Advanced Collaborative Emissions Study (ACES)

Cooperative multi-party effort to characterize emissions and possible health effects of new advanced heavy duty engine and control systems and fuels in the market 2007 – 2010.

DOE Merit Review June 2011

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This presentation does not contain any proprietary or confidential information

ID # ACE044

NETL Agreement 13919

Project Overview

Phases:

1. 2007 Engine Emissions Characterization (Southwest Research Institute® (SWRI®))
   - *CRC Technical Leader*
2. 2010 Engine Emissions Characterization
   - *CRC Technical Leader*
3. 2007/2010 Engine Health Effects Testing (Lovelace Respiratory Research Institute (LRRI)
   - *Short Term biological screening and Long-Term Health Effects Test on 2007 Engines*
   - *HEI Technical Leader ; CRC Technical Monitor*

Funding

Overall Project: $15.5 million

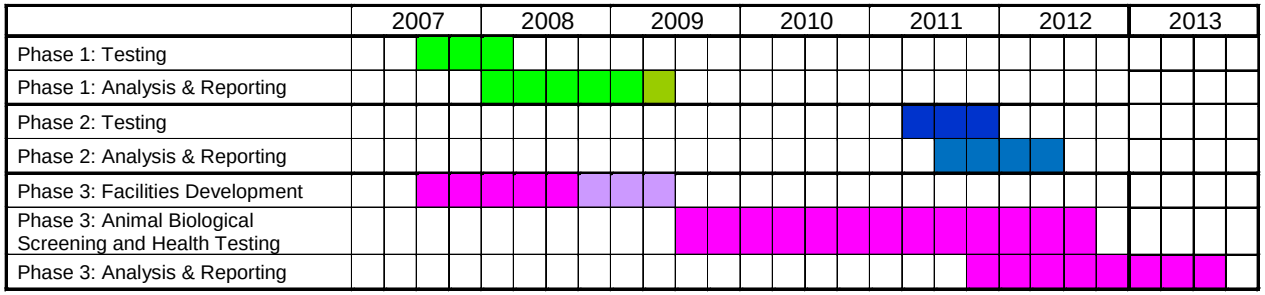
- Total DOE Contract: $5.95 million (Contractor Share: $3.98 million)
  - FY 10 DOE Funding: $500,000
  - FY 11 DOE Funding: $700,000 (planned)

Partners

- DOE OVT and NETL
- Engine Manufacturers Association (EMA)
- US Environmental Protection Agency (EPA)
- California Air Resources Board (ARB)
- American Petroleum Institute (API)
- Aftertreatment Manufacturers
- Coordinating Research Council (CRC)

Overall Project Timeline

Slight delays in Phase 2, 3



RELEVANCE:
Evaluating Emissions of Advanced Technology Diesels

- *DOE OVT MYPP Advanced Combustion R and D*: New Generation diesel engines are highly fuel efficient and a likely significant contributor to enhanced fuel economy for the next 15 – 20 years IF they gain wide acceptance
- The combination of advanced-technology, compression-ignition engines, aftertreatment systems, reformulated fuels and reformulated oils developed to meet the 2007/2010 emission standards will result in substantially reduced emissions.
- Substantial public health benefits and enhanced public acceptance and use are expected from these reductions.
- With any new technology it is prudent to conduct research to confirm benefits and to ensure that there are no adverse impacts to public health and welfare.

Overall Objective

- *to characterize emissions and possible health effects of new advanced heavy duty engine and control systems and fuels in the market 2007 – 2010*

HEI ACES Oversight Committee

Mark Utell, Chair	University of Rochester	David Kittelson	University of Minnesota
Richard Albertini	University of Vermont	Eugene McConnell	Consultant, Former NTP Director
Ken Demerjian	SUNY Albany	Gunter Oberdorster	University of Rochester
Helmut Greim	Technical University of Munich	Charles Plopper	University of California, Davis
Uwe Heinrich	Fraunhofer Institute	Howard Rockette	University of Pittsburgh
Tom Kensler	Johns Hopkins University	James Swenberg	University of North Carolina, Chapel Hill

Partners: CRC ACES Panel

Reynaldo Agama	**Caterpillar**	**M. Matti Maricq**	**Ford Motor Company**
James Ball	**Formerly Ford Motor Company**	**Mani Natarajan**	**Marathon Petroleum Company LLC**
Nicholas Barsic	**John Deere**	**Ralph Nine**	**US Department of Energy / NETL**
Steve Berry	**Volvo**	**Robert Okamoto**	**California Air Resources Board**
Steven Cadle	**Formerly General Motors R&D Center**	**Charles Schleyer**	**ExxonMobil**
Timothy French	**Engine Manufacturers Association**	**Shirish Shimpi**	**Cummins**
Thomas Hesterberg	**International**	**Joseph Somers**	**US Environmental Protection Agency**
Donald Keski-Hynnila	**Detroit Diesel**	**Chris Tennant**	**CRC**
Chris Laroo	**US Environmental Protection Agency**	**Steve Trevitz**	**Volvo**
Douglas Lawson	**National Renewable Energy Laboratory**	**Urban Wass**	**Volvo**
Hector Maldonado	**California Air Resources Board**	**Rashid Shaikh**	**Health Effects Institute**

ACES Phase I Approach and Objectives

- Quantify the significant reduction in both regulated and unregulated emissions from advanced diesel engines,
- Provide regulated and unregulated emissions for this new engine technology,
- Provide initial guidance for ACES Phase 3 health study using the regulated and unregulated emissions information from ACES Phase 1
- Heavy Heavy Duty (Class 8) Engines from: Caterpillar, Cummins, Detroit Diesel, and Volvo

Summary – Phase 1 Results

- Regulated PM, CO, and NMHC emissions were at least 90% below the 2007 standard, and NO_x was 10% below standard
- Most unregulated emissions at least 90% below 2004 technology
- Average NO_2 emission of 0.68 g/hp-hr was 2 to 7 times higher than the emissions from 2004 engines
  - However, 2010 engine technology NO_x limit of 0.20 g/hp-hr will force NO_2 emissions to be substantially lower than both 2007 and 2004 technology engines
- Particle number emissions average was at least 90% below 2004 technology engines, even when DPF regeneration occurred
- Elemental carbon represented only 7 % of total PM mass, and the hydrated sulfuric acid determined from measured sulfate was the dominant PM component for the 16-Hour Cycle, 70 percent of total PM mass
- The final report issued June 30, 2009

ACES PHASE 2: 2010 Compliant Engines Approach and Objectives

- 2010 engines will offer substantial improvements in NOx emissions
- Phase 2 will conduct both Emissions Characterization and some possible Health Testing in 2010-compliant engines
- 2010 technology has evolved in multiple directions and, given credits, will not meet the specific requirements by that date
  - Testing likely to be on “2011” engines
- CRC actively planning with manufacturers, agencies, other sponsors for start in 2011

ACES PHASE 3 Health Bioscreening Approach and Objectives

Phase 3A: Characterization of emissions and exposure atmospheres

Phase 3B: Conduct of animal bioscreening studies

DOE Funding:

- **Characterization of animal exposures**
- **3 month mouse pulmonary bioscreening**

EPA Funding (leveraged by DOE investment):

- **Long-term rat carcinogenesis bioassay**
- **Pulmonary bioscreening at 1, 3, 12 & 24 mo**

