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Comparison of Particulate Matter Emission Measurements by Laser-Induced Incandescence to the Gravimetric Procedure

Tao Huai[1], Greg J. Smallwood[2], Alberto Ayala[1], William D. Bachalo[3], Greg Payne[3], Peter O. Witze[4], Kent Johnson[5], Tom Durbin[5], Donald J. Chernich[1], and Hector Maldonado[1]

[1]California Air Resources Board, Sacramento, CA
[2]National Research Council Canada, Institute for Chemical Process and Environmental Technology, Ottawa, Ontario, Canada
[3]Artium Technologies, Inc. Sunnyvale, CA
[4]Sandia National Laboratories (Retired)
[5]Department of Chemical and Environmental Engineering, Bourns College of Engineering, Center for Environmental Research and Technology (CE-CERT), University of California, Riverside, CA

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STUDY DRIVERS (I)

- In-kind collaboration by all participants upon the recognition of the need for evaluation of promising technology.

- A need to understand actual in-use emissions from diesel engines drives the development of portable emissions measurement systems (PEMS). These become the focus of new research into a practical alternative to fixed-laboratory reference methods.

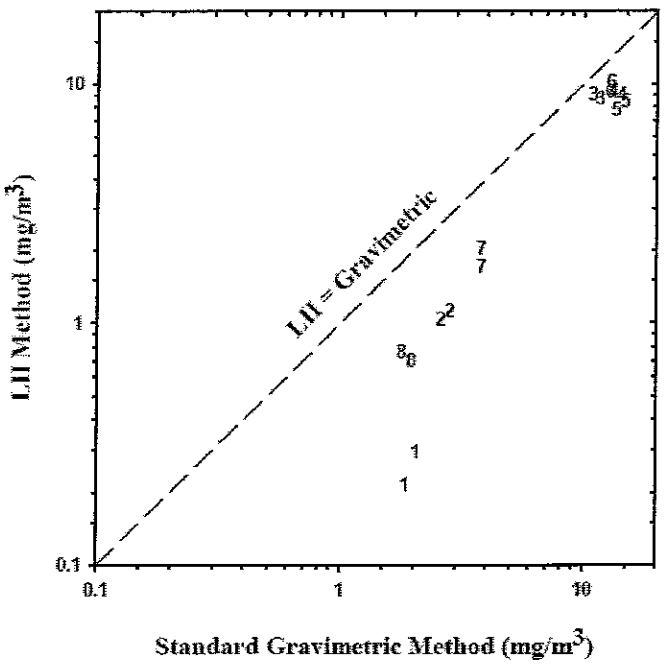
STUDY DRIVERS (II)

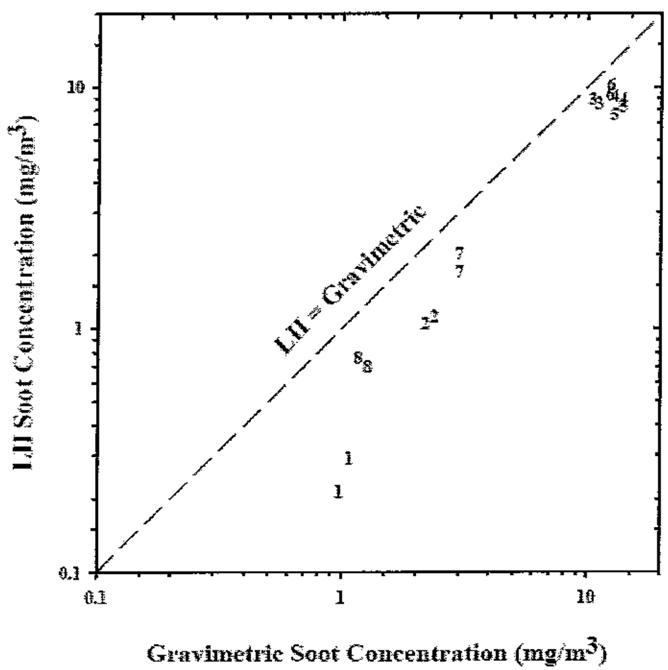
- Laser Induced Incandescence (LII) has several advantages over other measurement methods and emerges as a promising PEMS. LII attractive features include large measurement range, high sensitivity, nearly maintenance-free operation, direct raw-exhaust measurement (no need for dilution), wide range of applications, and superior time response (20Hz).

- LII is a new technique for in-use vehicle emission measurements that needs to be evaluated. Topics such as precision, repeatability, and the performance over real-world vehicle testing (comparisons to gravimetric methods & other real-time methods) remain to be independently determined.

BACKGROUND

- **LII has been presented to CRC in 2003 and 2004.**
- **In a number of earlier studies, primarily engine dynamometer testing, the LII technique was shown to be a viable tool for real-time PM measurements*.**





* Neill et al., Effect of EGR on heavy-duty diesel engine emissions characterized with laser-induced incandescence. ASME-ICED 2002 Fall Technical Conference.

