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 2010

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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

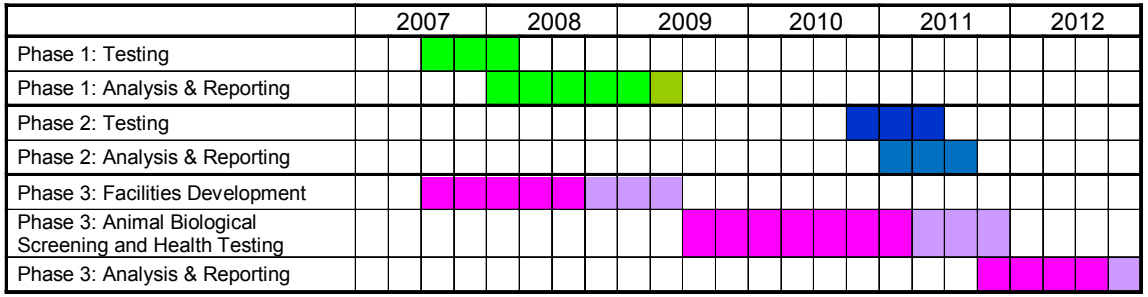
- Total DOE Contract: $5.95 million (Contractor Share: $3.98 million)
  - FY 09 DOE Funding: $600,000
  - FY 10 DOE Funding: $600,000 (planned)

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	**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	**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

CAT® C13, by Caterpillar

Cummins ISX, by Cummins

DDC Series 60, by Detroit Diesel

Mack MP7, by 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 engines
- 2010 technology has evolved in multiple directions and, given credits, will not meet the specific requirements by that date
- CRC initiating planning with manufacturers, agencies, other sponsors for start in early 2011

ACES PHASE 3 Health Bioscreening Approach and Objectives

Phase 3A: Characterization of emissions and exposure atmospheres

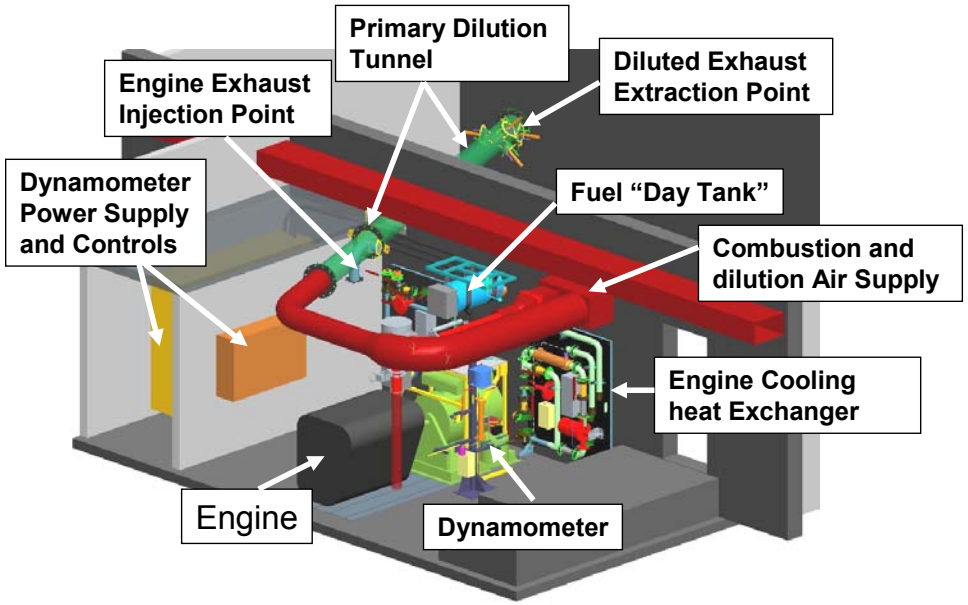
Phase 3B: Conduct of animal studies

DOE Funding:

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

EPA Funding:

