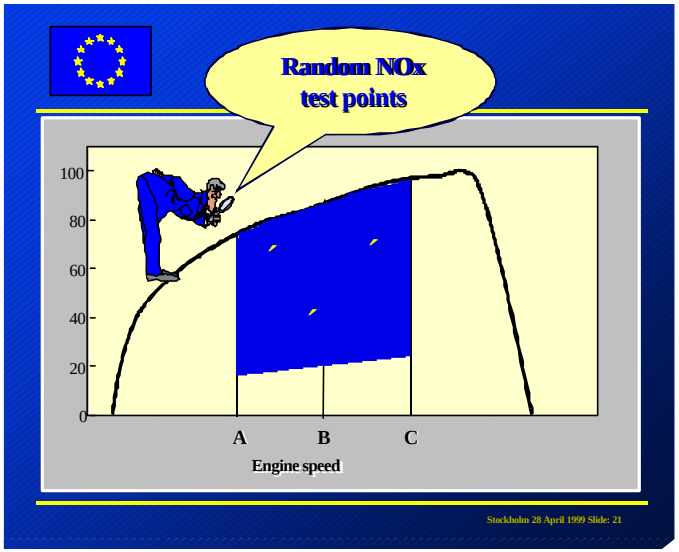
Off-Cycle Emissions



Stefan Rodt
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Examples:

- HDV
- LDV
- Motorcycle

Conclusions

Off cycle emissions from HDV

EURO II compared to EURO I, excessive NOx emissions between test speeds

EURO III compared to EURO II, excessive NOx emissions below control area

(cycle bypass)

The European Approach (HDV engines, 1999/96/EC)

-Non-homogeneous NO_x map permitted in the control area

-Linear interpolation of NO_x random points prevents unreasonable timing strategies within the control area

-Transient particulates determined indirectly through load response test

-For conventional diesel engines, gaseous emissions not determined under transient conditions

-Use of defeat device specifically prohibited in Euro 3 Directive

-Reporting of AECD and defeat device may be requested, but not specified

-Emissions refer to standard ambient conditions

-OBD and in-service testing planned for Euro 4 (2005)

Source: EPA, WHDC SG/FE Meeting, Brussels, 28/02/2000

DIRECTIVE 1999/96/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL (HDV)

2.28. ,**Defeat Device** means any element of engine or vehicle design which measures or senses vehicle speed, engine speed, gear used, temperature, intake pressure or any other parameter, with a view to activating, modulating delaying or deactivating the operation of any component of the emission control system so that the effectiveness of the emission control system is reduced under conditions encountered in normal vehicle use. Such a device will not be regarded as a defeat device if:

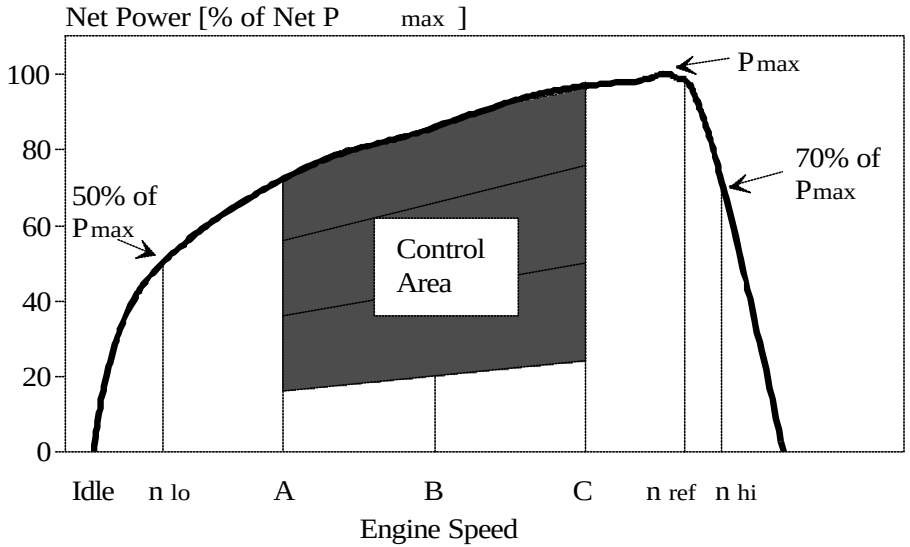
- the need for the device is justified temporarily to protect the engine against intermittent operating conditions that could lead to damage or failure and no other measures are applicable for the same purpose which do not reduce the effectiveness of the emission control system;

- the device operates only when needed during engine starting and/or warming-up and no other measures are applicable for the same purpose which do not reduce the effectiveness of the emission control system.

6.1.1. **The use of a defeat device and/or irrational emissions control strategy is forbidden**. If the type-approvalauthority suspects that a vehicle type utilises defeat device(s) and/or any irrational emission control strategy under certain operating conditions, upon request the manufacturer has to provide information on the operation and effect on emissions of the use of such devices and/or control strategy. Such information shall include a description of all emission control components, fuel control system logic including timing strategies and switch points during all modes of operation. These information should remain strictly confidential and not be attached to the documentation required in Annex I, section 3.

CYCLE BYPASS PREVENTION

ELEMENTS OF THE EU PROCEDURE – NOx CONTROL PROCEDURE



Speed A = n_{lo} + 25 %(n_{hi} - n_{lo})
Speed B = n_{lo} + 50 %(n_{hi} - n_{lo})
Speed C = n_{lo} + 75 %(n_{hi} - n_{lo})

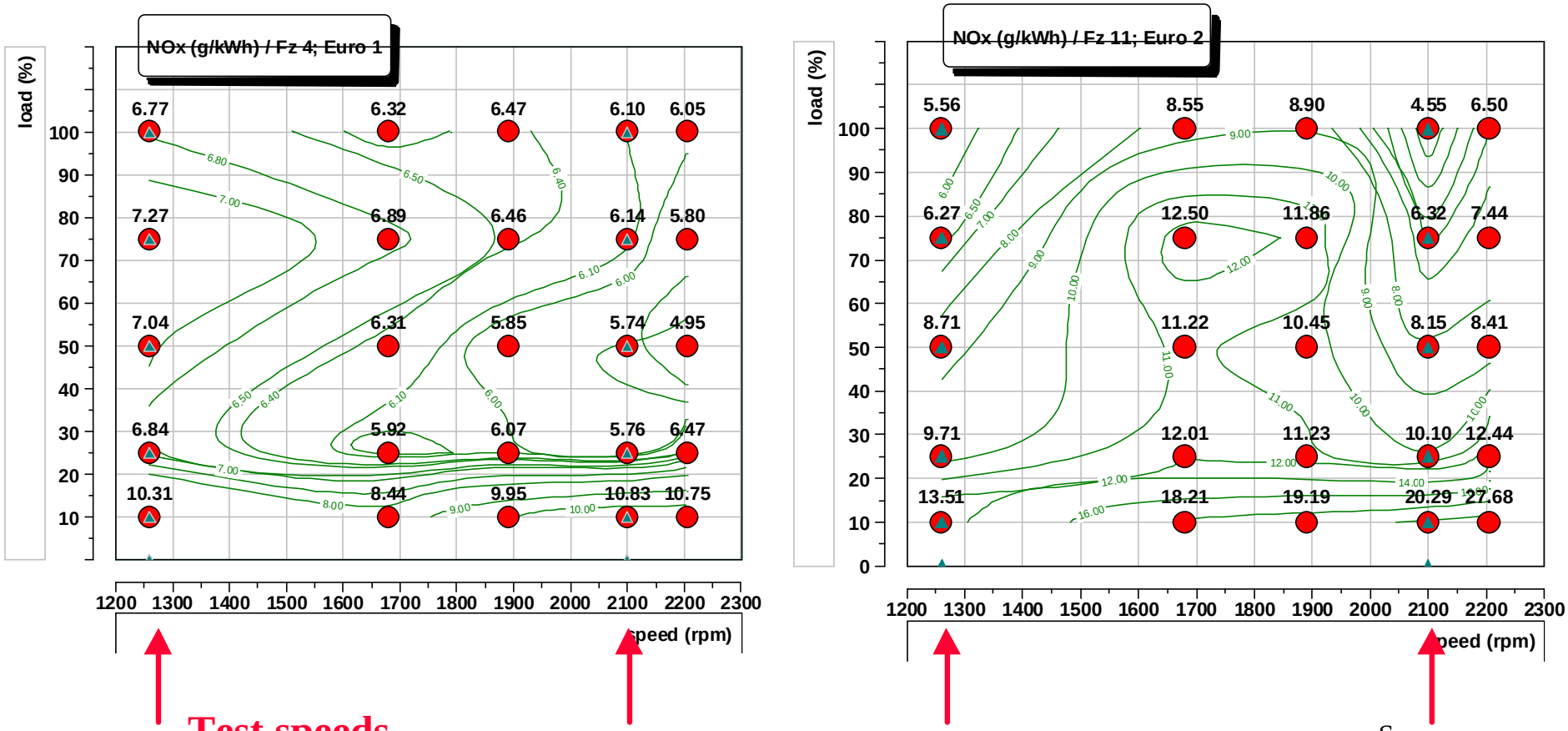
- Control area based on current EU driving patterns
- NO_x emission at the individual test modes can be adjusted according to the weighting factors to meet the limit over the test cycle
- Measured NO_x emission at any point within the control area must not exceed by more than 10 % the corresponding values interpolated from the adjacent test modes as measured during the test run

Source: EPA, WHDC SG/FE Meeting, Brussels, 28/02/2000

New findings on the emission factors of HDV in Europe

The emission factors were previously updated based on the measurement results for Euro 0 and Euro I engines according to the percentage limit value reductions of the subsequent limit value stages Euro II to Euro V. More recent studies indicate that the actual reduction rates of the new engine designs in actual operation most likely remain far behind earlier assumptions. Electronic injection systems in heavy-duty commercial vehicles – introduced as of the Euro II limit value – allow different injection strategies to be used in the various ranges of the engine map. Recent studies have shown that Euro II engines are deliberately optimised outside of the speeds driven in the type approval testing cycle to improve the specific consumption (cycle bypass). In return, this leads to a considerable increase in nitrogen oxide emissions. The NOx emission factors for heavy-duty vehicles must therefore be corrected upward to a considerable degree.

Heavy duty engines: comparison between EURO I and EURO II
NOx engine maps of two consecutive engine types



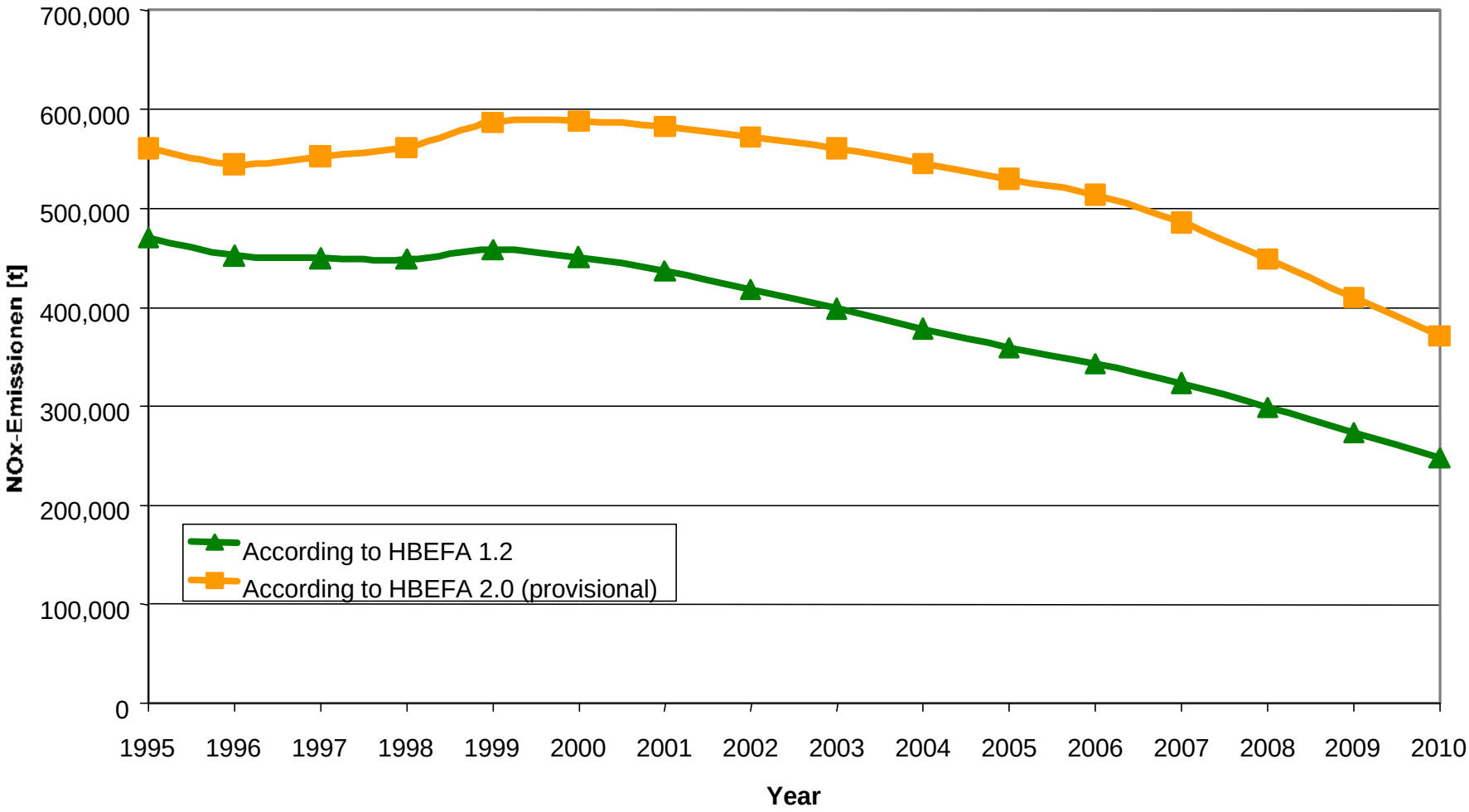
Source:
RWTÜV 2002

The average emission factors in g/km for NOx of HDV for the reference year 2003 are shown in the following table acoording to the handbook of emission factors HBEFA 1.2 and the new version HBEFA 2.0 (to be issued in autumn 2003) differenciated by emission classes.

