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Materials Science & Technology


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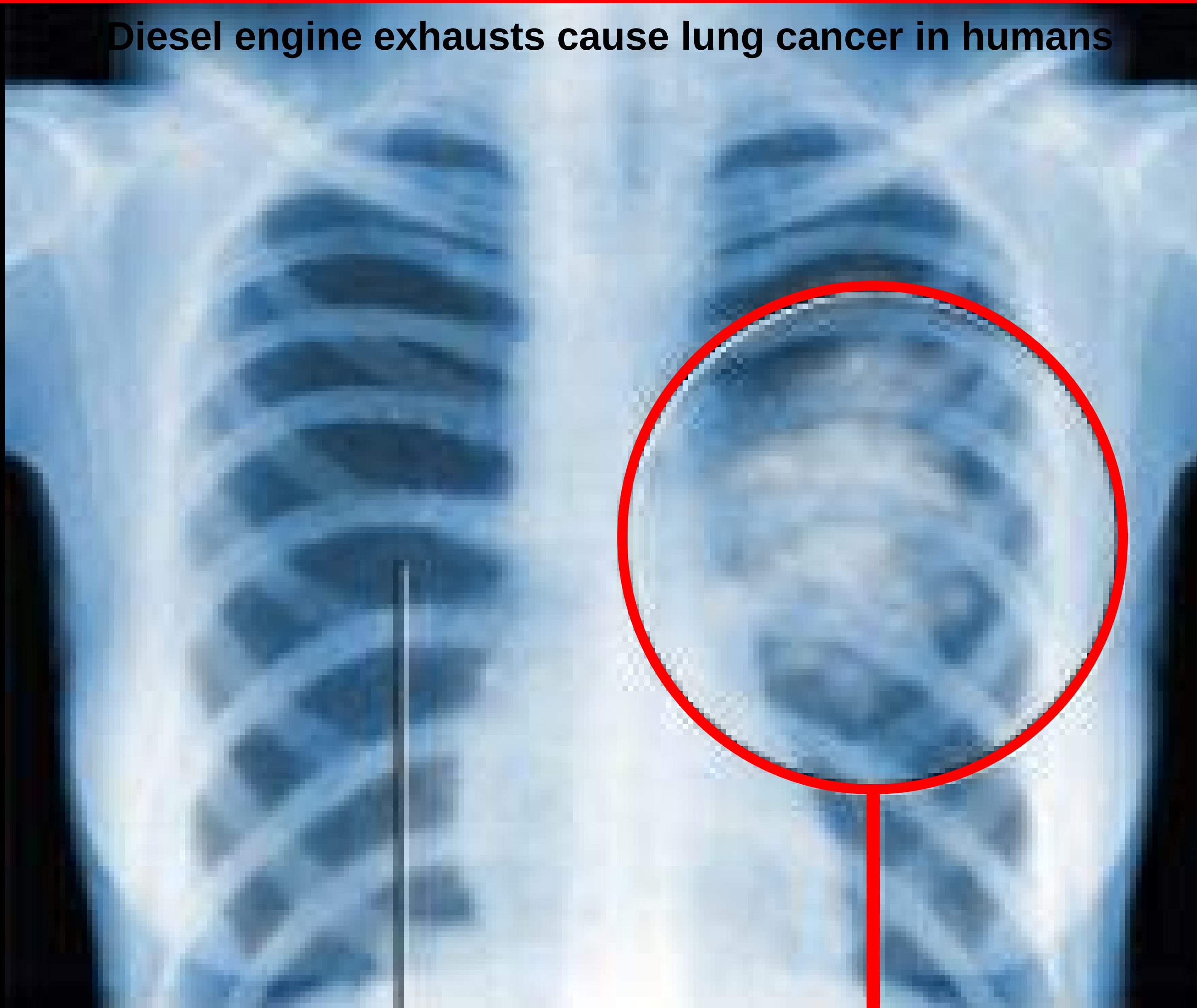
Catalysis, a key property of particle filters to lower genotoxicity of diesel exhaust

18th ETH Conference on Combustion Generated Nanoparticles

Zürich, June 22nd – 25th, 2014

World Health Organization, IARC
Diesel engine exhaust: A group 1 carcinogen



World Health Organization, IARC
Diesel engine exhaust: A group 1 carcinogen

Diesel engine exhausts cause lung cancer in humans

International Agency for Research on Cancer

World Health Organization

PRESS RELEASE
N° 213

12 June 2012

IARC: DIESEL ENGINE EXHAUST CARCINOGENIC

Lyon, France, June 12, 2012 -- After a week-long meeting of international experts, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), today classified diesel engine exhaust as **carcinogenic to humans (Group 1)**, based on sufficient evidence that exposure is associated with an increased risk for lung cancer.

Group 1

Background
In 1988, IARC classified diesel exhaust as *probably carcinogenic to humans (Group 2A)*. An Advisory Group which reviews and recommends future priorities for the IARC Monographs Program had recommended diesel exhaust as a high priority for re-evaluation since 1998.

There has been mounting concern about the cancer-causing potential of diesel exhaust, particularly based on findings in epidemiological studies of workers exposed in various settings. This was re-emphasized by the publication in March 2012 of the results of a large US National Cancer Institute/National Institute for Occupational Safety and Health study of occupational exposure to such emissions in underground miners, which showed an increased risk of death from lung cancer in exposed workers (1).

Lung cancer in exposed workers

World Health Organization, IARC
Diesel engine exhaust: a group 1 carcinogen

Diesel engine exhaust cause cancer in humans

The Diesel Exhaust in Miners Study: A Nested Case–Control Study of Lung Cancer and Diesel Exhaust

Debra T. Silverman, Claudine M. Samanic, Jay H. Lubin, Aaron E. Blair, Patricia A. Stewart, Roel Vermeulen, Joseph B. Coble, Nathaniel Rothman, Patricia L. Schleiff, William D. Travis, Regina G. Ziegler, Sholom Wacholder, Michael D. Attfield

Manuscript received February 16, 2011; revised June 3, 2011; accepted October 21, 2011.

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Background Most studies of the association between diesel exhaust exposure and lung cancer suggest a modest, but consistent, increased risk. However, to our knowledge, no study to date has had quantitative data on historical diesel exposure coupled with adequate sample size to evaluate the exposure–response relationship between diesel exhaust and lung cancer. Our purpose was to evaluate the relationship between quantitative estimates of exposure to diesel exhaust and lung cancer mortality after adjustment for smoking and other potential confounders.

Methods We conducted a nested case–control study in a cohort of 12315 workers in eight non-metal mining facilities, which included 198 lung cancer deaths and 562 incidence density–sampled control subjects. For each case subject, we selected up to four control subjects, individually matched on mining facility, sex, race/ethnicity, and birth year (within 5 years), from all workers who were alive before the day the case subject died. We estimated diesel exhaust exposure, represented by respirable elemental carbon (REC), by job and year, for each subject, based on an extensive retrospective exposure assessment at each mining facility. We conducted both categorical and continuous regression analyses adjusted for cigarette smoking and other potential confounding variables (eg, history of employment in high-risk occupations for lung cancer and a history of respiratory disease) to estimate odds ratios (ORs) and 95% confidence intervals (CIs). Analyses were both unlagged and lagged to exclude recent exposure such as that occurring in the 15 years directly before the date of death (case subjects)/reference date (control subjects). All statistical tests were two-sided.

Results We observed statistically significant increasing trends in lung cancer risk with increasing cumulative REC and average REC intensity. Cumulative REC, lagged 15 years, yielded a statistically significant positive gradient in lung cancer risk overall (P_{trend} = .001); among heavily exposed workers (ie, above the median of the top quartile [REC ≥ 1005 μg/m³-y]), risk was approximately three times greater (OR = 3.20, 95% CI = 1.33 to 7.69) than that among workers in the lowest quartile of exposure. Among never smokers, odd ratios were 1.0, 1.47 (95% CI = 0.29 to 7.50), and 7.30 (95% CI = 1.46 to 36.57) for workers with 15-year lagged cumulative REC tertiles of less than 8, 8 to less than 304, and 304 μg/m³-y or more, respectively. We also observed an interaction between smoking and 15-year lagged cumulative REC ($P_{interaction}$ = .086) such that the effect of each of these exposures was attenuated in the presence of high levels of the other.

Conclusion Our findings provide further evidence that diesel exhaust exposure may cause lung cancer in humans and may represent a potential public health burden.

J Natl Cancer Inst 2012;104:1–14

12315 workers, 8 mines
198 lung cancer death
(16 in 1000)

diesel exhaust exposure:
a potential public health burden

Swiss occupational health legislation

Grenzwerte am Arbeitsplatz 2009

suvapro
Sicher arbeiten

Stoff [CAS-Nummer]	MAK-Wert ml/m³ (ppm)	MAK-Wert mg/m³	Kurzzeitgrenzwerte ml/m³ (ppm)	Kurzzeitgrenzwerte mg/m³	Zeitl. Begrenzung (Häufigkeit x Dauer in min./Schicht)	HSB	C	M	R_F	R_E	SS	Messmethoden/ besondere Bemerkungen
1,3-Dichlorpropen (cis und trans) [542-75-6]	0,11	0,5				HS	2	3				
2,2-Dichlorpropionsäure [75-99-0] und ihr Natriumsalz [127-20-8]	1	6	1	6	15 min							
1,2-Dichlor-1,1,2,2-tetrafluorethan (R 114) [76-14-2]	1000	7000										DFG, NIOSH
Dicyclopentadienyleisen [102-54-5]		10 e										
Dieldrin (HEOD) [60-57-1]		0,25 e				H	3					NIOSH
Dieselmotor-Emissionen (gemessen als elementarer Kohlenstoff)		0,1 a					2					BG

„Für Dieselmotoremissionen beträgt der Arbeitsplatzgrenzwert 100 µg/m³ mit dem Zusatz des Minimierungsgebotes, da Dieselmotoremissionen als krebserzeugend eingestuft sind. Generell sind Massnahmen die zu einer Verringerung der Dieselmotoremissionen führen damit sinnvoll.“

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Ordinance on Air Pollution Control (OAPC): List of carcinogenic substances

Luftreinhalte-Verordnung (LRV)

814.318.142.1

83 Tabelle von krebserzeugenden Stoffen

Stoff	Summenformel	Klasse
Benzo(a)pyren	$C_{20}H_{12}$	1
Benzol	C_6H_6	3
Dibenz(a, h)anthracen	$C_{22}H_{14}$	1
1,2-Dibromethan	$C_2H_4Br_2$	3
1,4 Dichlorbenzol	$C_6H_4Cl_2$	3
1,2-Dichlorethan	$C_2H_4Cl_2$	3
Dieselruss		3
Diethylsulfat	$C_4H_{10}O_4S$	2

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What does asbestos has in common with diesel exhaust?

Ordinance on Air Pollution Control (OAPC): List of carcinogenic substances

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Dieselruss		1
Diethylsulfat	$C_4H_{10}O_4S$	

EMPA

Both are group 1 carcinogens and cause cancer in humans

The visible effect of a DPF

7 m^3 exhaust, released in 3 min from a 3.0 L Euro-III engine (100 kW)

Retrofitting of Euro-III to Euro-V heavy duty vehicles – an option for Switzerland?

CH national council rejected

12.3832 Ref. 10185

NATIONALRAT
Abstimmungsprotokoll

CONSEIL NATIONAL
Procès-verbal de vote

Geschäft / Objet

12.3832 Mo. Vischer Daniel. Nachrüstung von Dieselfahrzeugen mit Partikelfiltern
Mo. Vischer Daniel. Equiper les véhicules diesel de filtres à particules

Gegenstand / Objet du vote:

Abstimmung vom / Vote du: 06.05.2014 17:06:49

Aebi Andreas	-	V	BE
Aebischer Matthias	+	S	BE
Aeschi Thomas	-	V	ZG
Allemann	+	S	BE
Amarelle	+	S	VD
Amaudruz	-	V	GE
Amherd	-	CE	VS
Amstutz	-	V	BE
Aubert	+	S	VD
Baader Caspar	-	V	BL
Badran Jacqueline	+	S	ZH
Barazzone	-	CE	GE
Bäumle	+	GL	ZH
Bernasconi	+	S	GE
Bertschy	+	GL	BE
Binder	[illegible]	V	ZH

Fischer Roland	+	GL	LU
Flach	+	GL	AG
Flückiger Sylvia	-	V	AG
Fluri	-	RL	SO
Français	0	RL	VD
Frehner	-	V	BS
Freysinger	-	V	VS
Fridez	0	S	JU
Friedl	+	S	SG
Galladé	[illegible]	[illegible]	[illegible]
Gasche	[illegible]	[illegible]	[illegible]
Gasser	[illegible]	[illegible]	[illegible]
Geissbühler	-	V	BE
Germanier	0	RL	VS
Giezendanner	-	V	AG
Gilli	0	G	SG

Keller Peter	-	V	NW
Kessler	+	GL	SG
Kiener Nellen	0	S	BE
Killer Hans	-	V	AG
Knecht	-	V	AG
Landolt	-	BD	GL
Lehmann	-	CE	BS
Leuenberger-Genève	+	G	GE
Leutenegger Filippo	-	RL	ZH
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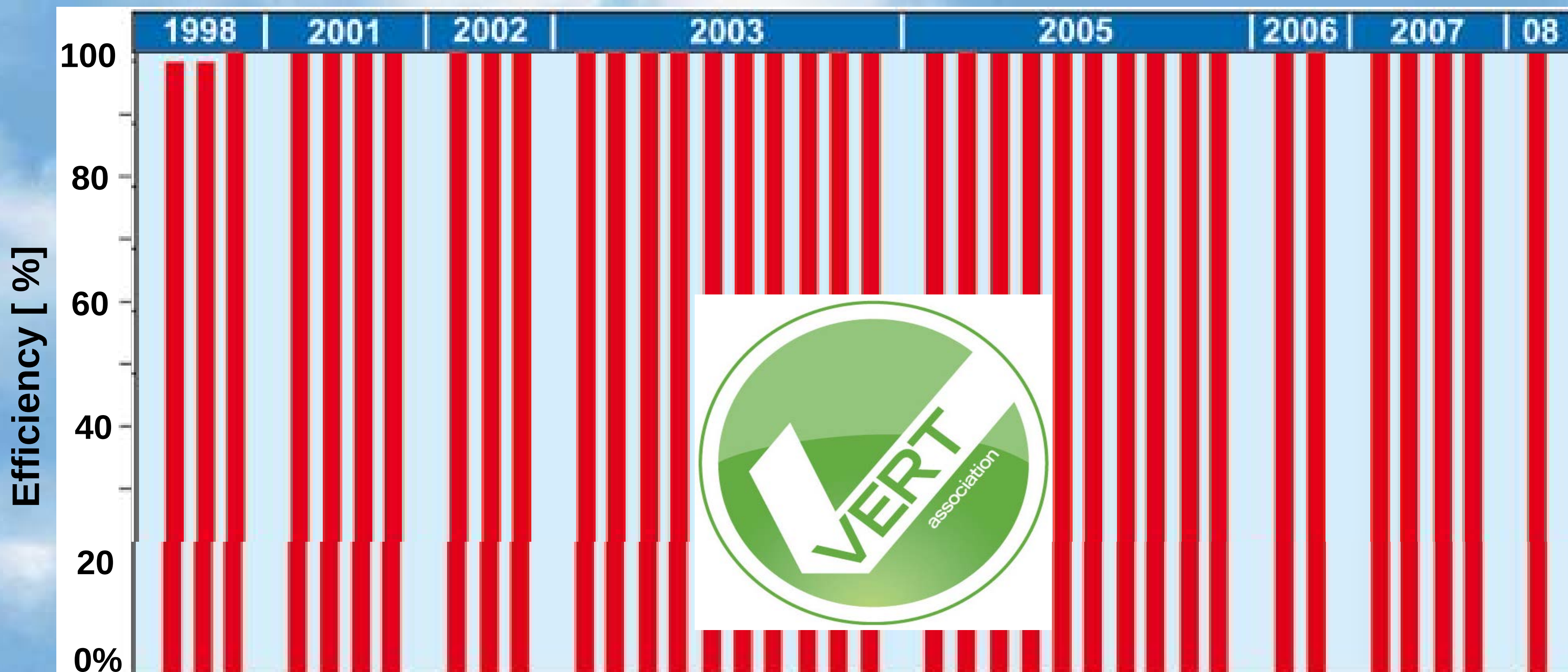
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Lustenberger	P	CE	LU
Mahrer	+	G	GE
Maier Thomas	+	GL	ZH
Maire Jacques André	+	S	NE

Reimann Maximilian	-	V	AG
Reynard	+	S	VS
Rickli Natalie	-	V	ZH
Riklin Kathy	=	CE	ZH
Rime	-	V	FR
Ritter	-	CE	SG
Romano	-	CE	TI
Rossini	+	S	VS
Rösti	-	V	BE
[illegible]	[illegible]	V	TI
[illegible]	[illegible]	V	ZH
[illegible]	[illegible]	G	BE
Schelbert	+	G	LU
Schenker Silvia	+	S	BS
Schibli	-	V	ZH
Schilliger	[illegible]	RL	LU

