A system to test the toxicity of brake wear particles

Michael Riediker[1], Michael Gasser[1,2], Alain Perrenoud[1,2], Peter Gehr[2], Barbara Rothen-Rutishauser[2]
[1]) Institute for Work and Health, Lausanne, Switzerland
[2]) Institute of Anatomy, University of Bern, Switzerland

Introduction:

Fine particulate matter from traffic increases mortality and morbidity. An important source of traffic particles is brake wear. American studies reported cars to emit break wear particles at a rate of about 11mg/km to 20mg/km of driven distance. A German study estimated that break wear contributes about 12.5% to 21% of the total traffic particle emissions. The goal of this study was to build a system that allows the study of brake wear particle emissions during different braking behaviours of different car and brake types. The particles should be characterize in terms of size, number, metal, and elemental and organic carbon composition. In addition, the influence of different deceleration schemes on the particle composition and size distribution should be studied. Finally, this system should allow exposing human cell cultures to these particles.

Method:

An exposure-box (0.25 cubic-m volume, Figure 1) was built that can be mounted around a car's braking system. This allows exposing cells to fresh brake wear particles. The inside of the box was covered with an aluminium foil to prevent electrostatic absorption and to facilitate cleaning. HEPA-filtered and humidified air was pumped into the box to providing a slight overpressure to prevent contamination by outside air. Concentrations of particle numbers, mass and surface, metals, and carbon compounds were quantified. Tests were conducted with A549 lung epithelial cells.

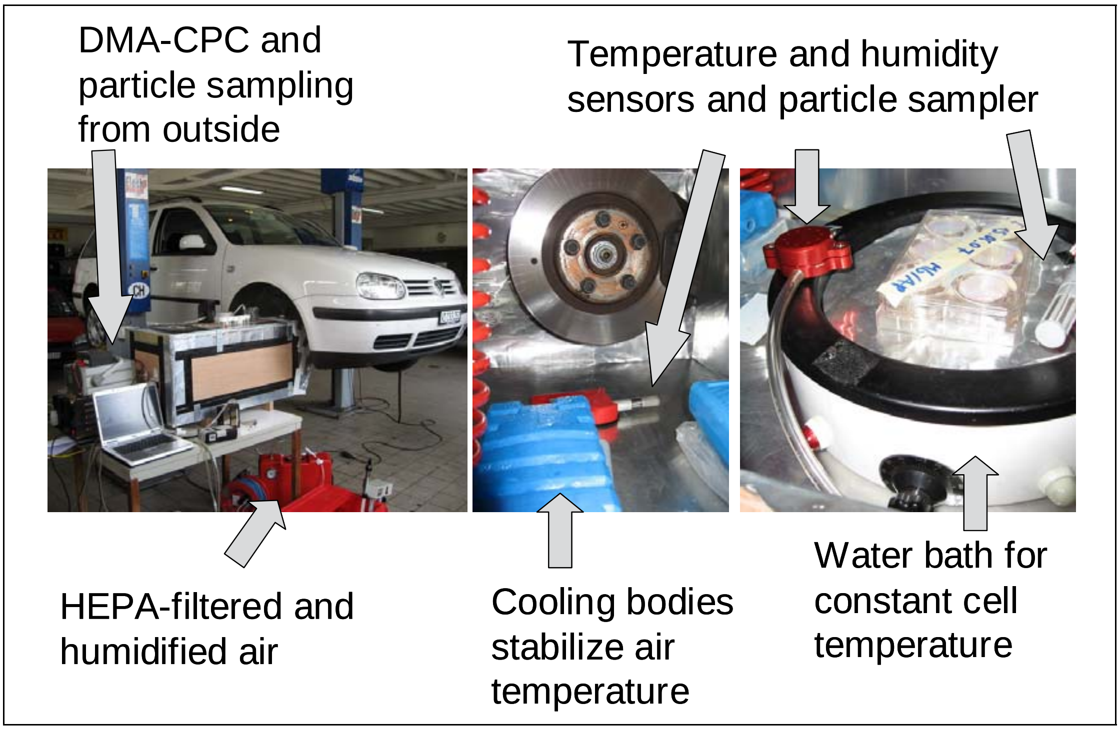

Figure 1: *Left:* Exterior view of the exposure box with particle measurement equipment (Grimm DMA-CPC, particle sampling pumps) and pump and humidification system for air preparation. *Middle:* View onto the brake disc with sensor placement ad cooling bodies to stabilize air. *Right:* A water bath was used to maintain stable cell culture temperature.

Five different cars were tested. The tested cars were: Opel Astra 1.6 Si Automatic, Opel Astra 1.4 G14 Cvan, Renault Modus 1.2 16V, Renault Laguna 2.0 Limousine, VW Golf Variant, and Fiat Panda 1.2.

Each car was tested with two typical braking behaviours (full stop and normal deceleration) and a control run (same duration of experiment but no braking):

Normal braking:	Two minutes in 3rd gear at 2’000 RPM, then 10 sec deceleration to 1750 RPM (gas position unchanged). Repetition of this scheme 4 to 10 times.
Full stop:	Two minutes in 3rd gear at 3’000 RPM, then full stop until the engine stalled (gas pedal position unchanged). Repetition of this scheme 4 to 10 times.
No stop:	16 minutes in 3rd gear at 2’000 RPM (control to measure the particles released from the turning wheel).

Results:
Particle number and size distribution was analysed for the first six minutes. In this time, two braking events occurred. Full stop produced significantly higher particle concentrations than normal deceleration (average of 23'000 vs. 10'400 #/cm3, p= 0.016). The particle number distribution was bi-modal with one peak at 60 to 100 nm (depending on the tested car and braking behaviour) and a second peak at 200 to 400 nm. Metal concentrations varied depending on the tested car type. Iron (range of 163 to 15'600 µg/m3) and Manganese (range of 0.9 to 135 µg/m3) were present in all samples, while Copper was absent in some samples (<6 to 1220 µg/m3). The overall "fleet" metal ratio was Fe:Cu:Mn = 128:14:1.

Temperature and humidity varied little. A549-cells were successfully exposed in the various experimental settings and retained their viability. Culture supernatant was stored and cell culture samples were fixated to test for inflammatory response. Analysis of these samples is ongoing.

Conclusions:
The established system allowed testing brake wear particle emissions from real-world cars. The large variability of chemical composition and emitted amounts of brake wear particles between car models seems to be related to differences between brake pad compositions of different producers. Initial results suggest that the conditions inside the exposure box allow exposing human lung epithelial cells to freshly produced brake wear particles.

