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# California's Efforts for Advancing Ultrafine Particle Number Measurements for Clean Diesel Exhaust

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*Research Division*
*Sacramento, California*

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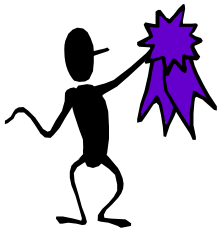
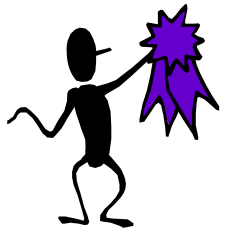


# ACKNOWLEDGEMENTS




TSI Inc.

Kindly provided the EEPS 3090, 3010D, and 3786 for the study.

CARB Emissions Laboratory Staff

Mr. Keshav Sahay, Mr. John Karim, Mr. Ralph Rodas, Mr. George Gatt, and Dr. William Robertson provided invaluable laboratory assistance.

# BACKGROUND

- New 2007 particulate matter (PM) emission standard for HDEs requires diesel engines to emit at or below 0.01 g / bhp-hr.
- The precision and accuracy of the gravimetric method may still be challenged by the post-DPF emission level.
- A particle number measurement may be a more precise, accurate, and appropriate option.
- A new measurement protocol to measure solid particles and supplement the filter-based method has been developed under the auspices of the United Nations Economic Commission for Europe - Particle Measurement Program (PMP).
- California is following these significant developments in Europe and CARB investigators are evaluating the utility of the European proposal.

# PROCESS

- **Initial focus is sampling raw exhaust using PMP protocol**
- Next is sampling from CVS per PMP intent
- After completion of pilot, actual investigation begins:
  - CARB investigators in collaboration with partners from UCR, UoM, Ricardo, Matter Engineering, TTM, and EU-JRC

# OBJECTIVE OF PILOT

- Evaluate and compare several particle counting instruments, especially multi-channel spectrometers.
- Implement the PMP particle number measurement protocol

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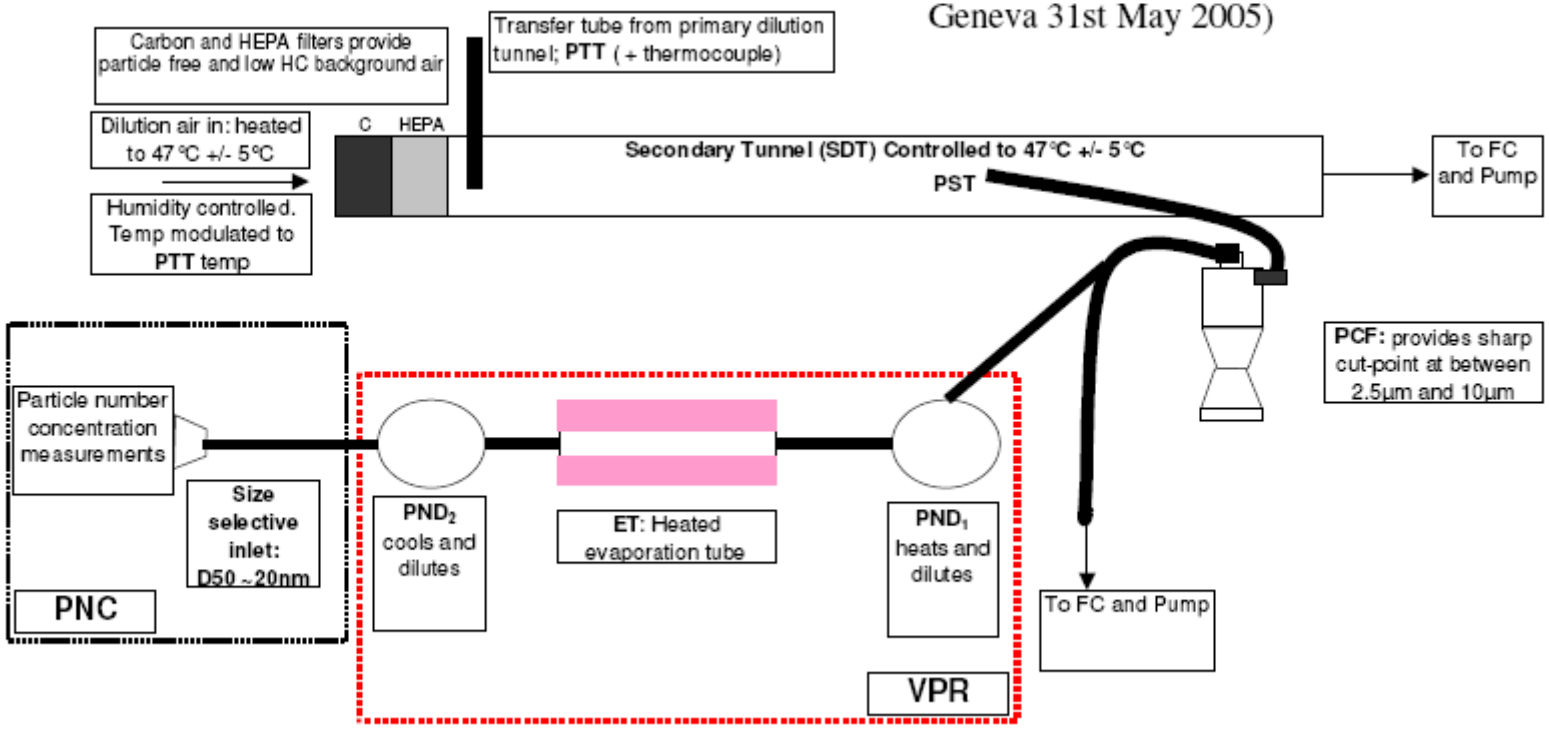
# THE PMP PROTOCOL

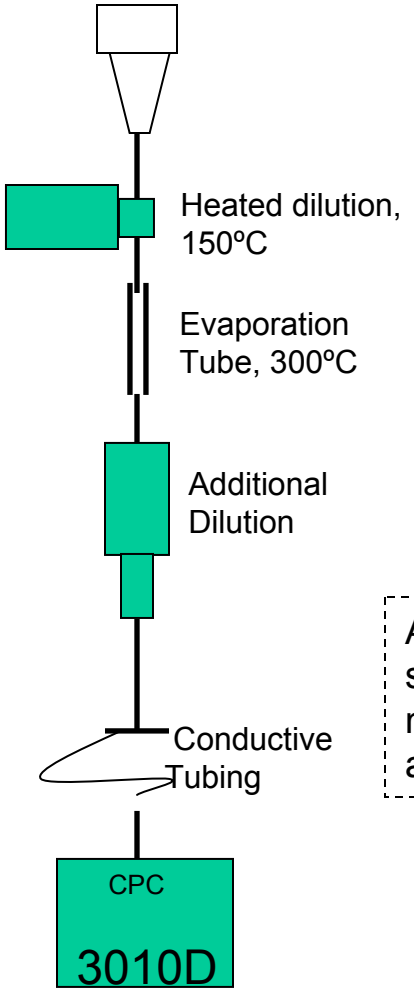
Working paper No. **GRPE-PMP-15-4**
(15th PMP working meeting,
Geneva 31st May 2005)