- **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**

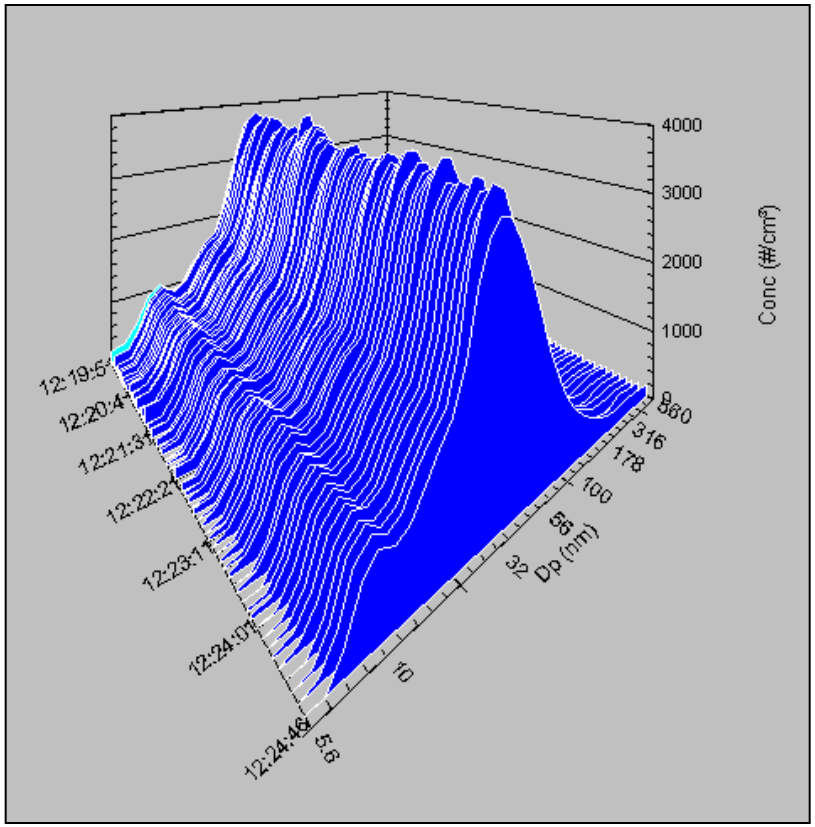
- **Determined dilutions required to meet targets set by HEI**
  - **Dilutions set to achieve 4.2, 0.8 & 0.1 ppm NO_2**
  - **Dilutions ≈ 40:1, 210:1 & 1680:1**

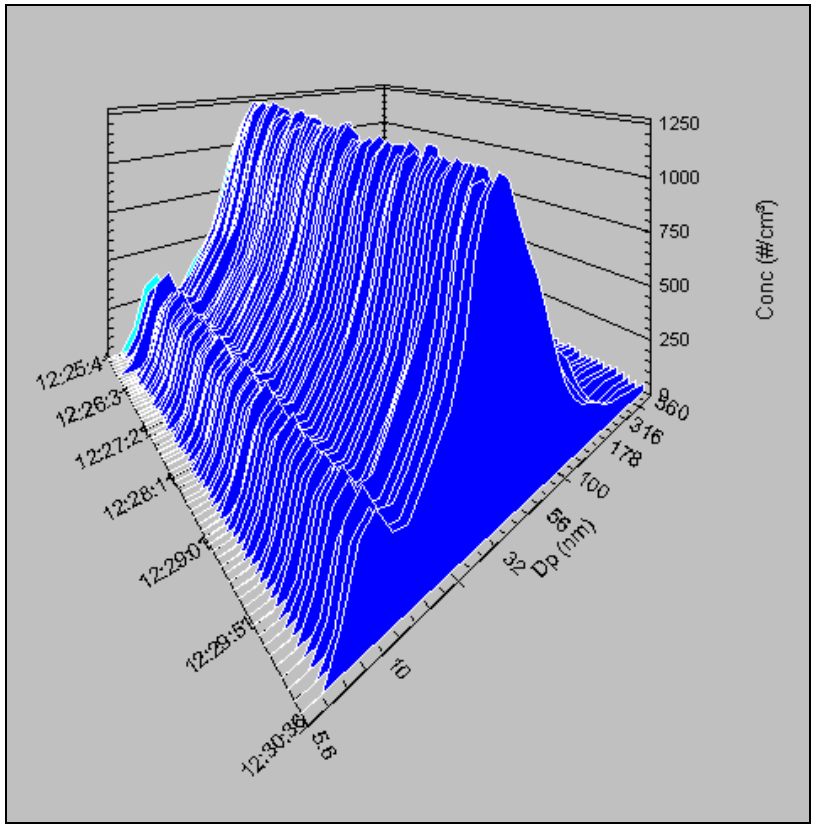
- **Characterized chamber atmosphere in detail**

