California Environmental Protection Agency
AIR RESOURCES BOARD

Informational Package for the

HEAVY-DUTY VEHICLE INSPECTION PROGRAM

PERIODIC SMOKE INSPECTION PROGRAM

Enforcement Division
Heavy-Duty Diesel Enforcement
http://www.arb.ca.gov/enf/hdvip/hdvip.htm

January 2009

California Environmental Protection Agency
AIR RESOURCES BOARD

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January 2009

California Environmental Protection Agency
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Overview of the

HEAVY-DUTY VEHICLE INSPECTION PROGRAM

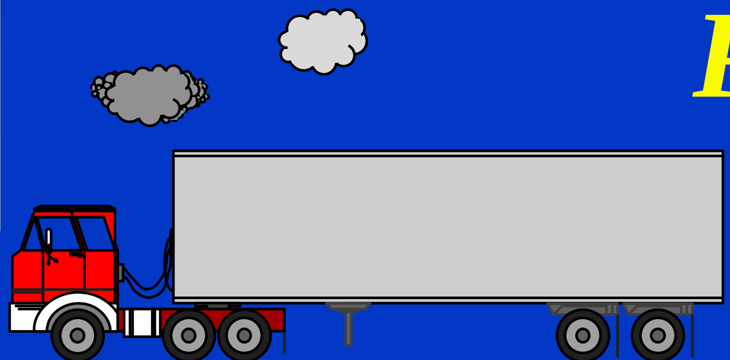
PERIODIC SMOKE INSPECTION PROGRAM

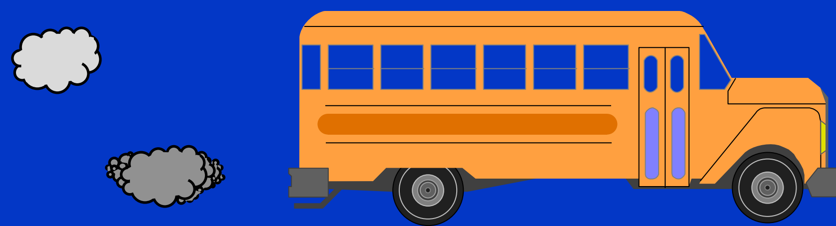
January 2009

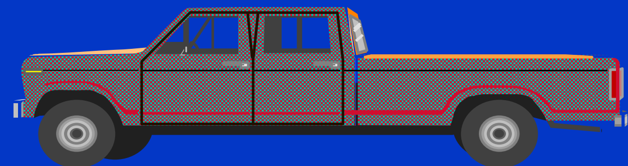
Heavy Duty Vehicle

Inspection

Program







Heavy Duty Vehicle Inspection Program

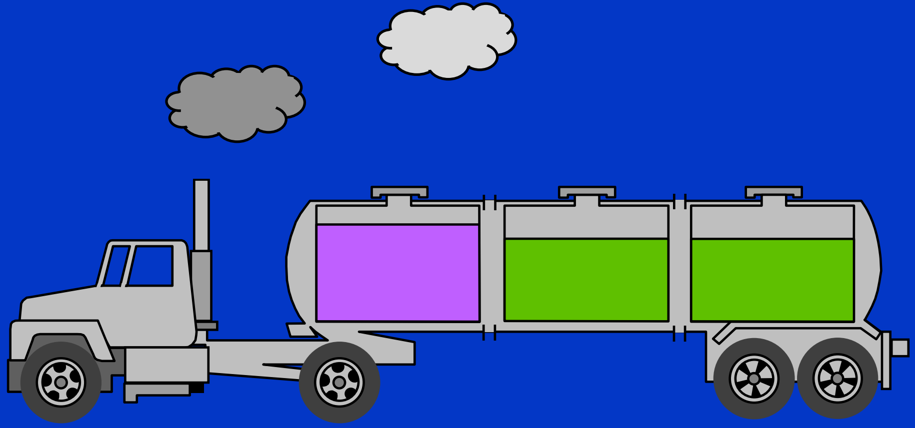
- Established by SB 1997 in 1988
- Amended by AB 584 of 1993
- Health and Safety Code 44011.6

HDVIP Purpose

- To Improve Air Quality
- Reduce Public's Exposure to Toxic Emissions
- Address Public Concern over Smoking Trucks and Buses