UN-GRPE PMP Phase 3
Inter-laboratory Correlation Exercise: Updated Framework and Laboratory Guide for HD Engine Testing
A Document For The UK Department for Transport

# THE PMP PROTOCOL

- A proposed methodology for counting solid particles >23nm from diesel automobiles.




Pre-classifier with a $PM_{2.5}$ size cut

Primary dilution at 150º±5ºC, DR 1-1000

Evaporation Tube 240mm±10mm and inner diameter 6mm±1mm, gas residence time of 0.2s±0.05s and constant temperature of 300º±20ºC

Secondary dilution, DR ~10

All sampling lines shall be either TYGON, conductive silicone tubing or stainless steel composition, contain smooth internal surfaces and be of minimal length. Sharp bends and abrupt changes in section should be avoided in all sampling lines. **Distance no more than 2.5m.**

Particle counting with TSI CPC 3010D.
Concentration <10,000 p/cc and Temp <35ºC

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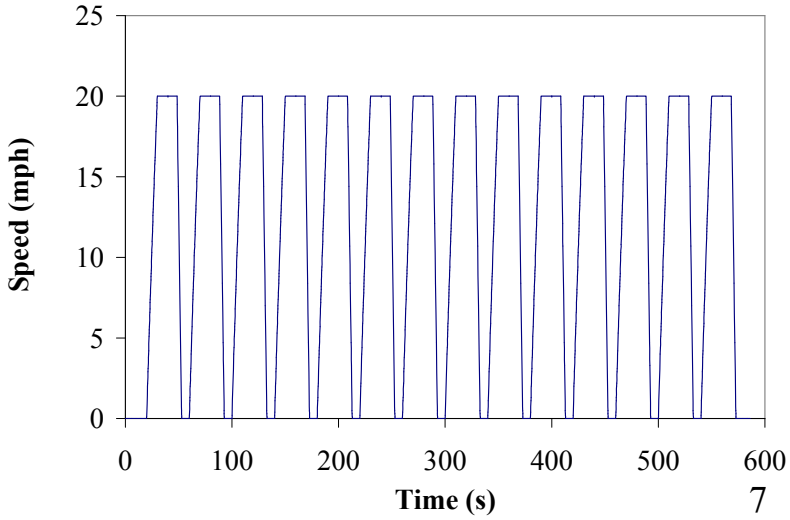
# EXPERIMENTAL SETUP

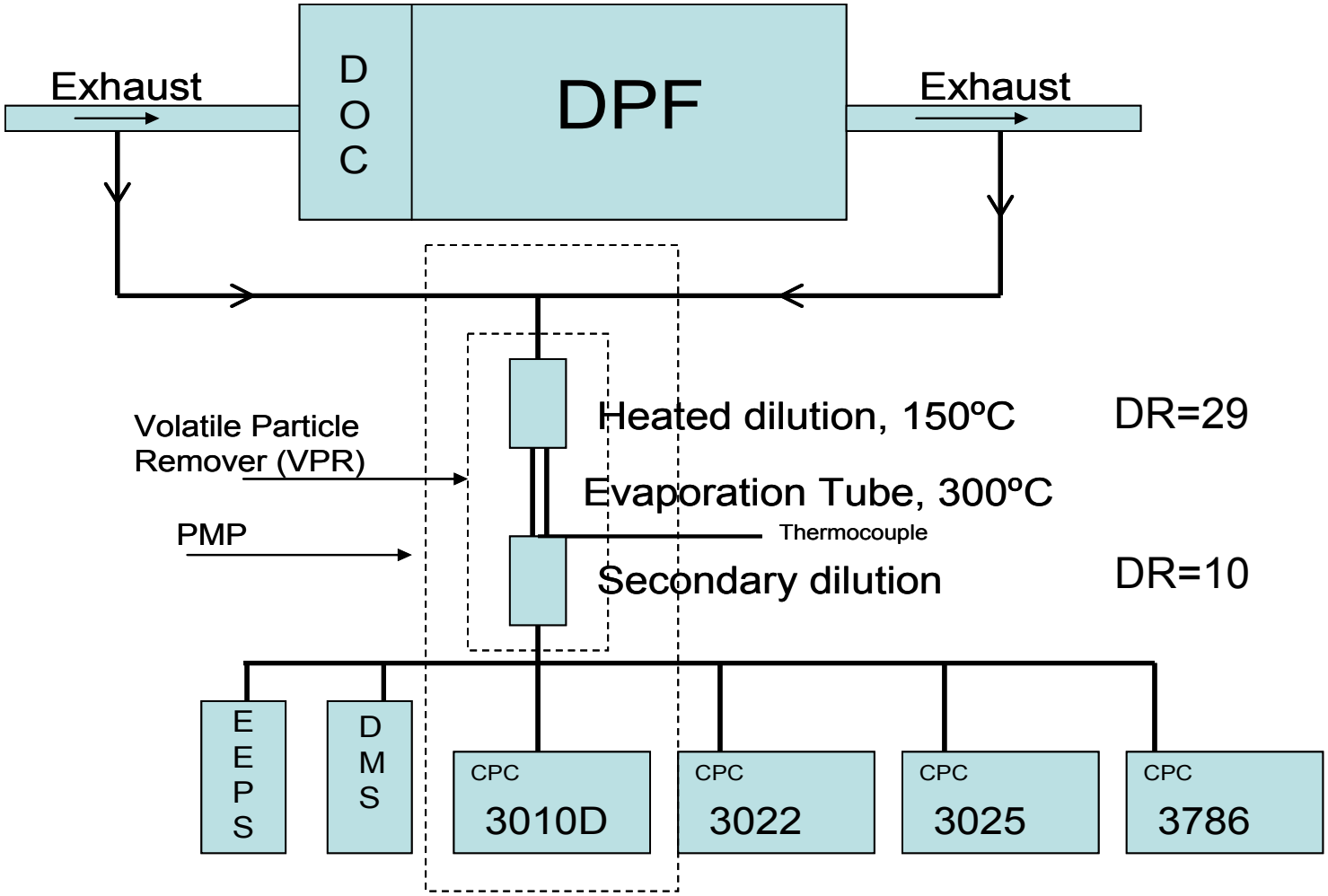
## EMISSIONS LABORATORY

- CARB Heavy Duty Emissions Laboratory in Los Angeles, CA
- Test vehicle Model-year 2000 Isuzu diesel medium-heavy-duty delivery truck (6HK1XN, 7.8L engine, GVWR of 22,285 lbs)
- Tested at 18,000 lbs
- Johnson Matthey CRT and fueled by ultra low sulfur diesel (ULSD, <15ppm sulfur)
- Cycles include idle, cruise at 50mph and CBD.

