19th ETH Conference on Combustion Generated Nanoparticles
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Genotoxicity of Diesel Emissions in Real World Driving: Effects of Cold Starts, Congestion, DPF

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Problematic engine operating conditions

- **Light vehicle gasoline – fast transients, full load**
- **Light vehicle diesel – fast transients, full load, prolonged idle**
- **Heavy vehicle diesel – prolonged idle and creep**

<u>Most of these are outside of the current driving cycles:</u>

- **<u>no extended low-speed driving, no high speed or load</u>**
- **<u>no extended low-load operation</u>**

Most of these are common in congested urban areas…

Engine exhaust toxicity project:

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Innovative Methods of Monitoring of Diesel Engine Exhaust Toxicity in Real Urban Traffic.

EU LIFE+ program (LIFE10 ENV/CZ/651), 2011-2016

Participating institutions

Institute of Experimental Medicine, Academy of the Sciences of the Czech Republic –

Faculty of Mechanical Engineering, TU Liberec

Ministry of the Environment of the Czech Republic

Goal:

Demonstrating innovative methods of monitoring toxicity

on-board sampling system, focus on urban driving

off-line toxicological assays on collected samples

PEMS – Portable emissions monitoring system

-> PETS – Portable exhaust toxicity assessment system

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Coindicence of problems in dense - congested urban areas

High concentration of vehicles

-> high ambient concentrations

High population density

-> high number of people exposed

High frequency of problematic operating modes

- **extended idling and creep**
- **dynamic / transient operation**
- **full-power accelerations**

-> higher and/or more hazardous emissions

For toxicity evaluation, focus should be on <u>realistic</u> <u>urban</u> driving conditions.

Focus of this work: Severe congestion

Measurement of gases and PM with on-board system
Sampling of PM with on-board proportional sampling system

Portable proportional sampling

Diluted sample flow through filter is constant (20-50 dm3/min).

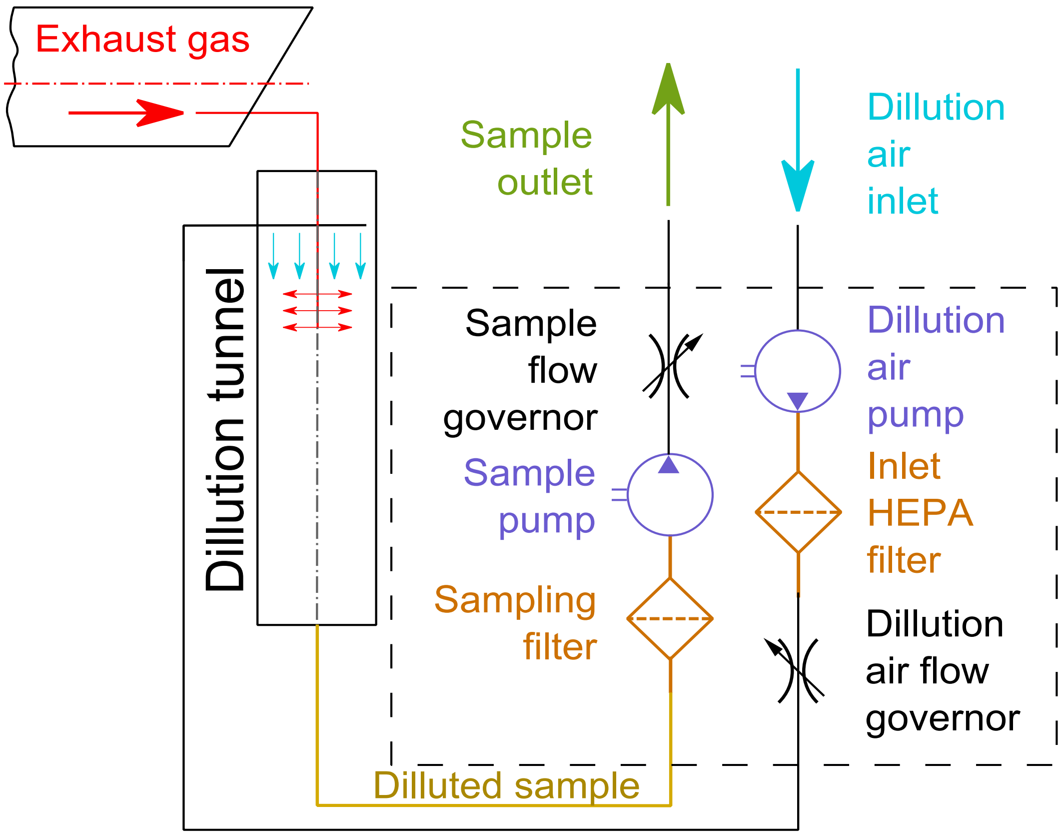
Dilution air flow is regulated so that raw exhaust flow into microdilution tunnel is proportional to the total exhaust flow.