PHASE 3A

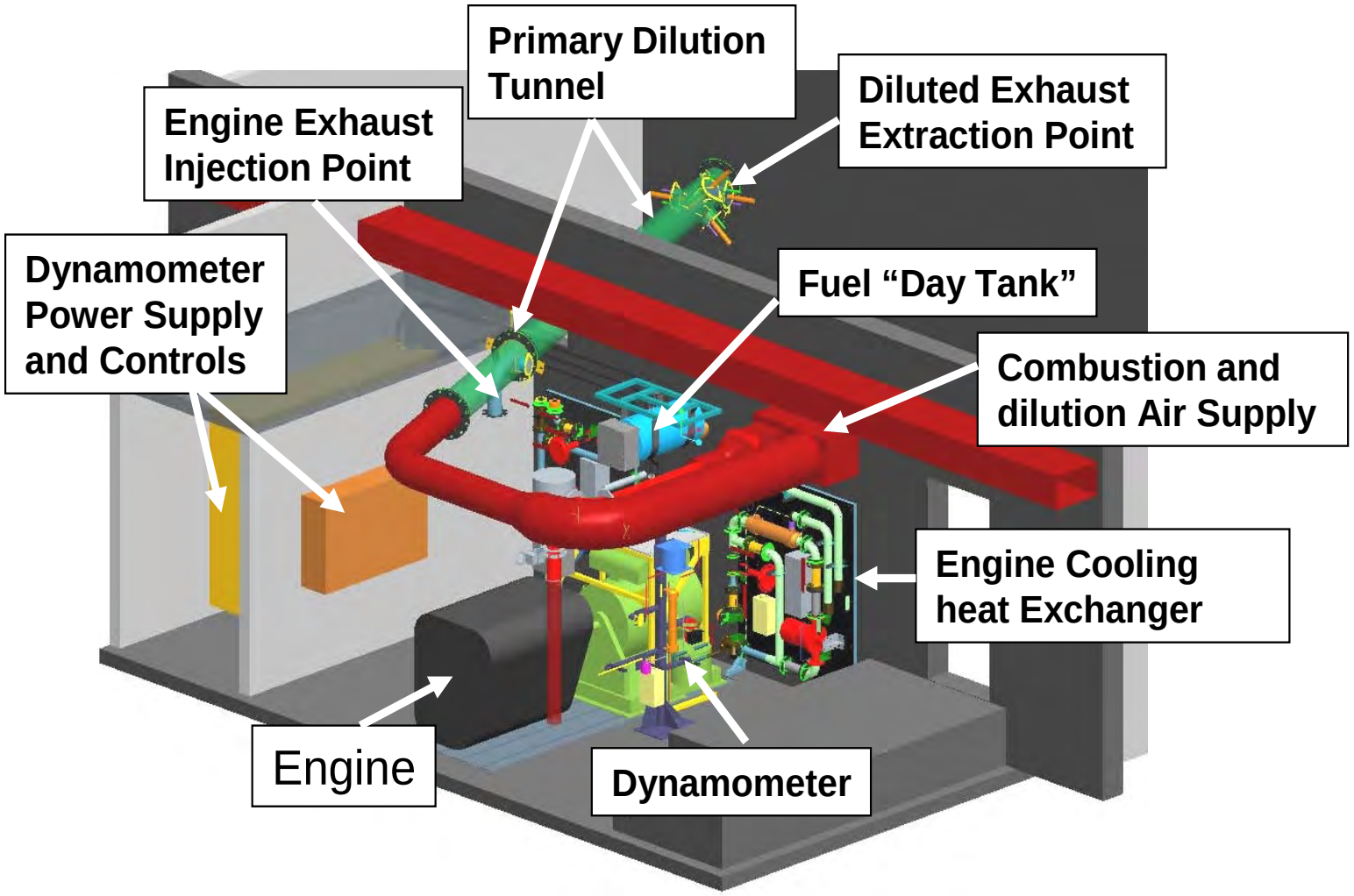
- **2007-compliant "engine B' "** **(selected from four candidates)**
  - **Installed at LRRI in facility created under preceding contract**
  - **Confirmed that engine/control systems met performance criteria**
    - **Steady-state (SS) and Federal Test Procedure (FTP) cycles**
    - **16-hr ACES cycle (4 repeats of 4 hr cycle with cold start)**

- **Evaluated diluted emissions in empty animal chamber, and compared to SwRI results** **(using same fuel)**
  - **Emissions = exhaust + crankcase blow-by**
  - **FTP, SS modes 1, 3 & 5, ACES cycle**
  - **Constant pressure primary dilution tunnel**

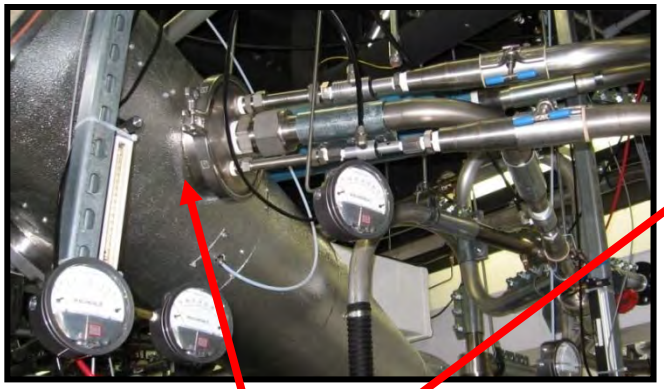
- **Determined dilutions required to meet targets set by HEI**
  - **Dilutions set to achieve 4.2, 0.8 & 0.1 ppm NO_2**
  - **Dilutions ≈ 40:1, 210:1 & 1680:1**

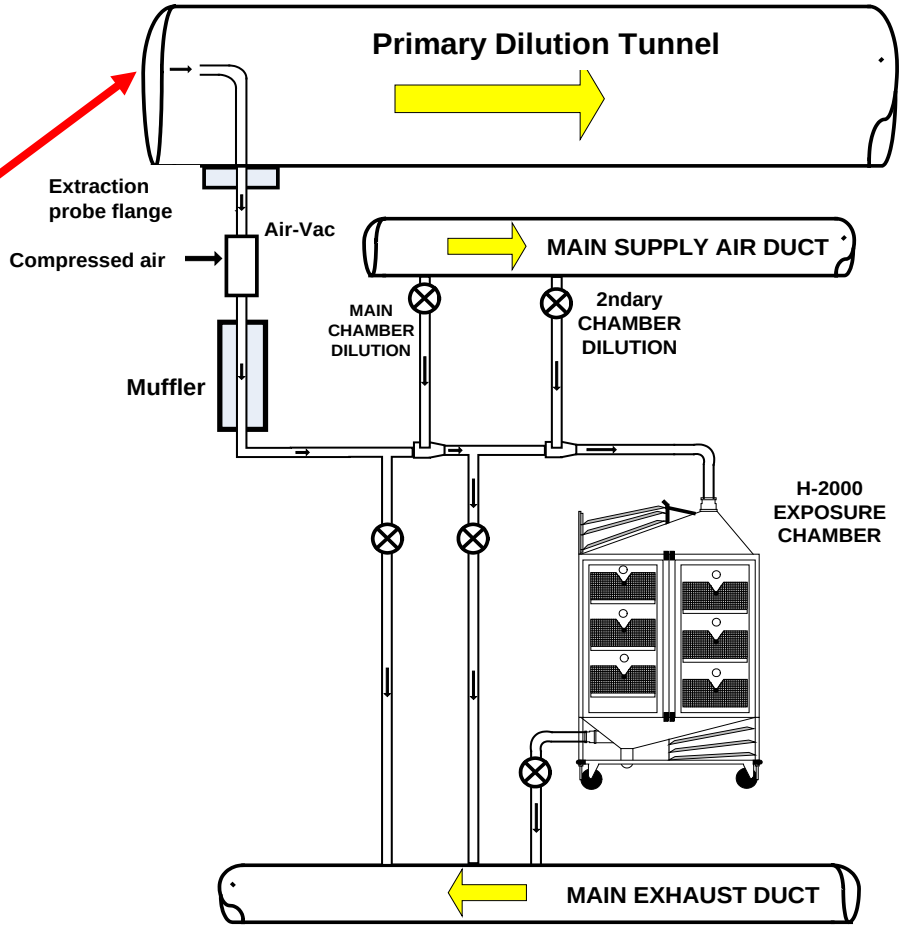
- **PM levels are very low; study may primarily detect effects of NO_2 if any effects are seen**

