Umwelt Bundes Amt
Für Mensch und Umwelt

Section I 3.2 1 November 2010

Measuring Procedure for the Determination of Nitrogen Dioxide Emissions from Diesel Engines Fitted with Particulate Reduction Systems

General remarks and explanatory notes:

The following procedure is used to determine the nitrogen dioxide (NO_2) emissions from commercial vehicles and non-road mobile machinery retrofitted with particulate reduction systems. It is hoped that the provision of appropriate information about emissions performance will increase the deployment of particulate reduction systems that show a tendency to produce less NO_2.

The system with the greatest potential to produce NO_2 is examined to determine the alteration in NO_2 emissions. The following points apply to the particulate reduction systems to be examined:

- The particulate reduction systems must possess approvals under Annex XXVII to the German Road Traffic Registration Regulations (StVZO).
- The system to be examined consists of the particulate reduction system with the greatest active volume and, if a diesel oxidation catalyst (DOC) is used, upstream catalytic converter with the greatest active surface area.
- Furthermore, the measurements are taken on the particulate reduction system in the range supplied by the manufacturer with the highest proportion of precious metal relative to the weight of the filter or the maximum-weight precious metal coating.
- The point where the system under examination is fitted is to be chosen in such a way that the most favourable conditions for the production of NO_2 within its area of application are replicated.
- The particulate reduction system under examination must be unloaded and may not have been run in for longer than 50 hours or aged.

Further requirements, e.g. with regard to the composition of the coating on the particulate reduction system, will be found in section 2.2.

The requirements set out in section 5 of this procedure apply with regard to the establishment of system families for particulate reduction systems.

The manufacturer of the particulate reduction system must confirm that the system under examination complies fully with the requirements set out in the measurement procedure (among other things with regard to its volume, precious metal loading and service accumulation). A copy of the test report for the approval of the particulate reduction system required by Annex XXVII to the StVZO is also to be appended.

The NO_2 emissions are verified in accordance with the testing procedure described below and communicated in the form of a standardised test report issued by an accredited technical service, a motor vehicle surveyor, a motor vehicle assessor or an employee of one of the above parties.

If a particulate reduction system is tested and approved for several engines of the same engine size class under Annex XXVII to the StVZO, the NO_2 emissions are only to be verified using one engine in this engine size class.

The determination of NO_2 emissions in accordance with this measuring procedure must be carried out by an accredited technical service, a motor vehicle surveyor, a motor vehicle assessor or an employee of one of the above parties.

Measurement Procedure for the Determination of Nitrogen Dioxide Emissions from Diesel Engines Fitted with Particulate Reduction Systems

1. General

1.1 Scope of application

This procedure governs the determination of NO_2 emissions from engines fitted with particulate reduction systems that are intended for retrofitting in commercial vehicles powered by compression-ignition engines or non-road mobile machinery where the machinery or its engine is covered by section 47(6) or (8b) of the StVZO.

Within the meaning of this procedure, the following are to be referred to as motor vehicles:

- Class M motor vehicles, with the exception of cars (M_1)
- Class N motor vehicles

that are subject to Annex II.A and Annex II.C of Directive 70/156/EEC of 6 February 1970 on the approximation of the laws of the Member States relating to the type-approval of motor vehicles and their trailers (OJ L 42, p. 1), as adapted by Directive 2001/116/EC of 20 December 2001 (OJ 2002 L 18, p. 1), that are powered by compression-ignition engines and fuelled with diesel fuel subject to Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC (OJ L 350, p. 58), amended by Directive 2003/17/EC of 3 March 2003 (OJ L 76, p. 10), and self-propelling machinery subject to section 12 of the German Ordinance on the Licensing of Vehicles (FZV) that is powered by compression-ignition engines.

1.2 Definition of terms and abbreviations

ESC test cycle:
Test cycle – consisting of 13 steady state test modes – as specified in Appendix 1 to Annex III of Directive 2005/55/EC of the European Parliament and of the Council of 28 September 2005 (OJ L 275, p. 1) on the approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines for use in vehicles, and the emission of gaseous pollutants from positive-ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles as amended by Commission Directive 2006/51/EC of 6 June 2006 (OJ L 152, p. 11).

