

Ultrafine Particles – SCAQMD/CARB Los Angeles April 30 – May 2, 2006

**Why use Size, Substance and Number  
of Solid Particles instead of PM-Mass  
to characterize and limit  
Particle Emissions of IC-Engines**

**A. Mayer**

# History of Evidence

- 1775 P.Pott „cancer and soot correlated“
- 1868 Tyndall „ultrafines measured“
- 1916 **number count** correlates with silicosis (english mines)
- 1936 Staub: ultrafines more dangerous but not measureable
- 1954 VDI regulation against opacity of Diesel smoke
- 1959 Johannesburg convention on **size**
- 1982 PM-Limit for Diesel cars in California
- 2000 Filter efficiency by number and size in CH

## *Claim 1*

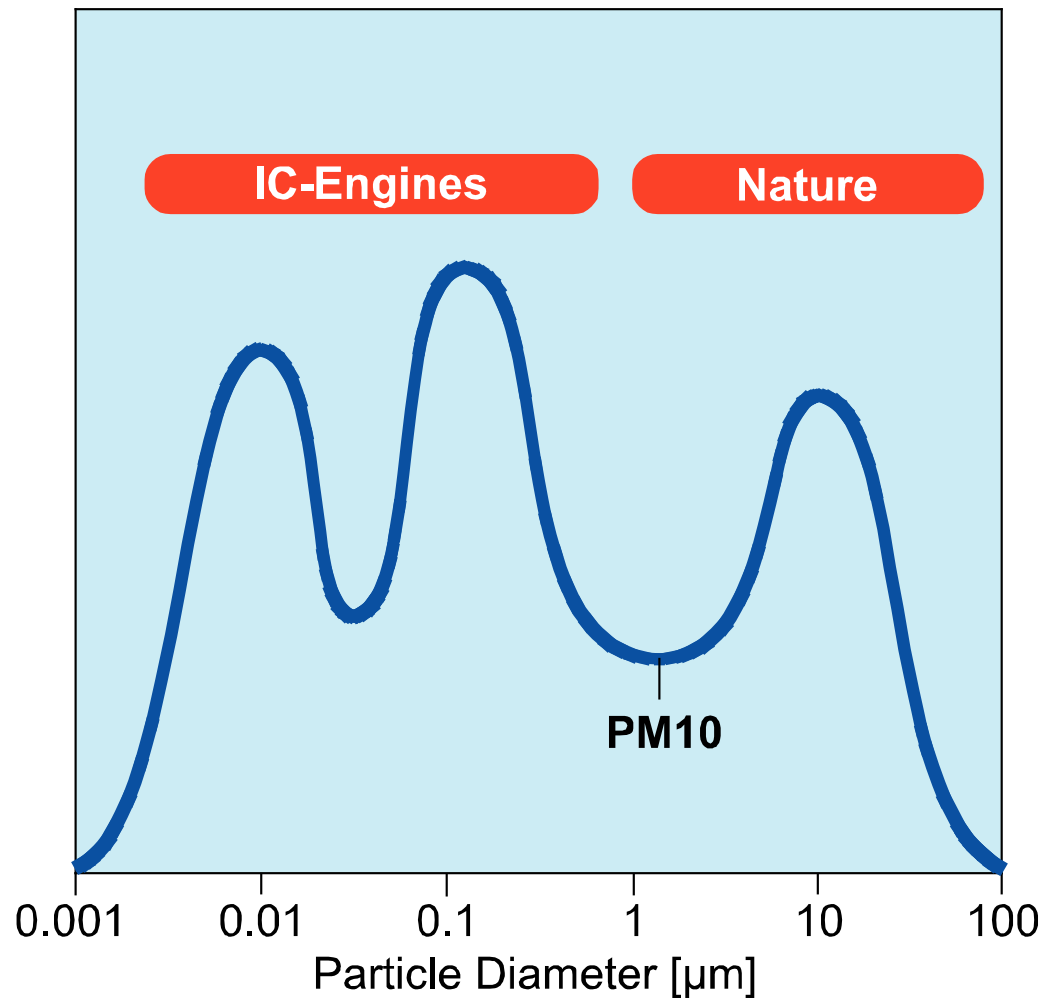
# **Particle Size matters**

*simply because we are dealing with an aerosol in size range 10 – 10'000 Nanometer and*

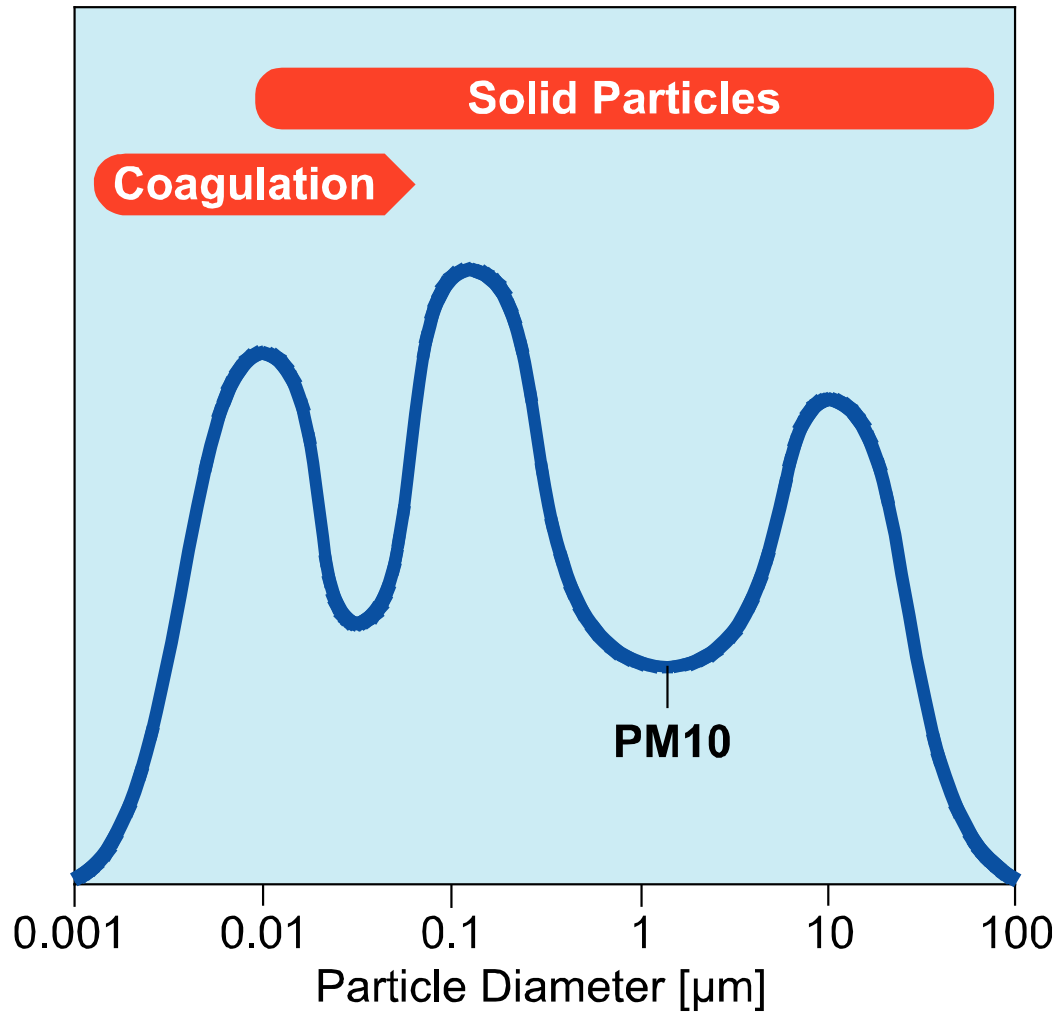
*because aerosols = f (size and number) have very different properties*

# Size Distribution of Ambient Particles

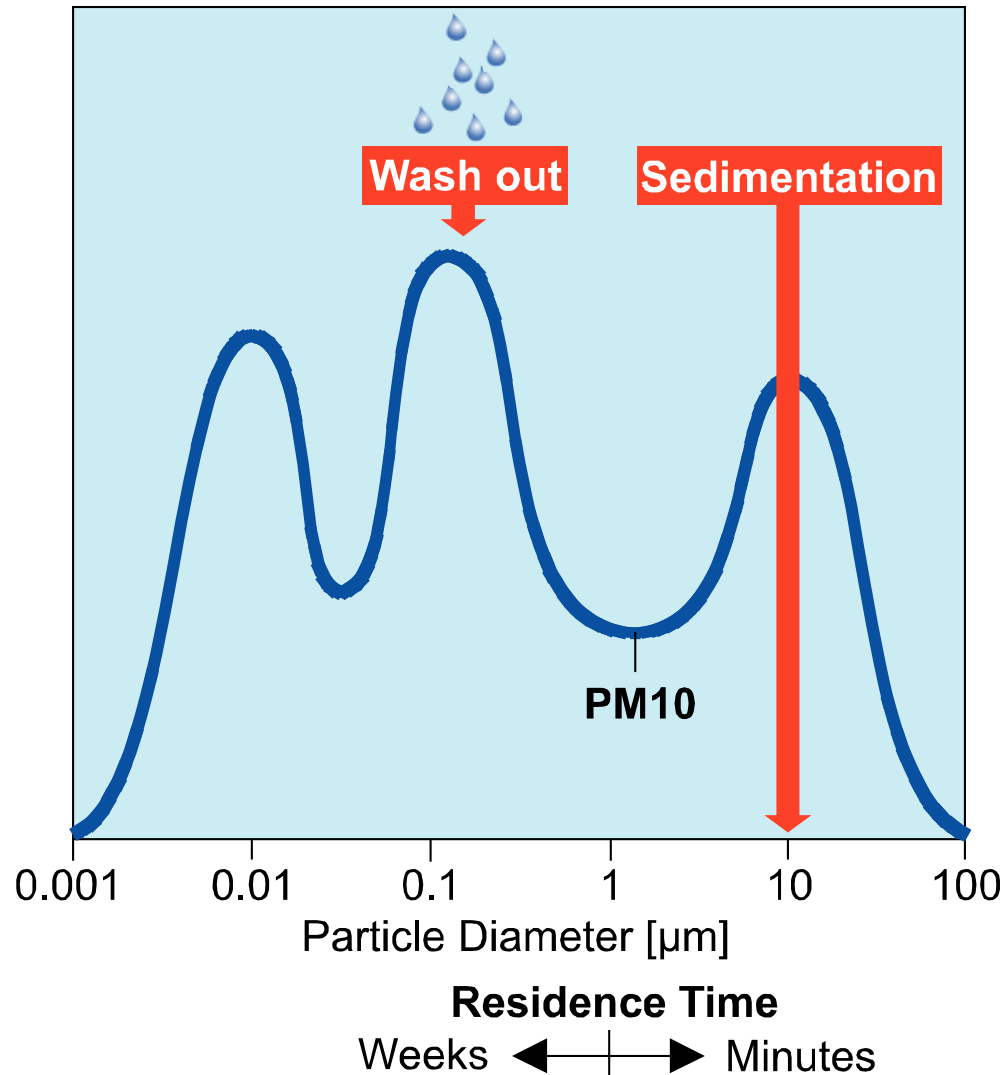
2 entirely different Formation Mechanismes



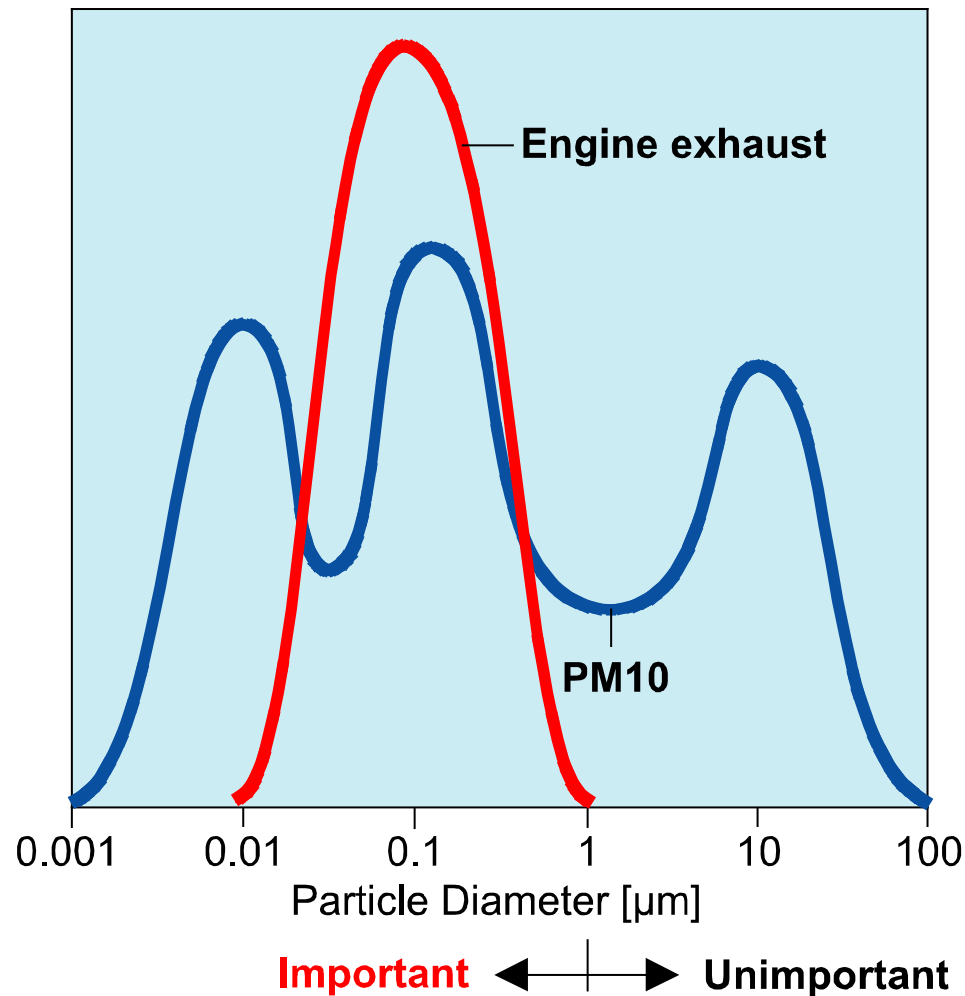
# Mix of Solid Particles and Condensates



