Measurement and evaluation of ultra-fine particle emissions from laser printers

T. Salthammer [1,2], M. Wensing [1],
T. Schripp [1], E. Uhde [1],
C. He [2], P. McGarry [2], R Jayaratne [2],
G. Johnson [2], H. Wang [2], T. Bostrom [2],
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2) QUT, Brisbane, Australia

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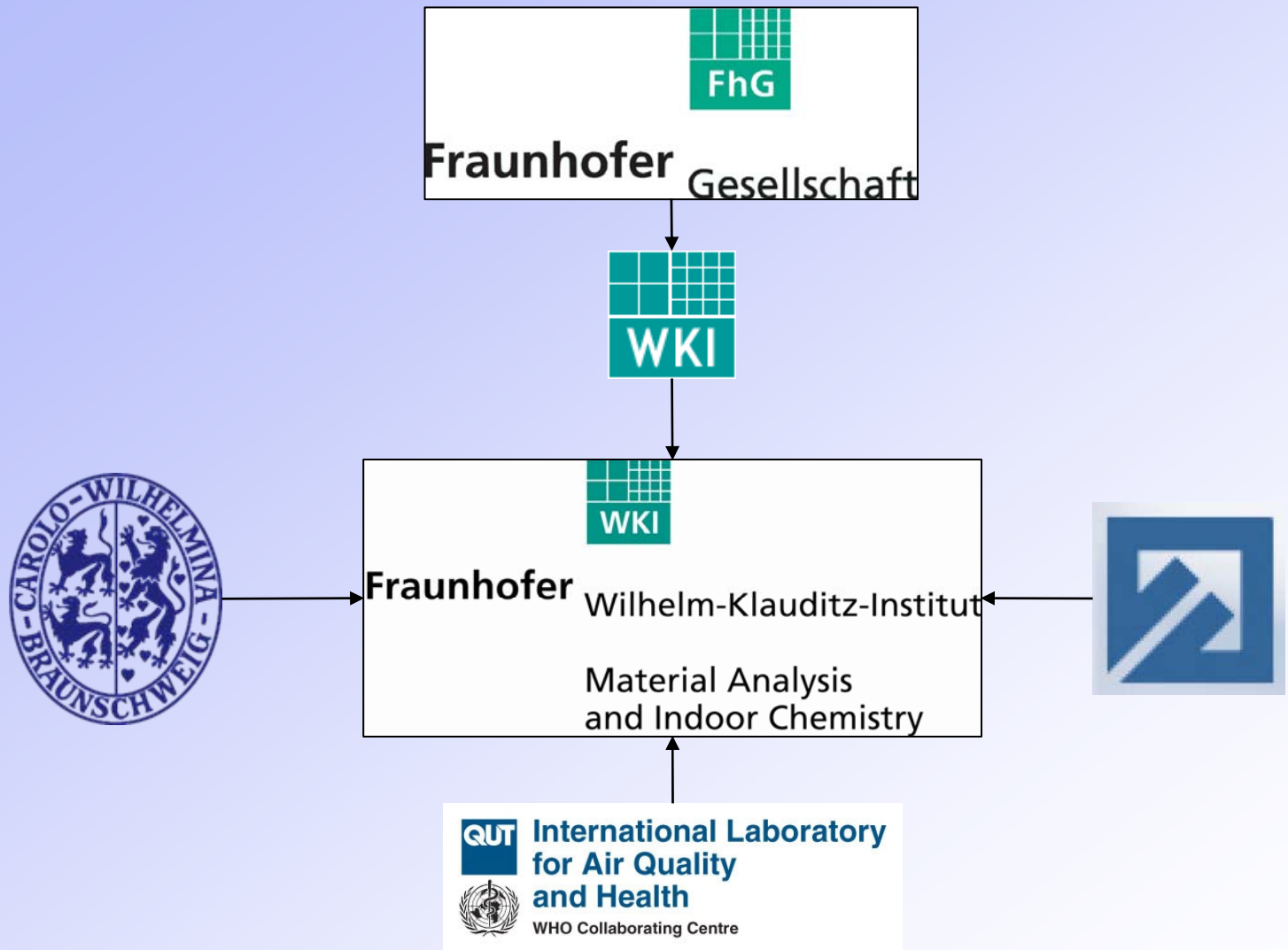
Material Analysis
and Indoor Chemistry

WKI: Institute location


FhG
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WKI
WKI
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Material Analysis
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CAROLO-WILHELMINA BRAUNSCHWEIG
QUT International Laboratory for Air Quality and Health
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Scientific Collaboration

Waseda University
Tokyo, 1996 - 2001

DTU, Lyngby
Guest Professor
2006 - 2007

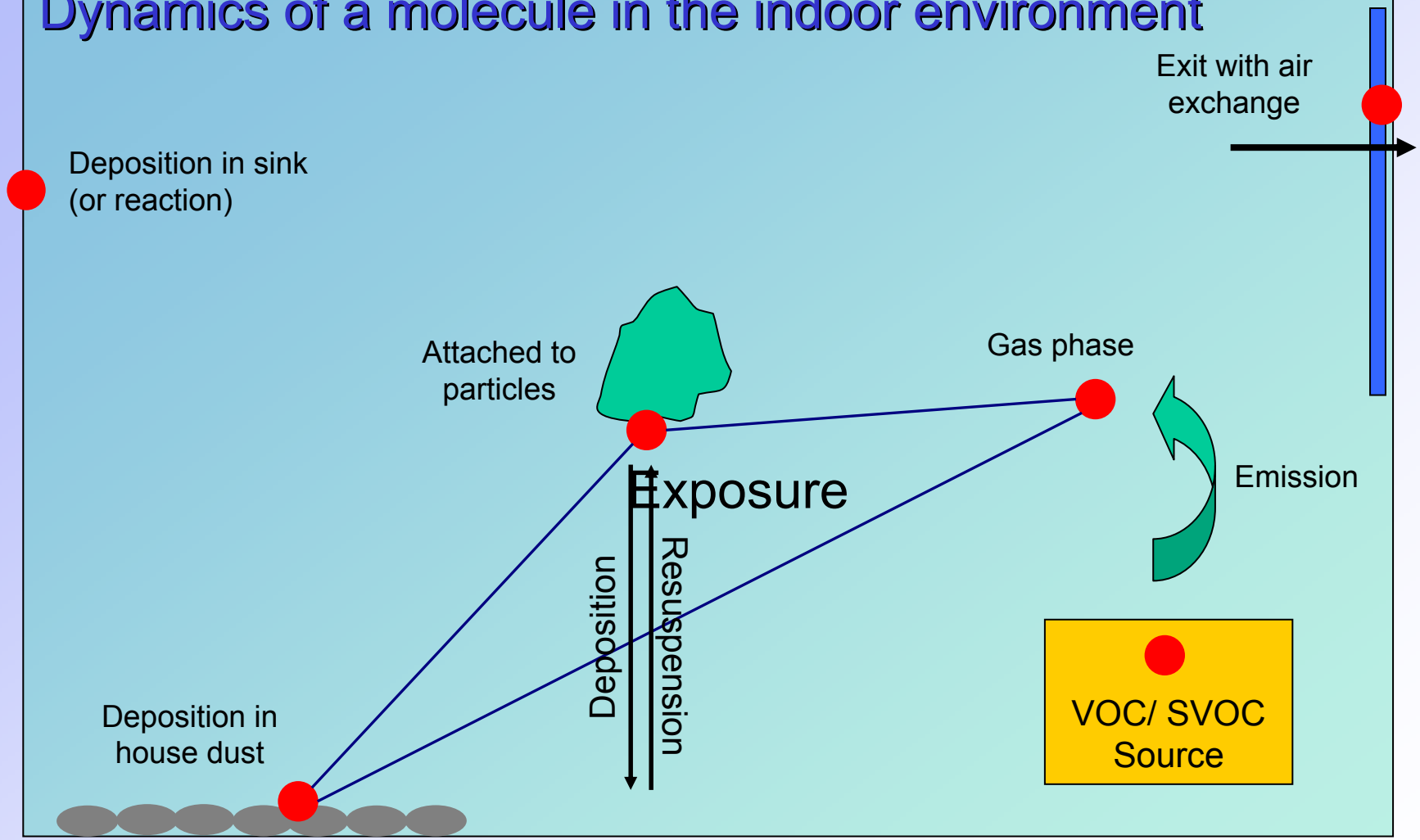
QUT Brisbane
since 2001,
Adjunct Professor
since 2007

Tsinghua University
Beijing
Guest Professor 2007

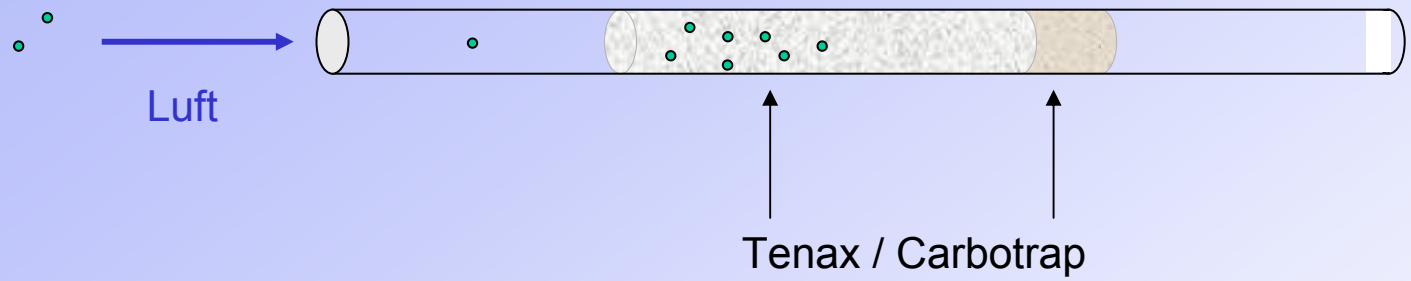
University of Kuopio
Lecturer 2005

VirginiaTech

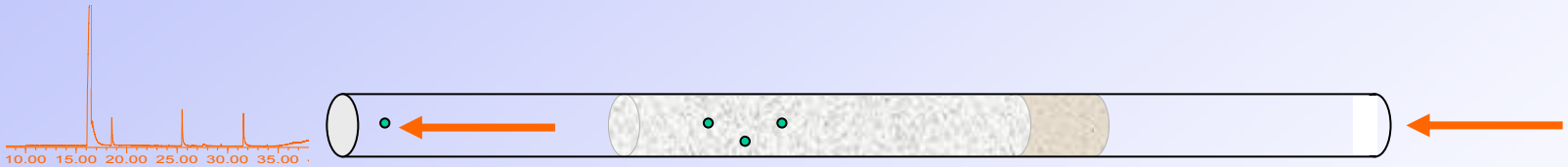
Dynamics of a molecule in the indoor environment



Thermodesorptions GC/MS



Thermal Desorption (300 °C)



GC/MS Standards 2007 in WKI

available GC/MS Standards: 910

used in 2007: 542

Frequently used GC-Standards

- Benzene
- Toluene
- 2-Chlornaphthalene
- Ethyldiglycol
- Cyclohexane
- Chlorobenzene
- 4-Phenylcyclohexene
- Ethylenglykolmonomethylether
- Ethylbenzene
- Xylene (o-, m-, p-)
- 1-Chloronaphthalene
- Ethylglykolacetate
- 2-Phenoxyethanol
- Pentanal
- trans-2-Decenal
- Ethoxypropylacetat
- n-Hexane
- Benzaldehyde
- Acetone
- Methylacetate
- Hexanal
- α-Pinene
- Limonene
- Nonanal
- Styrene
- 2-Butanone

Online-Methods

- **Photoacustics**

  → CO_2, $TVOC_{PAS}$ (calibrations vs. propane)

- **Chemoluminescence**

  → NO, NO_2

- **UV/Fluorescence**

  → Ozone

- **Proton-Reaction-Mass-Spectrometry (PTR-MS)**

  → Selective mass monitoring [M+1]

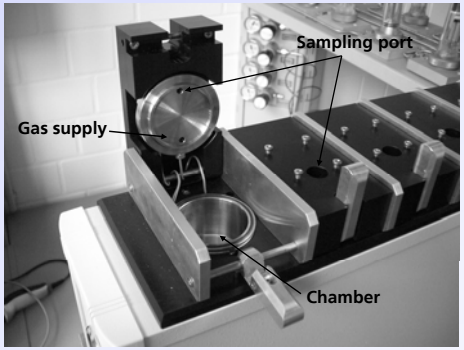
- **Online-Derivatisation**

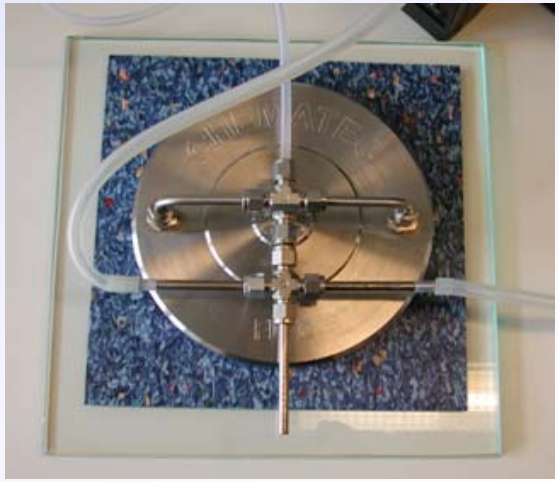
  → Formaldehyde (Acetylacetone-Method)