OBJECTIVES

- **Evaluate the utility of LII as a PEMS tool for real-world, in-use PM measurements.**
- **Investigate the PM emissions as measured with LII over various heavy-duty diesel vehicles and driving conditions.**
- **Draw interpretations and conclusions about LII's potential.**

EXPERIMENTAL MATRIX

1. **Preliminary Investigation (November 2004)**
   - **CARB Stockton heavy-duty emissions lab (SL) w/ Partial flow PM sampling system (Total PM only)**
   - **Vehicle chassis dynamometer (steady-state)**
   - **Sandia LII system**

2. **CARB PEMS Study (April 2005)**
   - **CARB Los Angeles heavy-duty emissions lab**
   - **CE-CERT MEL* full-flow CVS (Total PM, EC/OC & Real-time)**
   - **Vehicle chassis dynamometer**
   - **Artium LII 200 instrument**

3. **On-road Investigation (June 2005)**
   - **CE-CERT MEL* full-flow CVS (Total PM & EC/OC)**
   - **On-road driving test (Stockton routes)**
   - **Artium LII 200 instrument**

*The Mobile Emissions Laboratory (MEL) is a CFR-compliant "CVS on wheels" that has been described extensively in the research literature

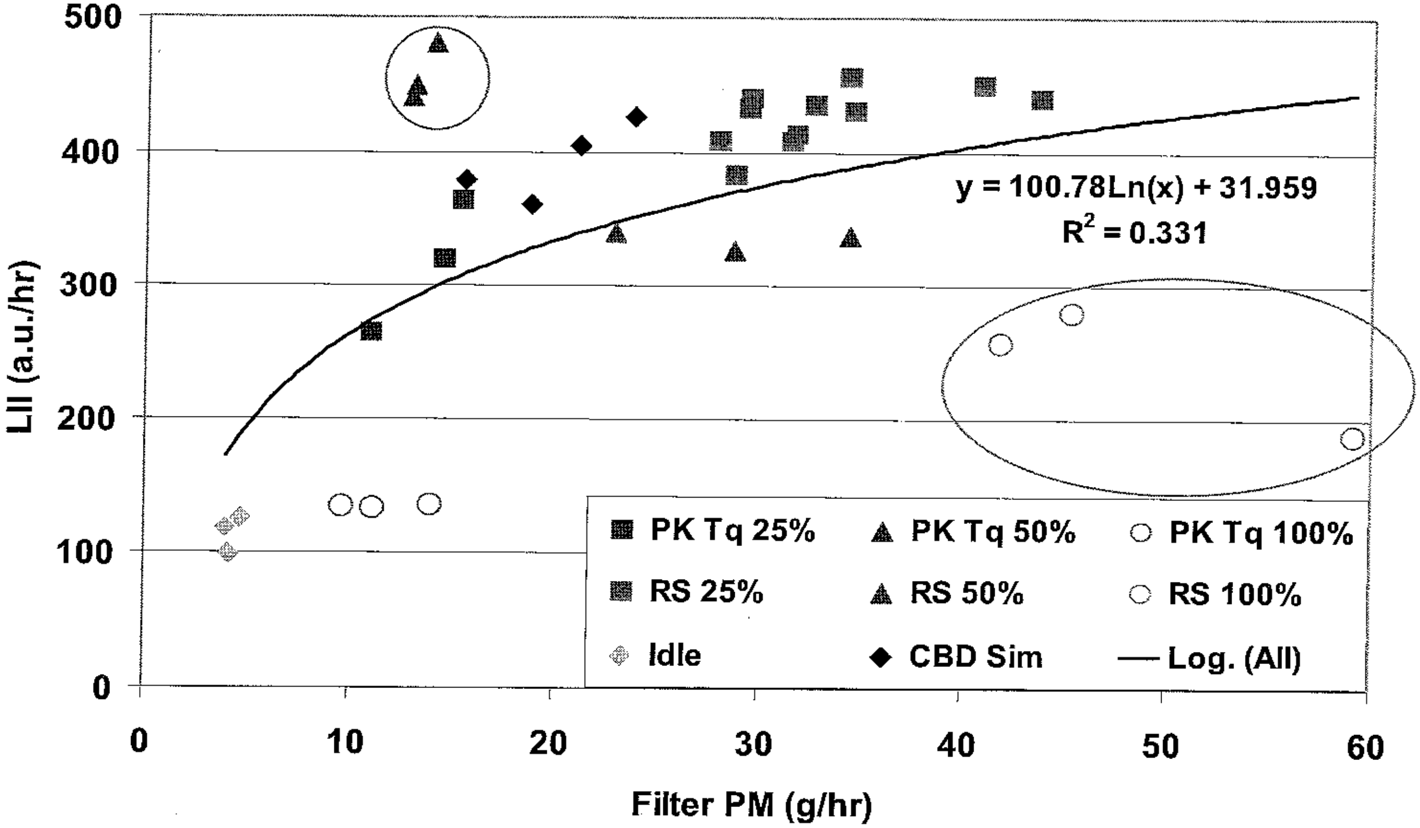
1. PRELIMINARY INVESTIGATION

- **Experimental Procedure**
  - **Sandia LII system**

ID	Testing Mode	Load	Run
1	Peak Torque Speed	25%	4
2	Peak Torque Speed	50%	3
3	Peak Torque Speed	100%	3
4	Rated Speed	25%	11
5	Rated Speed	50%	3
6	Rated Speed	100%	3
7	Idle		3
8	CBD Simulation		4