Emission class	HBEFA 1.2 in g/km	HBEFA 2.0 in g/km	Difference in %
EURO I	6,18	7,12	+15,2%
EURO II	6,3	8,99	**+42,7%**
EURO III	4,5	7,5	**+67%**

Based on the updated emission factors the additional NOx emissions of HDV expressed in % are shown in the following table as a result of provisonal calculations (TREMOD/ Hausberger/ifeu). Although the share of EURO II vehicles in annual HDV milage is only 13% in 2010 the excessive NOx emissions amount to almost 50%, because the average emission factors are substantially higher not only for EURO II vehicles, but for EURO III vehicles as well, compared to earlier assumptions.

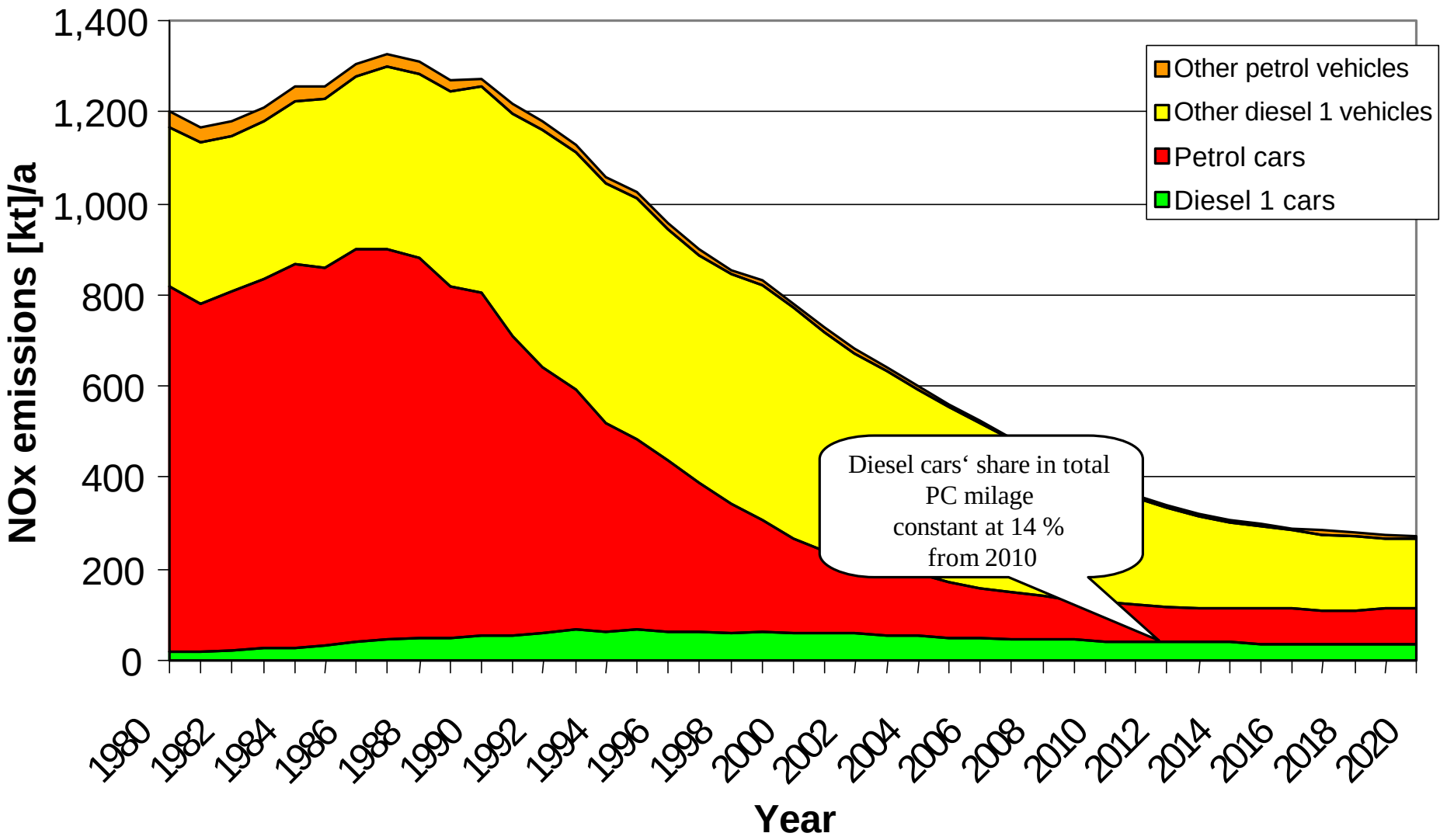
year	1995	1996	1997	1998	1999	2000	2001	2002
Exzessive NOx from HDV	19,2 %	20,4%	22,9%	25,2%	28,0%	30,6%	33,4%	36,9%
year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Exzessive NOx from HDV	40,6%	44,1%	47,5%	49,7%	50,2%	50,1%	49,9%	**49,5%**



NO_x emissions from HDV in Germany according to HBEFA 1.2 and HBEFA 2.0

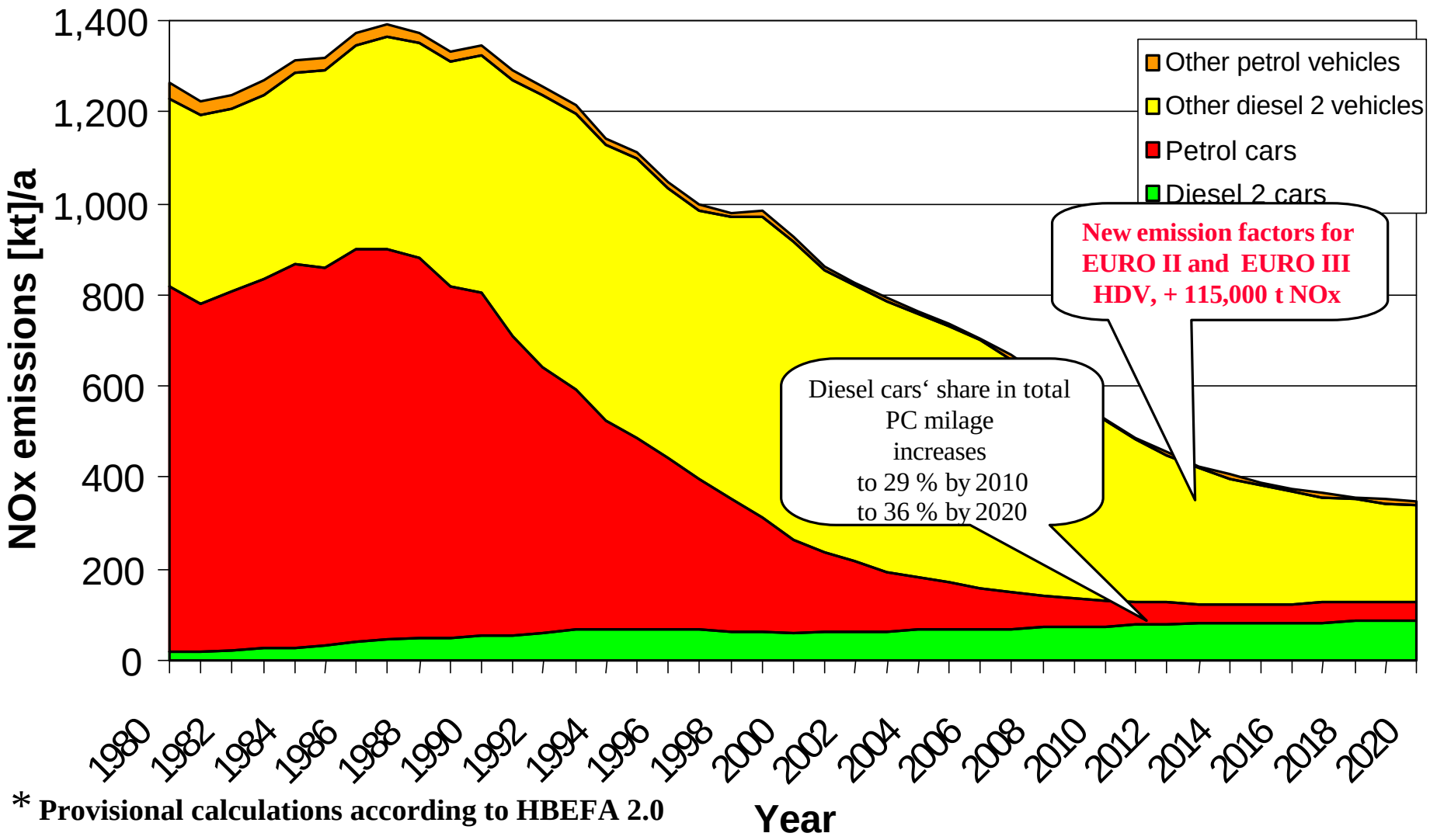
Federal Environmental Agency (UBA), Berlin
I 3.2 - Air Pollution Abatement and Energy Saving in the Transport Sector

NOx emissions (kt/a) in Germany – TREMOD 2.0 (08/2000)

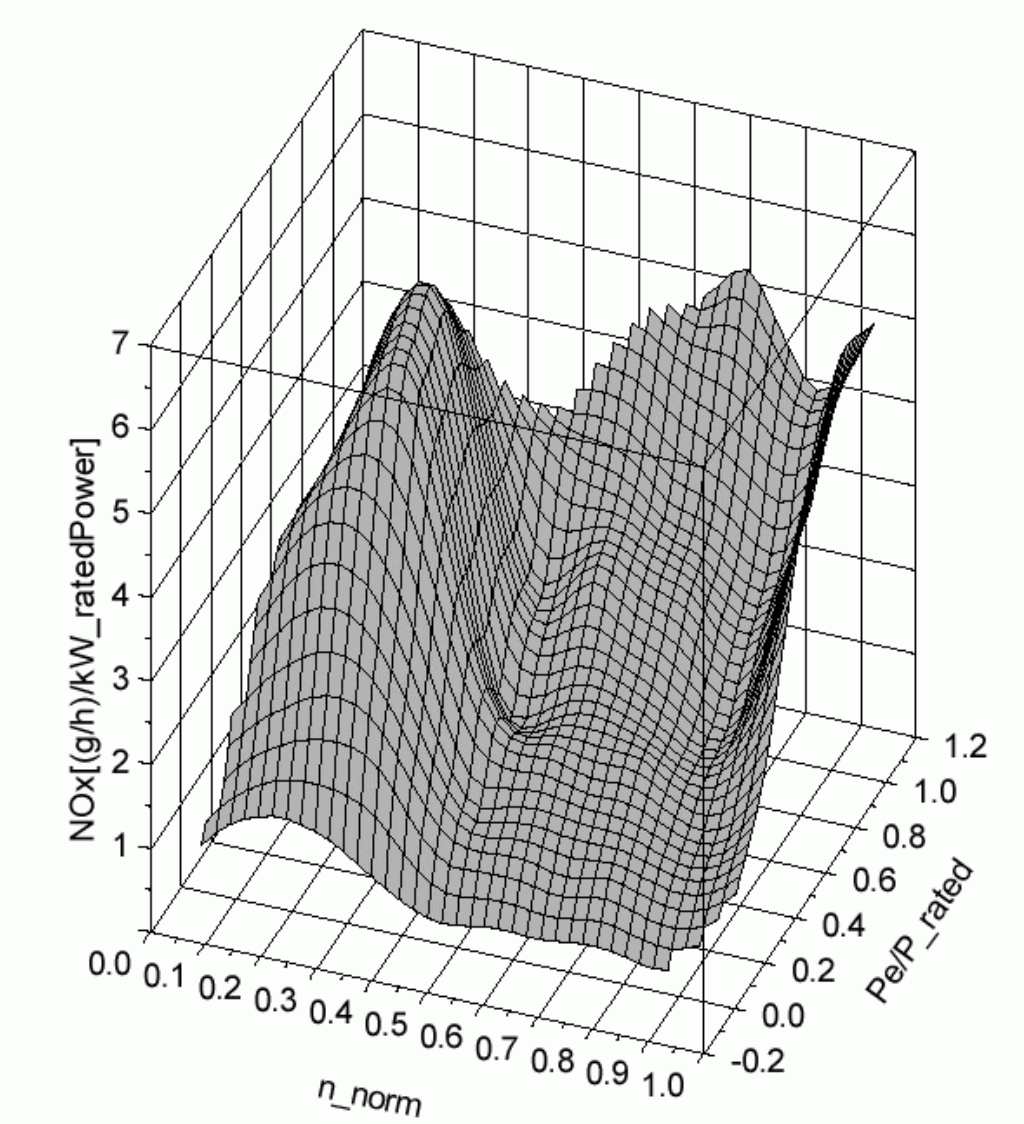


Federal Environmental Agency (UBA), Berlin
I 3.2 - Air Pollution Abatement and Energy Saving in the Transport Sector

