Application of Johnson Matthey CRT™ Particle Filter System for Retrofit Emission Control of Heavy Duty Diesel Engines

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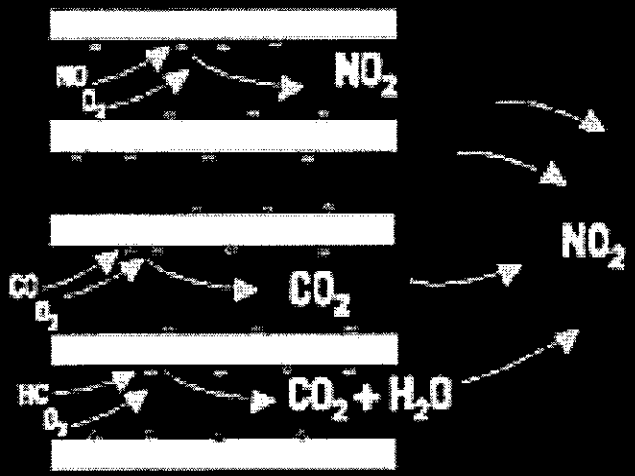
Outline

- Introduction - PM Control
- CRT™ Particulate Filter
- CRT™ Field Experiences - NY City Transit
- CRT™ Field Experiences - California
- Concluding Remarks

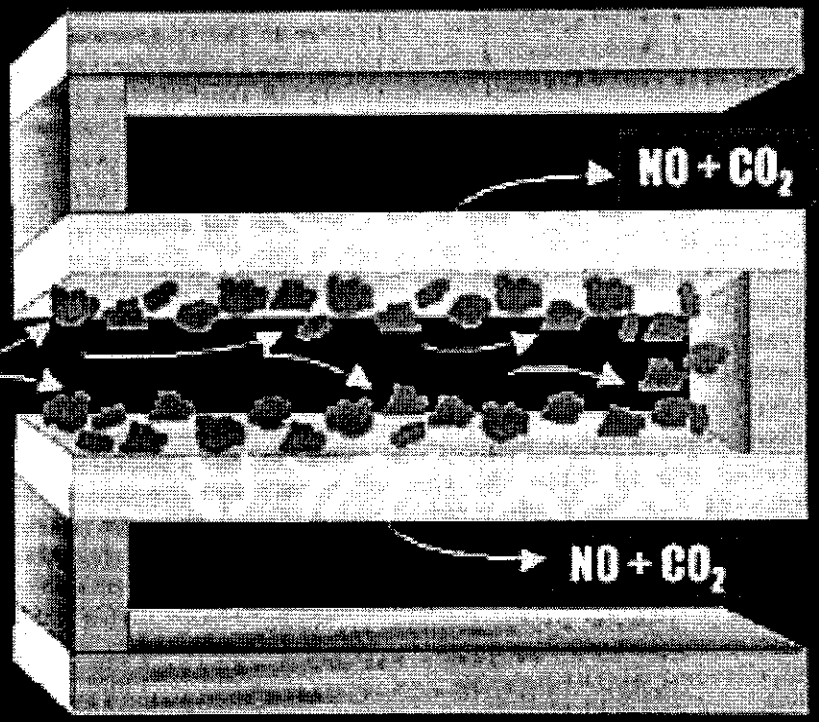
Johnson Matthey CRT™ System HDD FTP Test Results

Engine	Test	HC g/bhp-hr	CO g/bhp-hr	NOx g/bhp-hr	PM g/bhp-hr
1986 6V92 MUI	Baseline	0.57	0.67	9.67	0.13
	W/ CRT System	0.06	0.09	9.74	0.013
1999 Series 50	Baseline	0.39	0.631	3.381	0.089
	W/ CRT System	0.000	0.174	3.189	0.008
1998 Series 60	Baseline	0.109	1.20	3.84	0.063
	W/ CRT System	0.005	0.077	3.90	0.008

NO_2 Reaction in a CRT™



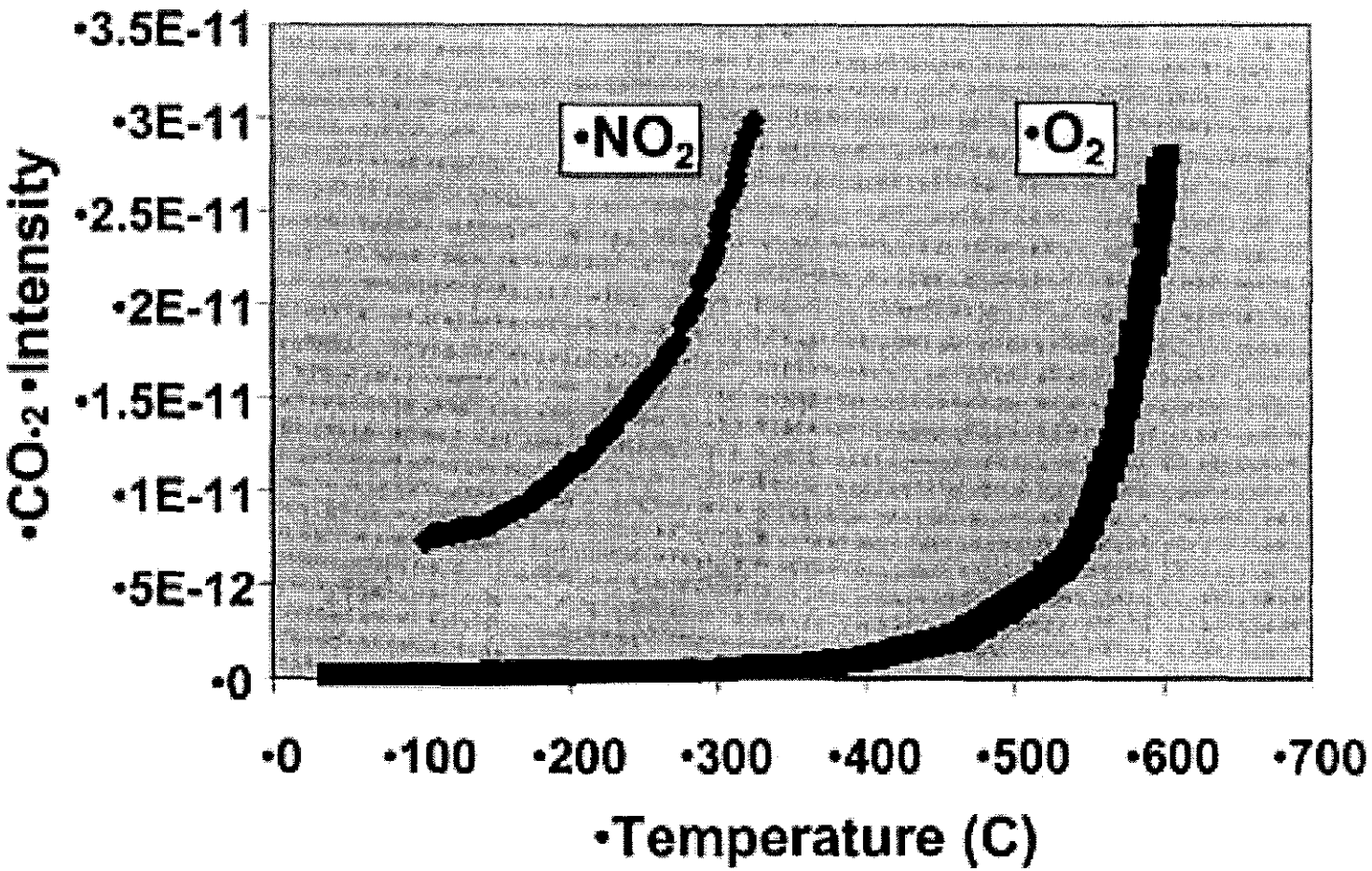
FLOW THROUGH
MONOLITH



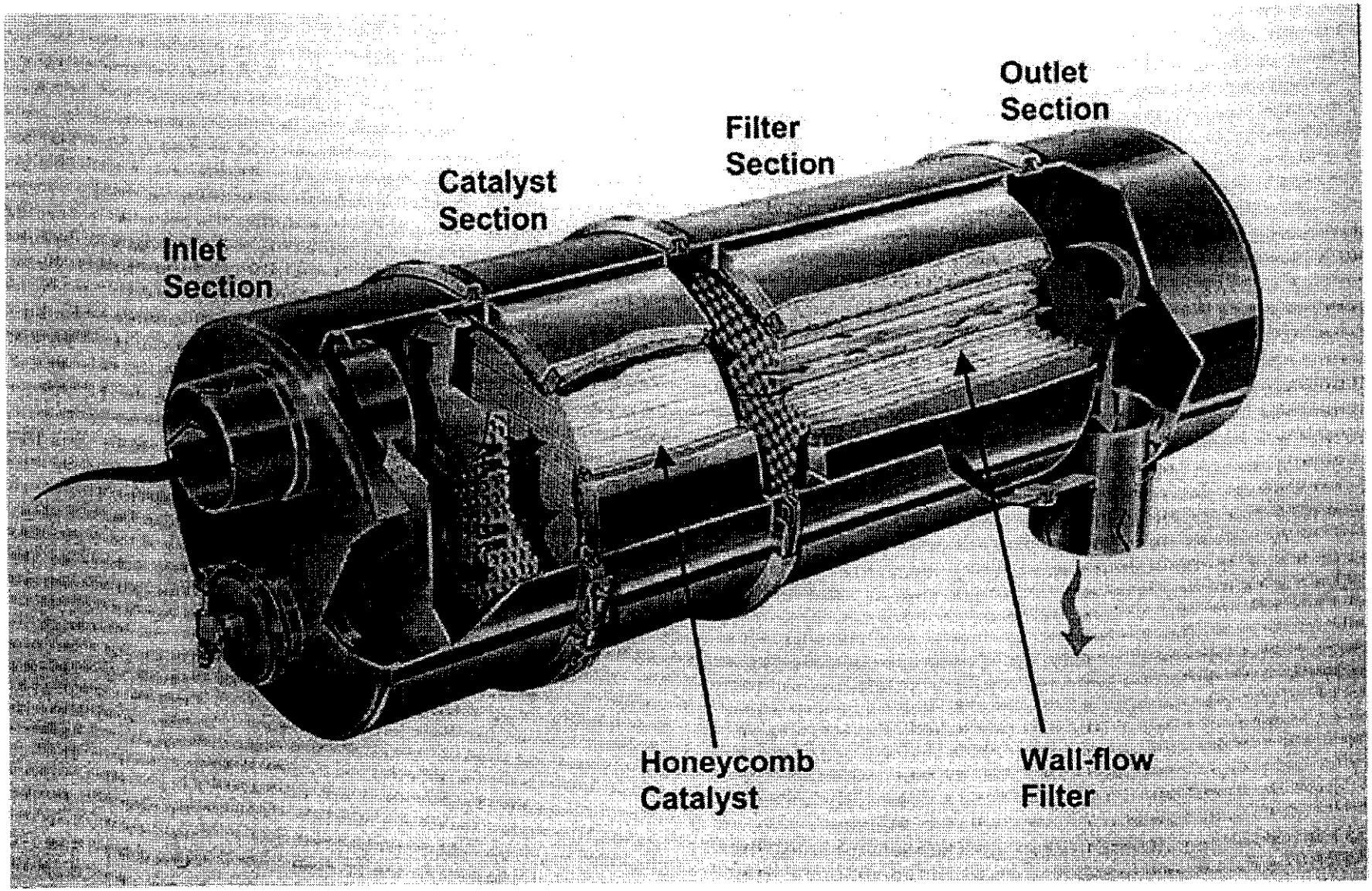
WALL FLOW FILTER

JM Catalyst Technology

Effectiveness of NO_2 and O_2 Combustion of Diesel Particulate



CRT™ Particulate Filter



Unique Patented Johnson Matthey System

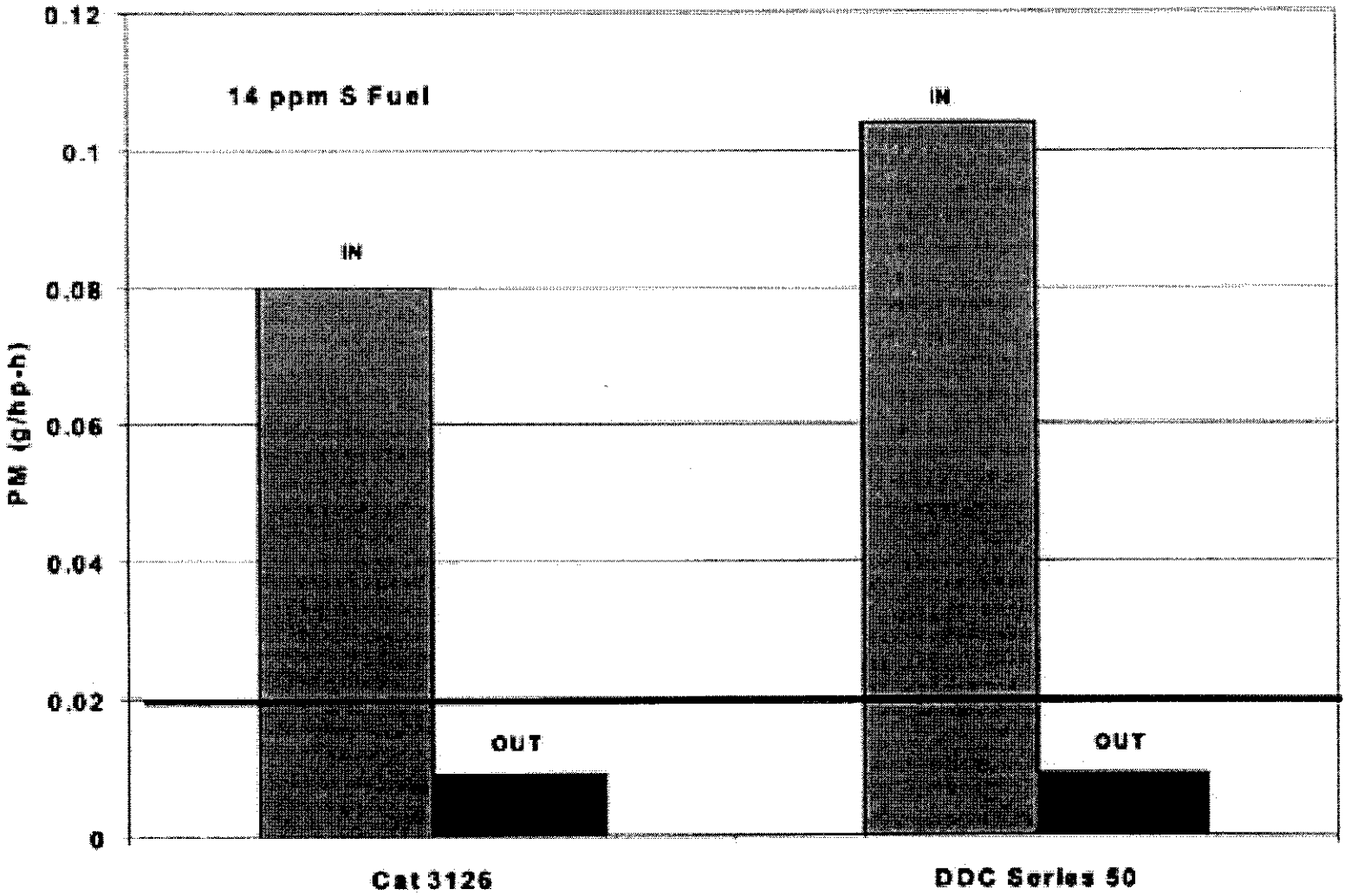
CRT™ Particulate Filter for >90% PM Removal

- Patented CO/HC/PM Emission Control System combining Oxidation Catalyst & Filter
- Engineered as a totally passive emission control system which requires no supplemental heat
- Uses NO_2 produced by a specially formulated catalyst to burn soot collected by the filter at typical operating temperatures of diesel engine exhaust
- Ultra Low Sulfur fuel for high efficiency and durability