1. PRELIMINARY INVESTIGATION

- **Results (Sandia's LII System)**



* a.u.: arbitrary units

1. PRELIMINARY INVESTIGATION

- Observations
  - The correlation was poor, specially both "PK Tq 50%" and "RS 100%" were likely outliers.
    - Ayala et al., SAE 2005-01-3798 states that lower load shows higher PM emission rates compared to higher load.
  - A linear trend can be found between the LII signal and the PM filter mass below 20 g/hr.
  - Lower response in the LII signal to changes in PM filter mass above 20 g/hr.

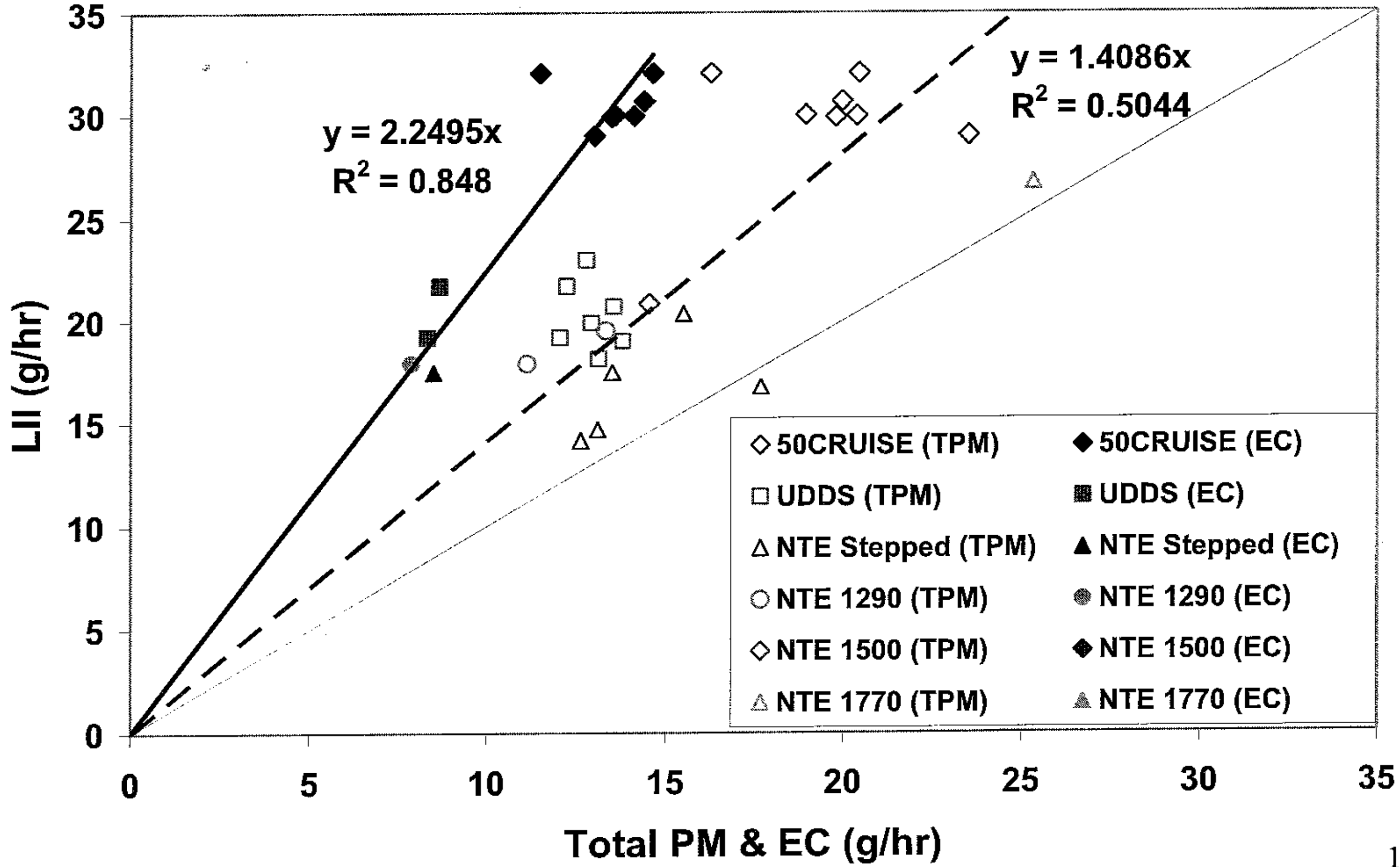
2. CARB PEMS STUDY

- **Experimental Procedure**
  - **Artium LII 200 instrument**

ID	Testing Mode	Valid Runs #	Valid EC Runs #
1	UDDS	7	2
2	50CRUISE	7	7
3	NTE_1290	2	1
4	NTE_1500	1	0
5	NTE_1770	2	0
6	NTE_Stepped	6	1