NOx emissions (kt/a) in Germany – TREMOD 2.2 (03/2003)*



* Provisional calculations according to HBEFA 2.0

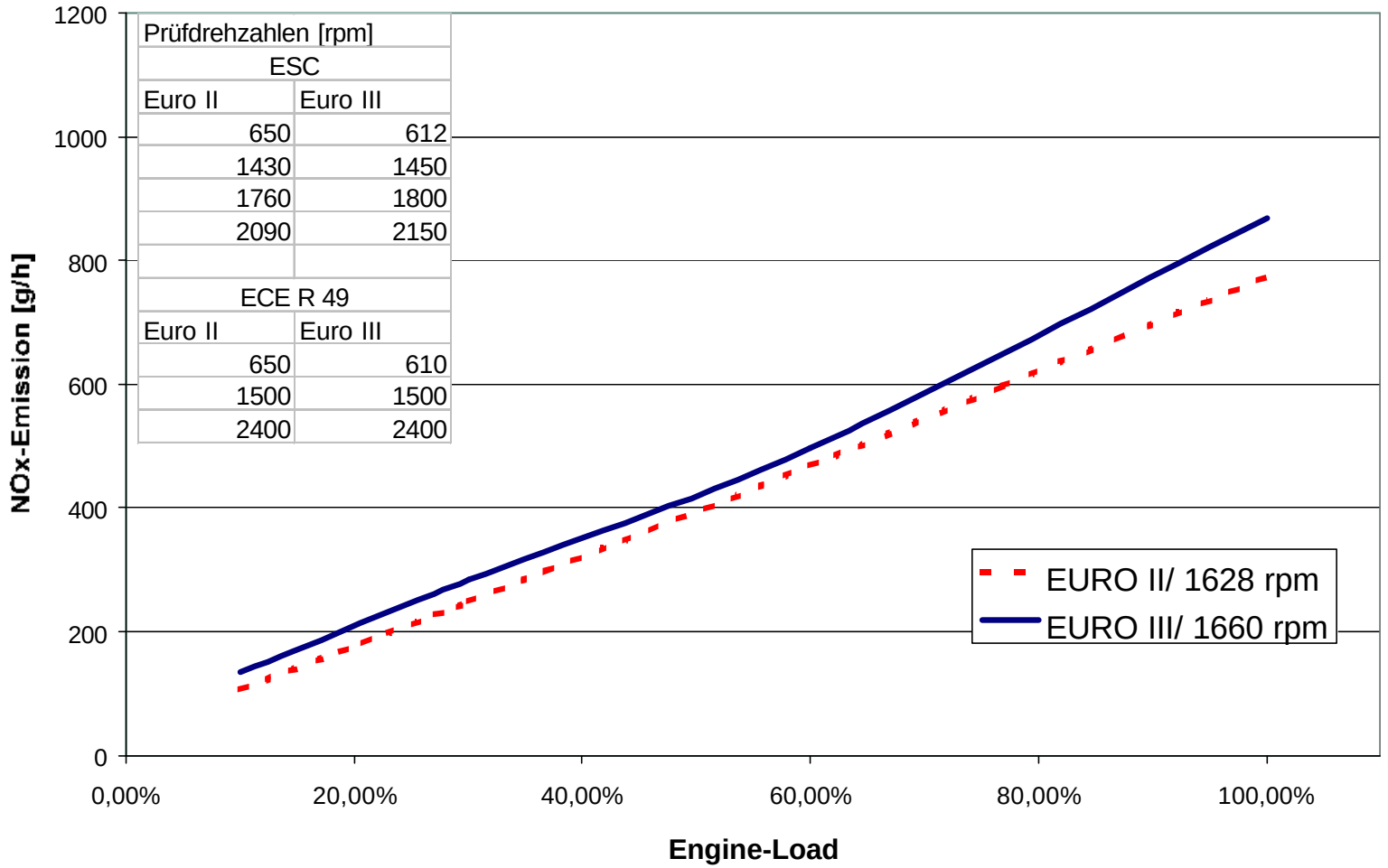


Normalized NOx map of a EURO III HDV engine

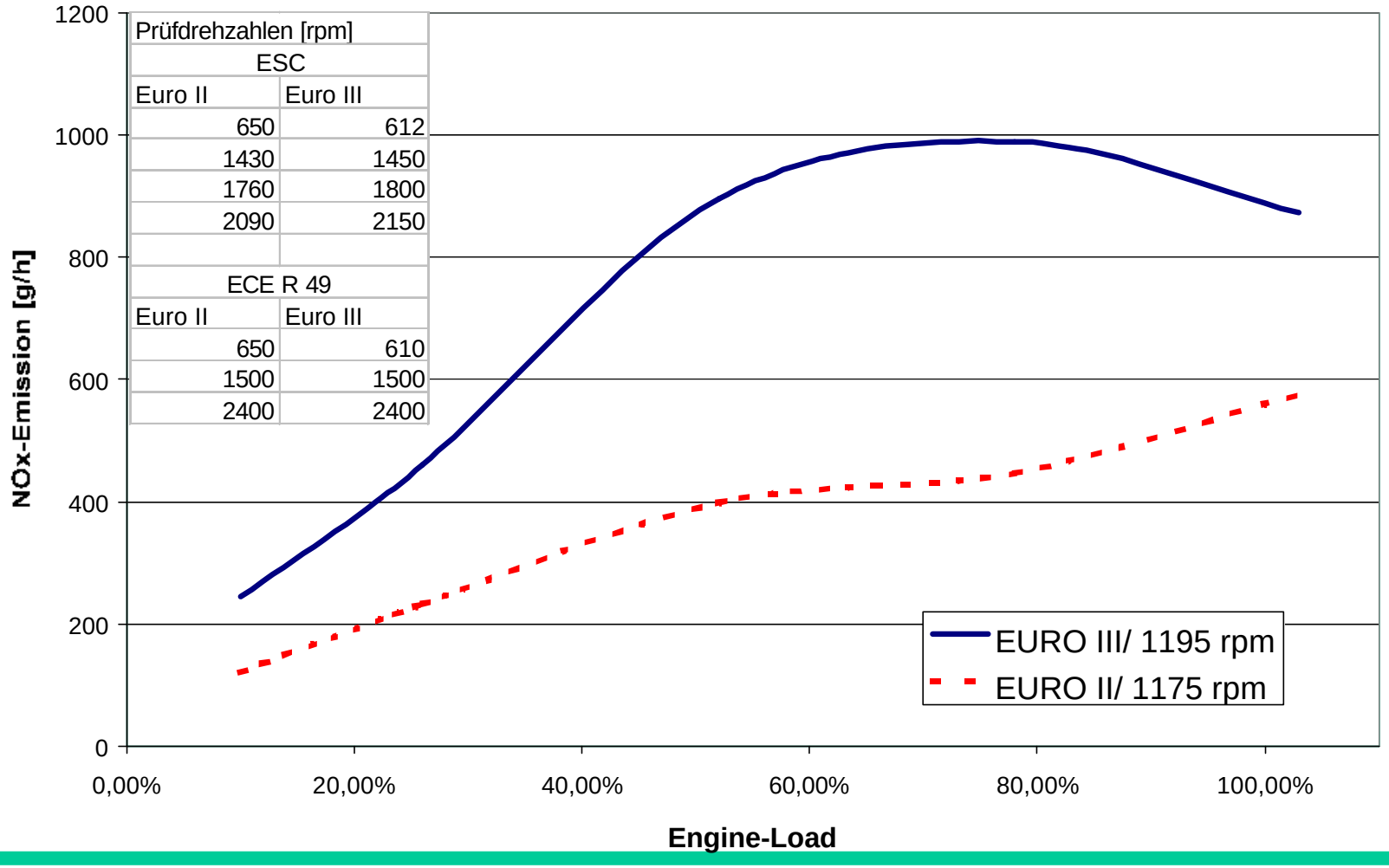
Sharp increase of NOx emissions outside the control area at low speeds.

Quelle: Hausberger et al.

Comparison of a EURO II engine and a EURO III engine (both 162 kW) NOx emission versus load in the medium test speed range (1628/1660 rpm)

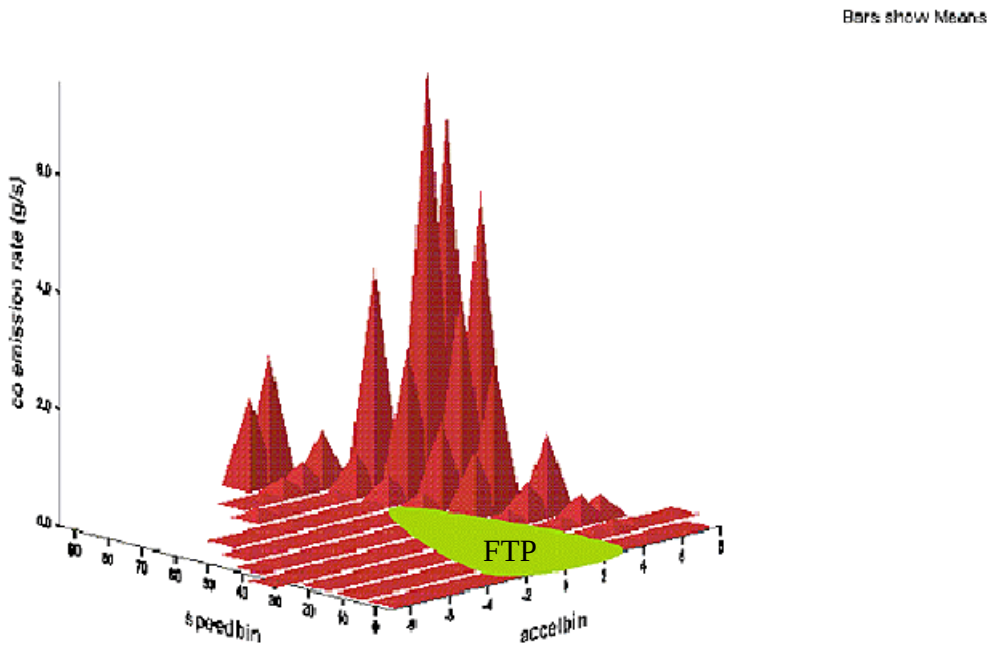


Comparison of a EURO II engine and a EURO III engine (both 162 kW) NOx emission outside test speed range (low speed, 1175/1195 rpm)



CO emissions of a HDV over vehicle speed and acceleration

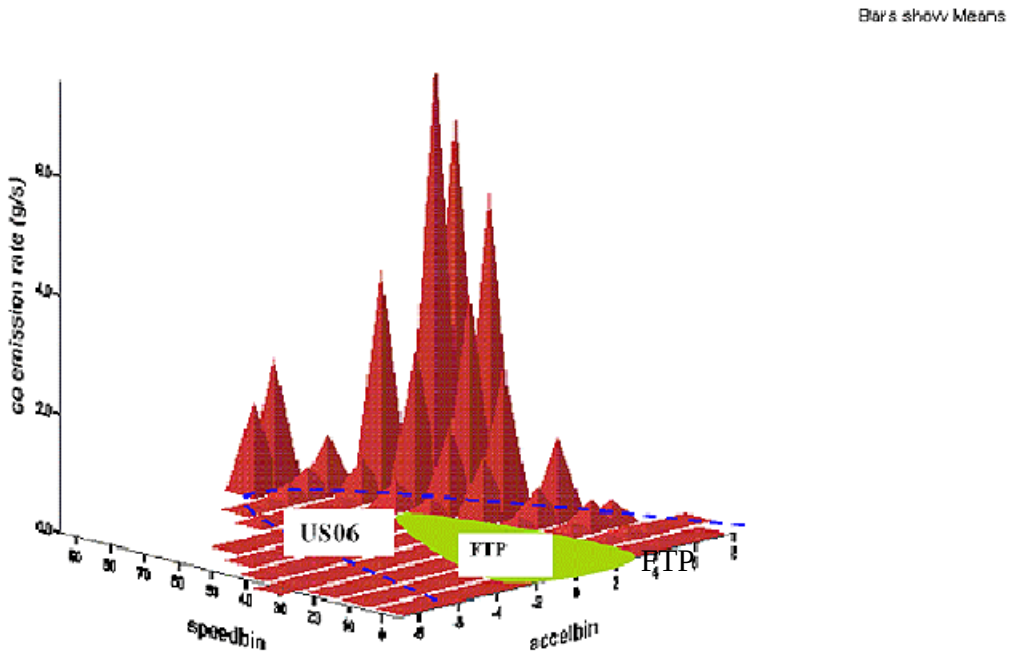
Real World vs. Lab



Source: U.S. EPA ,October 21, 2002

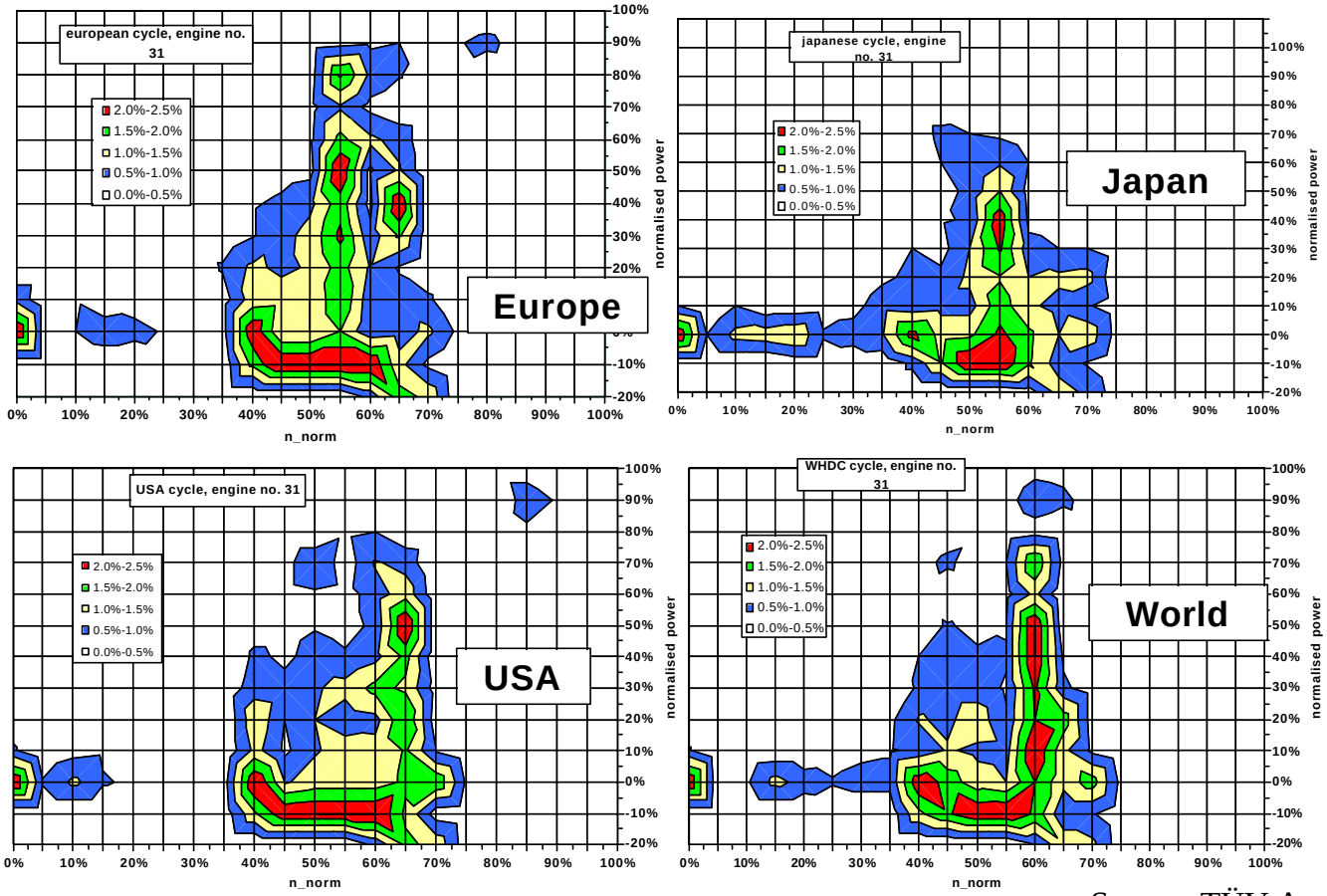
CO emissions of a HDV over vehicle speed and acceleration

