9. VERT Focus 16.3.2018 Dübendorf

VERT Holistic Approach

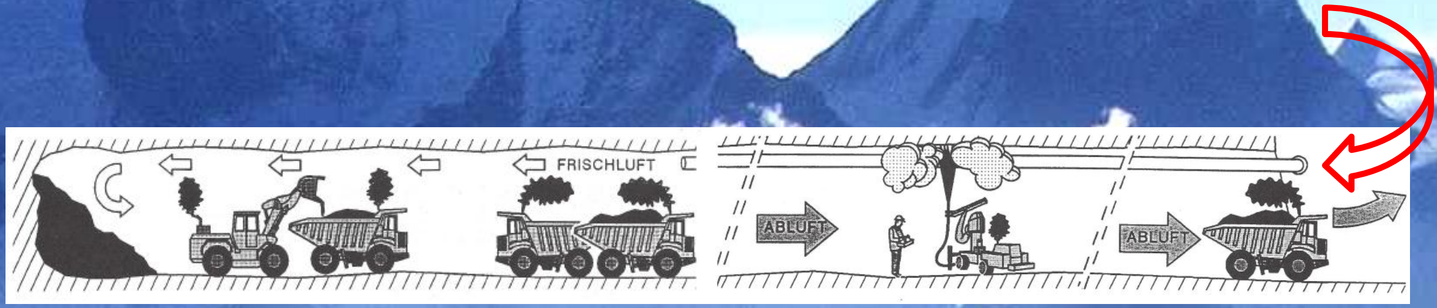
to characterize and eliminate toxic aerosols emitted by combustion engines

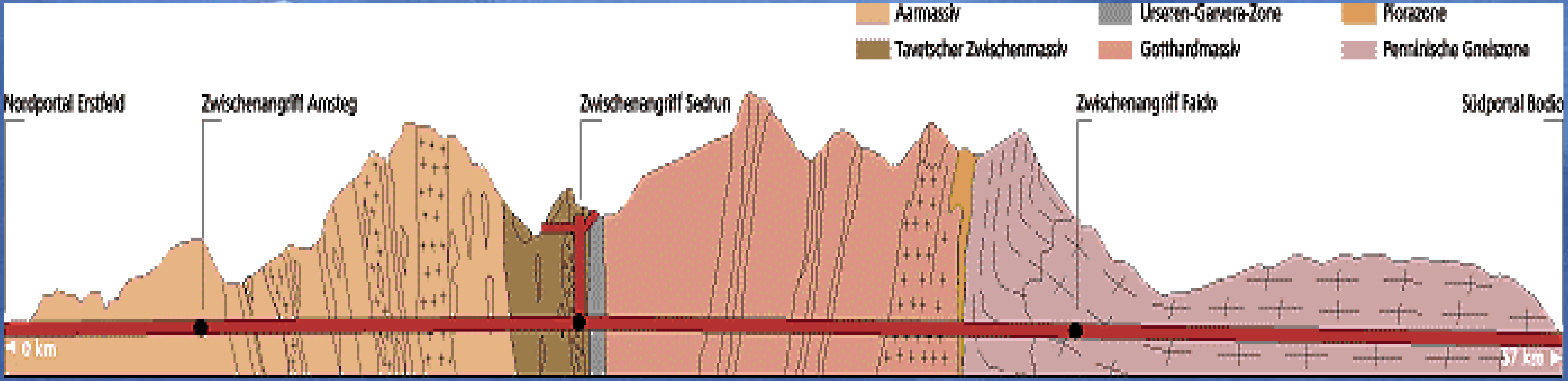
a challenge across disciplines

A.Mayer TTM, VERT

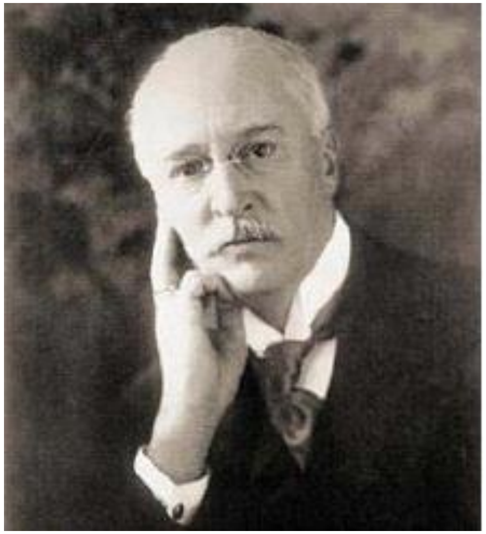
Start with NEAT 1993

Clean Air for Tunneling Workers





Tunneling needs Diesels



Rudolf DIESEL

1893 first patent – first engine 1897 (26.2 % !)

By far best efficiency, very robust and powerful engine

- 53 % large marine engines
- 45 % HDV (50 % in reach)
- 35 % LDV
- 42 % steam turbine
- 36 % gas turbine

However, 2 problems: Soot and NOx

→ Soot = Toxic air contaminant nº 1

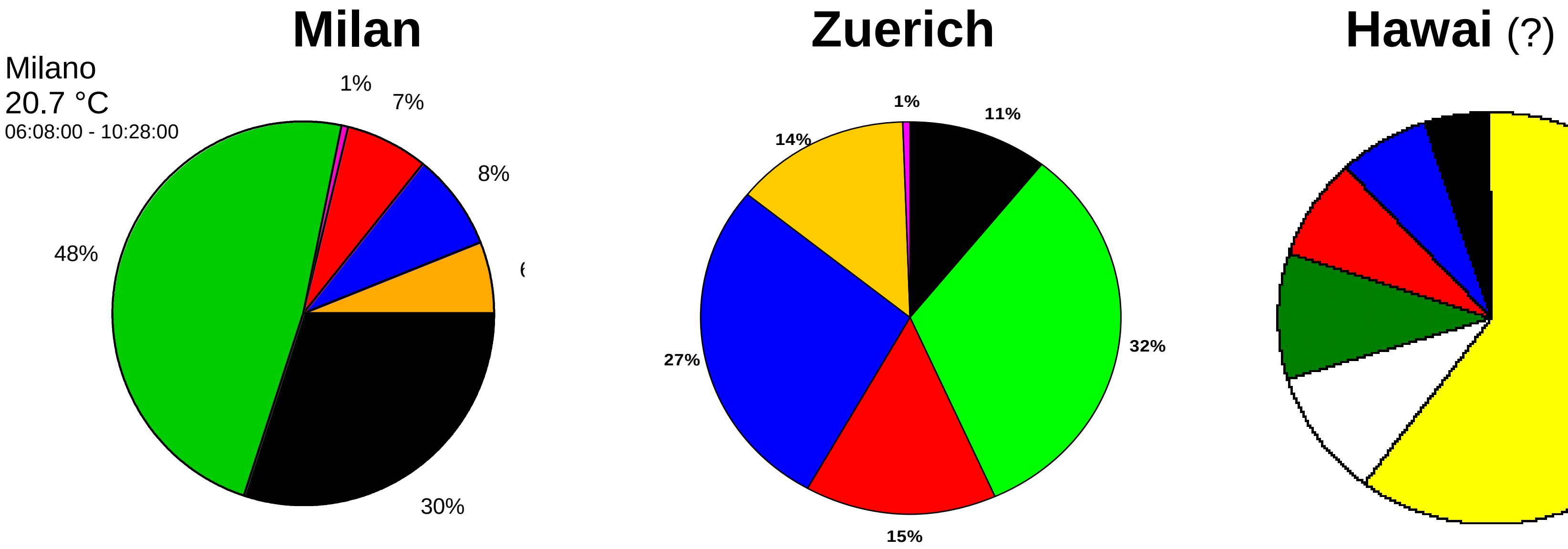
→ Soot = global warming substance nº 2

Priority for PM Elimination based on Occupational Health Limit Values

	Gases				Aerosols	
mg/Nm^3	CO	NO	NO_2	SO_2	**PM**	H_2SO_4
Emissions	1000	2700	300	100	**250**	25
Limit Values • Switzerland • Germany • MSHA 2007	33	30	6	5	**0.1** **0.1** **0.16**	1
Required Dilution Actual Dilution 1:40 4 m3/kWmin required	> 28	> 90	>50	> 20	**2500** → Filter 98%	> 25

What is PM - Mass [mg/m3] of what ?

mix of unspecified substances – which is the toxic one ?



Public Health Science 1993 – 2018 …
«Total mass of airborne particulate matter is the correct parameter for health impact»

Black Carbon
Organic mass
Nitrate
Sulfate
Ammonium
Chloride

Is this true? -- dubito ergo sum

far too complex

need science for characteriszation

“ .. esto importa poco a nuestro cuento; basta que no se salga un punto de la verdad ”

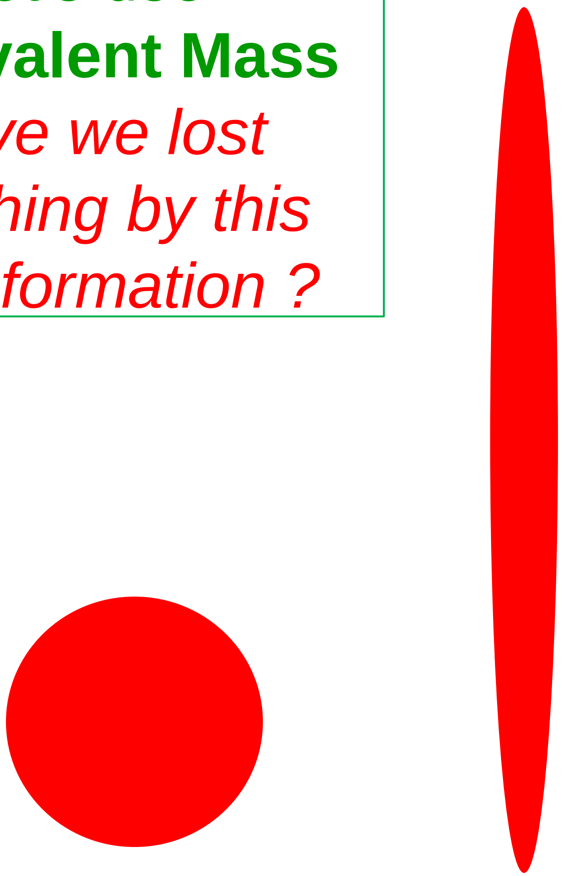
Miguel de Cervantes
El ingenioso hidalgo ….

