UNECE GRPE

Particle Measurement Programme

Update and Report on Results: Light-duty Inter-laboratory Correlation Exercise

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J. Andersson (Ricardo Consulting Engineers, UK)
P. Dilara, R. Bueno-Munoz (DG JRC, Ispra, Italy)

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The Particle Measurement Programme (PMP)

- **Initiating Governments:**
  - France, Germany, Netherlands, Sweden & UK. Joined by Japan and Switzerland.
- **Forum**
  - UN/ECE - GRPE
- **Key Objective:**
  - Development of type approval test protocols for assessing vehicles fitted with advanced particulate reduction technology that would complement or replace the current legislative measurement procedure for particulate mass.
- **Duration:** 2003 to 2007/8
- **Status:** Revised mass and number methodologies recommended after two phases of system evaluations and validation exercises.
  - Light-duty Inter-laboratory exercise approaching completion
  - Heavy-duty Inter-laboratory exercise in start-up phase

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Inter-laboratory Correlation Exercises
Summary

- Light-duty Exercise prioritised through EC legislative requirements
- Commenced late summer 2004
- 9 labs participating (11 repetitions)
- Project managed by DG JRC (Ispra, Italy): Penny Dilara
- Golden Engineer funded by DfT (UK): Jon Andersson, Ricardo
- Completion of light-duty phase late Summer 2006
- Heavy-duty programme planned for late 2006

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Overview of light-duty inter-laboratory exercise

- Repeated measurements at several laboratories (with JRC bookends)
- Travelling 'Golden Engineer' + two of JRC staff to ensure best and reproducible testing practice
- Very low PM 'Golden Vehicle' tested at all labs
  Repeatability/Reproducibility
- Test 'Golden Measurement System' for 'solid' particle numbers
- Test modified measurement system for filter-based mass
- Test additional vehicles of various types and current technologies
- Test alternative systems (to PMP specification) for particle numbers

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Vehicles tested

- **PEUGEOT 407 HDi FAP 2000 cc (in all labs)**
- BMW 525d catalysed DPF equipped, 2500 cc
- Mazda Bongo catalysed DPF, 2000cc

DPF DIESEL

- Audi A2, TDi, EURO-4, Oxicat, 1500 cc
- Honda Accord i-CTDi, EURO-4, Oxicat/deNOx, 2200 cc
- VW, GOLF TDi, non-DPF, Oxicat, 1800 cc
- Kia Pride, non-DPF, 1500cc

DIESEL

- Mitsubishi, Carisma, GDI, TWC/deNOx 1800 cc
- VW, GOLF FSI, TWC/deNOx 1600 cc
- Toyota Crown G-DI, 3000cc

DISI

- FIAT, Idea, MPI, EURO-4, TWC, 1400cc

MPI

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Mass systems tested

- Pallflex TX40 filter medium mandated; single batch for all tests
- Inertial protection of filter from massive particles (2.5µm to 10µm cut-point cyclone)
- No back-up filter and single filter for entire NEDC for DPF equipped vehicles
  - To eliminate weighing errors and minimise volatility issues
- Modified filter holders for even deposition of material
  - US2007 compliant
- External heating systems: Lab modified systems with tapes and mantles
  - Most labs
  - Sample passes through zone held at 47°C +/- 5°C for >0.2s
  - Temperatures recorded
- Heated Enclosure Systems e.g: HORIBA HFU-4770 (3 labs)
  - Heated enclosure containing cyclone, transfer tubing and filter holders
    - Controlled to 47°C +/- 5°C, residence time >0.2s

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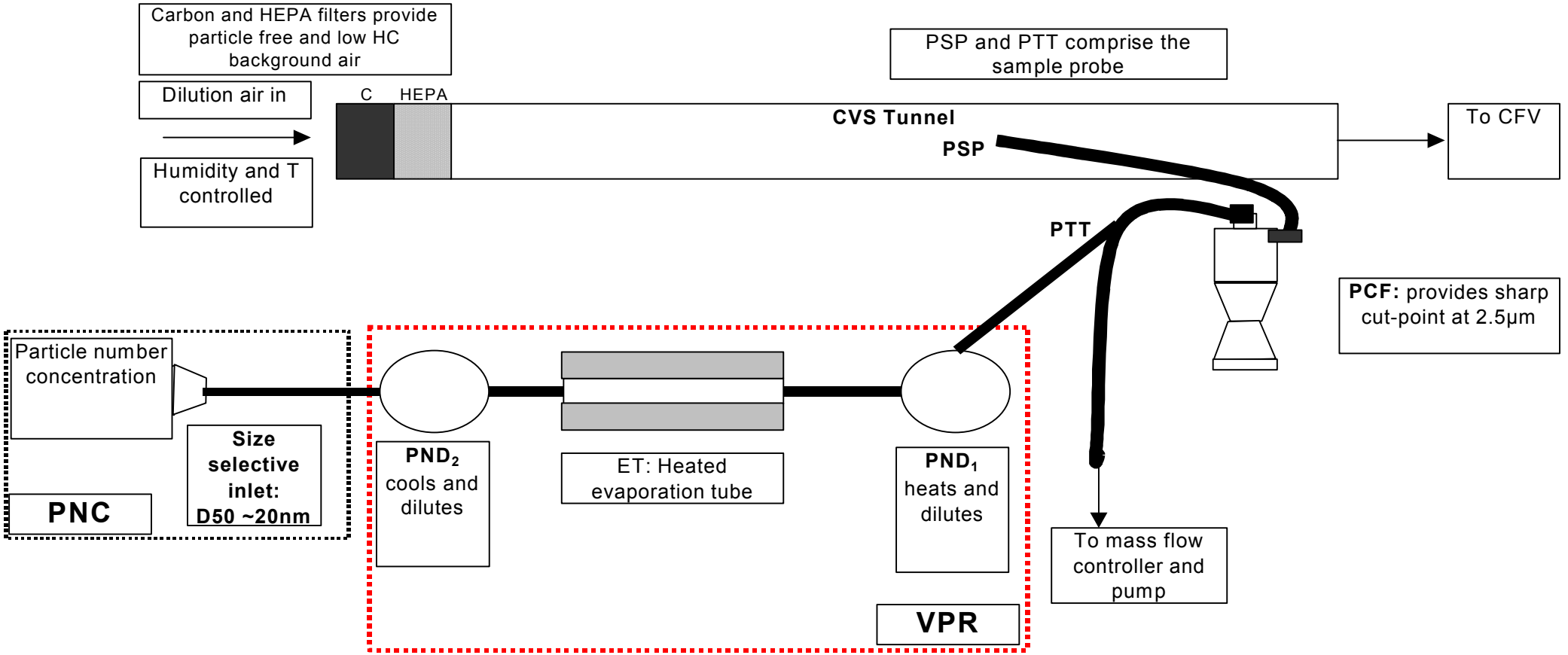
Particle Number System