Real World vs Lab



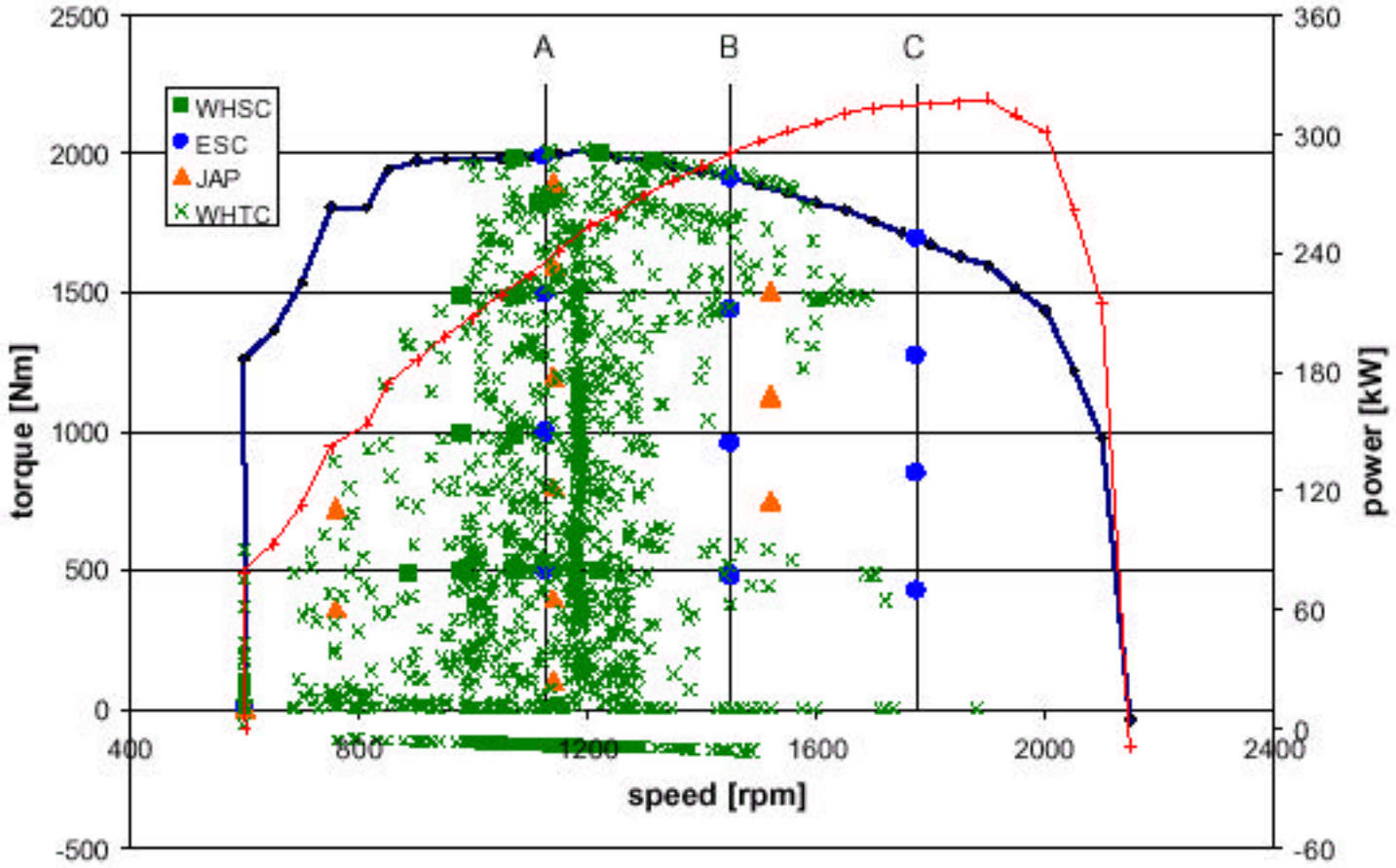
Source: U.S. EPA ,October 21, 2002

Operatinp patterns of HDV in different parts of the world



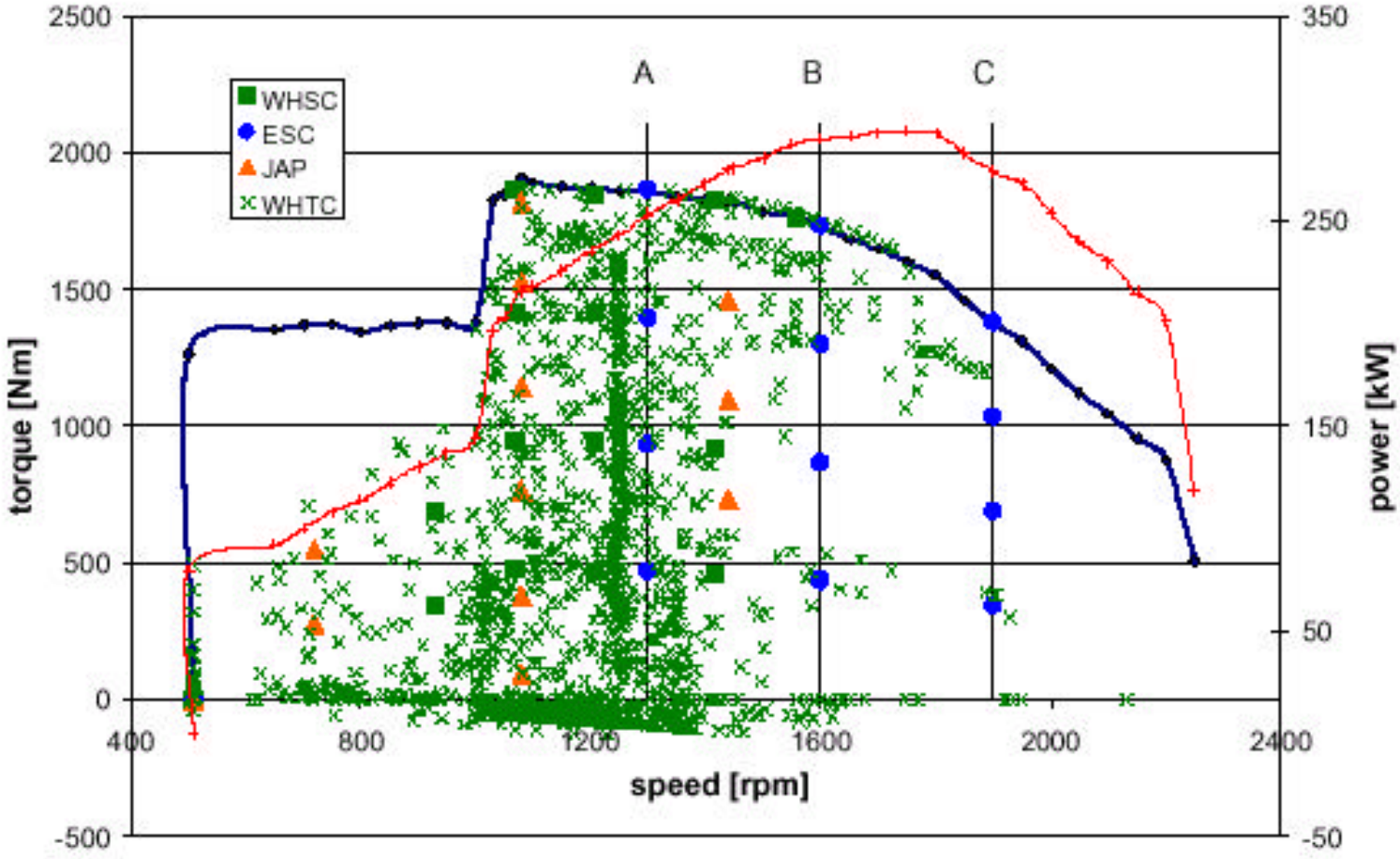
Source: TÜV Automotive, 2000

Characteristics and Test Cycle Measuring Points of a HDV Engine



Source: EMPA, 01/2002

Characteristics and Test Cycle Measuring Points of a HDV Engine



Source: EMPA, 01/2002

The American Approach

-Transient and steady-state determination of all regulated emissions through use of FTP and supplemental test procedures (ESC, MAEL, NTE)

-MAELs set for each point within the ESC control area for all regulated emissions under transient and steady-state conditions

-Non-homogeneity of all regulated emissions within the NTE zone limited to the factor of 1.25 times the applicable FTP limit value

-Compliance required under expanded ambient conditions and altitudes that are typically encountered in-use

-Use of defeat device specifically prohibited in US Federal Register

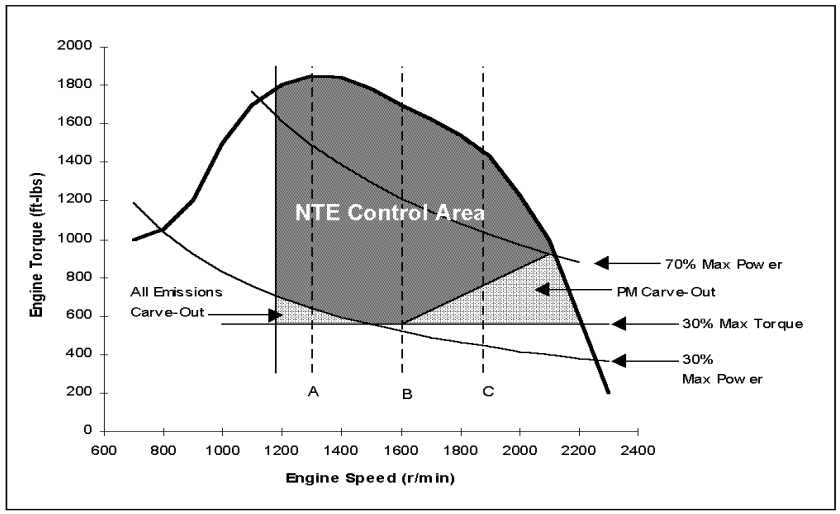
-Reporting of AECD required

-Guidance for reporting of AECD and determination of defeat device on the basis of design screening thresholds

Source: EPA, WHDC SG/FE Meeting, Brussels, 28/02/2000

CYCLE BYPASS PREVENTION

ELEMENTS OF THE USA PROCEDURE - NTE CONCEPT



- Definition of a new control area (the "NTE" zone) that is broader than the ESC control area
- Definition of specific emissions carve-out zones under low load operation
- Each regulated emission must not exceed 1.25 times the FTP standard within the NTE zone
- NTE standards apply under any conditions of normal vehicle operation including steady state and transient and expanded ambient conditions

Source: EPA, WHDC SG/FE Meeting, Brussels, 28/02/2000

Off cycle emissions from LDV, Passenger Cars

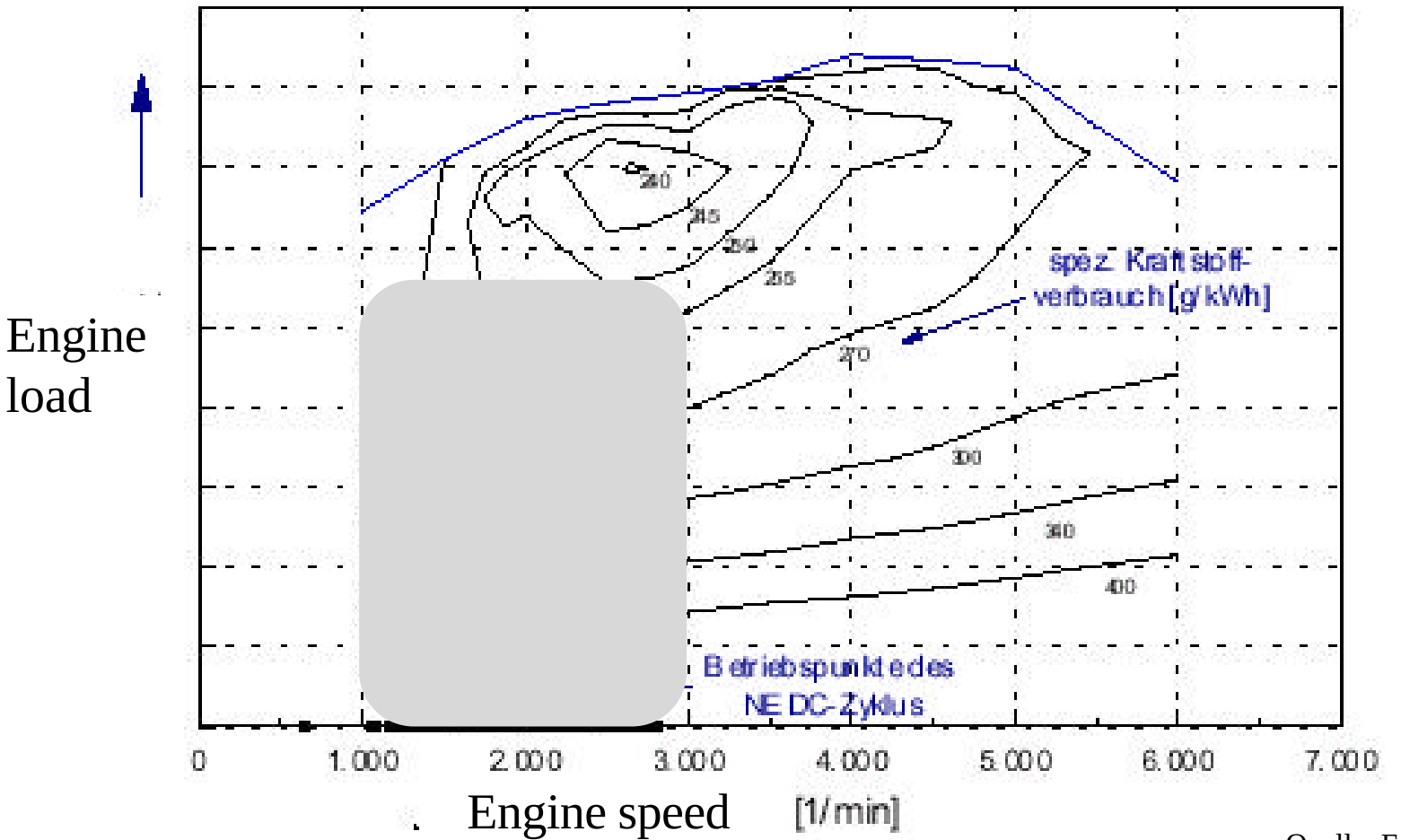
Effects of ?-control deactivation at vehicle speeds above the maximum speed of the NEDC (120 km/h)

