PROGRESS IN THE PARTICLE MEASUREMENT PROGRAMME (PMP) INTER-LABORATORY EXERCISES FOR HEAVY-DUTY ENGINES

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The PMP is an inter-governmental research programme conducted under the auspices of UNECE GRPE to develop new vehicle exhaust particle measurement procedures for regulatory use. The PMP was inaugurated due to health concerns over nanoparticles and concerns over the ability of the current particulate mass measurement method to enable the forced adoption of technologies which effectively control their emissions. The PMP mandate was to develop techniques to replace or complement the particulate mass measurement method that must be applicable to Light Duty Vehicle & Heavy Duty Engine type approval testing. A further objective was to provide data on the performance of different vehicle technologies according to the new measurement procedures.

The PMP has proceeded in 3 phases:

- Phase I (2001-2) developed protocols for examining different candidate measurement systems.
- Phase II (2002-3) evaluated a range of measurement techniques and sample conditioning systems.
- Phase III (2004-) is validating the recommended measurement techniques via inter laboratory test programmes.

The validation exercise for light duty testing completed in 2006 and reported in 2007[1]. Recommendations from Phase II included:

- A revised PM method developed for DPF equipped vehicles and engines featuring a single PM filter from the entire transient cycle, controlled face velocity sampling, a defined filter medium, several changes to the weighing procedure and environment plus recommendations for improved quality of measurements.
- A new method for quantifying particle numbers which defines the 'non-volatile' particle according to its size and volatility by the measurement procedure. The measurement systems employs filtration to limit the inclusion of background particles, evaporation and dilution to eliminate volatile particles and a particle counter with specific counting efficiency at the inlet to quantify the particles while controlling those to be measured.

Results from the light-duty PMP inter-laboratory correlation exercise (PMP Phase 3) indicated that particulate mass emissions substantially below 5mg/km were achievable from Diesels equipped with a variety of DPFs. A mass limit of 4.5mg/km was selected for Euro 5.

A particle number limit of 6×10^{11}/km was selected for particle numbers.

Main conclusions of this work were:

- The particle number method proved more sensitive (>15x) and more accurate than mass
- DPF fill state and preconditioning proved to be major influences on repeatability
- Both mass and number are able to discriminate between DPF and non-DPF Diesels
- The mass method is unable to discriminate high and lower efficiency DPFs
- The majority of particle number measurement systems directly provide by laboratories correlated closely with the reference system circulated between labs.
- Number and mass measurement systems proved robust

[1] http://ies.jrc.cec.eu.int/fileadmin/Documentation/Reports/Emissions_and_Health/EUR_2006-2007/EUR_22775_EN.pdf

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Following completion of the light-duty inter-laboratory correlation exercise (ILCE_LD) of the Particle measurement programme (PMP), the focus has now moved to heavy-duty engines' testing.

The heavy-duty phase of the work comprises two parallel exercises: firstly, a validation exercise with two Golden Particle Measurement Systems (GPMS) and a Golden Engineer, and secondly a standard round-robin exercise in which labs use their own particle measurement systems. It is expected that complete particle number systems from Matter Engineering, AVL, Horiba and Dekati will be tested.

Each exercise will use a different Euro III compliant Diesel engine retrofitted with and oxidation catalyst and an uncatalysed wallflow DPF: an Iveco Cursor 8 in the validation exercise and a Mercedes OM 501 in the round-robin. Measurements of both particle mass and particle number will be made from full and partial flow dilution systems following the test protocol and procedures described in a guide book circulated to all labs.

The test matrix comprises cold-start WHTC and, following a 10 minute soak, a hot-start WHTC, WHSC ETC, and ESC testing. 8 repetitions of each cycle are planned.

First results are due soon from the round-robin testing, but in the validation exercise, testing has completed at the first two laboratories: JRC and AVL-MTC.

Preliminary results show good repeatability from the test engine of the validation exercise and PM emissions in the range 2mg to 5mg/kWh. Particle number emissions from the cold start WHTC cycle are ~5 x 10^{11}/kWh, but emissions from the following hot start cycle decreased by a factor of almost 100 – this reflects the cold vs hot NEDC effects seen in the light-duty validation exercise.

For both PM and particle numbers, good agreement is apparent between full and partial flow dilution system measurements.

