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TEST REPORT 09/00003

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SUBJECT : **Diesel Vehicle Particle Number Round Robin Test**

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SUMMARY

The new European regulation 692/2008 regarding motor vehicles with respect to the emissions (Euro5 and Euro6) introduces particle number (PN) measurement for diesel vehicles for Euro5b. On behalf of ACEA, UTAC has carried out a round robin test in seven laboratories and on two DPF diesel vehicles in order to:

- determine whether the PN test protocol is similar in all laboratories or if interpretation flexibility remains in the Euro5b legislative specifications,
- collect enough data to determine the PN protocol measurement uncertainty under type-approval conditions.

The tests took place from November 2008 to April 2009. Each laboratory carried out the tests (on NEDC cycle) with its own PN equipment and according to its interpretation of the legislative specifications.

Overall, the round robin test reached its initial objectives.

For the seven participating laboratories and the three PN equipments used, the regulation specifications did not let any interpretation be significant for the measurement set up; however the influence of interpretations in the calibration procedure has not been studied in this programme. Some recommendations to ensure measurement quality and decrease the variability of the measurement are suggested: ensure a stable PN background, checking the PN traces for electronic artefacts and carrying out the tests when possible in stabilised DPF conditions.

The PN procedure including all its influencing factors (vehicle, PN equipment and environment) has a high variability; its uncertainty (2σ) is about 100%. Although the uncertainties are very high, the protocol is appropriate for type approval as far as the present limits are concerned, but variability still needs to be improved especially when it comes to measuring emissions close to the limit.

The round robin test shows that at the low levels of emissions measured during the programme the biggest part of the variability comes from the sensitivity of PN emissions to the environment and from the variation of the vehicles in terms of PN which are much higher than for gaseous emissions. In order to reduce total variability of the measurement, the implication of the different factors (vehicle, PN equipment, calibration or environment) need to be better understood, further investigation need to be done.

Besides the calibration protocol which is still under discussion, different development trends are possible of which:

- A full error analysis study would identify efficiently the priority actions.
- The carrying out of tests with identical PN equipments set in parallel would give an estimation of the variability inherent to the manufacturing of the fully PMP compliant PN measurement systems.

Linked to the future limit, a similar round robin test should be carried out for gasoline direct injection vehicles

Contents

Abbreviations

CI = confidence interval

VPR = volatile particle remover

PNC = Particulate number counter

PND = particle number diluter

Fr = particle concentration reduction factor

PN = particle number

PM = particulate mass

CO = carbon monoxyde

HC = total hydrocarbons

NOx = nitrogen oxydes

CO2 = carbon dioxyde

FC = fuel consumption

1 INTRODUCTION

The new European regulation 692/2008 regarding motor vehicles with respect to the emissions (Euro5 and Euro6) introduces particle number (PN) measurement. The determination of the PN emissions is in addition to the particle mass (PM) measurement. This new requirement is applicable for Euro5b for diesel vehicles (starting September 2011 for new types) and later for direct injection gasoline vehicles when passing to Euro6a for which limit values have not been established. The PN measurement procedure is described in the Annex 4a of the R83 regulation (Rev1/Add82/Rev3/Amend2 from the 16^{th} of April 2009) to which the European regulation refers.

Early studies have been made to elaborate the PN procedure, including the PMP validation exercise. At this time only the calibration procedure is still in discussion. Although it is close to mandatory introduction for new types of vehicles, no round robin test has been carried out and the true variability of PN measurements is not known. ACEA wished to add to the knowledge already established by these studies by carrying out a round robin test, taking advantage of the fact that now many laboratories have started to do PN measurements with their own equipment in accordance with the regulation.

Therefore the objective of this programme was to apply the regulation PN procedure in type-approval conditions in order to:

- determine whether the test protocol is similar in all laboratories or if interpretation flexibility remains in the legislative specifications,
- collect enough data to determine its measurement uncertainty in type-approval conditions.

To reach this objective, tests were carried out in each laboratory with its own PN equipment and according to its interpretation of the legislative specifications.

Seven laboratories from vehicle manufacturers participated in this programme. From these laboratories a total of eight different PN equipments were tested out of which three suppliers were represented.

The tests were performed on two mass-produced diesel vehicles meeting Euro4 standards for gaseous emissions, but fitted with a DPF (diesel particle filter) hence meeting Euro5b standards for PM and PN.

The measurements carried out concerned:

- regulated gaseous emissions (CO, HC and NOx)
- CO2 and fuel consumption
- PM according to the Euro5b regulation protocol, i.e. in one phase with only one filter
- PN according to the Euro5b regulation protocol.

2 TEST CONDITIONS

2.1 Participating Laboratories

The 7 laboratories were from ACEA manufacturers around Europe:

Audi – Ingolstadt Germany

BMW Motoren GmbH – Steyr Austria

Fiat Powertrain Technologies – Turin Italy

Ford Motor Company Ltd. – Basildon United Kingdom

Peugeot Citroën S.A. – La Garenne France

Volkswagen AG – Wolfsburg Germany

Volvo Cars Corporation – Goteborg Sweden

2.2 Round Robin Test Schedule

The round robin test stretched over 5 months.

Order	Time assigned*	Schedule
Lab 1.1	2 weeks	24-28 November 2008
Lab 2	3 weeks	08-16 December 2008
Lab 3	3 weeks	13-14 January 2009
Lab 4	3 weeks	04-11 February 2009
Lab 5	3 weeks	23 February - 02 March 2009
Lab 6	2 weeks	16-20 March 2009
Lab 7	3 weeks	30 March - 03 April 2009
Lab 1.2	2 weeks	22-29 April 2009

(*): The aim was to give to each laboratory a 3 week slot to carry out the tests and send the vehicles to the next laboratory.

2.3 Test Vehicles

The two diesel vehicles had a Euro4 gaseous emission level. The vehicles fitted with a DPF, were chosen in order to have two different levels of particle number (PN) emissions under the Euro5 limit i.e. 6.10^{11}#/km.

The vehicles were supplied by PSA and TOYOTA Motor Europe.

Manufacturer	**Peugeot**	**Toyota**
Type	**407**	**Avensis**
Engine	DW10 2.0L	D-4D 2.0L
Fuel	Diesel	Diesel
DPF	yes	yes
Gas Emission level	Euro 4	Euro 4
PN&PM Emission level	Euro 5b	Euro 5b
Transmission	Manual 6	Manual 6
Mileage at beginning of RR test	6600 km	5600 km
Test weight	1590kg	1590kg
Frequency of forced regeneration	In between each lab	Every 3 tests

Table 1 - Main characteristics of the vehicles

2.4 PN Equipments

During this programme, the laboratories have used their own PN equipments. In all, three different types have been tested:

→ HORIBA SPCS 1000

→ AVL Advanced APC 489

→ ECOMESURE RS-PMP

Make	**HORIBA**	**AVL**	**ECOMESURE**
Type	**SPCS 1000**	**APC 489**	**RS-PMP**
PNC Make	TSI	TSI	GRIMM
Number of laboratories	3	4	1 (set in parallel with another equipment in lab 7)
In accordance with R83 prescriptions	yes	yes	yes

Table 2 - PN equipments

The details of the PN equipment characteristics are in annex 5.

All of the PN equipments had fully valid calibrations certificates.

2.5 Test Cells

All the laboratories had valid certificates for the calibrations specified in regulation R83.

The details of the test cells characteristics are in annex 6.

2.6 Fuel

Both vehicles were tested with a Diesel fuel in accordance with Euro5 - “B5”. In order to minimize dispersion due to the fuel, each laboratory was supplied with fuel coming from the same batch.

The detailed analysis of the fuel is in annex 7.

3 TEST PROCEDURE

As mentioned in the introduction, one aim of the programme was the estimation of the variability of the R83 PN protocol in certification conditions:

- each laboratory used its own equipment,
- each laboratory followed the regulation specifications

In order to keep the focus on the variability of the method and so to minimize the variability due to the vehicles, all the test conditions concerning directly the vehicles were as similar as possible in all the laboratories. Apart from the forced regeneration procedures and the road load values, the test requirements were identical for both vehicles.

The tanks were filled up only when approximately half way empty.

Note: For the following reasons, it was decided not to use any "golden" PN equipment in addition to the test laboratories systems:
- risk of invalidating the already existing type approval set-up
- increase the complexity of the current procedure
- timing convenience, the round robin test being scheduled on a short period of time.

3.1 Testing Schedule

The tests were carried out in the following order:

1. Background (PM and PN)
2. Peugeot Vehicle 1
3. Toyota Vehicle 2

The PN emissions of Vehicle 1 being lower than the PN emissions of Vehicle 2, this order of testing allowed carrying out only one background per day and still compare it with the emissions of both vehicles.

3.2 Background Procedure

The background measurement was carried out during the same lap of time as a vehicle (1180s). The PM and PN results were respectively expressed in g/km and #/km using the theoretical NEDC driving distance (11.007 km).

The transfer line of the tunnel was closed during the tests.

3.3 Regeneration Procedure

To avoid test losses because of natural regeneration during the NECD cycle, the vehicles were forced into regeneration regularly according to the procedure and frequency given by the vehicle's manufacturer. In between each forced regeneration and the following test, the vehicles were preconditioned with 3EUDCs.

- Vehicle 1 was regenerated once in between each laboratory,
- Vehicle 2 was regenerated after 3 tests and in between each laboratory.

The regulation (R83 Annex4a §6.6.9.3) recommends that before testing, "the vehicle has completed >1/3 of the mileage between scheduled regenerations". For practical reasons it was not possible to meet this recommendation. A priority was given to having all laboratories test the vehicles in the same conditions, and preconditioning Vehicle 1 according to the recommendation of the regulation in all the laboratories was not conceivable.

3.4 Synoptic of the Test Procedure

Steps	Protocol
1-Background (Day 2+)	– 1180s – Transfer line closed
2- Warm-up of chassis dynamometer	Warm-up of the chassis dynamometer 80km/h for 30min (if test is the first of the day)
3- Road load setting (Day 1) *4- Type I test* (Day 2+)	– Tyre pressure adjusted to <u>260kPa for single roller</u> and <u>310kPa for twin roller</u> – All <u>accessories off</u> (ESP, AC, Radio, lights…) – Engine hood closed – Cooling fan set according to the regulation (~30cm from the front of vehicle and ~20cm from the ground) – Connect tail pipe to the CVS with a <u>silicon hose</u> provided by each laboratory – Warm-up of the vehicle with 1 <u>NEDC cycle</u> – Driver shall be in the vehicle (or equivalent weight) – Cooling fan should be on – 1 phase for PM and PN – 2 phases for gaseous emissions (CO, HC, NOx and CO2)
5- Check of the coast down time	Check road load is within 5% from 120km/h down to 30km/h and within 10% for 20km/h
6- Preconditionning	EUDC x 3
7- Soaking	Soaking 20-30°C for 6-36hours

4 ROUND ROBIN TEST PROGRESS

4.1 Test overview

Each laboratory had an objective of 4 PN valid tests per vehicle. For schedule purposes, it was accepted for a laboratory to give only three valid results if the 4th test involved delay.

	Vehicle 1	Vehicle 2	Total	Total %
Number of tests :				
Objective	32	32	64	
Total carried out	36	36	72	+11% of the objective
PN valid	**28**	**31**	**59**	92% of the objective
PN non valid	8	5	13	18% of total carried out
Number of labs :				
Objective	8	8	16	
w/ 4 PN valid tests	4	7	11	
w/ 3 PN valid tests	4	1	5	
Cause of non validity (13) :				
Vehicle	2	2	4	31% of non valid tests
Test cell	2	1	3	23% of non valid tests
PM	0	0	0	0% of non valid tests
Background	2	2	4	31% of non valid tests
PN equipment (VPR + PNC)	2	0	2	15% of non valid tests
PN measurement set up [Background + PN equipment]	4	2	6	46% of non valid tests

Table 3 – Summary of the round robin test progress

4.2 Causes for Tests Rejection

Type	**Vehicle 1** (total of 8)	**Vehicle 2** (total of 5)
Vehicle	- (1) NOx and PN too high, regeneration not completed, the forced regeneration was carried out again and the problem disappeared - (1) Speed was limited to 80km/h during the cycle, identified as a failure mode, problem was solved by doing another forced regeneration	- (1) Battery not charged - (1) PN very high, regeneration not completed, the forced regeneration was carried out again and the problem disappeared
Test cell	- (2) CO, CO2 and NOx value too high, the test was considered as non valid although the cause was not identified - (1) CO2 value too low, the test was considered as non valid although the cause was not identified	
Background	- (2) HEPA filter pierced, the PN background was too high - (2) PN too high, due to tunnel pollution	
PN equipment	- (2) PN trace not valid, there was an electronic artefact during the test	

Table 4 – Summary of the causes encountered of tests rejection

Note: None of the tests were rejected because of the coast down check.

5 SUMMARY OF THE RESULTS

The graphic representations of each group of data are in annex 2.

5.1 Vehicle 1 Gaseous Emissions, PM and PN Results

Vehicle 1 Results											
Lab n°		1.1	2	3	4	5	6	7.1	7.2	1.2	Weighted mean (1)
CO mg/km	**Mean**	**121**	**128**	**168**	**132**	**143**	**126**	**142**		**135**	**137**
	σ	14	27	30	17	14	26	15		10	
	CI (2)	14	27	30	19	14	26	15		10	
HC mg/km	**Mean**	**16**	**18**	**19**	**17**	**20**	**15**	**17**		**16**	**17**
	σ	2	3	2	1	1	2	4		1	
	CI (2)	2	3	2	1	1	2	4		1	
NOx mg/km	**Mean**	**186**	**173**	**187**	**180**	**180**	**213**	**186**		**178**	**186**
	σ	10	4	8	6	2	25	6		8	
	CI (2)	10	4	8	6	2	25	6		8	
CO2 g/km	**Mean**	**150**	**150**	**143**	**147**	**142**	**147**	**147**		**145**	**146**
	σ	1	1	1	1	1	1	2		1	
	CI (2)	1	1	1	1	1	1	2		1	
FC L/100km	**Mean**	**5.71**	**5.71**	**5.44**	**5.56**	**5.37**	**5.57**	**5.58**		**5.51**	**5.55**
	σ	0.02	0.05	0.03	0.03	0.04	0.03	0.08		0.04	
	CI (2)	0.02	0.05	0.03	0.04	0.04	0.03	0.08		0.04	
PM mg/km	**Mean**	**0.7**	**0.0**	**0.0**	**0.2**	**0.1**	**0.5**	**0.3**		**0.3**	**0.3**
	σ	0.2	0.0	0.0	0.1	0.2	0.1	0.2		0.2	
	CI (2)	0.2	0.0	0.0	0.1	0.2	0.1	0.2		0.2	
PN #/km	**Mean**	**$0.69\ 10^{09}$**	**$0.57\ 10^{09}$**	**$0.26\ 10^{09}$**	**$1.30\ 10^{09}$**	**$1.02\ 10^{09}$**	**$1.51\ 10^{09}$**	**$2.10\ 10^{09}$**	**$1.73\ 10^{09}$**	**$0.40\ 10^{09}$**	**$1.11\ 10^{09}$**
	σ	$0.05\ 10^{09}$	$0.10\ 10^{09}$	$0.06\ 10^{09}$	$0.75\ 10^{09}$	$0.28\ 10^{09}$	$0.70\ 10^{09}$	$1.16\ 10^{09}$	$1.01\ 10^{09}$	$0.25\ 10^{09}$	
	CI (2)	$0.05\ 10^{09}$	$0.10\ 10^{09}$	$0.07\ 10^{09}$	$0.87\ 10^{09}$	$0.28\ 10^{09}$	$0.70\ 10^{09}$	$1.16\ 10^{09}$	$1.01\ 10^{09}$	$0.29\ 10^{09}$	

Table 5 – Vehicle 1 emission and fuel consumption results

(1): the term is explained in annex 2; weighted mean = $\dfrac{\sum_{i=1}^{N} n_i \times mean_i}{\sum_{i=1}^{N} n_i}$

(2): confidence interval, it applies to a mean value, the term is explained in annex 2; CI = $\dfrac{2\sigma}{\sqrt{number\_of\_tests}}$

Note: Any negative result for PM emissions was set to 0.

5.2 Vehicle 2 Gaseous Emissions, PM and PN Results

Vehicle 2 Results											
Lab n°		1.1	2	3	4	5	6	7.1	7.2	1.2	Weighted mean (1)
CO mg/km	**Mean**	**128**	**139**	**197**	**153**	**164**	**146**	**123**		**156**	**151**
	σ	7	9	14	5	5	9	7		25	
	CI (2)	7	9	14	5	5	10	7		25	
HC mg/km	**Mean**	**13**	**13**	**18**	**14**	**16**	**13**	**11**		**13**	**14**
	σ	1	1	3	1	0	2	2		2	
	CI (2)	1	1	3	1	0	2	2		2	
NOx mg/km	**Mean**	**170**	**175**	**167**	**178**	**183**	**198**	**195**		**171**	**179**
	σ	3	6	4	9	4	22	6		3	
	CI (2)	3	6	4	9	4	25	6		3	
CO2 g/km	**Mean**	**154**	**157**	**151**	**153**	**153**	**157**	**156**		**151**	**154**
	σ	1	1	1	1	0	2	1		1	
	CI (2)	1	1	1	1	0	3	1		1	
FC L/100km	**Mean**	**5.86**	**5.97**	**5.77**	**5.81**	**5.81**	**5.95**	**5.92**		**5.74**	**5.85**
	σ	0.03	0.04	0.03	0.03	0.01	0.09	0.03		0.02	
	CI (2)	0.03	0.04	0.03	0.03	0.01	0.11	0.03		0.02	
PM mg/km	**Mean**	**0.9**	**0.2**	**0.4**	**0.4**	**0.5**	**0.6**	**0.7**		**0.7**	**0.5**
	σ	0.1	0.1	0.2	0.0	0.4	0.1	0.1		0.3	
	CI (2)	0.1	0.1	0.2	0.0	0.4	0.1	0.1		0.3	
PN #/km	**Mean**	**0.56 10^{11}**	**2.05 10^{11}**	**0.52 10^{11}**	**1.29 10^{11}**	**0.90 10^{11}**	**1.21 10^{11}**	**0.88 10^{11}**	**0.80 10^{11}**	**1.49 10^{11}**	**1.07$10^{11}$**
	σ	0.41 10^{11}	0.90 10^{11}	0.37 10^{11}	0.94 10^{11}	0.88 10^{11}	1.53 10^{11}	0.67 10^{11}	0.59 10^{11}	0.41 10^{11}	
	CI (2)	0.41 10^{11}	0.90 10^{11}	0.37 10^{11}	0.94 10^{11}	0.88 10^{11}	1.77 10^{11}	0.67 10^{11}	0.59 10^{10}	0.41 10^{11}	

Table 6 - Vehicle 2 emission and fuel consumption results

(1): the term is explained in annex 2.
(2): confidence interval, the term is explained in annex 2.
Note: Any negative result for PM emissions was set to 0.

5.3 Background Results

Background Results											
Lab n°		1.1	2	3	4	5	6	7.1	7.2	1.2	Weighted mean (1)
PM mg/km	**Mean**	**0.5**	**0.1**	**0.1**	**0.0**	**0.0**	**0.6**	**0.4**		**0.4**	**0.3**
	σ	0.1	0.1	0.1	0.0	0.0	0.1	0.3		0.3	
	CI (2)	0.2	0.1	0.1	0.0	0.0	0.1	0.3		0.3	
PN #/km	**Mean**	**2.34 10^{08}**	**0.52 10^{08}**	**10.57 10^{08}**	**0.11 10^{08}**	**9.09 10^{08}**	**9.36 10^{08}**	**4.08 10^{08}**	**1.85 10^{08}**	**0.72 10^{08}**	**4.15 10^{08}**
	σ	1.48 10^{08}	0.52 10^{08}	2.08 10^{08}	0.08 10^{08}	2.34 10^{08}	3.94 10^{08}	1.27 10^{08}	0.21 10^{08}	0.62 10^{08}	
	CI (2)	1.71 10^{08}	0.46 10^{08}	2.08 10^{08}	0.05 10^{08}	2.34 10^{08}	3.94 10^{08}	1.27 10^{08}	0.21 10^{08}	0.62 10^{08}	

Table 7 – Background results

(1): the term is explained in annex 2.
(2): confidence interval, the term is explained in annex 2.
Note: Any negative result for PM emissions was set to 0.

The background PM levels are under 1mg/km, which is the maximum value that is allowed to be subtracted to the vehicle PM measurement (§6.2.4 annex 4 of R83).

5.4 Check for Vehicle Drifting

Laboratory 1 was repeated at the end of the round robin test in order to identify any significant vehicle drifting. Some differences were measured and are described in the paragraphs below, but none challenge the relevance of the data collected.

CO2 for the Vehicle 1 and Vehicle 2

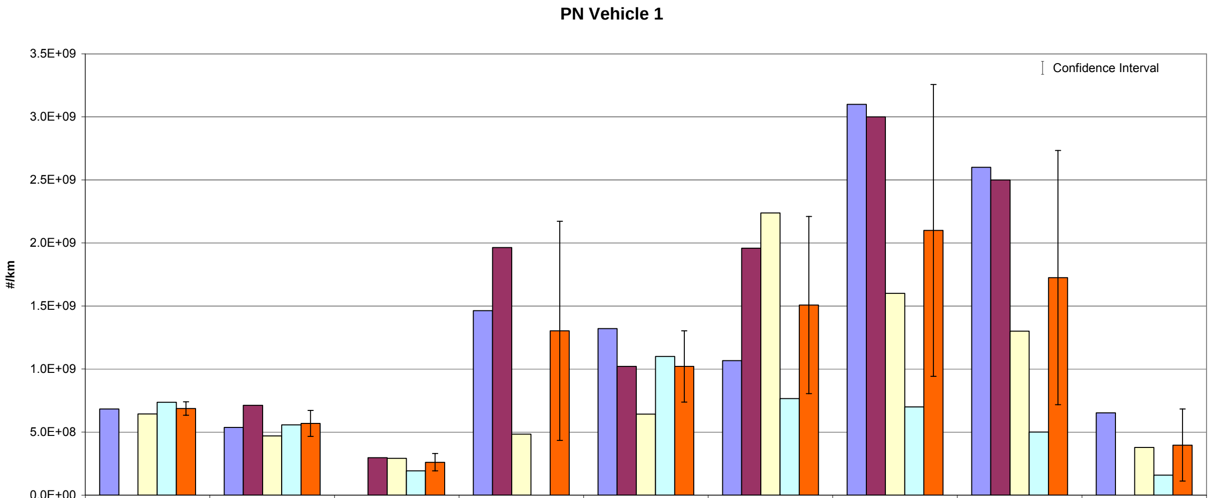
Both vehicles had lower CO_2 emissions in laboratory 1.2 than in laboratory 1.1; respectively -3.6% for the vehicle 1 and
-2.1% for the Vehicle 2. These remain smaller than the uncertainty of the measurement (see URepro in §7.2.3) which are respectively 4.7% and 2.9% for vehicles 1 and 2.

NOx for Vehicle 2

The NOx emissions for Vehicle 2 has had a fluctuation going upwards from laboratory 3 to laboratory 6 (see annex 1 figure A1.5). The results in laboratories 1.1 and 1.2 are similar (respectively 170 mg/km and 171 mg/km).

6 PN EMISSION RESULTS

6.1 Vehicle 1 PN Emissions



	1.1	2	3	4	5	6	7.1	7.2	1.2
1	0.68E+09	0.54E+09		1.46E+09	1.32E+09	1.07E+09	3.1E+09	2.6E+09	0.65E+09
2		0.71E+09	0.30E+09	1.96E+09	1.02E+09	1.96E+09	3.0E+09	2.5E+09	
3	0.64E+09	0.47E+09	0.29E+09	0.48E+09	0.64E+09	2.24E+09	1.6E+09	1.3E+09	0.38E+09
4	0.74E+09	0.56E+09	0.19E+09		1.10E+09	0.77E+09	0.7E+09	0.5E+09	0.16E+09
Average	0.69E+09	0.57E+09	0.26E+09	1.30E+09	1.02E+09	1.51E+09	2.1E+09	1.7E+09	0.40E+09

Figure 1 - PN Graph for Vehicle 1

There is a factor of 8 between the highest value (lab 7.1) and the smallest value (lab 3). Put into context with the regulation Euro5b limit, this does not affect the conformity of the vehicle to the regulation. Vehicle 1 has PN emissions from ~300 to ~2300 times lower than the limit.

Over the 5 months testing, laboratories 4 to 7 have measured higher PN emissions than the three first laboratories and have had higher variability in the results. Both facts are visible on figure 1, the variability being illustrated by the confidence interval (1). The trend is not confirmed by vehicle 2 results (see §6.2), the phenomenon cannot only be explained by bias between laboratories.

The higher values have different sources which are detailed in §10.1 with the interpretation of the PN traces.