HEPA filtered air is metered into microdilution tunnel near sampling point.

Raw exhaust flow =

= total sample flow – dilution air flow

Exhaust flow ~ measured intake air flow



Study in real traffic with 2 types of diesel engines

- 2 types of trucks:
  - **#1: Iveco Daily** (EURO 5) with DOC and DPF; 7 tons
  - **#2: Iveco Trakker** (EURO 3) without DPF, 23 tons
  - Trucks were used in Prague area for 2 days
- Emissions were measured and sampled by portable emission monitoring system
- Particles sampled on teflon filters Pall TX40HI20 WW(47 mm)

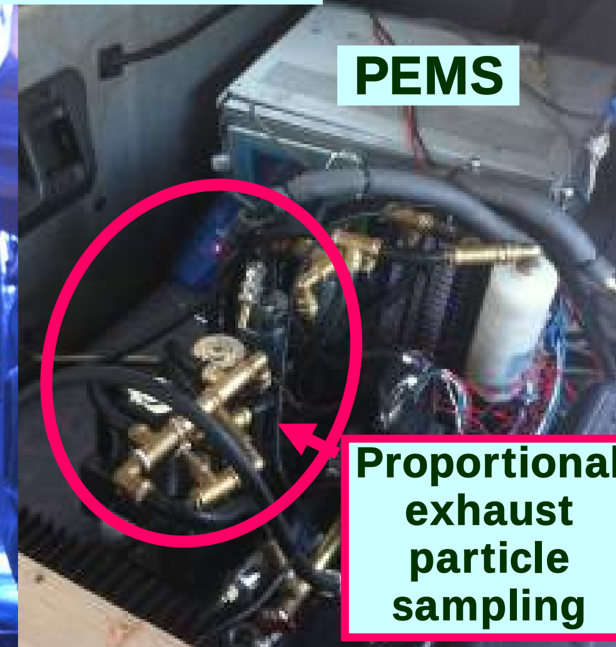
Vehicle #1: 2012 Iveco daily, Euro 5, DOC+DPF

Total of two days driving around Prague including two one-hour idling periods

Emissions of PM were very low even during 1-hour idle, PM in exhaust generally below 1 mg/m3