- **Particle counting methods**

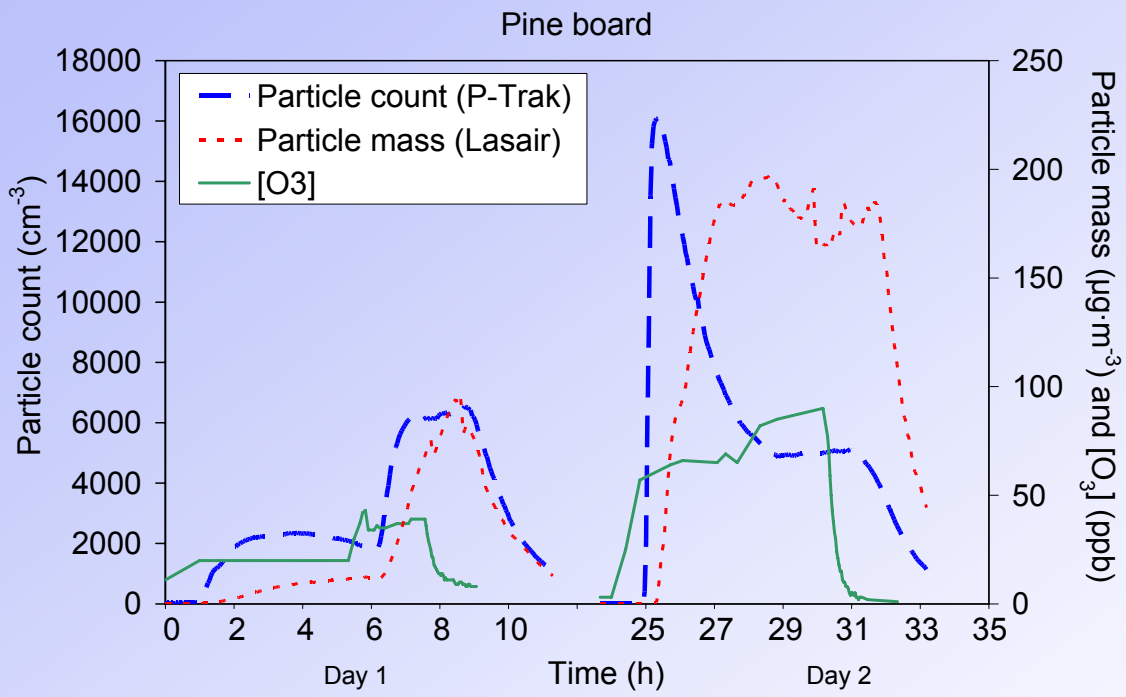
  → Size distribution

WEISS


Sampling port
Gas supply
Chamber



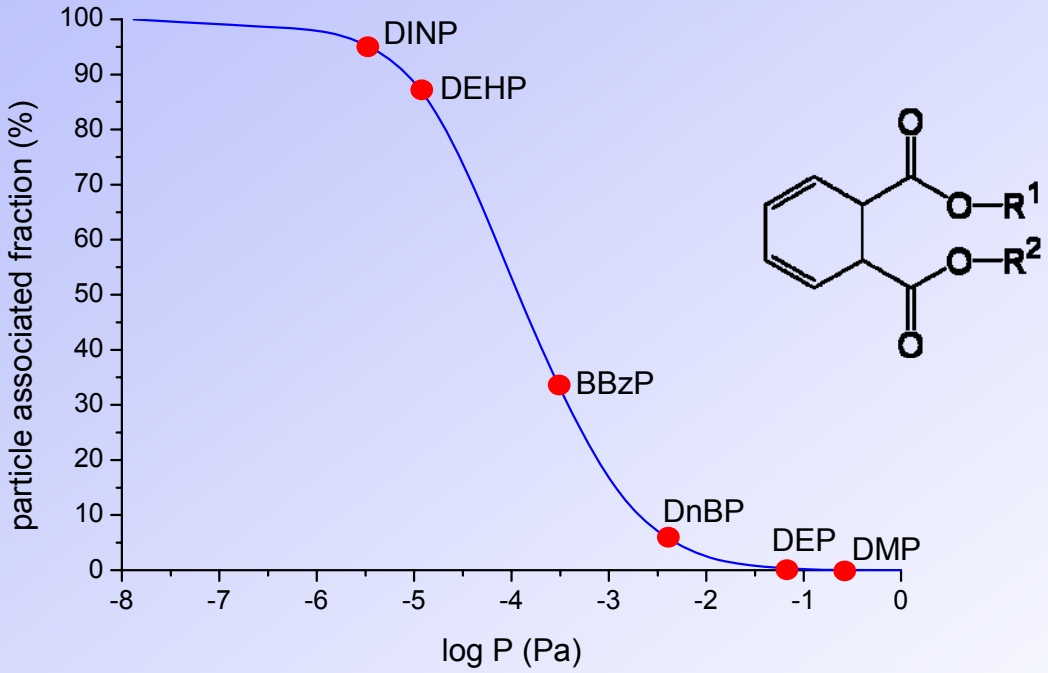
Research



Building product terpene/ozone-reactions and particle formation

Toftum et al. (2008) Atmospheric Environment, available online

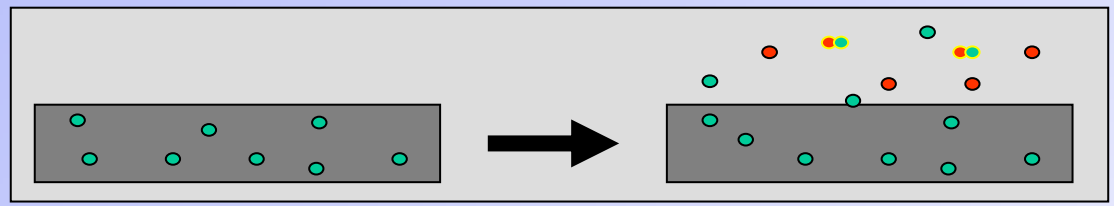
Research

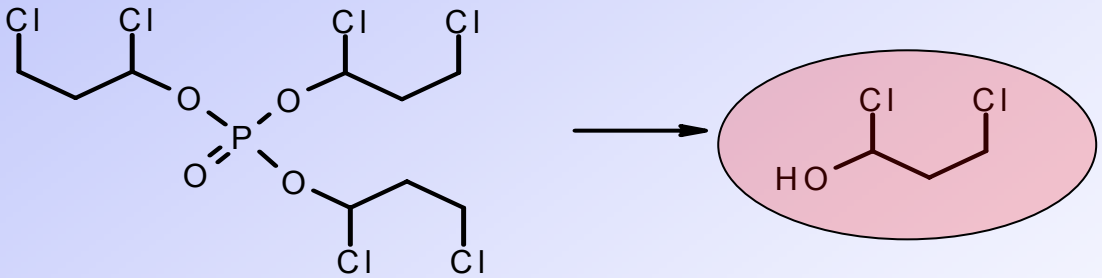


Gas-/Particle distribution of SVOCs

Weschler et al. (2008) Atmospheric Environment, 42, 1449

Research



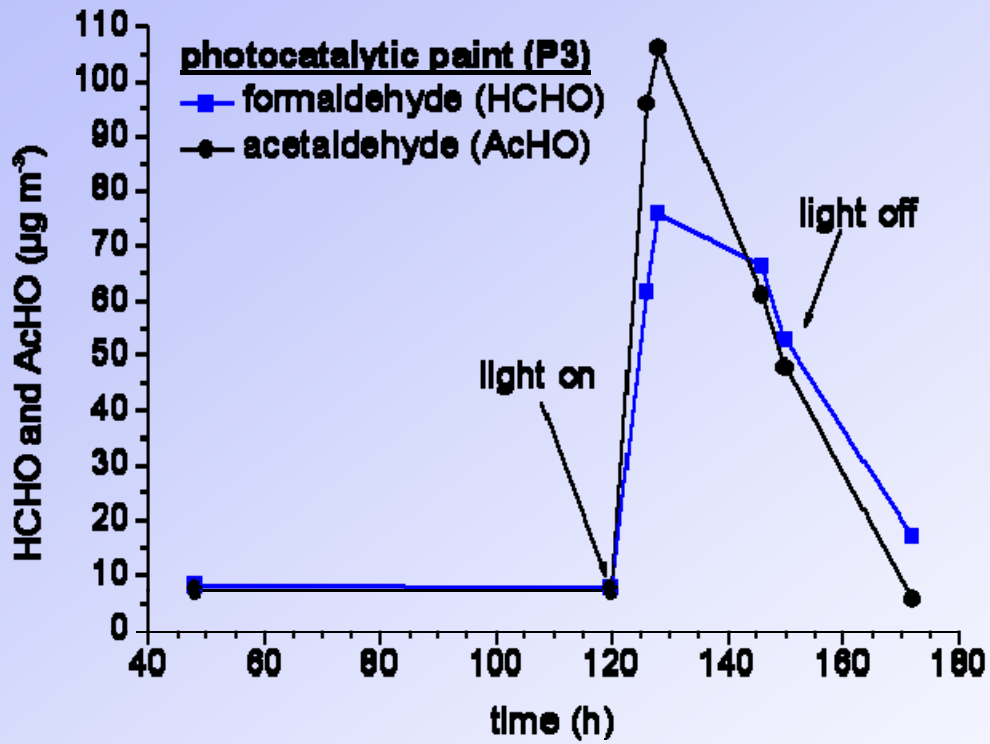


Degradation of TDCPP

Indoor Chemistry

Uhde and Salthammer (2007), Atmospheric Environment, 41, 3111

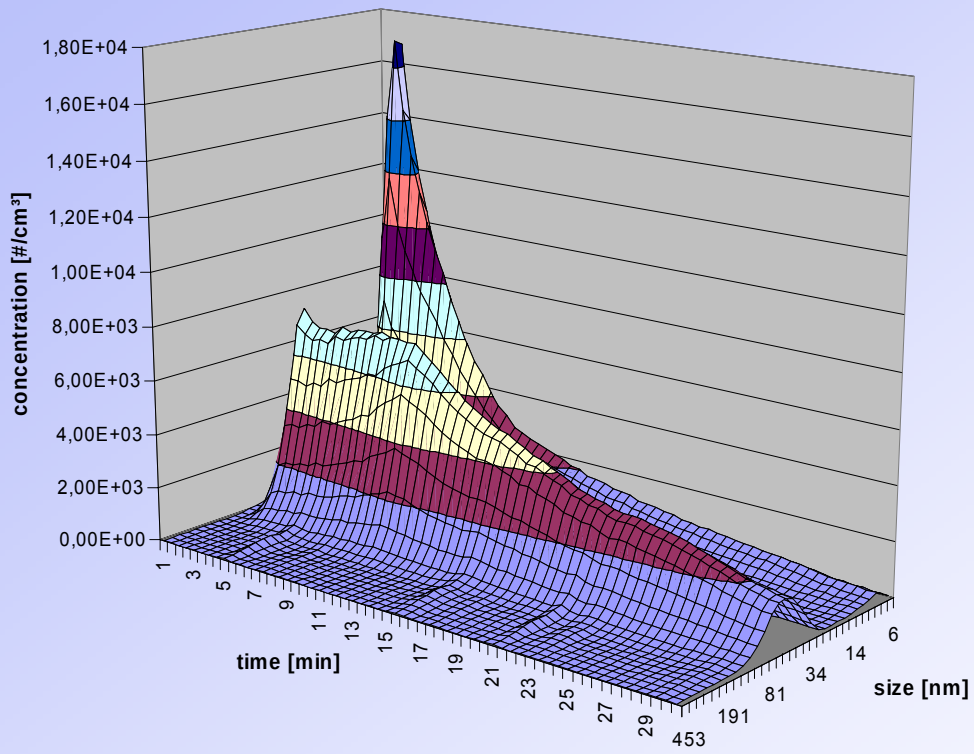
Research



Photocatalytic reaction on indoor wall paint

Salthammer and Fuhrmann (2007), ES&T, 41, 6573

Research



Emission of nanoparticles from electronic equipment

Schripp et al. (2008), ES&T, 4338

Wensing et al. (2008) Sci. Tot. Environ., available online

Research

Emission of formaldehyde from mineral wool

Salthammer and Mentese (2008), Chemosphere, available online

Environ. Sci. Technol. **2007**, *41*, 6039–6045

Particle Emission Characteristics of Office Printers

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LIDIA MORAWSKA,[*,†] AND LEN TAPLIN[‡]
International Laboratory for Air Quality and Health, Queensland University of Technology, Brisbane, QLD 4001, Australia, and Queensland Department of Public Works, Brisbane, QLD 4001, Australia

Printer particle emissions add up

When researchers in Australia discovered that particulate matter levels were five times higher during the workday inside a non-smoking office building than outside near a freeway, they looked for indoor culprits. After testing more than 50 printers throughout the building, they found that particle emissions varied depending on the type and age of the printer. In one case, standing near a working printer was much like standing next to a cigarette smoker. The results are described in new research published in *ES&T* (pp 6039–6045).

Lidia Morawska of the Queensland University of Technology (Australia) and colleagues monitored printers of numerous makes and models with printer toner cartridges at various stages of use—from new to depleted. They also tested several representative printers in an experimental chamber to carefully track the concentrations and distributions of different size particles from high to low emitters.

Only a handful of studies on modern printers exist in the literature, says Morawska. Further research should include performance tests of multiple printers of the same model and make. Her team intends to follow up with more studies that analyze the chemistry of the particles, which will also have implications for health impacts.

Ten years ago, the U.S. EPA evaluated printers and photocopiers, but these data are now "interesting historical information," comments Charles Weschler of the University of Medicine and Dentistry of New Jersey. Printers have changed a lot since then: most have shifted to ink jets and other technology, and dramatic improvements have changed cartridges and even "the nature of toner itself," Weschler says. These new data are only the first steps in getting modern assessments of exposure to printer particulate matter, he says.

LIDIA MORAWSKA

This printer in a Brisbane, Australia, office building contributed to higher particulate matter concentrations indoors than those outside near a freeway.

Weschler notes that the team found a wide range of emissions levels. "Emissions may be highest with a brand-new cartridge, just opened," he speculates, when the solvent is highest and the toner is "ripe". But even with one printer, such as the one the team observed that was particularly offensive, "if we were to look at 10,000 printers, which isn't realistic, how common is that one bad apple?" Weschler asks. Perhaps not very, he suggests, considering that companies themselves conduct testing to meet certain criteria, like Germany's Blue Angel certification, introduced in 1977 to certify eco-friendly products. HP reports that it tests a new inkjet or laser printer for emissions of primary volatile organic compounds, ozone, and dust in test chambers before rolling it out on the market.

Erik Uhde of the Fraunhofer Institute for Wood Research (Wilhelm Klauditz Institute) in Germany says that printers even within a manufacturer's series can vary, depending on where the parts were purchased, among other factors. "The sources of particulate matter in the printer are not completely clear," he says, and toner may not have as much impact as suspected.

Nevertheless, the research underscores the importance of printer emissions when considering human exposure to particulate matter. "Most of your time is [spent] indoors at the office or indoors at home," Weschler says, so "most of your exposure is indoors, either to chemicals that originated indoors or that are brought in by ventilation."