One of the possible contributors for the higher instability of the results in those four laboratories could come from the change of performance of the DPF after regenerating. In normal operating conditions, a bed of soot is formed and the efficiency of the device is improved. During the round robin test, the regenerations have been processed more frequently than the DPF is designed for, the stabilisation of the device could have eventually been deteriorated. This assumption is grounded by the 4^{th} tests of laboratories 4 to 7 which come down close to the level of emissions of the three first laboratories: at this point of the testing, it could be assumed that the DPF has stabilised again.

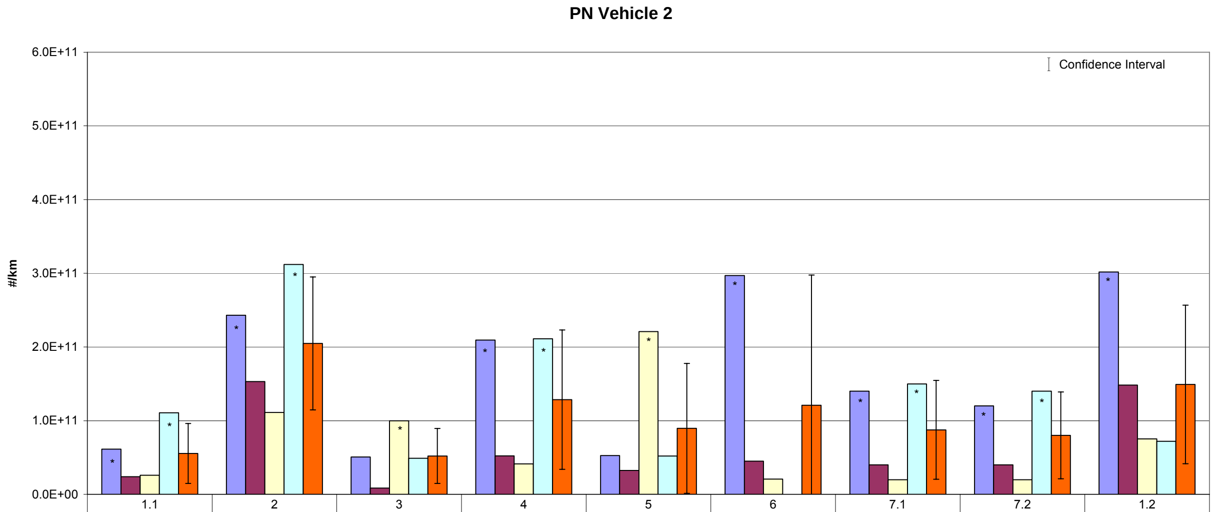
All the same, this assumption does not explain why the results in laboratory 1.2 would go back down to be similar to laboratory 1.1 results. Therefore other factors must influence the results, but the knowledge in the field is not yet sufficient to explain it all.

Stabilisation of the DPF is a recurrent item in this programme and is developed in §6.2.2 for Vehicle 2.

(1): definition in annex 2

6.2 Vehicle 2 PN Emissions

6.2.1 Vehicle 2 PN Emission Graph



	1.1	2	3	4	5	6	7.1	7.2	1.2
1	0.62E+11	2.43E+11	0.51E+11	2.09E+11	0.53E+11	2.97E+11	1.4E+11	1.2E+11	3.02E+11
2	0.24E+11	1.53E+11	0.09E+11	0.52E+11	0.33E+11	0.45E+11	0.4E+11	0.4E+11	1.48E+11
3	0.26E+11	1.11E+11	1.00E+11	0.41E+11	2.21E+11	0.21E+11	0.2E+11	0.2E+11	0.75E+11
4	1.11E+11	3.12E+11	0.49E+11	2.11E+11	0.52E+11		1.5E+11	1.4E+11	0.72E+11
Average	0.56E+11	2.05E+11	0.52E+11	1.29E+11	0.90E+11	1.21E+11	0.9E+11	0.8E+11	1.49E+11

Figure 2 - PN Graph for Vehicle 2

Note: the bar graphs marked with a * correspond to the tests following directly a forced regeneration.

Vehicle 2 PN emissions, although higher than Vehicle 1 PN emissions, remain 2 to 10 times lower than the regulation limit. No general trend is obvious besides a post-regeneration effect (see §6.2.2).

The factor between the highest value (lab 2) and the smallest value (lab 3) is of 4. It is less than for Vehicle 1, but applies to PN emissions level 10 to 11 times higher.

6.2.2 Vehicle 2 Post-Regeneration Effect

PN emissions are known to be unstable for a period after regeneration. It can be observed in this programme for both vehicles (see §6.1 for Vehicle 1).

For Vehicle 1, the forced regeneration was carried out only once per laboratory before the entire battery of testing. Therefore no two tests were carried out in one laboratory with the exact same status of the DPF: there is no possibility of discerning any post-regeneration effect.

On the other hand Vehicle 2 was regenerated after 3 tests and between each laboratory (hence twice per laboratory), which allowed five laboratories to have two tests directly following the forced regeneration and two tests in stabilised conditions. The results on figure 3 show clearly a higher level of the PN emissions for the tests directly following regeneration:

a. Mean value for tests directly following regeneration: 1.87 10^{11} #/km

b. Mean value for tests not directly following regeneration (stabilised conditions): 5.40 10^{10} #/km

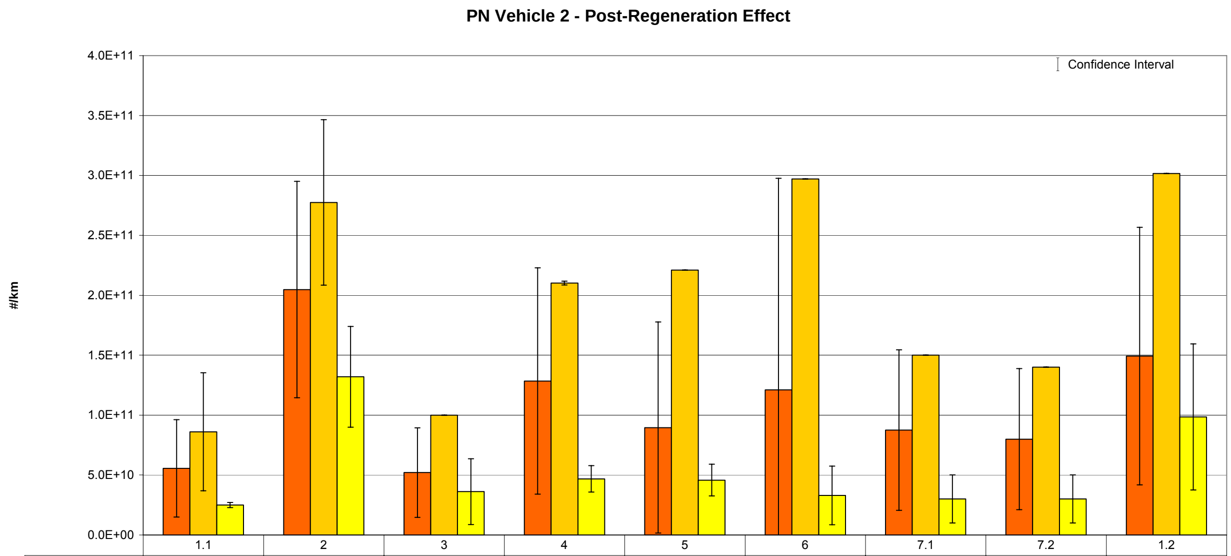
There is a significant factor of 3.5 between the mean values of groups a and b. It is interesting that the factor 4 between the minimum and maximum mean values of the laboratories (see §6.2.1) is of the same magnitude.

The aim of the programme is to estimate the uncertainty of the method; hence in order to minimize the vehicle effect in the uncertainty calculation, the PN data for Vehicle 2 have been studied in 3 groups:

- All Vehicle 2 results – “Vehicle 2 All” or “Vehicle 2”
- Vehicle 2 tests directly following a forced regeneration – “Vehicle 2 w/ p-reg effect”
- Vehicle 2 tests not directly following a forced regeneration – “Vehicle 2 w/o p-reg effect”

The group “Vehicle 2 All” remains an interesting group as all the tests have been carried out according to the regulation and so are representative of what could happen with a vehicle during type-approval testing.

Separating the data has the inconvenience of decreasing the number of tests taken into account for the statistical process. For this matter, as the post-regeneration effect only occurs with PN emissions, the data for the gaseous emissions were all considered as one group “Vehicle 2 All”. The PM emissions were split out to be homogeneous with the PN (see §7.2.4).



	1.1	2	3	4	5	6	7.1	7.2	1.2
Average	0.56E+11	2.05E+11	0.52E+11	1.29E+11	0.90E+11	1.21E+11	0.9E+11	0.8E+11	1.49E+11
Average w p-reg	0.86E+11	2.78E+11	1.00E+11	2.10E+11	2.21E+11	2.97E+11	1.5E+11	1.4E+11	3.02E+11
Average w/o p-reg	0.25E+11	1.32E+11	0.36E+11	0.47E+11	0.46E+11	0.33E+11	3.0E+10	3.0E+10	0.98E+11

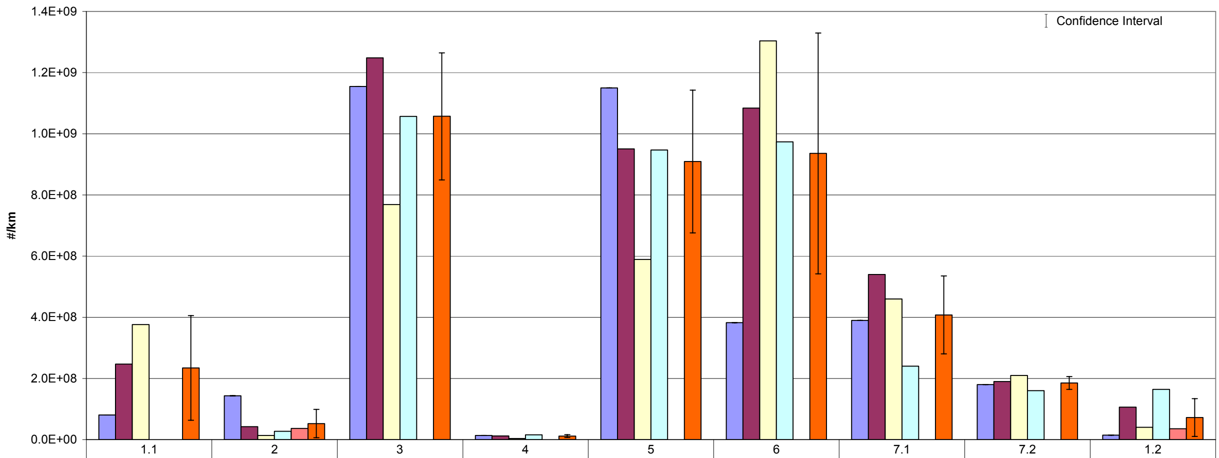
Figure 3 – Post-regeneration effect for Vehicle 2

Note: The confidence interval appears to be null, when there was only one single value taken into account, hence no calculation could be made.

The factor between the highest mean value and the smallest mean value remains equivalent for the three groups of data (from 3.5 to 5.3). Then taking into account the post-regeneration effect has not decreased the relative difference between the highest and the smallest mean values, but the confidence intervals drawn on the graph show that the variability has been improved.

The influence of the post-regeneration effect is confirmed §7.2.5.

6.3 PN Background



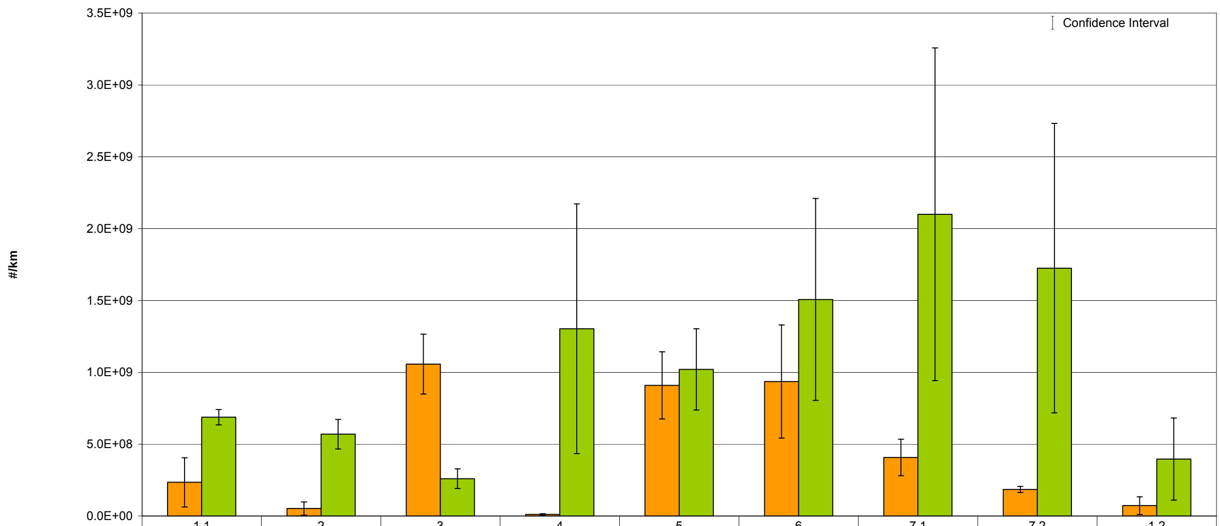
	1.1	2	3	4	5	6	7.1	7.2	1.2
1	0.80E+08	1.43E+08	11.55E+08	0.14E+08	11.5E+08	3.82E+08	3.9E+08	1.8E+08	0.14E+08
2	2.47E+08	0.42E+08	12.48E+08	0.12E+08	9.51E+08	10.84E+08	5.4E+08	1.9E+08	1.06E+08
3	3.76E+08	0.13E+08	7.68E+08	0.04E+08	5.89E+08	13.04E+08	4.6E+08	2.1E+08	0.41E+08
4		0.27E+08	10.57E+08	0.16E+08	9.47E+08	9.74E+08	2.4E+08	1.6E+08	1.64E+08
5		0.36E+08							0.35E+08
Average	2.34E+08	0.52E+08	10.57E+08	0.11E+08	9.09E+08	9.36E+08	4.1E+08	1.9E+08	0.72E+08

Figure 4 - PN graph for background

The factor between the highest value (lab 3) and the smallest value (lab 4) is 100. The difference in between the background levels from one laboratory to the other is quite important. The background level represents less than 1% of the regulation limit.

The reasons for having higher backgrounds in some laboratories were investigated, but no explicit reason could be found except for Laboratory 3. Laboratory 3 has the highest mean backgrounds, but also the lowest PN emissions for both vehicles. Vehicle 1 results are even smaller than the background (figure 5). This leaves to assume that in spite of the verifications, the exhaust line was not tightly sealed when measuring the backgrounds.

Vehicle 1 emissions come down close to the measured levels of backgrounds. Despite the closeness of the results, there is no obvious linear correlation between the background and Vehicle 1 results (figure 5). Now for laboratory 6, the background level has an influence on Vehicle 1 results (see §10.1).



	1.1	2	3	4	5	6	7.1	7.2	1.2
Average BkG	0.23E+09	0.05E+09	1.06E+09	0.01E+09	0.91E+09	0.94E+09	0.41E+09	0.19E+09	0.07E+09
Average Vehicle 1	0.69E+09	0.57E+09	0.26E+09	1.30E+09	1.02E+09	1.51E+09	2.1E+09	1.7E+09	0.40E+09

Figure 5- Comparison of PN background levels and Vehicle 1 PN emissions

7 STATISTICAL RESULTS

7.1 Definitions

The statistical calculations for this programme have been done according to the standard ISO 5725 - *Accuracy (trueness and precision) of measurement methods and results* - and ISO/TS 21748:2005 - *Guidance for the use of repeatability, reproducibility and trueness estimates in measurement uncertainty estimation.*

The global definitions and calculations of the terms and formula used can be found in annex 2.

Standard Deviation

The estimate of the variability of the method is based on the standard deviation calculation (results available in annex 3). From its calculation follows the calculation of the confidence interval (see annex 2) and the uncertainty of the measurement.

σRepeat = standard deviation in repeatability conditions (within labs – no changing factors, same lab, same equipment…)

σRepro = standard deviation in reproducibility conditions (total variability = within labs + between labs)

Expanded Uncertainty (U) – Coverage Interval

The "expanded uncertainty" U of the method is defined so that 95% of the distribution of the values is encompassed in the interval defined by ±U over a measurement result. The coverage factor used for this purpose is k=2 (§13.2.3 of ISO/TS 21748:2005).

URepeat = expanded uncertainty in repeatability conditions
= k*σRepeat
= 2*σRepeat

URepro = expanded uncertainty in reproducibility conditions
= k*σRepro
= 2*σRepro

If the participating laboratories are considered to be representative of any testing laboratory than, the URepeat and URepro calculated can be applied to the testing protocol as:

- If a test (X) is carried out according to the protocol used in this programme, there is 95% chance that any following measurement in the same laboratory would be encompassed in the coverage interval X±URepeat.
- If a test (X) is carried out according to the protocol used in this programme, there is 95% chance that any following measurement in any laboratory would be encompassed in the coverage interval X±URepro.

As they are defined, URepro ≥ URepeat. When the dispersion of the values within the laboratories is high (URepeat high), it can happen that URepro = URepeat: the difference between the calculated mean values of the laboratories is overwhelmed by the dispersion of the values within the laboratories.

Note: To ease out the comprehension of the report the "expanded uncertainty" will be referred in the rest of the document as "uncertainty".

Outlying Laboratories (Outliers)

Laboratories which have:

- a high dispersion within their results compared to the dispersion in the other laboratories,

or/and

- a mean value thrown off the centre compared to the mean values of the other laboratories,

are considered as outliers. Their data are taken out of the statistical calculation.

The purpose of taking out the outliers results from the data being processed is to prevent from overestimating the variability of the method because of a single dispersed or thrown off the centre result.

7.2 Uncertainty for the Emissions and Fuel Consumption

The statistical calculation results in a whole are in annex 3.

In order to calculate the uncertainties in the most discerning way, were taken into account:

- the Vehicle 2 post-regeneration effect (see §6.2.2),
- outlying laboratories – the outliers were identified independently for each pollutant.

The total number of tests for each vehicle is satisfactory to estimate relevantly the variability of the method.

The group of data "Vehicle 2 w/ p-reg effect" was not processed without the outliers, as not a high enough number of data remained, hence statistical calculations would not have been robust.

The mean values in §5 have been calculated with all the data, the mean values in the following sections can be different as they do not include the results of laboratories considered as outliers.

The values to be kept for the conclusion of this programme are stressed in blue bold writing.

7.2.1 Uncertainty for CO and HC

The regeneration of Vehicle 2 has no significant effect on the emissions of CO and HC. The data were not split, keeping a higher number of tests.

CO (mg/km)	Mean	Uncertainty (2xσ)	
		URepeat	URepro
Vehicle 1	132	37 (28%)	37 (28%)
Vehicle 2	142	14 (10%)	33 (24%)

HC (mg/km)	Mean	Uncertainty (2xσ)	
		URepeat	URepro
Vehicle 1	17	4 (22%)	5 (27%)
Vehicle 2	13	3 (19%)	4 (28%)

As URepro is close for both vehicles, a general value of URepro can be taken as:

- for **CO URepro = 35mg/km (25%)**,
- for **HC URepro = 4mg/km (28%)**.

7.2.2 Uncertainty for NOx

The regeneration of Vehicle 2 has no significant effect on the emissions of NOx.

Taking the outliers data out of the calculation is particularly interesting in this case as there is a known technical explanation to the high values. The outlying laboratory (lab 6) has used a fixed speed fan at 30km/h, which is in accordance with the regulation, but different from all the other laboratories which have used proportional speed fans with maximum speeds of 70 km/h to 120 km/h. Vehicle 1 has been quite sensitive to this difference of testing condition.

NOx (mg/km)	Mean	Uncertainty (2xσ)	
		URepeat	**URepro**
Vehicle 1	181	14 (7.5%)	**16 (8.7%)**
Vehicle 2	177	11 (6.3%)	**22 (12.4%)**

7.2.3 Uncertainty for CO2 and FC

The regeneration of Vehicle 2 has no significant effect on the emissions of CO2 and FC.

The outliers for the CO2 emissions and FC (1 per vehicle) had a higher dispersion within the laboratory than the others, but none were thrown off the centre.

CO2 (g/km)	Mean	Uncertainty (2xσ)	
		URepeat	**URepro**
Vehicle 1	146.2	1.9 (1.3%)	**6.8 (4.7%)**
Vehicle 2	153.7	1.6 (1.0%)	**4.5 (2.9%)**

FC (L/100km)	Mean	Uncertainty (2xσ)	
		URepeat	**URepro**
Vehicle 1	5.56	0.07 (1.3%)	**0.26 (4.7%)**
Vehicle 2	5.85	0.06 (1.0%)	**0.17 (2.9%)**

Vehicle 1 has a higher variability for the CO2 emissions and FC than Vehicle 2. Although all the coast down checks were valid, the front drive losses measurement of the vehicle seemed more sensitive to warm-up temperature and have brought in higher vehicle variability.

7.2.4 Uncertainty for PM

Out of concern for homogeneity with PN, only “Vehicle 2 w/o p-reg effect” is to be taken into account, but the regeneration of Vehicle 2 has only a slight influence on the emissions of PM. Hence separating the data does not influence the conclusions.

PM (mg/km)	Mean	Uncertainty (2xσ)	
		URepeat	URepro
Vehicle 1	0.2	0.3 (129%)	0.4 (210%)
Vehicle 2	0.5	0.3 (67%)	0.5 (94%)
Vehicle 2 w/o p-reg effect	0.5	0.3 (57%)	0.5 (90%)
Background	0.2	0.3 (113%)	0.5 (225%)

The mean values being very low, the relative URepro turn out to be very high.

The absolute URepro is equivalent for the two vehicles and the background, a general value of URepro can be taken as:

- **PM URepro = 0.5mg/km**.

This value of URepro infers that any PM measurement (X) has a coverage interval with an amplitude of 1mg/km (interval=[X-0.5; X+0.5]). This interval is obviously too wide to be able to differentiate vehicles with PM emissions lower than 1mg/km.

7.2.5 Uncertainty for PN

The regeneration of Vehicle 2 has a significant effect on the emissions of PN, only the "Vehicle 2 w/o p-reg effect" is then taken into account for the uncertainty calculations.

PN (#/km)	Mean	Uncertainty (2xσ)	
		URepeat	**URepro**
Vehicle 1	$0.97\ 10^{09}$	$1.1\ 10^{09}$ (113%)	**$1.4\ 10^{09}$ (144%)**
Vehicle 2	$0.95\ 10^{11}$	$1.6\ 10^{11}$ (169%)	$1.6\ 10^{11}$ (169%)
Vehicle 2 w/o p-reg effect	$0.36\ 10^{11}$	$0.3\ 10^{11}$ (81%)	**$0.3\ 10^{11}$ (81%)**
Background	$3.52\ 10^{08}$	$2.6\ 10^{08}$ (74%)	**$8.4\ 10^{08}$ (239%)**

URepro is in the magnitude of the vehicle PN emission level. Hence the relative URepro is close or higher than 100%. This is the same magnitude as the relative PM URepro. The variability of the PN protocol should be improved to completely fulfil the PN protocol objective as a reliable method to type approve low PN emitting vehicles.

The PN relative URepro are of course very high compared to those of NOx (8.7%-12.4%) and CO2 (4.7%-2.9%).

The relative URepro from the background confirms §6.3 and shows a very high dispersion in between the different laboratories.

8 POSSIBLE FACTORS OF INFLUENCE ON THE RESULTS

8.1 PN Equipment comparison

8.1.1 Comparison between the Three Types of PN Equipments

Figures 8 and 9 show respectively the means and standard deviations measured with the different systems independently from the laboratories (testing environment). No systematic difference could be made between the PN measurements and the three PN equipments used in the laboratory.

For neither of the vehicles does a system stand out against the others. The variability between the systems is either:

- overwhelmed by the vehicle and environment variability (factors 1 and 3 in table 8)
- or the make has less influence than the manufacturing of the system, meaning there can be bigger differences between two systems of the same make than between two systems of different makes.

The first assumption is the most likely.