Far too complex

let’s use

Equivalent Mass

have we lost anything by this transformation ?



“ .. esto importa poco a nuestro cuento; basta que no se salga un punto de la verdad ”

The overall PM-Mass Definition for toxic aerosols was a misleading concept from beginning – **we had to move away in 8 steps**

→ by multiparametric DPF Efficiency Definition
→ by Development of new PN Instruments
→ by Secondary Emission
→ by expanding ETH-Nanoparticle Conference
→ by Triple Cell Research by Aerosol Eposure
→ by HEQ - the Health Equivalent Model
→ by Metal Toxicity Research
→ by Petrol Engine Emissions

away from «frozen» public health and type approval priciples **and Europe followed**

If mass is wrong, what is wright to make a DPF BAT ?

→ So from 1996 we measured all we could (follow G.Galilei)

- **Filtration by total number**
- **Filtration in 60 size classes**
- **Filtration by total mass**
- **Filtration by EC+OC**
- **Filtration by PAS (PAH?)**
- **Filtration by DC**

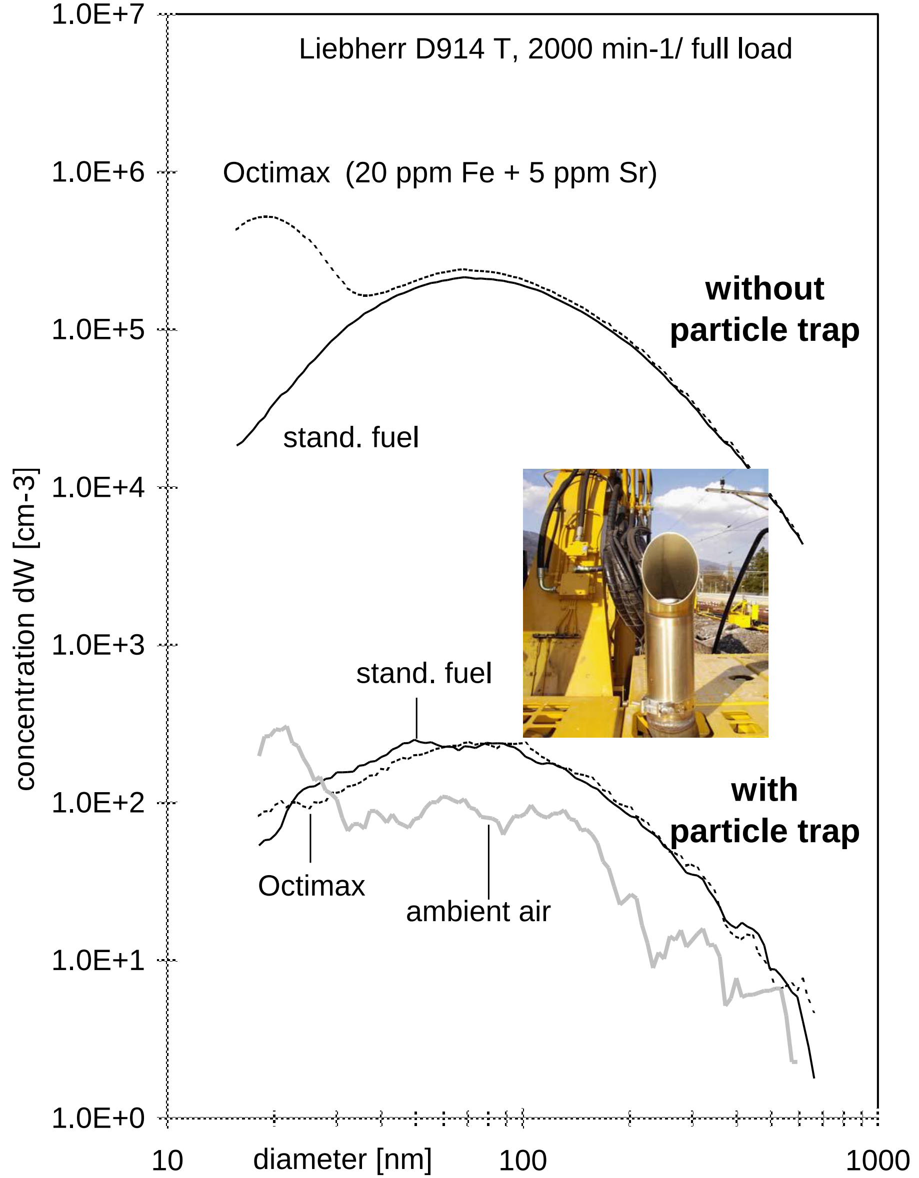
\+ **CO, NO, NO2, HC**

and later

\+ Secondary Emissions

\+ Metal Oxides

\+ Surface, Morphology, Activity



Going into the depth and using all available instrumentation we had from beginning information on

- Particle number distribution by SMPS
- Particle size distribution by SMPS
- Particle surface (Fuchs surface) by DC
- Particle BET-surface by primary particle size evaluation
- Particle mass distribution calculated from SMPS
- Total particle mass gravimetric acc. to the legal requirement
- Total Particle number 23-2500 nm as later required by PMP
- Indications on PAH coating by the NanoMet PAS-Sensor
- Secondary Emissions by HR-MS for trace substance analysis
- Metal Oxides by HR ICP-MS for all metals

Guided by

Occupational Health

starting aerosol science in mines had defined Particles Sizes deposited in Lung Compartments in 1959

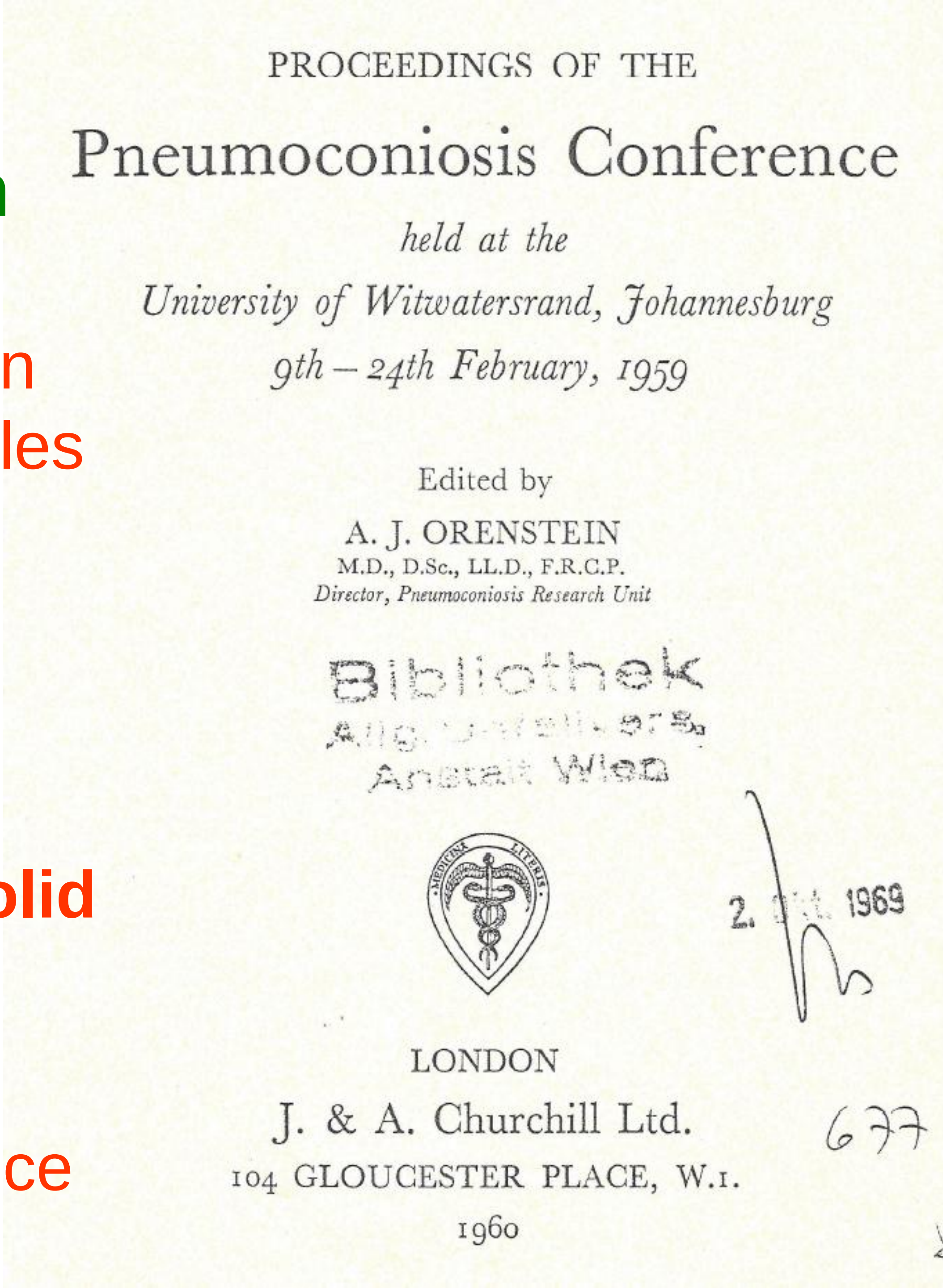
VERT:

SUVA, AUVA, TBG

required elimination of **solid insoluble particles**

< 500 nm

and to limit each substance inividually



PROCEEDINGS OF THE

Pneumoconiosis Conference

held at the

University of Witwatersrand, Johannesburg

9th – 24th February, 1959

Edited by

A. J. ORENSTEIN

M.D., D.Sc., LL.D., F.R.C.P.