- A particle number measurement employing a condensation nucleus counter (CNC)
  - Uses sample pre-conditioning to eliminate the most volatile particles which may contribute significantly to variability
  - DEFINES THE PARTICLE TO BE MEASURED

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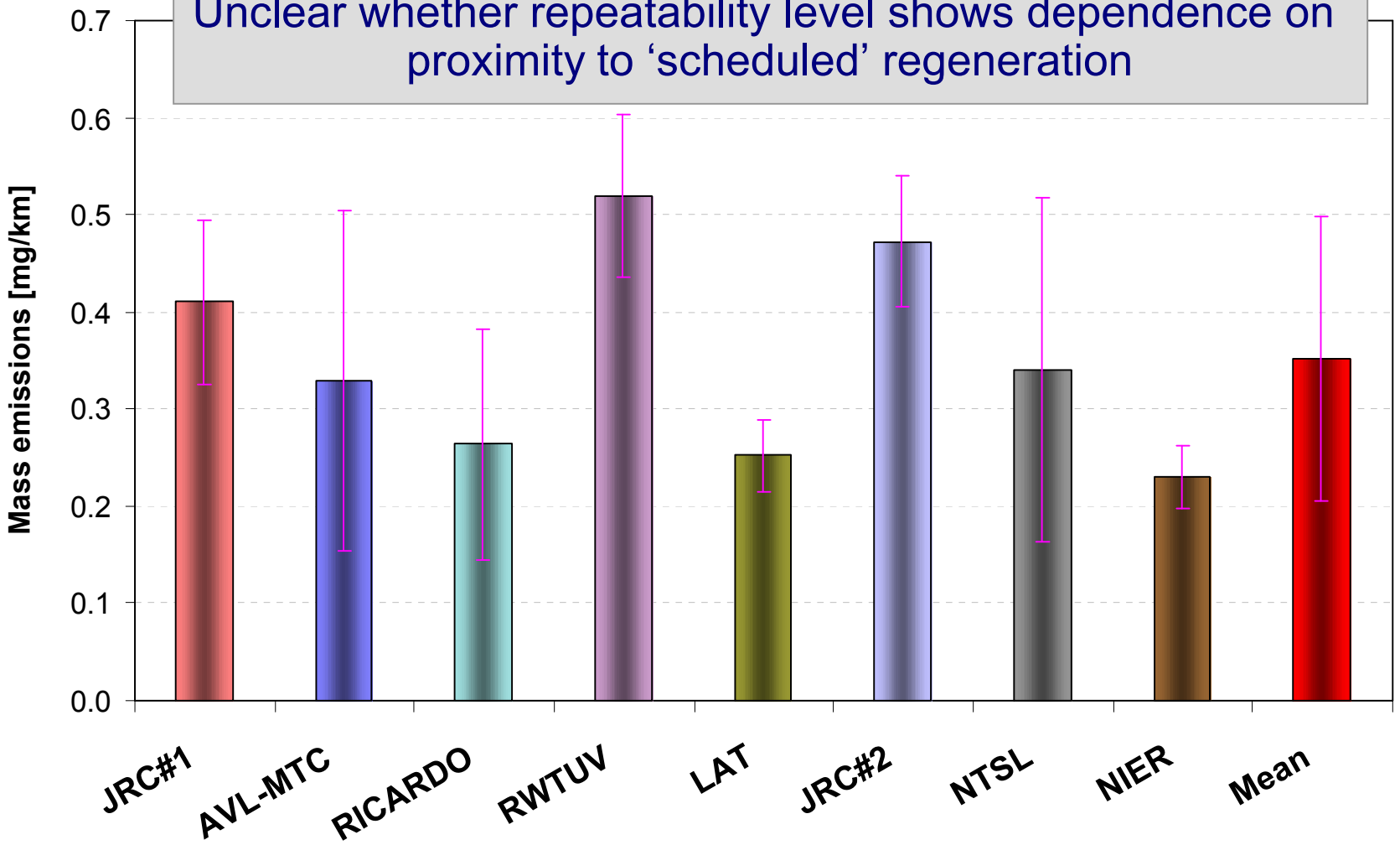
Particulate Mass Emissions From Golden Vehicle Below 1mg/km

mean PM emissions for all labs **Golden Vehicle**

Unclear whether repeatability level shows dependence on proximity to 'scheduled' regeneration



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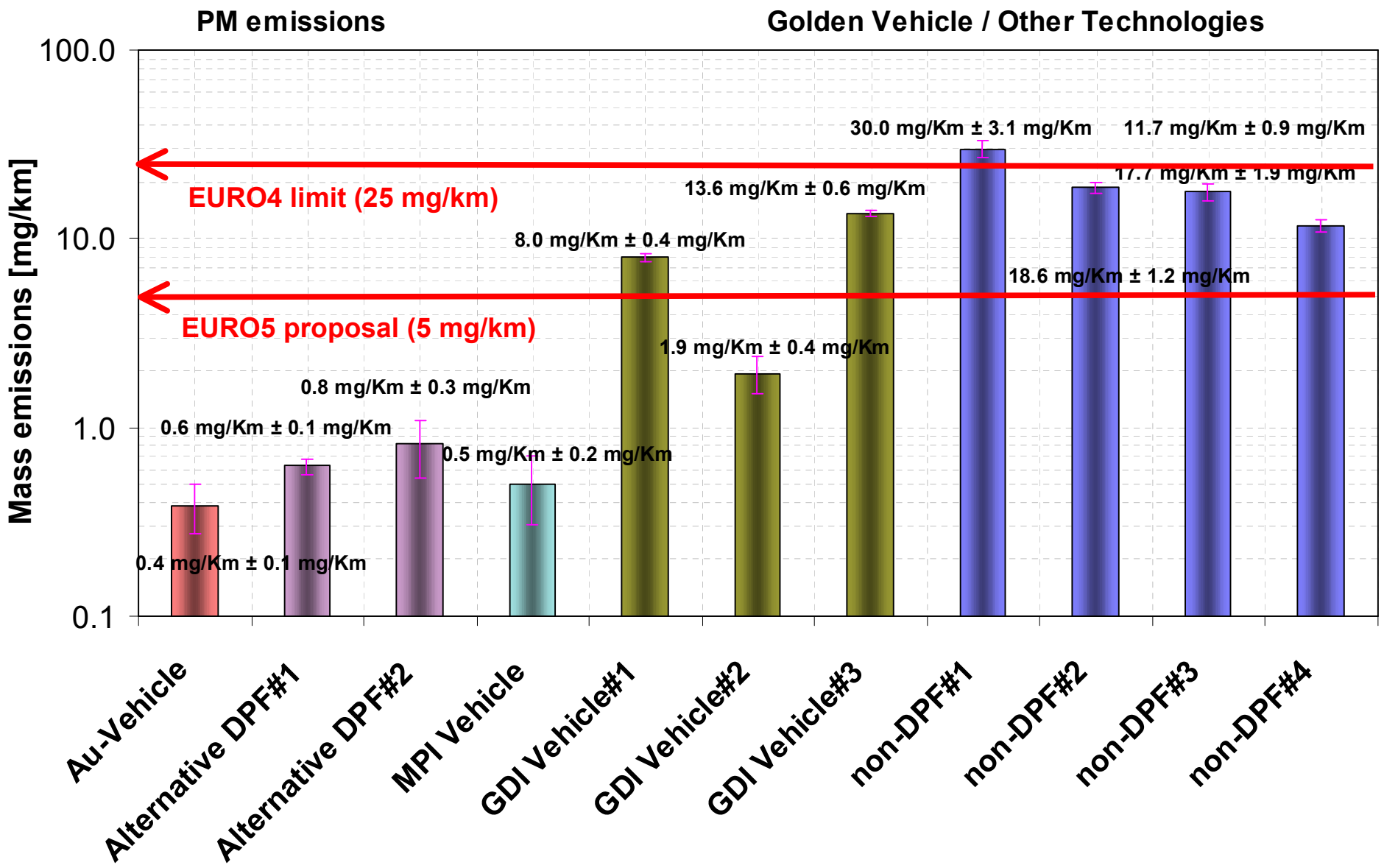
DPF Particulate Mass Emissions (mg/km) 1/20th of Non-DPF Levels