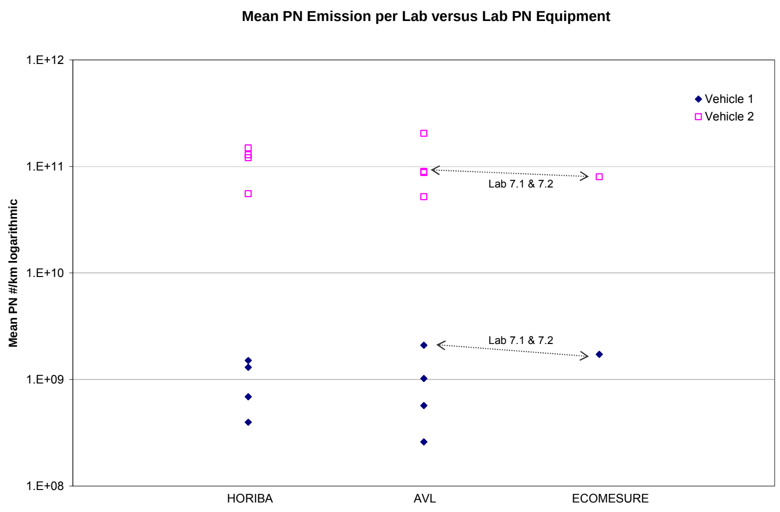


Figure 6

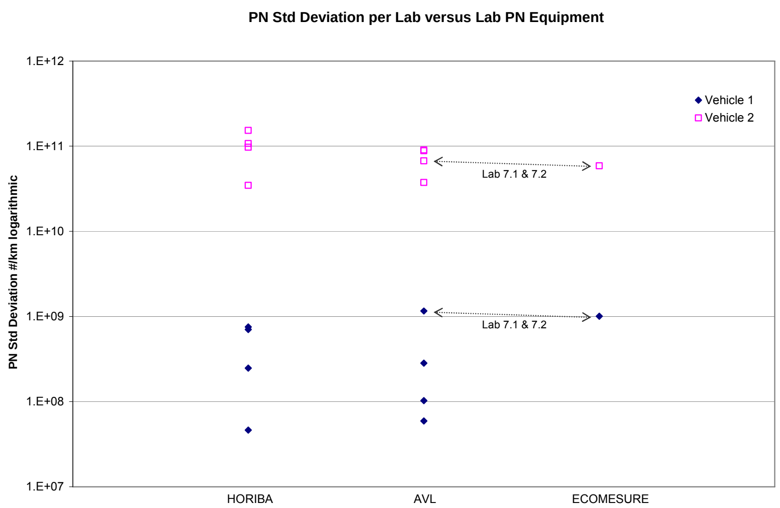


Figure 7

8.1.2 Direct Comparison of two PN Equipments

A direct comparison of PN equipments was made in laboratory 7; laboratories 7.1 and 7.2 differ only by the PN equipments (figures 1, 2 & 4). Both PN systems were set in parallel with their PN probes at the same tunnel section. The 7.2 PN equipment gave systematically lower (or equal) results than the 7.1 PN equipment. The differences are of:

- about -55% for the background (going from -34% to 65%)
- about -18% for Vehicle 1 (going from -16% to -29%)
- about -9% for Vehicle 2 (going from 0 to -14%)

The PN results for both vehicles follow the same trend for the four tests carried out simultaneously in laboratories 7.1 and 7.2 (figures 1, 2). This implies that the variations observed in the results from one day to the other are due to vehicle PN emissions variation. This can come from:

- an intrinsic variation of the PN emissions of the vehicle (DPF stabilisation),
- and/or a higher sensitivity of PN emissions to the testing environment than the rest of the gaseous emissions.

The two systems are in accordance with the regulation (both systems had calibration certificates according to R83), but have different VPR technologies and PNCs of different makes. Testing two PN equipments from the same supplier in parallel would help identify whether the differences for laboratories 7.1 and 7.2 are due to the different PN equipment designs or if the difference remains in the magnitude of manufacturing dispersion.

8.2 VPR Dilution Factor

No VPR dilution factor was specifically required in the test protocol.

Some system displays ask to set the VPR dilution factor and others directly the fr (reduction factor). The influence of the dilution in figure 10 is represented with the fr, this factor being more representative of the real dilution that actually occurs during the PN counting. Over the seven laboratories, the fr value were set from 100 to 250. For diluted exhaust PN measurements, this range of fr is likely to be used in most laboratories.

From figure 10, no influence regarding the dilution with fr values from 100 to 250 can be seen.

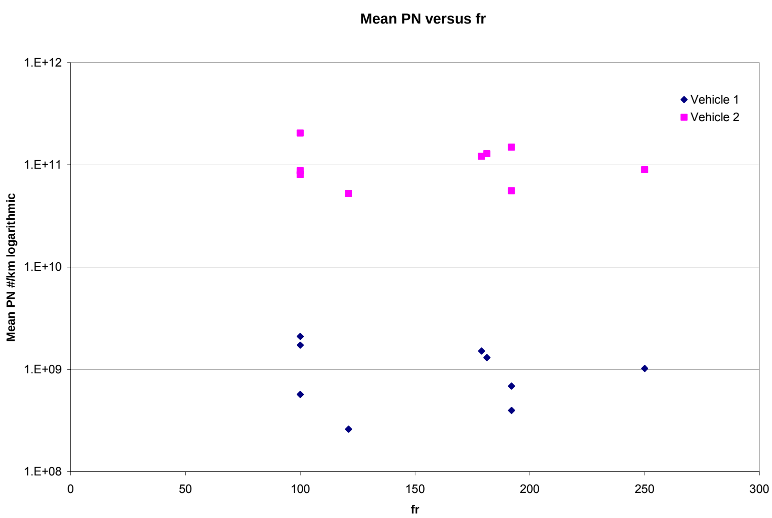


Figure 8

8.3 Regulation interpretations

In addition to estimating the variability of the method, the other objective was to check if the regulation's specifications are precise enough to leave out any interpretation from the laboratories which could influence significantly the results. This point has been quite satisfying. No important differences in the laboratories procedures have been recorded.

PN equipments

All the PN equipments used met the regulation specifications. The fact that only two makes of PN equipments AVL and HORIBA supplied all the laboratories limited the possible differences to the compliance to the regulation. Further more these two systems are both equipped with the same TSI particle counter. The third counter type ECOMESURE which doubled an AVL system in laboratory 7 was also designed in accordance with the regulation.

PN equipment set up and checks

Their installation in the test cells was satisfactory. All the test cells were equipped with cyclones integrated to the PN equipment or probes with Chinese hats (the Chinese hats have not been removed from the tunnel to check their conformity). The zero checks were done before each test as well as the daily HEPA filter check. AVL and HORIBA PN equipments had automatic checks.

PN equipment data processing

The processing of the data supplied by the PN equipment was automatic or manual depending on the time the laboratories had had to develop their system since the PN equipments installation. Either way the calculations were checked, the differences encountered are detailed in §8.4.

8.4 PN Emissions Calculation Formula

The formula from the regulation (R83 Annex4a 6.6.8) protocol for PN is $N = \frac{k.\overline{fr}.\overline{C}.V.10^3}{d}$.

Where:

- k = PNC linearity coefficient
- $\overline{fr}$= mean reduction factor of VPR measured during calibration, defined in R83 Annex4a §2.2.2 as

  $$\bar{fr} = \frac{fr(100nm) + fr(50nm) + fr(30nm)}{3}$$

- $\overline{C}$= mean value of raw PN concentration (#/cm^3) at 0°C - only corrected with the coincidence factor
- V = CVS volume (m^3) at 0°C
- d = distance (km)

Procedure variations in the laboratories

The linearity coefficient k is taken into account directly in the PNC raw count or is integrated in the test cell software. In any case it is always integrated in the calculation.

Laboratories supplied with HORIBA and ECOMESURE systems do the calculation according to the R83 formula. Both systems can also do the calculation as AVL.

Laboratories supplied with the AVL system, correct the raw count second per second by the instantaneous measured fr instead of correcting the mean raw values with the $\overline{fr}$ determined during annual calibration. This has a slight influence on the results, but that remains insignificant compared to the dispersions of the PN results.

For instance for laboratory 2 comparing these two methods gives:

- -2% to +1% for background
- -1% to +3% for the Vehicle 1 tests
- -1% to 0% for the Vehicle 2 tests

On the AVL system display the user selects a fr value from 100 to 20000. The dilution is in fact set to "fr displayed / $\overline{fr}$ ". Therefore when the user selects a fr of 100, the dilution factor DF actually applied is usually lower than 100.

Considering the measurement levels, none of the differences described in the previous paragraphs are significant at the moment, but could become significant if PN measurement levels were higher.

9 BACKGROUND SUBTRACTION FOR PN

The subtraction of the PN background has been done by subtracting directly the terms in #/km without any correction of the CVS dilution factor as it is specified in the regulation for gaseous and PM emissions.

PN #/km	Mean	Mean w/ subtracted BkG	Relative difference
Vehicle 1	0.97 10^{09}	0.56 10^{09}	-43%
Vehicle 2	0.95 10^{11}	1.01 10^{11}	+7%
Vehicle 2 w/o reg effect	0.36 10^{11}	0.36 10^{11}	-1%
Background	3.52 10^{08}	-	-

Table 8 – Comparison of PN mean values with and without subtracting the background

PN #/km	URepro	URepro w/ subtracted BkG
Vehicle 1	1.4 10^{09} (144%)	1.4 10^{09} (252%)
Vehicle 2	1.6 10^{11} (169%)	1.7 10^{11} (168%)
Vehicle 2 w/o reg effect	0.3 10^{11} (81%)	0.3 10^{11} (81%)
Background	8.4 10^{08} (239%)	8.4 10^{08} (239%)

Table 9– Comparison of PN URepro with and without subtracting the Background

Note1: some mean values may be higher with the subtracted background. This is due to non valid backgrounds which prevent from doing the subtraction with the vehicle PN emissions; therefore in this part not all the valid PN results are taken into account which modifies the global mean value.

Note2: when the background value was higher than the vehicle PN value, the subtraction result was set to 0.

Vehicle 2 PN emission levels being overwhelmingly higher than the background levels (~100-400 times higher), subtracting the background has no influence on the Vehicle 2 results, this regarding either the mean value or the uncertainty URepro.

On the other hand it lowers significantly the mean value on Vehicle 1; the vehicle emission level is in the same magnitude of the background. Vehicle 1 emissions being far from the limit (~500 times lower), the subtraction of the background does not influence the compliance margin of the results with the regulation limit.

In all when the background levels are under 10^{09} #/km, subtracting the PN background from the vehicles PN emissions does not improve the variability of the method or the compliance margin. If the background were significantly higher, then there could be an influence on the final result. Measuring the background is a good quality check.

10 PN DATA ACQUISITIONS AND INTERPRETATION

The PN concentrations in #/cm^3 shown on the PN trace graphs are corrected with the fr coefficient. For PN equipments which give the PN raw concentrations (Horiba and Ecomesure), the $\overline{fr}$ from the calibration was multiplied with the raw concentrations s per s. For the other systems (AVL), the data was taken directly from the data supplied.

The laboratories had different CVS flow rates, all the PN concentrations are corrected to a reference CVS flow rate of 9 m^3/min.

It is reminded that the two test vehicles were chosen to represent two distinct PN emission levels, the scales of the graphs are then not at all comparable.

The PN trace graphs are in annex 4.

10.1 PN Global Traces

Vehicle 1

Vehicle 1 (figure 11) which has the lowest emissions of the two vehicles mainly generates PN in the first 200s.

Laboratory 7 has very high peaks during the first part of the cycle and is the only one to measure peaks up to 300s. Both its PN equipments show this trend (figure 16); hence the vehicle and environment are responsible of the global high results given in figure 1.

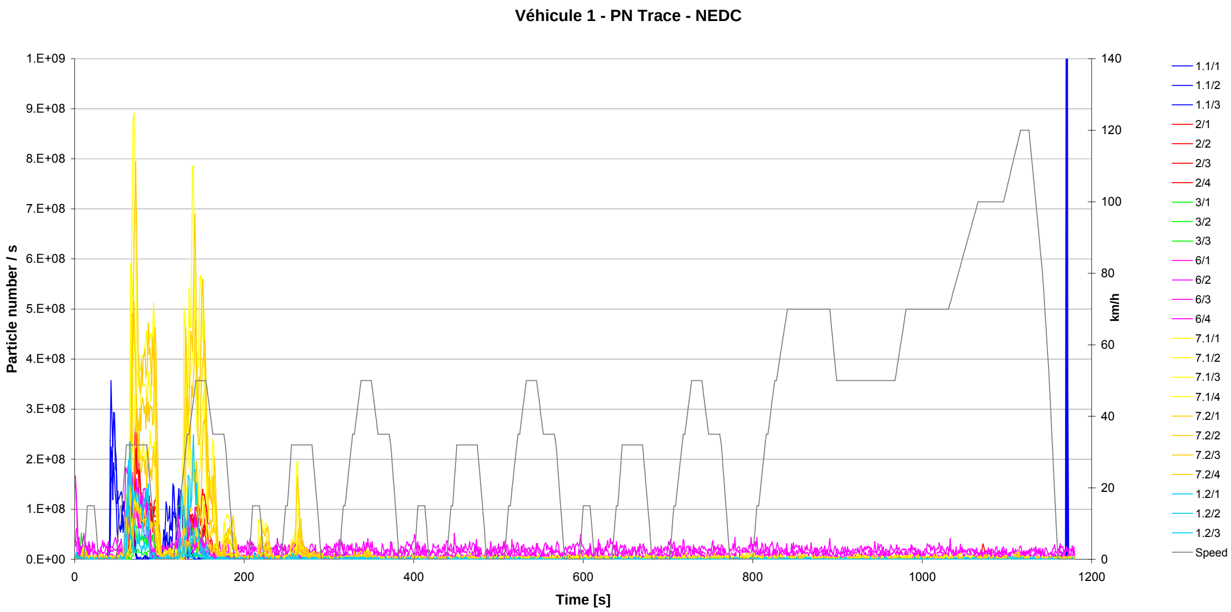


Figure 9

In accordance with the PN traces, the cumulated traces (figure 12) are practically constant after 200s (300s for laboratory 7).

Laboratory 6 is the only exception. Its PN cumulated concentrations continue to increase in a linear way. At this point from what was measured in the other laboratories, Vehicle 1 generates practically no PN. Hence the increase must come from the background which is high in this test cell (figure 17) and overwhelms the vehicle emissions. This phenomenon can explain the high global results in figure 1.

As mentioned in §9, the influence that the PN background (at the level measured in this programme) can have on such a low level of emissions is not decisive for the vehicle to pass the regulation limits.

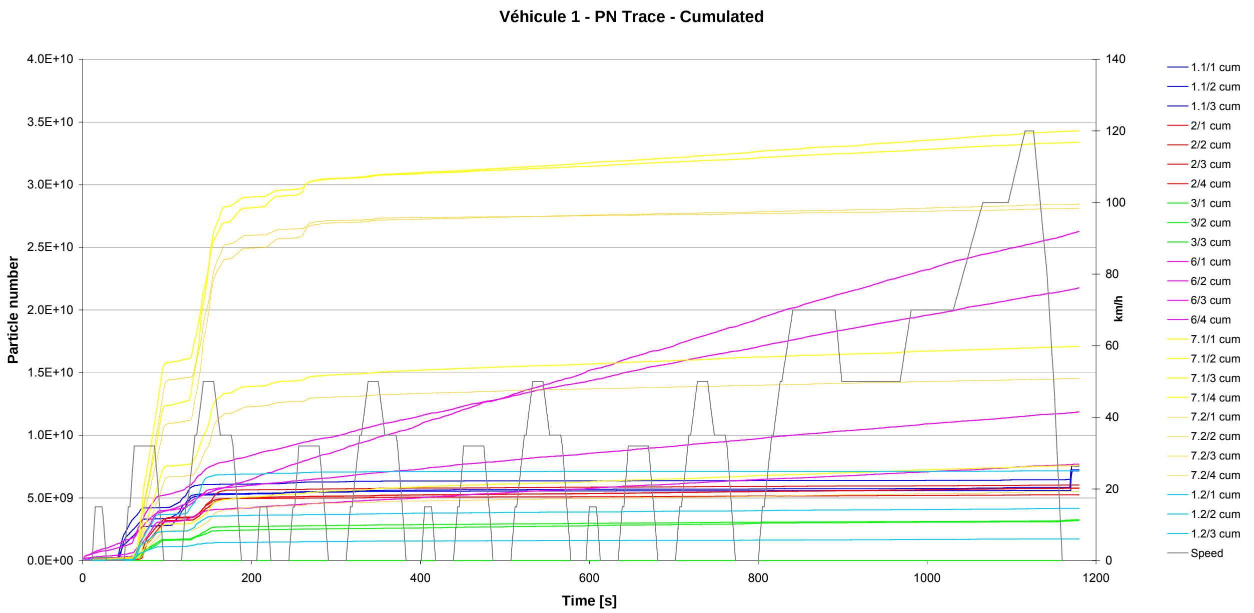


Figure 10

Vehicle 2

Vehicle 2 traces (figure 13) show emissions of PN during the entire cycle and mostly during the first 400s and on the last bump (120 km/h) of the cycle. Every acceleration generates a peak.

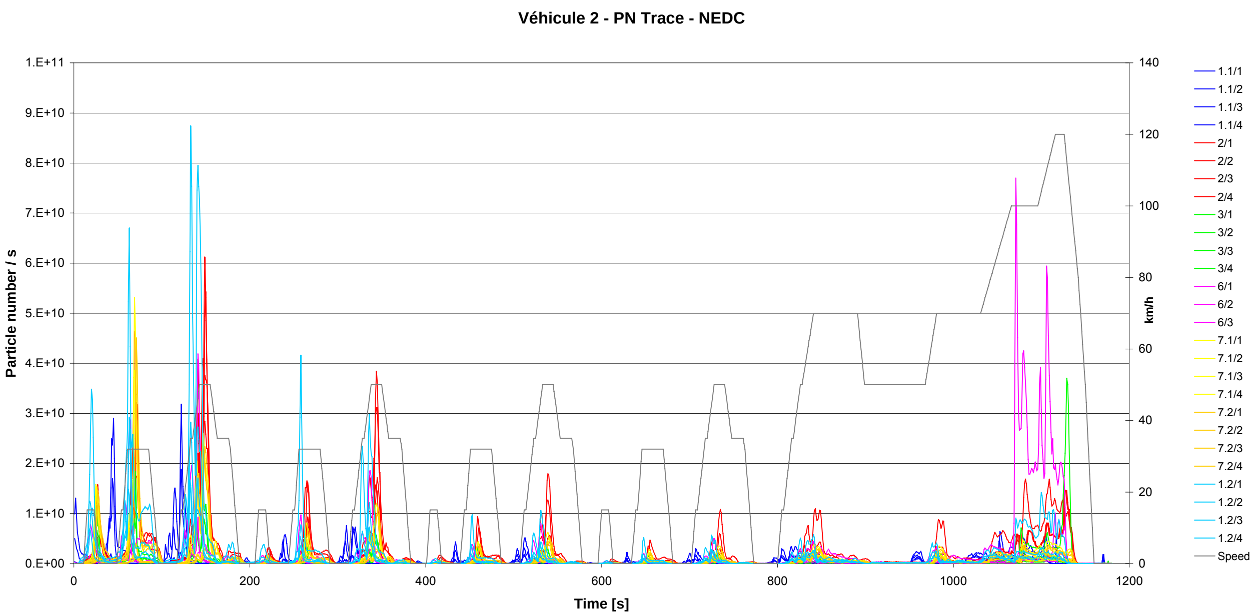


Figure 11

Vehicle 2 cumulated PN concentrations increase during the entire cycle and stabilise on the last idling segment (figure 14).

All the tests have very similar traces apart from four tests with particularly high final levels (1.2/1, 2/1, 2/4 & 6.1).

For test 6.1 unusually high emissions were measured at the end of the EUDC cycle. This results in a sudden high increase of the cumulated concentrations at 1050s. Test 6.1 has also the highest CO2 measured value (annex 1 figure A1.8); hence the high PN peak probably comes from the carrying out of the test and does not involve the PN measurement protocol. But again demonstrates of the sensitivity of the PN emissions.

Nothing concerning the results of the gaseous emissions of the three other tests (1.2/1, 2/1 & 2/4) help to explain the PN emission high values. All four tests followed a forced regeneration and so not carried out in stabilised conditions for the DPF.

Globally in all the laboratories, tests carried out directly after forced regeneration give higher final values than when carried out in DPF stabilised conditions. But it is not true when it comes to comparing the laboratories together, the series of tests in stabilised conditions overlaps with the series with post-regeneration effect.

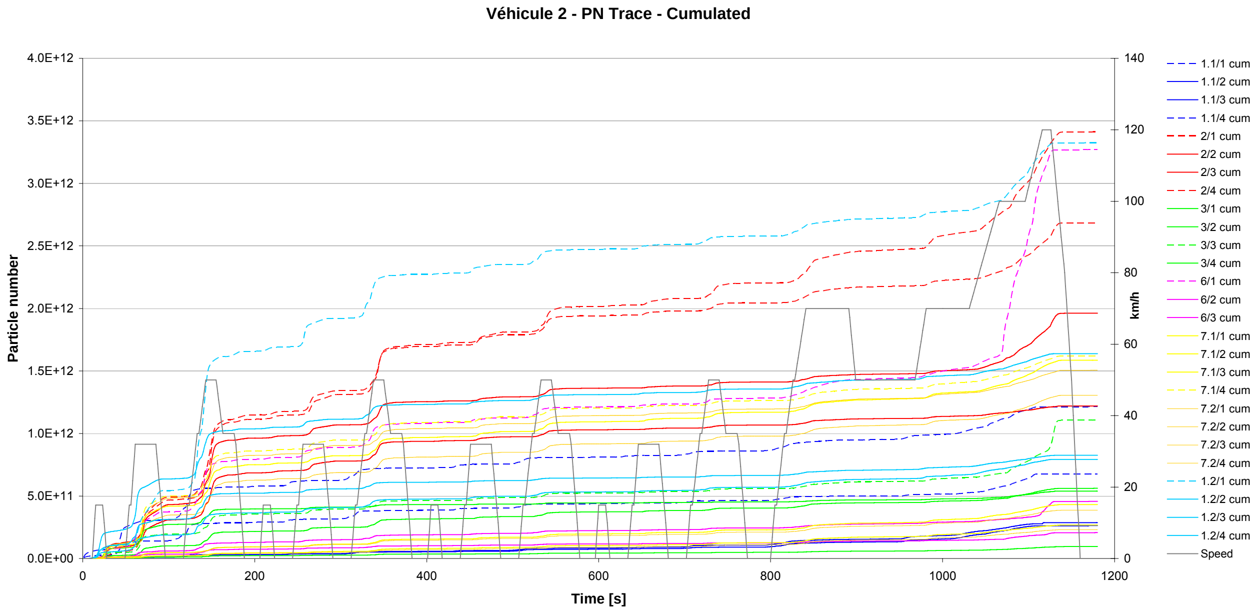


Figure 12

Note: the ---- lines correspond to the tests following directly a forced regeneration (with post-regeneration effect).

10.2 Vehicle Behaviour and PN Equipment Response

Tests Comparison in a Given Laboratory

From one test to the other in a given laboratory, the form of the traces is broadly identical over the entire cycle. The differences in the global results come from the magnitude of the peaks of PN generated by the vehicles in acceleration phases. Figure 15 illustrates this matter with laboratory 2 results over the ECE cycle.

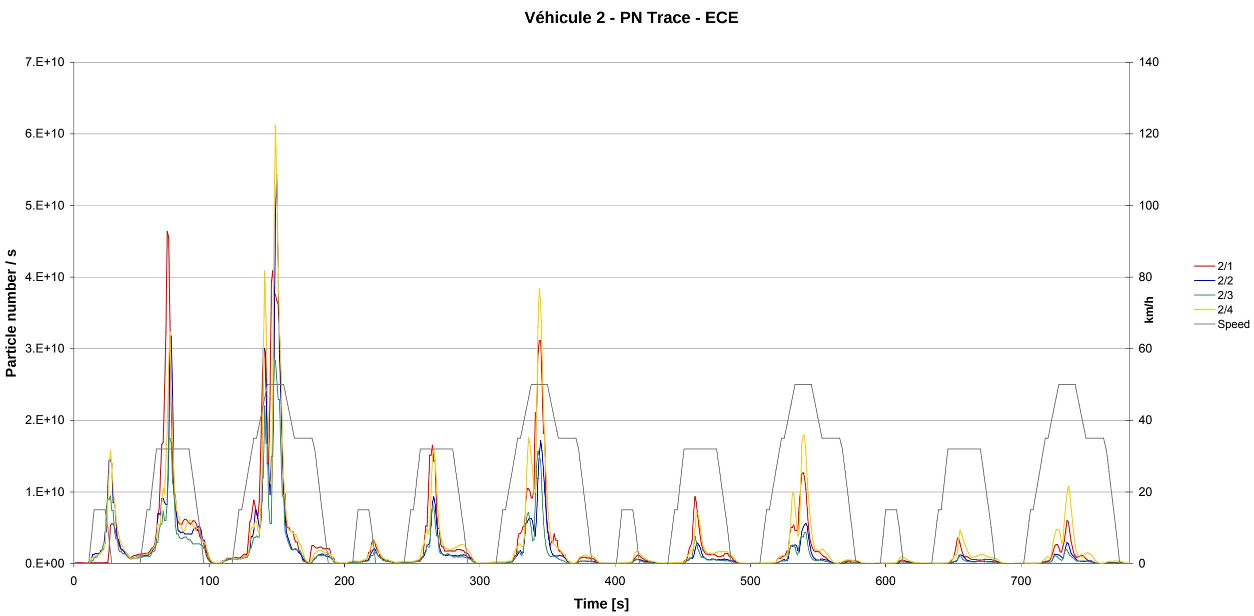


Figure 13 – PN traces for laboratory 2

<u>Comparison of the Response of Two PN Equipments</u>

The traces shown on figure 16 complete the previous paragraph. The PN concentrations of laboratories 7.1 and 7.2 show identical traces for both systems. Hence the differences of the results from one day to the other are mainly due to the variations in the vehicle PN emissions and not to the PN equipment itself.