Director, Pneumoconiosis Research Unit

LONDON

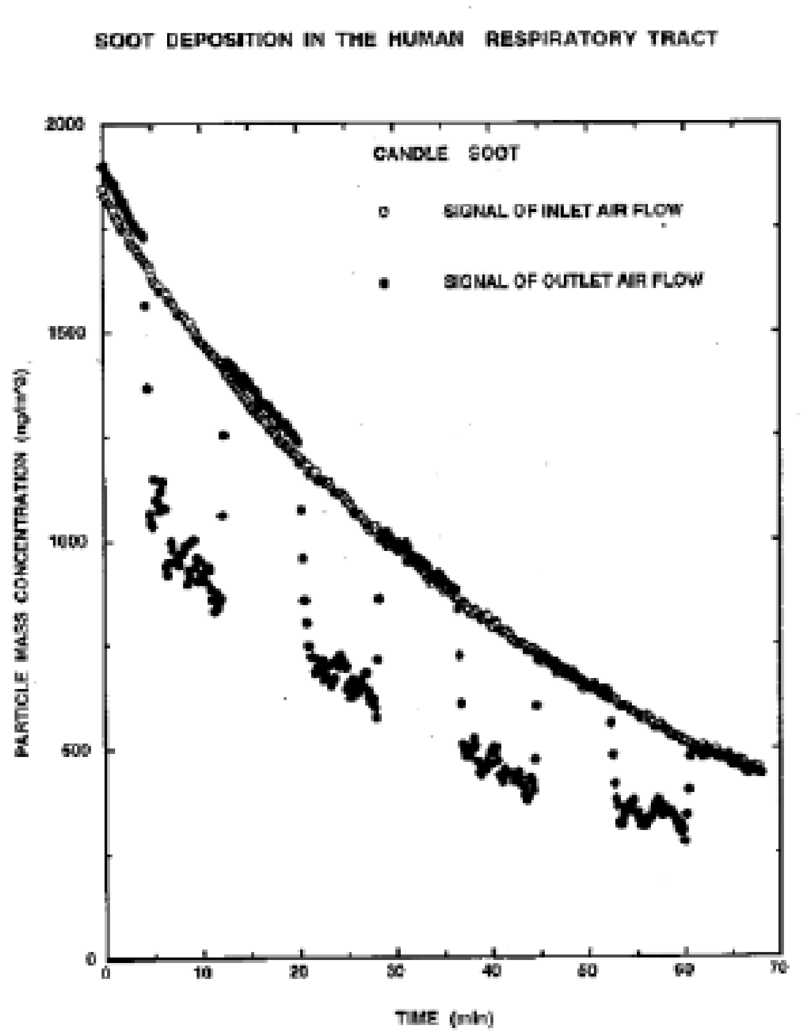
J. & A. Churchill Ltd.

104 GLOUCESTER PLACE, W.1.

1960

Guided by aerosol physics

ETH – Prof.H.C.Siegmann

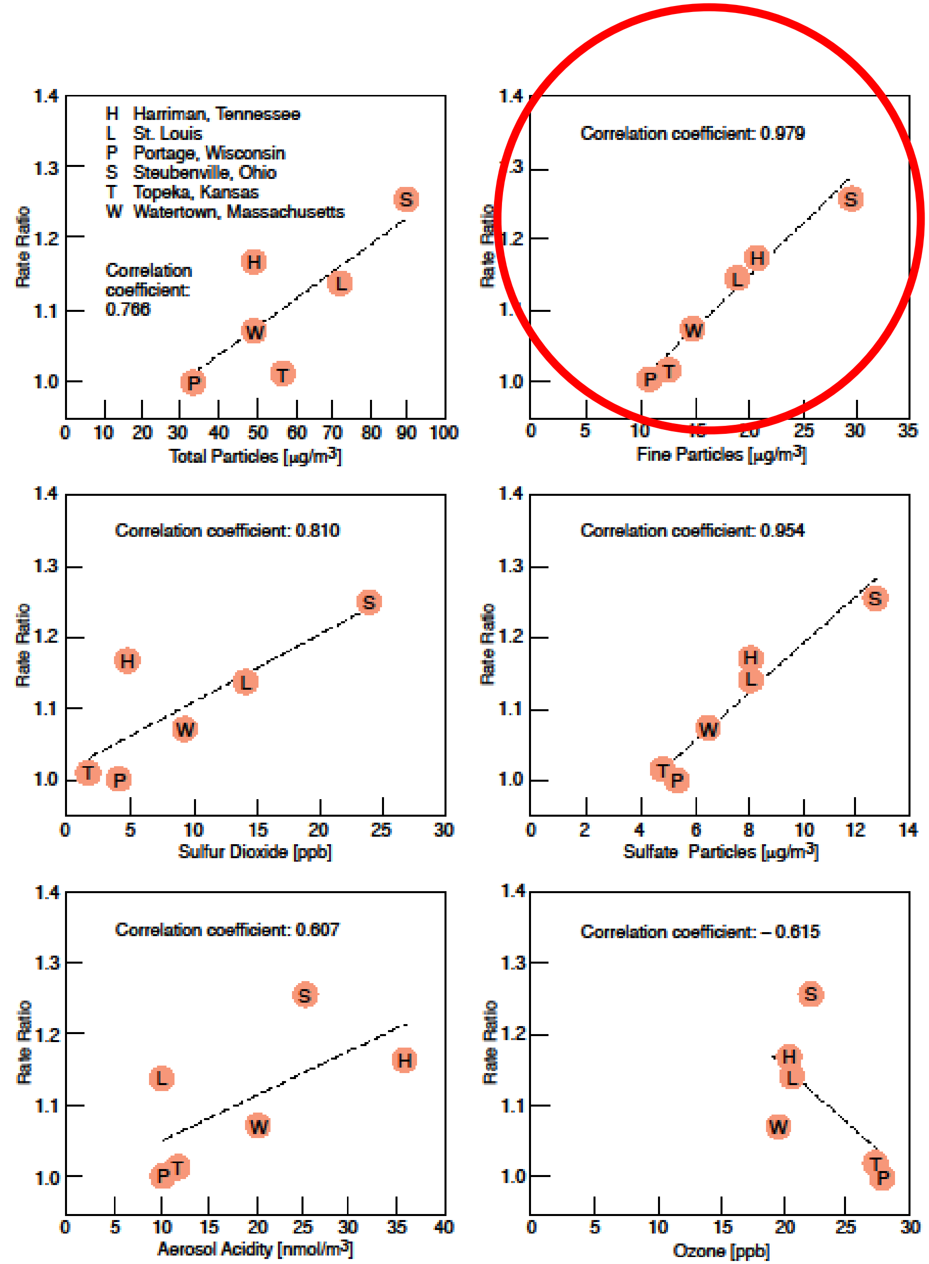


Guided by

Dockery NEJM 1993

6-Cities-Study
USA 1978-93
15‘000 cases

Correlation with fine particles only:

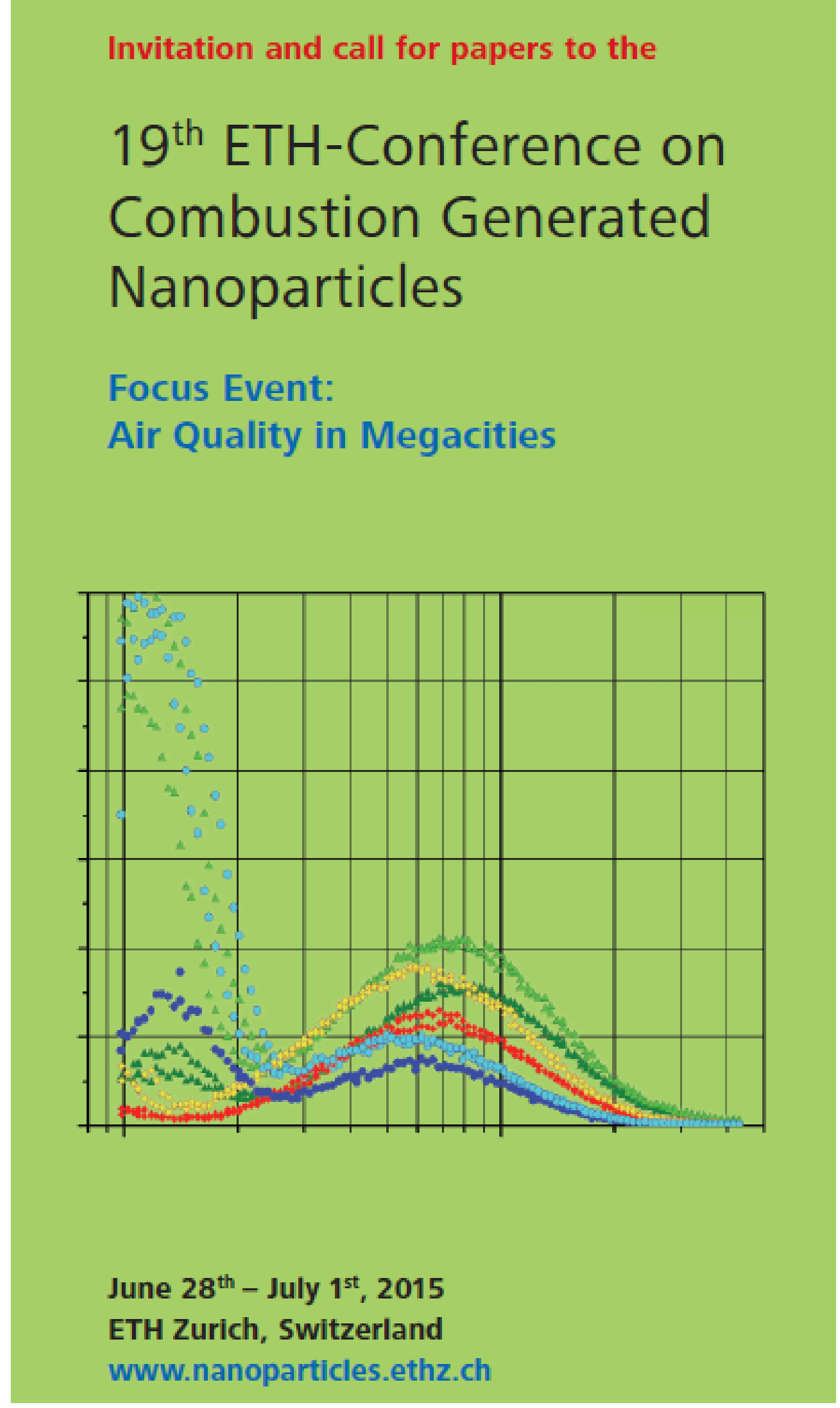


Never wait for Epidemiology, it comes always far too late

D.Dockery ETH-NPC 2014

Guided by a scientific network wordwide expanded

- 1997 first international ETH-NP-workshop - 40 participants
- Today ETH-NPC is the annual event of UFP experts from science to technology > 400
- 20th conference June 2016 13th to 16th – no participation fee



