Submitted by the IWG on RDE

Informal document **GRPE-82-15**

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agenda item 3(c)

Submitted by the RDE IWG

Current Status of Development of the Global Technical Regulation on Real Driving Emissions

The text reproduced below shows the current status of the work to develop a new Global Technical Regulation on Real Driving Emissions. The current version of this draft GTR reflects to a large extent the method and procedure which is already found in the proposed UNR on RDE with changes made in order to make it applicable for more regions. Since the UNR on RDE has been finalised, there is no immediate need to introduce the same methodology at a GTR level. Given this fact, the draft GTR text below has not yet been updated to fully reflect the developments in the UNR. In particular cross-references to other sections need to be updated to reflect the new structure of the GTR – which has been modified to reflect the structure of the UNR RDE. There are also sections of the GTR which would need to be updated, where appropriate, to align with the requirements in UNR RDE. Comments, placeholders and highlighting are used throughout the text to indicate where changes would be needed.

The RDE IWG is now considering to proceed directly in the second phase of development in order to address the concerns of some contracting parties that the current procedure does not represent adequately all conditions of use. An appropriate mandate request will be prepared and submitted to GRPE in due time.

I. Statement of technical rationale and justification

[To be prepared]

II. Text of the GTR

1. Purpose

This United Nations global technical regulation (UN GTR) aims at providing a worldwide harmonised method to determine the levels of Real Driving Emissions (RDE) of gaseous compounds and particles from light-duty vehicles. The results will provide the basis for the regulation of these vehicles within regional type approval and certification procedures.

2. Scope and application

This UN GTR applies to vehicles of categories 1-2 and 2, both having a technically permissible maximum laden mass not exceeding 3,500 kg, and to all vehicles of category 1-1.

3. Definitions

For the purposes of this GTR, the following definitions shall apply:

3.1. Reserved

3.2. Test equipment

3.2.1. "Accuracy" means the difference between a measured value and a reference value, traceable to a national standard and describes the correctness of a result.

3.2.2. *"Adapter"* means a pipe attachment that connects the exhaust tailpipe of the tested vehicle to the exhaust mass flow meter.

3.2.3. "Analyser" means any measurement device that is not part of the vehicle but installed to determine the concentration or the amount of gaseous or particle criteria emissions.

3.2.4. "Calibration" means the process of setting a measurement system's response so that its output agrees with a range of reference signals.

3.2.5. "Calibration gas" means a gas mixture used to calibrate gas analysers.

3.2.6. "Delay time" means the difference in time between the change of the component to be measured at the reference point and a system response of 10 per cent of the final reading (t_{10}) with the sampling probe being defined as the reference point.

3.2.7. "Full scale" means the full range of an analyser, flow-measuring instrument or sensor as specified by the equipment manufacturer. If a sub-range of the analyser, flow-measuring instrument or sensor is used for measurements, full scale shall be understood as the maximum reading of the sub-range.

3.2.8. "Hydrocarbon response factor" of a particular hydrocarbon species means the ratio between the reading of a FID and the concentration of the hydrocarbon species under consideration in the reference gas cylinder, expressed as ppmC1.

3.2.9. "Major maintenance" means the adjustment, repair or replacement of a component or module that could affect the accuracy of a measurement.

3.2.10. "Noise" means two times the root mean square of ten standard deviations, each calculated from the zero responses measured at a constant frequency which is a multiple of 1,0 Hz during a period of 30 seconds.

3.2.11. "Non-methane hydrocarbons" (NMHC) means the Total Hydrocarbons (THC) minus the methane (CH4) contribution.

3.2.12. "Precision" means the degree to which repeated measurements under unchanged conditions show the same results (Figure 1).

3.2.13. "Reading" means the numerical value displayed by an analyser, flow-measuring instrument, sensor or any other measurement devise applied in the context of vehicle emission measurements.

3.2.14. "Reference value" means a value traceable to a national or international standard (Figure 1).

3.2.15. "Response time" (t_{90}) means the difference in time between the change of the component to be measured at the reference point and a system response of 90 per cent of the final reading (t_{90}) with the sampling probe being defined as the reference point, whereby the change of the measured component is at least 60 per cent full scale (FS) and takes place in less than 0.1 second. The system response time consists of the delay time to the system and of the rise time of the system

3.2.16. "Rise time" means the difference in time between the 10 per cent and 90 per cent response of the final reading (t_{10}tot$_{90}$)

3.2.17. "Sensor" means any measurement device that is not part of the vehicle itself but installed to determine parameters other than the concentration of criteria emissions and the exhaust mass flow.

3.2.18. "Set point" means the target value a control system aims to reach.

3.2.19. "Span" means to adjust an instrument so that it gives a proper response to a calibration standard that represents between 75 per cent and 100 per cent of the maximum value in the instrument range or expected range of use.

3.2.20. "Span response" means the mean response to a span signal over a time interval of at least 30 seconds.

3.2.21. "Span response drift" means the difference between the mean response to a span signal and the actual span signal that is measured at a defined time period after an analyser, flow-measuring instrument or sensor was accurately spanned.

3.2.22. "Total hydrocarbons" (THC) means the sum of all volatile compounds measurable by a flame ionization detector (FID).set

3.2.23. "Traceable" means the ability to relate a measurement or reading through an unbroken chain of comparisons to a national or international standard.

3.2.24. "Transformation time" means the time difference between a change of concentration or flow (t_0) at the reference point and a system response of 50 per cent of the final reading (t_{50}).

3.2.25. "Type of analyser", also referred to as "analyser type" means a group of analysers produced by the same manufacturer that apply an identical principle to determine the concentration of one specific gaseous component or the number of particles.

3.2.26 "Type of exhaust mass flow meter" means a group of exhaust mass flow meters produced by the same manufacturer that share a similar tube inner diameter and function on an identical principle to determine the mass flow rate of the exhaust gas.

3.2.27. "Verification" means the process of evaluating whether the measured or calculated output of an analyser, flow-measuring instrument, sensor or signal or method agrees with a reference signal or value within one or more predetermined thresholds for acceptance.

3.2.28. "Zero" means the calibration of an analyser, flow-measuring instrument or sensor so that it gives an accurate response to a zero signal.

3.2.29. "Zero gas" means a gas containing no analyte, which is used to set a zero response on an analyser.

3.2.30. "Zero response" means the mean response to a zero signal over a time interval of at least 30 seconds.

3.2.31. "Zero response drift" means the difference between the mean response to a zero signal and the actual zero signal that is measured over a defined time period after an analyser, flow-measuring instrument or sensor has been accurately zero calibrated.

Figure 1 - Definition of accuracy, precision and reference value

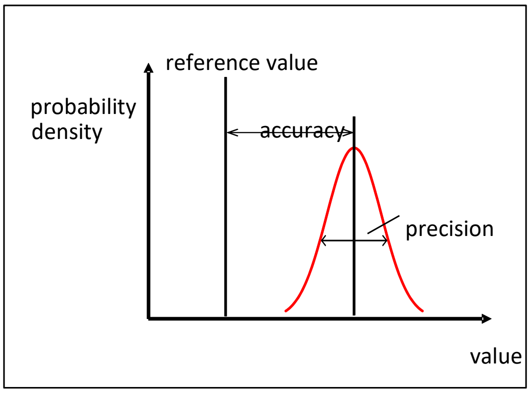
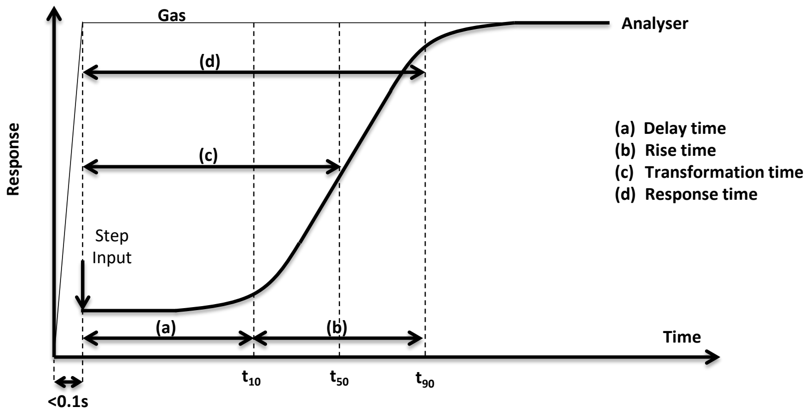


Figure 2 - Definition of delay, rise, transformation and response times



3.3. Vehicle characteristics and driver

3.3.1. "Actual mass of the vehicle" means the mass in running order plus the mass of the fitted optional equipment to an individual vehicle.

3.3.2. "Auxiliary devices" means energy consuming, converting, storing or supplying non-peripheral devices or systems which are installed in the vehicle for purposes other than the propulsion of the vehicle and are therefore not considered to be part of the powertrain.

3.3.3. "Mass in running order" means the mass of the vehicle, with its fuel tank(s) filled to at least 90 per cent of its or their capacity/capacities, including the mass of the driver, fuel and liquids, fitted with the standard equipment in accordance with the manufacturer's specifications and, when they are fitted, the mass of the bodywork, the cabin, the coupling and the spare wheel(s) as well as the tools.

3.3.4. "Maximum Permissible Test mass of the vehicle" means the sum of:
- the actual mass of the vehicle;
- 90% of the difference between the technically permissible maximum laden mass and the actual mass of the vehicle (Figure 3).

3.3.5. "Odometer" means an instrument indicating to the driver the total distance driven by the vehicle since its production.

3.3.6. "Optional equipment" means all the features not included in the standard equipment which are fitted to a vehicle under the responsibility of the manufacturer, and that can be ordered by the customer.

3.3.7. "Power-to-test mass-ratio" corresponds to the ratio of the rated engine power and of the test mass.

3.3.8. *"Power-to-mass-ratio"* is the ratio of rated power to the mass in running order.

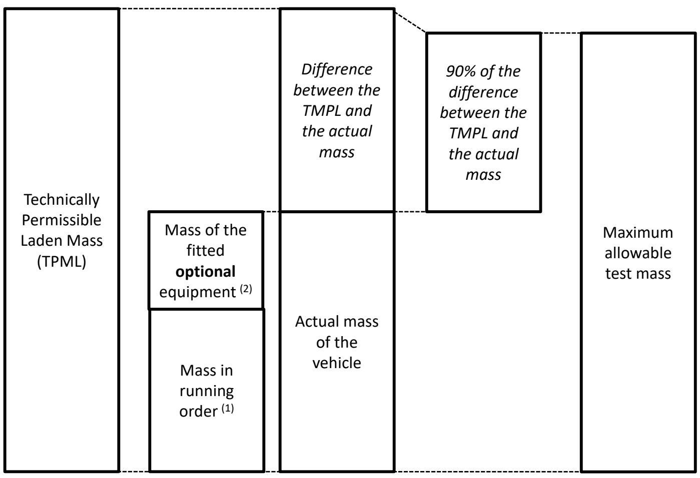
3.3.9. "Rated engine power (P_{rated})" means maximum net power of the engine or motor in kW as per the certification procedure based on current regional regulation. In the absence of a definition, the rated engine power shall be declared by the manufacturer according to Regulation No. 85.

Commented [RG 1606201]: NB: Differs from UNR – which needs to be more prescriptive

3.3.10. "Technically permissible maximum laden mass" means the maximum mass allocated to a vehicle on the basis of its construction features and its design performances.

3.3.11. "Vehicle OBD information" means information relating to an on-board diagnostic system for any electronic system on the vehicle

Figure 3 - Mass definitions



(1) means the mass of the vehicle, with its fuel tank(s) filled to at least 90 per cent of its or their capacity/capacities, including the mass of the driver, fuel and liquids, fitted with the **standard equipment** in accordance with the manufacturer's specifications and, when they are fitted, the mass of the bodywork, the cabin, the coupling and the spare wheel(s) as well as the tools.

(2) means all the features not included in the standard equipment which are fitted to a vehicle under the responsibility of the manufacturer, and that can be ordered by the customer.

3.4. Pure electric, pure ICE, hybrid electric, fuel cell, alternatively-fuelled and other vehicles

Commented [RG 1606202]: NB: Not in UNR

3.4.1. "Flex fuel vehicle" means a vehicle with one fuel storage system that can run on different mixtures of two or more fuels.

3.4.2. "Mono-fuel vehicle" means a vehicle that is designed to run primarily on one type of fuel.

3.4.3. "Not off-vehicle charging hybrid electric vehicle" (NOVC-HEV) means a hybrid electric vehicle that cannot be charged from an external source.

3.4.4. "Off-vehicle charging hybrid electric vehicle" (OVC-HEV) means a hybrid electric vehicle that can be charged from an external source.

3.4.5. “M1/M2/N1 Low Powered Vehicles” class 1vehicles having a power to kerb weight ratio < 22W/kg and max design speed < 70 kmph.

Commented [RG 1606203]: NB: Not in UNR

3.5. Calculations

"Axis intercept" of a linear regression (a_0) means:

$$a_0 = \overline{y} - (a_1 \times \overline{x})$$

where:

a_1 is the slope of the regression line

$\overline{x}$ is the mean value of the reference parameter

$\overline{y}$ is the mean value of the parameter to be verified

Commented [RG 1606204]: NB: Not in UNR

3.5.1. "Coefficient of determination" (r^2) means:

$$r^2 = 1 - \frac{\sum_{i=1}^{n}[y_i - a_0 - (a_1 \times x_i)]^2}{\sum_{i=1}^{n}(y_i - \overline{y})^2}$$

where:

a_0 is the axis intercept of the linear regression line

a_1 is the slope of the linear regression line

x_i is the measured reference value

y_i is the measured value of the parameter to be verified

$\overline{y}$ is the mean value of the parameter to be verified

n is the number of values

3.5.2. "Cross-correlation coefficient" (r) means:

$$r = \frac{\sum_{i=1}^{n-1}(x_i - \overline{x}) \times (y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n-1}(x_i - \overline{x})^2} \times \sqrt{\sum_{i=1}^{n-1}(y_i - \overline{y})^2}}$$

where:

x_i is the measured reference value

y_i is the measured value of the parameter to be verified

$\overline{x}$ is the mean reference value

$\overline{y}$ is the mean value of the parameter to be verified

n is the number of values

3.5.3. "Root mean square" (x_{rms}) means the square root of the arithmetic mean of the squares of values and defined as:

$$x_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}$$

where:

x_i is the measured or calculated value

n is the number of values

3.5.4. "Slope" of a linear regression (a_1) means:

$$a_1 = \frac{\sum_{i=1}^{n}(x_i - \overline{x}) \times (y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

where:

x_i is the actual value of the reference parameter

y_i is the actual value of the parameter to be verified

$\overline{x}$ is the mean value of the reference parameter

$\overline{y}$ is the mean value of the parameter to be verified

n is the number of values

3.5.5. "Standard error of estimate" (SEE) means:

$$SEE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \acute{y})^2}{n-2}}$$

where:

$\acute{y}$ is the estimated value of the parameter to be verified

y_i is the actual value of the parameter to be verified

n is the number of values

3.6. General

3.6.1. "Cold start period" means the period from the test start until the point when the vehicle has run for 5 minutes. If the coolant temperature is determined, the cold start period ends once the coolant is at least 70 °C for the first time, but no later than 5 minutes after test start. In the case that measuring the coolant temperature is not feasible, on request of the manufacturer and with approval of the approval authority, instead of using the coolant temperature, the engine oil temperature may be used.

3.6.2. "Criteria emissions" means those emission compounds for which limits are set in regional legislation.

3.6.3. "Deactivated internal combustion engine" means an internal combustion engine for which one of the following criteria apply:
- the recorded engine speed is < 50 rpm;

- or when the engine speed is not recorded, the exhaust mass flow rate is measured at < 3 kg/h.

3.6.4. "Engine capacity" means either of the following:
- for reciprocating piston engines, the nominal engine swept volume;
- for rotary piston (Wankel) engines, double the nominal engine swept volume.

3.6.5. "Engine control unit" means the electronic unit that controls various actuators to ensure the optimal performance of the engine.

3.6.6. "Exhaust emissions" means the emission of gaseous, solid and liquid compounds from the tailpipe.

3.6.7. "Extended factor" means a factor which accounts for the effect of extended ambient temperature or altitude conditions upon criteria emissions

3.7. Particles

The term "particle" is conventionally used for the matter being characterised (measured) in the airborne phase (suspended matter), and the term "particulate" for the deposited matter.

3.7.1. "Particle number emissions" (PN) means the total number of solid particles emitted from the vehicle exhaust quantified according to the dilution, sampling and measurement methods as specified in this UN GTR.

3.7.2. "Particulate matter emissions" (PM) means the mass of any particulate material from the vehicle exhaust quantified according to the dilution, sampling and measurement methods as specified in this UN GTR.

Commented [RG 1606205]: NB: Not in UNR

3.8. Procedure

3.8.1. "Cold start PEMS trip" means a trip with conditioning of the vehicle prior to the test (as described in point 5.3 in the present Regulation).

Commented [JRC-ISPRA6]: Highlight means that references needed to be corrected at the end

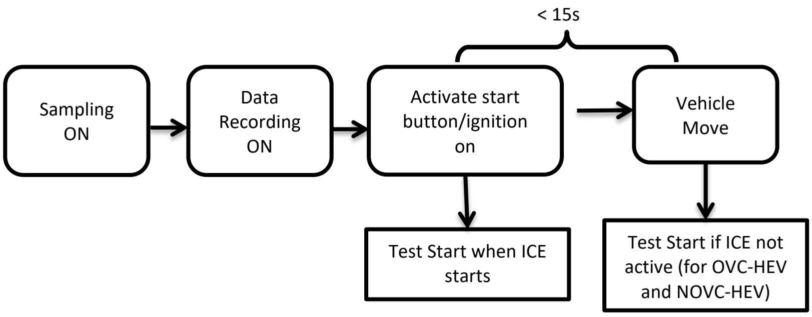
3.8.2. "Hot start PEMS trip" means a trip without conditioning of the vehicle prior to the test (as described in point 5.3 in the present Regulation), but with a warm engine with engine coolant temperature and/or engine oil temperature above 70 °C. In the case that measuring the coolant temperature is not feasible, on request of the manufacturer and with approval of the approval authority, instead of using the coolant temperature, the engine oil temperature may be used.

3.8.3. "Periodically regenerating system" means an exhaust emissions control device (e.g. catalytic converter, particulate trap) that requires a periodical regeneration.

3.8.4. "Reagent" means any product other than fuel that is stored on-board the vehicle and is provided to the exhaust after-treatment system upon request of the emission control system.

3.8.5. "Test start" means (Figure 4) whichever occurs first from:
- the first activation of the internal combustion engine;
- the first movement of the vehicle with speed greater than 1 km/h for OVC-HEVs and NOVC-HEVs.

Figure 4 - Test start definition



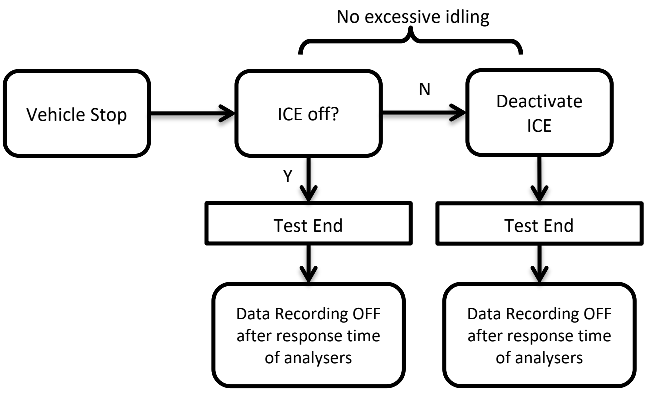
3.8.6. *"Test end"* means (Figure 5) that the vehicle has completed the trip and whichever occurs last from:

- the final deactivation of the internal combustion engine;

- the vehicle stops and the speed is lower than or equal to 1 km/h for OVC-HEVs and NOVC-HEVS finishing the test with deactivated internal combustion engine.

Figure 5

Test end definition



3.8.7. "Validation of PEMS" means the process of evaluating the correct installation and functionality of a Portable Emissions Measurement System and the correctness of exhaust mass flow rate measurements as obtained from one or multiple non-traceable exhaust mass flow meters or as calculated from sensors or ECU signals.

4. *Abbreviations*

Abbreviations refer generically to both the singular and the plural forms of abbreviated terms.

[To be added at the end of drafting.]

Commented [RG 2506207]: NB: in UNR section 4 is "Application for Approval"

5. GENERAL REQUIREMENTS

Commented [RG 2506208]: NB: in UNR Section 5 is “Approval”

5.1. Compliance requirements:

Commented [RG 2506209]: Update to align with UNR (where appropriate)?

The compliance of a vehicle during an RDE test performed in accordance with this GTR shall be evaluated against the regional requirements on emission limits as defined by the Contracting Party.

The requirements on emission limits regulated by each Contracting Party shall be fulfilled for the urban operation and the complete PEMS trip.

The RDE performance shall be demonstrated by testing vehicles on public roads (or track or on private roads, both with normal road surface) operated over their normal driving patterns, conditions and payloads. The RDE test shall be representative for vehicles operated on their real driving routes, with their normal load.

A Contracting Party may choose, in case of difficulty to conduct RDE testing on public roads due to regional law, to use a test track with normal road surface following a driving situation recorded during a typical valid RDE test on the road. The validity of a test conducted on a test track will be judged on the actual test driven on the test track.

5.2. Facilitation of PEMS Testing:

A Contracting Party shall ensure that vehicles can be tested with PEMS on public roads in accordance with the procedures under their own national law, while respecting local road traffic legislation and safety requirements.

Manufacturers shall ensure that vehicles can be tested with PEMS. This shall include:

(a) constructing the exhaust pipes in order to facilitate sampling of the exhaust, or making available suitable adapters for exhaust pipes for testing by the authorities;

(b) As a Contracting Party option, in case the exhaust pipe construction does not facilitate sampling of the exhaust, the manufacturer shall also make available to independent parties, adapters for purchase or rent via their spare parts or service tools network (e.g. RMI portal), through authorised dealers or via a contact point on the referred publically accessible website.

(c) providing guidance available online, without the need of registration or login, on how to attach a PEMS system to vehicles approved under this Regulation;

(d) granting access to ECU signals [relevant to this Regulation, as mentioned in Table 1 of Annex 3]; and

(e) making the necessary administrative arrangements.

5.3. Selection of vehicles for PEMS testing

Commented [RG 25062010]: Align with UNR (where appropriate)?

[Xxx]

5.4. Validation of a PEMS test family

Commented [RG 25062011]: Align with UNR (where appropriate)?

[Xxx]

6. Rounding requirements:

Commented [RG 25062012]: From UNR

Rounding of data in the data exchange file, created according to Annex 7, paragraph 10., is not permitted. In the pre-processing file, the data may be rounded to the same order of magnitude of the accuracy of the measurement of a respective parameter.

The intermediate and final emission test results, as calculated in Annex 11, shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus one additional significant figure. Preceding steps in the calculations shall not be rounded.

7. Performance Requirements for instrumentation

The instrumentation used for RDE tests shall comply with the requirements found in Annex 5.

8. Test Conditions:

Only an RDE test performed according to the conditions specified in this Section shall be accepted as valid. Tests performed outside the test conditions specified in this Section shall be considered as invalid.

8.1. Ambient conditions

The test shall be conducted under ambient conditions (such as altitude, temperature, humidity) selected by CPs[1]. If a CP decides that there is a need to define ranges of ambient conditions for which the measured emissions need to be balanced, in order to prove compliance with the emission limits, then the provision of [xxx] will apply.