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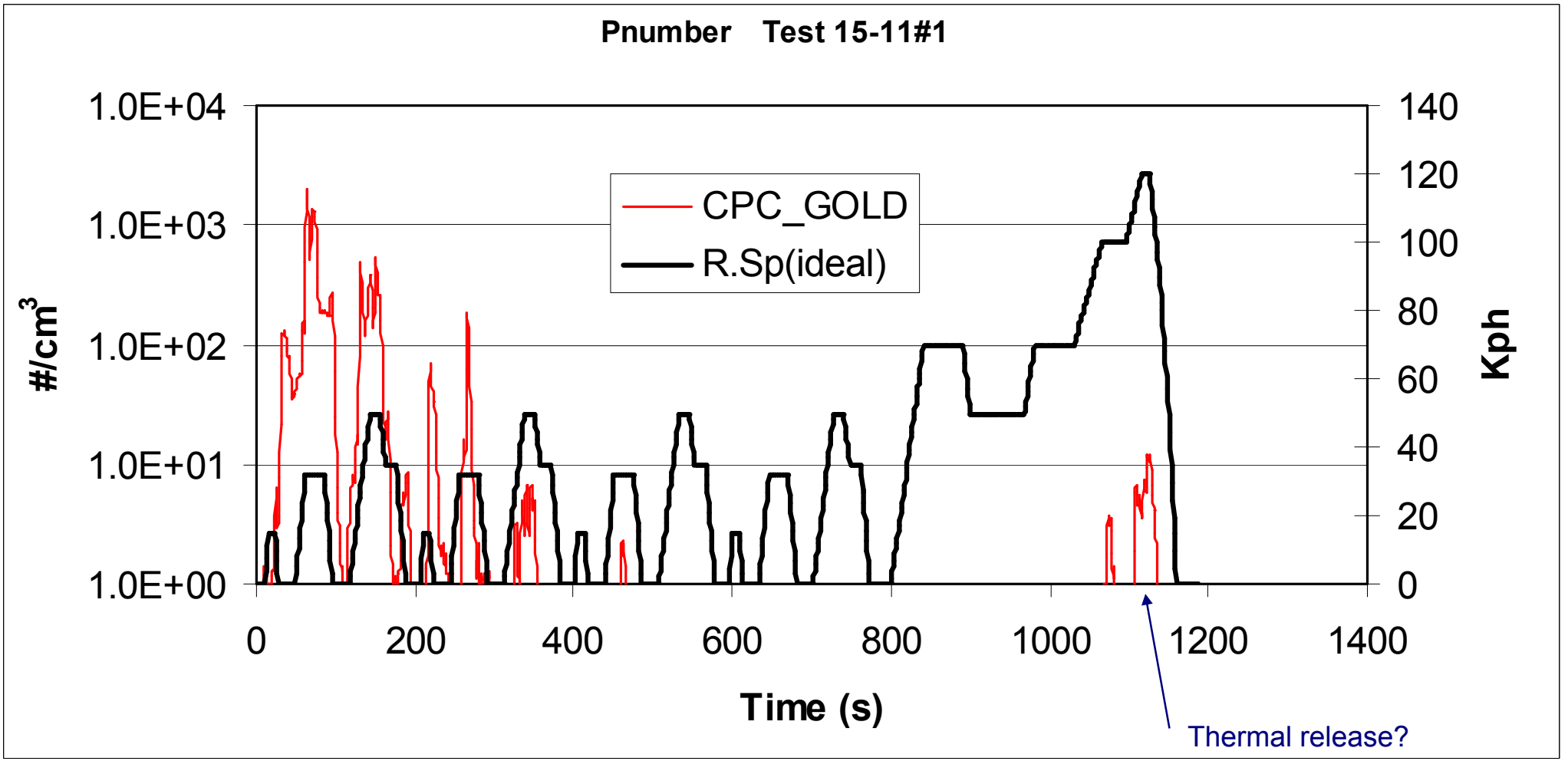
Majority of Particle Numbers Emitted During Cold-Start Testing



