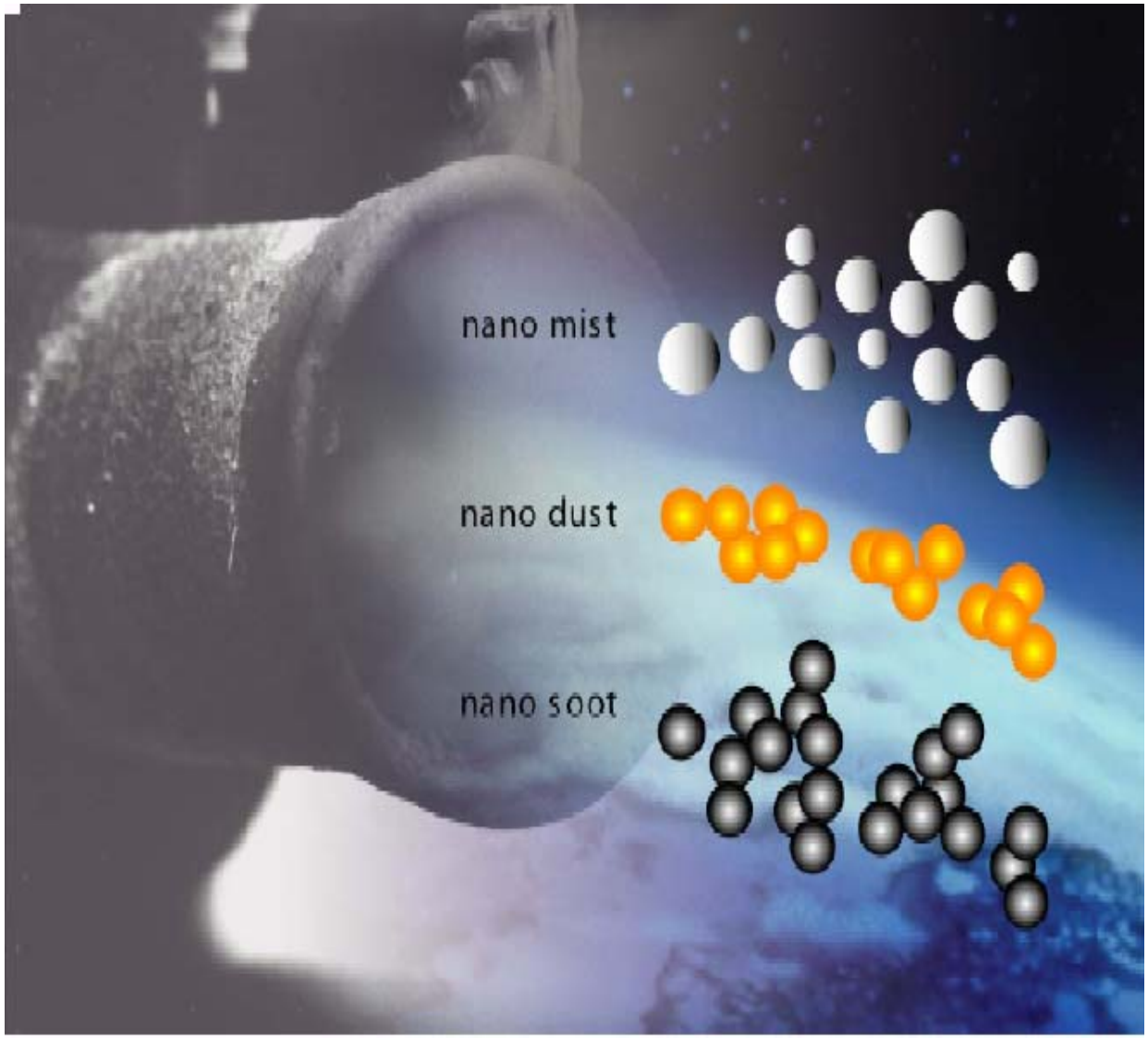
International Conference on Ultrafines – Los Angeles May 2006

Experience with 10’000 DPF- Retrofits of Construction Machines, Locomotives and Transit Buses in Switzerland

A.Mayer / TTM

Pollutant defined

„Solid Particles
Size range 20-300 nm“

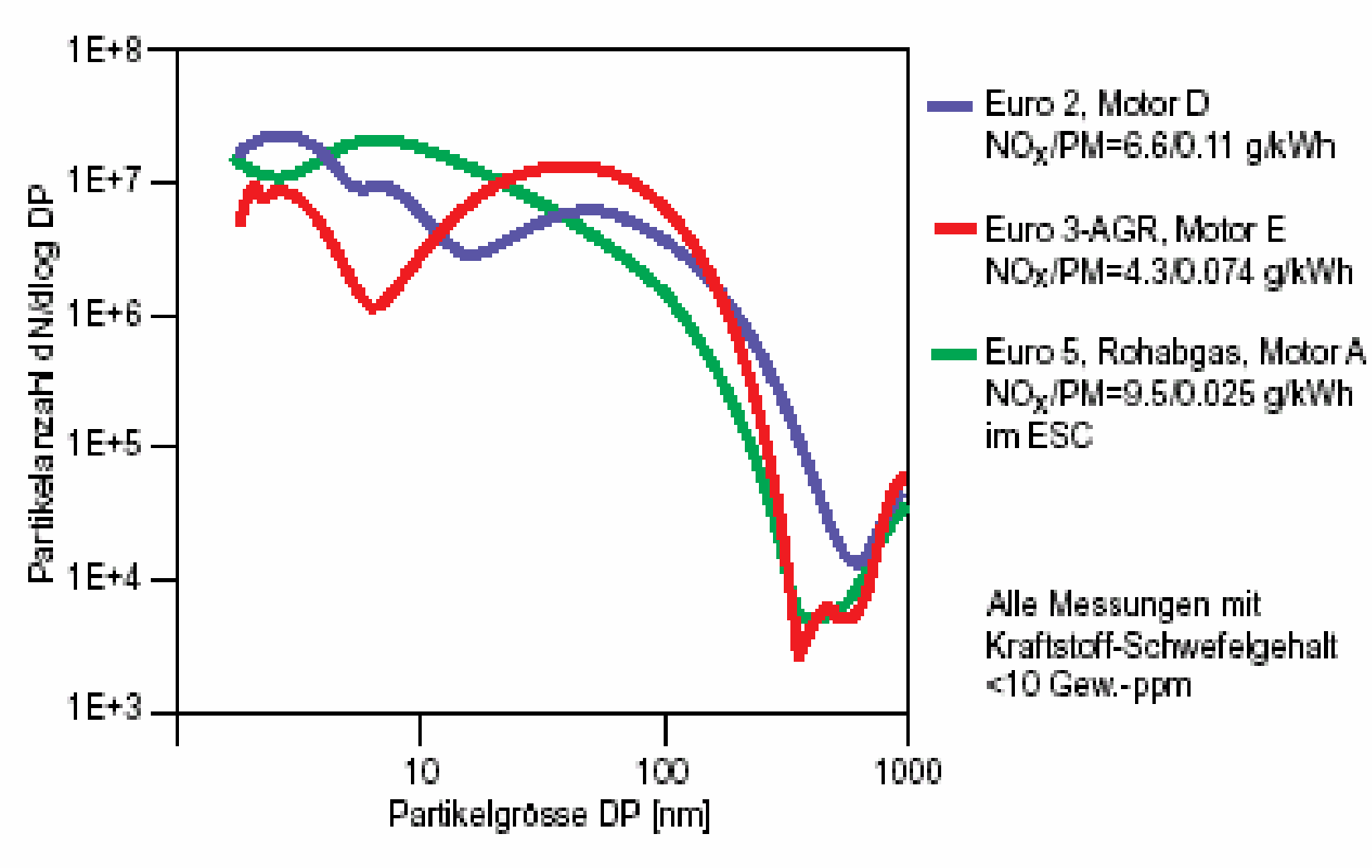


(Quelle:
M.Kasper/ ME)

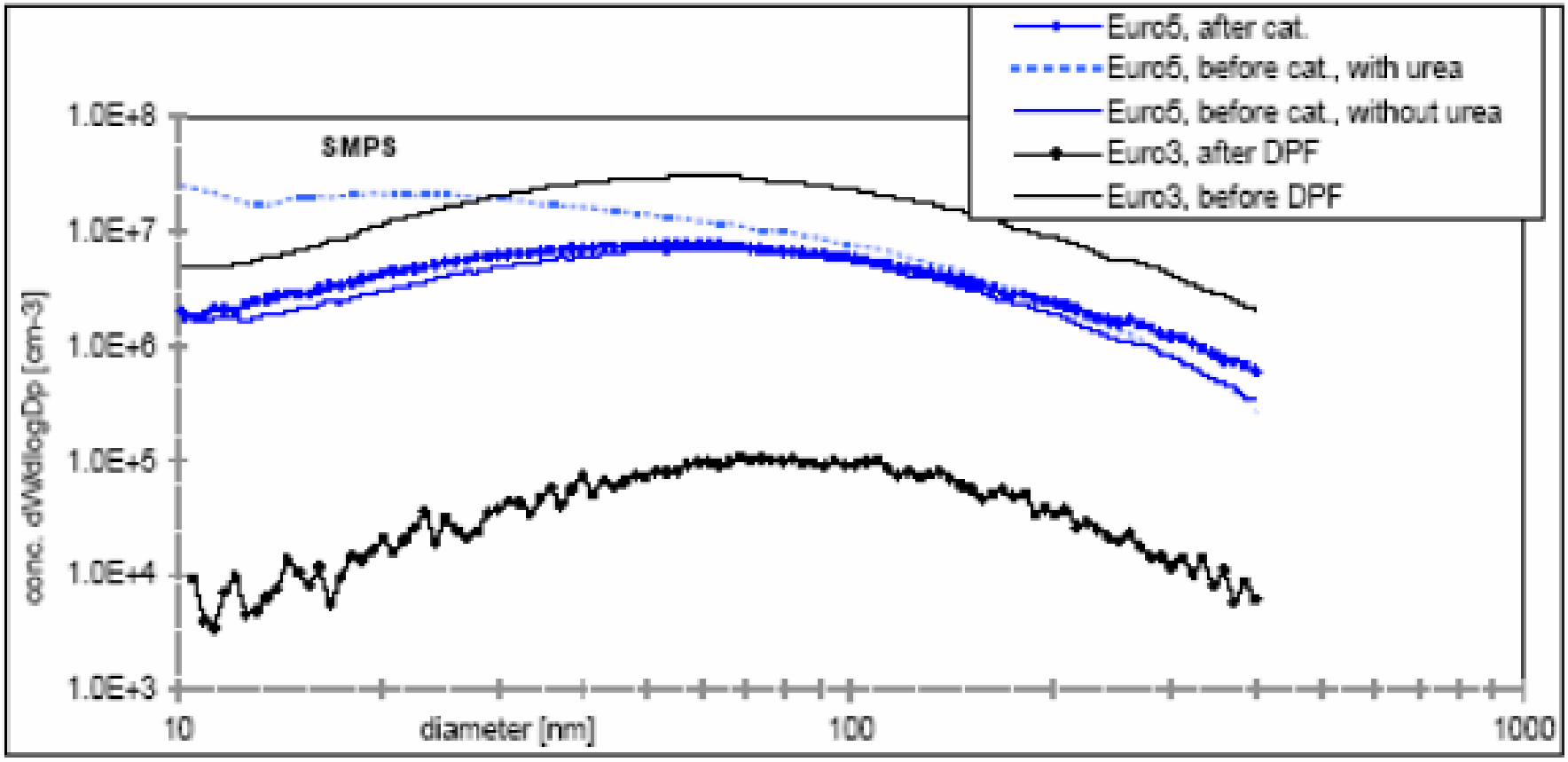
Target

Retrofit of new and older Engines

(AVL, Zelenka)