8.2. Dynamic conditions of trip

The dynamic conditions encompass the effect of road gradient, head wind and driving dynamics (accelerations, decelerations) and auxiliary devices upon energy consumption and emissions of the test vehicle. The assessment of the normality of dynamic conditions shall be done after the test is completed, using the recorded PEMS data. This assessment shall be conducted in 2 steps:

STEP i: The excess or insufficiency of driving dynamics during the trip shall be checked using the methods described in Appendix 7a.

STEP ii: If the trip is valid following the verifications in accordance with STEP i, the methods for verifying the validity of the trip as laid down in Annexes 8 and 10 shall be applied.

[11] Harmonized provisions will be developed during the phase 2 of the UN GTR development.

8.3. VEHICLE CONDITION AND OPERATION

8.3.1. Vehicle condition

The vehicle, including the emission related components, shall be in good mechanical condition and shall have been run in and driven at least 3,000 km before the test. The mileage and the age of the vehicle used for RDE testing shall be recorded.

All vehicles, and in particular OVC-HEVs vehicles may be tested in any selectable mode, including battery charge mode. On the basis of technical evidence provided by the manufacturer and with the agreement of the responsible authority, the dedicated driver-selectable modes for very special limited purposes shall not be considered (e.g. maintenance mode, race driving, crawler mode). All remaining modes used for forward driving shall be considered and the criteria emissions limits shall be fulfilled in all these modes.

Modifications that affect the vehicle aerodynamics are not permitted with the exception of the PEMS installation. The tyre types and pressure shall be according to the vehicle's manufacturer recommendations. The tyre pressure shall be checked prior to the pre-conditioning and adjusted to the recommended values if needed. Driving the vehicle with snow chains is not permitted.

Vehicles should not be tested with an empty starter battery. In case the vehicle has problems starting, the battery shall be replaced following the recommendations of the vehicle's manufacturer.

The vehicle's test mass comprising of the driver, a witness of the test (if applicable), the test equipment, including the mounting and the power supply devices and any artificial payload shall be between the actual mass of the vehicle and the maximum permissible test mass of the vehicle at the beginning of the test and shall not be increased during the test.

The test vehicles shall not be driven with the intention to generate a passed or failed test due to extreme driving that do not represent normal conditions of use. If necessary, verification of normal driving may be based on expert judgement made by or on behalf of the granting type approval authority through cross-correlation on several signals, which may include exhaust flow rate, exhaust temperature, CO2, O2 etc. in combination with vehicle speed, acceleration and GNSS data and potentially further vehicle data parameters like engine speed, gear, accelerator pedal position etc.

8.3.2. Vehicle conditioning for cold engine-start testing

Before RDE testing, the vehicle shall be preconditioned in the following way:

The vehicle shall be driven, preferably on the same route as the planned RDE testing or for at least 10 min per type of operation (e.g. urban, rural, motorway). The vehicle shall then be parked with doors and bonnet closed and kept in engine-off status within moderate or extended altitude and temperatures, in accordance with points 5.2.2. to 5.2.6., for between 6 and 64 hours. Exposure to extreme atmospheric conditions (such as heavy snowfall, storm, hail) and excessive amounts of dust or smoke should be avoided.

Before the test start, the vehicle and equipment shall be checked for damages and the presence of warning signals that may suggest malfunctioning. In the case of a malfunction the source of the malfunctioning shall be identified and corrected or the vehicle shall be rejected.

8.3.3. Auxiliary devices

The air conditioning system or other auxiliary devices shall be operated in a way which corresponds to their typically intended use during real driving on the road. Any use shall be documented. The vehicle windows shall be closed when the air conditioning or heating are used.

8.3.4. Vehicles equipped with periodically regenerating systems

8.3.4.1. All results shall be corrected with the relevant factors or offsets used to take into account regeneration events.

Commented [JPN Sep2013]: JPN proposes to modify to same text as UNR

8.3.4.2. If the emissions do not fulfil the emission limits, then the occurrence of regeneration shall be verified. The presence of the regeneration may be based on expert judgement through cross-correlation of several signals, which may include exhaust temperature, PM, PN, CO_2, O_2 measurements in combination with vehicle speed and acceleration.

Commented [JPN Sep2014]: JPN proposes to modify to same text as UNR

Commented [DP15]: Same problem with exceeding limits

Commented [RG 25062016]: UNR updates this

If the manufacturer declares that the vehicle has a regeneration recognition feature it shall provide to any possible testing party the procedure needed in order to use this feature. In such a case, the procedure may be used to determine the occurrence of regeneration. The manufacturer shall also declare the procedure needed in order to complete the regeneration. The manufacturer may advise how to recognise whether regeneration has taken place in case such a signal is not available.

8.3.4.3. If regeneration occurred during the test, the result without the application of either the regeneration factor or offset, if applicable, shall be checked against the regional requirements. If the resulting emissions do not fulfil the requirements, then the test shall be voided and repeated once. The completion of the regeneration and stabilisation through approximately 1 hour of driving shall be ensured prior to the start of the second valid test. The second valid test shall not be voided even if regeneration occurs during it.

Commented [JPN Sep2017]: JPN proposes to modify to same text as UNR

Even if the vehicle fulfils the requirements of point 3.1.0., the occurrence of regeneration may be verified as in point 5.5.2.3 above. If the presence of regeneration can be proved and with the agreement of the Type Approval Authority, the final results will be calculated without the application of any regeneration factors or offsets related to the regeneration event.

8.4. **OPERATIONAL REQUIREMENTS of PEMS**

The trip shall be selected in such a way that the testing is uninterrupted and the data continuously recorded to reach the minimum test duration defined in point 6.10.

Electrical power shall be supplied to the PEMS by an external power supply unit and not from a source that draws its energy either directly or indirectly from the engine of the test vehicle.

The installation of the PEMS equipment shall be done in a way to minimise the influence on the vehicle's emissions or performance or both to the greatest extent possible. Care should be exercised to minimise the mass of the installed equipment and potential aerodynamic modifications of the test vehicle. The vehicle payload shall be in accordance with point 5.1.

A validation test in the laboratory shall be performed before running an RDE test according to Annex 6. For OVC-HEV the applicable type approval test shall be conducted in the Charge Sustaining mode.

8.5. LUBRICATING OIL, FUEL AND REAGENT

The fuel, lubricant and reagent (if applicable) used for RDE testing shall be within the specifications issued by the manufacturer for vehicle operation by the customer.

As a Contracting Party option, if the RDE results exceed the limits, the reference fuel defined in Annex 3 of GTR15 Regional Regulation may be used for a second RDE test. In the case that an RDE result is repeated with reference fuel, the fuel sampling requirements of the paragraph below are not valid.

In the case of an RDE test with a failed result, samples of liquid fuel, lubricant and reagent (if applicable) shall be taken and kept by the testing party for at least 1 year under conditions guaranteeing the integrity of the sample. Once analysed to confirm they meet specifications issued by the manufacturer for vehicle operation by the customer, the samples can be discarded but the analysis shall be retained in the test documentation.

Commented [JPN Sep2018]: Should make it clear that this paragraph is also CP option?

9. **Test Procedure**

Test composition

The composition of the RDE test shall broadly reflect the composition and characteristics of the relevant regulatory cycles against which compliance will be checked.

Type of operation based on speed

The RDE test results shall be binned based on speed according to the speed limits chosen by the Contracting Party.

Shares of trip operations

The RDE trip/s shall cover a wide range of driving conditions associated with normal operation of the vehicle chosen by the Contracting Party.

As example, the following apply based on various regulatory cycles:

The Contracting Party applying WLTC 4 phase	The Contracting Party applying WLTC 3 phase (Japan)	"The Contracting Party applying WLTC 3 phase (India)
6.1. The shares of urban, rural and motorway driving, classified by instantaneous speed as described in points 6.3 to 6.5, shall be expressed as a percentage of the total trip distance.	6.1. The shares of urban, rural and motorway driving, classified by instantaneous speed as described in points 6.3 to 6.5, shall be expressed as a percentage of the total trip distance.	6.1. The shares of urban, rural and motorway driving, classified by instantaneous speed as described in points 6.3 to 6.5, shall be expressed as a percentage of the total trip distance.
6.2. The trip shall always start with urban driving followed by rural and motorway driving in accordance with the shares specified in point 6.6. The urban, rural and motorway operation shall be run consecutively in accordance with point 6.12, but may also include a trip which starts and ends at the same point. Rural operation may be interrupted by short periods of urban operation when driving through urban areas. Motorway operation may be interrupted by short periods of urban or rural operation, e.g., when passing toll stations or sections of road work.	6.2. The trip shall always start with urban/rural driving followed by motorway driving in accordance with the shares specified in point 6.6.	6.2. The trip shall always start with urban driving followed by rural and motorway driving in accordance with the shares specified in point 6.6. The urban, rural and motorway operation shall be run consecutively in accordance with point 6.12, but may also include a trip which starts and ends at the same point. Rural operation may be interrupted by short periods of urban operation when driving through urban areas. Motorway operation may be interrupted by short periods of urban or rural operation, e.g., when passing toll stations or sections of road work.
6.3. Urban operation is characterised by vehicle speeds lower than or equal to 60 km/h.	6.3. Urban/rural operation is characterised by vehicle speeds lower than or equal to 60 km/h.	6.3. Urban operation (Phase I) is characterised by vehicle speeds lower than 45 km/h for M, 40 km/h for N1, and 45 km/h for M1/M2/N1 low powered categories of vehicles."
6.4. Rural operation is characterised by vehicle speeds higher than 60 km/h and lower than or equal to 90 km/h. For N2 category vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 90 km/h, rural operation is characterised by vehicle speed higher than 60 km/h and lower than or equal to 80 km/h.		6.4. Rural operation (Phase II) is characterised by vehicle speeds higher than or equal to 45 km/h and lower than 65 km/h for M, speeds higher than or equal to 40 km/h and lower than 60 km/h for N1 and for M1/M2/N1 low powered categories of vehicles since only 2 phases considered will be higher than or equal to 45 km/h."

6.5. Motorway operation is characterised by speeds above 90 km/h. For N2 category vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 90 km/h, motorway operation is characterised by speed higher than 80 km/h.	6.5. Motorway operation is characterised by speeds above 60 km/h.	6.5. Motorway operation (Phase III) is characterized by speeds higher than or equal to 65 km/h for M, higher than or equal to 60 km/h for N1.
6.6. The trip shall consist of approximately 34 % per cent urban, 33 % per cent rural and 33 % per cent motorway driving classified by speed as described in points 6.3 to 6.5 above. 'Approximately' shall mean the interval of ±10 per cent points around the stated percentages. The urban driving shall however never be less than 29% of the total trip distance.	6.6. The trip shall consist of approximately 55 % per cent urban/rural and 45 % per cent motorway driving classified by speed as described in points 6.3 to 6.5 above. 'Approximately' shall mean the interval of ±10 per cent points around the stated percentages. As an exception, the urban/rural driving however can be lower than 45% but never be less than 40% of the total trip distance.	6.6. The trip shall consist of approximately 34% urban (Phase I), 33% rural (Phase II) and 33% motorway (Phase III) driving for M & N1 categories; 50% Phase I and 50% Phase II driving for M1/M2/N1 low powered classified by speed as described in Points 6.3 to 6.5 above. ""Approximately"" shall mean the interval of ±10% points around the stated percentages."
6.7. The vehicle velocity shall normally not exceed 145 km/h. This maximum speed may be exceeded by a tolerance of 15 km/h for not more than 3 % of the time duration of the motorway driving. Local speed limits remain in force during a PEMS test, notwithstanding other legal consequences. Violations of local speed limits per se do not invalidate the results of a PEMS test.		6.7. Wherever legal max speed limit permits, the vehicle of M category can be driven above 100 km/h but not for more than 3 % of the time duration of the Phase III driving. For N1 Category of vehicles, the vehicle velocity shall not normally exceed 80 km/h and for M1/M2/N1 low powered category vehicles, it should not exceed70 km/h. Local speed limits remain in force during a PEMS test, notwithstanding other legal consequences. Violations of local speed limits per se do not invalidate the results of a PEMS test."
6.8. The average speed (including stops) of the urban driving part of the trip should be between 15 and 40 km/h. Stop periods, defined by vehicle speed of less than 1 km/h, shall account for 6-30 % of the time duration of urban operation. Urban operation may contain several stop periods of 10 s or longer. However, individual stop periods shall not exceed 300	6.8. Stop periods, defined by vehicle speed of less than 1 km/h, shall account for 6-30 % of the time duration of urban/rural operation. Urban/rural operation may contain several stop periods of 10 s or longer. However, individual stop periods shall not exceed 300 consecutive seconds; else the trip shall be voided.	6.8. The average speed (including stops) of the urban driving part of the trip should be between 15 km/h and 30 km/h for M, N1 and M1/M2/N1 low powered categories of vehicles. Stop periods, defined as vehicle speed of less than 1 km/h, shall account for 6 to 30% of the time duration of urban operation. Urban operation shall contain several stop periods of 10s

consecutive seconds; else the trip shall be voided.If stop periods in urban driving part are over 30% or there are individual stop periods exceeding 300 consecutive seconds, the test shall be invalid only if applicable emissions do not fulfil the regional requirement.		or longer. However, individual stop periods shall not exceed 300 consecutive seconds; else the trip shall be voided. Vehicle should not be driven continuously below 20 km/h for 20 minutes."
6.9. The speed range of the motorway driving shall properly cover a range between 90 and at least 110 km/h. The vehicle's velocity shall be above 100 km/h for at least 5 minutes. For M2 category vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 100 km/h, the speed range of the motorway driving shall properly cover a range between 90 and 100 km/h. The vehicle's velocity shall be above 90 km/h for at least 5 minutes. For N2 category vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 90 km/h, the speed range of the motorway driving of shall properly cover a range between 80 and 90 km/h. The vehicle's velocity shall be above 80 km/h for at least 5 minutes.		6.9. For M1/M2/N1 low powered category vehicles and The speed range of the Phase II driving shall properly cover a range between 45 km/h and up to 70 km/h. The vehicle's velocity shall be above 55 km/h for at Least 5min." For M category vehicles and The speed range of the motorway driving shall properly cover a range between 65 km/h and up to the applicable legal limit, if possible, based upon the test route. The vehicle's velocity shall be above 75km/h for at least 5min. For N1 category vehicles and The speed range of the motorway driving shall properly cover a range between 60km/h and up to 80km/h. The vehicle's velocity shall be above 70 km/h for at least 5min.
6.10. The trip duration shall be between 90 and 120 minutes.	6.10. The trip duration shall be between 90 and 120 minutes.	6.10. The trip duration shall be between 90 and 120 minutes.
6.11. The start and the end point of a trip shall not differ in their elevation above sea level by more than 100 m. In addition, the proportional cumulative positive altitude gain over the entire trip and over the urban part of the trip as determined in accordance with point 4.3 shall be less than 1200 m/100 km and be determined in accordance with Appendix 7b.	6.11. The start and the end point of a trip shall not differ in their elevation above sea level by more than 100 m. In addition, the proportional cumulative positive altitude gain over the entire trip and over the urban/rural part of the trip as determined in accordance with point 4.3 shall be less than 1200 m/100 km and be determined in accordance with Appendix 7b.	6.11. The start and the end point of a trip shall not differ in their elevation above sea level by more than 100 m. In addition, the proportional cumulative positive altitude gain over the entire trip and over the urban/rural part of the trip as determined in accordance with point 4.3 shall be less than 1200 m/100 km and be determined in accordance with Appendix 7b.

6.12. The minimum distance of each, the urban, rural and motorway operation shall be 16 km.	6.12. The minimum distance of each, the urban/rural operation shall be 32km and motorway operation shall be 16 km.	6.12. The minimum distance of each, the urban, rural and motorway operation shall be 16km for M and N1 categories vehicles. (vii) For M1/M2/N1 low powered category of vehicle, the minimum distance of each, Phase I & Phase II operation shall be 24 km."
6.13. The average speed (including stops) during cold start period as defined in Appendix 4, point 4 shall be between 15 and 40 km/h. The maximum speed during the cold start period shall not exceed 60 km/h.	6.13. The average speed (including stops) during cold start period as defined in Appendix 4, point 4 shall be between 15 and 40 km/h. The maximum speed during the cold start period shall not exceed 60 km/h.	6.13. The average speed (including stops) during cold start period as defined in clause 4 of Appendix 4 of this Chapter, shall be between 15 and 30 km/h. The maximum speed during the cold start period shall not exceed 45 km/h for M, M1/M2/N1 Low Powered and 40 km/h for N1 category of vehicles."

9.3. RDE tests to be performed

The RDE performance shall be demonstrated by testing vehicles on the road (or on the track), operated over their normal driving patterns, conditions and payloads. RDE tests shall be conducted on paved roads (e.g. off-road operation is not permitted).

9.4. Other trip requirements

If the engine stalls during the test, it may be restarted, but the sampling shall not be interrupted. If the engine stops during the test, the sampling shall not be interrupted.

The collection of ECU data shall not influence the vehicle's emissions or performance.

The responsible authority may verify if the test setup and the equipment used fulfil the requirements of the GTR through a direct inspection or an analysis of the supporting evidence (e.g. photographs, records).

9.5. Compliance of software tools

Any software tool used to verify the trip validity and calculate emissions compliance with the provisions of this GTR shall be validated by an entity defined by the Contracting Party. Where such software tool is incorporated in the PEMS instrument, proof of the validation shall be provided along with the instrument.

10. Test Data Analysis

10.1. EMISSIONS AND TRIP EVALUATION

The test shall be conducted in accordance with Appendix 1 of this Regulation.

10.2. The trip validity shall be assessed in a three-step procedure as follows:

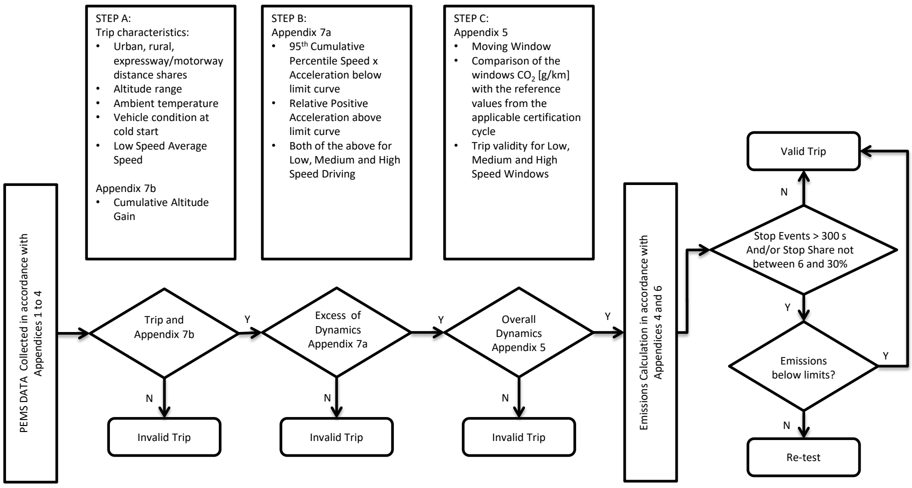
STEP A: The trip complies with the general requirements, boundary conditions, trip and operational requirements, and the specifications for lubricating oil, fuel and reagents set out in points 4 to 8 and with Appendix 7b;

STEP B: The trip complies with the requirements set out in Appendices 7a.

STEP C: The trip complies with the requirements set out in Appendix 5.

The steps of the procedure are detailed in Figure 1.

Figure 1.Assessmentof trip validity



If at least one of the requirements is not fulfilled, the trip shall be declared invalid.

10.3. In order to preserve data integrity, it shall not be permitted to combine data of different RDE trips in a single data set or to modify or remove data (except for cases mentioned explicitly in this GTR) from an RDE trip.

9.4. After establishing the validity of a trip in accordance with point 9.2., emission results shall be calculated using the methods laid down in Appendix 4 and Appendix 6. The emissions calculations shall be made using all valid data between test start and test end, as defined in Appendix 1, points 5.1. and 5.3., respectively.

9.6. Criteria emissions during cold start, as defined in point 4 of Appendix 4, shall be included in the normal evaluation in accordance with Appendices 4 and 6.

Compliance with emission limits

PASS or FAIL test

Commented [DP19]: Same here

Commented [DP20]: Change everywhere pollutant to criteria emissions

10.4. Emission results shall be calculated using the methods laid down in Annex 7 and Annex 11. The emissions calculations shall be made between test start and test end, as defined in paragraphs 5.1. and 5.3. of Annex 4 respectively.

10.5. The extended factor for this Regulation is set at 1.6. If during a particular time interval the ambient conditions are extended, in accordance with paragraph 8.1., then the criteria emissions calculated according to Annex 11, during that particular time interval, shall be divided by the extended factor. This provision does not apply to carbon dioxide emissions.

10.6. Gaseous pollutant and particle number emissions during the cold start period, as defined in paragraph 3.6.1., shall be included in the normal evaluation in accordance with Annexes 7, 8 and 11.

If the vehicle was conditioned for the last three hours prior to the test at an average temperature that falls within the extended range in accordance with paragraph 8.1., then the provisions of paragraph 10.5. apply to the data collected during the cold start period, even if the test ambient conditions are not within the extended temperature range.

ANNEX 1

TEST PROCEDURE FOR VEHICLE EMISSIONS TESTING WITH A PORTABLE EMISSIONS MEASUREMENT SYSTEM (PEMS)

1. INTRODUCTION

This annex describes the test procedure to determine exhaust emissions from light passenger and commercial vehicles using a Portable Emissions Measurement System.

2. SYMBOLS, PARAMETERS AND UNITS

p_e	—	evacuated pressure [kPa]
q_{vs}	—	volume flow rate of the system [l/min]
$ppmC_1$	—	parts per million carbon equivalent
V_s	—	system volume [l]

3. GENERAL REQUIREMENTS

3.1. PEMS

The test shall be carried out with a PEMS, composed of components specified in points 3.1.1 to 3.1.5 following the performance requirements in Appendix 2. If applicable, a connection with the vehicle ECU may be established to determine relevant engine and vehicle parameters as specified in point 3.2.

3.1.1. Analysers to determine the concentration of compounds in the exhaust gas.

3.1.2. One or multiple instruments to measure or determine the exhaust mass flow.

3.1.3. A Global Positioning System to assist in the determination of the position, altitude and, speed of the vehicle.

3.1.4. If applicable, sensors and other appliances being not part of the vehicle, e.g., to measure ambient temperature, relative humidity and air pressure.

3.1.5. An energy source independent of the vehicle to power the PEMS.

3.2. Test parameters

Test parameters as specified in Table 1 of this Appendix shall be measured, where applicable, at a constant frequency of 1.0 Hz or higher and recorded and reported in accordance with the requirements of Appendix 8 at a frequency of 1.0 Hz. If ECU parameters are obtained, these may be obtained at a substantially higher frequency but the recording rate shall be 1.0 Hz. The PEMS analysers, flow-measuring instruments and sensors shall comply with the requirements laid down in Appendices 2 and 3.