- Chemistry of cold-start particles to be investigated in last JRC test set

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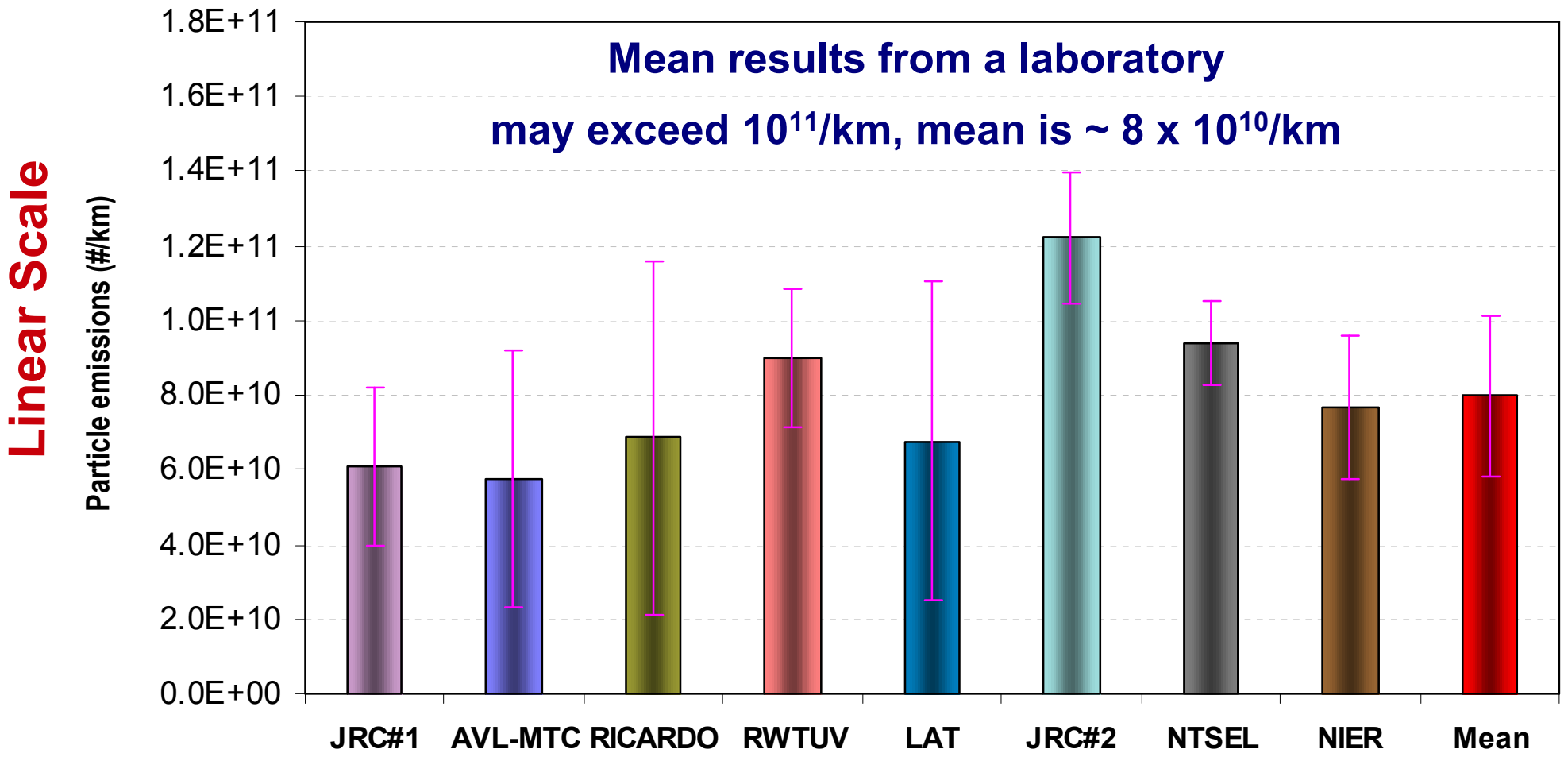
Particle Numbers from NEDC ~ 10^{11}/km

Particle emissions (#/km) Valid tests (DPF stable conditions)



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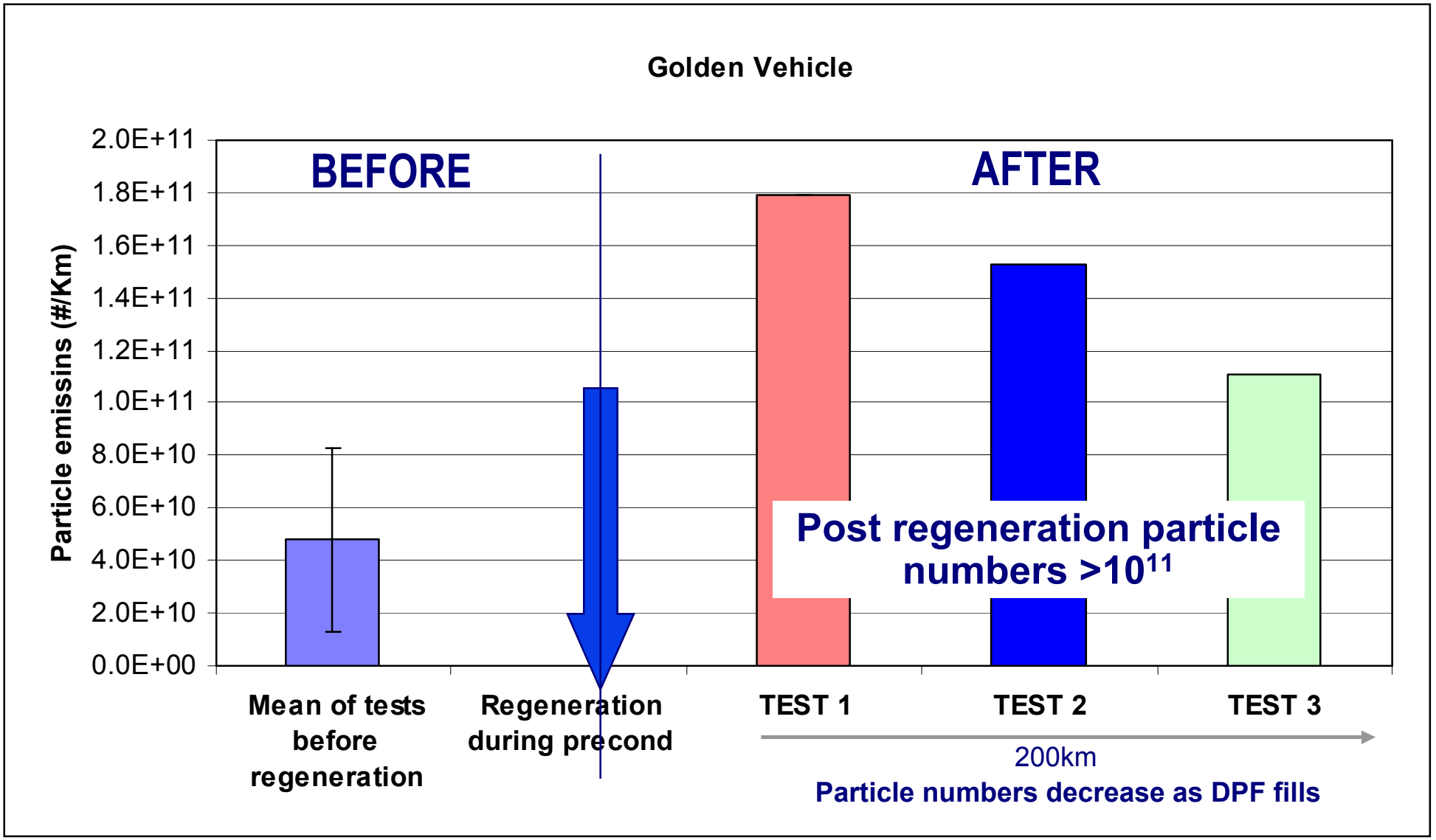
DPF fill state influences NEDC particle numbers – and repeatability!