ETC test cycle:
Test cycle – consisting of non-steady state, transient modes – as specified in Appendix 2 to Annex III of Directive 2005/55/EC of the European Parliament and of the Council of 28 September 2005 (OJ L 275, p. 1) as amended by Commission Directive 2006/51/EC of 6 June 2006 (OJ L 152, p. 11).

NRTC:
Dynamic test for non-road mobile machinery as specified in Annex III.4 of Directive 97/68/EC as amended by Directive 2004/26/EC.

Particulate reduction system:
System for the aftertreatment of exhaust gases to reduce particulate emissions by mechanical and/or aerodynamic separation and by diffusion and/or inertial separation. Engine-specific modifications to structural components and electronic elements and electronic components are not regarded as part of a particulate reduction system. However, if it is necessary for additional work to be carried out on emissions-relevant structural components and/or system components in order to retrofit the PRS, for example a modification of the exhaust gas recirculation (EGR) control system to ensure its continued faultless functioning, the engine manufacturer must give its approval for these measures.

Filtration efficiency:
Ratio between the particulate matter captured by the particulate reduction system and the particulate matter emitted by the vehicle in its original configuration, measured over the ESC test cycle for Particulate Reduction Class (PRC) 0 and PRC 1, and over the ETC test cycle for PRC 2, or over the NRSC cycle for PRC 0 and PRC 1, and over the NRTC cycle for PRC 2, and calculated using the formula set out in Annex XXVII.5.1 or Annex XXVII.6.1 to the StVZO.

Abbreviations:

ABE	*Allgemeine Betriebserlaubnis*, German Type Approval
CLD	Chemiluminescence detector
DOC	Diesel oxidation catalyst
ESC	European Steady State Cycle
ETC	European Transient Cycle
FTIR	Fourier transformation infrared spectrometer
HC	Hydrocarbon
HCLD	Heated chemiluminescence detector
KBA	German Federal Motor Transport Authority
N_2	Nitrogen
NO*	Nitrogen monoxide (calculated from NO density)
NO_2	Nitrogen dioxide (calculated in accordance with Directive 2005/55/EC from the NO_2/NO_x ratio derived from the NO_x value determined in accordance with Directive 2005/55)
NO_2*	Nitrogen dioxide (calculated from NO_2 density)
NO_x	Nitrogen oxides (calculated in accordance with Directive 2005/55/EC)
NO_x*	Nitrogen oxides (sum of NO* and NO_2*)
O_2	Oxygen
PM	Particulate matter
StVZO	*Straßenverkehrs-Zulassungs-Ordnung*, German Road Traffic Registration Regulations
PRS	Particulate reduction system
V_{fl}	Greatest active volume in use, consisting of a particulate reduction system and, where available, the upstream catalytic converter with the greatest active surface area

2. Selection of test engine and particulate reduction system

The procedure for the determination of NO_2 emissions from the engines to be tested is described below. For the testing, the engine is to be mounted on an engine test bed and connected to the exhaust gas analytical instruments.

2. 1. Selection of engine

For the determination of NO_2 emissions, the size of the test engine is to be matched to the particulate reduction system under examination. The engine used in this case must come from the area of application stated in the Type Approval (ABE) for the particulate reduction system. If possible, furthermore, the engine should already have been used for the approval of the particulate reduction system under Annex XXVII to the StVZO and generate between 100 % and 60 % of the power attributed to the parent engine in the area of application (parent engine of an engine family in accordance with Annex I.8).