Table 1		
Test parameters		
Parameter	Recommended unit	Source[2]
THC concentration[3],[4] (if applicable)	ppm C_1	Analyser
CH_4 concentration[5],[6](if applicable)	ppm C_1	Analyser
NMHC concentration[7],[8](if applicable)	ppm C_1	Analyser[9]
CO concentration[10],[11]	Ppm	Analyser
CO_2 concentration[12]	Ppm	Analyser
NO_X concentration[13],[14]	Ppm	Analyser[15]
PN concentration[16] (if applicable)	#/m^3	Analyser
PM (if applicable	Mg/m3	Analyser
Exhaust mass flow rate	kg/s	EFM, any methods described in point 7 of Appendix 2
Ambient humidity	%	Sensor
Ambient temperature	K	Sensor
Ambient pressure	kPa	Sensor
Vehicle speed	km/h	Sensor, GNSS, or ECU[17]
Vehicle latitude	Degree	GNSS

Commented [RG 25062021]: Footnotes need to be sorted to avoid duplication

Commented [DP22]: Calculated value, not measured

Commented [PB23]: Indicated in footnote 8

2 Multiple parameter sources may be used.
3 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
4 parameter only mandatory if measurement required by Annex IIIA, section 2.1
5 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
6 parameter only mandatory if measurement required by Annex IIIA, section 2.1
7 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
8 parameter only mandatory if measurement required by Annex IIIA, section 2.1
9 may be calculated from THC and CH_4 concentrations according to point 9.2 of Appendix 4
10 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
11 parameter only mandatory if measurement required by Annex IIIA, section 2.1
12 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
13 to be measured on a wet basis or to be corrected as described in point 8.1 of Appendix 4
14 parameter only mandatory if measurement required by Annex IIIA, section 2.1
15 may be calculated from measured NO and NO_2 concentrations
16 parameter only mandatory if measurement required by Annex IIIA, section 2.1
17 method to be chosen according to point 4.7

Vehicle longitude	Degree	GNSS
Vehicle altitude[18],[19]	M	GNSS or Sensor
Exhaust gas temperature[20]	K	Sensor
Engine coolant temperature[21]	K	Sensor or ECU
Engine speed[22]	Rpm	Sensor or ECU
Engine torque[23]	Nm	Sensor or ECU
Torque at driven axle[24] (if applicable)	Nm	Rim torque meter
Pedal position[25]	%	Sensor or ECU
Engine fuel flow[26] (if applicable)	g/s	Sensor or ECU
Engine intake air flow[27] (if applicable)	g/s	Sensor or ECU
Fault status[28]	—	ECU
Intake air flow temperature	K	Sensor or ECU
Regeneration status[29] (if applicable)	—	ECU
Engine oil temperature[30]	K	Sensor or ECU
Actual gear[31]	#	ECU

18 to be determined only if necessary to verify the vehicle status and operating conditions
19 The preferable source is the ambient pressure sensor.
20 to be determined only if necessary to verify the vehicle status and operating conditions
21 to be determined only if necessary to verify the vehicle status and operating conditions
22 to be determined only if necessary to verify the vehicle status and operating conditions
23 to be determined only if necessary to verify the vehicle status and operating conditions
24 to be determined only if necessary to verify the vehicle status and operating conditions
25 to be determined only if necessary to verify the vehicle status and operating conditions
26 to be determined only if indirect methods are used to calculate exhaust mass flow rate as described in paragraphs 10.2 and 10.3 of Appendix 4
27 to be determined only if indirect methods are used to calculate exhaust mass flow rate as described in paragraphs 10.2 and 10.3 of Appendix 4
28 to be determined only if necessary to verify the vehicle status and operating conditions
29 to be determined only if necessary to verify the vehicle status and operating conditions
30 to be determined only if necessary to verify the vehicle status and operating conditions
31 to be determined only if necessary to verify the vehicle status and operating conditions

Desired gear (e.g. gear shift indicator)[32]	#	ECU
Other vehicle data[33]	unspecified	ECU

3.4. Installation of PEMS

3.4.1. *General:*

The installation of the PEMS shall follow the instructions of the PEMS manufacturer and the local health and safety regulations. When the PEMS is installed inside the vehicle, the vehicle should be equipped with gas monitors or warning systems for hazardous gases (e.g. CO).The PEMS should be installed as to minimise electromagnetic interferences during the test as well as exposure to shocks, vibration, dust and variability in temperature. The installation and operation of the PEMS shall be such that it avoids leakage and minimise heat loss. The installation and operation of PEMS shall not change the nature of the exhaust gas nor unduly increase the length of the tailpipe. To avoid the generation of particles, connectors shall be thermally stable at the exhaust gas temperatures expected during the test. It is recommended not to use elastomer connectors to connect the vehicle exhaust outlet and the connecting tube. Elastomer connectors, if used, shall have no contact with the exhaust gas to avoid artefacts at high engine load. If the test performed with the use of elastomer connectors fails, the test shall be repeated without the use of elastomer connectors.

3.4.2. *Permissible backpressure*

The installation and operation of the PEMS sampling probes shall not unduly increase the pressure at the exhaust outlet in a way that may influence the representativeness of the measurements. It is thus recommended that only one sampling probe is installed in the same plane. If technically feasible, any extension to facilitate the sampling or connection with the exhaust mass flow meter shall have an equivalent, or larger, cross sectional area than the exhaust pipe.

3.4.3. *Exhaust mass flow meter*

Whenever used, the exhaust mass flow meter shall be attached to the vehicle's tailpipe(s) in accordance with the recommendations of the EFM manufacturer. The measurement range of the EFM shall match the range of the exhaust mass flow rate expected during the test. It is recommended to select the EFM in order to have the maximum expected flow rate during the test covering at least 75% of the EFM full range. The installation of the EFM and

[32] to be determined only if necessary to verify the vehicle status and operating conditions
[33] to be determined only if necessary to verify the vehicle status and operating conditions

any exhaust pipe adaptors or junctions shall not adversely affect the operation of the engine or exhaust after-treatment system. A minimum of four pipe diameters or 150 mm of straight tubing, whichever is larger, shall be placed at either side of the flow-sensing element. When testing a multi-cylinder engine with a branched exhaust manifold, it is recommended to position the exhaust mass flow meter downstream of where the manifolds combine and to increase the cross section of the piping such as to have an equivalent, or larger, cross sectional area from which to sample. If this is not feasible, exhaust flow measurements with several exhaust mass flow meters may be used. The wide variety of exhaust pipe configurations, dimensions and exhaust mass flow rates may require compromises, guided by good engineering judgement, when selecting and installing the EFM(s). It is permissible to install an EFM with a diameter smaller than that of the exhaust outlet or the total cross-sectional area of multiple outlets, providing it improves measurement accuracy and does not adversely affect the operation or the exhaust after-treatment as specified in point 3.4.2. It is recommended to document the EFM set-up using photographs.

3.4.4. *Global Positioning System (GNSS)*

The GNSS antenna shall be mounted as near as possible to the highest location on the vehicle, as to ensure good reception of the satellite signal. The mounted GNSS antenna shall interfere as little as possible with the vehicle operation.

3.4.5. *Connection with the Engine Control Unit (ECU)*

If desired, relevant vehicle and engine parameters listed in Table 1 can be recorded by using a data logger connected with the ECU or the vehicle network through national or international standards, such as ISO 15031-5 or SAE J1979, OBD-II, EOBD or WWH-OBD. If applicable, manufacturers shall disclose labels to allow the identification of required parameters.

3.4.6. *Sensors and auxiliary devices*

Vehicle speed sensors, temperature sensors, coolant thermocouples or any other measurement device not part of the vehicle shall be installed to measure the parameter under consideration in a representative, reliable and accurate manner without unduly interfering with the vehicle operation and the functioning of other analysers, flow-measuring instruments, sensors and signals. Sensors and auxiliary equipment shall be powered independently of the vehicle. It is permitted to power any safety-related illumination of fixtures and installations of PEMS components outside of the vehicle's cabin by the vehicle's battery.

3.5. *Emissions sampling*

Emissions sampling shall be representative and conducted at locations of well-mixed exhaust where the influence of ambient air downstream of the sampling point is minimal. If applicable, emissions shall be sampled downstream of the exhaust mass flow meter, respecting a distance of at least 150 mm to the flow sensing element. The sampling probes shall be fitted at least 200 mm or three times the inner diameter of the exhaust pipe, whichever is larger, upstream of the point at which the exhaust exits the PEMS sampling installation into the environment.

If the PEMS feeds part of the sample back to the exhaust flow, this shall occur downstream of the sampling probe in a manner that does not affect the nature of the exhaust gas at the sampling point(s). If the length of the sampling line is changed, the system transport times shall be verified and, if necessary, corrected. If the vehicle is equipped with more than one tailpipe then all functioning tailpipes shall be connected before sampling and measuring exhaust flow.

If the engine is equipped with an exhaust after-treatment system, the exhaust sample shall be taken downstream of the exhaust after-treatment system. When testing a vehicle with a branched exhaust manifold, the inlet of the sampling probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions of all cylinders. In multi-cylinder engines, having distinct groups of manifolds, such as in a ‘V’ engine configuration, the sampling probe shall be positioned downstream of where the manifolds combine. If this is technically not feasible, multi-point sampling at locations of well-mixed exhaust may be used. In this case, the number and location of sampling probes shall match as far as possible those of the exhaust mass flow meters. In case of unequal exhaust flows, proportional sampling or sampling with multiple analysers shall be considered.

If particles are measured, they shall be sampled from the centre of the exhaust stream. If several probes are used for emissions sampling, the particle sampling probe should be placed upstream of the other sampling probes. The particle sampling probe should not interfere with the sampling of gaseous criteria emissions. The type and specifications of the probe and its mounting shall be documented in detail.

If hydrocarbons are measured, the sampling line shall be heated to 463 ± 10 K (190 ± 10 °C). For the measurement of other gaseous components with or without cooling the sampling line shall be kept at a minimum of 333 K (60 °C) to avoid condensation and to ensure appropriate penetration efficiencies of the various gases. For low-pressure sampling systems, the temperature can be lowered correspondingly to the pressure decrease provided that the sampling system ensures a penetration efficiency of 95 % for all regulated gaseous criteria emissions. If particles are sampled and not diluted at the tailpipe, the sampling line from the raw exhaust sample point to the point of dilution or particle detector shall be heated to a minimum of 373 K (100 °C). The residence time of the sample in the particle sampling line shall be less than 3 s until reaching first dilution or the particle detector.

All parts of the sampling system from the tailpipe up to the particle detector, which are in contact with raw or diluted exhaust gas, shall be designed to minimise deposition of particles. All parts shall be made from antistatic material to prevent electrostatic effects.

4. PRE-TEST PROCEDURES

4.1. PEMS leak check

After the installation of the PEMS is completed, a leak check shall be performed at least once for each PEMS-vehicle installation as prescribed by the PEMS manufacturer or as follows. The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be switched on. After an initial stabilization period all flow meters shall read approximately zero in the absence of a leak. Else, the sampling lines shall be checked and the fault be corrected.

The leakage rate on the vacuum side shall not exceed 0.5 per cent of the in-use flow rate for the portion of the system being checked. The analyser flows and bypass flows may be used to estimate the in-use flow rate.

Alternatively, the system may be evacuated to a pressure of at least 20 kPa vacuum (80 kPa absolute). After an initial stabilization period the pressure increase Δp (kPa/min) in the system shall not exceed:

$$\Delta p = \frac{p_e}{V_s} \times \ q_{vs} \times 0.005$$

where:

p_e is the evacuated pressure [Pa],

$V_s$is the system volume [l],

q_{vs} is is volume flow rate of the system [l/min].

Alternatively, a concentration step change at the beginning of the sampling line shall be introduced by switching from zero to span gas while maintaining the same pressure conditions as under normal system operation. If, for a correctly calibrated analyser after an adequate period of time, the reading is ≤ 99 per cent compared to the introduced concentration, the leakage problem shall be corrected.

4.2. Starting and stabilizing the PEMS

The PEMS shall be switched on, warmed up, and stabilised in accordance with the specifications of the PEMS manufacturer until key functional parameters, e.g., pressures, temperatures and flows have reached their operating set points before test start. To ensure correct functioning, the PEMS may be kept switched on or can be warmed up and stabilised during vehicle conditioning. The system shall be free of errors and critical warnings.

4.3. *Preparing the sampling system*

The sampling system, consisting of the sampling probe and sampling lines, shall be prepared for testing by following the instruction of the PEMS manufacturer. It shall be ensured that the sampling system is clean and free of moisture condensation.

4.4. *Preparing the Exhaust mass Flow Meter (EFM)*

If used for measuring the exhaust mass flow, the EFM shall be purged and prepared for operation in accordance with the specifications of the EFM manufacturer. This procedure shall, if applicable, remove condensation and deposits from the lines and the associated measurement ports.

4.5. *Checking and calibrating the analysers for measuring gaseous emissions*

Zero and span calibration adjustments of the analysers shall be performed using calibration gases that meet the requirements of point 5 of Appendix 2. The calibration gases shall be chosen to match the range of criteria emission concentrations expected during the RDE test. To minimise analyser drift, it is recommended to conduct the zero and span calibration of analysers at an ambient temperature that resembles, as closely as possible, the temperature experienced by the test equipment during the trip.

4.6. *Checking the analyser for measuring particle emissions*

The zero level of the analyser shall be recorded by sampling HEPA filtered ambient air at an appropriate sampling point, ideally at the inlet of the sampling line. The signal shall be recorded at a constant frequency which is a multiple of 1.0 Hz averaged over a period of 2 minutes. The final concentration shall be within the manufacturer's specifications, but shall not exceed 5,000 particles per cubic-centimetre.

4.7. *Determining vehicle speed*

Vehicle speed shall be determined by at least one of the following methods:

(a) a sensor (e.g., optical or micro-wave sensor); if vehicle speed is determined by a sensor, the speed measurements shall comply with the requirements of point 8 of Appendix 2, or alternatively, the total trip distance determined by the sensor shall be compared with a reference distance obtained from a digital road network or topographic map. The total trip distance determined by the sensor shall deviate by no more than 4 % from the reference distance.

(b) the ECU; if vehicle speed is determined by the ECU, the total trip distance shall be validated according to point 3 of

Appendix 3 and the ECU speed signal adjusted, if necessary to fulfil the requirements of point 3.3 of Appendix 3. Alternatively, the total trip distance as determined by the ECU can be compared with a reference distance obtained from a digital road network or topographic map. The total trip distance determined by the ECU shall deviate by no more than 4 % from the reference.

(c) a GNSS; if vehicle speed is determined by a GNSS, the total trip distance shall be checked against the measurements of another method according to point 7 of Appendix 4.

4.8. Check of PEMS set up

The correctness of connections with all sensors and, if applicable, the ECU shall be verified. If engine parameters are retrieved, it shall be ensured that the ECU reports values correctly (e.g., zero engine speed [rpm] while the combustion engine is in key-on-engine-off status). The PEMS shall function free of errors and critical warnings.

5. EMISSIONS TEST

5.1. Test start

Sampling, measurement and recording of parameters shall begin prior to the test start. Before the test start it shall be confirmed that all necessary parameters are recorded by the data logger.

To facilitate time alignment, it is recommended to record the parameters that are subject to time alignment either by a single data recording device or with a synchronised time stamp. 5.2. Test

Sampling, measurement and recording of parameters shall continue throughout the on-road test of the vehicle. The engine may be stopped and started, but emissions sampling and parameter recording shall continue. Repeated stalling of the engine (i.e. unintentional stopping of the engine) should be avoided during an RDE trip. Any warning signals, suggesting malfunctioning of the PEMS, shall be documented and verified. If any error signal(s) appear during the test, the test shall be voided. Parameter recording shall reach a data completeness of higher than 99 %. Measurement and data recording may be interrupted for less than 1 % of the total trip duration but for no more than a consecutive period of 30 s solely in the case of unintended signal loss or for the purpose of PEMS system maintenance. Interruptions may be recorded directly by the PEMS but it is not permissible to introduce interruptions in the recorded parameter via the pre-processing, exchange or post-processing of data. If conducted, auto zeroing shall be performed against a traceable zero standard similar to the one used to zero the analyser. It is strongly recommended to initiate PEMS system maintenance during periods of zero vehicle speed.

5.3. Test end

Excessive idling of the engine after the completion of the trip shall be avoided. The data recording shall continue until the response time of the sampling systems has elapsed. For vehicles with a signal detecting regeneration, the OBD-check shall be performed and documented directly after data recording and before any further driven distance is driven.

6. POST-TEST PROCEDURE

6.1. Checking the analysers for measuring gaseous emissions

The zero and span of the analysers of gaseous components shall be checked by using calibration gases identical to the ones applied under point 4.5 to evaluate the analyser's zero and response drift compared to the pre-test calibration. It is permissible to zero the analyser prior to verifying the span drift, if the zero drift was determined to be within the permissible range. The post-test drift check shall be completed as soon as possible after the test and before the PEMS, or individual analysers or sensors, are turned off or have switched into a non-operating mode. The difference between the pre-test and post-test results shall comply with the requirements specified in Table 2.

Table 2

Permissible analyser drift over a PEMS test

Criteria emission	Absolute Zero response drift	Absolute Span response drift[34]
CO_2	≤ 2000 ppm per test	≤ 2 % of reading or ≤ 2000 ppm per test, whichever is larger
CO	≤ 75 ppm per test	≤ 2 % of reading or ≤ 75 ppm per test, whichever is larger
NO_X	≤ 5 ppm per test	≤ 2 % of reading or ≤ 5 ppm per test, whichever is larger
CH_4	≤ 10 ppm C_1 per test	≤ 2 % of reading or ≤ 10 ppm C_1 per test, whichever is larger
THC	≤ 10 ppm C_1 per test	≤ 2 % of reading or ≤ 10 ppm C_1 per test, whichever is larger

If the difference between the pre-test and post-test results for the zero and span drift is higher than permitted, all test results shall be voided and the test repeated.

[34] If the zero drift is within the permissible range, it is permissible to zero the analyser prior to verifying the span drift.

6.2. *Checking the analyser for measuring particle emissions*

The zero level of the analyser shall be recorded in accordance with point 4.6.

6.3. *Checking the on-road emission measurements*

The span gas concentration that was used for the calibration of the analysers in accordance with paragraph 4.5 at the test start shall cover at least 90 % of the concentration values obtained from 99 % of the measurements of the valid parts of the emissions test. It is permissible that 1 % of the total number of measurements used for evaluation exceeds the concentration of the span gas used by up to a factor of two. If these requirements are not met, the test shall be voided.

6.4. *Consistency check of vehicle altitude*

In case well-reasoned doubts exist that a trip has been conducted above of the permissible altitude as specified in point 5.2 of this Annex and in case altitude has only been measured with a GNSS, the GNSS altitude data shall be checked for consistency and, if necessary, corrected. The consistency of data shall be checked by comparing the latitude, longitude and altitude data obtained from the GNSS with the altitude indicated by a digital terrain model or a topographic map of suitable scale. Measurements that deviate by more than 40 m from the altitude depicted in the topographic map shall be manually corrected and marked.

The instantaneous altitude data shall be checked for completeness. Data gaps shall be completed by data interpolation. The correctness of interpolated data shall be verified by a topographic map. It is recommended to correct interpolated data if the following condition applies:

$$\left|h_{GPS}(t) - h_{map}(t)\right| > 40\ m$$

The altitude correction shall be applied so that:

$$\left|h(t) - h_{map}(t)\right| < 40\ m$$

where:

h(t)	—	vehicle altitude after the screening and principle check of data quality at data point t [m above sea level]
$h_{GNSS}(t)$	—	vehicle altitude measured with GNSS at data point t [m above sea level]
$h_{map}(t)$	—	vehicle altitude based on topographic map at data point t [m above sea level]

6.5. *Consistency check of GNSS vehicle speed*

The vehicle speed as determined by the GNSS shall be checked for consistency by calculating and comparing the total trip distance with reference measurements obtained from either a sensor, the validated ECU or, alternatively, from a digital road network or topographic map. It is mandatory to correct GNSS data for obvious errors, e.g., by applying a dead reckoning sensor, prior to the consistency check. The original and uncorrected data file shall be retained and any corrected data shall be marked. The corrected data shall not exceed an uninterrupted time period of 120 s or a total of 300 s. The total trip distance as calculated from the corrected GNSS data shall deviate by no more than 4 % from the reference. If the GNSS data do not meet these requirements and no other reliable speed source is available, the test results shall be voided.

6.6. *Consistency check of the ambient temperature*

The ambient temperature data shall be checked for consistency and inconsistent values corrected by substituting outliers with the average of the neighbouring values. The original and uncorrected data shall be retained and any corrected data shall be marked.

ANNEX 2

SPECIFICATIONS AND CALIBRATION OF PEMS COMPONENTS AND SIGNALS

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1. INTRODUCTION

This annex sets out the specifications and calibration of PEMS components and signals.

2. SYMBOLS, PARAMETERS AND UNITS

A	—	undiluted CO_2 concentration [%]
a_0	—	y-axis intercept of the linear regression line
a_1	—	slope of the linear regression line
B	—	diluted CO_2 concentration [%]
C	—	diluted NO concentration [ppm]
c	—	analyser response in the oxygen interference test
C_b		Measured diluted NO concentration through bubbler
$c_{FS,b}$	—	full scale HC concentration in step (b) [ppmC_1]
$c_{FS,d}$	—	full scale HC concentration in step (d) [ppmC_1]
$c_{HC(w/NMC)}$	—	HC concentration with CH_4 or C_2H_6 flowing through the NMC [ppmC_1]
$c_{HC(w/o\ NMC)}$	—	HC concentration with CH_4 or C_2H_6 bypassing the NMC [ppmC_1]
$c_{m,b}$	—	measured HC concentration in step (b) [ppmC_1]
$c_{m,d}$	—	measured HC concentration in step (d) [ppmC_1]
$c_{ref,b}$	—	reference HC concentration in step (b) [ppmC_1]
$c_{ref,d}$	—	reference HC concentration in step (d) [ppmC_1]
D	—	undiluted NO concentration [ppm]
D_e	—	expected diluted NO concentration [ppm]
E	—	absolute operating pressure [kPa]
E_{CO2}	—	per cent CO_2 quench
$E(d_p)$	—	PEMS-PN analyser efficiency

E_E	—	ethane efficiency
E_{H2O}	—	per cent water quench
E_M	—	methane efficiency
E_{O2}	—	oxygen interference
F	—	water temperature [K]
G	—	saturation vapour pressure [kPa]
H	—	water vapour concentration [%]
H_m	—	maximum water vapour concentration [%]
$NO_{X,dry}$	—	moisture-corrected mean concentration of the stabilised NO_X recordings
$NO_{X,m}$	—	mean concentration of the stabilised NO_X recordings
$NO_{X,ref}$	—	reference mean concentration of the stabilised NO_X recordings
r^2	—	coefficient of determination
t_0	—	time point of gas flow switching [s]
t_{10}	—	time point of 10 % response of the final reading
t_{50}	—	time point of 50 % response of the final reading
t_{90}	—	time point of 90 % response of the final reading
tbd	—	to be determined
X	—	independent variable or reference value
χ_{min}	—	minimum value
Y	—	dependent variable or measured value

3. LINEARITY VERIFICATION

3.1. General

The accuracy and linearity of analysers, flow-measuring instruments, sensors and signals, shall be traceable to international or national standards. Any sensors or signals that are not directly traceable, e.g., simplified flow-measuring instruments shall be calibrated alternatively against chassis dynamometer laboratory equipment that has been calibrated against international or national standards.

3.2. *Linearity requirements*

All analysers, flow-measuring instruments, sensors and signals shall comply with the linearity requirements given in Table 1. If air flow, fuel flow, the air-to-fuel ratio or the exhaust mass flow rate is obtained from the ECU, the calculated exhaust mass flow rate shall meet the linearity requirements specified in Table 1.

Table 1

Linearity requirements of measurement parameters and systems

Measurement parameter/instrument	$\lvert \chi_{min} \times (a_1 - 1) + a_0 \rvert$	Slope a_1	Standard error of the estimate SEE	Coefficient of determination r^2
Fuel flow rate[35]	≤ 1 % max	0.98 – 1.02	≤ 2 %	≥ 0.990
Air flow rate[36]	≤ 1 % max	0.98 – 1.02	≤ 2 %	≥ 0.990
Exhaust mass flow rate	≤ 2 % max	0.97 – 1.03	≤ 3 %	≥ 0.990
Gas analysers	≤ 0.5 % max	0.99 – 1.01	≤ 1 %	≥ 0.998
Torque[37]	≤ 1 % max	0.98 – 1.02	≤ 2 %	≥ 0.990
PN analysers[38]	≤ 5 % max	0.85 – 1.15[39]	≤ 10 %	≥ 0.950

3.3. *Frequency of linearity verification*

The linearity requirements pursuant to point 3.2 shall be verified:

(a) for each gas analyser at least every 12 months or whenever a system repair or component change or modification is made that could influence the calibration;

(b) for other relevant instruments, such as PN analysers, exhaust mass flow meters and traceably calibrated sensors, whenever damage is observed, as required by internal audit procedures or by the instrument manufacturer but no longer than one year before the actual test.