- **Evaluated chamber temperatures & operating reliability**

THE EXPOSURE SYSTEM HAS LITTLE EFFECT ON PARTICLE SIZE DISTRIBUTION

Particle number vs diameter with time during 75% throttle at 1800 rpm





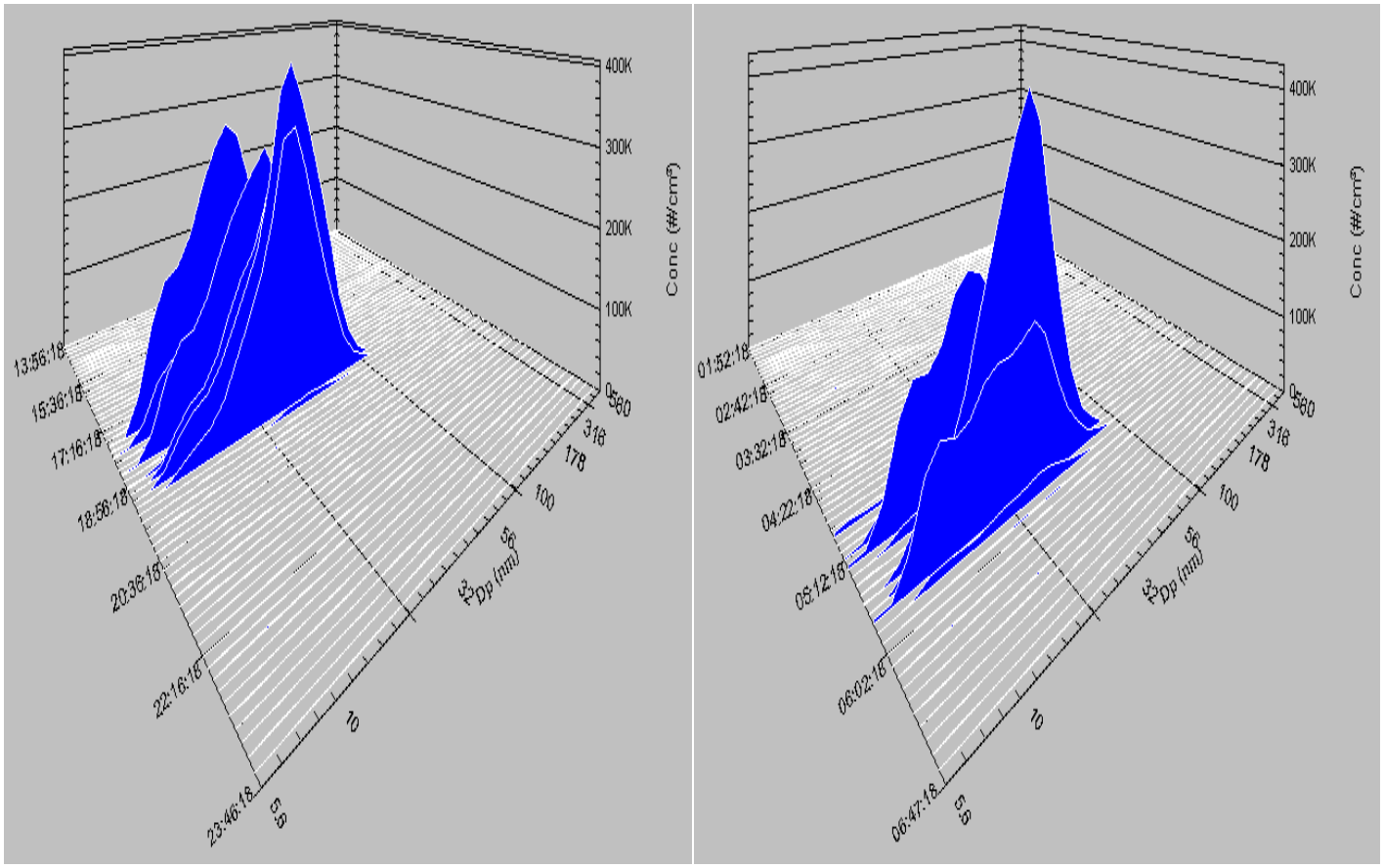