Linear Scale

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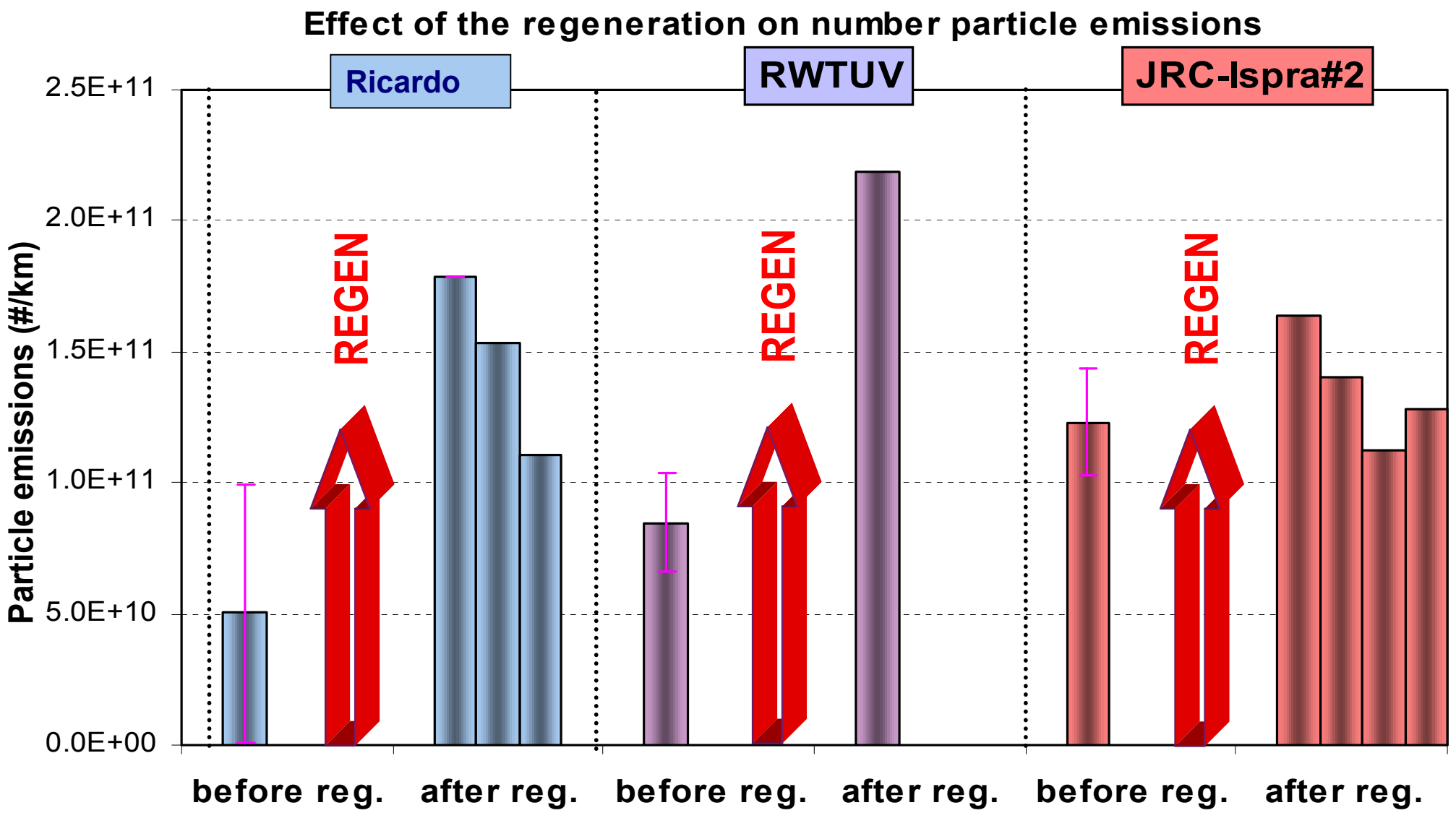
Regeneration fill effects seen in several labs



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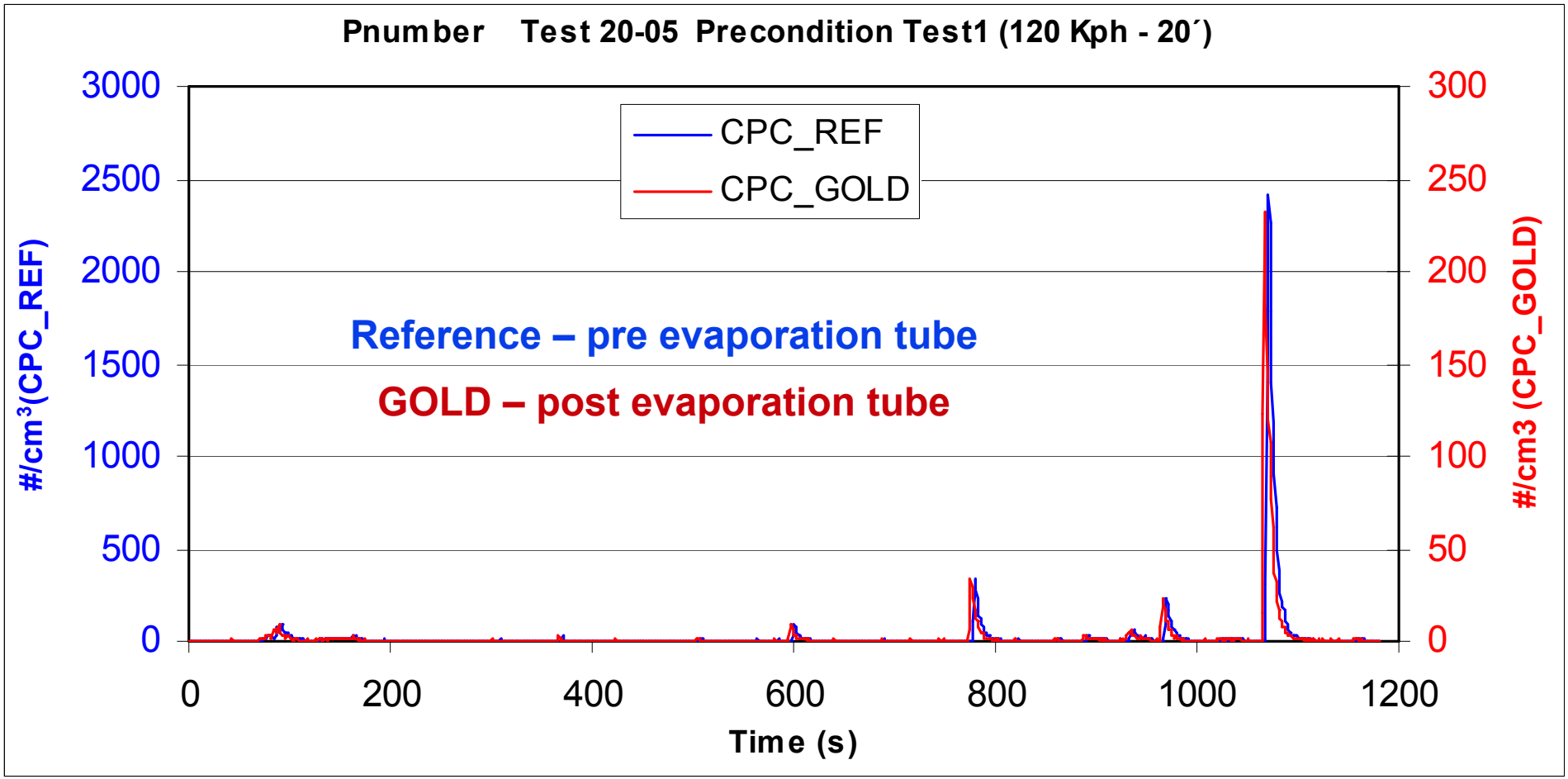
High temperature preconditioning (20 minutes @ 120kph) liberates some solid particles