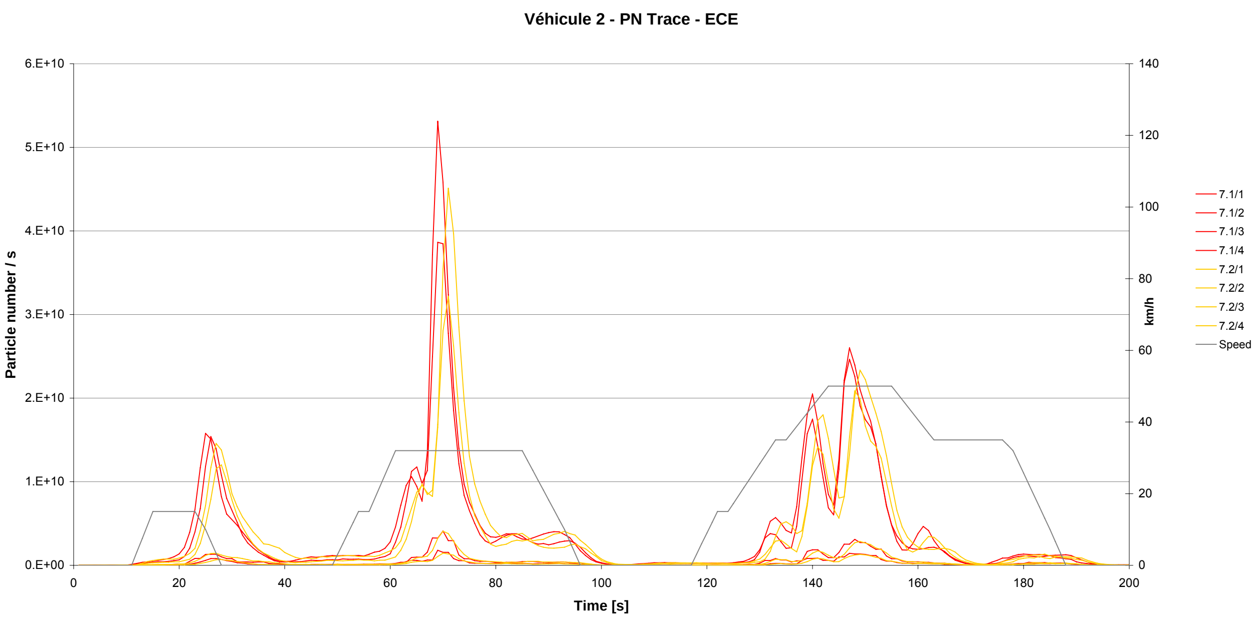


Figure 14 – Comparison of laboratory equipments 7.1 and 7.2 results [AVL&ECOMESURE]

10.3 Synchronisation

Only laboratories 1 and 6 have synchronized signals. The other laboratories measure with time offsets way under 20s which is the maximum allowed by the regulation. The last 20s of the NEDC cycle being idling, the offsets has no influence on the final result. Indeed figure 14 shows flat cumulated emissions on the end of the cycle. The 20s time response required by the regulation are satisfying.

Laboratory 1 has readjusted its synchronisation between its two testing sessions; for the first battery of tests its synchronisation was too short and cut the first seconds of the data acquisition. The modification is clearly visible on figures 11 and 12, but as the previous paragraph mentions, there was no influence due to the readjustment.

10.4 Background

The cumulated PN concentrations over the 1180s are linear (figure 17). Therefore the differences in the background global results are mostly due to a constant level of background. Some peaks may interfere which of course tend to increase the results.

Laboratories 3 and 6 show high PN backgrounds. As explained in §6.3, laboratory 3 must have had the transfer line not tightly sealed during the background test.

Background 6.4 has had an unexpected PN trace because of peaks that appeared at about 40s and 400s. These are similar to electronic artefact observed in laboratory 1.2 for which the tests were not considered as valid because of the high final PN result (see table 4). This background was considered valid before checking on the PN trace as its global value was homogeneous with the other background measurements. The background was kept in as a valid test; in type approval conditions it not asked to check the traces.

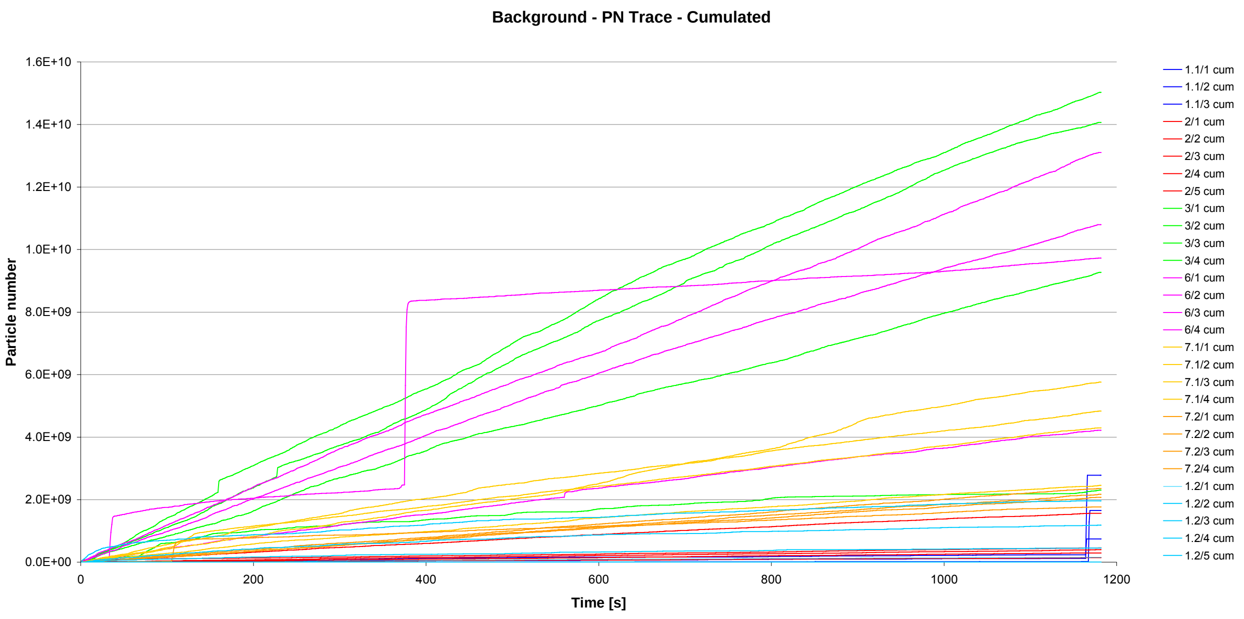


Figure 15

11 COMPARISON OF PN AND PM MEASUREMENT VARIABILITY

The aim of this paragraph is to show visually the variability of the methods for PM and PN measurements. The Euro5b limits are also represented in order to place Vehicle 1 and Vehicle 2 emissions in the regulation context.

Legend for figures 18-20

☆ Mean values

Confidence area over the mean value (at most 95% probability that it will contain the mean of the values)

URepro, set around the mean value as if it was one measurement (coverage interval)

The Confidence Intervals (see annex 2 for definitions)

The confidence interval applies to a mean value. In this programme it has been calculated for about 30 tests per vehicle (Vehicle 1 and Vehicle 2 All).

The confidence areas for Vehicle 1 and Vehicle 2 drawn on figure 18 as boxes indicate that the mean value of the tests has at the most 95% chance to be in the box. The confidence areas of Vehicle 1 and Vehicle 2 being completely distinct in terms of PM and PN, it can be inferred that Vehicle 1 has strictly lower PM and PN emissions than Vehicle 2. Hence, that the method is able to differentiate the two vehicles in terms of PM and PN when 30 tests are carried out; this irrespective of the post regeneration effect of Vehicle 2.

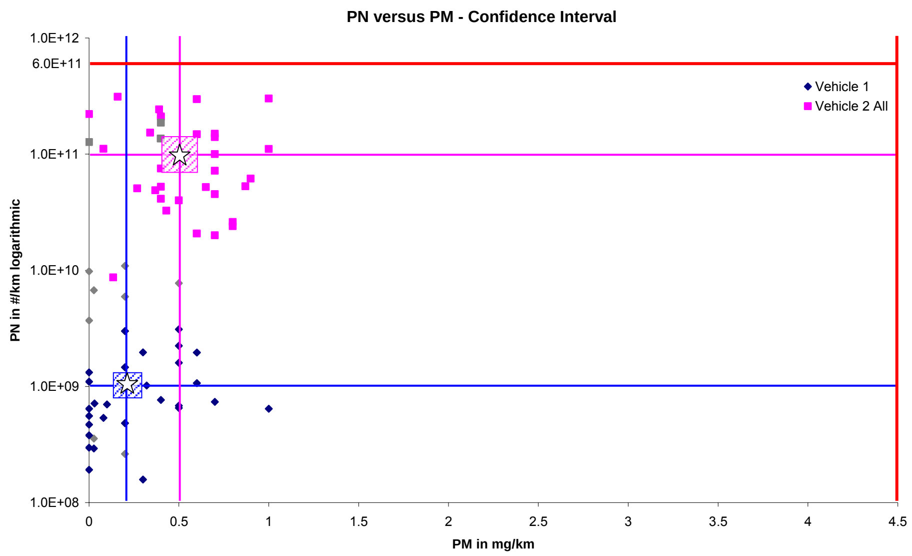


Figure 16

The Uncertainty – Coverage Area

When considering only one measurement, which is more realistic and close to what will happen in the application of the Euro5b regulation; the variability of the method should be estimated with the uncertainty (URepro). On figure 19 URepro is represented by the coverage areas centred on the mean values of each vehicle which are considered as representative measurements. The coverage area from “Vehicle 2 All” completely covers the coverage area of Vehicle 1. From the statistical point of view this means that the vehicles in principle cannot be strictly differentiated in terms of PM or PN emissions when only one test is carried out.

The scatters of plots (figures 19) for the two vehicles overlap each other when considering PM. It confirms what the coverage interval points out: the vehicles in terms of PM emissions cannot be differentiated.

On the other hand the scatters of plots do not overlap each other when considering PN results. This is also the fact when the data are processed with common logarithm (figure 20). Transforming data into common logarithm to stabilise the variability is justifiable when the linear uncertainty is proportional to the level of emissions. It is the case for the PN results of this round robin test (see §7.2.5). Figure 20 shows that indeed the common logarithmic coverage areas using common logarithmic values do not overlap each other. Then although the "Vehicle 2 All" PN coverage interval overlaps the Vehicle 1 PN coverage interval in (figure 19), the PN measurement method has the potential to differentiate the two vehicles. The logarithmic method does not allow expressing the uncertainty in #/km which is what the measurements and the regulation limit are expressed in. For this reason the logarithm method is not well adapted to the objectives of this round robin test.

Figure 20 shows, that providing the post-regeneration effect is taken out of the processed data, the vehicles can be differentiated with just carrying out one test. Indeed, on that particular graph, only the data from "Vehicle 2 w/o p-reg effect" are processed and the coverage areas for PN emissions are completely disjointed.

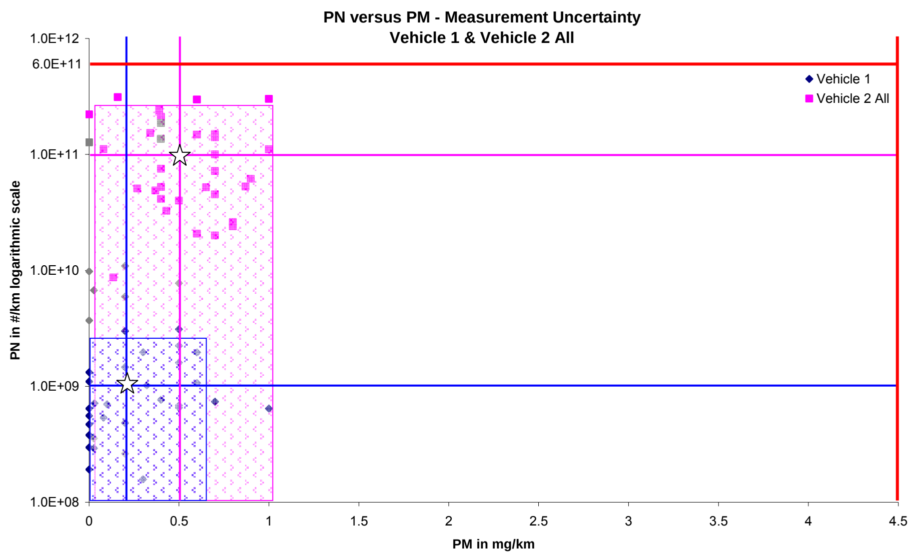


Figure 17

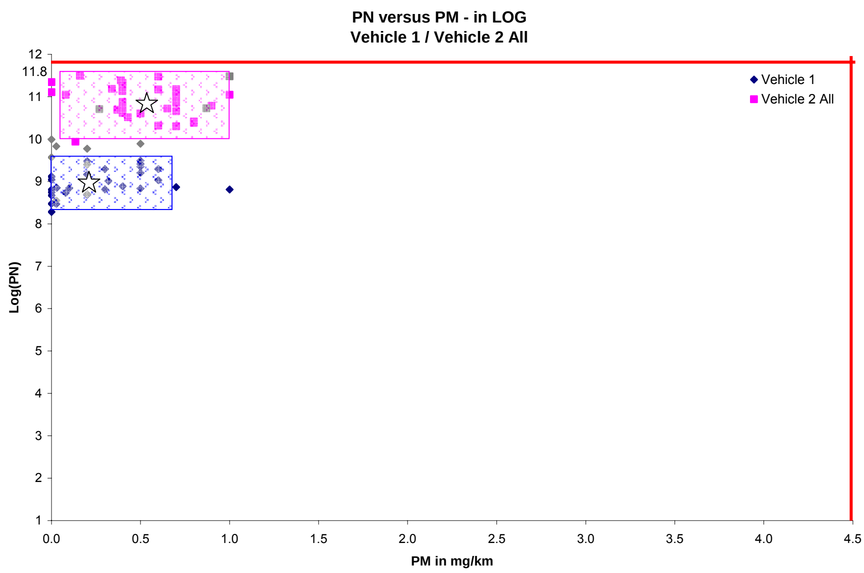


Figure 18

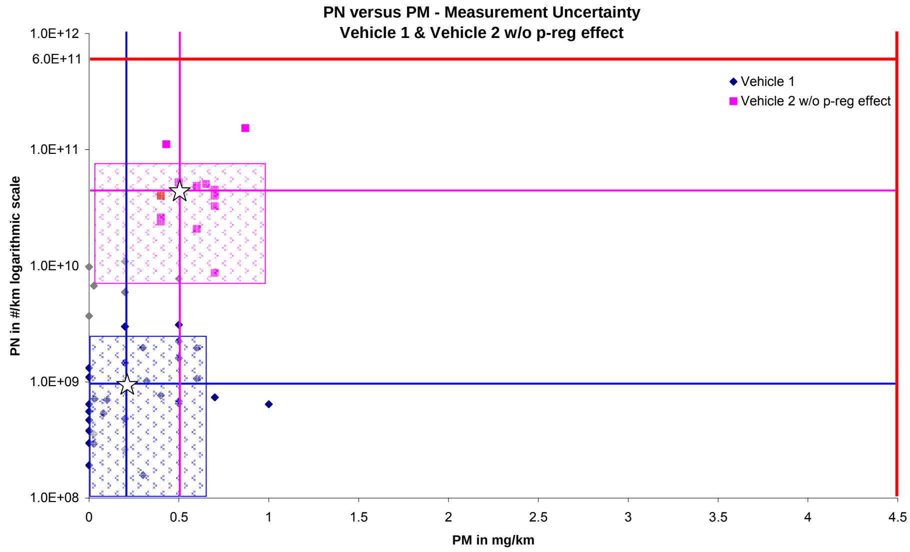


Figure 19

PM/PN Correlation

The variability overwhelms PM/PN correlation.

12 RECOMMENDATIONS

From the results of this round robin test, several recommendations can be made to ensure the quality of the PN measurements:

- Make sure that the PN background level is stable by ensuring that the HEPA filter is well sealed and that the tunnel is clean. A background below 10^9 #/km does not influence the following PN measurements regarding the compliance of the vehicle with the regulation (§9).
- Take care to avoid electronic artefacts, unusual spikes can show up (§10.4).
- When technically possible, carry out tests on vehicles in stabilised DPF conditions as recommended in R83 Annex4a §6.6.9.3, it improves significantly the variability.

13 CONCLUSION

Overall, the round robin test reached its initial objectives:

- Determine whether the PN test protocol is similar in the seven laboratories and with the three PN equipments tested, or if interpretation flexibility remains in the Euro5b legislative specifications.
- Collect enough data to determine the PN protocol uncertainty under type approval conditions.

The regulation is satisfactory with respect to describing the test procedure in terms of operation during measurement; however the influence of interpretations in the calibration procedure has not been studied in this programme. The PN equipments functioned correctly; still 15% of the non valid tests which is 3% of the total tests carried out were rejected due to PN equipment. No test has been rejected only for PM equipments.

Recommendations to ensure measurement quality and decrease the variability are: ensure a stable PN background, check the PN trace for electronic artefact and carry out the tests when possible in stabilised DPF conditions.

The variability of the method in type approval conditions is globally expressed with the uncertainty, for which the calculated values are summarised in the table below. In the objective of not overestimating the uncertainty of the PN protocol, outlying laboratories results were excluded from the calculation, as well as the vehicle effect were minimized by taking into account post-regeneration effect for Vehicle 2.

Uncertainty	Absolute	Relative
CO	35 mg/km	25%
HC	4 mg/km	28%
NOx	16 mg/km - 22 mg/km	9% - 12%
CO2	4.5 g/km - 6.8 g/km	2.9% - 4.7%
FC	0.17 L/100km - 0.26 L/100km	2.9% - 4.7%
PM	0.5 mg/km	90% - 210%
PN	In the magnitude of the PN emission level $1.4\ 10^{09}$ - $2.9\ 10^{10}$ #/km when Vehicle 2 data are w/o post-regeneration effect $1.4\ 10^{09}$ – $1.6\ 10^{11}$ #/km when all Vehicle 2 data are taken into account	81% - 144% 144% - 169%

The PN procedure including all its influencing factors (vehicle, PN equipment and environment) has a high variability; its relative uncertainty is of about 100%. The relative uncertainties of PN are comparable to those of PM which sensitivity is sufficient to resolve compliance with the Euro5 and Euro6 PM limits considering the very low levels of PM emissions of modern vehicles. Compared to the uncertainties for CO2 (5%) and NOx (10%), the PN uncertainty remains of course very high.

In stabilised DPF conditions, the protocol can differentiate the round robin test diesel vehicles in terms of PN emissions, when the PM emissions protocol does not. Now the actual uncertainty of the PN measurement remains high in particular for vehicles which PN emissions are close to the limit; the protocol variability still needs to be improved. When considering all the data (including outlying laboratories), whether the DPF is in stabilised conditions or not, the difference in between the minimum and maximum mean values of the laboratories remains to a factor about 4.

The round robin test shows that part of the total variability of the method comes from the PN equipment (a direct comparison shows up to 18% difference between two systems), but at these low levels the variability comes mostly from the sensitivity of PN emissions to the environment and the variation of the vehicles in terms of PN which are much higher than for gaseous emissions.

To focus on improving the factors with the highest contribution and hence to reduce total variability, the implication of the different factors (vehicle, PN equipment, calibration or environment) need to be better understood.

Besides the calibration protocol which is still in discussion, different development trends are possible of which:

- A full error analysis study would orientate efficiently the priority axes to work on.
- The carrying out of tests with identical PN equipments set in parallel would give an estimation of the variability inherent to the manufacturing of the systems.

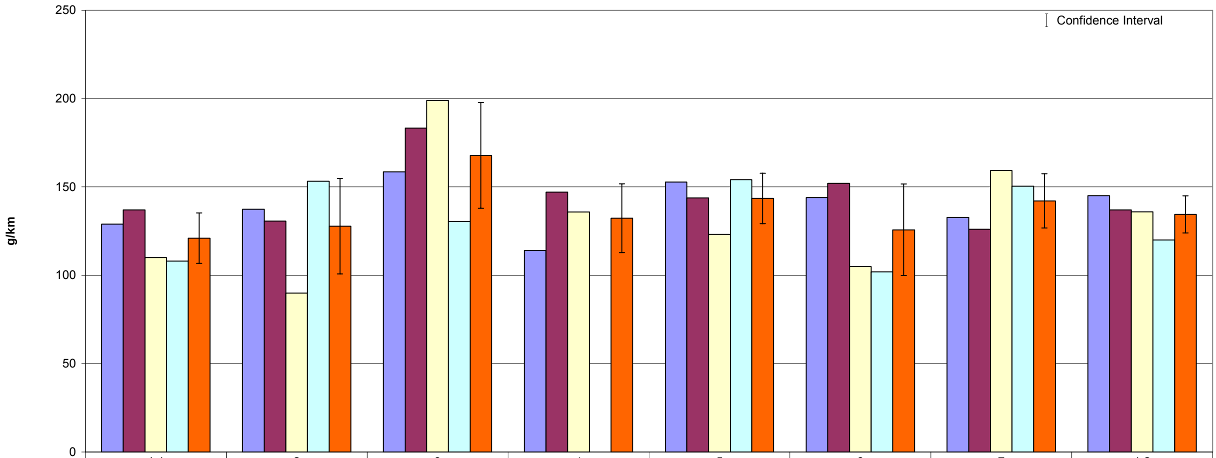
To look ahead to Euro6a, the protocol should be tested on gasoline direct injection engines.

Annex 1 – Graphic Representation of the results

The number of digits in the tables is in accordance with each laboratory's data formatting.