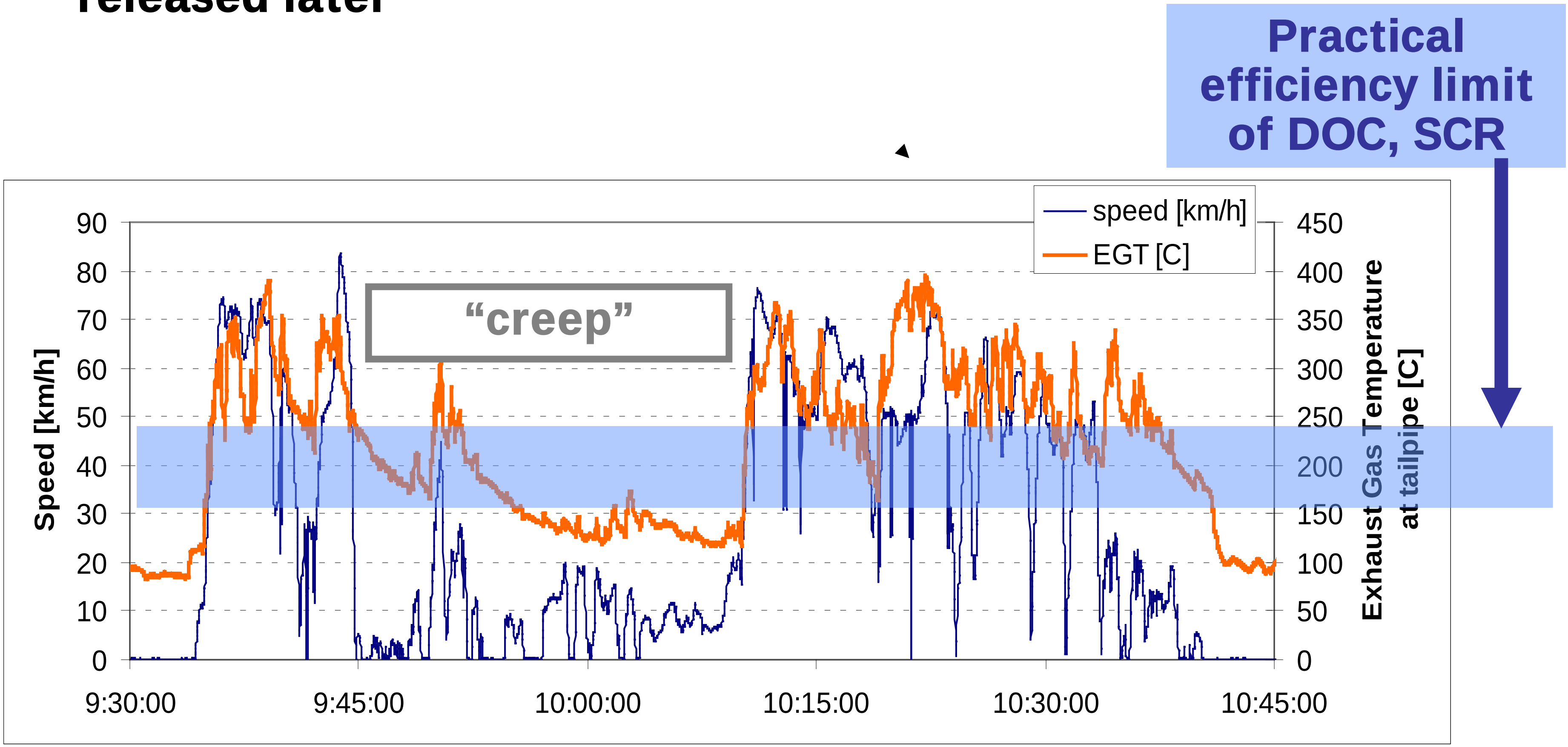
Vehicle #2, 2003 Iveco Trakker, Euro 3, no aftertreatment

Two days driving around Prague including cold starts and congested traffic



Heavy vehicle creep problem

* Deterioration of combustion at idle
* Low exhaust gas temperatures decrease efficiency of catalytic devices (DOC, SCR)
* Particulate matter stored in exhaust system to be released later



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Methods

Analysis of PM a PAHs

- **PM mass on filters measured gravimetrically**
- **Filters extracted by the mixture of dichlormethane/hexane (20:1, v/v)**
- **Aliquots of extracts used for the analysis of priority PAHs including 7 carcinogenic PAHs by HPLC**

Analysis of genotoxity and oxidative DNA damage

- Organic extracts evaporated to propandiol and diluted by DMSO
- Calf thymus DNA (1ml, 1mg/ml) incubated with 10 μl of extracts with and without metabolic activation (+/- S9), 24h
- DNA isolation
- Analysis of the genotoxic potential (DNA adducts) by ^{32}P-postlabelling methods in acellular test with ctDNA with/without metabolic activation by S9 fraction.
- Oxidative damage to DNA (8-oxo-dG) by ELISA.

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Results

Filters and PM mass

	N [filters]	Total PM mass/sample [μg]
IVECO DAILY		
All runs including idle	4	160
Blank	5	0
IVECO TRAKKER		
Cold idle after cold start	1	1012
First run after cold start	2	2451
Cold engine urban driving	3	1474
Driving after congestion	7	1097
Highway driving	11	1247
Urban driving	4	408
Congested traffic	4	598
Blank	9	0