—NAOMI LUBICK

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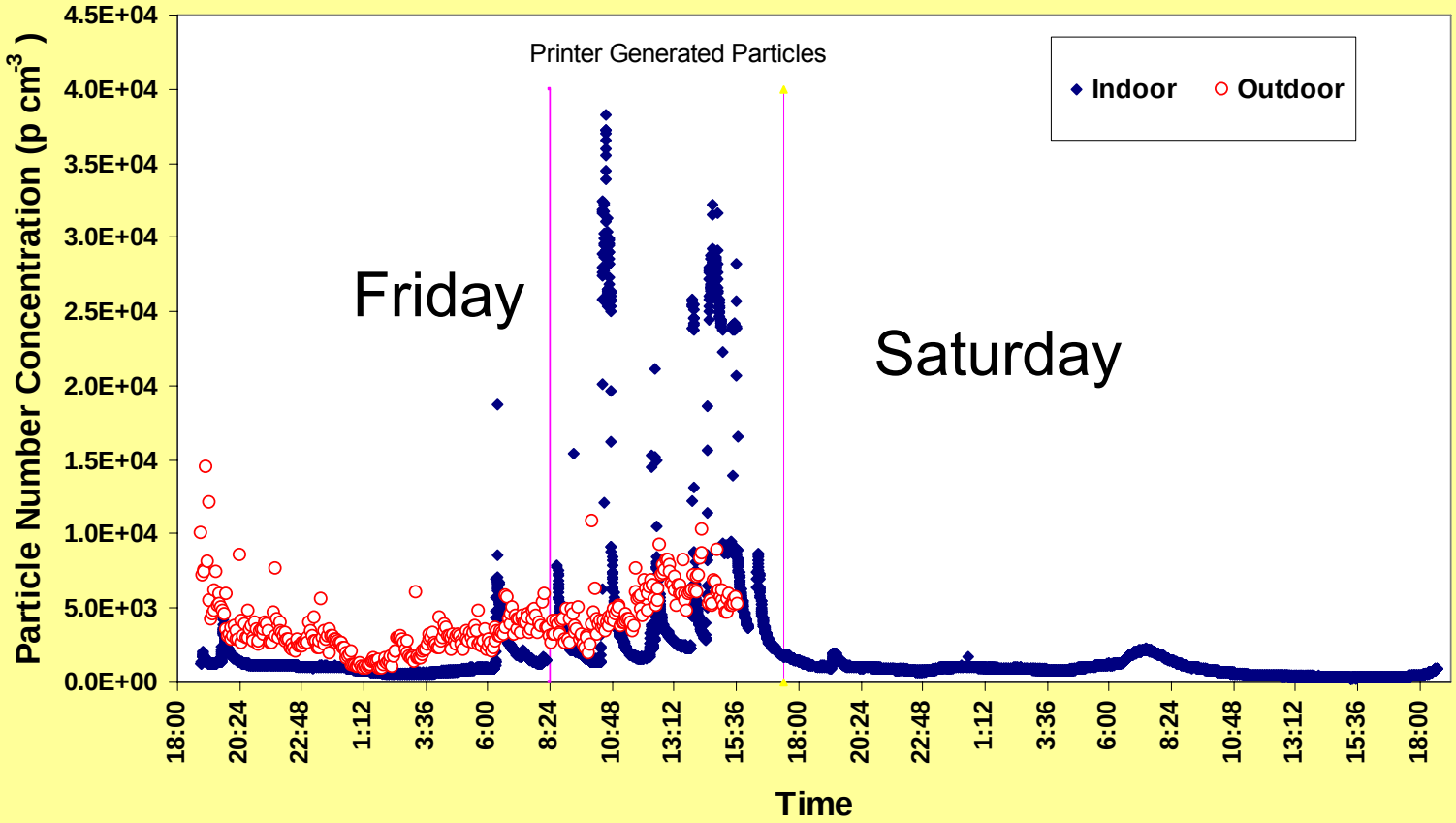
Particle concentrations in a Brisbane office room



He et al. (2007) ES&T, 41, 6039

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ROGERS
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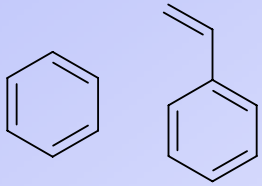
IT'S GETTING CROWDED OUT HERE!
SMOKING AREA
LASER PRINTER
MICRO-WAVE POPCORN

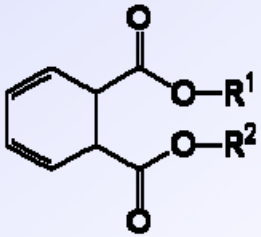
Emissions from Electronic Devices

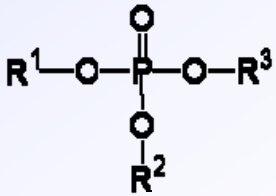
- Particle Number Concentration
- Total Particle Number
- Particle Mass
- Particle Size Distribution
- True Particle Emission Rate (SER)
- Particle Deposition
- Particle Composition

Particles



VOCs





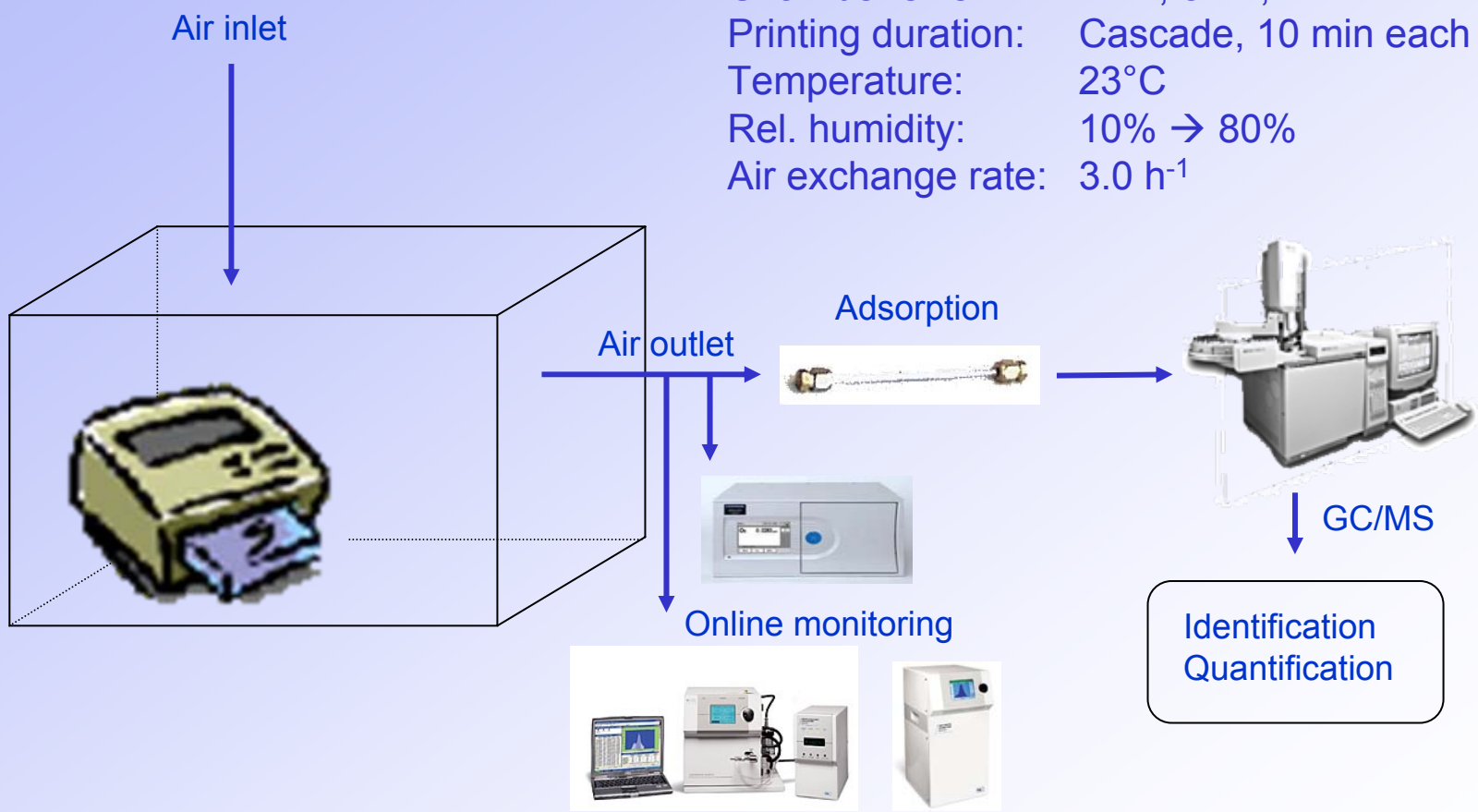
SVOCs

O_3 Ozone

Destaillats et al. (2008) AE, 42, 1371

Performance of a chamber emission test

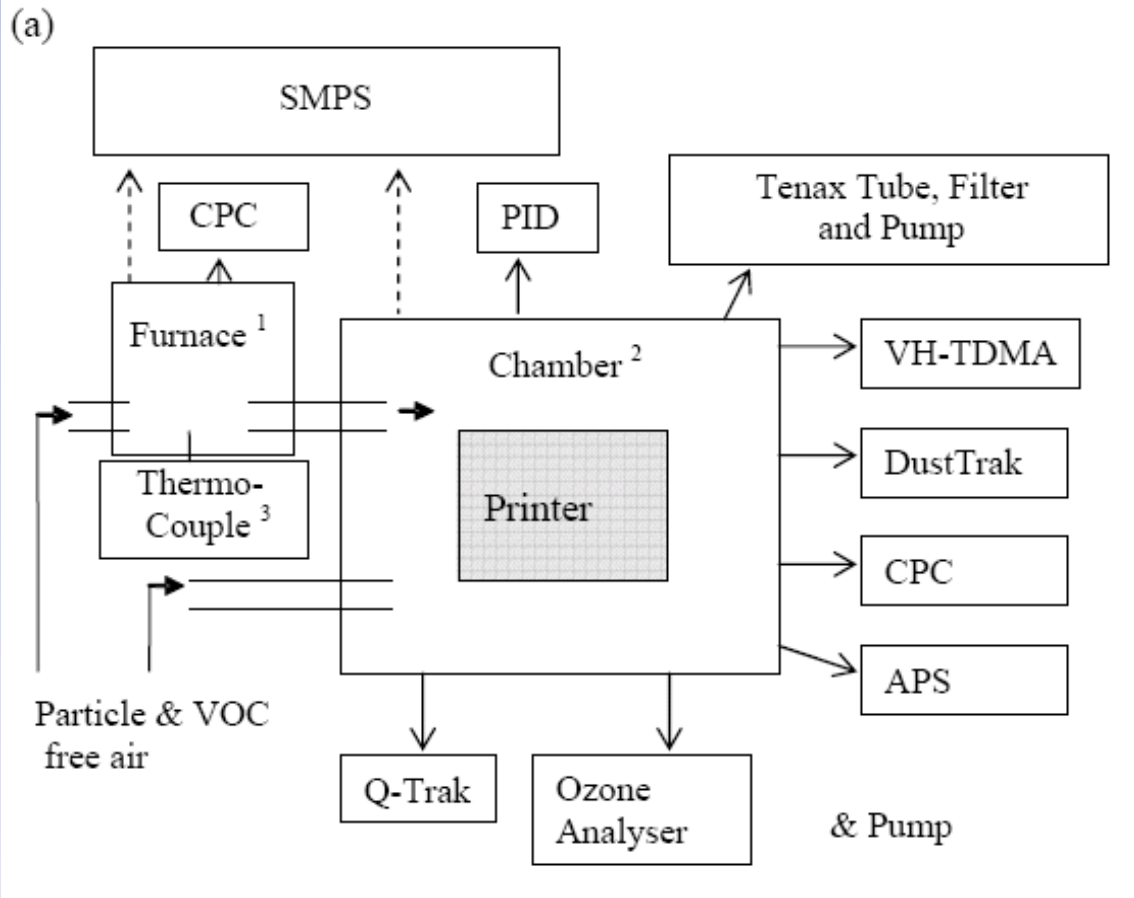
Loading factor:	1 unit/chamber
Chamber size:	1 m³; 8 m³, 24 m³
Printing duration:	Cascade, 10 min each
Temperature:	23°C
Rel. humidity:	10% → 80%
Air exchange rate:	3.0 h^{-1}



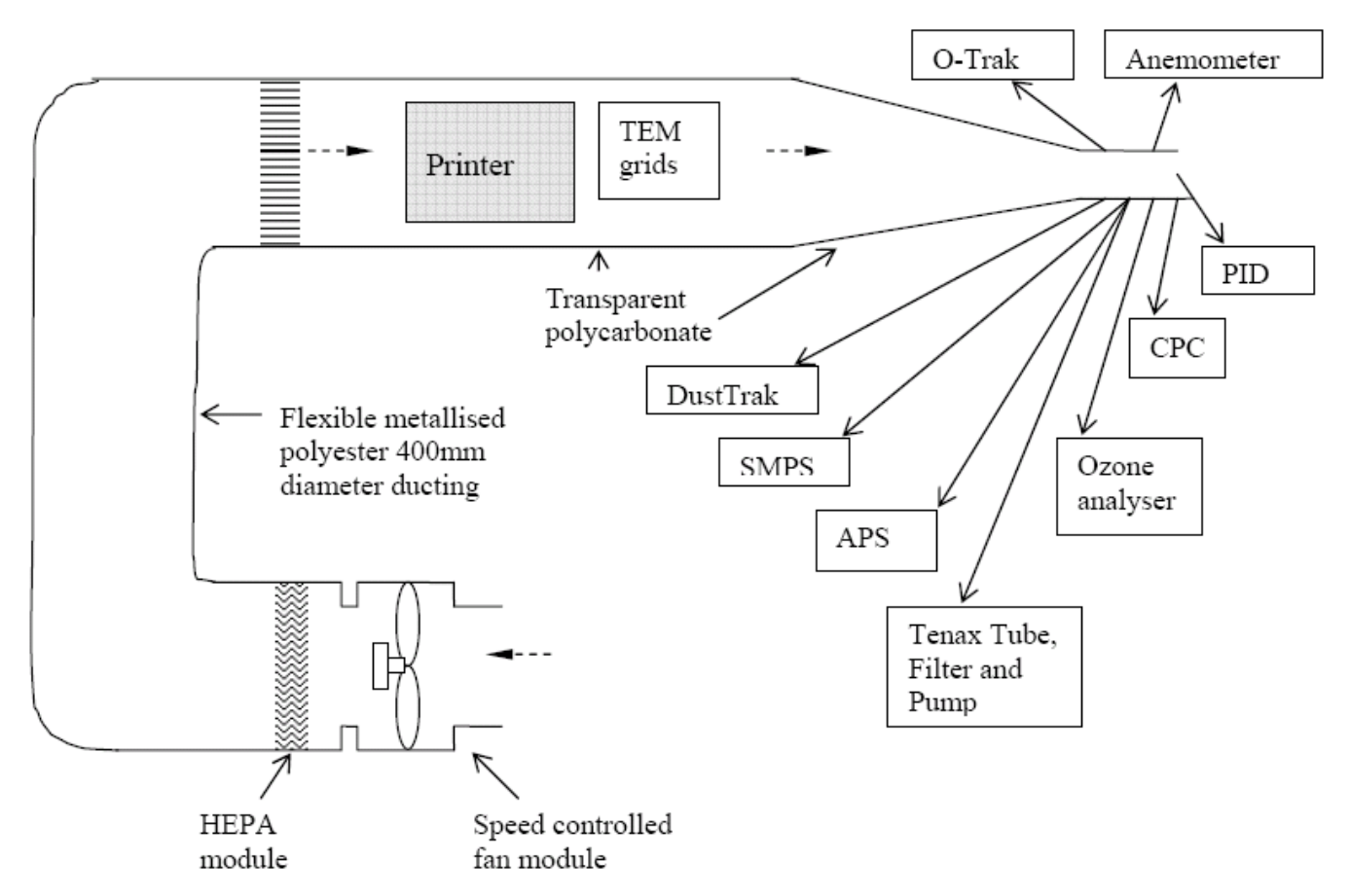
WKI 1 m³ chamber for printer particle emission testing