Next steps in the programme include firstly, compilation of interim VE results including comparison of GPMS and Alternative Systems for Review in November 2008. These data will be analysed and used to prepare reports for the PMP Working Group in Geneva.

Further VE testing will be undertaken with an aim to complete in Summer 2009. Round Robin testing will continue until Summer 2010, with on-going data feeding into the regulatory process.

At the end of both exercises, final data analysis and reporting will be conducted and findings used to revise the draft regulatory document (R49). This will include consideration of the implications of differences between light and heavy-duty measurement system results.

Eventually, proposals to incorporate new measurement procedures in R49 will be submitted to GRPE and WP29 in Geneva followed by EC consideration in Brussels of revised R49 procedures as part of Euro VI requirements.

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Update on the UN-ECE GRPE Particle Measurement Programme – Summer 2008

Delivering Value Through Innovation & Technology

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Background to PMP

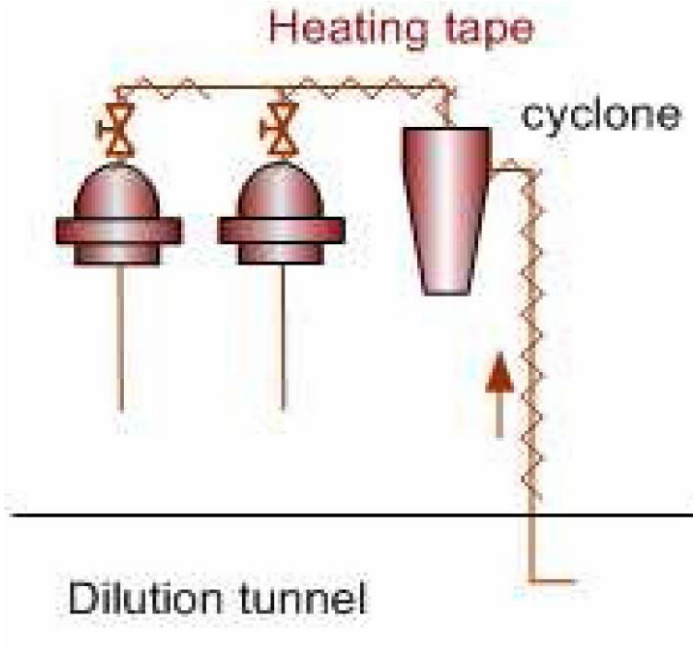
- Inter-governmental research programme under the auspices of UNECE GRPE to develop new vehicle exhaust particle measurement procedures for regulatory use
- Set up due to health concerns over nanoparticles…
- …and concerns over the ability of the current particulate mass measurement method to enable the forced adoption of technologies which effectively control their emissions
- Mandate was to develop techniques to replace or complement the particulate mass measurement method
  - must be applicable to Light Duty Vehicle & Heavy Duty Engine type approval testing
- PMP also to provide data on the performance of different vehicle technologies according to the new measurement procedures

