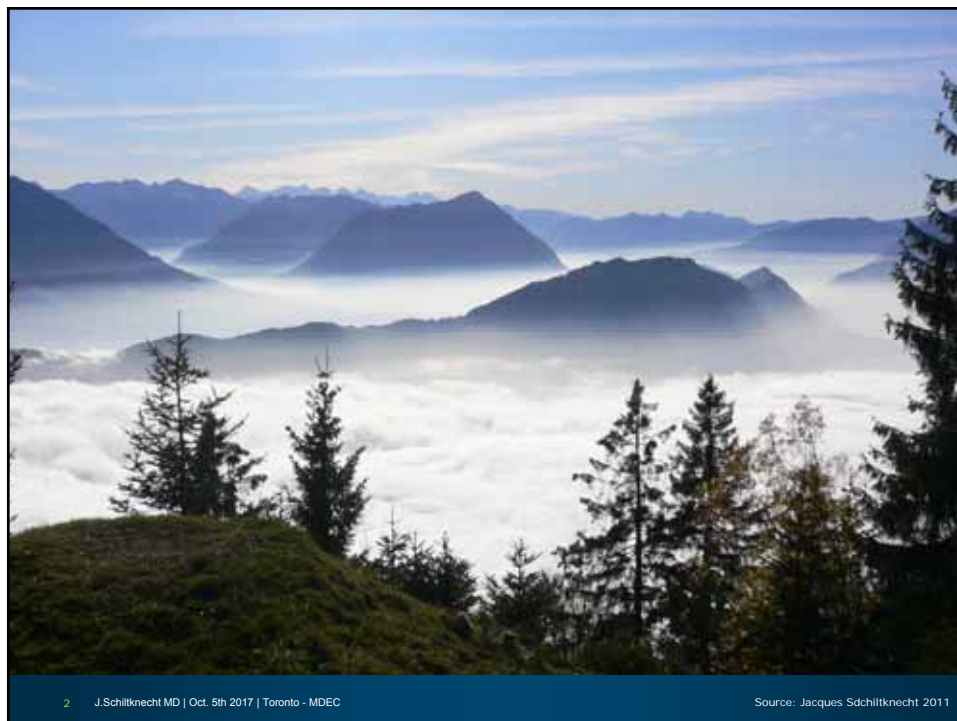


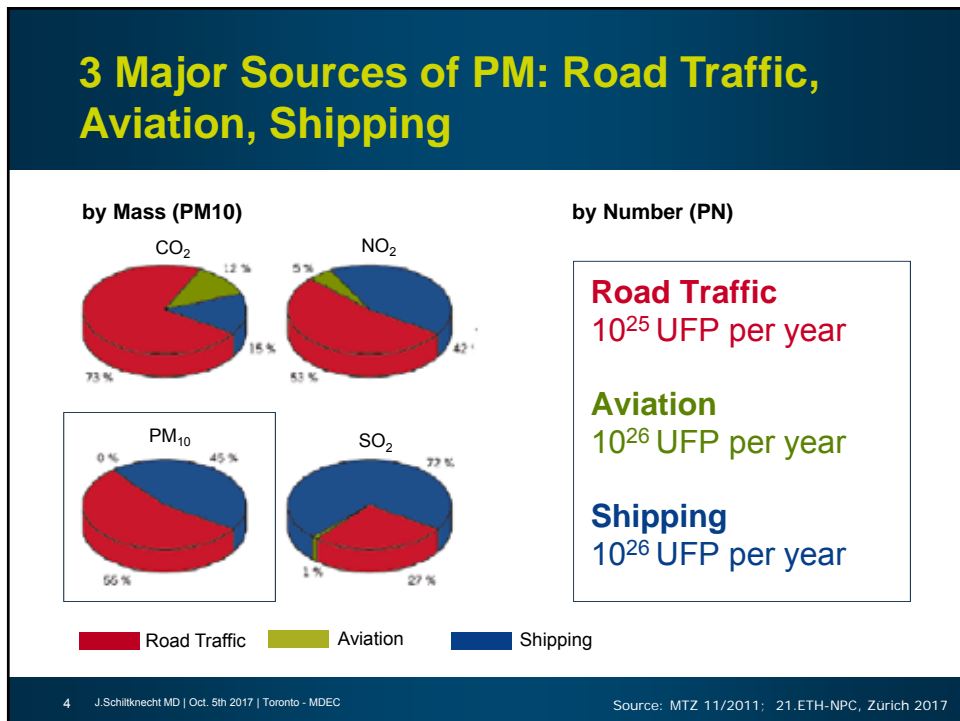
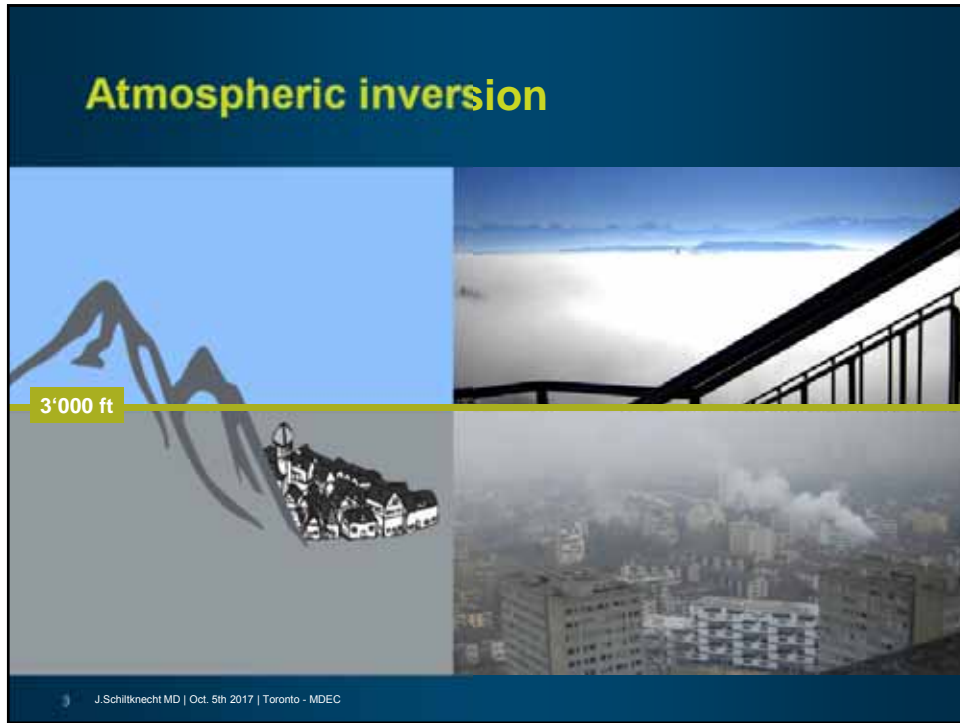
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The Health Impact of Engine Generated Ultrafine Particles