Engine and Primary Dilution System



Exhaust Extraction and Secondary Dilution Systems





(Note: Drawing is not to scale)

Exposure Atmosphere and Operational Criteria

Exposures Initiated February 21

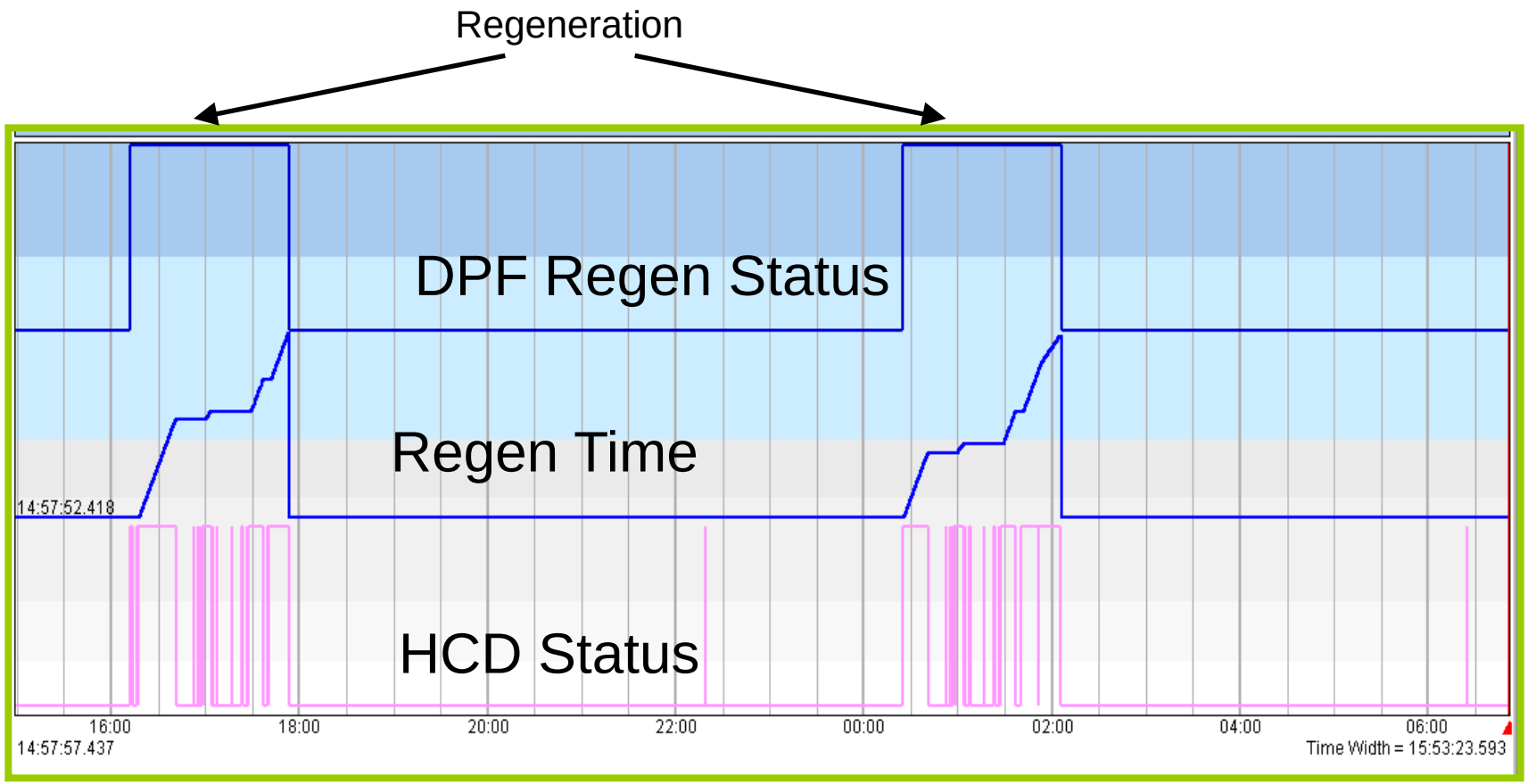
Additional measurements include Particle Mass (inlet and chamber) and CO, CO_2, and Total Hydrocarbons from High Level. Size measured at each level once/week.

Exposures conducted 16 hrs/day, 5 days per week
Exposure chamber temperatures require <26.7°C

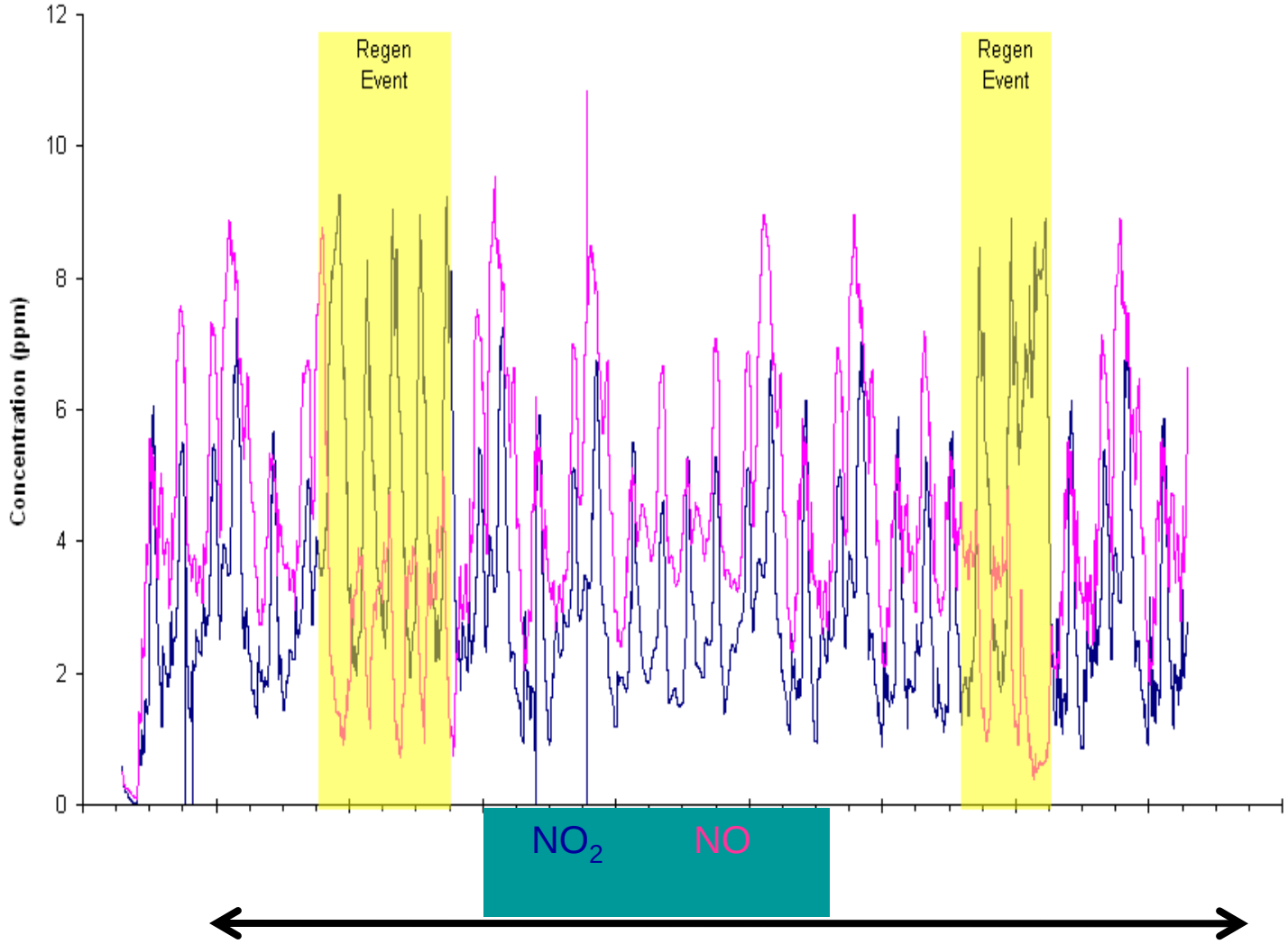
Protocol defines actionable limits for engine system performance