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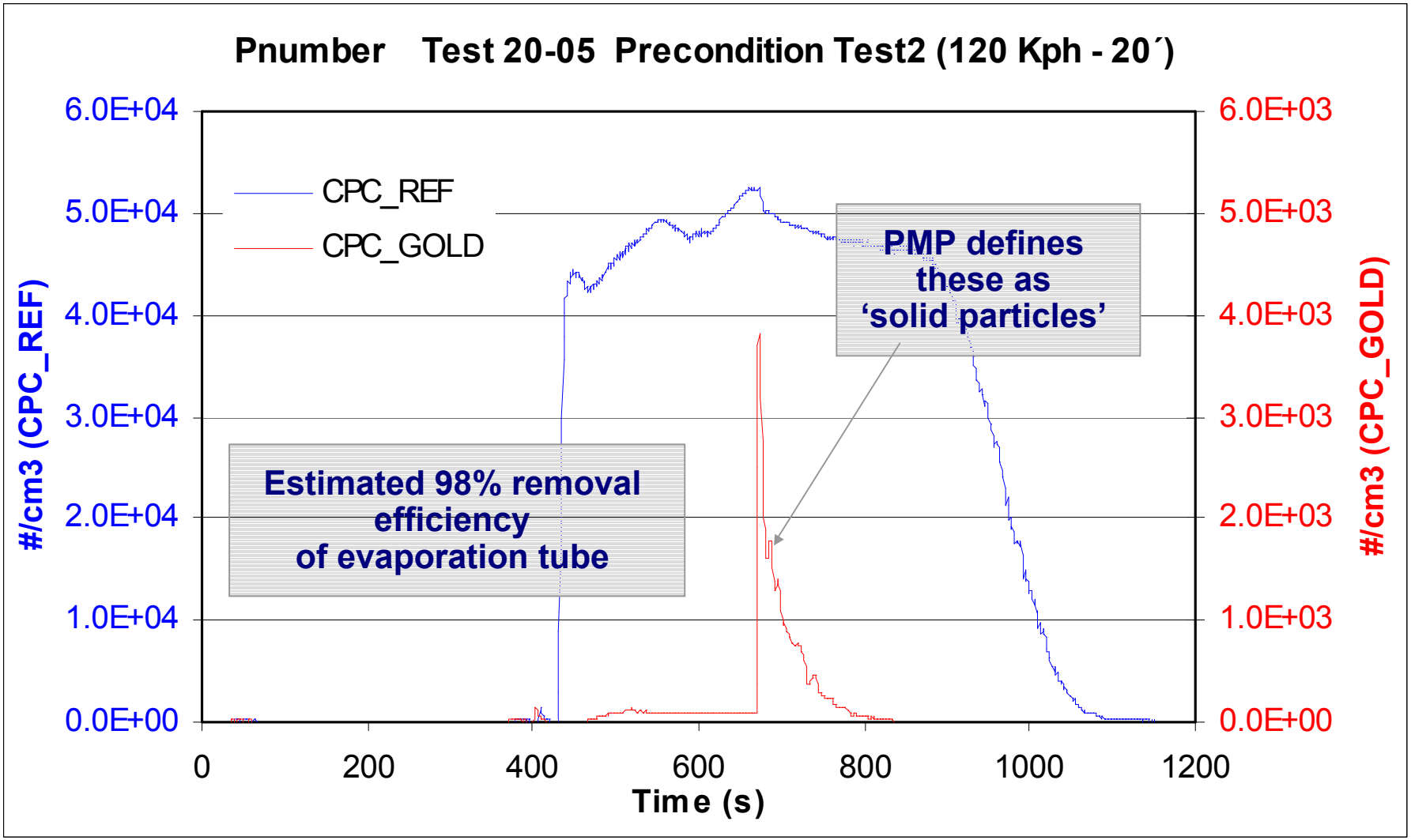
Regeneration liberates solid and volatile particles (Scheduled regeneration during 20 minutes @ 120kph, engine throttled, oxygen restricted)



Linear Scale

Low oxygen levels may lead to poor oxidation and breakthrough of carbon during regeneration

$T_{exhaust}$ = ~100°C higher than non-regenerating 120kph

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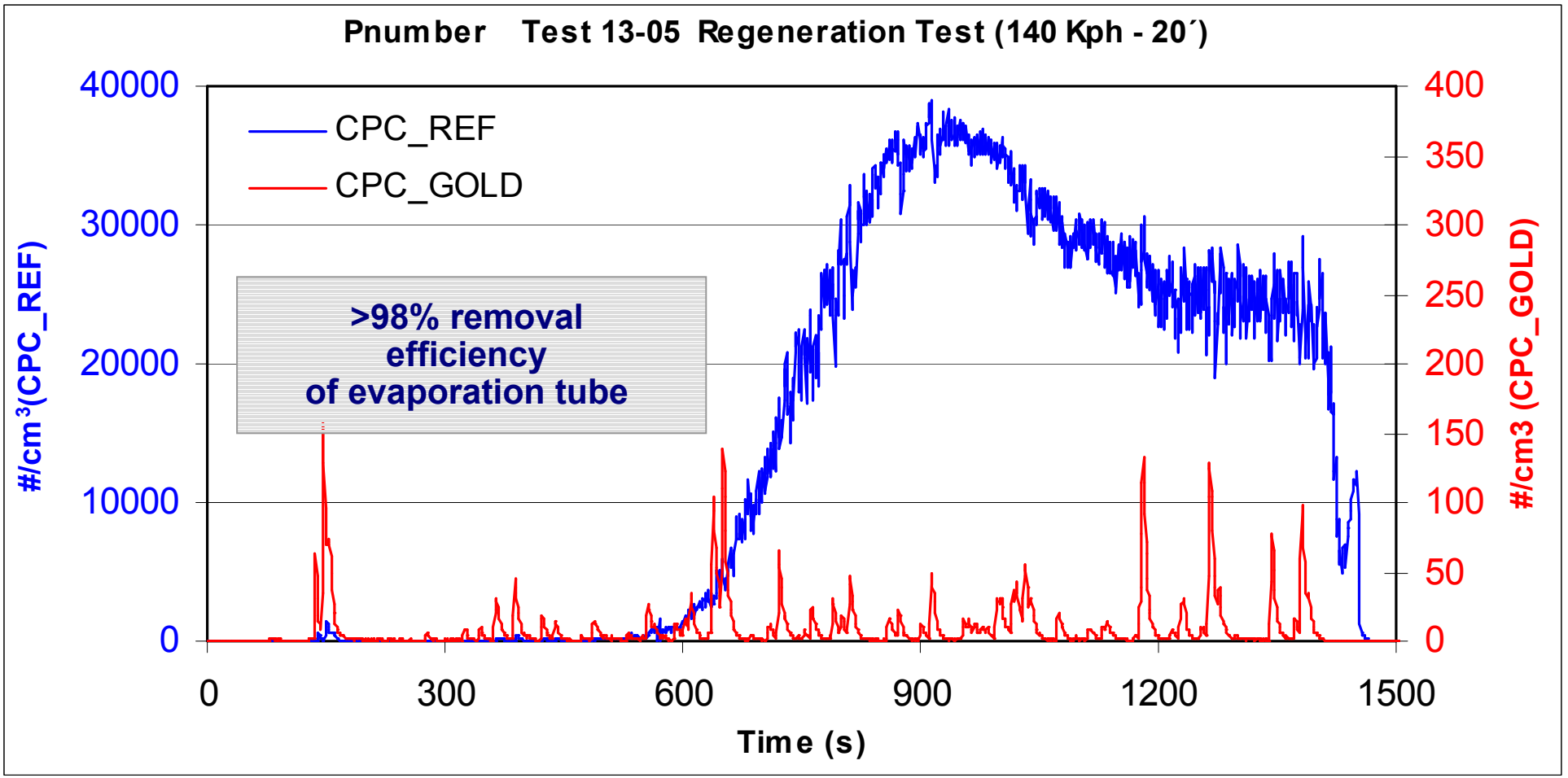
Passive (Continuous) Regeneration at 140km/h
High oxygen levels lead to more efficient oxidation – few solid particles post ET