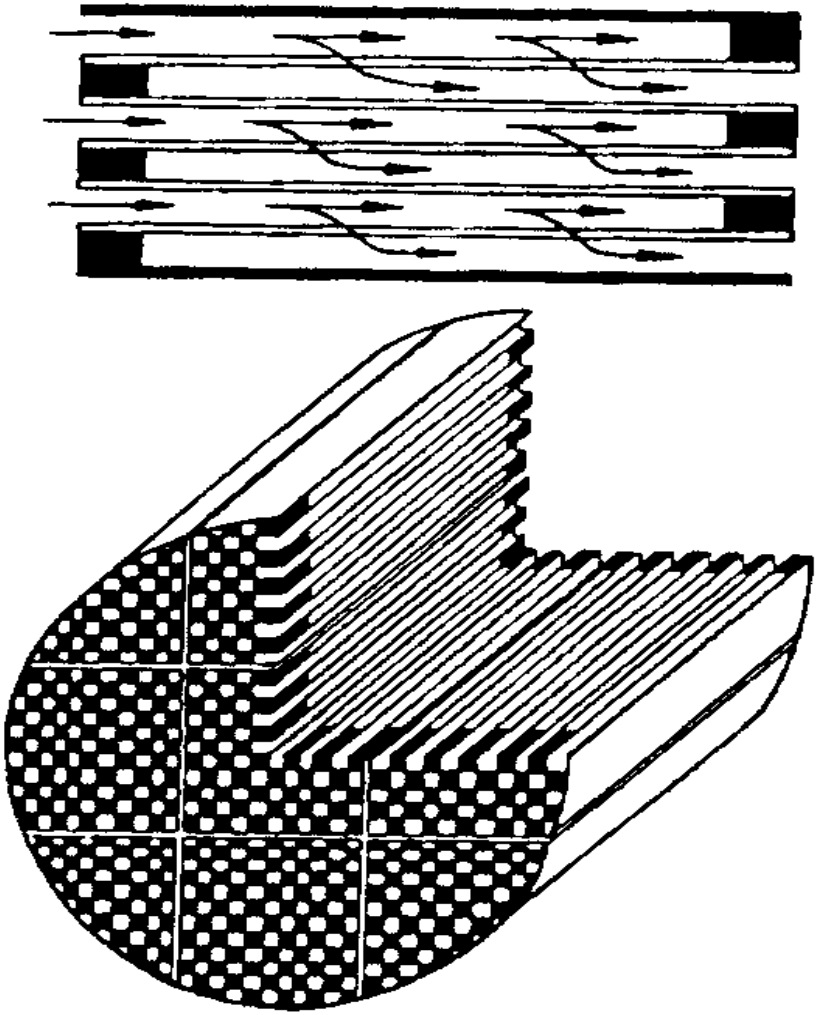
EURO 5/3 at 50 % load



Technology is available

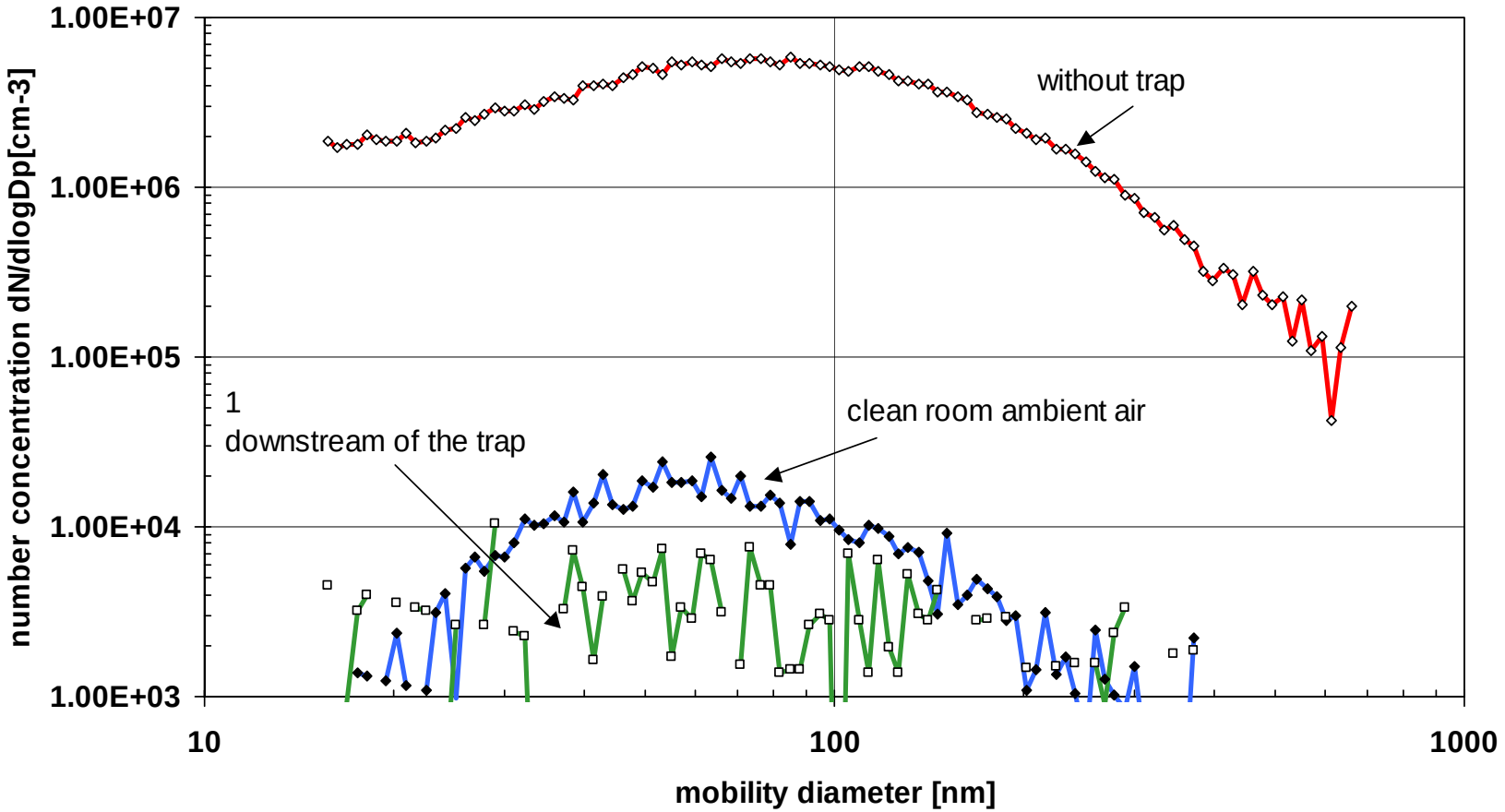
Wall flow ceramic substrate - 10 micron pore size

The classic CORNING 1982



BACT required by Law

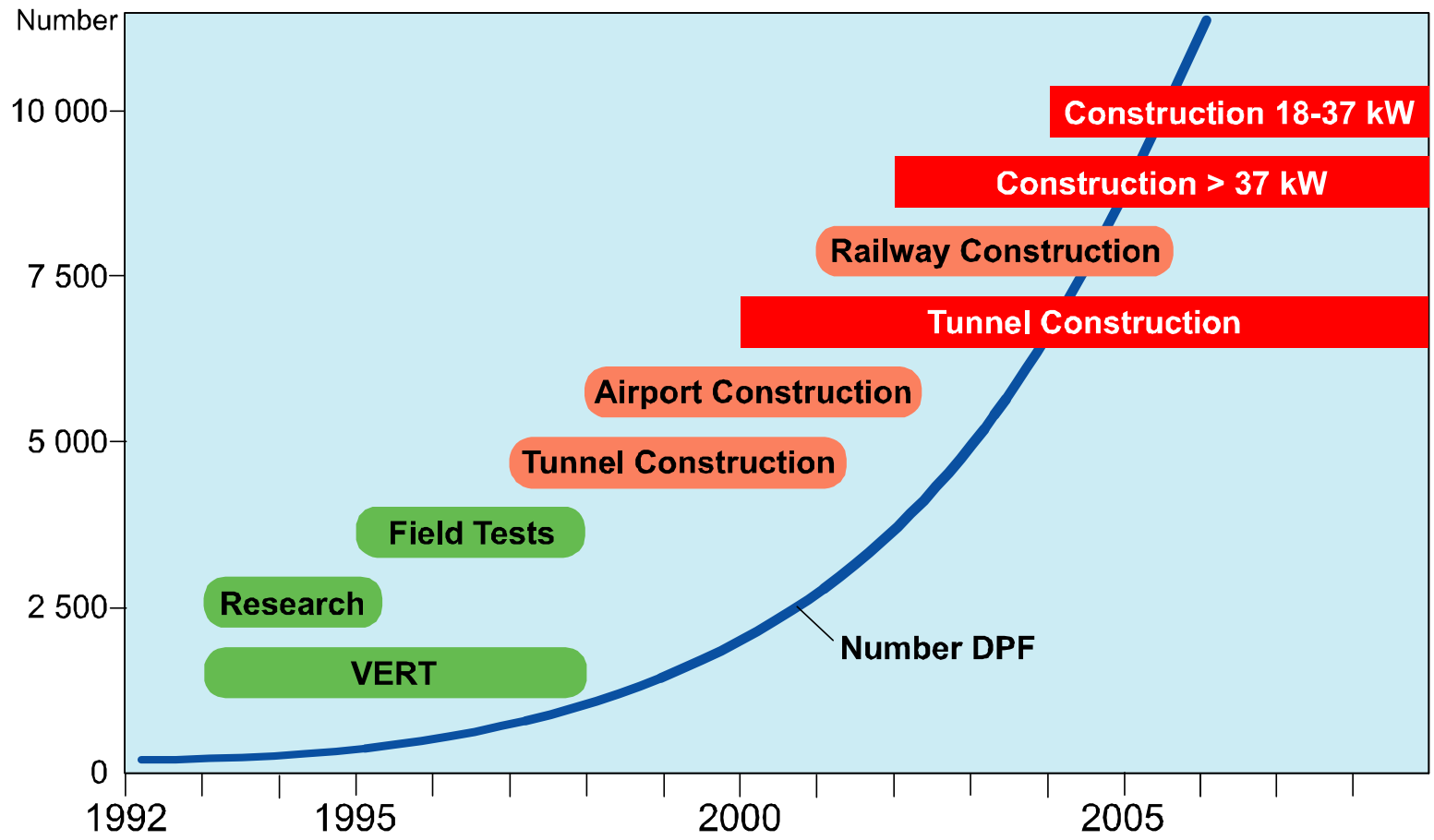
Exhaust Gas downstream Filter is cleaner than Ambient Air !



Swiss Particle Filter Regulations

- **1990** (EJPD): Retrofit permitted under conditions:
  - no additional Noise Emission
  - no Formation of **secondary toxic Air Contaminants**
- **1994**: Diesel-Emissions classified **carcinogenic--**
- **1998:** Limit for stationary engines < 5 mg/m3 EC→BACT
- **1998:** VERT PFS specification and verification protocol
- **2000:** VERT-**PFS mandatory in tunneling**
- **2002:** VERT-**PFS mandatory for construction**
- **2003**: only VERT approved PFS for onroad vehicles

Stepwise build-up by Public & Private Demonstration Projects



History of PFS-Retrofit in Switzerland

Year	Number of Retrofits	Number of Retrofitters	Faillures per Year [%]	Comments
Before 1995	453	3	15	
95-98	382	8	10	VERT-Procedure
1999	577	9	9	Public Demonstrations
2000	971	12	8	Mandatory in tunneling
2001	1057	6	6	VERT VFT2/3 introduced
2002	1481	7	3	Construction Guideline
2003	1567	11	2	VERT for Road Vehicles
2004	2390	12	1	
2005	ca 2500	21		

VERT Retrofit Principles

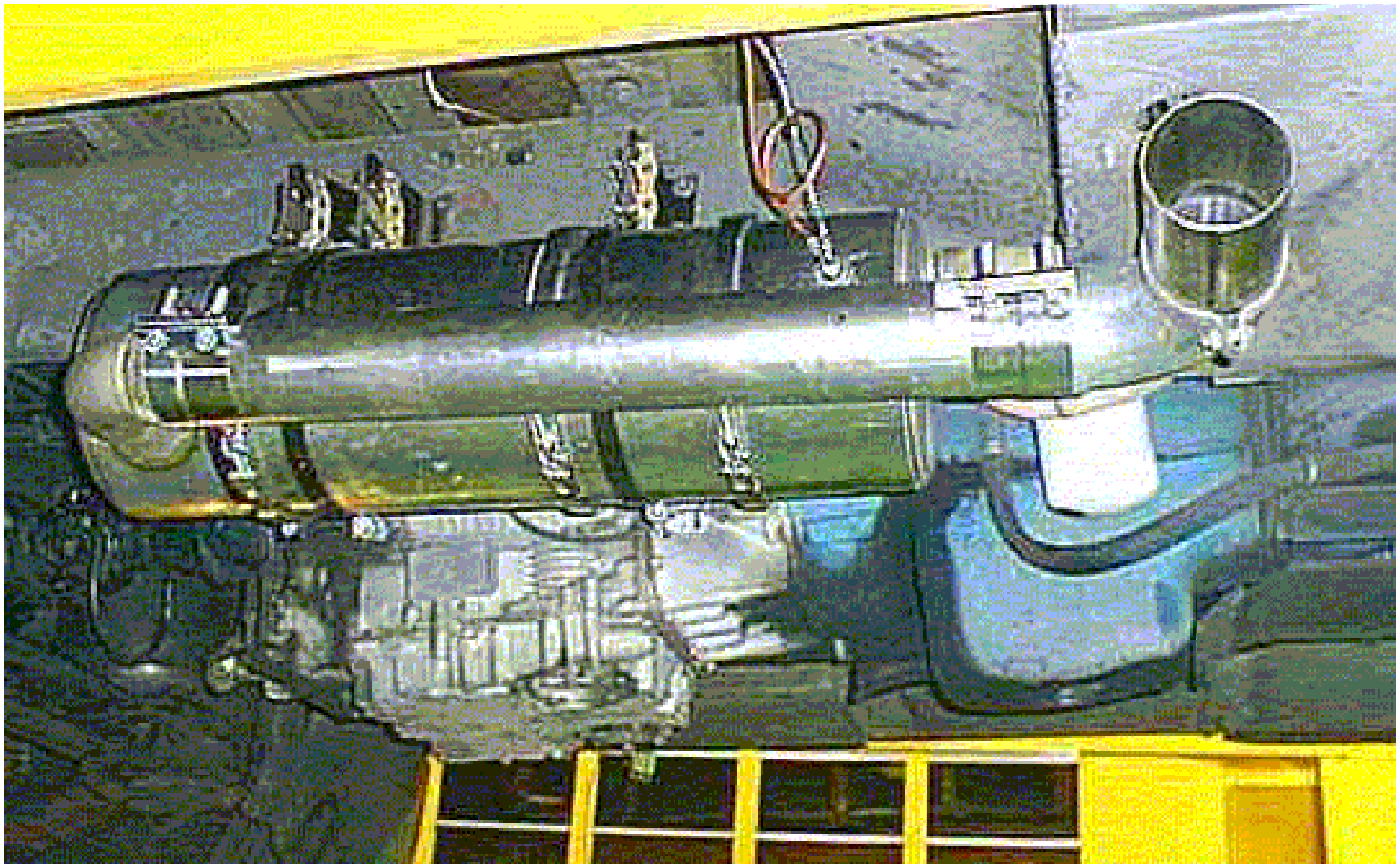
- Filter system verification - not “filter+engine”
  - efficiency > 95 % under worst case operation conditions
  - efficiency based on number count 20-500 nm
  - no secondary toxic emissions
  - noise and safety criteria respected
  - backpressure < 200 mbar → electronic OBC
  - 2000 hrs endurance without aging test before sales
- 2 years guarantee on system function and material
- on board monitoring
- engine maintenance and 100% emission control 1x pa
- 3 level Q-control: Authority + Manufacturer + User