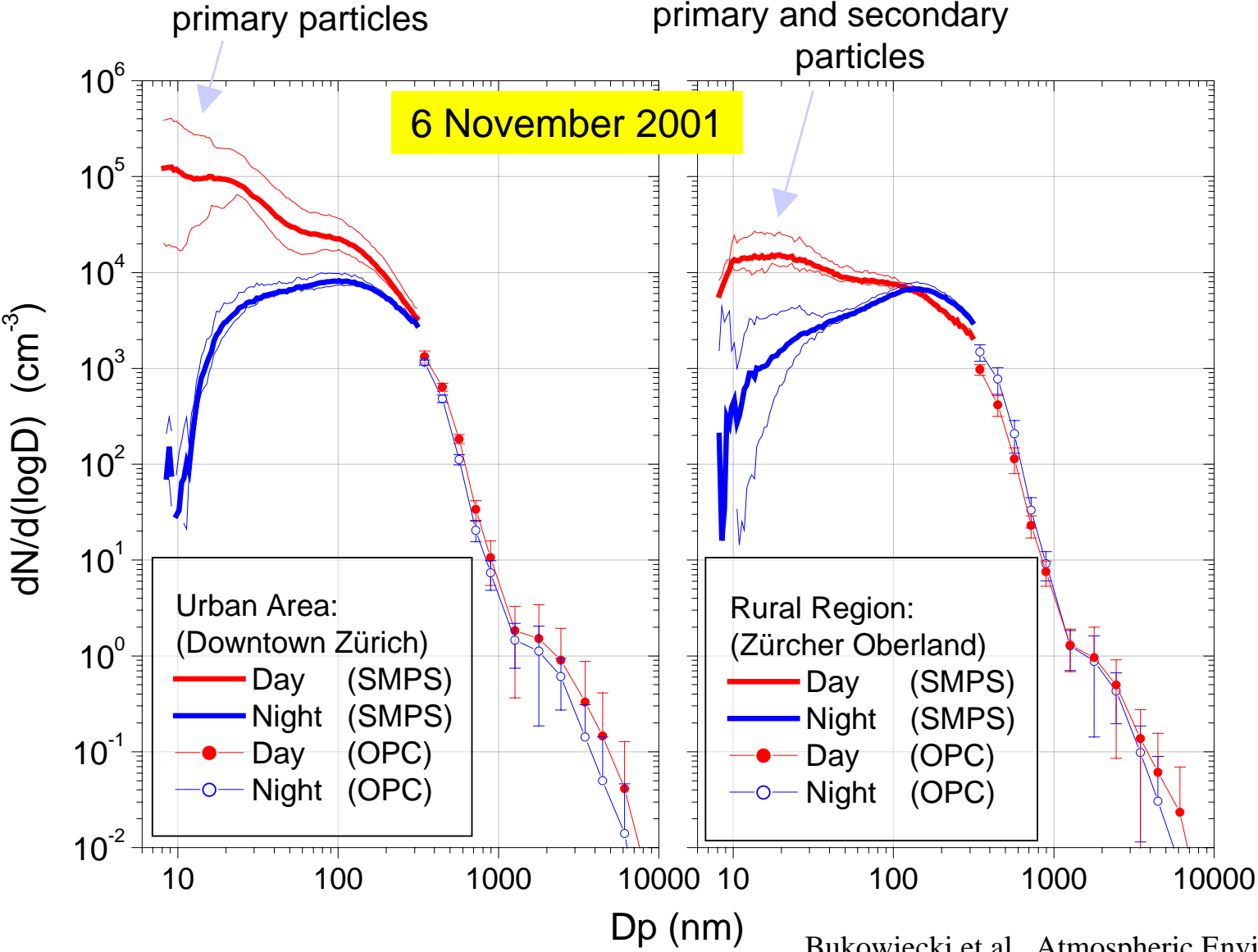
# Ultrafines can have very long Life until cleaned out



# IC-Engine-emitted solid Nanoparticles a Part of PM10 but the most critical Fraction

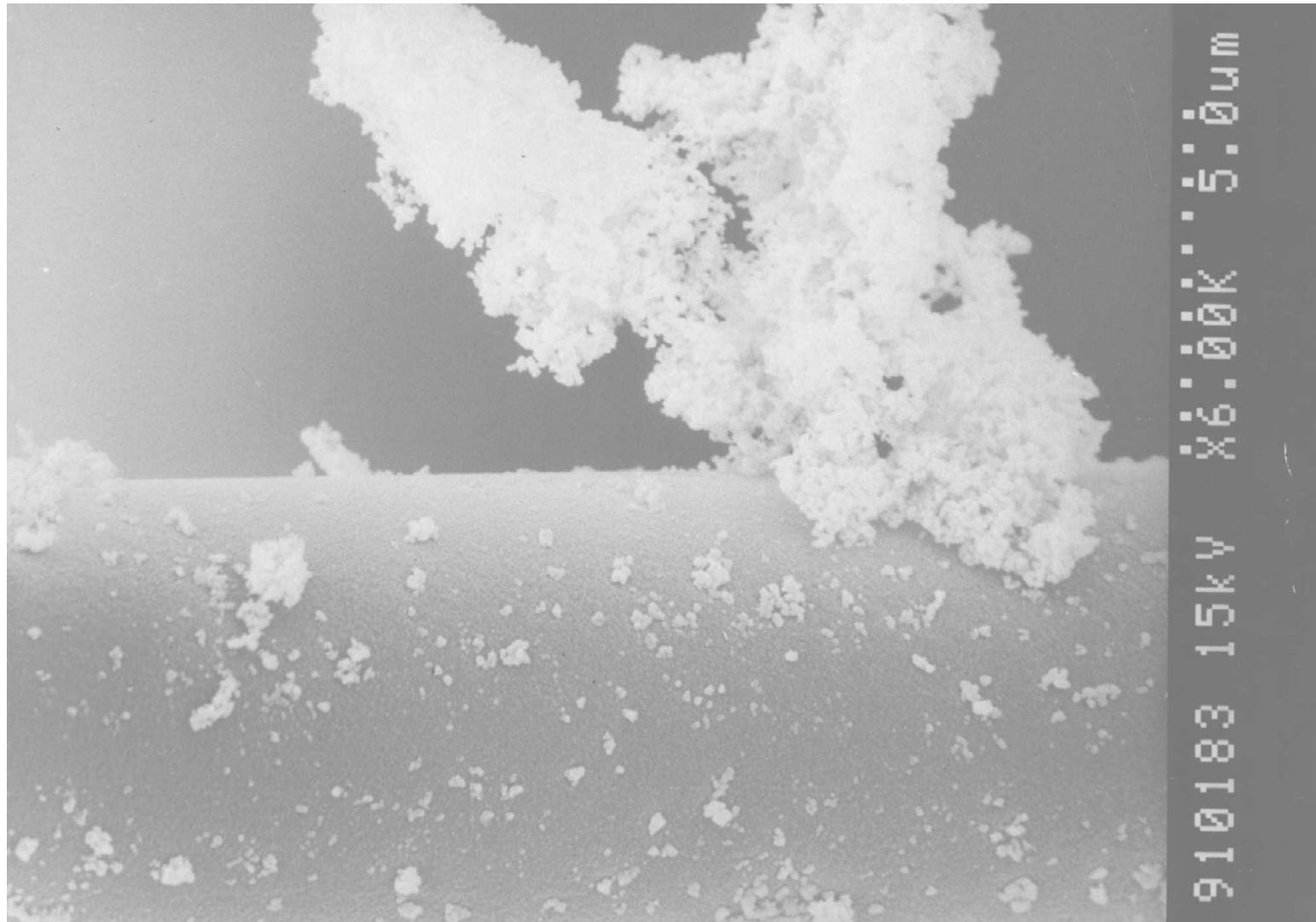


# Aerosol Number-Size distributions in the Zürich area

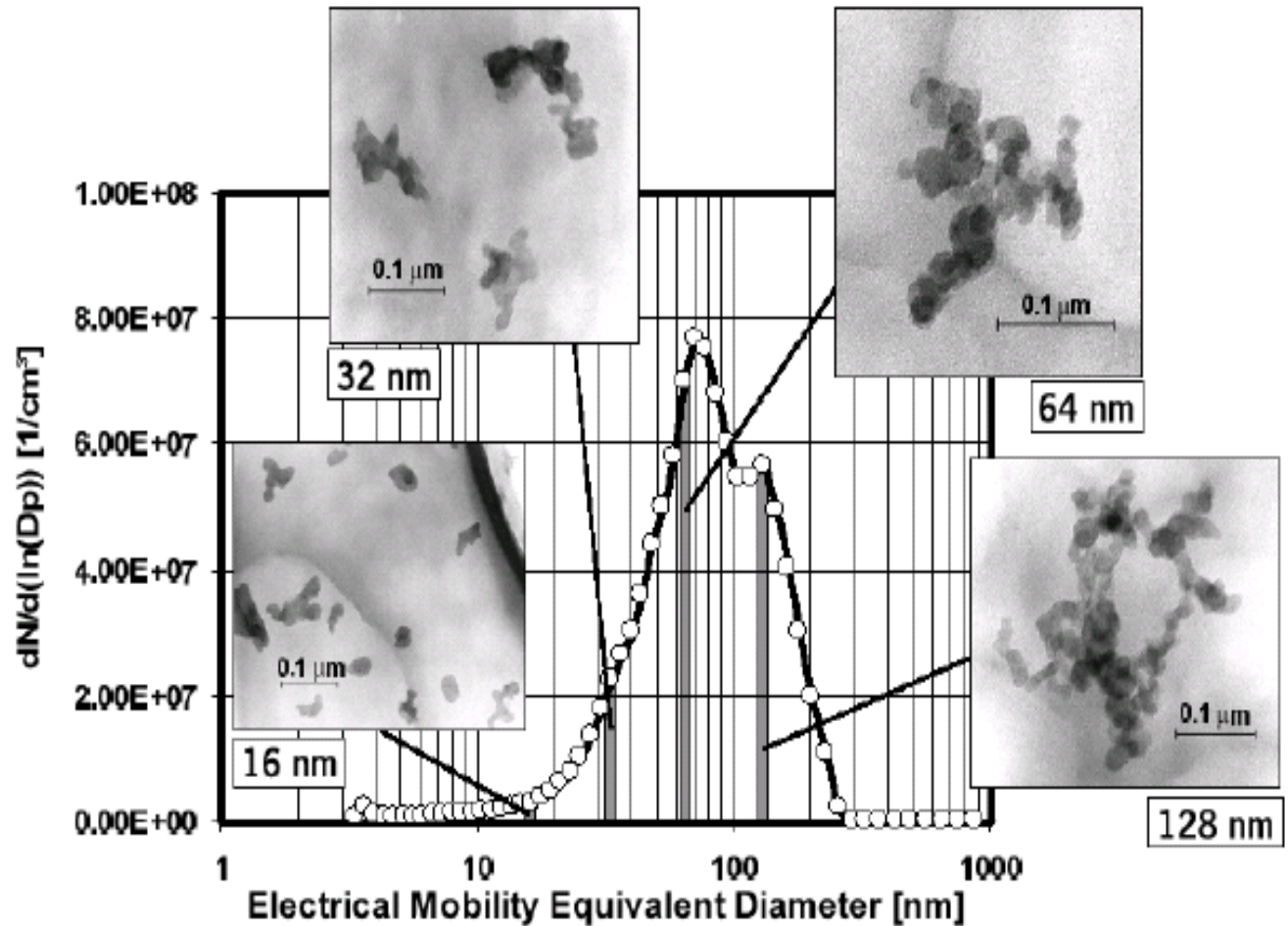




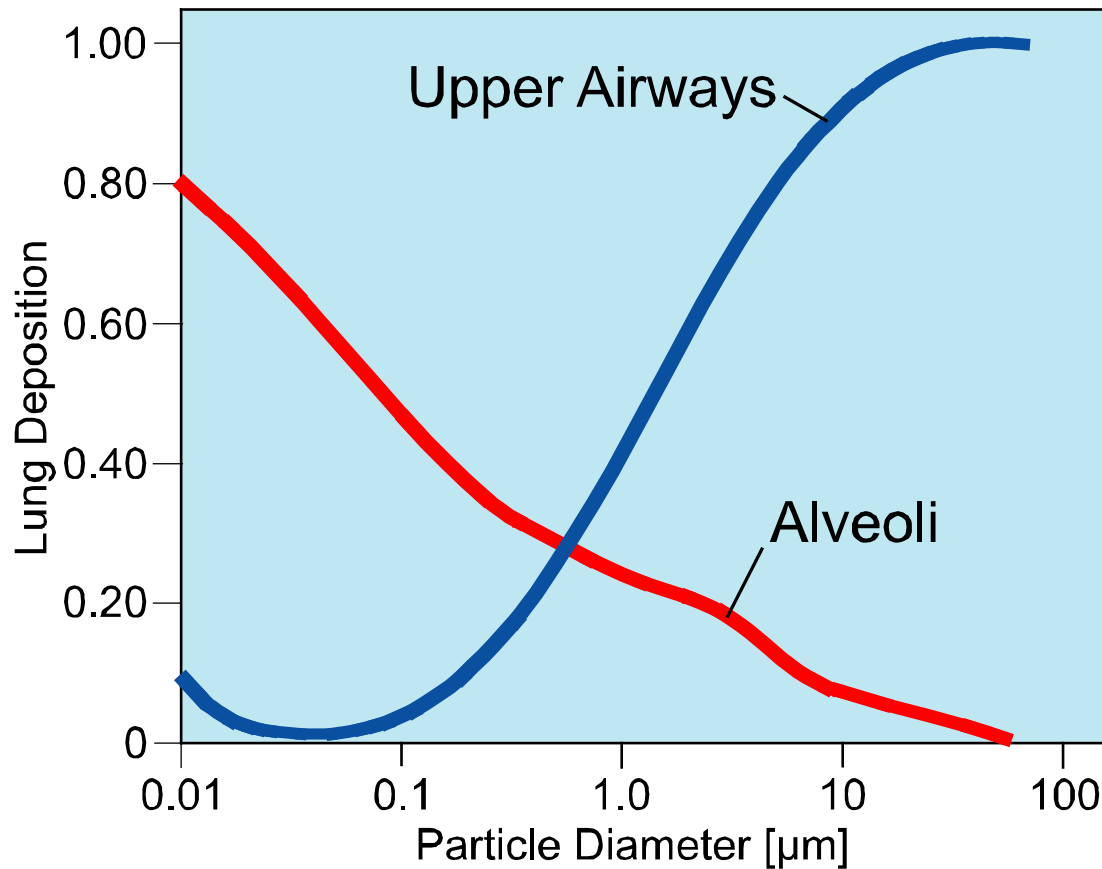
# Soot Particles deposited on a 5 micron Filter Fibre



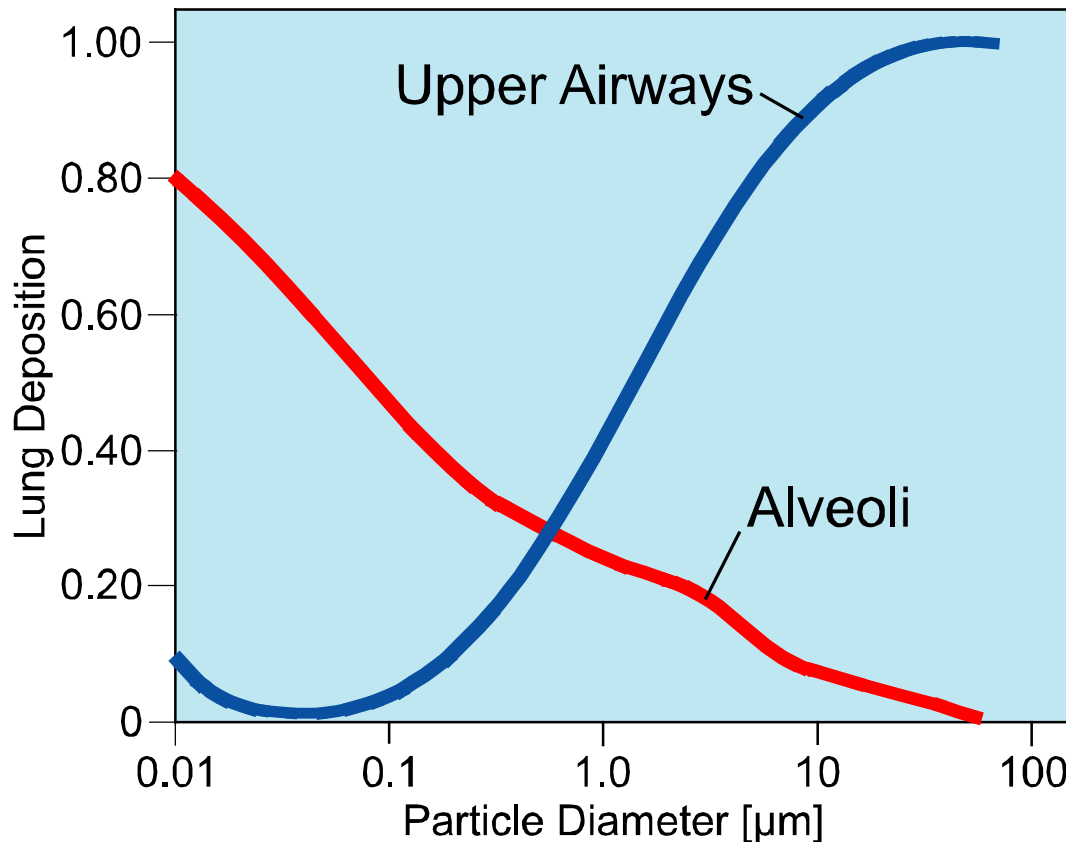
**Diesel  
Soot**  
invisible  
no taste  
no smell  
inert