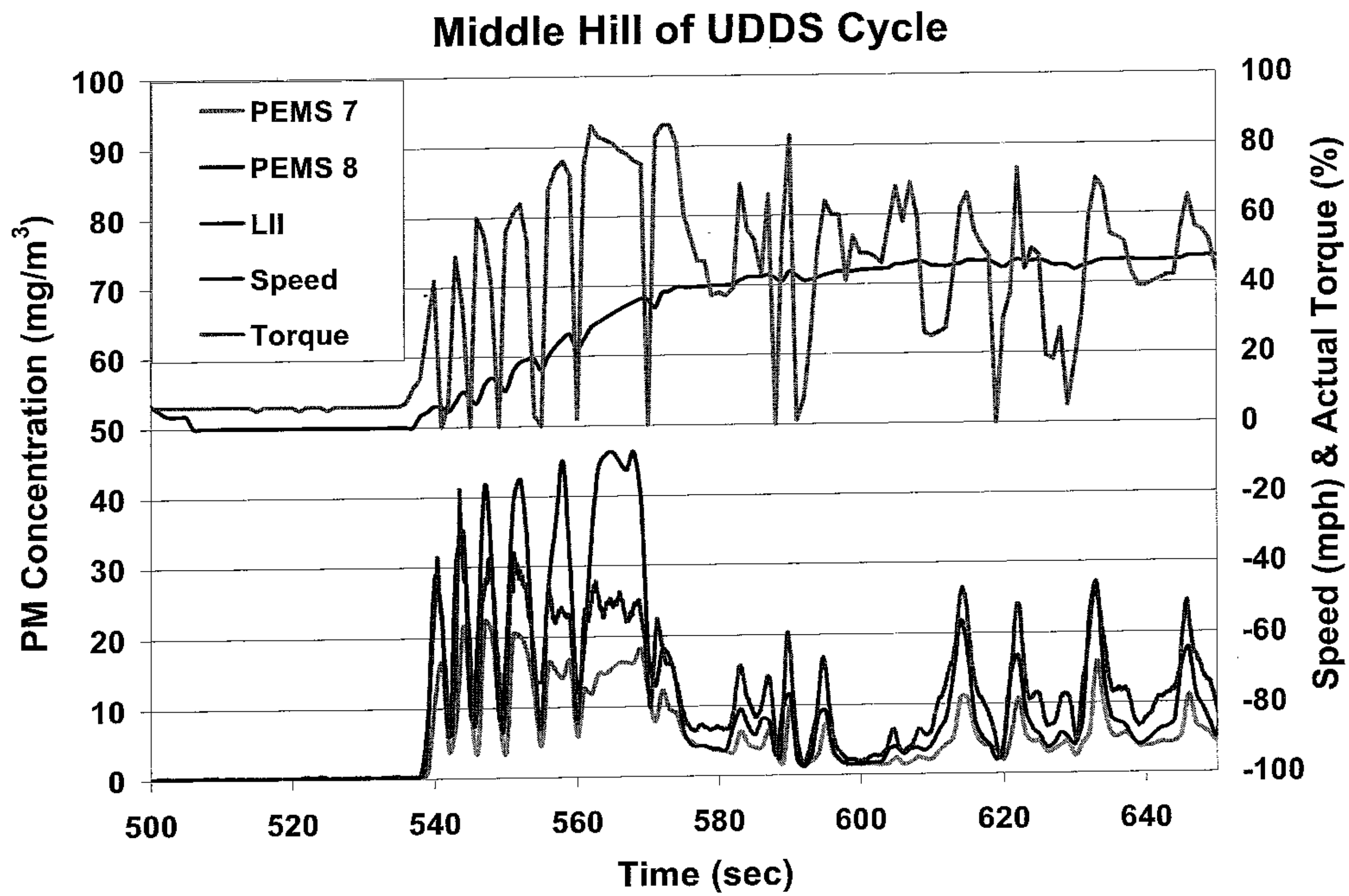
2. CARB PEMS STUDY

- Results (cycle base)