35 optional to determine exhaust mass flow
36 optional to determine exhaust mass flow
37 optional parameter
38 The linearity check shall be verified with soot-like particles, as these are defined in point 6.2
39 To be updated based on error propagation and traceability charts.

The linearity requirements pursuant to point 3.2 for sensors or ECU signals that are not directly traceable shall be performed using a measurement device with a traceable calibration on the chassis dynamometer, once for each PEMS-vehicle setup.

3.4. *Procedure of linearity verification*

3.4.1. *General requirements*

The relevant analysers, instruments, and sensors shall be brought to their normal operating condition according to the recommendations of their manufacturer. The analysers, instruments, and sensors shall be operated at their specified temperatures, pressures and flows.

3.4.2. *General procedure*

The linearity shall be verified for each normal operating range by executing the following steps:

(a) The analyser, flow-measuring instrument, or sensor shall be set to zero by introducing a zero signal. For gas analysers, purified synthetic air or nitrogen shall be introduced to the analyser port via a gas path that is as direct and short as possible.

(b) The analyser, flow-measuring instrument, or sensor shall be spanned by introducing a span signal. For gas analysers, an appropriate span gas shall be introduced to the analyser port via a gas path that is as direct and short as possible.

(c) The zero procedure of (a) shall be repeated.

(d) The linearity shall be verified by introducing at least 10, approximately equally spaced and valid, reference values (including zero). The reference values with respect to the concentration of components, the exhaust mass flow rate or any other relevant parameter shall be chosen to match the range of values expected during the emissions test. For measurements of exhaust mass flow, reference points below 5 % of the maximum calibration value can be excluded from the linearity verification.

(e) For gas analysers, known gas concentrations in accordance with point 5 shall be introduced to the analyser port. Sufficient time for signal stabilisation shall be given.

(f) The values under evaluation and, if needed, the reference values shall be recorded at a constant frequency which is a multiple of 1.0 Hz over a period of 30 seconds.

(g) The arithmetic mean values over the 30 seconds period shall be used to calculate the least squares linear regression parameters, with the best-fit equation having the form:

$$y = a_1 x + a_0$$

where:

y is the actual value of the measurement system

a_1 is the slope of the regression line

x is the reference value

a_0 is the y intercept of the regression line

The standard error of estimate (SEE) of y on x and the coefficient of determination (r^2) shall be calculated for each measurement parameter and system.

(h) The linear regression parameters shall meet the requirements specified in Table 1.

3.4.3. *Requirements for linearity verification on a chassis dynamometer*

Non-traceable flow-measuring instruments, sensors or ECU signals that cannot directly be calibrated according to traceable standards, shall be calibrated on a chassis dynamometer following the applicable requirements. If necessary, the instrument or sensor to be calibrated shall be installed on the test vehicle and operated according to the requirements of Appendix 1. The calibration procedure shall follow whenever possible the requirements of point 3.4.2. At least 10 appropriate reference values shall be selected as to ensure that at least 90% of the maximum value expected to occur during the RDE test is covered.

If a non-traceable flow-measuring instrument, sensor or ECU signal for determining exhaust flow is to be calibrated, a reference exhaust mass flow meter with traceable calibration or the CVS shall be attached to the vehicle's tailpipe. It shall be ensured that the vehicle exhaust is accurately measured by the exhaust mass flow meter according to point 3.4.3 of Appendix 1. The vehicle shall be operated by applying constant throttle at a constant gear selection and chassis dynamometer load.

4. ANALYSERS FOR MEASURING GASEOUS COMPONENTS

4.1. Permissible types of analysers

4.1.1. *Standard analysers*

The gaseous components shall be measured with analysers specified in points 1.3.1 to 1.3.5 of Appendix 3, Annex 4A to UN/ECE Regulation No 83, 07 series of amendments. If an NDUV analyser measures both NO and NO_2, a NO_2/NO converter is not required.

Commented [DP25]: JRC to evaluate. In principle, we should reference correct text from Reg 83 (or better GTR 15) on analysers

4.1.2. *Alternative analysers*

Any analyser not meeting the design specifications of point 4.1.1. is permissible provided that it fulfils the requirements of point 4.2. The manufacturer shall ensure that the alternative analyser achieves an equivalent or higher measurement performance compared to a standard analyser over the range of criteria emission concentrations and co-existing gases that can be expected from vehicles operated with permissible fuels under moderate and extended conditions of valid RDE testing as specified in points 5, 6 and 7 of this Annex. Upon request, the manufacturer of the analyser shall submit in writing supplemental information, demonstrating that the measurement performance of the alternative analyser is consistently and reliably in line with the measurement performance of standard analysers. Supplemental information shall contain:

(a) a description of the theoretical basis and the technical components of the alternative analyser;

(b) a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 over the expected range of criteria emission concentrations and ambient conditions of the type-approval test defined in Annexes Part B to UN Regulation No. 154 as well as a validation test as described in point 3 of Appendix 3 for a vehicle equipped with a spark-ignition and compression-ignition engine; the manufacturer of the analyser shall demonstrate the significance of equivalency within the permissible tolerances given in point 3.3 of Appendix 3.

(c) a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 with respect to the influence of atmospheric pressure on the measurement performance of the analyser; the demonstration test shall determine the response to span gas having a concentration within the analyser range to check the influence of atmospheric pressure under moderate and extended altitude conditions defined in point 5.2 of this Annex. Such a test can be performed in an altitude environmental test chamber.

(d) a demonstration of equivalency with the respective standard analyser specified in point 4.1.1 over at least three on-road tests that fulfil the requirements of this Annex.

(e) a demonstration that the influence of vibrations, accelerations and ambient temperature on the analyser reading does not exceed the noise requirements for analysers set out in point 4.2.4.

Approval authorities may request additional information to substantiate equivalency or refuse approval if measurements demonstrate that an alternative analyser is not equivalent to a standard analyser.

4.2. *Analyser specifications*

4.2.1. *General*

In addition to the linearity requirements defined for each analyser in point 3, the compliance of analyser types with the specifications laid down in points 4.2.2 to 4.2.8 shall be demonstrated by the analyser manufacturer. Analysers shall have a measuring range and response time appropriate to measure with adequate accuracy the concentrations of the exhaust gas components at the applicable emissions standard under transient and steady state conditions. The sensitivity of the analysers to

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shocks, vibration, aging, variability in temperature and air pressure as well as electromagnetic interferences and other impacts related to vehicle and analyser operation shall be limited as far as possible.

4.2.2. *Accuracy*

The accuracy, defined as the deviation of the analyser reading from the reference value, shall not exceed 2 % of reading or 0.3 % of full scale, whichever is larger.

4.2.3. *Precision*

The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be no greater than 1 % of the full scale concentration for a measurement range equal or above 155 ppm (or $ppmC_1$) and 2 % of the full scale concentration for a measurement range of below 155 ppm (or $ppmC_1$).

4.2.4. *Noise*

The noise shall not exceed 2 % of full scale. Each of the 10 measurement periods shall be interspersed with an interval of 30 seconds in which the analyser is exposed to an appropriate span gas. Before each sampling period and before each span period, sufficient time shall be given to purge the analyser and the sampling lines.

4.2.5. *Zero response drift*

The drift of the zero response, defined as the mean response to a zero gas during a time interval of at least 30 seconds, shall comply with the specifications given in Table 2.

4.2.6. *Span response drift*

The drift of the span response, defined as the mean response to a span gas during a time interval of at least 30 seconds, shall comply with the specifications given in Table 2.

Table 2		
Permissible zero and span response drift of analysers for measuring gaseous components under laboratory conditions		
Pollutant	Absolute Zero response drift	Absolute Span response drift
CO_2	≤ 1,000 ppm over 4 h	≤ 2 % of reading or ≤ 1,000 ppm over 4 h, whichever is larger
CO	≤ 50 ppm over 4 h	≤ 2 % of reading or ≤ 50 ppm over 4 h, whichever is larger

PN	5000 particles per cubic centimetre over 4 h	According to manufacturer specifications
NO_X	≤ 5 ppm over 4 h	≤ 2 % of reading or 5 ppm over 4 h, whichever is larger
CH_4	≤ 10 ppm C_1	≤ 2 % of reading or ≤ 10 ppm C_1 over 4 h, whichever is larger
THC	≤ 10 ppm C_1	≤ 2 % of reading or ≤ 10 ppm C_1 over 4 h, whichever is larger

4.2.7. *Rise time*

The rise time, defined as the time between the 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$; see point 4.4), shall not exceed 3 seconds.

4.2.8. *Gas drying*

Exhaust gases may be measured wet or dry. A gas-drying device, if used, shall have a minimal effect on the composition of the measured gases. Chemical dryers are not permitted.

4.3. *Additional requirements*

4.3.1. *General*

The provisions in points 4.3.2 to 4.3.5 define additional performance requirements for specific analyser types and apply only to cases, in which the analyser under consideration is used for RDE emission measurements.

4.3.2. *Efficiency test for NO_X converters*

If a NO_X converter is applied, for example to convert NO_2 into NO for analysis with a chemiluminescence analyser, its efficiency shall be tested by following the requirements in paragraph 5.5. of Annex B5 to UN Regulation No. 154. The efficiency of the NO_X converter shall be verified no longer than one month before the emissions test.

4.3.3. *Adjustment of the Flame Ionisation Detector (FID)*

(a) Optimization of the detector response

If hydrocarbons are measured, the FID shall be adjusted at intervals specified by the analyser manufacturer by following paragraph 5.4.1. of Annex B5 to UN Regulation No.154. A propane-in-air or propane-in-nitrogen span gas shall be used to optimise the response in the most common operating range.

(b) Hydrocarbon response factors

If hydrocarbons are measured, the hydrocarbon response factor of the FID shall be verified by following the provisions of paragraph

5.4.3. of Annex B5 to UN Regulation No.154, using propane-in-air or propane-in-nitrogen as span gases and purified synthetic air or nitrogen as zero gases, respectively.

(c) Oxygen interference check

The oxygen interference check shall be performed when introducing a FID into service and after major maintenance intervals. A measuring range shall be chosen in which the oxygen interference check gases fall in the upper 50 per cent. The test shall be conducted with the oven temperature set as required. The specifications of the oxygen interference check gases are described in point 5.3.

The following procedure applies:

(i) The analyser shall be set at zero;

(ii) The analyser shall be spanned with a 0 per cent oxygen blend for positive ignition engines and a 21 per cent oxygen blend for compression ignition engines;

(iii) The zero response shall be rechecked. If it has changed by more than 0.5 per cent of full scale, steps (i) and (ii) shall be repeated;

(iv) The 5 per cent and 10 per cent oxygen interference check gases shall be introduced;

(v) The zero response shall be rechecked. If it has changed by more than ±1 per cent of full scale, the test shall be repeated;

(vi) The oxygen interference E_{O2}[%] shall be calculated for each oxygen interference check gas in step (iv) as follows:

$$E_{O2} = \frac{(c_{ref,d} - c)}{c_{ref,d}} \times 100$$

where the analyser response is:

$$c = \frac{(c_{ref,d} \times c_{FS,b})}{c_{m,b}} \times \frac{c_{m,b}}{c_{FS,d}}$$

where:

$c_{ref,b}$		is the reference HC concentration in step (ii) [ppmC$_1$]
$c_{ref,d}$		is the reference HC concentration in step (iv) [ppmC$_1$]
$c_{FS,b}$		is the full scale HC concentration in step (ii) [ppmC$_1$]
$c_{FS,d}$		is the full scale HC concentration in step (iv) [ppmC$_1$]

$c_{m,b}$		is the measured HC concentration in step (ii) [ppmC$_1$]
$c_{m,d}$		is the measured HC concentration in step (iv) [ppmC$_1$]

(vii) The oxygen interference E_{O2} shall be less than ±1.5 per cent for all required oxygen interference check gases.

(viii) If the oxygen interference E_{O2} is higher than ±1.5 per cent, corrective action may be taken by incrementally adjusting the air flow (above and below the manufacturer's specifications), the fuel flow and the sample flow.

(ix) The oxygen interference check shall be repeated for each new setting.

4.3.4. *Conversion efficiency of the non-methane cutter (NMC)*

If hydrocarbons are analysed, a NMC can be used to remove non-methane hydrocarbons from the gas sample by oxidizing all hydrocarbons except methane. Ideally, the conversion for methane is 0 per cent and for the other hydrocarbons represented by ethane is 100 per cent. For the accurate measurement of NMHC, the two efficiencies shall be determined and used for the calculation of the NMHC emissions (see point 9.2 of Appendix 4). It is not necessary to determine the methane conversion efficiency in case the NMC-FID is calibrated according to method (b) in point 9.2 of Appendix 4 by passing the methane/air calibration gas through the NMC.

(a) Methane conversion efficiency

Methane calibration gas shall be flown through the FID with and without bypassing the NMC; the two concentrations shall be recorded. The methane efficiency shall be determined as:

$$E_M = 1 - \frac{c_{HC(w/NMC)}}{c_{HC(w/o\ NMC)}}$$

where:

$c_{HC(w/NMC)}$		is the HC concentration with CH_4 flowing through the NMC [ppmC$_1$]
$c_{HC(w/o\ NMC)}$		is the HC concentration with CH_4 bypassing the NMC [ppmC$_1$]

(b) Ethane conversion efficiency

Ethane calibration gas shall be flown through the FID with and without bypassing the NMC; the two concentrations shall be recorded. The ethane efficiency shall be determined as:

$$E_E = 1 - \frac{c_{HC(w/NMC)}}{c_{HC(w/o\ NMC)}}$$

where:

$c_{HC(w/NMC)}$		is the HC concentration with C_2H_6 flowing through the NMC [ppmC$_1$]
$c_{HC(w/o\ NMC)}$		is the HC concentration with C_2H_6 bypassing the NMC [ppmC$_1$]

4.3.5. *Interference effects*

(a) General

Other gases than the ones being analysed can affect the analyser reading. A check for interference effects and the correct functionality of analysers shall be performed by the analyser manufacturer prior to market introduction at least once for each type of analyser or device addressed in points (b) to (f).

(b) CO analyser interference check

Water and CO_2 can interfere with the measurements of the CO analyser. Therefore, a CO_2 span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range of the CO analyser used during the test shall be bubbled through water at room temperature and the analyser response recorded. The analyser response shall not be more than 2 per cent of the mean CO concentration expected during normal on-road testing or ± 50 ppm, whichever is larger. The interference check for H_2O and CO_2 may be run as separate procedures. If the H_2O and CO_2 levels used for the interference check are higher than the maximum levels expected during the test, each observed interference value shall be scaled down by multiplying the observed interference with the ratio of the maximum expected concentration value during the test and the actual concentration value used during this check. Separate interference checks with concentrations of H_2O that are lower than the maximum concentration expected during the test may be run and the observed H_2O interference shall be scaled up by multiplying the observed interference with the ratio of the maximum H_2O concentration value expected during the test and the actual concentration value used during this check. The sum of the two scaled interference values shall meet the tolerance specified in this point.

(c) NO_X analyser quench check

The two gases of concern for CLD and HCLD analysers are CO_2 and water vapour. The quench response to these gases is proportional to the gas concentrations. A test shall determine the quench at the highest concentrations expected during the test. If the CLD and HCLD analysers use quench compensation algorithms that utilise H_2O or CO_2 measurement analysers or both, quench shall be evaluated with these analysers active and with the compensation algorithms applied.

(i) CO_2 quench check

A CO_2 span gas having a concentration of 80 to 100 per cent of the maximum operating range shall be passed through the NDIR analyser; the CO_2 value shall be recorded as A. The CO_2 span gas shall then be diluted by approximately 50 per cent with NO span gas and passed through the NDIR and CLD or HCLD; the CO_2 and NO values shall be recorded as B and C, respectively. The CO_2 gas flow shall then be shut off and only the NO span gas shall be passed through the CLD or HCLD; the NO value shall be recorded as D. The per cent quench shall be calculated as:

$$E_{CO2} = \left[1 - \left(\frac{C \times A}{(D \times A) - (D \times B)}\right)\right] \times 100$$

A		is the undiluted CO_2 concentration measured with the NDIR [%]
B		is the diluted CO_2 concentration measured with the NDIR [%]
C		is the diluted NO concentration measured with the CLD or HCLD [ppm]
D		is the undiluted NO concentration measured with the CLD or HCLD [ppm]

Alternative methods of diluting and quantifying of CO_2 and NO span gas values such as dynamic mixing/blending are permitted upon approval of the approval authority.

(ii) Water quench check

This check applies to measurements of wet gas concentrations only. The calculation of water quench shall consider dilution of the NO span gas with water vapour and the scaling of the water vapour concentration in the gas mixture to concentration levels that are expected to occur during an emissions test. A NO span gas having a concentration of 80 per cent to 100 per cent of full scale of the normal operating range shall be passed through the CLD or HCLD; the NO value shall be recorded as *D*. The NO span gas shall then be bubbled through water at room temperature and passed through the CLD or HCLD; the NO value shall be recorded as *C*. The analyser's absolute operating pressure and the water temperature shall be determined and recorded as E and F, respectively. The mixture's saturation vapour pressure that corresponds to the water temperature of the bubbler *F* shall be determined and recorded as *G*. The water vapour concentration *H* [%] of the gas mixture shall be calculated as:

$$H = \frac{G}{E} = 100$$

The expected concentration of the diluted NO-water vapour span gas shall be recorded as D_e after being calculated as:

$$D_e = D \times \left(1 - \frac{H}{100}\right)$$

For diesel exhaust, the maximum concentration of water vapour in the exhaust gas (in per cent) expected during the test shall be recorded as H_m after being estimated, under the assumption of a fuel H/C ratio of 1.8/1, from the maximum CO_2 concentration in the exhaust gas A as follows:

$$H_m = 0.9 \times A$$

The per cent water quench shall be calculated as:

$$E_{H2O} = \left(\frac{D_e - C}{D_e}\right) \times \left(\frac{H_m}{H}\right) \times 100$$

where:

D_e		is the expected diluted NO concentration [ppm]
C		is the measured diluted NO concentration [ppm]
H_m		is the maximum water vapour concentration [%]

H		is the actual water vapour concentration [%]

(iii) Maximum allowable quench

The combined CO_2 and water quench shall not exceed 2 per cent of full scale.

(d) Quench check for NDUV analysers

Hydrocarbons and water can positively interfere with NDUV analysers by causing a response similar to that of NO_X. The manufacturer of the NDUV analyser shall use the following procedure to verify that quench effects are limited:

(i) The analyser and chiller shall be set up by following the operating instructions of the manufacturer; adjustments should be made as to optimise the analyser and chiller performance.

(ii) A zero calibration and span calibration at concentration values expected during emissions testing shall be performed for the analyser.

(iii) A NO_2 calibration gas shall be selected that matches as far as possible the maximum NO_2 concentration expected during emissions testing.

(iv) The NO_2 calibration gas shall overflow at the gas sampling system's probe until the NO_X response of the analyser has stabilised.

(v) The mean concentration of the stabilised NO_X recordings over a period of 30 s shall be calculated and recorded as $NO_{X,ref}$.

(vi) The flow of the NO_2 calibration gas shall be stopped and the sampling system saturated by overflowing with a dew point generator's output, set at a dew point of 50 °C. The dew point generator's output shall be sampled through the sampling system and chiller for at least 10 minutes until the chiller is expected to be removing a constant rate of water.

(vii) Upon completion of (iv), the sampling system shall again be overflown by the NO_2 calibration gas used to establish $NO_{X,ref}$ until the total NO_X response has stabilised.

(viii) The mean concentration of the stabilised NO_X recordings over a period of 30 s shall be calculated and recorded as $NO_{X,m}$.

(ix) $NO_{X,m}$ shall be corrected to $NO_{X,dry}$ based upon the residual water vapour that passed through the chiller at the chiller's outlet temperature and pressure.

The calculated $NO_{X,dry}$ shall at least amount to 95 % of $NO_{X,ref}$.

(e) Sample dryer

A sample dryer removes water, which can otherwise interfere with the NO_X measurement. For dry CLD analysers, it shall be demonstrated that at the highest expected water vapour concentration H_m the sample dryer maintains the CLD humidity at ≤ 5 g water/kg dry air (or about 0.8 per cent H_2O), which is 100 per cent relative humidity at 3.9 °C and 101.3 kPa or about 25 per cent relative humidity at 25 °C and 101.3 kPa. Compliance may be demonstrated by measuring the temperature at the outlet of a thermal sample dryer or by measuring the humidity at a point just upstream of the CLD. The humidity of the CLD exhaust might also be measured as long as the only flow into the CLD is the flow from the sample dryer.

(f) Sample dryer NO_2 penetration

Liquid water remaining in an improperly designed sample dryer can remove NO_2 from the sample. If a sample dryer is used in combination with a NDUV analyser without an NO_2/NO converter upstream, water could therefore remove NO_2 from the sample prior to the NO_X measurement. The sample dryer shall allow for measuring at least 95 per cent of the NO_2 contained in a gas that is saturated with water vapour and consists of the maximum NO_2 concentration expected to occur during emission testing.

4.4. Response time check of the analytical system

For the response time check, the settings of the analytical system shall be exactly the same as during the emissions test (i.e. pressure, flow rates, filter settings in the analysers and all other parameters influencing the response time). The response time shall be determined with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0.1 second. The gases used for the test shall cause a concentration change of at least 60 per cent full scale of the analyser.

The concentration trace of each single gas component shall be recorded.

For time alignment of the analyser and exhaust flow signals, the transformation time is defined as the time from the change (t_0) until the response is 50 per cent of the final reading (t_{50}).

Commented [DP27]: JRC: Check if there is a better description elsewhere, or need to define proper methods

The system response time shall be ≤ 12 s with a rise time of ≤ 3 s for all components and all ranges used. When using a NMC for the measurement of NMHC, the system response time may exceed 12 seconds.

5. GASES

5.1. Calibration and span gases for RDE tests

5.1.1. General

The shelf life of calibration and span gases shall be respected. Pure as well as mixed calibration and span gases shall fulfil the specifications of UN Regulation No. 154.

5.1.2. NO_2 calibration gas

In addition, NO_2 calibration gas is permissible. The concentration of the NO_2 calibration gas shall be within two per cent of the declared concentration value. The amount of NO contained in the NO_2 calibration gas shall not exceed 5 per cent of the NO_2 content.

5.1.3. Multicomponent mixtures

Only multicomponent mixtures which fulfil the requirements of point 5.1.1. shall be used. These mixtures may contain two or more of the components. Multicomponent mixtures containing both NO and NO_2 are exempted of the NO_2 impurity requirement set out in points 5.1.1 and 5.1.2.

5.2. Gas dividers

Gas dividers, i.e., precision blending devices that dilute with purified N_2 or synthetic air, can be used to obtain calibration and span gases. The accuracy of the gas divider shall be such that the concentration of the blended calibration gases is accurate to within ± 2 per cent. The verification shall be performed at between 15 and 50 per cent of full scale for each calibration incorporating a gas divider. An additional verification may be performed using another calibration gas, if the first verification has failed.

Optionally, the gas divider may be checked with an instrument which by nature is linear, e.g. using NO gas in combination with a CLD. The span value of the instrument shall be adjusted with the span gas directly connected to the instrument. The gas divider shall be checked at the settings typically used and the nominal value shall be compared with the concentration measured by the instrument. The difference shall in each point be within ±1 per cent of the nominal concentration value.