Fast Mobility Particle Sizer (FMPS)
5.6 – 560 nm
32 channels
time resolution: 1 s

Chamber experiments at QUT

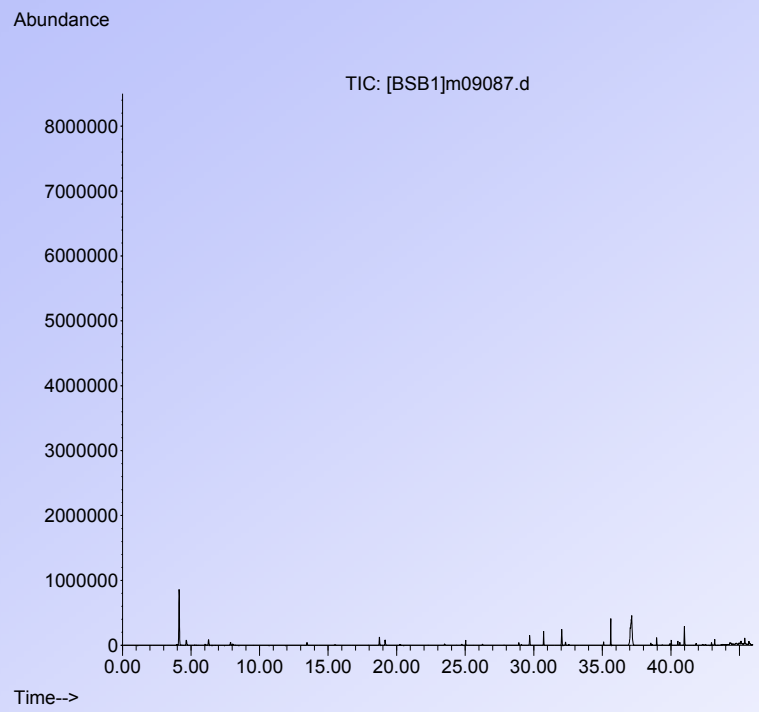


Flow tunnel experiments at QUT

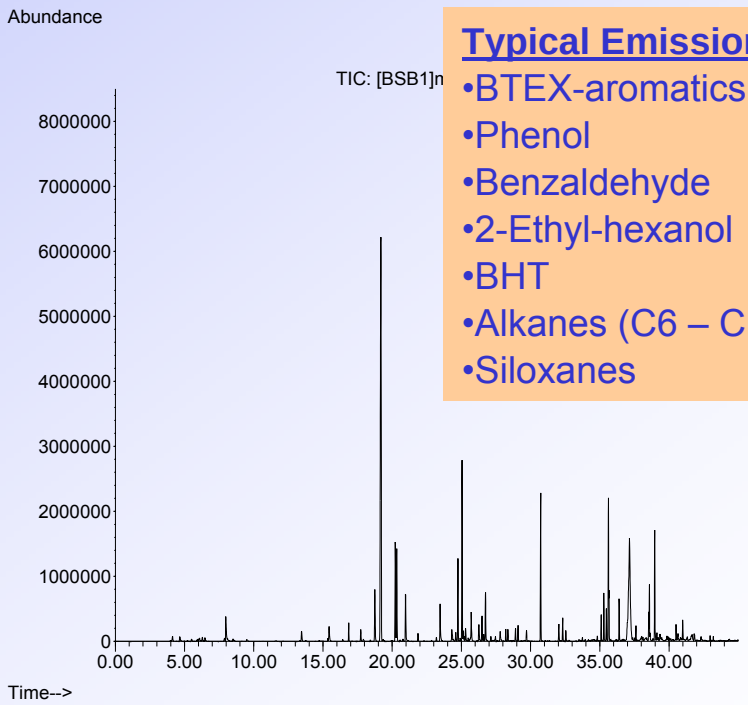


VOC-Emissions from a laser printer

Standby



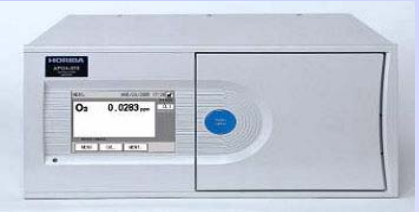
Printing



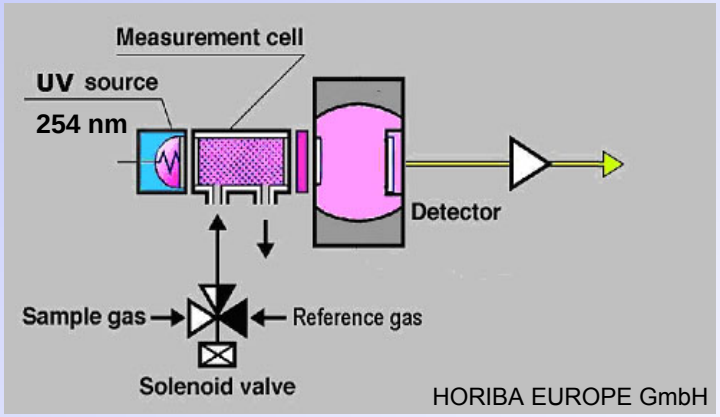
Typical Emissions

- BTEX-aromatics
- Phenol
- Benzaldehyde
- 2-Ethyl-hexanol
- BHT
- Alkanes (C6 – C14)
- Siloxanes

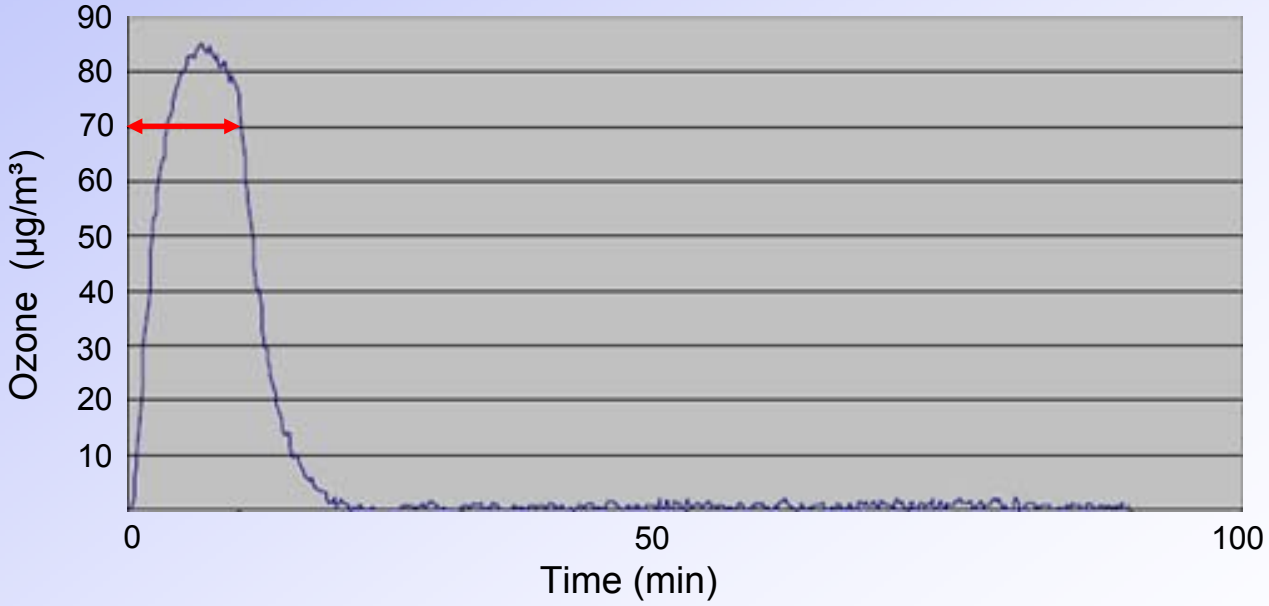
Measuring Ozone using UV-Absorption (254 nm)



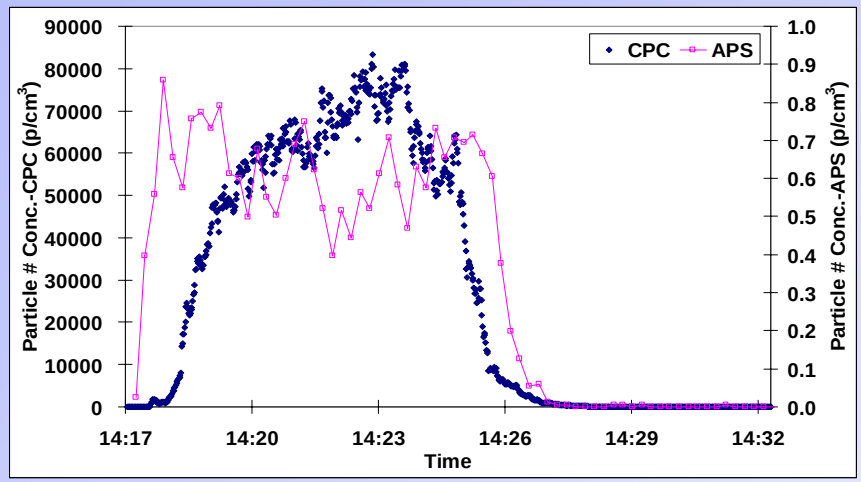
HORIBA EUROPE GmbH

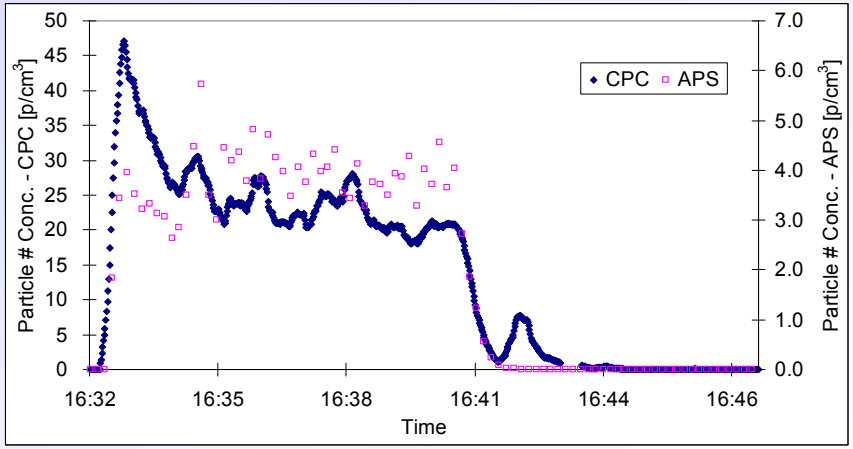


HORIBA EUROPE GmbH

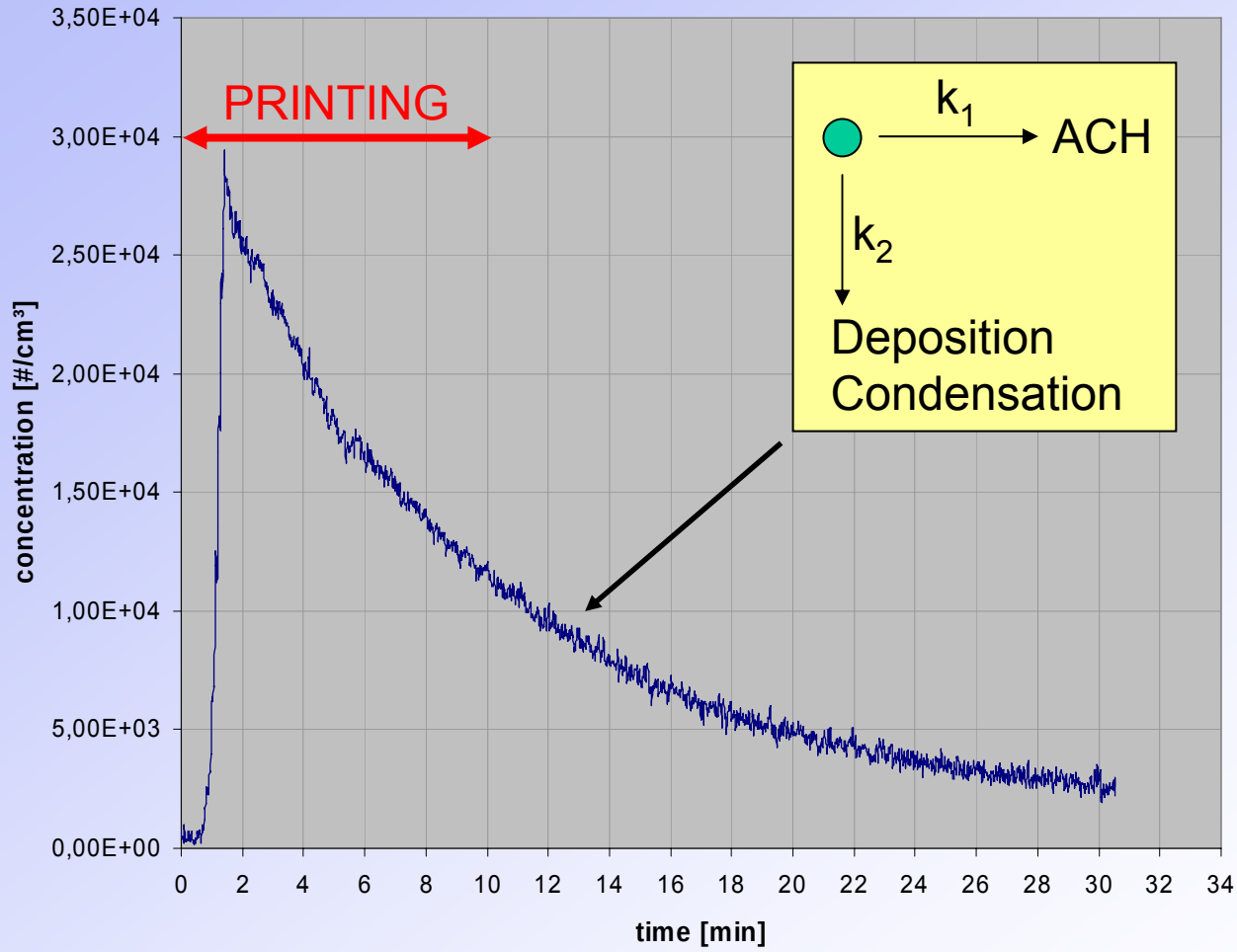


Emissions in flow tunnel (expriments at QUT)