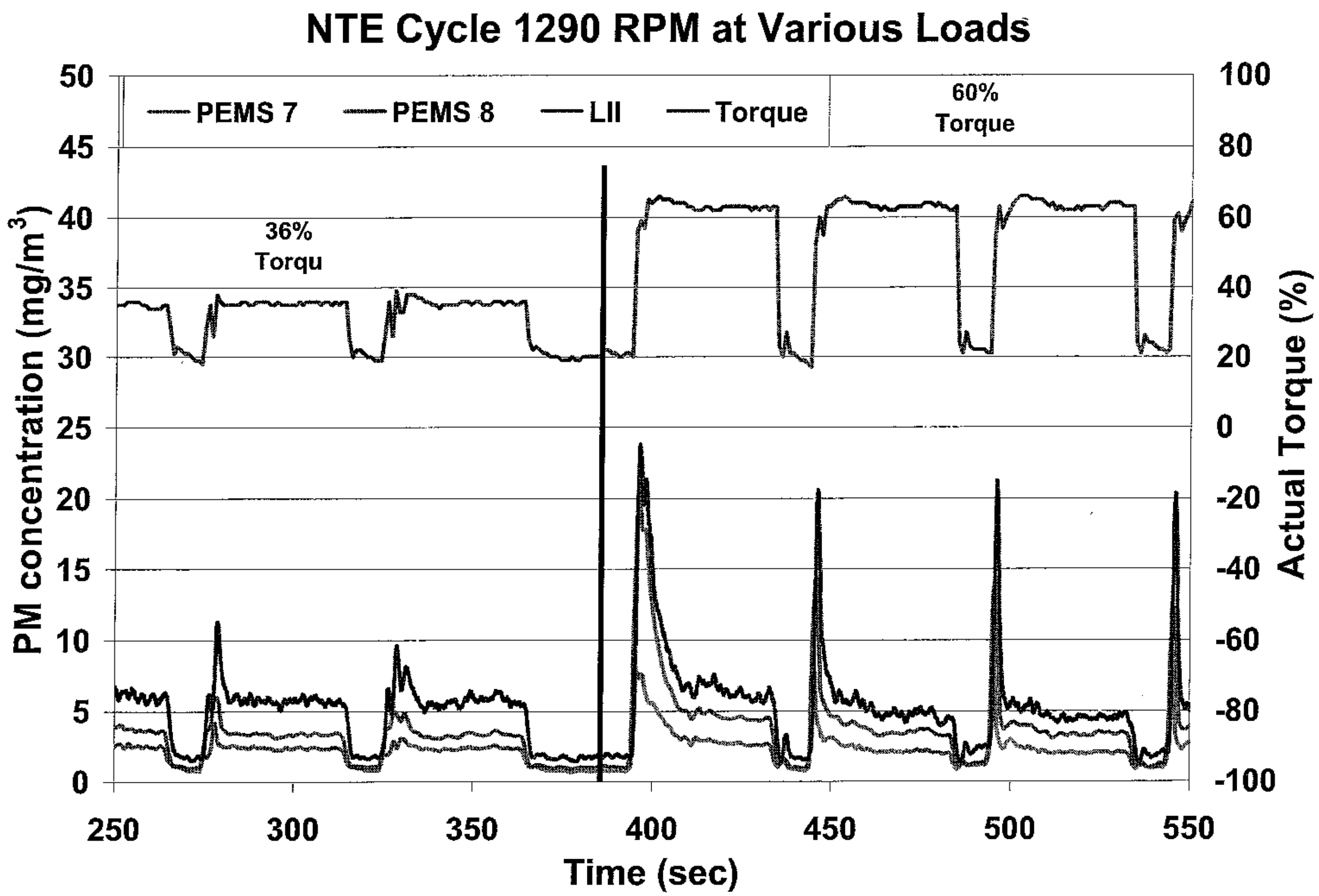
2. CARB PEMS STUDY

- Results (real-time base)