J. Schiltknecht MD | VERT

1





DPF - introduction

Road: pioneering in Switzerland

1988: 200 Busses retrofitted with DPF

1993: Start DPF- for Diesel engines in tunneling and construction

2017: 120'000 000 DPF equipped engines

USA/Canada: no PN monitoring → no DPF

Elimination of vehicle-PN-emissions



- Switzerland pioneered with busses, construction, rail and ship 1990
- PSA France pioneered Y 2000 with DPF in modern Diesel cars
- EU introduction of $PN < 6 \times 10^{11} P/kWh$

- **EU introduction of DPF for...**
 - Diesel Cars 2011
 - Trucks/Buses 2014
 - Petrol Cars DI 2017
 - Nonroad NRMM 2018

2018: nonroad and spark ignition Engines

Reduction of aircraft-PN-emissions



2017: first global PM emission standard adopted by ICAO

- Regulatory limit established for PM
- 2020: large aircraft engines must be certified to the new standard
- 2020: Public database
- Excellent engines already available
- Reductions for NO_x and CO₂ and Fuel Sulfur reduction foreseen.

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Source: Proposals by L, BAZSwiss office of civil aviation / Dr. A Mayer

Shipping: urgent need for PN reduction



- Emission controlled areas (ECA)
- Sulfur reduction (3.5% → 0.1%)
- SCR-systems for NO_x reduction

**PN:
FILTER SYSTEM
DEVELOPMENT
VERT-PROJECT**

PN: Up to 250'000 #/cm³ on decks of cruise ships

Up to 50'000 **premature deaths** due to ship emissions in European waterways (source: CEEH)

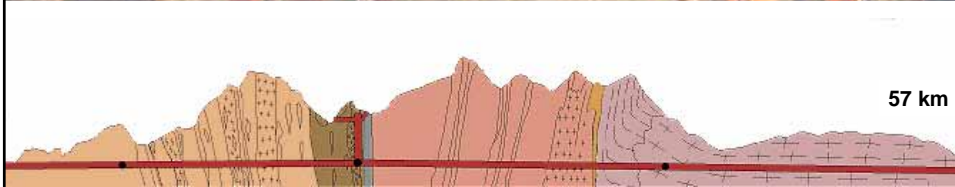


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Source: CUUH / Dr. A Mayer

Going underground: NEAT -tunnel

57 km Length Gotthard railway base tunnel
First full scale DPF project 1993-2016



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Source : VERT

Tunneling: „VERT-filter for each Diesel“

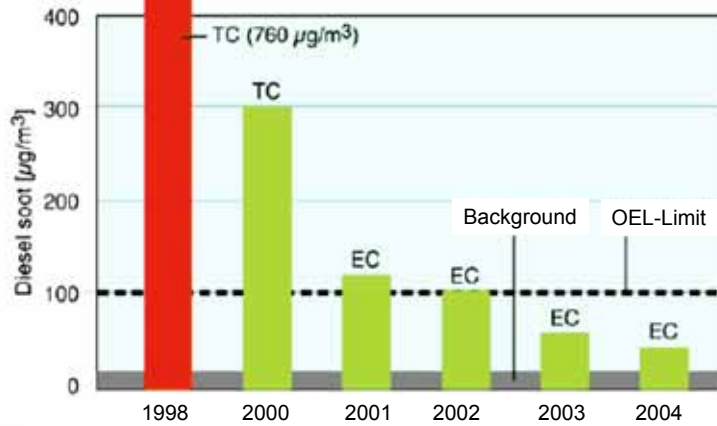
SUVA: Swiss council for occupational health and accident prevention



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Source: Dr. A. Mayer

Improvement of air quality in Swiss tunneling



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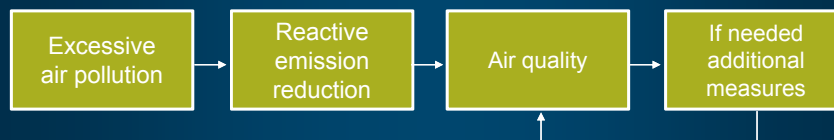
Source: SUVA

2 principles for emission reduction and ambient air quality:

“Preventive” partly implemented in Switzerland



“Reactive”



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Source: Dr. J. Schiltknecht / FOEN Switzerland

World Medical Association Resolution

adopted by the 65th WMA assembly South Africa Oct. 2014

- To introduce best available technology (BAT) as standard for all new Diesel engines - both on-road and off-road
- To incentivize retrofitting with BAT-filters of all on- and off-road used engines
- To monitor and limit the concentration of nanosize soot particles in urban (and underground) breathing air

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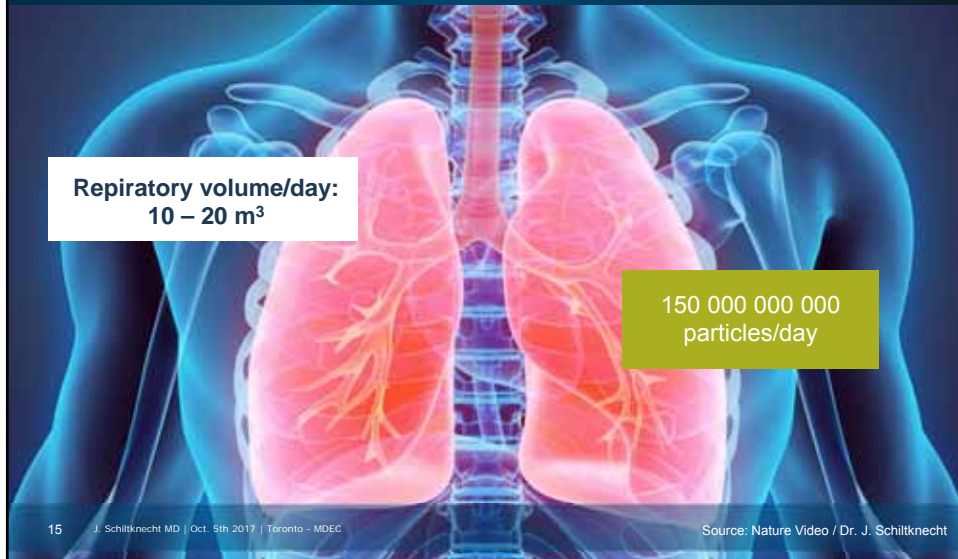
Source: WMA