5.3. Oxygen interference check gases

Oxygen interference check gases consist of a blend of propane, oxygen and nitrogen and shall contain propane at a concentration of 350 ± 75 $ppmC_1$. The concentration shall be determined by gravimetric methods, dynamic blending or the chromatographic analysis of total hydrocarbons plus impurities. The oxygen concentrations of the oxygen interference check gases shall meet the requirements listed in Table 3; the remainder of the oxygen interference check gas shall consist of purified nitrogen.

Table 3		
Oxygen interference check gases		
	Engine type	
	Compression ignition	Positive ignition
O_2 concentration	21 ± 1 %	10 ± 1 %
	10 ± 1 %	5 ± 1 %
	5 ± 1 %	0.5 ± 0.5 %

6. ANALYSERS FOR MEASURING (SOLID) PARTICLE EMISSIONS

Commented [DP28]: Add another section for PM pems

This section defines requirements for analysers for measuring particle number emissions, once their measurement becomes mandatory.

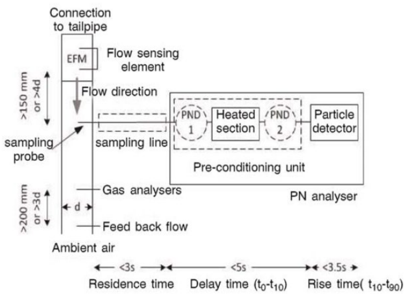
6.1. General

The PN analyser shall consist of a pre-conditioning unit and a particle detector that counts with 50 % efficiency from approximately 23 nm. It is permissible that the particle detector also pre-conditions the aerosol. The sensitivity of the analysers to shocks, vibration, aging, variability in temperature and air pressure as well as electromagnetic interferences and other impacts related to vehicle and analyser operation shall be limited as far as possible and shall be clearly stated by the equipment manufacturer in its support material. The PN analyser shall only be used within its manufacturer's declared parameters of operation.

Commented [DP(29]: This section will be updated with new methodology for sub 23 nm PEMS-PN developed by PMP IWG

Figure 1

Example of a PN analyser setup: Dotted lines depict optional parts. EFM = Exhaust mass Flow Meter, d = inner diameter, PND = Particle Number Diluter.



The PN analyser shall be connected to the sampling point via a sampling probe which extracts a sample from the centreline of the tailpipe tube. As specified in point 3.5. of Appendix 1, if particles are not diluted at the tailpipe, the sampling line shall be heated to a minimum temperature of 373 K (100 °C) until the point of first dilution of the PN analyser or the particle detector of the analyser. The residence time in the sampling line shall be less than 3 s.

All parts in contact with the sampled exhaust gas shall be always kept at a temperature that avoids condensation of any compound in the device. This can be achieved, e.g. by heating at a higher temperature and diluting the sample or oxidizing the (semi)volatile species.

The PN analyser shall include a heated section at wall temperature ≥ 573 K. The unit shall control the heated stages to constant nominal operating temperatures, within a tolerance of ± 10 K and provide an indication of whether or not heated stages are at their correct operating temperatures. Lower temperatures are acceptable as long as the volatile particle removal efficiency fulfils the specifications of paragraph 6.4.

Pressure, temperature and other sensors shall monitor the proper operation of the instrument during operation and trigger a warning or message in case of malfunction.

The delay time of the PN analyser shall be ≤ 5 s.

The PN analyser (and/or particle detector) shall have a rise time of ≤ 3.5 s.

Particle concentration measurements shall be reported normalised to 273 K and 101.3 kPa. If necessary, the pressure and/or temperature at the inlet of the detector shall be measured and reported for the purposes of normalizing the particle concentration.

PN systems that comply with the calibration requirements of the UNECE Regulations 83 or 49 or GTR 15 automatically comply with the calibration requirements of this Annex.

Commented [RG 04012130]: Add UNR 154?

6.2. *Efficiency requirements*

The complete PN analyser system including the sampling line shall fulfil the efficiency requirements of Table 3a.

Table 3a

PN analyser (including the sampling line) system efficiency requirements

d_p [nm]	Sub-23	23	30	50	70	100	200
$E(d_p)$ PN analyser	To be determined	0.2 – 0.6	0.3 – 1.2	0.6 – 1.3	0.7 – 1.3	0.7 – 1.3	0.5 – 2.0

Efficiency $E(d_p)$ is defined as the ratio in the readings of the PN analyser system to a reference Condensation Particle Counter (CPC)'s ($d_{50\%}$ = 10 nm or lower, checked for linearity and calibrated with an electrometer) or an Electrometer's number concentration measuring in parallel monodisperse aerosol of mobility diameter d_p and normalised at the same temperature and pressure conditions.

The material should be thermally stable soot-like (e.g. spark discharged graphite or diffusion flame soot with thermal pre-treatment). If the efficiency curve is measured with a different aerosol (e.g. NaCl), the correlation to the soot-like curve must be provided as a chart, which compares the efficiencies obtained using both test aerosols. The differences in the counting efficiencies have to be taken into account by adjusting the measured efficiencies based on the provided chart to give soot-like aerosol efficiencies. The correction for multiply charged particles should be applied and documented but shall not exceed 10 %. These efficiencies refer to the PN analysers with the sampling line. The PN analyser can also be calibrated in parts (i.e. the pre-conditioning unit separately from the particle detector) as long as it is proven that PN analyser and the sampling line together fulfil the requirements of Table 3a. The measured signal from the detector shall be > 2 times the limit of detection (here defined as the zero level plus 3 standard deviations).

6.3. *Linearity requirements*

The PN analyser including the sampling line shall fulfil the linearity requirements of point 3.2 in Appendix 2 using monodisperse or polydisperse soot-like particles. The particle size (mobility diameter or count median diameter) should be larger than 45 nm. The reference instrument shall be an Electrometer or a Condensation Particle Counter (CPC) with d_{50} = 10 nm or lower, verified for linearity. Alternatively, a particle number system compliant with GTR 15.

In addition the differences of the PN analyser from the reference instrument at all points checked (except the zero point) shall be within 15 % of their mean value. At least 5 points equally distributed (plus the zero) shall be checked. The maximum checked concentration shall be the maximum allowed concentration of the PN analyser.

If the PN analyser is calibrated in parts, then the linearity can be checked only for the PN detector, but the efficiencies of the rest parts and the sampling line have to be considered in the slope calculation.

6.4. *Volatile removal efficiency*

The system shall achieve > 99 % removal of ≥ 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles with an inlet concentration of ≥ 10000 particles per cubic-centimetre at the minimum dilution.

The system shall also achieve a > 99 % removal efficiency of polydisperse alcane (decane or higher) or emery oil with count median diameter > 50 nm and mass > 1 mg/m^3.

The volatile removal efficiency with tetracontane and/or polydisperse alcane or oil have to be proven only once for the instrument family. The instrument manufacturer though has to provide the maintenance or replacement interval that ensures that the removal efficiency does not drop below the technical requirements. If such information is not provided, the volatile removal efficiency has to be checked yearly for each instrument.

[ANALYSERS for Measuring PM emissions]

Commented [DP31]: USA and Canada to provide this text

7. INSTRUMENTS FOR MEASURING EXHAUST MASS FLOW

7.1. General

Instruments or signals for measuring the exhaust mass flow rate shall have a measuring range and response time appropriate for the accuracy required to measure the exhaust mass flow rate under transient and steady state conditions. The sensitivity of instruments and signals to shocks, vibration, aging, variability in temperature, ambient air pressure, electromagnetic interferences and other impacts related to vehicle and instrument operation shall be on a level as to minimise additional errors.

7.2. Instrument specifications

The exhaust mass flow rate shall be determined by a direct measurement method applied in either of the following instruments:

(a) Pitot-based flow devices;

(b) Pressure differential devices like flow nozzle (details see ISO 5167);

(c) Ultrasonic flow meter;

(d) Vortex flow meter.

Each individual exhaust mass flow meter shall fulfil the linearity requirements set out in point 3. Furthermore, the instrument manufacturer shall demonstrate the compliance of each type of exhaust mass flow meter with the specifications in points 7.2.3 to 7.2.9.

It is permissible to calculate the exhaust mass flow rate based on air flow and fuel flow measurements obtained from traceably calibrated sensors if these fulfil the linearity requirements of point 3., the accuracy requirements of point 8 and if the resulting exhaust mass flow rate is validated according to point 4 of Appendix 3.

In addition, other methods that determine the exhaust mass flow rate based on not directly traceable instruments and signals, such as simplified exhaust mass flow meters or ECU signals are permissible if the resulting exhaust mass flow rate fulfils the linearity requirements of point 3 and is validated according to point 4 of Appendix 3.

7.2.1. *Calibration and verification standards*

The measurement performance of exhaust mass flow meters shall be verified with air or exhaust gas against a traceable standard such as, e.g. a calibrated exhaust mass flow meter or a full flow dilution tunnel.

7.2.2. *Frequency of verification*

The compliance of exhaust mass flow meters with points 7.2.3. and 7.2.9. shall be verified no longer than one year before the actual test.

7.2.3. *Accuracy*

The accuracy of the EFM, defined as the deviation of the EFM reading from the reference flow value, shall not exceed ± 3 per cent of the reading, 0.5 % of full scale or ± 1.0 per cent of the maximum flow at which the EFM has been calibrated, whichever is larger.

7.2.4. *Precision*

The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given nominal flow, approximately in the middle of the calibration range, shall not exceed 1 per cent of the maximum flow at which the EFM has been calibrated.

7.2.5. *Noise*

The noise shall not exceed 2 per cent of the maximum calibrated flow value. Each of the 10 measurement periods shall be interspersed with an interval of 30 seconds in which the EFM is exposed to the maximum calibrated flow.

7.2.6. *Zero response drift*

The zero response drift is defined as the mean response to zero flow during a time interval of at least 30 seconds. The zero response drift can be verified based on the reported primary signals, e.g., pressure. The drift of the primary signals over a period of 4 hours shall be less than ±2 per cent of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated.

7.2.7. *Span response drift*

The span response drift is defined as the mean response to a span flow during a time interval of at least 30 seconds. The span response drift can be verified based on the reported primary signals, e.g., pressure. The drift of the primary signals over a period of 4 hours shall be less than ± 2 per cent of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated.

7.2.8. *Rise time*

The rise time of the exhaust flow instruments and methods should match as far as possible the rise time of the gas analysers as specified in point 4.2.7 but shall not exceed 1 second.

Commented [DP32]: JRC: Method for time alignment to be checked.

7.2.9. *Response time check*

The response time of exhaust mass flow meters shall be determined by applying similar parameters as those applied for the emissions test (i.e., pressure, flow rates, filter settings and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the exhaust mass flow meter. The gas flow switching shall be done as fast as possible, but highly recommended in less than 0.1 second. The gas flow rate used for the test shall cause a flow rate change of at least 60 per cent full scale of the exhaust mass flow meter. The gas flow shall be recorded. The delay time is defined as the time from the gas flow switching (t_0) until the response is 10 per cent (t_{10}) of the final reading. The rise time is defined as the time between 10 per cent and 90 per cent response ($t_{90} - t_{10}$) of the final reading. The response time (t_{90}) is defined as the sum of the delay time and the rise time. The exhaust mass flow meter response time (t_{90}) shall be ≤ 3 s with a rise time ($t_{90} - t_{10}$) of ≤ 1 s in accordance with point 7.2.8.

8. SENSORS AND AUXILIARY EQUIPMENT

Any sensor or auxiliary equipment used to determine, e.g., temperature, atmospheric pressure, ambient humidity, vehicle speed, fuel flow or intake air flow shall not alter or unduly affect the performance of the vehicle's engine and exhaust after-treatment system. The accuracy of sensors and auxiliary equipment shall fulfil the requirements of Table 4. Compliance with the requirements of Table 4 shall be demonstrated at intervals specified by the instrument manufacturer, as required by internal audit procedures or in accordance with ISO 9000.

Table 4

Accuracy requirements for measurement parameters

Measurement parameter	Accuracy
Fuel flow[40]	± 1 % of reading[41]
Air flow[42]	± 2 % of reading

[40] optional to determine exhaust mass flow

[41] The accuracy shall be 0.02 per cent of reading if used to calculate the air and exhaust mass flow rate from the fuel flow according to point 10 of Appendix 4.

[42] optional to determine exhaust mass flow

Vehicle speed[43]	± 1.0 km/h absolute
Temperatures ≤600 K	± 2 K absolute
Temperatures >600 K	± 0.4 % of reading in Kelvin
Ambient pressure	± 0.2 kPa absolute
Relative humidity	± 5 % absolute
Absolute humidity	± 10 % of reading or, 1 gH_2O/kg dry air, whichever is larger

[43] This requirement applies to the speed sensor only; if vehicle speed is used to determine parameters like acceleration, the product of speed and positive acceleration, or RPA, the speed signal shall have an accuracy of 0.1 % above 3 km/h and a sampling frequency of 1 Hz. This accuracy requirement can be met by using the signal of a wheel rotational speed sensor.

ANNEX 3

VALIDATION OF PEMS AND NON-TRACEABLE EXHAUST MASS FLOW RATE

Commented [RG 25062033]: Update to align with UNR (where appropriate)?

1. INTRODUCTION

This appendix describes the requirements to validate under transient conditions the functionality of the installed PEMS as well as the correctness of the exhaust mass flow rate obtained from non-traceable exhaust mass flow meters or calculated from ECU signals.

2. SYMBOLS, PARAMETERS AND UNITS

a_0	—	y intercept of the regression line
a_1	—	slope of the regression line
r^2	—	coefficient of determination
x	—	actual value of the reference signal
y	—	actual value of the signal under validation

3. VALIDATION PROCEDURE FOR PEMS

3.1. *Frequency of PEMS validation*

It is recommended to validate the correct installation of a PEMS on a vehicle via comparison with laboratory installed equipment on a test performed on a chassis dynamometer either before the RDE test or, alternatively, after the completion of the test.

3.2. *PEMS validation procedure*

3.2.1. *PEMS installation*

The PEMS shall be installed and prepared according to the requirements of Appendix 1. The PEMS installation shall be kept unchanged in the time period between the validation and the RDE test.

3.2.2. *Test conditions*

The validation test shall be conducted on a chassis dynamometer, as far as possible, using an applicable test cycle. It is recommended to feed the exhaust flow extracted by the PEMS during the validation test back to the CVS. If this is not feasible, the CVS results shall be corrected for the extracted exhaust mass. If the exhaust mass flow rate is validated with an exhaust mass flow meter, it is recommended to cross-check the mass flow rate measurements with data obtained from a sensor or the ECU.

3.2.3. *Data analysis*

The total distance-specific emissions [g/km] measured with laboratory equipment shall be calculated in accordance with the applicable Regulation. The emissions as measured with the PEMS shall be calculated according to point 9 of Appendix 4, summed to give the total mass of criteria emissions [g] and then divided by the test distance [km] as obtained from the chassis dynamometer. The total distance-specific mass of criteria emissions [g/km], as determined by the PEMS and the reference laboratory system, shall be evaluated against the requirements specified in point 3.3. For the validation of NO_X emission measurements, humidity correction shall be applied in accordance with the applicable Regulation.

3.3. *Permissible tolerances for PEMS validation*

The PEMS validation results shall fulfil the requirements given in Table 1 for a validation using an appropriate regulatory cycle. If any permissible tolerance is not met, corrective action shall be taken and the PEMSvalidation shall be repeated.

The permissible tolerances for PEMS validation for M1/M2/N1 Low Powered vehicles to be reviewed based on RDE learnings.

Commented [JPN Sep2034]: this should be set with para.9.(test procedure)

Table 1	
Permissible tolerances for WLTC validations (add other CP validation parameters)	
Parameter [Unit]	Permissible absolute tolerance for WLTC
Distance [km][44]	250 m of the laboratory reference
THC[45] [mg/km]	15 mg/km or 15 % of the laboratory reference, whichever is larger
CH_4[46] [mg/km]	15 mg/km or 15 % of the laboratory reference, whichever is larger
NMHC[47] [mg/km]	20 mg/km or 20 % of the laboratory reference, whichever is larger
PN[48] [#/km]	$1 \cdot 10^{11}$ p/km or 50 % of the laboratory reference[49] whichever is larger
CO[50] [mg/km]	150 mg/km or 15 % of the laboratory reference, whichever is larger

Commented ["35]: Same here. Are tolerances appropriate?

[44] only applicable if vehicle speed is determined by the ECU; to meet the permissible tolerance it is permitted to adjust the ECU vehicle speed measurements based on the outcome of the validation test

[45] parameter only mandatory if measurement required by point 2.1 of this Annex.

[46] parameter only mandatory if measurement required by point 2.1 of this Annex.

[47] parameter only mandatory if measurement required by point 2.1 of this Annex.

[48] parameter only mandatory if measurement required by point 2.1 of this Annex.

[49] PMP system.

[50] parameter only mandatory if measurement required by point 2.1 of this Annex.

CO_2 [g/km]	10 g/km or 10 % of the laboratory reference, whichever is larger
NO_x[51] [mg/km]	15 mg/km or 15 % of the laboratory reference, whichever is larger

4. VALIDATION PROCEDURE FOR THE EXHAUST MASS FLOW RATE DETERMINED BY NON-TRACEABLE INSTRUMENTS AND SENSORS

4.1. Frequency of validation

In addition to fulfilling the linearity requirements of point 3 of Appendix 2 under steady-state conditions, the linearity of non-traceable exhaust mass flow meters or the exhaust mass flow rate calculated from non-traceable sensors or ECU signals shall be validated under transient conditions for each test vehicle against a calibrated exhaust mass flow meter or the CVS.

4.2. Validation procedure

The validation shall be conducted on a chassis dynamometer under type approval conditions, as far as applicable. As reference, a traceably calibrated flow meter shall be used. The ambient temperature can be any within the range specified in point 5.2 of this GTR. The installation of the exhaust mass flow meter and the execution of the test shall fulfil the requirement of point 3.4.3 of Appendix 1 of this GTR.

The following calculation steps shall be taken to validate the linearity:

(a) The signal under validation and the reference signal shall be time corrected by following, as far as applicable, the requirements of point 3 of Appendix 4.

(b) Points below 10 % of the maximum flow value shall be excluded from the further analysis.

(c) At a constant frequency of at least 1.0 Hz, the signal under validation and the reference signal shall be correlated using the best-fit equation having the form:

$$y = a_1 x + a_0$$

where:

y		is the actual value of the signal under validation
a		is the slope of the regression line

[51] parameter only mandatory if measurement required by point 2.1 of this Annex.

x		is the actual value of the reference signal
a		is the y intercept of the regression line

The standard error of estimate (SEE) of y on x and the coefficient of determination (r^2) shall be calculated for each measurement parameter and system.

(d) The linear regression parameters shall meet the requirements specified in Table 2.

4.3. *Requirements*

The linearity requirements given in Table 2 shall be fulfilled. If any permissible tolerance is not met, corrective action shall be taken and the validation shall be repeated.

Table 2

Linearity requirements of calculated and measured exhaust mass flow

Measurement parameter/system	a_0	Slope a_1	Standard error of estimate SEE	Coefficient of determination r^2
Exhaust mass flow	0.0 ± 3.0 kg/h	1.00 ± 0.075	≤10 % max	≥ 0.90

ANNEX 4

DETERMINATION OF INSTANTANEOUS EMISSIONS

Commented [RG 25062036]: Update to align with UNR (where appropriate)?

1. INTRODUCTION

This annex describes the procedure to determine the instantaneous mass and particle number emissions [g/s; #/s] that shall be used for the subsequent evaluation of a RDE trip and the calculation of the final emission result as described in Appendix 6.

2. SYMBOLS, PARAMETERS AND UNITS

α	—	molar hydrogen ratio (H/C)
β	—	molar carbon ratio (C/C)
γ	—	molar sulphur ratio (S/C)
δ	—	molar nitrogen ratio (N/C)
$\Delta t_{t,i}$	—	transformation time t of the analyser [s]
$\Delta t_{t,m}$	—	transformation time t of the exhaust mass flow meter [s]
ε	—	molar oxygen ratio (O/C)
ρ_e	—	density of the exhaust
ρ_{gas}	—	density of the exhaust component 'gas'
λ	—	excess air ratio
λ_i	—	instantaneous excess air ratio
A/F_{st}	—	stoichiometric air-to-fuel ratio [kg/kg]
c_{CH4}	—	concentration of methane
c_{CO}	—	dry CO concentration [%]
c_{CO2}	—	dry CO_2 concentration [%]
c_{dry}	—	dry concentration of a criteria emission in ppm or per cent volume
$c_{gas,i}$	—	instantaneous concentration of the exhaust component 'gas' [ppm]
c_{HCw}	—	wet HC concentration [ppm]

$c_{HC(w/NMC)}$	—	HC concentration with CH_4 or C_2H_6 flowing through the NMC [$ppmC_1$]
$c_{HC(w/oNMC)}$	—	HC concentration with CH_4 or C_2H_6 bypassing the NMC [$ppmC_1$]
$c_{i,c}$	—	time-corrected concentration of component *i* [ppm]
$c_{i,r}$	—	concentration of component *i* [ppm] in the exhaust
c_{NMHC}	—	concentration of non-methane hydrocarbons
c_{wet}	—	wet concentration of a criteria emission in ppm or per cent volume
E_E	—	ethane efficiency
E_M	—	methane efficiency
H_a	—	intake air humidity [g water per kg dry air]
i	—	number of the measurement
$m_{gas,i}$	—	mass of the exhaust component 'gas' [g/s]
$q_{maw,i}$	—	instantaneous intake air mass flow rate [kg/s]
$q_{m,c}$	—	time-corrected exhaust mass flow rate [kg/s]
$q_{mew,i}$	—	instantaneous exhaust mass flow rate [kg/s]
$q_{mf,i}$	—	instantaneous fuel mass flow rate [kg/s]
$q_{m,r}$	—	raw exhaust mass flow rate [kg/s]
r	—	cross-correlation coefficient
r^2	—	coefficient of determination
r_h	—	hydrocarbon response factor
u_{gas}	—	*u* value of the exhaust component 'gas'

3. TIME CORRECTION OF PARAMETERS

For the correct calculation of distance-specific emissions, the recorded traces of component concentrations, exhaust mass flow rate, vehicle speed, and other vehicle data shall be time corrected. To facilitate the time correction, data which are subject to time alignment shall be recorded either in a single data recording device or with a synchronised timestamp following point 5.1 of Appendix 1. The time correction and alignment of parameters shall be carried out by following the sequence described in points 3.1. to 3.3.

3.1. *Time correction of component concentrations*

The recorded traces of all component concentrations shall be time corrected by reverse shifting according to the transformation times of the respective analysers. The transformation time of analysers shall be determined according to point 4.4. of Appendix 2:

$$c_{i,c}(t - \Delta t_{t,i}) = c_{i,r}(t)$$

where:

$c_{i,c}$		is the time-corrected concentration of component i as function of time t
$c_{i,r}$		is the raw concentration of component i as function of time t
$\Delta t_{t,i}$		is the transformation time t of the analyser measuring component i

3.2. *Time correction of exhaust mass flow rate*

The exhaust mass flow rate measured with an exhaust flow meter shall be time corrected by reverse shifting according to the transformation time of the exhaust mass flow meter. The transformation time of the mass flow meter shall be determined according to point 4.4. of Appendix 2:

$$q_{m,c}(t - \Delta t_{t,m}) = q_{m,r}(t)$$

where:

$q_{m,c}$		is the time-corrected exhaust mass flow rate as function of time t
$q_{m,r}$		is the raw exhaust mass flow rate as function of time t
$\Delta t_{t,m}$		is the transformation time t of the exhaust mass flow meter

In case the exhaust mass flow rate is determined by ECU data or a sensor, an additional transformation time shall be considered and obtained by cross-correlation between the calculated exhaust mass flow rate and the exhaust mass flow rate measured following point 4. of Appendix 3.