2.1.1 Engines for commercial vehicles

The test engines selected for the determination of NO_2 emissions in the commercial vehicle sector must be type-approved in accordance with Directive 88/77/EEC as amended by 1999/96/EC or 2001/27/EC, Row A (EURO III). In addition to this, where use is made of Euro III[1] diesel engines intended for commercial vehicles, the raw HC and NO_2 emissions of the engine selected must also lie within the ranges given in Table 1 to ensure compliance with the corresponding limit values set out in Directive 88/77/EEC.[2] The emissions measured are to be detailed in the test report. The raw emissions from the test engines are determined over the ETC and ESC cycles prior to the determination of the NO_2 emissions from the particulate reduction system. Alternatively, by agreement with the technical service commissioned to carry out the testing, use may also be made of reliable data on the emissions performance of the test engine where these are already available. In this case, proof is to be provided that the measurements in question were taken in accordance with the guidelines set out in Directive 2005/55/EC using the ETC and ESC, and that the raw emissions over both cycles lay within the required ranges. Furthermore, it is to be confirmed by the technical service that no changes in the emission performance of the test engine have occurred in the intervening period.

[1] If the use of a Euro II engine is necessary, this is to be done in consultation with the German Federal Environment Agency.
[2] If the HC emissions from a test engine lie below the values given in Table 1, it is necessary to reach agreement with the German Federal Environment Agency concerning the use of the engines.

Table 1: HC and NO_2 emission ranges for the test engines used

Euro stage		HC in g/kWh	NO_2 in g/kWh
EURO III (Cylinder capacity: up to 800 cm^3)	ESC	0.20-0.40	0.40-0.50
	ETC	0.10-0.25	0.70-0.80
EURO III (Cylinder capacity: over 800 cm^3)	ESC	0.05-0.20	0.15-0.20
	ETC	0.10-0.25	0.20-0.30
EURO III (Engines with EGR systems[3])	ESC		
	ETC		

An appropriate information document on the system covering all points required by Annex XXVII to the StVZO is to be appended to the test report for the test engine.

2.1.2 Engines for non-road mobile machinery

The engines used in the non-road mobile machinery sector must comply with the limit values for the Euro stage under which they have been type-tested. The foundation for the verification of the raw emissions is the ISO 8178-4 Type C1 test cycle.
For particulate reduction systems with filtration efficiencies > 90 % over the ISO 8178-4 C1 cycle that are deployed exclusively in mobile machinery not intended to carry goods or passengers on public roads, use may be made of a test engine approved under stage II in accordance with Directive 97/68/EC as most recently amended. An engine of this kind may also be used if a Federal Motor Transport Authority (KBA) approval has been issued for the particulate reduction system (filtration efficiency > 90 % over the ISO 8178-4 C1 cycle) for use in non-road mobile machinery under Annex XXVII to the StVZO and there are no commercial vehicle engines that are equivalent to the engines deployed in the machinery in terms of cylinder capacity.

2.2 Selection and fitting of the system to be examined

The system with the greatest potential for NO_2 production is examined.

- The system to be examined consists of the particulate reduction system with the greatest active volume and, if a diesel oxidation catalyst (DOC) is used, upstream catalytic converter with the greatest active surface area.

The system to be examined is that with the maximum coating weight (g/ft^3) and the maximum total metal loading. If a manufacturer supplies systems with various metal compositions or Pt contents, the system to be examined must be selected in accordance with the following criteria:

- Proportion of platinum ≥ 10 % of the total metal loading:
  - Test specimen must contain the maximum platinum loading and the maximum content of other precious metals found in systems with this platinum content.
- Proportion of platinum ≤ 10 % of the total metal loading:
  - Test specimen must have the maximum content of precious metals, platinum content must not not be zero.

[3] Given the lack of information available to date, it has not as yet been possible for emission ranges to be defined for engines with EGR systems. The use of engines with EGR systems will therefore only be possible once appropriate emission ranges have been defined by the Federal Environment Agency.

If the particulate reduction systems to be examined do not contain any platinum, the system with the maximum total metal loading must be examined.

The following applies to particulate reduction systems with zone coatings:
The properties of the coated zone on the system to be investigated, which has the maximum loading of precious metal, may not deviate from those of the other systems in the family (section 5). Furthermore, where a system has a zone coating, use must be made of the system with the highest specific precious metal loading relative to the active volume.

The particulate reduction system is to be fitted in such a way that the shortest distance appropriate to the area of application specified for the family covered by its Type Approval is left between the engine and the particulate reduction system.