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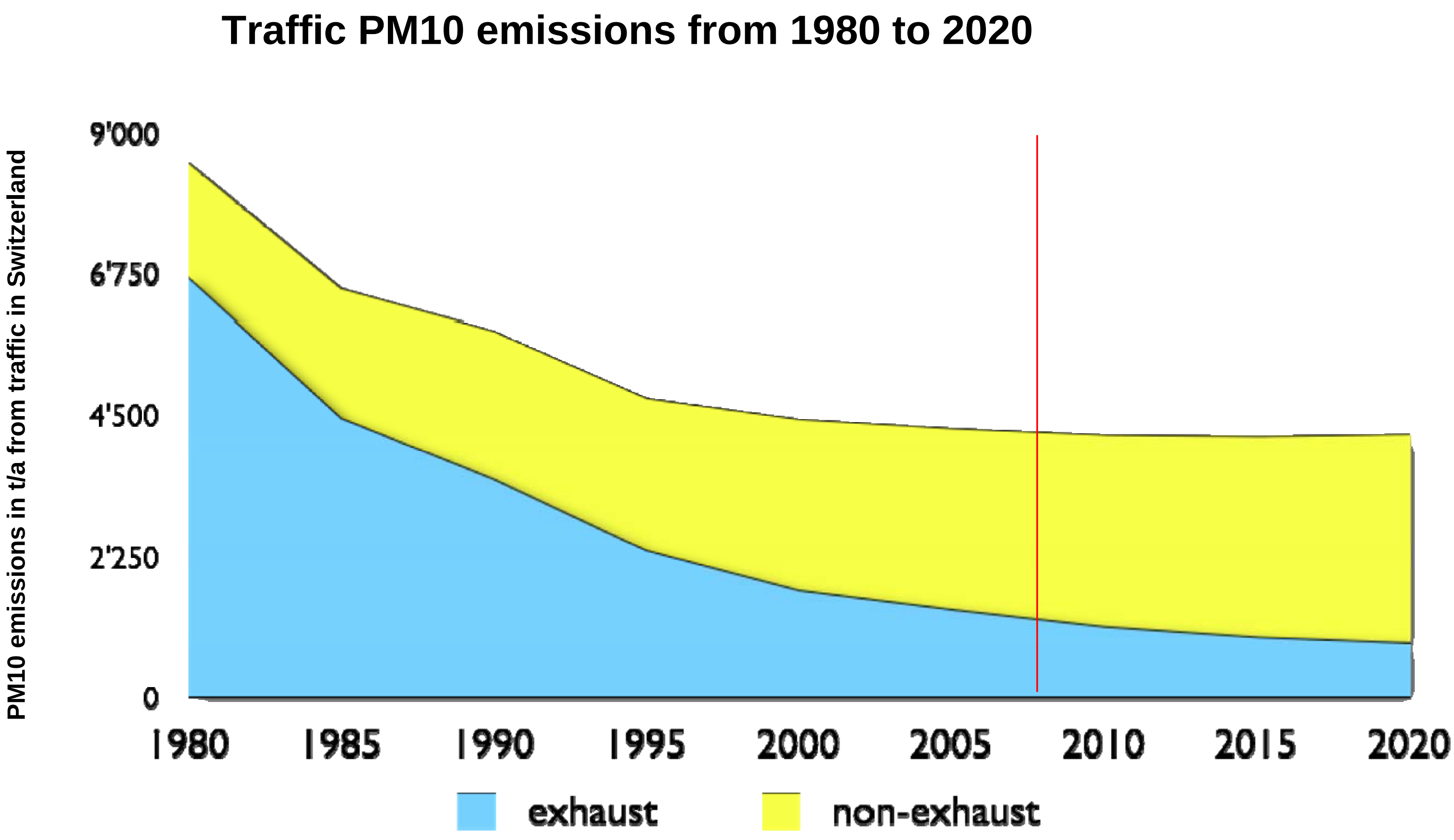
Traffic particle development



After BUWAL Report Nr. 355, Swiss UVEK, BUWAL, 2004. Annex A4, p.57

Starting point

Traffic particles and cardiovascular health

- NC highway patrol troopers have exposure to copper from brakes
- Brake wear is part of a source indicative of stop-and-go traffic
- This source was strongly linked to heart rhythm changes, and a pro-inflammatory and pro-coagulatory response

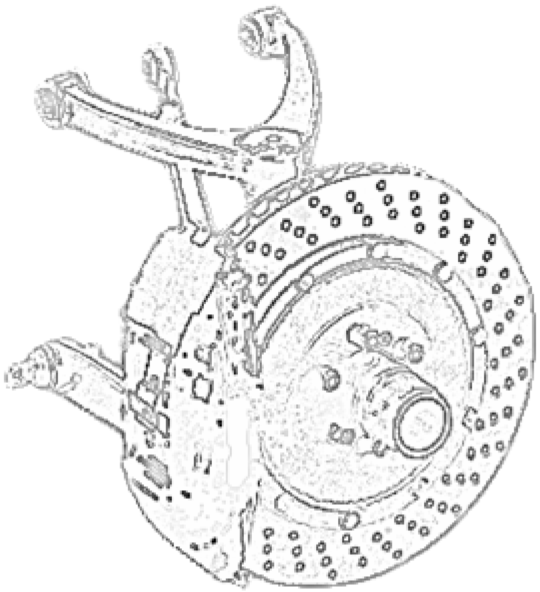
Riediker, et al. 2003. Environ Sci Technol. 37:2084-2093.

Riediker, et al. 2004. Am J Respir Crit Care Med. 169:934-940.

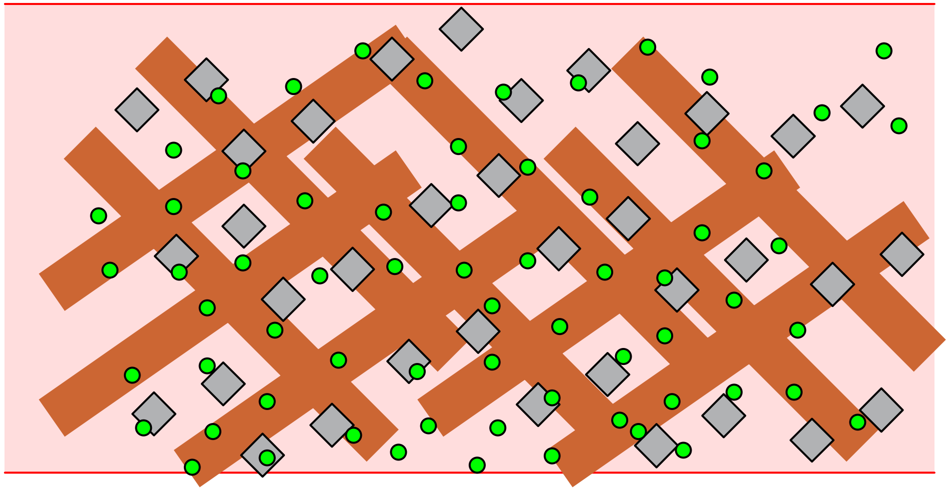
Riediker et al. 2004. Part Fib Toxicol. 1:2.