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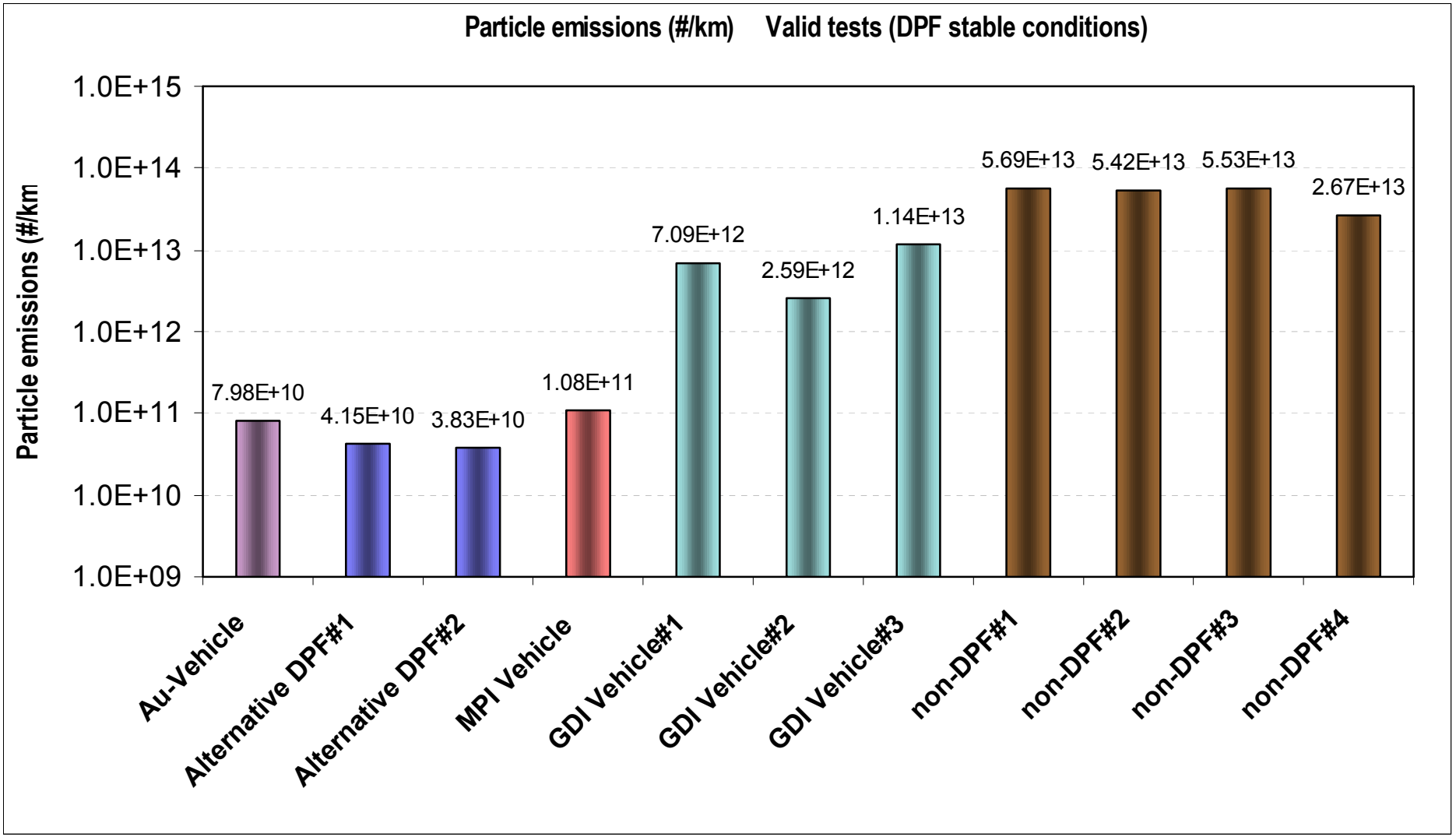
NEDC Particle Numbers (#/km)
Factor of 500 –1000 between DPF & Non-DPF Diesels