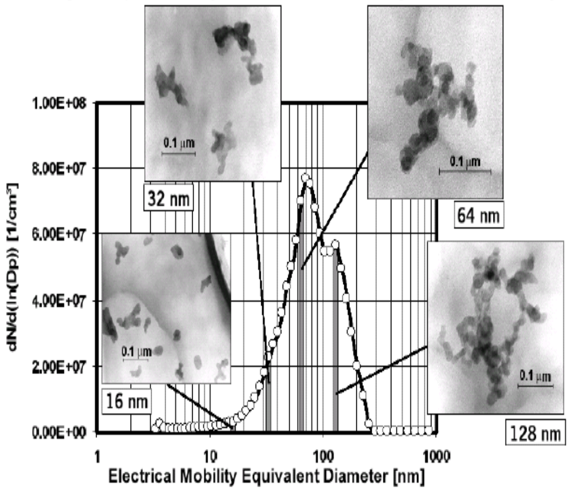
Develop Nano-Metrologie

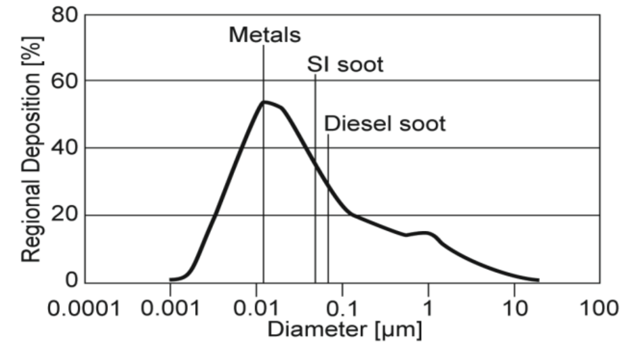
→ The Golden Instrument

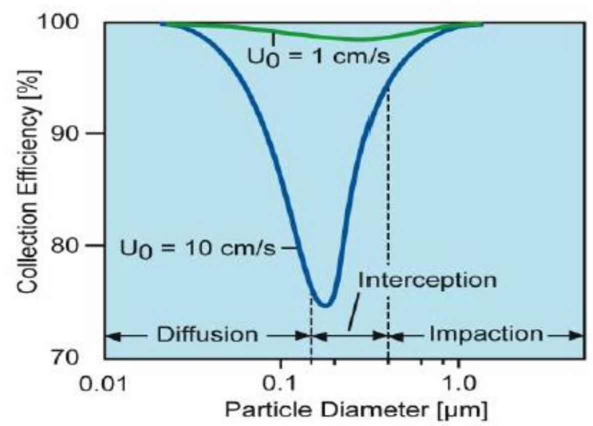
Aerosol Research

strange coincidence

The most sensitive size range
of the Lungs
is the most intensive emission range
of the Engines
and the weakest size range of
Filtration





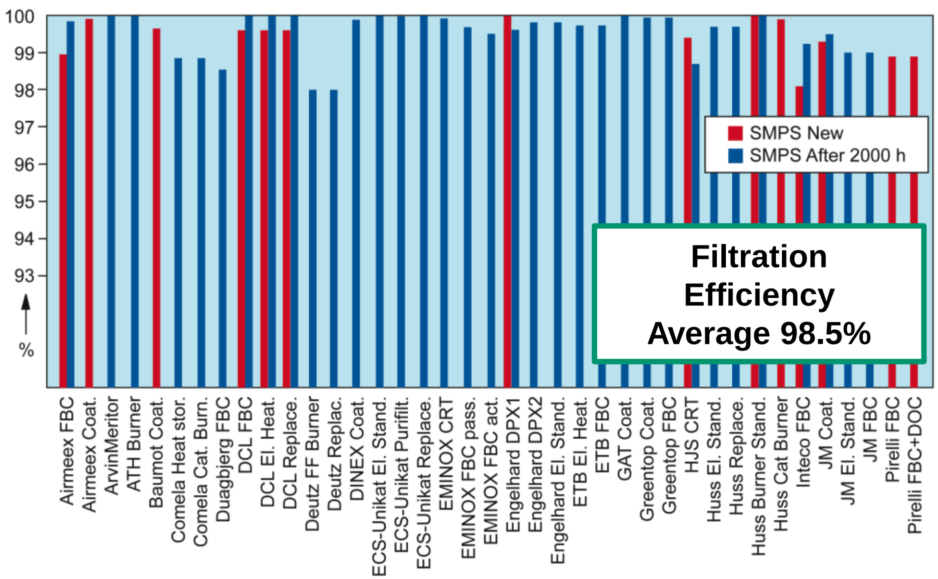


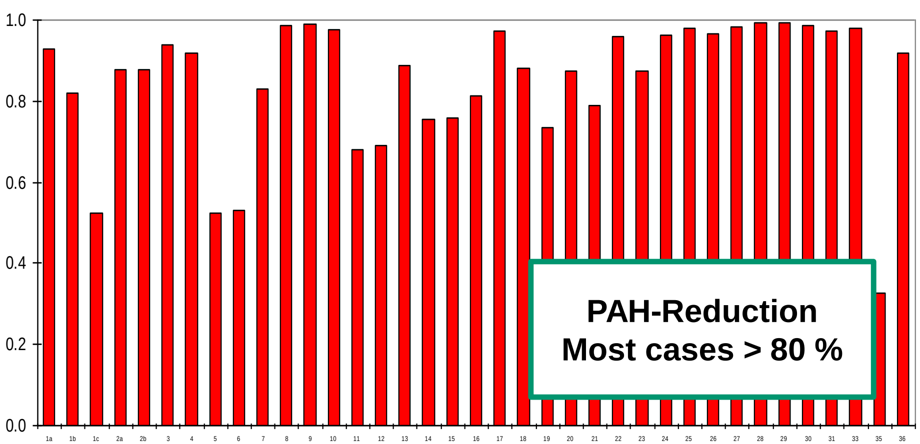
→ VERT Basic Conclusion:

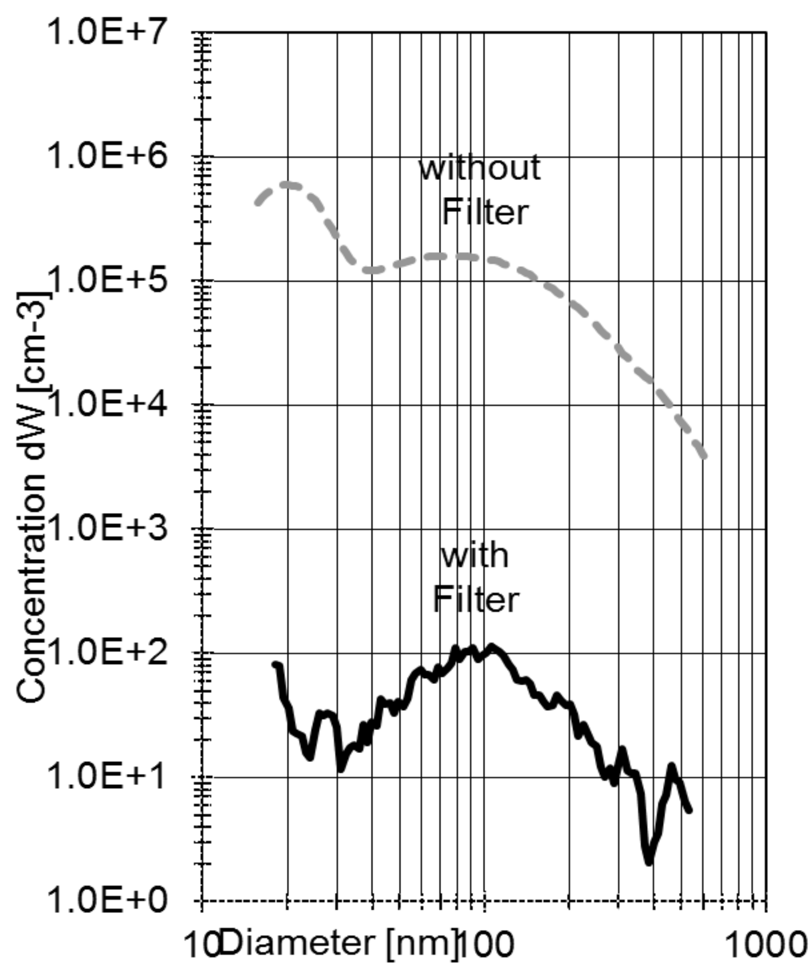
Filter quality depends on aerosol properties like size distribution and on space velocity and not on engine properties → test on one engine for worst case conditions is enough, but scrutinize on chemistry for toxicity

Product Certification

VERT-Parameters on Filtration and Detoxification resulted in Best Available Technology