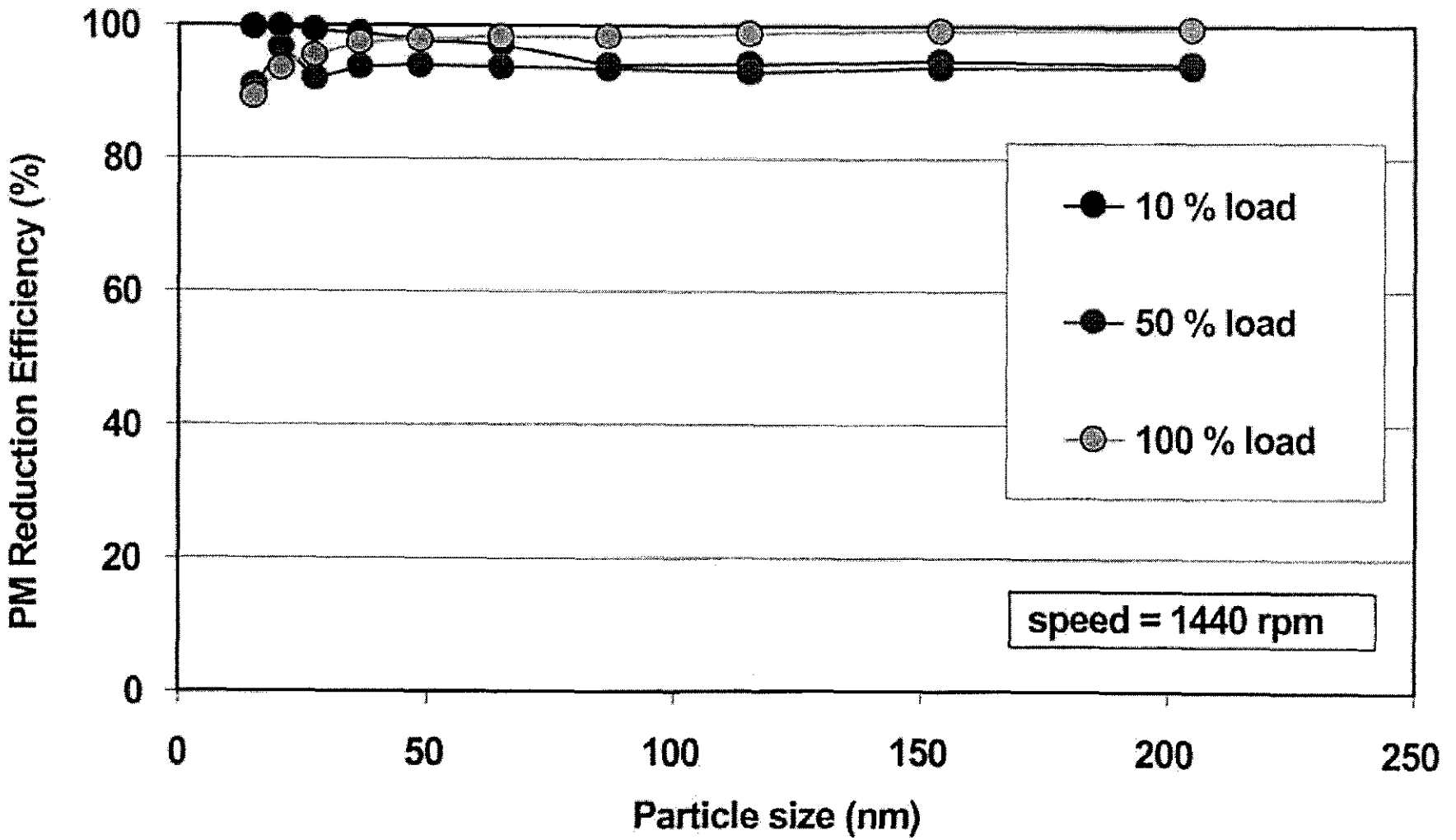
PM Control

- Why?
  - Diesel PM toxicity and health effects
- Regulations
  - EPA OE emissions standards
  - EPA voluntary retrofit program
  - CARB rules
  - SCAQMD rules & programs
- Technology
  - Particle filters for >90% PM reduction