# EXPERIMENTAL SETUP

## PARTIAL FLOW SAMPLING (EFFICIENCY OF DPF)



# INSTRUMENTATION

## Particle Counters

TSI 3786
2.5nm

TSI 3025A
3nm

Cambustion DMS-500
5.6nm

## Diluters

Matter Engineering
MD-19

TSI EEPS
5.6nm

TSI 3022A
7nm


TSI 3010D
23nm

Dekati DI 1000

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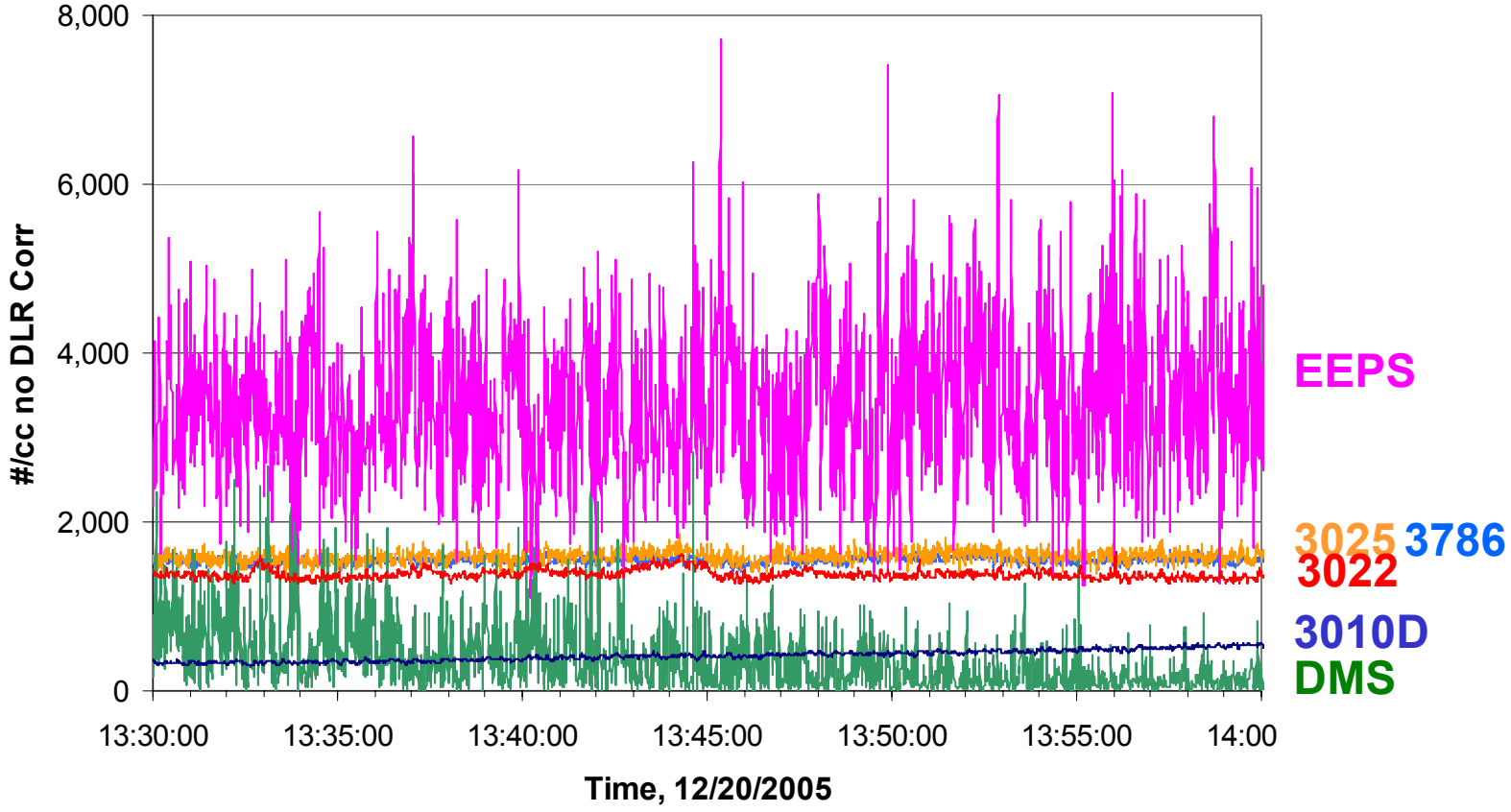
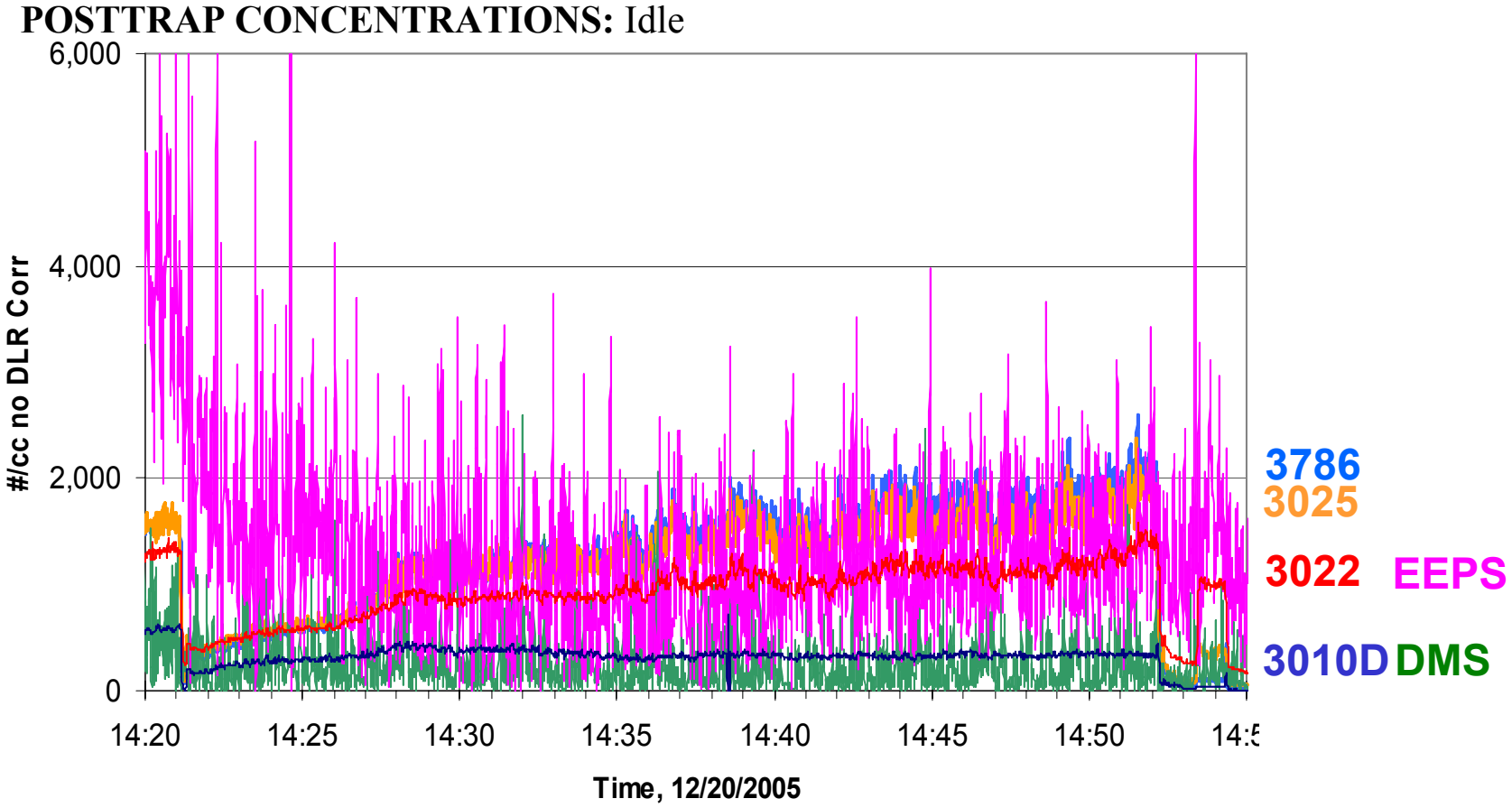
# INSTRUMENT COMPARISON