Based on:
NOx (within 100 % of Daily Tunnel Concentrations)
Black Carbon (< 15 µg/m^3)
Particle Mass (<100 µg/m^3)
Diesel particle trap (DPF) pressure (<3.8 lbs/sq inch)
Power/Torque on Engine Maps (20 % of Target)

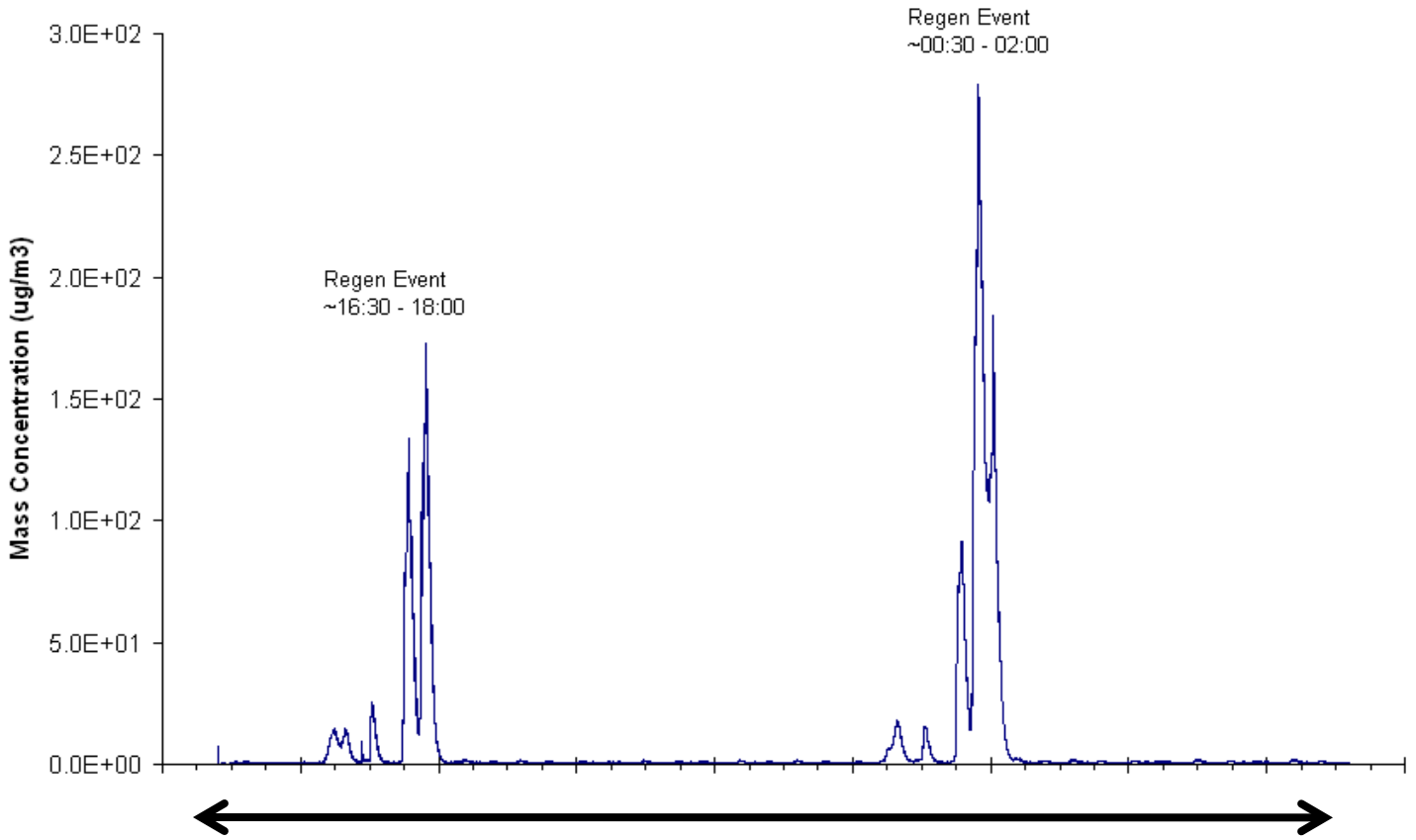
ACES 16-Hr Cycle DPF Zone, Regen Time, and Doser Fuel Cutoff Valve Status (Engine B)