# Particles of different Size are deposited in different Parts of the Lungs

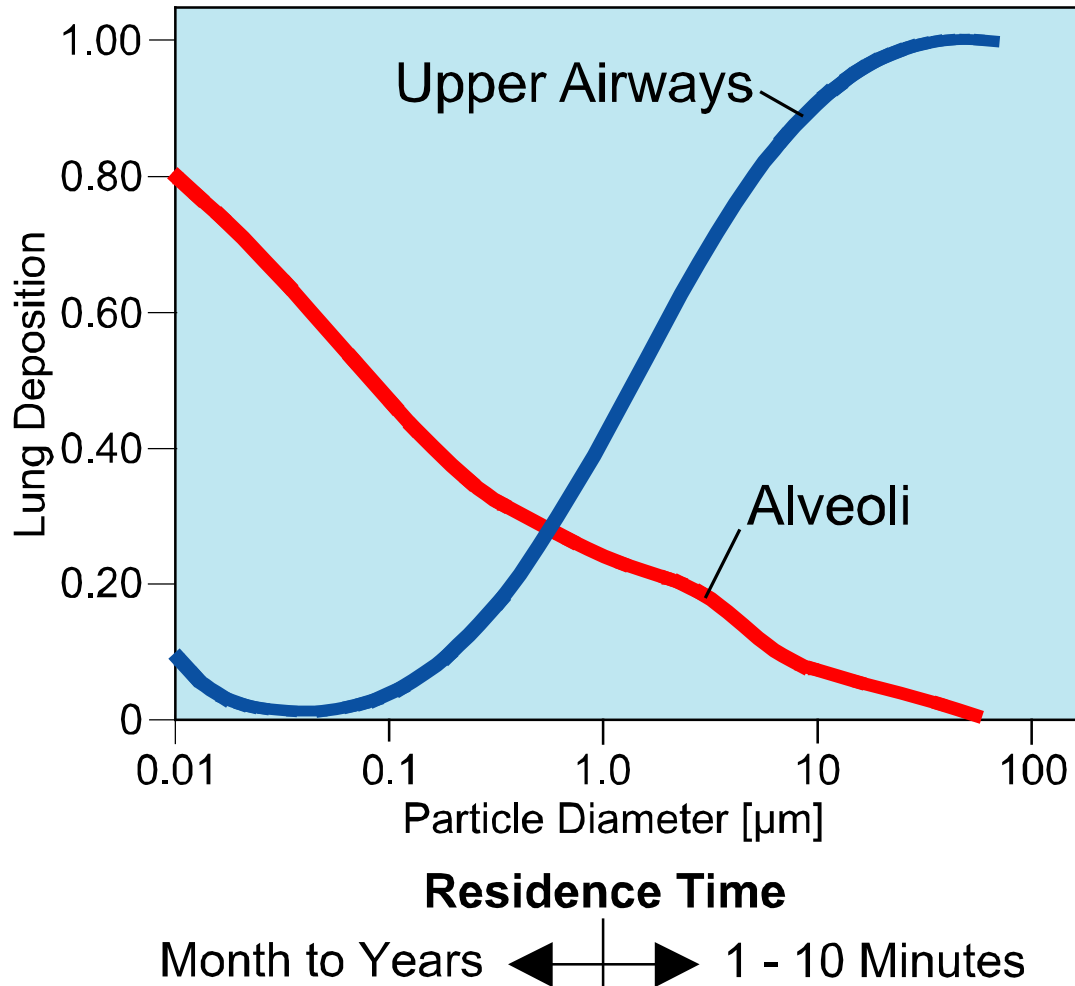


# Perfect Clearing Mechanisms for large Particles – hardly any for Nanoparticles

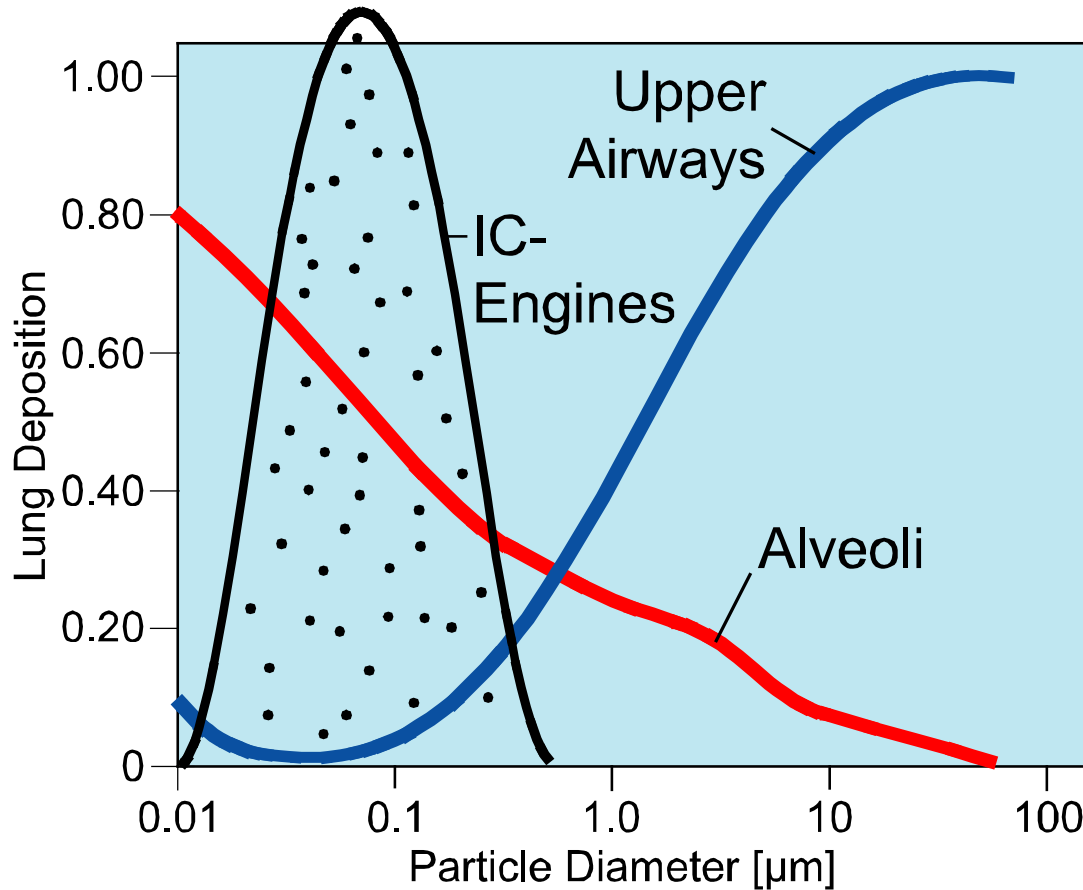


**Invasion** ← | → **Cleaning**  
Deposition Wet surface  
Penetration Cilia, Mucus

# Residence time is short for large (natural) Particles – extremely lang for Nanoparticles

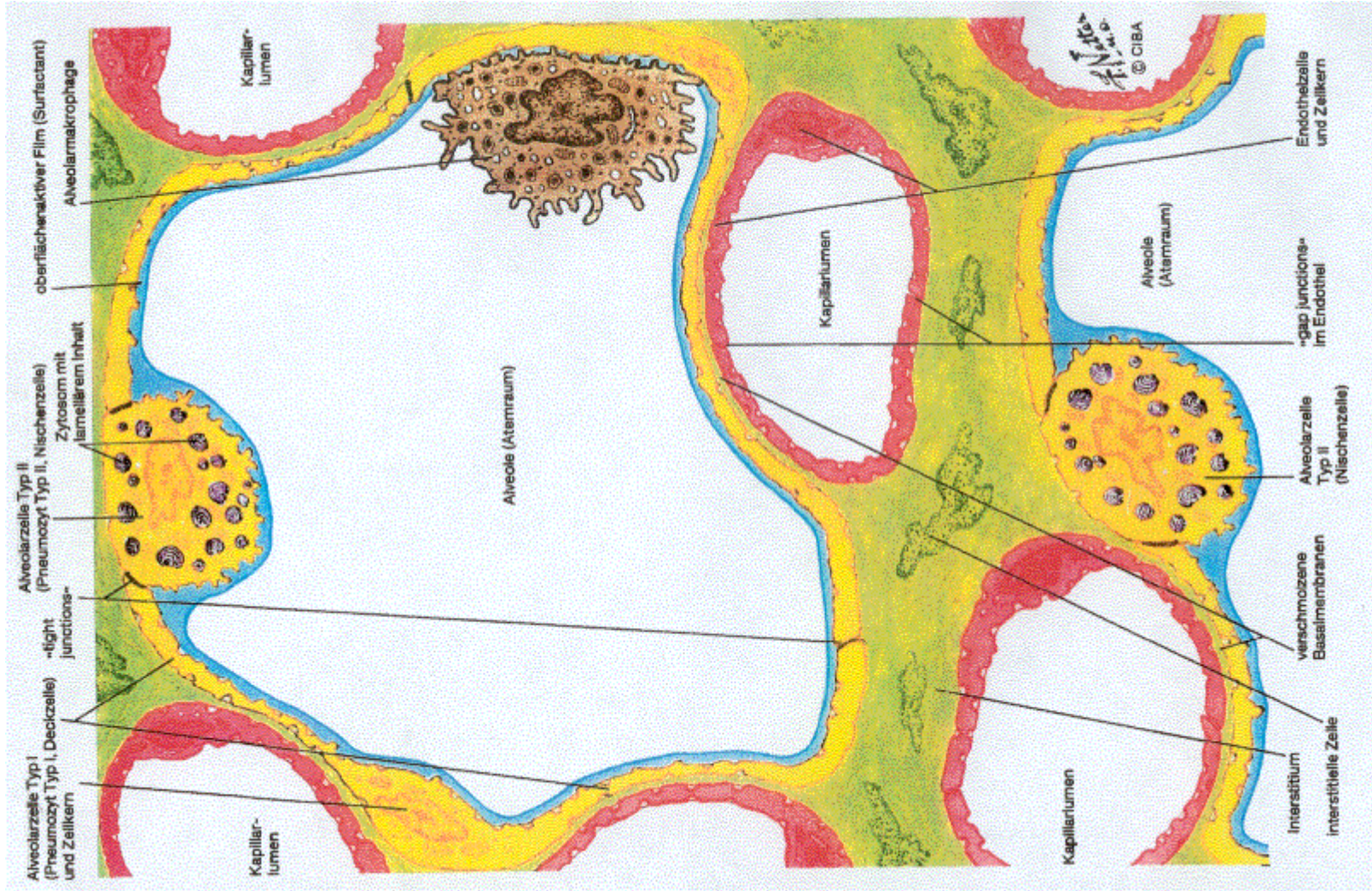


# Combustion generated Particles fall into a very critical Size Range



**Technology must eliminate**  $\leftarrow$   $\rightarrow$  **Nature takes care**

# Alveoli and Blood Veins – 1 $\mu$ Membrane

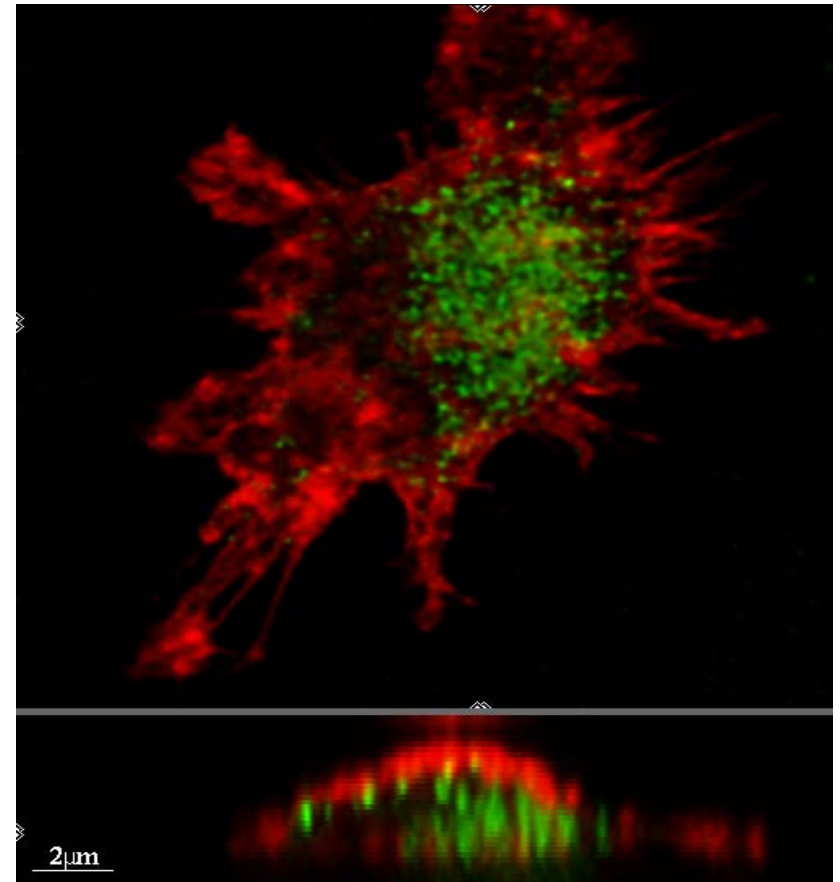
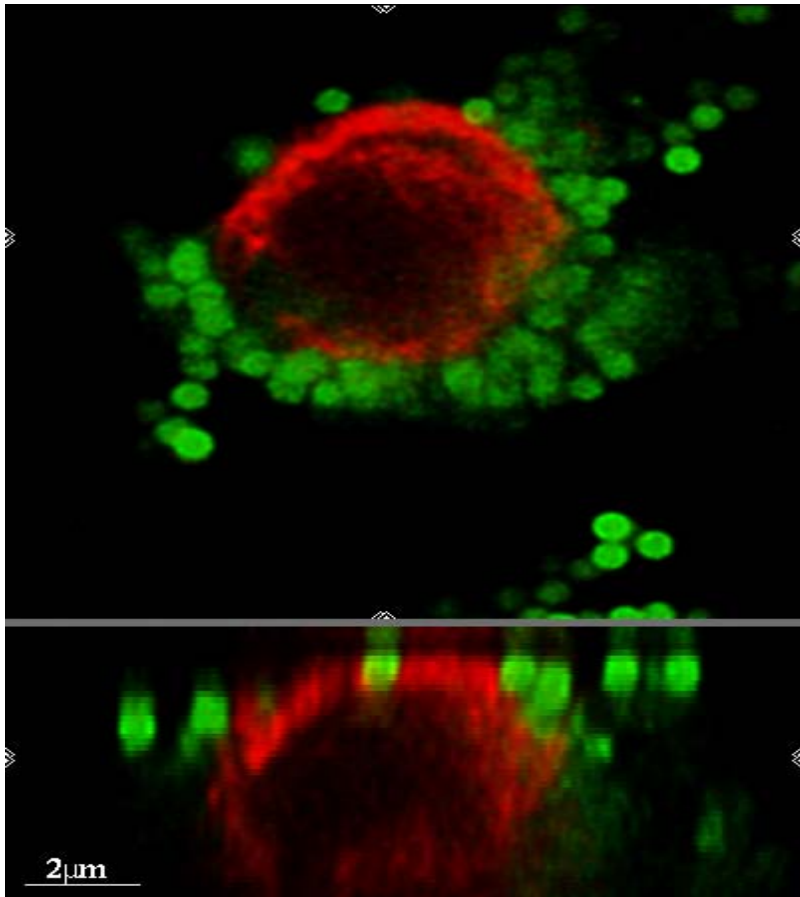