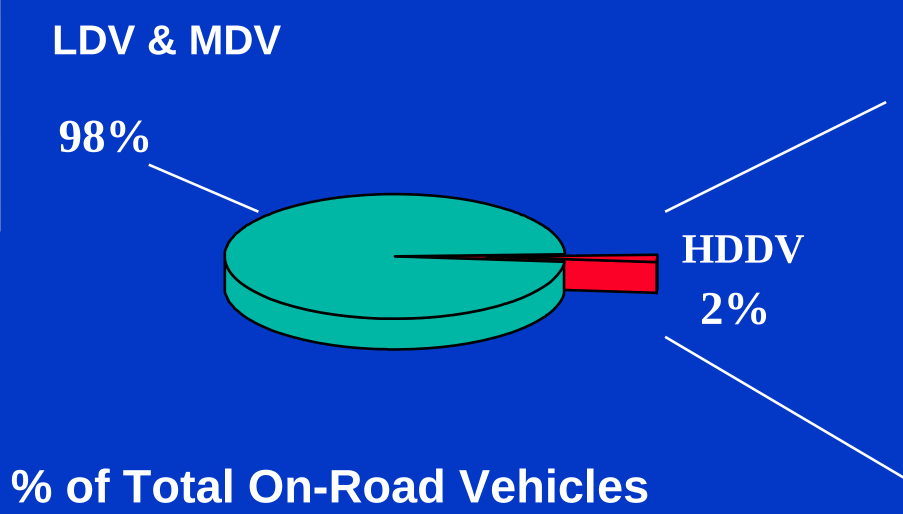
HDVIP Goal

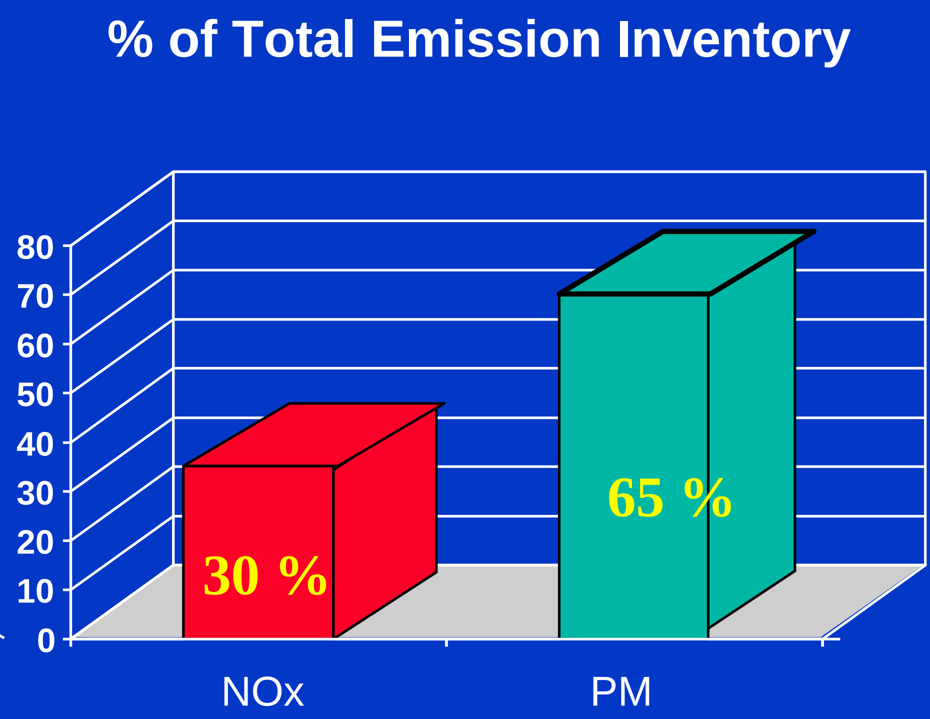
- To Reduce Excessive Smoke Emissions and Tampering on Gasoline and Diesel Powered Vehicles above 6000 Pounds G.V.W.R.



Heavy-Duty Diesel Emissions

(NOx & PM)





Health and Safety Code Section 44011.6

(Established by SB 1997 of 1988)

(Amended by AB 584 of 1993)

(Amended by ARB 1460 of 1996)

Mandated Requirements

- Set up Ad Hoc Advisory Committee (Industry-Government)
- Develop Test Procedures to Detect Excessive Smoke Emissions Which Produce Consistent and Repeatable Results (fulfilled by adoption of SAE J1667 as required by AB 584)

Health and Safety Code Section 44011.6

(Established by SB 1997 of 1988)

(Amended by AB 584 of 1993)

(Amended by AB 1460 of 1996)

Mandated Requirements

- Established Procedures to Remedy “False Failures”
- Develop Inspection Procedures for Emission Controls to Detect Tampering
- Develop Opacity Standards and Penalty Structure

Ad Hoc Advisory Committee

- Air Resources Board (ARB)
- California Highway Patrol (CHP)
- California Trucking Association (CTA)
- Engine Manufacturers Association (EMA)
- South Coast Air Quality Management District (SCAQMD)

Ad Hoc Advisory Committee
(Continued)

- Diesel Fuel Refineries
- California Bus Association
- California Energy Commission (CEC)
- Heavy Duty Diesel Service Industry
- Highway Carriers Association