Rejected with 64 yes against 102 no's

The visible effect of a DPF

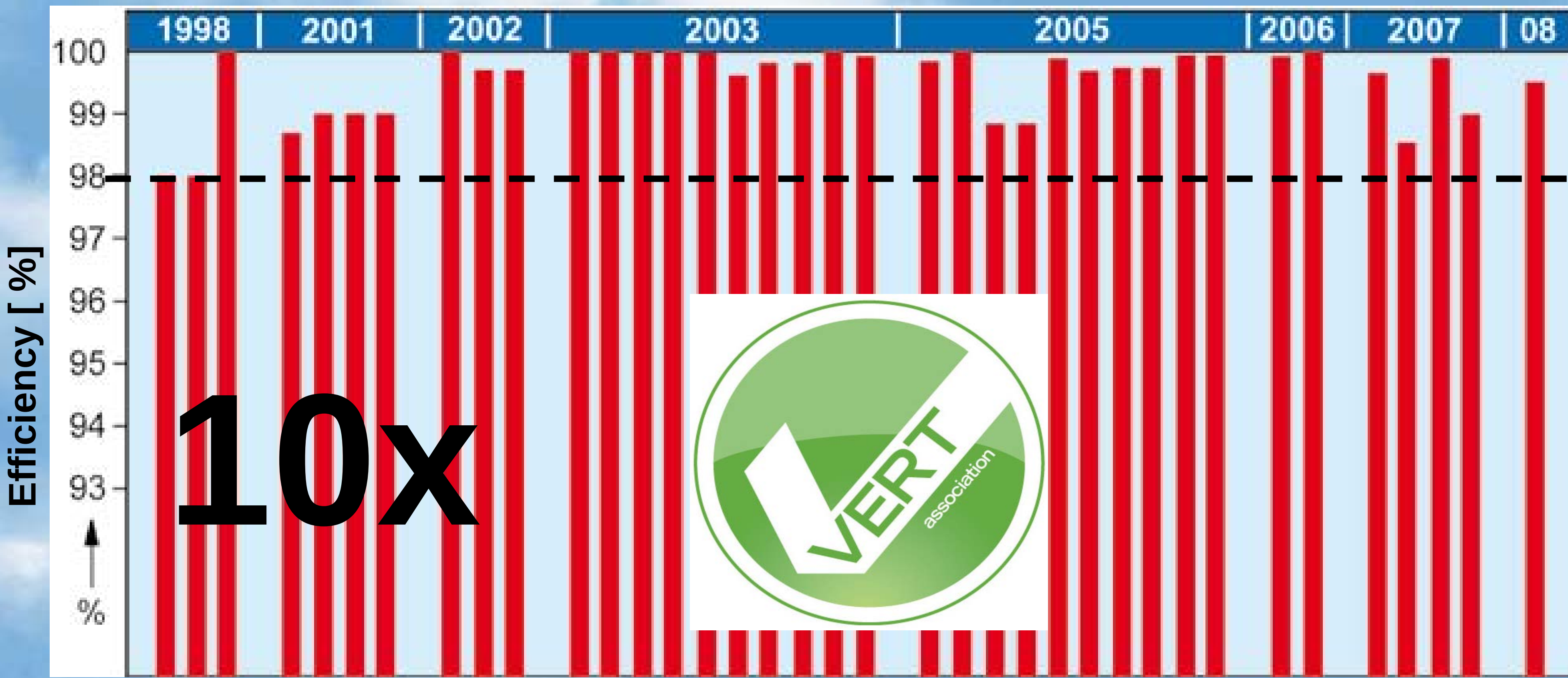
More than 40 VERT-tested DPFs. All approved systems are excellent particle filters



Mayer et al. MTZ, **2009**, 70, 72-79

The visible effect of a DPF

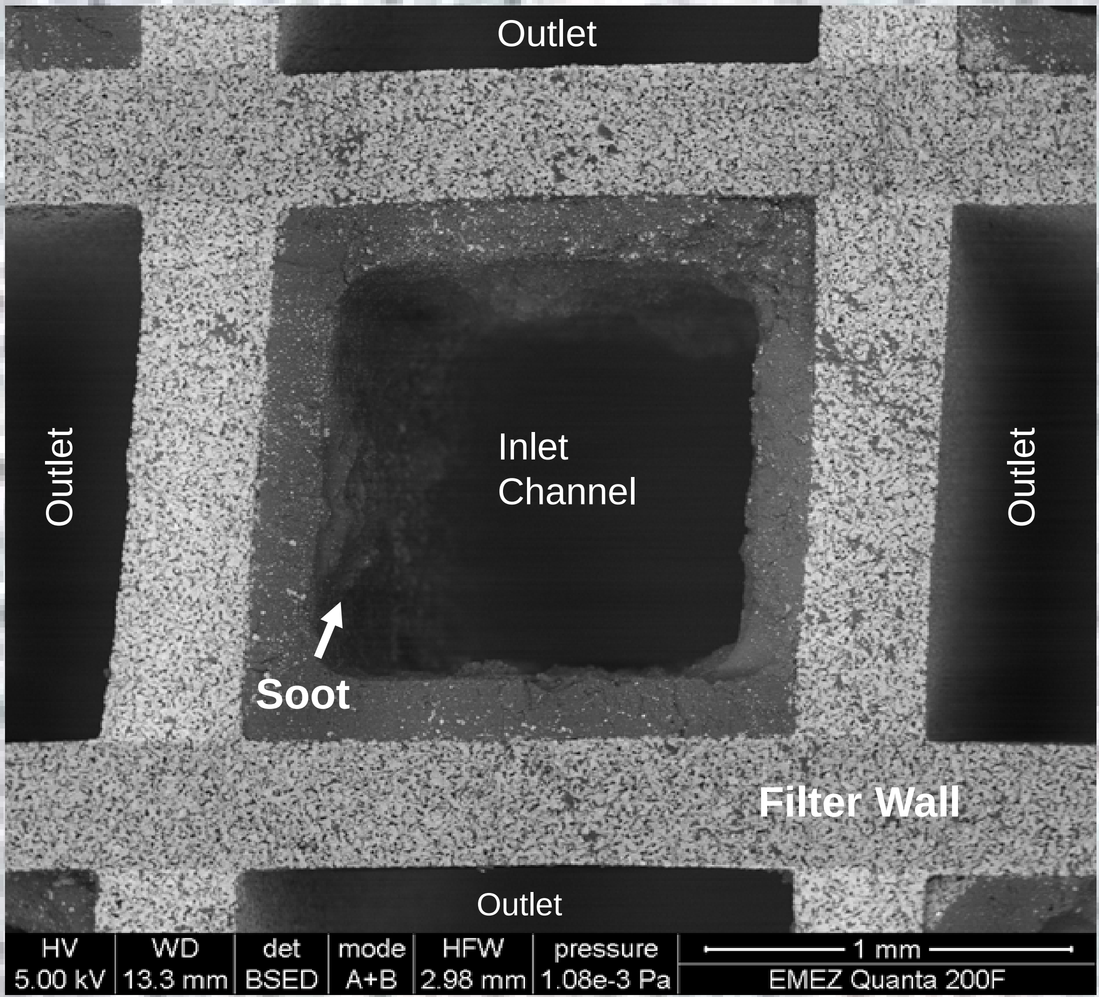
You have to zoom in to see differences among filters



Mayer et al. MTZ, **2009**, 70, 72-79

The visible effect of a DPF

Wall-through filters are highly efficient for soot

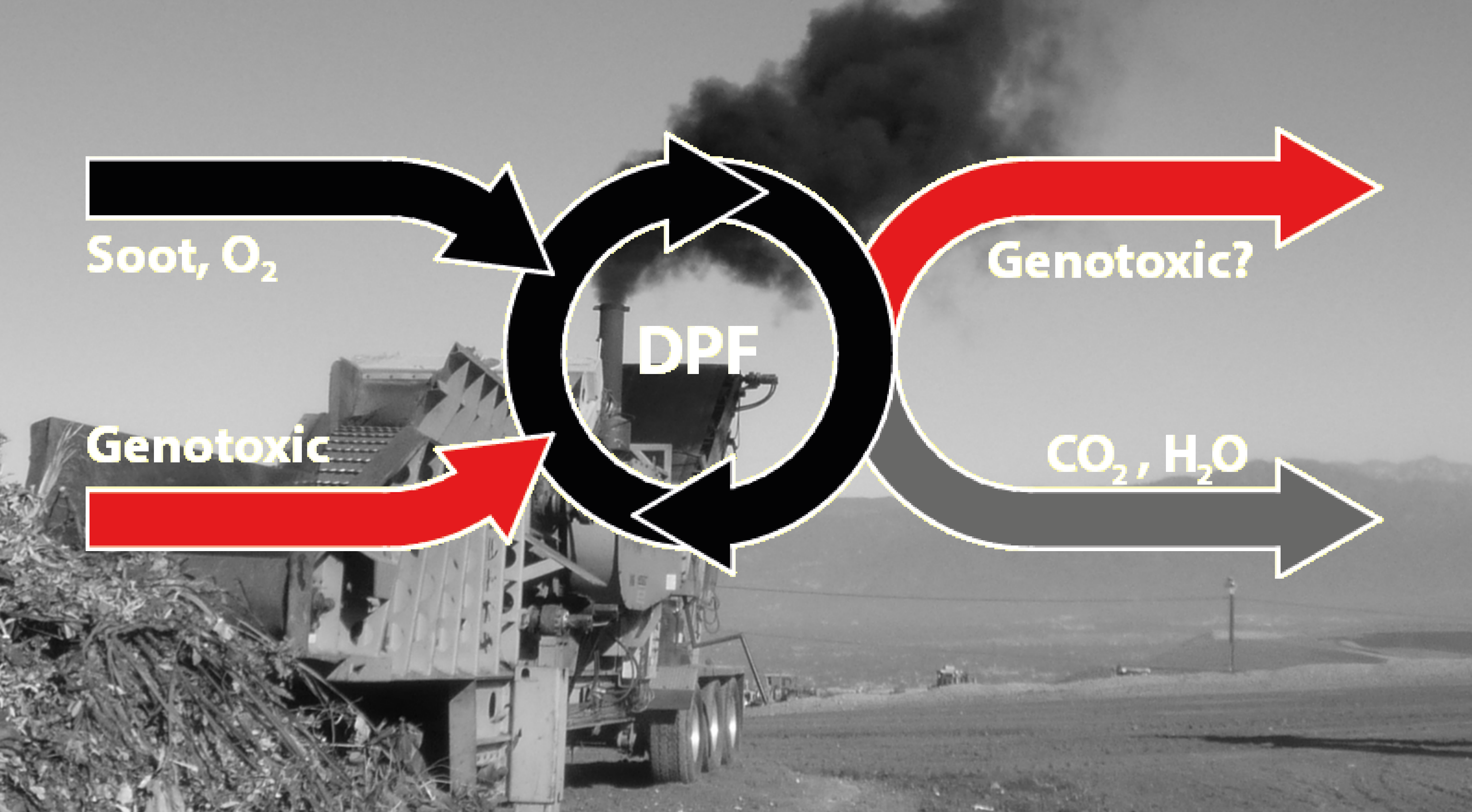


VERT-approved DPFs:

- Reduce PN-emissions (>98%)
- Reduce genotoxic compounds (a.m.a.p.)
- Low risks of toxic secondary emissions

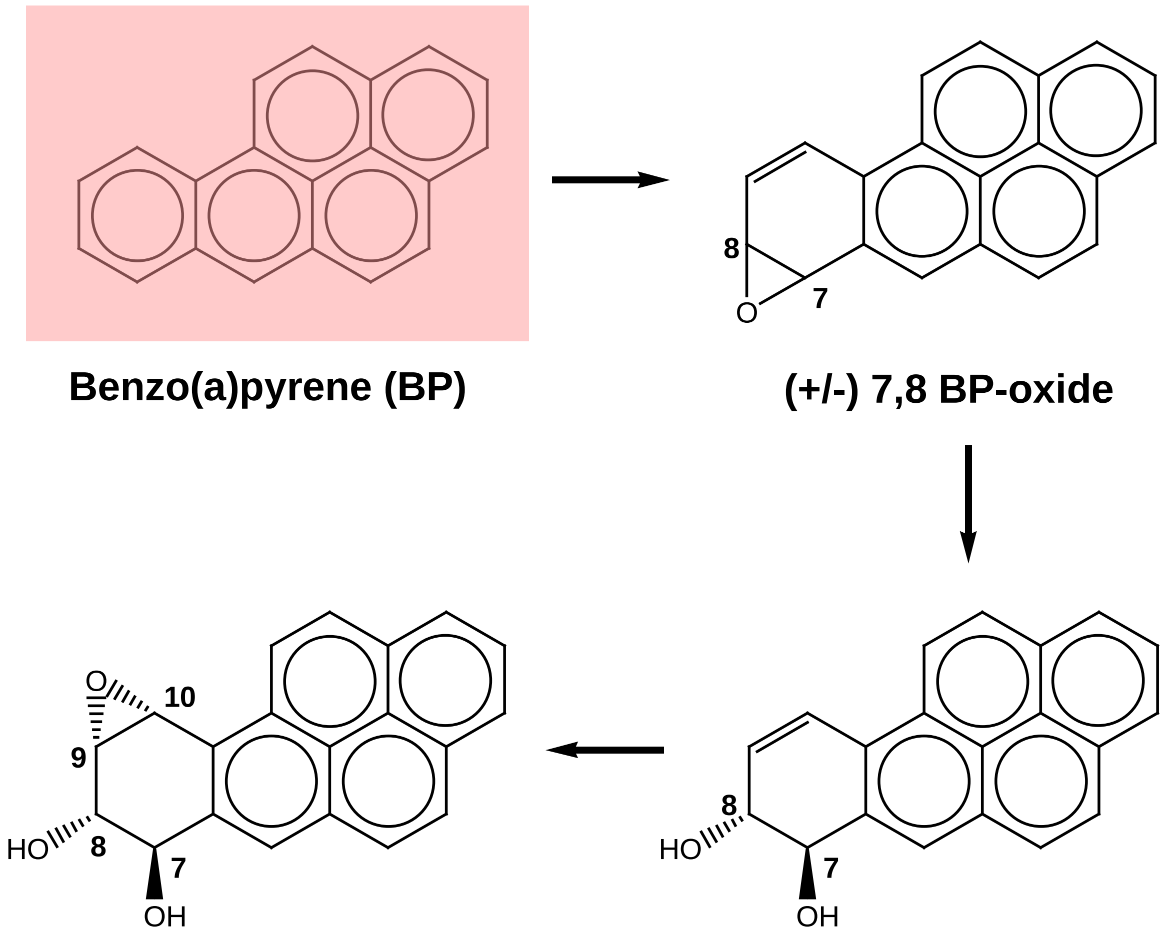
Impact of DPFs on genotoxicity

Is efficient filtration of soot sufficient to lower the genotoxicity of diesel exhaust?