# Macrophages *in vitro*: Laser Scanning Microscopy

■ 1000 nm  
Polystyrene Particles

+

■ 78 nm  
Polystyrene Particles



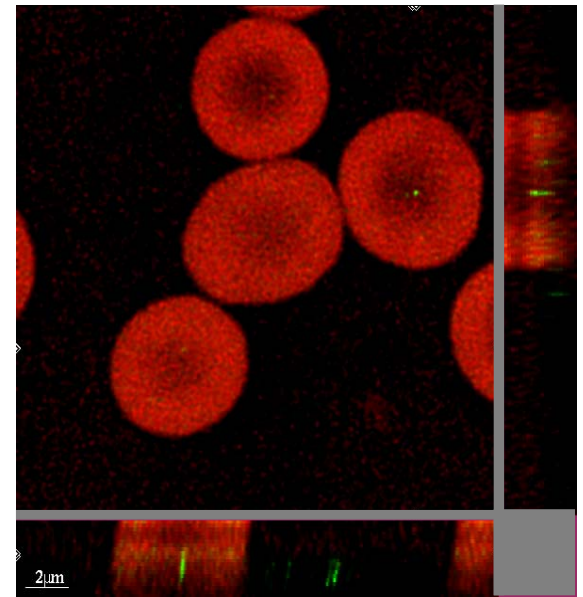
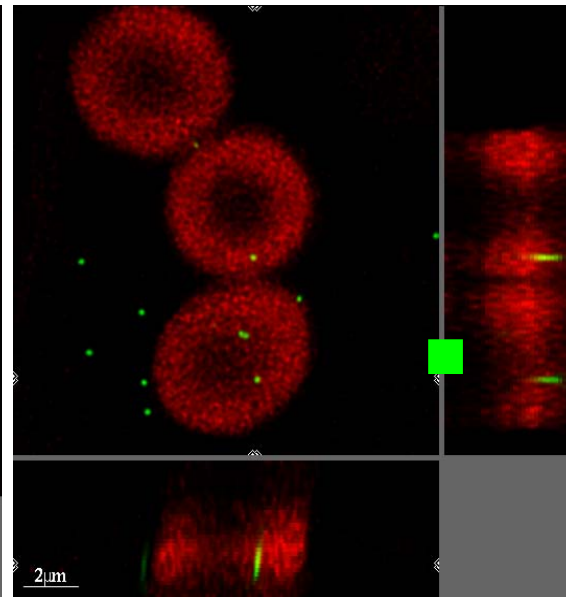
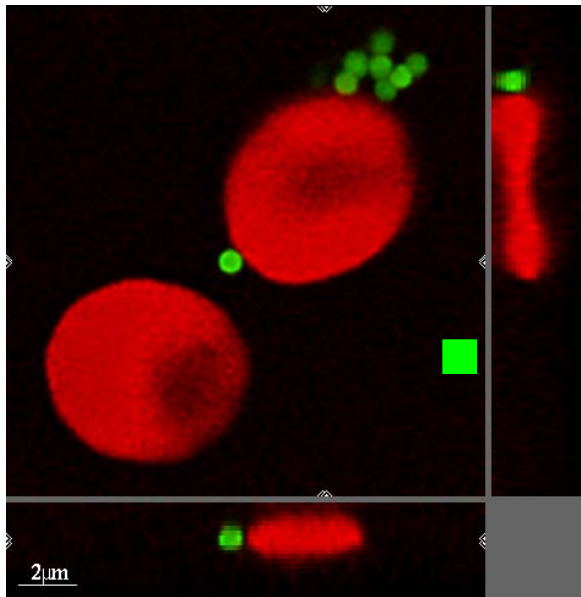


# Red Blood Cells *in vitro*: Laser Scanning Microscopy

**1000 nm = 1mm  
polystyrene particles**

**0.2 mm  
polystyrene particles**

**78 nm  
polystyrene particles**



# Particle Size matters

*because but our organisme has no barrier for Nanoparticles !*

*→ Technology must take care for man-made particles < 1 micron*

*This does not mean that larger particles are healthy but nature takes much better care of them and engine technology is not responsible*

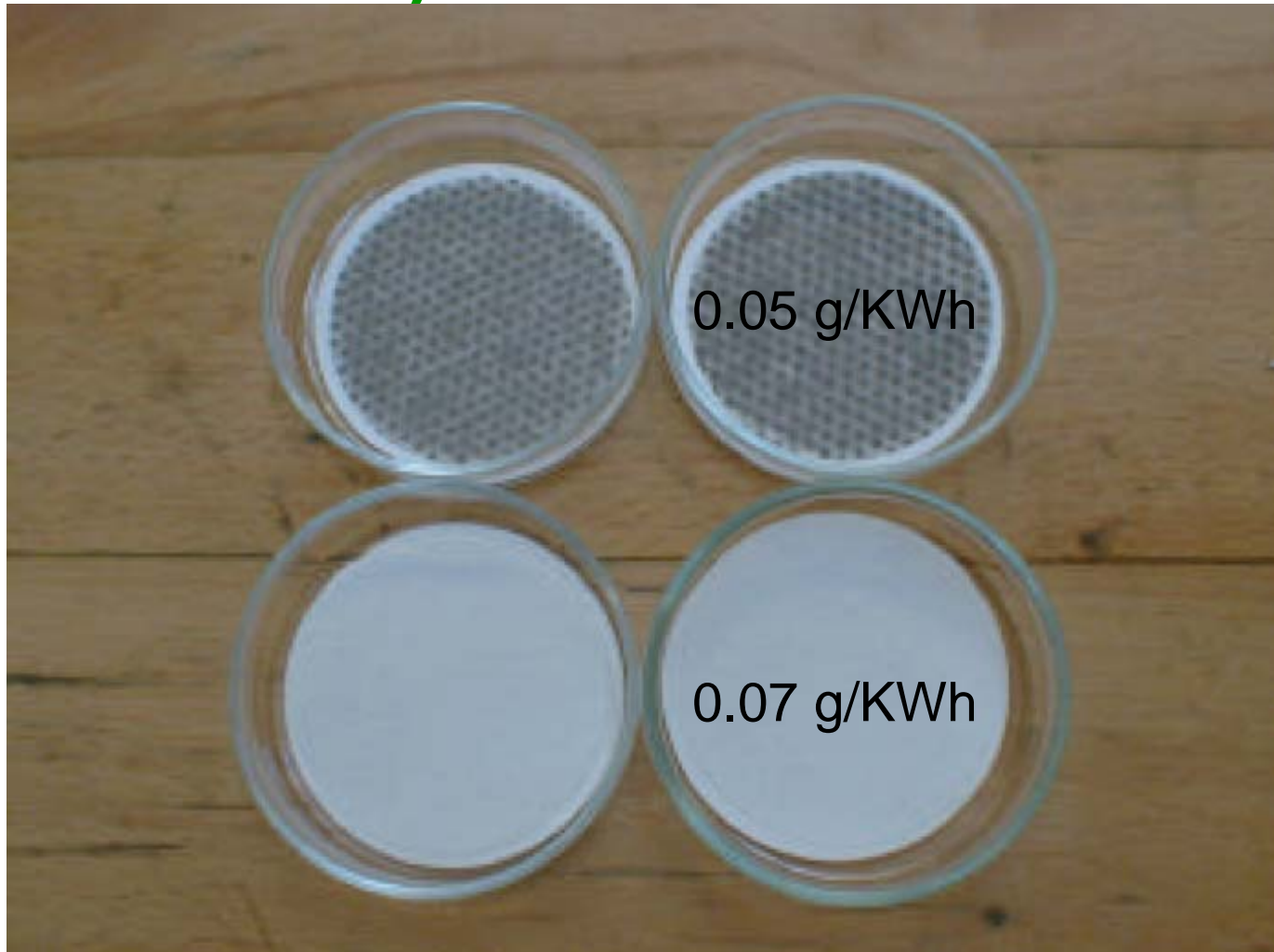
## *Claim 2*

# Particle Composition matters

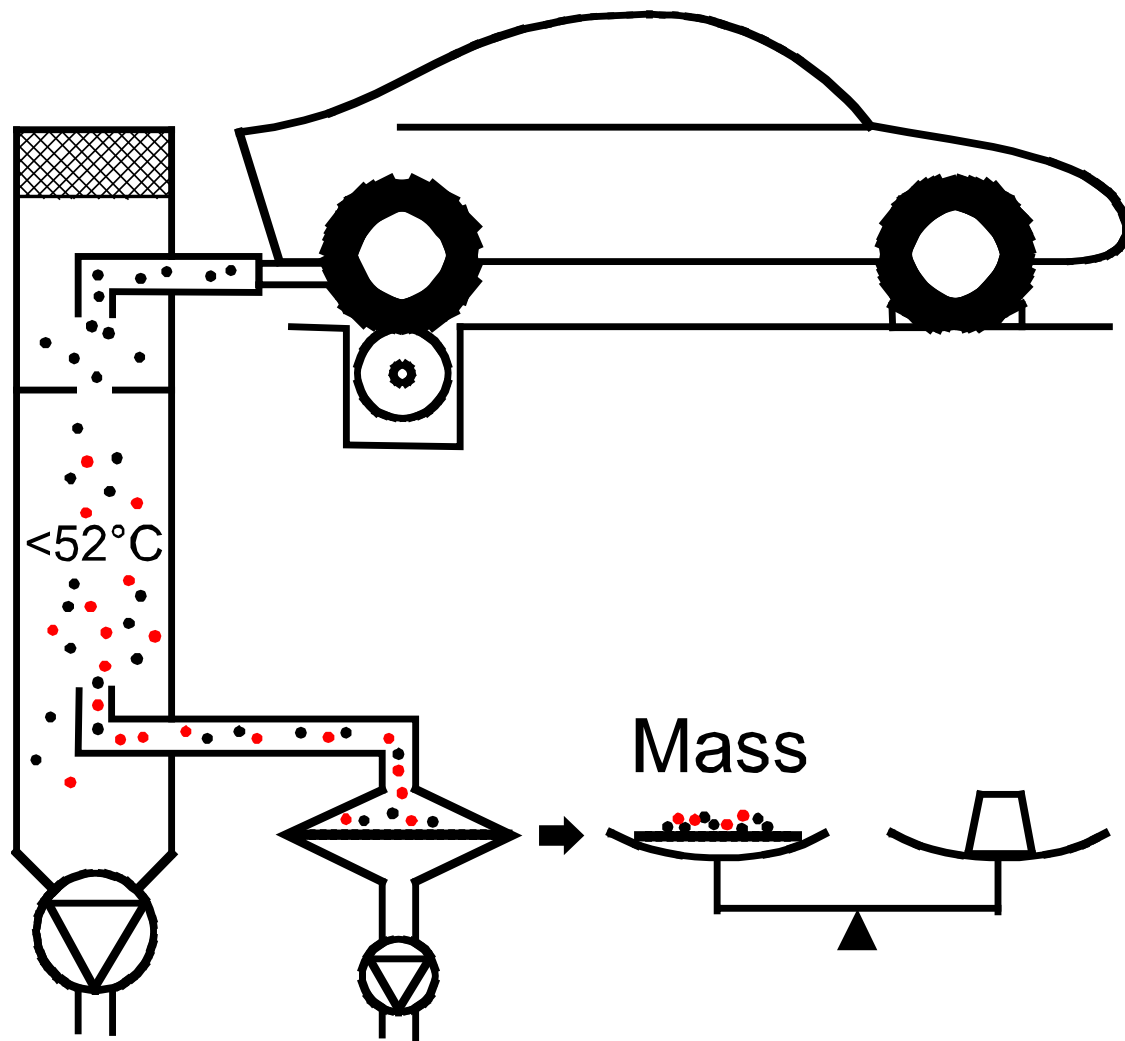
*because of*

- *toxicity*
- *solubility*
- *residence time*

# Particulate Mass Samples upstream and downstream of a Particle Filter in a Bus (Odense Test 2003 )

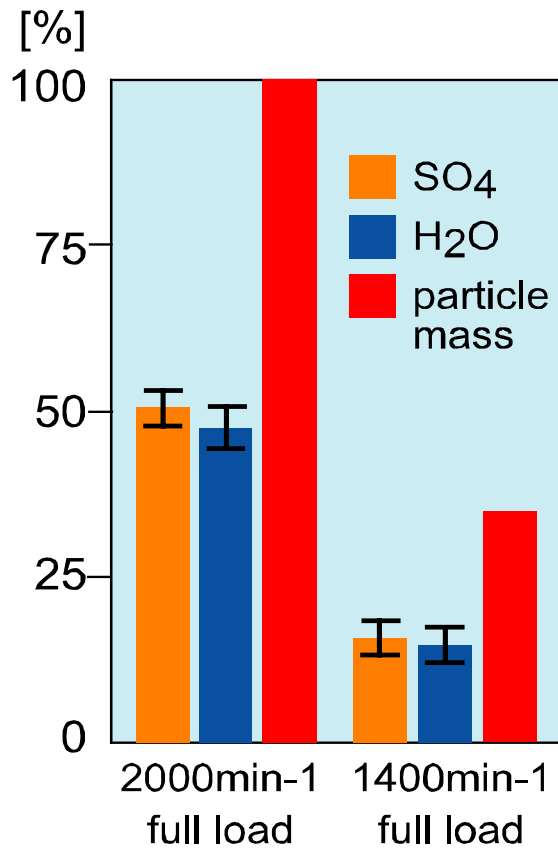


# How do we measure Particle Mass PM according to the legal procedure

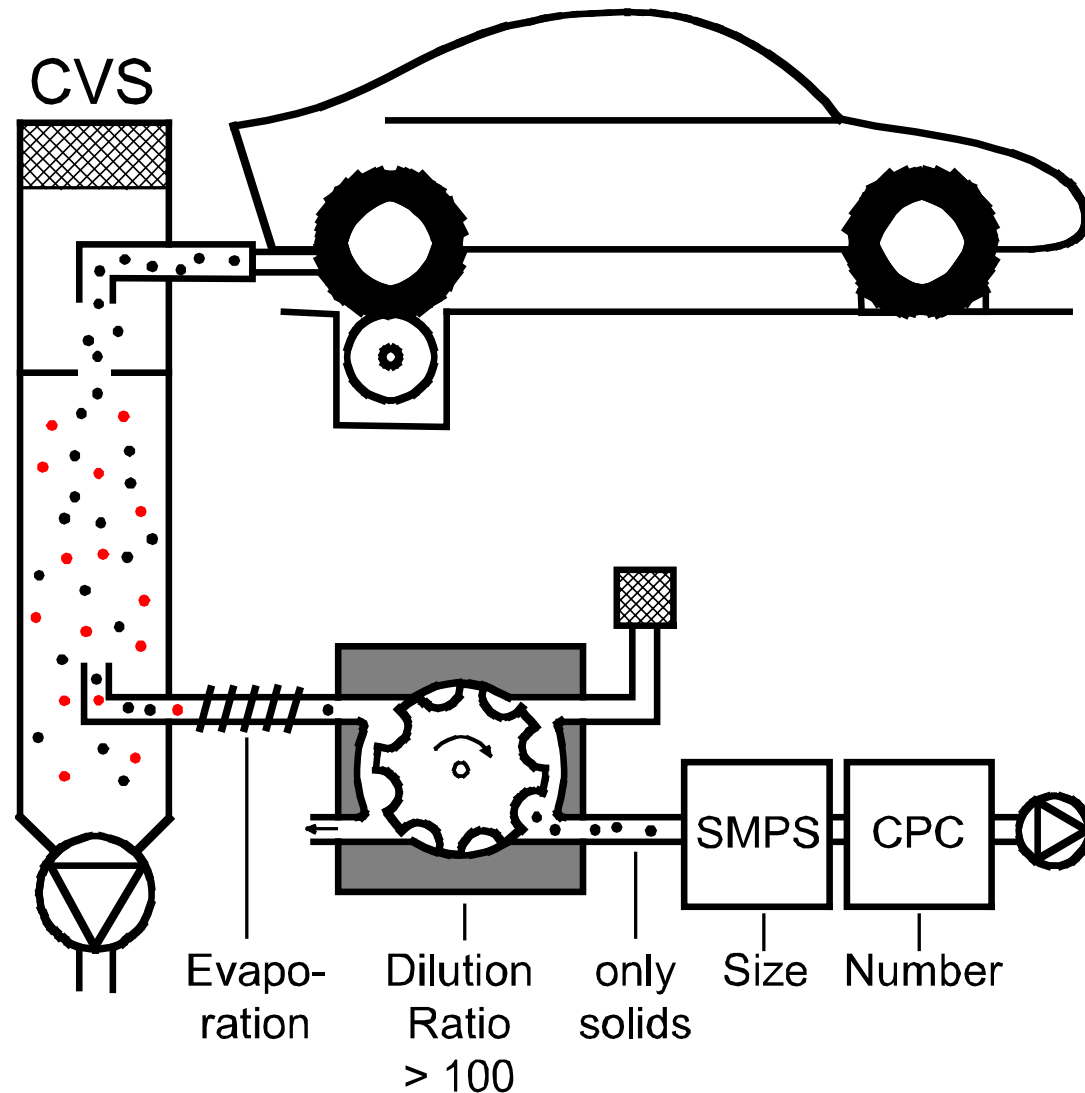


# What is the result?

**Filtration Efficiency by mass: - 40 %**



# How do we measure solid Particle Number and Size acc. to EU-PMP



# What is the result ?

Filtration Efficiency  
by number  
of solid particles

**99.9 %**





**PM = particle mass** is an excellent metric **only** if composition and properties of the sample are identical

**If composition and properties are different — mass becomes a secondary criterion for comparison, difficult to handle and can be very misleading**