CO Emissions

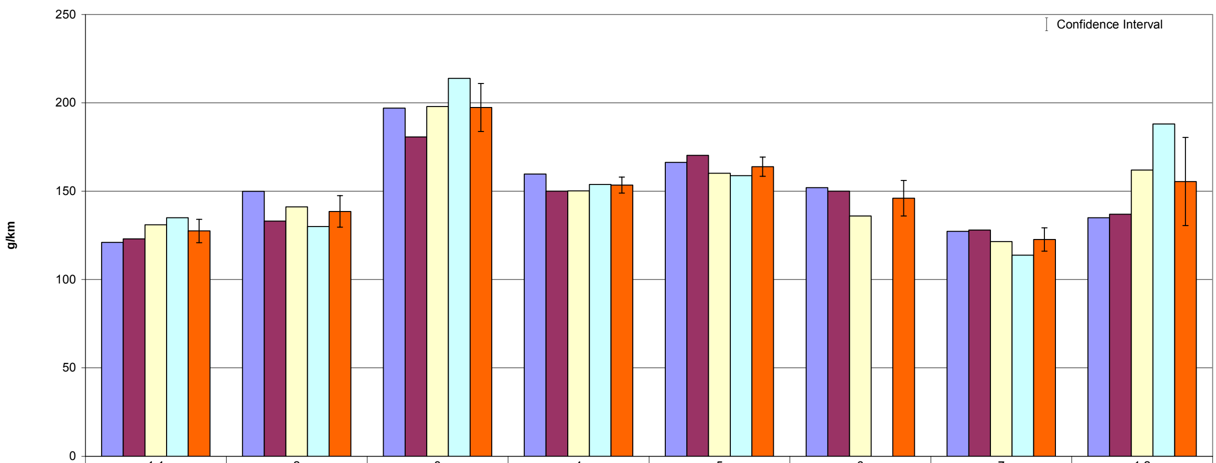
CO Vehicle 1



	1.1	2	3	4	5	6	7	1.2
1	129	137.33	158.57	114.0	152.8	144	132.79	145
2	137	130.72	183.30	147.1	143.8	152	126.08	137
3	110	89.91	198.90	135.8	123.2	105	159.27	136
4	108	153.27	130.51		154.1	102	150.45	120
Average	121	127.81	167.82	132.3	143.5	126	142.15	135

Figure A1. 1

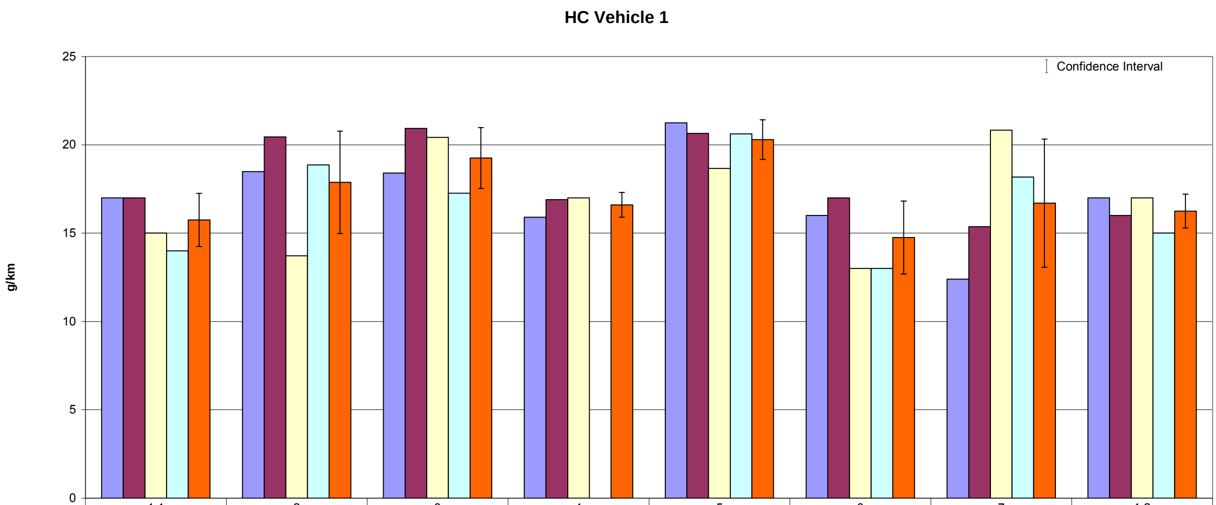
CO Vehicle 2



	1.1	2	3	4	5	6	7	1.2
1	121	149.87	197.03	159.7	166.3	152	127.31	135
2	123	133.09	180.65	150	170.3	150	127.98	137
3	131	141.11	197.88	150.2	160.1	136	121.51	162
4	135	129.97	213.88	153.8	158.8		113.75	188
Average	128	138.51	197.36	153.4	163.9	146	122.64	156

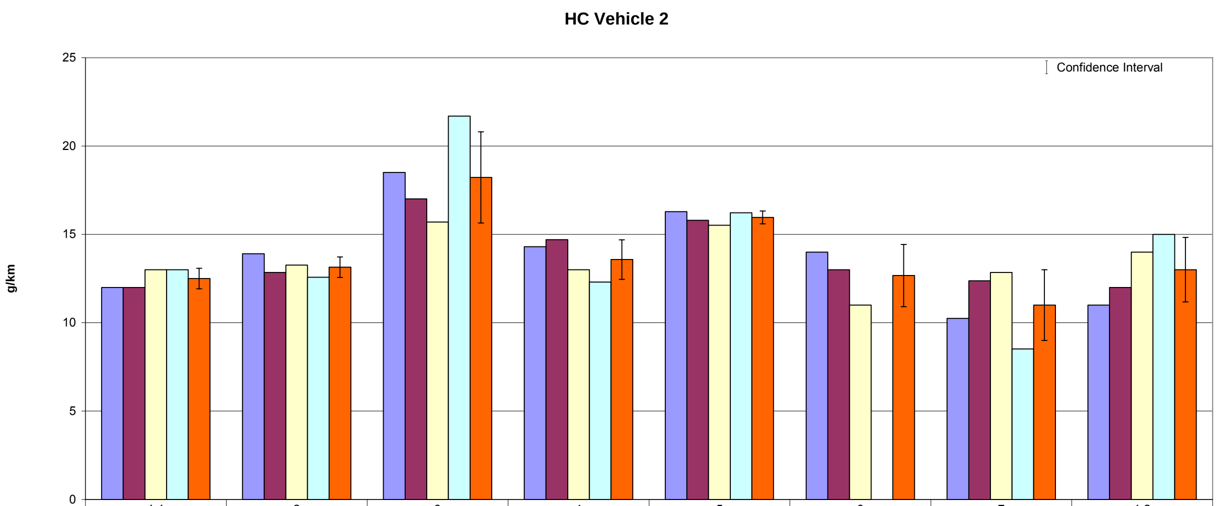
Figure A1. 2

HC Emissions



	1.1	2	3	4	5	6	7	1.2
1	17	18.48	18.40	15.9	21.25	16	12.4	17
2	17	20.45	20.93	16.9	20.65	17	15.37	16
3	15	13.72	20.42	17.0	18.67	13	20.83	17
4	14	18.86	17.26		20.62	13	18.18	15
Average	16	17.88	19.25	16.6	20.30	15	16.70	16

Figure A1. 3

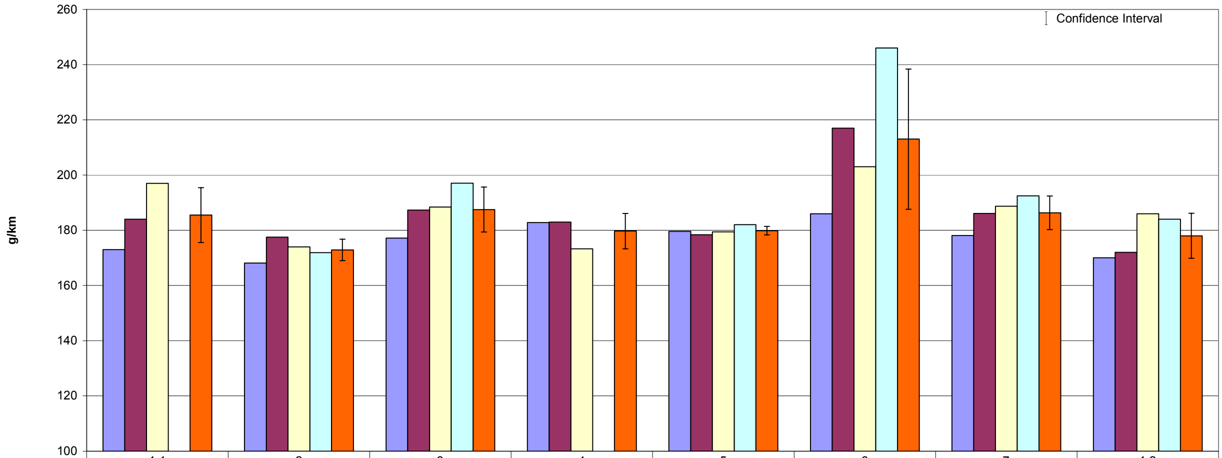


	1.1	2	3	4	5	6	7	1.2
1	12	13.90	18.50	14.3	16.29	14	10.25	11
2	12	12.84	17.01	14.7	15.80	13	12.37	12
3	13	13.26	15.69	13	15.52	11	12.85	14
4	13	12.57	21.69	12.3	16.22		8.52	15
Average	13	13.14	18.22	13.6	15.96	13	11.00	13

Figure A1.4

NOx Emissions

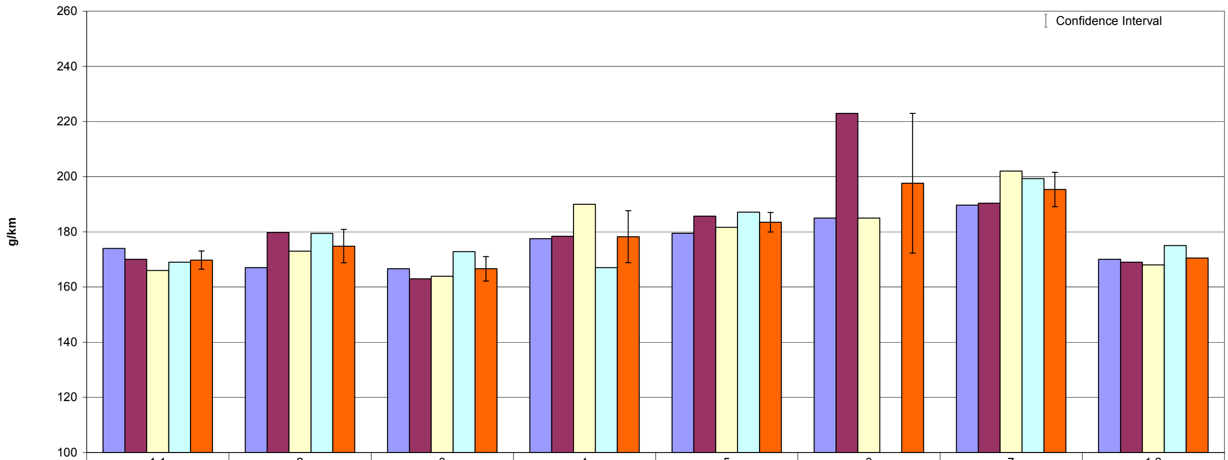
NOx Vehicle 1



	1.1	2	3	4	5	6	7	1.2
1	173	168.17	177.14	182.8	179.6	186	178.06	170
2	184	177.53	187.35	183.0	178.4	217	186.1	172
3	197	173.95	188.42	173.3	179.4	203	188.69	186
4		171.93	197.05		182.0	246	192.45	184
Average	186	172.90	187.49	179.7	179.9	213	186.33	178

Figure A1.5

NOx Vehicle 2

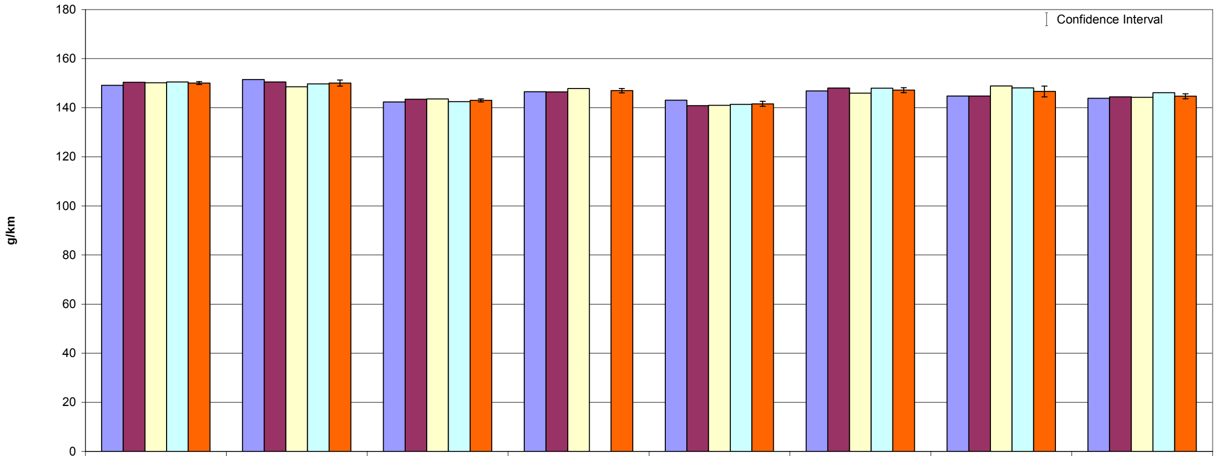


	1.1	2	3	4	5	6	7	1.2
1	174	167.04	166.66	177.5	179.5	185	189.66	170
2	170	179.80	162.99	178.4	185.7	223	190.38	169
3	166	172.97	163.92	190	181.6	185	202.02	168
4	169	179.41	172.80	167	187.1		199.30	175
Average	170	174.81	166.59	178.2	183.5	198	195.34	171

Figure A1.6

CO2 Emissions

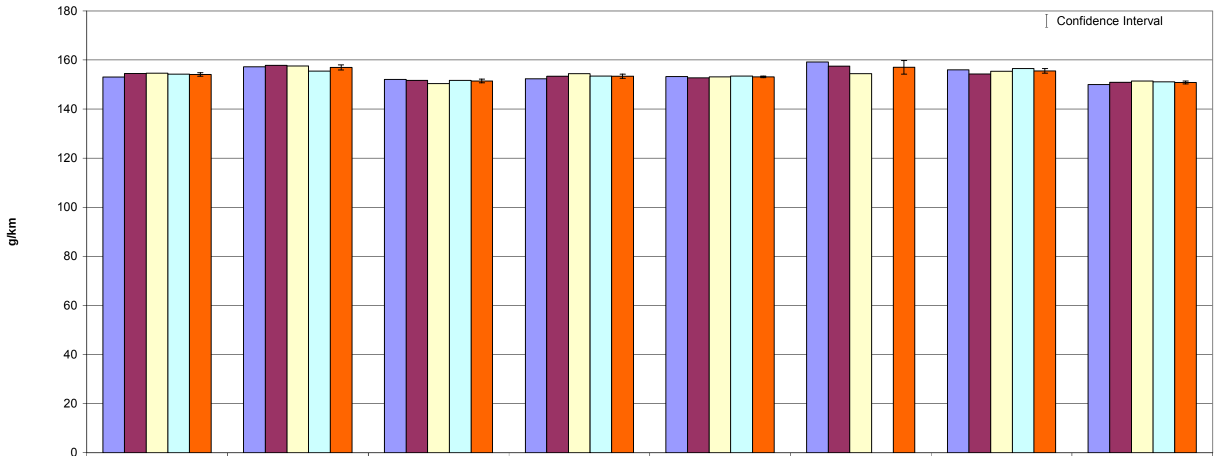
CO2 Vehicle 1



	1.1	2	3	4	5	6	7	1.2
1	149.2	151.5	142.4	146.5	143.1	146.9	144.8	143.8
2	150.4	150.5	143.5	146.5	140.9	148.0	144.8	144.5
3	150.2	148.6	143.6	147.8	141.0	145.9	148.9	144.3
4	150.5	149.7	142.5		141.4	148.0	148.1	146.1
Average	150.1	150.1	143.0	146.9	141.6	147.2	146.7	144.7

Figure A1.7

CO2 Vehicle 2



	1.1	2	3	4	5	6	7	1.2
1	153.0	157.2	152.1	152.4	153.3	159.2	156.0	150.0
2	154.5	157.8	151.7	153.4	152.7	157.5	154.3	150.9
3	154.6	157.5	150.38	154.4	153.2	154.4	155.4	151.4
4	154.2	155.5	151.7	153.4	153.5		156.5	151.1
Average	154.1	157.0	151.5	153.4	153.1	157.0	155.6	150.9

Figure A1.8

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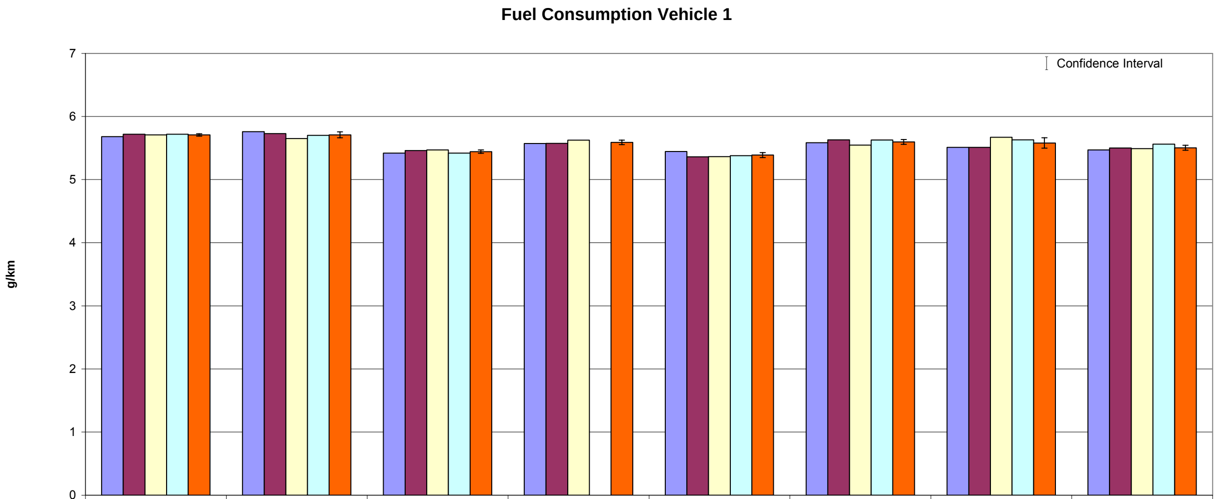
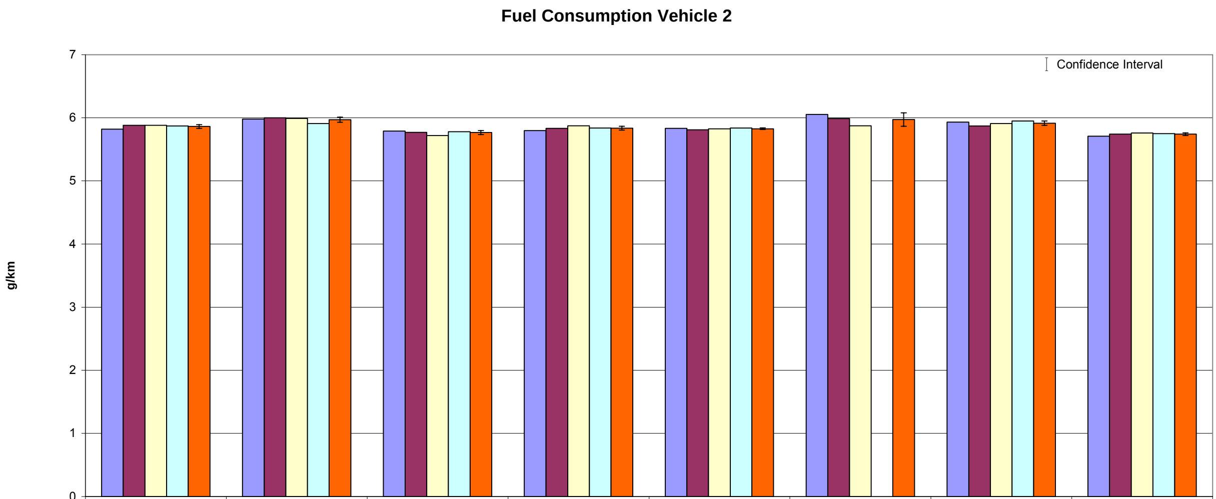
Annex 1

Fuel Consumption



	1.1	2	3	4	5	6	7	1.2
1	5.68	5.76	5.42	5.57	5.45	5.59	5.51	5.47
2	5.72	5.73	5.46	5.57	5.36	5.63	5.51	5.50
3	5.71	5.65	5.47	5.62	5.36	5.55	5.67	5.49
4	5.72	5.70	5.42		5.38	5.63	5.63	5.56
Average	5.71	5.71	5.44	5.59	5.39	5.60	5.58	5.51

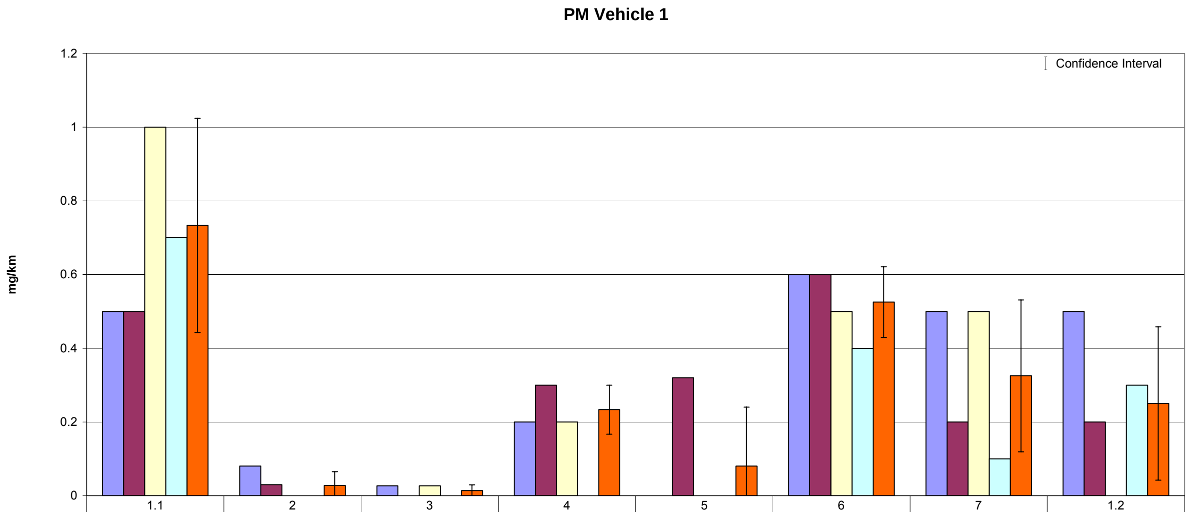
Figure A1. 9



	1.1	2	3	4	5	6	7	1.2
1	5.82	5.98	5.79	5.80	5.83	6.05	5.93	5.71
2	5.88	6.00	5.77	5.83	5.81	5.99	5.87	5.74
3	5.88	5.99	5.72	5.87	5.83	5.87	5.91	5.76
4	5.87	5.91	5.78	5.84	5.84		5.95	5.75
Average	5.86	5.97	5.77	5.84	5.83	5.97	5.92	5.74

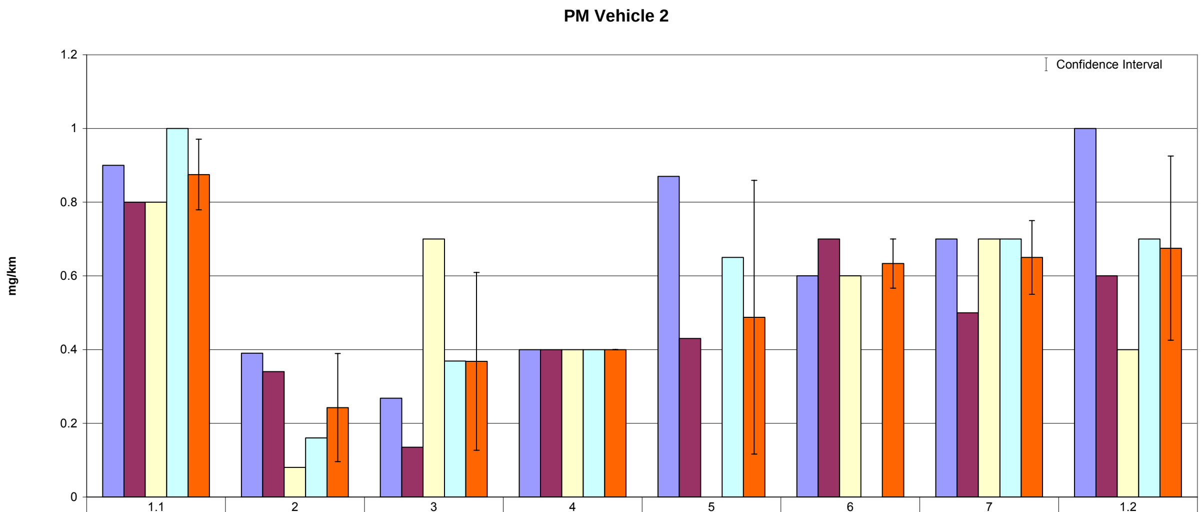
Figure A1. 10

PM Emissions



	1.1	2	3	4	5	6	7	1.2
1	0.5	0.08	0.03	0.2	0.00	0.6	0.5	0.5
2	0.5	0.03	0.00	0.3	0.32	0.6	0.2	0.2
3	1.0	0.00	0.03	0.2	0.00	0.5	0.5	0.0
4	0.7	0.00	0.00		0.00	0.4	0.1	0.3
Average	0.7	0.03	0.01	0.2	0.08	0.5	0.3	0.3

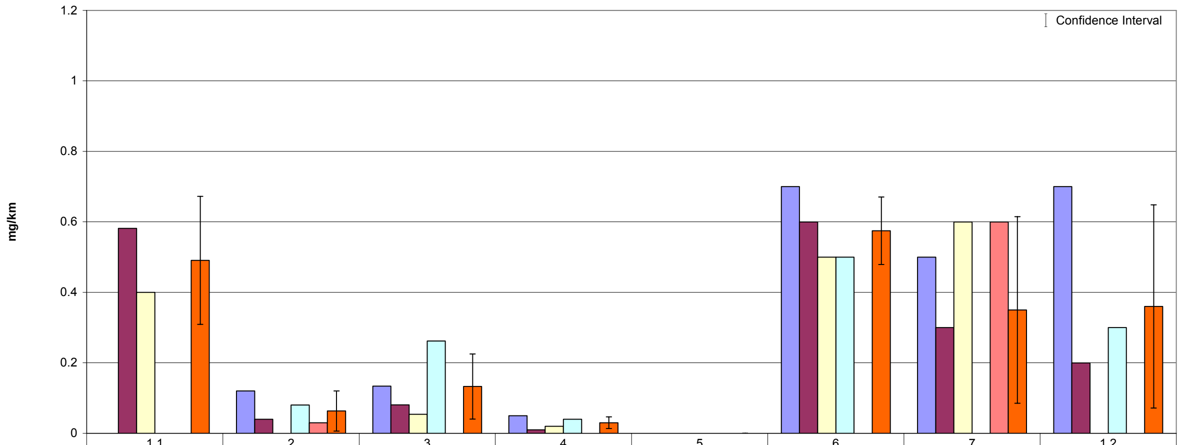
Figure A1. 11



	1.1	2	3	4	5	6	7	1.2
1	0.9	0.39	0.27	0.4	0.87	0.6	0.7	1.0
2	0.8	0.34	0.14	0.4	0.43	0.7	0.5	0.6
3	0.8	0.08	0.70	0.4	0.00	0.6	0.7	0.4
4	1.0	0.16	0.37	0.4	0.65		0.7	0.7
Average	0.9	0.24	0.37	0.4	0.49	0.6	0.7	0.7