Sum of particle number concentration (5.6-560 nm) vs. time (1 m³ chamber)

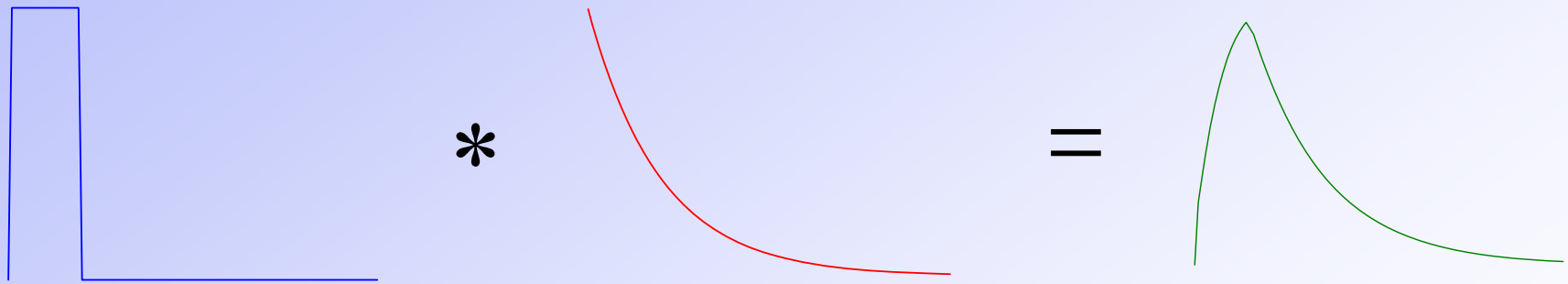


Calculation of the true printer emission rate (SER)

True Particle Emission Rate SER(t)

Chamber Response Function $D(t) = e^{-kt}$

Experimental Concentration Curve C(t)



Convolution →

← Deconvolution

Schripp et al. (2008) ES&T, 42, 4338

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The Convolution Integral

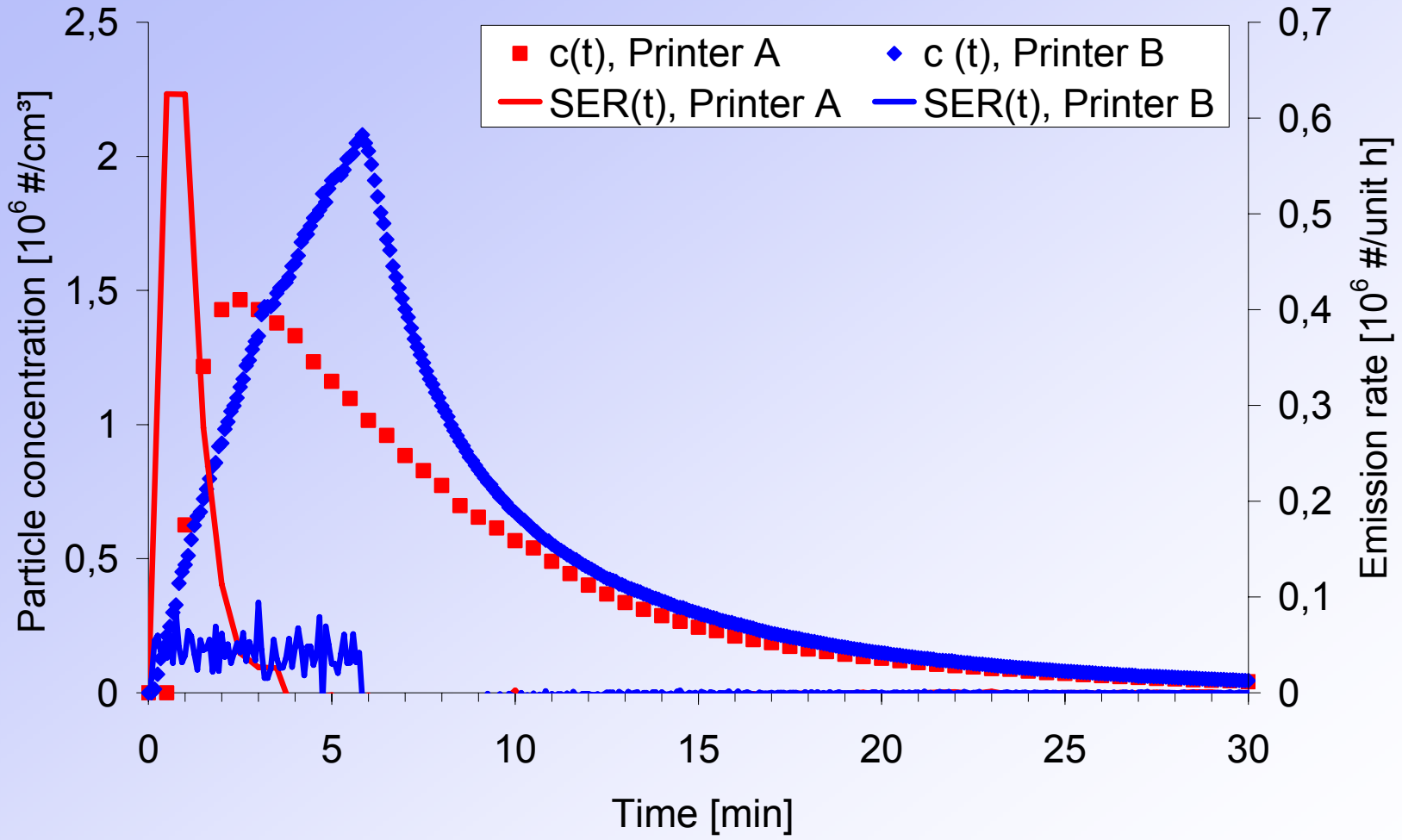
$$c(t) = [L \cdot SER(t)] * D(t) = \int_0^t [L \cdot SER(\tau)] \cdot D(t-\tau)\, d\tau$$

numerical solution
with $D(t) = e^{-kt}$ ($k = k_1 + k_2$)

$$SER_u(t) = \frac{c(t) - c(t-\Delta t) \cdot e^{-k \cdot \Delta t}}{L \cdot \Delta t \cdot e^{-k \cdot \Delta t}}$$

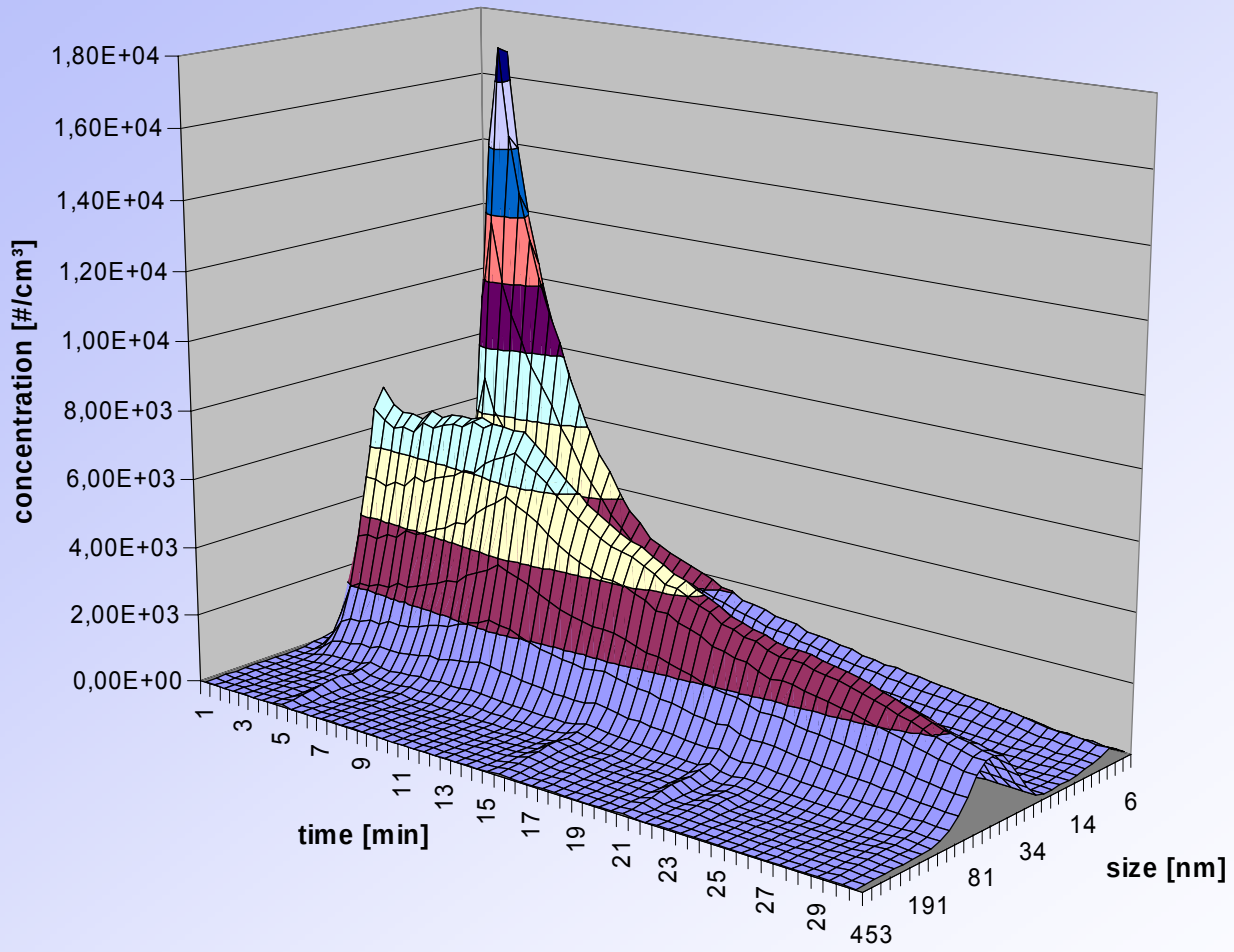
Schripp et al. (2008) ES&T, 42, 4338

Calculation of the Specific Emission Rate SER – experimental data

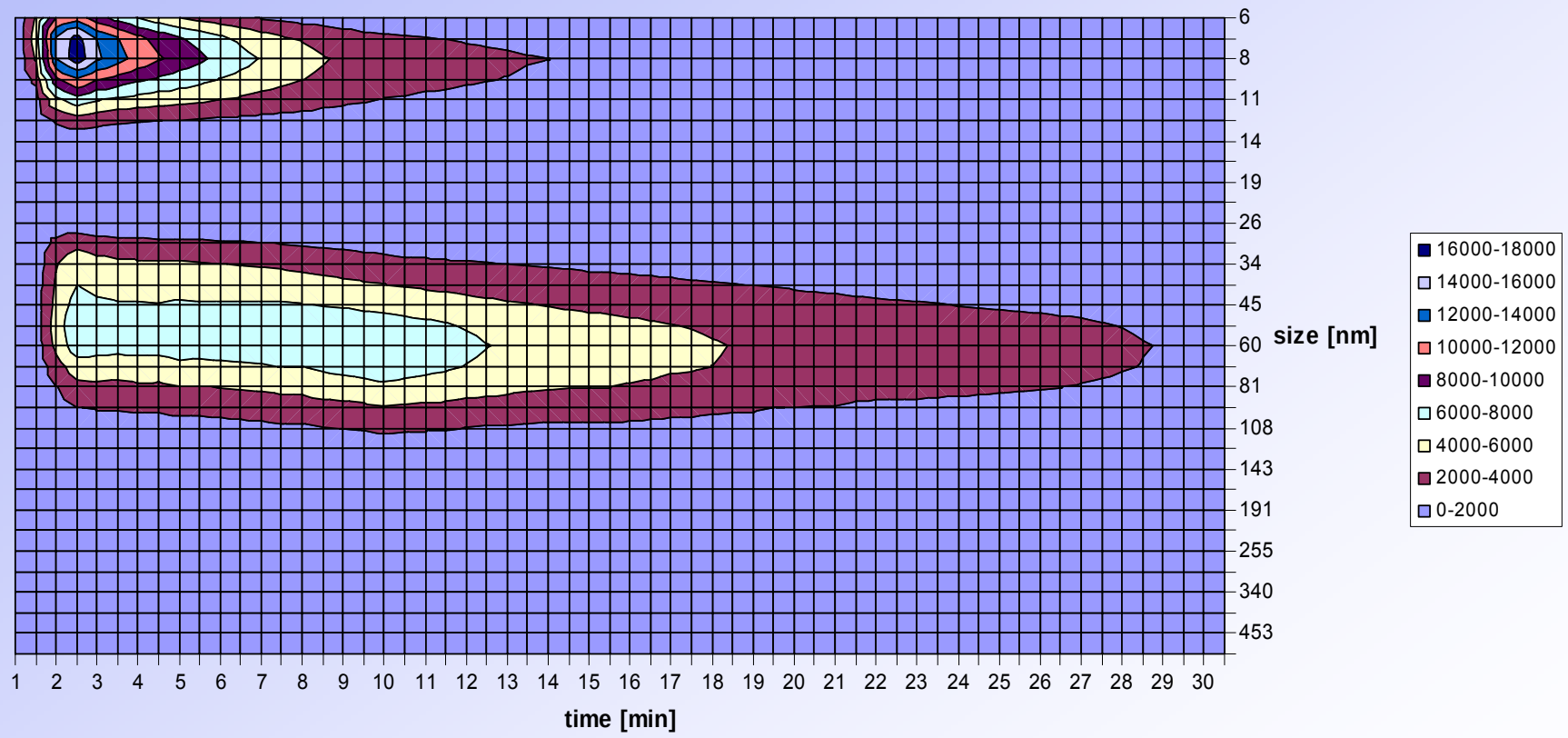


Schripp et al. (2008) ES&T, 42, 4338

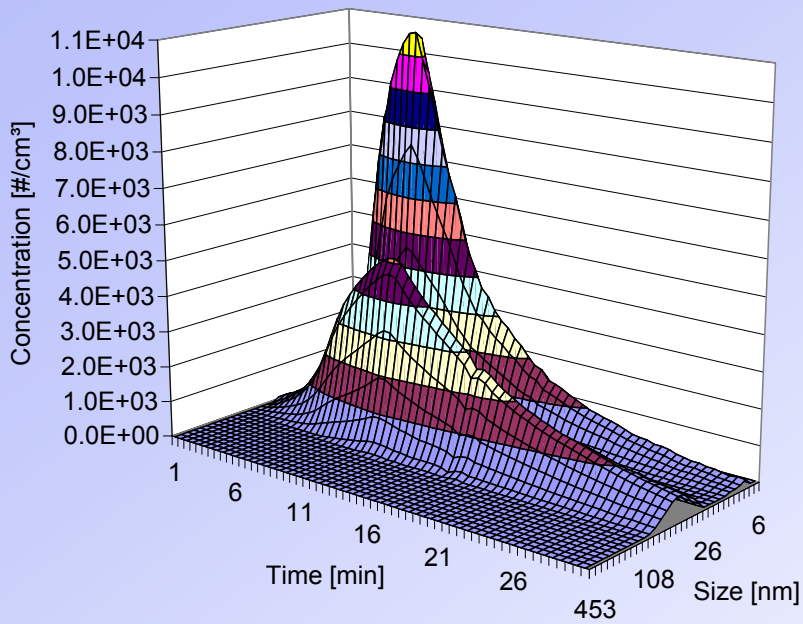
Hardcopy device: particle number concentration vs. particle size and time (25 m³ chamber)