Truck-Installation in place of Muffler

ca 300 trucks

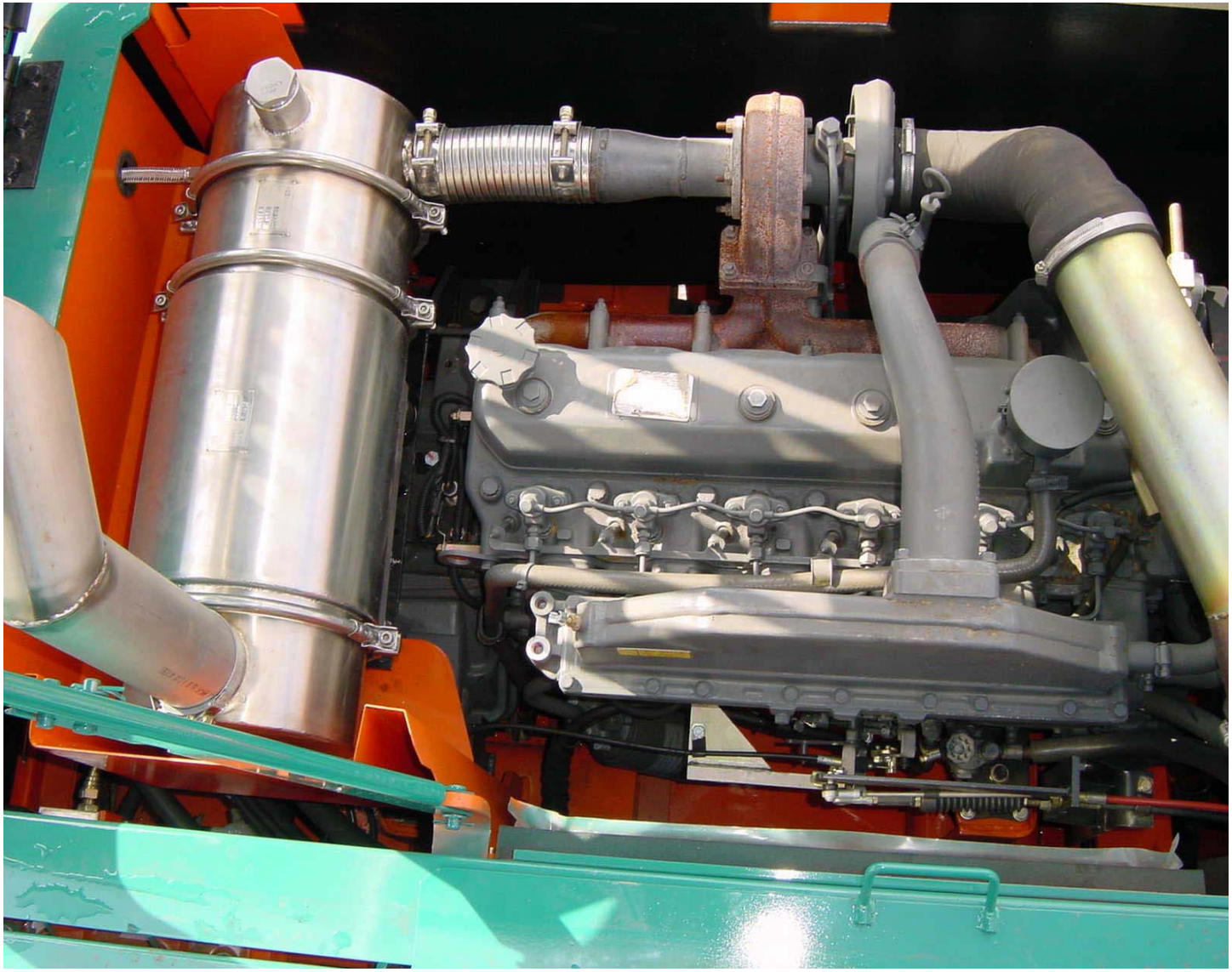
Installation underneath a City Bus

650 Buses – 1`000`000 km in operation



Installation on an Excavator

9000 Construction Machines; > 10‘000 operation hours



DPF on Locomotives and Ships

> 300 locomotives 300-3000 kW ,

Locomotives > 15‘000 op.hrs. 1 ship > 30‘000 op. hrs.