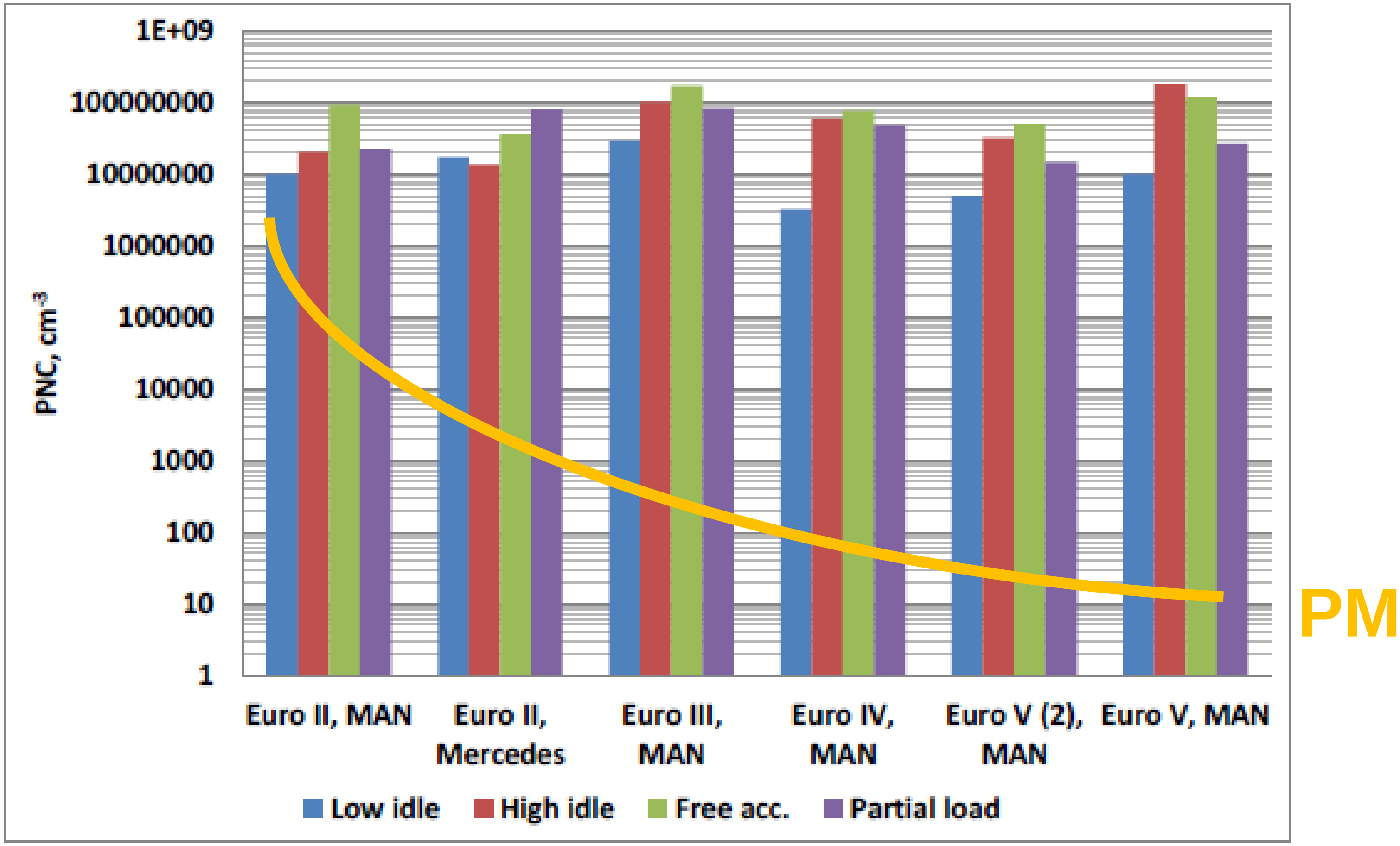






What happened in Europe and in the USA?

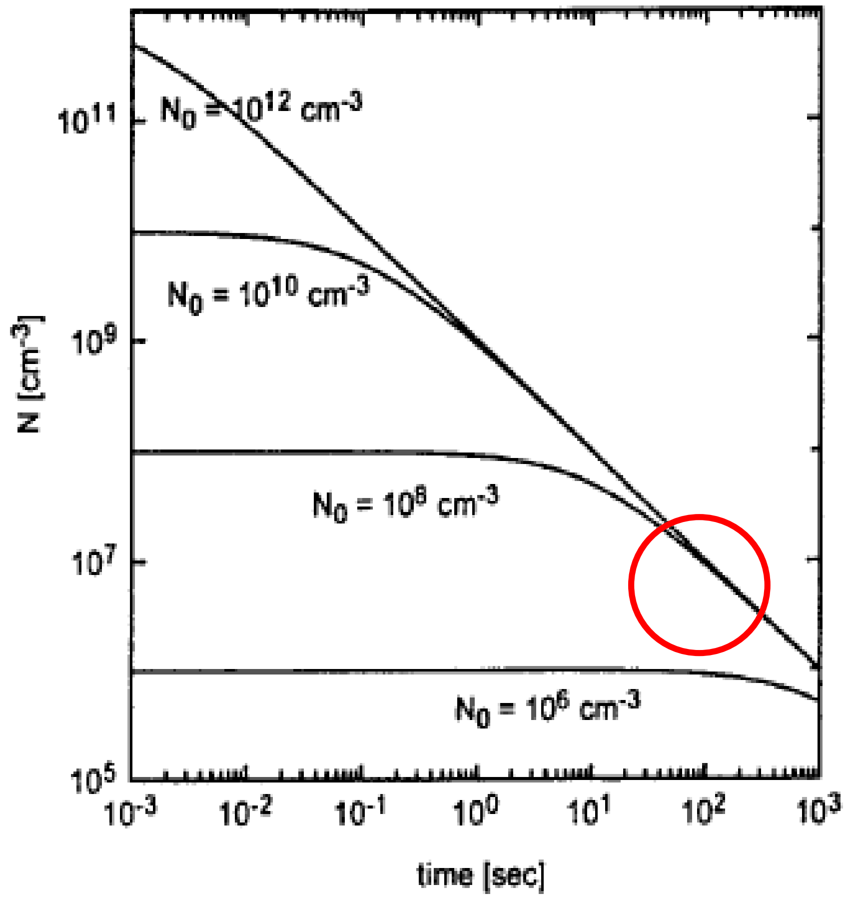
→ PM reduction – PN stagnation



From fresh to aged Aerosol →

by Agglomeration, Scavenging, Condensation, SOA-formation

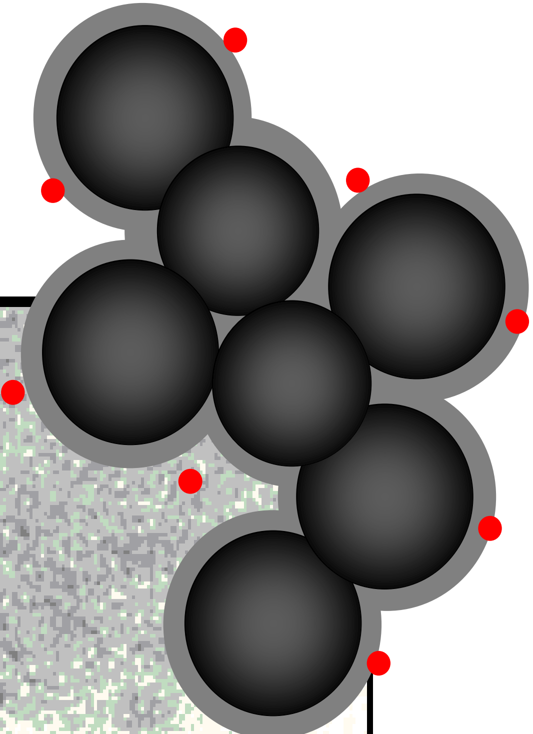
Primary particles have a diameter of 20 nm – they agglomerate very fast and we measure about 1-10 Mio P/cc with old and with new engines in the tail pipe