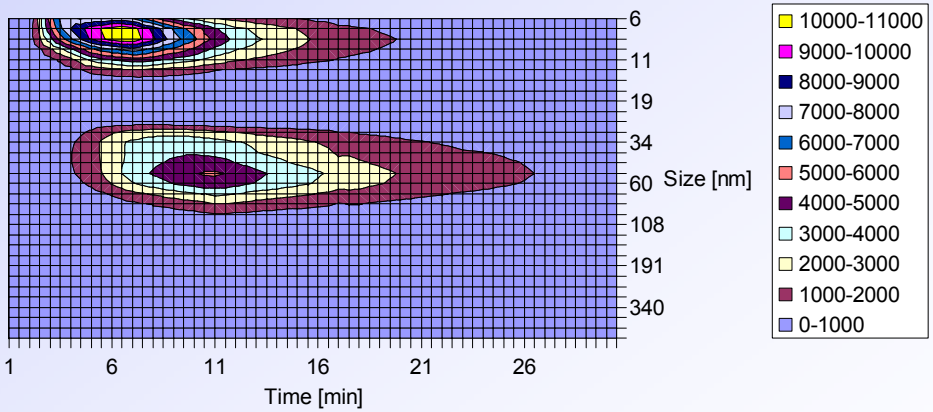


Hardcopy Device: particle number concentration vs. particle size and time (25 m³ chamber)



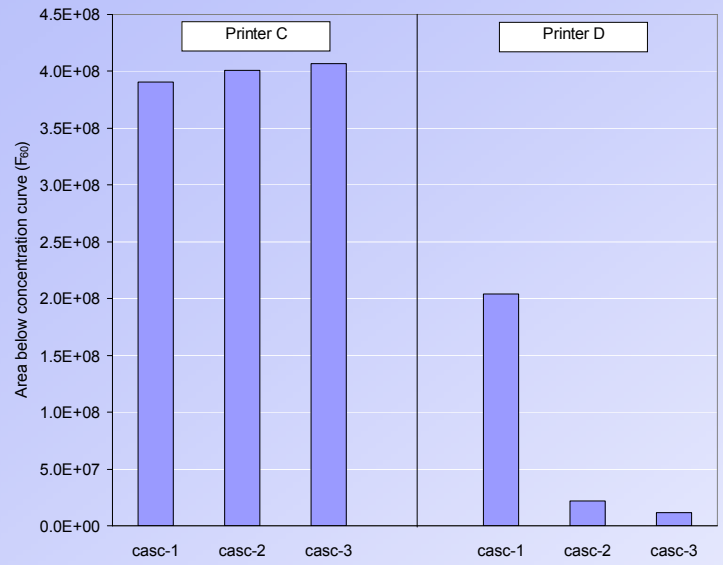
Laser printer UFP emission – FMPS results particle number concentration vs. particle size and time bimodal size distribution



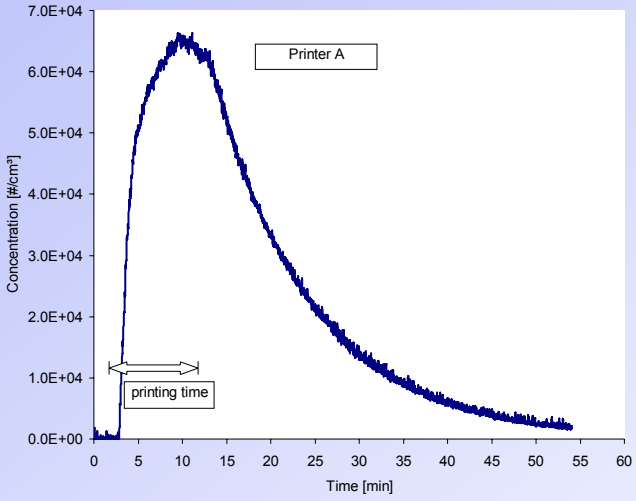


Wensing et al. (2008) Sci. Tot. Environ., available online

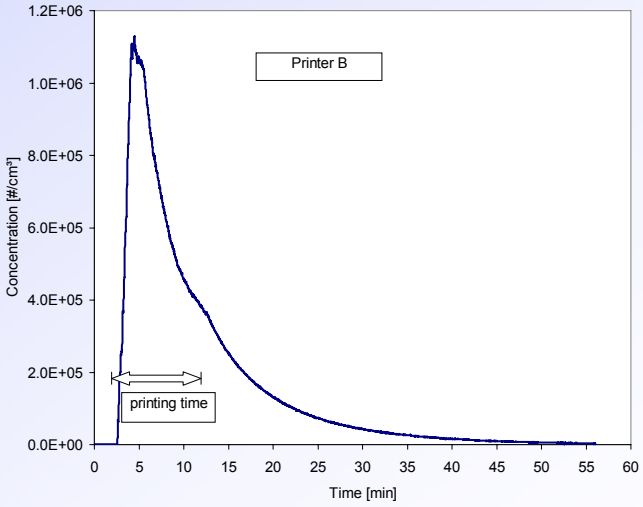
print-to-print repeatable



print-to-print decreasing



constant emitter



initial burst emitter

Wensing et al. (2008) Sci. Tot. Environ., available online

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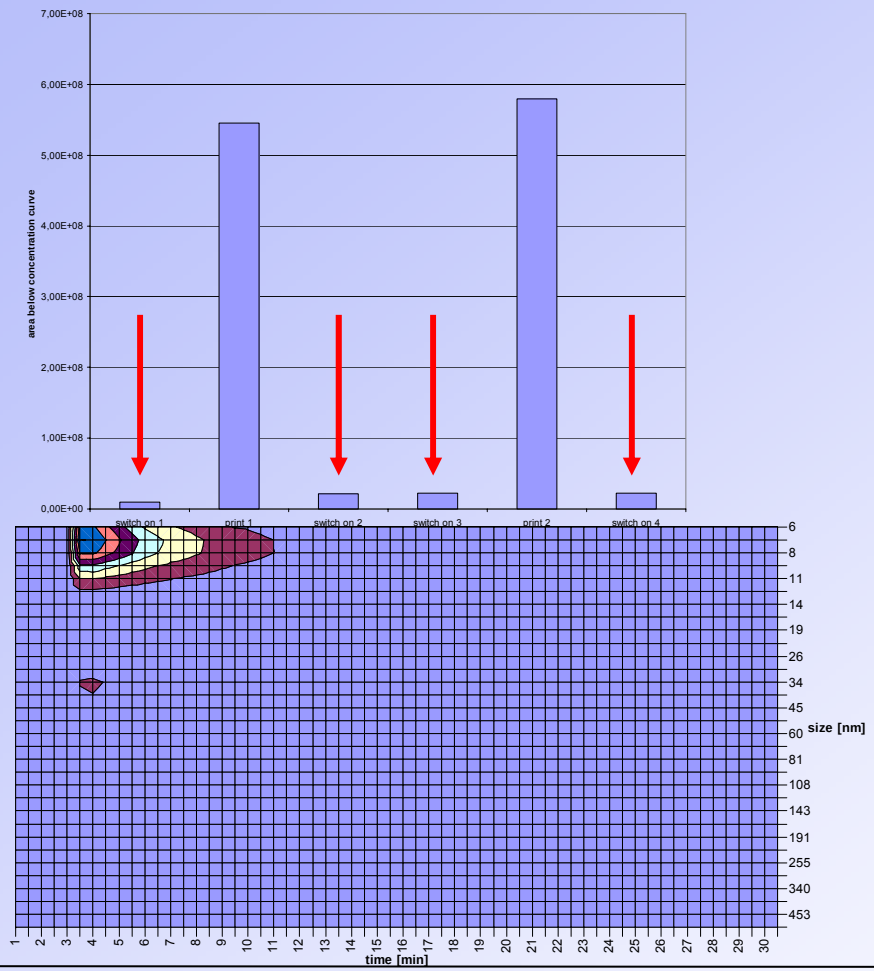
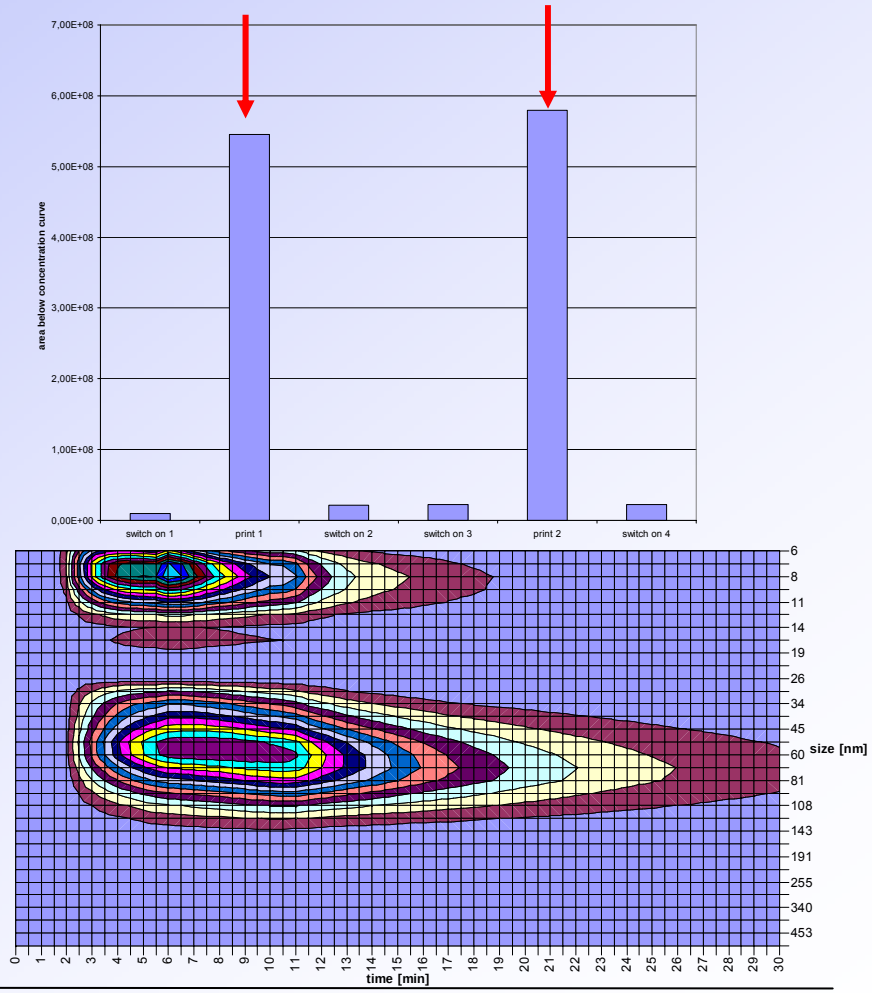
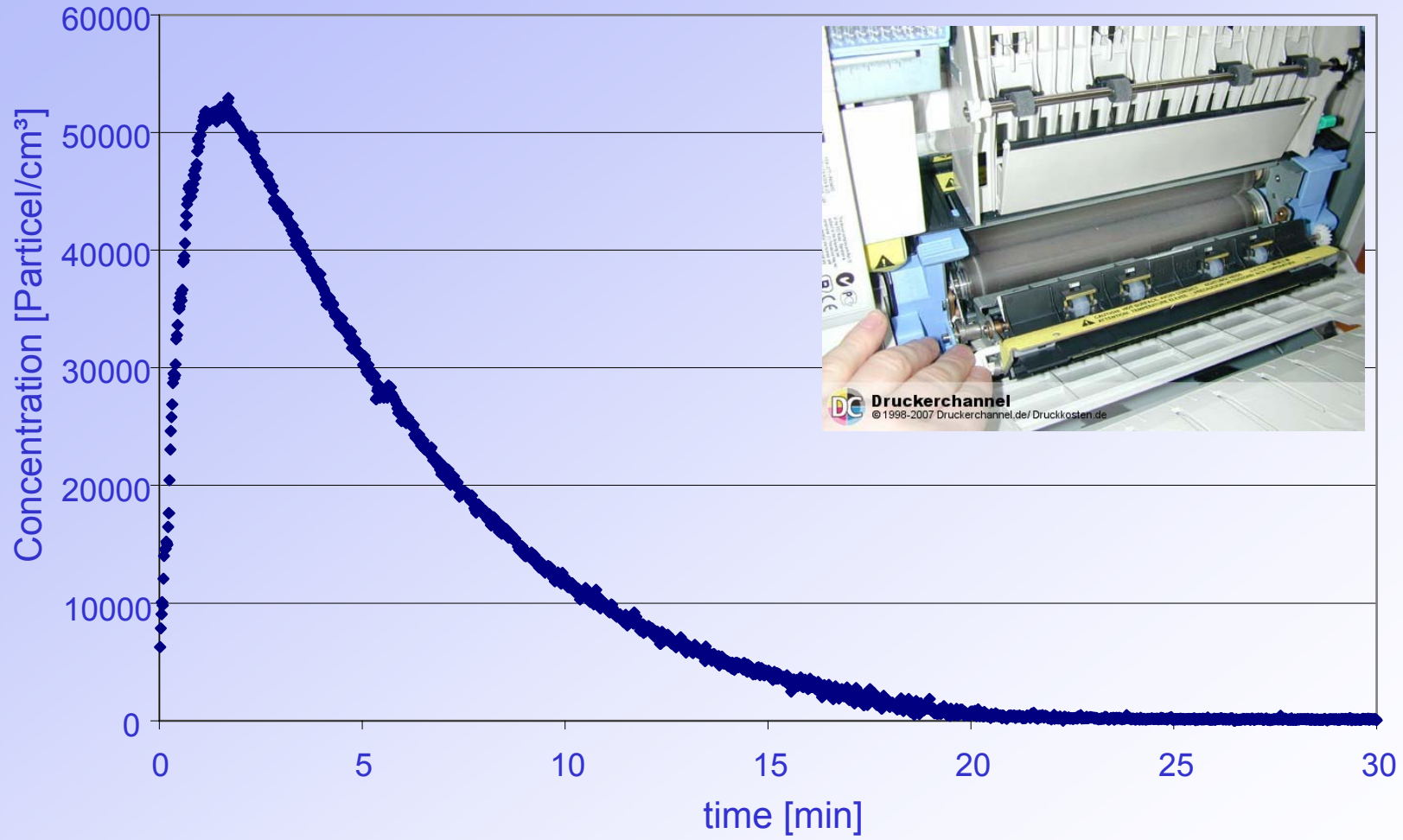
UFP-Emission from laser printer "Switch on"