Primary Dilution tunnel

High Level Exposure Chamber

EFFECT OF PARTICLE TRAP REGENERATION

- **Very little PM is emitted except during regeneration**

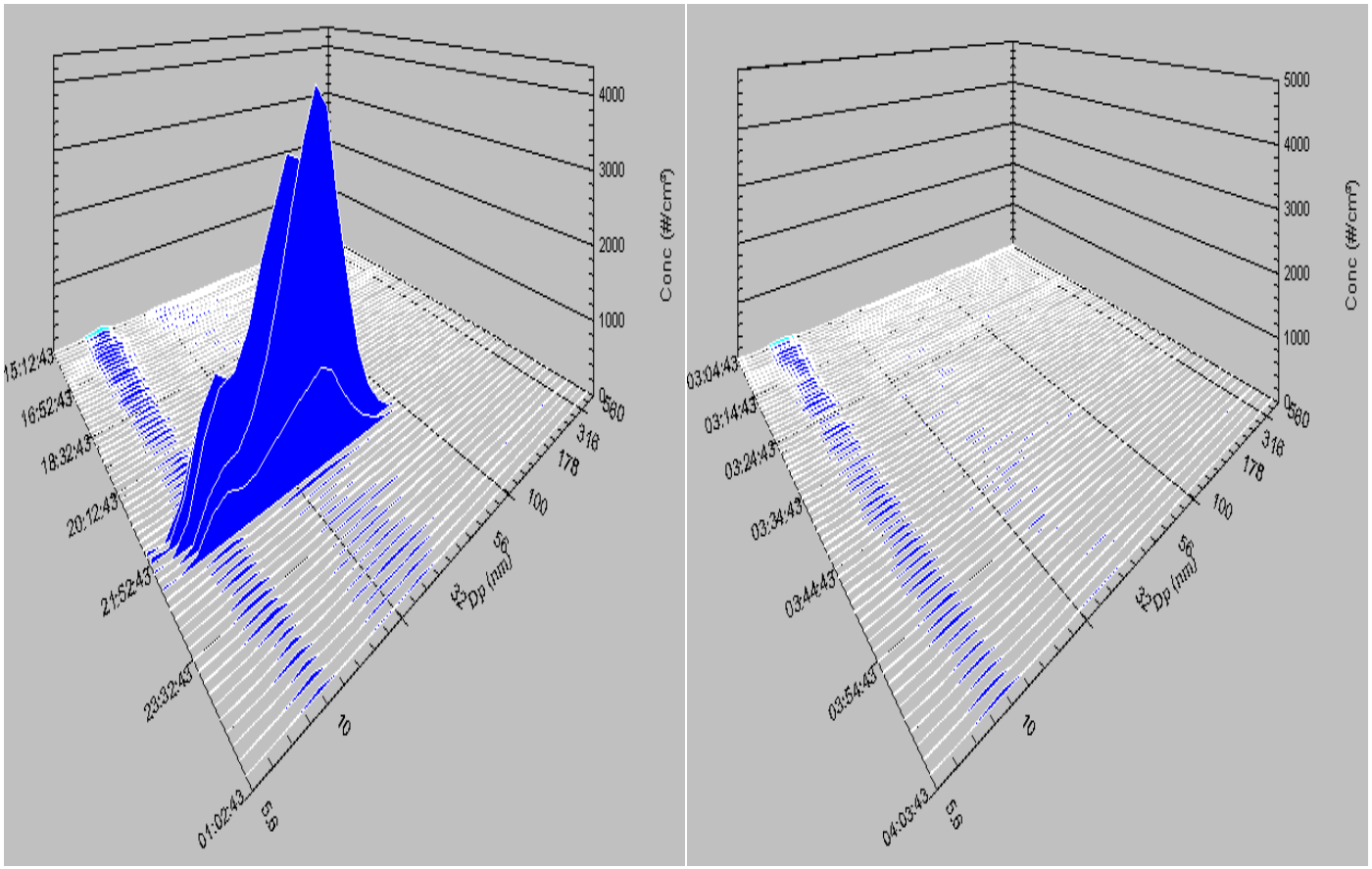
- **Regeneration occurs twice during 76% of 16-hr cycles, once during 24%**