3.3. *Time alignment of vehicle data*

Other data obtained from a sensor or the ECU shall be time-aligned by cross-correlation with suitable emission data (e.g., component concentrations).

3.3.1. *Vehicle speed from different sources*

To time align vehicle speed with the exhaust mass flow rate, it is first necessary to establish one valid speed trace. In case vehicle speed is obtained from multiple sources (e.g., the GNSS, a sensor or the ECU), the speed values shall be time aligned by cross-correlation.

3.3.2. *Vehicle speed with exhaust mass flow rate*

Vehicle speed shall be time aligned with the exhaust mass flow rate by cross-correlation between the exhaust mass flow rate and the product of vehicle speed and positive acceleration.

3.3.3. *Further signals*

The time alignment of signals whose values change slowly and within a small value range, e.g. ambient temperature, can be omitted.

4. EMISSION MEASUREMENTS DURING STOP OF THE COMBUSTION ENGINE

Any instantaneous emissions or exhaust flow measurements obtained while the combustion engine is deactivated shall be recorded.

Any instantaneous emissions or exhaust flow measurements obtained while the combustion engine is deactivated shall be recorded in the data exchange file.

5. CORRECTION OF Measured Values

5.1.. Dry-wet correction

If the emissions are measured on a dry basis, the measured concentrations shall be converted to a wet basis as:

where:

$$c_{\mathrm{wet}} = k_{\mathrm{w}} \times c_{\mathrm{dry}}$$

c_{wet}		is the wet concentration of a criteria emission in ppm or per cent volume
c_{dry}		is the dry concentration of a criteria emission in ppm or per cent volume
k_{w}		is the dry-wet correction factor

The following equation shall be used to calculate k_{w}:

$$\boldsymbol{k_{\mathrm{w}}} = \left(\frac{\mathbf{1}}{\mathbf{1} + \boldsymbol{\alpha} \times \mathbf{0.005} \times \left(\boldsymbol{c_{\mathrm{CO_2}}} + \boldsymbol{c_{\mathrm{CO}}} \right)} - \boldsymbol{k_{\mathrm{w1}}} \right) \times \mathbf{1.008}$$

where:

$$\boldsymbol{k_{\mathrm{w1}}} = \frac{\mathbf{1.608} \times \boldsymbol{H_{\mathrm{a}}}}{\mathbf{1000} + (\mathbf{1.608} \times \boldsymbol{H_{\mathrm{a}}})}$$

where:

H_a		is the intake air humidity [g water per kg dry air]
c_{CO2}		is the dry CO_2 concentration [%]
c_{CO}		is the dry CO concentration [%]
α		is the molar hydrogen ratio of the fuel (H/C)

5.2. *Correction of NO_x for ambient humidity and temperature*

NO_x emissions shall not be corrected for ambient temperature and humidity.

5.3. *Correction of negative emission results*

Negative instantaneous results shall not be corrected.

5.4. *Correction for extended conditions*

If a CP decides that a correction factor needs to be applied for emissions measured under extended boundary conditions, then the second-by second emissions calculated in accordance with this Appendix under these extended boundary conditions shall be divided by an appropriate factor (Extended Factor, or EF).

The EF shall be applied only once. The EF applies to criteria emissions but not to CO_2.

6. DETERMINATION OF THE INSTANTANEOUS GASEOUS EXHAUST COMPONENTS

6.1. *Introduction*

The components in the raw exhaust shall be measured with the measurement and sampling analysers described in Appendix 2. The raw concentrations of relevant components shall be measured in accordance with Appendix 1. The data shall be time corrected and aligned in accordance with point 3.

6.2. *Calculating NMHC and CH_4 concentrations*

For methane measurement using a NMC-FID, the calculation of NMHC depends on the calibration gas/method used for the zero/span calibration adjustment. When a FID is used for THC measurement without a NMC, it shall be calibrated with propane/air or propane/N_2 in the normal manner. For the calibration of the FID in series with a NMC, the following methods are permitted:

(a) the calibration gas consisting of propane/air bypasses the NMC;

(b) the calibration gas consisting of methane/air passes through the NMC.

It is strongly recommended to calibrate the methane FID with methane/air through the NMC.

In method (a), the concentrations of CH_4 and NMHC shall be calculated as follows:

$$c_{CH4} = \frac{c_{HC(w/o\,NMC)} \times (1 - E_M) - c_{HC(w/NMC)}}{E_E - E_M}$$

$$c_{NMHC} = \frac{c_{HC(w/NMC)} - c_{HC(w/o\,NMC)} \times (1 - E_E)}{r_h \times (E_E - E_M)}$$

In method (b), the concentration of CH_4 and NMHC shall be calculated as follows:

$$c_{CH_4} = \frac{c_{HC(w/NMC)} \times r_h \times (1 - E_M) - c_{HC(w/o\,NMC)} \times (1 - E_E)}{r_h \times (E_E - E_M)}$$

$$c_{NMHC} = \frac{c_{HC(w/o\,NMC)} \times (1 - E_M) - c_{HC(w/\,NMC)} \times r_h \times (1 - E_M)}{(E_E - E_M)}$$

where:

$c_{HC(w/oNMC)}$		is the HC concentration with CH_4 or C_2H_6 bypassing the NMC [ppmC_1]
$c_{HC(w/NMC)}$		is the HC concentration with CH_4 or C_2H_6 flowing through the NMC [ppmC_1]
r_h		is the hydrocarbon response factor as determined in point 4.3.3.(b) of Appendix 2
E_M		is the methane efficiency as determined in point 4.3.4.(a) of Appendix 2
E_E		is the ethane efficiency as determined in point 4.3.4.(b) of Appendix 2

If the methane FID is calibrated through the cutter (method b), then the methane conversion efficiency as determined in point 4.3.4.(a) of Appendix 2 is zero. The density used for calculating the NMHC mass shall be equal to that of total hydrocarbons at 273.15 K and 101.325 kPa and is fuel-dependent.

7. DETERMINATION OF EXHAUST MASS FLOW RATE

7.1. Introduction

Commented [DP37]: JRC, USA: Check if some of these can be copied from ISO and/or CFR.

The calculation of instantaneous mass emissions according to points 11 and 12 requires determining the exhaust mass flow rate. The exhaust mass flow rate shall be determined by one of the direct measurement methods specified in point 7.2. of Appendix 2. Alternatively, it is permissible to calculate the exhaust mass flow rate as described in points 10.2. to 10.4.

7.2. *Calculation method using air mass flow rate and fuel mass flow rate*

The instantaneous exhaust mass flow rate can be calculated from the air mass flow rate and the fuel mass flow rate as follows:

$$q_{\mathrm{mew,i}} = q_{\mathrm{maw,i}} + q_{\mathrm{mf,i}}$$

where:

$q_{\mathrm{mew,i}}$		is the instantaneous exhaust mass flow rate [kg/s]
$q_{\mathrm{maw,i}}$		is the instantaneous intake air mass flow rate [kg/s]
$q_{\mathrm{mf,i}}$		is the instantaneous fuel mass flow rate [kg/s]

If the air mass flow rate and the fuel mass flow rate or the exhaust mass flow rate are determined from ECU recording, the calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust mass flow rate in point 3 of Appendix 2 and the validation requirements specified in point 4.3 of Appendix 3.

7.3. *Calculation method using air mass flow and air-to-fuel ratio*

The instantaneous exhaust mass flow rate can be calculated from the air mass flow rate and the air-to-fuel ratio as follows:

$$q_{mew,i} = q_{maw,i} \times \left(1 + \frac{1}{(A/F)_{st} \times \lambda_i}\right)$$

where:

$$(A/F)_{st} = \frac{138.0 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right)}{12.011 + 1.008 \times \alpha + 15.9994 \times \varepsilon + 14.0067 \times \delta + 32.0675 \times \gamma}$$

$$\lambda_i = \frac{\left(100 - \frac{c_{CO} \times 10^{-4}}{2} - c_{HCw} \times 10^{-4}\right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{CO} \times 10^{-4}}{3.5 \times c_{CO2}}}{1 + \frac{c_{CO} \times 10^{-4}}{3.5 \times c_{CO2}}} - \frac{\varepsilon}{2} - \frac{\delta}{2}\right) \times (c_{CO2} + c_{CO} \times 10^{-4})}{4.764 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \times (c_{CO2} + c_{CO} \times 10^{-4} + c_{HCw} \times 10^{-4})}$$

where:

$q_{\mathrm{maw,i}}$		is the instantaneous intake air mass flow rate [kg/s]
A/F_{st}		is the stoichiometric air-to-fuel ratio [kg/kg]
λ_{i}		is the instantaneous excess air ratio
c_{CO2}		is the dry CO_2 concentration [%]
c_{CO}		is the dry CO concentration [ppm]
c_{HCw}		is the wet HC concentration [ppm]

α		is the molar hydrogen ratio (H/C)
β		is the molar carbon ratio (C/C)
γ		is the molar sulphur ratio (S/C)
δ		is the molar nitrogen ratio (N/C)
ε		is the molar oxygen ratio (O/C)

Coefficients refer to a fuel $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$ with $\beta = 1$ for carbon based fuels. The concentration of HC emissions is typically low and may be omitted when calculating λ_i.

If the intake air mass flow rate and air-to-fuel ratio are determined from ECU recording, the calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust mass flow rate in point 3 of Appendix 2 and the validation requirements specified in point 4.3 of Appendix 3.

7.4. *Calculation method using fuel mass flow and air-to-fuel ratio*

The instantaneous exhaust mass flow rate can be calculated from the fuel flow and the air-to-fuel ratio (calculated with A/F_{st} and λ_i according to point 10.3.) as follows:

$$\boldsymbol{q_{mew,i} = q_{mf,i} \times \left(1 + \frac{1}{A/F_{st} \times \lambda_i}\right)}$$

$$\boldsymbol{q_{mew,i} = q_{maw,i} \times (1 + A/F_{st} \times \lambda_i)}$$

The calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust gas mass flow rate in point 3 of Appendix 2 and the validation requirements specified in point 4.3. of Appendix 3.

8. CALCULATING THE INSTANTANEOUS MASS EMISSIONS OF GASEOUS COMPONENTS

The instantaneous mass emissions [g/s] shall be determined by multiplying the instantaneous concentration of the criteria emission under consideration [ppm] with the instantaneous exhaust mass flow rate [kg/s], both corrected and aligned for the transformation time, and the respective u value of Table 1. If measured on a dry basis, the dry-wet correction according to point 8.1 shall be applied to the instantaneous component concentrations before executing any further calculations. If occurring, negative instantaneous emission values shall enter all subsequent data evaluations. Parameter values shall enter the calculation of instantaneous emissions [g/s] as reported by the analyser, flow-measuring instrument, sensor or the ECU. The following equation shall be applied:

$$\boldsymbol{m_{\mathrm{gas,i}} = u_{\mathrm{gas}} \cdot c_{gas,i} \cdot q_{\mathrm{mew,i}}}$$

where:

$m_{gas,i}$		is the mass flow rate of the exhaust component ‘gas’ [g/s]
u_{gas}		is the ratio of the density of the exhaust component ‘gas’ and the overall density of the exhaust as listed in Table 1
$c_{gas,i}$		is the measured concentration of the exhaust component ‘gas’ in the exhaust [ppm]
$q_{mew,i}$		is the measured exhaust mass flow rate [kg/s]
gas		is the respective component
i		number of the measurement

Table A7/1

Commented [RG 30112038]: Update to align with equivalent table in UNR RDE

Raw exhaust gas u values depicting the ratio between the densities of exhaust component or pollutant i [kg/m^3] and the density of the exhaust gas [kg/m^3]

Fuel	ρ_e [kg/m^3]	Component or pollutant i					
		NO_x	CO	HC	CO_2	O_2	CH_4
		ρ_{gas} [kg/m^3]					
		2.052	1.249	(1)	1.9630	1.4276	0.715
		u_{gas} (2,6)					
Diesel (B0)	1.2893	0.001593	0.000969	0.000480	0.001523	0.001108	0.000555
Diesel (B5)	1.2893	0.001593	0.000969	0.000480	0.001523	0.001108	0.000555
Diesel (B7)	1.2894	0.001593	0.000969	0.000480	0.001523	0.001108	0.000555
Ethanol (ED95)	1.2768	0.001609	0.000980	0.000780	0.001539	0.001119	0.000561
CNG(3)	1.2661	0.001621	0.000987	0.000528(4)	0.001551	0.001128	0.000565

Propane	1.2805	0.001603	0.000976	0.000512	0.001533	0.001115	0.000559
Butane	1.2832	0.001600	0.000974	0.000505	0.001530	0.001113	0.000558
LPG(5)	1.2811	0.001602	0.000976	0.000510	0.001533	0.001115	0.000559
Petrol (E0)	1.2910	0.001591	0.000968	0.000480	0.001521	0.001106	0.000554
Petrol (E5)	1.2897	0.001592	0.000969	0.000480	0.001523	0.001108	0.000555
Petrol (E10)	1.2883	0.001594	0.000970	0.000481	0.001524	0.001109	0.000555
Ethanol (E85)	1.2797	0.001604	0.000977	0.000730	0.001534	0.001116	0.000559

(1) depending on fuel

(2) at $\lambda = 2$, dry air, 273 K, 101.3 kPa

(3) u values accurate within 0.2% for mass composition of: C=66-76%; H=22-25%; N=0-12%

(4) NMHC on the basis of $CH_{2.93}$ (for THC the u_{gas} coefficient of CH_4 shall be used)

(5) u accurate within 0.2% for mass composition of: C_3=70-90%; C_4=10-30%

(6) u_{gas} is a unitless parameter; the u_{gas} values include unit conversions to ensure that the instantaneous emissions are obtained in the specified physical unit, i.e., g/s

As an alternative to the above method, emission rates might also be calculated with the method described in Annex 7 of GTR 11.

9. CALCULATING THE INSTANTANEOUS Particulate Matter and PARTICLE NUMBER EMISSIONS

a. PN emissions

The instantaneous particle number emissions [particles/s] shall be determined by multiplying the instantaneous concentration of the criteria emission under consideration [particles/cm^3] with the instantaneous exhaust mass flow rate [kg/s], both corrected and aligned for the transformation time. If applicable, negative instantaneous emission values shall enter all subsequent data evaluations. All significant digits of intermediate results shall enter the calculation of the instantaneous emissions. The following equation shall apply:

$$PN_i = c_{PN,i} q_{mew,i} / \rho_e$$

where:

PN_i			is the particle number flux [particles/s]
$c_{PN,i}$			is the measured particle number concentration [#/m^3] normalised at 0 °C
$q_{mew,i}$			is the measured exhaust mass flow rate [kg/s]
ρ_e			is the density of the exhaust gas [kg/m^3] at 0 °C (Table 1)

b. PM emissions

10. DATA EXCHANGEAND REPORTING FILES

Data Exchange File: The data shall be exchanged between the measurement systems and the data evaluation software by a standardised data exchange file found in the WIKI.

Any pre-processing of data (e.g. time correction according to point 3 or the correction of the GNSS vehicle speed signal according to point 7) shall be done with the control software of the measurement systems and shall be completed before the data exchange file is generated.

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ANNEX 5

ASSESSMENT OF OVERALL TRIP DYNAMICS USING THE MOVING AVERAGING WINDOW METHOD

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1. INTRODUCTION

The Moving Averaging Window method is used to assess the overall trip dynamics. The test is divided in sub-sections (windows) and the subsequent analysis aims at determining whether the trip is valid for RDE purposes. The 'normality' of the windows is assessed by comparing their CO_2 distance-specific emissions with a reference curve obtained from the vehicle CO_2 emissions measured in accordance with the applicable type approval cycle.

2. SYMBOLS, PARAMETERS AND UNITS

Index (i) refers to the time step.

Index (j) refers to the window.

Index (k) refers to the category (t=total, u=low speed average speed class, r=medium speed average speed class, m=high speed average speed class) or to the CO_2 characteristic curve (cc).

a_1, b_1 - coefficients of the CO_2 characteristic curve

a_2, b_2 - coefficients of the CO_2 characteristic curve

M_{CO_2} - CO_2 mass, [g]

$M_{CO_2,j}$ - CO_2 mass in window j, [g]

t_i - total time in step i, [s]

t_t - duration of a test, [s]

v_i - actual vehicle speed in time step i, [km/h]

$\overline{v}_j$ - average vehicle speed in window j, [km/h]

tol_{1H} - upper tolerance for the vehicle CO_2 characteristic curve, [%]

tol_{1L} - lower tolerance for the vehicle CO_2 characteristic curve, [%]

3. MOVING AVERAGING WINDOWS

3.1. Definition of averaging windows

The instantaneous CO_2 emissions calculated according to Appendix 4 shall be integrated using a moving averaging window method, based on an appropriate reference CO_2 mass. The reference CO_2 mass shall be defined by each Contracting Party.

The moving window calculations are conducted with a time increment Δt corresponding to the data sampling frequency. These sub-sets used to calculate the vehicle on-road CO_2 emissions and its average speed are referred to as 'averaging windows' in the following sections. The calculation described in the present point shall be run from the first data point (forward).

The following data shall not be considered for the calculation of the CO_2 mass, the distance and the vehicle average speed in each averaging window:

The periodic verification of the instruments and/or after the zero drift verifications;

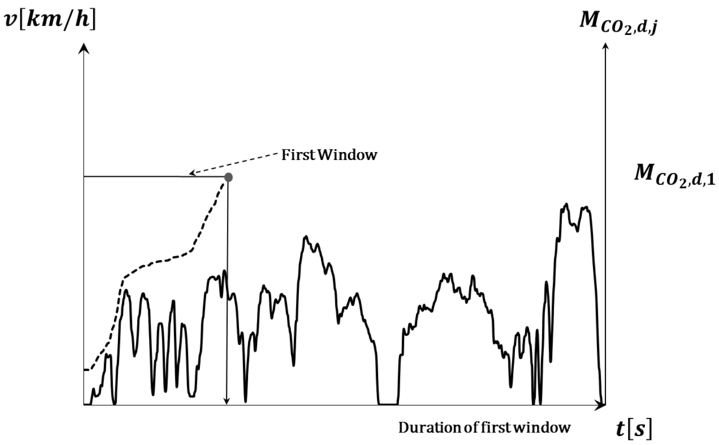
Vehicle ground speed < 1 km/h;

The calculation shall start from test start.

The mass emissions $M_{CO_2,j}$ shall be determined by integrating the instantaneous emissions in g/s as specified in Annex 4 to this Regulation.

Figure 1

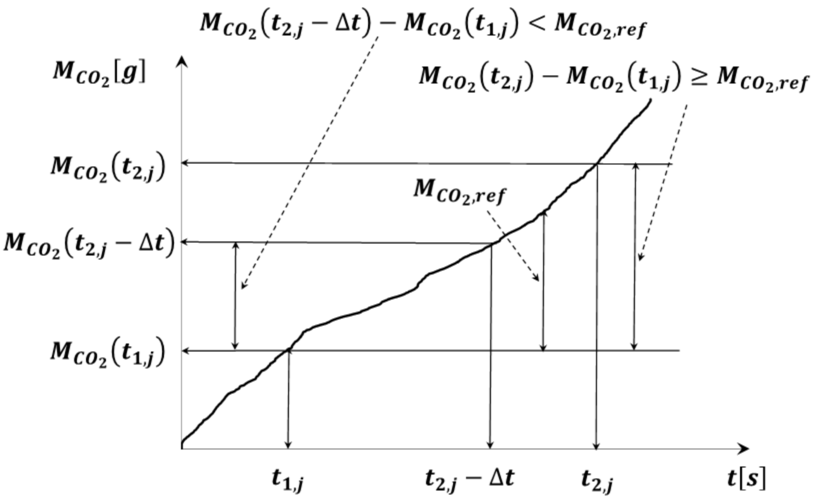
Vehicle speed versus time - Vehicle averaged emissions versus time, starting from the first averaging window



Commented [RG 16062042]: The usage of the reference CO_2 mass is illustrated in Figure A8/2. The principle of the calculation is as follows: The RDE distance-specific CO_2 mass emissions are not calculated for the complete data set, but for sub-sets of the complete data set, the length of these sub-sets being determined so as to match always the same fraction of the CO_2 mass emitted by the vehicle over the applicable WLTP test (after all appropriate corrections e.g. ATCT are applied, where relevant). The moving window calculations are conducted with a time increment Δt corresponding to the data sampling frequency. These sub-sets used to calculate the vehicle on-road CO_2 emissions and its average speed are referred to as 'averaging windows' in the following sections. The calculation described in this point shall be run from the first data point (forward), as shown in Figure A8/1.

Figure 2

Definition of CO_2 mass based on averaging windows



The duration $(t_{2,j} - t_{1,j})$ of the j[th] averaging window is determined by:

$$M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j}) \geq M_{CO_2,ref}$$

Where:

$M_{CO_2}(t_{i,j})$ is the CO_2 mass measured between the test start and time $t_{2,j}$, [g];

$M_{CO_2,ref}$ is the reference CO_2 mass

$t_{2,j}$ shall be selected such as:

$$M_{CO_2}(t_{2,j} - \Delta t) - M_{CO_2}(t_{1,j}) < M_{CO_2,ref} \leq M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j})$$

where $\Delta t$is the data sampling period.

The CO_2 masses $M_{CO_2,j}$ in the windows are calculated by integrating the instantaneous emissions calculated as specified in Annex 4 to this Regulation.

Examples of applications by contracting parties

Contracting party using	Reference CO_2 mass
WLTP 3 and 4 phases	Half of the CO_2 mass emitted during the applicable WLTP cycle Half of the CO2 mass emitted by OVC-HEV vehicles in Charge Sustaining mode WLTP cycle
WLTC 3 Phase (India)	India adopts the CP option for Reference CO2 mass and shall update the same in future after further validation.

3.2. *Calculation of window characteristics*

The following shall be calculated for each window determined in accordance with point 3.1.,

– The distance-specific CO_2 emissions $M_{CO_2,d,j}$;

– The average vehicle speed $\bar{v}_j$

4. EVALUATION OF WINDOWS

4.1. *Introduction*

The windows are assessed by comparing their CO_2 distance-specific emissions with a curve obtained from the vehicle CO_2 emissions measured in accordance with the applicable type approval cycle. For that purpose, the windows are classified in urban, rural and motorway average speed classes.

4.2. *CO_2 characteristic curve reference points*

The distance-specific CO_2 emissions to be considered in this paragraph for the definition of the characteristic curve shall be obtained from the tests conducted on the vehicle using the applicable type approval cycle(s).

For OVC-HEV vehicles, the values shall be obtained from the applicable type approval cycle conducted using the Charge Sustaining mode.

The reference points P_1,P_2 and P_3 required to define the vehicle CO_2 characteristic curve are as follows:

4.2.1. *Point P_1 - Low speed point*

The co-ordinates for $P_1$are the following:.

$\overline{v_{P1}}$ is the average speed for the type approval cycle (or cycle phases) **selected as representative for urban operation** by the contracting party, [km/h]

M_{CO_2,d,P_1} are the distance-specific vehicle CO_2 emissions of the type approval cycle or cycle phases **selected as representative for urban operation** by the contracting party [g/km]

4.2.2. *Point P_2 - Medium speed point*

The co-ordinates for P_2 are the following:.

$\overline{v_{P2}}$ is the average speed of the type approval cycle (or cycle phases) **selected as representative for rural operation** by the contracting party, [km/h]

M_{CO_2,d,P_2} are the distance-specific vehicle CO_2 emissions of the type approval cycle or cycle phases **selected as representative for rural operation** by the contracting party [g/km]

4.2.3. *Point P_3 - High speed point*

The co-ordinates for P_3 are the following:.