The particulate reduction system under examination must be unloaded and may not have been run in for longer than 50 hours or aged.

Where a system family has been established (section 5), the system within the system family that has the greatest potential to produce NO_2 is to be examined.

3. Preparation for the testing and analytical method

The calibration procedure and analytical procedures set out in Appendix 5 to Annex III of Directive 2005/55/EC are applied. Furthermore, the whole sampling line, from the sampling probe to the inlet into the analyser, is to be heated in such a way that any possible condensation is avoided. The use of a gas dehydrator and the application of chemical desiccants to remove water from the sample prior to the measurement of NO_2 are not permitted. The requirements set out in Annex I.6.2 of Directive 2005/55/EC apply with regard to the use of alternative analytical procedures.
If a CLD is used, it must be a heated chemiluminescence detector with an NO_2/NO converter. This must possess two parallel measuring chambers to determine NO_x and NO continuously at the same time. The use of two individual devices that are connected in parallel is not permitted.

4. Measuring procedure for the determination of NO_2 emissions

4.1 Conditioning

4.1.1 Conditioning of the test engine

The preconditioning phase is intended to prevent the forthcoming measurement from being influenced by deposits in the exhaust system left behind from an earlier test. For this purpose, the engine is to be warmed up at maximum power as stipulated by Directive 2005/55/EC in order to stabilise the engine parameters in accordance with the manufacturer's recommendations. The declared maximum power (P_{max}) is the maximum engine power (net power) declared by the manufacturer in its application for the issue of a type approval in accordance with Directive 80/1269/EC.
Once the engine has been stabilised, the first test cycle, the urban part of the ETC, must be begun within 20 seconds after the completion of the preconditioning phase.

4.1.2 Conditioning of the particulate reduction system

The particulate reduction system is conditioned for at least 60 minutes long at the rated engine speed and maximum torque.

4.2 Determination of gaseous components and particulates

An analytical system is deployed in the raw exhaust gas or diluted exhaust gas to determine the gaseous emissions. The particulates and gaseous components are determined in accordance with the guidelines set out in Directive 2005/55/EC. The probe for the sampling of the gaseous emissions is to be fitted in the dilution tunnel close to the particulate sampling probe at a point where the dilution air and exhaust gas are well mixed.

4.3 Test cycles

A distinction is made between particulate reduction systems that are approved for commercial vehicles and particulate reduction systems that are intended for use in non-road mobile machinery. The test cycle for commercial vehicles is the urban part of the ETC cycle, which approximates to the real performance of commercial vehicle engines in urban traffic. The NRTC cycle is used to test systems intended for non-road mobile machinery. Where a particulate reduction system is approved for use in both non-road mobile machinery and commercial vehicles, both cycles must be completed and both results recorded.

4.3.1 Urban part of the ETC for commercial vehicles

The NO_2 emissions are to be measured during the first 600 seconds of the dynamic ETC cycle downstream from the particulate reduction system. The measurements are taken with the engine at operating temperature.