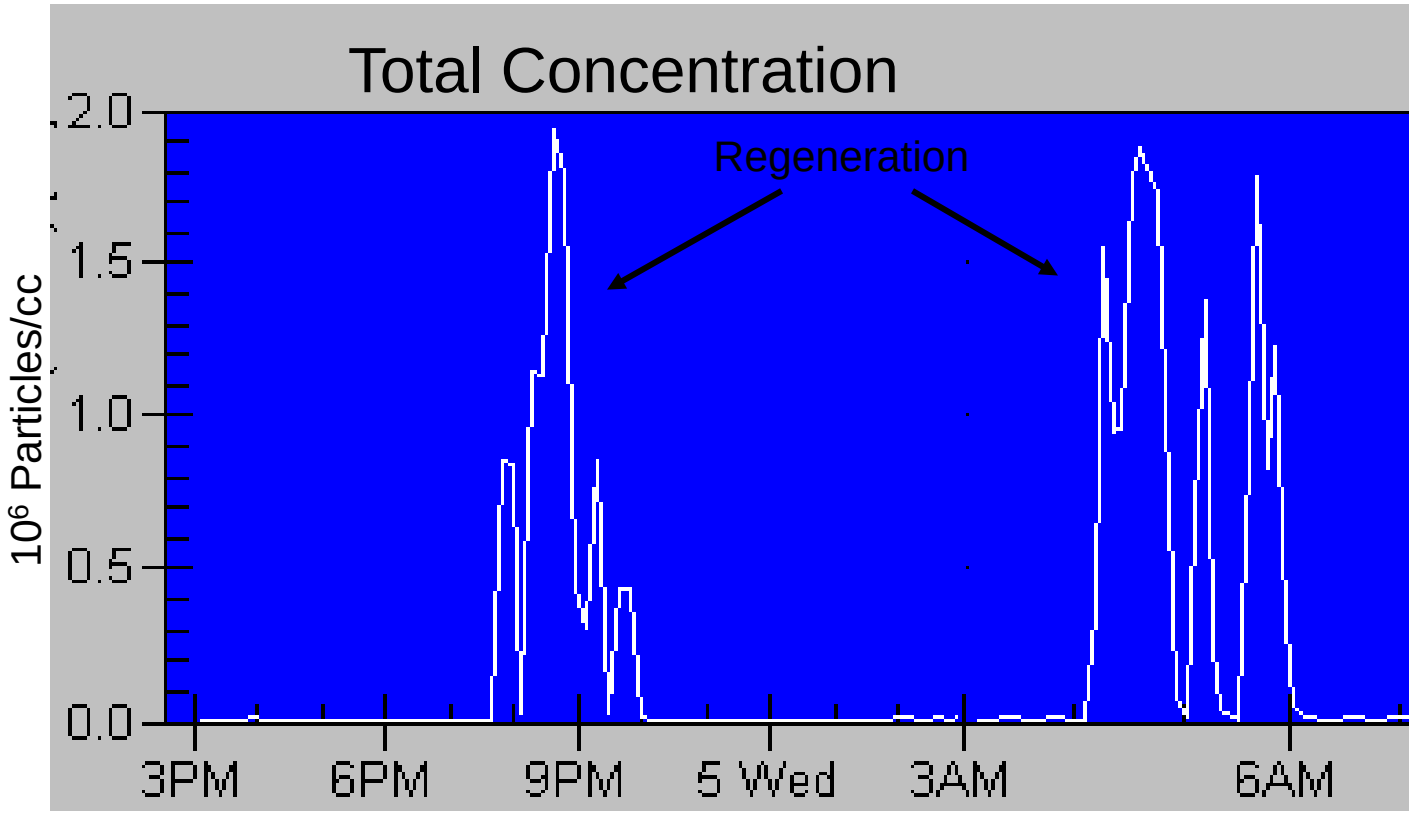
Chamber real-time gas data at High Target



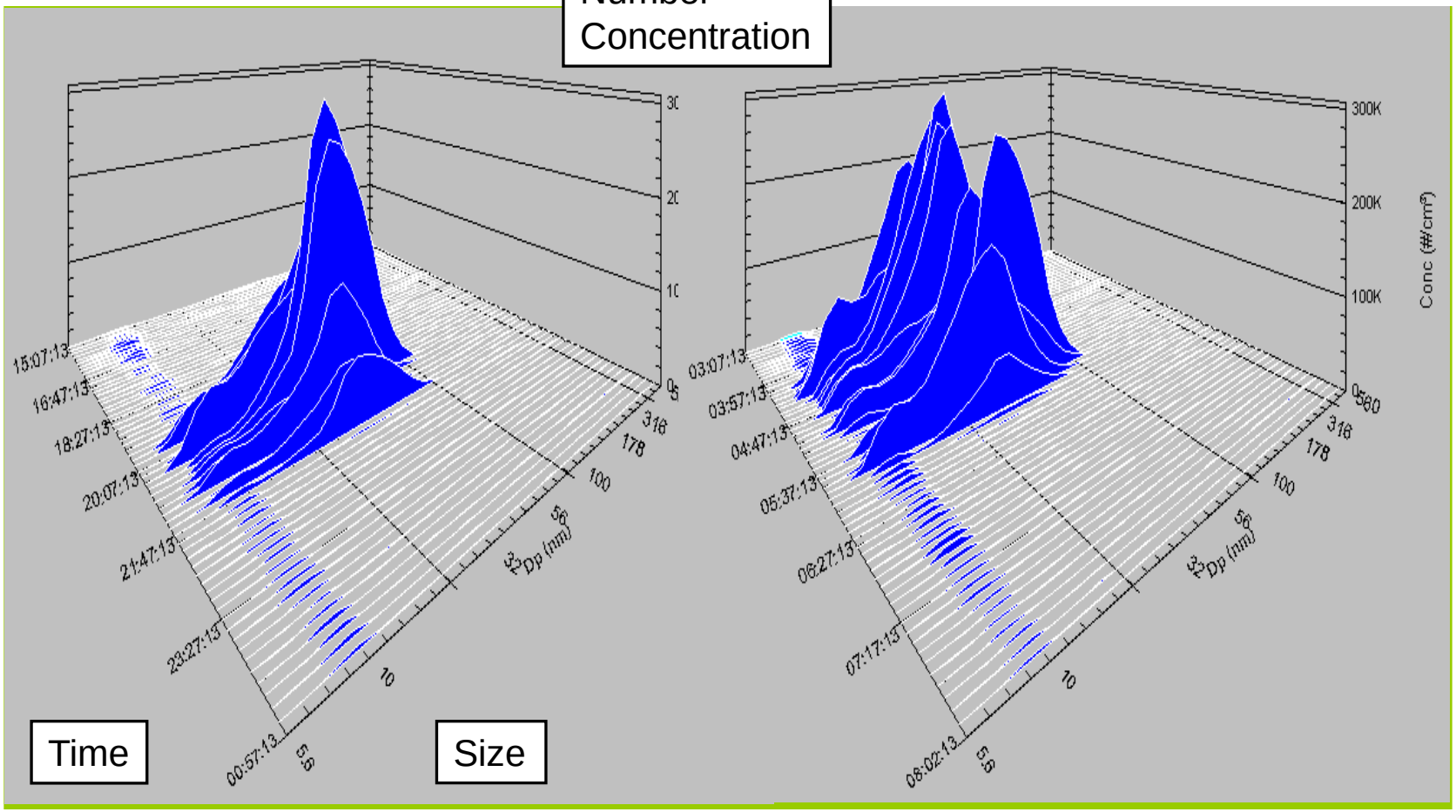
ACES 16-Hr Cycle
Dekati, DMM Mass Concentration