PMP Phases

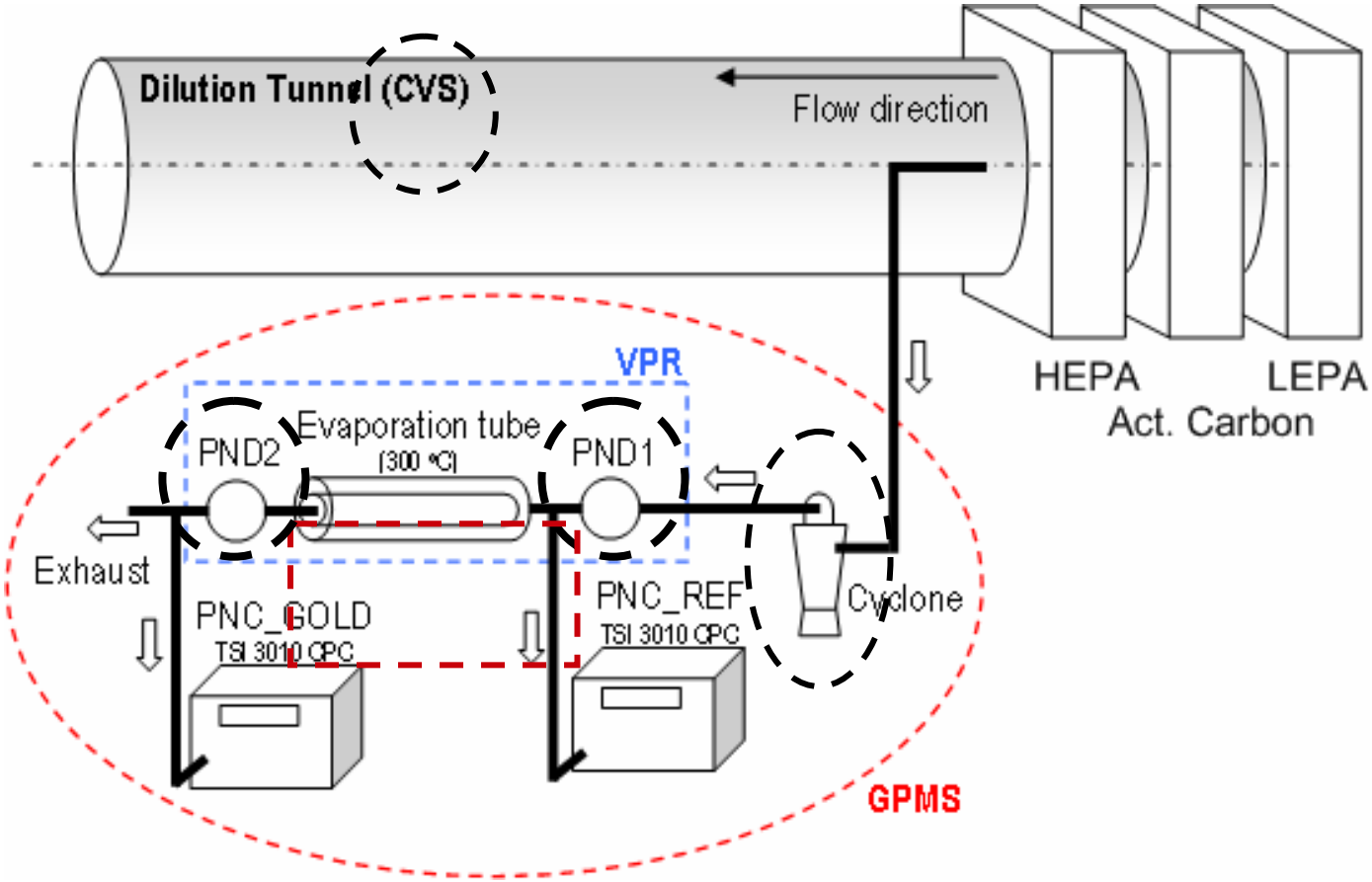
- Phase I (2001-2) developed protocols for examining different candidate measurement systems.
- Phase II (2002-3) evaluated a range of measurement techniques and sample conditioning systems.
- Phase III (2004-) is validating the recommended measurement techniques via inter laboratory test programmes.
- Validation for light duty testing completed in 2006 and reported in 2007.

PMP Phase II Recommendations – Improved Particulate Mass Measurement

- Improved dilution air filters
- Cyclone (2.5µm to 10µm cut-point)
- Sample to be held at 47°C +/- 5°C for >0.2s
- Filter face velocity (50cm/s to 80cm/s)
- Pallflex TX40 filters with no backup
  - One filter for whole NEDC
- Weighing
  - Static charge neutralisation
  - Buoyancy correction