Do the brakes play a role ?

Brakes



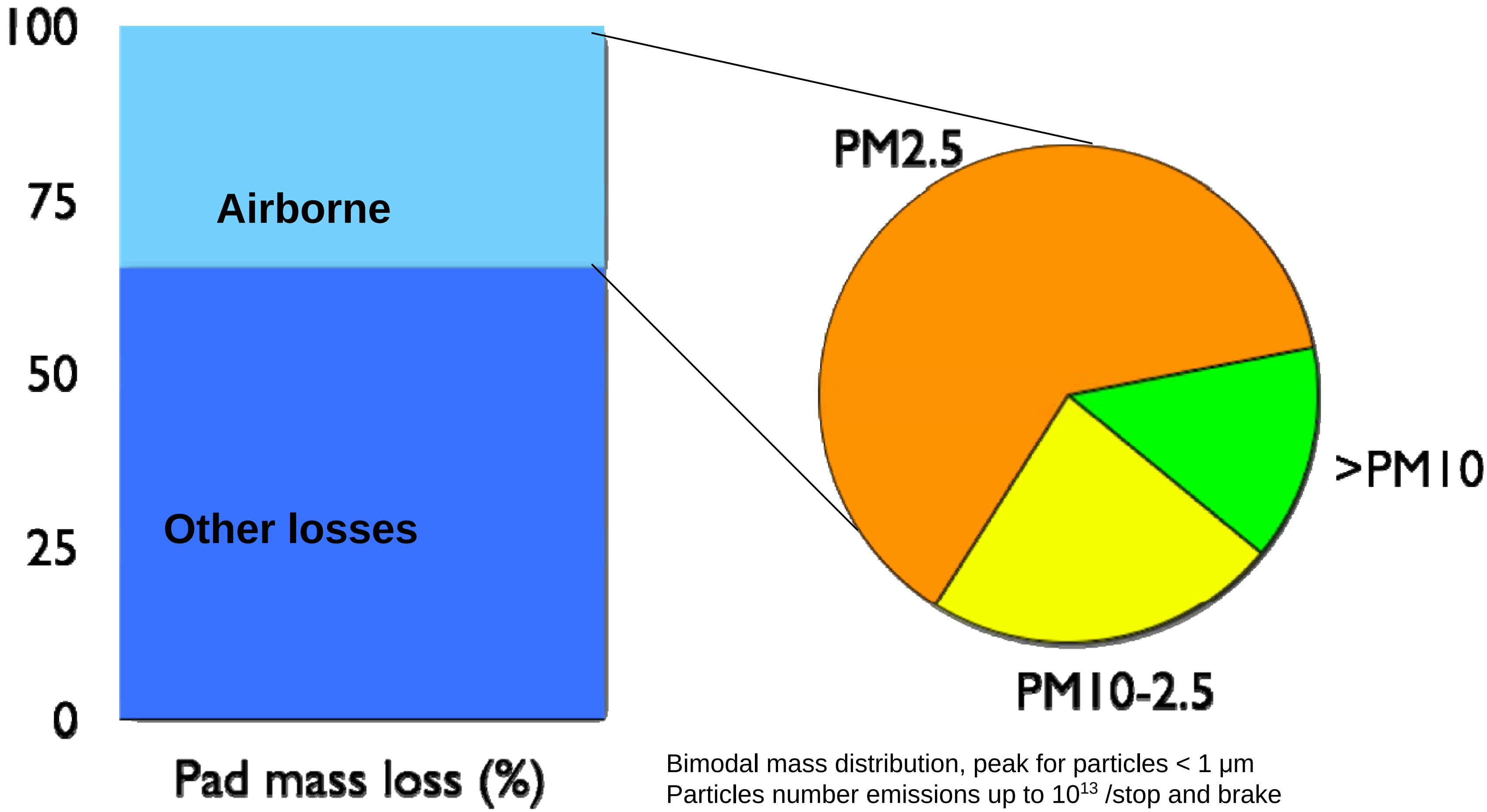
Pad = Binders + Fibers + Fillers + Modifiers



Max. pressure up to 10 MPa
Power dissipation over 30 kW
Max. temperature over 500°C

-> Heat transformation processes
-> Formation of ultrafine (Cu) particles ?
-> Could this cause oxidative stress to cells ?

Brake wear particles



Bimodal mass distribution, peak for particles < 1 µm
Particles number emissions up to 10^{13} /stop and brake
Most of copper leaches out in standard test *)

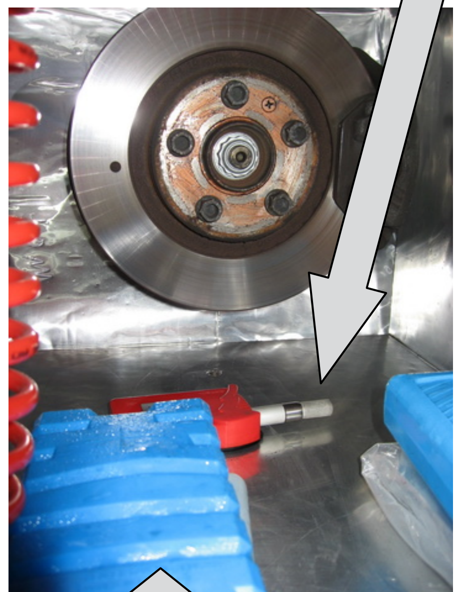
Test bench brake wear emissions - after Garg et al. ES&T 2000; *) Hur et al., J Environ Monit 2003

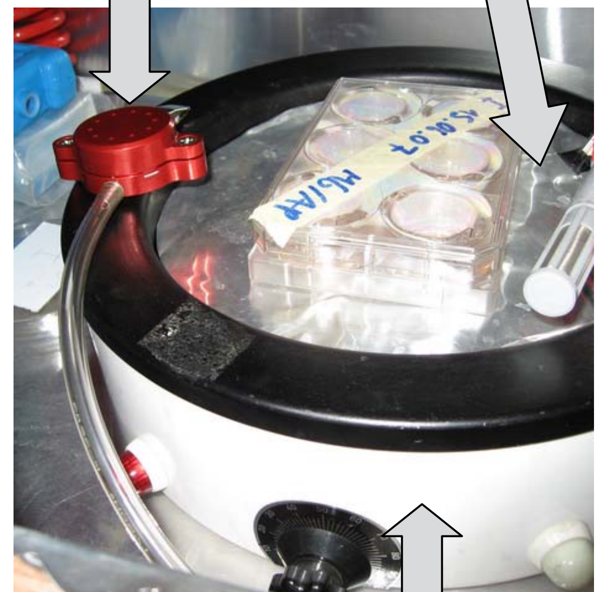
Exposure-box to mount around axle with brake