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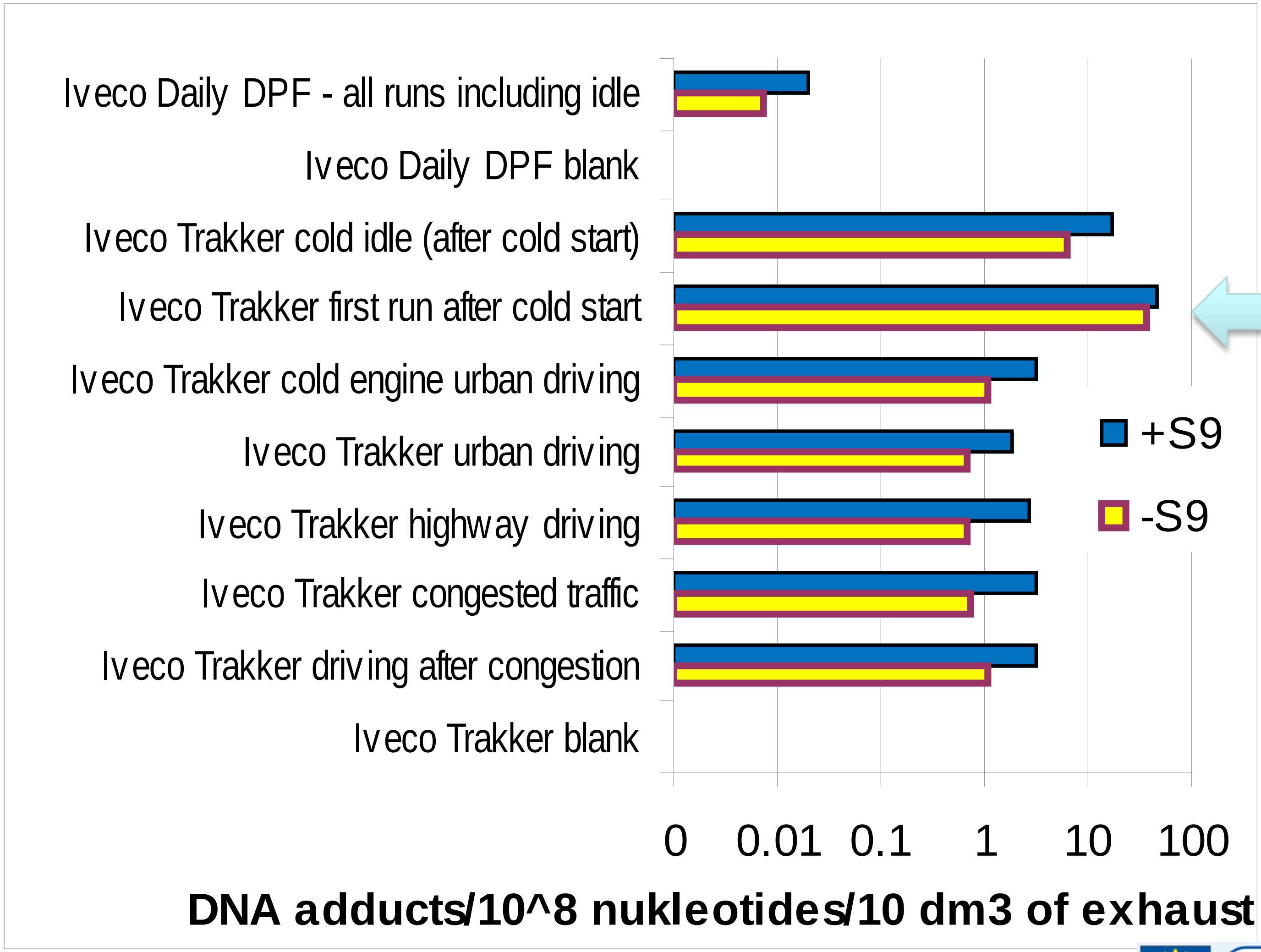
Analysis of carcinogenic PAHs bound to PM [ng/sample]