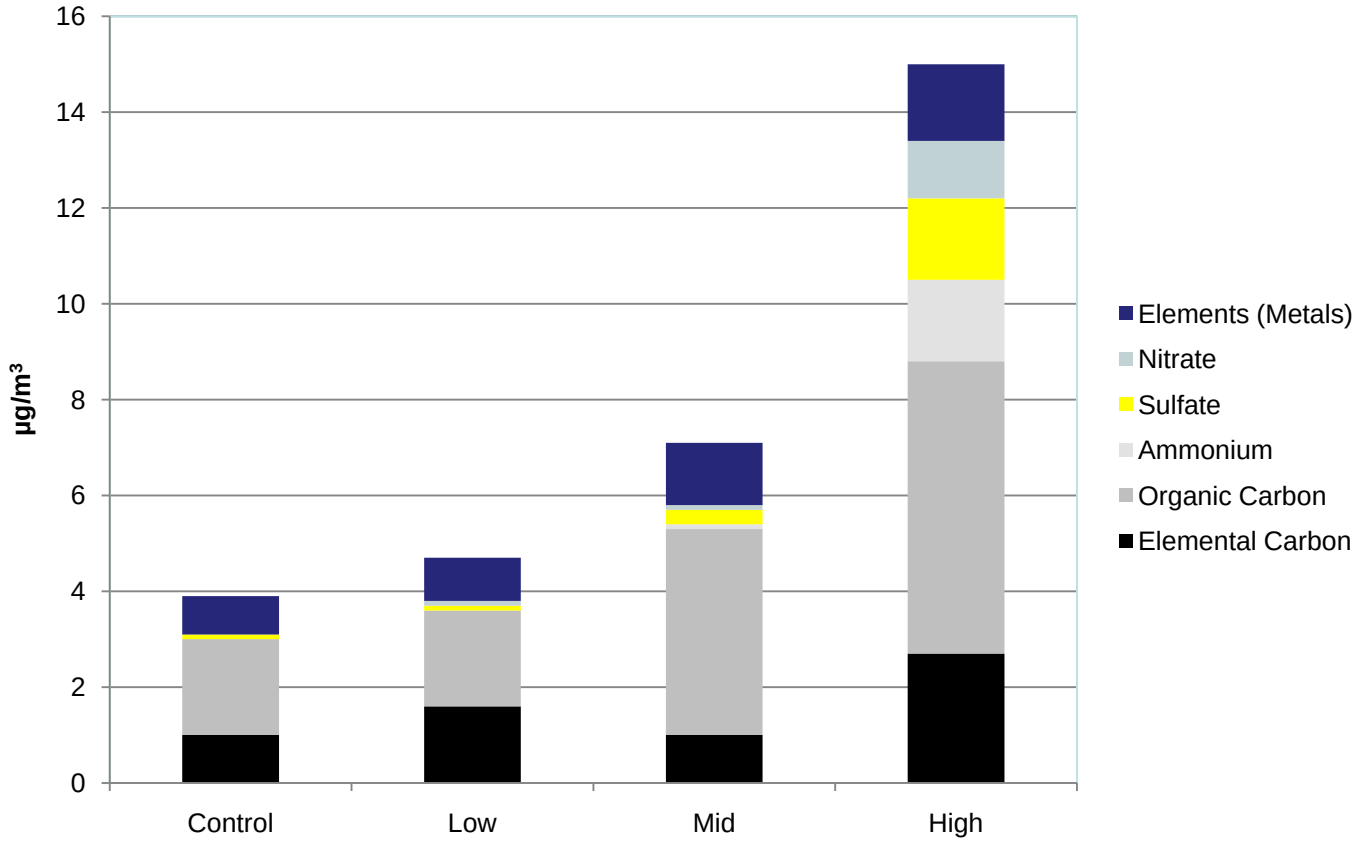
Real-time particle number concentration (FMPS)



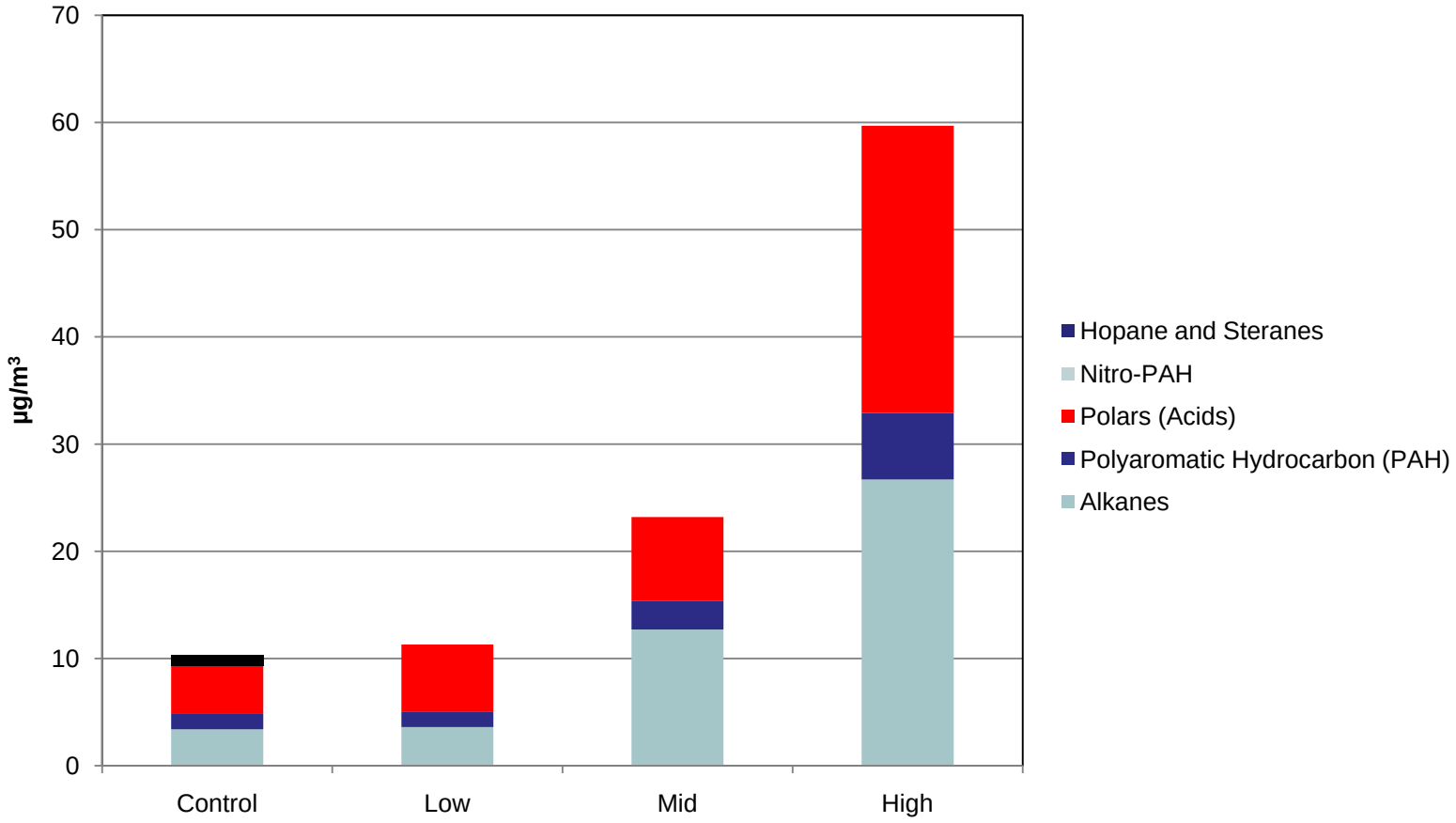
Real-time PM size distribution (FMPS)



Chamber Atmosphere Composition Particulate Matter



Chamber Atmosphere Composition
Semivolatile Organics



CORE BIOSCREENING STUDY: DESIGN

3-Month Exposure of C57BL/6 Mice:

- Expose 120/group 16 hr/day, 5 days/wk for 3 months (13 wk)
- 60/group allocated for evaluation at 1 & 3 months
  - Lung lavage & cell proliferation
  - Hematology & serum chemistry (3 mo)
  - Save tissues for histopathology (evaluation not budgeted)

Chronic Carcinogenicity Bioassay of Wistar Han Rats:

- Expose 288/group 16 hr/day, 5 days/wk for 24-30 months
- 3 dilutions of whole emissions + clean air controls
- 166/group committed to carcinogenesis bioassay
  - ~ 80% power to detect 10% difference from control
- 122/group allocated for interim evaluations at 1, 3, 12, & 24 months
  - Pulmonary function (3, 12, & 24 mo)
  - Lung lavage & cell proliferation
  - Hematology & serum chemistry (3, 12, & 24 mo)
  - Histopathology

Accommodate ancillary biological studies of rats and mice

- Markers of potential Cancer, vascular inflammation effects

Lovelace

CORE BIOSCREENING STUDY: STATUS

- 1- and 3-month exposures of both rats and mice complete; Rats now in Month 10 of long term exposure
- 1- and 3-month Health Evaluations complete at LRRI, 3 of 5 Ancillary Study Sites
- Statistical analysis underway
- Preliminary results presented to Oversight/Advisory Committee April 26, 2011
- Mice and rats generally healthy and gaining weight as expected
    - Updated details at presentation

Preliminary Findings: Rodent 1 and 3 Month Sacrifices

The majority of the analyses showed no difference between diesel exhaust exposure and clean air control.