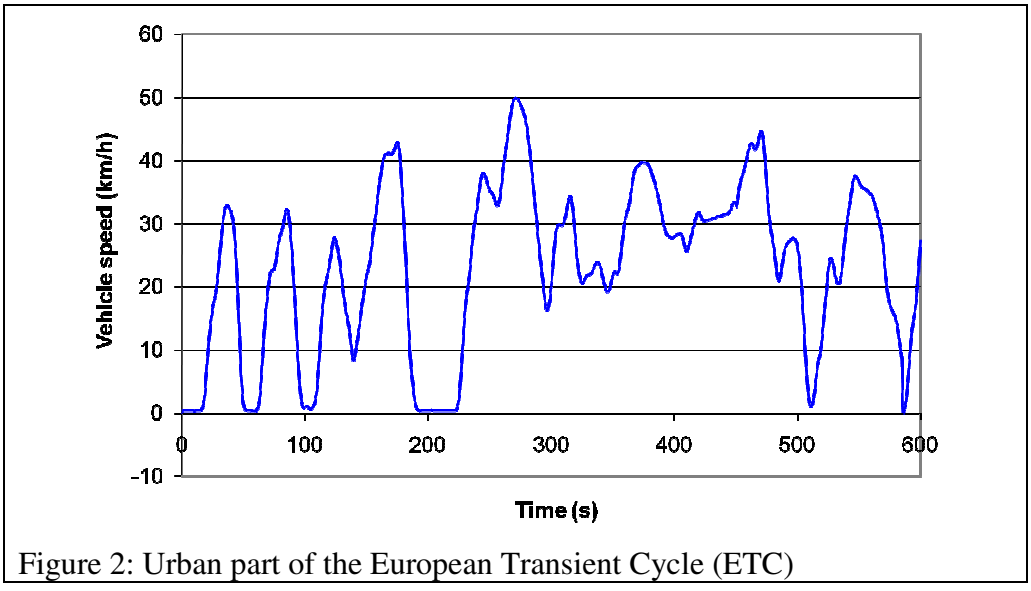

Figure 2: Urban part of the European Transient Cycle (ETC)

4.3.2 NRTC for non-road mobile machinery

The NRTC test cycle is used to determine the NO_2 emissions from particulate reduction systems approved for non-road mobile machinery.

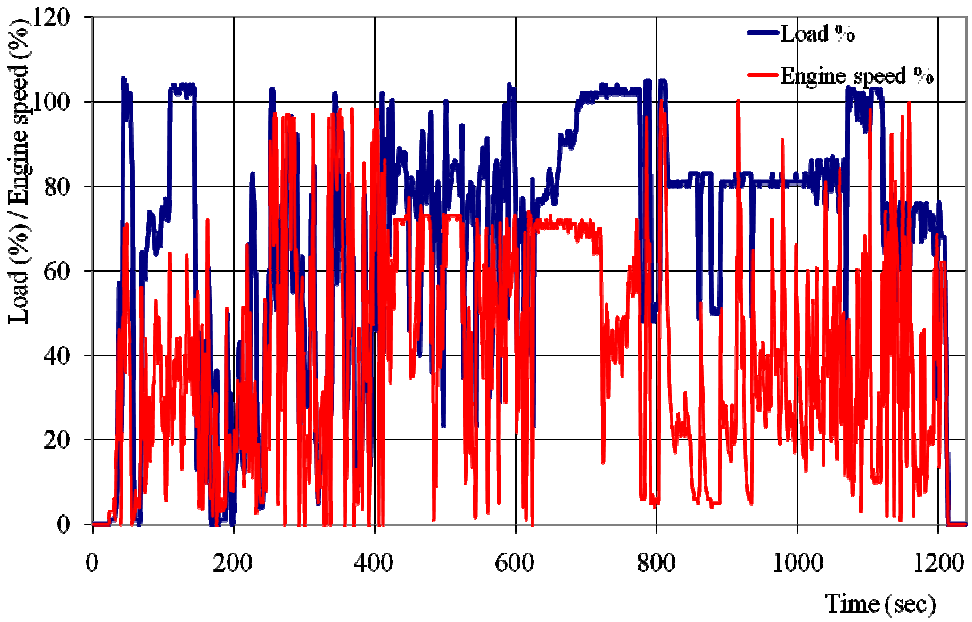

Figure 3: Non-Road Transient Cycle (NRTC) (Source: TÜV Nord)

4.3.3 Determination of emissions

The power output in the course of the cycle, from which the work generated by the engine over the cycle is found, is to be integrated using the feedback signals that come from the engine test bed, plotted against the engine torque and engine speed. The NO/NO_2 concentration that arises during the cycle is determined by integrating the analyser signal. The mass flow rate is to be determined over the cycle in order to calculate the mass emission values of the pollutants in the exhaust gas (for the raw exhaust gas) or the mass flow rate of the diluted exhaust gas. The mass emission values are to be related to the engine work in order to calculate the quantities of the individual pollutants released in grams per kilowatt hour.