**POSTTRAP CONCENTRATIONS:** Cruise at 50 mph (no correction for dilution ratio)




- CPC report concentrations in a logical order (according to lower size cut)
- At low concentrations DMS and EEPS are very noisy
- Relative to CPCs, DMS is reporting too low and EEPS too high

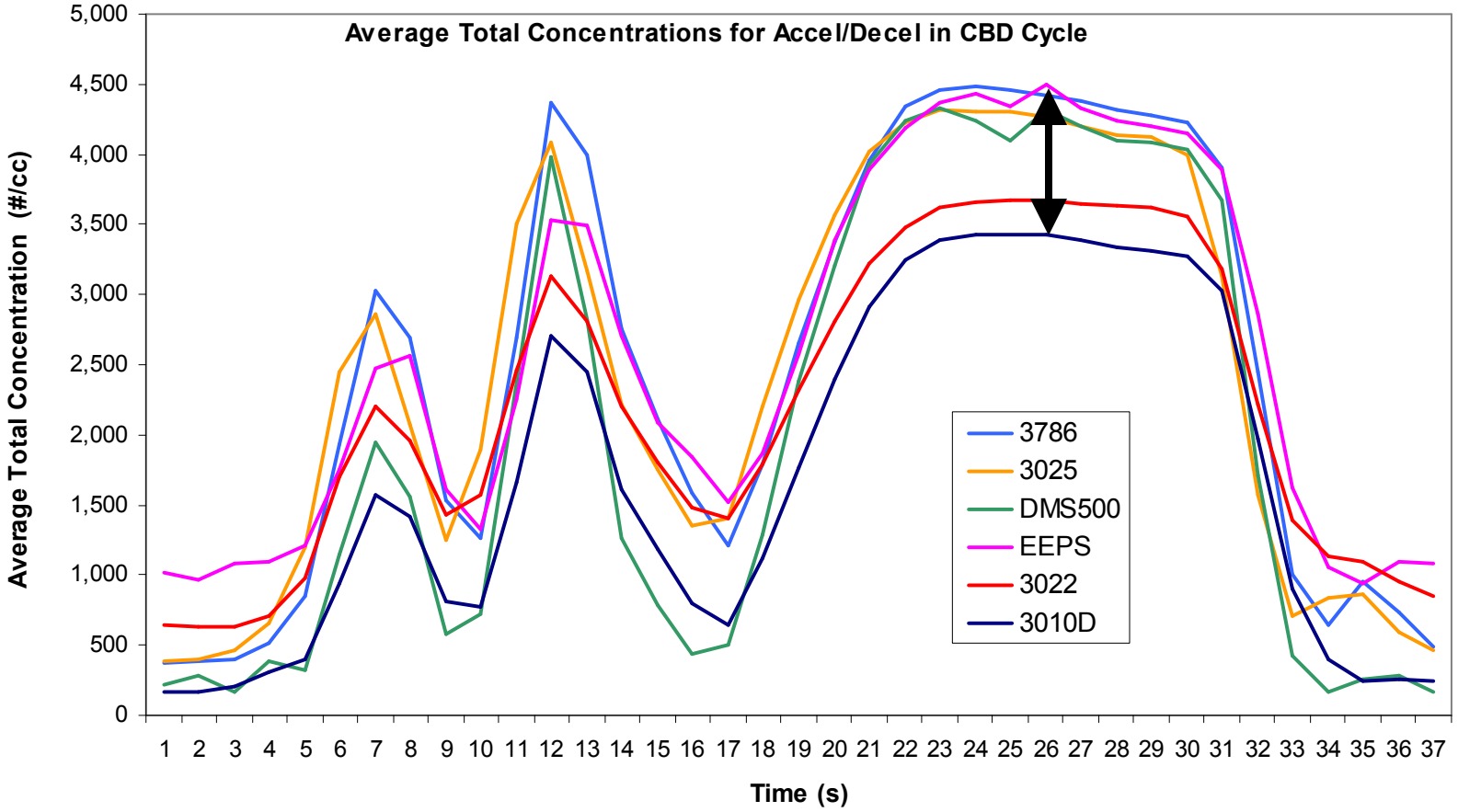
# INSTRUMENT COMPARISON




- CPC report concentrations in a logical order
- At low concentrations DMS and EEPS are very noisy
- DMS is reporting too low but EEPS appears more accurate