UFP-Emission from laser printer "Print"



Print without toner and paper – fuser only



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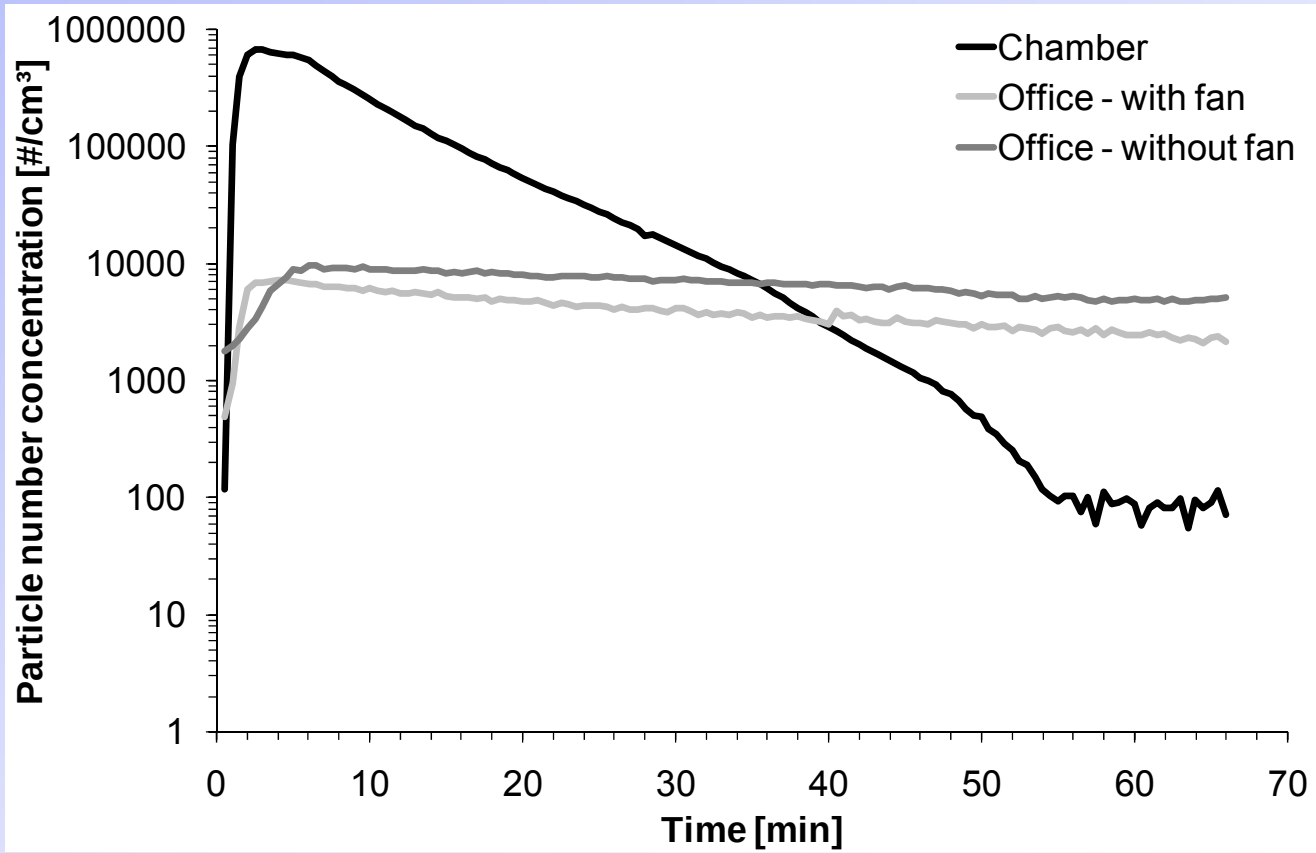
Results from real-room and chamber measurements with one printer



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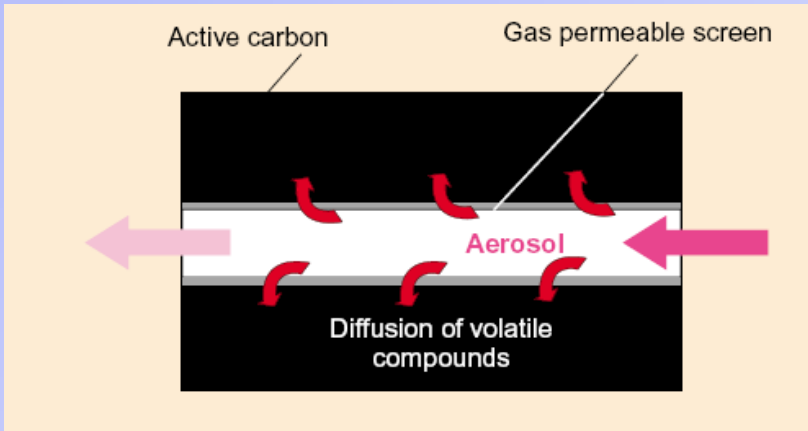
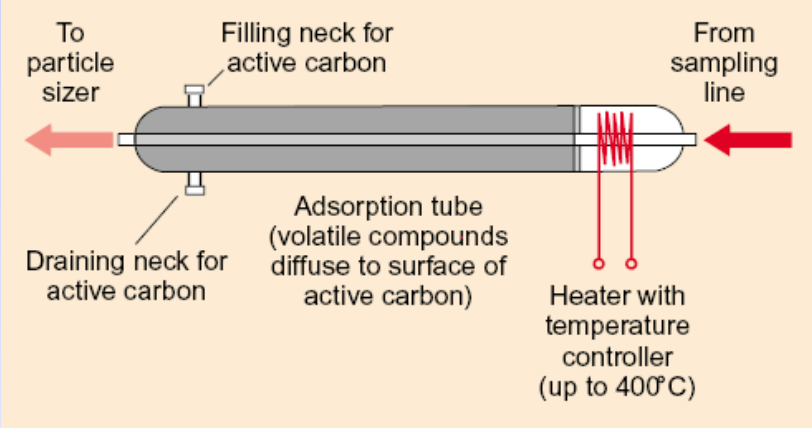
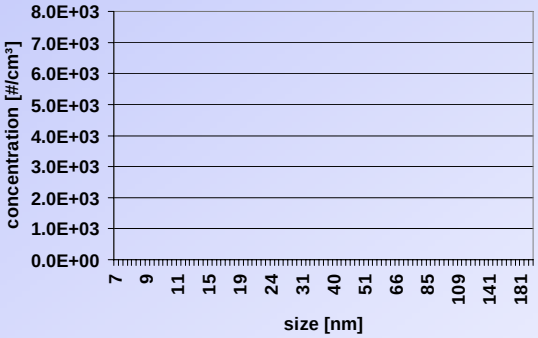
Volatility of UFP - TSI Thermodenuder 3065

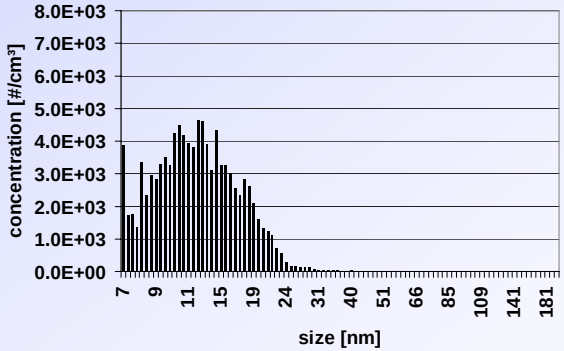




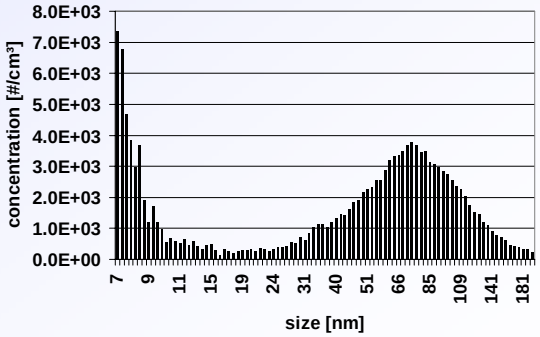
400°C



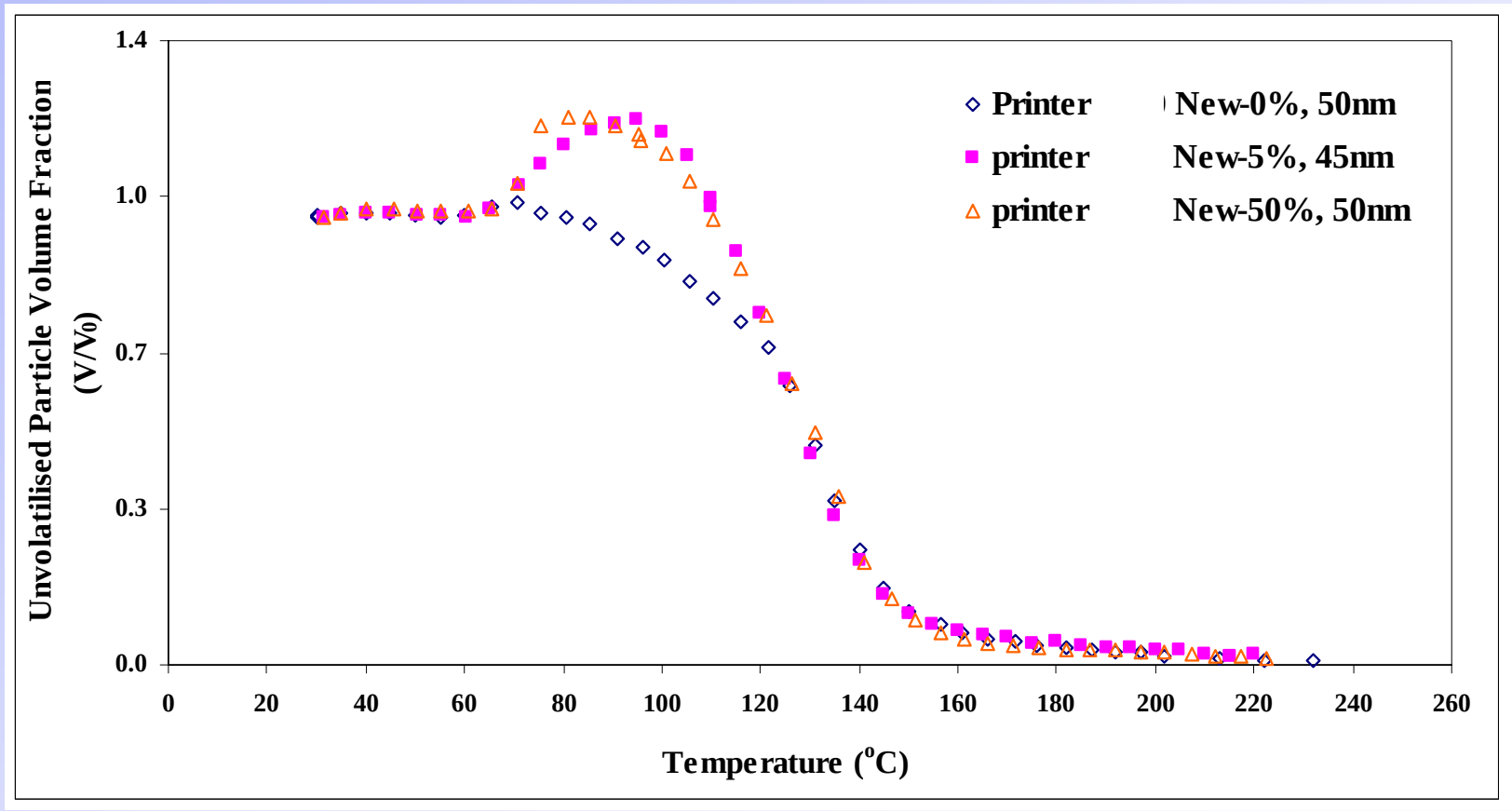
320°C



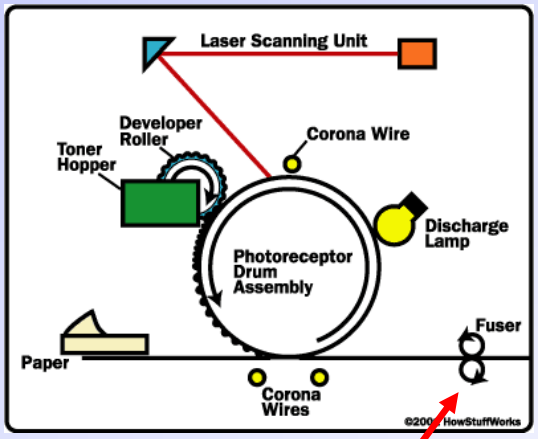
160°C

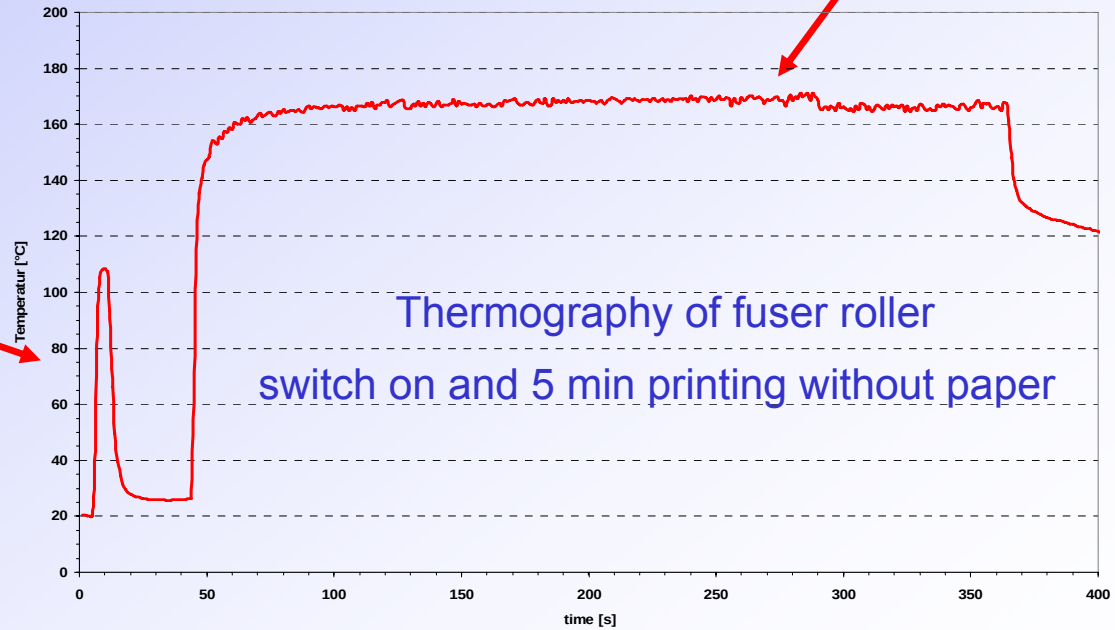


Volatalisation temperature of particles generated by printer



Fuser unit as major source for heat (ca. 170 °C)