$\overline{v_{P3}}$ is the average speed of the type approval cycle (or cycle phases) **selected as representative for motorway/expressway operation** by the contracting party, in [km/h]

M_{CO_2,d,P_3} are the distance-specific vehicle CO_2 emissions of the type approval cycle or cycle phases **selected as representative for motorway/expressway operation** by the contracting party, expressed in [g/km]

Examples of applications by contracting parties

Contracting party using	**Points for the CO_2 characteristic curve**
WLTP 4 phases	$\overline{v_{P1}} = 18.882\ km/h$(Average S*peed of the Low Speed phase of the WLTP cycle)* M_{CO_2,d,P_1}= Vehicle CO_2 emissions over the Low Speed phase of the WLTP cycle [g/km] $\overline{v_{P2}} = 56.664\ km/h$(Average S*peed of the High Speed phase of the WLTP cycle)* M_{CO_2,d,P_2}= Vehicle CO_2 emissions over the High Speed phase of the WLTP cycle [g/km] $\overline{v_{P3}} = 91.997\ km/h$(Average S*peed of the Extra High Speed phase of the WLTP cycle)* M_{CO_2,d,P_3} = Vehicle CO_2 emissions over the Extra High Speed phase of the WLTP cycle [g/km]
WLTP 3 phases	$\overline{v_{P1}} = 18.882\ km/h$(Average S*peed of the Low Speed phase of the WLTP cycle)* M_{CO_2,d,P_1}= Vehicle CO_2 emissions over the Low Speed phase of the WLTP cycle [g/km]

	$\overline{v_{P2}} = 56.664\ km/h$(Average S*peed of the High Speed phase of the WLTP cycle)* M_{CO_2,d,P_2}= Vehicle CO_2 emissions over the High Speed phase of the WLTP cycle [g/km] $\overline{v_{P3}} = 91.997\ km/h$ $M_{CO_2,d,P_3} = M_{CO_2,d,P_2}$
WLTC 3 Phase (India)	The average speeds shall correspond to the respective WLTP 3 Phase cycle used, based on the class of vehicle as per GTR 15.

4.3.1 CO_2 characteristic curve definition

Using the reference points defined in section 4.2., the characteristic curve CO_2 emissions are calculated as a function of the average speed using two linear sections (P_1, P_2) and (P_2, P_3). The section (P_2, P_3) is limited to 145 km/h on the vehicle speed axis. The characteristic curve is defined by equations as follows:

For the section (P_1, P_2):

$$M_{CO_2,d,CC}(\bar{v}) = a_1\bar{v} + b_1$$

$with$: $a_1 = \left(M_{CO_2,d,P_2} - M_{CO_2,d,P_1}\right)/(\overline{v_{P2}} - \overline{v_{P1}})$

and: $b_1 = M_{CO_2,d,P_1} - a_1\overline{v_{P1}}$

For the section (P_2, P_3):

$$M_{CO_2,d,CC}(\bar{v}) = a_2\bar{v} + b_2$$

$with$: $a_2 = \left(M_{CO_2,d,P_3} - M_{CO_2,d,P_2}\right)/(\overline{v_{P3}} - \overline{v_{P2}})$

and: $b_2 = M_{CO_2,d,P_2} - a_2\overline{v_{P2}}$

Figure 3

Vehicle CO_2 characteristic curve and tolerances for ICE and NOVC-HEV vehicles(Illustrated for the case $M_{CO_2,d,P_3} \neq M_{CO_2,d,P_2}$)

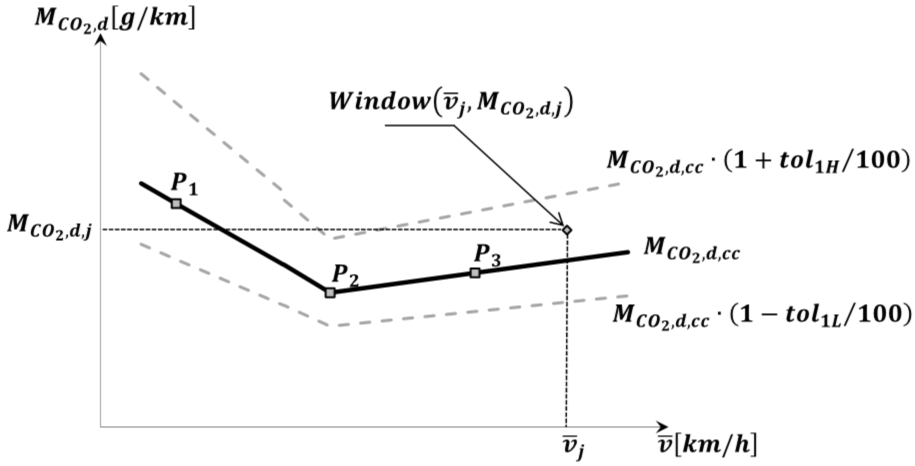
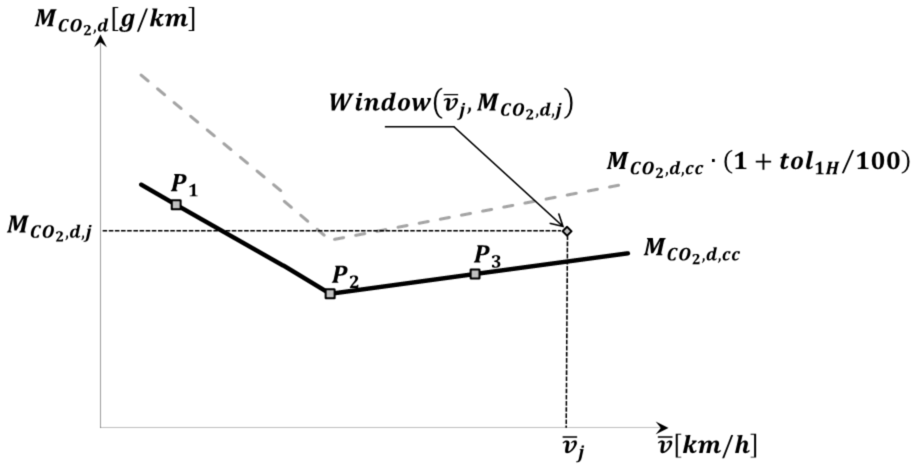


Figure 4:

Vehicle CO_2 characteristic curve and tolerances for OVC-HEV vehicles (Illustrated for the case $M_{CO_2,d,P_3} \neq M_{CO_2,d,P_2}$)



4.4.1. *Classifying windows in low, medium and high average speed classes*

The moving averaging windows shall be classified into the low, medium and high average speed classes selected by the contracting parties.

Examples of applications by contracting parties

Contracting party using	**Average speed ranges for window classification** ($\bar{v}_j$ being the **window average speed)**
WLTP 4 phases	Low speed: 0<$\bar{v}_j$≤45 km/h Medium speed: 45<$\bar{v}_j$≤80 km/h High speed: 80<$\bar{v}_j$km/h N2 category vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 90 km/h, motorway windows are characterised by average vehicle speeds greater than or equal to 70 km/h and lower than 90 km/h
WLTP 3 phases	Low speed: 0<$\bar{v}_j$≤50 km/h High speed: 50<$\bar{v}_j$≤100 km/h km/h
WLTC 3 Phase (India)	India adopts the CP option for Average speed ranges for window classification and shall update the same in future after further validation.

Figure 5

Vehicle CO_2 characteristic curve: low, medium and high average speed definitions(Illustrated for WLTP 4 phases ICE and NOVC-HEV vehicles) except N2 category vehicles that are equipped in *accordance with Directive 92/6/EEC with a device limiting vehicle speed to 90 km/h)*

Commented [DP43]: Replace U/R.M, with low, medium high speed bins

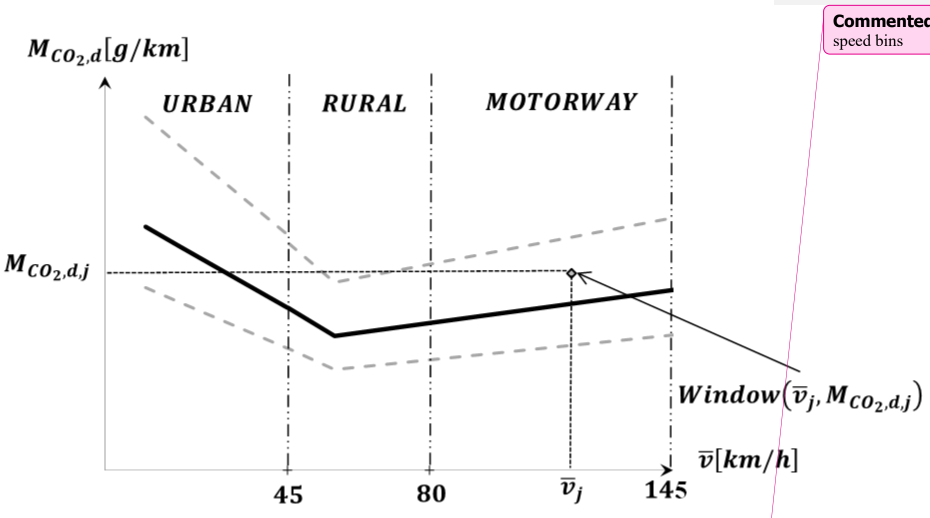


Figure 6.

Vehicle CO_2 characteristic curve: low, medium and high average speed definitions (Illustrated for OVC-HEV vehicles) WLTP 4 phases, except N2 category vehicles that are equipped in accordance with Directive 92/6/EEC with a device limiting vehicle speed to 90 km/h)

Commented [DP44]: Same here

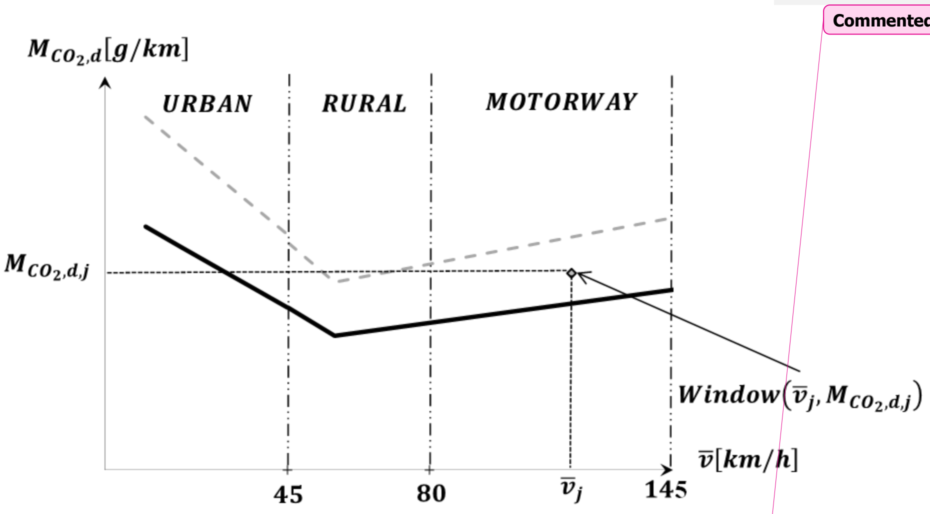


Figure 5-2

Vehicle CO_2 characteristic curve: low and high average speed definitions(Illustrated for ICE and NOVC-HEV vehicles)

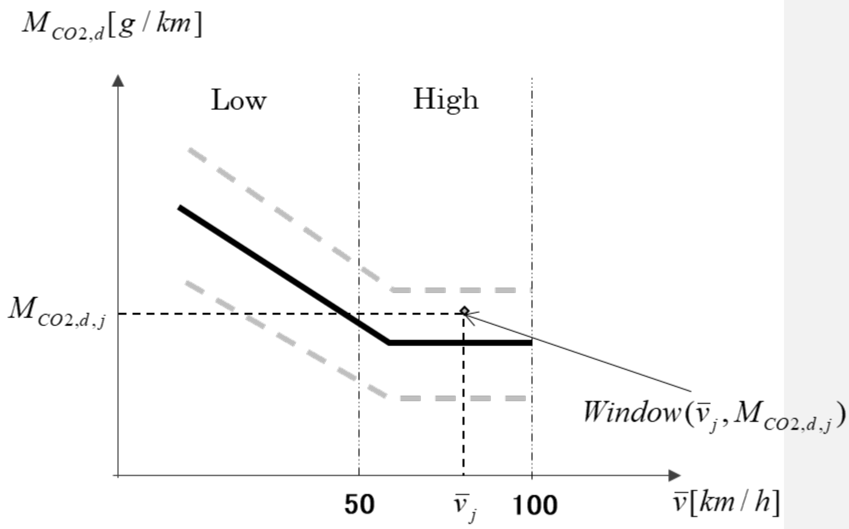
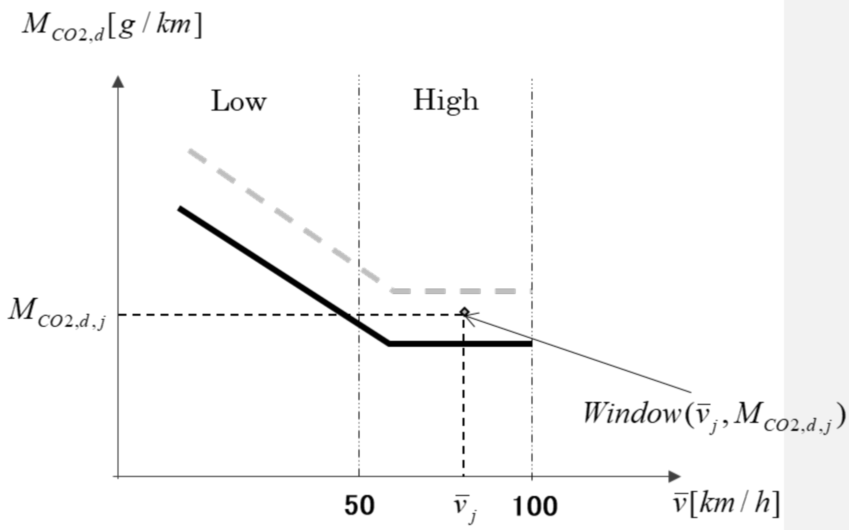


Figure 6-2.

Vehicle CO_2 characteristic curve: low and high average speed definitions (Illustrated for OVC-HEV vehicles)



4.5.1. Assessment of trip validity

The test is valid when at least 50% of the windows in the low, medium and high (medium and high, when applicable) speed classes are within the tolerances tol_{1H} and tol_{1L}.

To reflect the driving behaviour in a region, the tolerances are selected by the contracting party.

For NOVC-HEVs and OVC-HEVs, if the minimum requirement of 50 % between tol_{1H} and tol_{1L} is not met, the upper positive tolerance tol_{1H} may be increased by steps of 1 % until the 50 % target is reached. When using this mechanism, the value of tol_{1H} shall never exceed 50 %.

Commented [RG 16062045]: NB: UNR has:

4.5.2. Assessment of trip validity (for analysis with 3-phase WLTP)

This is because 4.5.1. covers the 4-phase WLTP

Examples of applications by contracting parties

Contracting party using	Tolerances
WLTP 3 and 4 phases	$tol_{1H} = 45\%$ for low speed windows $tol_{1H} = 40\%$ for medium and high speed windows $tol_{1L} = 25\%$ for all windows OVC-HEV vehicles: $tol_{1L} = 100\%$ for all windows
WLTC 3 Phase (India)	India adopts the CP option for Tolerances and shall update the same in future after further validation.

ANNEX 6

ASSESSMENT OF EXCESS OR ABSENCE OF TRIP DYNAMICS

1. INTRODUCTION

The RDE trip dynamics shall be representative of typical in-use driving. This annex describes the calculation procedures to assess the trip dynamics by determining the excess or absence of dynamics during an RDE Trip.

2. SYMBOLS, PARAMETERS AND UNITS

a	—	acceleration [m/s^2]
a_i	—	acceleration in time step i [m/s^2]
a_{pos}	—	positive acceleration greater than 0.1 m/s^2 [m/s^2]
$a_{pos,i,k}$	—	positive acceleration greater than 0.1 m/s^2 in time step i considering the urban, rural and motorway/expressway shares [m/s^2]
a_{res}	—	acceleration resolution [m/s^2]
d_i	—	distance covered in time step i [m]
$d_{i,k}$	—	distance covered in time step i considering the urban, rural and motorway/expressway shares [m]
Index (i)	—	discrete time step
Index (j)	—	discrete time step of positive acceleration datasets
Index (k)	—	refers to the respective category (t=total, u=urban, r=rural, m=motorway, e=expressway)
M_k	—	number of samples for urban, rural and motorway/expressway shares with positive acceleration greater than 0.1 m/s^2
N_k	—	total number of samples for the urban, rural and motorway/expressway shares and the complete trip
RPA_k	—	relative positive acceleration for urban, rural and motorway/expressway shares [m/s^2 or kWs/(kg*km)]
t_k	—	duration of the urban, rural and motorway/expressway shares and the complete trip [s]
v	—	vehicle speed [km/h]
v_i	—	actual vehicle speed in time step i [km/h]
$v_{i,k}$	—	actual vehicle speed in time step i considering the urban, rural and motorway/expressway shares [km/h]
$(v \times a)_i$	—	actual vehicle speed per acceleration in time step i [m^2/s^3 or W/kg]

Commented [RG 25062046]: Term not used in deleted GTR text above

$(v \times a)_{j,k}$	—	actual vehicle speed per positive acceleration greater than 0.1 m/s^2 in time step j considering the urban, rural and motorway/expressway shares [m^2/s^3 or W/kg].
$(v \times a_{pos})_{k\_}[95]$	—	95th percentile of the product of vehicle speed per positive acceleration greater than 0.1 m/s^2 for urban, rural and motorway/expressway shares [m^2/s^3 or W/kg]
$\bar{v}_k$	—	average vehicle speed for urban, rural and motorway/expressway shares [km/h]

3. TRIP INDICATORS

3.1. Calculations

3.1.1. *Data pre-processing*

Dynamic parameters like acceleration,$(v \times a_{pos})$ or RPA shall be determined with a speed signal of an accuracy of 0.1 % for all speed values above 3 km/h and a sampling frequency of 1 Hz. This accuracy requirement is generally fulfilled by distance calibrated signals obtained from a wheel (rotational) speed sensor. Otherwise, acceleration shall be determined with an accuracy of 0.01 m/s^2 and a sampling frequency of 1 Hz. In this case the separate speed signal, in $(v \times a_{pos})$, shall have an accuracy of at least 0.1 km/h.The correct speed trace builds the basis for further calculations and binning as described in paragraphs 3.1.2. and 3.1.3.

3.1.2. *Calculation of distance, acceleration and* $(v \times a)$

The following calculations shall be performed over the whole time based speed trace (1 Hz resolution) from second 1 to second N_t (last second).

The distance increment per data sample shall be calculated as follows:

$$d_i = \frac{v_i}{3.6} \quad i = 1 \; to \; N_t$$

The acceleration shall be calculated as follows:

$$a_i = \frac{v_{i+1} - v_{i-1}}{2 \times 3.6} \quad i = 1 \; to \; N_t$$

The product of vehicle speed per acceleration shall be calculated as follows:

$$(v \times a)_i = v_i \times a_i / 3.6$$

3.1.3.1. *Binning of the results in speed bins*

After the calculation of a_i and $(v \times a)_i$, the values v_i, d_i, a_i and $(v \times a)_i$ shall be ranked in ascending order of the vehicle speed.

Commented [RG 25062047]: NB: UNR has 4-phase in 3.1.3.1. and 3-phase in 3.1.3.2.

All datasets shall be binned into the urban, rural and motorway/expressway speed bins according to the speed boundaries chosen by the Contracting Party. Special provisions may be applied for light commercial vehicles.

For each speed bin the average vehicle speed ($\overline{v}_k$) shall be calculated as follows:

$$\overline{v}_k = \frac{1}{N_k}\sum_i v_{i,k} \quad i = 1\ to\ N_k, k = u, r, m$$

where:

In each speed bin, there shall be a minimum number N_k of datasets with acceleration values a_i>0.1 m/s. The minimum number of datasets may be specified by the Contracting Party but shall not be lower than 100.

Example of applications by contracting parties

Contracting party using	**Speed boundaries to bin the dataset into low, medium and high speed driving bins**
WLTP 4 phases	*Speed bin boundaries:* Urban: 1<v_i≤60 km/h Rural: 60<v_i≤90 km/h Motorway: 90<v_i km/h For N2 category vehicles that are equipped with a device limiting vehicle speed to 90 km/h, all datasets with v_i ≤ 60 km/h belong to the "urban" speed bin, all datasets with 60 km/h <v_i ≤ 80 km/h belong to the "rural" speed bin and all datasets with v_i> 80 km/h belong to the "motorway" speed bin. *Minimum number of datasets N_k per speed bin:* Urban and rural: 150 Motorway: 100
WLTP 3 phase (Japan)	Add appropriate bins
WLTC 3 Phase (India)	*Speed bin boundaries - M category vehicles:* Urban: 1<v_i≤45 km/h Rural: 45<v_i≤65 km/h Motorway: 65<v_i km/h *Speed bin boundaries - N1 category vehicles:*

Commented [OH48]: Following will be add in line with UNR (Annex 9 Para 3.1.3.2)
Speed bin boundaries:
Urban: v_i≤60 km/h
Expressway: 60<v_i km/h
Minimum number of datasets N_k per speed bin:
Urban: 100
Expressway: 100
(or 100 in each speed bin)

	Urban: 1<v_i≤40 km/h Rural: 40<v_i≤60 km/h Motorway: 60<v_i km/h *Speed bin boundaries -M1/M2/N1 low powered category of vehicles:* Urban: 1<v_i≤45 km/h Rural: 45 km/h <v_i *Minimum number of datasets N_k per speed bin:* For M & N1 Category: Urban and rural: 150 Motorway: 100 For *M1/M2/N1 low powered category of vehicles:* Urban: 150 Rural: 100

3.1.4.1. *Calculation of* $(v \times a_{pos})_{k-}[95]$ *per speed bin*

The 95th percentile of the $(v \times a_{pos})$ values shall be calculated as follows:

The $(v \times a)_{i,k}$ values in each speed bin shall be ranked in ascending order for all datasets with $a_{i,k}$ (0.1 >m/s^2)(≥ 0.1 m/s^2) and the total number of these samples M_k shall be determined.

Percentile values are then assigned to $(v \times a)_{i,k}$values with $a_{i,k}$≥ 0.1 m/s^2 as follows:

The lowest $(v \times a_{pos})$value gets the percentile 1/M_k, the second lowest 2/M_k, the third lowest 3/M_k and the highest value (M_k/M_k= 100 %.)

$(v \times a_{pos})_{k-}[95]$ is the$(v \times a_{pos})_{j,k}$ value, with j/M_k= 95 %). If j/M_k= 95 % cannot be met, $(v \times a_{pos})_{k-}[95]$ shall be calculated by linear interpolation between consecutive samples *j* and *j+1* with *j/M_k*<95 % and (*j+1*)/M_k>95%.

3.1.4.2. *Calculation of* RPA_k *per speed bin*

The relative positive acceleration per speed bin shall be calculated as follows:

$$RPA_k = \frac{\sum_j \Delta t \times (v \times a_{pos})_{j,k}}{\sum_i d_{i,k}}, \quad j = 1\ to\ M_k, i = 1\ to\ N_k, k = u,r,m$$

4. ASSESSMENT OF TRIP VALIDITY

The trip validity shall be checked against the following criteria selected by Contracting Parties in order to reflect typical driving in their region, in order to avoid too aggressive or too mild driving during an RDE test.