Topics addressed

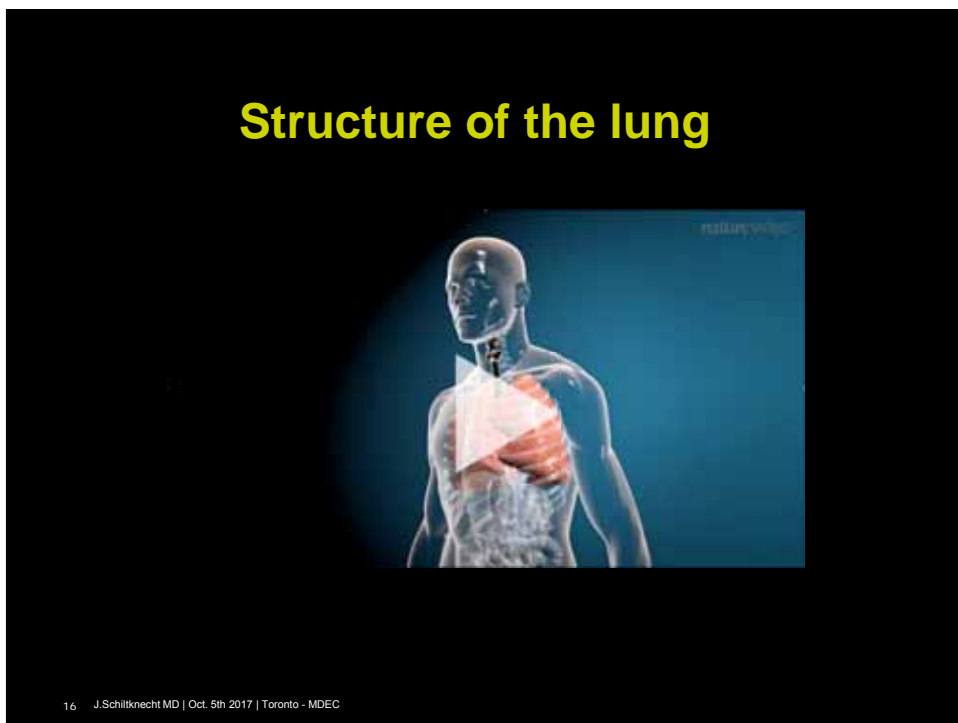
- **Health**
 - Function and structure of the lungs and natural defense mechanisms
 - Health impact of air pollutants: the importance of UFP
 - Epidemiologic findings and toxicological reflections on UFP
- **Technical solutions and regulatory approach**
 - the success story of the Diesel Particle Filter
 - Metrology, certification, regulation and public awareness

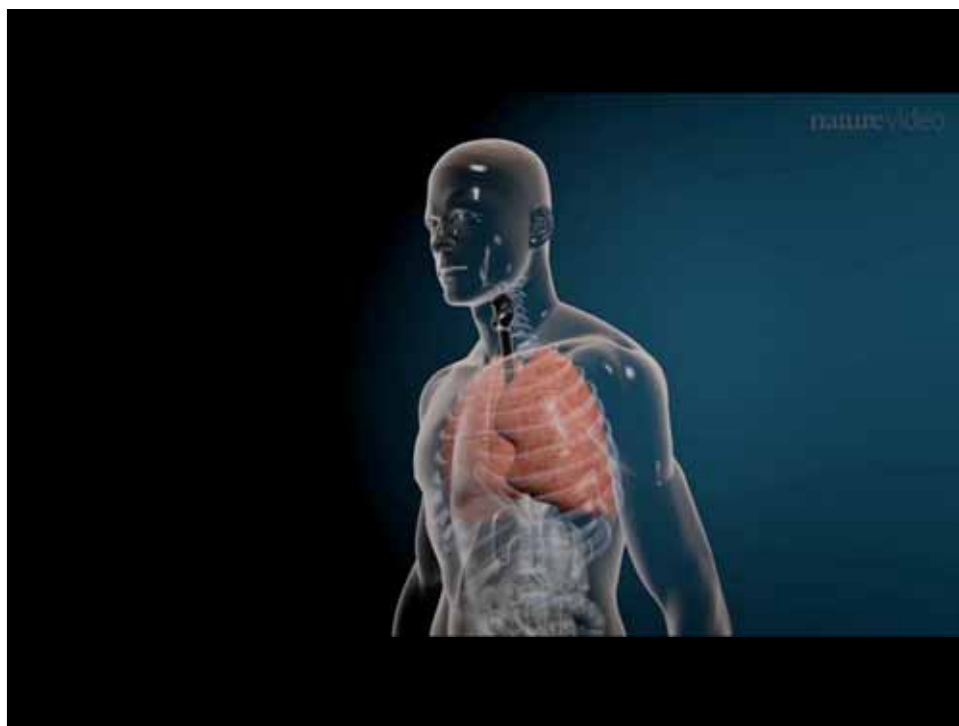
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Lung performance