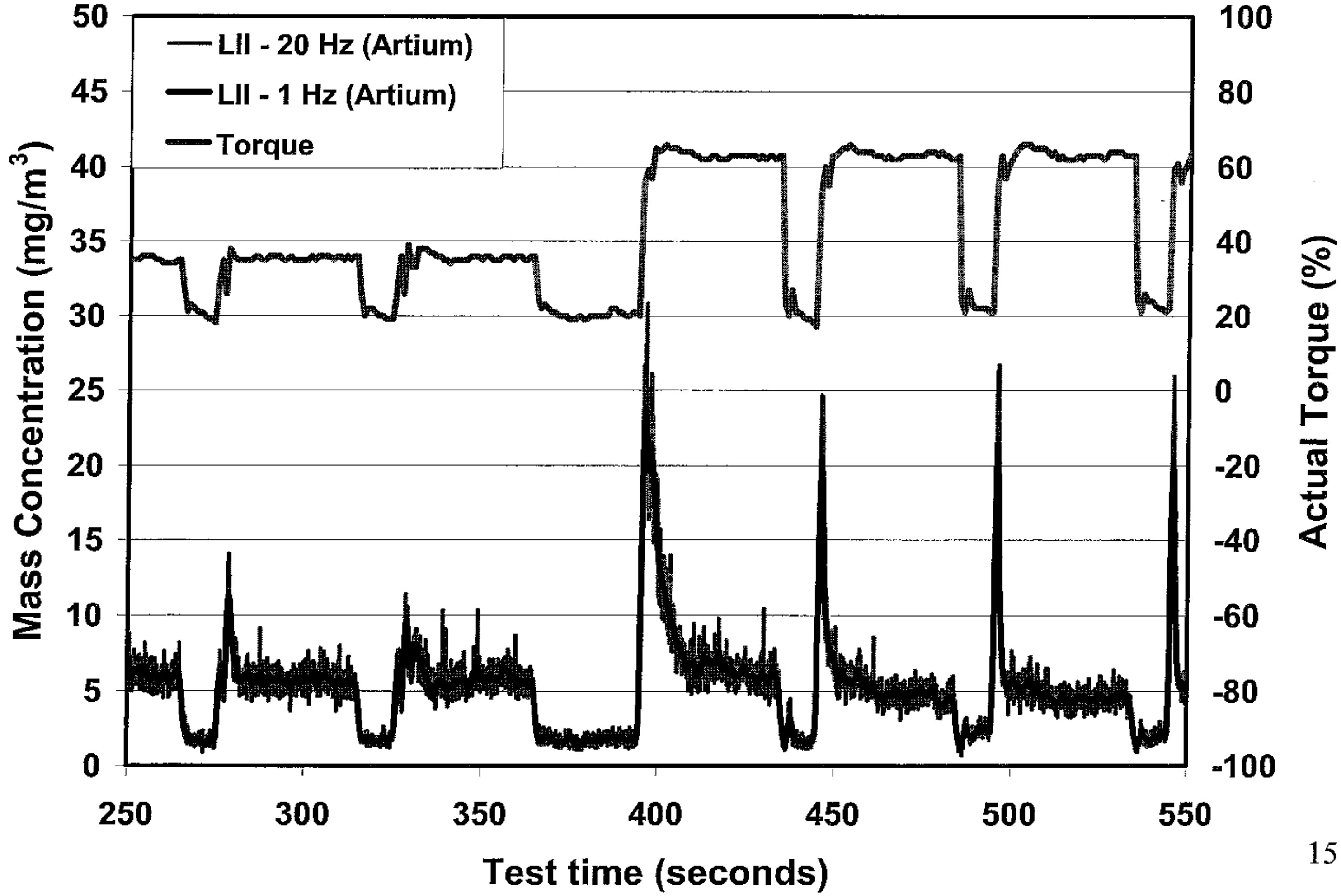
2. CARB PEMS STUDY

- Results (real-time base)



2. CARB PEMS STUDY

- Results (20 Hz and 1 Hz)



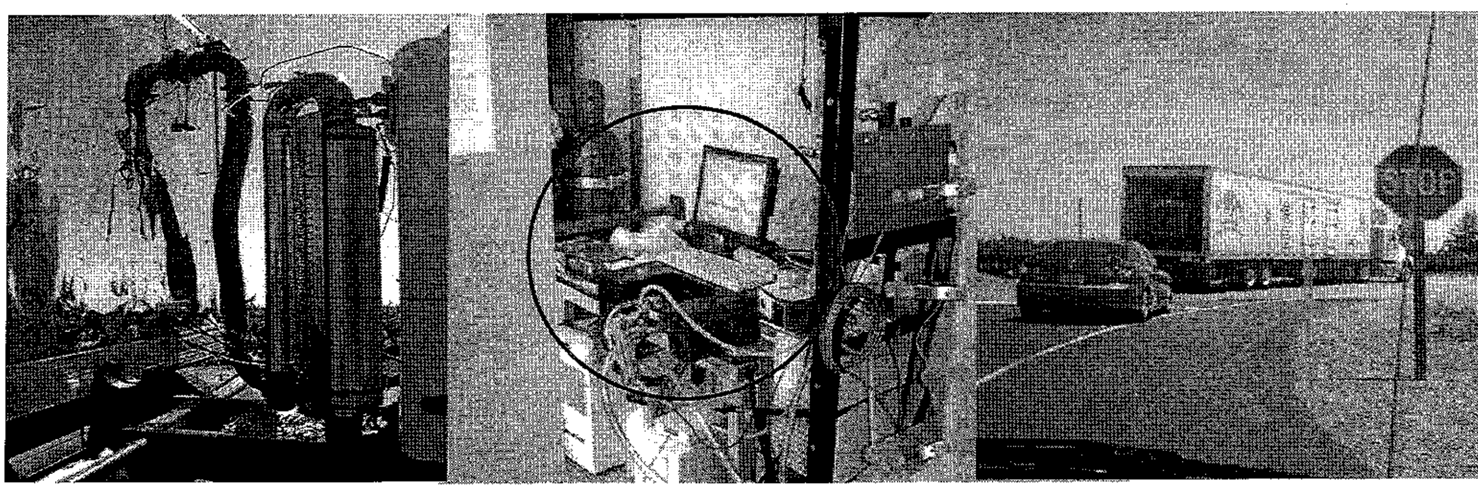
2. CARB PEMS STUDY

- **Observations:**
  - The peak temperatures reported by LII system used were lower than expected when Artium was acquiring data. This was later determined to be caused by an incorrect calibration.
  - The LII and EC fraction of the PM show reasonable agreement. However, when looking at total PM, the results are further apart.
    - LII is higher than total PM and it cannot to be attributable solely to the OC fraction.
    - The higher LII values would be the consequence of the incorrect calibration of the instrument.
  - Like other PEMS, the LII instrument has been shown to reliably follow the torque transients in all of the different cycles (UDDS, NTE, 50CRUISE).