Carcinogenesis from benzo(a)pyrene

Oxidative metabolic activation of benzo(a)pyrene by cytochrome P450 enzymes



Benzo(a)pyrene (BP)

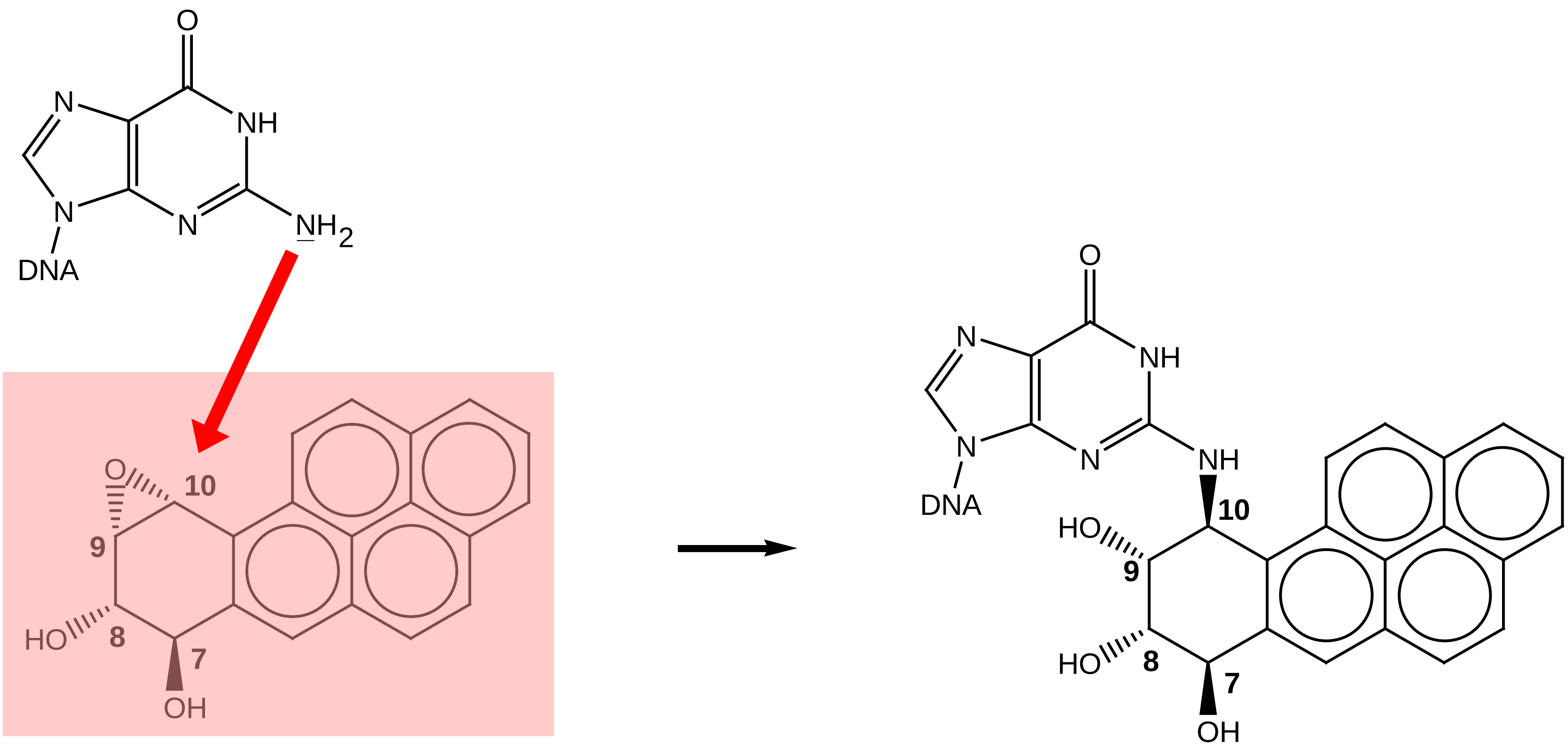
(+/-) 7,8 BP-oxide

(+/-) 7,8 BP-dihydrodiol

(+) anti 7R,8S,9S,10R-BP-dihydrodiol-epoxide

Carcinogenesis from benzo(a)pyrene

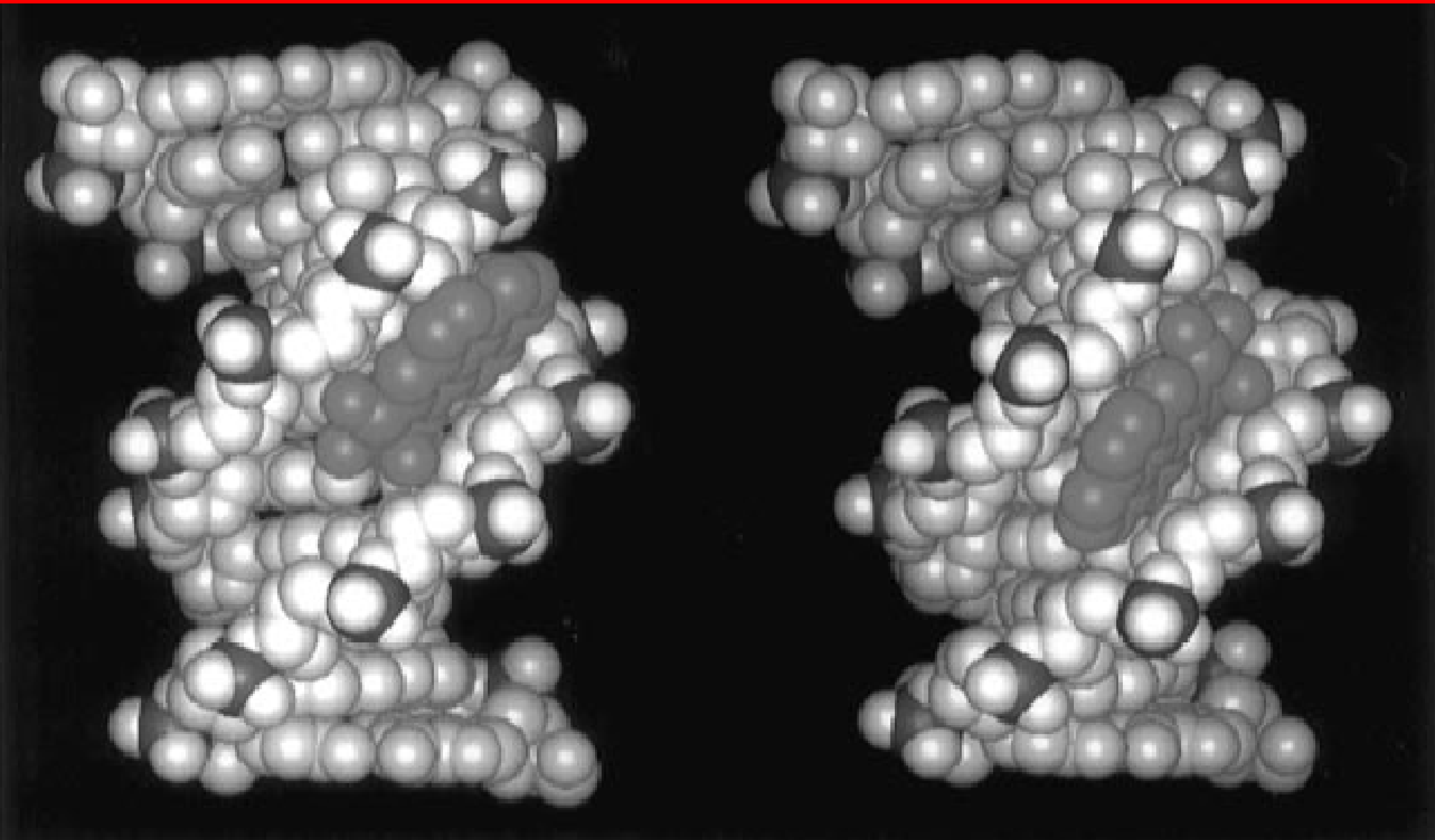
Selective formation of benzo(a)pyrene-DNA-adducts



(+) anti 7R,8S,9S,10R-BP-dihydrodiol-epoxide

(-) 10R trans-anti-[BP]-triol-N2-deoxy-guanosine-adduct

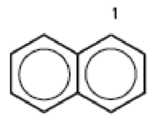
Carcinogenesis from benzo(a)pyrene



Polycyclic aromatic hydrocarbons

PAHs - a diverse class of compounds with variable physicochemical properties

2- to 6-ring PAHs



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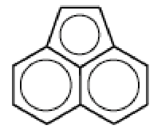

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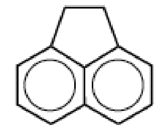

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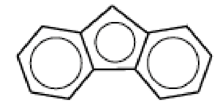

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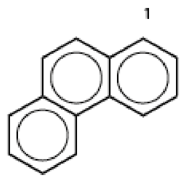

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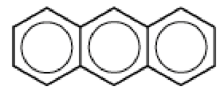

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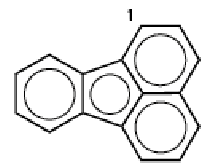

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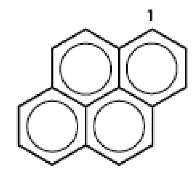

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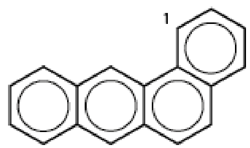

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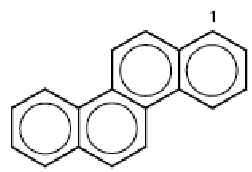

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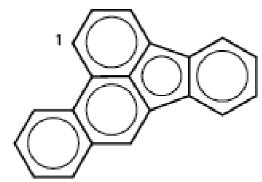

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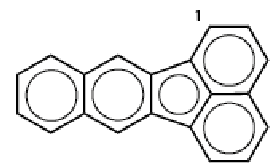

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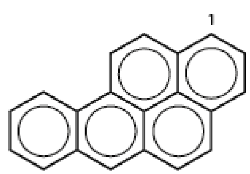

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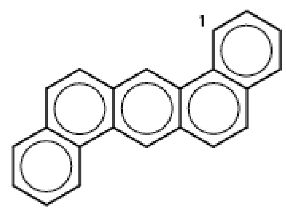

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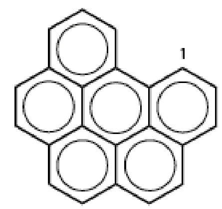

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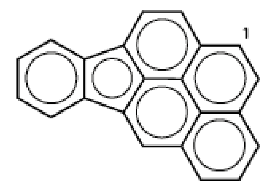

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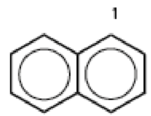
Polycyclic aromatic hydrocarbons

PAHs - a diverse class of compounds with variable physicochemical properties

2- to 6-ring PAHs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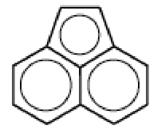
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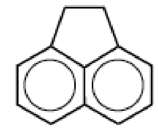
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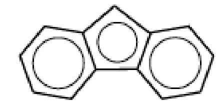
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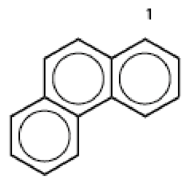
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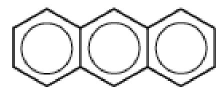
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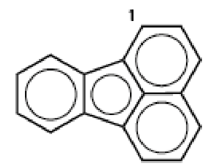
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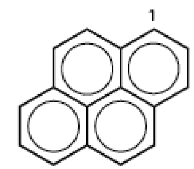
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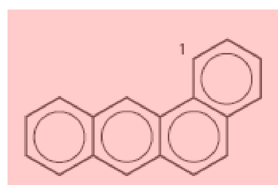
genotoxic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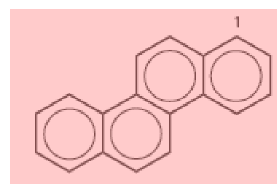
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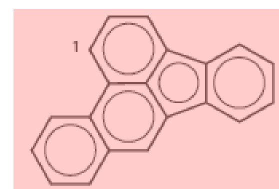
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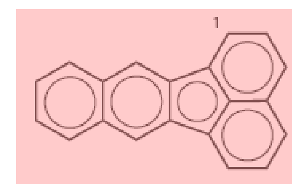
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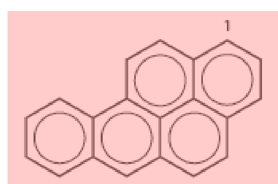
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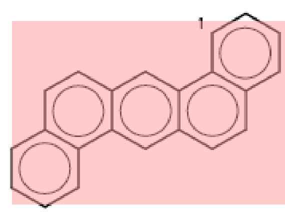
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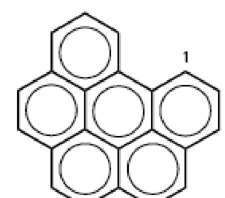
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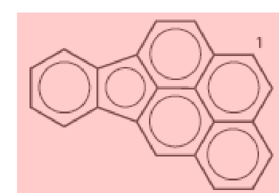
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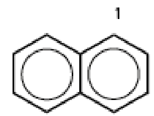
Polycyclic aromatic hydrocarbons

PAHs - a diverse class of compounds with variable physicochemical properties

2- to 6-ring PAHs

precursors for genotoxic NPAHs



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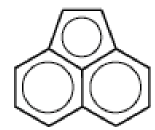

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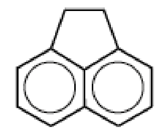

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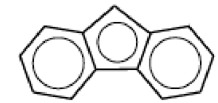

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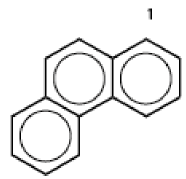

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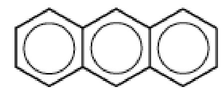

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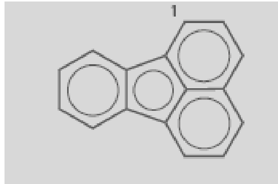

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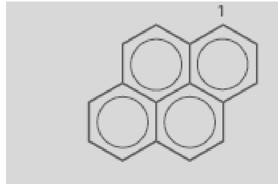

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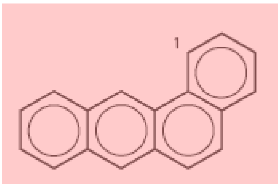

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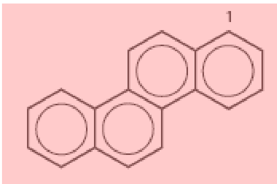

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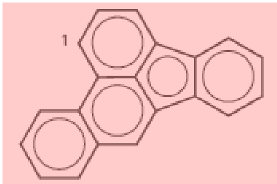

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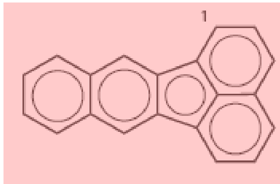

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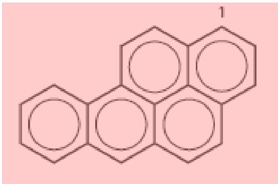

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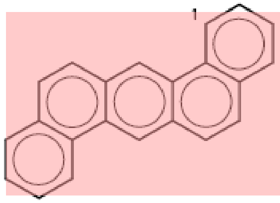

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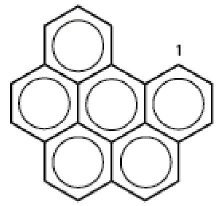

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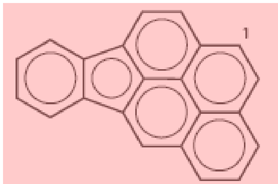


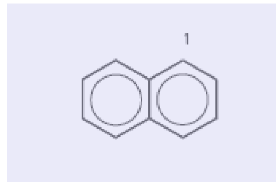
16

Polycyclic aromatic hydrocarbons

PAHs - a diverse class of compounds with variable physicochemical properties

2- to 6-ring PAHs

differ in mass, size & volatility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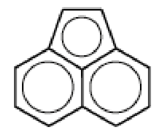
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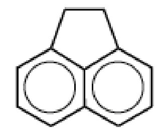
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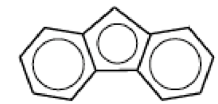
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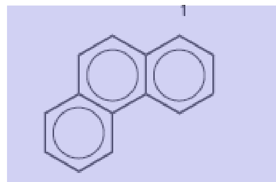
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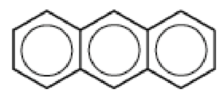
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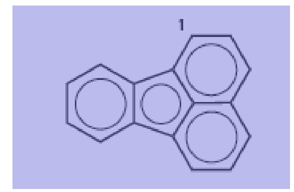
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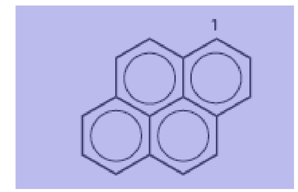
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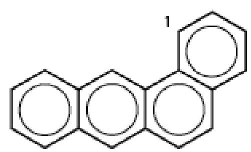
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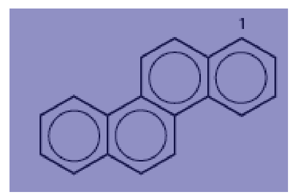
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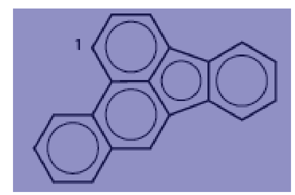
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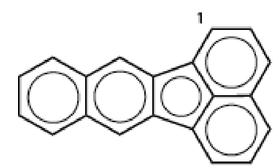
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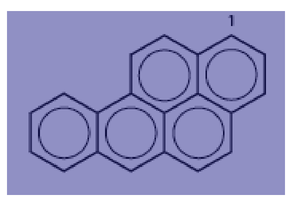
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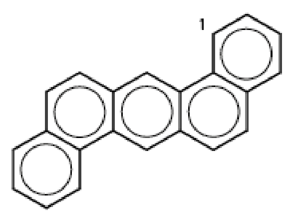
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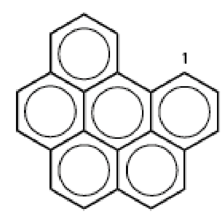
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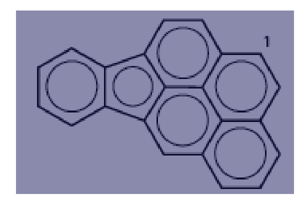

16

PAH Penetration of a non-catalyzed DPF

Non-catalyzed filters are as efficient for soot. How about genotoxic compounds?