# INSTRUMENT COMPARISON

**POSTTRAP CONCENTRATIONS:** Average Single CBD cycle




- At low concentrations during the CBD cycle all instruments appear to be working very well
- Lots of solid particles in the very small size ranges (ie <20nm)

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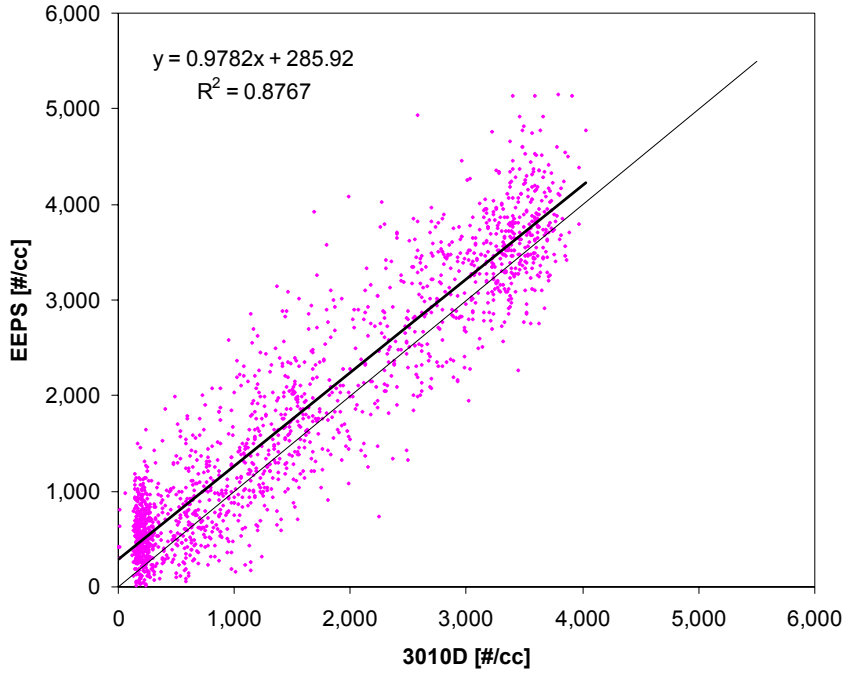
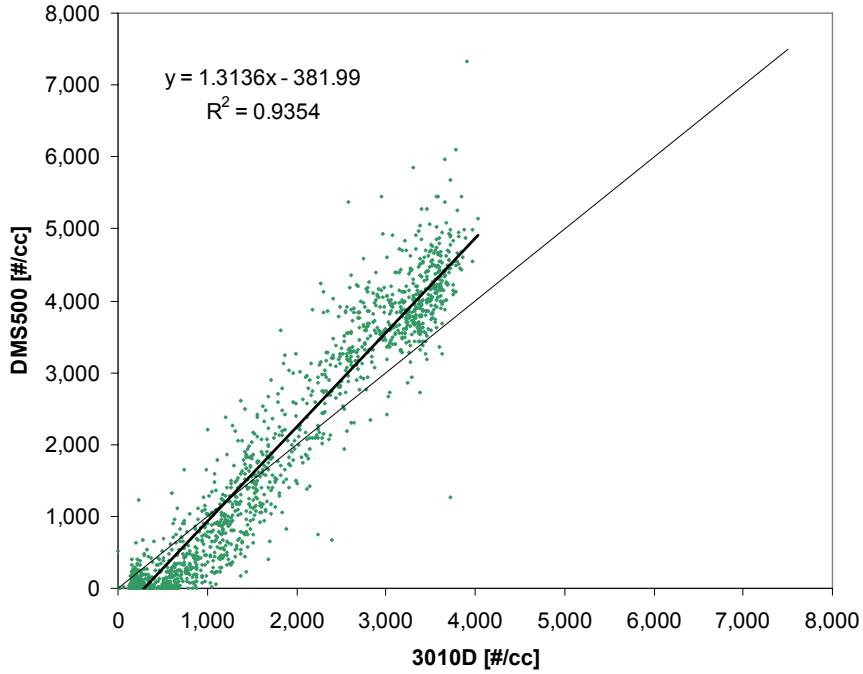
# INSTRUMENT COMPARISON

**POSTTRAP CONCENTRATIONS:**

## EEPS and DMS vs 3010D (CBD Cycle) @ >23nm




**EEPS**

Accurate

(0.9782 ~ 1)

**DMS**

Precise

(0.9354 ~ 1)

