN_{CPC} \approx 30,000$  and  $D_{p, MEAN} \approx 60$  nm, approx. representative of traffic site conditions) were also within the CEN ( $\leq 50\%$  below 20 nm,  $\leq 10\%$  in the range 20-200 nm, and  $\leq 20\%$  above 200 nm) criteria. Above findings implies that the reference MPSS fulfils all the existing CEN criteria for a reference MPSS confirming its usability for the subsequent validation of the test MPSS under fast-scan mode and lab generated soot particles. Consequently, a modified MPSS calibration procedure has been implemented at PTB, featuring a 1-minute scan time, a scan range of 10–300 nm, and soot particles as the test aerosol. Furthermore, the investigations in current study highlights that the uncertainties in PNSD measurements by a MPSS can be higher than the CEN criteria under specific conditions such as DMA operating with high-voltage negative polarity or when  $PN_{CPC}$  are low. Consequently, a modified criteria in the form of well-established  $E_n$ -score metric is proposed for validation of test MPSS calibrated at PTB.