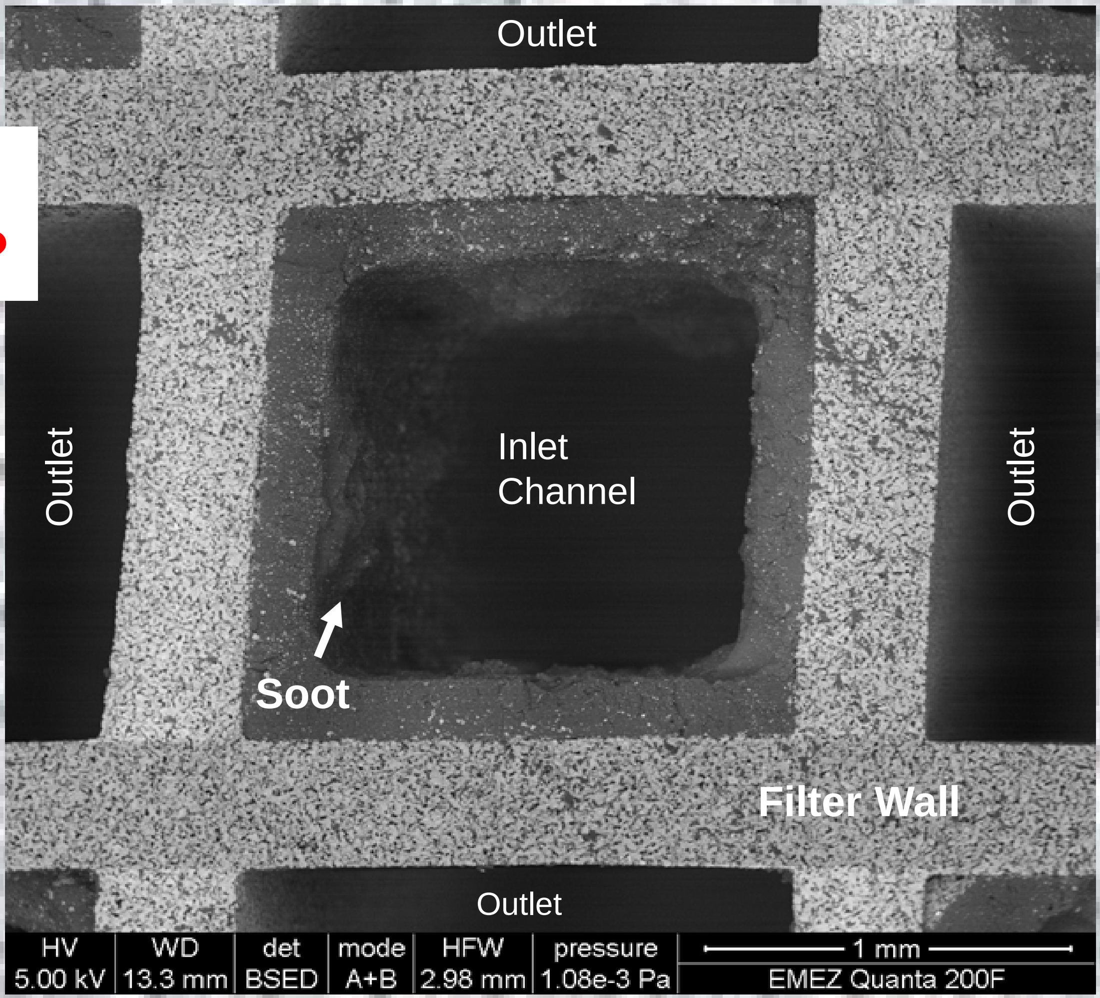
What do you expect,
can PAHs penetrate DPFs?

Non-catalyzed DPFs:

- Accumulate soot (>98%)

→ Do they reduce genotoxic compounds a.m.a.p?

→ Do they have toxic secondary emissions?



PAH Penetration of a non-catalyzed DPF

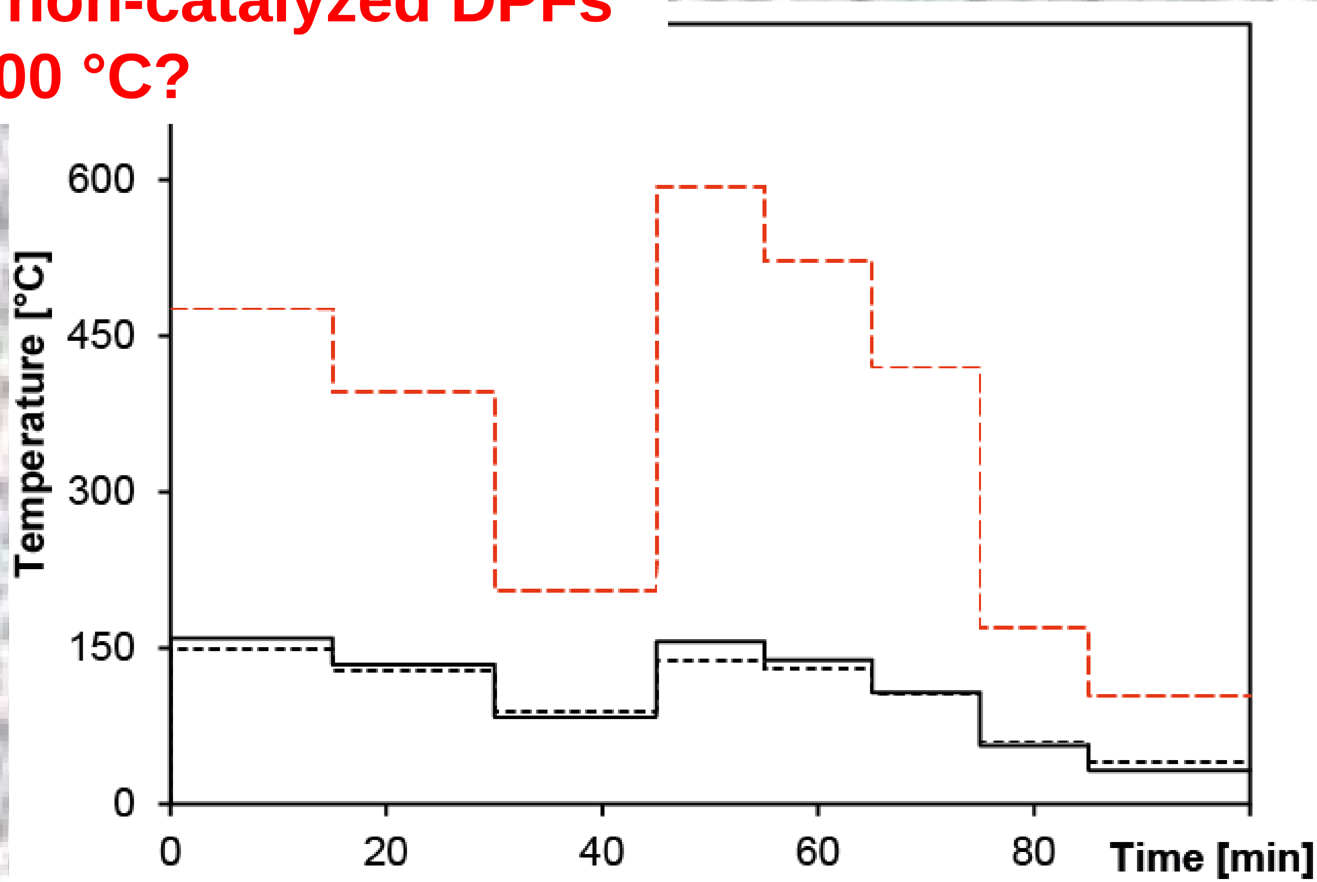
Non-catalyzed filter operated <200 °C accumulate soot. How about hydrocarbons?

Do PAHs penetrate non-catalyzed DPFs if operated below 200 °C?

engine-out

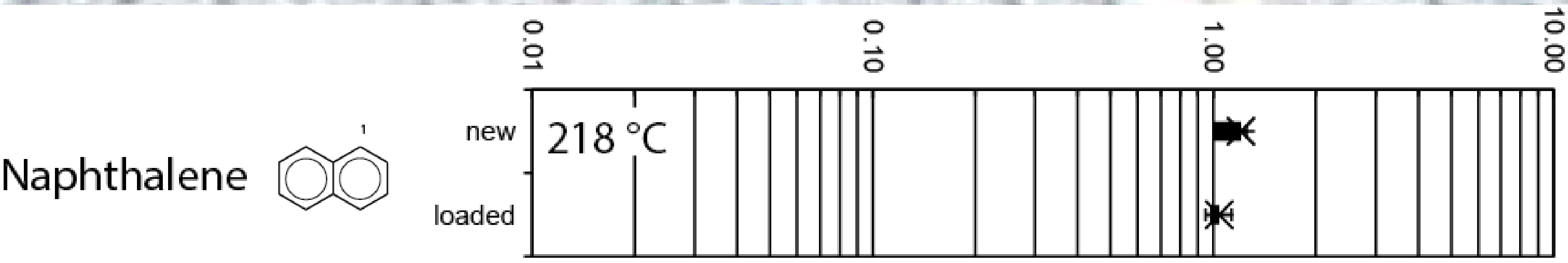
before DPF

after DPF



PAH Penetration of a non-catalyzed DPF

Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons

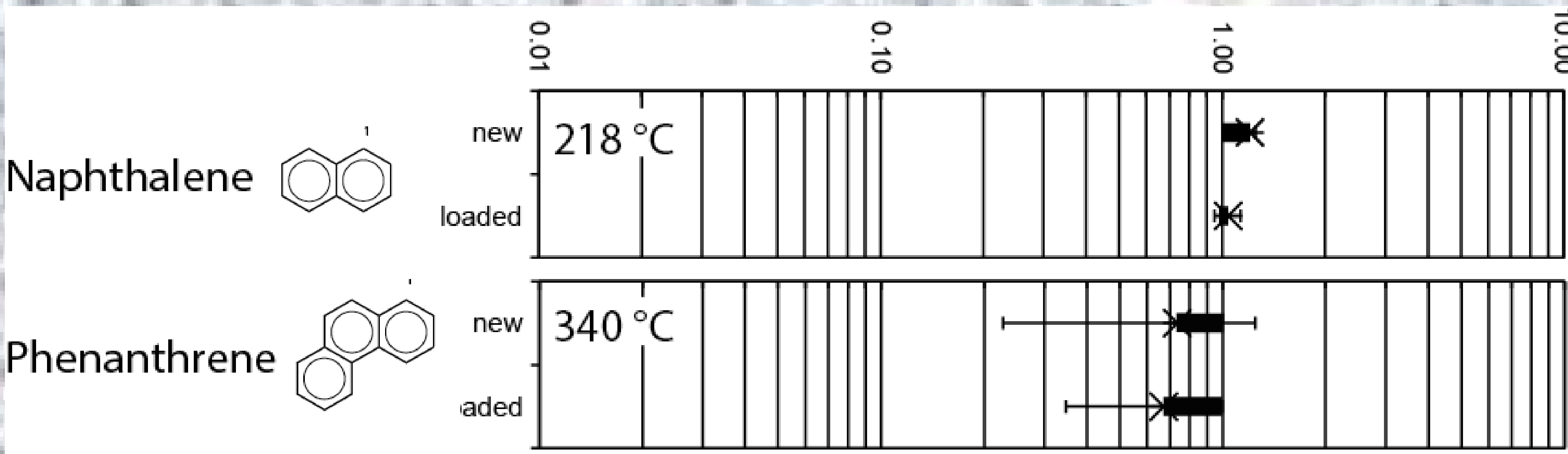


- No retention of naphthalene in a new and a soot-loaded DPF

- Naphthalene is too volatile, it even escapes from a cold filter (<200 °C)

PAH Penetration of a non-catalyzed DPF

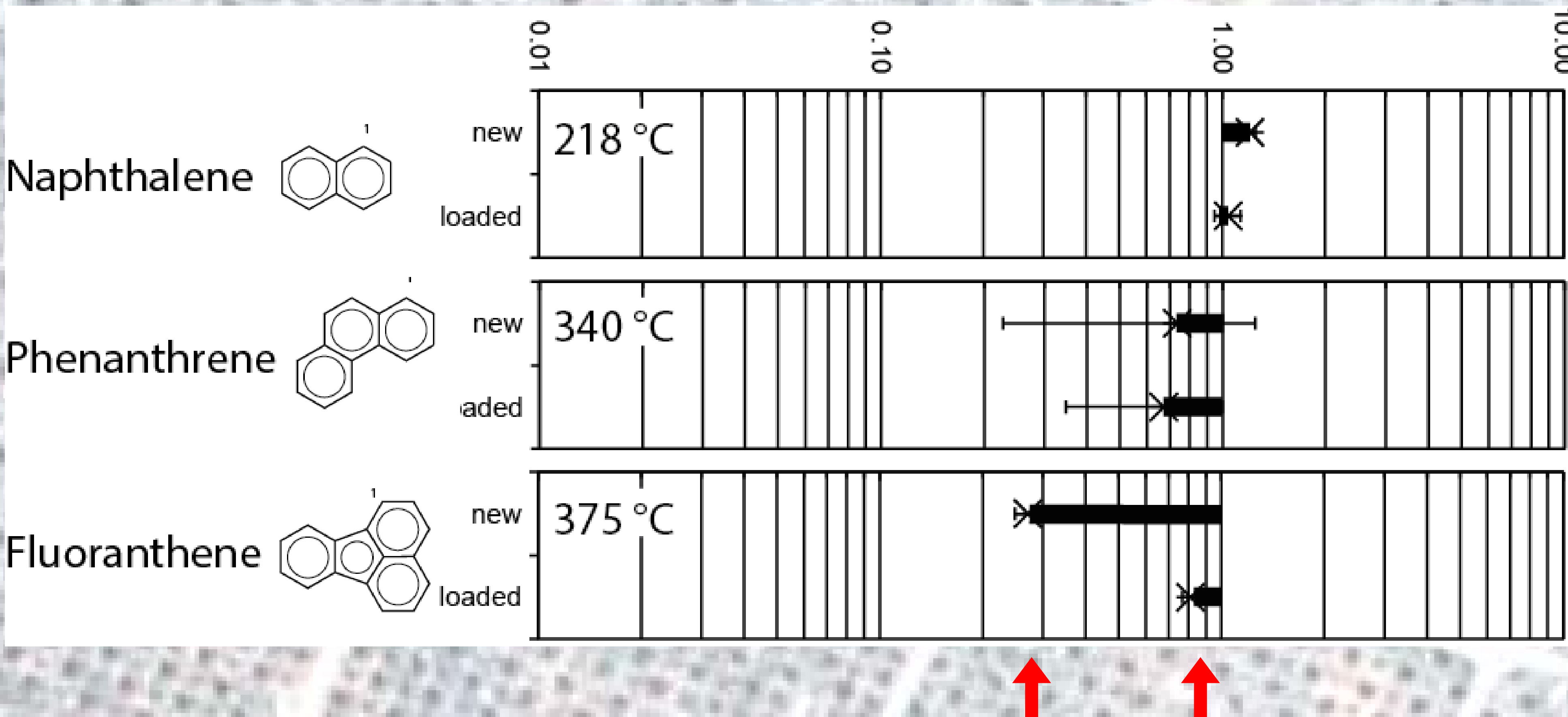
Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons



- **About 30% retention, both in a new and a soot-loaded DPF**
- **Phenanthrene is partly stored in a cold filter (<200 °C)**

PAH Penetration of a non-catalyzed DPF

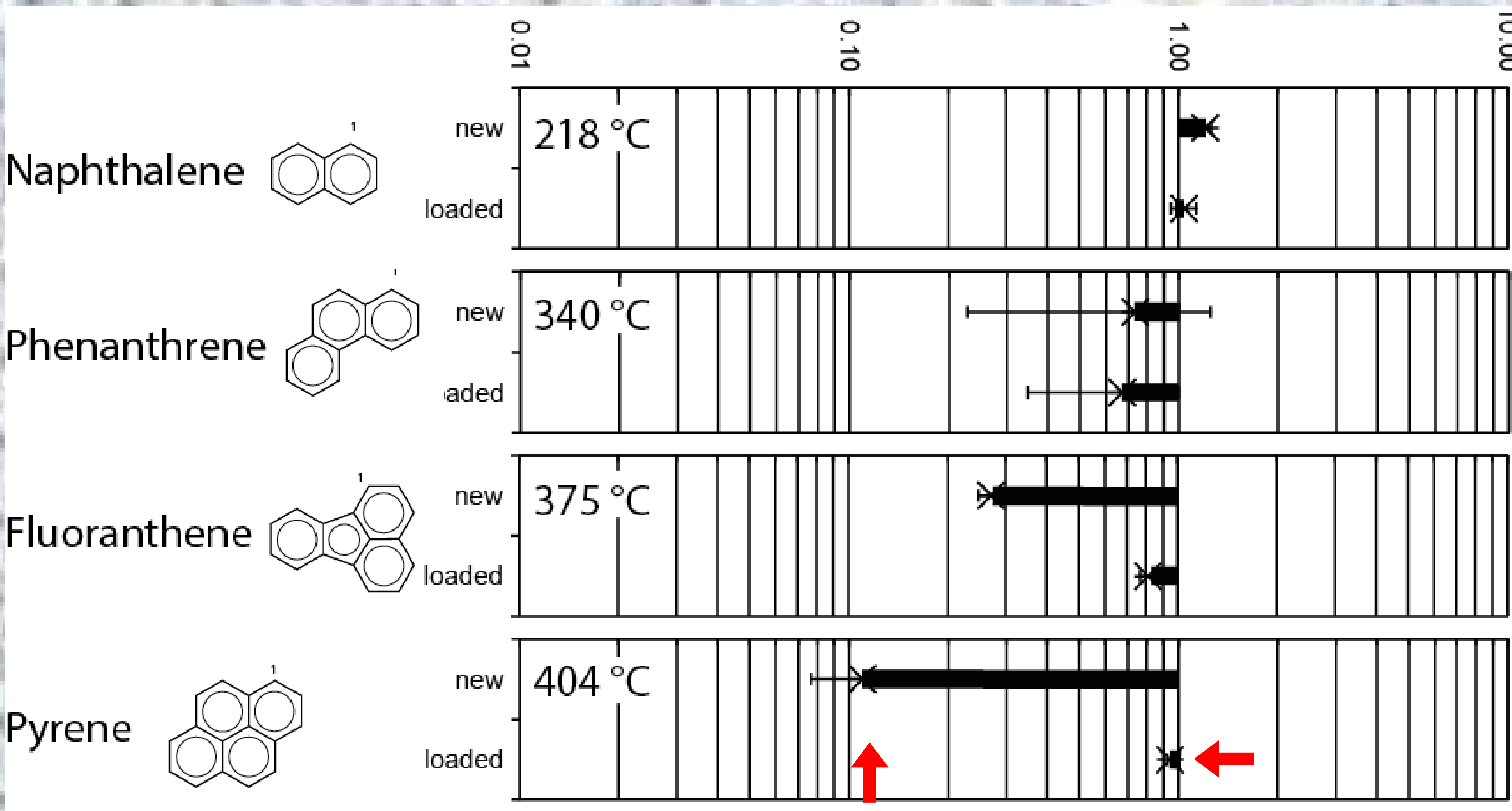
Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons



- 70% is retained in the new, only 15% in the soot-loaded DPF?