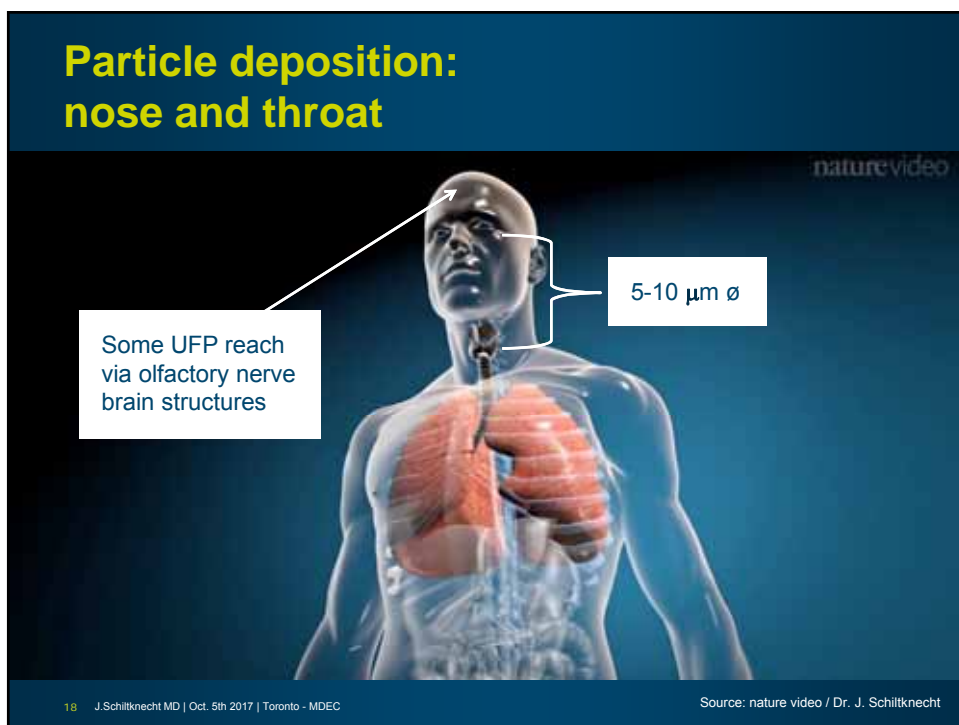


Structure of the lung

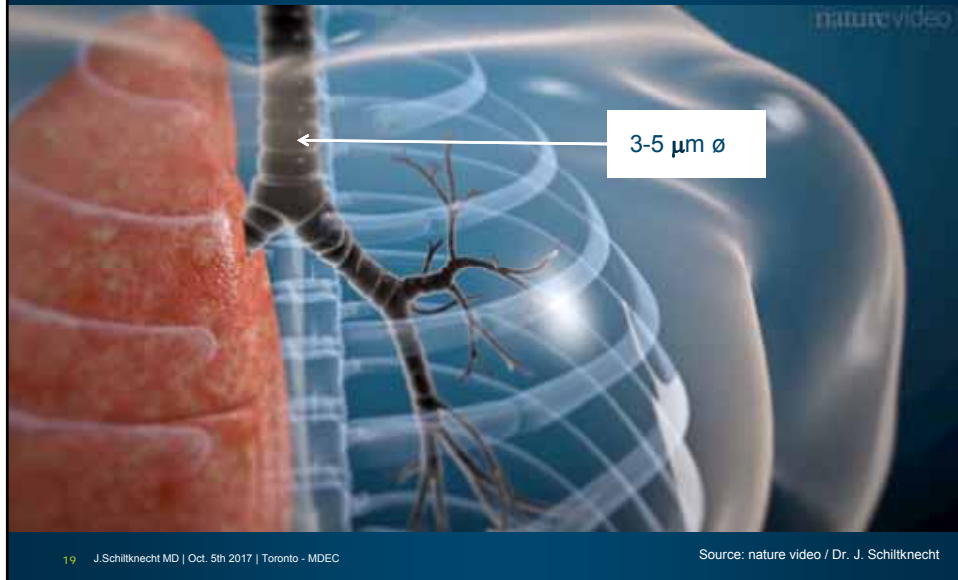




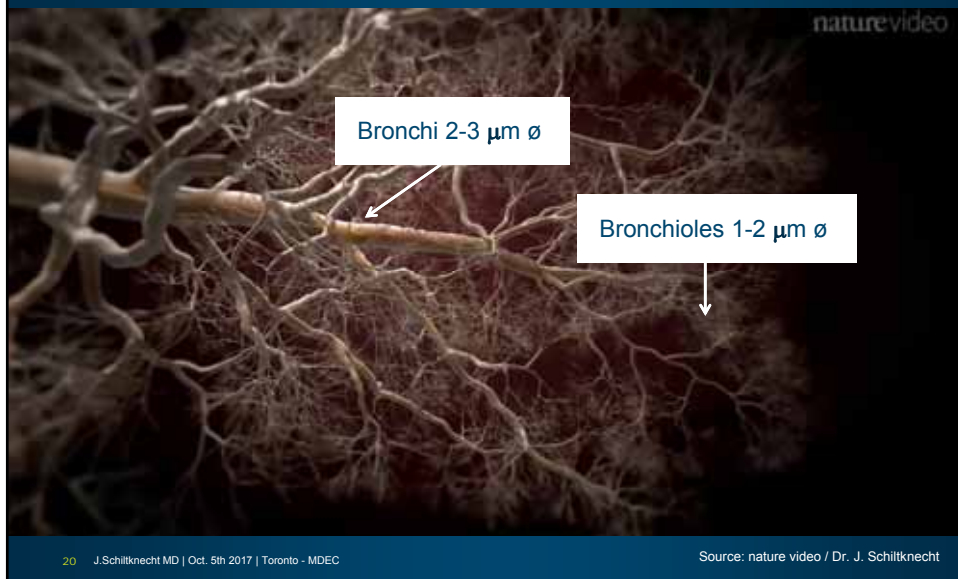
Particle deposition: nose and throat



Particle deposition trachea and major bronchi



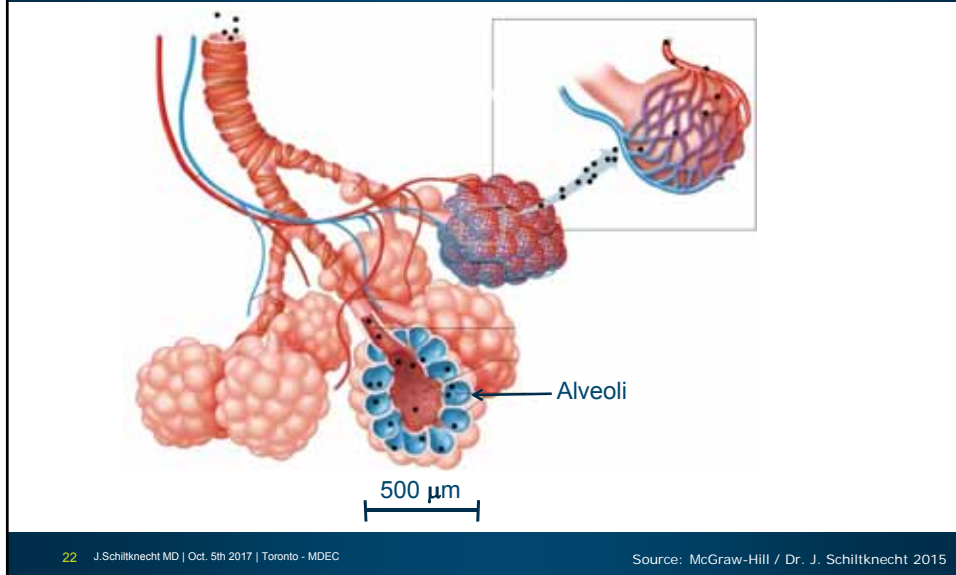
Particle deposition: bronchi and bronchioles