3. ON-ROAD INVESTIGATION

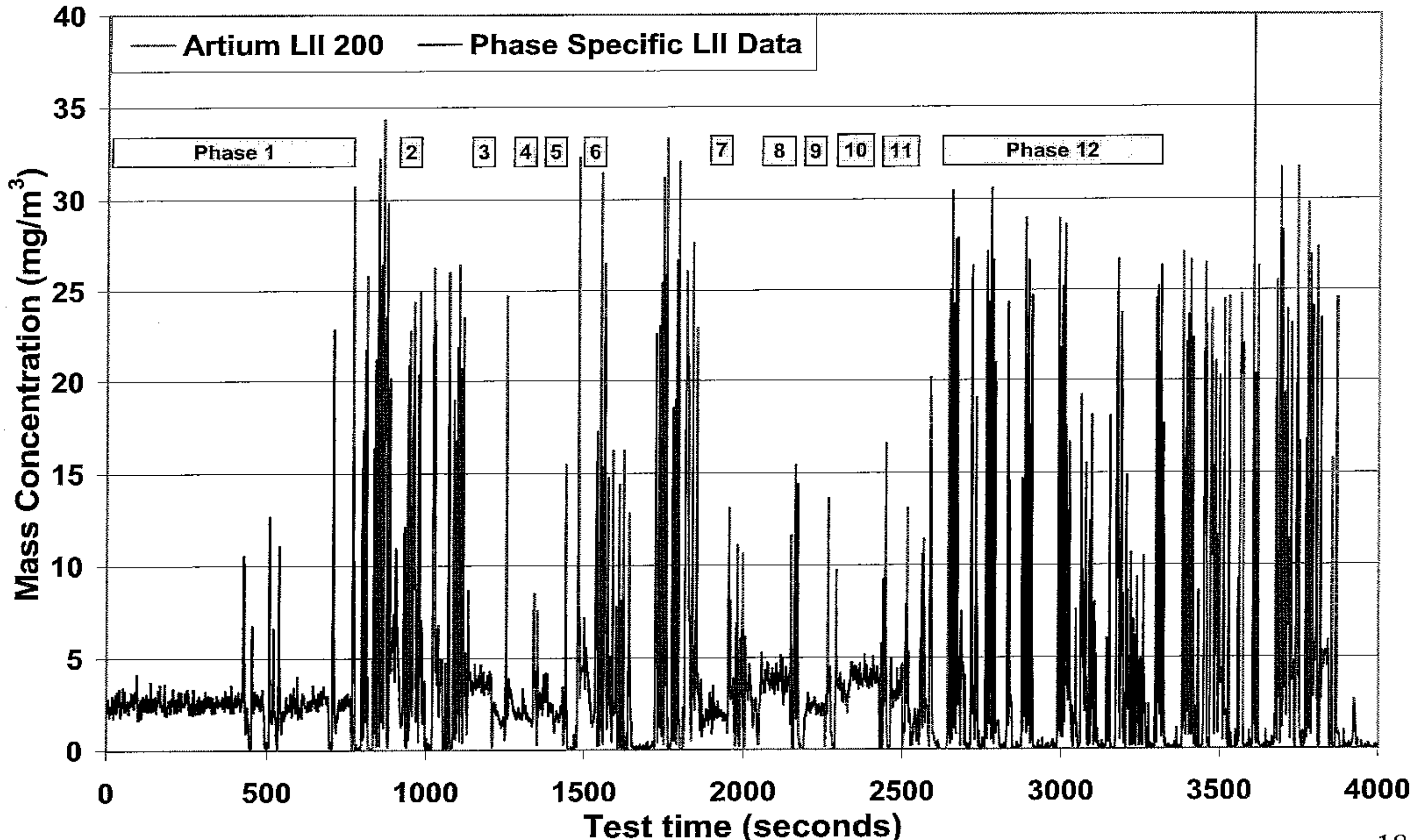
- **Experimental Procedure**

Mfg/Model/Yr	Phase #	Trace	Filter PM (CE-CERT)	Real-time PM (LII)
DDC/Series60/2002	1	55Cruise	√	√
CUM/ISM/2004	2	PowerLug		√
Mack/AC427/2003	3	40Cruise		√
	4	40NoCruise		√
	5	40Cruise		√
	6	PowerLug		√
	7	55NoCruise		√
	8	65Cruise		√
	9	55Cruise		√
	10	70Cruise		√
	11	55Cruise		√
	12	HammerRd	√	√