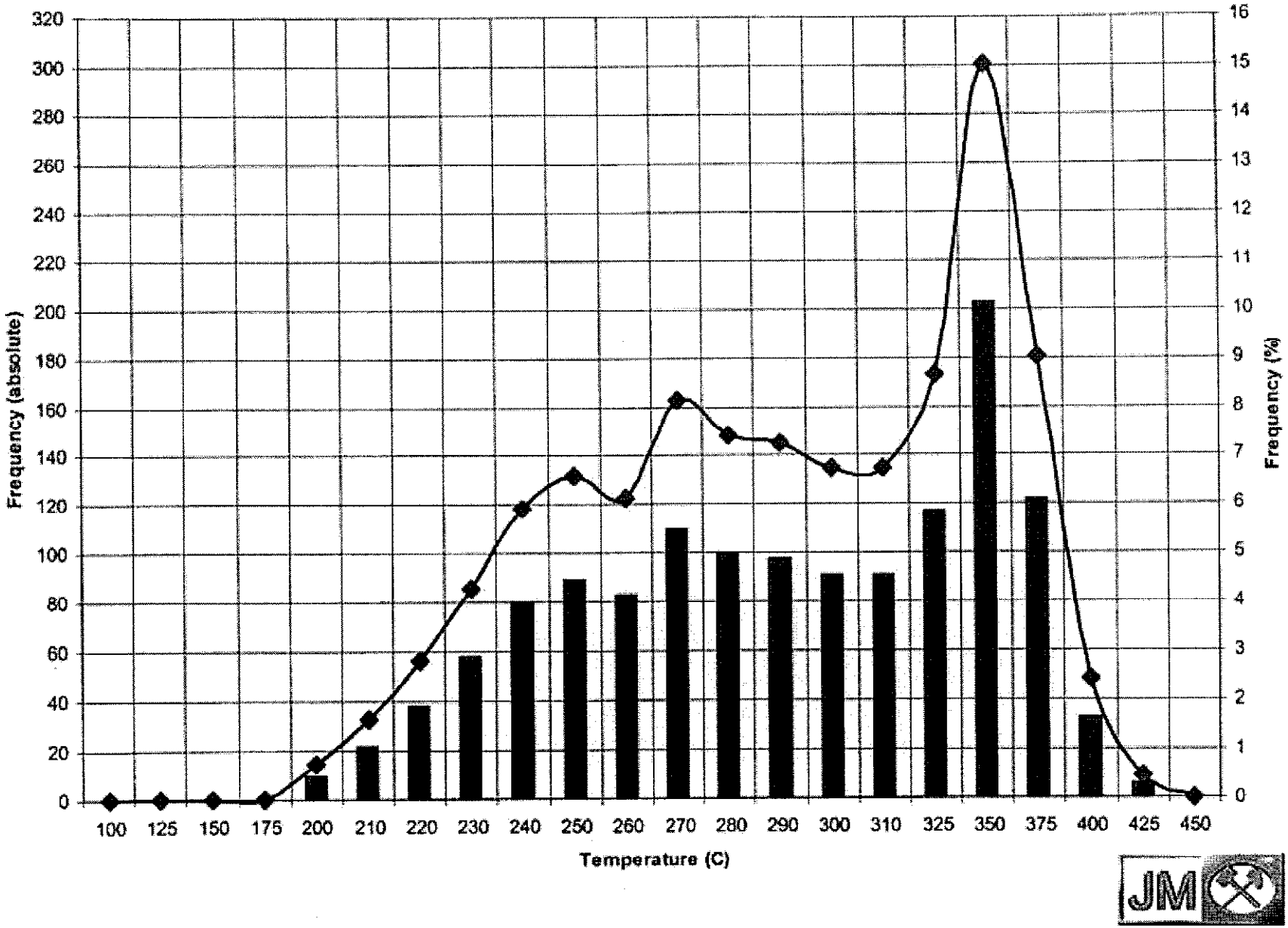
CRT Performance over US HDD FTP



CRT™ Particle Size Reduction Efficiency

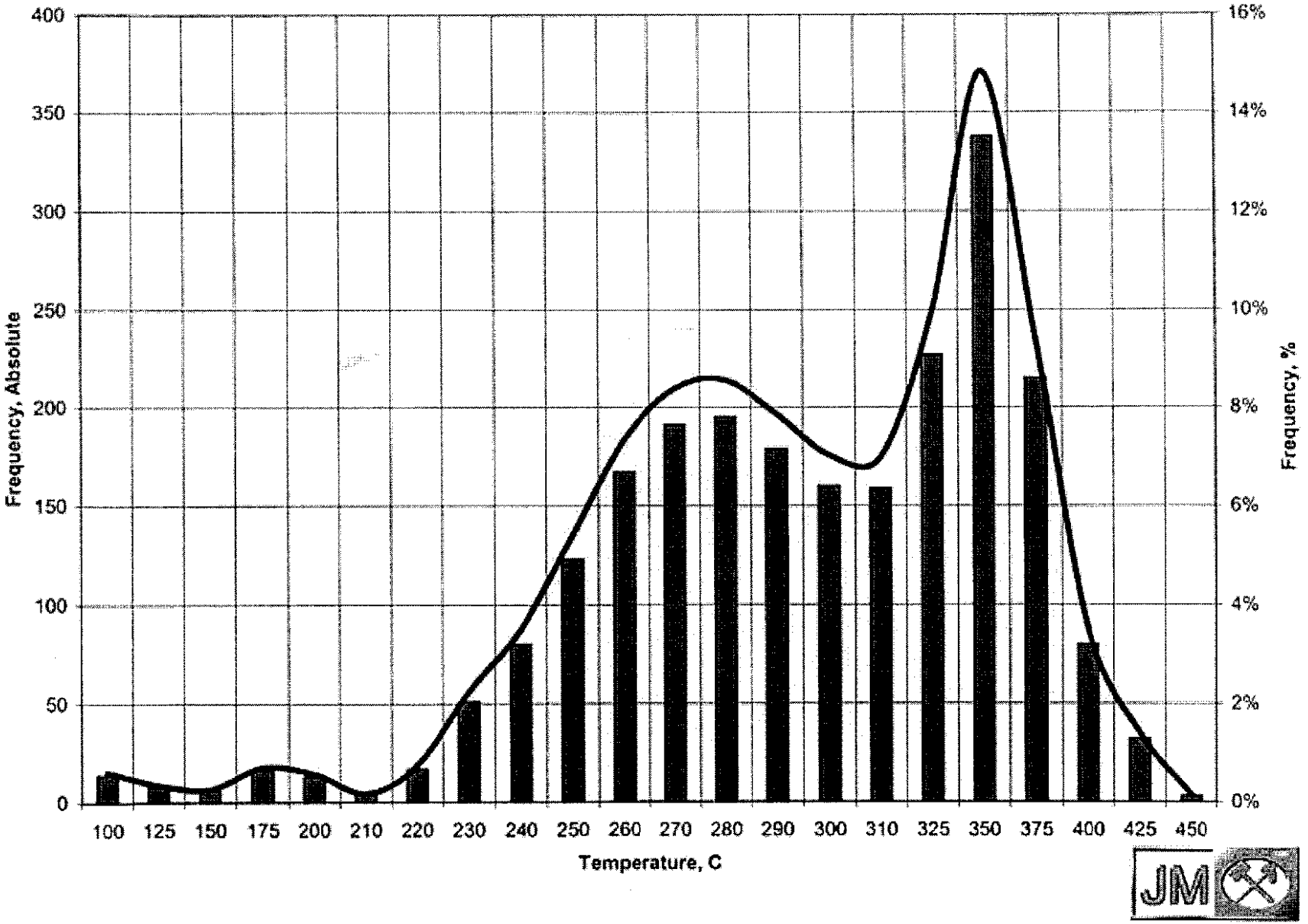


Temperature Histogram of ISC 8.3 in Hemet School Bus



Hemet School Bus with Cummins ISC 8.3

Temperature Histogram of Cat 3116 in LA School Bus

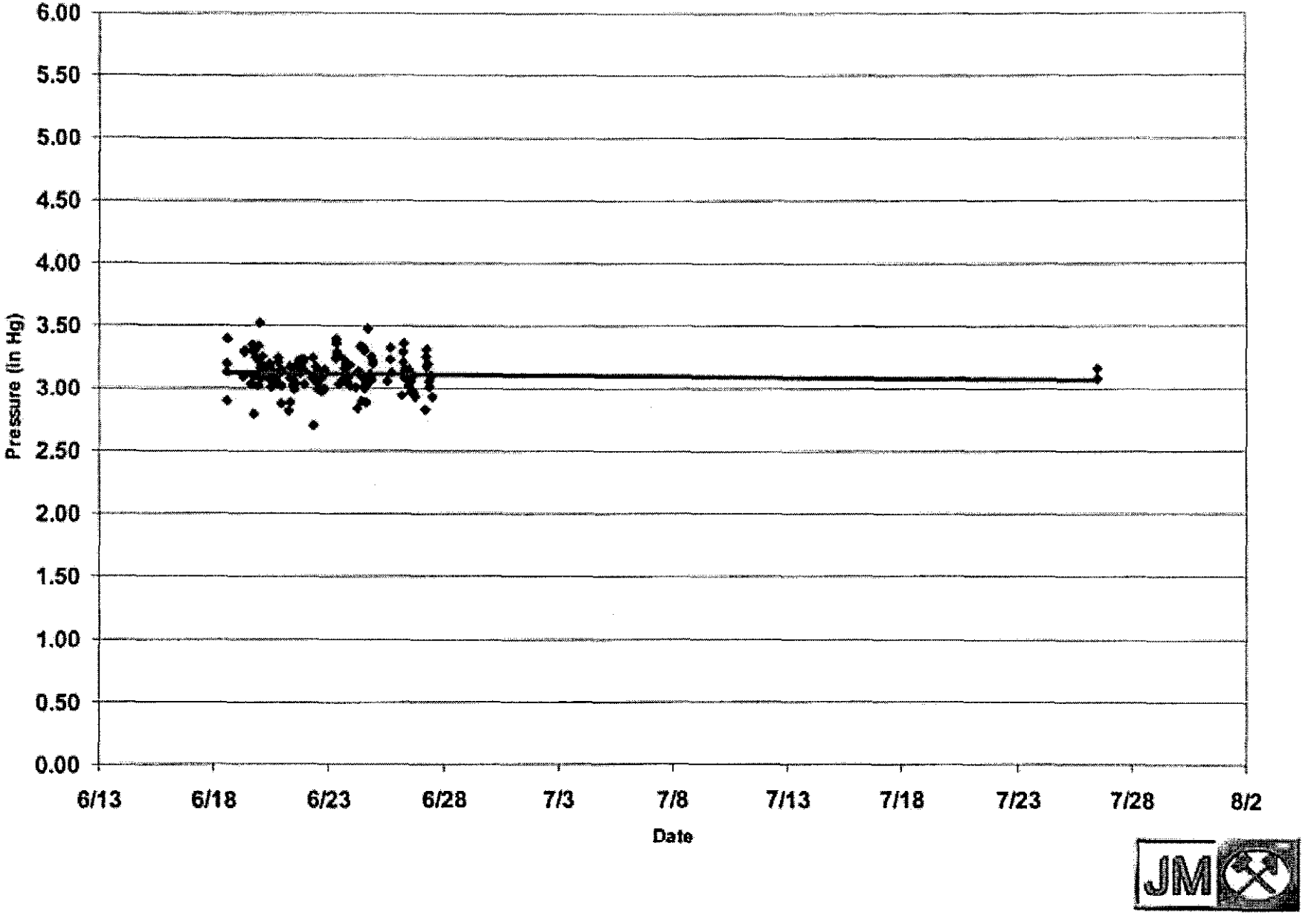


LA Unified School Bus with Cat 3116

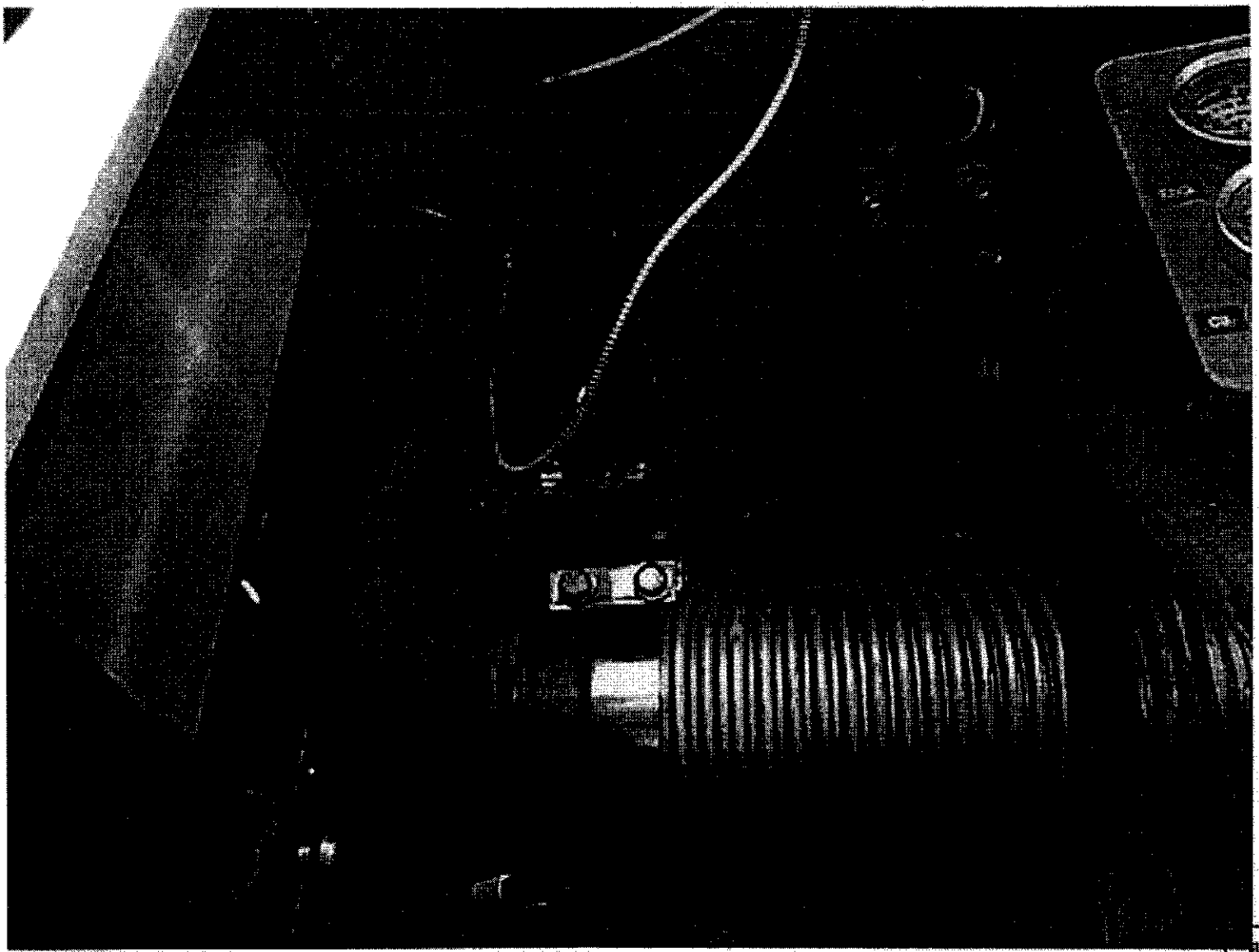
SCAQMD School Bus Retrofit Program

- Vehicle Types:
  - LA Unified School District: Navistar 466D
    Cat 3116
    Cat 3208
  - Hemet Unified School District: Cummins ISC 8.3
    DDC 6V92 DDEC
- On-road Durability and Emissions Testing
- Start-up 9/00

Peak Back Pressure with CRT™ on LA MTA Bus - 275 Hp DDC Ser 50



CRT™ on LA MTA Ser 50 Bus



CRT™ on LA MTA Ser 50 Bus

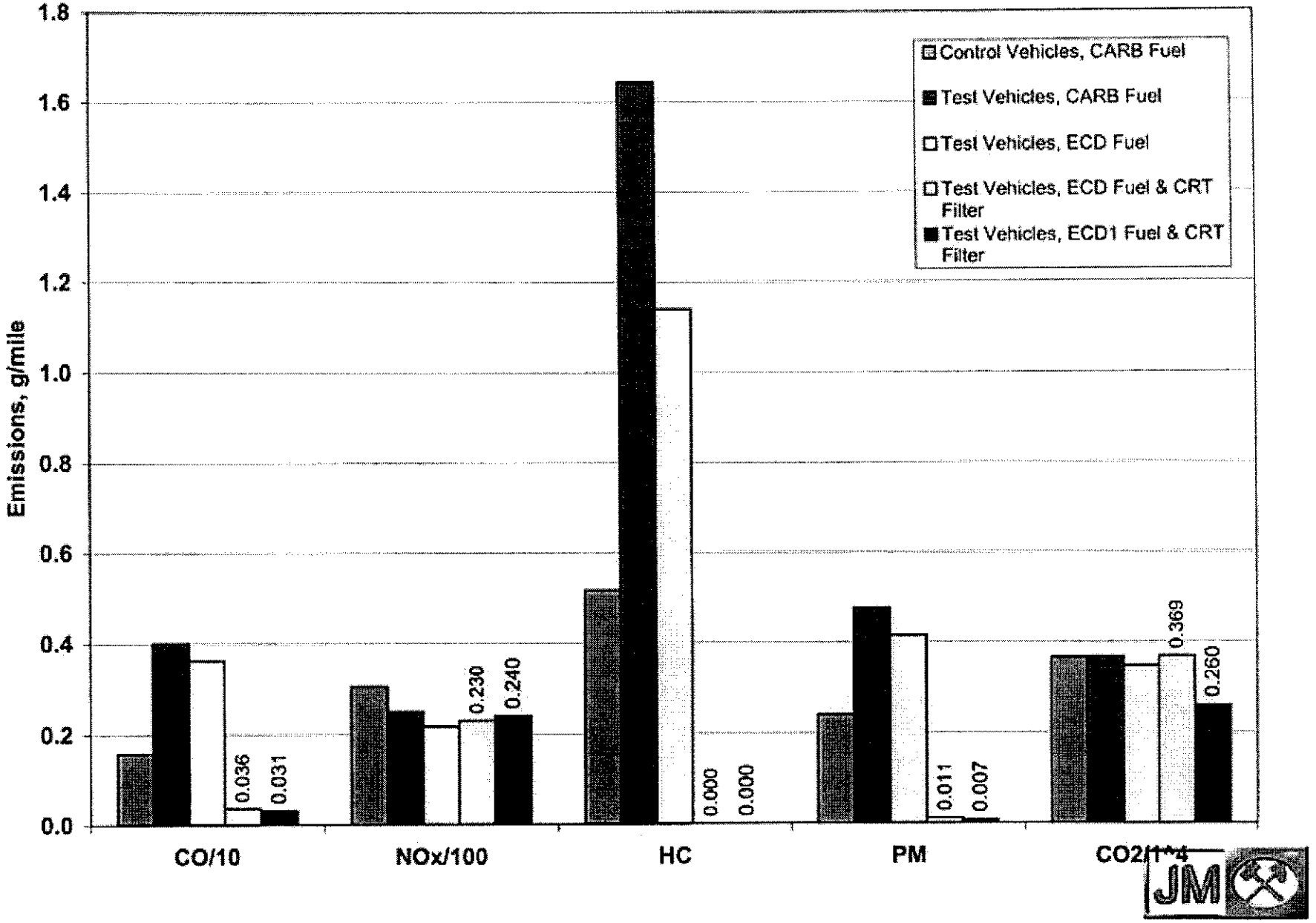
LA MTA Program Outline

- Vehicle Types:

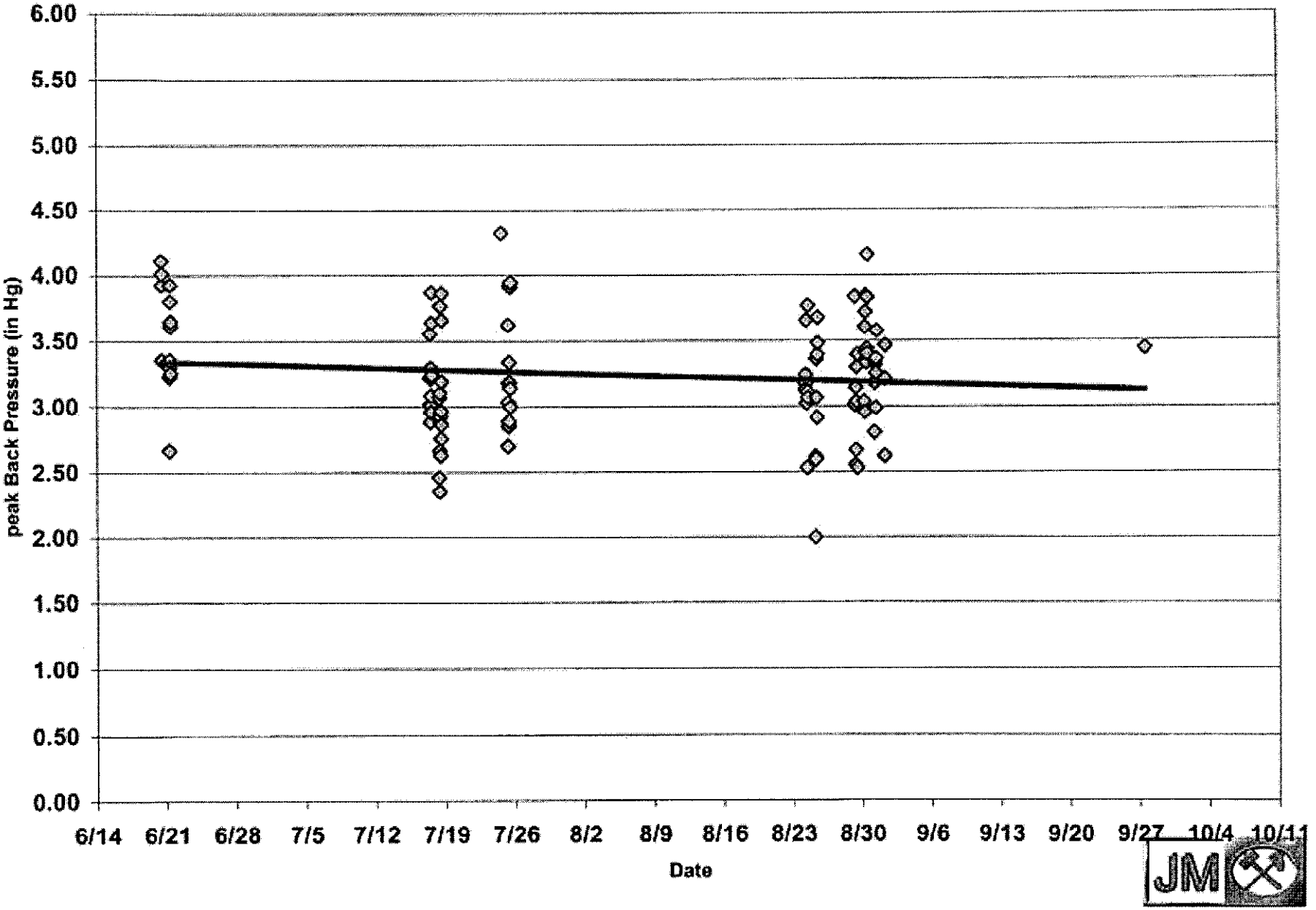
  DDC Series 50 Transit Bus

  DDC 6V92 DDEC Transit Bus

Emission Testing with CRT on Sanitation ISM305 Truck - CBD

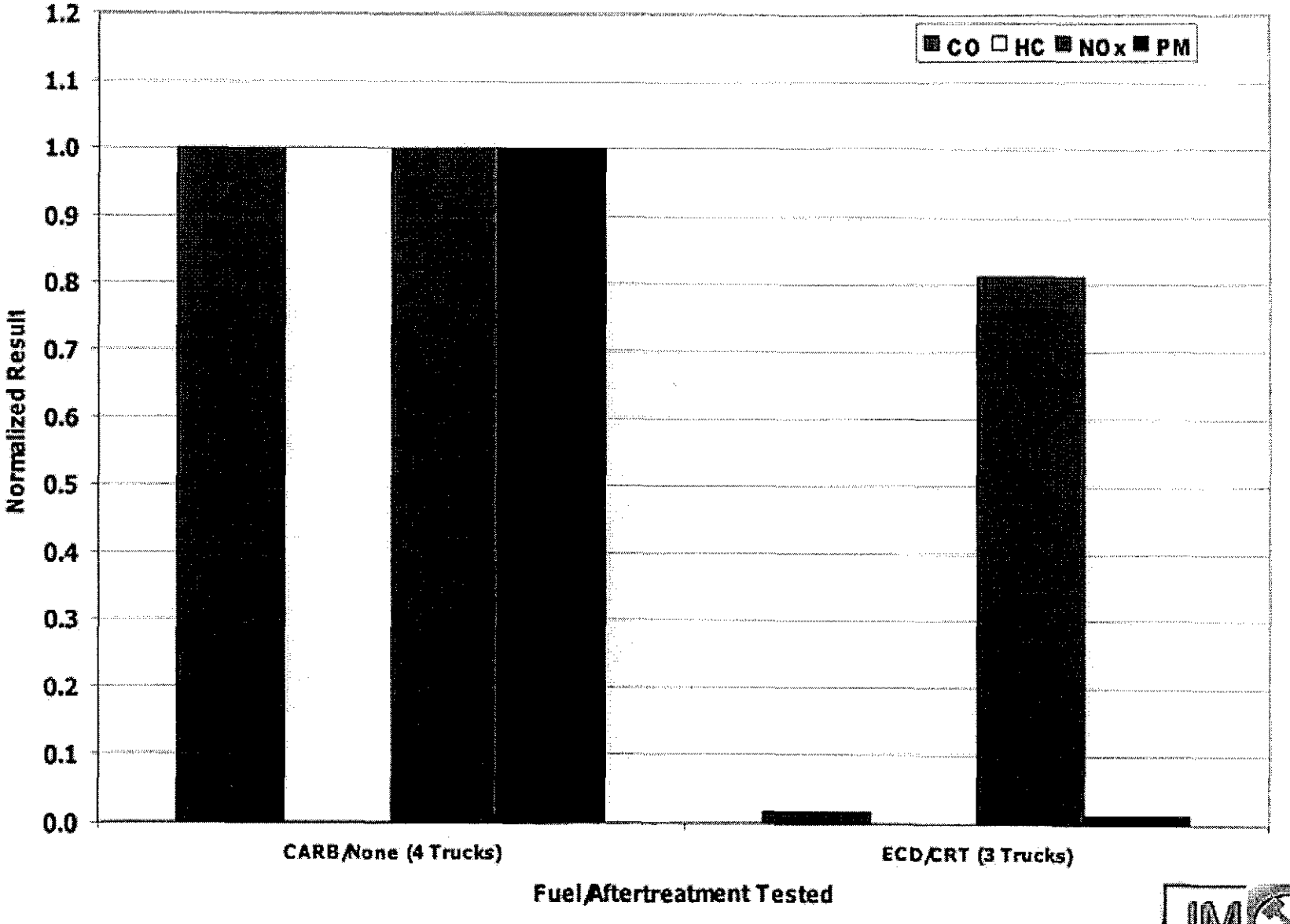


Peak Back Pressure with CRT™ on LA City Sanitation Truck 37066

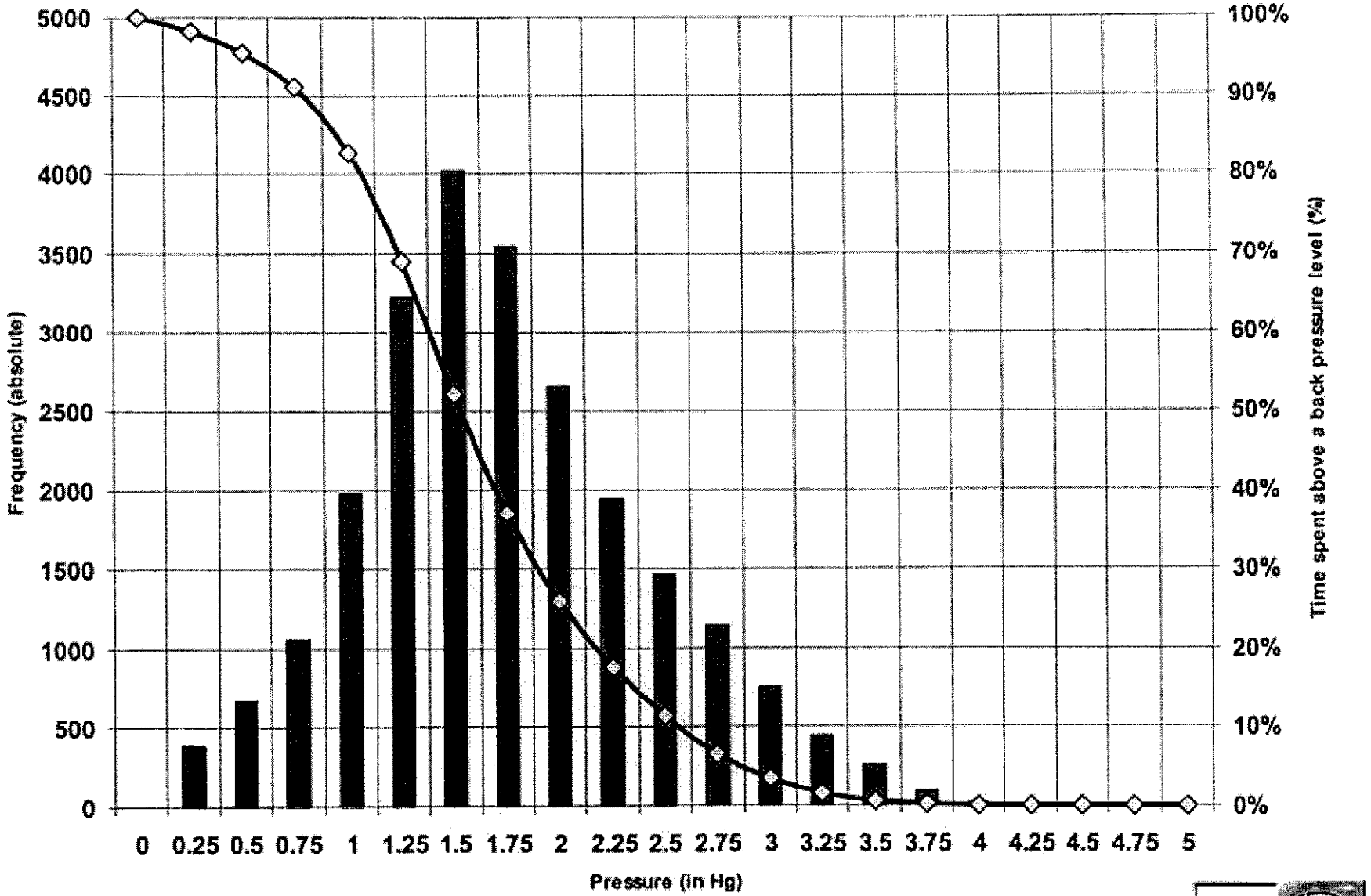


CRT™ on LA City Sanitation Truck ISM 305V

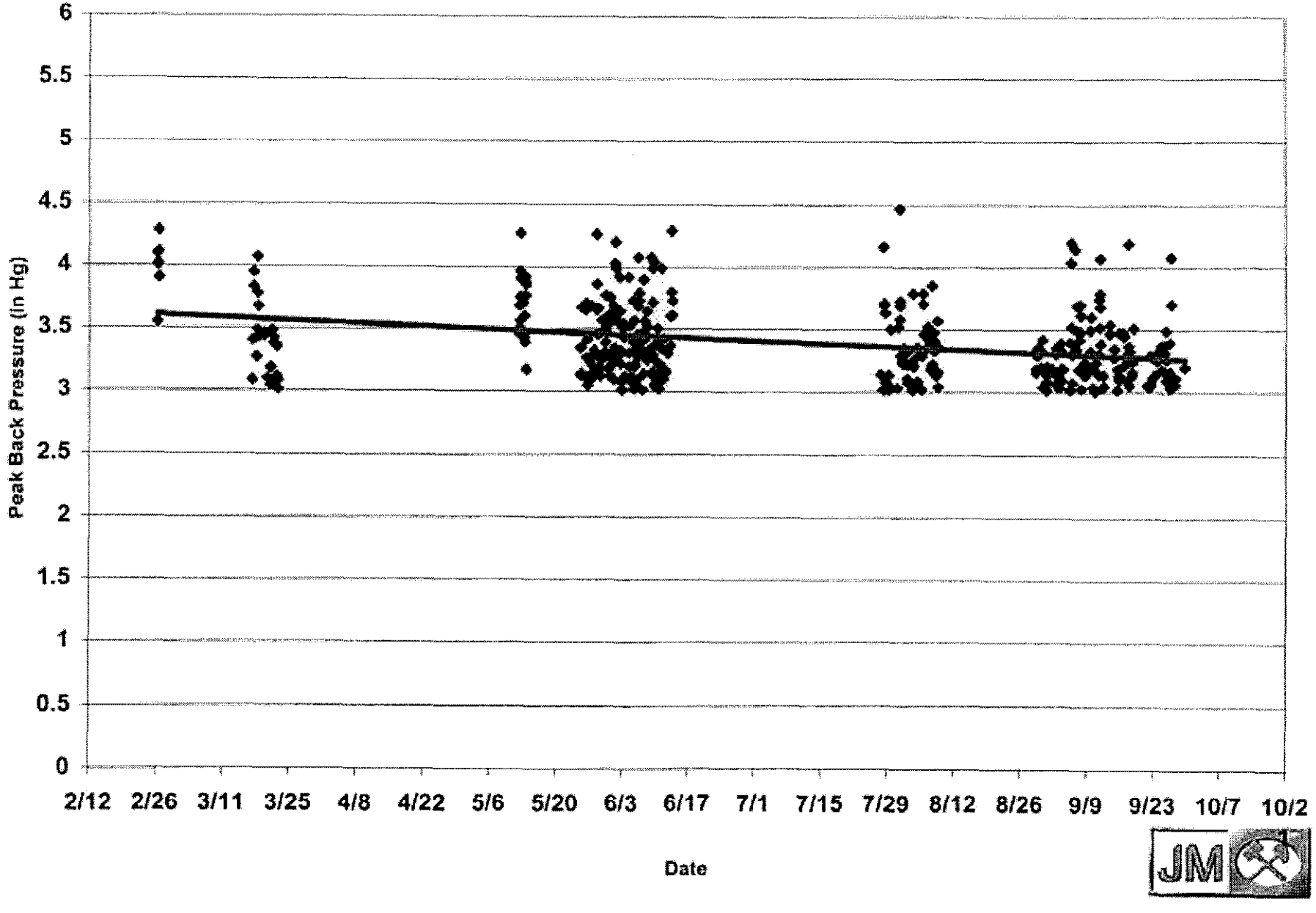
Emission Testing with CRT on Ser. 60 Truck - CSHVR



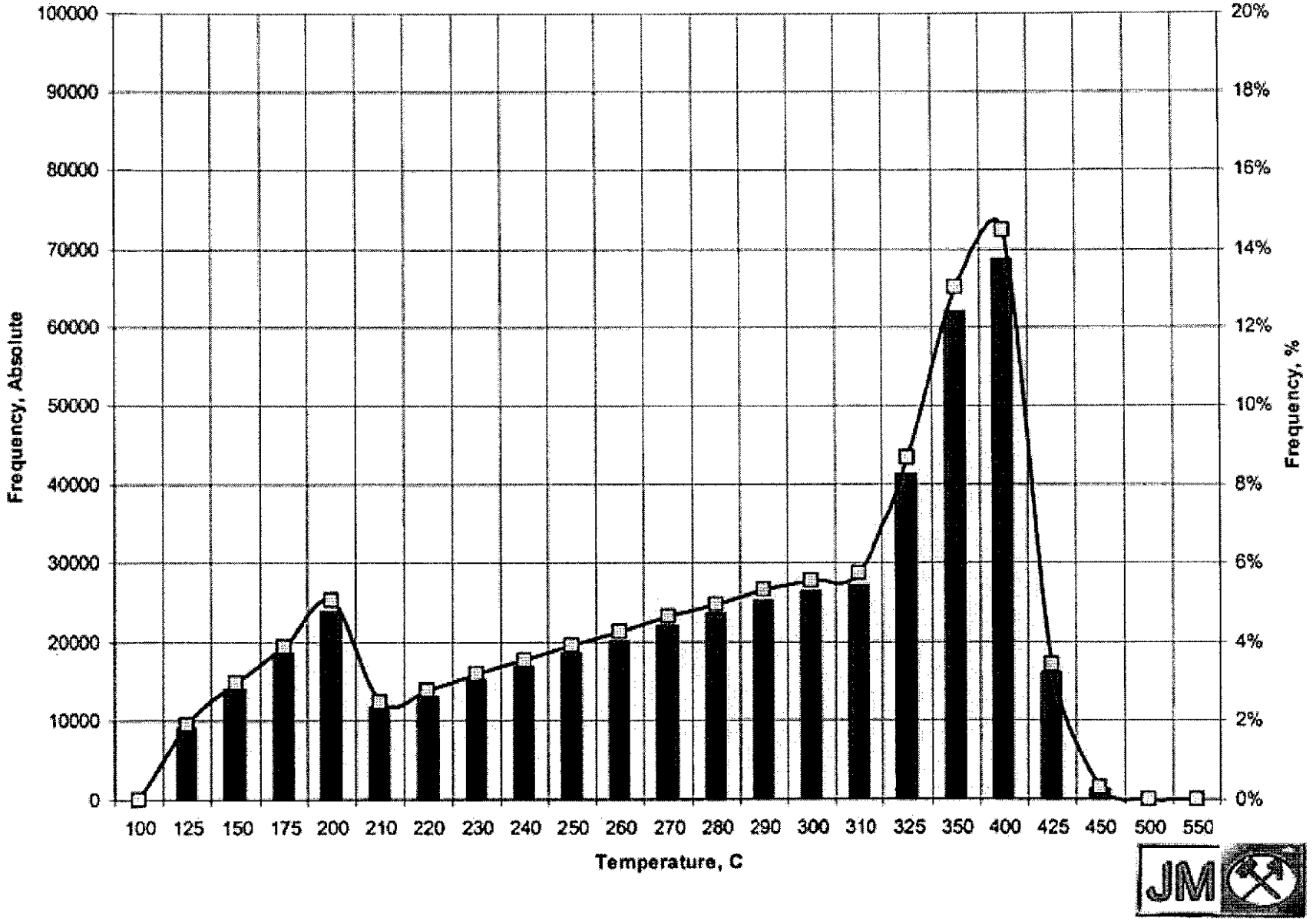
Back Pressure Histogram with CRT™ on Ralphs Truck 430 Hp DDC Ser 60



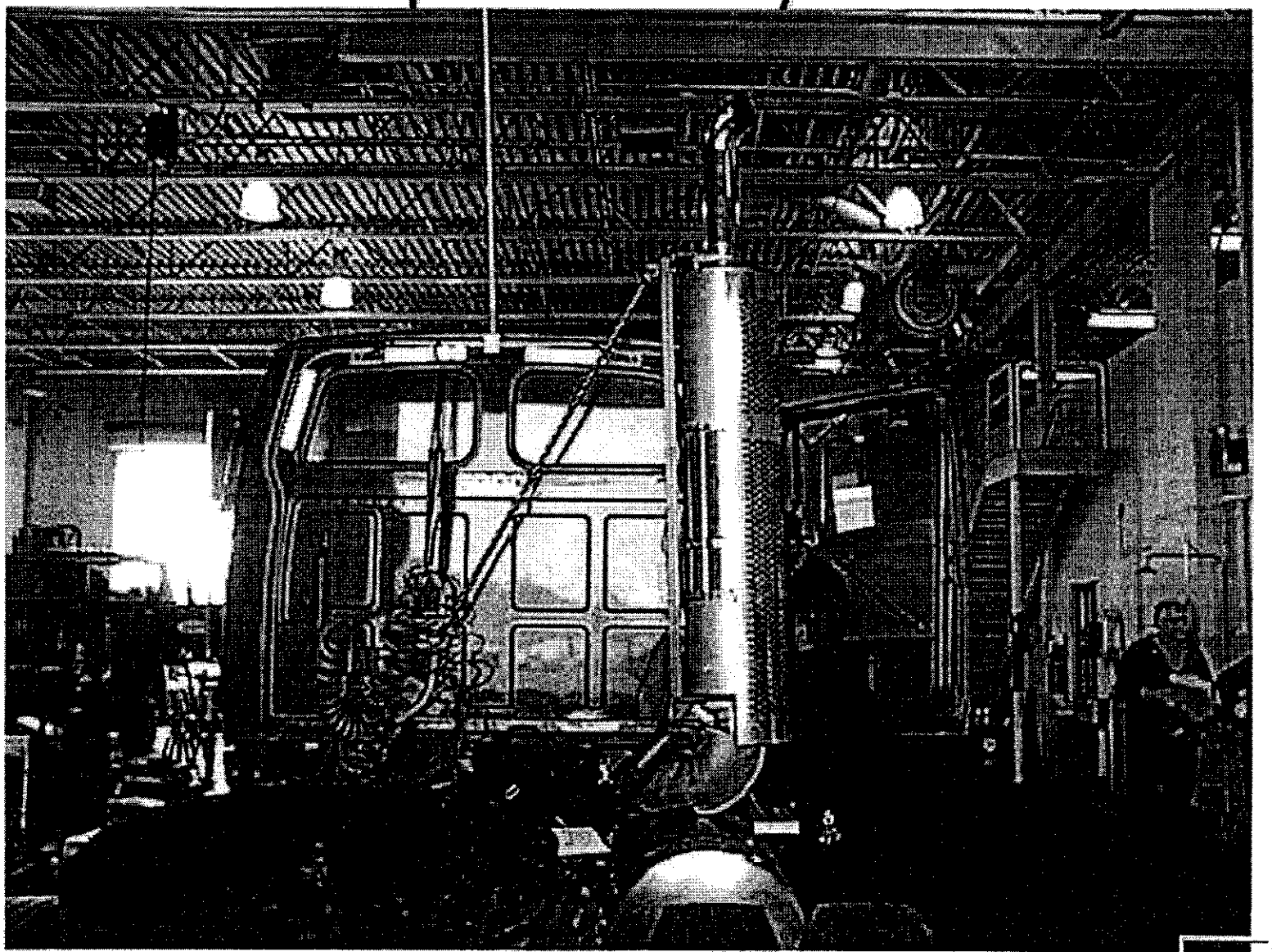
Peak Back Pressure with CRT™ on Ralphs Truck - 430 Hp DDC Ser 60



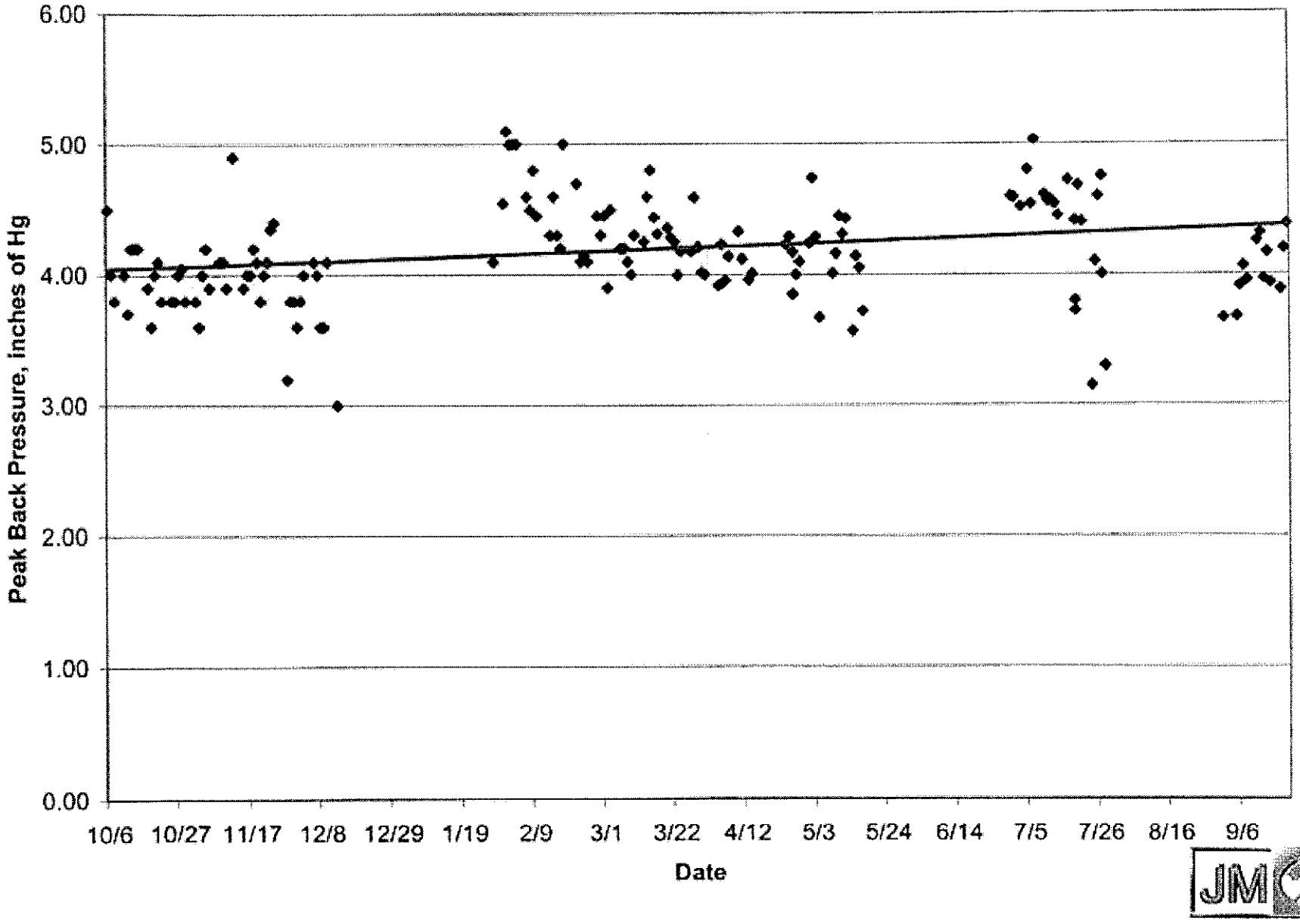
Temperature Histogram with CRT™ on Ralphs Truck