DIRECTIVE 98/69/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL (LDV)

2.16. **"Defeat device"** means any element of design which senses temperature, vehicle speed, engine RPM, transmission gear, manifold vacuum or any other parameter for the purpose of activating, modulating, delaying or deactivating the operation of any part of the emission control system, that reduces the effectiveness of the emission control system under conditions which may reasonably be expected to be encountered in normal vehicle operation and use. Such an element of design may not be considered a defeat device if:
I. the need for the device is justified in terms of protecting the engine against damage or accident and for safe operation of the vehicle, or
II. the device does not function beyond the requirements of engine starting, or
III. conditions are substantially included in the Type I or Type VI test procedures.'

Section 5.1.1:
The technical measures taken by the manufacturer must be such as to unsure that the tailpipe and evaporative emissions are effectively limited, pursuant to this Directive, throughout the normal life of the vehicle and under normal conditions of use. This will include the security of those hoses and their joints and connections, used within the emission control systems, which must be so constructed as to conform with the original design intent. For tailpipe emissions, these provisions are deemed to be met if the provisions of sections 5.3.1.4 (type-approval) and section 7 (conformity of production and in-service vehicles) respectively are complied with.

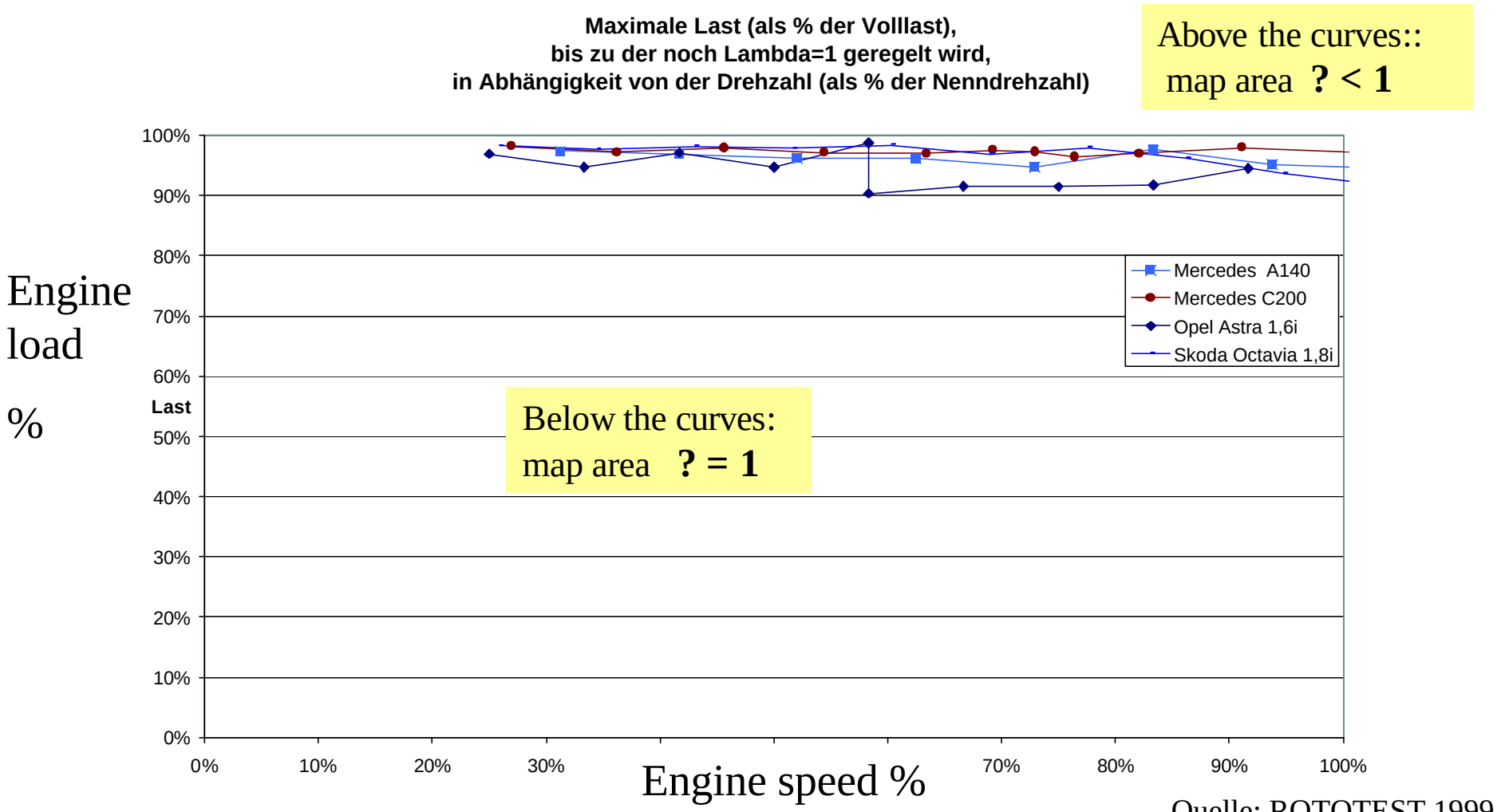
The use of a defeat device is prohibited.



Quelle: Fa. META, 2000

Fuel consumption map of a SI PC engine and operating range in the NEDC

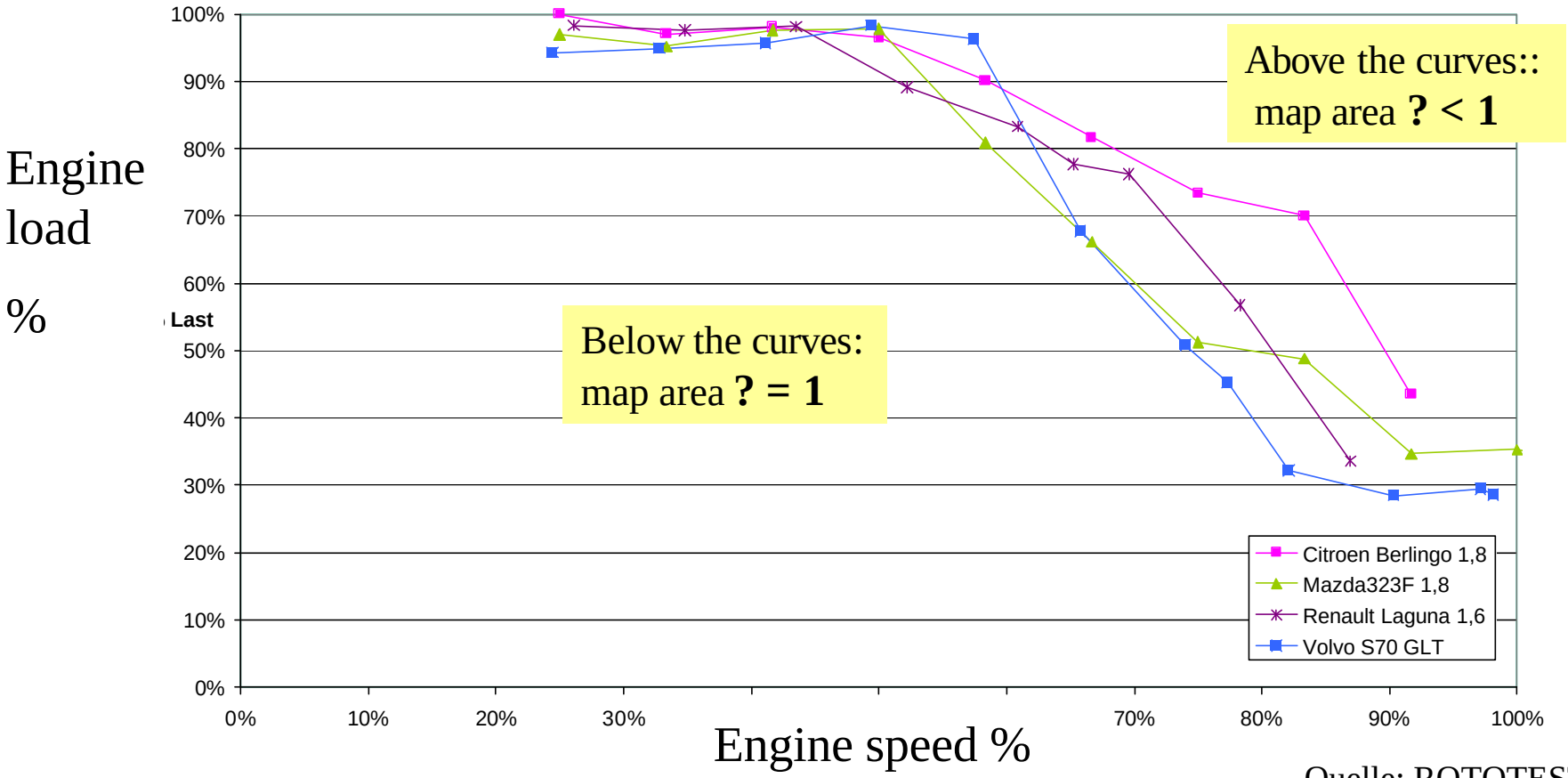
Examples of car types with a small area of ?-control deactivation in the engine map



Quelle: ROTOTEST 1999

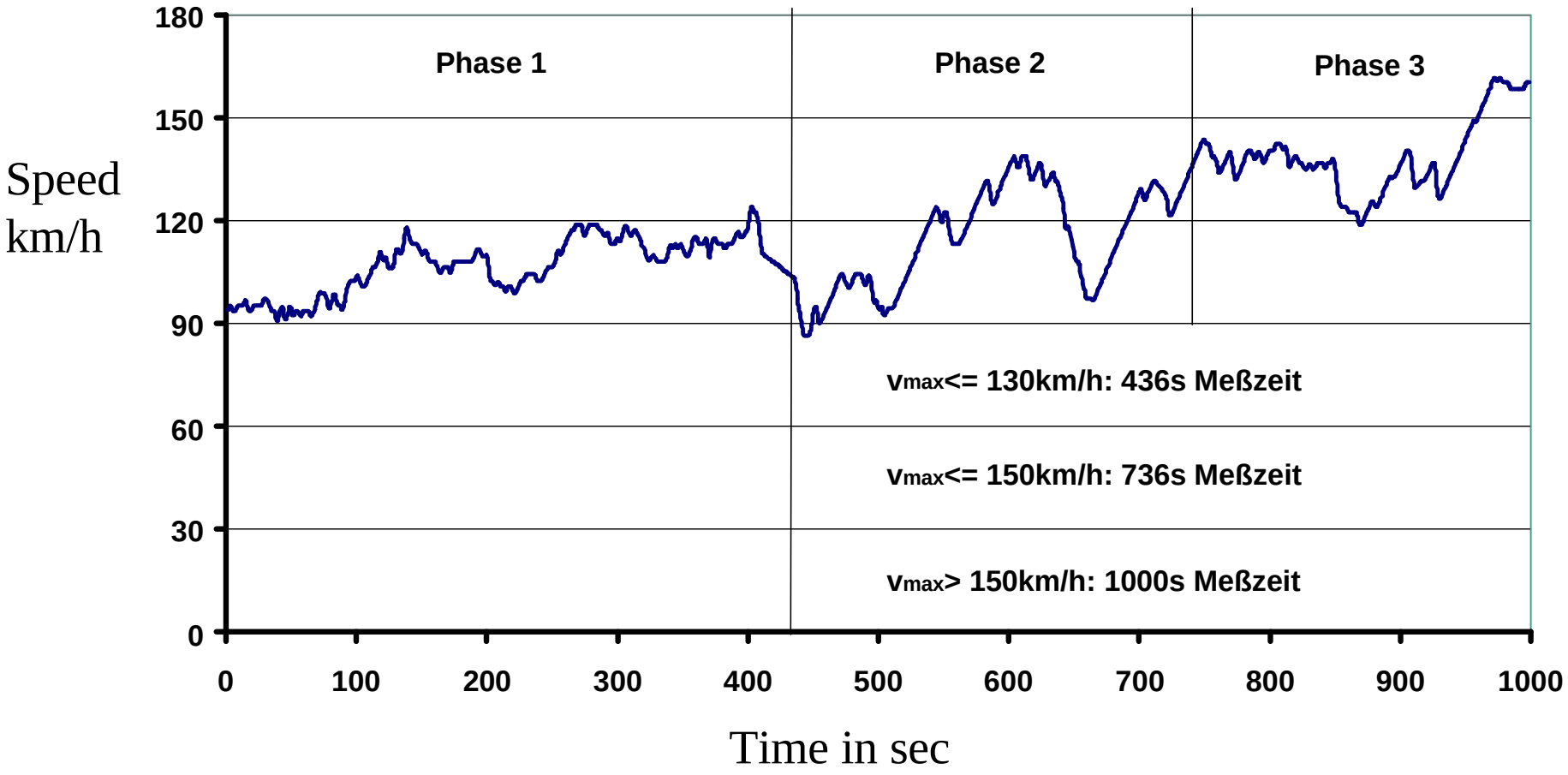
Examples of car types with a large area of ?-control deactivation in the engine map