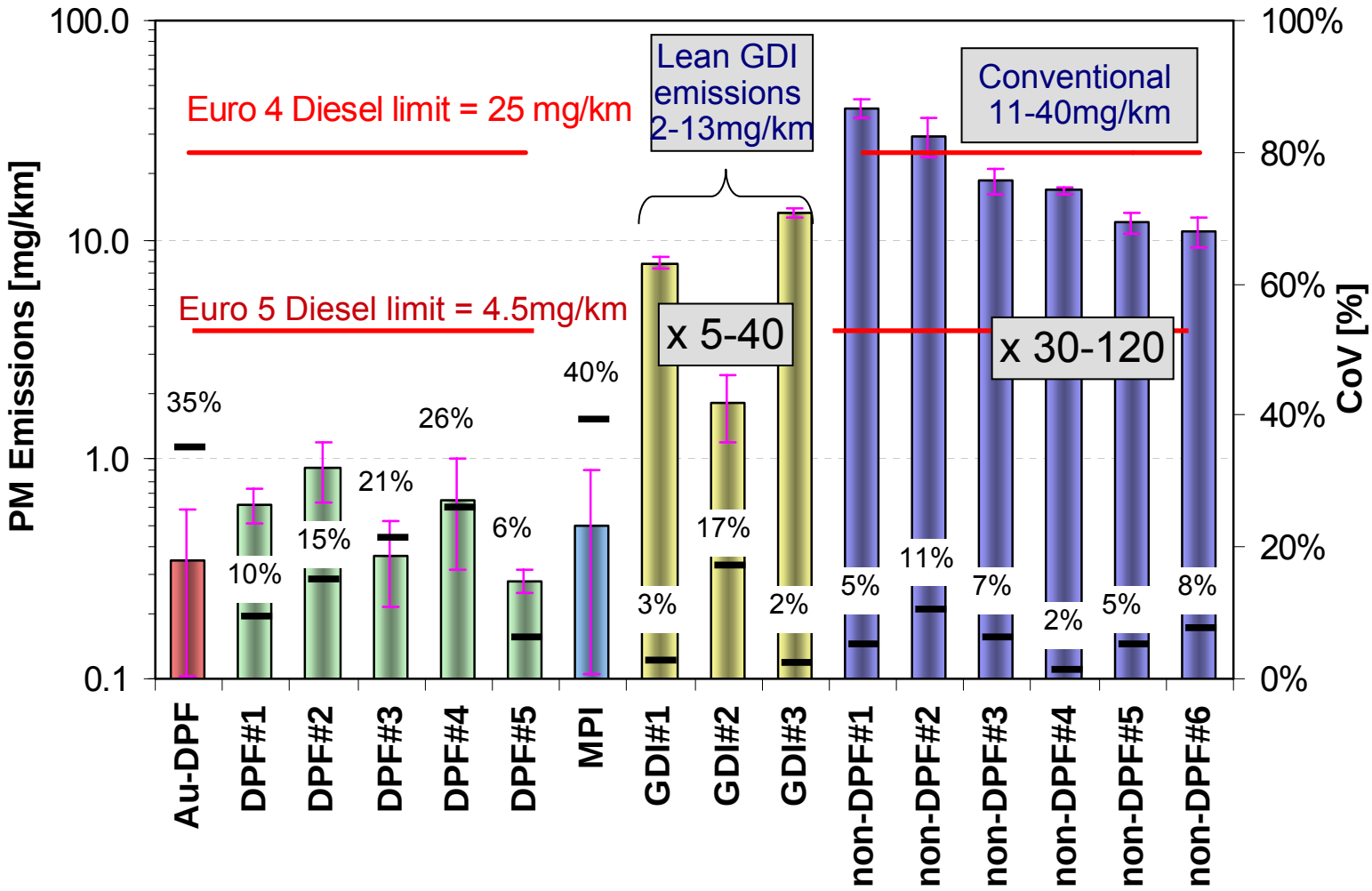


PMP Phase II Recommendations – Solid Particle Number Count



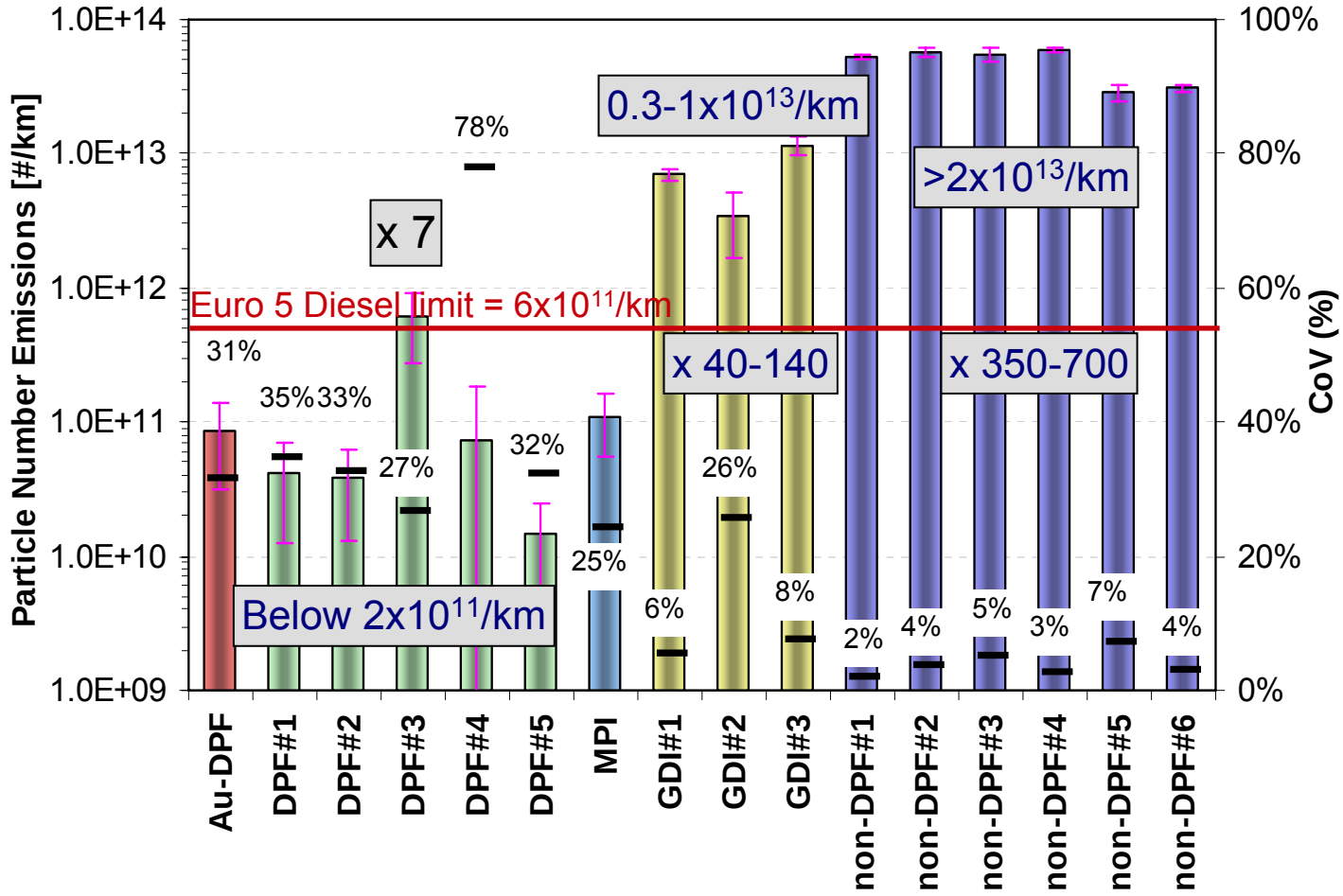
- A method employing a condensation nucleus counter, but using sample pre-conditioning to eliminate the most volatile particles which may contribute significantly to variability
- The method defines the particle measured

PMP Phase 3 Conclusions Led to a Euro 5 Particulate Mass Limit Recalibrated from 5mg/km to 4.5mg/km



PMP Phase 3 Conclusions Led to a Euro 5 Particle Number Limit Set to 6x10^{11}/km

- Original proposal value of 5x10^{11}/km increased by 20% by introduction of correction for losses and dilution factor (particle concentration reduction factor correction)



PMP Phase III – Key Conclusions of the Light-Duty Vehicles' Validation Exercise

- Number method more sensitive (>15x) and more accurate than mass
- DPF fill state and preconditioning proved to be major influences on repeatability
- Both mass and number able to discriminate between DPF and non-DPF Diesels
  - Mass unable to discriminate high and lower efficiency DPFs
- The majority of alternative systems correlated closely with the GPMS
  - +/- 15% of the reference system
- Number and mass measurement systems proved robust
- Full final report at:

http://ies.jrc.cec.eu.int/fileadmin/Documentation/Reports/Emissions_and_Health/EUR_2006-2007/EUR_22775_EN.pdf

PMP Inter-laboratory Correlation Exercises for Heavy Duty Engines (ILCE_HD)

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ILCE_HD Objectives

- Evaluate measurement systems developed for light-duty programme in heavy-duty testing context
- Demonstrate repeatability between nominally identical systems within single laboratories
- Demonstrate reproducibility between nominally identical systems between laboratories
- Demonstrate inter-lab reproducibility between commercially available PMP compliant systems from a variety of manufacturers
- Evaluate the draft test protocols and measurement methods to assist in their development

ILCE_HD Timing and Participants

- ILCE_HD comprises two programmes:
  - Validation exercise (VE)
    - similar to the light-duty validation exercise
  - Round-robin (RR)
    - typical industry round-robin
- Five laboratories have committed to the VE_HD (which is restricted to 5 laboratories in Europe)
- Twelve laboratories in the Round-Robin
  - permits participation from labs Worldwide.
- JRC, UTAC and Ricardo are participating in both exercises