Log Scale



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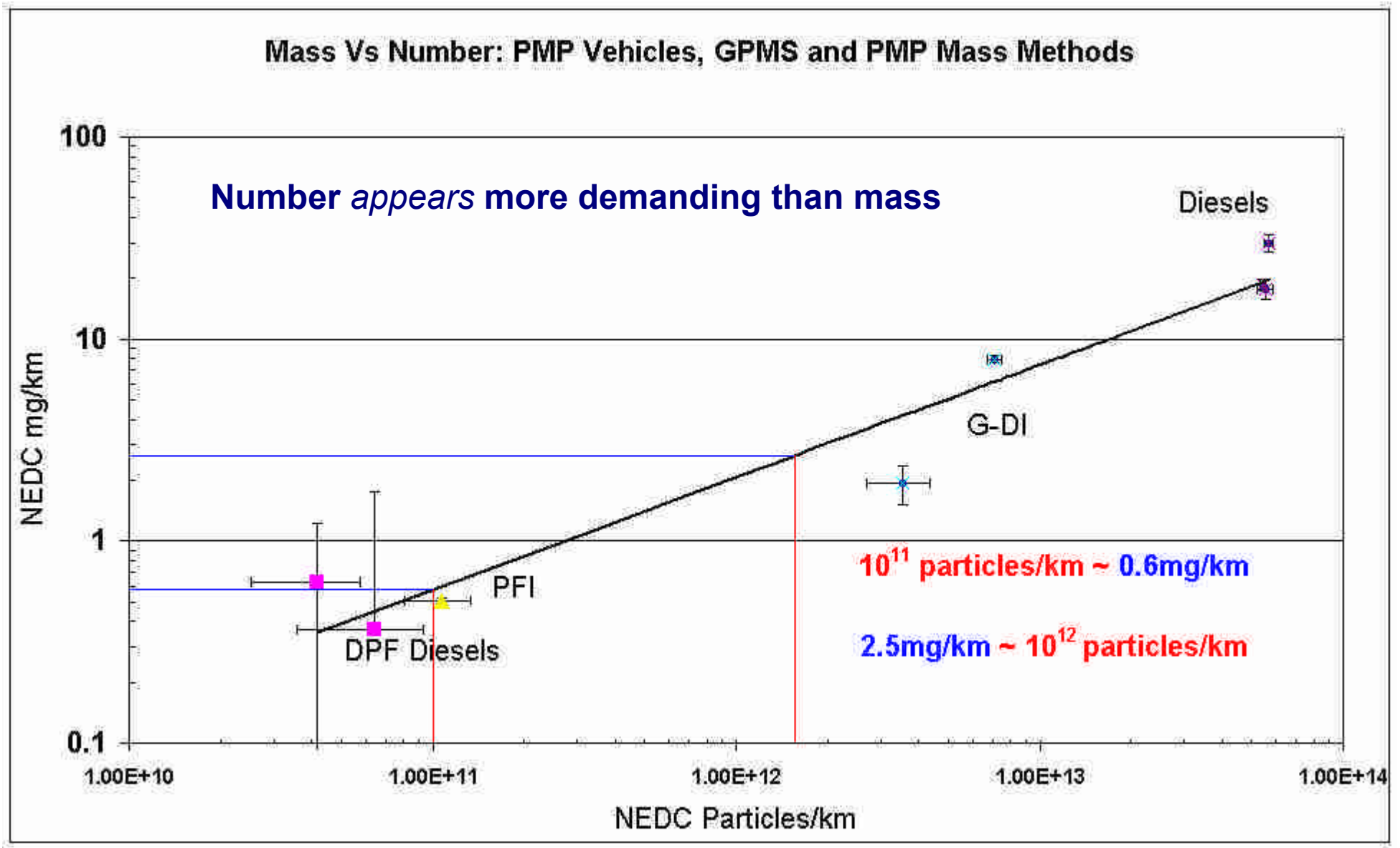
PMP Mass and PMP Number shows Directional Relationship



Log Scale

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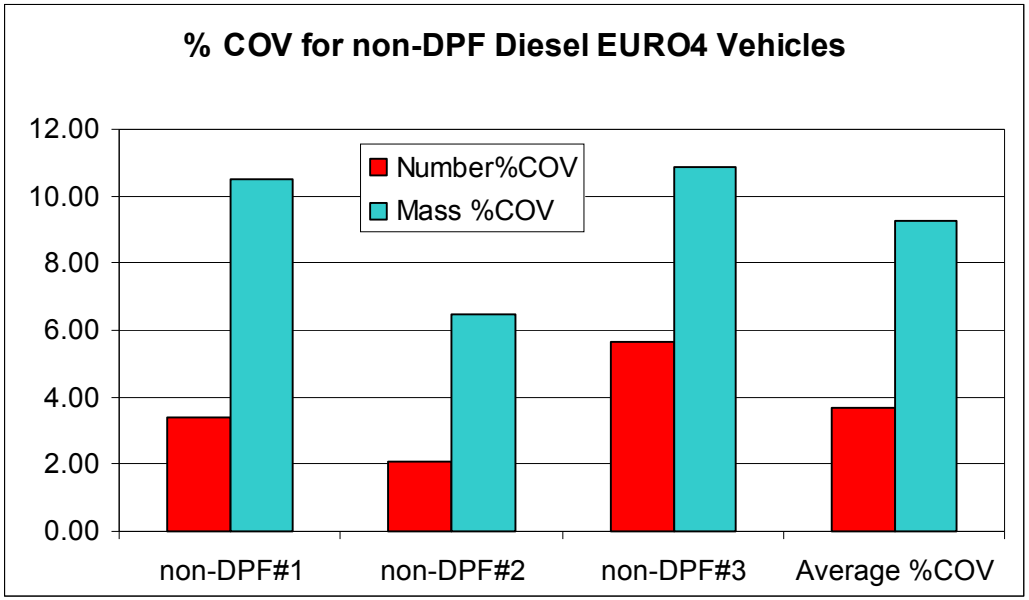
Comparison between mass and number EURO 4 Conventional Diesel Vehicles

	non-DPF#1	non-DPF#2	non-DPF#3	Average %COV
Number	5.69E+13	5.42E+13	5.53E+13	
STD	1.91E+12	1.13E+12	3.10E+12	
%COV	**3.36**	**2.08**	**5.62**	**3.69**
Mass	29.943	18.666	17.695	
STD	3.143	1.21	1.93	
%COV	**10.50**	**6.49**	**10.88**	**9.29**



- With PMP solid particles, number measurements are much less variable than mass for EURO-4 non-DPF Diesel cars

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Preliminary Conclusions

- Mass method sufficiently sensitive to permit repeatable measurements at well below 2.5 mg/km level
  - Significant questions remain regarding sampling and retention of volatiles by various filter media in absence of carbon
- Number method ~20 times more sensitive than mass
  - Emissions of ~10^{11}/km achievable with DPF Diesels, similar to modern MPI
  - GDIs between 10^{12} /km and 10^{13}/km
  - Conventional Diesels' emissions ~ 500 times higher (at ~5 x 10^{13}/km) than DPF equipped ones
- PMP number method less variable than PMP (or current) mass method for EURO-4 non-DPF diesel cars

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Preliminary Conclusions-2

- Mass and number measurement equipment presented no significant functional or maintenance challenges during the programme
- PMP mass and number methods sufficiently sensitive to discriminate between current non-DPF and DPF equipped Diesels
- PMP number metric provides best sensitivity and avoids uncertainties with volatile components for DPF equipped Diesels
- Current technology GDI falls between DPF Diesel and non-DPF Diesel both in mass and number
- Solid particle numbers from DPF regenerations depend on the vehicle driving prehistory and type of regeneration

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Next Steps

- 2nd Phase of testing underway
  - Europe (SHELL, complete but results not yet assessed; UTAC, underway; JRC)
- Analyse all data and prepare final reports for PMP WG
- Further revision of draft regulatory documents
  - Fine tuning
  - Integration of necessary validation and calibration procedures for number measurement equipment
- Submission of drafts to EC in Brussels as protocols in regulation format for consideration as part of Euro V
- Heavy Duty Inter-lab exercise – Currently under development, candidate engines sought

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Thank you for your attention

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