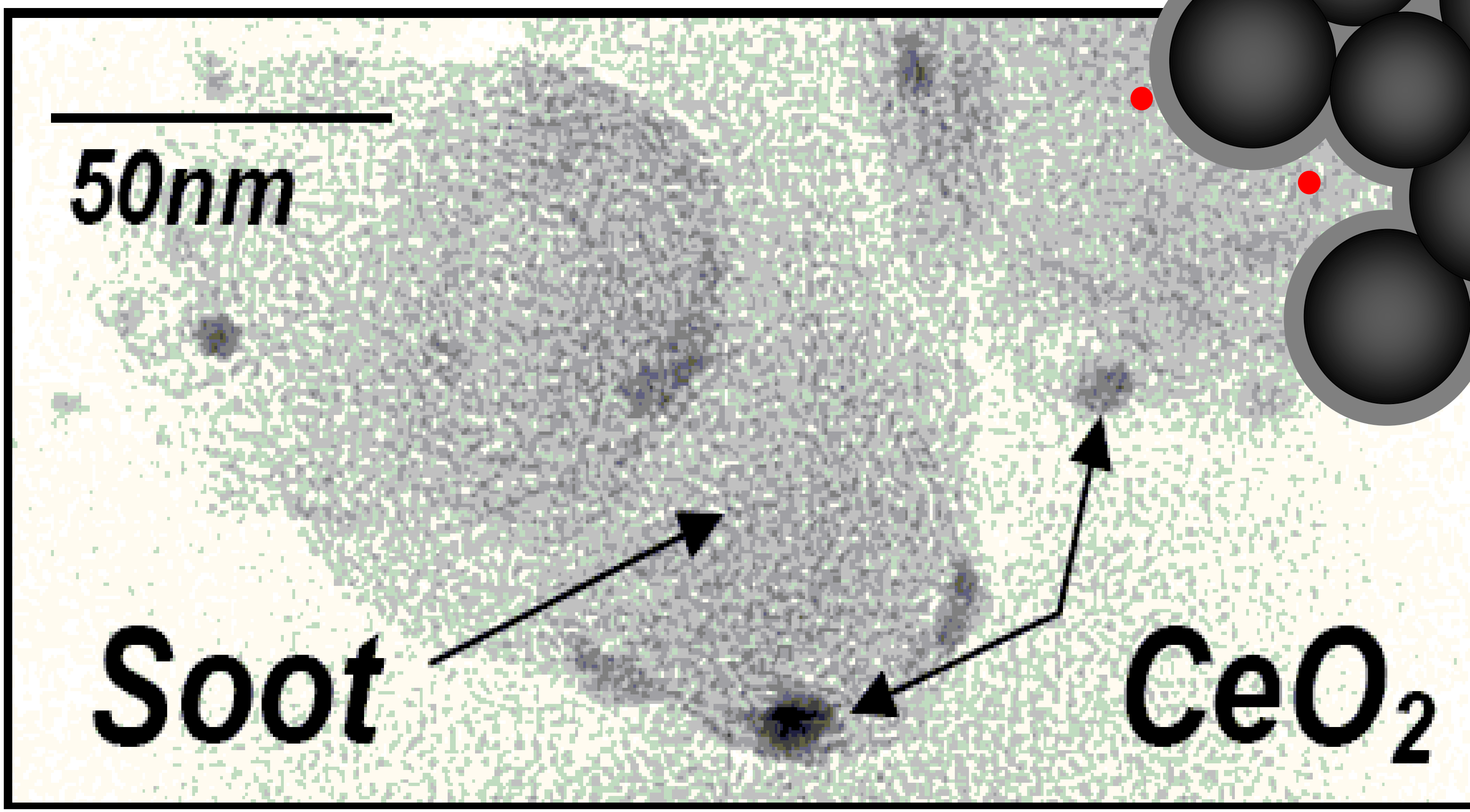


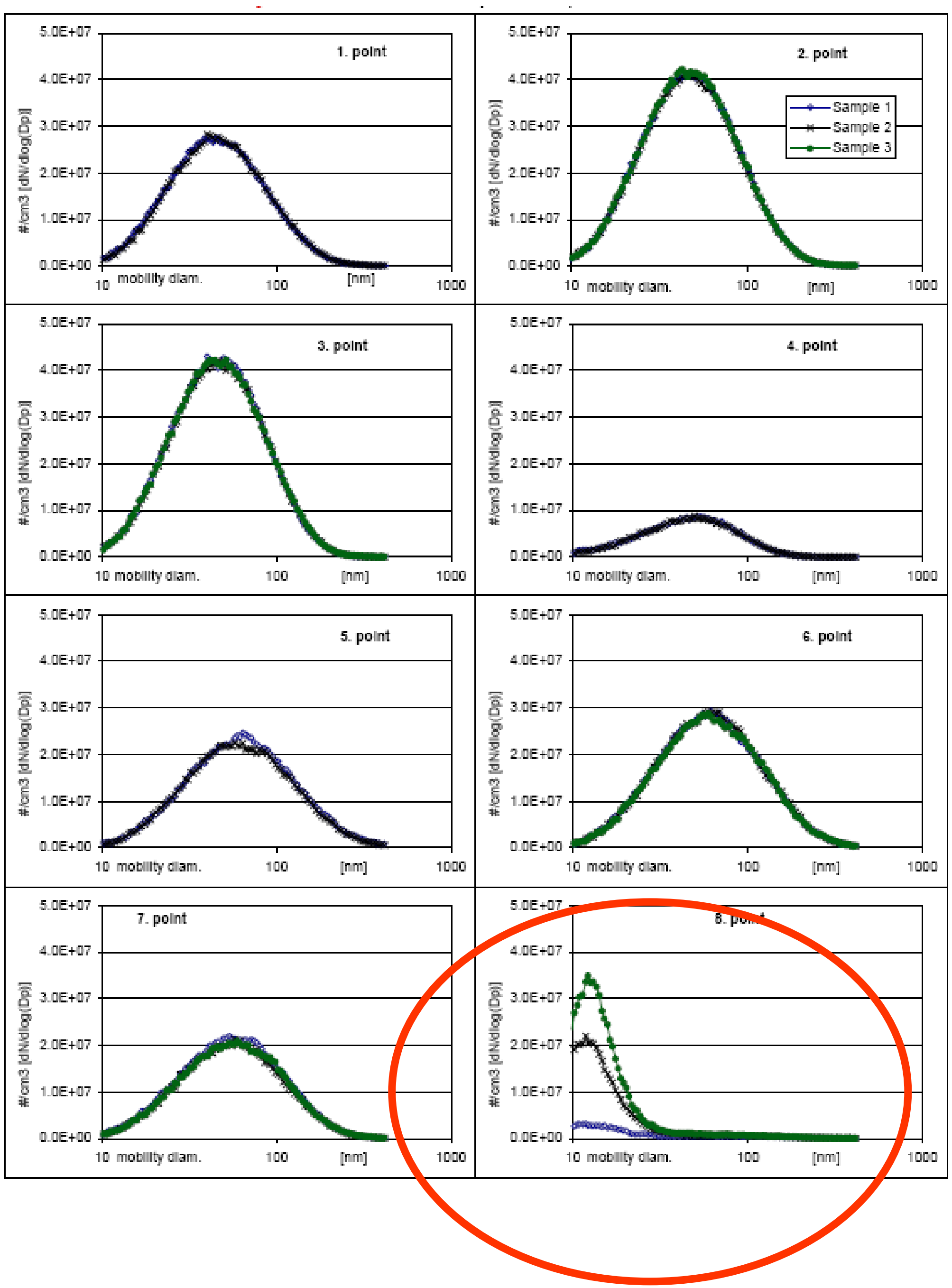
Hinds-Textbook 1982

Particles are coated by PAH and decorated by metal oxides

The Trojan Horse Effect







Finding Metal Particles

Liebherr Diesel

110 kW

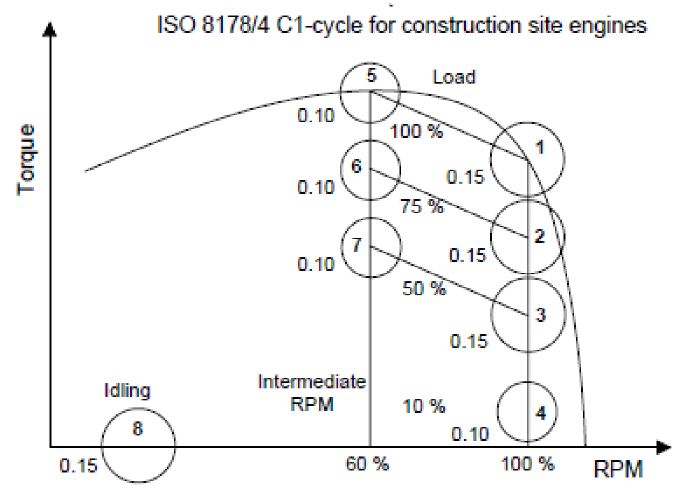
8 operation points of

ISO 8178/4 C1 test cycle

OP 8 = idle

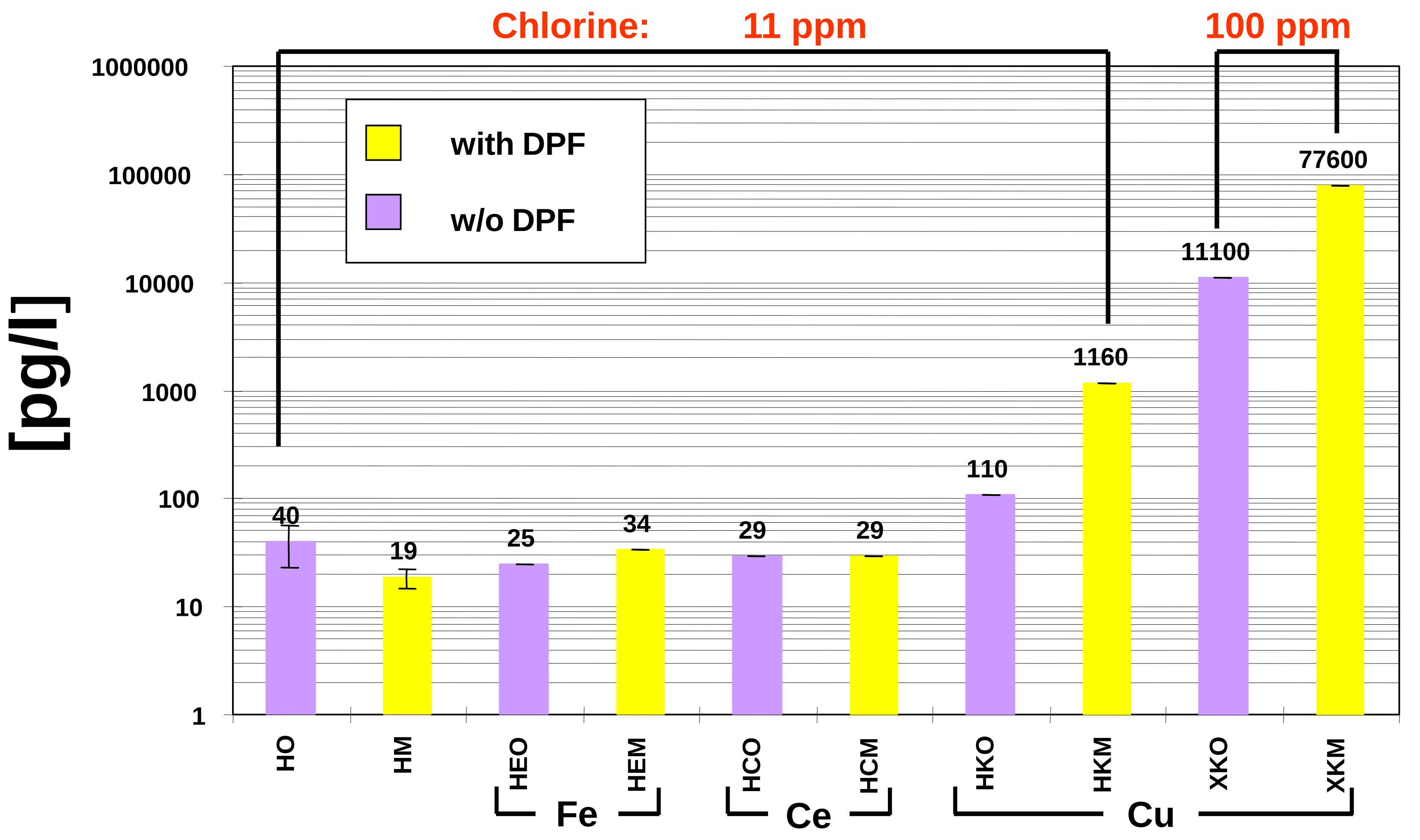
Sampling: 300°C,

Dilution Ratio DR=100



Finding Dioxins, Furans, PAH and more

→ VERT filter industry w/o secondary emissions



Finding Petrol Engine Particle Emission

Diesel

Sootpeak: 80 nm; 10^6

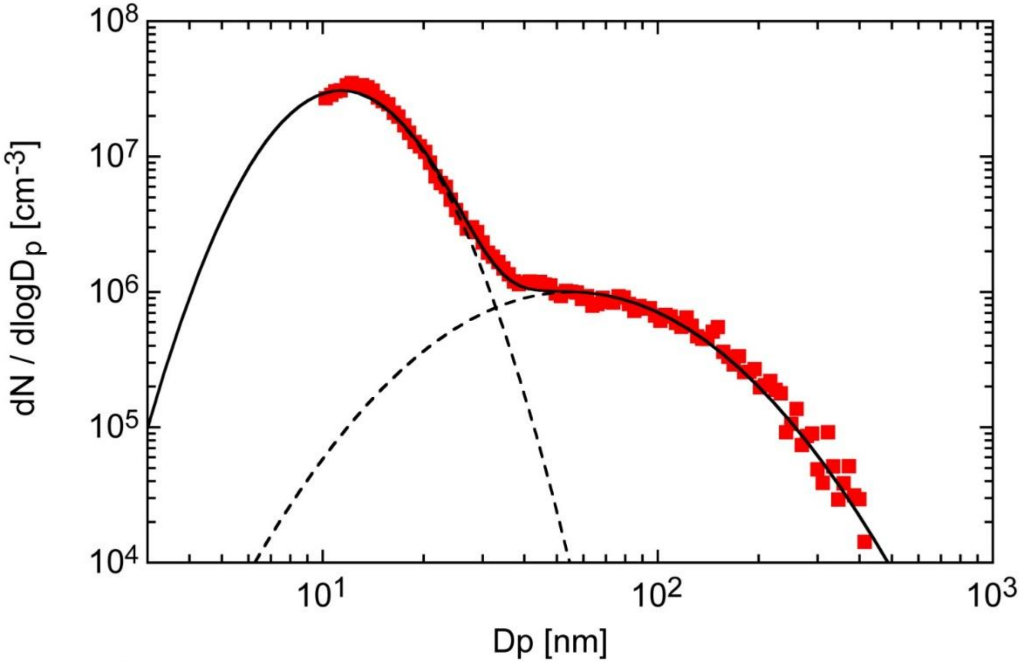
Ashpeak: 10 nm; 10^7

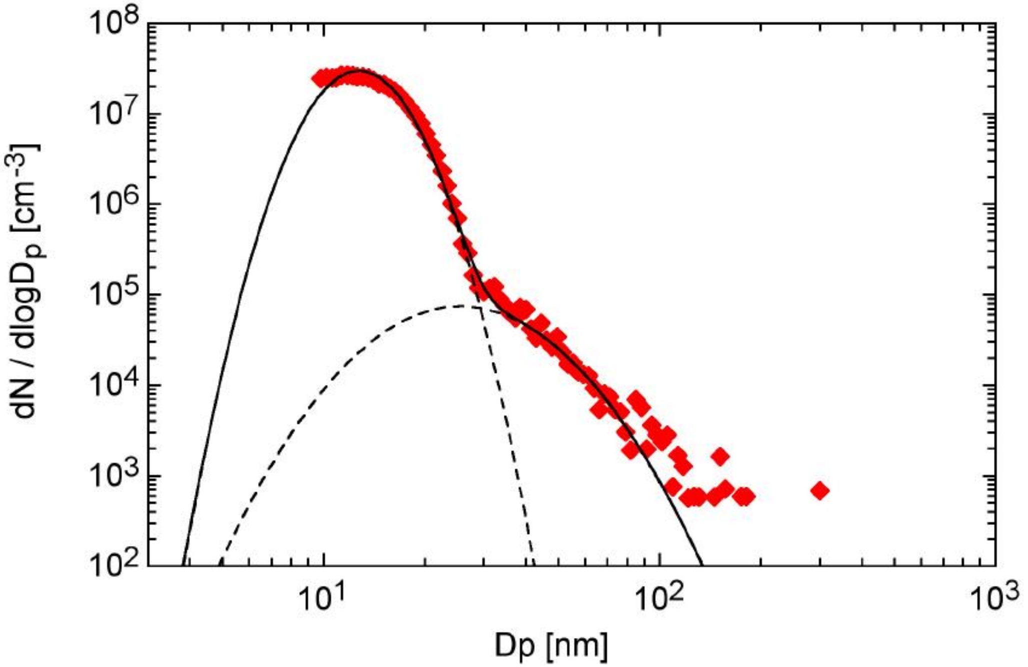
Petrol

Sootpeak: 40 nm; 10^5

Ashpeak: 10 nm; 10^7

→ And a whole new market

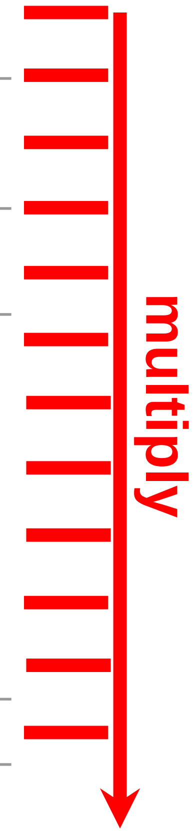




Understand Toxicity Contributors

along the way of the particle entering the organisme

process	parameters	quantify
Location of aerosol deposition	Diffusion	**Size,**
		Hygroscopicity
Contact with body surface	Solubility in water…	**solubility**
	... in Mucus, Surfactants?	Lipophility