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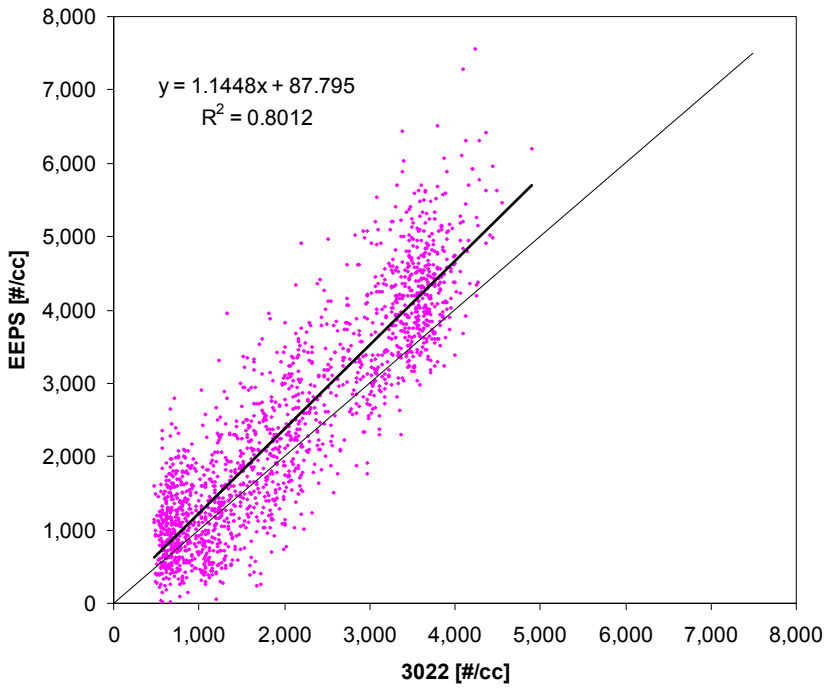
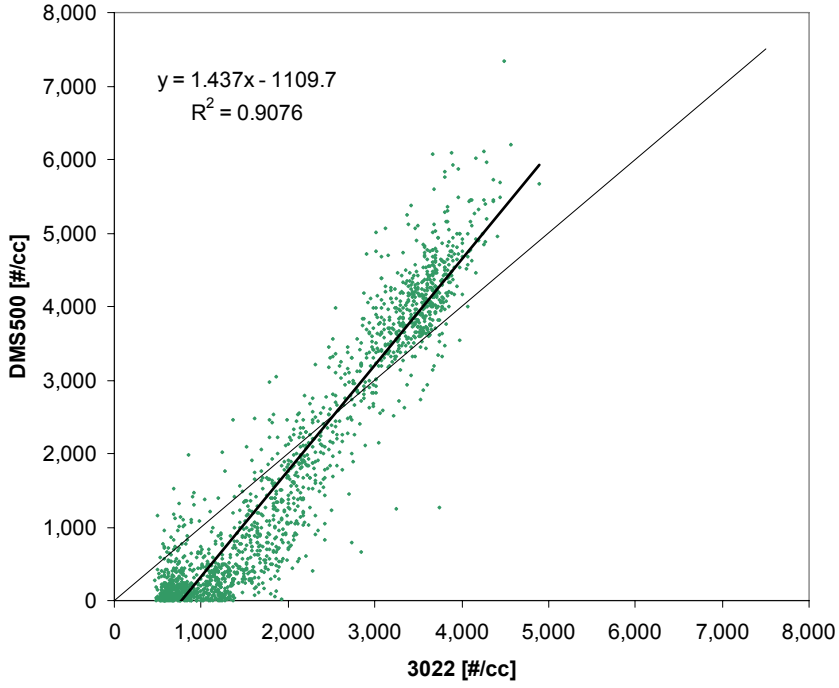
# INSTRUMENT COMPARISON

**POSTTRAP CONCENTRATIONS:**

## EEPS and DMS vs 3022 (CBD Cycle)




**EEPS** — Accurate

**DMS** — Precise

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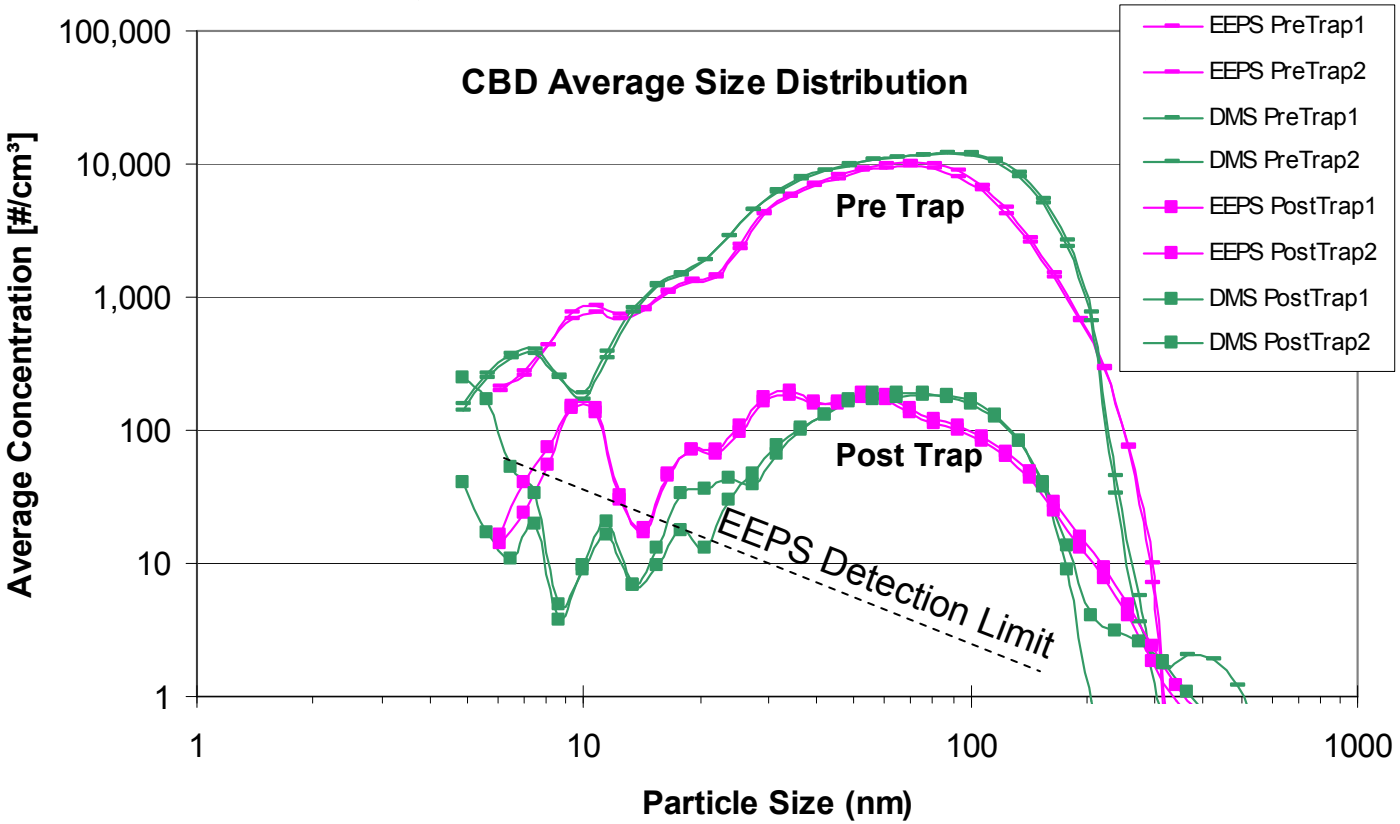
# COMPARISON OF SIZE DISTRIBUTIONS (EEPS vs. DMS w/ CBD)




- Both instruments very reproducible both pre- and post-trap.
- EEPS and DMS have relatively good agreement during this cycle even though the accumulation mode peak is still slightly off set.
- The instruments are barely above detection limits post-trap.