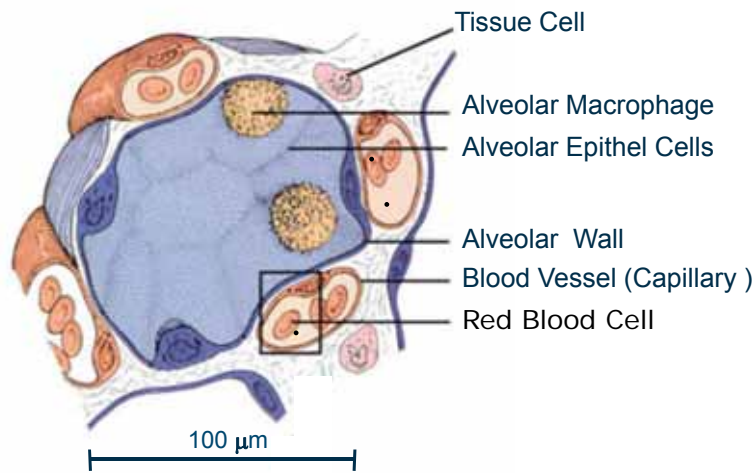
Particle deposition: alveoli



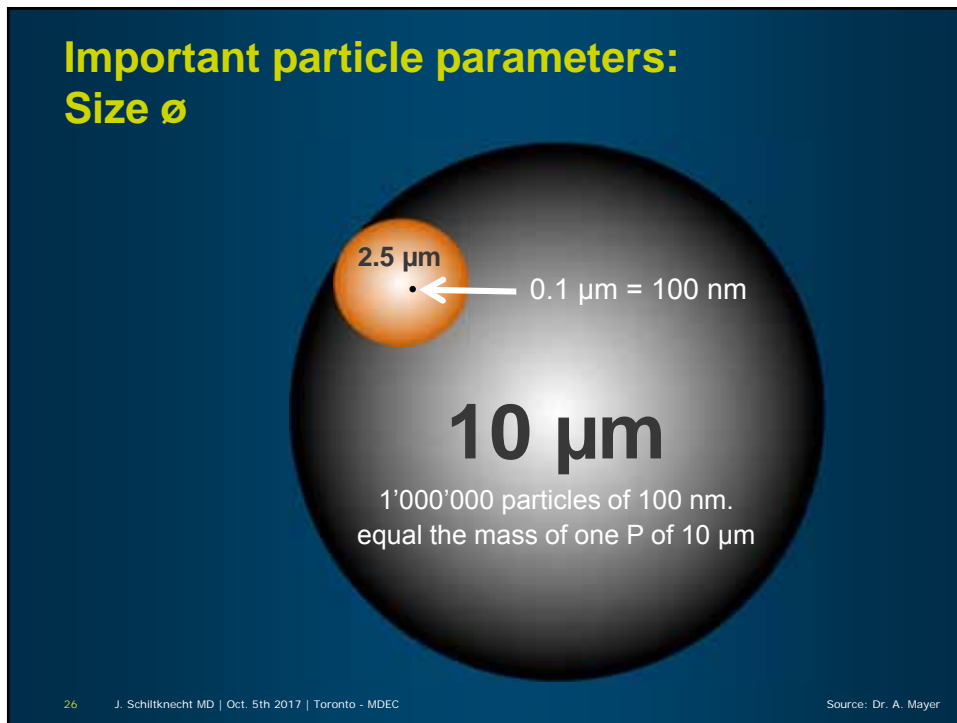
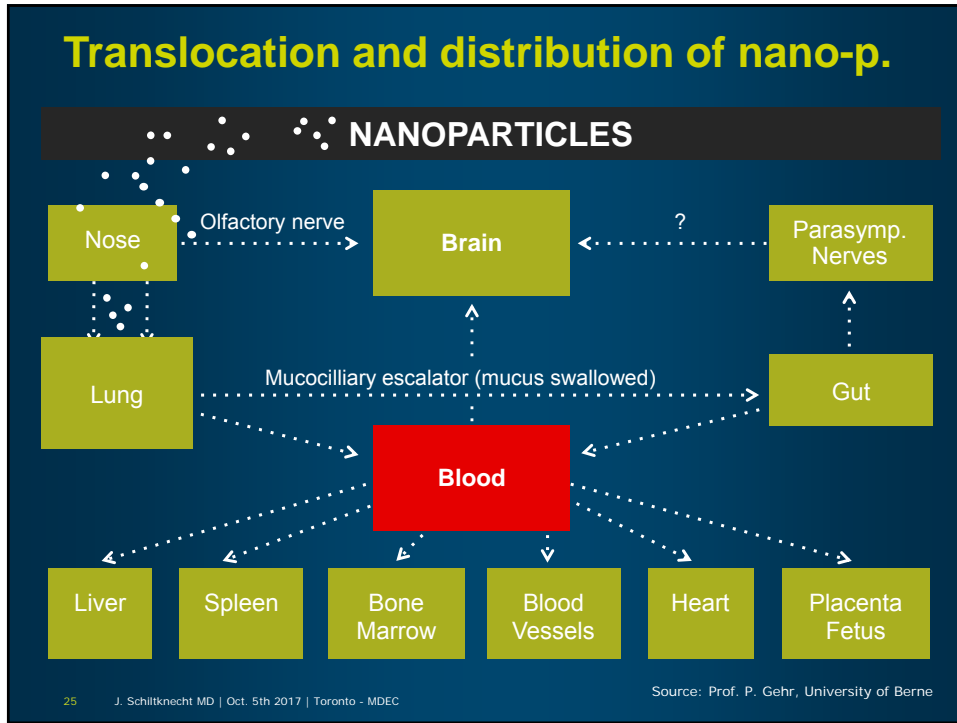
Translocation into blood circulation



Section of alveole surrounded by capillaries



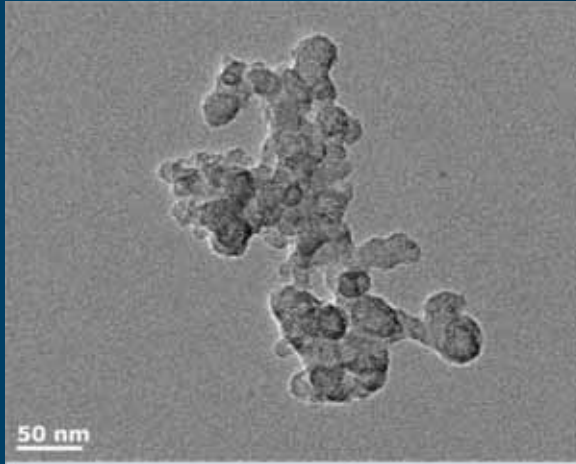
Defense mechanisms of the lung



Important particle parameters: Surface

typical: 200 m² /g

Soot particle,
transmission
electron
microscopy



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Source: De la Roca, University of Nottingham

Important particle parameters: Persistence

Lung Tissue
1952 London
Smog Autopsy
Multiple
Nanoparticles

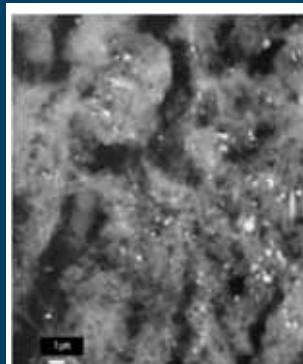


Figure 2. BE micrograph of section of airway aggregate from case 2 revealing abundant sub-micrometer inorganic (bright) particles.