Maximale Last (als % der Volllast),
bis zu der noch Lambda=1 geregelt wird,
in Abhängigkeit von der Drehzahl (als % der Nenndrehzahl)



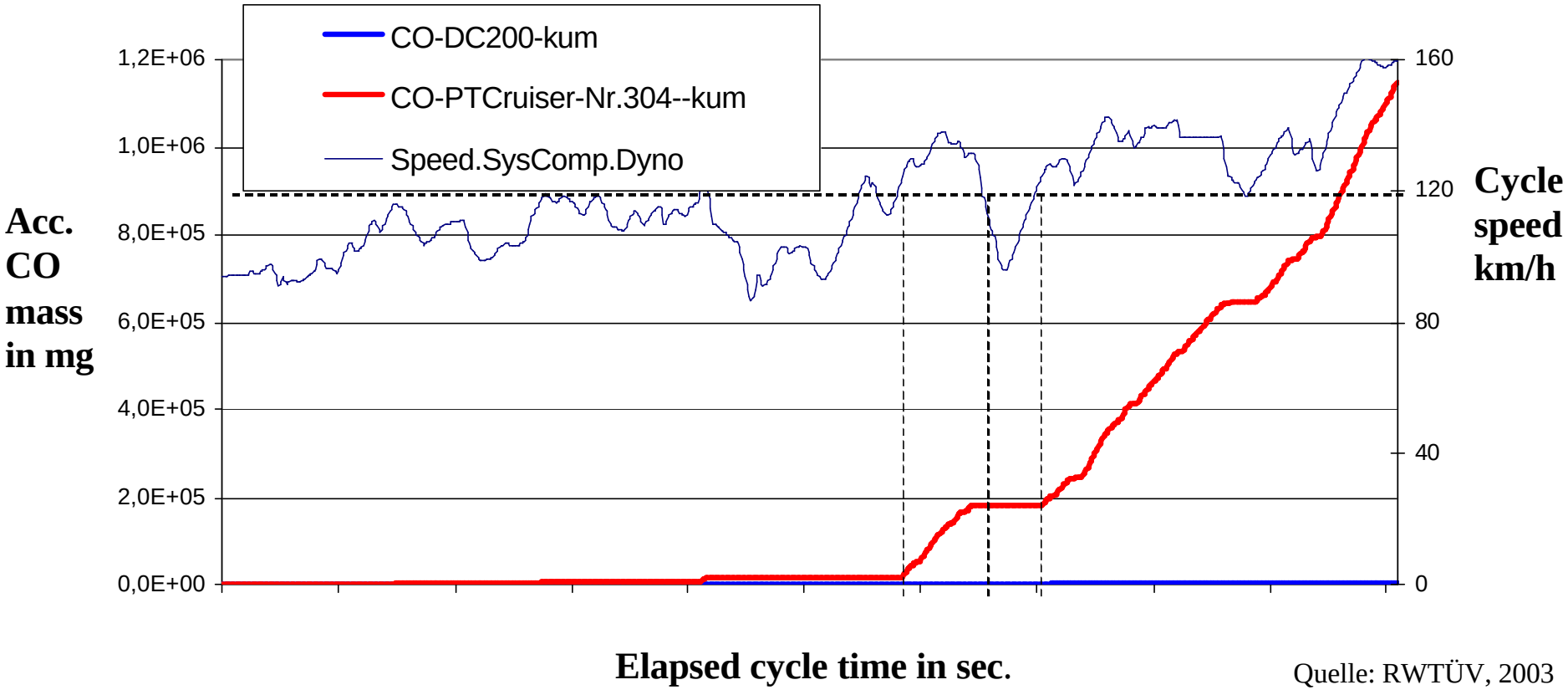
Quelle: ROTOTEST 1999

German Autobahn test cycle (used in the emission factors programme)



Accumulated CO emissions over elapsed Autobahn cycle time

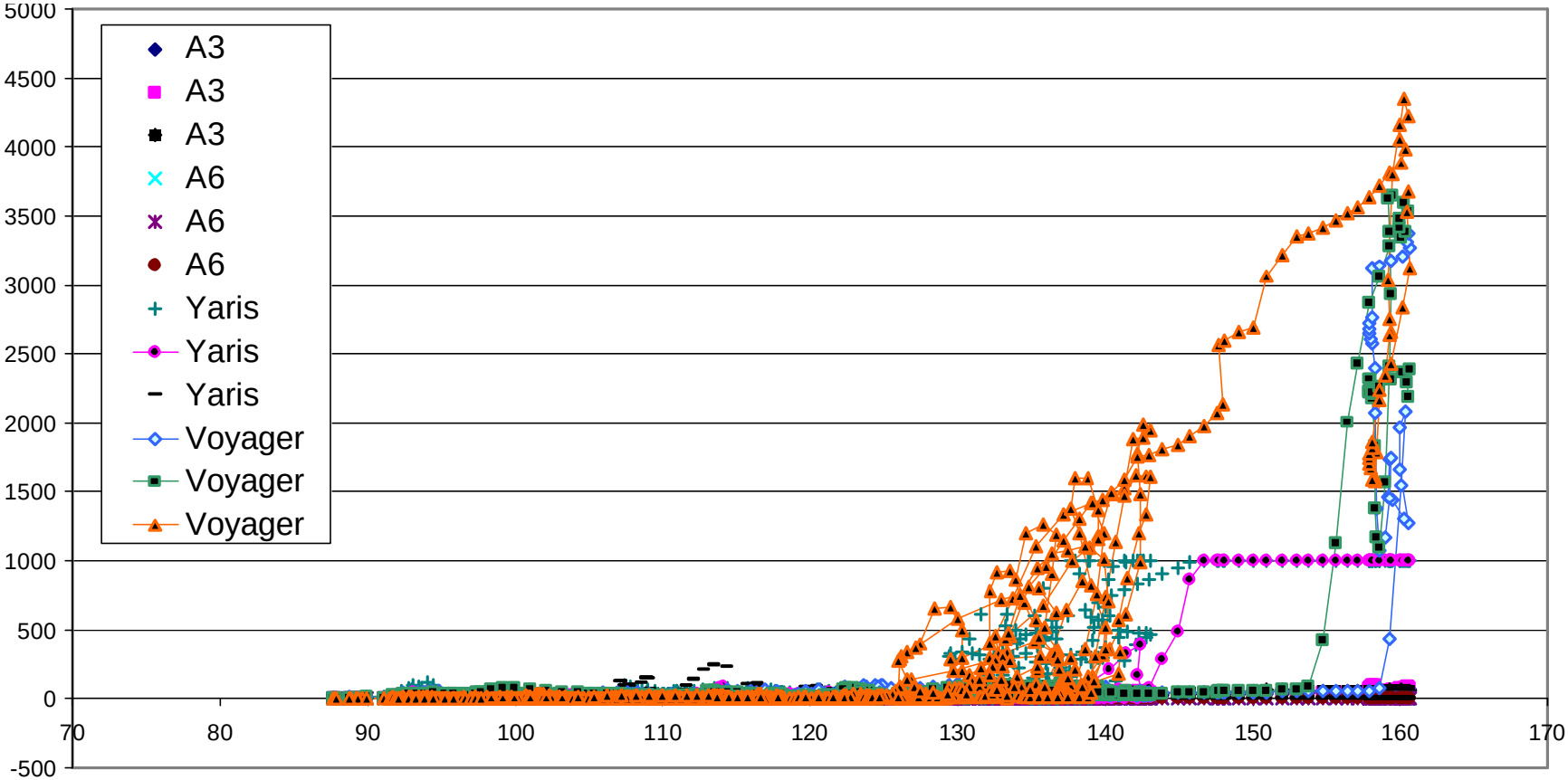
DaimlerChrysler 200 (EURO 4) and PT Cruiser (EURO 3)