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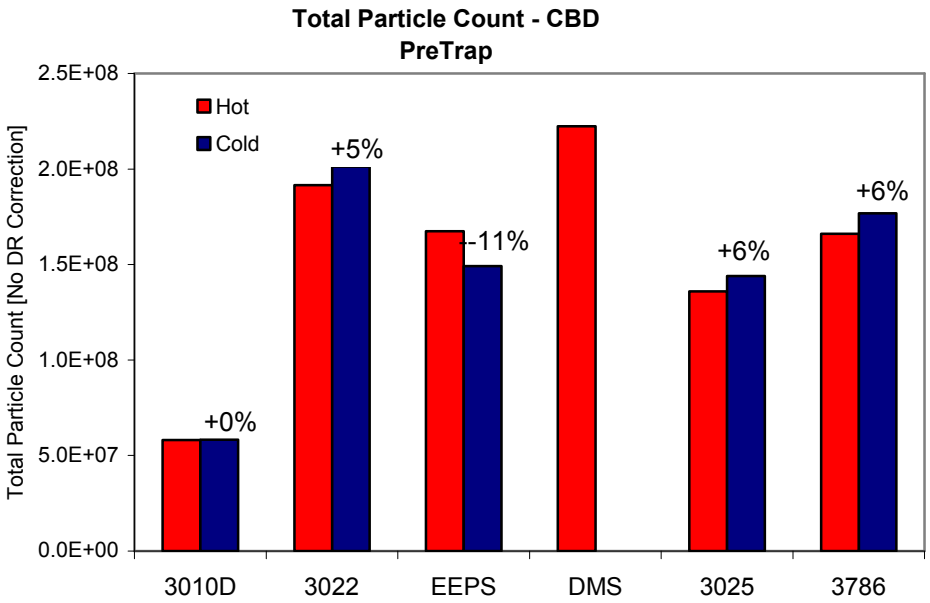
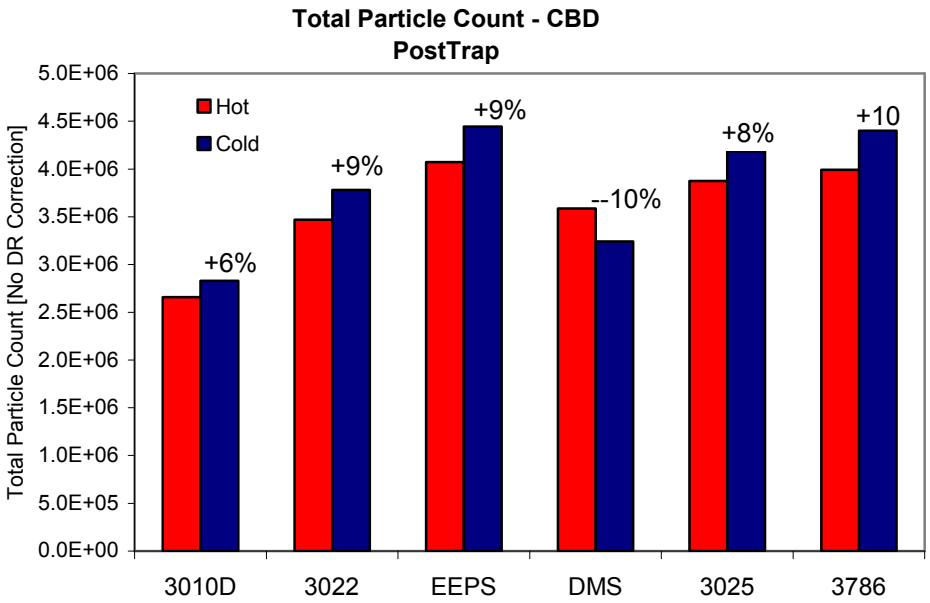
# THE PMP EVALUATION