3. ON-ROAD INVESTIGATION

- **LII and MEL Time-aligned Data**



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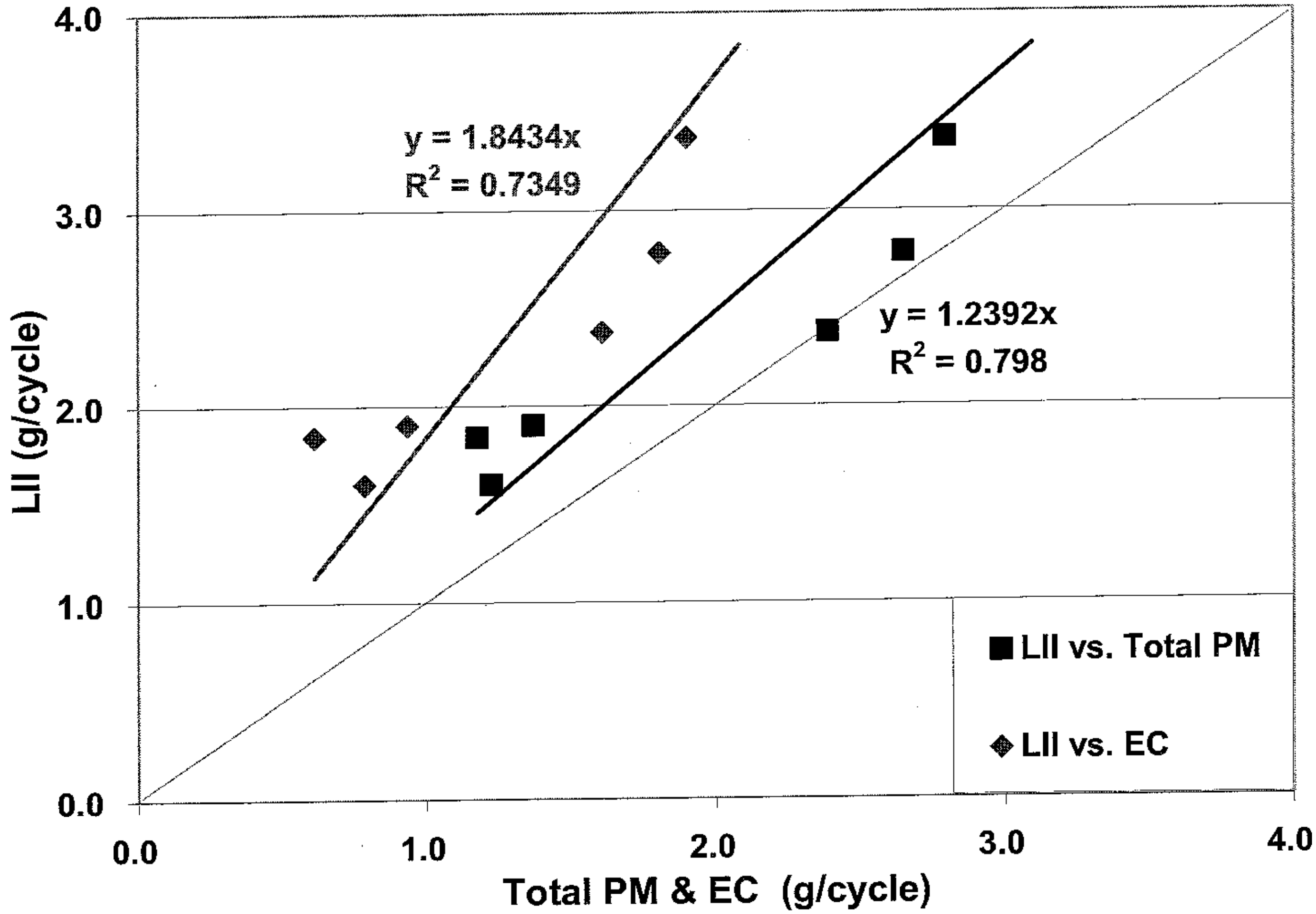
3. ON-ROAD INVESTIGATION

- Results



3. ON-ROAD INVESTIGATION

- **Observations:**
  - Real-time response provides unparallel resolution for discretizing transient events during real-world driving.
  - Integrated LII results show good linear agreement with both EC and total PM filter sample.
  - Similar findings here to those from CARB's PEMS study: LII cumulative results are higher than both EC and total PM. This is due to the incorrect calibration.

LESSONS LEARNED

- **Calibrate religiously <u>before</u> and <u>after</u> each experiment**
  - **Especially when using a novel technique!**
- **Ensure that data transmission between instruments is accurate (digital is best)**
- **Collect EC/OC filters on <u>every</u> cycle**
  - **For on-road testing, collect a series of filters during entire run.**
- **Enhance instrument fail-safe operation**
  - **Automatic self-tests to flag off-specification results, such as peak particle temperature, detector failure, etc.**
  - **Higher sensitivity (100-fold) to significantly improve the resolution and accuracy at low concentrations.**
  - **Develop software to simplify data analysis, plotting and presentation for more display of real time information.**
  - **Devise and develop a quick in-field means for verifying the calibration.**

NEXT STEPS

- More steady–state chassis dyno experiments (well-controlled conditions)
  - Direct measurement comparisons of LII to gravimetric over a range of speed/load operating conditions
  - Investigate repeatability and uncertainty in both measurements
  - Determine effects of varying EC/OC ratio
  - Compare dilute LII to undilute LII measurements over the same range of speed/load operating conditions
  - Perform before and after trap measurements with LII to establish sensitivity limits
- The next CARB/NRC/Artium/CE-CERT collaboration will take us back to more over-the-road testing in the near-future (so we will be back next year to CRC!).
- Investigate derivation of a correlation for total PM based on the LII measurements, with engine speed/load/EGR (and other parameters relevant to the EC/OC ratio) as inputs to the correlation.

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Maria Clancy
National Research Council Canada
Inst For Chem Process & Envir Tech
M-12, Room 141, 1200 Montreal Rd.
Ottawa, ON K1A 0R6
CANADA

Telephone: 613/993-4041

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