Two regenerations during single 16 hr cycle at <u>high</u> exposure level

EFFECT OF PARTICLE TRAP REGENERATION

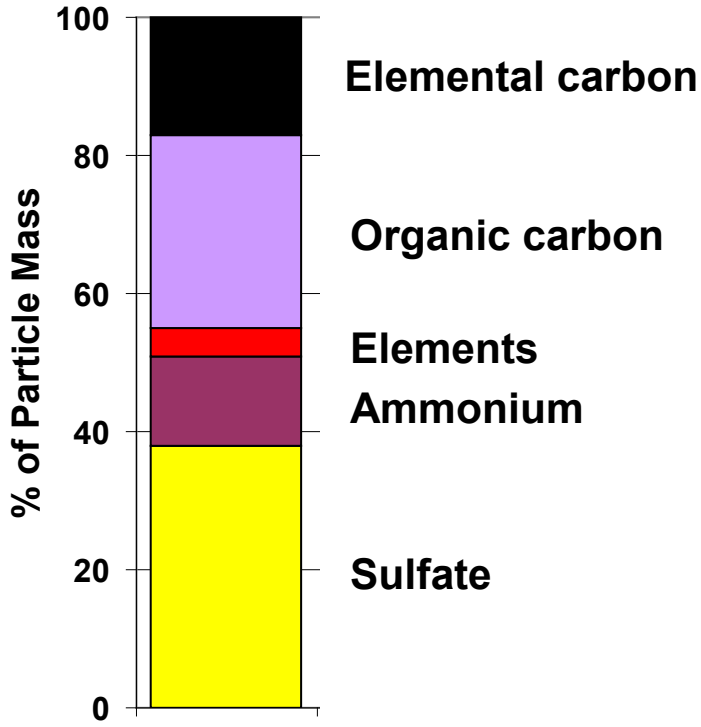
- **Very little PM is emitted except during regeneration**
- **Regeneration occurs once during 24% of 16-hr cycles, twice during 76%**