# Why do we claim

## Solid Particles more important than Liquid Droplets

**Solid Particles:** EC and Metal Oxides are

- invasive (Size)
- persistent (Substance: inert by nature)
- carcinogenic (each single particle can trigger cancer !)
- carriers of toxics like PAH and Nitro-PAH

**they can be measured accurately and eliminated by filters**

**Liquid Droplets :** Water, Sulfate, HC

- not persistent: dilution and emulgation by surfactants
- thresholds well known → dose far below critical
- not invasive
- not carcinogenic

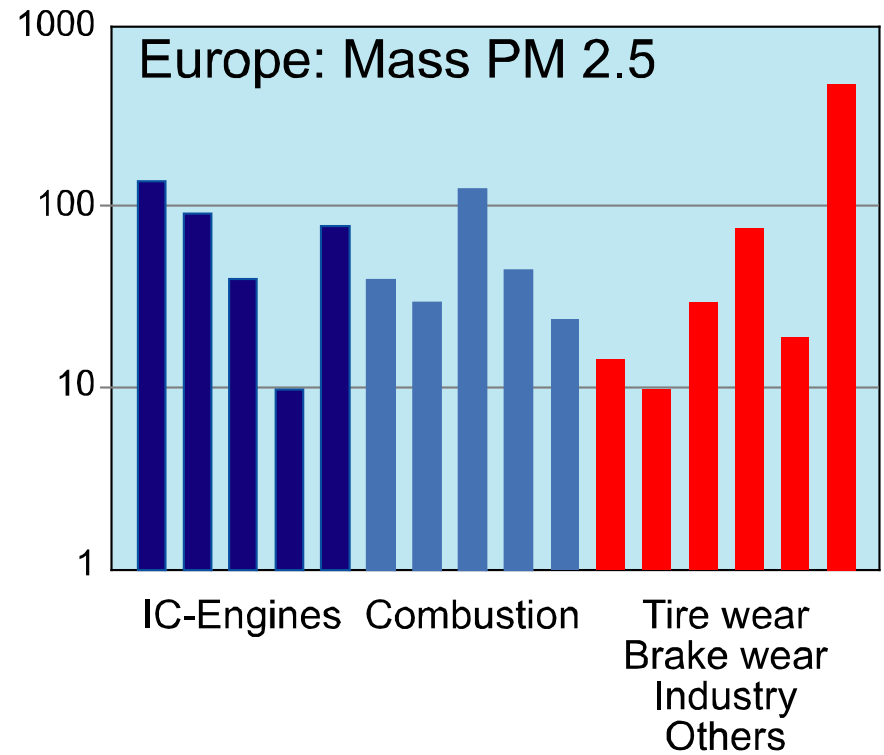
Fuel Quality (ULSF) and DOC take perfectly care

## *Claim 3*

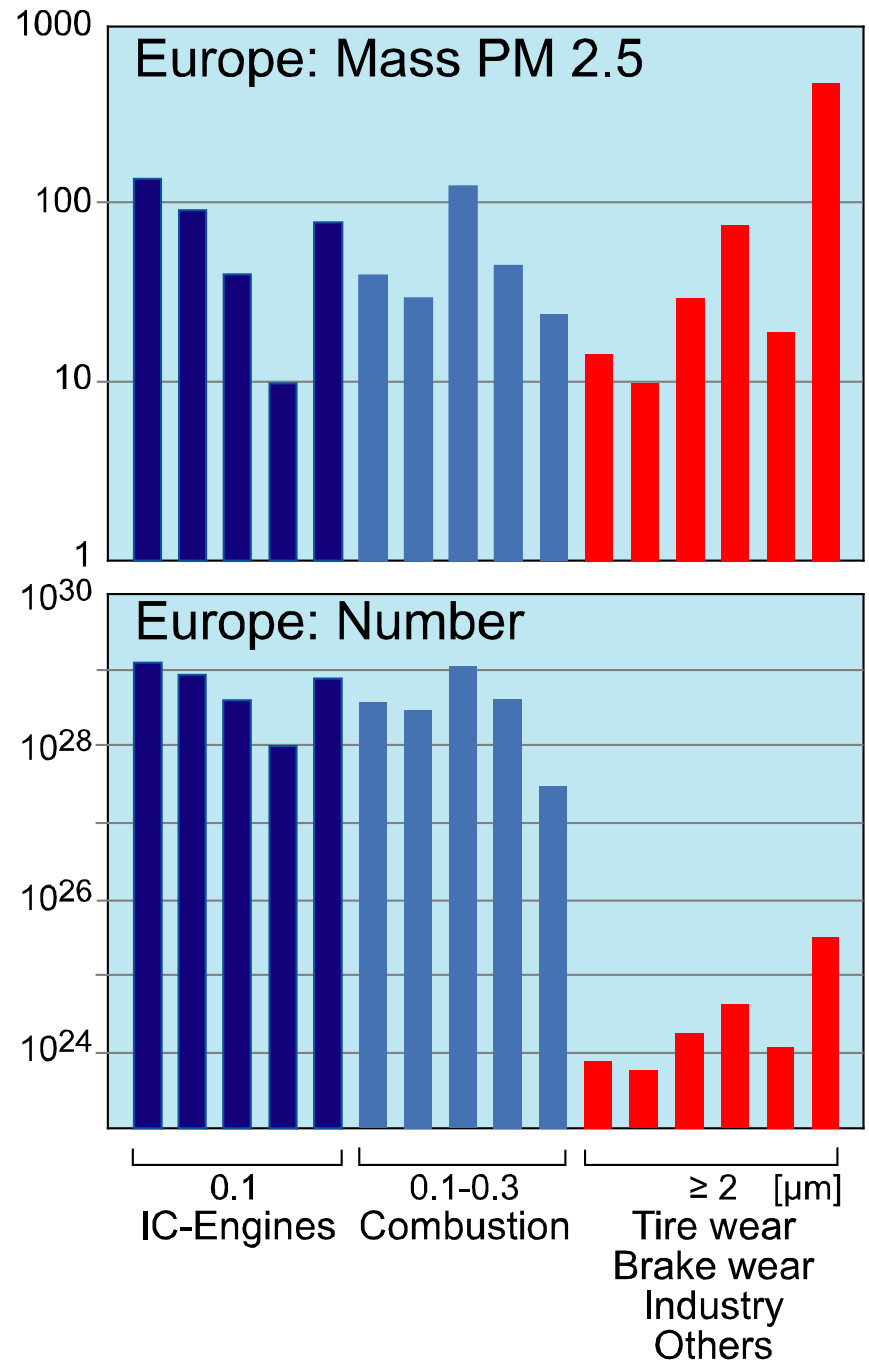
# Particle Number matters

*because Nanoparticles are well represented  
by number and hardly by overall mass  
size range is 1:100 - mass range 1: 1000'000*

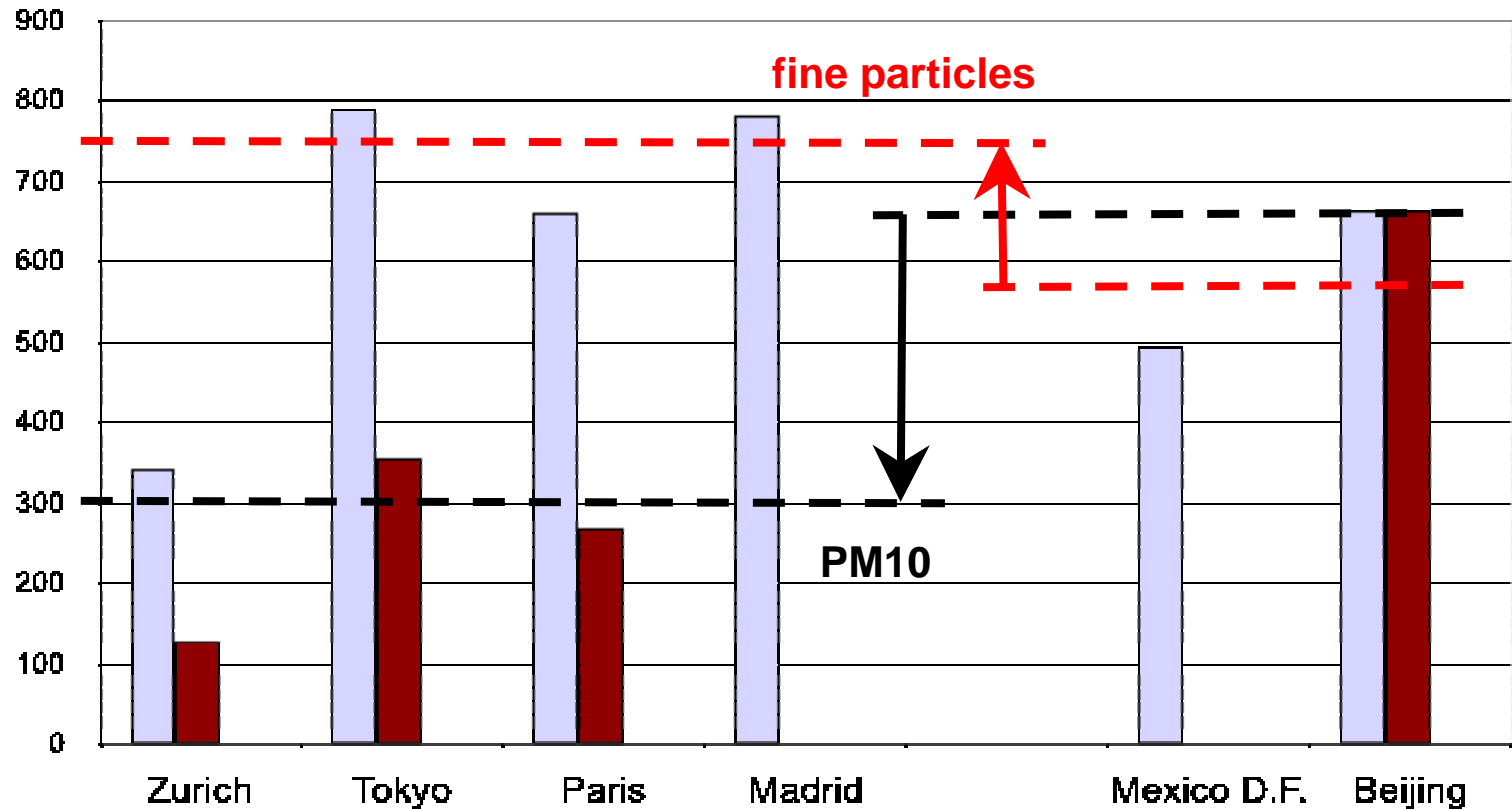
# Sources of PM 2.5 Particulate Mass in Europe



... And the same  
Inventory  
represented in  
Particle Number  
→ Particles larger than  
 $1\mu$  can be neglected