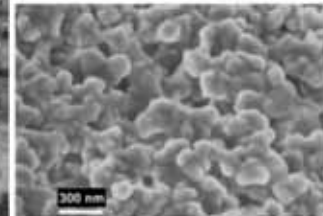


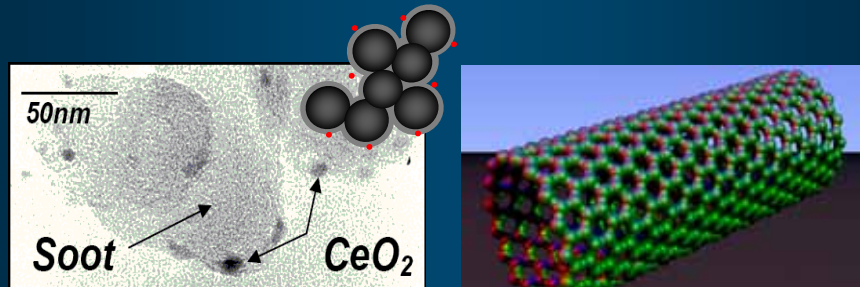
Figure 3. High-magnification field emission scanning electron micrograph of airway aggregate from case 2 showing ultrafine PM structure.

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Source: Dr. A. Mayer

Important particle parameters: Chemical composition and structure

Core with adherent molecules



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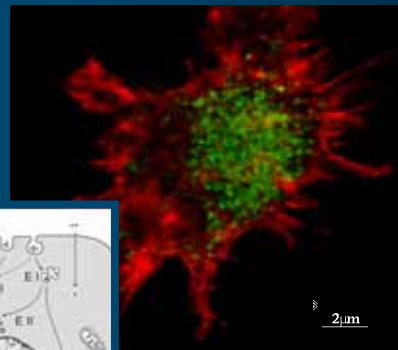
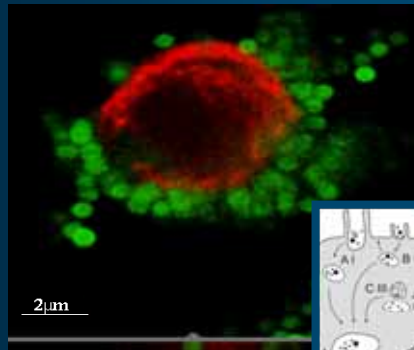
Source:

Cellular Uptake of Particles and Size

Polystyrene Particles

1000 nm

78 nm



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Source: B. Røthen-Rutishauser
University of Fribourg
Brandenberger et al., Small, 2010

Most important air pollution related diseases worldwide

Ischemic Heart Disease	IHD
Chronic Obstructive Pulmonary Disease	COPD
Cerebrovascular Disease	CEV
Acute Lower Respiratory Disease	ALRI
Lung Cancer	LC

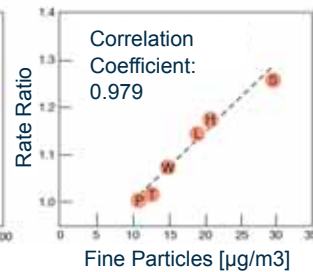
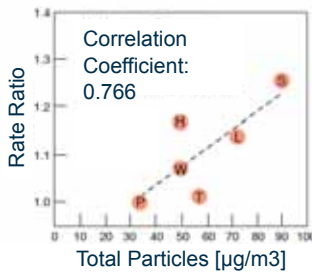
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Source : Lelieveld et al. Nature 2015

6-Cities Study 1978 – 93



Douglas Dockery



15'000 cases in 6 cities:

H Harriman TN	S Steubenville OH
L St. Louis MO	T Topeka KS
P Portage WI	W Watertown MA

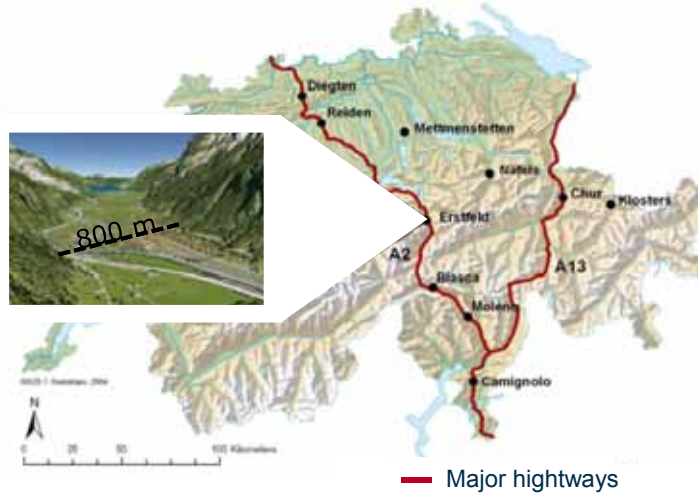
Mortality due to PM_{2.5} quantified

Correlation with fine particles only

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Source : Dockery NEJM 1993

Increase of respiratory symptoms near highways



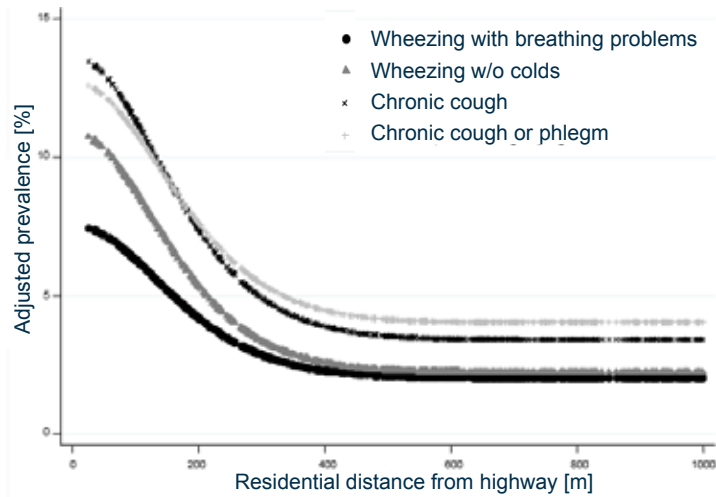
35

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Source: Hazenkamp-von Arx et al. Environmental Health 2011