Exposure box equipment

DMA-CPC and particle sampling from outside

Temperature and humidity sensors and particle sampler





HEPA-filtered and humidified air

Cooling bodies stabilize air temperature

Water bath for constant cell temperature

Cars tested = frequent on Swiss streets

Brand	Brand Rank	Model	# new registrations in Switzerland (Model)	Kilometrage of the tested car	Year of registration
Opel	2	Astra 1.6 Si Automatic	6’017 (Astra total)	84'000 (Brake pads changed 1x)	NA
Renault	4	Modus 1.2 16V	727	530	2007
VW	1	Golf Variant	10’016 (Golf total)	102’000 (Brake pads changed 1x)	2000
Fiat	13	Panda 1.2	1’784	30’700	2005
Opel	2	Astra 1.4 G14 Cvan	6’017 (Astra total)	62’700	2003
Renault	4	Laguna 2.0 Limousine	1’384	221’000 (Brake pads changed 3x)	1994

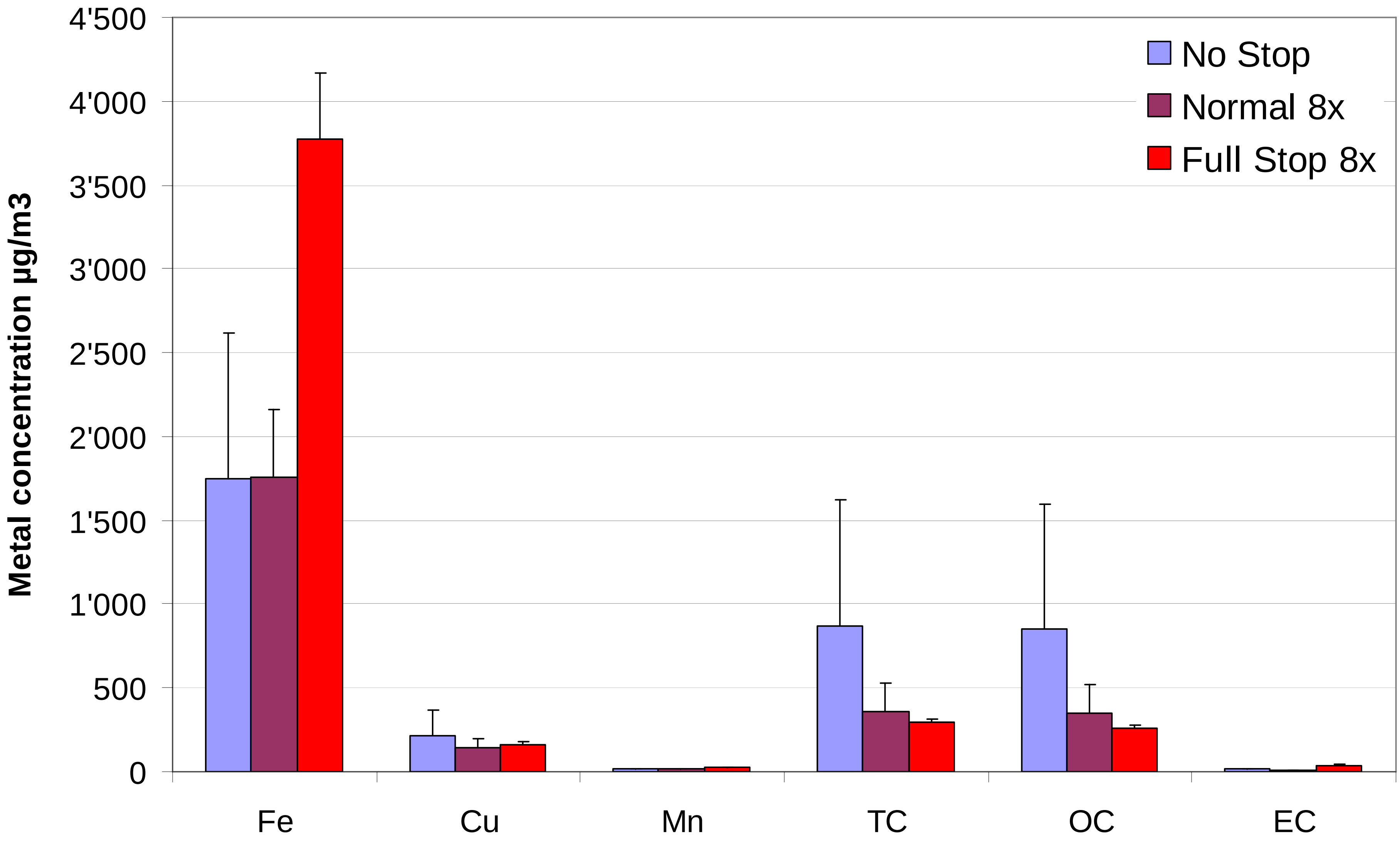
Braking protocols

Normal braking: Two minutes in 3rd gear at 2’000 RPM, then 10 sec deceleration to 1750 RPM (gas position unchanged).