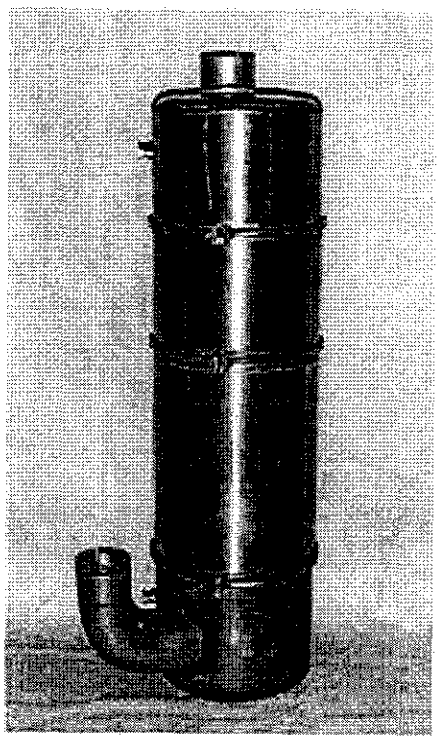
CRT™ on Ralphs Grocery Truck - Ser. 60

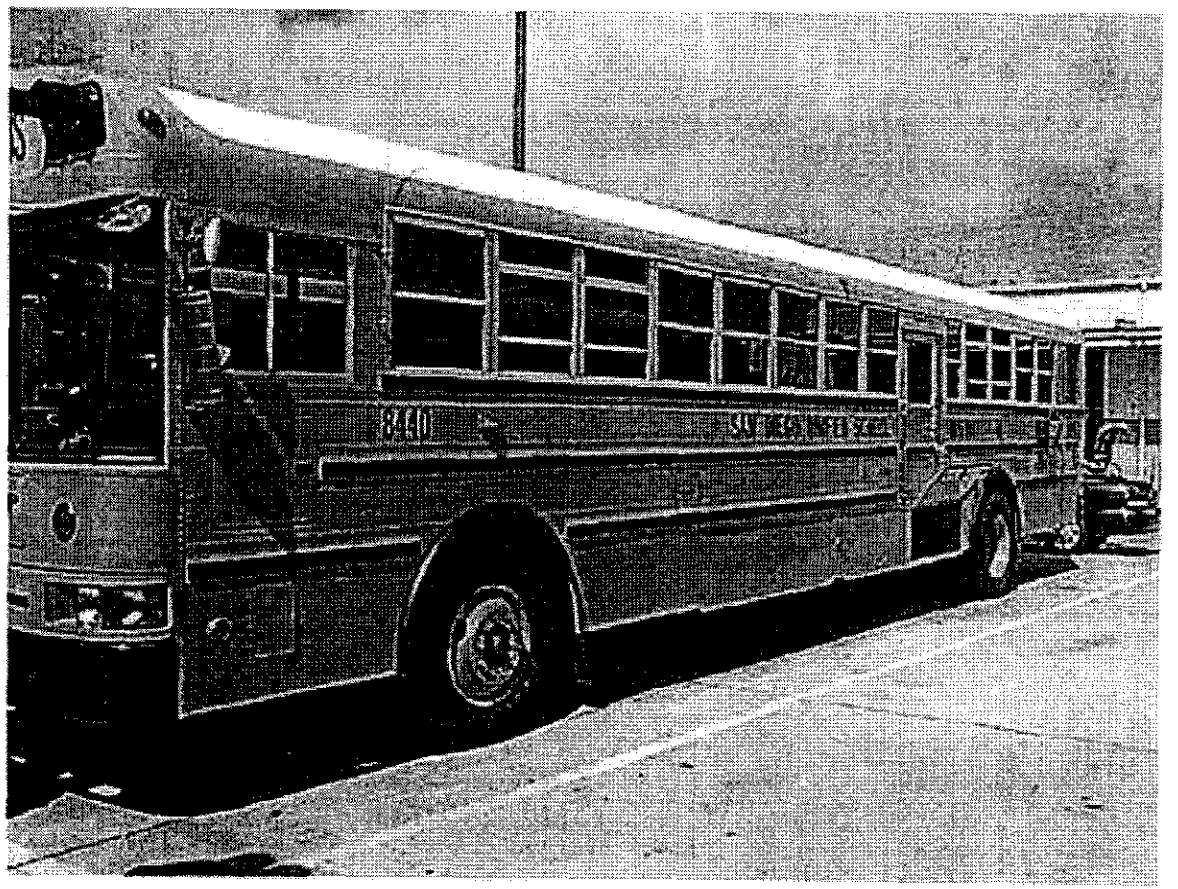


Peak Back Pressure with CRT™ on San Diego School Bus

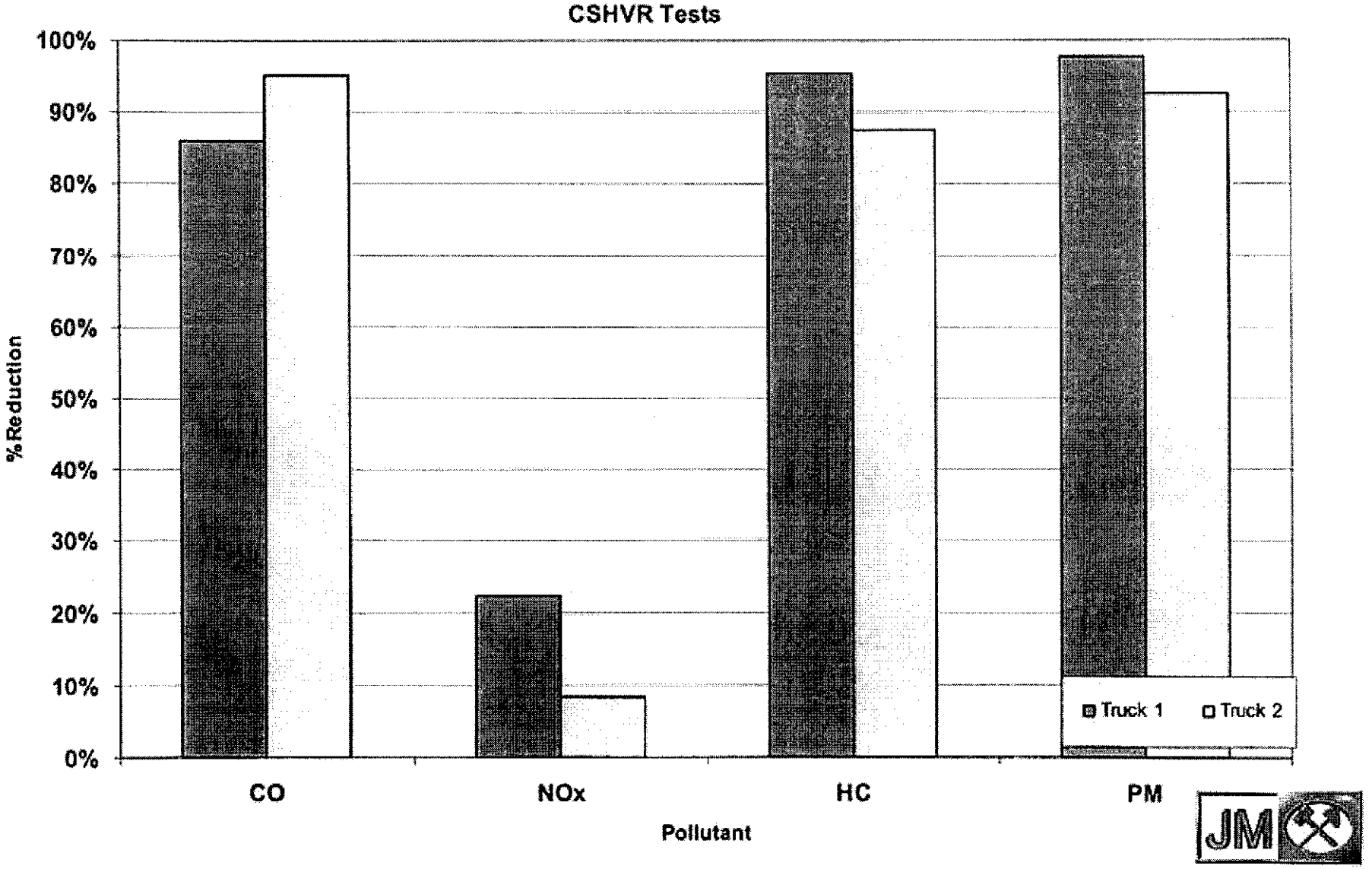


CRT™ on San Diego School Bus - Navistar 530 E

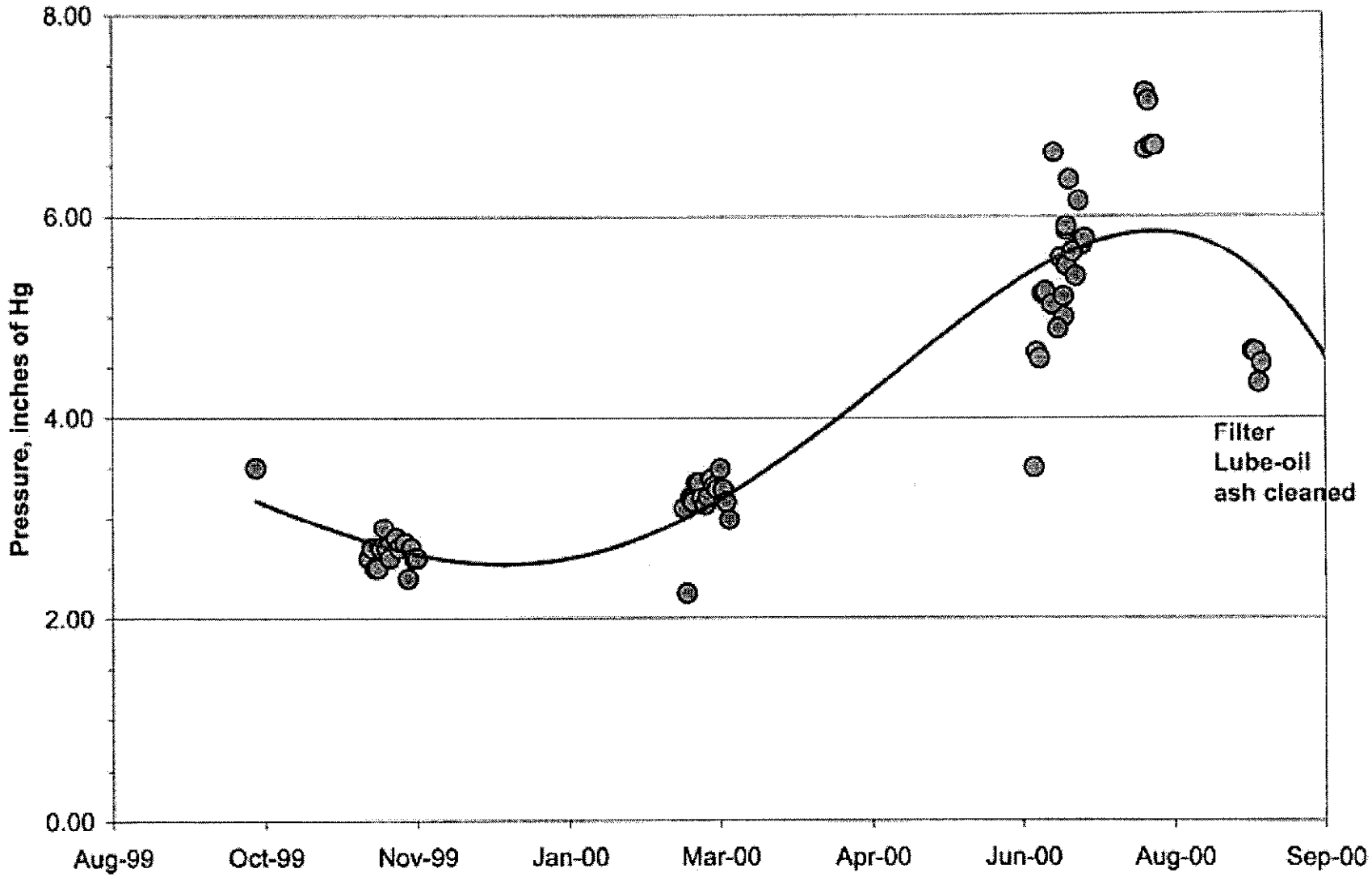




Emissions Reduction with CRT on Truck with Cummins M-11



On-Road Peak Back Pressure with CRT™ on ARCO Truck



CRT™ on ARCO Fuel Truck

ARCO Program Outline

- Vehicle Types:
  - **ARCO Fuel Delivery Truck:** **Cummins M11, 360 Hp**
  - **San Diego School Bus:** **Navistar 530E, 275 Hp**
  - **Ralphs Grocery Truck:** **DDC Ser. 60, 430 Hp**
  - **Santa Monica Transit Bus:** **DDC Ser. 50, 275 Hp**
  - **Universal Studios Tram:** **DDC Ser. 40E, 330 Hp**
  - **LA City Garbage Truck:** **Cummins ISM, 305 Hp**
  - **LA City Garbage Truck:** **Cummins ISM, 370 Hp**
  - **Hertz Utility Truck:** **Navistar Power Stroke 225 Hp**

CRT™ Retrofit Applications in California

- **ARCO EC Diesel Evaluation Program**
- **LA MTA Transit Bus Retrofit**
- **SCAQMD School Bus Retrofit**