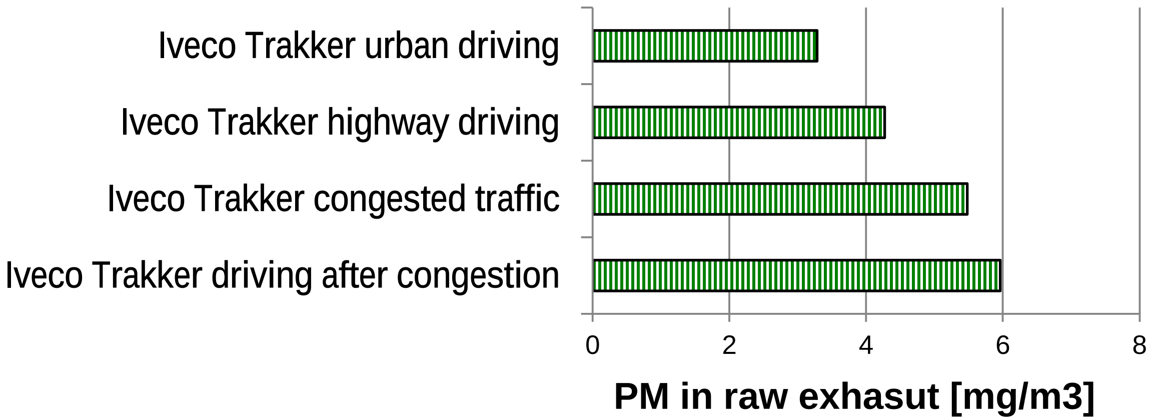
IVECO DAILY	BaP	BaA	CHRY	BbF	BkF	DBahA	IcdP	ΣcPAHs
All runs including idle	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Blank	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
IVECO TRAKKER								
Cold idle after cold start	35	12	36	29	13	n.d.	25	150
First run after cold start	10	23	111	39	12	n.d.	7	202
Cold engine urban driving	21	12	44	29	9	n.d.	12	124
Driving after congestion	n.d.	n.d.	10	n.d.	n.d.	n.d.	n.d.	10
Highway driving	n.d.	n.d.	14	4	n.d.	n.d.	n.d.	18
Urban driving	n.d.	n.d.	n.d.	4	n.d.	n.d.	n.d.	4
Congested traffic	9	5	12	9	n.d.	n.d.	8	43
Blank	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

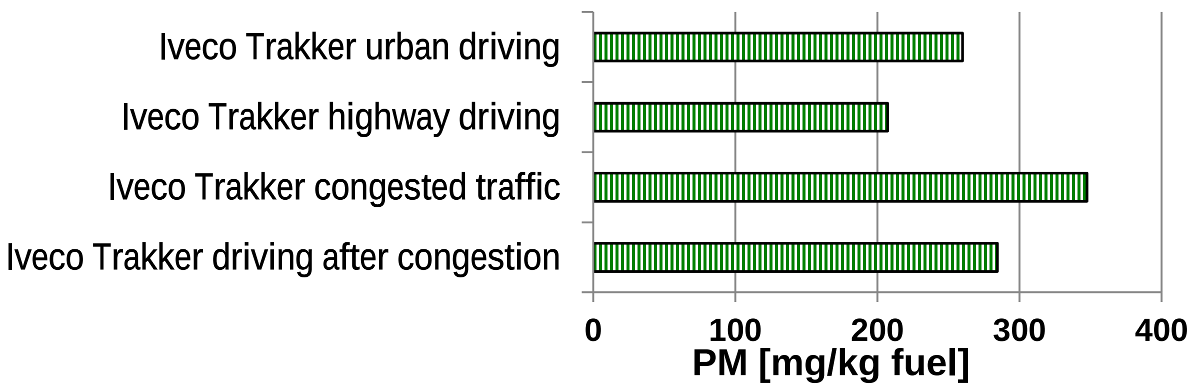
No c-PAHs detected

Analysis of genotoxic potential DNA adducts in acellular test



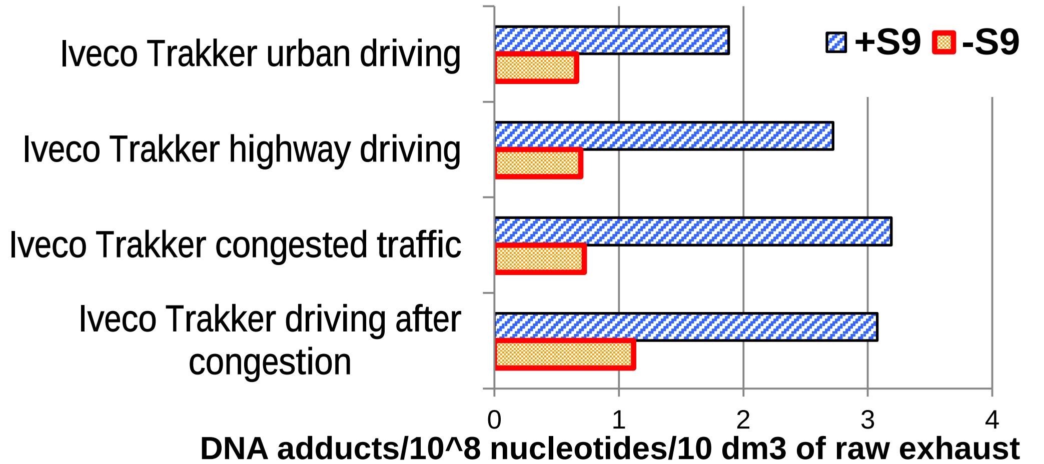
PM mass by Iveco Trakker
Comparison of driving conditions