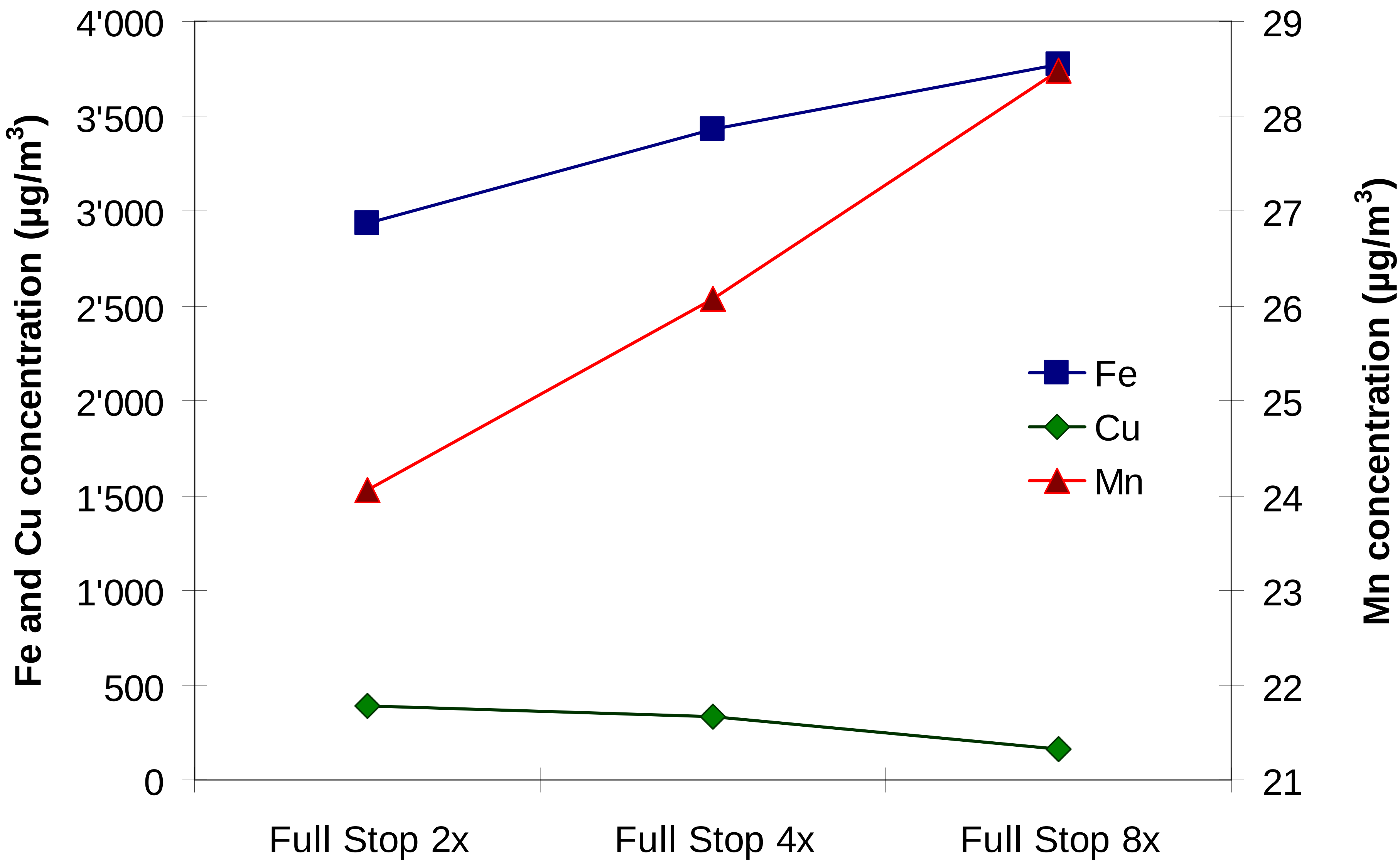
Full stop: Two minutes in 3rd gear at 3’000 RPM, then full stop until the engine stalled (gas pedal position unchanged).

No stop: 16 minutes in 3rd gear at 2’000 RPM (control to measure the particles released from the turning wheel).