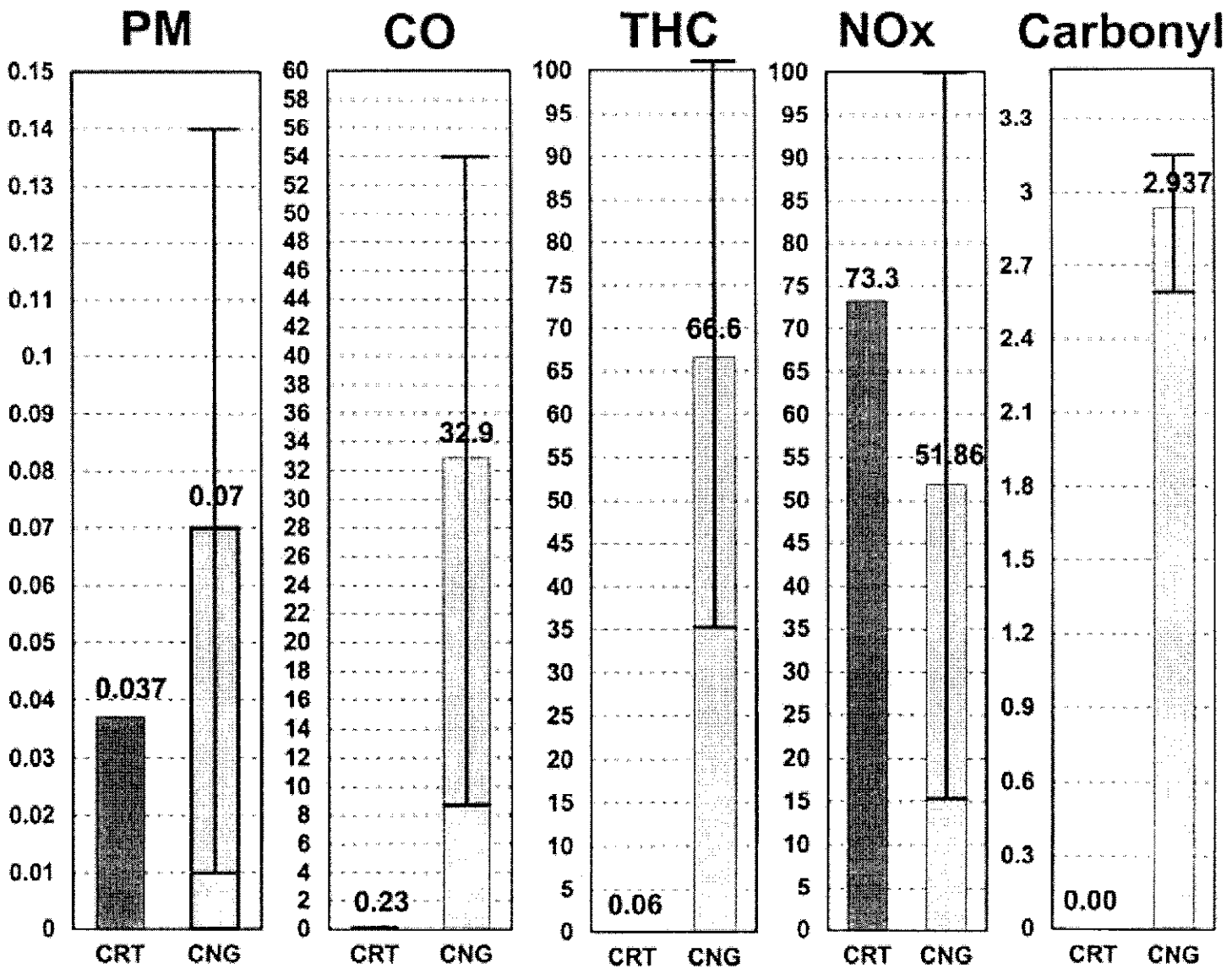
NYCT CRT Project - Moving Forward

- CRT Project - Continue Durability testing until November
- CRT Project - At conclusion of durability phase, emissions test same buses
- CRT Project - Fuel matrix portion of project - explore different fuel chemistries and how they affect emissions
- CRT Project - Explore short term durability of "best" fuel chemistry from matrix
- MTA NYCT has contracted for Ultra Low Sulfur Diesel Fuel for its entire fleet for the next three years starting in September 2000
- MTA NYCT has contracted to retrofit 500 buses with CRT filters starting from September 2000

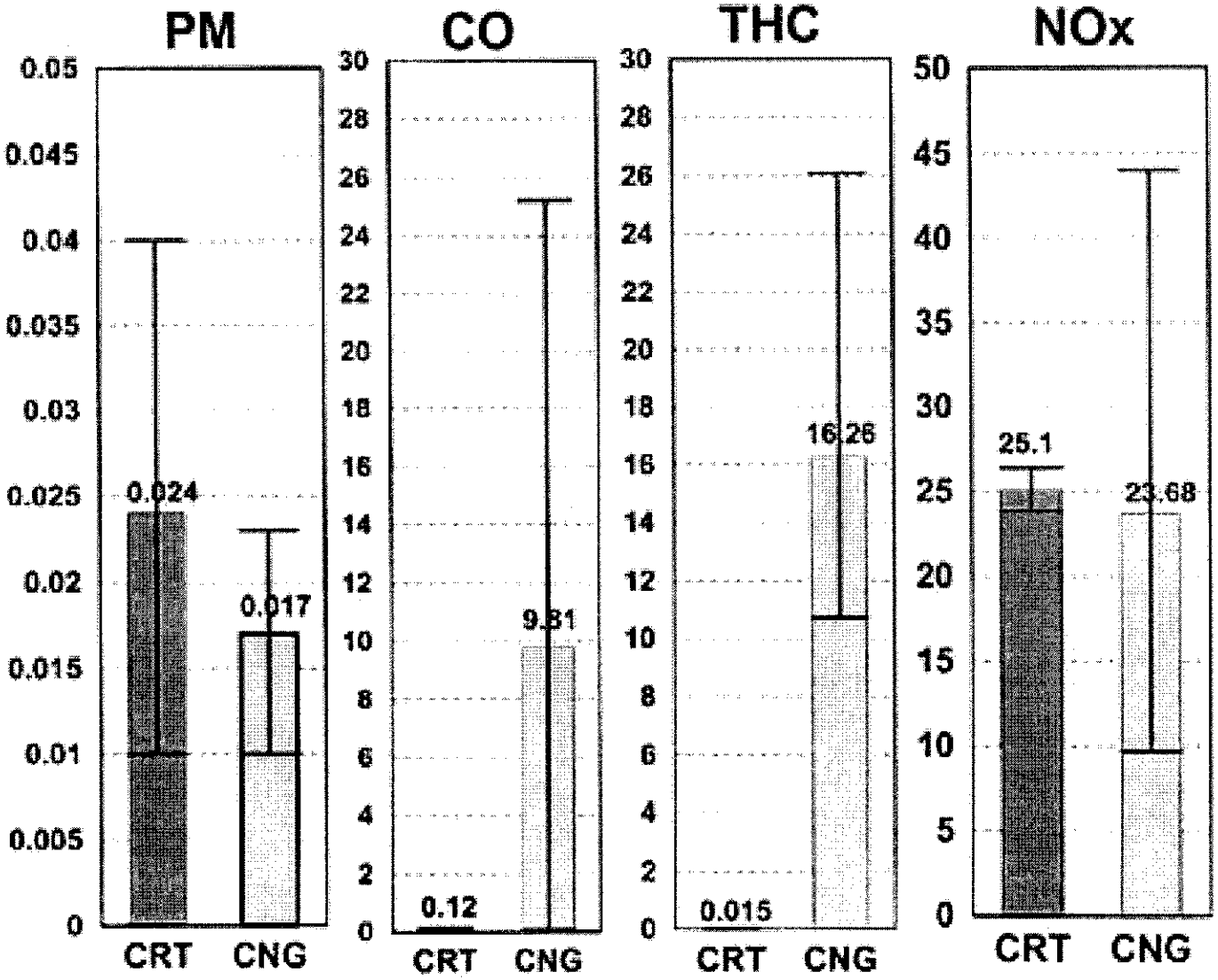
Clean Diesel vs. CNG

- PM emissions from CRT-equipped buses appear to be equivalent to those from CNG buses
  - Average PM emissions with CNG is lower on CBD cycle, but higher on NY Bus cycle
  - Much wider range of values with CNG, especially on NY Bus cycle
- CO and HC emissions from CRT-equipped buses are much lower than those from CNG buses
- NOx emissions are generally lower from CNG buses than from CRT-equipped buses, but show a wider range of variability
- Carbonyl emissions from CNG buses are much higher than from CRT-equipped buses.

Emissions Test Results - CRT vs. CNG
NY Bus Cycle



Emissions Test Results - CRT vs. CNG
CBD Cycle



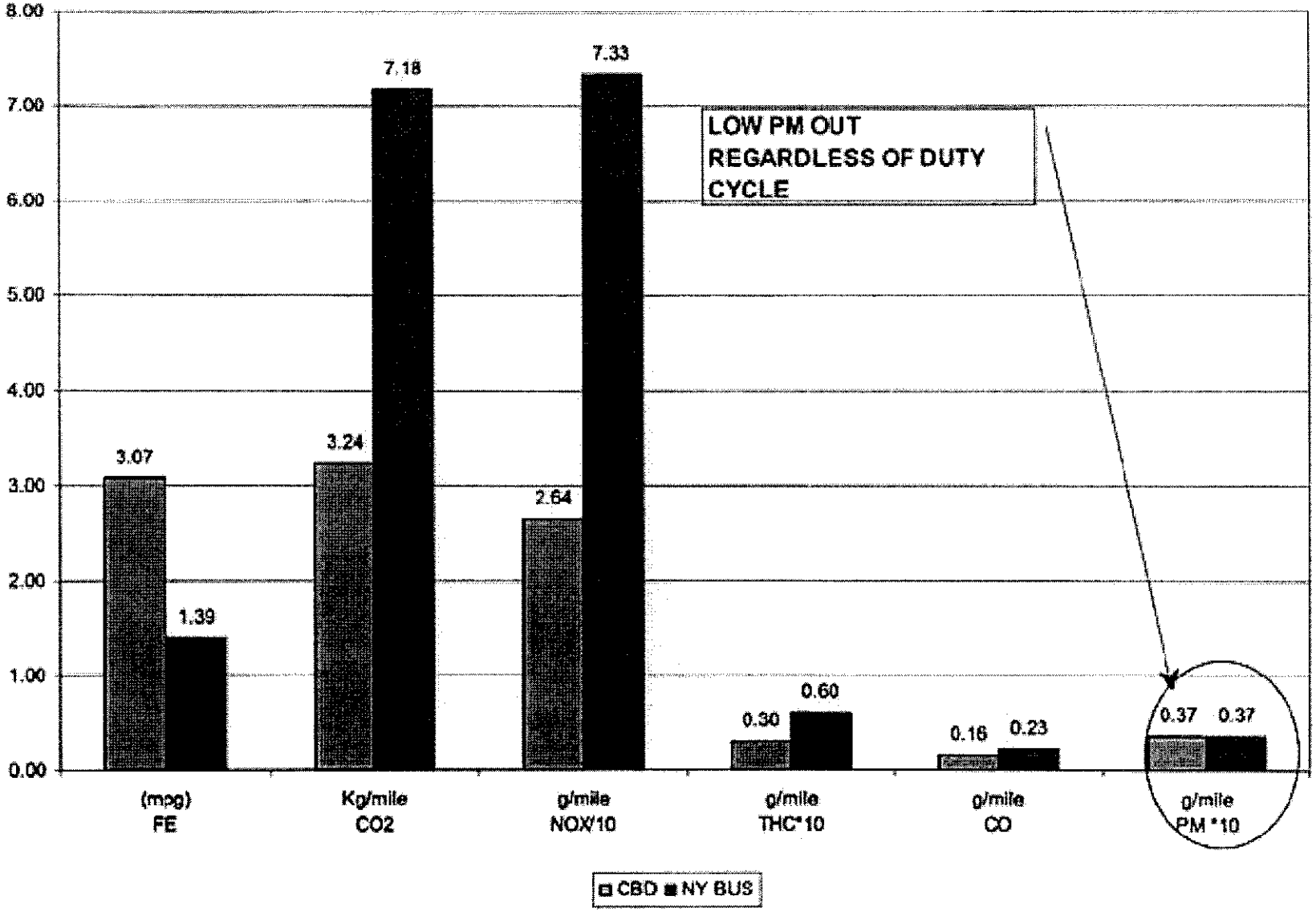
Emissions Comparison Clean Diesel vs. CNG

- Data on CNG emissions gathered from 3 test sites
  - CARB Testing (LA MTA)
  - NAVC Test Program (WVU)
  - NYCT Testing (Environment Canada)
- All CNG buses tested were equipped with as-in OE Muffler
- CNG test data showed large variability in some emission components - for comparison to CRT, the average is shown, along with "error bars" showing the range of individual results
- In addition to regulated emissions, data is included on total CARBONYL emissions. This is a class of hydrocarbon species, primarily consisting of aldehydes and ketones. Many of these compounds such as Formaldehyde, Acetaldehyde, Acrolein and Propionaldehyde are considered very toxic and are listed in EPA's Hazardous Air Pollutants (Title II HAP) list.

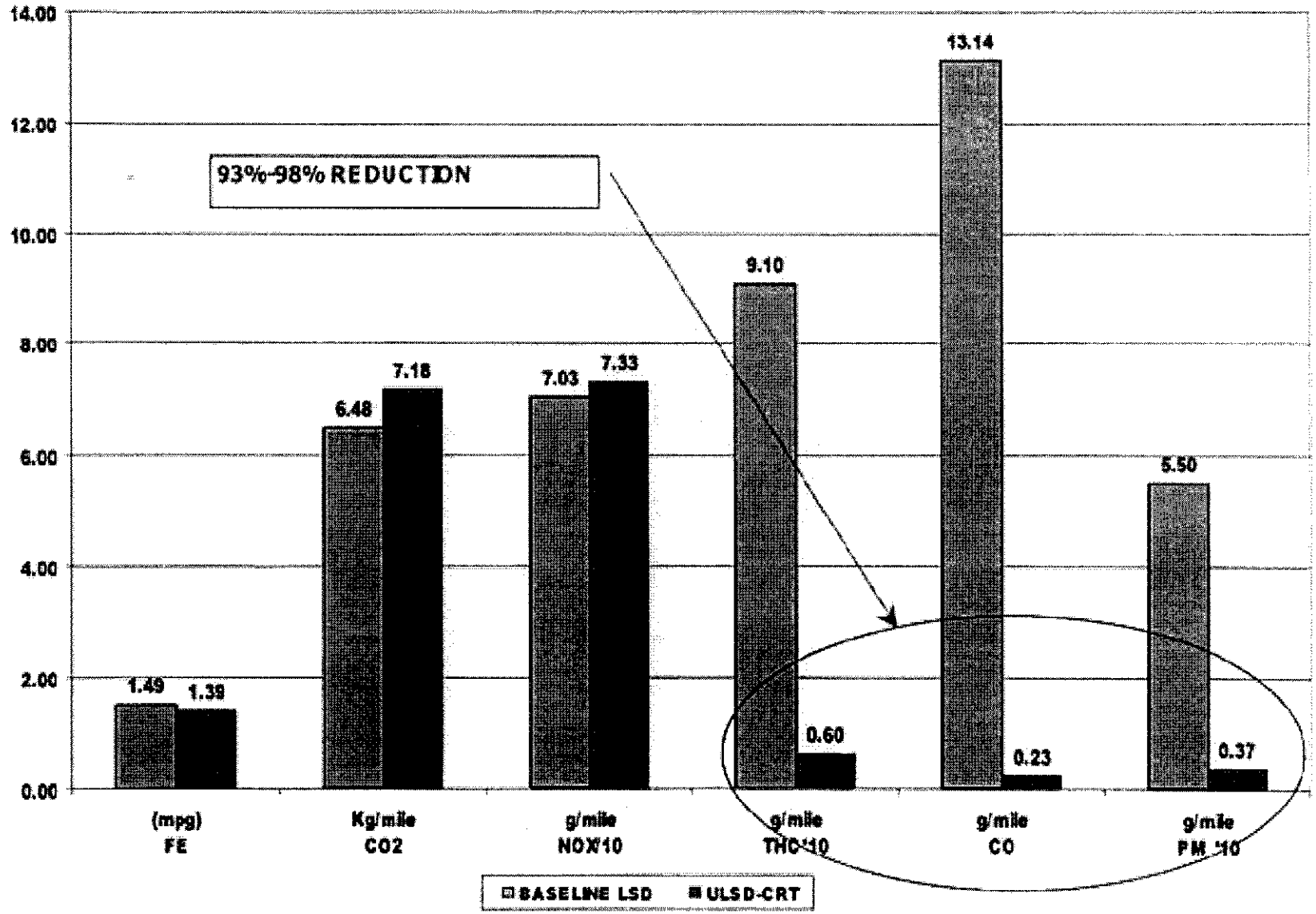
Emissions Testing Results

- ***Fuel effects:*** Going from ***Baseline LSD to ULSD*** *on the CBD Cycle* results in 76% average reduction in THC, 29% average reduction in CO, and 29% average reduction in PM
- ***CRT effects:*** *On CBD cycle, reduction* in Average Emissions compared to ***Baseline Fuel & Catalyst Muffler*** - 92% for THC, 94% for CO, and 88% for PM
- Emissions reductions on **NY Bus Cycle** with the **CRT** filter are even higher than on CBD: 93 - 98% Reduction in THC, CO, and PM
- The PM Emissions appear to be **independent of duty cycle** with the CRT - CO2 emissions and Fuel Economy indicate that NY Bus Cycle requires twice as much work as CBD, but there is ***NO INCREASE IN PM OUT***