Histopathology analysis revealed mild exposure-related hyperplasia in the rats after 3 months of exposure, but not in mice.

Statistical findings were noted for several pathology indicators of pulmonary stress and inflammation in rats; some indications in mice as well.

Pulmonary function assessments in rats showed slight statistical differences in exposed rats compared with control after 3 months of exposure.

***Note*: When designing the study, it was expected that at the high concentration (at 4.2 ppm NO_2) some NO_2-related effects may be observed. Results so far are not inconsistent with that.**

Preliminary Findings: Pulmonary Inflammation/Stress in rats at 3 Months

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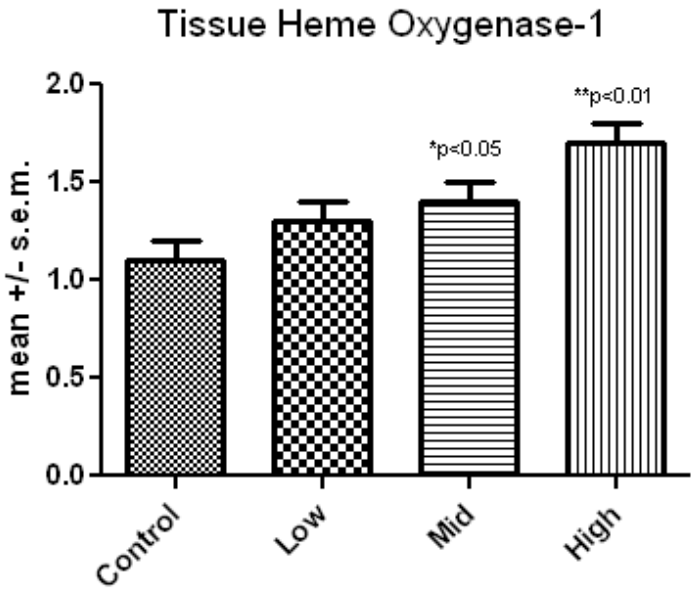

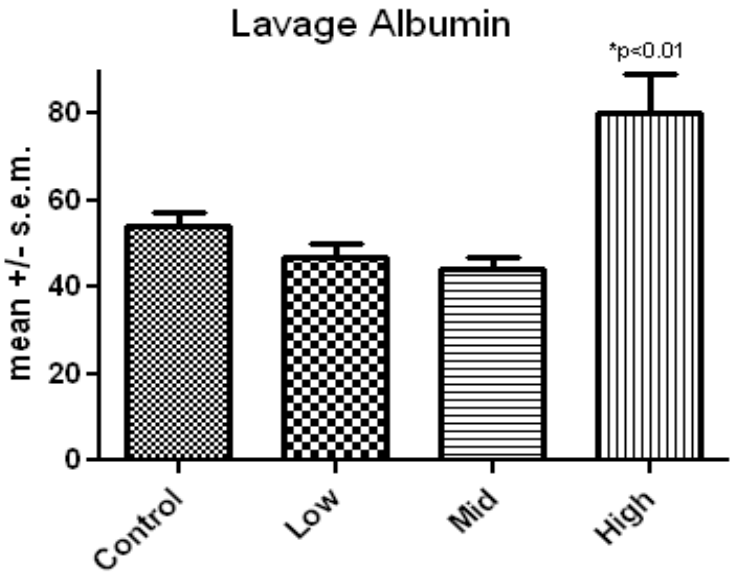

Preliminary Findings: Neutrophils in Mouse Lung Fluid at 3 Months

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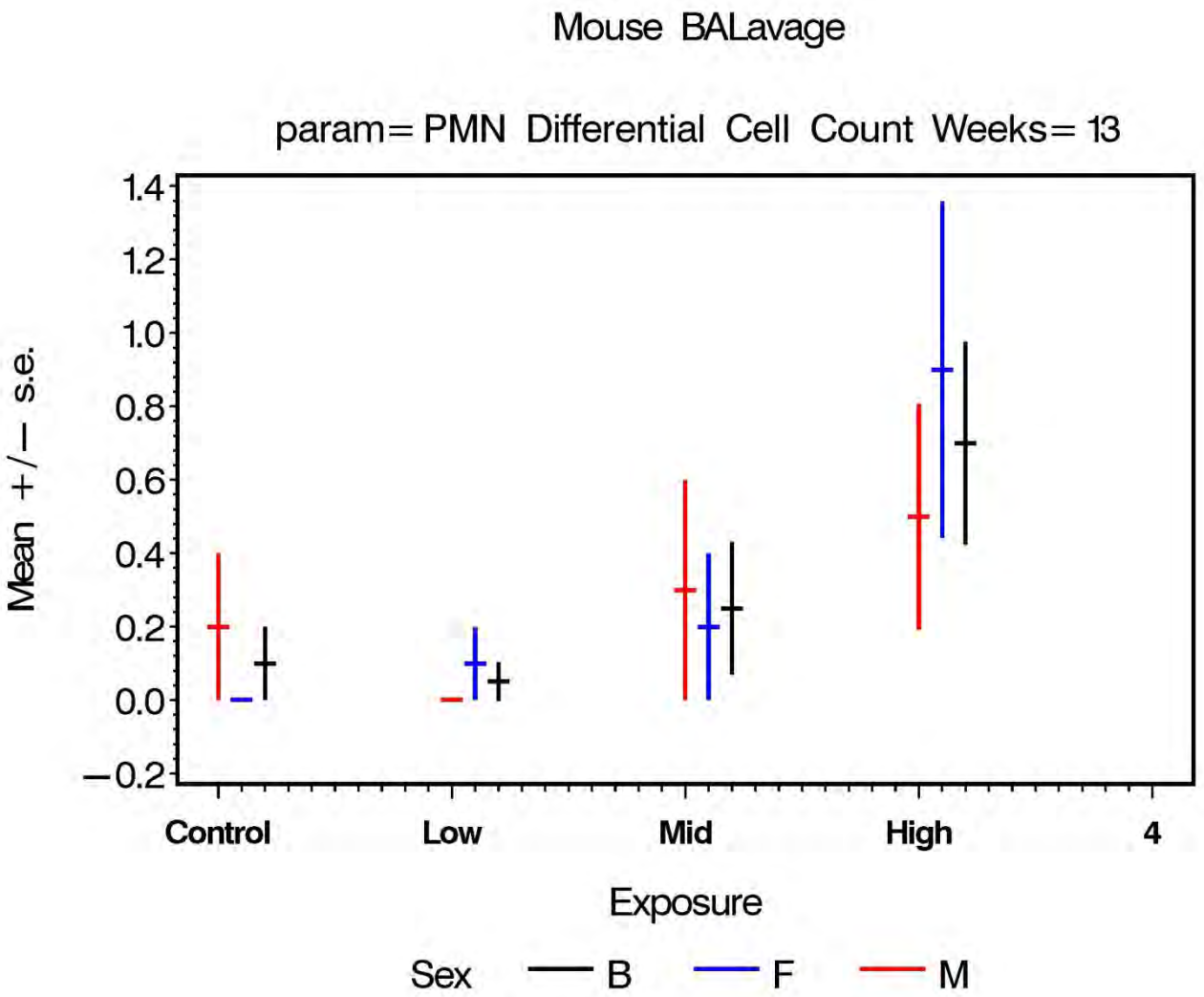