PAH Penetration of a non-catalyzed DPF

Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons



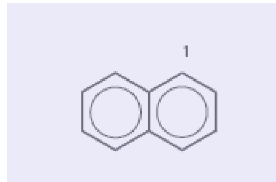
- 90% is retained in the new, only 5% in the soot-loaded DPF?

Polycyclic aromatic hydrocarbons

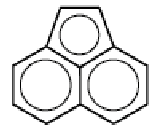
PAHs - a diverse class of compounds with variable physicochemical properties

2- to 6-ring PAHs

High penetration of volatile 2-4-ring PAHs



218 °C



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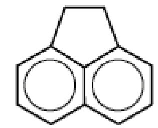

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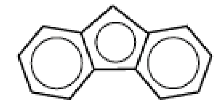

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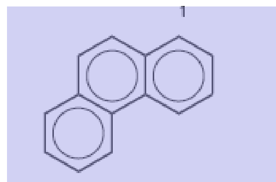
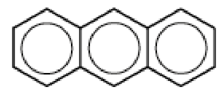


340 °C



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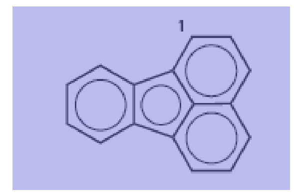
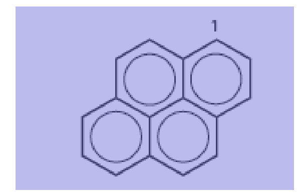
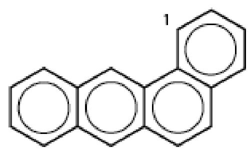


375 °C



404 °C



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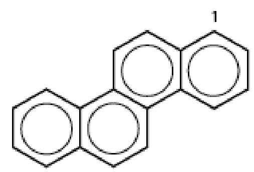

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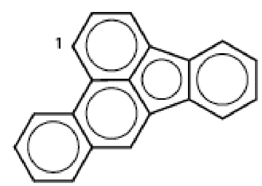

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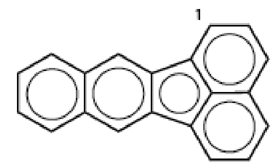

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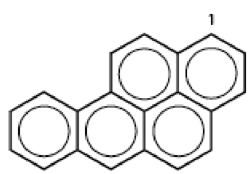

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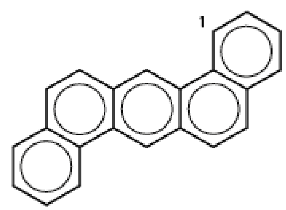

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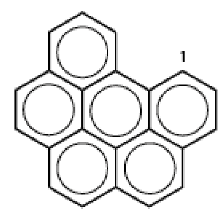

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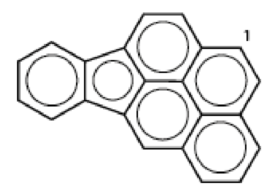


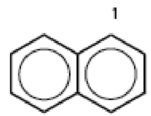
16

Polycyclic aromatic hydrocarbons

PAHs - a diverse class of compounds with variable physico-chemical properties

2- to 6-ring PAHs

What do we expect for less volatile PAHs?



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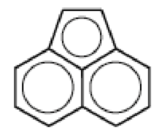

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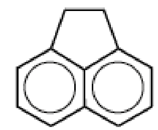

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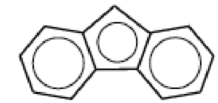

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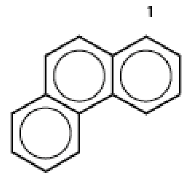

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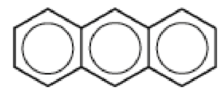

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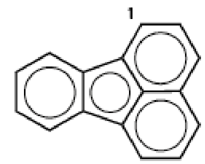

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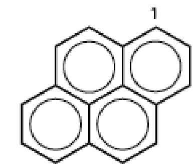

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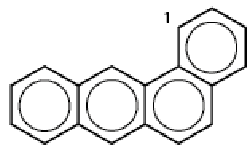

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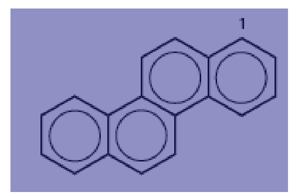
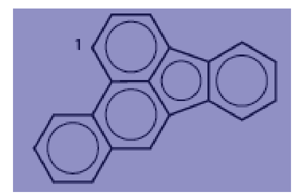
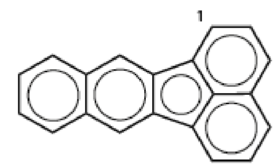


448 °C



481 °C



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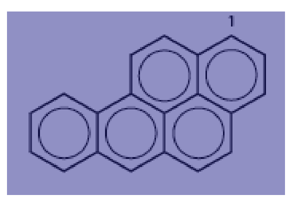
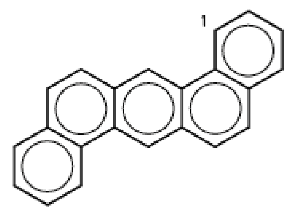


495 °C



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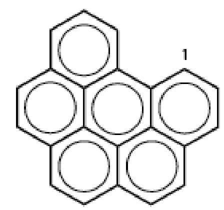

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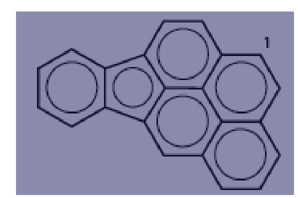
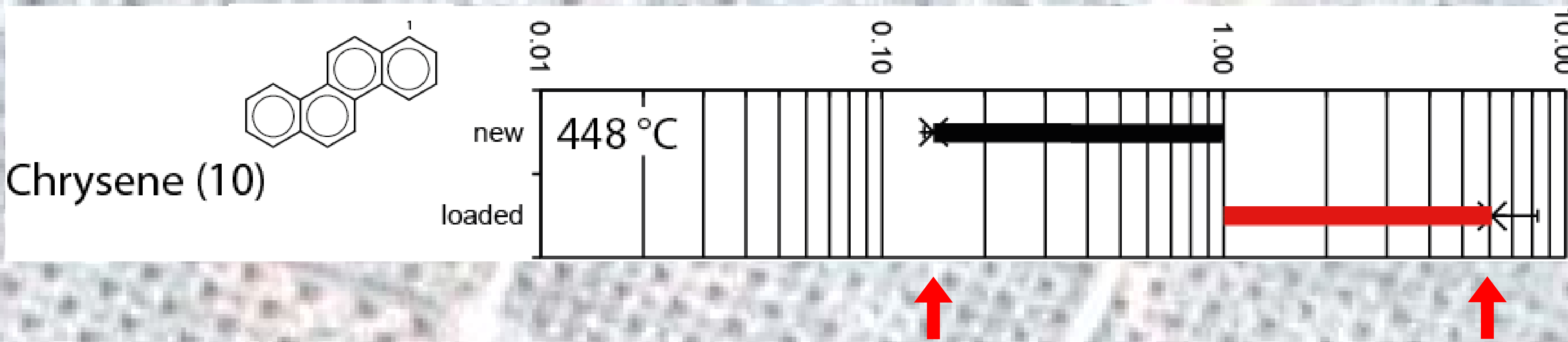


536 °C

PAH Penetration of a non-catalyzed DPF

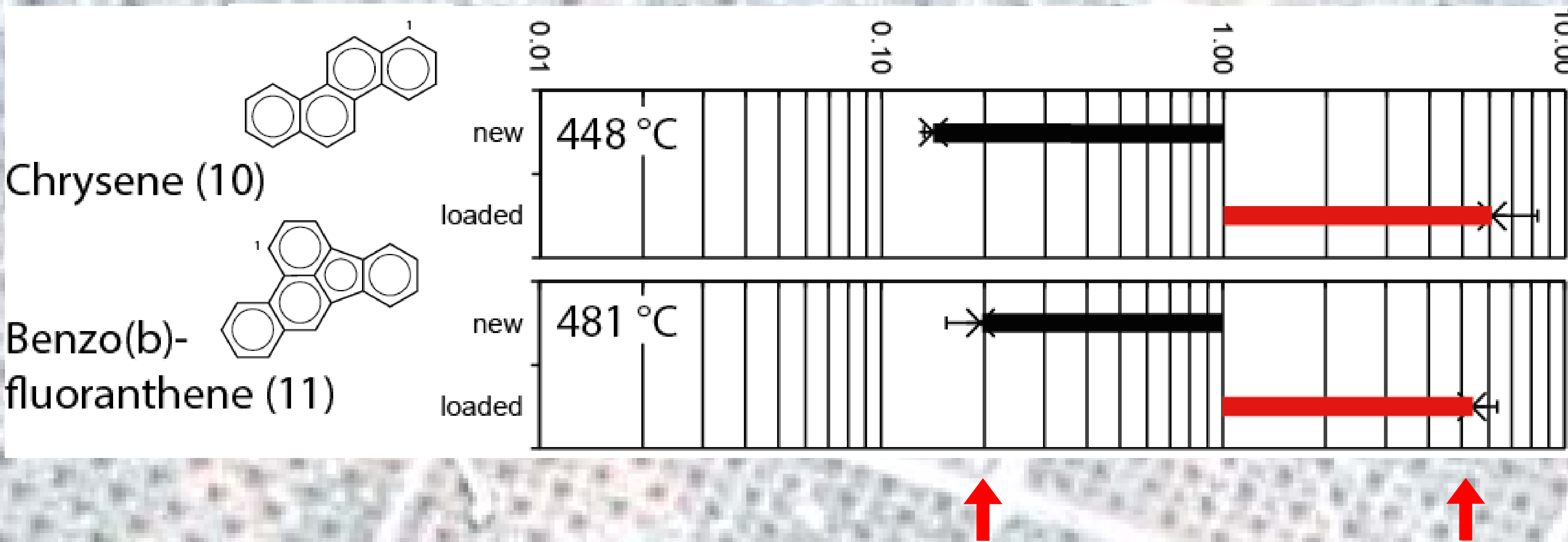
Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons



- **85% retention in the new DPF**
- **6x higher emissions from the soot-loaded DPF**

PAH Penetration of a non-catalyzed DPF

Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons

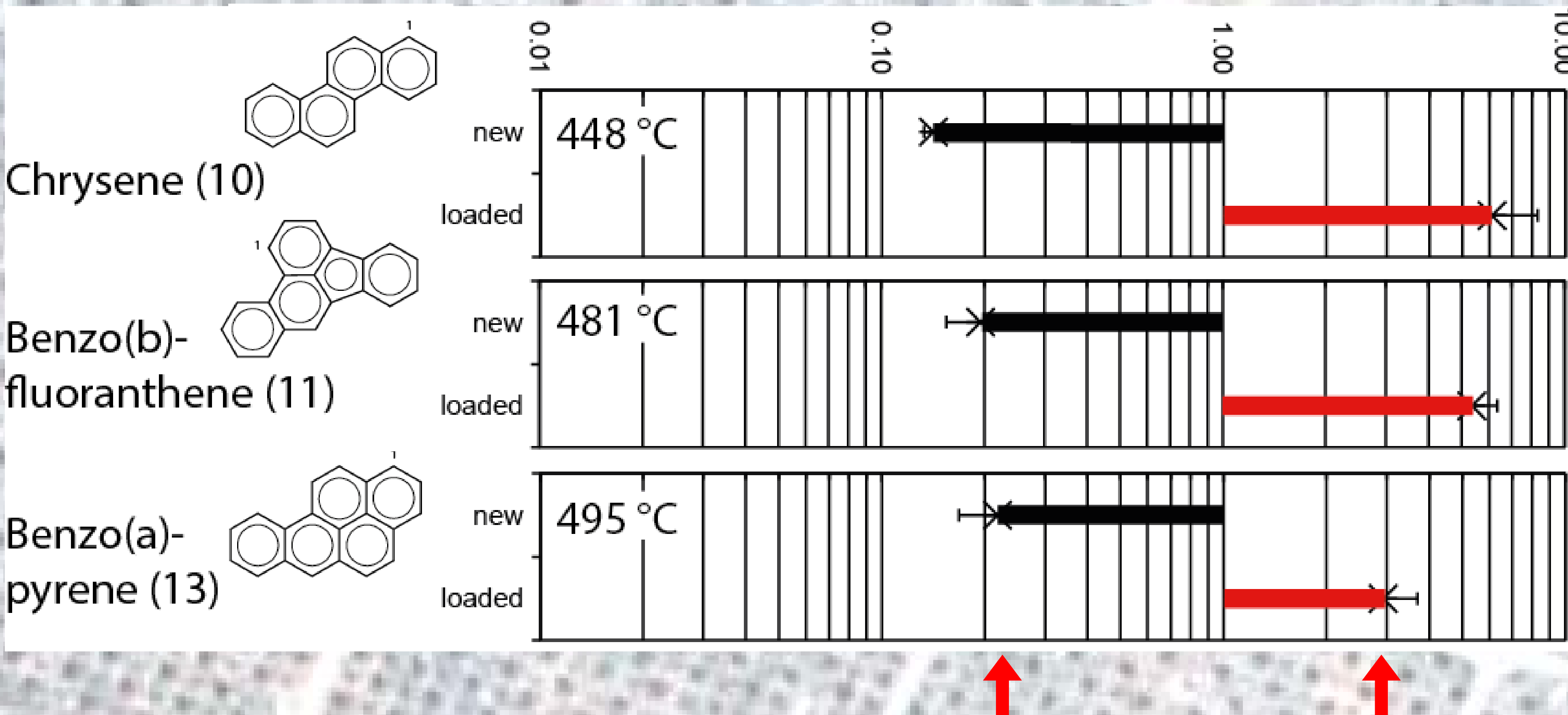


- 80% retention in the new DPF

- 5x higher emissions from the soot-loaded DPF

PAH Penetration of a non-catalyzed DPF

Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons

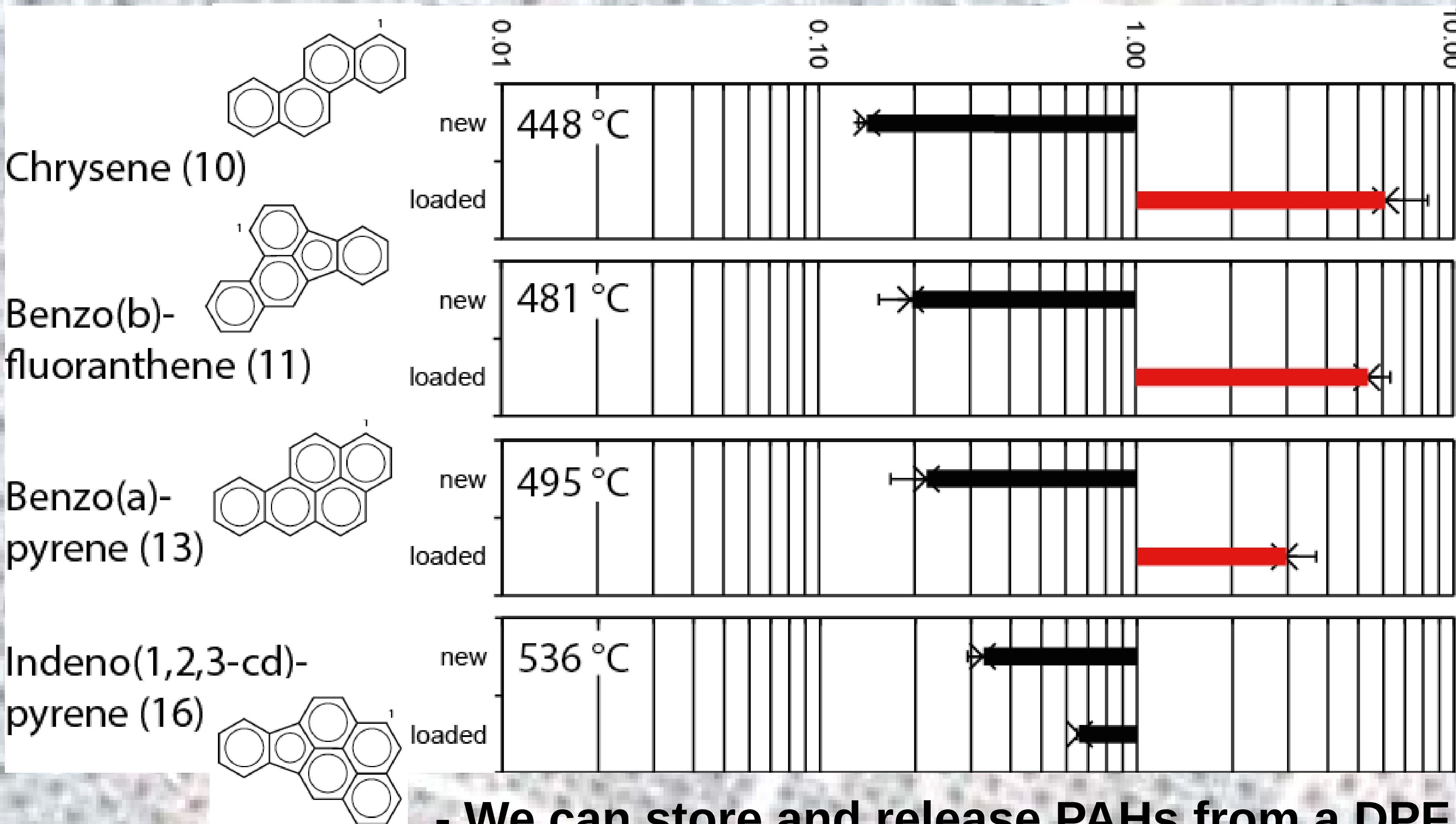


- 80% retention in the new DPF

- 3x higher emissions from the soot-loaded DPF

PAH Penetration of a non-catalyzed DPF

Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons



- We can store and release PAHs from a DPF

Polycyclic aromatic hydrocarbons

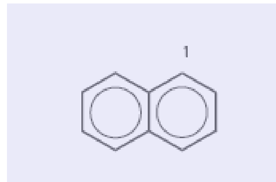
PAHs - a diverse class of compounds with variable physicochemical properties