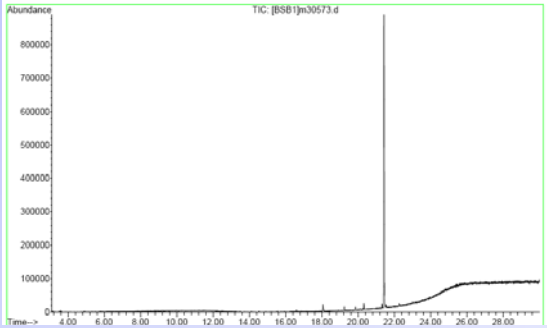




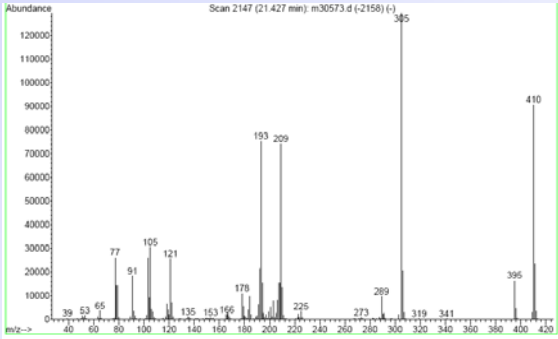
Chemical characterization of UFP

Nanometer Aerosol Sampler

Gas Chromatography



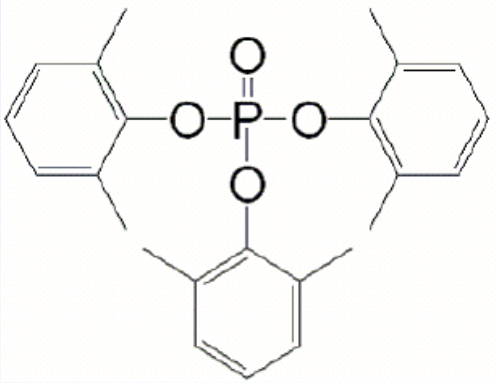
Mass Spectrometry



Analysis of collected „Aerosol“

Trixylyl phosphate, MW = 410
Flame retardant; content of fuser unit

Di-isopropylnaphthalene
Traces; content of paper



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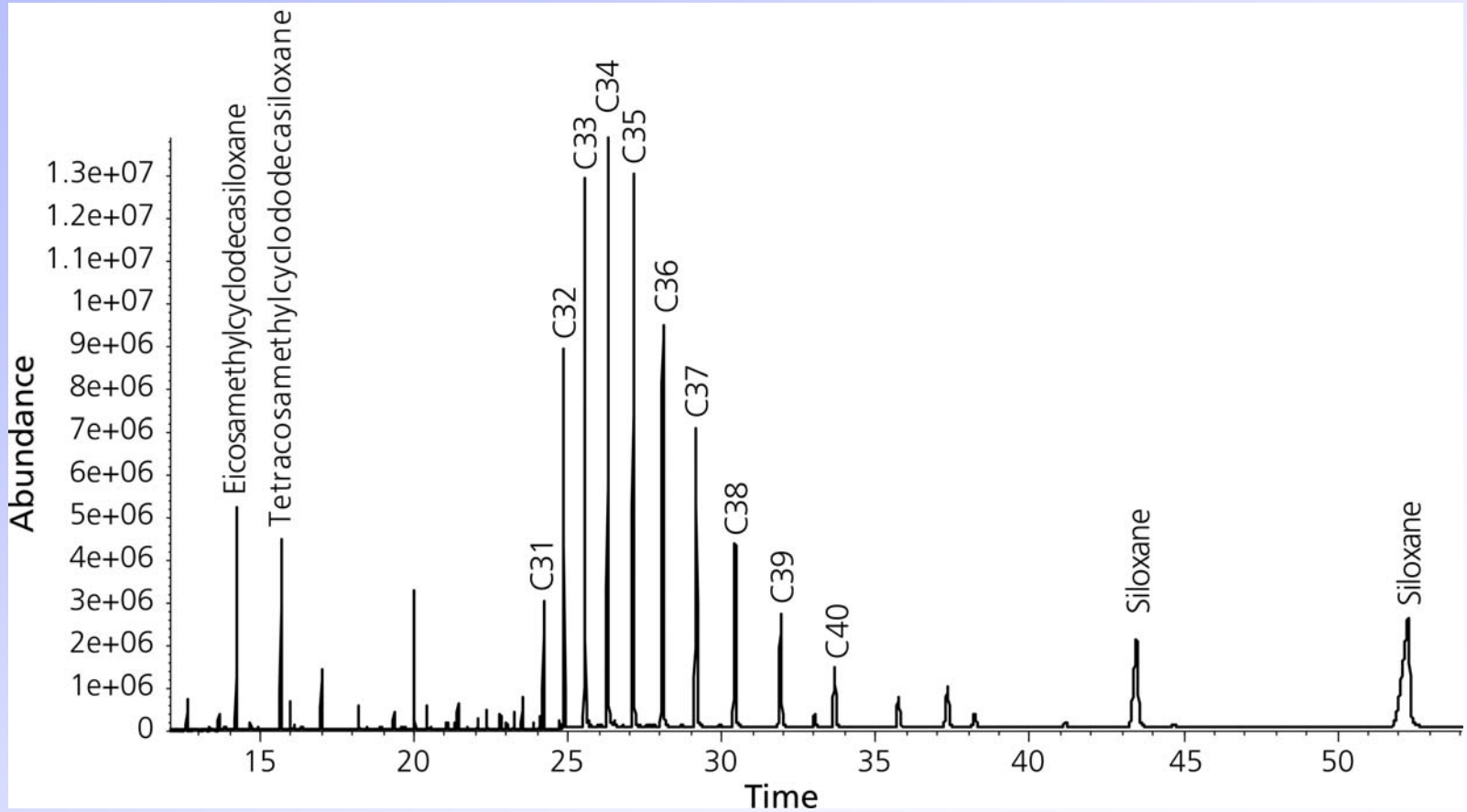
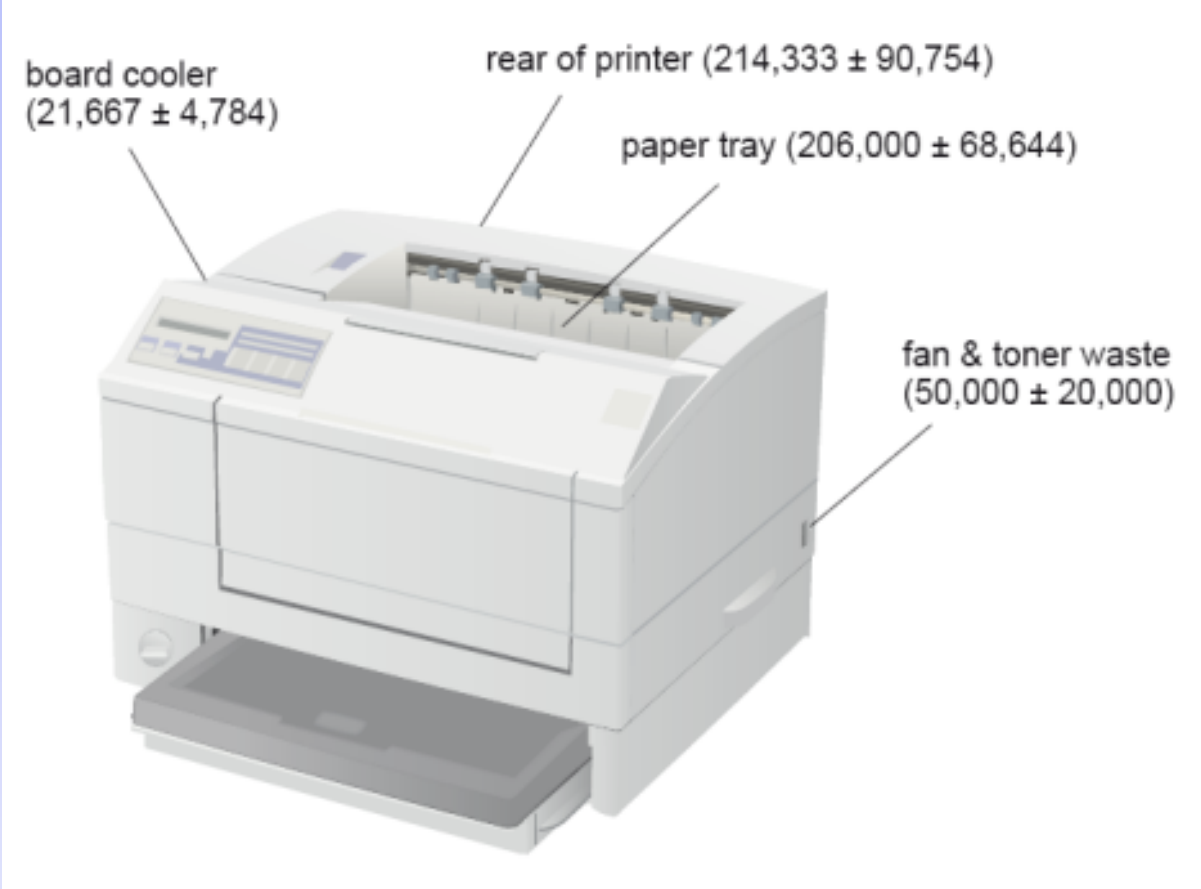
International Laboratory for Air Quality and Health
WHO Collaborating Centre

Fraunhofer Wilhelm-Klauditz-Institut Material Analysis and Indoor Chemistry

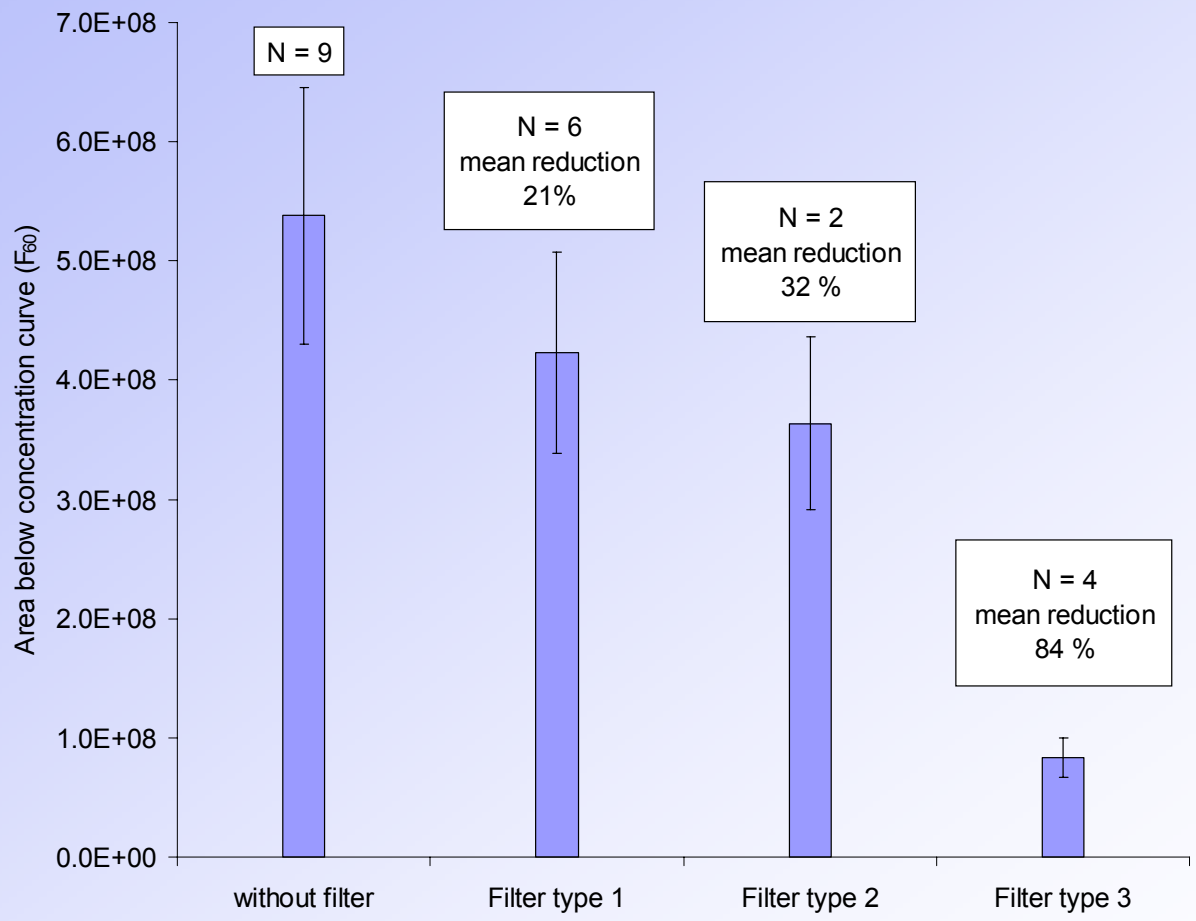
Analysis of SVOCs sampled on a particle filter



Release of particles from a laser printer



Efficiency of filters



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Summary and Conclusion

- Chamber measurements are useful for characterizing the physical and chemical nature of UFP emissions from laser printer → standardization of a test method required.
- The available results indicate that laser printers can be classified in view of different UFP emission behaviors, e.g. **“constant emitter”** and **“initial burst emitter”**.
- UFP release can also be detected in the absence of paper and toner.
- The particles are formed in the printer from VOC and SVOC by nucleation and condensation.
- The particles evaporate at higher temperatures.
- The (hot) fuser unit seems to be one important source for the release of UFPs.
- The time vs. concentration behavior of emitted particles is different in the test chamber and in real rooms.
- If negative health impacts of the released UFPs can be verified, the necessary minimization procedures should be done by variation of construction details and thus modulating sources, not by adding filter accessories.