Quelle: RWTÜV, 2003

CO emission in the Autobahn test cycle over vehicle speed

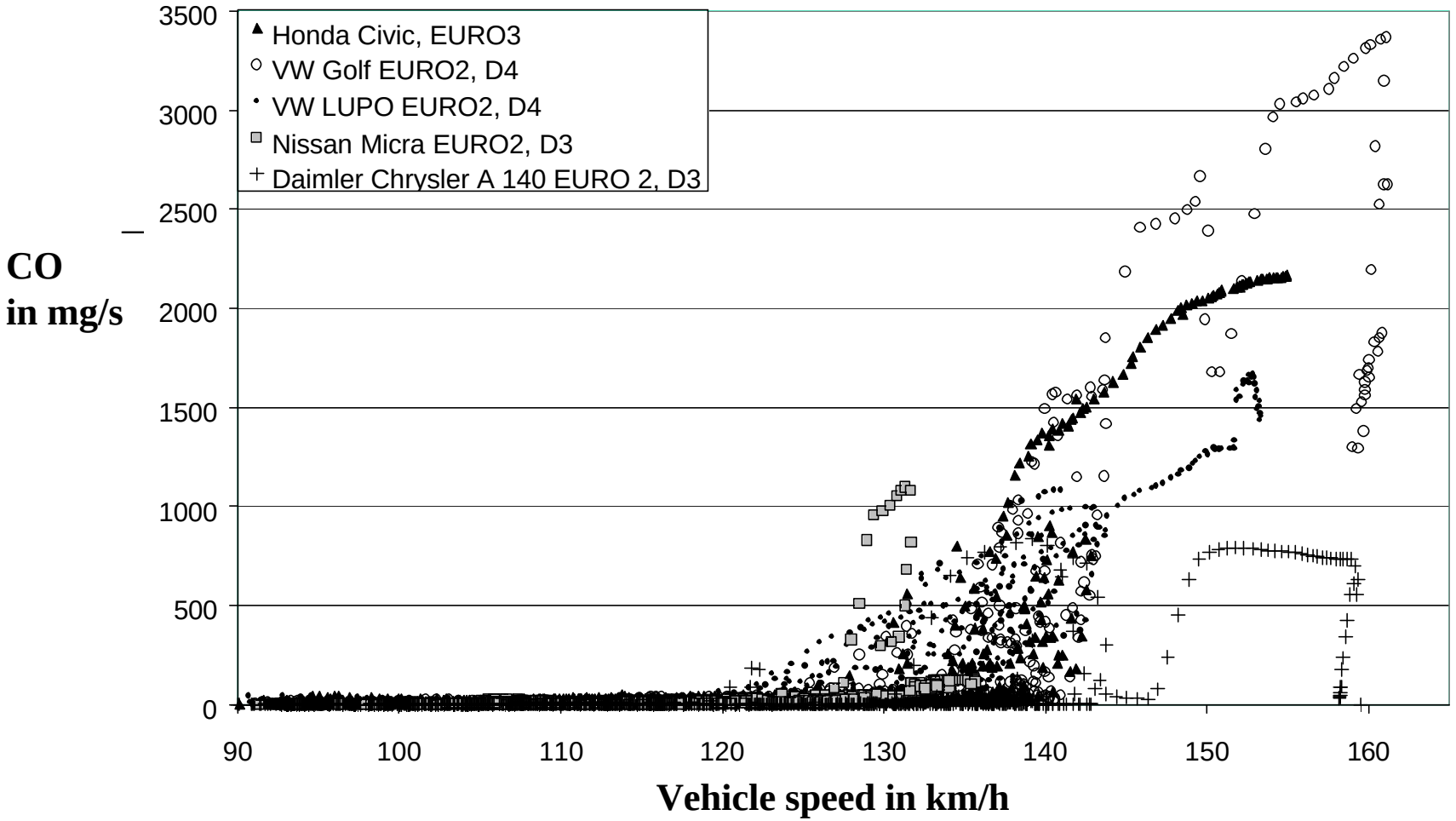
CO in mg/km



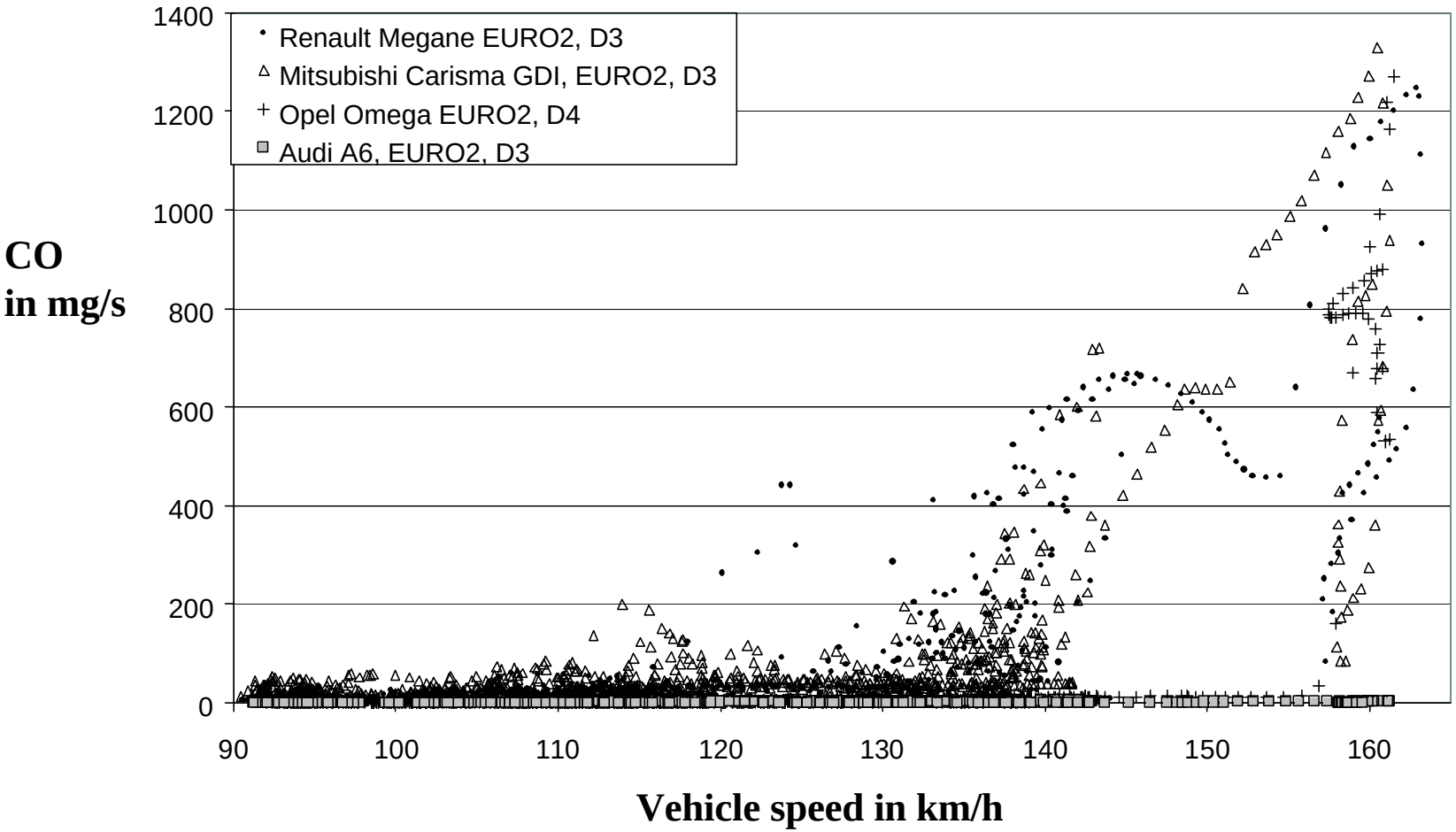
Vehicle speed in km/h

Quelle: RWTÜV, Feldüberwachung

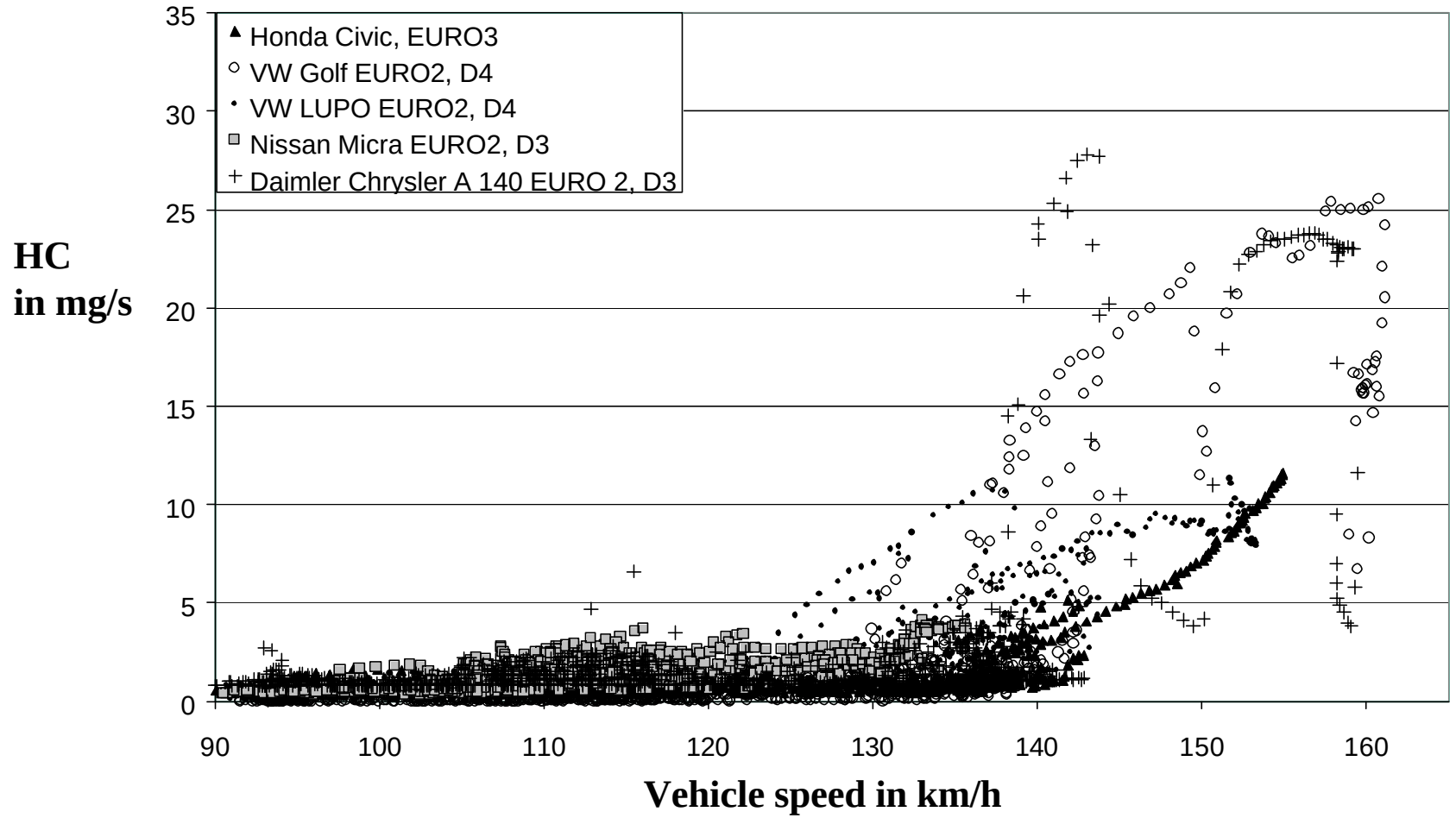
CO emission in the Autobahn test cycle over vehicle speed examples of cars with small engine capacity (< 1.4 liters)



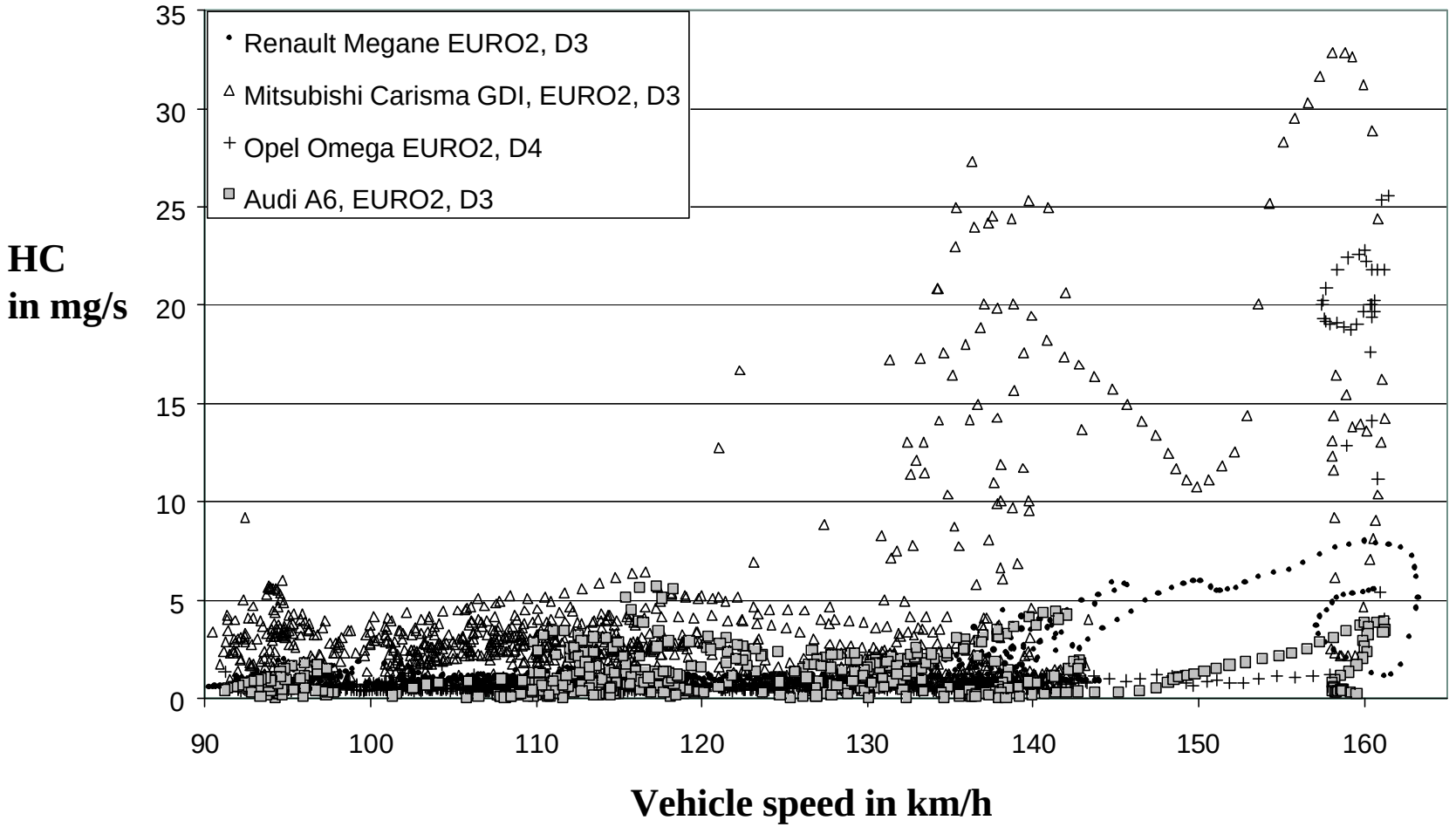
CO emission in the Autobahn test cycle over vehicle speed examples of cars with medium engine capacity (> 1.4 liters)



HC emission in the Autobahn test cycle over vehicle speed examples of cars with small engine capacity (< 1.4 liters)



HC emission in the Autobahn test cycle over vehicle speed examples of cars with medium engine capacity (> 1.4 liters)



Excessive off cycle emissions caused by ?-control deactivation in cars with SI engines at speeds above 120 km/h related to total emissions from raod traffic in Germany:

Provisional calculations:

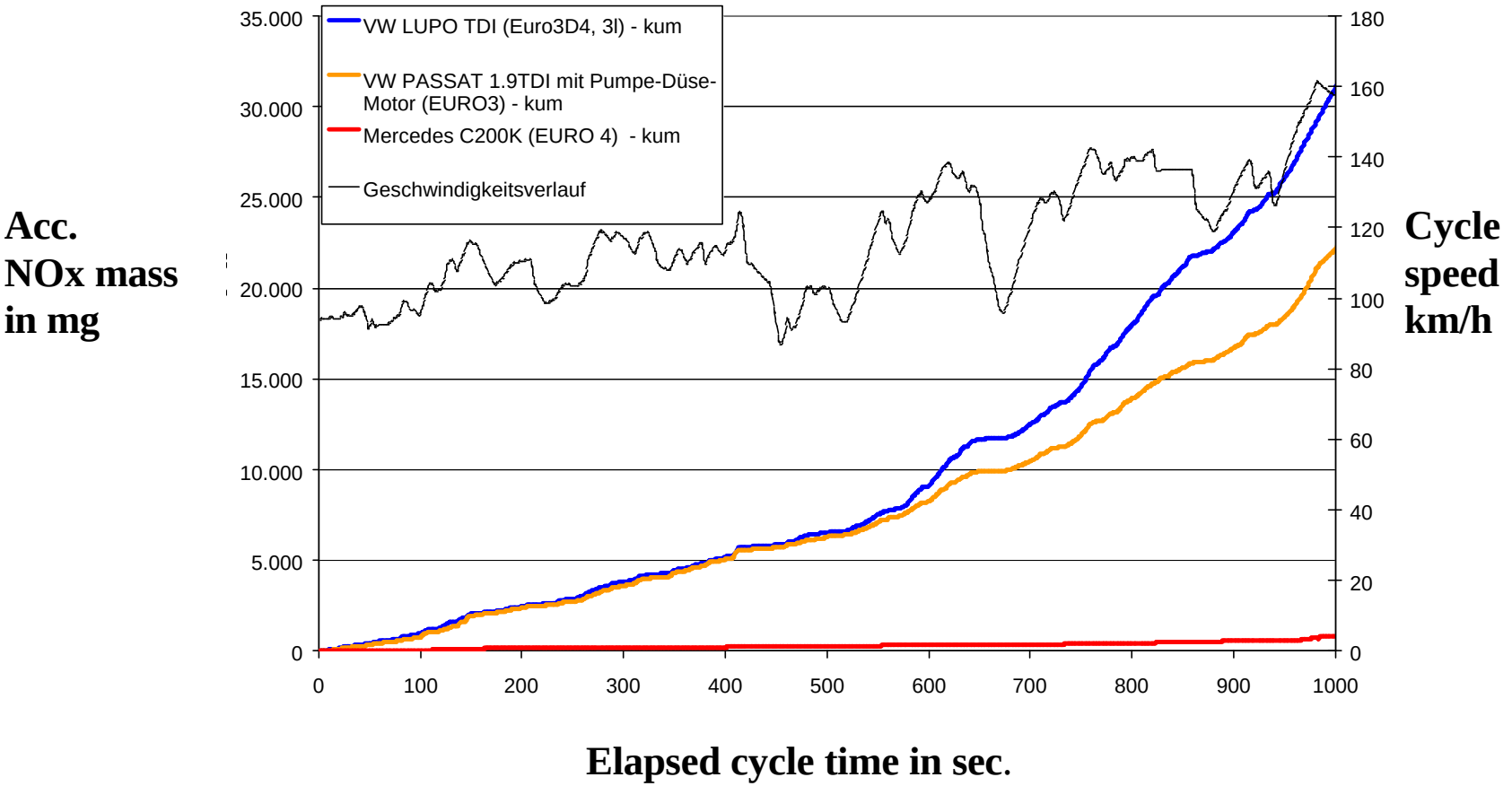
CO emissions:	in the range of 8 % up to 36 %
CO_2 emissions:	in the range of 0.15 % up to 1.1 % due to oxidation of excessive CO, (excessive CO_2 caused by increased fuel consumption not yet quantified)
HC emissions:	in the range of 0.6 % up to 5 %