Translocation	Cell membrane penetration; Phagocytosis	**Size**
Interaction	Overall Toxixity	**MAK (Threshold)**
	Bioavailability	?
	Cytotoxicity	?
	Mutagenicity	?
	Carcinogenicity	?
Excretion	Biopersistence	Decay Time



HEQ Index Value

Source: M.Kasper, ETH-NPC 2007

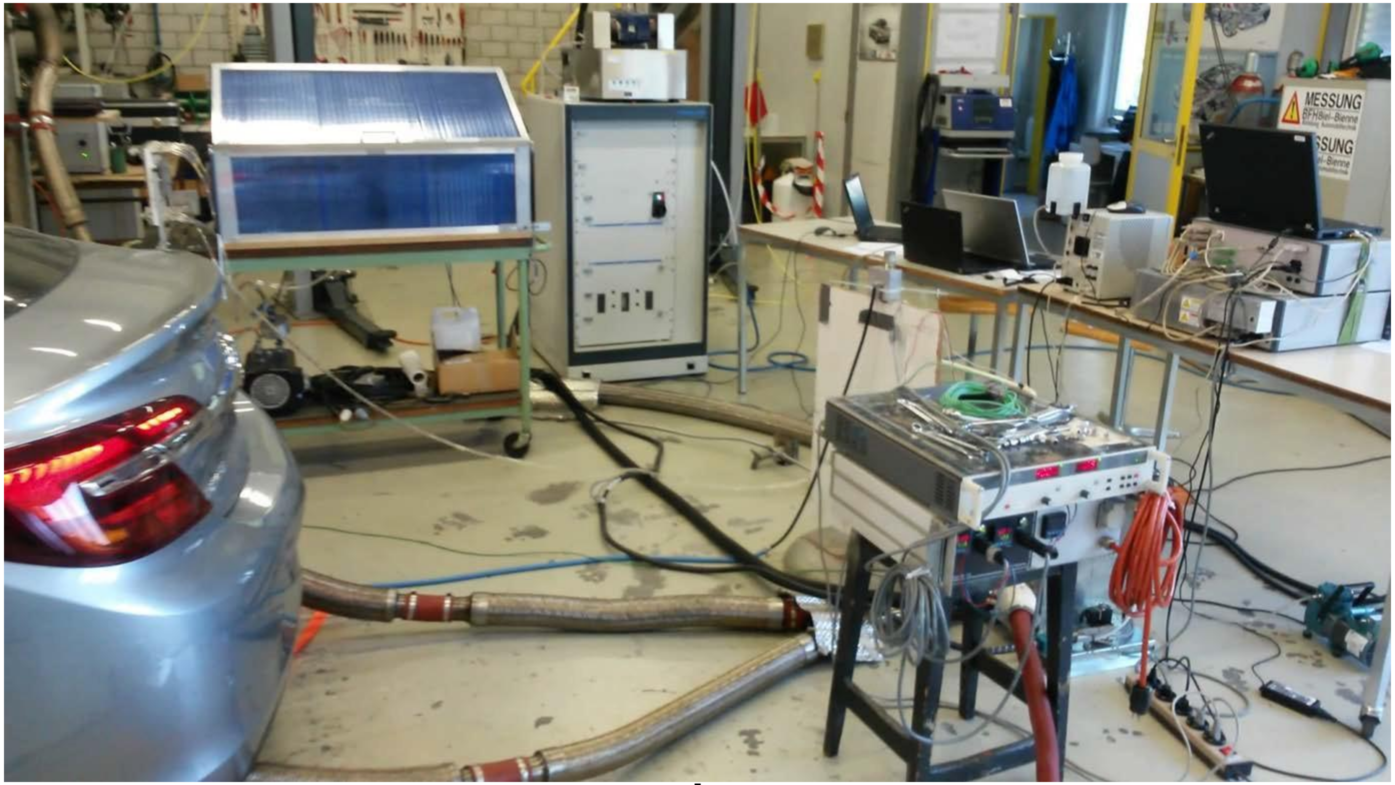
HEQ Health Effect Equivalent based on physico-chemical parameters

PM10-HEQ Influence Factors *Example*

PM10-Compounds	EC < 500 nm	EC > 500 nm	Metals Minerals > 500 nm	Metals <100 nm	Sea Salt	OM	Benz(a) Pyren	Ammonia	Nitrate	Sulfate	Water
Mass %	15	2	10	2	15	20	0.01	10	10	10	6
Solubility	1	1	1	1	0.001	0.2	1	0.01	0.01	0.1	0.0001
Mobility	1	0.1	0.1	1	1	1	1	1	1	1	1
Toxicity	1	0.1	0.1	10	0.01	0.1	50	0.1	0.1	0.1	0.001
HEQ -Index	1	0.01	0.01	10	0.00001	0.02	50	0.001	0.001	0.01	0.000001
PM10-HEQ	15	0.02	0.1	20	0.00015	0.4	0.5	0.01	0.01	0.1	0.000006

Starting Biologic Research

aerosol exposure from different technology
to human lung cells
the closest one can be to reality
→ Metals → NO_2 → SOA → Fuels → Lubes → Catalysts



Test vehicle **Exhaust sampling**

and ambient Air Criteria?