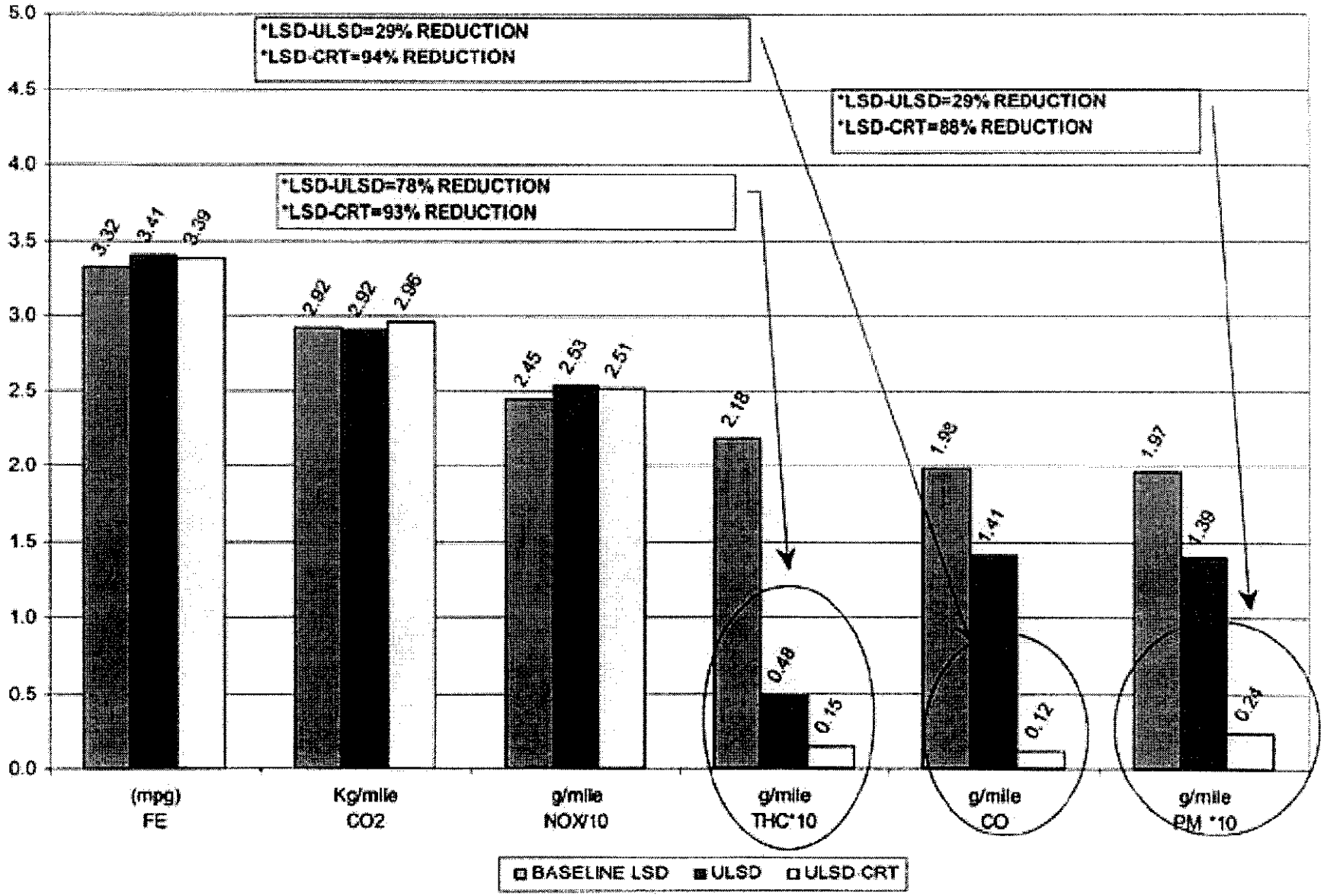
Emissions Test Results with CRT
CBD vs. NY Bus Cycle



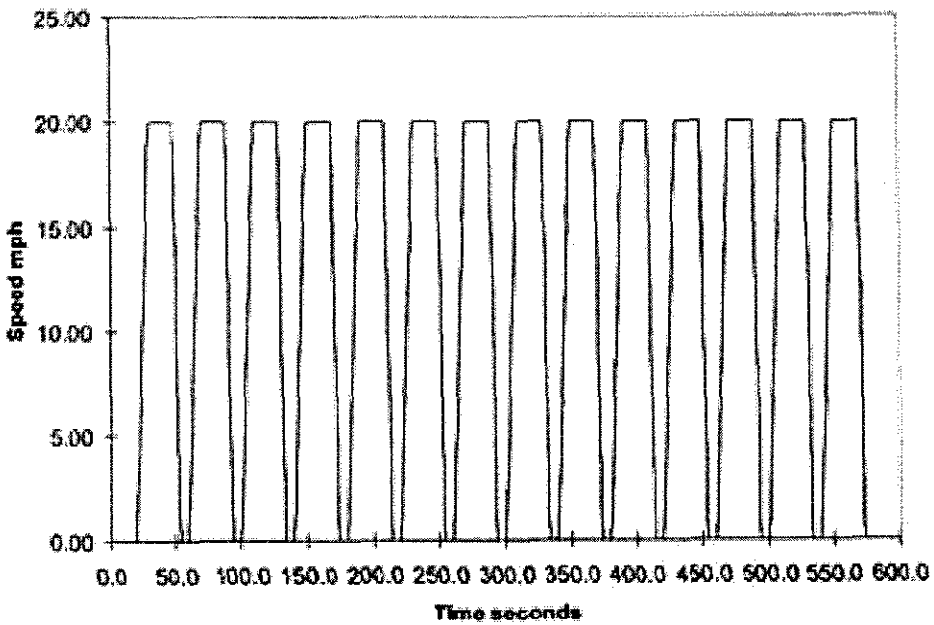
Series 50 Emissions Results
NY Bus Cycle



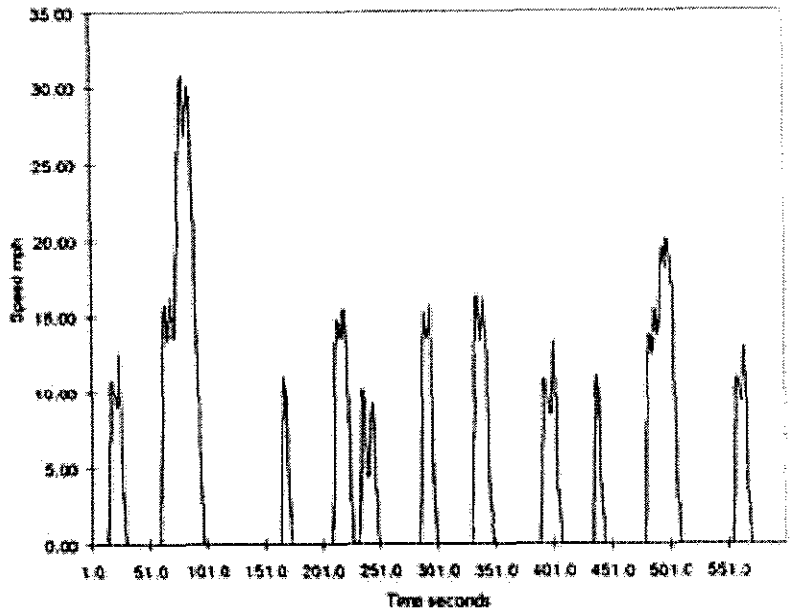
Average Series 50 Emissions Results
CBD Cycle



Emissions Test Cycles



CBD Cycle

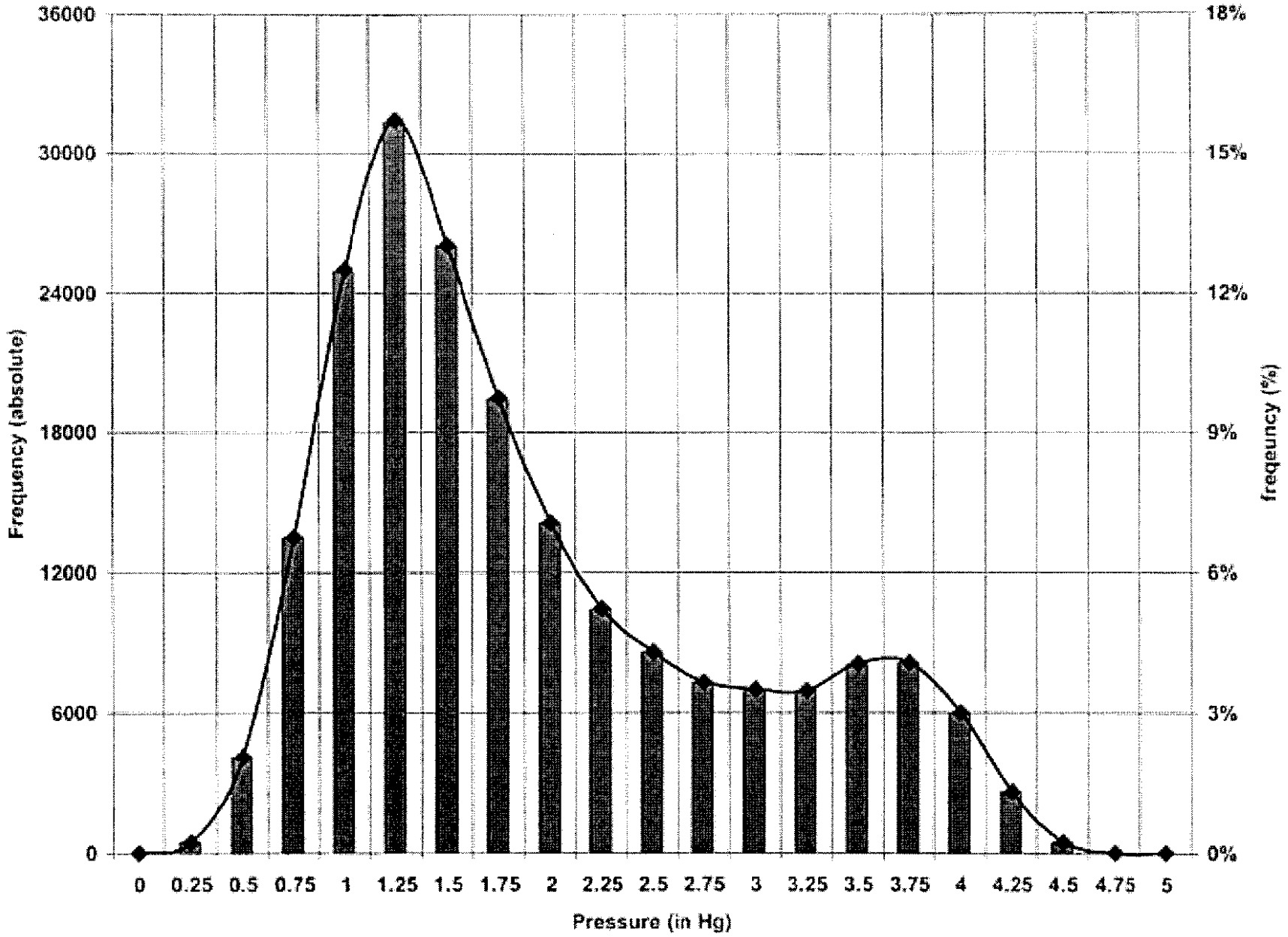


NY Bus Cycle

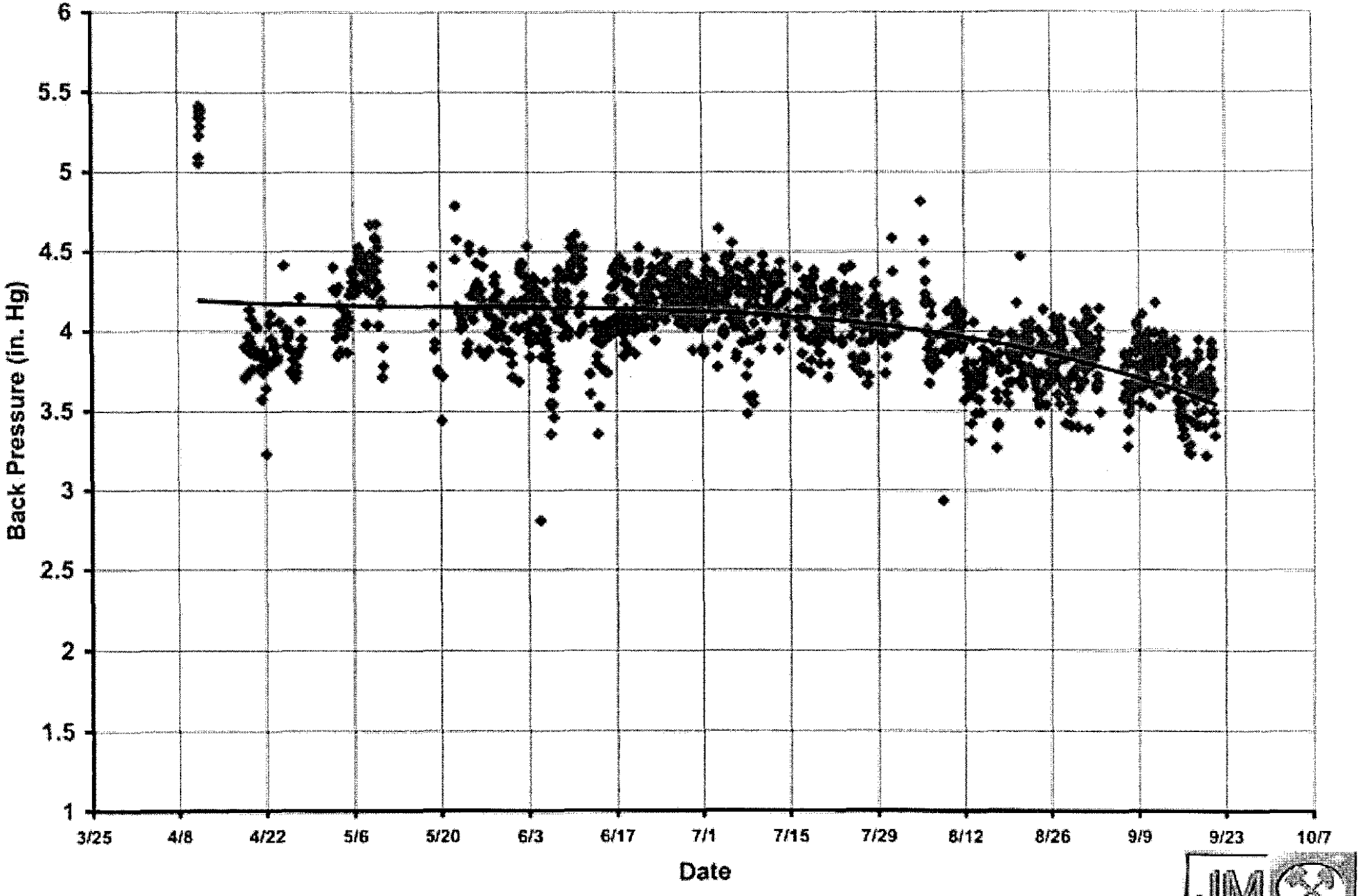
Emissions Testing

- 2 Series 50 buses tested at the beginning of the program
  - Each bus tested with OEM Catalyst/standard fuel (350 ppm S), with OEM Catalyst/ultra low sulfur fuel (30 ppm), and with CRT system/ultra low sulfur fuel (30 ppm)
- Test on chassis dynamometer using CBD and New York bus cycles
- Collect info on criteria pollutants (CO, HC, NOx, PM), plus particle size and toxicity
- Re-test both buses after 9 - 12 months of service with installed CRT filter system
- Comparison of CRT filter Data with recent CNG Test Data