Figure A1. 12

PM Background

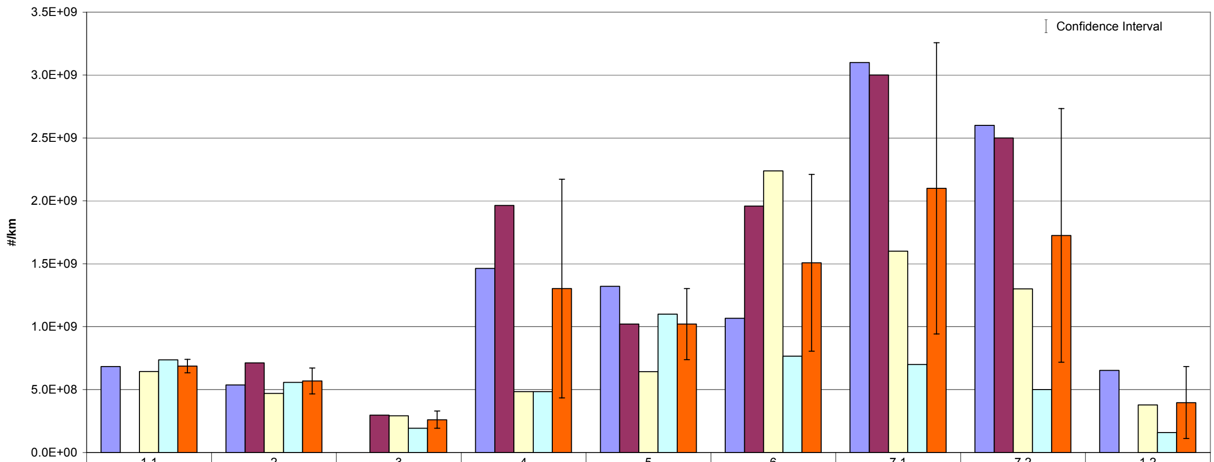


	1.1	2	3	4	5	6	7	1.2
1		0.12	0.13	0.05	0.00	0.7	0.5	0.7
2	0.6	0.04	0.08	0.01	0.00	0.6	0.3	0.2
3	0.4	0.00	0.05	0.02	0.00	0.5	0.6	0.0
4		0.08	0.26	0.04	0.00	0.5	0.0	0.3
5		0.03					0.6	
Average	0.5	0.06	0.13	0.03	0.00	0.6	0.4	0.4

Figure A1. 13

PN Emissions

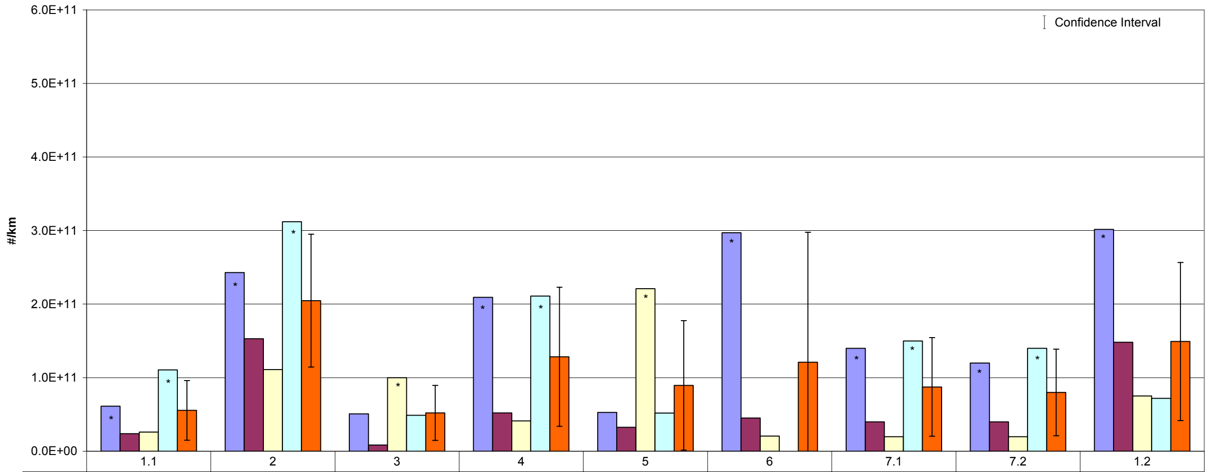
PN Vehicle 1



	1.1	2	3	4	5	6	7.1	7.2	1.2
1	0.68E+09	0.54E+09		1.46E+09	1.32E+09	1.07E+09	3.1E+09	2.6E+09	0.65E+09
2		0.71E+09	0.30E+09	1.96E+09	1.02E+09	1.96E+09	3.0E+09	2.5E+09	
3	0.64E+09	0.47E+09	0.29E+09	0.48E+09	0.64E+09	2.24E+09	1.6E+09	1.3E+09	0.38E+09
4	0.74E+09	0.56E+09	0.19E+09	0.48E+09	1.10E+09	0.77E+09	0.7E+09	0.5E+09	0.16E+09
Average	0.69E+09	0.57E+09	0.26E+09	1.30E+09	1.02E+09	1.51E+09	2.1E+09	1.7E+09	0.40E+09

Figure A1. 14

PN Vehicle 2

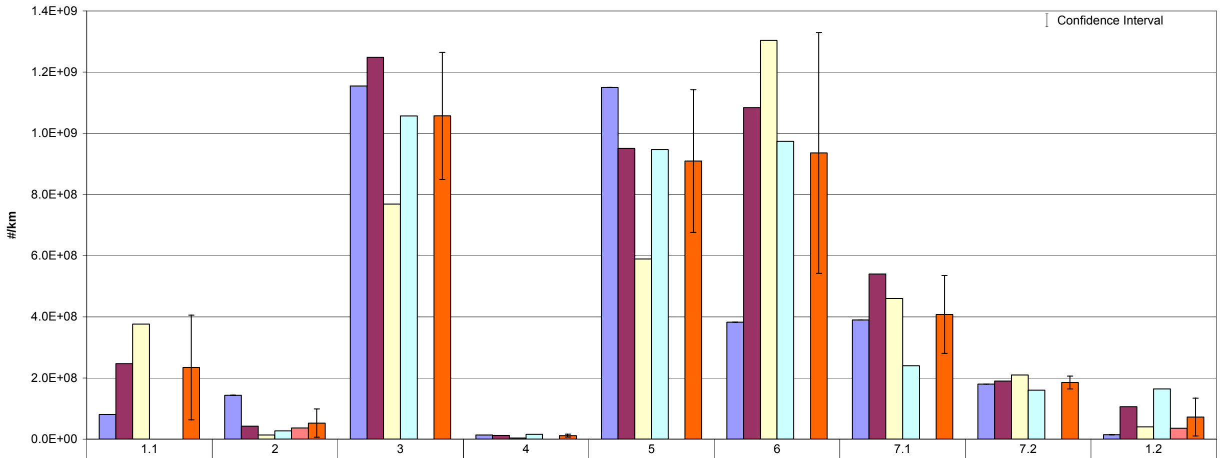


	1.1	2	3	4	5	6	7.1	7.2	1.2
1	0.62E+11	2.43E+11	0.51E+11	2.09E+11	0.53E+11	2.97E+11	1.4E+11	1.2E+11	3.02E+11
2	0.24E+11	1.53E+11	0.09E+11	0.52E+11	0.33E+11	0.45E+11	0.4E+11	0.4E+11	1.48E+11
3	0.26E+11	1.11E+11	1.00E+11	0.41E+11	2.21E+11	0.21E+11	0.2E+11	0.2E+11	0.75E+11
4	1.11E+11	3.12E+11	0.49E+11	2.11E+11	0.52E+11		1.5E+11	1.4E+11	0.72E+11
Average	0.56E+11	2.05E+11	0.52E+11	1.29E+11	0.90E+11	1.21E+11	0.9E+11	0.8E+11	1.49E+11

Figure A1. 15

Note: the bar graphs marked with a * correspond to the test following directly a forced regeneration.

PN Background



	1.1	2	3	4	5	6	7.1	7.2	1.2
1	0.80E+08	1.43E+08	11.55E+08	0.14E+08	11.5E+08	3.82E+08	3.9E+08	1.8E+08	0.14E+08
2	2.47E+08	0.42E+08	12.48E+08	0.12E+08	9.51E+08	10.84E+08	5.4E+08	1.9E+08	1.06E+08
3	3.76E+08	0.13E+08	7.68E+08	0.04E+08	5.89E+08	13.04E+08	4.6E+08	2.1E+08	0.41E+08
4		0.27E+08	10.57E+08	0.16E+08	9.47E+08	9.74E+08	2.4E+08	1.6E+08	1.64E+08
5		0.36E+08							0.35E+08
Average	2.34E+08	0.52E+08	10.57E+08	0.11E+08	9.09E+08	9.36E+08	4.1E+08	1.9E+08	0.72E+08

Figure A1. 16

Annex 2 – Statistical Definitions and Formula

The statistical calculations for this programme have been done according to the standard ISO 5725 - *Accuracy (trueness and precision) of measurement methods and results* - and ISO/TS 21748:2005 - *Guidance for the use of repeatability, reproducibility and trueness estimates in measurement uncertainty estimation*.

1. Definitions

Repeatability conditions:
Observation conditions where independent test/measurement results are obtained with the same method on identical test/measurement items in the same test or measuring *(measurement)* facility *(laboratory)* by the same operator using the same equipment within short intervals of time.

NOTE: Repeatability conditions include:
- the same measurement procedure *or test procedure*;
- the same operator;
- the same measuring or test equipment used under the same conditions;
- the same location;
- repetition over a short period of time.

[ISO 3534-2: 2006, §3.3.6]

Reproducibility conditions:
Observation conditions where independent test/measurement results are obtained with the same method on identical test/measurement items in different test or measurement facilities *(laboratories)* with different operators using different equipments.
[ISO 3534-2: 2006, §3.3.11]

Repeatability standard deviation:
Standard deviation of test results or measurement results obtained under repeatability conditions.

NOTE 1: It is a measure of the dispersion of the distribution of test or measurement results under repeatability conditions.
[ISO 3534-2: 2006, §3.3.7]

Reproducibility standard deviation:
Standard deviation of test results or measurement results obtained under reproducibility conditions.

NOTE 1: It is a measure of the dispersion of the distribution of test or measurement results under reproducibility conditions.
[ISO 3534-2: 2006, §3.3.12]

Expanded uncertainty:
Quantity defining an interval about the result of a measurement that can be expected to encompass a large fraction (95% in this programme) of the distribution of values that could reasonably be attributed to the measurand.
[ISO 3534-2: 2006, §3.4.8]

Outlier:
A member of a set of values which is inconsistent with the other members of that set.
[ISO 5725-1: 1994, §3.21]

Weighted mean:

The formula is: $\dfrac{\sum_{i=1}^{N} n_i \times mean_i}{\sum_{i=1}^{N} n_i}$ where n_i is the number of results of the i^{th} laboratory.

Confidence interval of a mean value:
Interval estimator (T_0, T_1) for the parameter θ with the statistics T0 and T1 as interval limits and for which it holds that the probability $P[T_0 < \theta < T_1] \geq 1 - \alpha$.
[ISO 3534-1: 2006, §1.28]

In this report it is determined so that $P[mean - CI < \theta < mean + CI] \geq 0.95$ where:

$$CI = \frac{2\sigma}{\sqrt{number\_of\_tests}}.$$

A test of means equality may be done by comparing the associated means confidence intervals.
When the confidence intervals are disjointed, it can be concluded that there is not equality of the means (one of the mean value is actually higher or lower than the other).
Otherwise a further calculation is needed to conclude.

2. Expanded Uncertainty Calculation

The following calculations are valid in the case that the number of tests for each lab is equal (balanced data). Otherwise an iterative calculation is needed and cannot be simply explained. The calculations in that case are done with a software.

Mathematical Model Used:

$y_{i,j} = \mu + L_i + \varepsilon_{i,j}$. (A) where:

i: index of the lab number from 1 to I
j: index of number of tests in each lab from 1 to J

- μ, general effect (estimated by the mean value)
- $y_{i,j}$, value of the studied characteristic of the j^{th} test of i^{th} lab
- L_i, laboratory factor effect due to i^{th} laboratory, presumed distributed according to a normal distribution with mean 0 and variance σ_L^2
- $\varepsilon_{i,j}$, residue of the j^{th} test of i^{th} lab, presumed distributed according to a normal distribution with mean 0 and variance σ_ε^2

(a) The variance of repeatability corresponds to the variance within laboratory $\sigma_r^2 = \sigma_\varepsilon^2$
(b) The variance of reproducibility is equal to the sum of the variance between laboratories and the variance within laboratory (variance of repeatability) $\sigma_R^2 = \sigma_L^2 + \sigma_r^2$
(c) The standard deviation of repeatability is equal to the square root of the variance of repeatability $\sigma_r = \sqrt{\sigma_r^2}$
(d) The standard deviation of reproducibility is equal to the square root of the variance of reproducibility $\sigma_R = \sqrt{\sigma_R^2}$
(e) The expanded uncertainty on the test result in conditions of repeatability, with a coverage probability of 95 %, is equal to $U_r = 2 * \sigma_r$
(f) The expanded uncertainty on the test result in conditions of reproducibility, with a coverage probability of 95 %, is equal to $U_R = 2 * \sigma_R$

Formulas

j[th] repetition (test) of the i[th] laboratory: $y_{i,j}$

Global mean of the test programme: $$\bar{\bar{y}} = \frac{\sum_{i=1}^{i=I}\sum_{j=1}^{J} y_{i,j}}{I * J}$$

Mean of the laboratory i: $$\bar{y}_i = \frac{\sum_{j=1}^{j=J} y_{i,j}}{J}$$

Variance of the laboratory i: $$\sigma_i^2 = \frac{\sum_{j=1}^{j=J}(y_{i,j} - \bar{y}_i)^2}{J-1}$$

Variance of repeatability: $$\sigma_r^2 = \frac{\sum_{i=1}^{I}(J-1) * \sigma_i^2}{I(J-1)}$$

Variance between laboratories: $$\sigma_L^2 = \frac{\sum_{i=1}^{I}(\bar{y}_i - \bar{\bar{y}})^2}{I-1} - \frac{\sigma_r^2}{J}$$

Variance of reproducibility: $$\sigma_R^2 = \sigma_L^2 + \sigma_r^2$$

Standard deviation of repeatability: $$\sigma_r = \sqrt{\sigma_r^2}$$

Standard deviation of reproducibility: $$\sigma_R = \sqrt{\sigma_R^2}$$

Expanded uncertainty (k=2) in conditions of repeatability: $U_r = 2 * \sigma_r$

Expanded uncertainty (k=2) in conditions of reproducibility: $U_R = 2 * \sigma_R$

3. Elimination by the contributions method (determination of the outliers)

Calculations of within and between laboratories contributions replace respectively Cochran and Grubbs tests detailed in the standard ISO 5725.
“Within laboratory” analysis is used to study the dispersion of the test results within a laboratory.
“Between laboratories” analysis is used to study the dispersion of laboratories test averages.

Notations :
I is the total number of laboratories,
n_i is the number of tests in the laboratory i,
$\bar{y}_i$ is the average of tests in the laboratory i,
$\bar{y}$ is the average of all tests on the whole of the laboratories.

<u>"Within laboratory" contributions</u>

If the dispersion of the tests were identical in I laboratories, each laboratory i would have a "within laboratory" relative contribution CD_i equal to $\frac{1}{I}\times 100$ called « control threshold » with:

$$D_i = \frac{1}{n_i}\sum_{k=1}^{n_i}(y_{i,k} - \overline{y_i})^2$$ (Standard deviation)

$$CD_i = \frac{D_i}{\sum_{i=1}^{I} D_i} * 100 .$$

<u>"Between laboratories" contributions</u>

If the throwing off centre were identical for the I laboratories, each laboratory i would have a "between laboratories" relative contribution CE_i equal to $\frac{1}{I}\times 100$ called « control threshold » with:

$$E_i = (\overline{y}_i - \overline{y})^2$$

$$CE_i = \frac{E_i}{\sum_{i=1}^{I} E_i} * 100 .$$

An "alert threshold" based on work knowledge is established, generally as a multiple of the control threshold. Laboratories are considered as outliers and are eliminated when their dispersion or throwing off centre is too important. In this programme, the alert threshold has been taken equal to $\frac{3}{I}\times 100$.

Annex 3 – Statistical Results

Results calculated with the data from all the laboratories

CO mg/km All labs	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	137.00	20.50 (15%)	23.12 (17%)	40.99 (30%)	46.23 (34%)
Vehicle 2	150.75	11.82 (8%)	25.69 (17%)	23.63 (16%)	51.38 (34%)
Vehicle 2 w/o reg effect	154.62	13.77 (9%)	26.30 (17%)	27.54 (18%)	52.60 (34%)
Vehicle 2 w reg effect	144.62	10.20 (7%)	24.43 (17%)	20.39 (14%)	48.87 (34%)

HC mg/km All labs	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	17.20	2.09 (12%)	2.59 (15%)	4.17 (24%)	5.18 (30%)
Vehicle 2	13.79	1.51 (11%)	2.63 (19%)	3.03 (22%)	5.25 (38%)
Vehicle 2 w/o reg effect	14.45	1.35 (9%)	2.62 (18%)	2.71 (19%)	5.23 (36%)
Vehicle 2 w reg effect	12.75	1.11 (9%)	2.20 (17%)	2.22 (17%)	4.40 (35%)

NOx mg/km All labs	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	185.53	11.13 (6.0%)	15.57 (8.4%)	22.27 (12.0%)	31.14 (16.8%)
Vehicle 2	178.96	8.38 (4.7%)	13.68 (7.6%)	16.77 (9.4%)	27.36 (15.3%)
Vehicle 2 w/o reg effect	180.23	9.56 (5.3%)	15.09 (8.4%)	19.12 (10.6%)	30.18 (16.7%)
Vehicle 2 w reg effect	176.95	6.75 (3.8%)	10.63 (6.0%)	13.50 (7.6%)	21.26 (12.0%)

CO2 g/km All labs	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	146.3	1.2 (0.8%)	3.2 (2.1%)	2.3 (1.5%)	6.4 (4.3%)
Vehicle 2	154.0	1.0 (0.6%)	2.5 (1.6%)	2.1 (1.4%)	5.0 (3.2%)
Vehicle 2 w/o reg effect	153.8	0.8 (0.5%)	2.2 (1.4%)	1.5 (1.0%)	4.4 (2.9%)
Vehicle 2 w reg effect	154.3	0.8 (0.5%)	3.1 (2.0%)	1.7 (1.1%)	6.3 (4.1%)

FC L/100km All labs	Mean	Standard deviation		Uncertainty	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	5.56	0.04 (0.7%)	0.12 (2.2%)	0.09 (1.6%)	0.24 (4.3%)
Vehicle 2	5.86	0.04 (0.7%)	0.09 (1.5%)	0.08 (1.4%)	0.19 (3.2%)
Vehicle 2 w/o reg effect	5.85	0.03 (0.5%)	0.08 (1.4%)	0.06 (1.0%)	0.17 (2.9%)
Vehicle 2 w reg effect	5.87	0.03 (0.5%)	0.12 (2.0%)	0.07 (1.2%)	0.23 (3.9%)

PM mg/km All labs	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	0.27	0.15 (56%)	0.27 (100%)	0.31 (115%)	0.54 (200%)
Vehicle 2	0.54	0.20 (37%)	0.27 (50%)	0.40 (74%)	0.53 (98%)
Vehicle 2 w/o reg effect	0.51	0.14 (27%)	0.23 (45%)	0.29 (57%)	0.46 (90%)
Vehicle 2 w reg effect	0.58	0.09 (16%)	0.34 (59%)	0.18 (31%)	0.68 (117%)
Background	0.27	0.18 (67%)	0.27 (100%)	0.35 (130%)	0.54 (200%)

PN #/km All labs	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	$1.11\ 10^{09}$	$6.6\ 10^{08}$ (59%)	$8.5\ 10^{08}$ (77%)	$1.3\ 10^{09}$ (117%)	$1.7\ 10^{09}$ (153%)
Vehicle 2	$1.07\ 10^{11}$	$8.5\ 10^{10}$ (79%)	$8.9\ 10^{10}$ (83%)	$1.7\ 10^{11}$ (159%)	$1.8\ 10^{11}$ (168%)
Vehicle 2 w/o reg effect	$5.40\ 10^{10}$	$2.4\ 10^{10}$ (44%)	$4.1\ 10^{10}$ (76%)	$4.8\ 10^{10}$ (89%)	$8.2\ 10^{10}$ (152%)
Vehicle 2 w reg effect	$1.87\ 10^{11}$	$2.8\ 10^{10}$ (15%)	$8.5\ 10^{10}$ (46%)	$5.6\ 10^{10}$ (30%)	$1.7\ 10^{11}$ (91%)
Background	$4.15\ 10^{08}$	$1.8\ 10^{08}$ (43%)	$4.5\ 10^{08}$ (108%)	$3.5\ 10^{08}$ (84%)	$9.0\ 10^{08}$ (217%)

Results calculated without the data from the outliers

CO mg/km w/o the outliers	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	132.43	18.29 (14%)	18.29 (14%)	36.57 (28%)	36.57 (28%)
Vehicle 2	141.82	6.86 (5%)	16.74 (12%)	13.72 (10%)	33.49 (24%)
Vehicle 2 w/o reg effect	143.02	5.97 (4%)	15.87 (11%)	11.95 (8%)	31.73 (22%)
Vehicle 2 w reg effect	139.74	8.18 (6%)	17.26 (12%)	16.36 (12%)	34.53 (25%)

HC mg/km w/o the outliers	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	16.75	1.83 (11%)	2.26 (13%)	3.66 (22%)	4.52 (27%)
Vehicle 2	13.14	1.28 (10%)	1.86 (14%)	2.56 (19%)	3.73 (28%)
Vehicle 2 w/o reg effect	13.58	0.99 (7%)	1.58 (12%)	1.97 (15%)	3.17 (23%)
Vehicle 2 w reg effect	12.65	0.98 (8%)	2.35 (19%)	1.96 (15%)	4.71 (37%)

NOx mg/km w/o the outliers	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	181.46	6.77 (3.7%)	7.92 (4.4%)	13.55 (7.5%)	15.84 (**8.7%**)
Vehicle 2	176.96	5.56 (3.1%)	11.01 (6.2%)	11.13 (6.3%)	22.02 (**12.4%**)
Vehicle 2 w/o reg effect	177.43	5.27 (3.0%)	11.27 (6.4%)	10.54 (5.9%)	22.54 (**12.7%**)
Vehicle 2 w reg effect	173.50	7.37 (4.2%)	7.37 (4.2%)	14.75 (8.5%)	14.75 (**8.5%**)

CO2 g/km w/o the outliers	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	146.2	0.9 (0.6%)	3.4 (2.3%)	1.9 (1.3%)	6.8 (**4.7%**)
Vehicle 2	153.7	0.8 (0.5%)	2.3 (1.5%)	1.6 (1.0%)	4.5 (**2.9%**)
Vehicle 2 w/o reg effect	153.0	0.4 (0.3%)	1.5 (1.0%)	0.9 (0.6%)	3.1 (**2.0%**)
Vehicle 2 w reg effect	153.8	0.7 (0.5%)	3.2 (2.1%)	1.4 (0.9%)	6.4 (**4.2%**)

FC L/100km w/o the outliers	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	5.56	0.04 (0.7%)	0.13 (2.3%)	0.07 (1.3%)	0.26 (**4.7%**)
Vehicle 2	5.85	0.03 (0.5%)	0.08 (1.4%)	0.06 (1.0%)	0.17 (**3.1%**)
Vehicle 2 w/o reg effect	5.82	0.02 (0.3%)	0.06 (1.0%)	0.03 (0.5%)	0.11 (**2.0%**)
Vehicle 2 w reg effect	5.85	0.03 (0.5%)	0.12 (2.1%)	0.06 (1.0%)	0.24 (**4.1%**)

PM (mg/km) w/o the outliers	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	0.21	0.14 (67%)	0.22 (105%)	0.27 (129%)	0.44 (**210%**)
Vehicle 2	0.49	0.16 (33%)	0.23 (47%)	0.33 (67%)	0.46 (**94%**)
Vehicle 2 w/o reg effect	0.51	0.14 (27%)	0.23 (45%)	0.29 (57%)	0.46 (**90%**)
Background	0.24	0.13 (54%)	0.27 (113%)	0.27 (113%)	0.54 (**225%**)