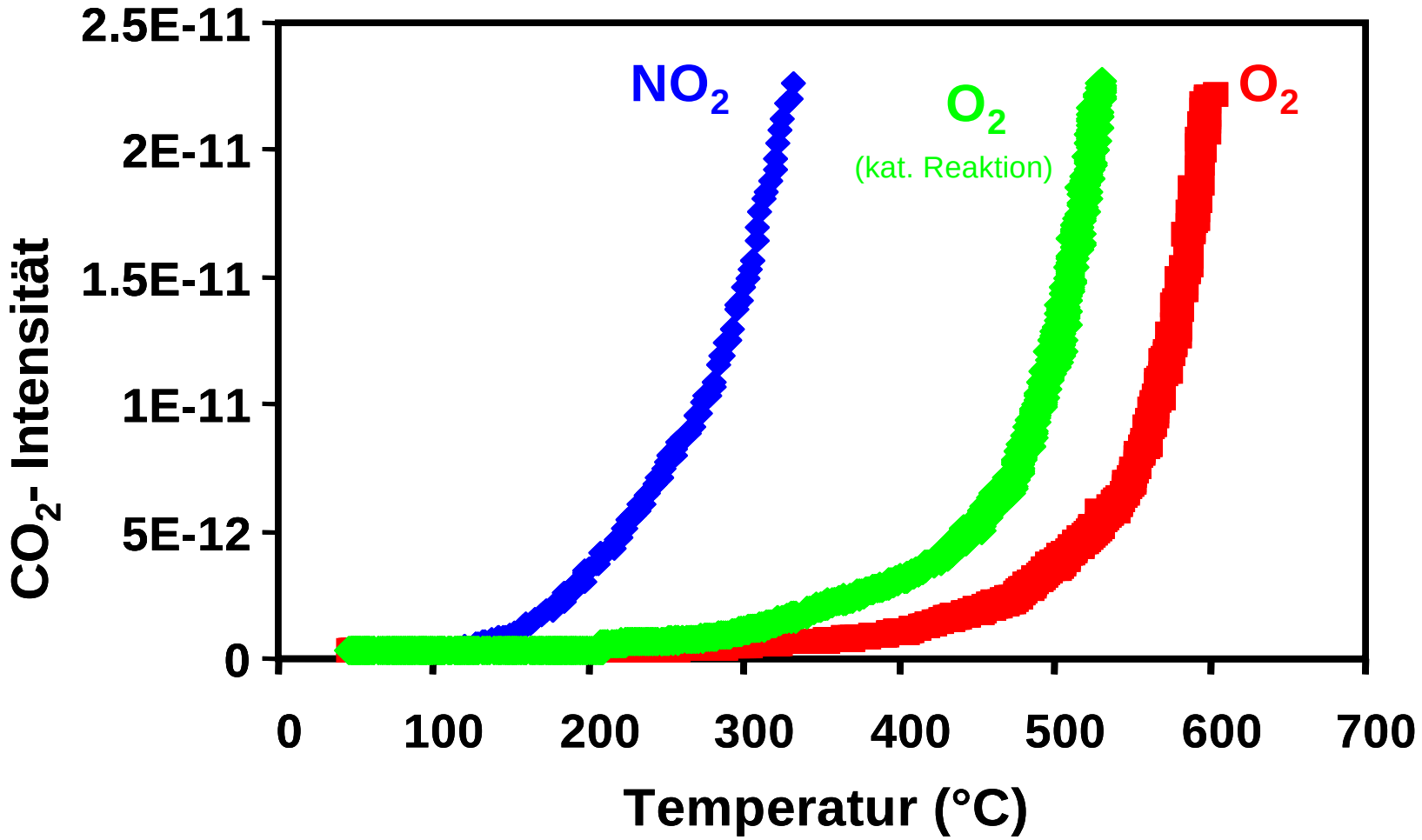
Filter System includes

Regeneration =

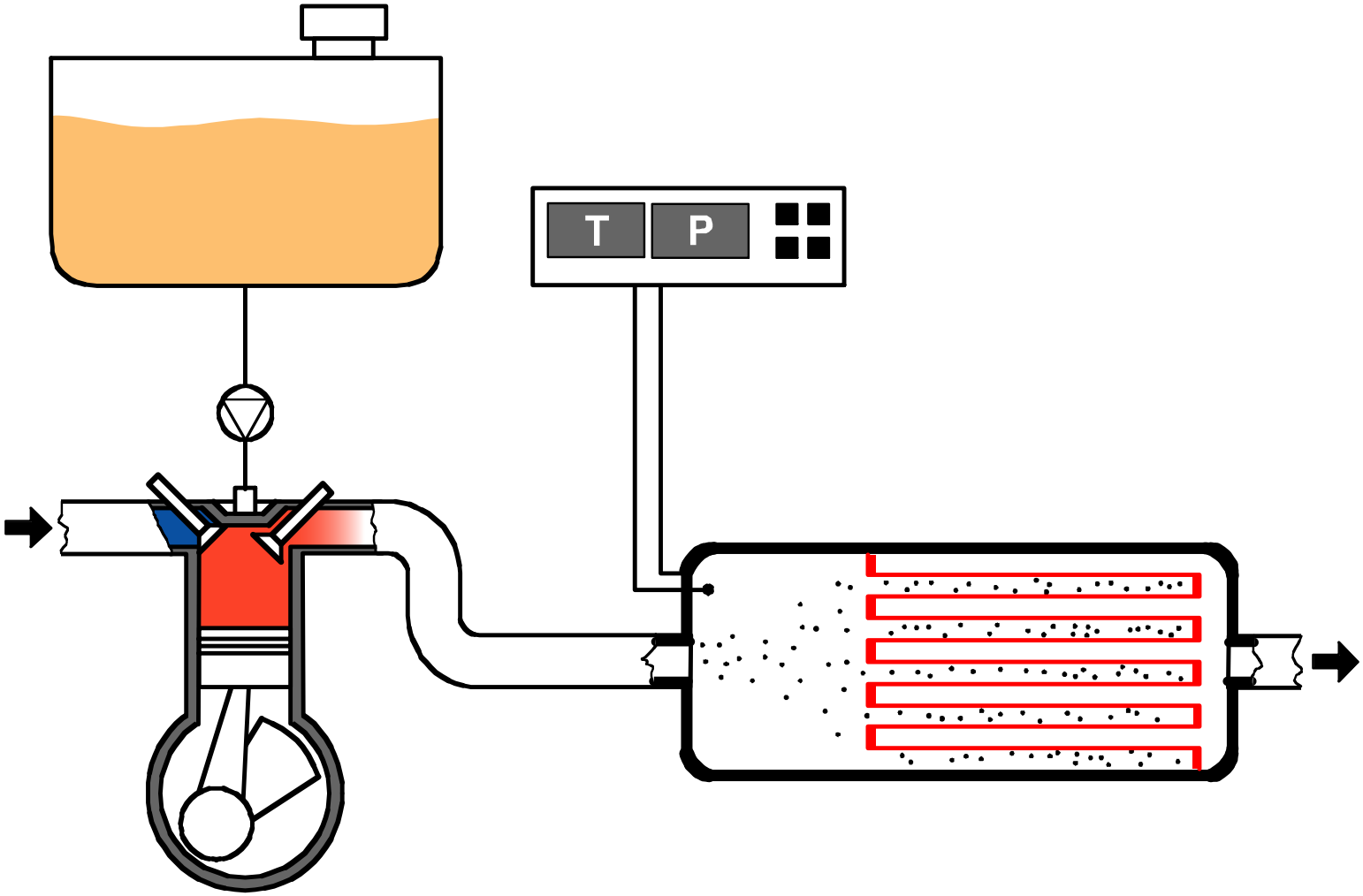
in situ Soot Combustion

every 5-20 operation hours

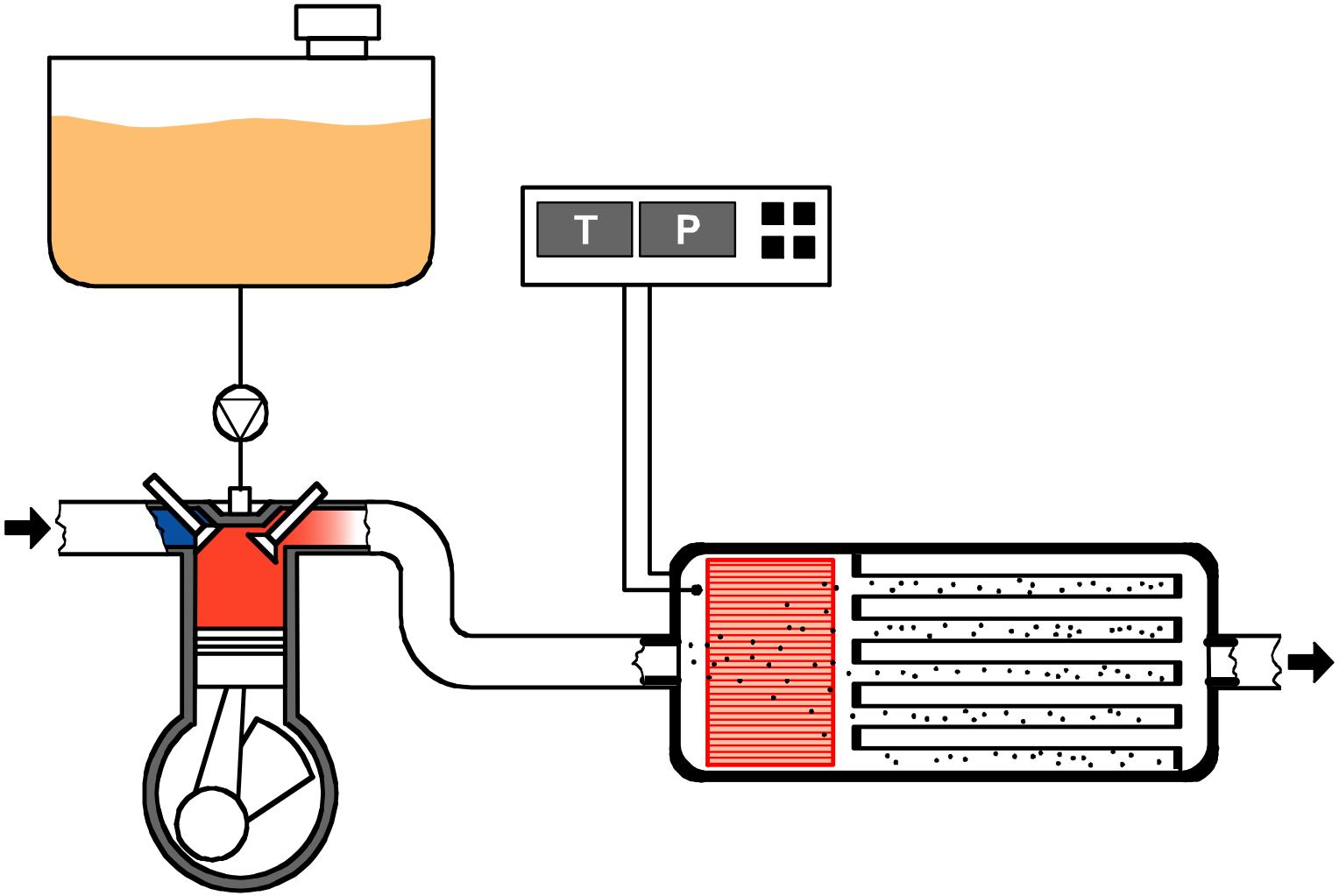
Soot-Reaction with O_2 und NO_2



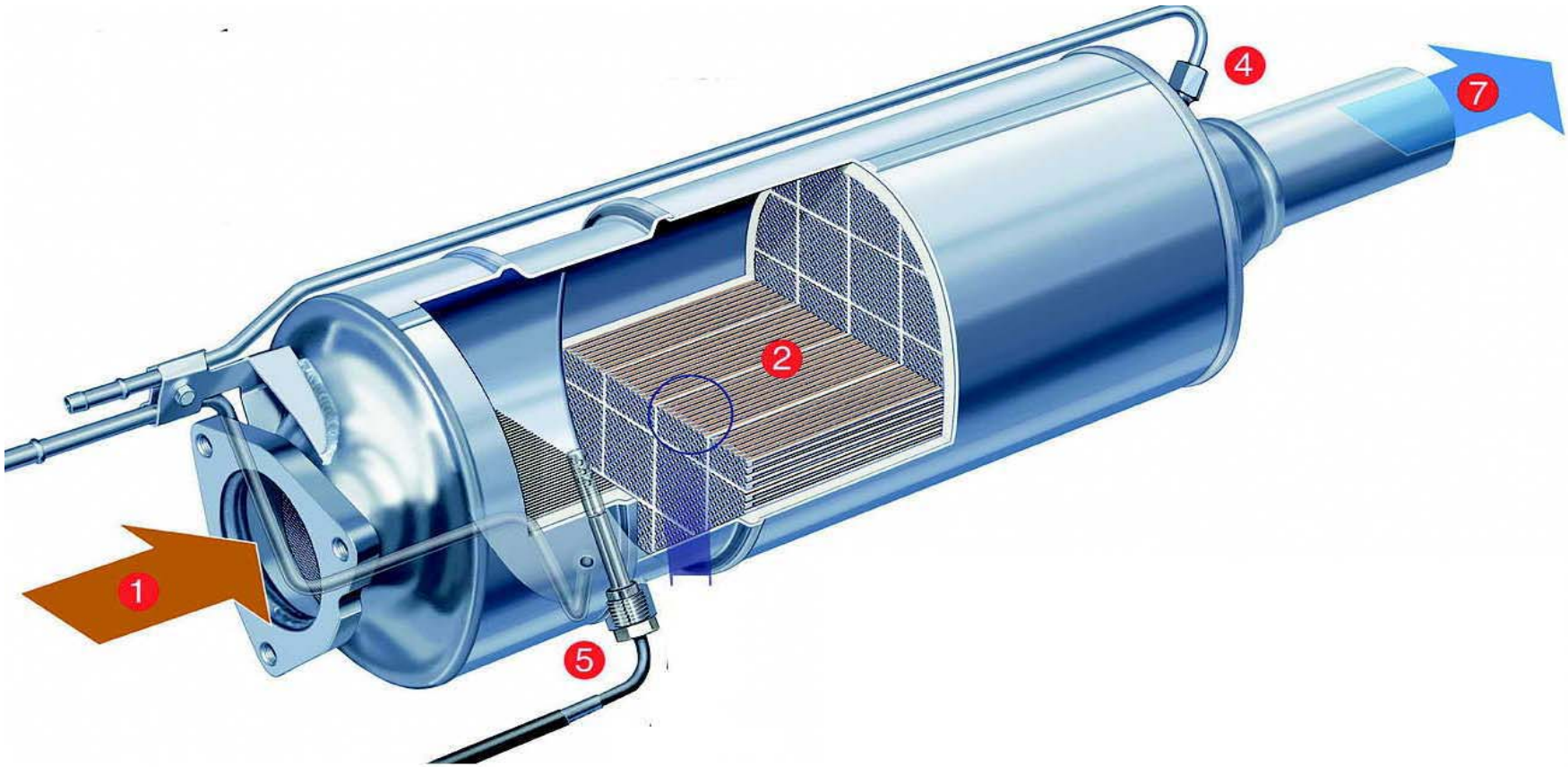
Catalysed Filter-Substrate



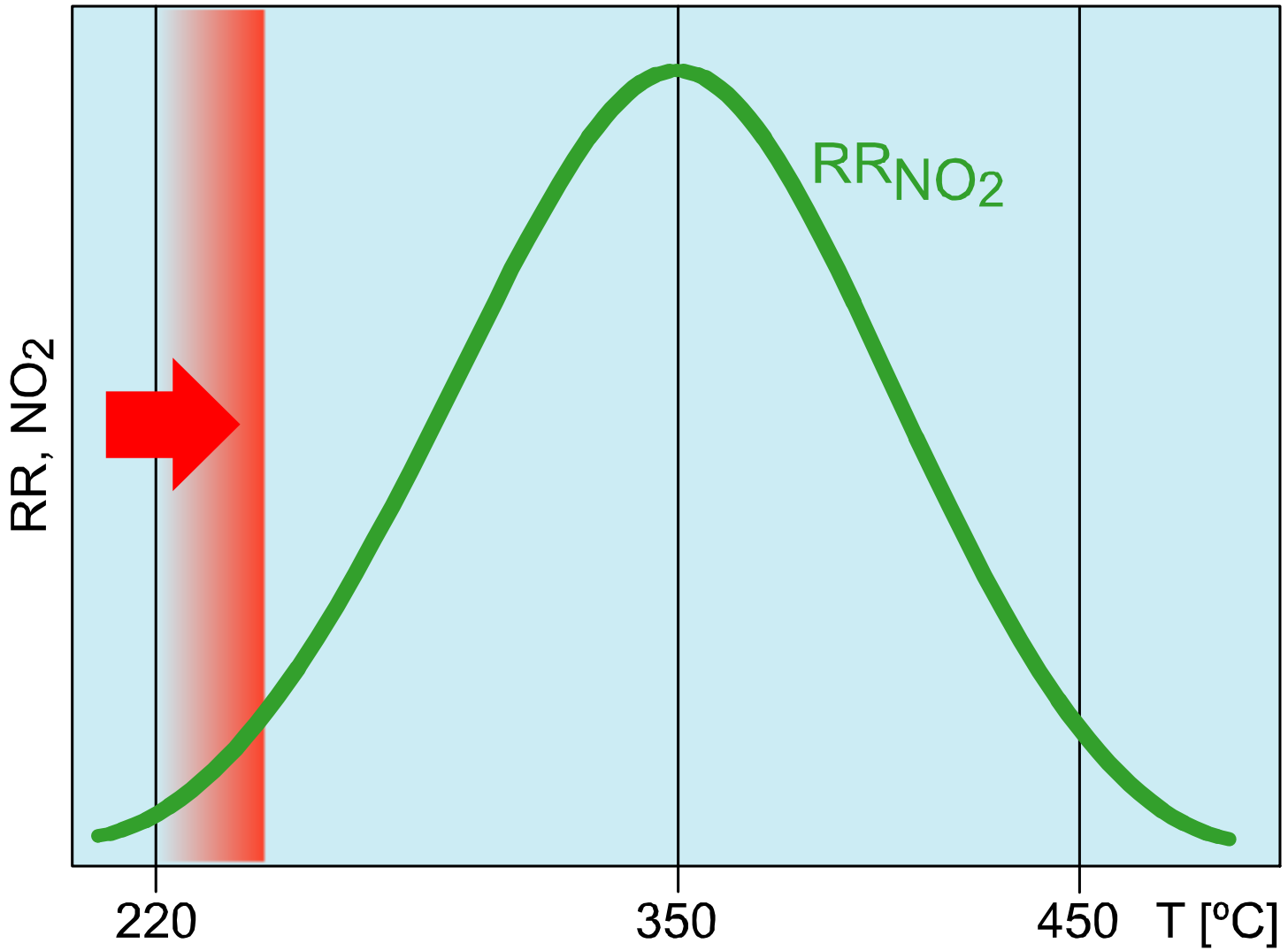
CRT : Continuous Regeneration by NO_2



CRT-Filter-System with DOC



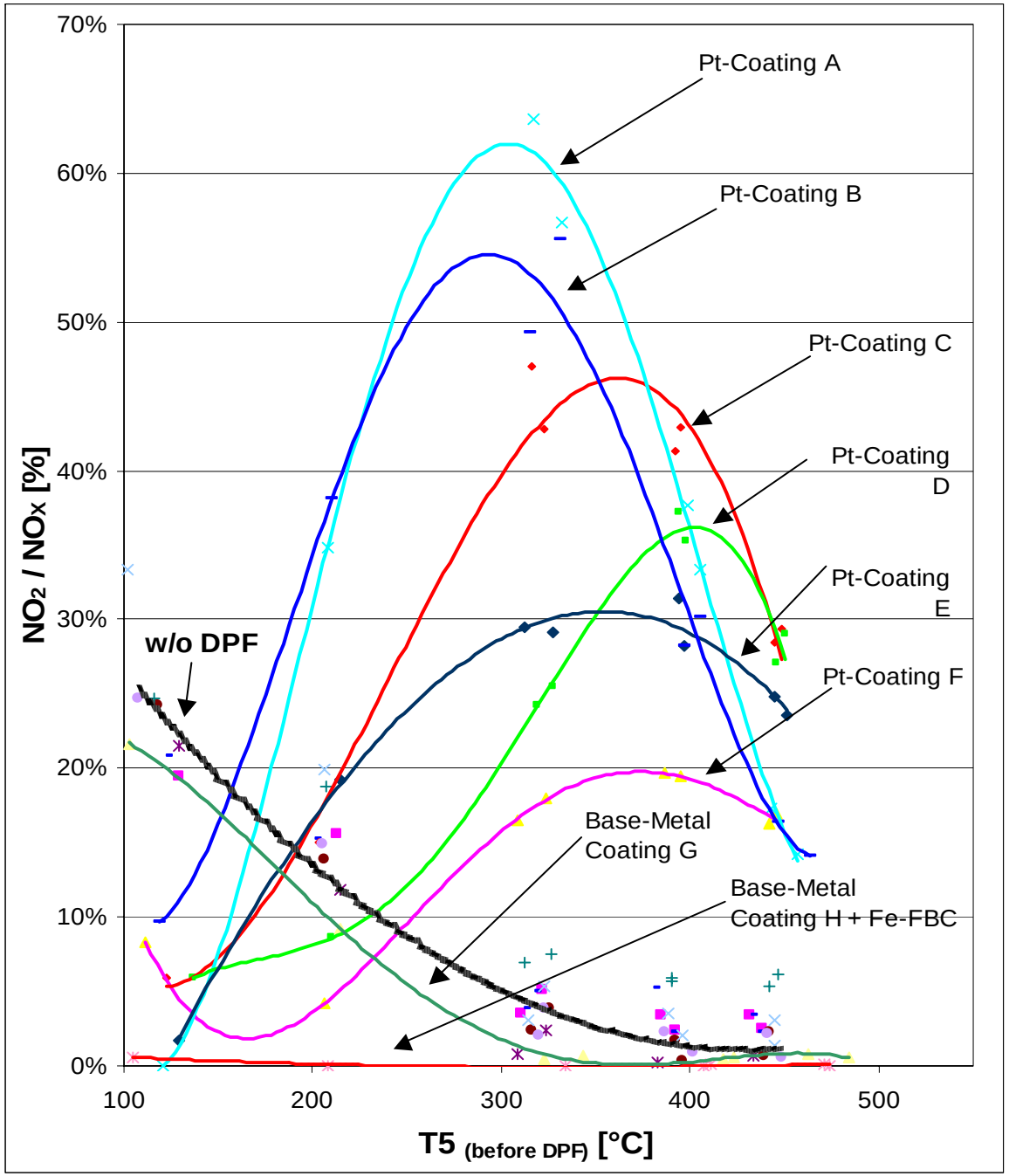
CRT-Regeneration Window



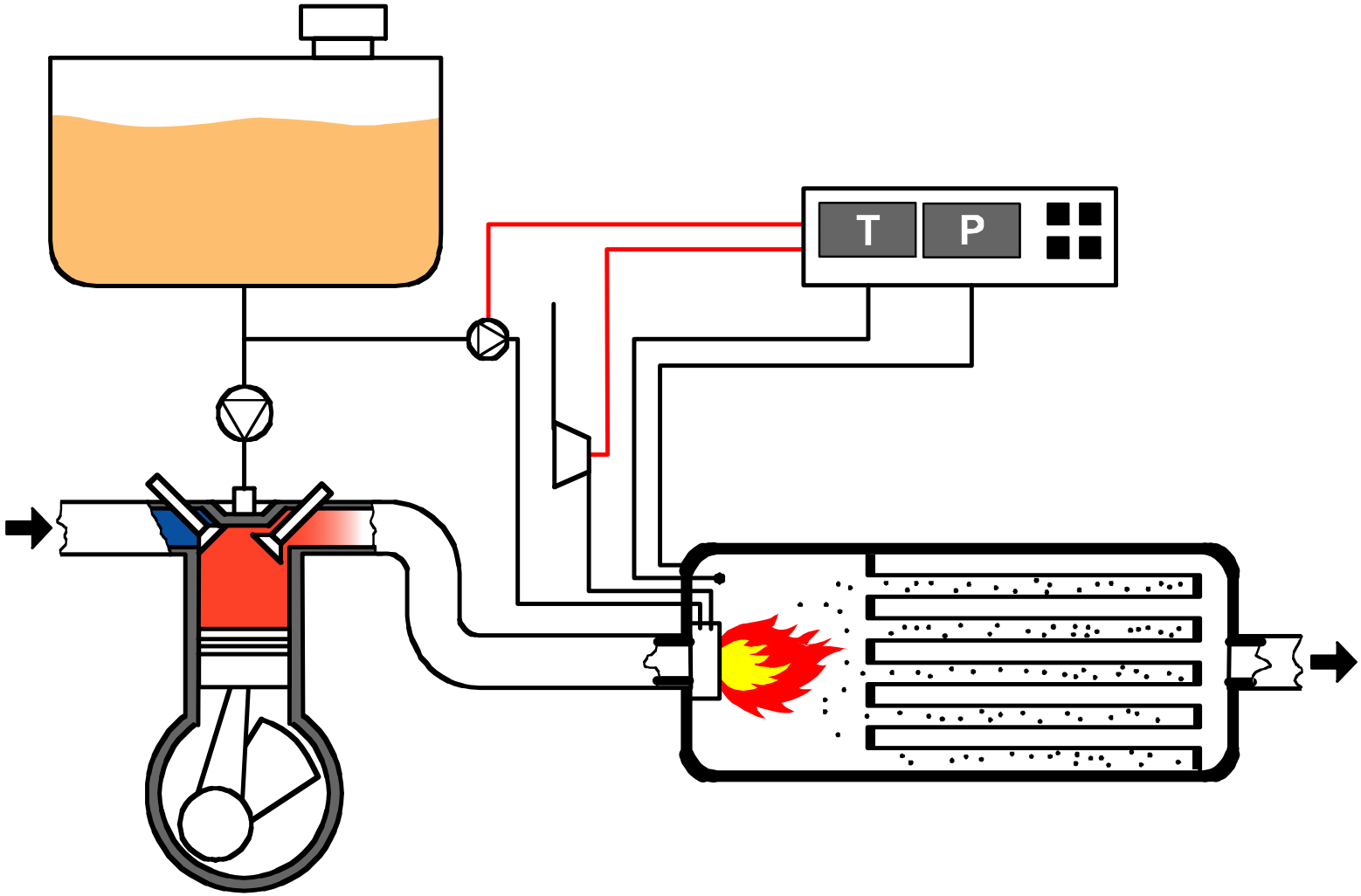
Emission of NO_2

with catalytic coatings

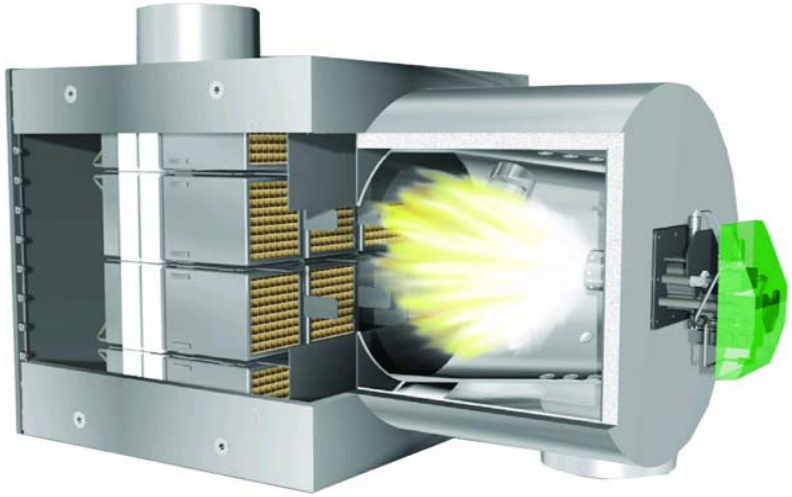
and NO_2-reduction with FBC



Full Flow Diesel Burner

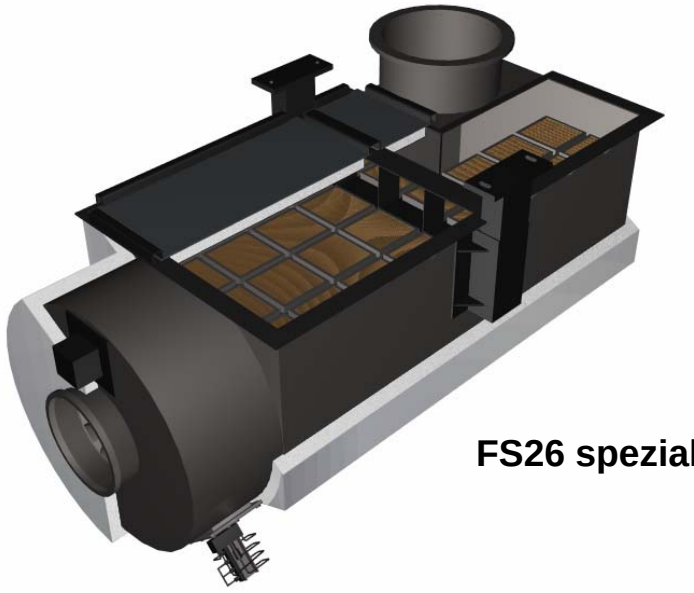


PFS for large engines in locomotives and ships



Standard Filtermodul

Restsauerstoff im Abgas:	> 8%
Heizleistungen:	30 – 400 kW
Druckluft > 5 bar:	20 Nm^3/h
Dieselkraftstoff:	3 – 40 l/h
Stromversorgung:	24 VDC



FS26 spezial

VERT-tested PFS after 2000 op.hrs