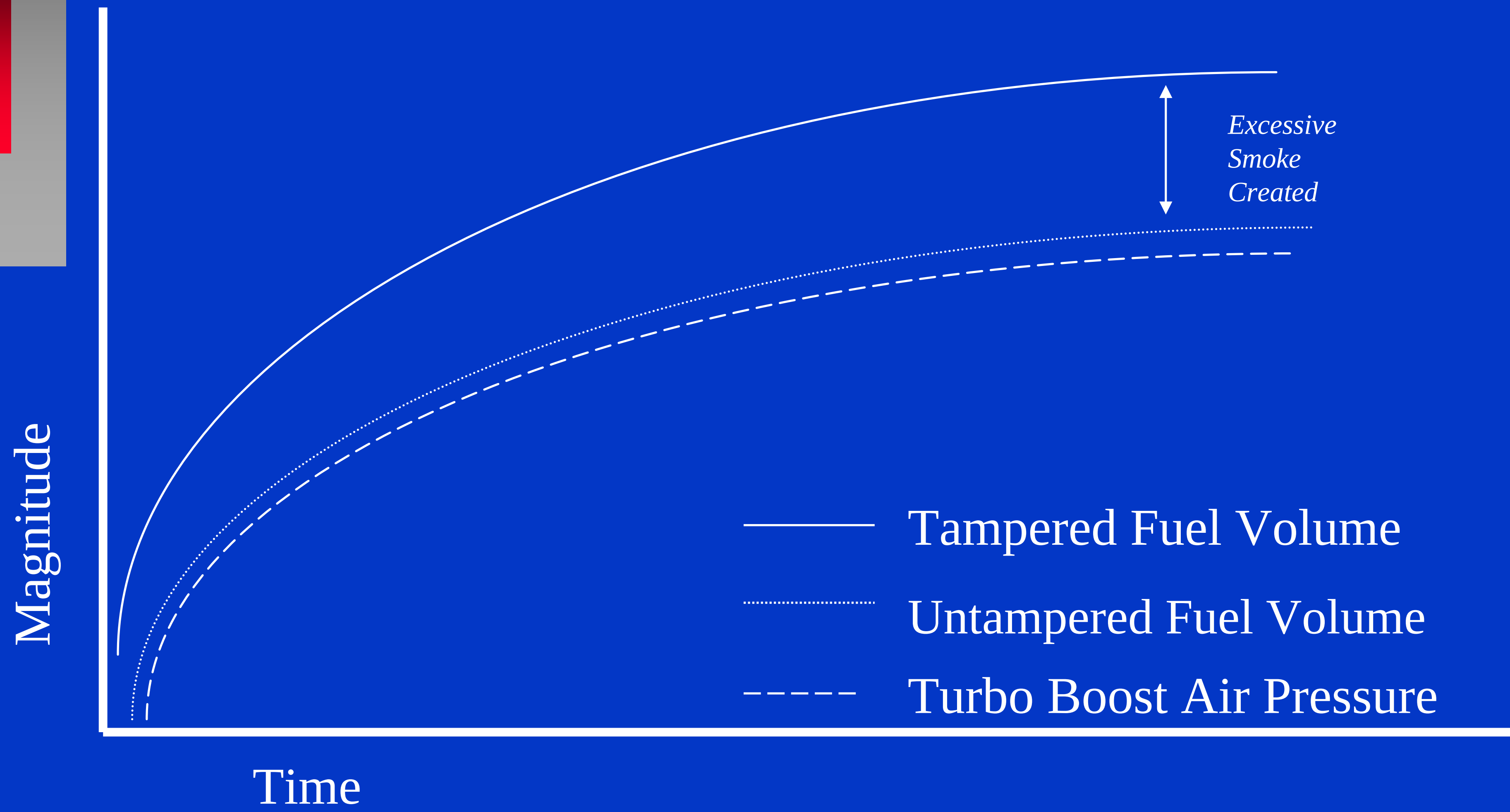
Opacity Measurement

- Electronic Instrumentation SAE J1667
- No Visual Ringelmann Scales
- Digital Print Out

Society of Automotive Engineers (SAE) J1667 Test Procedure

- Replaces SAE J1243 Test Procedure
- "Snap Acceleration" Test Cycle Replaces "Snap Idle" Test Cycle
- Peak Readings now Filtered 1/2 Second Readings
- Ambient Conditions and Altitude Corrected

Tampering Effect on Air/Fuel Ratio

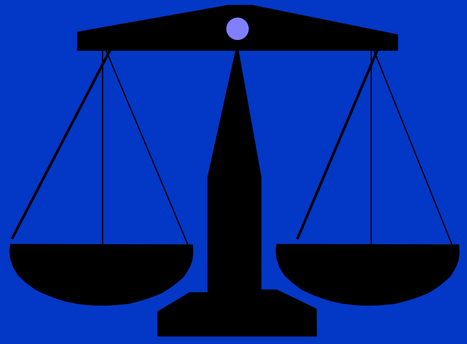


Snap Acceleration Test Cycle

- Engines at Operating Temperature
- Transmission in Neutral, Wheels Chocked
- Engines Kept Running
- Rapid Acceleration to Governed Speed
- Three Clean Out Snaps
- Three Test Snaps - Averaged
  - Closest Peak Smoke Readings are Averaged

Snap Acceleration Merits

- Easy to Perform
- Safe and Quick
- Perform Anywhere

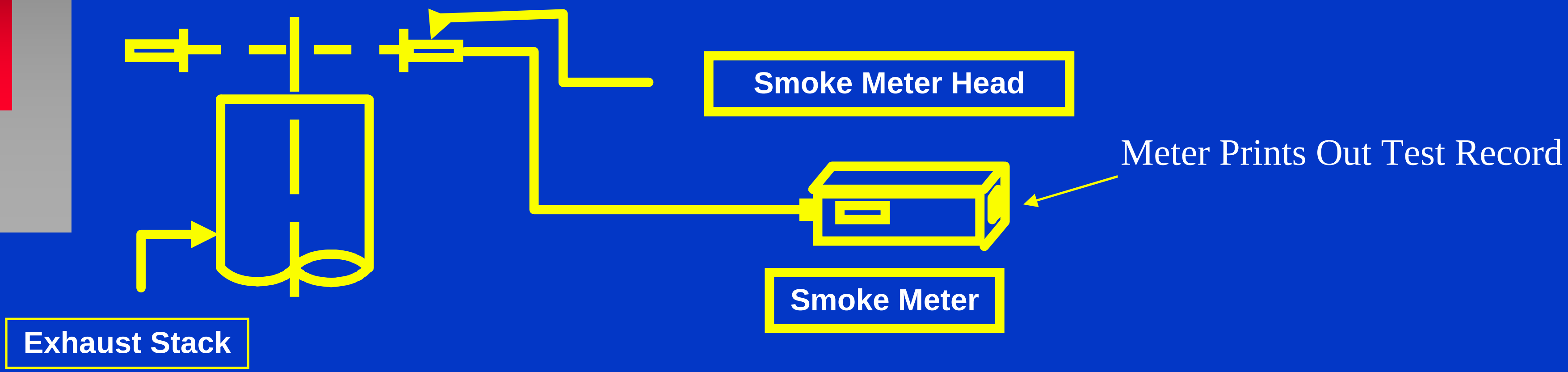


Snap Acceleration Merits
(Continued)

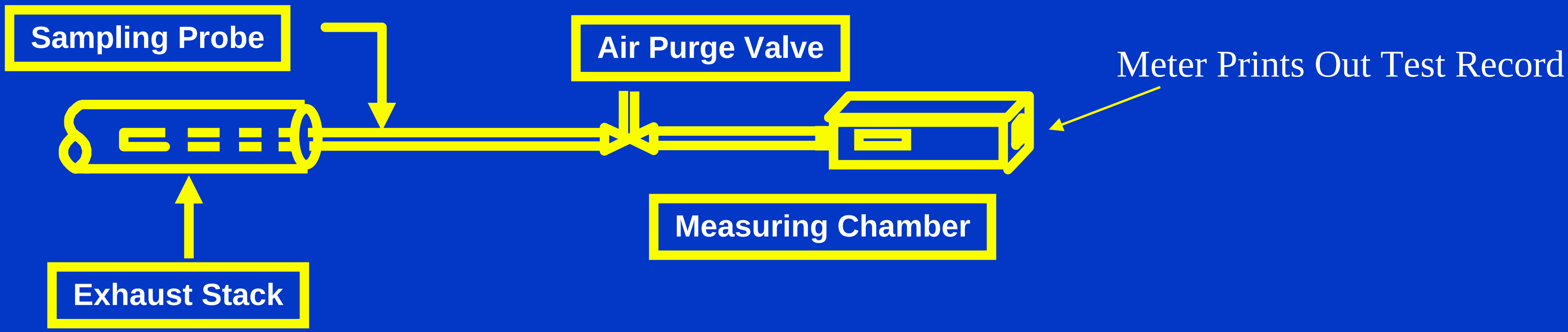
- Industry Approved Through the SAE J1667 Committee (ATA, CTA, EMA, Gov't Agencies, and Opacity Meter mfr.'s)
- Facilitates Meter Usage
- Very Effective
- Diagnostic Tool (To Detect Over Fueling and Air Restriction)