Distance to heavy traffic highways and respiratory symptoms

Estimated adjusted prevalence rates of health outcomes

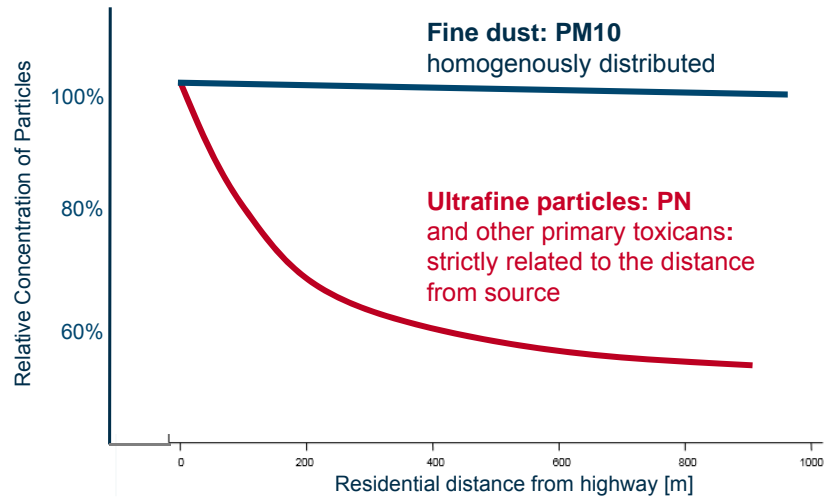


36

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Source: Hazenkamp-von Arx et al. Environmental Health 2011

Distance to highways and particle distribution

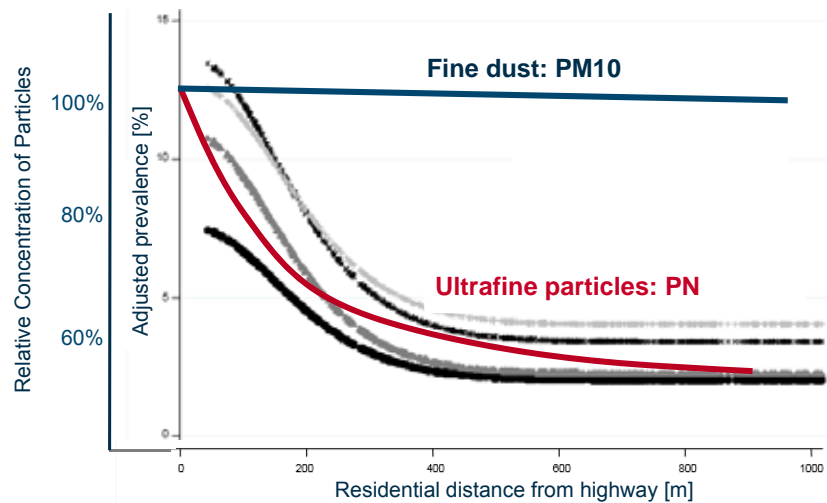


37

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Source: Zhu et al, J Air Waste Manage Assoc, 2002; 52: 1032

Ultrafine Particle distribution and health symptoms match!

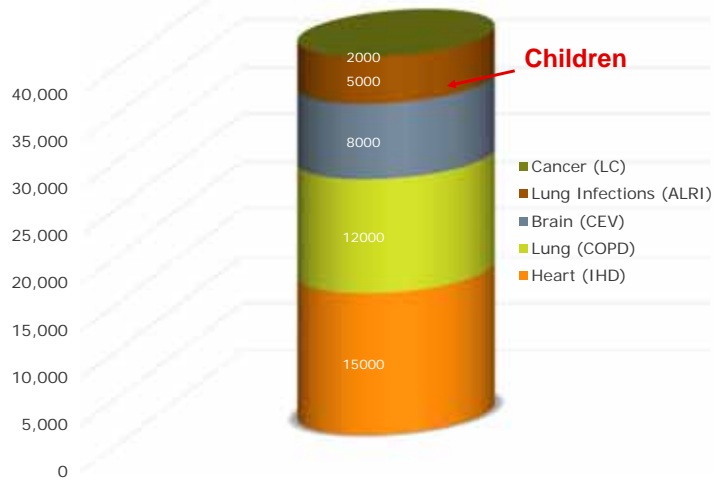


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Source: Zhu et al, J Air Waste Manage Assoc, 2002; 52: 1032

Premature Mortality p.a. related to PM 2.5 Estimate for Urban Population of 100 Million People



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Source: Lelieveld et al. Nature 2015

WHO OECD Report



Economic cost
of the health impact
of air pollution in Europe

*Clean air, health
and wealth*



Some examples

Economic cost of premature deaths from Ambient Particulate Matter Pollution in US\$ (millions)

	2005 ¹	2010 ²
Hungary	21 839	21 281
Iceland	62	96
Ireland	1 773	2 518
Israel	6 227	7 164
Italy	98 612	97 193

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Source: WHO Regional Office for Europe, OECD (2015)

**... so that air becomes good
for breathing again**



41



Introduction of the particle filter: A success story



From 10
VERT-filters 1996 to 120
Million road vehicles 2017

Development of particle filter

Filter available since 1982

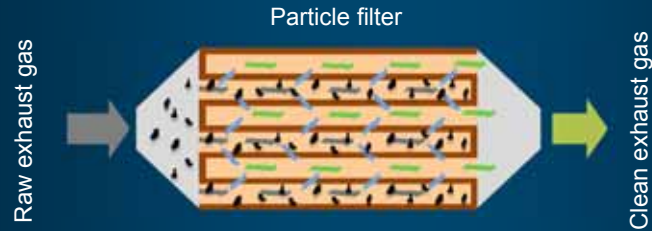


John J. Mooney

- **1982:** Ford patents ceramic honey comb filter, presentation of the product by Corning inc.
- SAE*: first particle conference in Detroit
- **1983:** A. Mayer develops at BBC** the filter upstream of turbo
- **Since 1985:** lots of industrial patents
- Daimler starts testing DPF
- *Society of Automotive Engineers
- **Brown,Boveri Co. Switzerland

Technical concept of a Diesel particulate filter

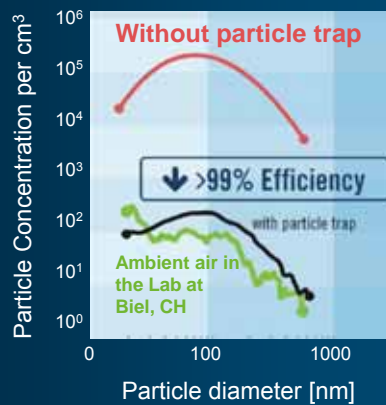
“Closed” Filter Systems capture > 99% of the particles



- Channels are reciprocally closed
- Exhaust gas is forced to penetrate the porous walls permeable to gas
- Soot particles are captured and collected on the walls of the filter material

Exhaust particles are eliminated

Particle concentration as function of particle diameter (Logarithmic scale)



- DPF remove up to 99.99% of engine generated particles
- Only 0.01 % is released to the environment



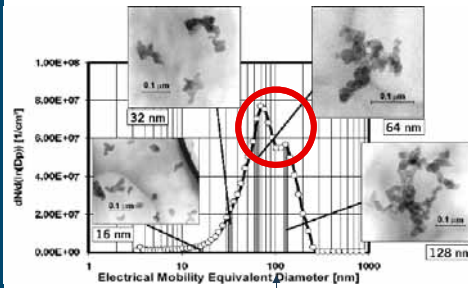
The lung: An open door for engine emitted particles?