Furthermore, the following points apply:
Following the conditioning of the engine or engine fitted with a particulate reduction system, three test cycles are conducted as measurement cycles in each case. As specified in this testing procedure, NO_x, NO_x*, NO*, NO_2, NO_2*, CO, HC and PM are determined separately for all three cycles. The variance in the NO_2 emissions may not be greater than 15 %. Should a higher variance be found, an additional measurement cycle must be conducted. If it is possible to select three results that have a variance of up to 15 % from the four measured results available, these three results are to be used for the determination of the mean value. All four measured results are to be given in the test report. If the variance is again greater than 15 %, the analytical instruments must be recalibrated and the engine conditioned once more.

$$Variance = \frac{\text{Standard deviation } (x_n)}{MeanValue(X_n)}$$

where:

$$x_n = \sqrt{\frac{n\sum x^2 - (\sum x)^2}{n^2}} \text{ and } X_n = (x_1 + x_2 + x_3 + ...x_n)/n$$

Where n = number of measured values, x = individual measured value

4.3.3.1 Determination of raw emissions from test engines <u>without</u> particulate reduction systems

The raw emissions from the test engines are determined in accordance with the guidelines set out in Directive 2005/55/EC using the appropriate driving cycle. Where engines for non-road mobile machinery comply with the limit values for the relevant Euro stage and, furthermore, where engines for commercial vehicles comply with the limit values set out in Table 1, the engines may be used for NO_2 testing.

Subsequently – as the basis for the determination of the alteration in NO_2 emissions due to the deployment of particulate reduction systems – the emissions from the test engines are determined without particulate reduction systems over the following cycles:

- Engines that are exclusively used in commercial vehicles: the urban part of the ETC cycle.
- Engines for non-road mobile machinery: the NRTC cycle. Where these engines are also used in commercial vehicles, they are to be tested additionally over the urban part of the ETC cycle.

4.3.3.2 Determination of emissions <u>with</u> particulate reduction systems

Following the conditioning of the particulate reduction system (section 4.1.2), three test cycles are conducted as measurement cycles in each case. When this is done, the first test cycle is, if possible, to begin once the stipulated test conditions have been attained and, at the latest, within 20 seconds from this point. As stipulated in this testing procedure, NO_x, NO_x*, NO*, NO_2, NO_2*, CO, HC and PM are to be determined separately for all three cycles. The following test cycles are used, depending on the area of application for which the particulate reduction system is intended:

- Particulate reduction systems for engines that are exclusively used in commercial vehicles: the urban part of the ETC cycle.
- Particulate reduction systems for engines that are used in non-road mobile machinery: the NRTC cycle and (for engines that are also used in commercial vehicles) the urban part of the ETC cycle.

4.4 Calculation of specific emissions

The specific emissions are calculated on the basis of the emission mass flow rates in accordance with Directive 2005/55/EC.

Calculation of emission mass flow rates
i) For raw exhaust gas:

$$m_{\text{gas}} = u_{\text{gas}} \times c_{\text{gas}} \times q_{\text{mew}}$$

u_{gas} = Ratio between the density of the exhaust gas component and the density of the exhaust gas
c_{gas} = Concentration of the exhaust gas component, measured in the exhaust gas, in ppm
q_{mew} = Mass flow rate of the exhaust gas, in kg/h

ii) For diluted exhaust gas:

$$m_{\text{gas}} = u_{\text{gas}} \times c_{\text{gas,c}} \times q_{\text{mdew}}$$

u_{gas} = Ratio between the density of the exhaust gas component and the density of the air
$c_{gas,c}$ = Background-corrected concentration of the exhaust gas component, measured in the diluted exhaust gas, in ppm
q_{mdew} = Mass flow rate of the diluted exhaust gas, in kg/h

Nitrogen oxides are also calculated in accordance with the specifications set out in Annex XXVII to the StVZO or Directive 2005/55/EC. In particular, this means:

NO_x: Determination and calculation in accordance with the guidelines set out in Directive 2005/55/EC

NO_2: Determination and calculation in accordance with the guidelines set out in Directive 2005/55/EC or Annex XXVII to the StVZO

In addition to this, the mass flows for NO* and NO_2* should be calculated from the measured concentration of the nitrogen oxide exhaust gas component (in ppm) on the basis of their true densities. The ratios between the densities of the exhaust gas components (NO* or NO_2*) and the density of the exhaust gas are listed in Table 3, in which respect the characteristics of the ideal gases and the fuels relevant under the directive are taken as the basis for the figures. The u_{gas} values given in Table 3 are to be used for the calculation. The total is to be found and NO_x* calculated from the calculated emission mass flow rates.