Test Instrumentation

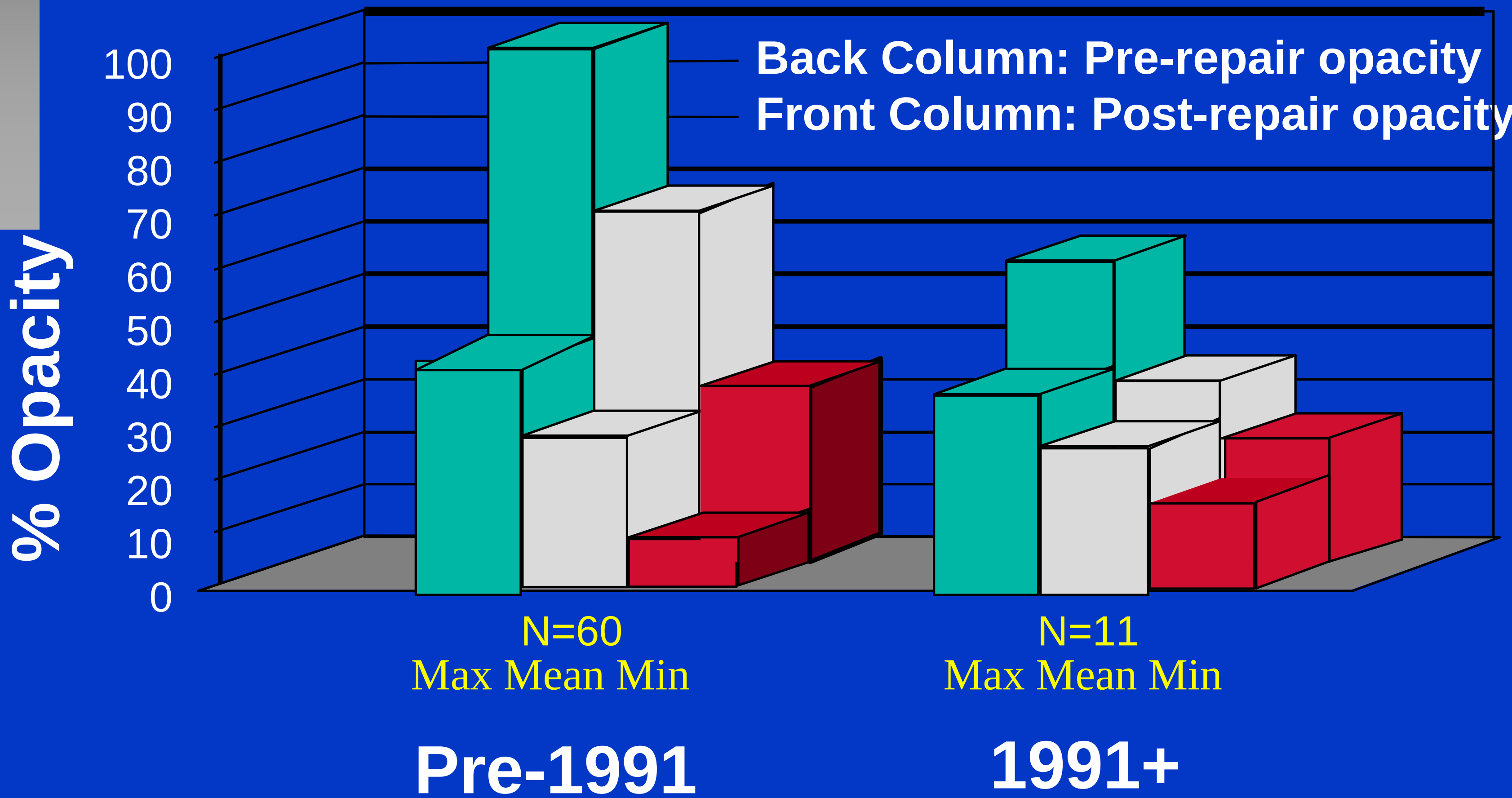
End-Of-Line Smoke Meter (eg "Full Flow)



In-Line Smoke Meter (eg "Partial Flow" or "Sample")



Smoke Reduction After Repair ARB Truck Repair Study (1997)



Smoke Opacity Standards

Vehicles with Pre-1991 Model Year Engines

Opacity Standard 55 %

Test Opacity	ARB Action	Post-Repair Standard
≥ 70 %	Issue Citation	< 55 %
55 - 69 %	Issue Notice of Violation (NOV)*	< 55 %

* : Only One NOV is Allowed in a 12 month Period Subsequent Violations, Between 55 - 69 % Opacity Result in a Citation

Smoke Opacity Standards

Vehicles with 1991 and

Newer Model Year Engines

Opacity Standard 40 %

Test Opacity	**ARB Action**	**Post-Repair Standard**
≥ 40 %	Issue Citation	< 40 %

Tampering Inspections

Diesel

- Governor
- Trap
- Seals
- Fuel Pump and Seals
- Others

Gasoline

- Catalyst
- E.G.R
- Air Injection
- Disconnected Hoses
- Evap System
- Others

Inspection Location

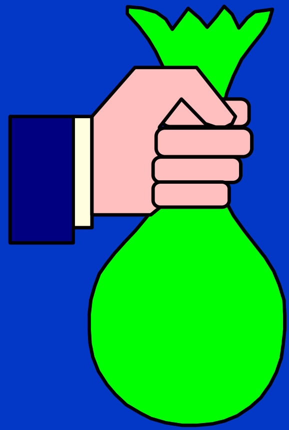
- CHP Inspection Facilities / Scales
- Fleet Yards
- Random Roadsides