# How was ambient PM10 and Particle Number Concentration influenced by Technology



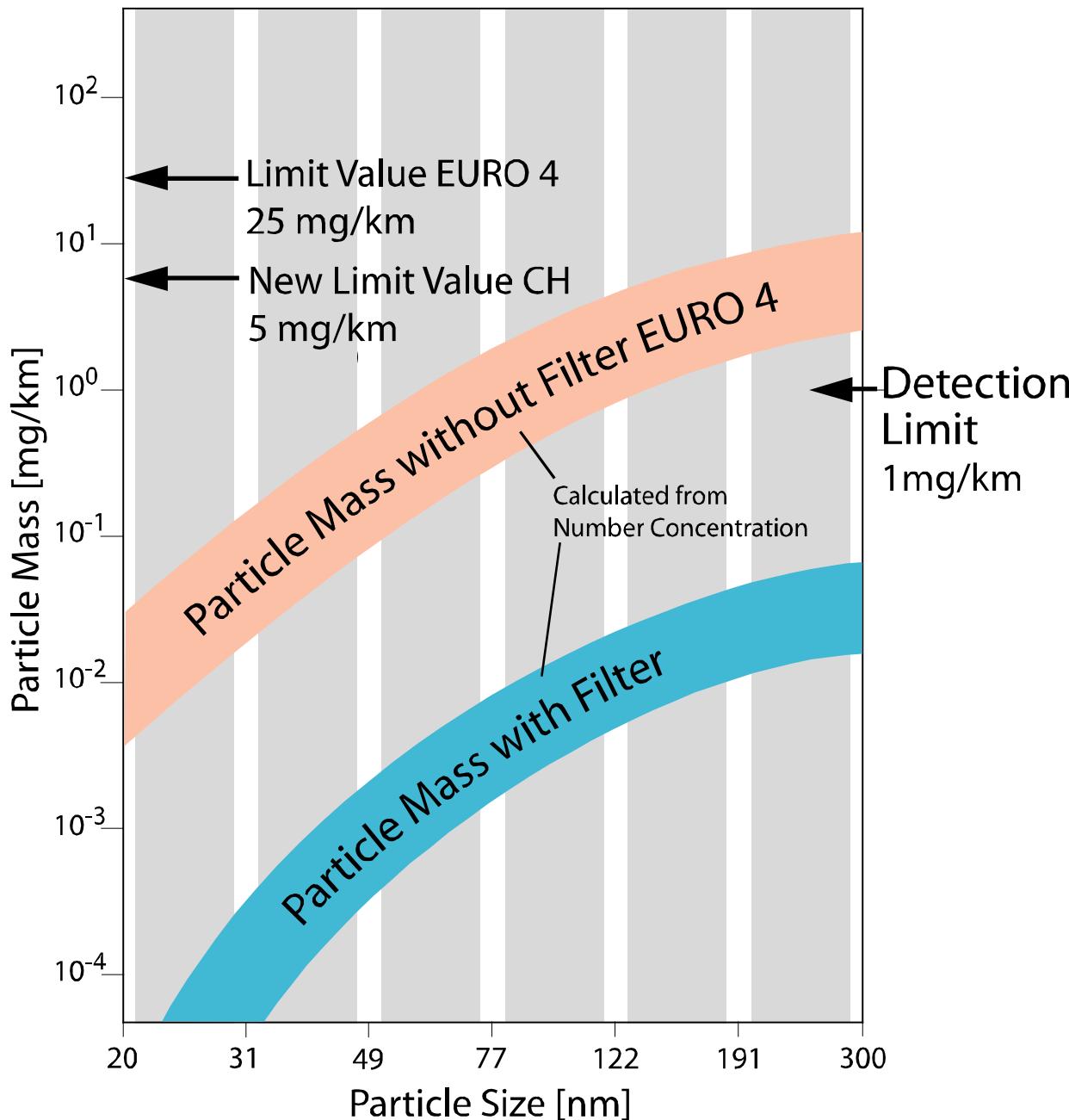
Source: Siegmann / ETH-Zürich

# Mass-Limits

underestimate  
ultrafine  
contribution

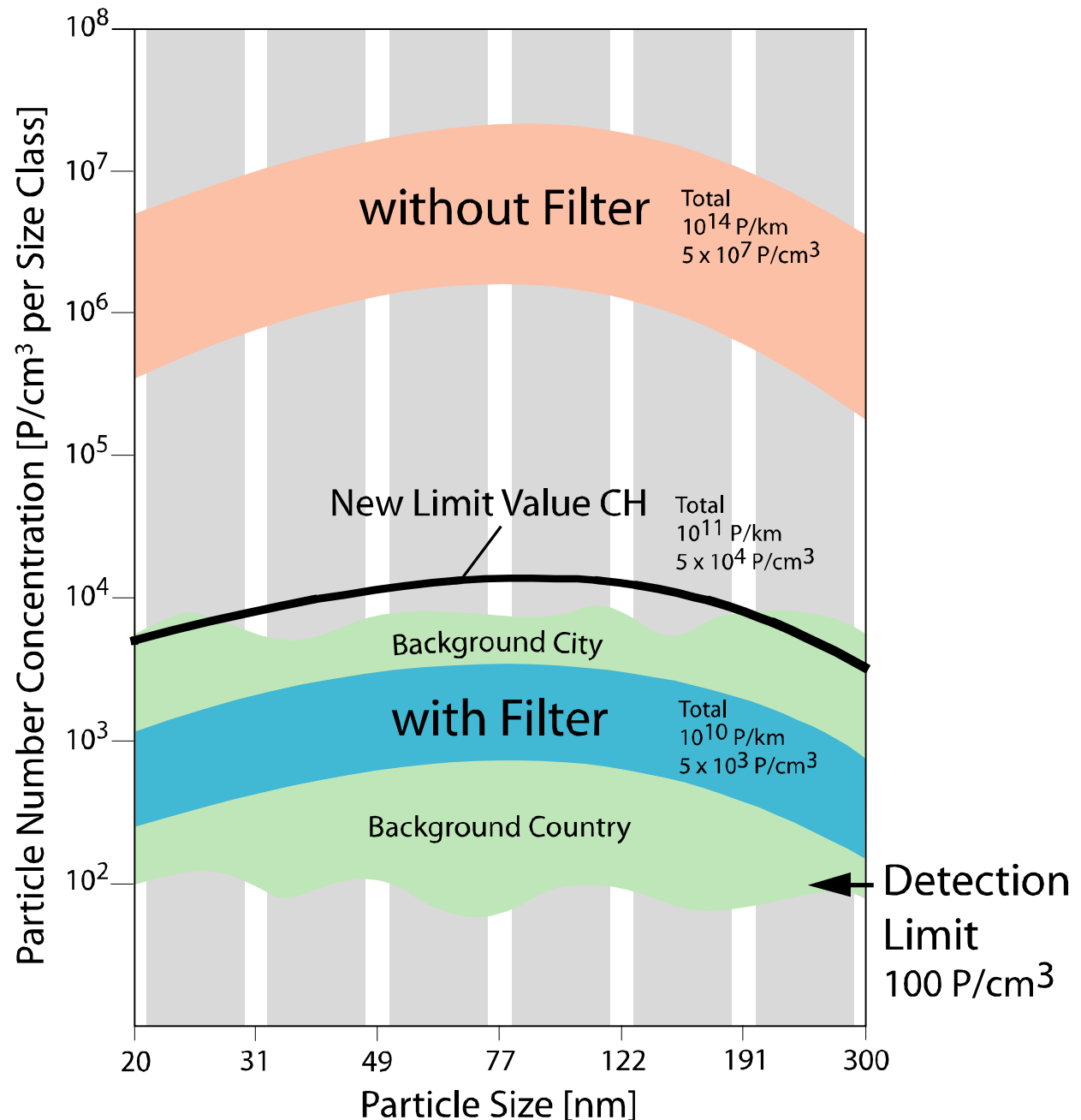
and can not  
exploit  
Filter

Technology



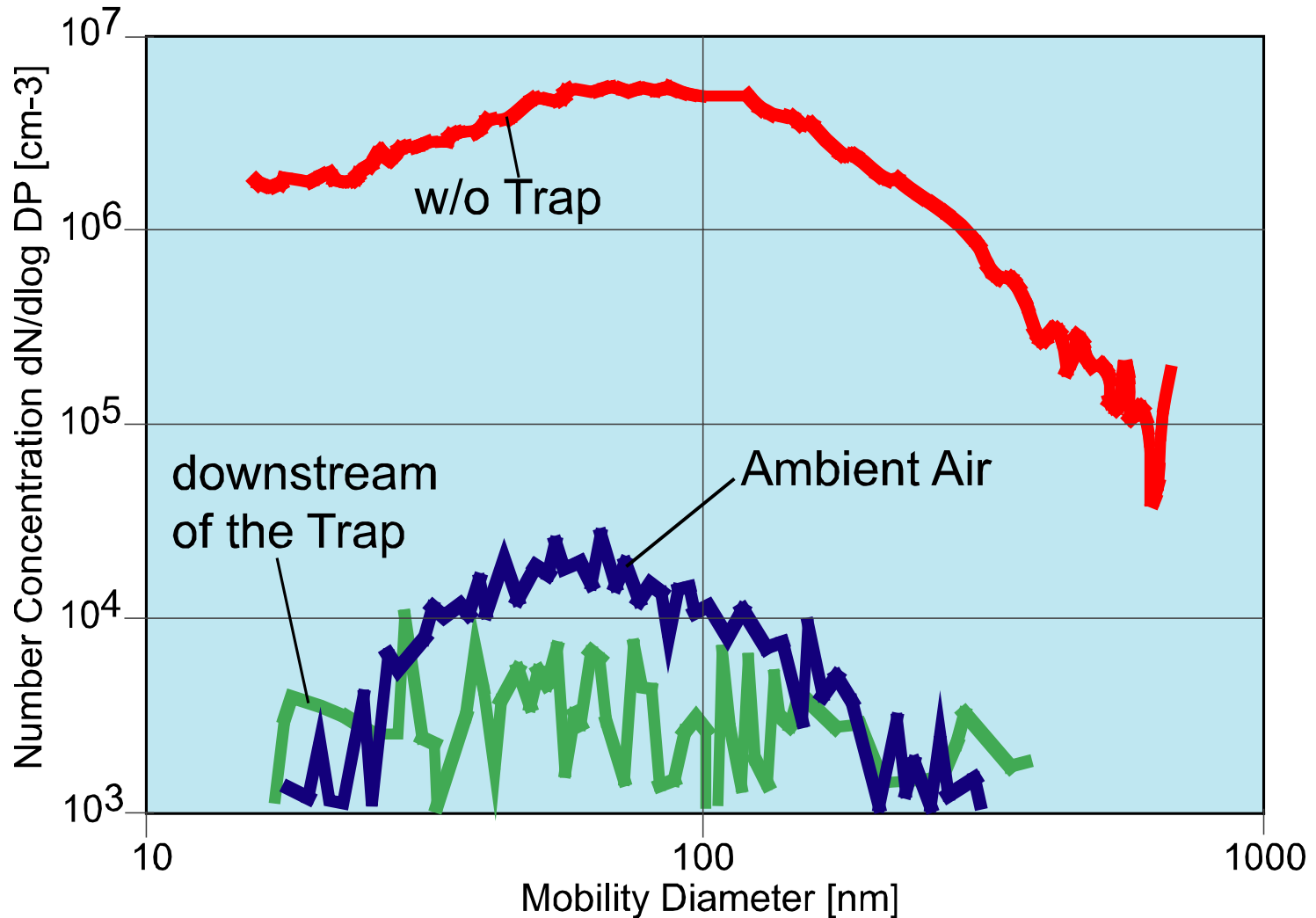
# Number – Limits

address the HE-metric and force the introduction of best available Technology





# Exhaust Gas downstream of the Filter is cleaner than Ambient Air !



# Counting particle numbers

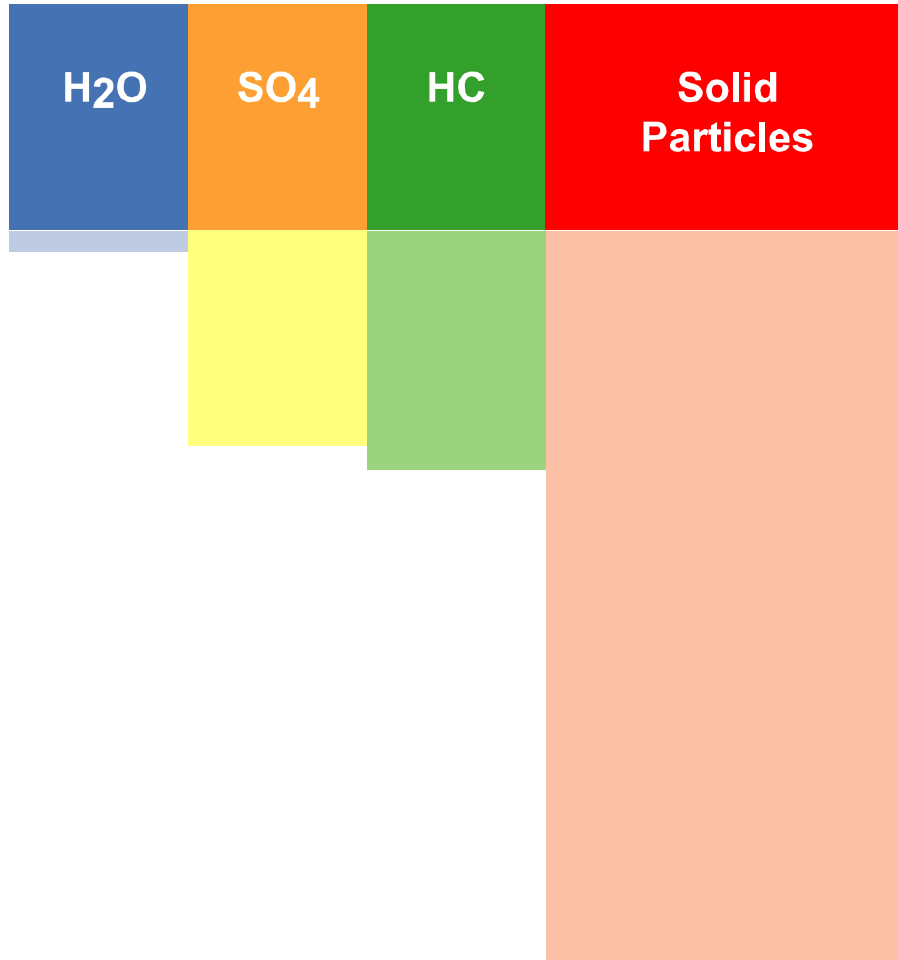
is the only way

- to introduce filters
- to ensure filter quality
- to drive filter technology
- to drive engine technology
- to perform in-compliance testing
- to guarantee high breathing air quality

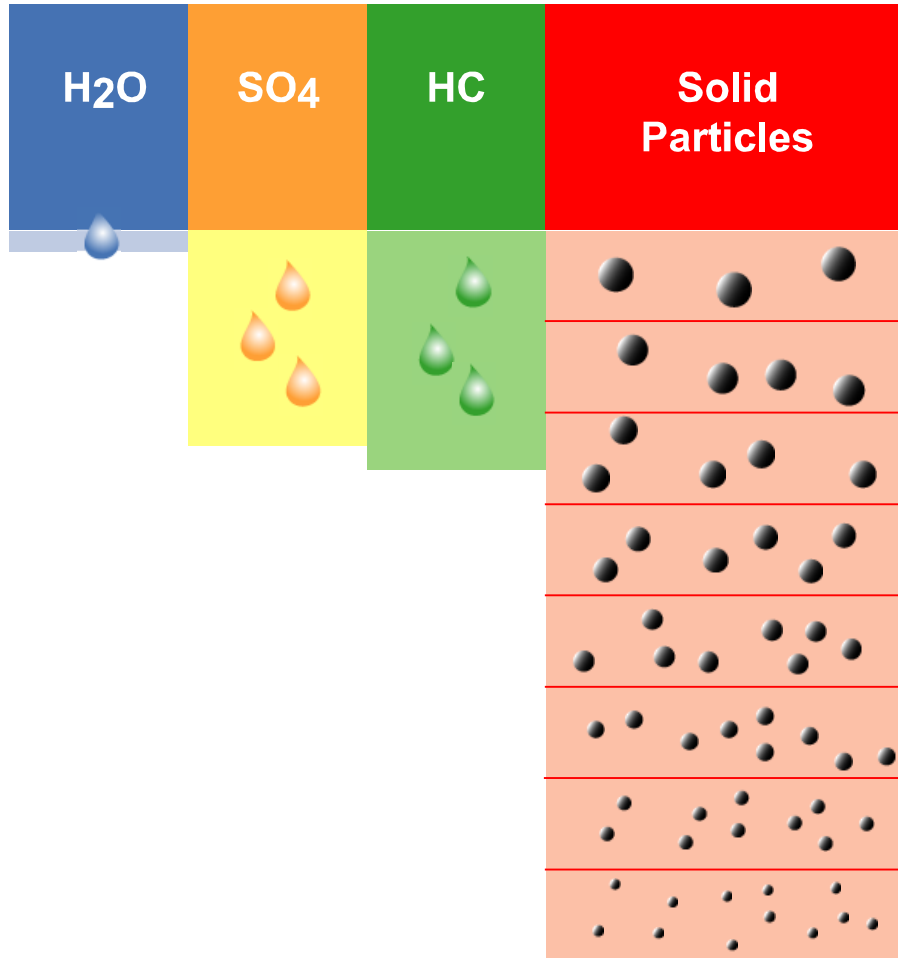
# PM consists of different Substances ...



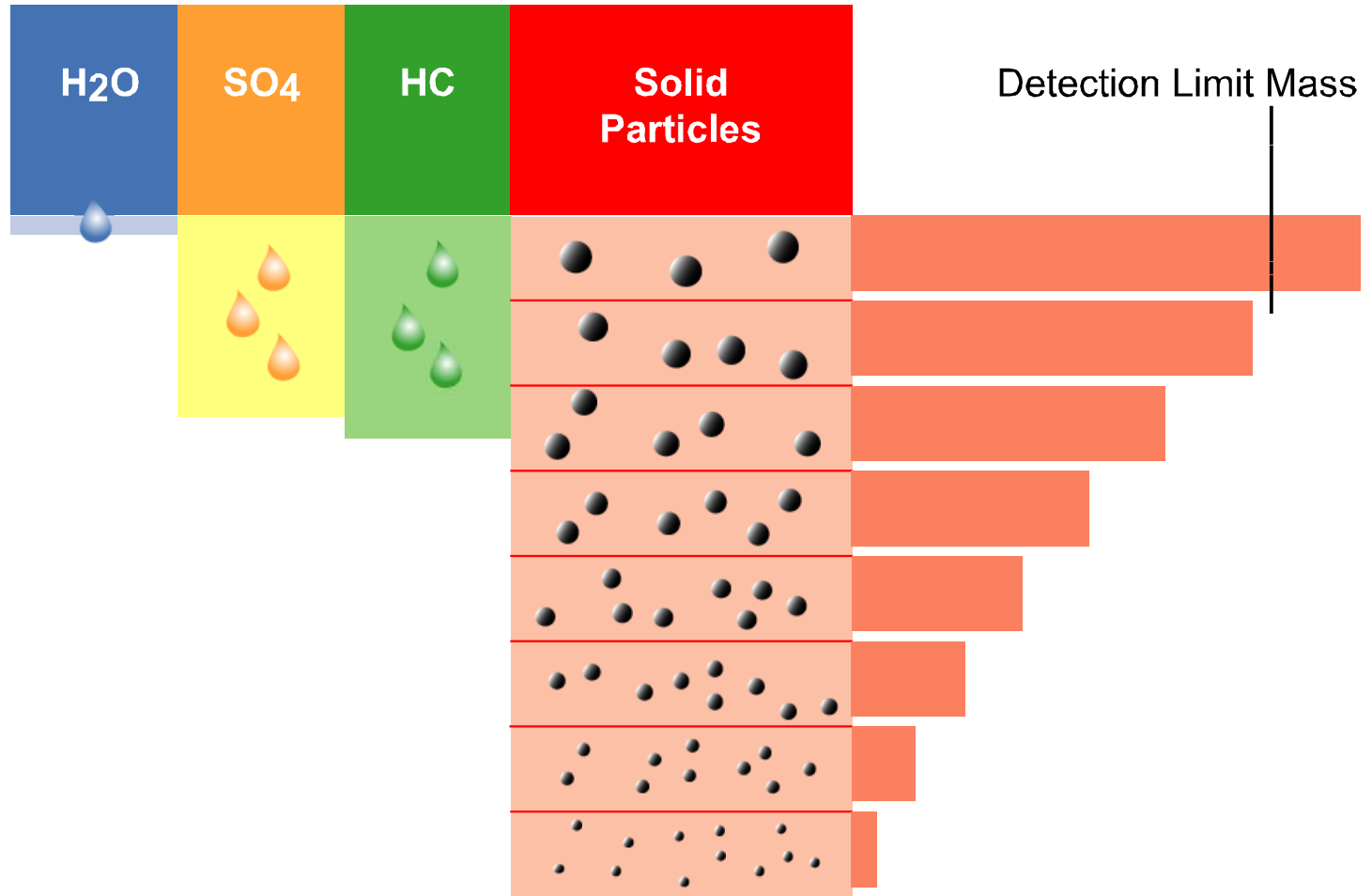
.... with very different Toxicity and different Tools must be applied