NO*: Calculation in accordance with Directive 2005/55/EC on the basis of the measured ppm and the density ratios specified in Table 3

NO_2*: Calculation in accordance with Directive 2005/55/EC on the basis of the measured ppm and the density ratios specified in Table 3

NO_x*: Total of NO* and NO_2*

Table 3: Values of u_{gas} in raw exhaust gas and diluted exhaust gas for various exhaust gas components

		NO_x	NO*[1]	NO_2*[1]
Diesel	Diluted	0.001588	0.001033	0.001588

	Undiluted	0.001587	0.001033	0.001587
Ethanol	Diluted	0.001609	0.001047	0.001609
	Undiluted	0.001588	0.001033	0.001588

[1]Basis for calculation: NO density: 1.34 g/cm^3
NO_2 density: 2.05 g/cm^3

The filtration efficiency is to be calculated in accordance with the guidelines set out in Annex XXVII to the StVZO from the data measured during the urban part of the ETC cycle or, for non-road mobile machinery, the NRTC, and detailed in the test report.

5. Requirements placed on particulate reduction systems for the establishment of a system family

It is, in principle, possible to establish system families for particulate reduction systems. The requirements set out in Annex XXVII to the StVZO apply, except where additional or other requirements are set out in this procedure (e.g. with regard to coatings and the fitting of the system).

6. Fuel quality

The measurements to be used for the testing of particulate reduction systems are taken with commercially available fuels specified in Annex XXVII.1.1 to the StVZO.