Number Count Efficiency PZAG is the Standard, Mass measurement PMAG is biased by condensation artefacts

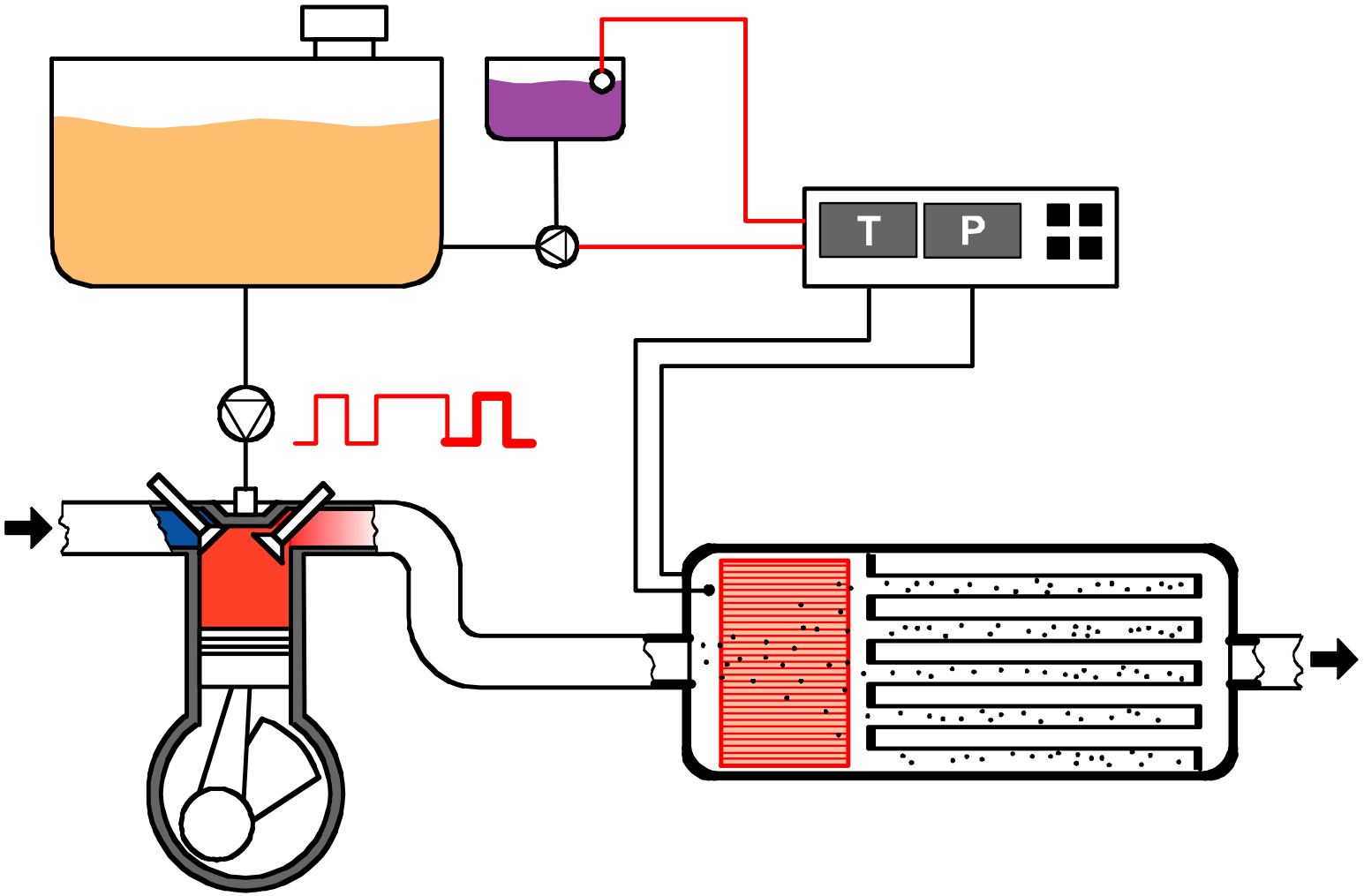
Manufacturer	Regeneration	PMAG	PZAG
		[%]	
ADASTRA	FBC	89.5	**99.351**
AIRMEEX	FBC	83.6	**99.973**
ARVINMERITOR	Full Flow Burner	91.0	**99.854**
ATH	Stand Still Burner	45.9	**99.998**
COMELA	Heat Storage with twin Filter Set	-382.9	**98.310**
DCL	Electric External	81.4	**99.999**
DINEX	Catalyzed	93.8	**99.906**
ECS (UNIKAT)	On Board Electric	91.0	**99.999**
ECS (UNIKAT)	Catalyzed	52.0	**99.955**

VERT-tested PFS

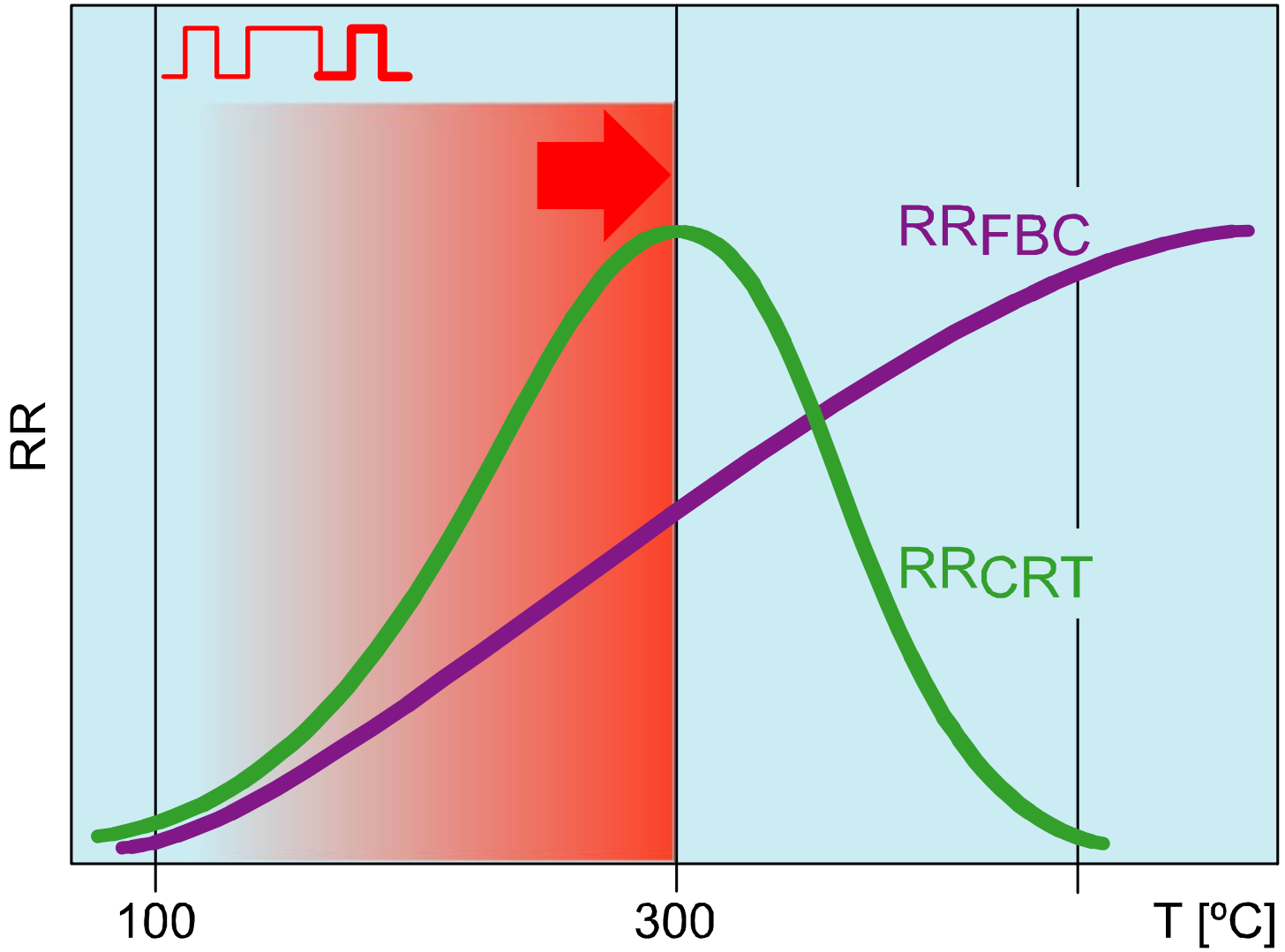
clear movement towards active PFS

Manufacturer	Regeneration	PMAG	PZAG
		[%]	
ENGELH. DPX1	Catalyzed	10.9	**99.255**
ENGELH. DPX2	Catalyzed	86.1	**99.772**
ETB	Onboard and Offborad Electric	61.6	**99.687**
GREENTOP	FBC and Catalyzed	94.4	**99.967**
HJS / DES	CRT	90.1	**96.412**
HUSS	Onboard and Offboard Electric	84.2	**99.392**
HUSS	Standstill Burner	55.9	**99.984**
JOHNSON M.	FBC	91.4	**99.552**
JOHNSON M.	CRT	-	**99.782**