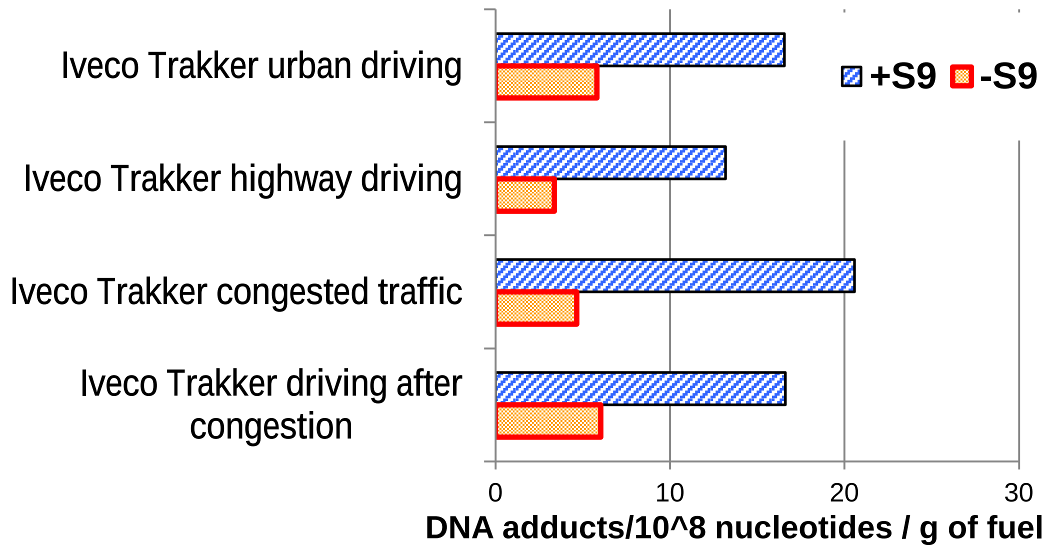




...highest PM mass for congestion and after congestion

DNA adducts by Iveco Trakker Comparison of driving conditions





Analysis of oxidative DNA damage
8-oxo-dG in acellular test

	+S9	-S9
	8-oxo/dG/10^5 nucleotides/sample	
IVECO DAILY		
All runs including idle	9.8	8.4
Blank	11.6	9.0
IVECO TRAKKER		
Cold idle after cold start	10.9	11.7
First run after cold start	12.6	10.2
Cold engine urban driving	15.7	13.5
Driving after congestion	12.4	8.9
Highway driving	11.2	9.1
Urban driving	14.2	7.4
Congested traffic	9.3	9.4
Blank	10.5	11.3

Almost no oxidative DNA damage induced by organic extracts !!!

Major conclusions from real driving measurements

- **Cold engine produces much higher quantity of particles, carcinogenic PAHs, genotoxicity (DNA adducts).**
- **Congestion is causing highest PM emissions and genotoxicity among “warm engine” driving conditions.**
- **Induction of oxidative damage by organic extracts from particulate fraction of engine emissions is negligible.**
- **Profit resulting from DPF and DOC was proved by substantial decrease of genotoxicity.**

Major conclusions from real driving measurements

- **Acellular test is sensitive and simple method to detect genotoxic potential of engine emissions. It detects genotoxicity even under the detection limit for carcinogenic PAHs.**
- **Other organic PM components than PAHs play significant role in its genotoxicity.**
- **Mass of samples collected by real driving does not enable complete toxicity testing in relevant human cell cultures**

Acknowledgements

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BIOTOX

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Mechanisms of toxicity of biofuel particulate emissions