Annex I

Overview of testing processes

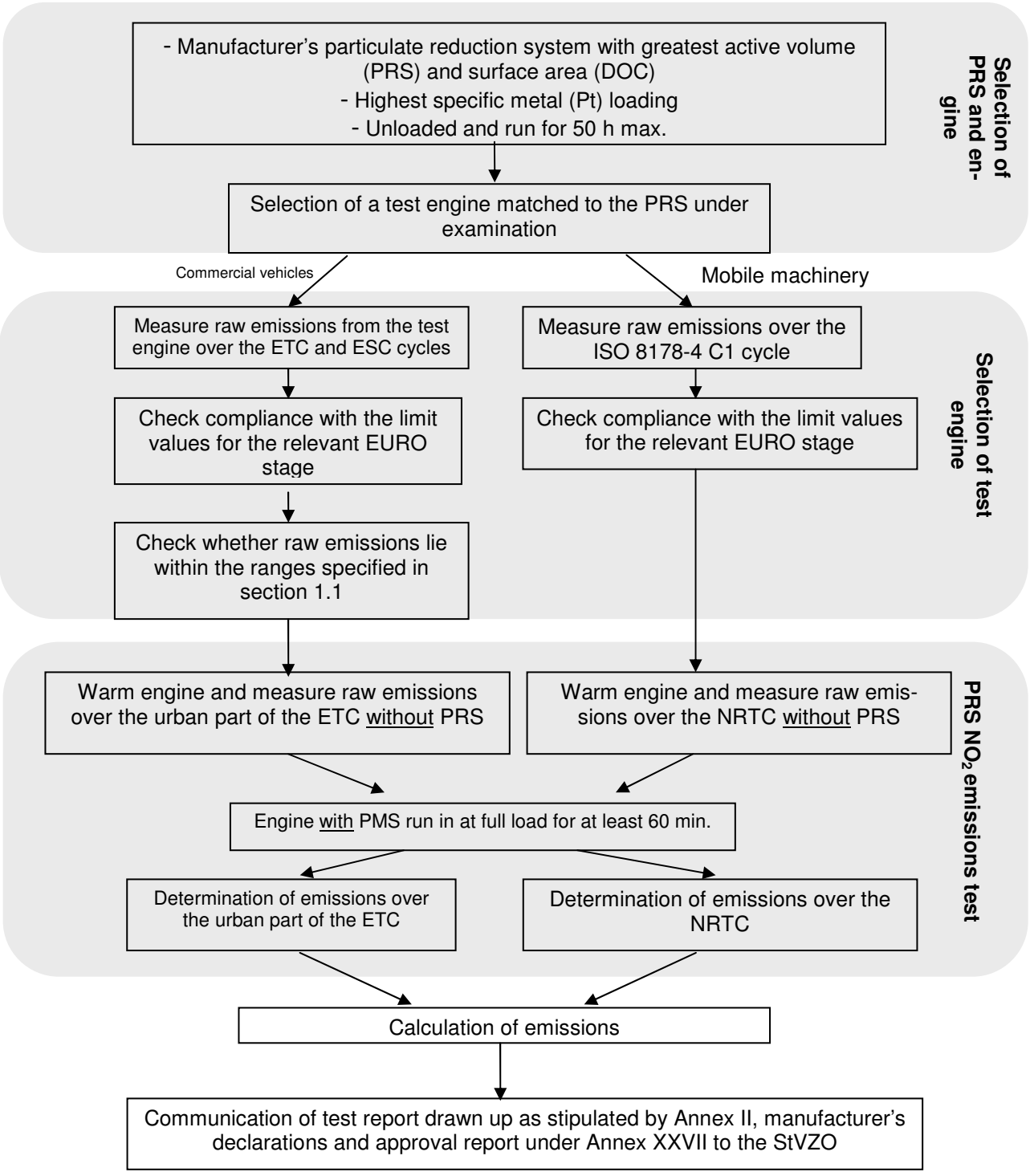

Figure 1: Testing processes

Annex II

Test report

The test report is to be submitted together with a copy of the test report for the system's certification under Annex XXVII to the StVZO and the confirmation that it is the particulate reduction system with the maximum-weight coating within its particulate reduction system family. The test report must include the following information:

- 0.1 Applicant's name and address
- 0.2 Manufacturer's name and address
- 0.3 Test laboratory's name and address
- 1.0 Type of particulate reduction system/particulate reduction system family, Type Approval, etc.
- 1.1 Particulate reduction system models
- 1.2 Type Approval number issued by the KBA, date Type Approval issued
- 1.3 Form(s) of marking
- 1.4 Details of fitting: distance between particulate reduction system and turbocharger
- 1.5 Temperature of the sampling line
- 2.0 Test engine
    - Manufacturer
    - Type
    - Bore
    - Stroke length
    - Number of cylinders
    - Cylinder capacity
    - Rated engine power
    - Rated engine speed
    - Maximum torque
    - Engine speed at max. torque
    - Supercharging
    - Boost pressure upstream from intercooler
    - Boost pressure downstream from intercooler
- 2.1 Raw emissions from test engine
    - Raw emissions over the ISO 8178-4 C1 cycle and/or the ETC and ESC cycles: NO_x, NO_x*, NO*, NO_2, NO_2*, CO, HC and PM
    - Raw emissions over the urban part of the ETC cycle: NO_x, NO_x*, NO*, NO_2, NO_2*, CO, HC and PM
- 2.2 Type of regeneration used in the particulate reduction system as specified in Annex XXVII to the StVZO
- 2.3 Emissions with particulate reduction system
    - Emissions over the NRTC cycle and/or the urban part of the ETC cycle: CO, HC, NO_x, NO*, NO_2, NO_2* and NO_x*
    - Particulate mass emissions and filtration efficiency over the NRTC cycle for non-road mobile machinery and/or the urban part of the ETC cycle
    - Variance of NO_2 emissions
- 3.0 Manufacturer's confirmation concerning the catalytic coating(s) and service accumulation of the particulate reduction system
- 4.0 Test report for approval under Annex XXVII to the StVZO