2- to 6-ring PAHs

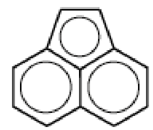
- Volatile PAHs penetrate DPFs

- Semi-volatile PAHs are stored, but can be released again

- Non-volatile PAHs are stored like soot



218 °C



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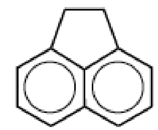

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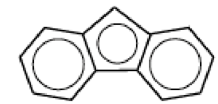

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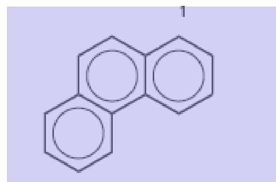
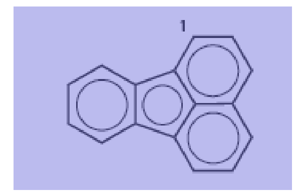
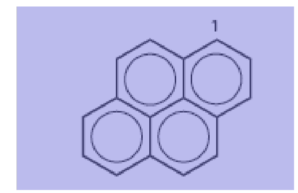


340 °C

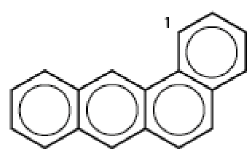
6



375 °C



404 °C



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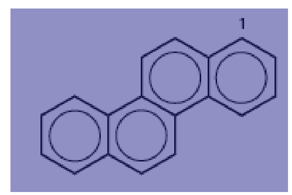
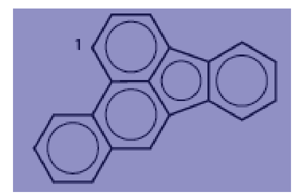
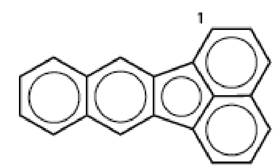


448 °C



481 °C



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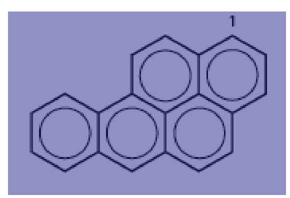
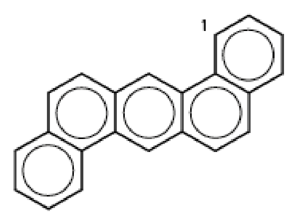


495 °C



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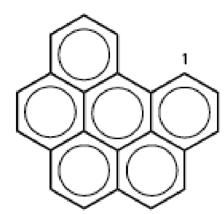

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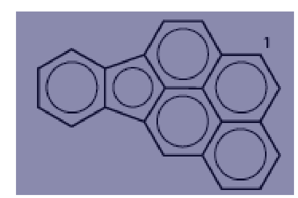


536 °C

Polycyclic aromatic hydrocarbons

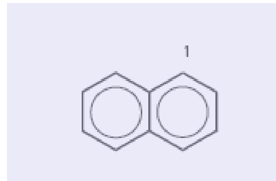
Many of the semi-volatile PAHs are genotoxic or precursors of genotoxic compounds

2- to 6-ring PAHs

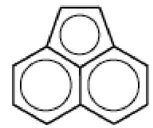
- Volatile PAHs penetrate DPFs

- Semi-volatile PAHs are stored, but can be released again

- Non-volatile PAHs are stored like soot



218 °C



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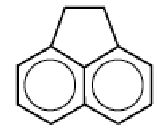

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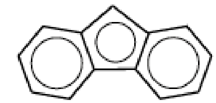

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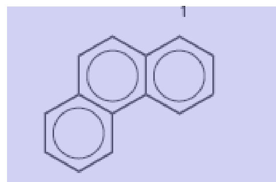
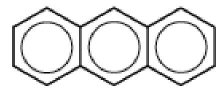


340 °C



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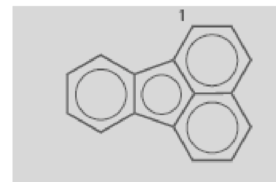
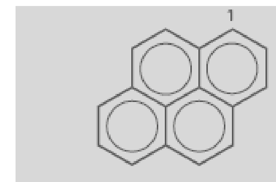
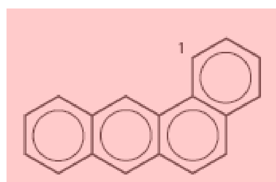


375 °C



404 °C



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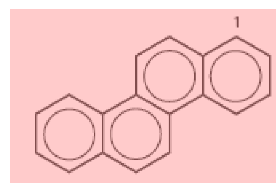
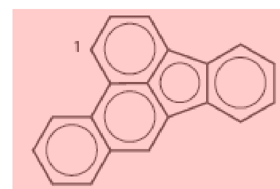
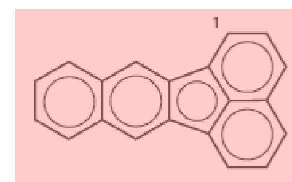


448 °C



481 °C



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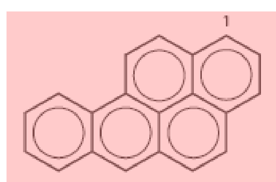
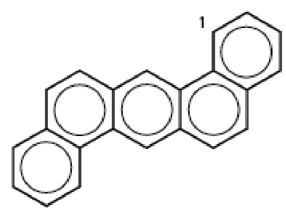


495 °C



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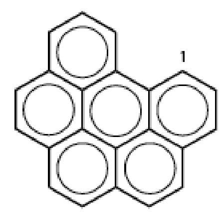

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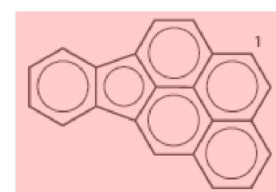
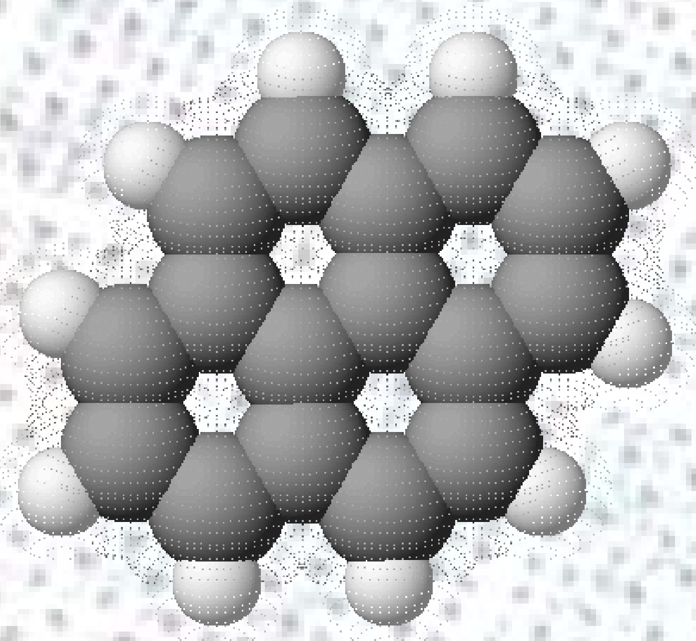


536 °C

The DPF – a chemical reactor

Is nitration of PAHs in NOx-rich diesel exhaust an issue?

Nitration of PAHs

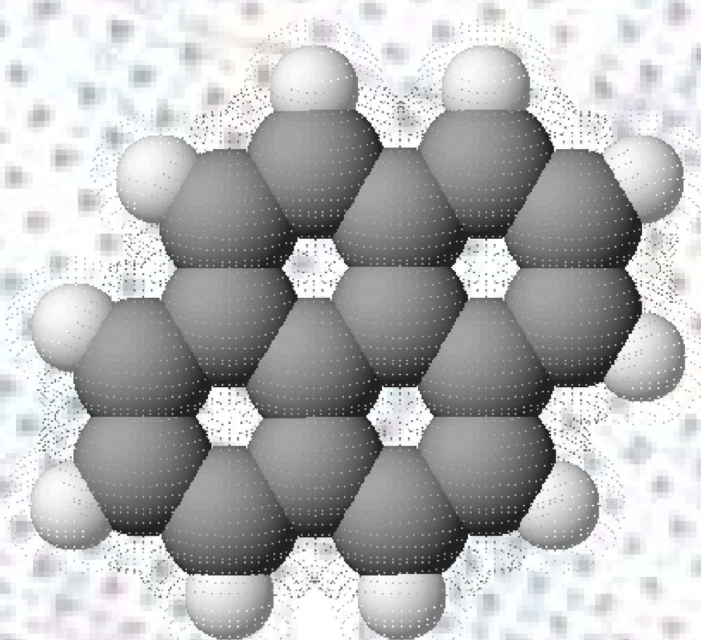


pyrene

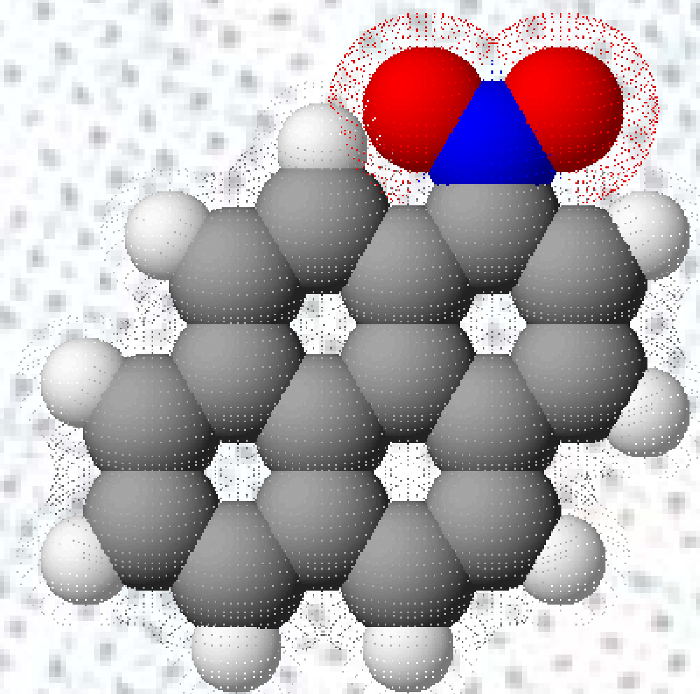
The DPF – a chemical reactor

In one step from a harmless precursor to a potent mutagen!

Nitration of PAHs



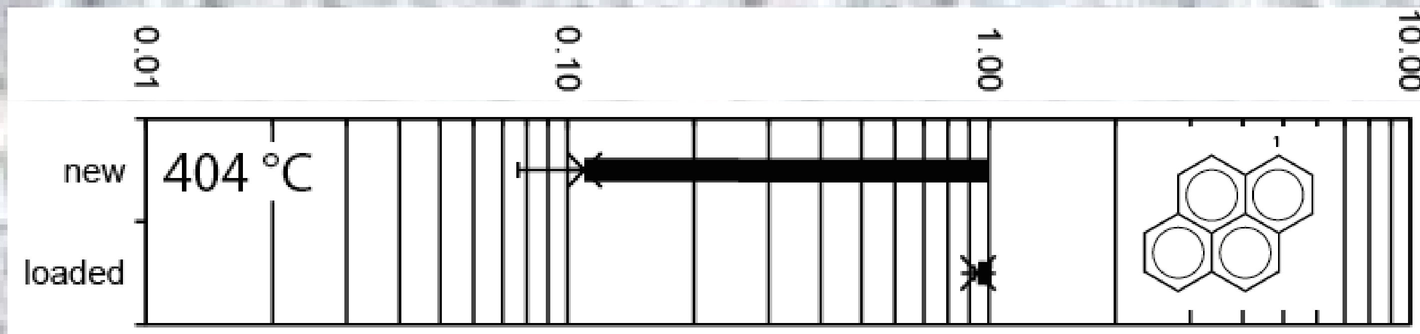
pyrene



1-nitro pyrene

Nitro-PAHs in non-catalyzed DPF

Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons

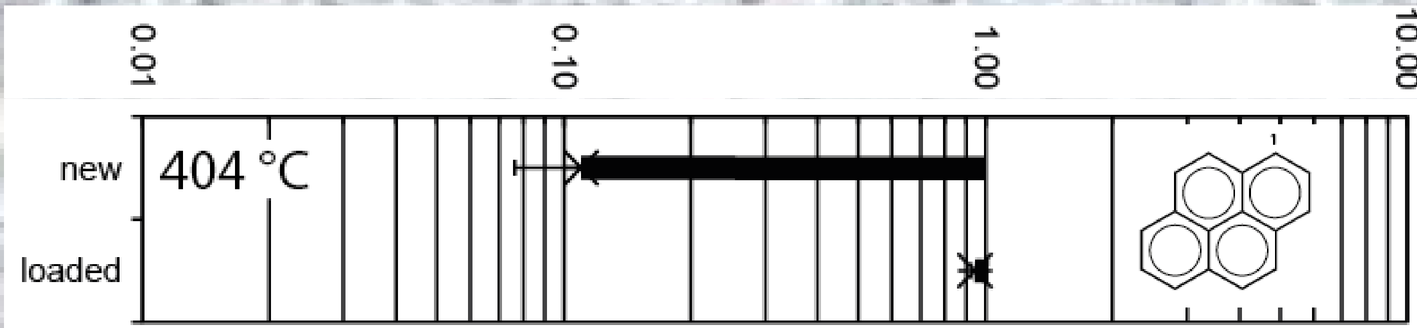


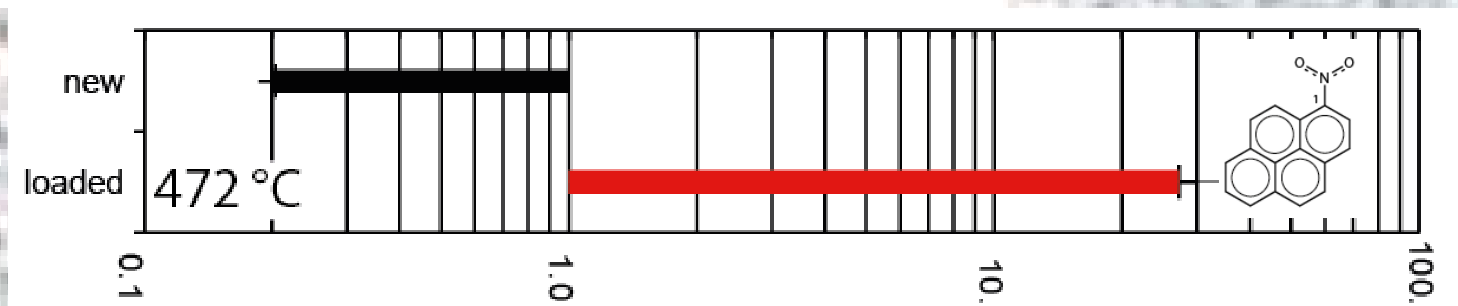
- Pyrene is stored in a new, but released from a soot-loaded DPF