Also to be considered, not yet quantified:

Formation of Benzene and other unregulated pollutants

Formation of particulates

Accumulated NOx emissions over elapsed Autobahn cycle time



Quelle: RWTÜV, 2003

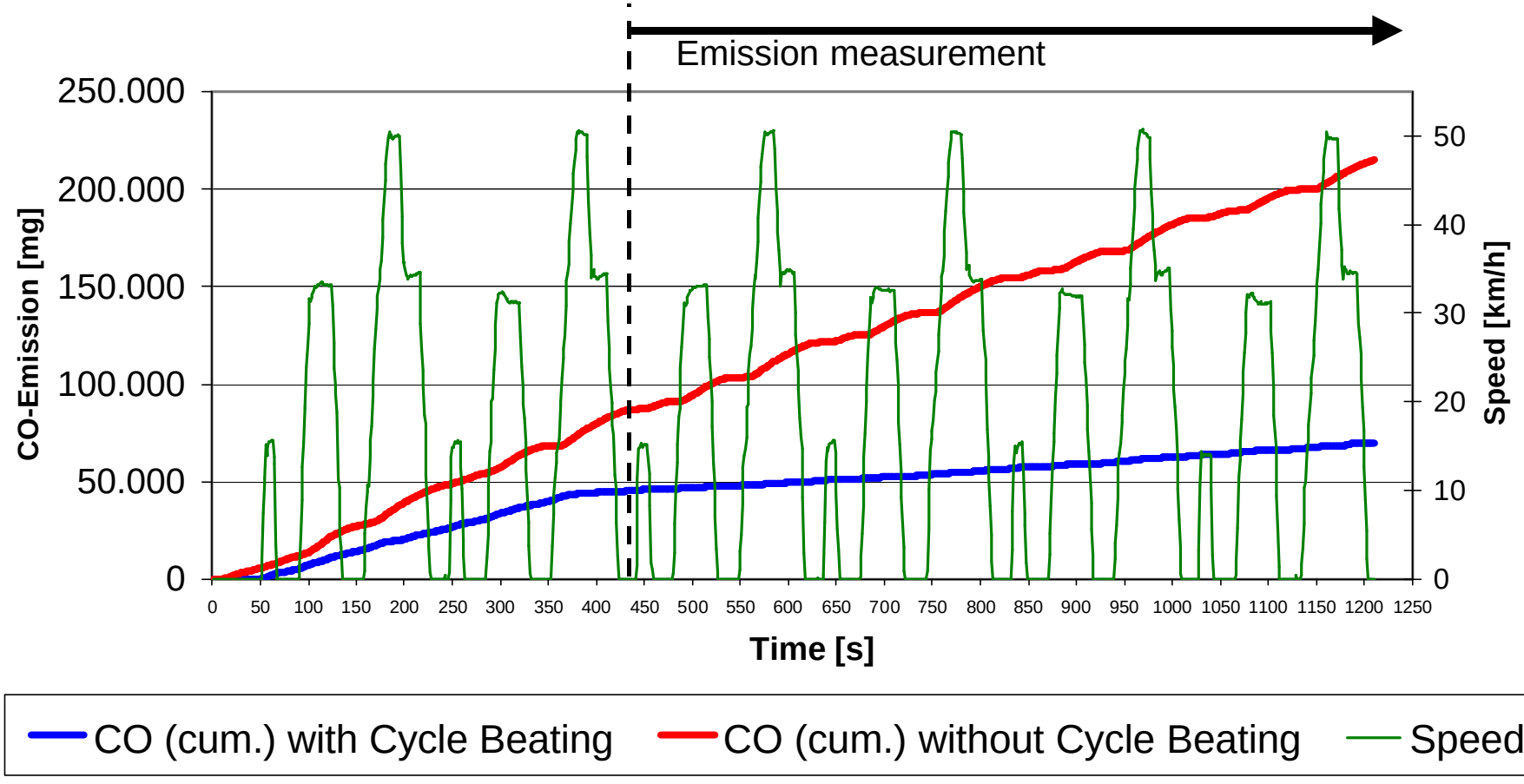
Off cycle emissions from a motorcycle

Switching of fuel injection and ignition control strategy, electronically identification of test conditions

(Cycle beating)

Cumulative CO-Emissions with and w./o. Cycle Beating

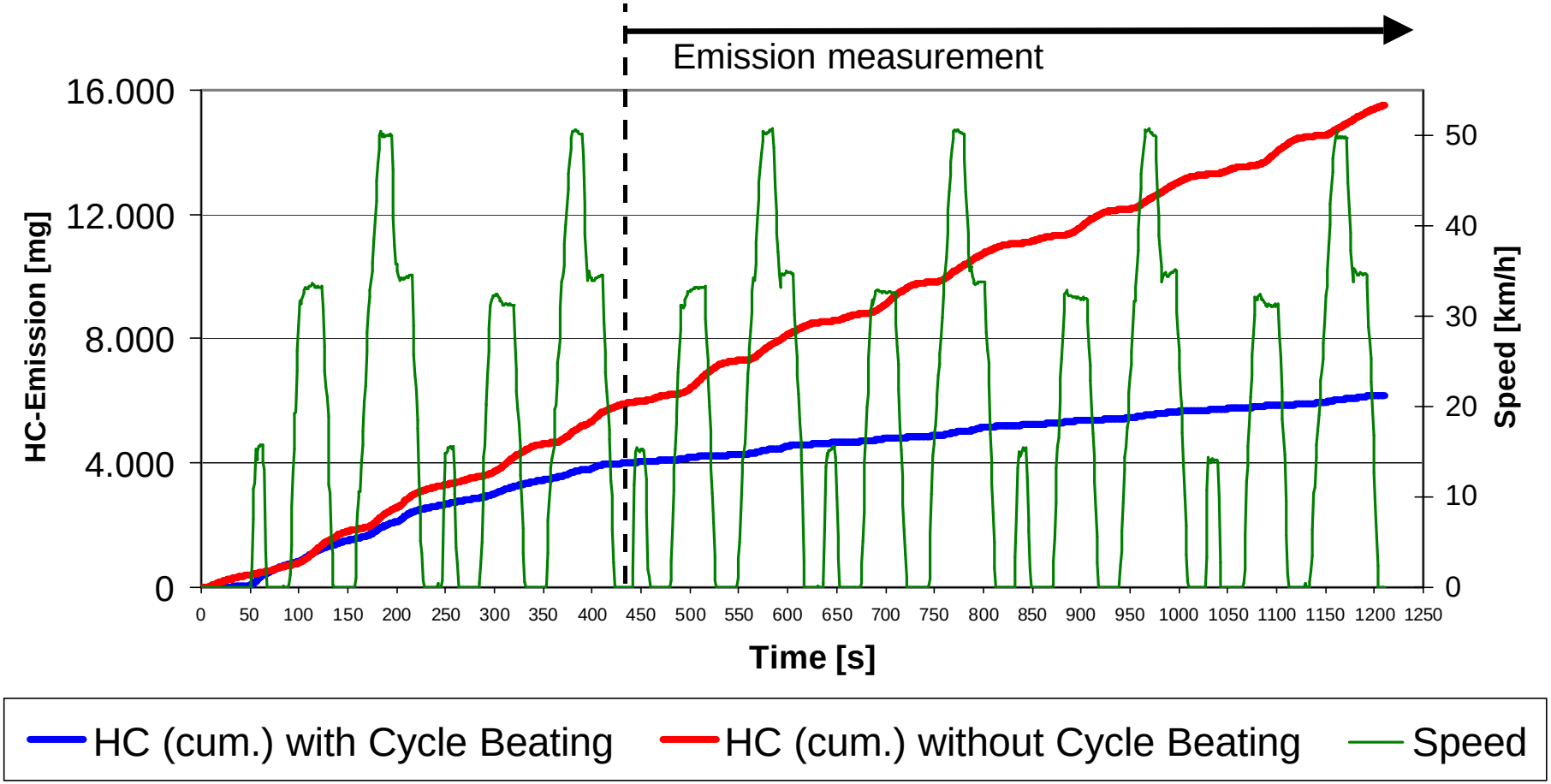
(Motorcycle BMW F650)



Source: RWTÜV, Essen, 2002

Cumulative HC-Emissions with and w./o. Cycle Beating

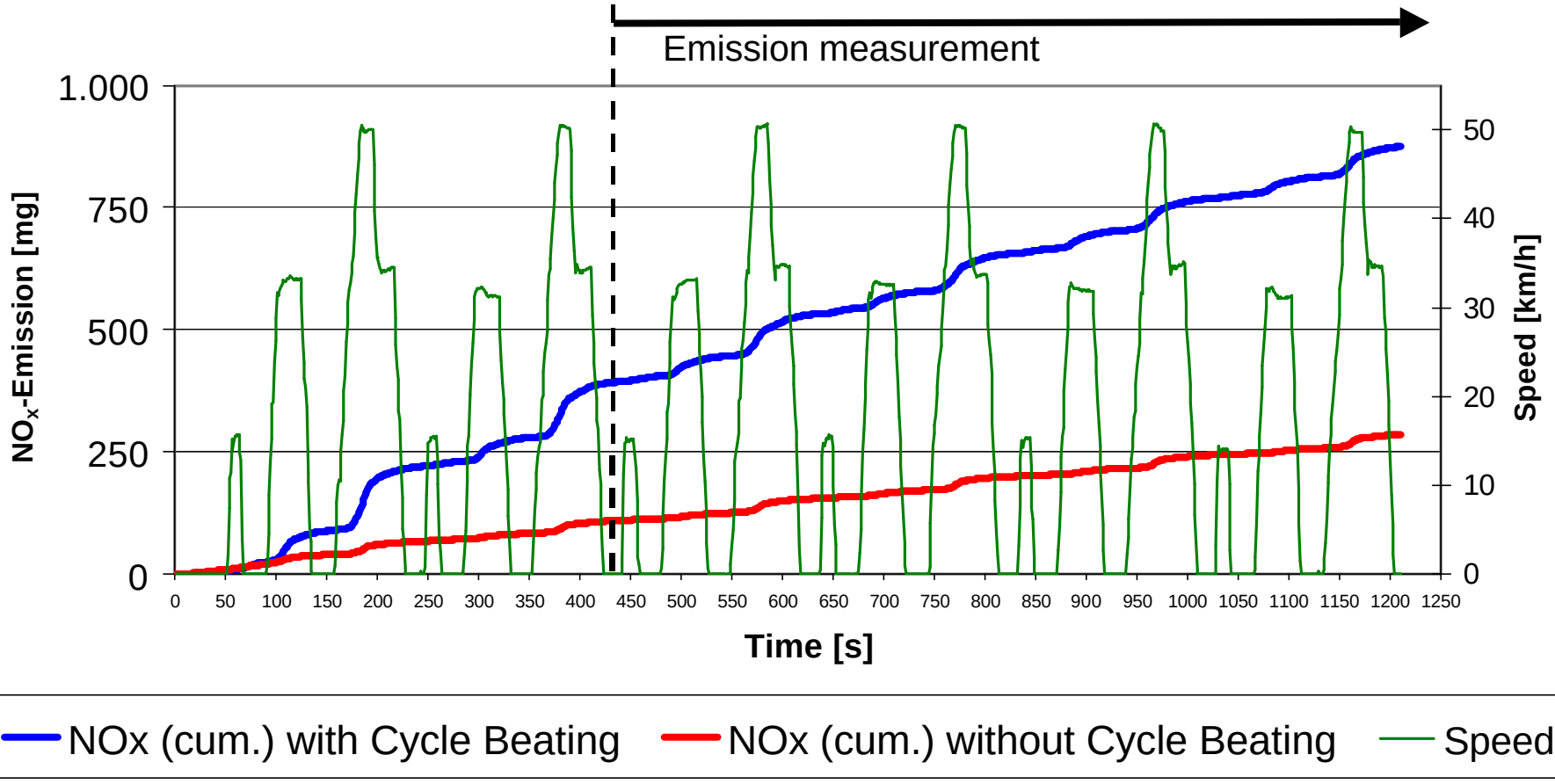
(Motorcycle BMW F650)



Source: RWTÜV, Essen, 2002

Cumulative NO_x-Emissions with and w./o. Cycle Beating

(Motorcycle BMW F650)



Source: RWTÜV, Essen, 2002

Conclusions: How to get off cycle emissions under control ?

- The political intention of updating emission legislation and reducing emission standards always is to achieve a certain overall emission level.
- The obligation of the industry is to comply with this intention, not to search for quasi legal loop holes or freedom of interpretation in the regulation which increases emissions above the desired level.
- Test cycles can never be perfect, neither regarding representativity for real life operation nor regarding safety against cycle bypass or cycle beating. Any test cycle or control area definition related to certain parameters of engine design has its weaknesses and can be bypassed or become oudated after some time due to further technical development.

- Emission requirements therefor must not be limited to a test cycle and a defined control area, but be extended to cover all possible operating conditions with not to exceed limits related to the basic emission standards. The engines resp. vehicles must comply with emission requirements in any randomly selected mode of operation under almost all ambient conditions which may occur in real life.
- The definition of defeat devices as well as of irrational control strategy becomes less important if a not to exceed concept and a clear definition of boundary conditions including ambient conditions etc. is in place. Exceptions have to be limited as far as possible.
- At the stage of type approval the manufacturer has to provide full information on the operation and effect on emissions of the use of any devices and/or control strategy. Such information shall include a description of all emission control components, fuel control system logic including timing strategies and switch points during all modes of operation.

- Since the type approval authorities will not be able to check this set of data in full technical detail, the manufacturer in addition should be obliged to sign a declaration that he does not apply any defeat device or irrational control strategy which violates either the legal provisions or the basic intention of the regulation, and that the engine or vehicle type complies with the not to exceed emission requirements.
- In use compliance testing is much more important than the type approval procedure, which in last consequence could be reduced to a formal act of self certification. In use compliance testing must be enabled to verify not to exceed emission requirements in any randomly selected mode of operation.
  In return the effort for measurements at the type approval stage could be minimized.