## EFFECT OF EVAPORATION TUBE (CBD)



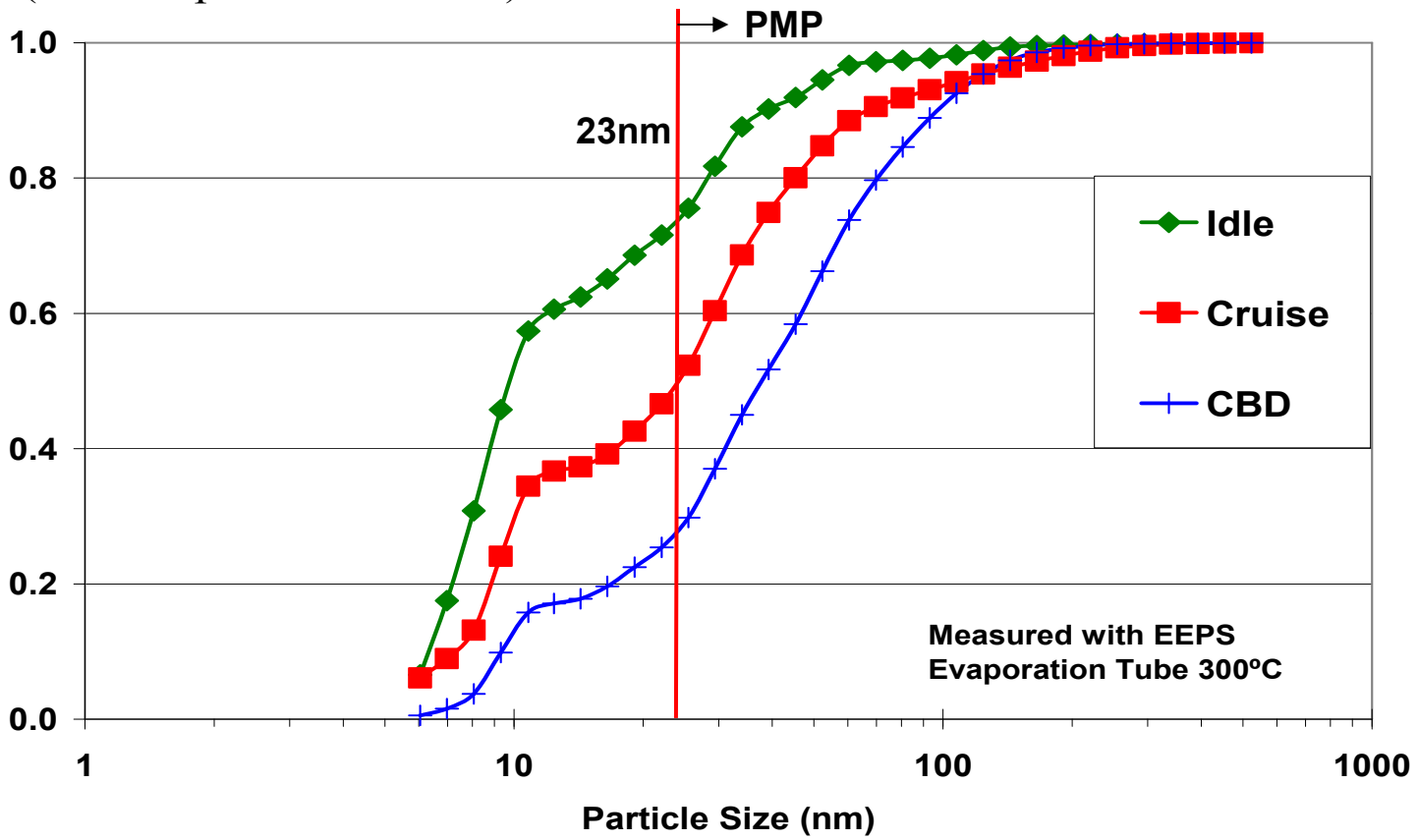

**Sample Hot: ~194°C**

**Sample Cold: ~57.5°C**

# THE PMP EVALUATION

## CUMULATIVE NORMALIZED AVERAGE SIZE DISTRIBUTION

(Post Trap Measurements)




•Depending on cycle, 25-75% of solid particles (i.e. VPR tube on) appear to be smaller than 23nm.

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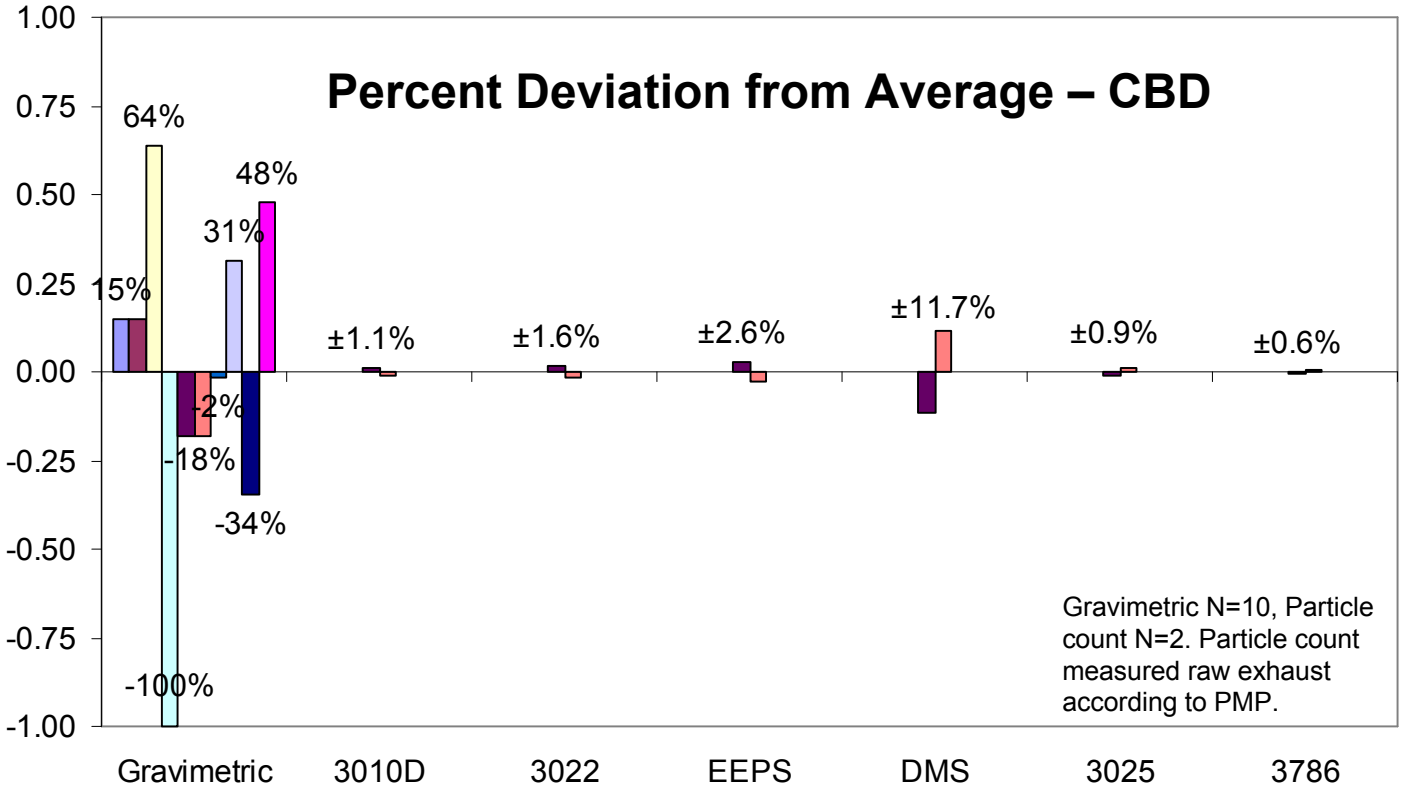
# THE PMP EVALUATION

## COUNTING STATISTICS (Post Trap Gravimetric and Particle Number)




**Size cut [nm]: →** **23** **7** **5.6** **3**

- Average Gravimetric: 0.006g/mile, measured according to current CFR
- Particle number measured with CPC's

**5.6** **2.5**

# CONCLUSION

## Instrument Comparison

- Relative CPC particle count is reasonable at all concentrations.
- Multi-channel instruments generally agree well with CPC's during transient cycles, but not during cruise and idle.
- Multi-channel instruments are noisy at the concentrations called by the PMP (<10,000 p/cc)

## PMP Evaluation

- The PMP particle number measurements are more precise than gravimetric measurements made under current CFR for a California Trap equipped diesel truck.
- There are solid particles smaller than 23nm that can be counted with comparable accuracy.
- Little difference seen whether evaporation tube is used or not for 3010D.

# UNSOLVED QUESTIONS

- Counting only solid particles >23nm misses a lot of particles and does not appear to improve repeatability.

- Discrepancies between PMP specifications and what is possible with the identified instrumentation.

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# FUTURE TEST PLAN

**Planning ARB Research Projects**

- Toxicity investigation of volatile and non-volatile particle emissions.
- Sample from CVS per PMP intent via dynamometer and on-road testing.

**The Golden Vehicle is On Its Way to California**

- PEGEUOT 407 HDi FAP 2000 cc.