Outlet

NPAHs in non-catalyzed DPF

Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons





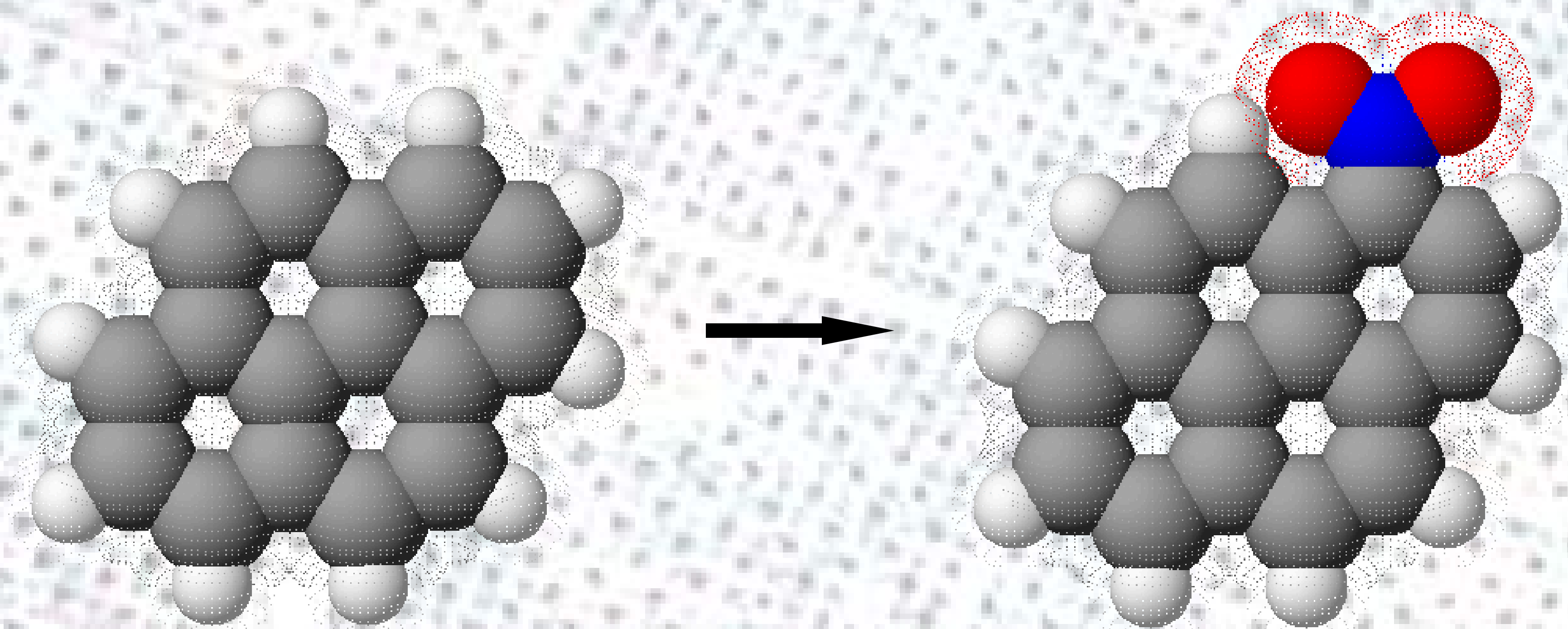
- Pyrene is stored in a new, but released from a soot-loaded DPF

- 1-Nitro pyrene is stored in a new, but formed and released from a soot-loaded DPF (30x)

Even a non-catalyzed DPF is a chemical reactor

The nitration potential of a non-catalyzed DPF is high.

Nitration of PAHs



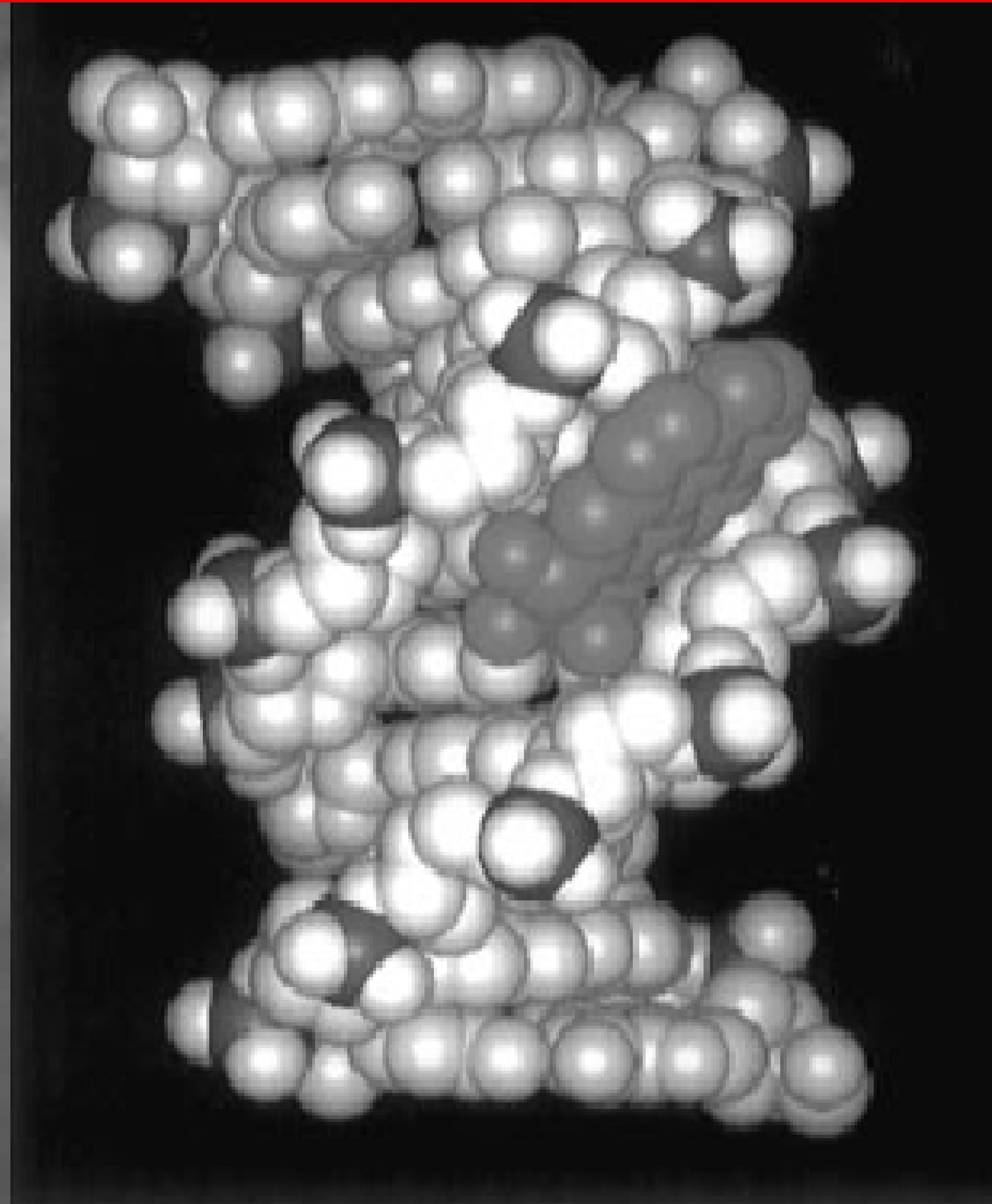
pyrene 1-nitro pyrene

Adverse health effects of diesel exhaust

Problem: Genotoxicity

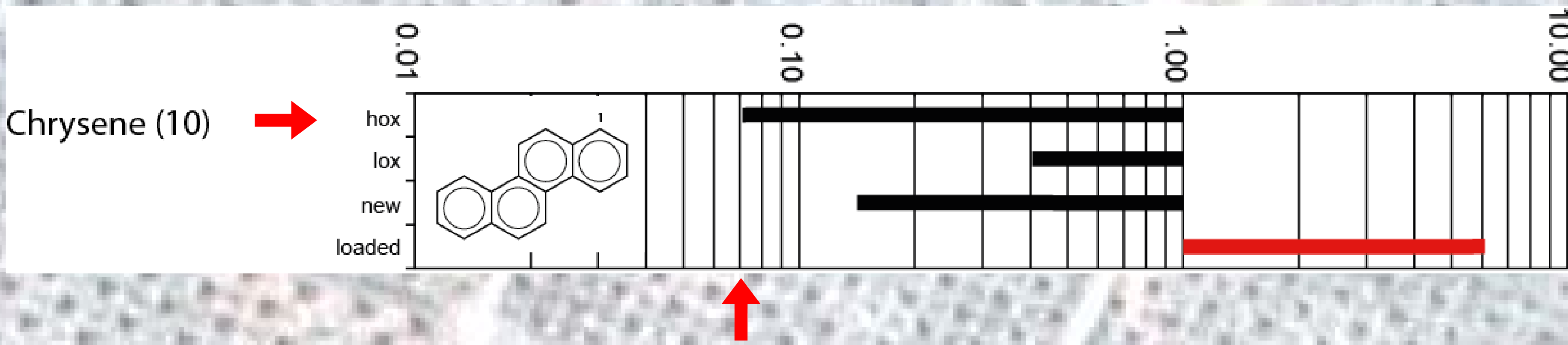
- Unfiltered diesel exhaust is genotoxic
- Filtration as such is not sufficient to remove all genotoxic compounds
- Efficient catalysts are needed to convert genotoxic compounds

We need catalyzed DPFs!



Catalyzed DPFs convert PAHs

Non-catalyzed filters operated <200 °C accumulate soot and hydrocarbons



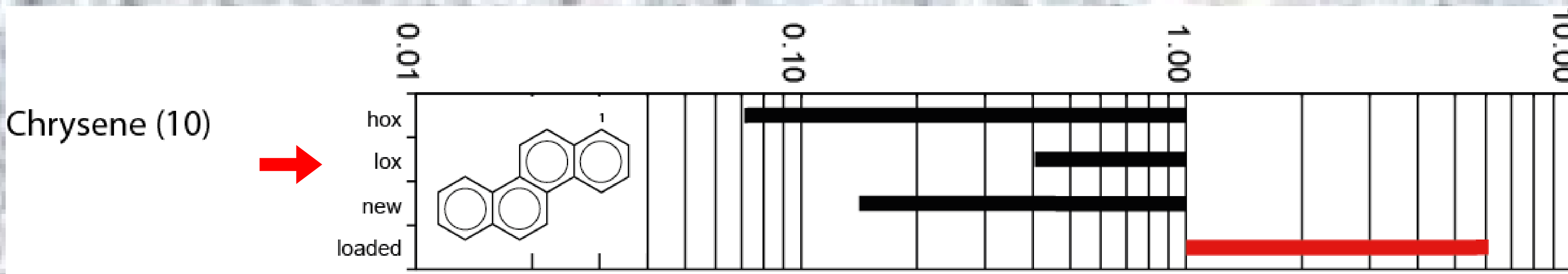
- Hox-DPF convert >90% chrysene

Outlet

Heeb et al. ES&T, **2010**, 42, 3773-3779

Catalyzed DPFs convert PAHs

Non-catalyzed filters operated <200 °C accumulate soot and hydrocarbons



- Hox-DPF convert >90% chrysene

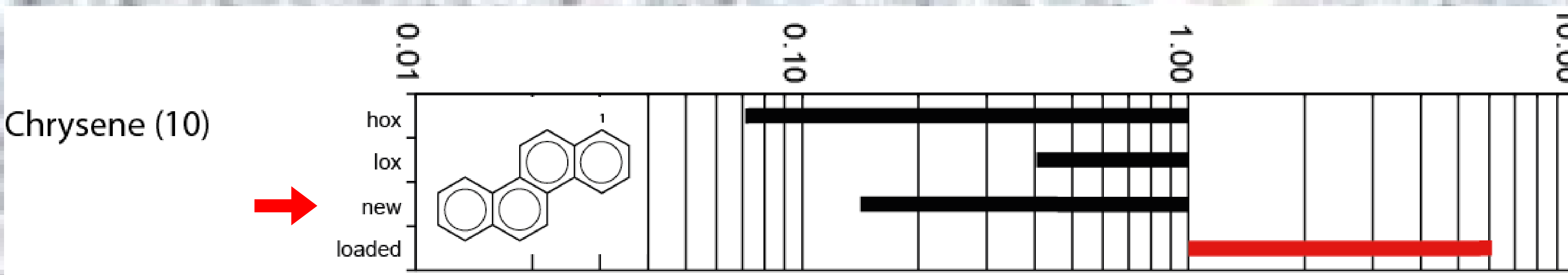
- Lox-DPF convert >60% chrysene

Outlet

Heeb et al. ES&T, **2010**, 42, 3773-3779

Catalyzed DPFs convert PAHs

Non-catalyzed filters operated <200 °C accumulate soot and hydrocarbons



- Hox-DPF convert >94% chrysene

- Lox-DPF convert >60% chrysene

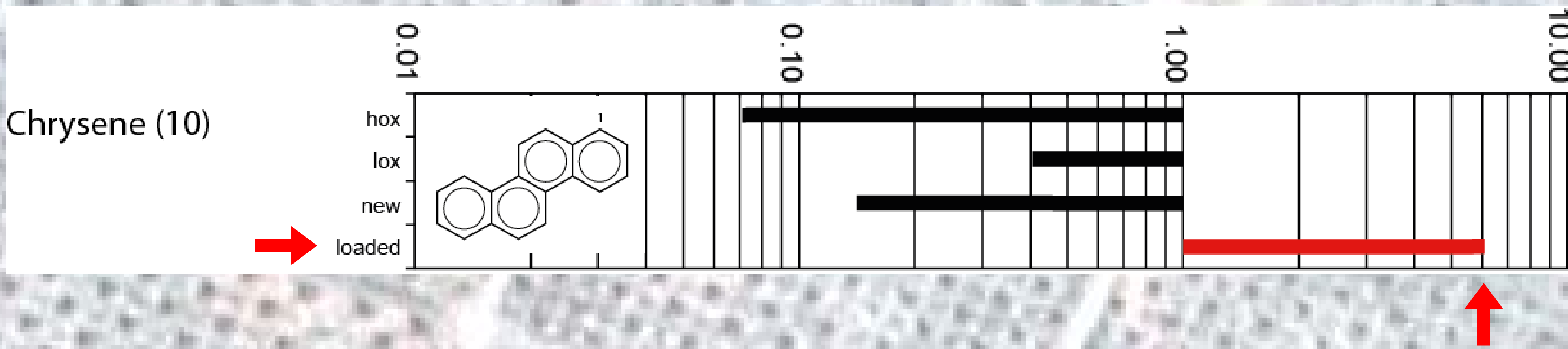
- A new non-catalyzed DPF stores chrysene

(at low temperatures even better than a lox-DPF)

Heeb et al. ES&T, **2010**, 42, 3773-3779

Catalyzed DPFs convert PAHs

Non-catalyzed filters operated <200 °C accumulate soot and hydrocarbons



- Hox-DPF convert >94% chrysene

- Lox-DPF convert >60% chrysene

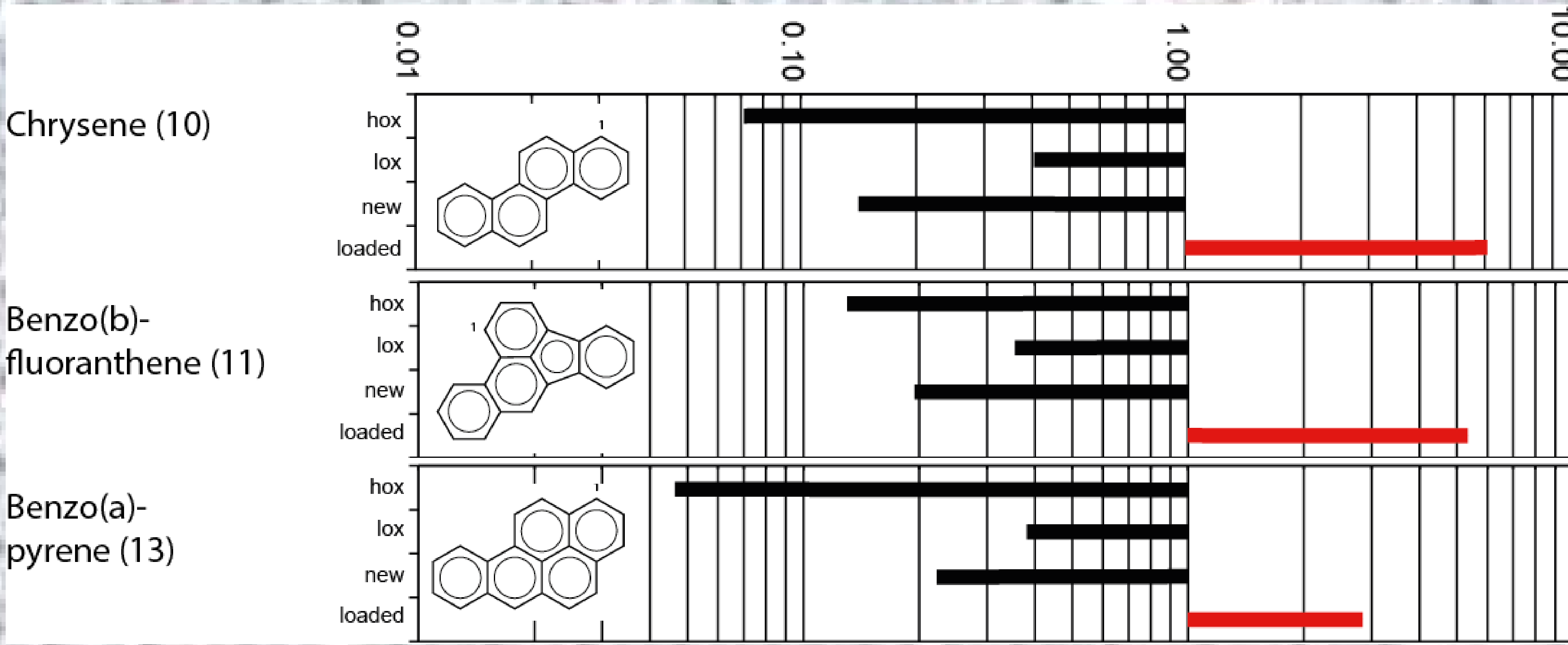
- A new non-catalyzed DPF stores chrysene
(at low temperatures even better than a lox-DPF)