PSA: Postinjection + FBC

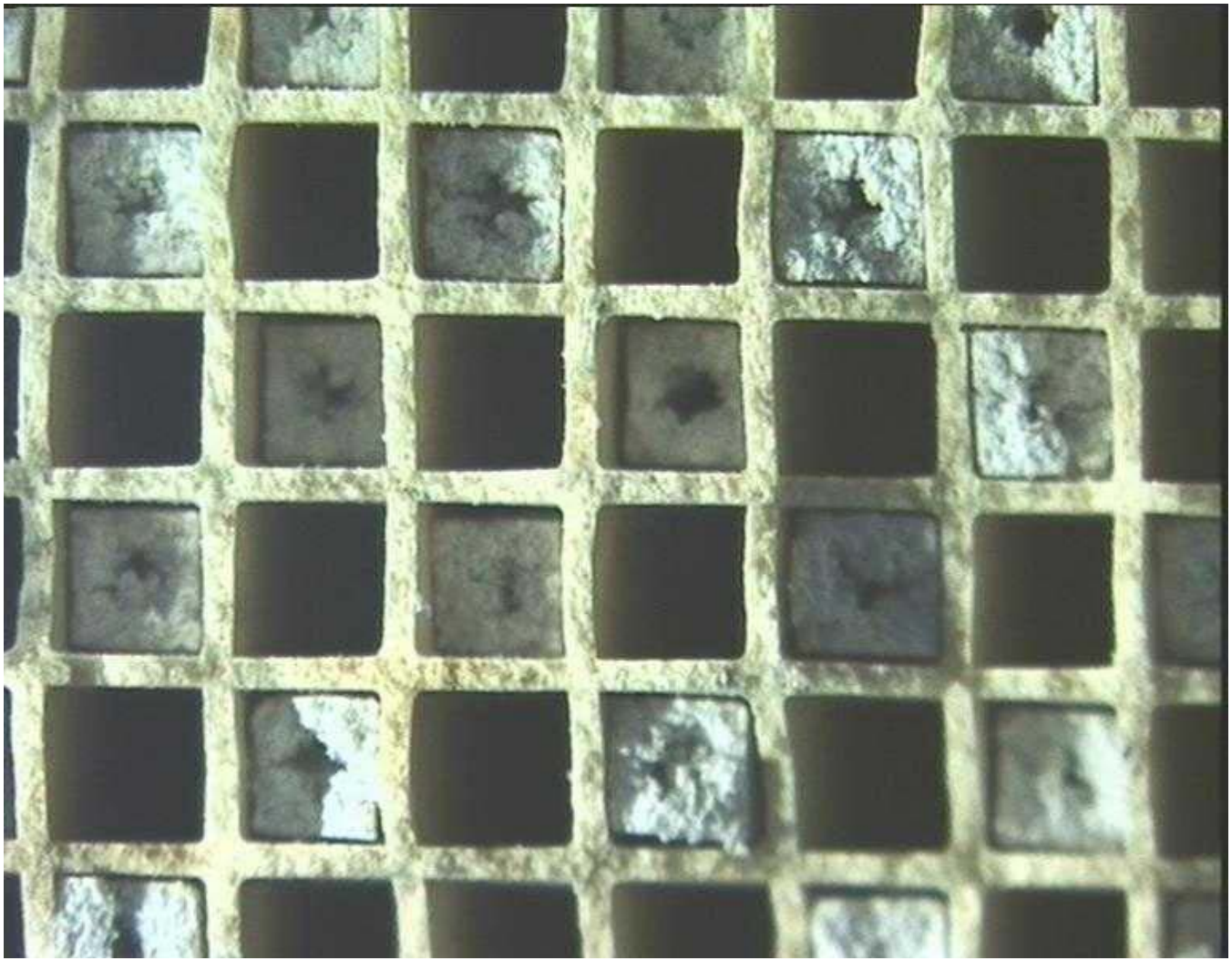


Late Postinjection + FBC + NO_2



Peugeot with FAP – 1.5 Mio ; total 3 Mio LDV successfully in operation !

Plugging of Filter Cells by Lube Oil Ashe



Filter-Cleaning from ash-deposits

automatic hermetically closed

Filter-System Selection

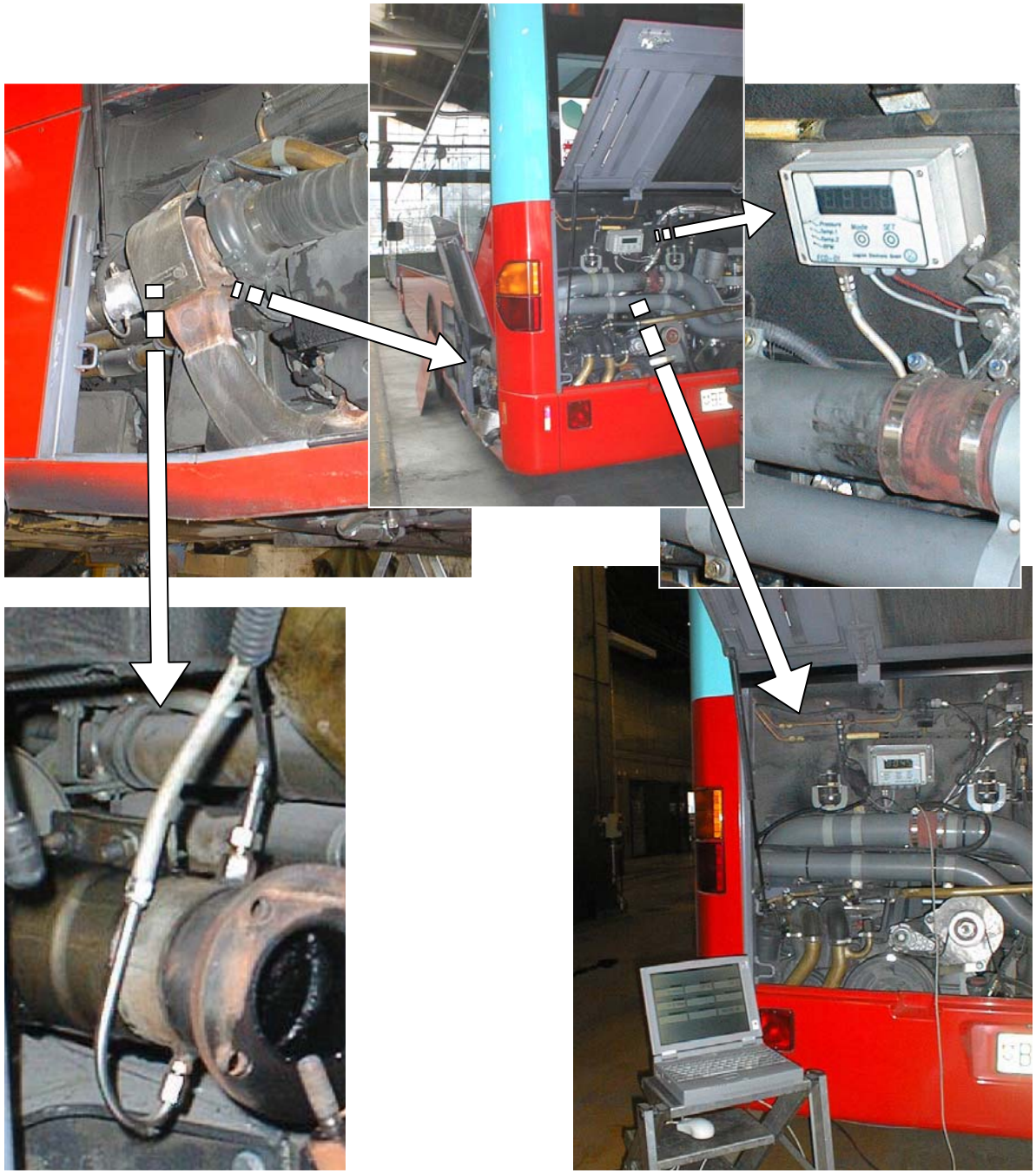
to select the appropriate PFS for a given application is the most difficult task – it is the retrofitter's expertise and responsibility

Tools

- **Datalogging prior to retrofitting**
- **Database of 2600 Retrofits**
- **Consulting by EPA's experts**
- **OBC and alarms**
- **low Ash Lubrication Oils**

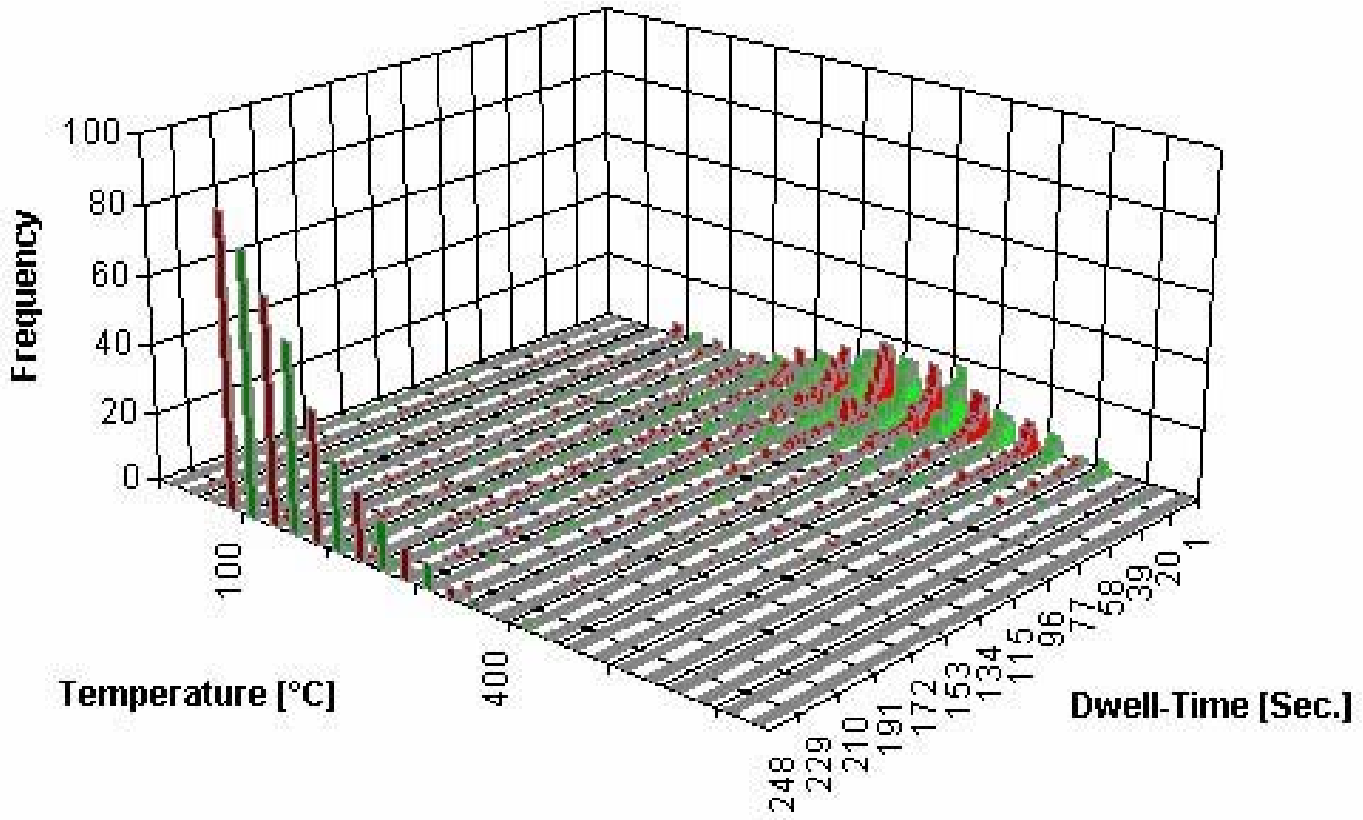
Each Retrofit Case is documented for Database
(Filter, Engines, Date, Backpressure, Filtration, Noise)

Datalogging



Episode Analysis on Thermal Dynamics

How long will a certain temperature level remain available for regeneration



Quality Control

VERT-Specifications
VERT-Verification Procedure
VERT-Filterlist – see www.buwal-umwelt.ch
Field Control 1 x per year documented
Maintenance Rules for Engine → Sticker
Manufacturers Reporting&Market Search

VERT specifications for particle trap systems
(1)

	New	2000 op. hours
▪ **Filtration efficiency** count - particle size range 20-300 nm	> 95%	> 95%
▪ **Filtration efficiency** EC mass concentration	> 90%	> 90%

▪ **Secondary emissions**: no relevant increase

▪ **No increase**

of limited emissions CO, HC, NOx and PM

VERT specifications for particle trap systems
(2)

- **Pressure loss** max. 200 mbar
- **On-road monitoring** with alarming + logging functions
- **Noise attenuation** equivalent to muffler
- **Durability:** Minimum 5,000 operation hours
- **Identification:** Flow direction marked
- **Safety:** compliance with legislation on safety of technical equipment
- **Diagnosis access** for exhaust gas sampling ahead of trap
- **Concept for cleaning and disposal**

VERT Filter Suitability Test

one filter system for one filter family of identical technology

- **VFT1:** Filtration Test up to max space velocity
  new, loaded, regenerated – during regeneration
- **VSET:** Secondary Emissions Test
- **VFT2:** 2000 Operation Hours Field Test
- **VFT3:** Repetition of VFT1 after Field Test