PN #/km w/o the outliers	Mean	Standard deviation		Uncertainty (2xσ)	
		σRepeat	σRepro	URepeat	**URepro**
Vehicle 1	$9.71\ 10^{08}$	$5.5\ 10^{08}$ (57%)	$7.1\ 10^{08}$ (73%)	$1.1\ 10^{09}$ (113%)	$1.4\ 10^{09}$ (**144%**)
Vehicle 2	$9.46\ 10^{10}$	$8.1\ 10^{10}$ (86%)	$8.1\ 10^{10}$ (86%)	$1.6\ 10^{11}$ (169%)	$1.6\ 10^{11}$ (**169%**)
Vehicle 2 w/o reg effect	$3.60\ 10^{10}$	$1.4\ 10^{10}$ (39%)	$1.4\ 10^{10}$ (39%)	$2.9\ 10^{10}$ (81%)	$2.9\ 10^{10}$ (**81%**)
Background	$3.52\ 10^{08}$	$1.3\ 10^{08}$ (40%)	$4.2\ 10^{08}$ (119%)	$2.6\ 10^{08}$ (74%)	$8.4\ 10^{08}$ (**239%**)

Annex 4 – PN Acquisitions

Vehicle 1 PN Traces

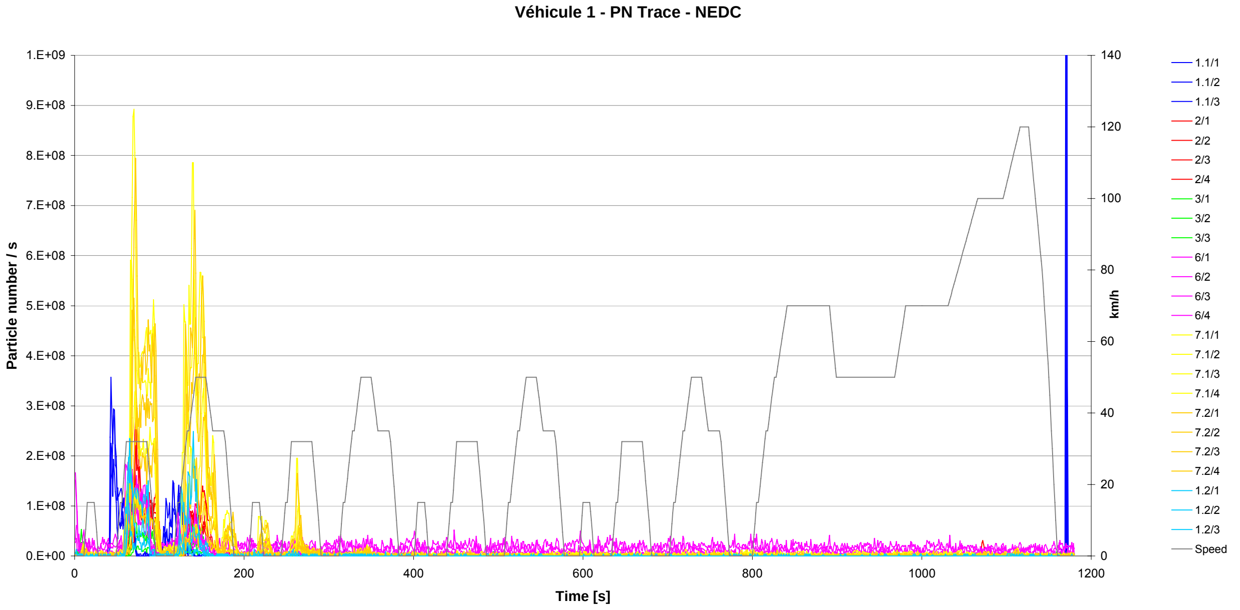


Figure A4. 1

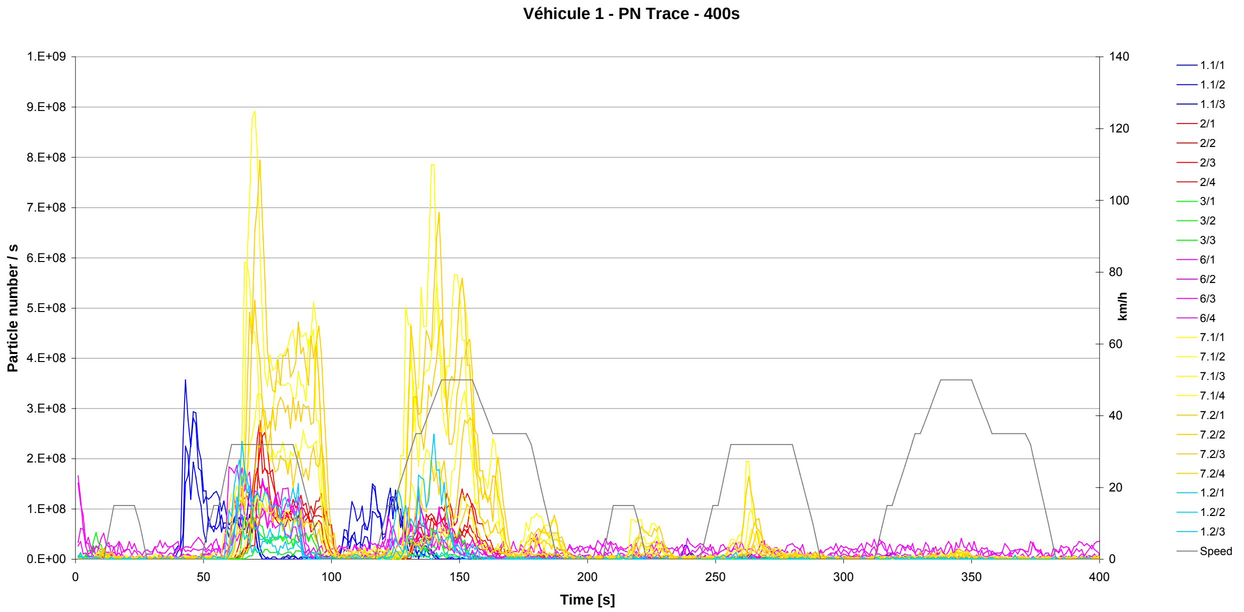


Figure A4. 2

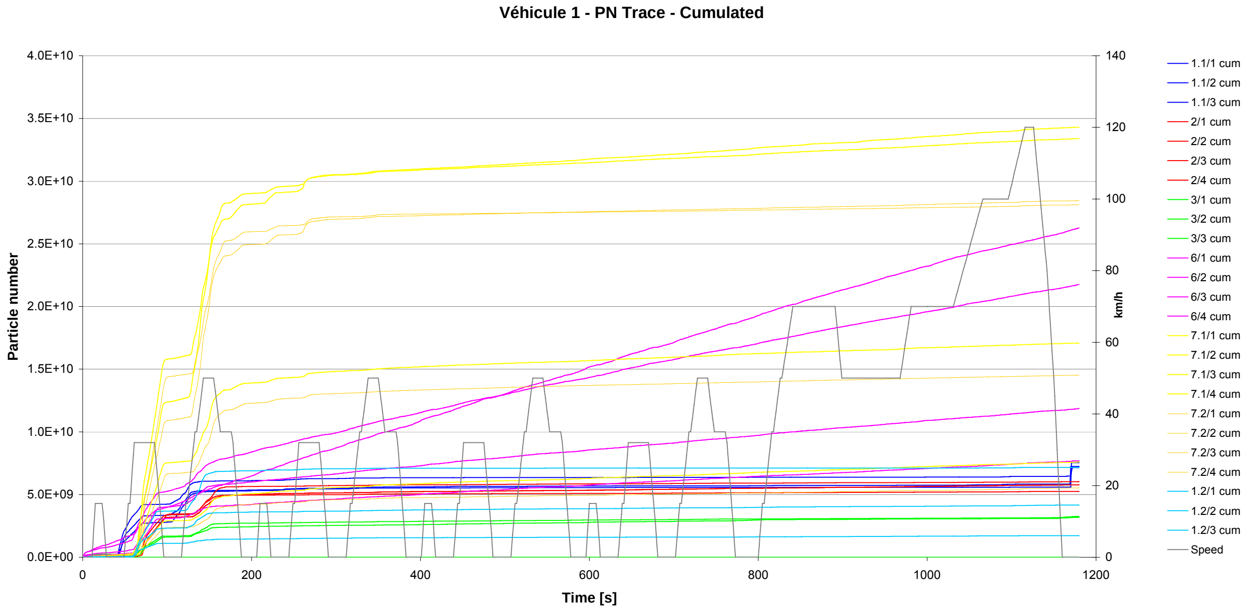

Véhicule 1 - PN Trace - Cumulated
Particle number
4.0E+10
3.5E+10
3.0E+10
2.5E+10
2.0E+10
1.5E+10
1.0E+10
5.0E+09
0.0E+00
0
200
400
600
800
1000
1200
Time [s]
140
120
100
80
60
40
20
0
km/h
1.1/1 cum
1.1/2 cum
1.1/3 cum
2/1 cum
2/2 cum
2/3 cum
2/4 cum
3/1 cum
3/2 cum
3/3 cum
6/1 cum
6/2 cum
6/3 cum
6/4 cum
7.1/1 cum
7.1/2 cum
7.1/3 cum
7.1/4 cum
7.2/1 cum
7.2/2 cum
7.2/3 cum
7.2/4 cum
1.2/1 cum
1.2/2 cum
1.2/3 cum
Speed

Figure A4. 3

Vehicle 2 PN Traces

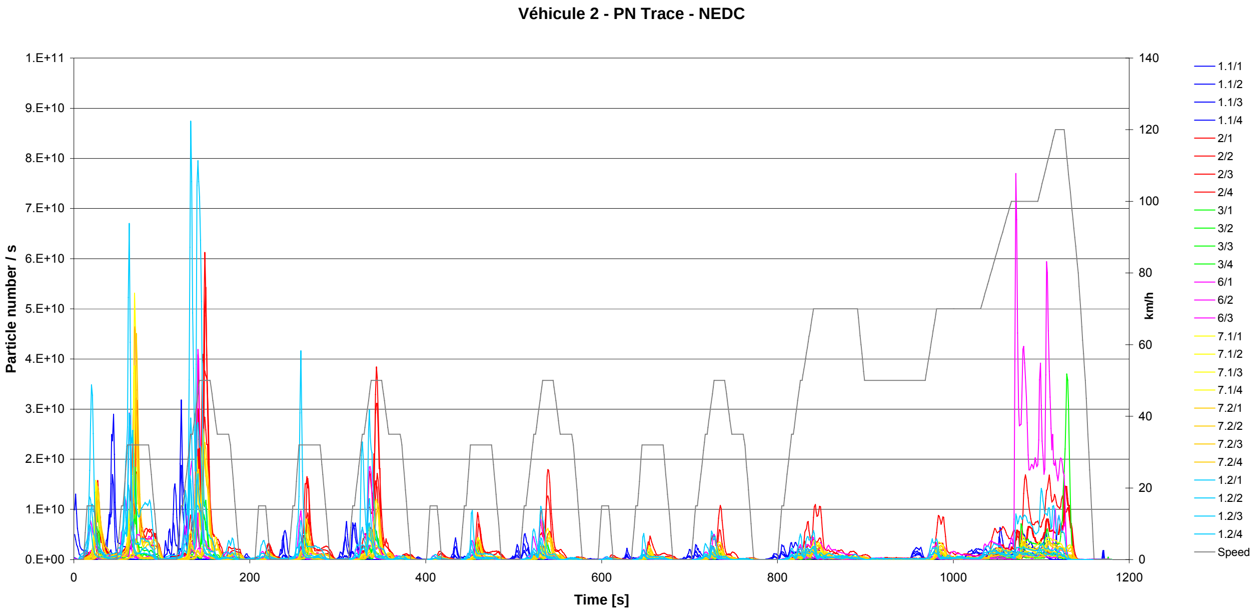


Figure A4. 4

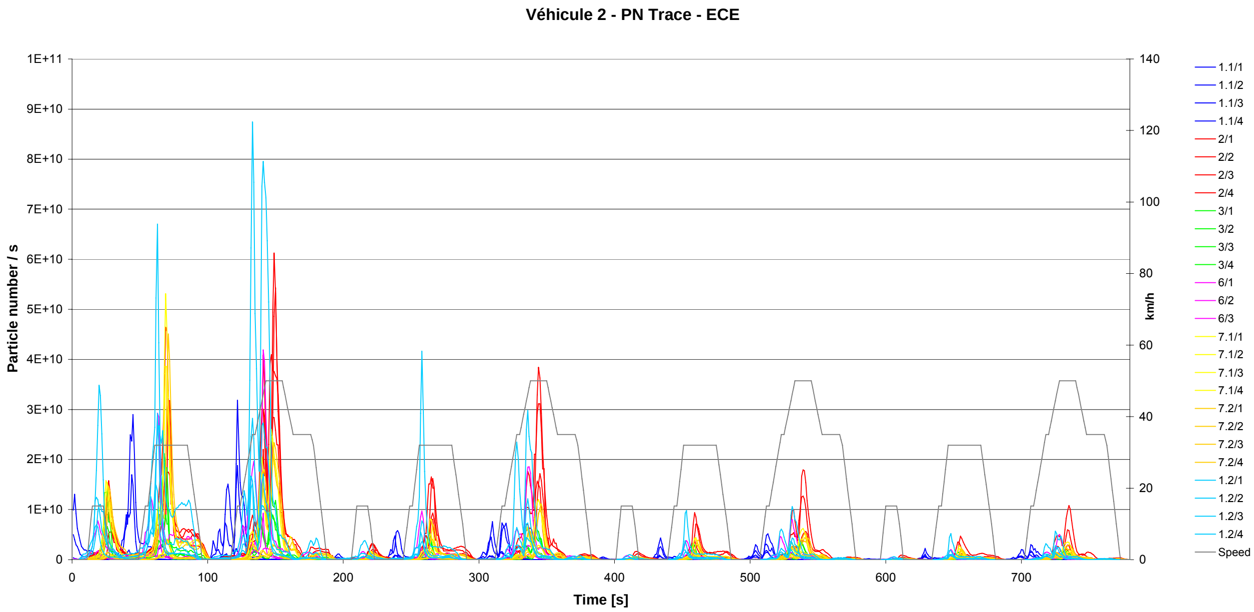


Figure A4. 5

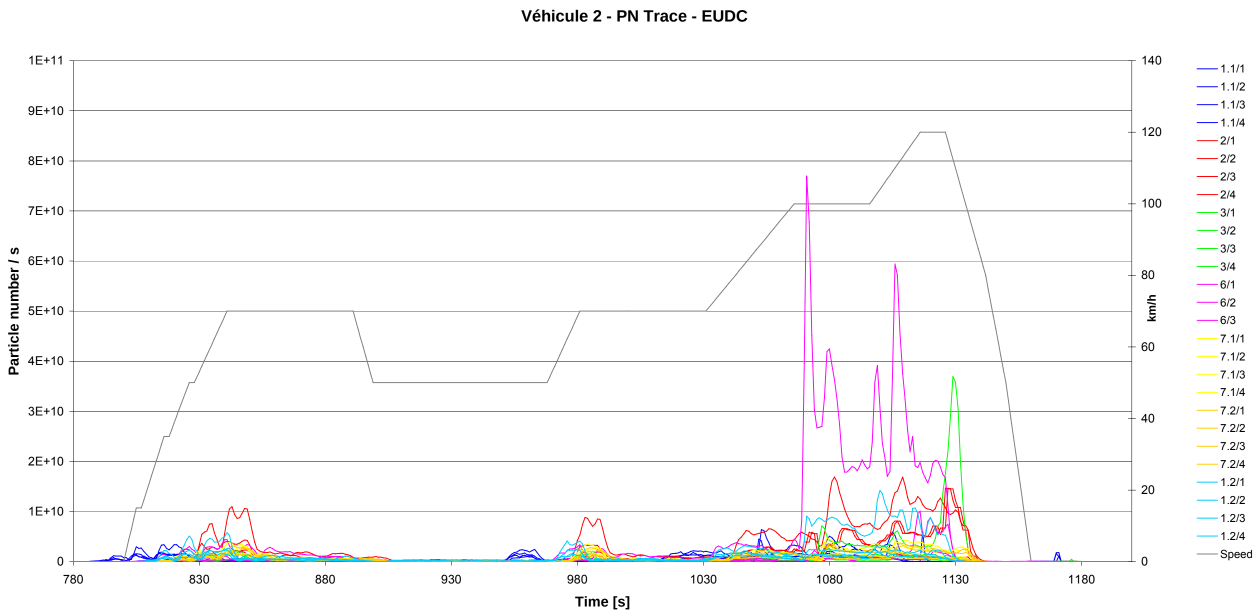


Figure A4. 6

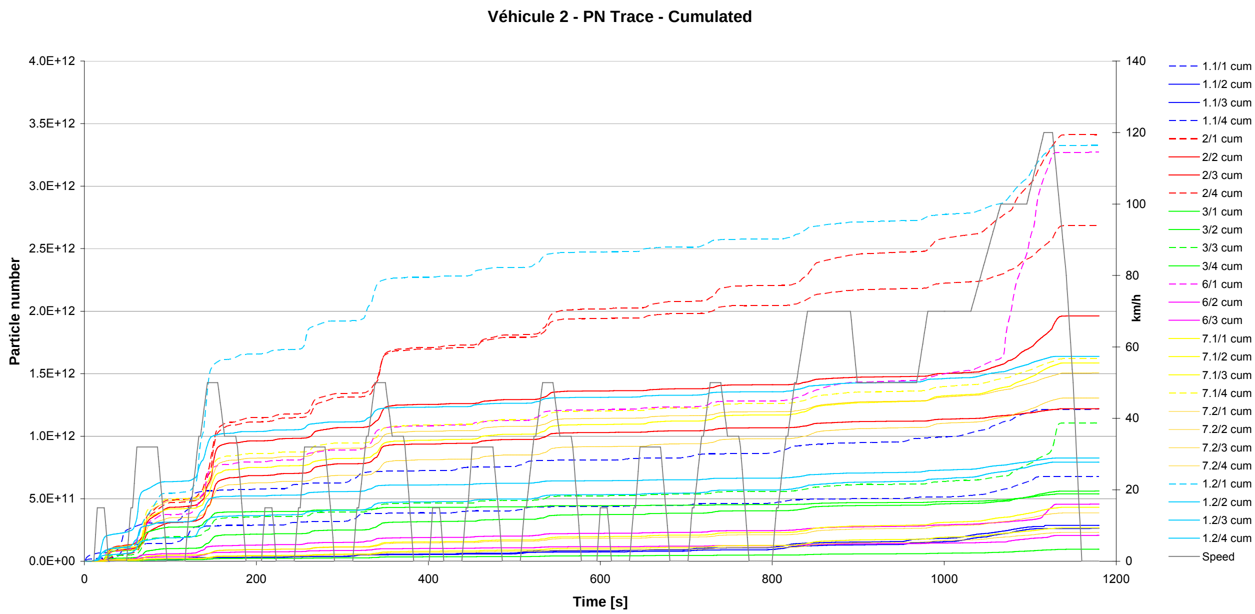


Figure A4. 7

Note: the ---- lines correspond to the tests following directly a forced regeneration

Background PN Traces

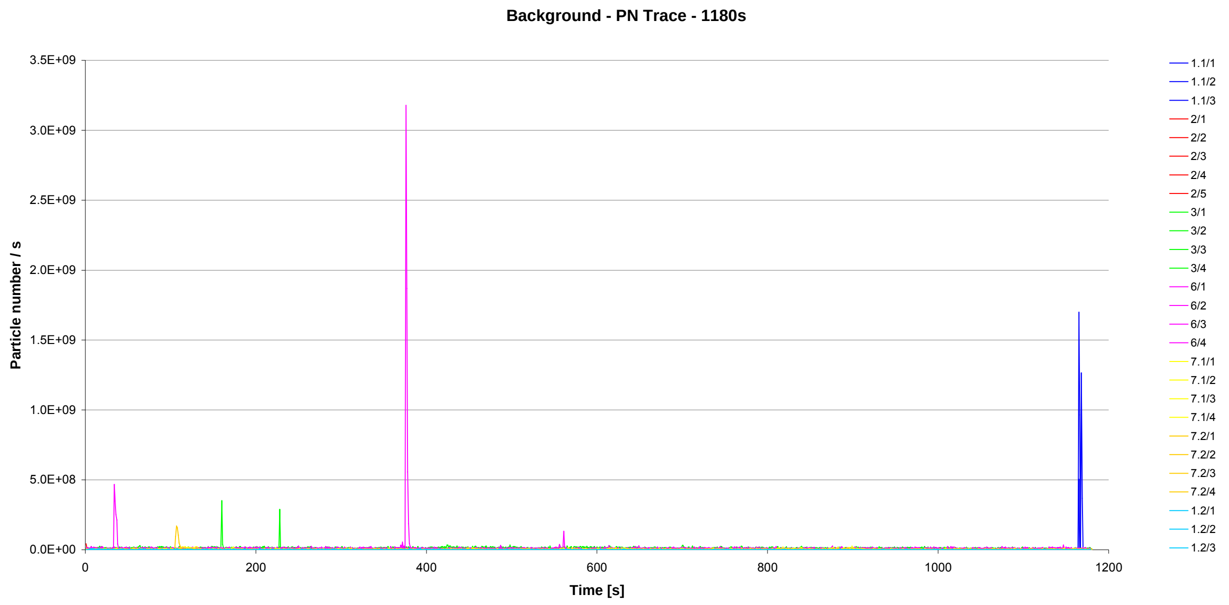


Figure A4. 8

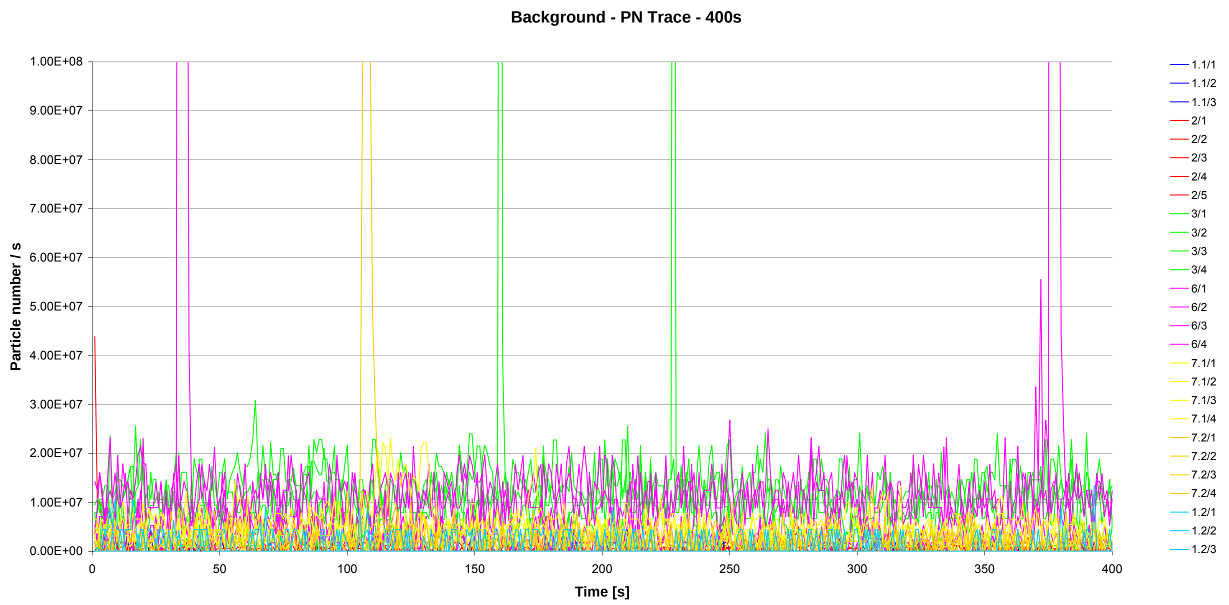


Figure A4. 9

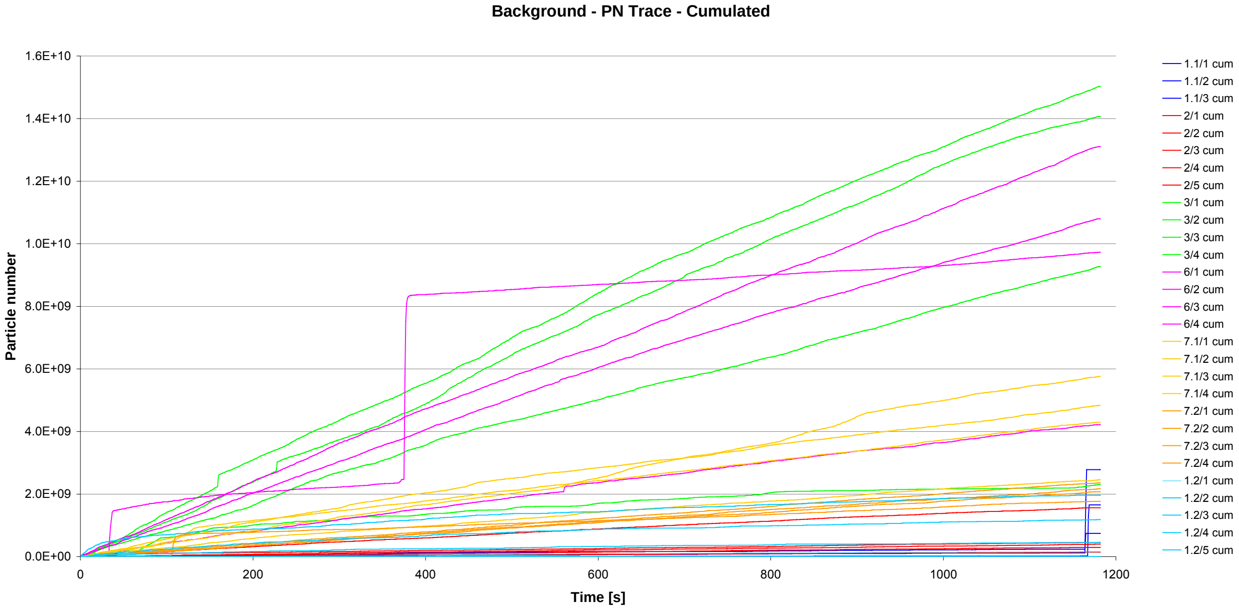

Background - PN Trace - Cumulated
Particle number
Time [s]
1.6E+10
1.4E+10
1.2E+10
1.0E+10
8.0E+09
6.0E+09
4.0E+09
2.0E+09
0.0E+00
0
200
400
600
800
1000
1200
1.1/1 cum
1.1/2 cum
1.1/3 cum
2/1 cum
2/2 cum
2/3 cum
2/4 cum
2/5 cum
3/1 cum
3/2 cum
3/3 cum
3/4 cum
6/1 cum
6/2 cum
6/3 cum
6/4 cum
7.1/1 cum
7.1/2 cum
7.1/3 cum
7.1/4 cum
7.2/1 cum
7.2/2 cum
7.2/3 cum
7.2/4 cum
1.2/1 cum
1.2/2 cum
1.2/3 cum
1.2/4 cum
1.2/5 cum