- **Peak** Particle Number in Diesel & SI Emissions Size Range 10-300 nm
- **No** defense in the Lung for UFP < 500 nm

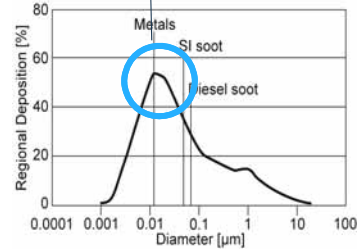
Solution:
DPF catches all
Particles down to 1 nm

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Engine emission



Deposition in the lung



Source: VERT

St. Gotthard Tunnel (NEAT)

- 1993 onset of the planning for the largest tunnel project in the world (57 km, total length of tunnel tubes 152 km)
- Legal Air Quality Limit: 100 µg/m³ EC
- Calculations show, that adequate ventilation is impossible

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Source: VERT

VERT Consortium

- SUVA forms a consortium to solve the problem within 3 years with A. Mayer as project manager
- **SUVA requests: Reduction of insoluble particles in the size range 10 – 500nm by factor 100**

→ **Start of Filter development for construction machines**

Health impact

VERT® evaluates different monitoring parameters:

- Surface
- Size
- EC/OC
- Particle number PN 10-500 nm – 60 classes
- PM – (today it is useless)
- 200 gaseous toxic substances: PAH, Nitro-PAH Dioxins, furans

Result:

- PN provides the best relation to health impact
- PN is 1000 times more significant than PM

Consequences:

- New measurement devices
- New filter concepts
- New standards

Results of full - scale implementation

- Filter reduce particle emission by 99.99%
- Ambient air quality improved by factor 20

2000:

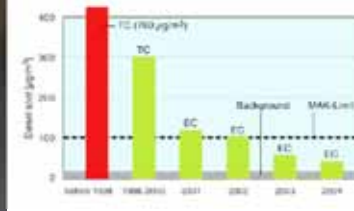
All Diesels in tunneling equipped with DPF

2002:

For all Diesels on Swiss construction sites DPF becomes obligatory

- Scientific research provides biological evidence (Prof. P. Gehr, Prof. B. Rothen and many others)
- Scientists require PN control also in ambient air

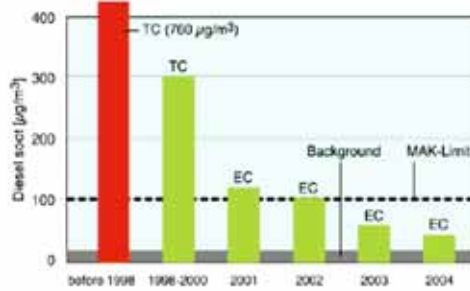
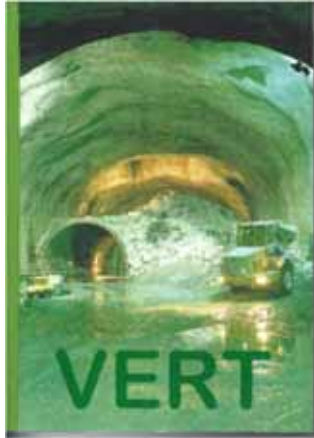
SUVA: Air quality in tunnel (1198 – 2004)



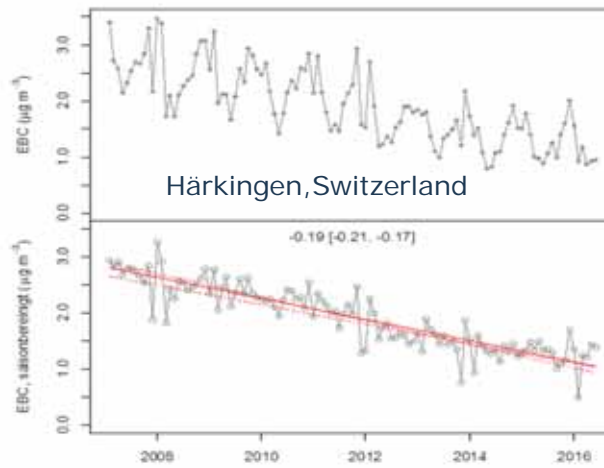
Today: 120 Mio. catalyzed filters on Diesel engines on european roads

- PN concentration in filtered exhaust gas is **10 times lower than in ambient air**
 - HC and CO are nearly eliminated
 - No toxic secondary effects
 - Globally more than 6'000 tons of highly carcinogenic particles retained
- Correlates to >333 billions CaD saved health-cost
- Benefit-Cost ratio 1 : 10

Improvement of air quality in Swiss tunneling



Black carbon monitoring at a motorway - crossing with intense traffic



Do we see the end of the tunnel?

Implementation of the precautionary principle

Legal regulatory framework:

- adequate monitoring
- adequate legal limits
- control of implementation

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Source

Do we see the end of the tunnel?

Implementation of the precautionary principle

Legal regulatory framework:

- adequate monitoring
- adequate legal limits
- control of implementation

Data collection and public access:

- personal and collective risk assessment of health- and environmental costs
- accessible publication

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Source

Do we see the end of the tunnel?

Implementation of the precautionary principle

Legal regulatory framework:

- adequate monitoring
- adequate legal limits
- control of implementation

Responsibility of state and corporate bodies in ethical and economical terms:

- Transparency and liability
- Polluter pays principle

Data collection and public access:

- personal and collective risk assesment of health- and environmental costs
- accessible publication

Certification of DPF

✔ Non-profit organization to eliminate particles and harmful substances from internal combustion engines – **concentrating on PN-Elimination since 1994**

✔ Certification of diesel particle filters with Best Available Technology

✔ International membership out of

- ✔ manufacturers of DPF / SCR systems
- ✔ testing devices
- ✔ substrate producers
- ✔ chassis builders
- ✔ engine manufacturers



✔ **ETH-Nanoparticle conference since 1997** VERT-network with ETH, EMPA, Berne, Fribourg, Biel (Engineering, Science, Biology, Medicine)

✔ Acting as partner of megacities to support and execute **pollution reduction programs** from road traffic and non-road vehicles. Projects in: Switzerland, Berlin, California, China, Iran, Bogotá, Chile, Mexico, Tel Aviv,...

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Thank you for your attention

and.....

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Welcome next year in Switzerland !

22nd ETH-Conference on
Combustion Generated
Nanoparticles

June 18th-21st, 2016
ETH Zurich, Switzerland



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