Preliminary Findings: IL-6 in Mouse Lung Tissue at 1 Month

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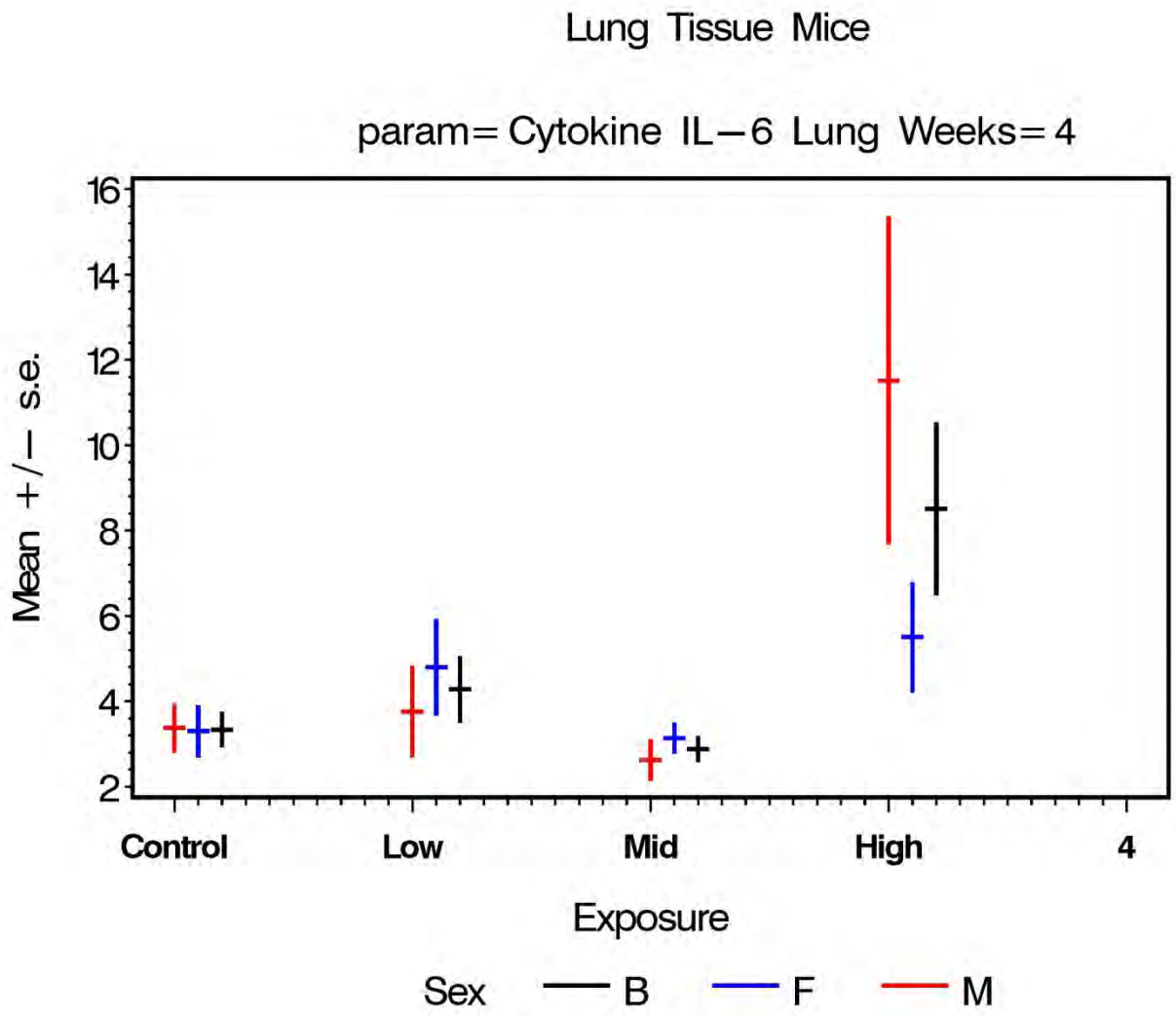

Preliminary Findings: Pulmonary Function in Rats at 3 Months

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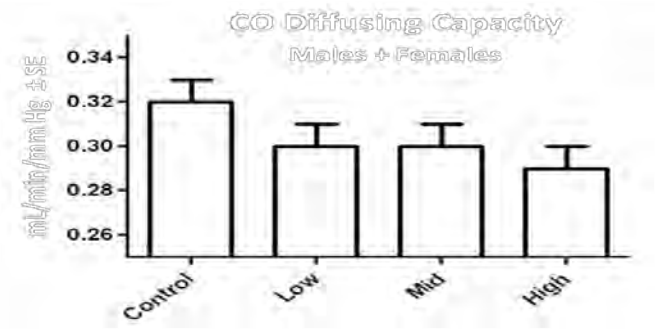

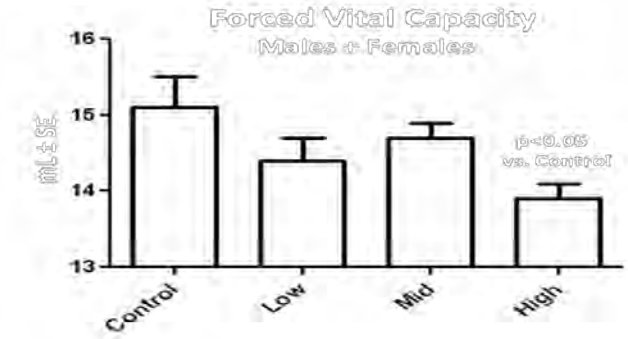

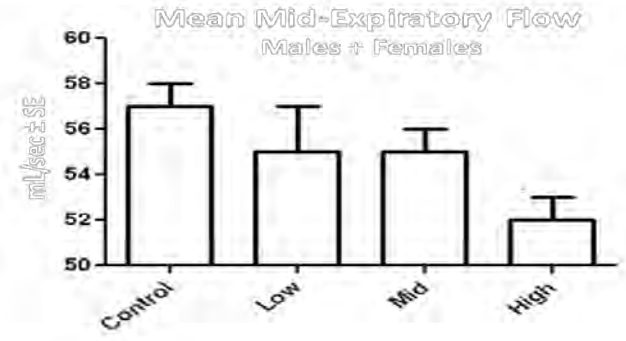

Significant ($p<0.05$) trend observed for each of these endpoints

SUMMARY

- **The study is progressing smoothly, and according to protocol**
- **No significant difficulties have been encountered with the engine or exposure systems; 1- and 3-month exposures now complete**
- **All operational parameters have been well within protocol limits; Cumulative mean NO_2 concentrations are acceptably close to target.**
- **Both mice and rats have apparently tolerated exposure well to date**
- **Preliminary health results suggest possible increase in markers of effect at high exposure levels**
  - **This has NOT been fully analyzed or peer-reviewed**
  - **Results may be consistent with effects of NO_2-only exposures seen in other studies**
- ***Reporting of shorter-term exposure results is entering review; publication expected in early 2012***

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