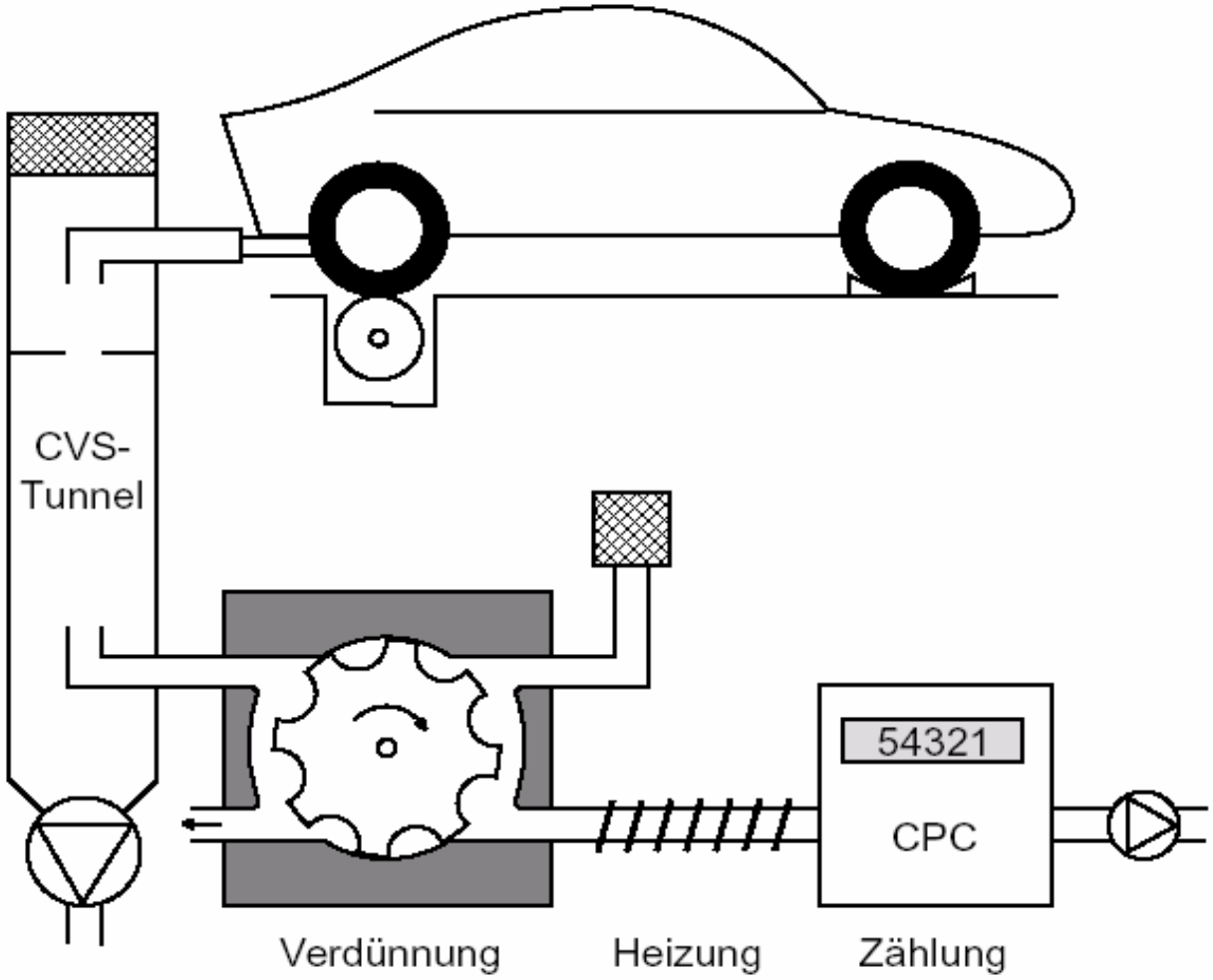
VERT-Approval → BUWAL Filterlist

VERT-Approval is lost at a Failure Level > 5 % pa

AFHB

PMP

Solid Particle Counting 20-300 nm



Objectives

- Test filtration properties
  - with respect to Nanoparticles 20-300 nm
  - for the new, loaded, aged filter
  - under worst case conditions
  - regarding space velocity and temperature
  - during extreme transients
  - during regenerations
- Test regeneration system
- Test gaseous emissions
- Test secondary emissions
- Test system reliability during 2000 hours in application
- Test functionality in application
- Test on board contols

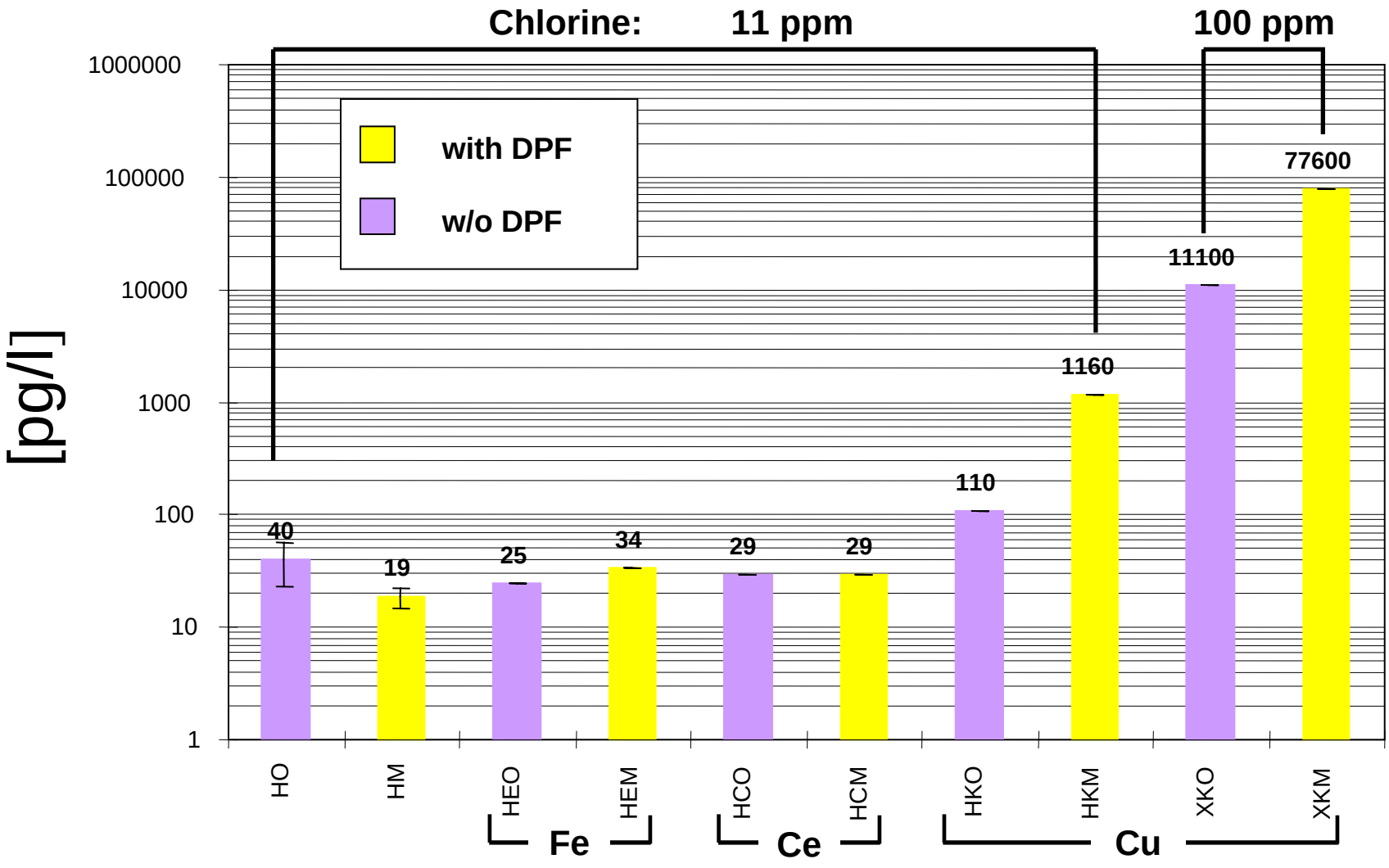
AFHB

What is measured during VERT-Tests

- Particle Properties:
  size, number, surface, EC/OC, PM-Mass
- limited gases: NOx, HC, CO and O2
- NO2 hot
- PAH, Nitro-PAH, VOC, Aldehydes
- Dioxines, Furanes
- Filter: backpressure, temperature up/down
- engine parameters: fuel consumption etc.
- noise

Measurements during steady state and transient conditions

Formation of Dioxins
in a catalytic active Particle Filter



VERT FILTER LIST

Tested and approved Particle-Trap-Systems for retrofitting Diesel Engines

accepted by

BUWAL, SUVA, TBG, AUVA, TRGS, UBA, MSHA, DEEP, CONAMA-CHILE, DTI-DANMARK

suvaPro
Swiss National Accident Insurance Organization

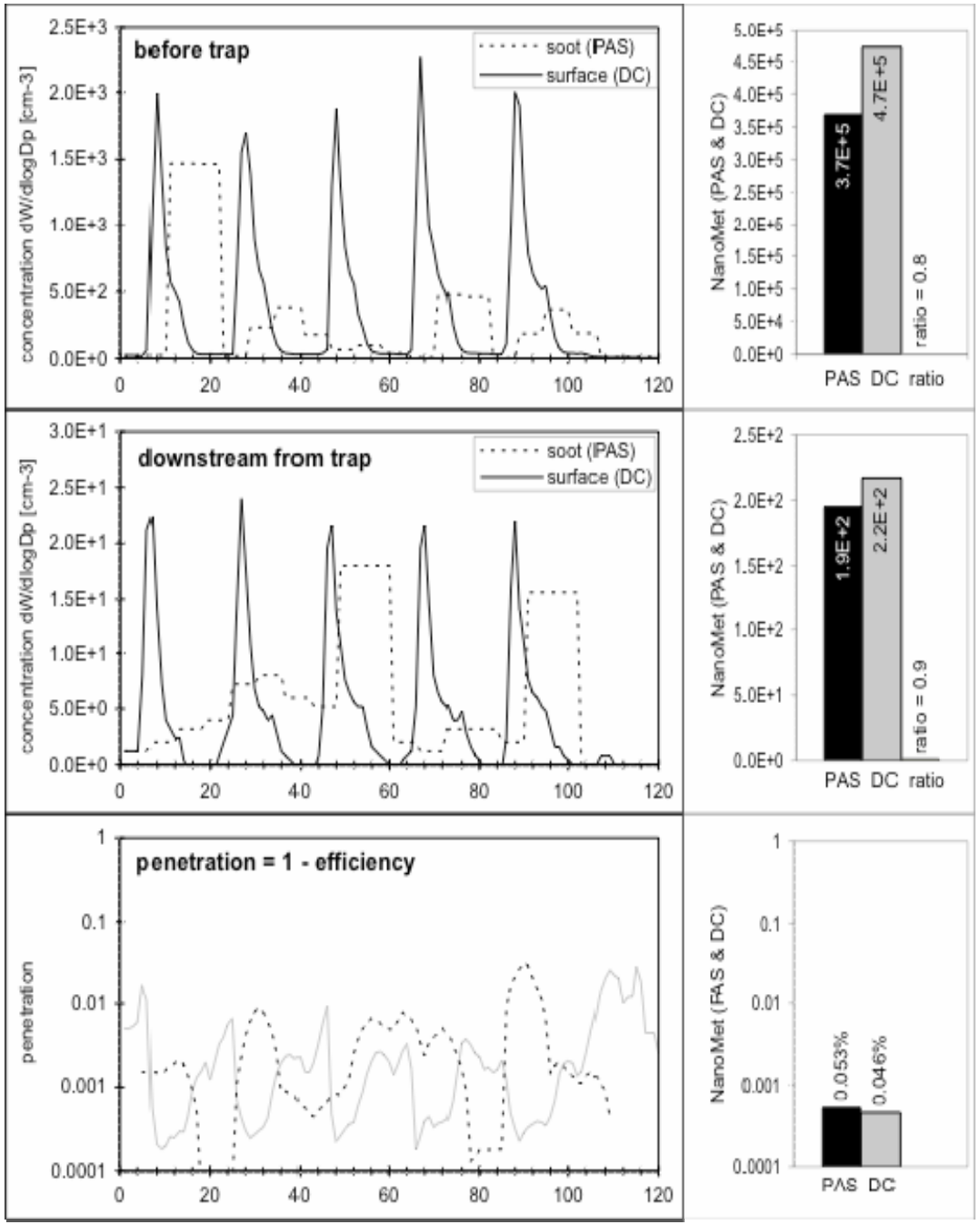
http://www.umwelt-schweiz.ch/buwal/eng/fachgebiete

Field Control

In-Compliance Test under Field Conditions

DPF Efficiency by Snap-Acceleration

today opacity → tomorrow number count



A portable Diffusion Size Classifier

M. Fierz, P. Steigmeier and H. Burtscher

University of Applied Sciences Northwestern Switzerland, 5210 Windisch

martin.fierz@fhnw.ch, heinz.burtscher@fhnw.ch, www.iast.ch

Introduction

Many state-of-the-art aerosol measurement instruments of today are large, heavy and expensive; and therefore not well suited for field measurements. We have built a diffusion size classifier (DiSC), which trades the accuracy and size distribution information of the larger instruments against simplicity and portability. DiSC is a simple modification of the well-known diffusion charger (DC).

Construction

The diffusion size classifier works as follows (see Fig. 1):

Aerosol is first charged in a unipolar diffusion charger, then it passes through 3 measurement stages:

- The induction stage, which is simply a Faraday cage through which the aerosol passes unhindered. During a rapid concentration change, a current is induced in both this stage and the diffusion stage.
- The diffusion stage, which consists of a number of stainless steel grids, where smaller particles are deposited by diffusion
- The filter stage, where all remaining particles are collected on a filter mounted in a Faraday cage

Sensitive current amplifiers measure the 3 currents I, D, and F (for the induction, diffusion and filter stage, respectively). For rapidly changing concentrations, the diffusion current D can be

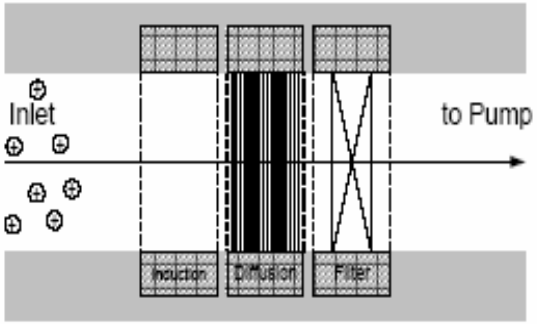
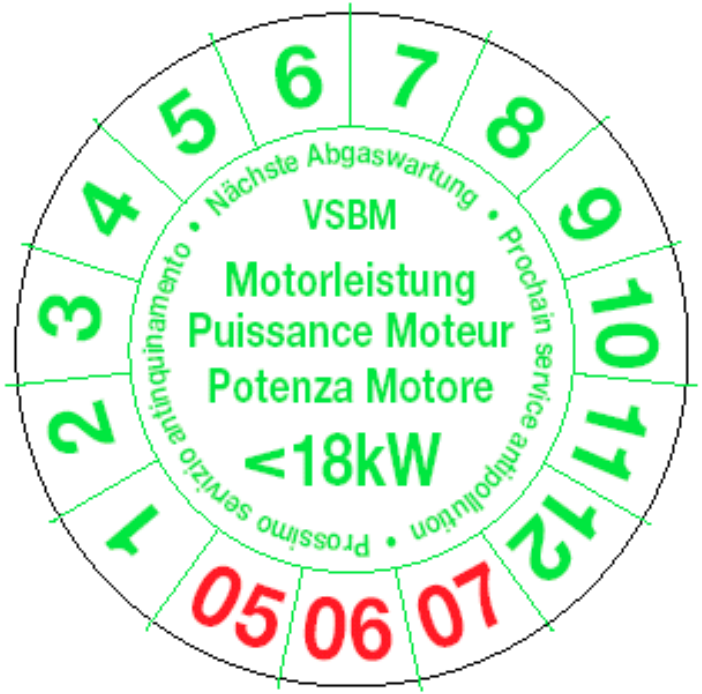
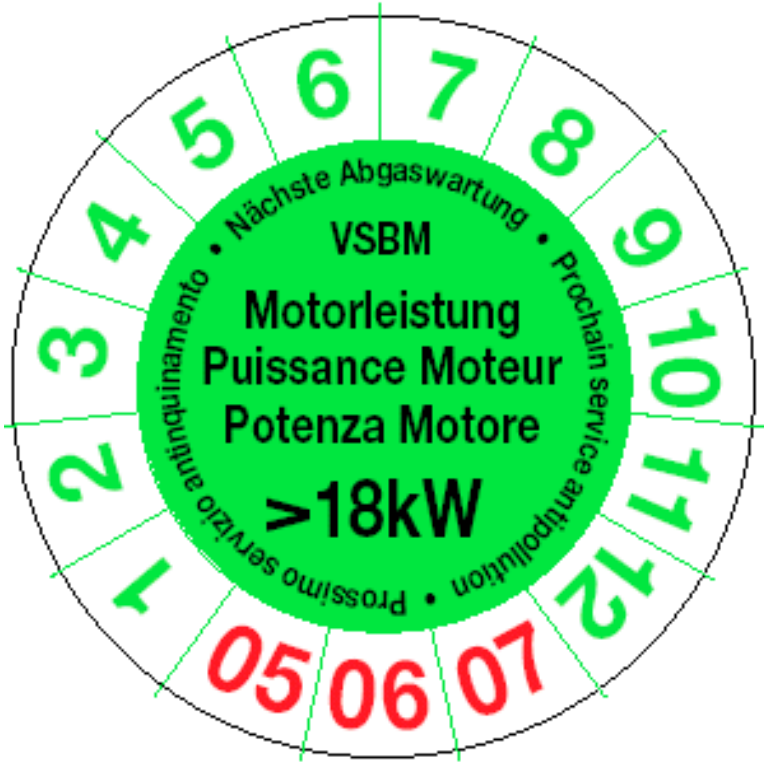