Figure A4. 10

Annex 5 – PN Equipment Description

Particle Number Emissions Measurement Equipment

		Laboratory N°	1	2	3	4	5	6	7.1	7.2
		PN equipment supplier	Horiba SPCS	Counter 489	Counter 489	Horiba SPCS	Counter 489	HORIBA SPCS	Counter 489	ECOMESURE
		Date of purchase	2007	2008	Dec 2008		sept-08	2009	2009	2009
		PNC make & type	TSI	TSI 3790	TSI 3790	TSI	TSI	TSI	TSI	GRIMM
		VPR make & type	HORIBA	AVL	AVL	HORIBA	AVL	HORIBA	AVL	DEKATI
R83 §	R83 Requirements									
1.1.2. & 1.4.3.	Size pre-classifier	cyclone, impactor, etc recommended	cyclone	chinese hat probe	chinese hat probe	cyclone	EURO Norm Sampling probe	cyclone	chinese hat probe	chinese hat probe
1.2.3.	All parts which are in contact with aerosol	electrically conductive material	Stainless steel and tygon	stainless steel and tygon	stainless steel and tygon	Stainless steel and tygon	Resistance of tubing in the range of 100 OHM, all other materials in contact with aerosol are stainless steel	Stainless steel and tygon	stainless steel and tygon	stainless steel and tygon
1.2.1. & 1.4.2.	PTS properties	inner diameter ≥8 mm, Re<1700, t≤3 s	10.7 mm ID, Re No. 1200-1800,	8 mm ID, Re No. 900 t=0.03 s	8 mm ID, Re No. 900 t=0.03 s	10.7 mm ID, Re No. 1200-1800,	ID 8mm, Re <1500, t<0.5s	10.7 mm ID, Re No. 1200-1800,	8 mm ID, Re No. 900 t=0.03 s	8 mm, Re=94
1.3.3.2. & 1.4.4.1.	T of PND1	T=150 - 400 °C	T=150°C ± 10°C	150°C +/- 10°C	150°C +/- 10°C	T=150°C ± 10°C	150°C +/- 5°C	T=150°C ± 10°C	150°C +/- 10°C	150°C +/- 10°C
1.3.3.2. & 1.4.4.1.	PND1 dilution factor	DF = 10 - 200	DF = 10 - 700	DF = 10 - 1000	DF = 10 - 200	DF = 10 - 700	10-1000	DF = 10 - 700	DF = 10 - 200	DF = 10
1.4.4.3.	PND2 dilution	single DF within 10-30	DF = 10 - 50	DF = 1, 10, 15, 20	DF = 11	DF = 10 - 50	10,15,20	DF = 10 - 50	DF = 10	DF = 10 3td dilution DF=1-20
1.3.3.4. & 1.4.4. & 2.2.3.	Evaporator particle reduction	>99% for 30 nm tetracontane particles at >10'000 cm^{-3}, full range of dil. Settings	>99% for 30 nm tetracontane particles at >10'000 cm^{-3}	>99% for 30 nm tetracontane particles at >10'000 cm^{-3}	>99% for 30 nm tetracontane particles at >10'000 cm^{-3}	>99% for 30 nm tetracontane particles at >10'000 cm^{-3}	99,9% for tetracontane particles >30nm at > 10000 1/cm³	>99% for 30 nm tetracontane particles at >10'000 cm^{-3}	>99% for 30 nm tetracontane particles at >10'000 cm^{-3}	>99% for 30 nm tetracontane particles at >10'000 cm^{-3}
1.4.4.2.	T of evaporation tube	T=300-400 °C	T=350°C ± 20°C	T=350°C ± 10°C	T=350°C ± 10°C	T=350°C ± 20°C	T=350°C	T=350°C ± 20°C	T=350°C ± 10°C	T=400°C
1.2.1. & 1.4.2.	OT properties	inner diameter ≥4 mm, residence time ≤0.8 s, equivalent penetration (30 nm) acceptable	4.35mm ID, flow 1L/min±0.5L/min	4.0mm ID, flow 1-5 L/min, t=0,3 s	4.0mm ID, flow 1-5 L/min, t <0.8s	4.35mm ID, flow 1L/min±0.5L/min	ID 5mm, residence time <0.5s	4.35mm ID, flow 1L/min±0.5L/min	4.0mm ID, flow 1-5 L/min, t <0.8s	4 mm, residence time ≤0.8 s
1.3.3.1. & 1.4.4.3.	Conditions at particle number counter	T<35 °C, number conc. < upper limit	T= 10°C- 35°C	T= <35 °C	T= <35 °C	T= 10°C- 35°C	T<35°C	T= 10°C- 35°C	T= <35 °C	T= <35 °C
1.3.4.2.	PNC counting accuracy	±10% for 1 cm^{-3} to upper limit, <100 cm^{-3} averaging over extended periods	For conc.<100 cm-3 a 6sec rolling sample is used	±10% for 1 cm^{-3} to upper limit, <100 cm^{-3} averaging over extended periods	±10% for 1 cm^{-3} to upper limit, <100 cm^{-3} averaging over extended periods	For conc.<100 cm-3 a 6sec rolling sample is used	±7% for 1 cm^{-3} to upper limit, <100 cm^{-3} averaging over 1s	For conc.<100 cm-3 a 6sec rolling sample is used	±10% for 1 cm^{-3} to upper limit, <100 cm^{-3} averaging over extended periods	±10% for 1 cm^{-3} to upper limit, <100 cm^{-3} averaging over extended periods
1.3.4.3.	PNC readability	0.1 cm^{-3} below 100 cm^{-3}	0.1 cm^{-3} below 100 cm^{-3}	0.1 cm^{-3} below 100 cm^{-3}	0.1 cm^{-3} below 100 cm^{-3}	0.1 cm^{-3} below 100 cm^{-3}	0.06 cm^{-3} below 100 cm^{-3}	0.1 cm^{-3} below 100 cm^{-3}	0.1 cm^{-3} below 100 cm^{-3}	0.1 cm^{-3} below 100 cm^{-3}
1.3.4.8.	PNC counting efficiency	50%(±12%) at 23(±1) nm, [>90% at 41(±1) nm]	50%(±12%) at 23nm, >90% at 41nm	50%(±12%) at 23(±1) nm, >90% at 41(±1) nm	50%(±12%) at 23(±1) nm, >90% at 41(±1) nm	50%(±12%) at 23nm, >90% at 41nm	53,4% at 23(±1) nm, 92,6% at 41(±1) nm prior to k-factor adjustment	50%(±12%) at 23nm, >90% at 41nm	50%(±12%) at 23(±1) nm, >90% at 41(±1) nm	54% at 23(±1) nm, 97% at 41(±1) nm
1.3.4.4. & 2.1.3.	PNC response linearity / calibration (electrometer or transfer standard)	between 0 and 10000 cm^{-3}, 6 points, conc. within +/-10%, R^2>0.97	7 points between 0 and 48,000 cm^{-3}, within +/- 10% of the reference PNC, R²>0.97	5 points between 2000 and 9000 cm^{-3} within +/- 10% of the reference PNC, R^2>0.999, k=0.95	5 points between 2000 and 11000 cm^{-3} within +/- 10% of the reference PNC, R^2>0.999, k=0.94	7 points between 0 and 48,000 cm^{-3}, within +/- 10% of the reference PNC, R²>0.97	between 0 and 50000 cm^{-3}, 6 points, conc. within +/-10%, R^2>0.97	7 points between 0 and 48,000 cm^{-3}, within +/- 10% of the reference PNC, R²>0.97	5 points between 2000 and 11000 cm^{-3} within +/- 10% of the reference PNC, R^2>0.999, k=0.92	8 points between 0 and 12000 cm^{-3} within +/- 10% of the reference PNC, R^2=0.998, k=0.98
1.3.4.5.	Data reporting frequency	better or equal 0.5 Hz	10 Hz	1 Hz	1 Hz	1 Hz	2Hz	1 Hz	1 Hz	1 Hz
1.3.4.6.	T90 response time	<5 s	3-15 s (adjustable by moving average function)	<3 s	<3 s	3-15 s (adjustable by moving average function)	<3s	3-15 s (adjustable by moving average function)		<3 s
1.3.4.7.	Coincidence correction	<10%	7-8%	<10%	<10%	7-8%	<10% at 50000^cm-3	7-8%	<10%	<10%
1.3.5. & 1.4.1	Residence time PTS+VPR+OT plus T90(PNC)	<=20 s	<20 s	<20 s	<20 s	<20 s	<5s	<20 s	<20 s	<20 s
2.4.2. & 2.4.3.	Zero check	<0.5 cm^{-3} for entire system with HEPA filter	<0.5 cm^{-3}	<0.5 cm^{-3}	<0.5 cm^{-3}	<0.5 cm^{-3}	0.01 cm^{-3} at fr = 100 for entire system with HEPA filter	<0.5 cm^{-3}	<0.5 cm^{-3}	<0.5 cm^{-3}
1.3.3.3. & 1.4.4. & 2.2.2.	Particle concentration reduction factor fr	fr(30nm)=fr(100nm) +30/-5%; fr(50nm)=fr(100nm) +20/-5%	new calibration according to new procedure	fr(30nm)=fr(100nm) +30/-5%; fr(50nm)=fr(100nm) +20/-5% Aerosol Material used: CAST + removal of	fr(30nm)=fr(100nm) +30/-5%; fr(50nm)=fr(100nm) +20/-5% Aerosol Material used: CAST + removal of	expressed in terms of penetration efficiencies (as per old R83 doc.) 30nm- 50% 50nm- 55% 100nm- 60%	fr(30nm)=fr(100nm) +8%; fr(50nm)=fr(100nm) +6%	new calibration according to new procedure		fr(30nm)=fr(100nm) +30/-5%; fr(50nm)=fr(100nm) +20/-5%

Status S / V = specified / verified: green (G) = okay, yellow (Y) = just outside or has to be redone with good chance to pass then

Annex 6 – Test Equipment Description

Item	Recommandation/Comment	R83§	692/2008 §	1.1	1.2	2	3	4
Test cell id				EP7	EP7	12	4	M
Dyno								BRUSH
Roller	1 or 2 rollers	Ap1 1.2.2		1		2	1	1
Inertia/force simulation	mechanical/electrical	Ap1 1.1.2		electrical		mechanical	electrical (do not use rotating mass	electrical
Force/Inertia verification	date/validation	Ap1 2.2		ok -once a year		basic daily check - every 3 months	oct-08	22/01/2008 / 15/04/2008
Vehicle connexion	silicon	Ap2 1.3.1		silicon		silicon	silicon	silicon
Blower								
Area	>0.2m2	3.4.2		Square 0.64X0.64		Circular diam=70 cm C=0.38m2	100x60	0.24
Hight lower edge	~0.2m	3.4.2		~0.2m		~0.2m	~0.2m	0.24m
Distance from front of vehicle	~0.3m	3.4.2		~0.3m		~0.3m	~0.3m	0.245
Maximum speed				Proportionnal - 120km/h at the entrance of the blower and ~95km/h at the exit		proportionnal - 70km/h at the entrance of the blower	Proportionnal - 120km/h	Proportionnal - 120km/h
CVS						Last maintenance 11/2008		
Make and type				Horiba 7200		Horiba 9500T PDP	AVL i60	HORIBA 7200
Air Filter Type	min HEPA H13	Ap2 1.3.2		H14		H14	H13	H14
Air filter efficiencies	>=99.95%	Ap2 1.3.2		ok		ok <3p/cm3 (measured with PNC)	ok	ok '99.997%
Number of gas phases	2			2		2	2	2
CVS flow rate at 20° (m3/min)				14.8		8.6	9	9
Analysers								
Make and type				Horiba 7500		PEUS system and ABB analysers (UV for Nox)	AVL i60	HORIBA 7200
CH4 : GC or cutter			Annex III 3.3	GC		cutter	cutter	GC
CH4 Response factor		Ap3 2.3		integrated in system 1.09 done every year		not integrated in calculation (response factor=1.127)	1.14	1.07
Zero/span/zero before gas analysis	yes	6.5.3.2 & Ap3 2.2		yes		yes	yes	Yes
Zero/span/zero after gas analysis	yes	6.5.3.6		yes		yes	yes	Yes
Pollutant calculation		6.6						
HC density	0.622	6.6.2	Annex III 3.4	real		0.622	0.622	0.617
FC calculation	(0.116/D)*(0.861xHC…)		Annex XII 3.3 e	ok		ok	ok	(0.1154/D)*(0.866xHC…)
Fuel density at 15°C	0.8337			0.8337		0.8340	0.8337	0.8337
PM								
Number of filters	1	6.2.6		1		1	1	1
Filter type	TX40	Ap4 1.3.3.4		TX40		TX40	TX40	TX40
PM sampling flow rate		Ap4 1.3.3.3		45L/min		25L/min	33L/min	42L/min
PM preclassifier	chinese hat / cyclone	Ap4 1.3.1.4		cyclone		chinese hat	chinese hat	chinese hat
Background correction		6.2.4		no		no	no	no
Background time	1180s			ok			ok	ok
Background flow rate	Same as CVS testing flow rate			ok except for 1st day		ok except for 1st day	ok	ok
Micro-balance resolution	1µg	Ap4 1.3.4.1		0.1µg		0.1µg but used w/ 1µg	0.1µg	0.1µg
Micro-balance deviation	2µg	Ap4 1.3.4.1		~1µg		ok	ok	0.25µg
Return of gaz in tunnel				no, volume not corrected				
Buoyancy correction	Yes	Ap4 1.3.4.2		yes		no	yes	Yes
PM backup filter	w or w/o	6.6.7		without		without	without	without
PN								
Date of last calibration VPR	6/12 months	Ap5 2.2.3		June 08 -Horiba	June 08 -Horiba	22/08/2008	bought in Dec 08	November 08
Date of last calibration PNC	12 months	Ap5 2.1.1		01/10/2008 -National Physics	April 09 (before testing)	15/10/2007	bought in Dec 08	November 08
Mass Flow meter	Every month/+-5% of the nominal PNC flow rate			01/09/2007 every year	April 09 (before testing)	15/10/2007	bought in Dec 08	02/11/2008
Preclassifier/chinese hat	chinese hat / cyclone	Ap4 1.1.2		Cyclone		chinese hat (same as PM, parrallel probe)	chines hat	cyclone (SPCS in-built)
PN probe lengh						85cm from exit of probe to PND1	2.5m	6m
PN probe location	,			next to PM		next to PM	next to PM	next to PM
Probe heated (to PND1)				yes		no	yes	yes
PND1				10		10	11	10
PND2				15		10	11	15
PN sampling flow rate				15L/min				
Return of extracted gaz in tunnel				no				
PN formula	N=(V.k.Cs.Fr.e3)/d)	6.6.8						
k				integrated in PNC raw count 1.0176	integrated in PNC raw count 1.0415	integrated in PNC raw count 1/0.96	integrated in PNC raw count	integrated in PNC raw count 1/0.9934
Coincidence				integrated in PNC raw count		integrated in PNC raw count	integrated in PNC raw count	integrated in PNC raw count
Fr				150)		real measured s per s ~100	real measured s per s ~121	real measured s per s ~150

Item	Recommandation/Comment	R83§	692/2008 §	5	6	7.1	7.2
Test cell id				34	9	PNR1	PNR1
Dyno							
Roller	1 or 2 rollers	Ap1 1.2.2		1 48" 4x4	1	2	
Inertia/force simulation	mechanical/electrical	Ap1 1.1.2		electrical	electrical	electrical	
Force/Inertia verification	date/validation	Ap1 2.2			13 Jan 09 - 14 Jul 09		
Vehicle connexion	silicon	Ap2 1.3.1		silicon	silicon	silicon	
Blower							
Area	>0.2m2	3.4.2		0.294 rectangular	>0.2m2	0.21	
Hight lower edge	~0.2m	3.4.2		~0.2m	~0.2m	24	
Distance from front of vehicle	~0.3m	3.4.2		~0.3m	~0.3m	~30	
Maximum speed				Proportionnal - 120km/h	fixed - 32 m/s	Proportionnal - 110km/h	
CVS							
Make and type				Pierburg 4000	Horiba - CVS-7100	HORIBA 9300T	
Air Filter Type	min HEPA H13	Ap2 1.3.2		H13	H13	H13	
Air filter efficiencies	>=99.95%	Ap2 1.3.2		yes	OK	ok	
Number of gas phases	2			2	2	1	
CVS flow rate at 20° (m3/min)				4.4 ECE and 9 EUDC	9	12	
Analysers							
Make and type				Pierburg 4000	Horiba	HORIBA 9400	
CH4 : GC or cutter			Annex III 3.3	cutter	GC	Cutter	
CH4 Response factor		Ap3 2.3		yes, used for calculation?	1.074	-	
Zero/span/zero before gas analysis	yes	6.5.3.2 & Ap3 2.2		yes	Yes	yes	
Zero/span/zero after gas analysis	yes	6.5.3.6		yes	Yes	yes	
Pollutant calculation		6.6					
HC density	0.622	6.6.2	Annex III 3.4	0.622	0.622	0.622	
FC calculation	(0.116/D)*(0.861xHC…)		Annex XII 3.3 e	ok	ok	ok	
Fuel density at 15°C	0.8337			0.8335	0.8337	0.834	
PM							
Number of filters	1	6.2.6		1	1	1	
Filter type	TX40	Ap4 1.3.3.4		TX40	TX40	TX40	
PM sampling flow rate		Ap4 1.3.3.3		40L/min	48 L/min	47	
PM preclassifier	chinese hat / cyclone	Ap4 1.3.1.4		chinese hat	chinese hat	chinise hat	
Background correction		6.2.4		no	no	no	
Background time	1180s			ok	ok	1180	
Background flow rate	Same as CVS testing flow rate			ok	ok	ok	
Micro-balance resolution	1µg	Ap4 1.3.4.1		1µg	1µg	2µg	
Micro-balance deviation	2µg	Ap4 1.3.4.1		ok	2µg	ok	
Return of gaz in tunnel				no, volume corrected		no, volume corrected	
Buoyancy correction	Yes	Ap4 1.3.4.2		no	No	no	
PM backup filter	w or w/o	6.6.7		without	with	with	
PN							
Date of last calibration VPR	6/12 months	Ap5 2.2.3			18 February 2009	31/03/2008	January 09
Date of last calibration PNC	12 months	Ap5 2.1.1			18 February 2009	27/03/2008	January 09
Mass Flow meter	Every month/+-5% of the nominal PNC flow rate				18 February 2009	27/03/2008	January 09
Preclassifier/chinese hat	chinese hat / cyclone	Ap4 1.1.2		chinese hat	cyclone	chinise hat	chinese hat+cyclone
PN probe lengh				30 cm inox	4 m	30 cm inox	~2m
PN probe location	,			next to PM	see picture	next to PM	next to PM
Probe heated (to PND1)				no	yes	no	yes
PND1				25	10	10	10
PND2				10	15	10	10x1.05
PN sampling flow rate				1 L/min		5L/min	5.3L/min
Return of extracted gaz in tunnel				no		no	no
PN formula	N=(V.k.Cs.Fr.e3)/d)	6.6.8					
k				not integrated in PNC raw count 1/0.9302	not integrated in PNC raw count 1/0.991	integrated in PNC raw count 1/0.915	integrated in PNC raw count 1.0181
Coincidence				integrated in PNC raw count	integrated in PNC raw count	integrated in PNC raw count	integrated in PNC raw count
Fr				real measured s per s ~250	150)	real measured s per s ~100	105)

Annex 7 – Fuel Analysis Certificate

Haltermann PRODUCTS

CERTIFICATE OF ANALYSIS

Diesel, EU V Draft Certification Fuel

Batch-No.:	Tank:	GMID:	Date of Analysis:
5 - WG30613AX8	916	283507	7/30/2008

Feature	Units	Result	Limits Minimum	Limits Maximum	Method
Cetane Number (CFR) (tested by subcontractor)	-	52.4	52.0	54.0	EN ISO 5165
Density @ 15degC	kg/m3	833.7	833.0	837.0	EN ISO 12185
Specific Gravity @	kg/L	834.5	----	----	EN ISO 12185
Distillation IBP	degC	209.1	----	----	EN ISO 3405
Dist. 50% v/v	degC	277.9	245.0	----	EN ISO 3405
Dist. 95% v/v	degC	345.1	345.0	350.0	EN ISO 3405
Distillation FBP	degC	356.5	----	370.0	EN ISO 3405
Flash Point	degC	89	55	----	EN ISO 2719
CFPP	degC	-21	----	-5	EN 116
Viscosity @ 40degC	mm2/s	2.937	2.300	3.300	EN ISO 3104
Aromatics, Poly (2+	% wt	4.5	2.0	6.0	EN 12916
Aromatics, Total	% wt	22.7	----	----	EN 12916
Aromatics, Mono	% wt	18.2	----	----	EN 12916
Aromatics, Di	% wt	4.3	----	----	EN 12916
Aromatics, Tri+	% wt	0.2	----	----	EN 12916
Sulfur	mg/kg	< 3,0	----	10.0	EN ISO 20846
Corrosion - Copper		1A		1	EN ISO 2160
Carbon Residue 10% Dist. Residue	% wt	< 0,01	----	0.20	EN ISO 10370
Ash Content (tested by subcontractor)	% wt	< 0,001	----	0.010	EN ISO 6245
Water	mg/kg	40	----	200	EN ISO 12937
Strong Acid Number	mg KOH/g	< 0,02	----	0.02	ASTM D974
Oxidation Stability (tested by subcontractor)	g/m3	< 1	----	25	EN ISO 12205
Oxidation Stability (modified; not accredited)	h	71	20	----	EN 14112
HFRR (wsd 1,4)	micron	197	----	400	EN ISO 12156-1
FAME	% vol	5.3	4.5	5.5	EN 14078
Oxygen Content (calculated)	% wt	0.7	----	----	EN 14078
Carbon (modified)	% wt	86	----	----	ASTM D3343
Hydrogen (modified)	% wt	13.44	----	----	ASTM D3343
C:H Ratio (H=1) (modified)	-	6.39	----	----	ASTM D3343
H:C Ratio (C=1) (modified)	-	0.156	----	----	ASTM D3343
Net Heating Value (modified)	MJ/kg	42.935	----	----	ASTM D3338
Net Heating Value (modified)	Btu/lb	18,457	----	----	ASTM D3338

Haltermann Products, Werk Hamburg,
Zweigniederlassung der DOW Olefinverbund GmbH
- Labor - Christine Behrens

DIN EN ISO/IEC 17025
DAR
Registriernummer: DAC-PL-416-05-40

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