One regeneration during single 16 hr cycle at <u>low</u> exposure level

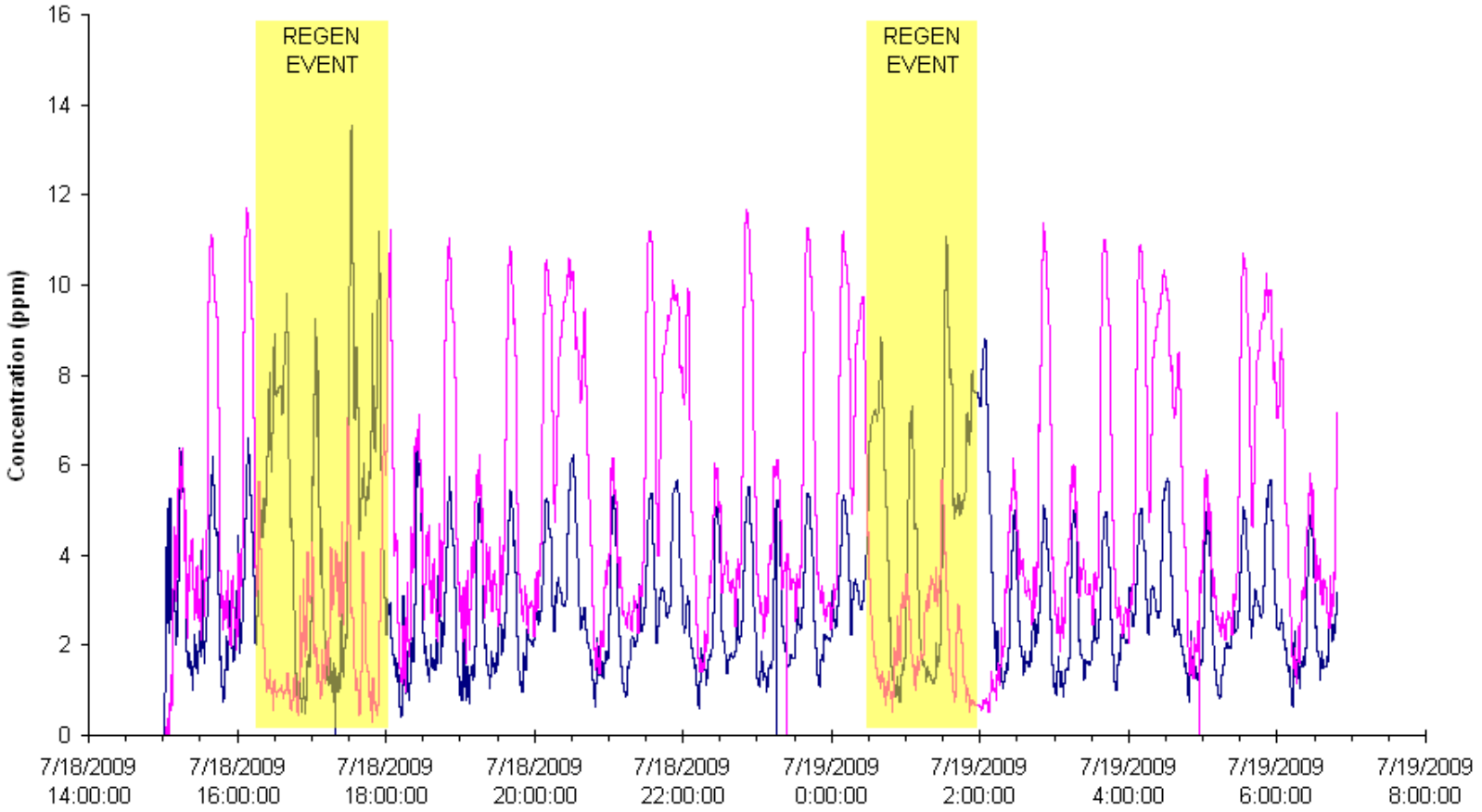
PARTICLE COMPOSITION

Measured in high level chamber without animals

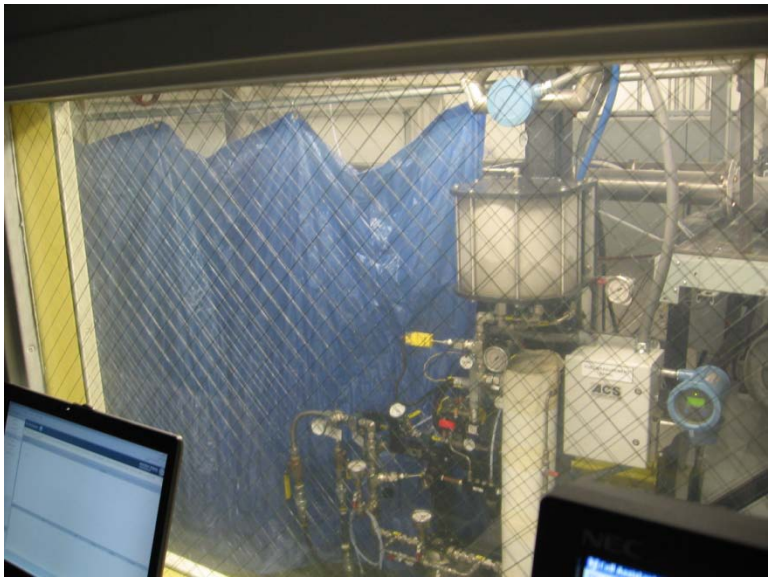


EFFECT OF REGENERATION ON GASES

- NO ↑ and NO_2 ↓ during regeneration - other gases are affected less



NO and NO_2 in high level chamber on day with 2 regenerations



Engine & Fuel Rack

Dynamometer & heat exchanger

Engine Control Room

Adjusting Dilution

Instrumentation in Exposure Room

Checking & Cleaning Chambers

Examining Mouse

Checking Identity of Mouse

MOUSE BIOSCREENING STUDY

- **Expose 132 mice/group 16 hr/day, 5 days/wk for 13 weeks**

  C57Bl/6

- **Three dilutions of whole emissions + clean air controls**

  Target mean NO_2 of 4.2, 0.8 & 0.1 ppm

  Commercial fuel from local supplier (Chevron)
  Engine lube oil same as at SwRI (Lubrizol)
  Engine maintenance per mfg. direction

- **40 mice/group allocated for evaluations at 1 and 3 months**

  Bronchoalveolar lavage **Cell proliferation**
  Hematology* **Serum chemistry***
  Histopathology ***3 mo only***

- **80 mice/group allocated for evaluations at 1 & 3 months by 5 ancillary studies**

  Blood and tissue collections

STATUS: 4 wk evaluations completed