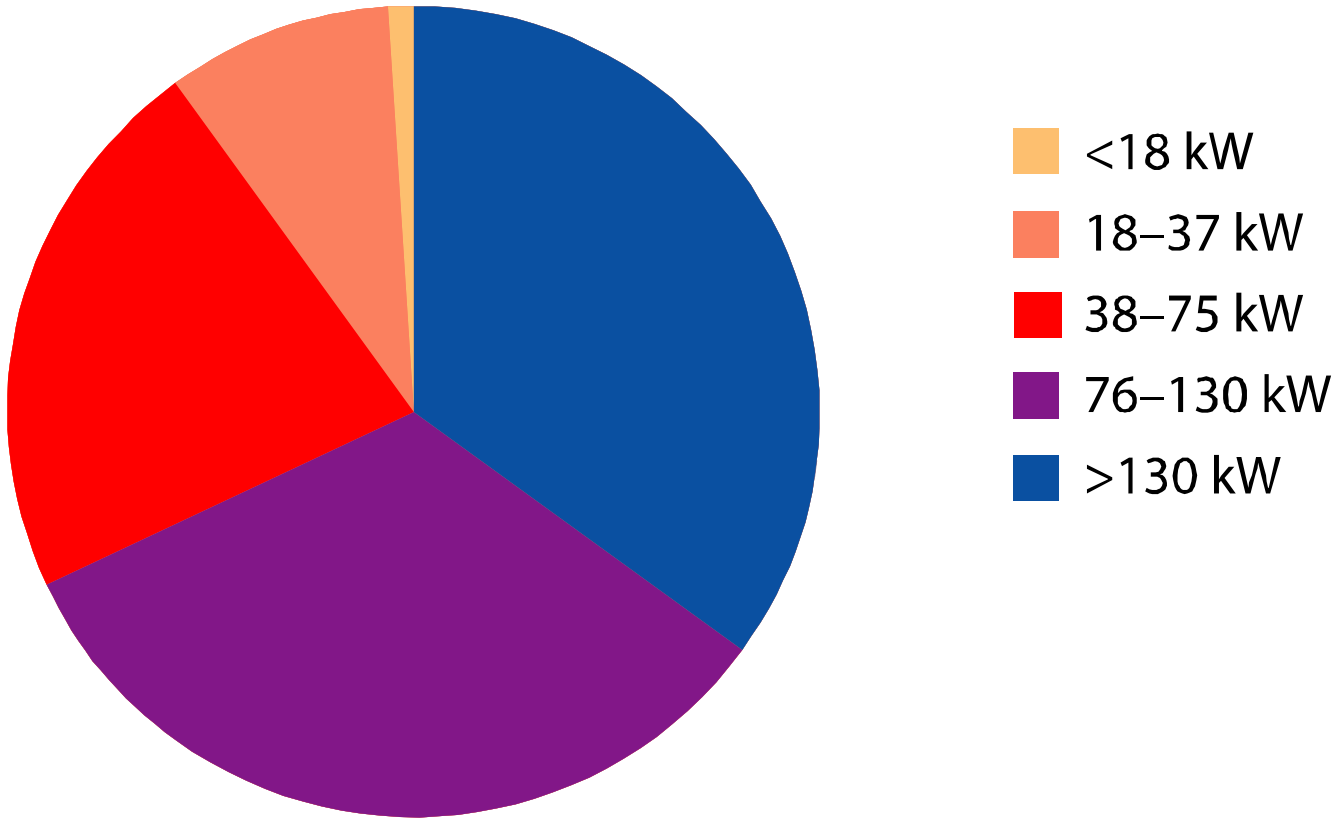
Figure 1: construction of the diffusion size classifier.

Figure 2: The diffusion size classifier with a PDA

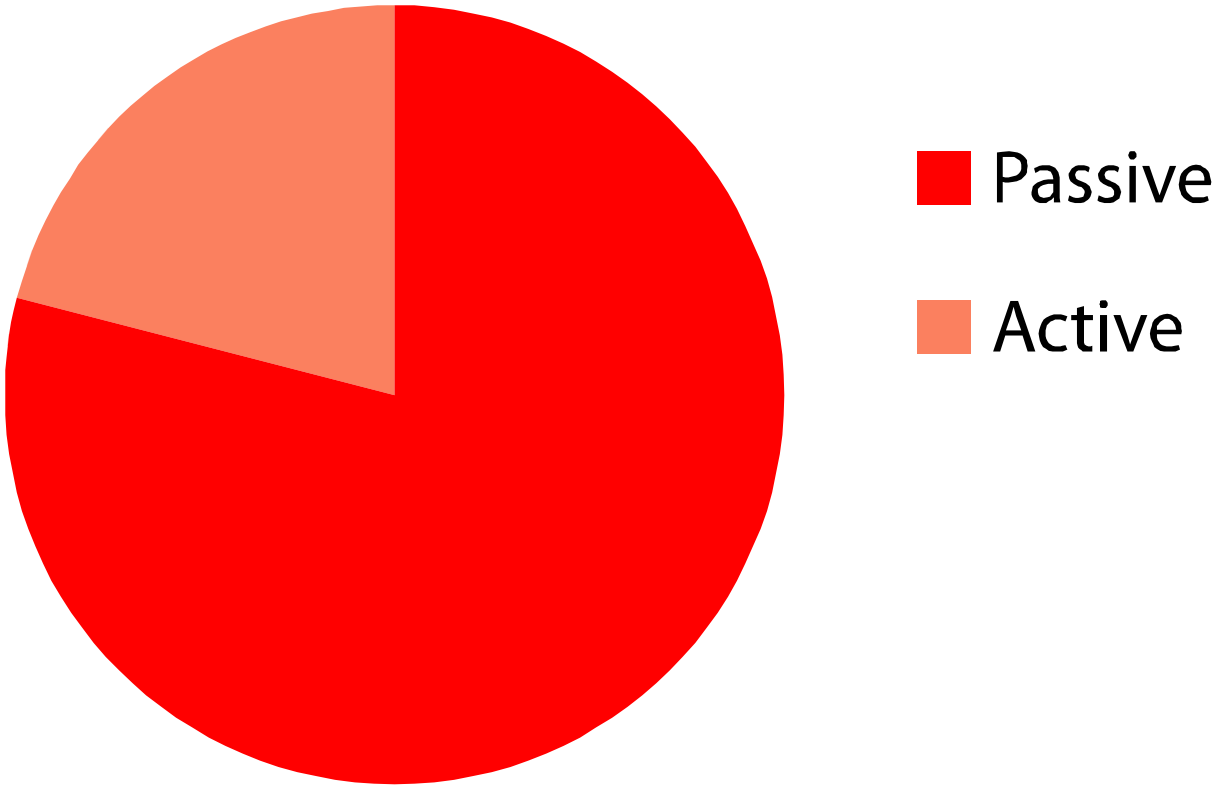
Maintenance Sticker for Engines < 18 kW	Emission Sticker for Engines > 18 kW
	

PFS Retrofit on 9000 Construction Machines

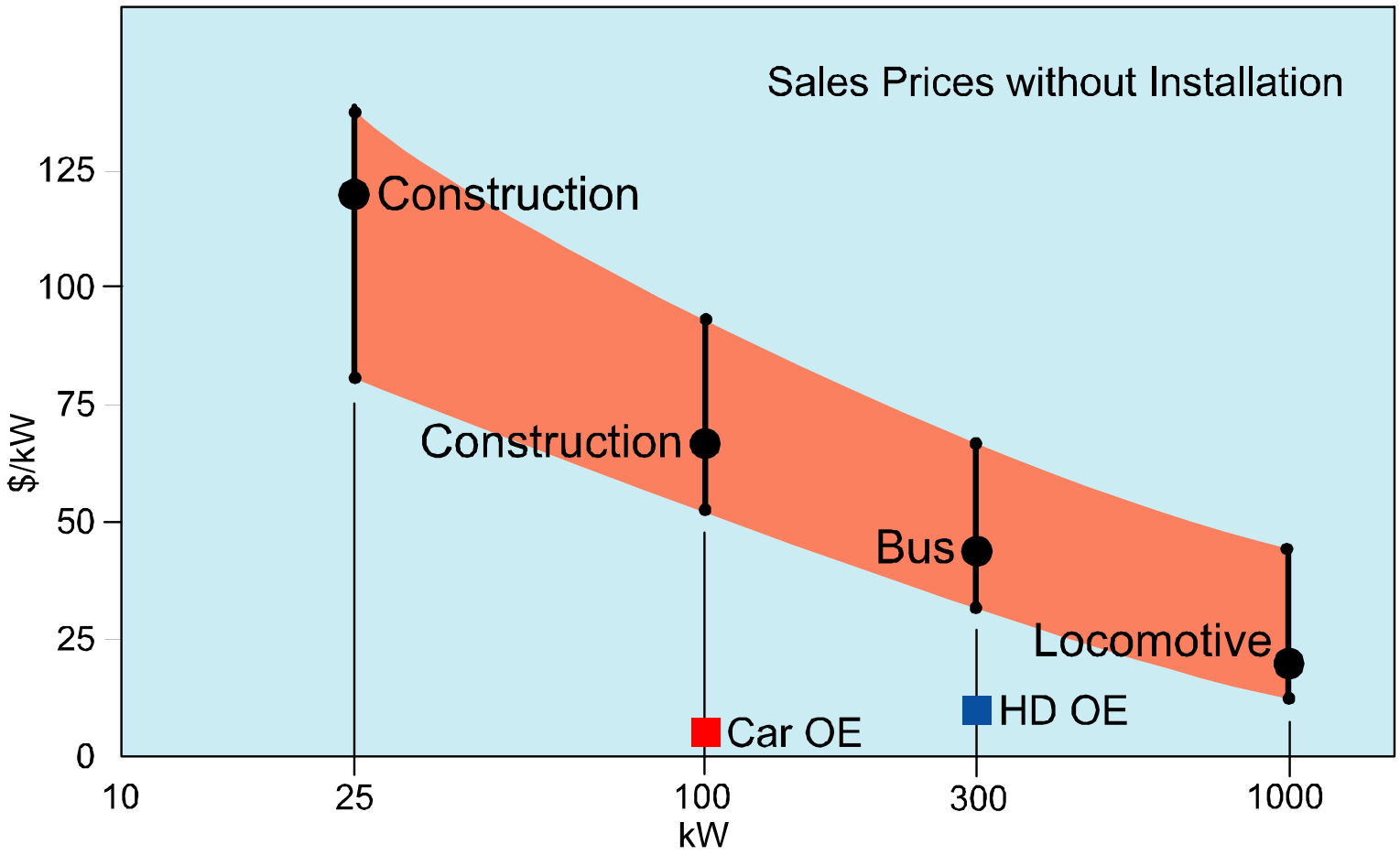
700 Buses, 300 Locomotives 500 Fork Lifts,Tucks and ...



Share of active Regeneration Systems is fast growing



Cost is still high but coming down by Competition and growing Volume



Reliability of PFS in Switzerland

- 1990: 230 Filters installed in Buses
  Failure rate probably 10 % pa

- 2000: 2400 PFS in Operation, > 6% Failures per year
  Failure rate > 6 % →
  Measures: 2000 h endurance, electronic OBC

- **2004:** **> 10'000 PFS in Operation**
  Failures 2-3 % per year
  > 1'000'000 km with Trucks and Buses
  > 10'000 op.hrs with Construction Machines
  > 30'000 op-hrs on a Ferry Boat

Failure Target: < 1% pa

Responsibilities

- **Authority**
  - Filtration & Emissions-Approval:VFT1, VSET
  - Reliablility-Approval: 2000 hrs. VFT2/3
- **Retrofitter**
  - Installation, Safety, Functionality, OBD
  - 2 Years Warranty
- **User**
  - Maintenance

Controls

- **Yearly Failure Statistics of Retrofitters**
  - Reporting to the EPA: installations, faillures

  → techn.modification if faillures exceed 3 %
- **Emission Test every 2 Years - documented**
  - Opacity measurement
  - Check of all emission-relating elements
- **Controls of local Authorities**
  - Fines up to 10 % of vehicle value

Summary and Conclusions (1)

- **PFS reduce particle emission by > 99%**
- **Careful homologation and selection is needed**
- **Filter OBC is needed**
- **PFS have long life – no filtration-deterioration**
- **PFS are available for all applications**
- **PFS-cost is acceptable**
- **Health Benefit to Cost is > 5**

Summary and Conclusions (2)

- **PFS-reliability is close to acceptable (2-3%)**
- **No risk for the engine life**
- **Backpressure limit set to 200 mbar**
- **Engine maintenance is very important**
- **Use of proper fuel and lube oil is important**
- **Filter retrofit can be applied to any Diesel Engine and Application !**

SUVA:Tunnel-Luftqualität 1998-2004