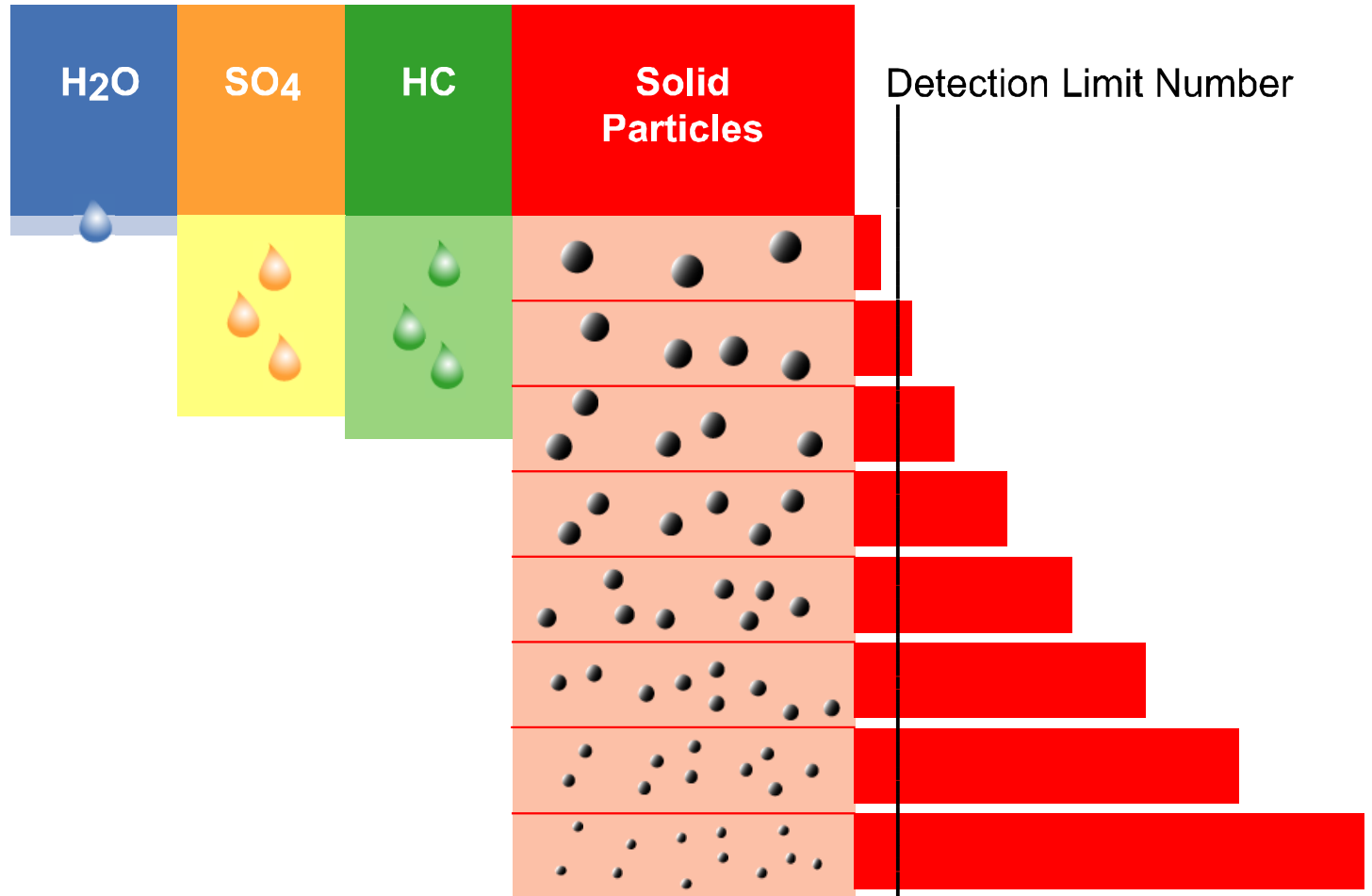
# for solid Particles Size must be respected



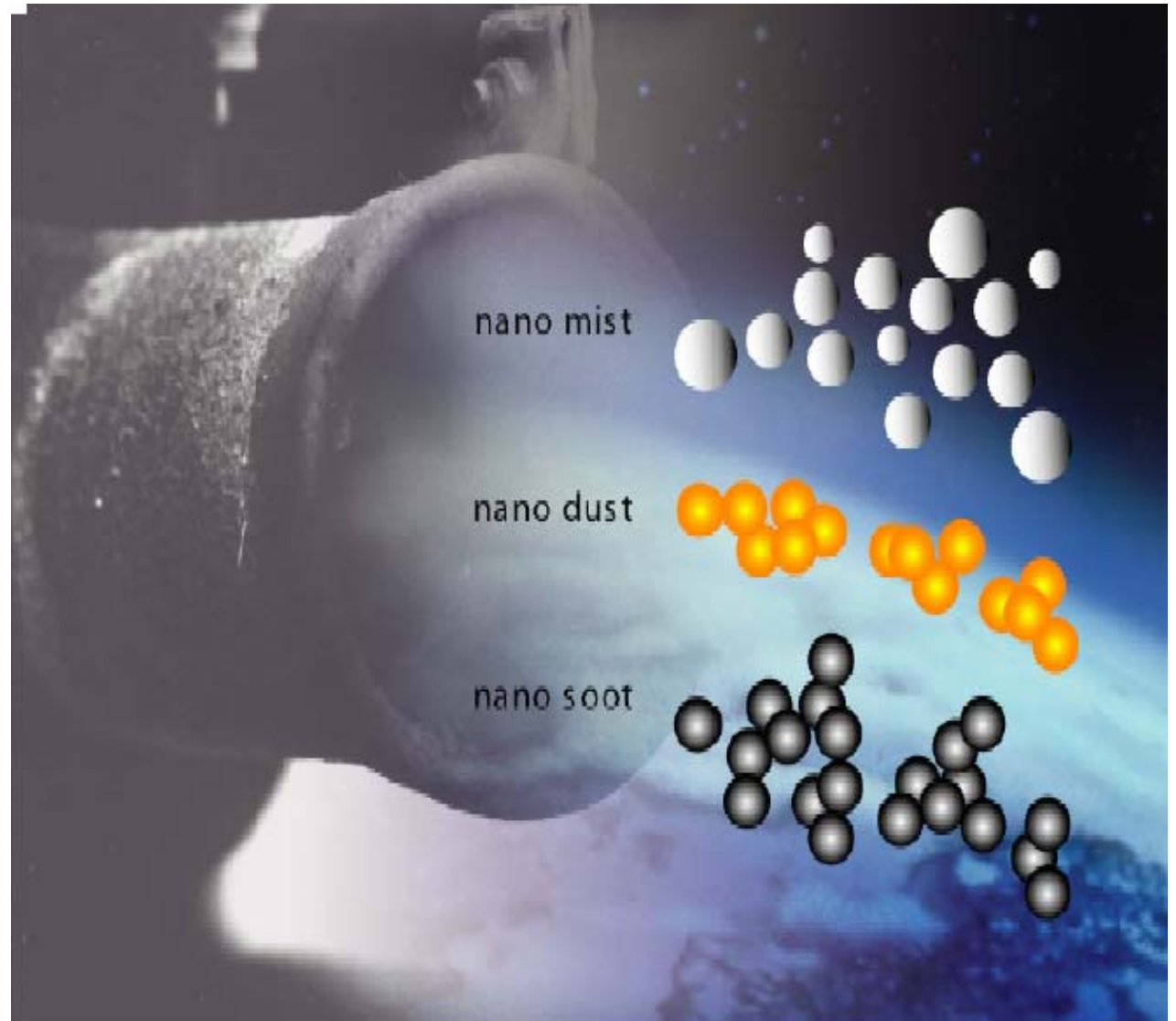
# Mass does not represent the ultrafine Particles penetrating the Alveoli and DL is too high



# Number Measurement addresses the right Metric and DL permits Technology Forcing



# Exhaust - Aerosols



(Quelle:  
M.Kasper/ ME )



# ***Conclusion***

- ***Particle Size matters***
- ***Particle Number matters***
- ***Particle Composition matters***

***Swiss retrofit projects are based on particle size, substance and number and require the elimination of solid particles size range 20-300 nm acc. to BACT***

# **Solid Particles 20-300 nm**

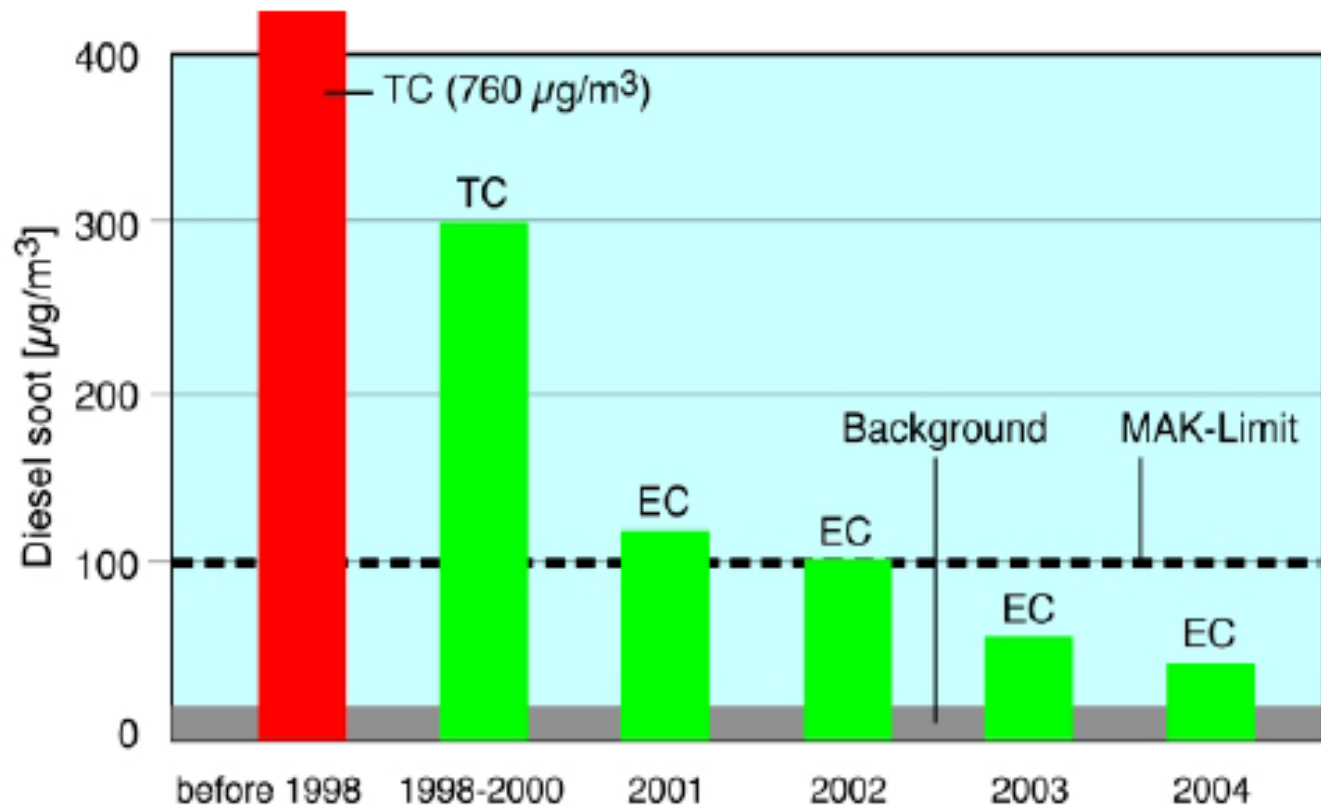
## **Air Contaminant No.1**

**once this definition is accepted**  
**Engineers can**

- **measure**
- **design and develop**
- **manufacture and distribute**
- **implement and enforce**
- **and control**

q.e.d.