13 wk evaluations scheduled for late May

RAT BIOSCREENING STUDY

- **Expose 280 rats/group 16 hr/day, 5 days/wk for 24-30 months**
  - **Harlan HsdRccHan:Wist (Wistar)**
- **Three dilutions of whole emissions + clean air controls**
  - **Same dilution targets as for mice (4.2, 0.8 & 0.1 ppm NO_2)**
- **200 rats/group committed to long-term carcinogenesis bioassay**
  - **Expect ~60+% survival to 30 mo**
- **80 rats/group allocated for evaluations at 1, 3, 12, & 24 months**

Bronchoalveolar lavage	**Cell proliferation**
Hematology*	**Serum chemistry***
Pulmonary function*	**Histopathology**

***Not measured at 1 mo**

- **Blood and tissue collected from same rats for 5 ancillary studies**

STATUS: Pending approval to order rats

SCHEDULE

2/22 – 3/8/10	Began mouse exposures (3 blocks)
3/22 – 4/510	1 mo mouse evaluations
5/24 – 6/7/10	3 mo mouse evaluations
5/17 – 5/31/10	Began rat exposures (3 blocks)
6/14 – 6/28/10	1 mo rat evaluations
8/16 – 8/30/10	3 mo rat evaluations
12/10	Submit report on short-term results
5/11	1 yr rat evaluations
5/12	2 yr rat evaluations
11/12	2.5 yr termination of surviving rats (est. 50-60% survival)
5/13	Submit report on all results

EXPOSURE ATMOSPHERES

(from 40 daily measurements 2/22 – 4/15/10)