Measurements in China:

20.12.2012 — **90-120.000 PN/cm^3 at reported PM2.5>300$\mu g/m^3$ $\rightarrow$ unhealthy air**

18.12.2013 — **200.000-500.000 P/cm^3 at reported PM2.5<50$\mu g/m^3$ $\rightarrow$ healthy air ??**

Apparent disconnect between PN number concentrations and PM concentrations in highly polluted atmospheres which metric characterizes pollution best ?

Aerosol Society is preparing the Standards

for ambient Air PN measurement to replace PM

NA 134-04-02-18 UA N 248

TECHNICAL SPECIFICATION

SPÉCIFICATION TECHNIQUE

TECHNISCHE SPEZIFIKATION

FINAL DRAFT
FprCEN/TS 16976

February 2016

ICS 13.040.20

English Version

Ambient air - Determination of the particle
concentration of atmospheric aeros

Air ambiant - Détermination de la concentration en nombre de particules de l'aérosol atmosphérique

Außenlu
Partikelanzahlkonz

This draft Technical Specification is submitted to CEN members for Vote. It has been drawn up b
CEN/TC 264.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, C
Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ir
Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain,
United Kingdom.

Recipients of this draft are invited to submit, with their comments, notification of any relevant p
aware and to provide supporting documentation.

Warning : This document is not a Technical Specification. It is distributed for review and comm
without notice and shall not be referred to as a Technical Specification.

Metrology always must come first

ICS 13.040.01 | VDI-RICHTLINIEN | September 2009

VEREIN DEUTSCHER INGENIEURE	Messen von Partikeln in der Außenluft Bestimmung der Partikelanzahlkonzentration und Anzahlgrößenverteilung von Aerosolen Grundlagen Measurement of particulate matter in ambient air Determination of the particle number concentration and number size distribution of aerosols Fundamentals	VDI 3867 Blatt 1 / Part 1 **Ausg. deutsch/englisch** **Issue German/English**

Der Entwurf dieser Richtlinie wurde mit Ankündigung im Bundesanzeiger einem öffentlichen Einspruchsverfahren unterworfen.

Die deutsche Version dieser Richtlinie ist verbindlich.

The draft of this guideline has been subject to public scrutiny after announcement in the Bundesanzeiger (Federal Gazette).

The German version of this guideline shall be taken as authoritative. No guarantee can be given with respect to the English translation.

BESTÄTIGT VDI zuletzt 2015

Inhalt Seite

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Table 1 Air pollution cost factors in EUR/ton of pollutant (€$_{2008}$ values)

Pollutant	$PM_{2.5}$ (exhaust)			PM_{10} (non-exhaust)			NO_x	NMVOC	SO_2
Region type	Metropolitan	Urban	Non-urban	Metropolitan	Urban	Non-urban			
Source	HEATCO	*UBA/ HEATCO	HEATCO	*UBA/ HEATCO	[illegible]	[illegible]	NEEDS	NEEDS	NEEDS
Country									
Austria	482,200	155,900	80,700	[illegible]	[illegible]	[illegible]	[illegible]	1'600	10'000
Belgium	483,400	156,000	104,400	[illegible]	[illegible]	[illegible]	[illegible]	2'600	10'900
Bulgaria	70,500	22,700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	400	6'200
Czech Republic	355,400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10'600	1'100	9'500
Denmark	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20,500	5'300	1'200	5'700
Estonia	[illegible]	[illegible]	[illegible]	[illegible]	34,000	17,700	2'800	600	4'500
Finland	[illegible]	[illegible]	[illegible]	[illegible]	55,800	14,400	2'600	600	3'500
France	[illegible]	[illegible]	[illegible]	175,500	56,500	35,100	10'500	1'400	9'900
Germany	430,300	[illegible]	[illegible]	172,100	55,500	33,600	12'700	1'400	10'900
Greece	338,600	[illegible]	[illegible]	135,400	43,600	19,100	2'700	600	5'800
Hungary	288,900	[illegible]	74,100	115,600	37,200	29,600	12'400	1'000	9'100
Ireland	537,200	173,400	56,200	214,900	69,300	22,500	4'400	1'100	5'400
Italy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8'700
Latvia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5'000
Lithuania	266,300	86,500	53,300	106,500	34,600	21,300	5'600	800	5'700
Luxembourg	877,100	282,400	125,000	350,800	112,900	50,000	12'700	2'400	10'300

and never forget the money involved

Benefit/Cost > 10

Switzerland	498,700	160,500	82,400

Switzerland	498,700	160,500	82,400
Poland	248,900	79,900	74,700

Value chosen: 460 CHF/kg PM10

and now with 100 Millions of DPF

we are again leading Europe with NPTI
developing new procedures and instruments for
maintenance and control

VERT-Team *power on demand*

Schweizerische Eidgenossenschaft
Bundesamt für Umwelt BAFU

A. Mayer

AKPF

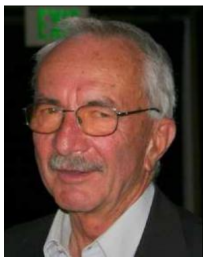
krebsliga schweiz

M. Wyser

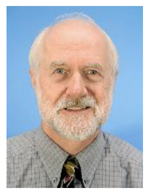
A. Stettler A. Mayer

F. Legerer

J. Mooney



ETH H.C. Siegmann
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich



G. Leutert

F. Jaussi

suva

H. Egli

W. Scheidegger

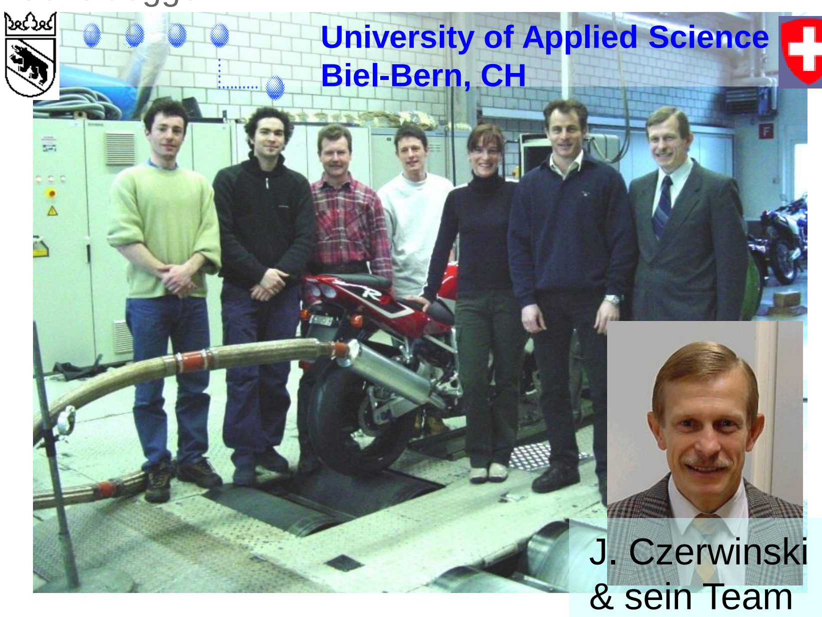
DieselNet

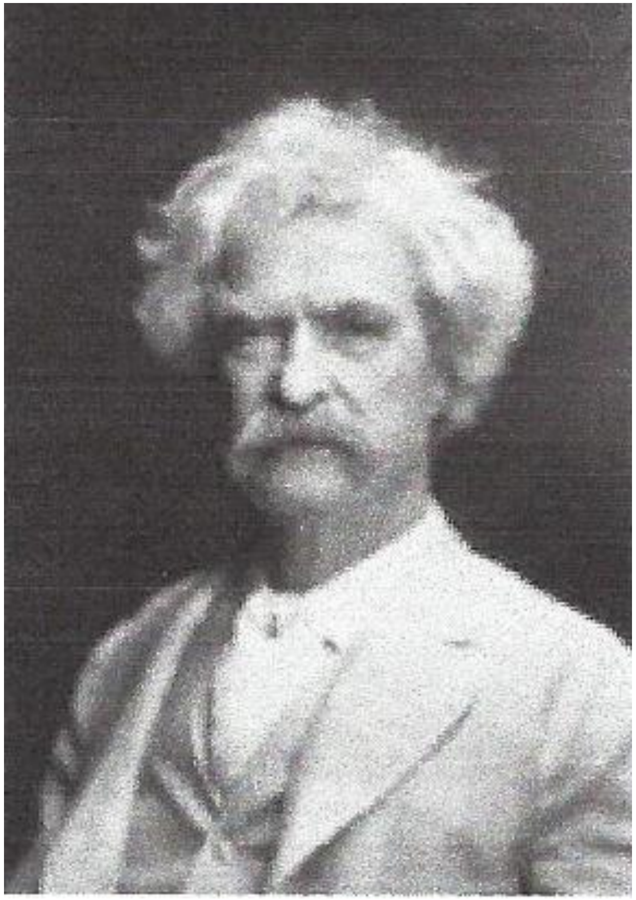
UNIVERSITÄT BERN

P. Gehr

n|w Fachhochschule Nordwestschweiz

H. Burtscher





Mark Twain

Keep in mind

«What gets us into trouble is not what we don't know It's what we know for sure that just ain't so»