4.1.1. Assessment of $(v \times a_{pos})_{k-}[95]$ per speed bin (with v in [km/h])

For each speed bin, the point $(\overline{v}_k, (v \times a_{pos})_{k-}[95])$ shall be below the applicable limit curve as defined by the Contracting Party.

Commented ["49]: CP: reevaluate these checks based on regional characteristics? Prepare a general level based on data from CPs.

Commented [DP50]: Limit curves are EU specific for the moment

Example of applications by contracting parties

Contracting Party using	**Conditions to be fulfilled for the limit curves**
WLTP 3 (Japan) and 4 phases	Trip invalid if $\overline{v}_k \leq 74.6\ km/h$ and $(v \times a_{pos})_{k-}[95] > (0.136 \times \overline{v}_k + 14.44)$ Trip invalid if $\overline{v}_k > 74.6\ km/h$ and $(v \times a_{pos})_{k-}[95] > (0.0742 \times \overline{v}_k + 18.966)$ Upon the request of the manufacturer, and only for those N1 or N2 vehicles where the vehicle power-to-test mass ratio is less than or equal to 44 W/kg then: Trip invalid if $\overline{v}_k \leq 74.6\ km/h$ and $(v \times a_{pos})_{k-}[95] > (0.136 \times \overline{v}_k + 14.44)$ Trip invalid if $\overline{v}_k > 74.6\ km/h$ and $(v \times a_{pos})_{k-}[95] > (-0.097 \times \overline{v}_k + 31.635)$ is fulfilled, the trip is invalid. To calculate the power-to-test mass ratio, the following values shall be used: - the mass which corresponds to the RDE test mass of the vehicle (kg); - the maximum rated engine power as declared by the manufacturer (W).
WLTC 3 Phase (India)	*M category vehicles:* Trip invalid if $\overline{v}_k \leq 56.9\ km/h$ and $(v \times a_{pos})_{k-}[95] > (0.0467 \times \overline{v}_k + 12.2490)$

	Trip invalid if $\overline{v}_k > 56.9\ km/h$ and $(v \times a_{pos})_{k-}[95] > (0.1665 \times \overline{v}_k + 5.4352)$ *N1 category vehicles:* Trip invalid if $\overline{v}_k \leq 55.9\ km/h$ and $(v \times a_{pos})_{k-}[95] > (0.0614 \times \overline{v}_k + 6.9439)$ Trip invalid if $\overline{v}_k > 55.9\ km/h$ and $(v \times a_{pos})_{k-}[95] > (0.0045 \times \overline{v}_k + 9.8664)$ M1/M2/N1 low powered category of vehicles: If $(v \times a_{pos})_{k-}[95] >$ (0.0142 · + 4.6214) is fulfilled, the trip is invalid."

4.1.2. *Assessment of RPA per speed bin*

For each speed bin (urban, rural and motorway), the point ($\overline{v}_k$, $\mathrm{RPA_k}$) shall be above the applicable limit curve as defined by the Contracting Party.

Example of applications by Contracting Parties

Contracting Party using	**Conditions to be fulfilled for the limit curves**
WLTP 3 (Japan) and 4 phases	Trip invalid if $\overline{v}_k \leq 94.05\ km/h$ and $RPA_k < (-0.0016 \cdot \overline{v}_k\ +\ 0.1755)$ Trip invalid if $\overline{v}_k > 94.05\ km/h$ and $\mathrm{RPA_k} < 0.025$
WLTP 3 Phases (India)	*M category vehicles:* Trip invalid if $\overline{v}_k \leq 55.9\ km/h$ and $RPA_k < (-0.001825 \cdot \overline{v}_k\ +\ 0.1755)$ Trip invalid if $\overline{v}_k > 55.9\ km/h$ and $RPA_k < (-0.0011 \cdot \overline{v}_k\ +\ 0.1350)$

	N1 category vehicles: $RPA_k < (-0.0016 \cdot \overline{v}_k + 0.1406)$ *M1/M2/N1 low powered category of vehicles:* Trip invalid if $\overline{v}_k \leq 54.76$ km/h and $RPA_k < (-0.0022 \cdot \overline{v}_k + 0.1271)$ Trip invalid if $\overline{v}_k > 54.76$ km/h and $RPA_k < 0.0066$

ANNEX 7

PROCEDURE TO DETERMINE THE CUMULATIVE POSITIVE ELEVATION GAIN OF A PEMS TRIP

Commented [RG 25062051]: Update to align with UNR (where appropriate)?

1. INTRODUCTION

If a Contracting Party decides that there is a need to limit the cumulative elevation gain of a PEMS trip the following methodology shall be applied.

2. SYMBOLS, PARAMETERS AND UNITS

$d(0)$	—	distance at the start of a trip [m]
d	—	cumulative distance travelled at the discrete way point under consideration [m]
d_0	—	cumulative distance travelled until the measurement directly before the respective way point d [m]
d_1	—	cumulative distance travelled until the measurement directly after the respective way point d [m]
d_a	—	reference way point at $d(0)$ [m]
d_e	—	cumulative distance travelled until the last discrete way point [m]
d_i	—	instantaneous distance [m]
d_{tot}	—	total test distance [m]
$h(0)$	—	vehicle altitude after the screening and principle verification of data quality at the start of a trip [m above sea level]
$h(t)$	—	vehicle altitude after the screening and principle verification of data quality at point t [m above sea level]
$h(d)$	—	vehicle altitude at the way point d [m above sea level]
$h(t-1)$	—	vehicle altitude after the screening and principle verification of data quality at point t-1 [m above sea level]
$h_{corr}(0)$	—	corrected altitude directly before the respective way point d [m above sea level]
$h_{corr}(1)$	—	corrected altitude directly after the respective way point d [m above sea level]
$h_{corr}(t)$	—	corrected instantaneous vehicle altitude at data point t [m above sea level]

$h_{corr}(t-1)$	—	corrected instantaneous vehicle altitude at data point t-1 [m above sea level]
$h_{GNSS,i}$	—	instantaneous vehicle altitude measured with GNSS [m above sea level]
$h_{GNSS}(t)$	—	vehicle altitude measured with GNSS at data point t [m above sea level]
$h_{\mathrm{int}}(d)$	—	interpolated altitude at the discrete way point under consideration *d* [m above sea level]
$h_{\mathrm{int,sm,1}}(d)$	—	smoothed and interpolated altitude, after the first smoothing run at the discrete way point under consideration *d* [m above sea level]
$h_{\mathrm{map}}(t)$	—	vehicle altitude based on topographic map at data point t [m above sea level]
$road_{grade,1}(d)$	—	smoothed road grade at the discrete way point under consideration *d* after the first smoothing run [m/m]
$road_{grade,2}(d)$	—	smoothed road grade at the discrete way point under consideration *d* after the second smoothing run [m/m]
sin	—	trigonometric sine function
t	—	time passed since test start [s]
t_0	—	time passed at the measurement directly located before the respective way point *d* [s]
v_i	—	instantaneous vehicle speed [km/h]
$v(t)$	—	vehicle speed at a data point t [km/h]

Index (k) refers to the respective category (t=total, u=urban, r=rural, m=motorway)

3. GENERAL REQUIREMENTS

The cumulative positive elevation gain of a RDE trip shall be determined based on three parameters: the instantaneous vehicle altitude $h_{GNSS,i}$ [m above sea level] as measured with the GNSS, the instantaneous vehicle speed v_i [km/h] recorded at a frequency of 1 Hz and the corresponding time *t* [s] that has passed since test start.

4. CALCULATION OF CUMULATIVE POSITIVE ELEVATION GAIN

4.1. General

The cumulative positive elevation gain of a RDE trip shall be calculated as a two-step procedure, consisting of (i) the correction of instantaneous vehicle altitude data, and (ii) the calculation of the cumulative positive elevation gain.

4.2. Correction of instantaneous vehicle altitude data

The deviation shall not be larger than 40 m. Any instantaneous altitude data *h(t)* shall be corrected if the following condition applies:

$$|h(t) - h(t-1)| > v(t)/3.6 \times sin45°$$

The altitude correction shall be applied so that:

$$h_{corr}(t) = h_{corr}(t-1)$$

where:

h(t)	—	vehicle altitude after the screening and principle check of data quality at data point t [m above sea level]
h(t-1)	—	vehicle altitude after the screening and principle check of data quality at data point t-1 [m above sea level]
v(t)	—	vehicle speed of data point t [km/h]
$h_{corr}(t)$	—	corrected instantaneous vehicle altitude at data point t [m above sea level]
$h_{corr}(t-1)$	—	corrected instantaneous vehicle altitude at data point t-1 [m above sea level]

Upon the completion of the correction procedure, a valid set of altitude data is established. This data set shall be used for the calculation of the cumulative positive elevation gain as described in the following.

4.3. Final calculation of the cumulative positive elevation gain

4.3.1. Establishment of a uniform spatial resolution

The cumulative elevation gain shall be calculated from data of a constant spatial resolution of 1 m starting with the first measurement at the start of a trip *d(0)*. The discrete data points at a resolution of 1 m are referred to as way points, characterized by a specific distance value d (e.g., 0, 1, 2, 3 m…) and their corresponding altitude *h(d)* [m above sea level].

The altitude of each discrete way point *d* shall be calculated through interpolation of the instantaneous altitude $h_{corr}(t)$ as:

$$h_{int}(d) = h_{corr}(0) + \frac{h_{corr}(1) - h_{corr}(0)}{d_1 - d_0} \times (d - d_0)$$

Where:

$h_{int}(d)$	—	interpolated altitude at the discrete way point under consideration *d* [m above sea level]
$h_{corr}(0)$	—	corrected altitude directly before the respective way point *d* [m above sea level]
$h_{corr}(1)$	—	corrected altitude directly after the respective way point *d* [m above sea level]
d	—	cumulative distance travelled at the discrete way point under consideration *d* [m]
d_0	—	cumulative distance travelled until the measurement located directly before the respective way point *d* [m]
d_1	—	cumulative distance travelled until the measurement located directly after the respective way point *d* [m]

4.3.2. Additional data smoothing

The altitude data obtained for each discrete way point shall be smoothed by applying a two-step procedure; d_a and d_e denote the first and last data point respectively (Figure 1). The first smoothing run shall be applied as follows:

$$road_{grade,1}(d) = \frac{h_{int}(d + 200m) - h_{int}(d_a)}{(d + 200\ m)} \quad for\ d \leq 200\ m$$

$$road_{grade,1}(d) = \frac{h_{int}(d + 200\ m) - h_{int}(d - 200\ m)}{(d + 200\ m) - (d - 200\ m)} \quad for\ 200\ m < d < (d_e - 200\ m)$$

$$road_{grade,1}(d) = \frac{h_{int}(d_e) - h_{int}(d - 200\ m)}{d_e - (d - 200\ m)} \quad for\ d \geq (d_e - 200\ m)$$

$$h_{int,sm,1}(d) = h_{int,sm,1}(d - 1\ m) + road_{grade,1}(d) \quad for\ d = (d_a + 1)\ to\ d_e$$

$$h_{int,sm,1}(d_a) = h_{int}(d_a) + road_{grade,1}(d_a)$$

Where:

$road_{grade,1}(d)$	—	smoothed road grade at the discrete way point under consideration after the first smoothing run [m/m]
$h_{int}(d)$	—	interpolated altitude at the discrete way point under consideration *d* [m above sea level]
$h_{int,sm,1}(d)$	—	smoothed interpolated altitude, after the first smoothing run at the discrete way point under consideration *d* [m above sea level]
d	—	cumulative distance travelled at the discrete way point under consideration [m]
d_a	—	reference way point at *d(0)* [m]
d_e	—	cumulative distance travelled until the last discrete way point [m]

The second smoothing run shall be applied as follows:

$$road_{grade,2}(d) = \frac{h_{int,sm,1}(d + 200\ m) - h_{int,sm,1}(d_a)}{(d + 200\ m)} \quad for\ d \leq 200\ m$$

$$road_{grade,2}(d) = \frac{h_{int,sm,1}(d + 200\ m) - h_{int,sm,1}(d - 200\ m)}{(d + 200\ m) - (d - 200\ m)} \quad for\ 200\ m < d < (d_e - 200\ m)$$

$$road_{grade,2}(d) = \frac{h_{int,sm,1}(d_e) - h_{int,sm,1}(d - 200\ m)}{d_e - (d - 200\ m)} \quad for\ d \geq (d_e - 200\ m)$$

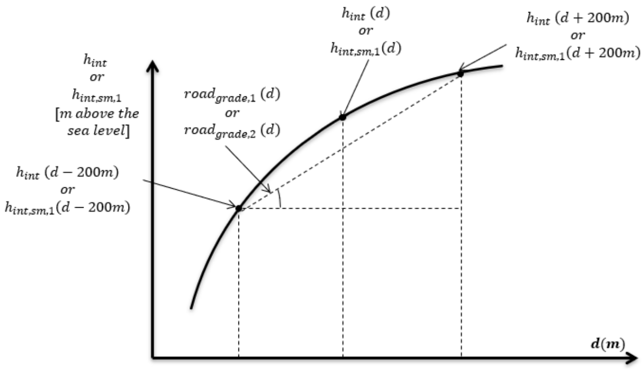
Where:

$road_{grade,2}(d)$	—	smoothed road grade at the discrete way point under consideration after the second smoothing run [m/m]
$h_{int,sm,1}(d)$	—	smoothed interpolated altitude, after the first smoothing run at the discrete way point under consideration *d* [m above sea level]
d	—	cumulative distance travelled at the discrete way point under consideration [m]
d_a	—	reference way point at *d(0)* [m]

d_e	—	cumulative distance travelled until the last discrete way point [m]

Figure A10/1

Illustration of the procedure to smooth the interpolated altitude signals



4.3.3. Calculation of the final result

The positive cumulative elevation gain of a total trip shall be calculated by integrating all positive interpolated and smoothed road grades, i.e., $road_{grade,2}(d)$. The result should be normalized by the total test distance d_{tot} and expressed in meters of cumulative elevation gain per one hundred kilometres of distance.

The waypoint vehicle speed v_w shall then be calculated over each discrete way point of 1m:

$$v_w = \frac{1}{(t_{w,i} - t_{w,i-1})}$$

For 3-phase WLTP evaluation all datasets with v_w ≤ 100 km/h are used for the calculation of the cumulative positive altitude gain of the complete trip.

All of the positive interpolated and smoothed road gradients that correspond to ≤ 100 km/h datasets shall be integrated.

The number of 1m waypoints which correspond to ≤ 100 km/h datasets shall be integrated and converted to km to define the ≤ 100 km/h test distance d100 [km].

The positive cumulative elevation gain of the ≤ 100 km/h part of trip shall then be calculated by dividing the ≤ 100 km/h elevation gain by the ≤ 100 km/h test distance, and expressed in metres of cumulative elevation gain per one hundred kilometres of distance.

All datasets with $v_w \leq 60$ km/h belong to the urban part of the trip.

All of the positive interpolated and smoothed road grades that correspond to urban datasets shall be integrated.

The number of 1m waypoints which correspond to urban datasets shall be integrated and converted to km to define the urban test distance d_{urban} [km].

The positive cumulative elevation gain of the urban part of trip shall then be calculated by dividing the urban elevation gain by the urban test distance, and expressed in metres of cumulative elevation gain per one hundred kilometres of distance.

- Add methods to establish the validity criteria (for Low Powered Vehicles)
- method for cumulative altitude gain check
- Vehicles with periodic regeneration

- Add PM methodology if ready

Commented [DP52]: For India

Annex 8

CALCULATION OF THE FINAL RDE EMISSIONS RESULTS

1. Introduction

This annex describes the procedure to calculate the final criteria emissions for the complete and urban part of an RDE.

2. Symbols, Parameters and Units

Index (k) refers to the category (t=total, u=urban)

IC_k	is the distance share of usage of the internal combustion engine for an OVC-HEV over the RDE trip
$d_{ICE,k}$	is the distance driven [km], with the internal combustion engine on for an OVC-HEV over the RDE trip
$d_{EV,k}$	is the distance driven [km], with the internal combustion engine off for an OVC-HEV over the RDE trip
$M_{RDE,k}$	is the final RDE distance-specific mass of gaseous pollutants [mg/km] or particle number [#/km]
$m_{RDE,k}$	is the distance-specific mass of gaseous pollutant [mg/km] or particle number [#/km] emissions, emitted over the complete RDE trip and prior to any correction in accordance with this annex
$M_{CO_2,RDE,k}$	is the distance-specific mass of CO_2 [g/km], emitted over the RDE trip
$M_{CO_2,TA,k}$	is the distance-specific mass of CO_2 [g/km], emitted over the applicable type approval cycle
$M_{CO_2,TA\_CS,k}$	is the distance-specific mass of CO_2 [g/km], emitted over the applicable type approval cycle for an OVC-HEV vehicle tested in charge sustaining vehicle operation

r_k	is the ratio between the CO_2 emissions measured during the RDE test and the applicable type approval test
RF_k	is the result evaluation factor calculated for the RDE trip
RF_{L1}	is the first parameter of the function used to calculate the result evaluation factor
RF_{L2}	is the second parameter of the function used to calculate the result evaluation factor

3. Calculation of the Intermediate RDE emissions results

For the valid trips, the intermediate RDE results are calculated as follows for vehicles with ICE, NOVC-HEV and OVC-HEV.

Any instantaneous emissions or exhaust flow measurements obtained while the combustion engine is deactivated, as defined in paragraph 3.6.3. of this Regulation, shall be set to zero.

Any correction of the instantaneous criteria emissions for Extended conditions according to paragraph 8.1. and 10.5. and 10.6. of this Regulation shall be applied.

For the complete RDE trip and for the urban part of the RDE trip (k=t=total, k=u=urban):

$$M_{RDE,k} = m_{RDE,k} \times RF_k$$

The values of the parameter RF_{L1} and RF_{L2} of the function used to calculate the result evaluation factors shall be defined by the Contracting Party.

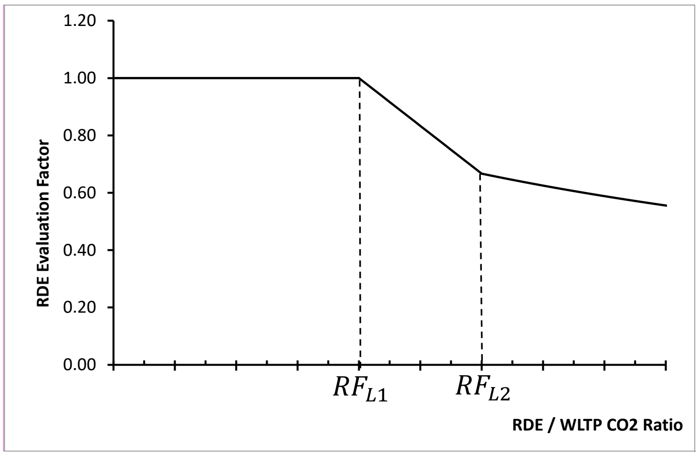
Example of application by contracting parties

Contracting party using	**Values for RF_{L1} and RF_{L2}**
WLTP 3 (Japan) and 4 phases	$RF_{L1} = 1.30$ $RF_{L2} = 1.50$

The RDE result evaluation factors RF_k (k=t=total, k=u=urban) shall be obtained using the functions laid down in paragraph 2.2. for vehicles with ICE and NOVC-HEV, and in paragraph 2.3. for OVC-HEV. A graphical illustration of the method is provided in Figure A11/1 below, while the mathematical formulas are found in Table A11/1:

Figure A11/1

Function to calculate the result evaluation factor



Commented [PB53]: The chart shall be modified to be generic and not specific to WLTP

Table A11/1

Result evaluation factors calculation

When:	*Then the Result evaluation factor* RF_k *is:*	*Where:*
$r_k \leq RF_{L1}$	$RF_k = 1$	
$RF_{L1} < r_k \leq RF_{L2}$	$RF_k = a_1 r_k + b_1$	$a_1 = \frac{RF_{L2} - 1}{[RF_{L2} \times (RF_{L1} - RF_{L2})]}$ $b_1 = 1 - a_1 RF_{L1}$
$r_k > RF_{L2}$	$RF_k = \frac{1}{r_k}$	

3.1. RDE result evaluation factor for vehicles with ICE and NOVC-HEV

The value of the RDE result evaluation factor depends on the ratio r_k between the distance specific CO_2 emissions measured during the RDE test and the distance-specific CO_2 emitted by the vehicle over the PEMS validation test conducted on this vehicle in accordance with the applicable type approval cycle. and including all appropriate corrections.

For the urban emissions, the phases of the type approval selected as representative for urban operation by the contracting party shall be considered.

Example of application by contracting parties

Contracting party using	**Phases of the type approval cycle corresponding to urban operation**
WLTP 3 (Japan) and 4 phases	(a) For ICE vehicles, the first two WLTC phases, i.e. the Low and the Medium speed phases (b) For NOVC-HEVs, all the phases of the WLTC driving cycle.

Commented [GND54]: For RDE result evaluation factor (rk) calculation, text explaining different requirements by CP's is removed. India request for retaining the CP option for these parameters.
Proposed Text
"For WLTC 3 Phase (India): India adopts the CP option for Reference laboratory cycles or cycle phases to be considered to obtain M_(〖CO〗_2,CC,k) and shall update the same in future after further validation."

Once, the phases of the type approval cycle representative for urban operation are selected, the result evaluation factor r_k (k=t=total, k=u=urban) shall be calculated as follows:

$$r_k = \frac{M_{CO_2,RDE,k}}{M_{CO_2,TA,k}}$$

3.2. RDE result evaluation factor for OVC-HEV

The value of the RDE result evaluation factor depends on the ratio r_k between the distance-specific CO_2 emissions measured during the RDE test and the distance-specific CO_2 emitted by the vehicle over the applicable type approval test conducted in Charge Sustaining vehicle operation including all appropriate corrections. The ratio r_k is corrected by a ratio IC_{TA} reflecting the respective usage of the internal combustion engine during the RDE trip and on the applicable type approval test, to be conducted in charge sustaining vehicle operation.

For either the urban or the total driving:

$$r_k = \frac{M_{CO_2,RDE,k}}{M_{CO_2,TA\_CS,t}} \times \frac{IC_{TA}}{IC_k}$$

where IC_k is the ratio of the distance driven either in urban or total trip with the combustion engine activated, divided by the total urban or total trip distance:

$$IC_k = \frac{d_{ICE,k}}{d_{ICE,k} + d_{EV,k}}$$

With determination of combustion engine operation in accordance with paragraph 3.6.3. of this Regulation.

Example of application by contracting parties

Contracting party using	IC_{TA} factor
WLTP 3 (Japan) and 4 phases	$IC_{TA} = 0.85$

4. Final RDE emission results taking into account the PEMS margin

In order to take into account the uncertainty of the PEMS measurements compared to the ones performed in the laboratory with the applicable type approval test, the intermediate calculated emission values $M_{RDE,k}$ shall be divided by 1+$margin_{pollutant}$., where $margin_{pollutant}$ defined in the table below:

The PEMS *margin* for each pollutant is specified as follows:

Pollutant	*Mass of oxides of nitrogen (NO_x)*	*Number of particles (PN)*	*Mass of carbon monoxide (CO)*	*Mass of total hydrocarbons (THC)*	*Combined mass of total hydrocarbons and oxides of nitrogen (THC + NO_x)*
$Margin_{pollutant}$	[0.43]	0.5	*Not yet specified*	*Not yet specified*	*Not yet specified*

As a Contracting Party option, the above margins can be modified to accommodate the local characteristics or the conditions of use of the PEMS instruments.

Any negative final results shall be set to zero.

Any Ki factors which are applicable, according to Section 8.3.4., shall be applied.

These values shall be considered the Final RDE emission results for NOx and PN.

Commented [GND55]: Contracting party option for PEMS margin should be provided in RDE GTR.