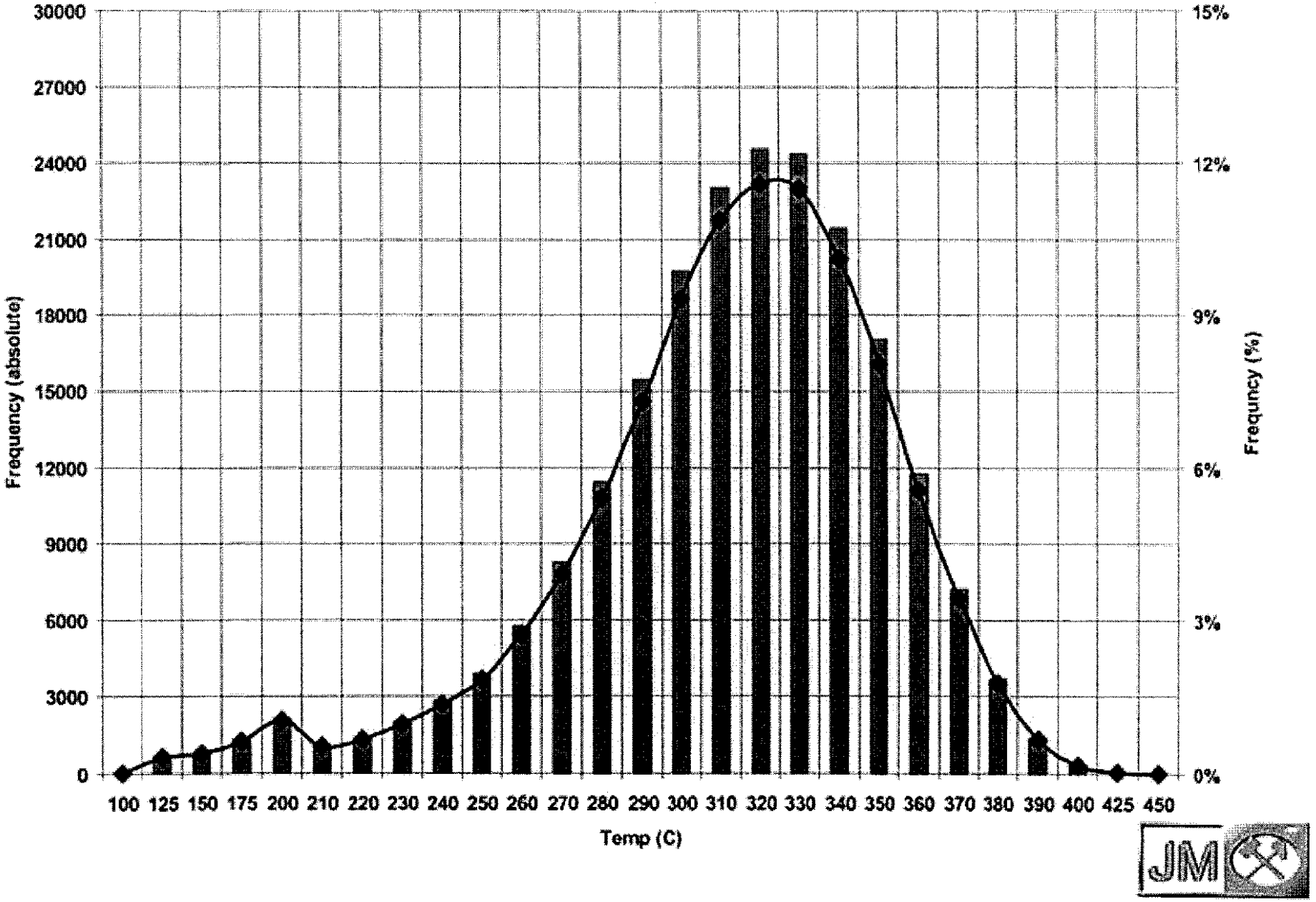
Pressure Histogram on Series 50 Bus with CRT at NYCT



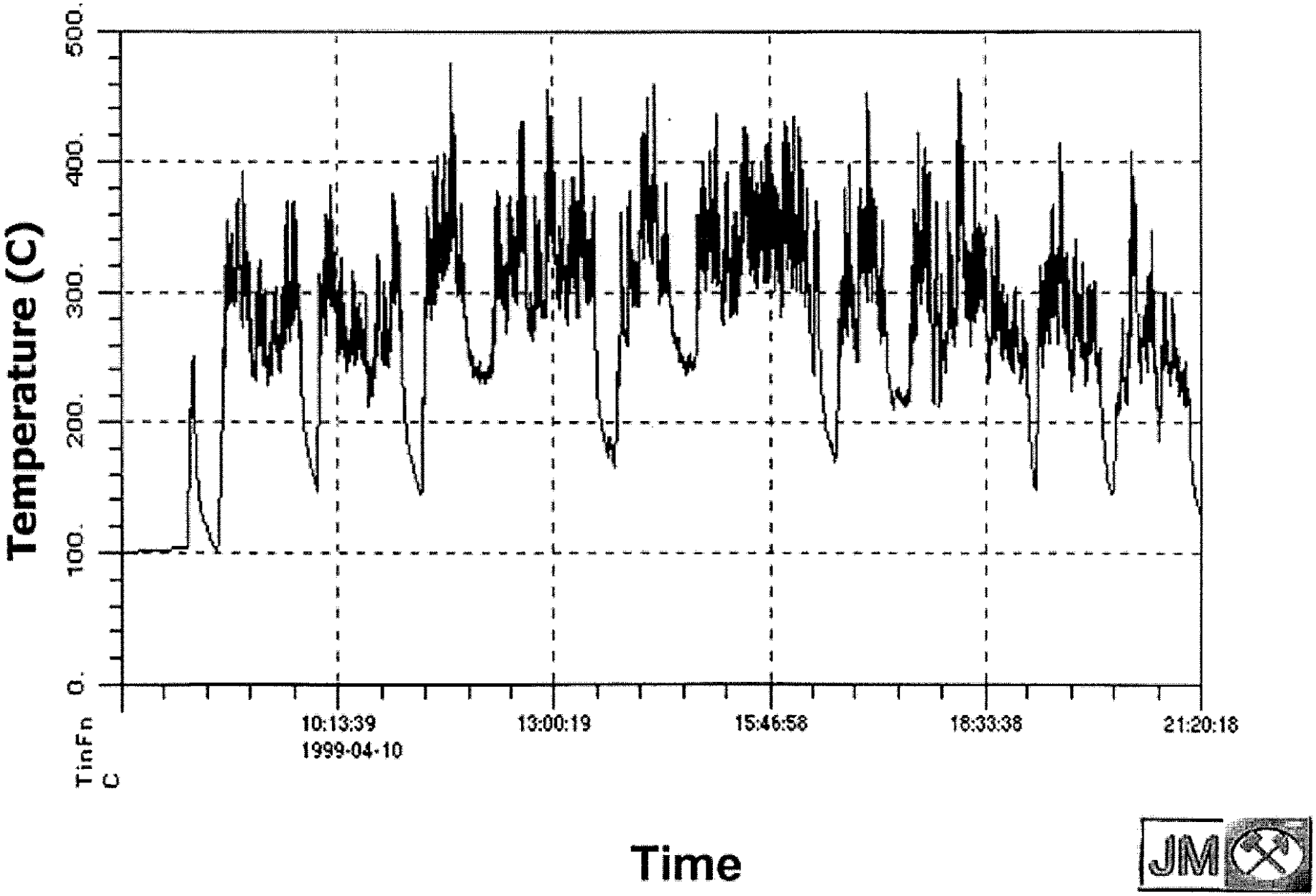
Peak Back pressure with CRT™ on Series 50 Bus; NY Road Test - Bus 6065



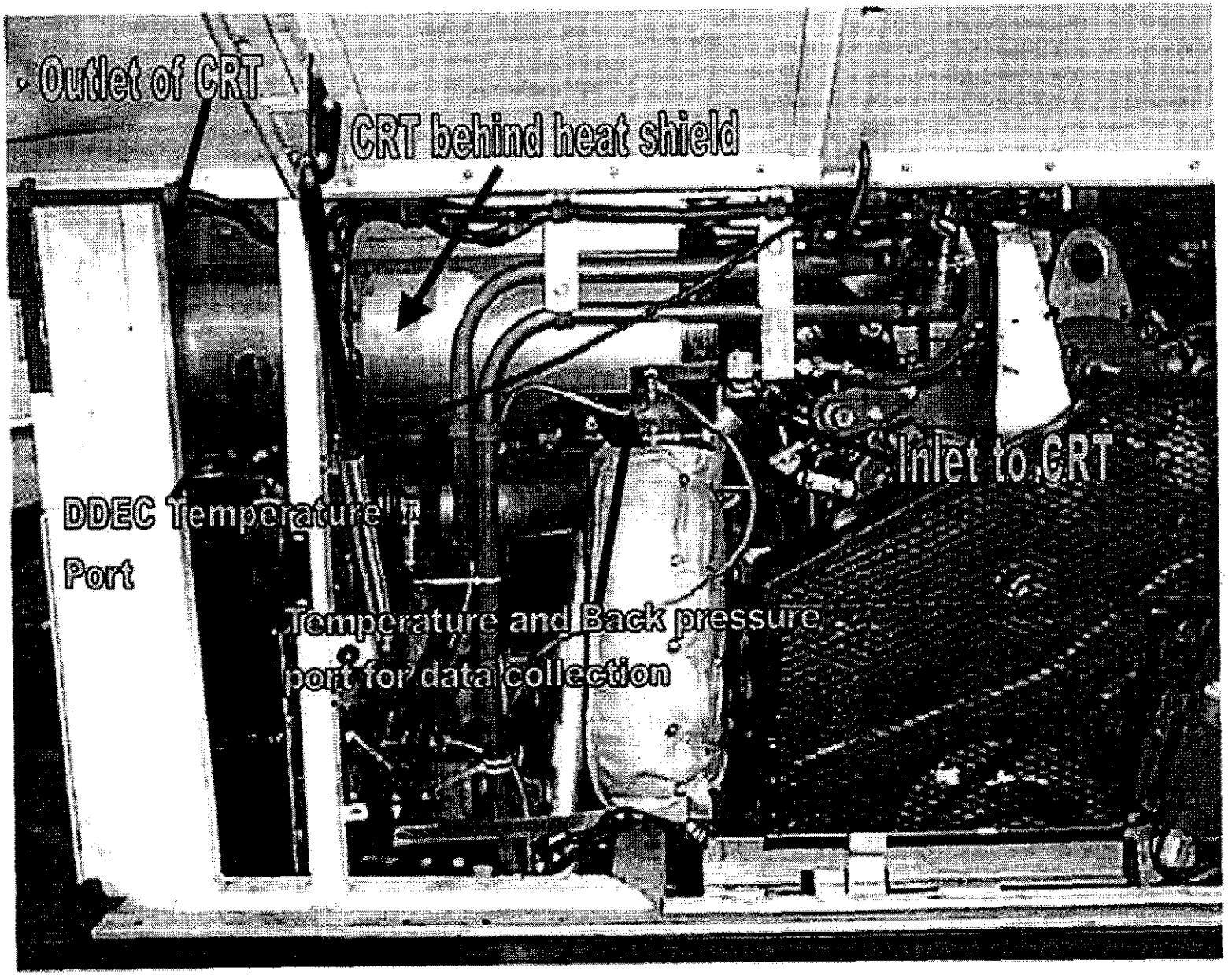
Temperature Histogram on Series 50 Bus



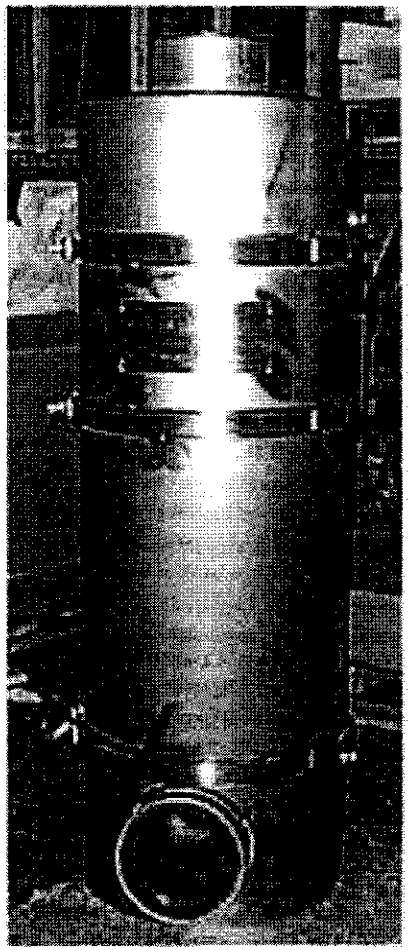
Exhaust Temperature with CRT™ on Series 50 Bus

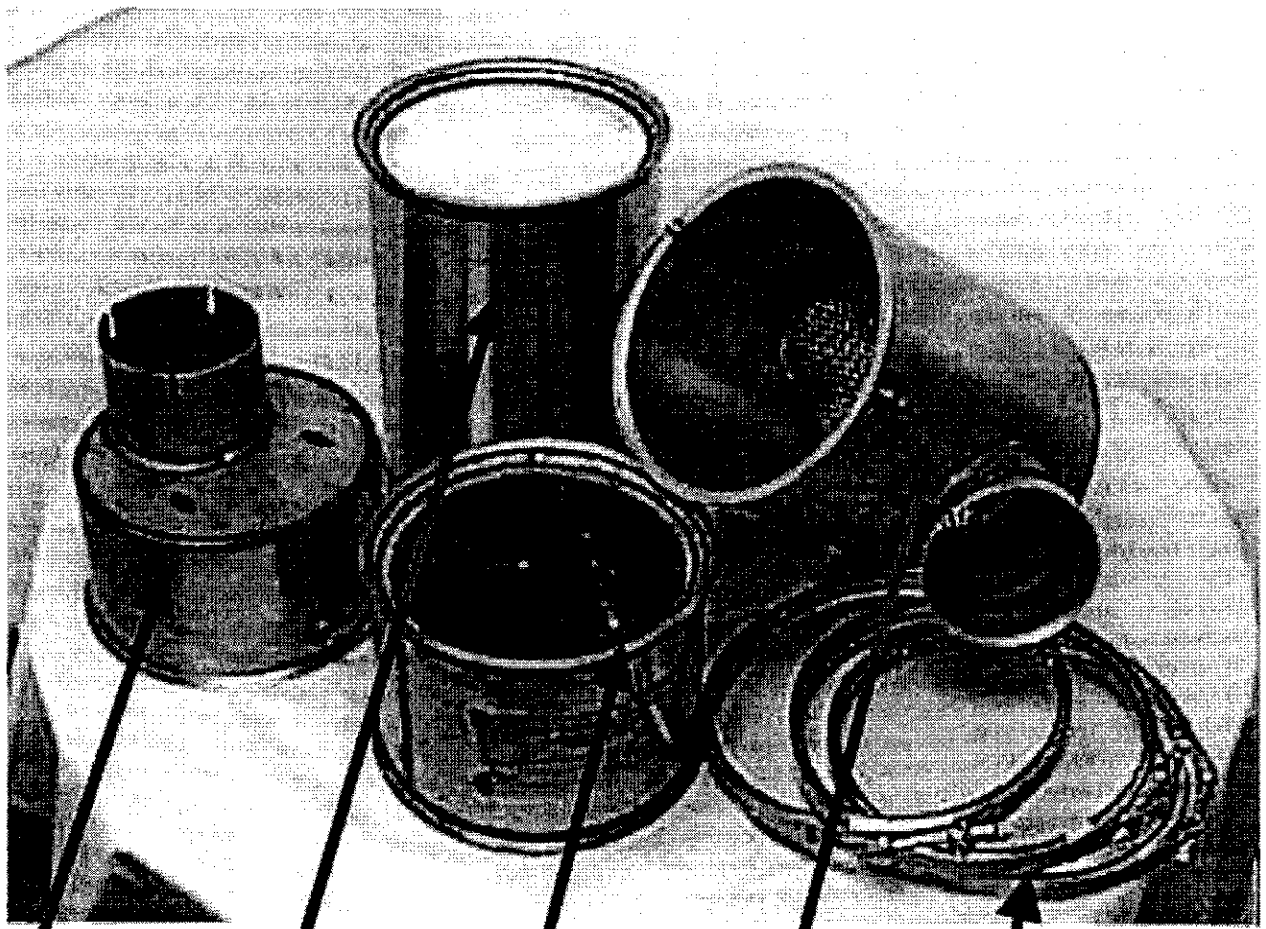


Series 50 DDEC Bus CRT™ installation



Typical CRT™ Particulate Filter





NYCT CRT Demonstration Program Outline

- Fleet demonstration *(Feb 2000 - Jan 2001)*
  - 25 Series 50 Buses; 275 Hp 1999 model year
  - Operate for 9-12 months in revenue service
  - Check back pressure and exhaust temperature
- Emissions testing *(April 2000; Feb 2001)*
  - 2 Series 50 Buses with CRT
  - Check emissions with chassis dyno under CBD & NYC Bus cycle
  - Measure at the start and at the end of program

CRT™ Field Applications

- Europe
  - Over 11,000 units installed since 1994
- North America
  - New York:
    - MTA NY City transit buses
    - NY Sanitation Trucks
    - NY DOT Trucks
  - California:
    - ARCO EC Diesel program
    - LA MTA
    - SCAQMD school bus program
  - Timing: 1999-2001

Benefits of Johnson Matthey CRT™ as Clean Diesel Retrofit

- Meets current and future regulations, thereby allowing operators to use diesel engines and retain all its benefits
- CRT filter reduces PM, THC and CO to levels equivalent or lower than alternative fuel vehicles;
- CRT diesel has much lower toxic Carbonyls than CNG
- CRT is effective for PM reduction in all particle ranges
- Patented SCRT systems reduce NOx emissions well below alternative fuels while simultaneously removing PM, THC and CO for future applications
- **CLEAN DIESEL** - is a reality!