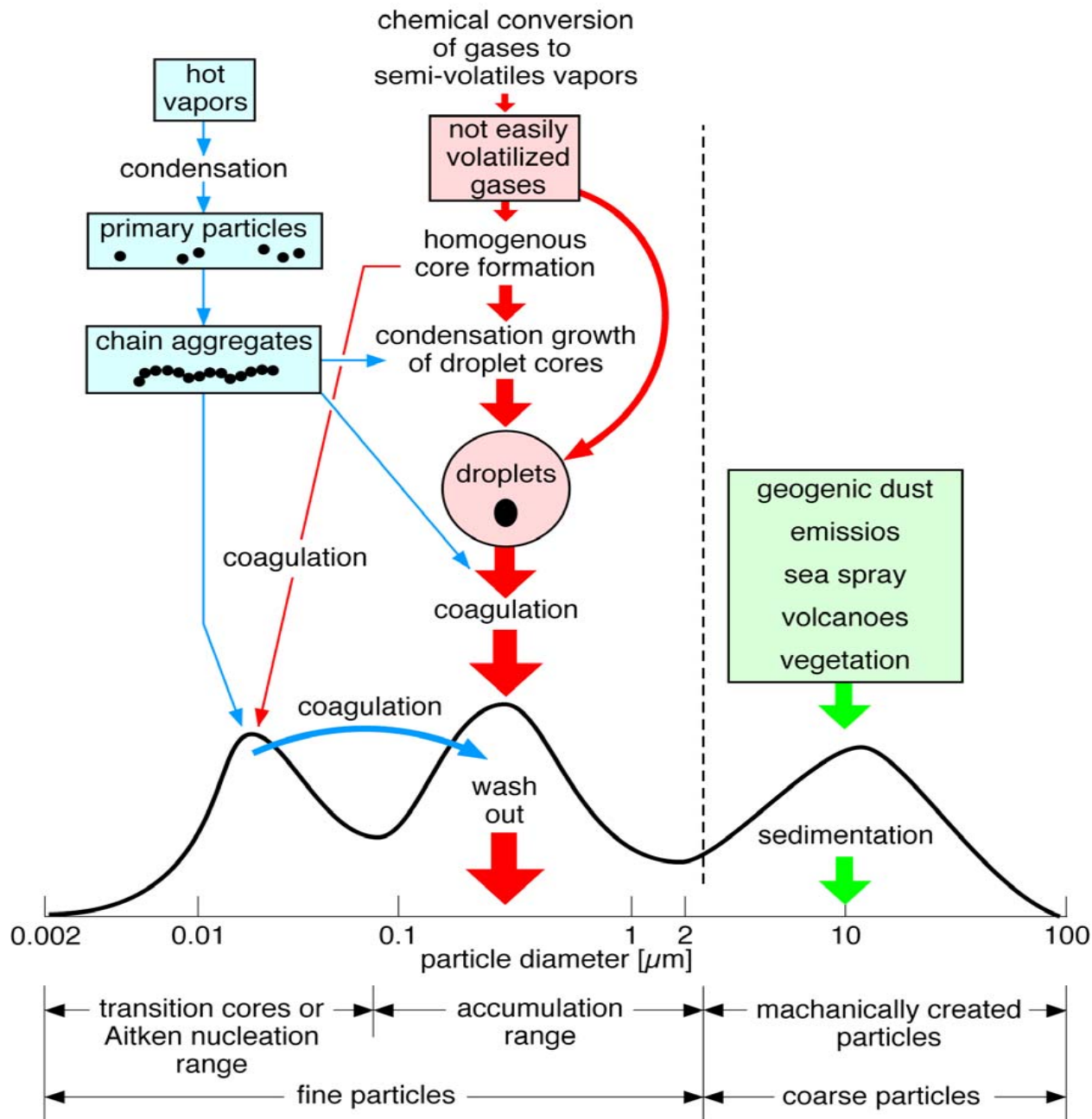
## SUVA:Tunnel-Luftqualität 1998-2004



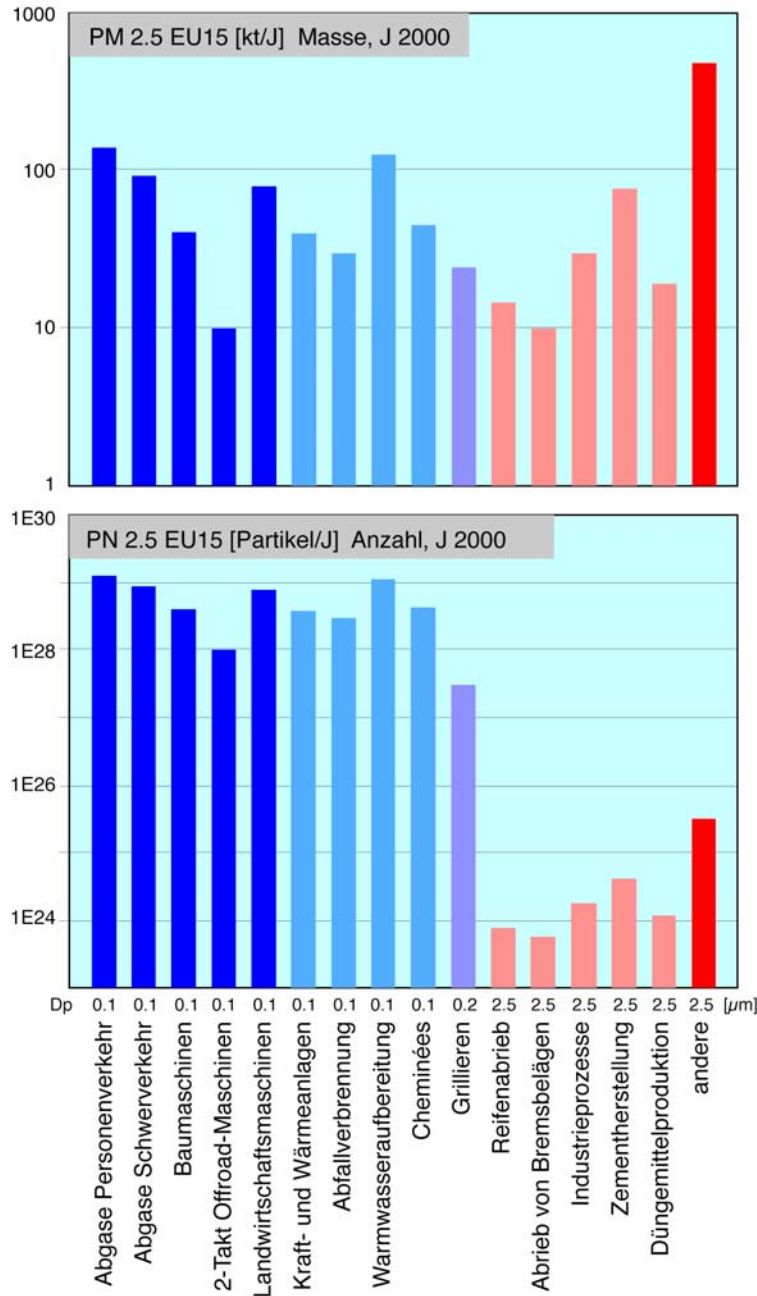
**and Air will become as clean as in Swiss Tunneling Sites by Filter Technology**



# Formation of fine and ultrafine Particles: 2 different Mechanismes



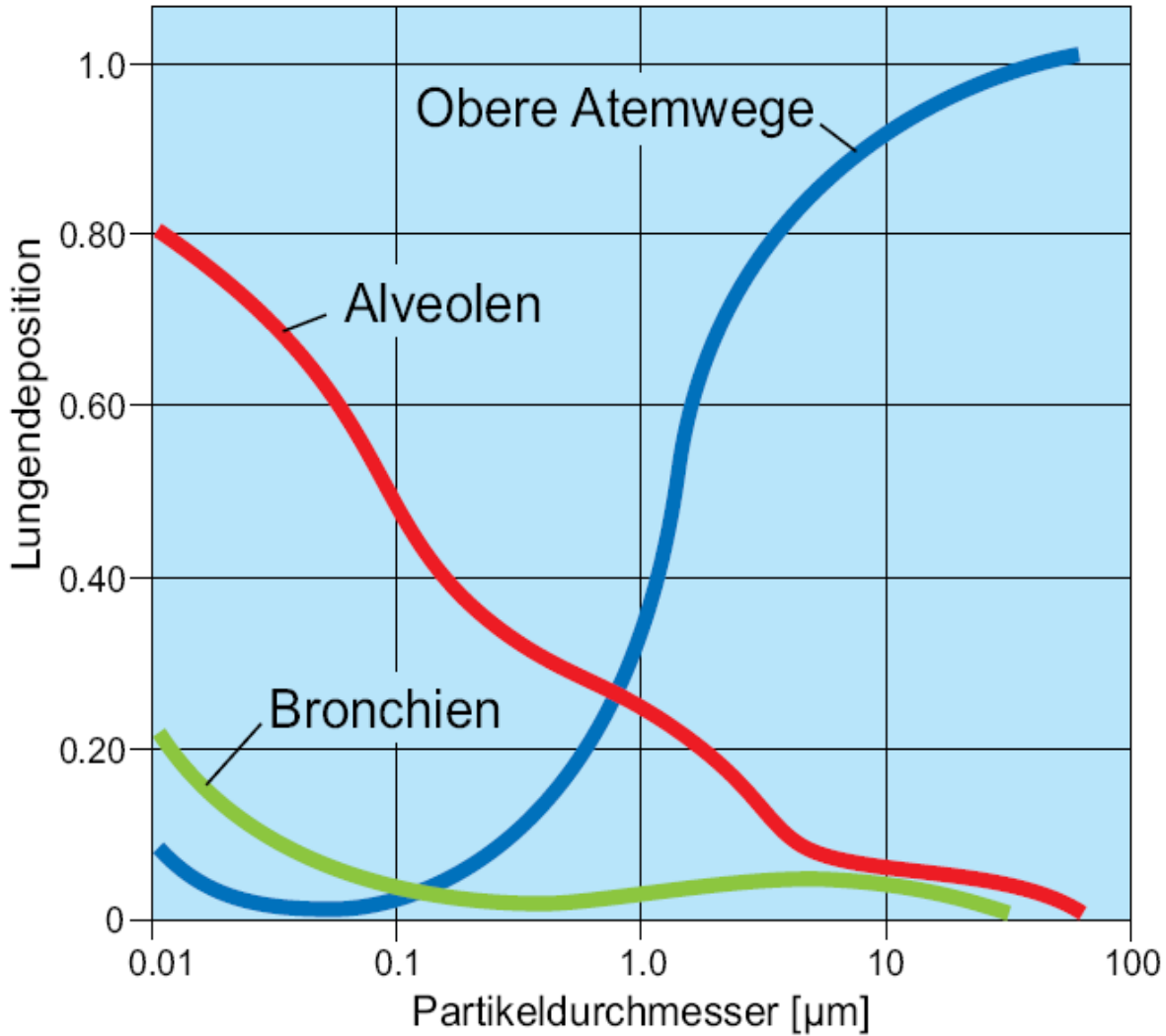
# HDT-3, Bild 5



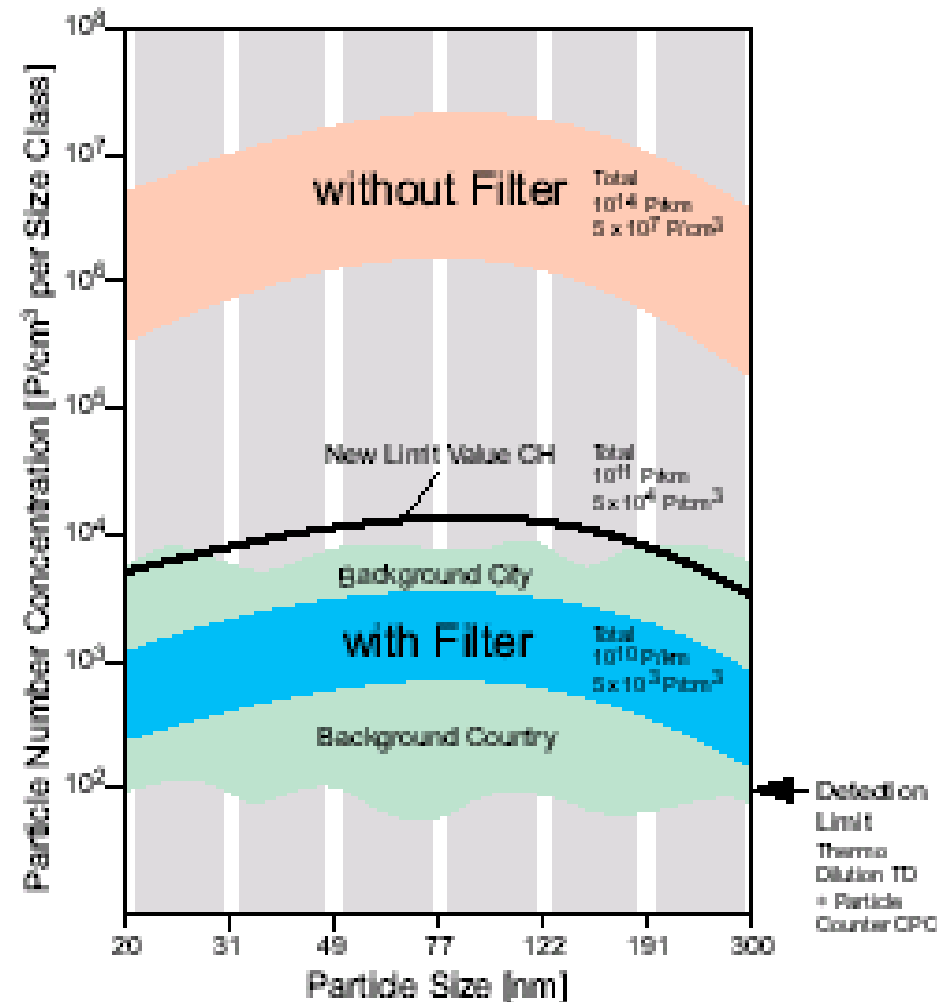
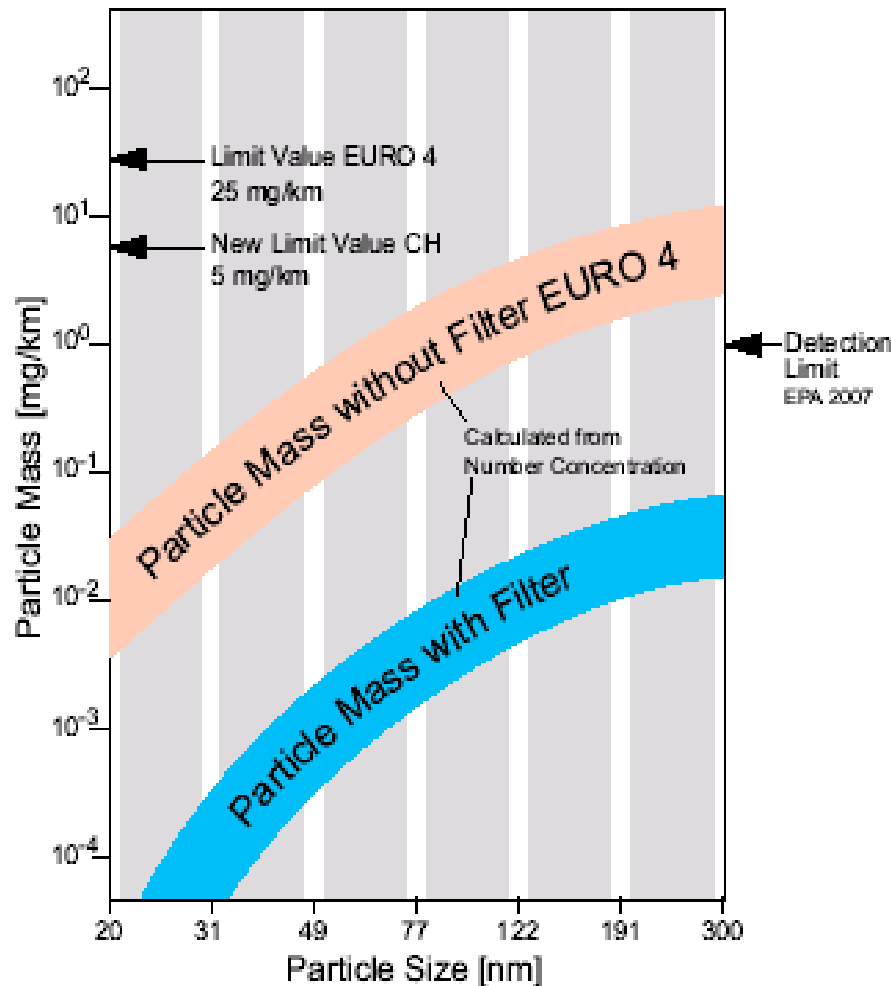
# Deposition of particles in the airways depends mainly on particle size not mass

(Source: Hinds, 1982 Aerosoltechnology )

Bronchien raus  
3-modale Verteilung einzeichnen  
Bereiche Clearing und Absorption  
Einzeichnen  
Innerhalb und ausserhalb des  
Körpers - Trennlinie

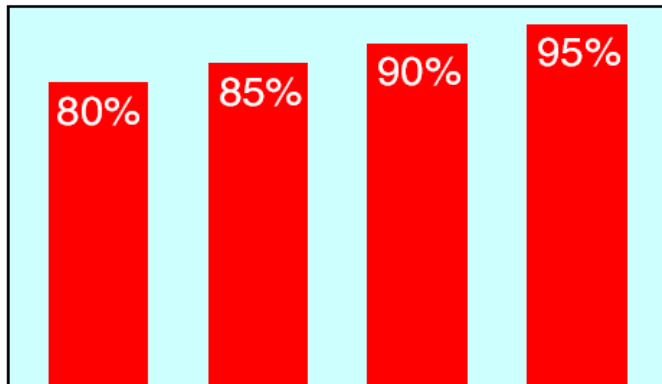
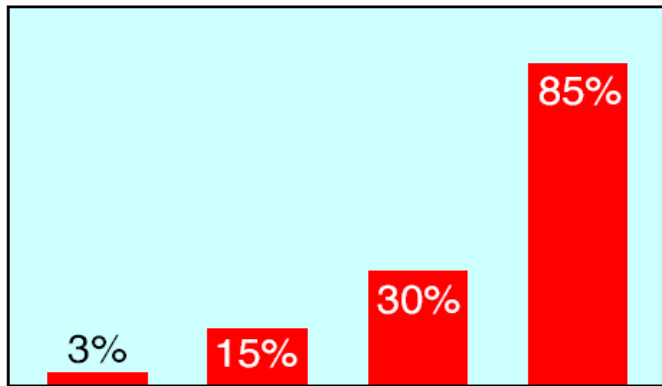


# Number Measurement → lower Emission Limits and better Control Technology





# Anteil der Partikelemission der Motoren an der Gesamt-Partikel“menge“



TSP    PM10    PM2.5    PM1

# Exhaust Gas downstream of the Filter is cleaner than Ambient Air !