First Violation

- $800.00 Penalty
- Reduced to $300.00 if Engine Repaired in 45 days
- School Buses Exempt From $300.00 Penalty First Violation Only

CORRECTIVE ACTION

- Penalty Payment
- Valid Repair Receipt and Post Repair Test



Second / Subsequent Violations

- Issued Within One Year of First Violation
- $1,800.00
- No Penalty Reduction

CORRECTIVE ACTION

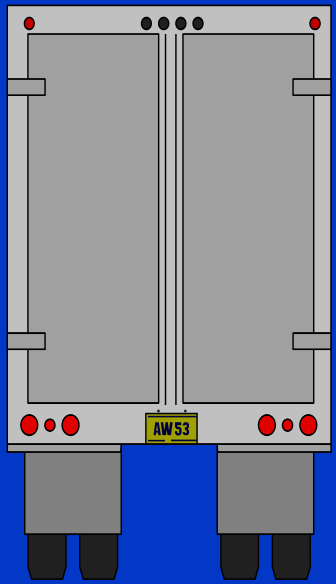
- Overdue Penalty Payment
- $1,800.00 Penalty Payment
- Mandatory ARB Post Repair Test

Out of Service

- CHP Action at ARB Request
- Vehicles Towed and Stored

CORRECTIVE ACTION

- Repair Vehicle Within 15 Days
- Mandatory ARB Post Repair Test
- Payment of All Storage, Repair and Pending Penalties

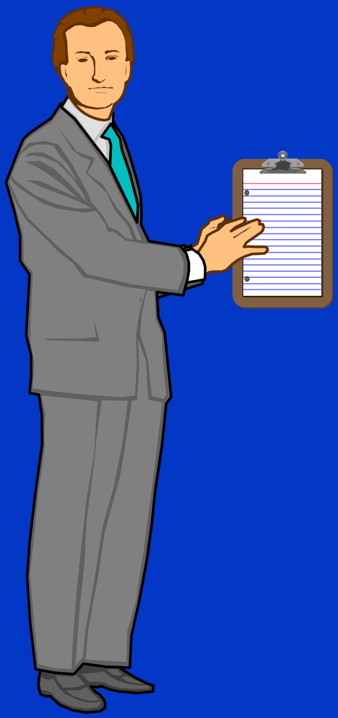


Hearings

- By Administration Law Judge
- Requested Within 45 days of Receiving Citation
- Appeal Process
  Title 17, CCR 60075.1
  (Senate Bill 1874 of 1990)

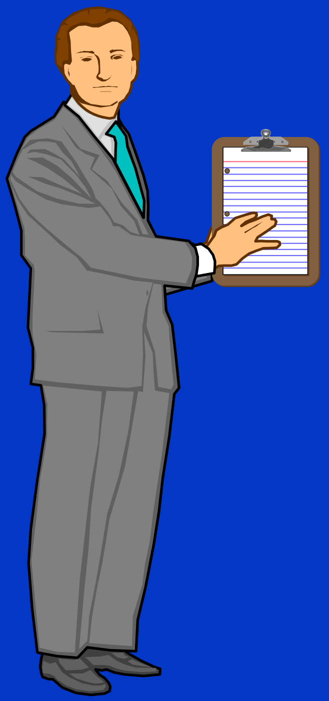
Causes of Excessive Smoke

- Worn/Failed Injectors
- Maladjusted Fuel Pump Timing
- Clogged Air Filter
- Damaged Turbo
- Worn Engine



Causes of Excessive Smoke
(Continued)

- Tampered Smoke Puff Limiter
  (e.g. “aneriod”, “throttle delay”)
- Boosted Fuel Pump
- Enlarged Injector Tips
- Pump Timing Advanced



Health and Environmental Effects of Diesel Exhaust Emissions

Constituent	*Detrimental Effect*
Particulates	Carcinogenic and Mutagenic
HC and NOx	Ozone (Smog) Precursors
NOx and SOx	Acid Rain / Deposition
NOx and SOx	Impairs Visibility/Fine Particulate Formation
Toxic Air Contaminants	Carcinogenic

Projected Emissions Benefits

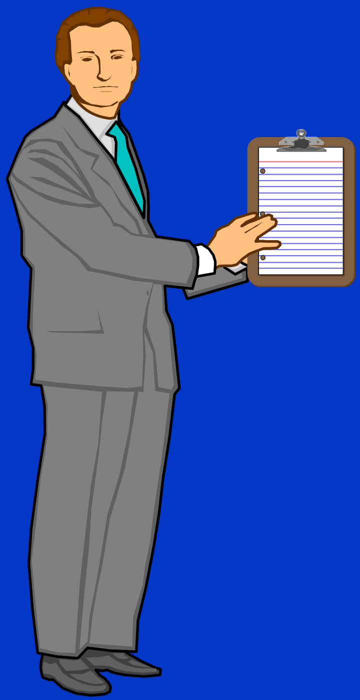
Combined HDVIP and PSI

Pollutant	*1999 Tons/Day*	*2010 Tons/Day*
PM	5.24	3.19
HC	6.37	5.30
NOx	12.24	14.03
Totals	23.85	22.52

Reduction of Smoking Trucks: 29 % — 1999, 36 % — 2010

Benefits of Smoke Emissions Reductions

- Improved Fuel Economy
- Reduced Fuel Costs
- Improved Public Relations
- Cleaner Trailers



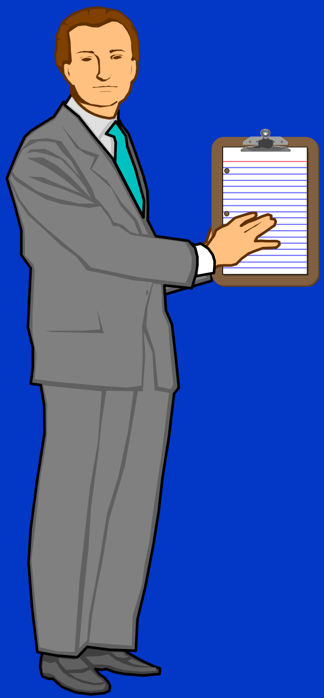
Estimated Fuel Savings

1999

- 16.7 Million gals/yr
- 0.69 % Reduction in Fuel Consumption
- $ 21 Million / Year Savings