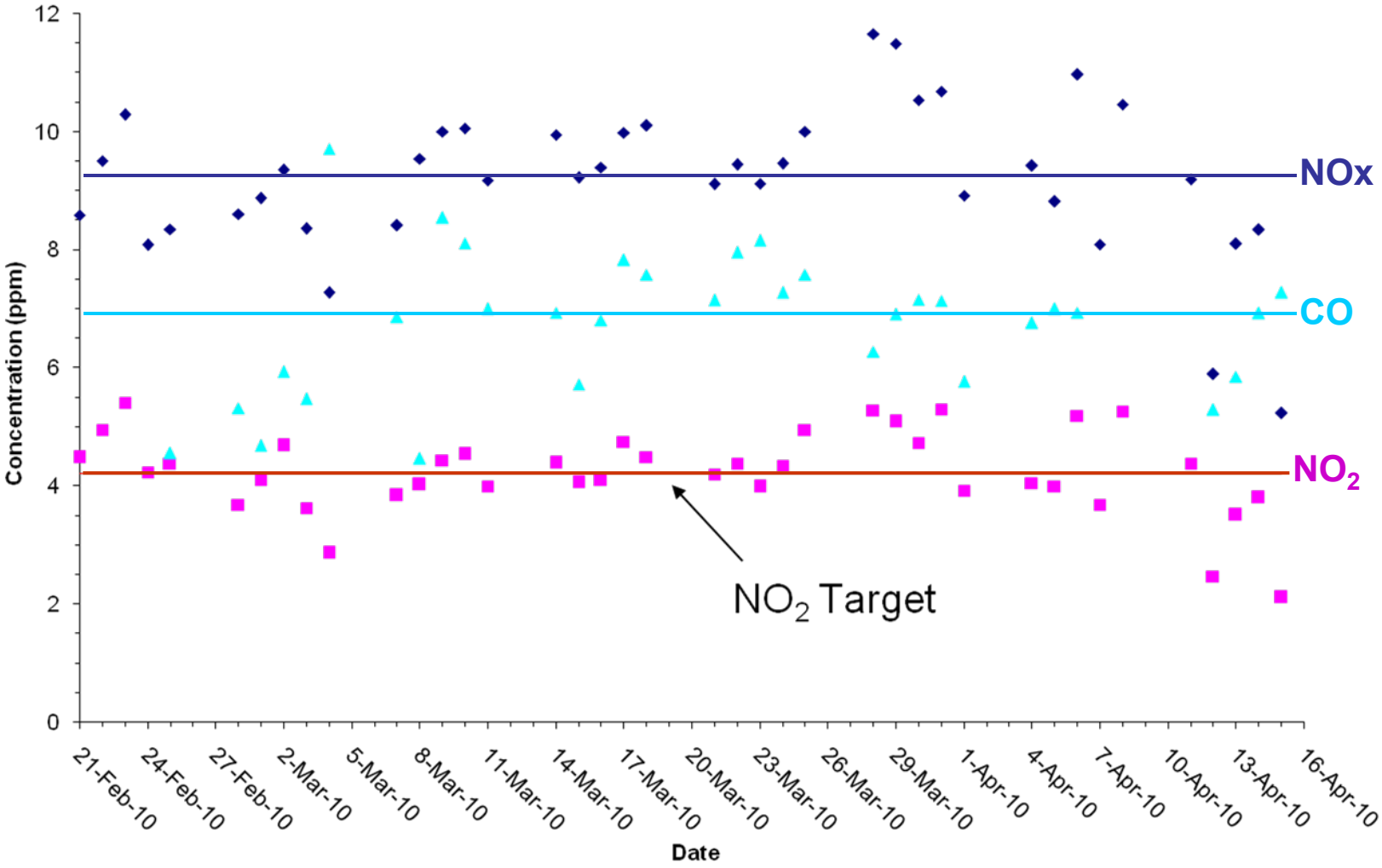
Gases (ppm)	High Mean	High SD	Medium Mean	Medium SD	Low Mean	Low SD
(NO_2 target)	4.2		0.8		0.1	
NO_2	4.19	0.74	0.87	0.19	0.10	0.04
NO	5.06	0.67	0.93	0.21	0.10	0.05
NOx	9.25	1.34	1.80	0.39	0.19	0.08
CO	6.9	1.1	*nmd**		*nmd*	
THC	0.4	0.3	*nmd*		*nmd*	
CO_2	3818	263	*nmd*		*nmd*	
PM ($\mu g/m^3$)						
Inlet filter	9	3	3	2	1	1
Chamber filter	38	20	43	59	34	17

**not measured daily*

The first detailed characterization is underway.

VARIABILITY OF GASES AT HIGH LEVEL

(first 40 days of exposure)



SUMMARY

- **The study is progressing smoothly, and according to protocol**
- **No significant difficulties have been encountered with the engine or exposure systems**
- **All operational parameters have been well within protocol limits**
- **Cumulative mean NO_2 concentrations are on or acceptably close to target. Although variability is similar to that in previous long-term NO_2 studies, the variability relative to mean is substantial at these low concentrations.**
- **The mice have apparently tolerated the exposure well to date**
- **No results are yet final, and we offer no speculation about potential exposure-related outcomes**
- ***Reporting of shorter-term exposure results is expected to enter review in early 2011***

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