Test Laboratories and Timeline

Date	*Validation Exercise*	*Round Robin*
Jan – Feb 2008	JRC	
Mar – Apr 2008	AVL_MTC	
May – Jun 2008	JRC	TUV
Aug-08		RICARDO
Sep-08	RICARDO	
Oct-08	UTAC	
Oct – Nov 2008	Data Review (Nov)	VOLVO
Dec – Jan 2009	EMPA	Japan (NTSEL, JARI)
	JRC	Korea (NIER)
Jul – Aug 2009		JRC
Sep – Oct 2009		UTAC
Nov – Dec 2009		TNO
Jan – Feb 2010		VTT
Mar – Apr 2010		SCANIA
May – Jun 2010		Environment Canada
Jul – Aug 2010		Daimler Chrysler

ILCE_HD Testing & Differences Between VE and RR

- Similarities and Differences Between VE and RR

PMP HD Validation Exercise (PMP_VE_HD)	PMP HD Round Robin Exercise (PMP_RR_HD)
Golden Engine (VE-E1: Euro III + DPF, Iveco Cursor 8)	Round Robin Engine (RR-E2: Euro III + DPF, Mercedes OM501)
2 x Golden Particle Measurement Systems	Labs' own Particle Measurement Systems
Golden Engineer and Written Guide	Written Guide only
Fuel and lubricant from single batches	Fuel of defined spec, same lube fill in all labs
Full and partial flow used in parallel	Full and partial flow in initial 3 labs, then partial flow alone permitted
European labs only	European, Asian and N. American Labs
Aims to investigate issues with measurement approaches	Uses repeatability as metric for assessing system
Reproducibility intended to demonstrate stability of dual systems	Reproducibility intended to demonstrate similarity of different systems

- Alternative systems welcomed in the VE

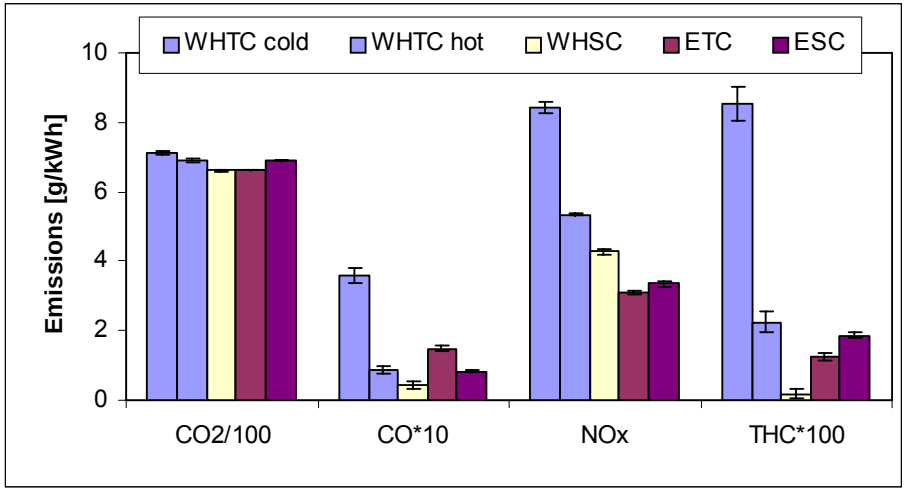
- Test Matrix addresses replicate European and World Cycles
  - Same tests for both VE and RR
- ≥8 repeats of each cycle
- Protocol includes limited DPF fill and validation exercises for particle measurement systems