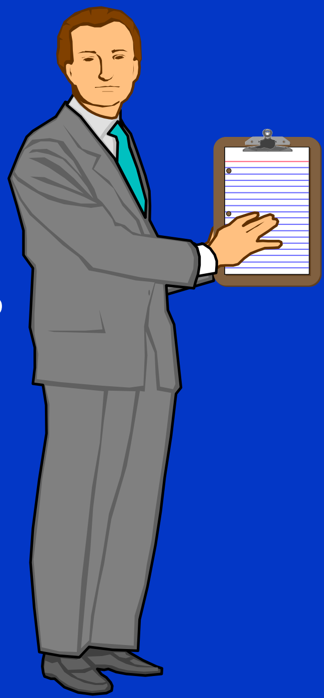
2010

- 19.2 Million gals/yr
- 0.66 % Reduction in Fuel Consumption
- $ 24 Million / Year Savings
  - Based on Diesel Fuel at $ 1.25 per Gallon



Recommendations

- Conduct Proper Maintenance
  (Per Manufacturer's Recommendation/Schedule)
- Prevent Engine Tampering
  (Tampering Constitutes Failure)
- Test Smoke Levels At Regular Intervals
- Have Engine Properly Identified
  (Correctly Label Engine)



** Some Engine Families May Be Exempted From The More Stringent Standards Upon Proper Identification

ARB Smoke Test Procedure VS California Vehicle Code 27153.5

H & S 44011.6

- Electronic Opacity Measurement
- Snap Acceleration, Stationary Vehicle

C V C 27153.5

- Visual Ringelmann Sighting
- Ten Second Sighting, Moving Vehicle

ARB Smoke Test Procedure VS California Vehicle Code 27153.5

H & S 44011.6	*C V C 27153.5*
40 % Standard, 1991 and Newer	Ringelmann 1, 1971 and Newer
55 % Standard, 1990 and older *	Ringelmann 2, 1970 and Older

* 70 % or Higher, Citation Issued

Between 55 - 69 % NOV Issued

27153.5 California Vehicle Code Penalty

- 1st Offense $250.00 to $2,500.00
- 2nd Offense $500.00 to $5,000.00

Key Program Elements

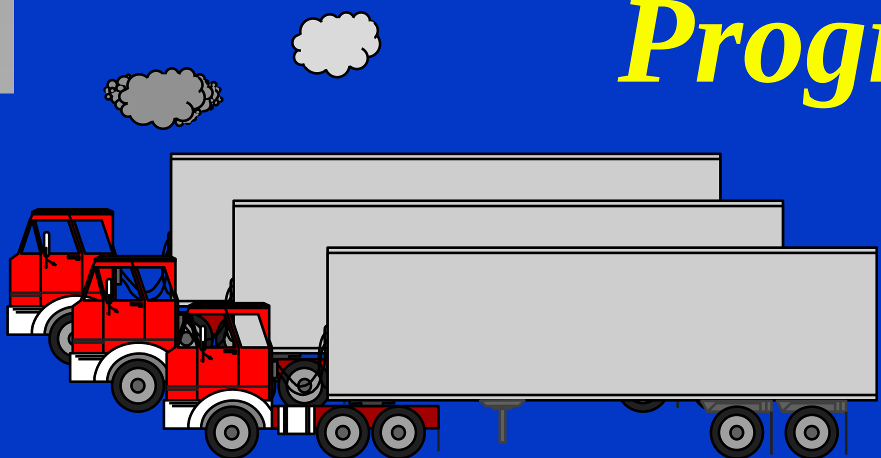
- Enforcement Implementation:
  June 1, 1998
- California Highway Patrol Assistance
- Snap Acceleration Test (SAE J1667)
  (Diesel Vehicles Only)
- Electronic Smoke Measurement
  (Smoke Meter)
- Emission Control System Tampering Check
  (Gas & Diesel)

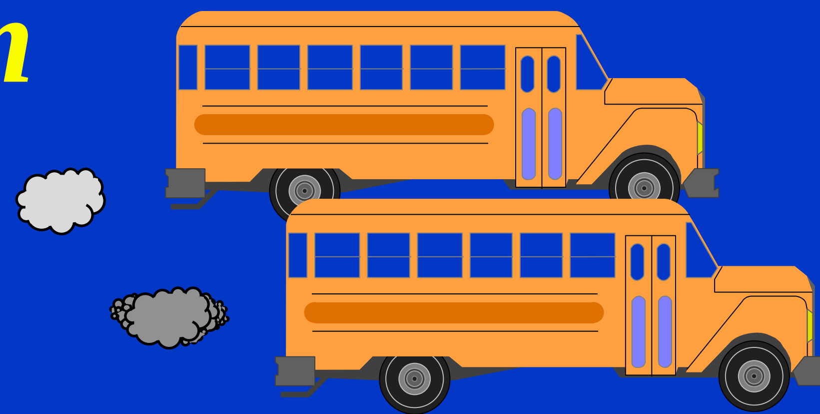
Key Program Elements
Continued

- Computerized Prior - Violation Check
- Inspections Conducted at CHP Weigh Stations/Fleets/Random
- California, Out-of-State, and Out-of-Country (NAFTA) Trucks & Buses
- Appeal Process
  Title 17, CCR 60075.1
  (Senate Bill 1874 of 1990)