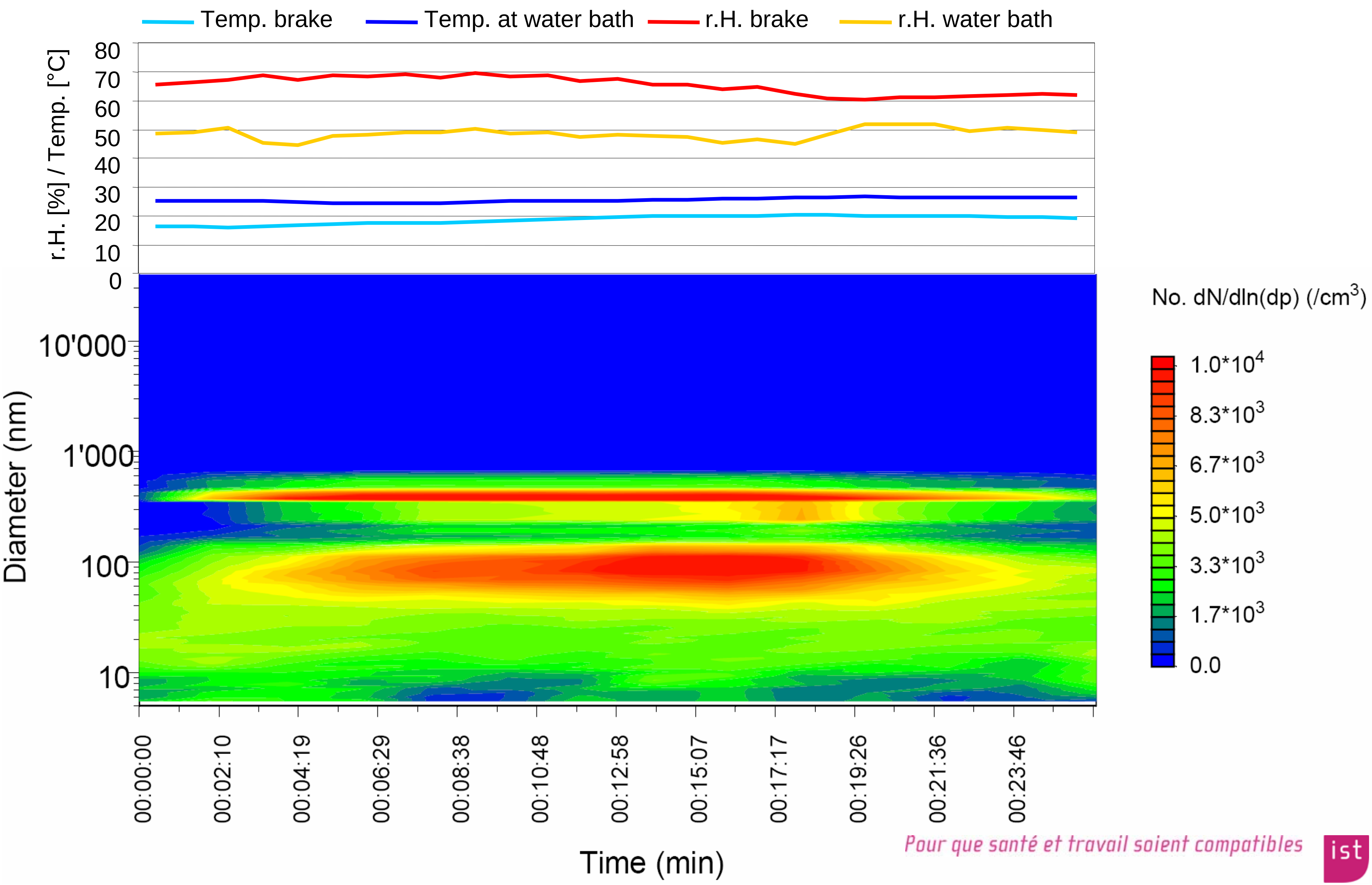
Composition of particles



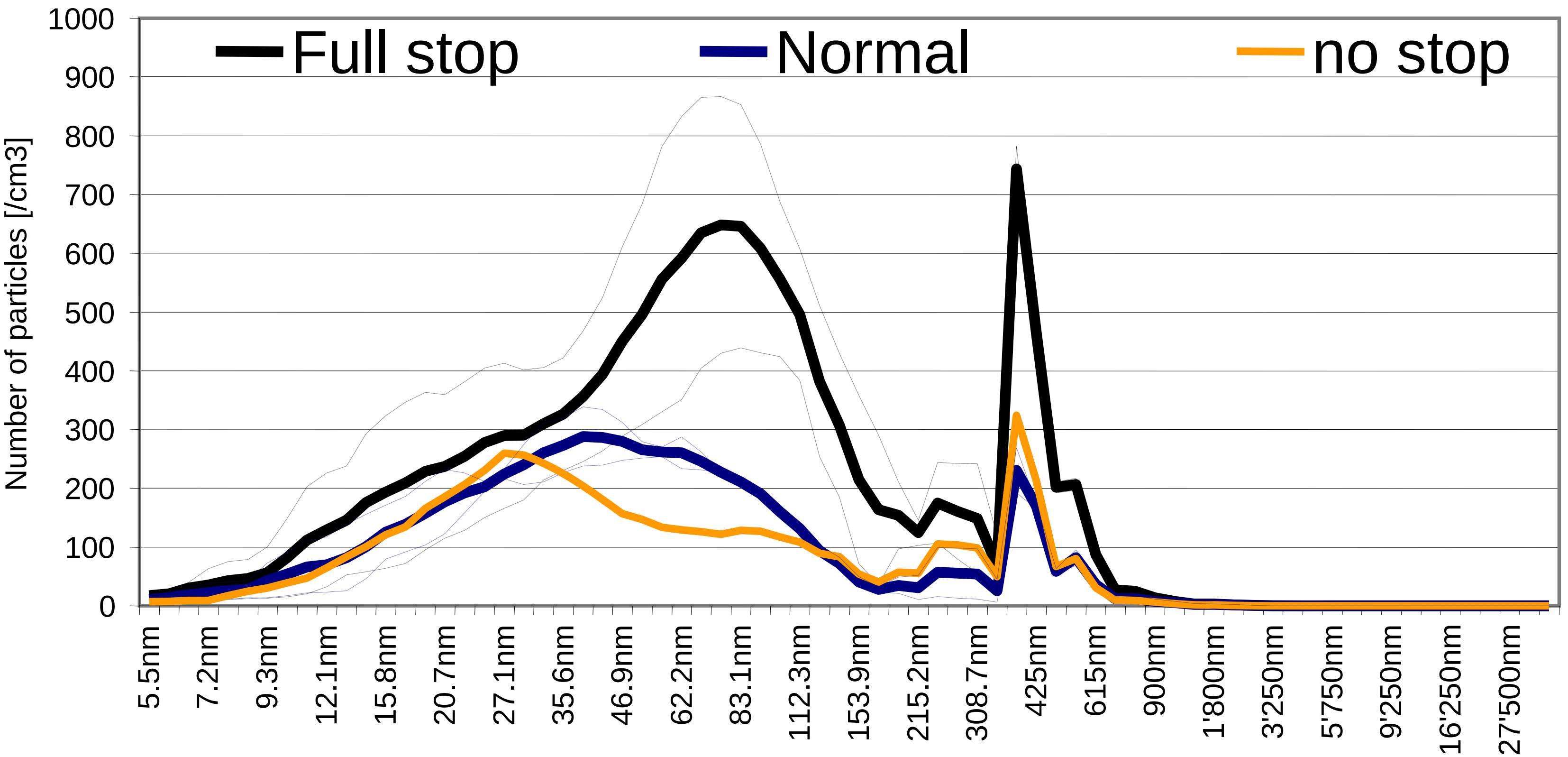
Influence of repeated full stop braking



Time profile normal braking



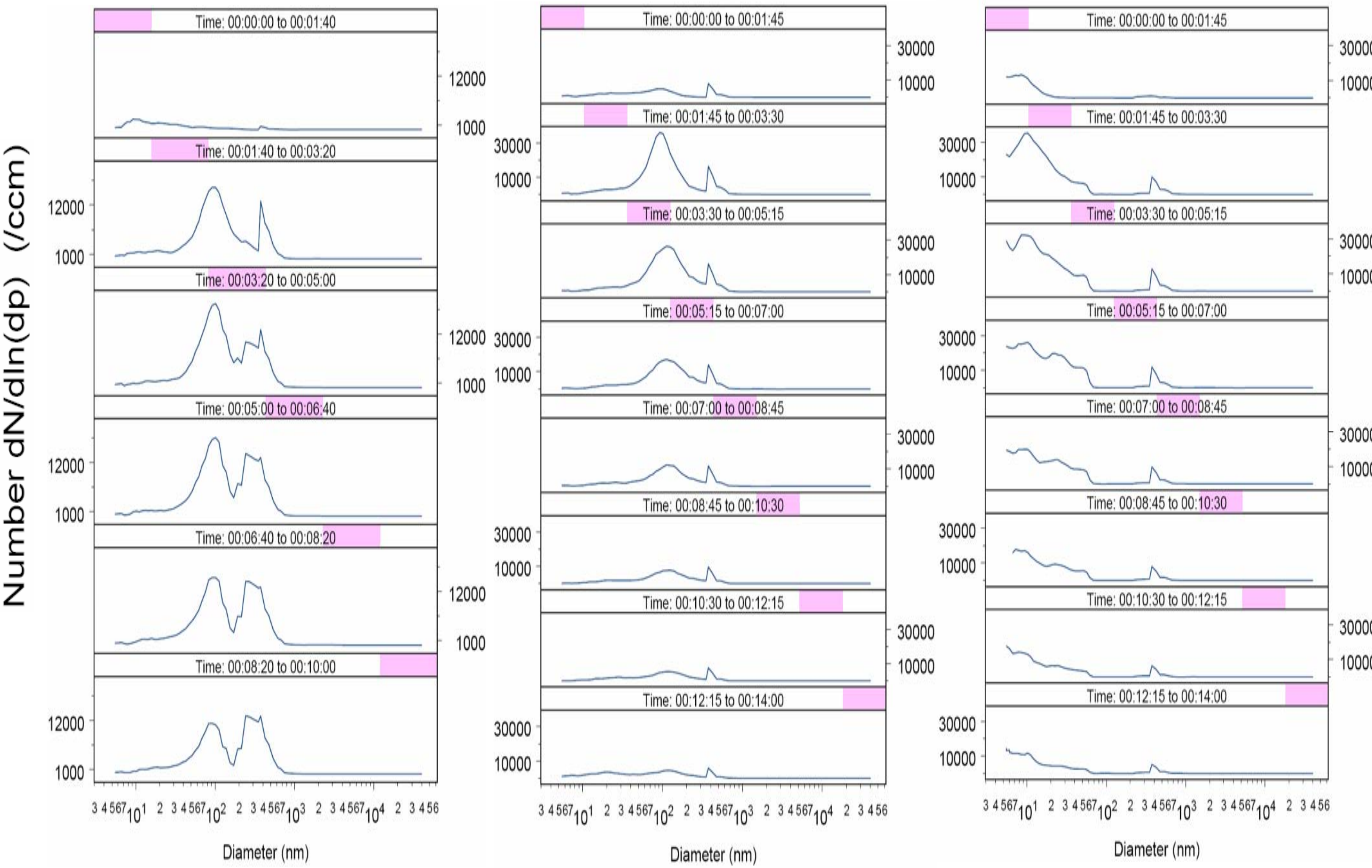
Comparison between braking behaviours



Full stops = more energy = more heat = more wear particles

"No stop runs" -> Do particles adhere to braking system ?

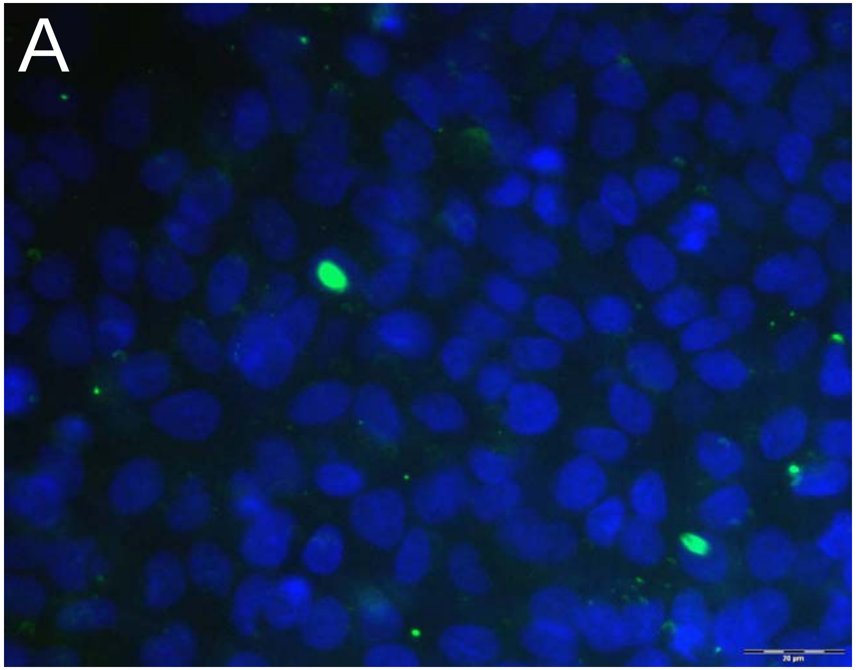
Time profile full stop braking - car differences

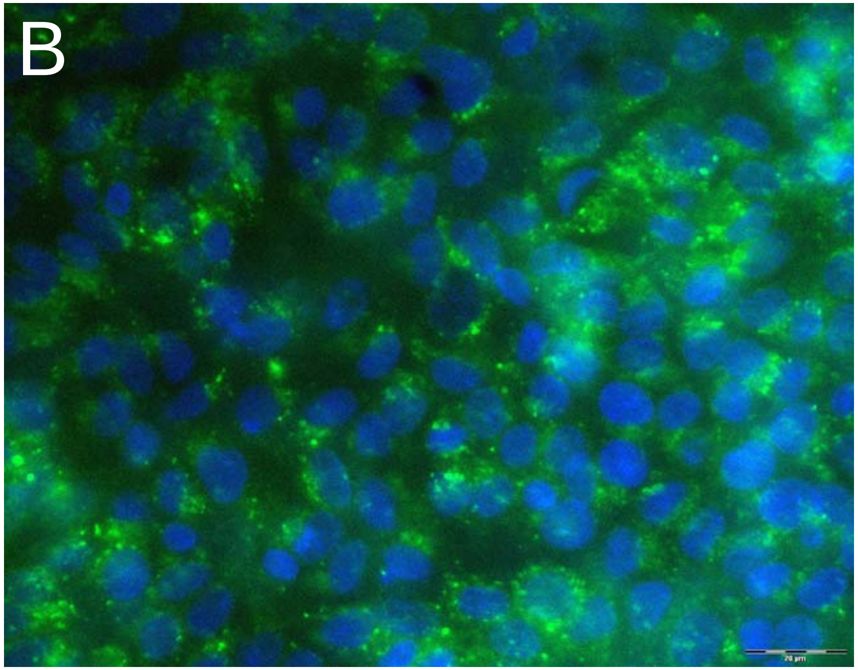


Reactive oxygen species (ROS) in A549-cells

Cells not exposed (control)

Cells exposed to brake particles (full stop, 8 repetitions)





Brake wear particles cause strong oxidative stress signal

Green: ROS, Blue: Cell nuclei

Conclusions

– The established system allowed testing brake wear particle emissions from real-world cars.

– Brake wear particles showed potent ROS-formation

➢ Which particle characteristics are behind this?
➢ What are the cardiovascular consequences?

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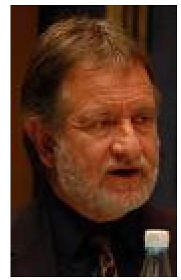
    