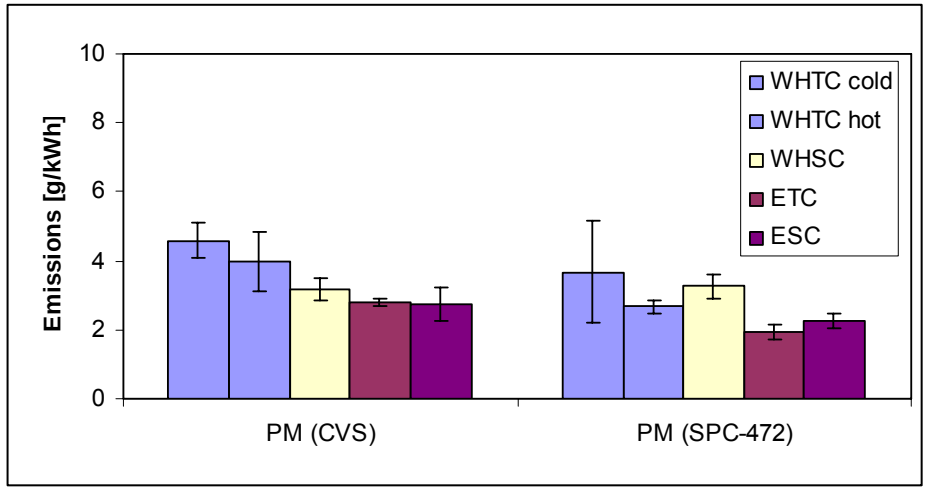
Previous lab	Day 0	Days 1-7	Day 8
	oil change	IFV	IFV
	2h ESC Mode 10	cold WHTC	cold WHTC
	3 x ETC	10 minute soak	10 minute soak
		hot WHTC	hot WHTC
		10 minutes at WHSC mode 9	10 minutes at WHSC mode 9
		WHSC	WHSC
		CP	CP
		ETC	ETC
		CP	CP
		ESC	ESC
*2 hours at ESC Mode 10	Precon	Precon	*2 hours at ESC Mode 10

ESC - European Steady State Cycle for emissions measurement [30 min]
ETC - European Transient Cycle for emissions measurement [30 min]
WHTC - World Harmonised Steady State Cycle for emissions measurement [30 min]
WHTC - World Harmonised Transient Cycle for emissions measurement [30 min]
IFV - Instrument Functional Verification
CP - Continuity Protocol
Precon - 15 miuntes ESC mode 10, 30 minutes ESC mode 7
* DPF regeneration only required if oil change and conditioning not performed