- A loaded non-catalyzed DPF can release chrysene
(at higher temperatures)

Heeb et al. ES&T, **2010**, 42, 3773-3779

Catalyzed DPFs convert PAHs

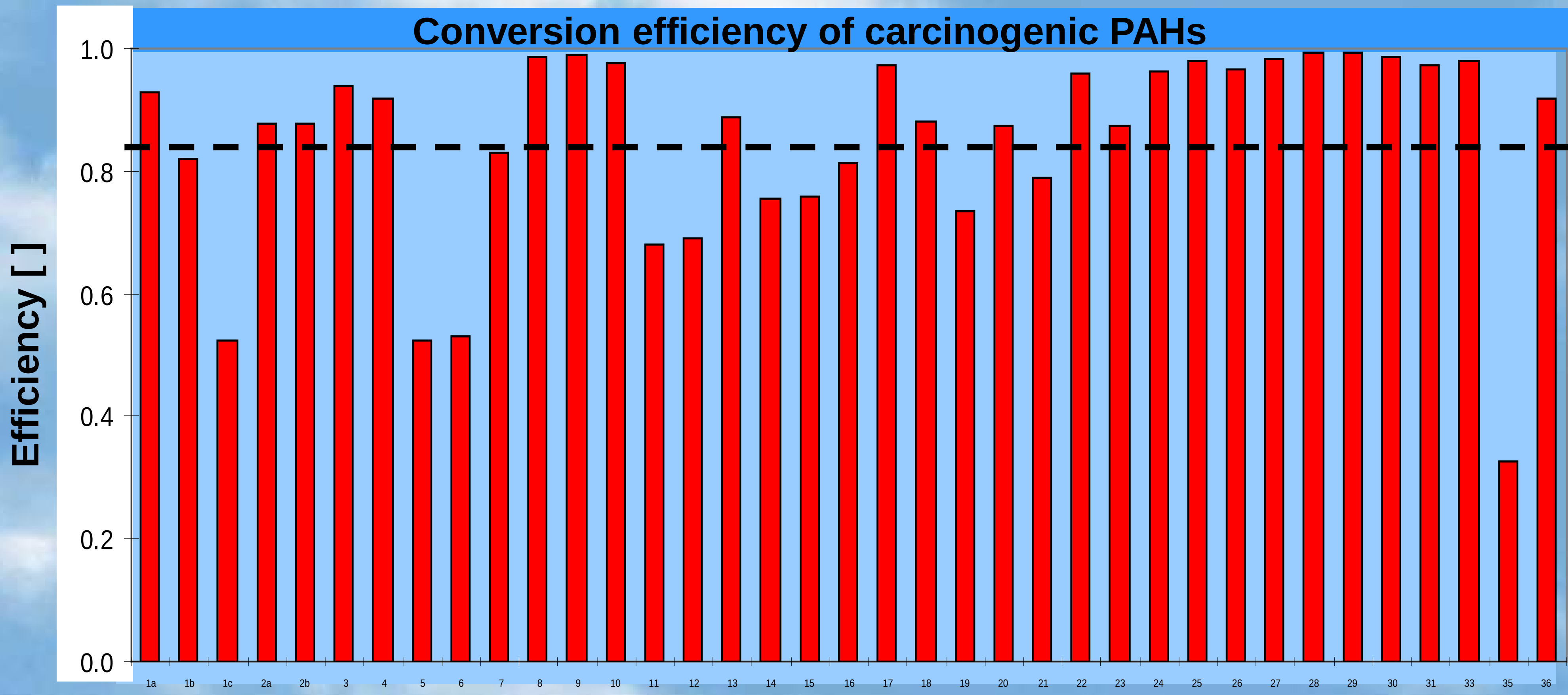
Non-catalyzed filter operated <200 °C to accumulate soot and hydrocarbons



This is the general trend for many genotoxic PAHs

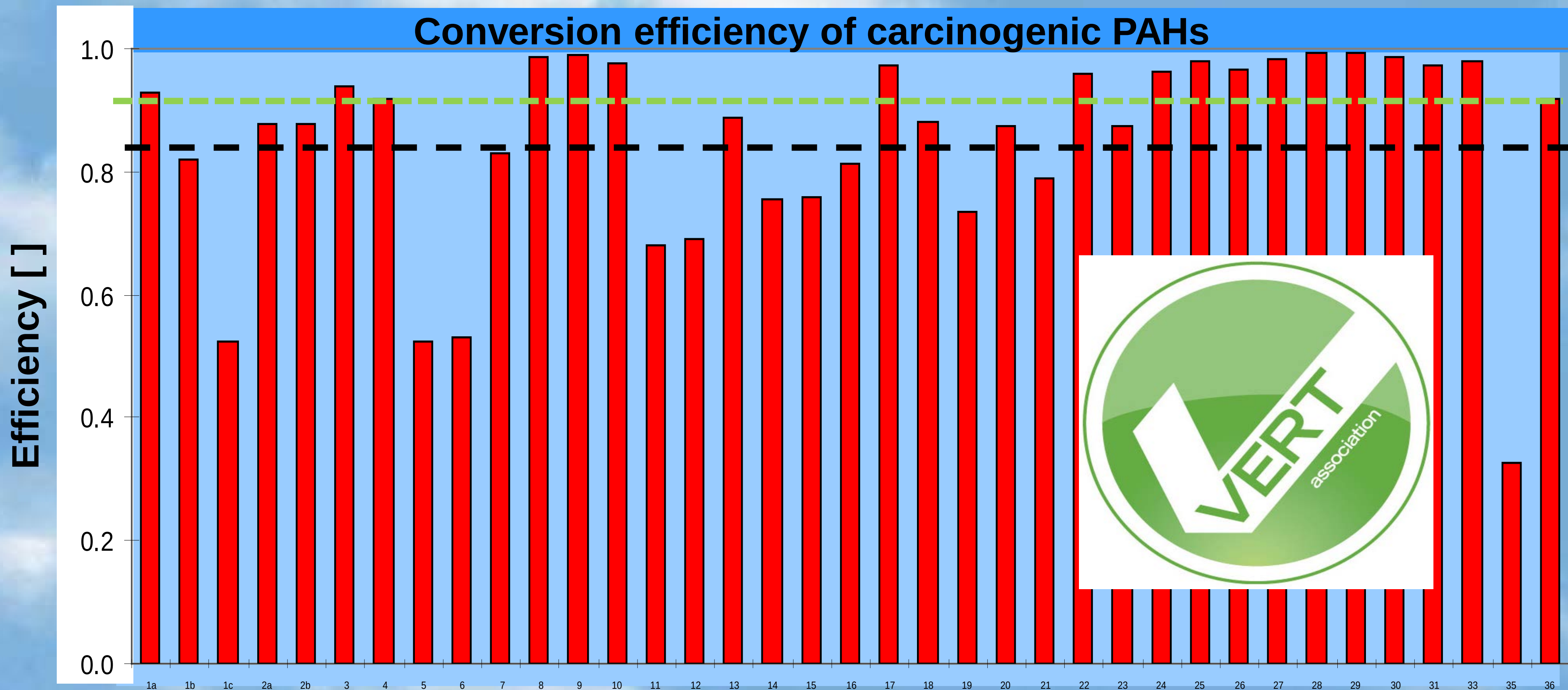
Adverse health effects of diesel exhaust

VERT-tested catalytic DPFs convert carcinogenic PAHs (on average 85%)



Adverse health effects of diesel exhaust

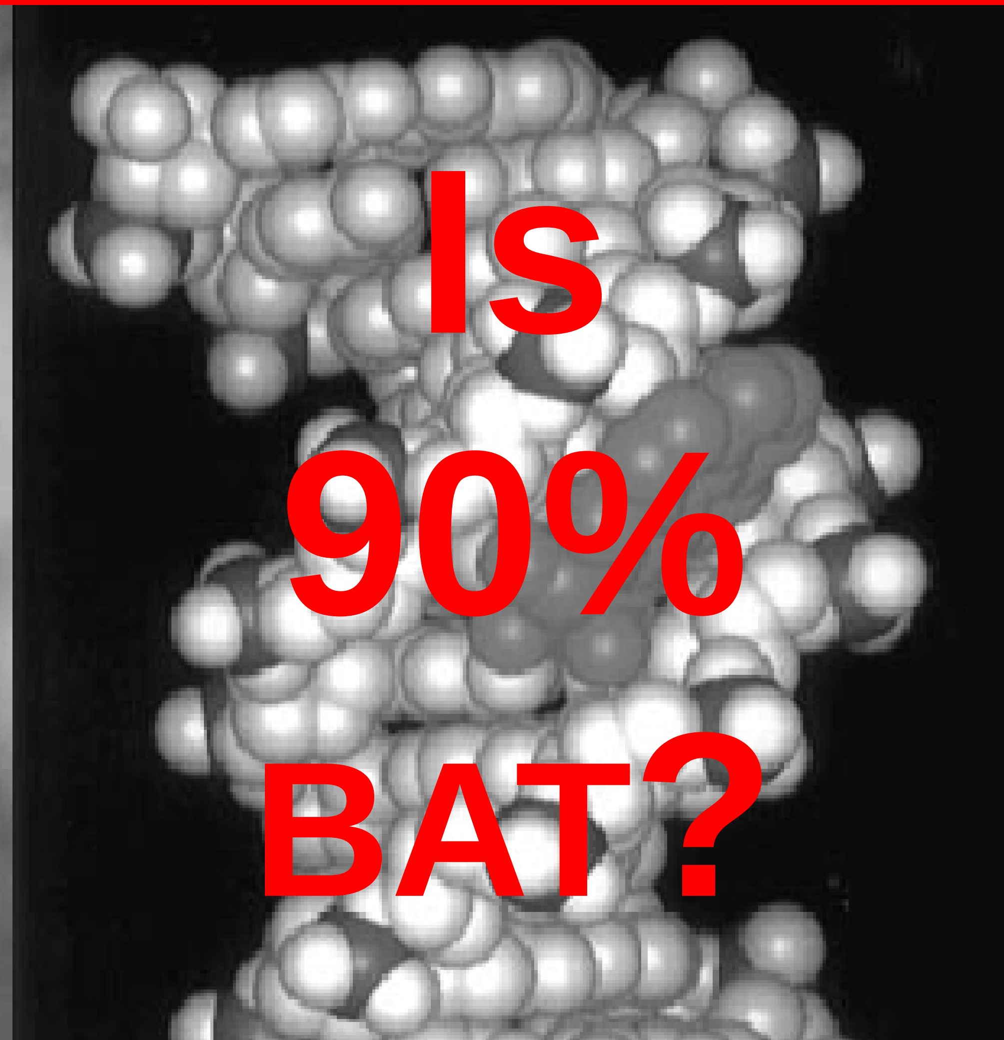
What is BAT today?



Catalysis, a key property of particle filters to lower genotoxicity of diesel exhaust

Problem: Genotoxicity

- **Non-filtered diesel exhaust is genotoxic**
- **Filtration as such is not sufficient to remove genotoxic compounds**
- **Efficient catalysts are needed to convert genotoxic compounds**



Catalytic DPFs are BAT to lower the genotoxicity of diesel exhaust, but some are considerably better than others!

Catalysis, a key property of particle filters to lower genotoxicity of diesel exhaust

A combined effort with many important contributions

Thanks:

- **VERT team:** Andreas Mayer, TTM, Niederrohrdorf
  Jan Czerwinski, Sandro Napoli, Tobias Neubert, Thomas Hilfiker, Samuel Bürki,
  Jean-Luc Petermann, Yan Zimmerli, Hervé Nauroy Uni. Appl. Sci., Biel.
  Markus Kasper, Adrian Hess, Thomas Mosimann, Matter Aerosols, Wohlen
  Hans Jaeckle, Urs Debrunner, Oliver Schumm, Intertek Caleb Brett, Schlieren.
- **Empa colleagues:** Brigitte Buchmann, Thomas Bührer, Lukas Emmenegger, Anna-Maria Forss, Urs Gfeller, Maria Guecheva, Peter Graf, Roland Graf, Erika Guyer, Regula Haag, Peter Honnegger, Judith Kobler, Martin Kohler, Peter Lienemann, Alfred Mack, Peter Mattrel, Martin Mohr, Joachim Mohn, Christof Moor, Andreas Paul, Peter Schmid, Cornelia Seiler, Andrea Ulrich, Heinz Vonmont, Thomas Walter, Max Wolfensberger, Daniela Wenger, Adrian Wichser, Markus Zennegg, Kerstin Zeyer.
- **Governement**: Philipp Hallauer, Giovanni D'Urbano, Felix Reutimann, Max Wyser, Gerhard Leutert, Martin Schiess, Swiss Fed. Office for Environment, Bern
  Thomas Gasser, Heinz Berger, Gerhard Stucki, Swiss Federal Road Office
- **Filter- & catalyst manufacturers**: >40 different diesel particulate filter systems

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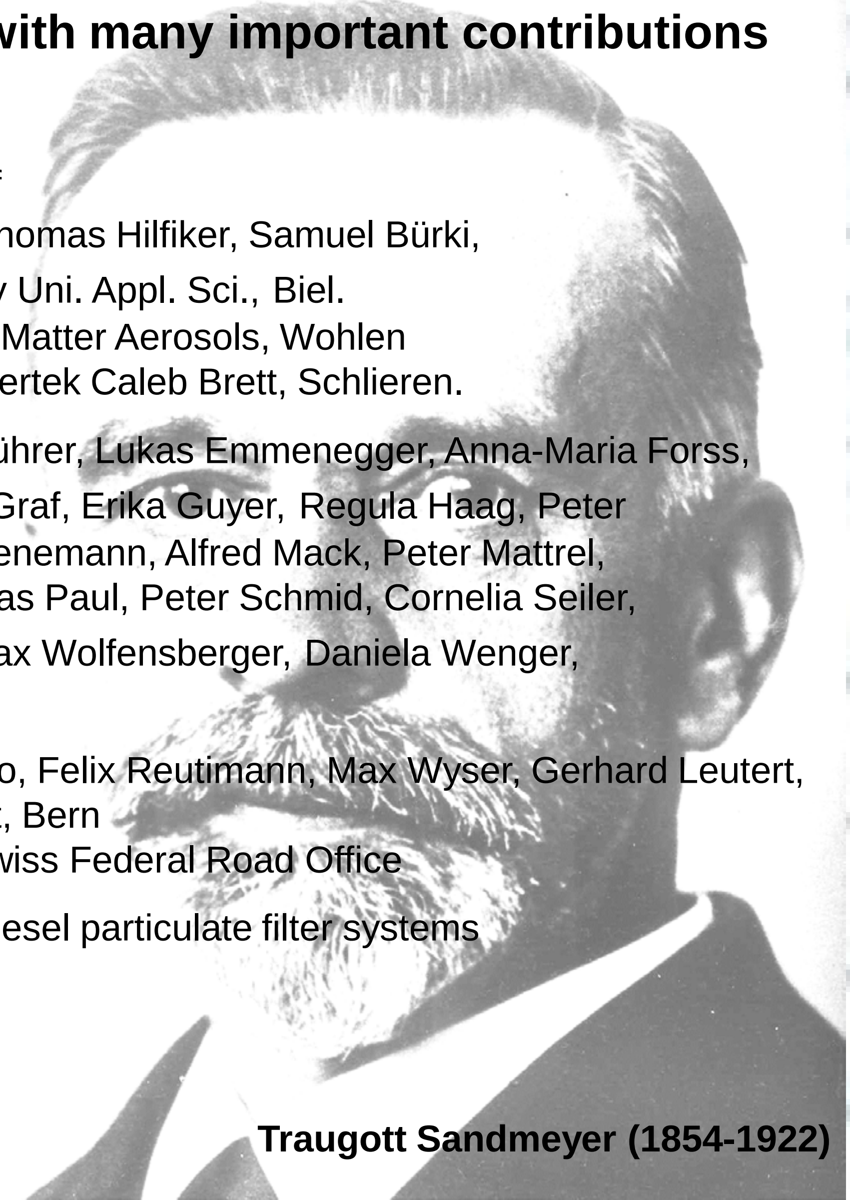
Traugott Sandmeyer (1854-1922)


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If you see smokers like this, you urgently ask for catalyzed DPFs