State of California
Air Resources Board

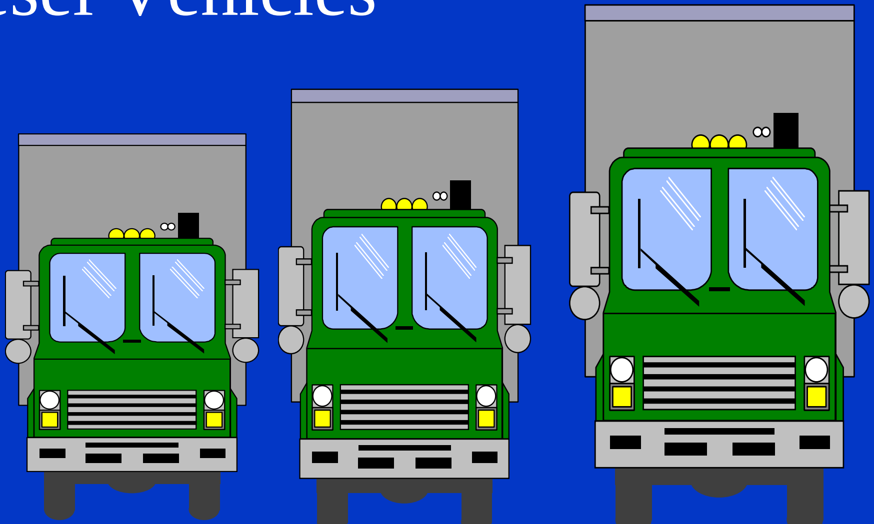
Periodic Smoke Inspection Program





Periodic Smoke Inspection Program (PSI Program)

- Health and Safety Code 43701(a)
- Annual Inspection and Test of Diesel Vehicle Fleets.
- Address Public's Concerns About the Health Impacts of Smoke Emissions From Heavy Duty Diesel Vehicles



PSI Goals

- Reduce Excessive Smoke Emissions from Heavy Duty Diesel Vehicles
- Detect Mal-Maintenance and/or Tampering of Heavy Duty Diesel Vehicles
- Emphasize Use of Manufacturer Specified Tune-Up and Maintenance Procedures

Health and Safety Code Section 43701 (a)

- Consult with the Bureau of Automotive Repair and the Inspection and Maintenance Review Committee
- Adopt Regulations Which Require the Owners or Operators of Heavy Duty Diesel Vehicles to Perform Periodic Smoke Inspections on Their Vehicles

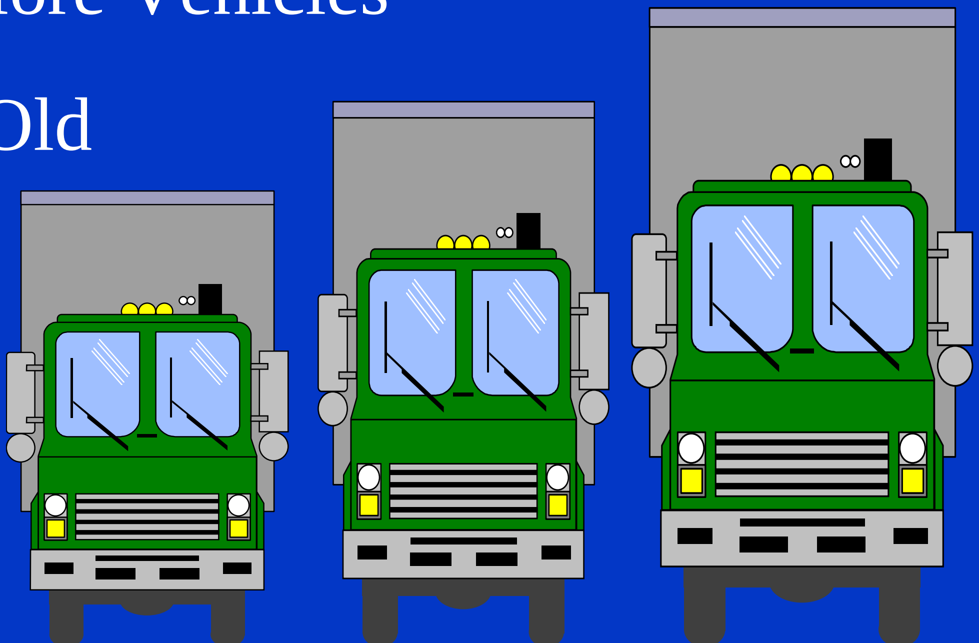
California Code of Regulations Title 13, Sections 2190 - 2194

Establishes :

- Applicability and Exemptions
- Inspection Intervals, Test Procedures, and Smoke Opacity Standards
- Vehicle Inspection Responsibilities
- Record Keeping Requirements

PSI Applications

- California - Only Based Vehicles
- Vehicles Over 6000 GVWR
- Fleets of Two or More Vehicles
- Engines > 4 Years Old



Smoke Opacity Test Procedure

- Perform the Snap Acceleration Test as Used in the Heavy Duty Vehicle Inspection Program

- Measure the Exhaust Smoke Opacity Level with a Smoke Meter

- Record the Exhaust Smoke Opacity Level

** Use SAE J1667 Test Procedures and Opacity Meters

Vehicle Inspection Responsibilities

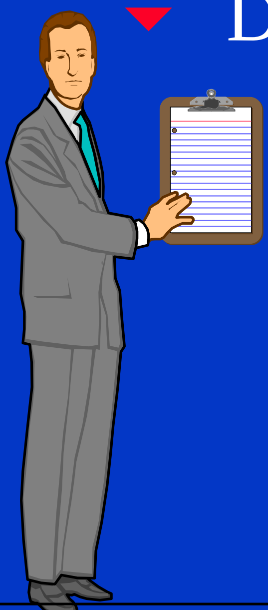
- Perform the Snap Acceleration Test on Heavy Duty Diesel Vehicles
- Repair the Vehicles When the Smoke Opacity Standards are Exceeded
- Re-Test the Vehicles When There are Initial Failures of Snap Acceleration Test
- Make Additional Repairs When Necessary to Comply with the Smoke Opacity Standards