Initial Results #1: Testing at JRC – Gases and PM

- Engine operation is consistent with previous results

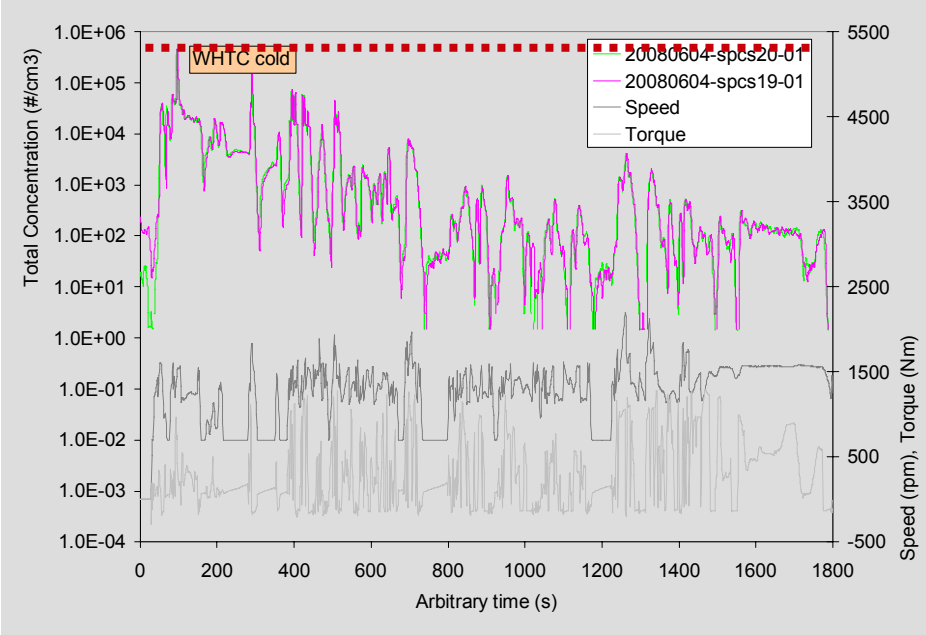


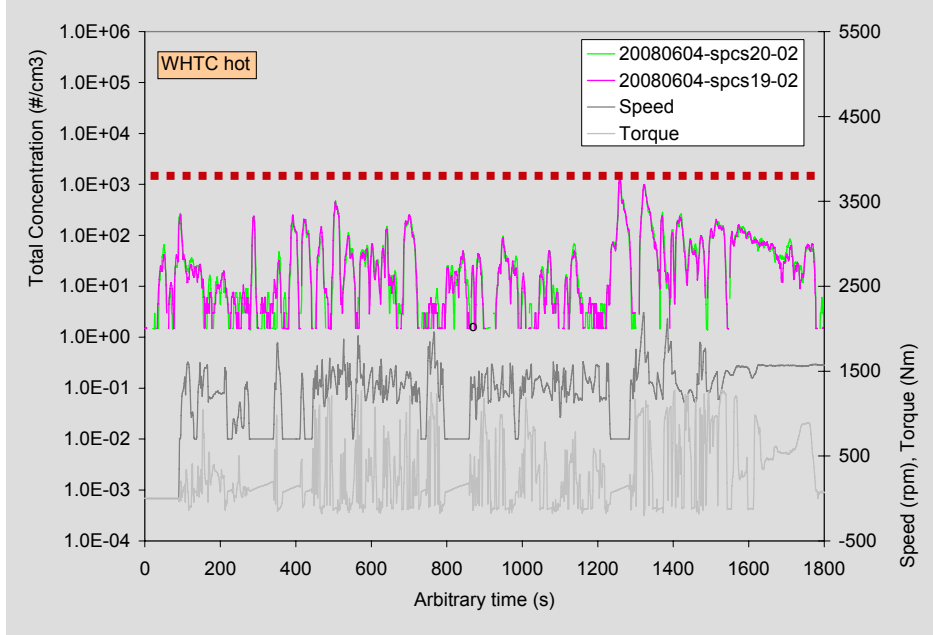


- Good repeatability for regulated gases
  - CoV <6% all regulated gases, all cycles
  - < 0.5% CO_2
- PM in the range 2 to 5 mg/kWh
- Mean CoV ~15%
- Similar results full and partial flow systems

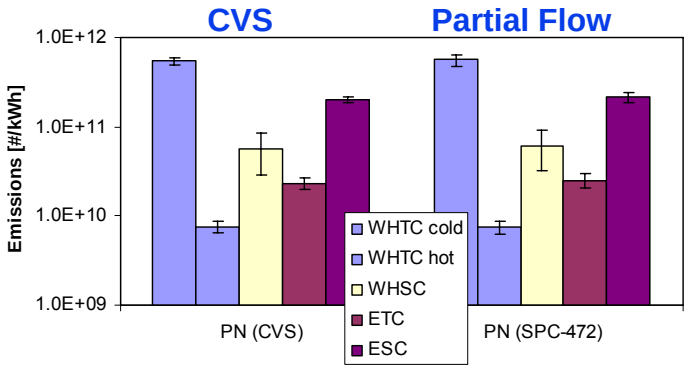
Initial Results #2: Testing at JRC – Particle Number

- Transient particle production from the WHTC shows high levels of particles under cold start, much lower from hot start. This is consistent with observations from light-duty vehicles' testing





- Particles/kWh levels >5x10^{11}/kWh from cold WHTC
- 75 times lower from hot WHTC
- ETC close to hot WHTC
- Steady cycles between cold and hot



- Repeatability levels good
  - CoV 7% to 50%
  - Mean CoV <20%
- Good agreement between partial flow and CVS
- PN systems detect emissions throughout cycle

Open Issues to be studied

- Robustness of VPR operating parameters when challenged with particles generated during prolonged high temperature and regeneration operation
  - Dilution and temperature settings (first diluter, ET) sufficient?
- Presence of mode comprising solid nanoparticles at or below PNC cut-point
  - Kittelson, CARB data suggests these may be present from some engines
- Particle emissions of modern (Euro 5, US'07 / 10) engines from PMP system
  - AECC data suggests that post-DPF + SCR shows similar particle numbers to VE engine
  - More engines' data required

Next Steps

- Compile interim VE results including Alternative Systems for Review in November 2008
- Analyse data and prepare reports for PMP WG
- Further VE testing to complete Summer 2009
- Consideration of on-going RR testing (to complete Summer 2010)
- Final data analysis and reporting
- On-going revision of draft regulatory document (R49)
  - Consideration of implications of differences between light and heavy-duty measurement system results
- Submission to GRPE and WP29 of proposals to incorporate new measurement procedures in R49
- EC consideration in Brussels of revised R49 procedures as part of Euro VI requirements