Merci pour votre attention

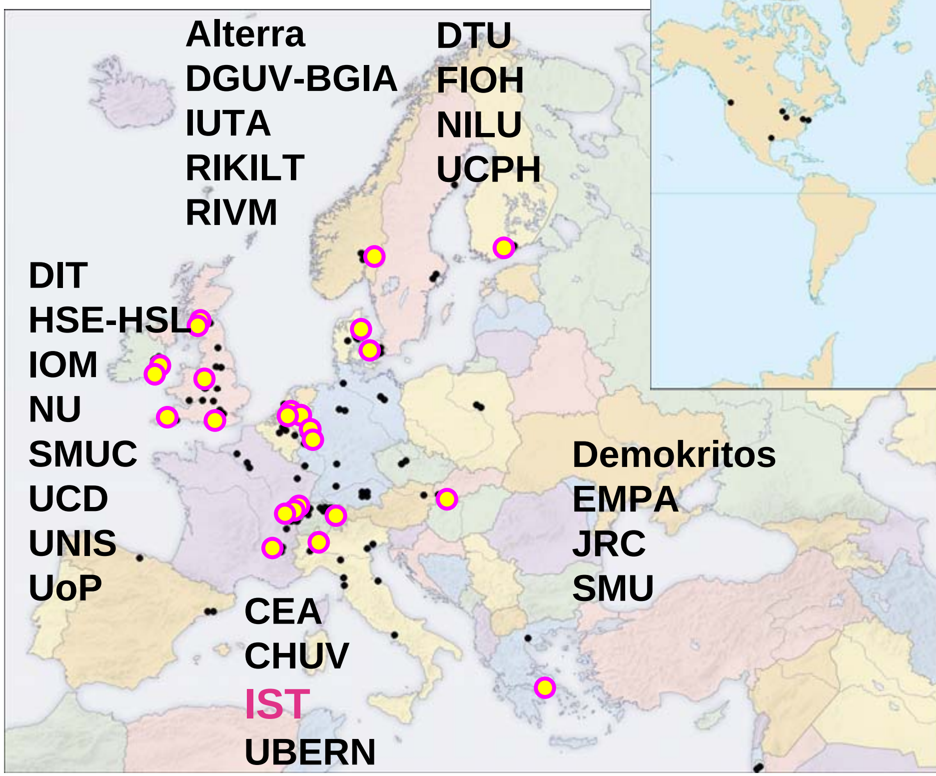
Funding for this study was kindly provided by the Swiss Federal Office for the Environment and ETH Zurich.

We thank the staff: Michele Berode, Christine Kohler, Ferdinando Storti, Kaspar Schmid (IST Lausanne); and Sandra Frank, Anna-Barbara Tschirren, Christina Brandenberger, Franziska Graber, Andrea Lehmann, Claudia Haller, Dimitri Vanhecke (Anatomy Bern).

NEWS

NanoImpactNet

The European Network on the Health and Environmental Impact of Nanomaterials just started



Additional information:

info@nanoimpactnet.eu

http://www.nanoimpactnet.eu

Dust from traffic

Engine exhaust
Tire wear
Brake wear
Road wear
Re-suspension

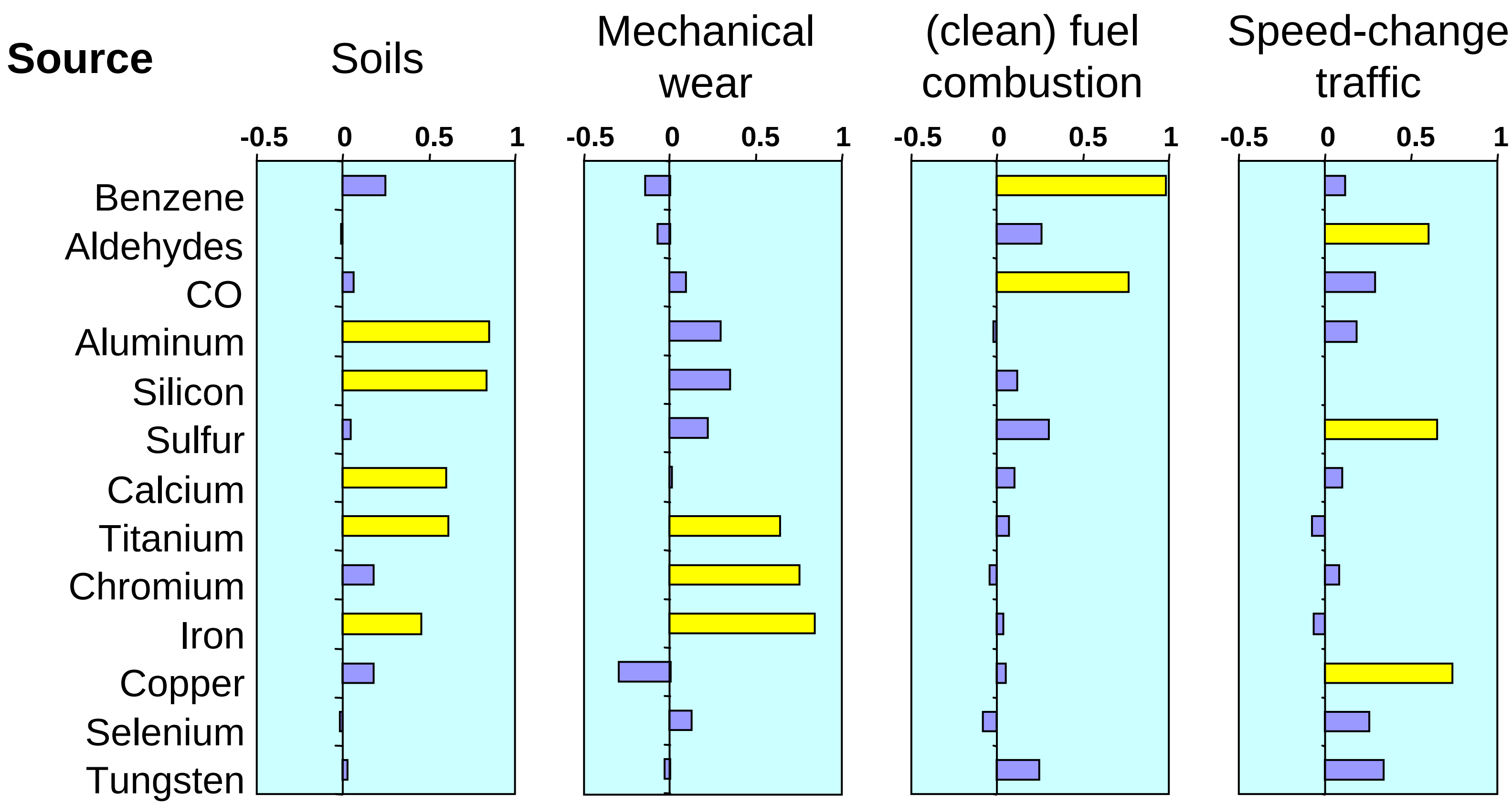
Estimated emissions

- Exhaust: 10 mg/km (car) to 500 mg/km (truck)
- Tire loss:
  = 120 mg/km, airborne ca. 5 mg/km (1 - 100, disputed)
- Brake pad loss:
  = airborne 10 - 50 mg/km

– **CAVE**: Emissions are dynamic! Speed *change* matters!

After Garg et al. ES&T 2003, Gehrig et al. IJEP 2004, BUWAL Nr. 355 and other sources

Speed-change traffic effects - could it be the brakes?



+ uric acid

+ BUN, +MCV
+ vWF, - protein C
+ neutrophils, - lymphocytes
+ MCL, + SDNN, + pNN50, + ectopy

Riediker et al, PFT 2004