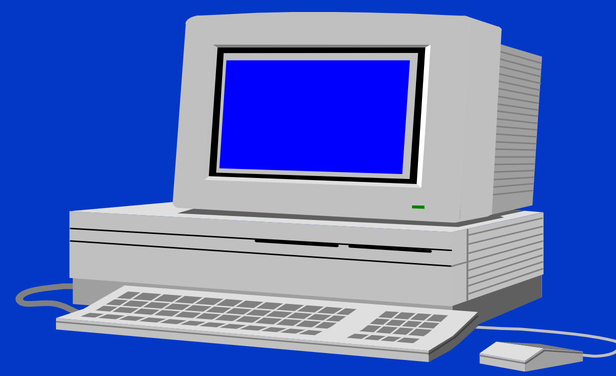
Vehicle Inspection Responsibilities
(Continued)

- Record the Snap Acceleration Test and Vehicle Repair Information
- Maintain the Records for Two Years
- Permit an ARB Inspector to Review/Audit the Records by Appointment

Record Keeping Requirements

- Hardcopy or Disk/Tape Storage Accepted
- Document the Test Equipment Information
- Document the Snap Acceleration Test Results
- Document the Vehicle Repair Information





** See Recommended Log Sheet

Exemption From PSI Program

Heavy Duty Diesel Vehicles Which :

- Are < 4 Years Old
- Are Not Part of a Fleet of Two or More Vehicles
- Operate in California Under Short-Term Vehicle Registration or Permits of 90 Days or Less

Exemption From PSI Program
(Continued)

Heavy Duty Diesel Vehicles Which Are Not Based in California and Which :

- Are Registered Under the International Registration Plan
- Operate in California Under Terms of Interstate Reciprocity Agreements or Other Apportioned Registration, Reciprocity or Bilateral Prorate Registration Agreements

Key Program Elements

- Use SAE J1667 Test Procedure with Snap Acceleration Cycle
- Apply 40% or 55% Opacity Standards
- Owner Must Repair Failed Vehicles
- ARB May Test Fleet Vehicles
- Citations May be Issued
- Fleet Audits

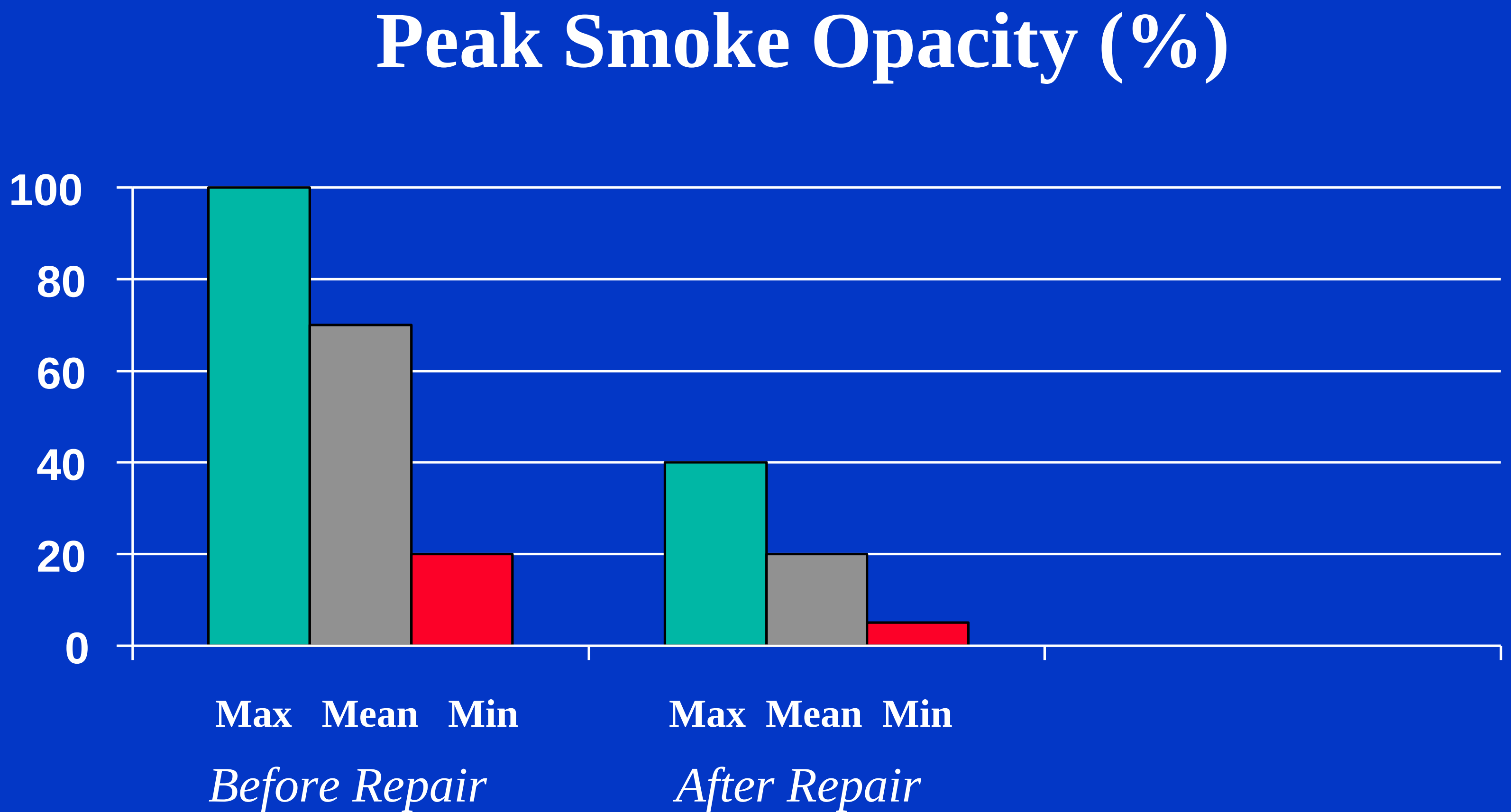
Your Program Benefits

- Increased Fuel Economy
- Improved Engine Reliability and Extended Engine Life
- Reduced Emergency Downtime
- Convenient and Decentralized Smoke Level Evaluation

Your Program Benefits
(Continued)

- No Citations
- Enhanced Public Image
- Reduced Emissions

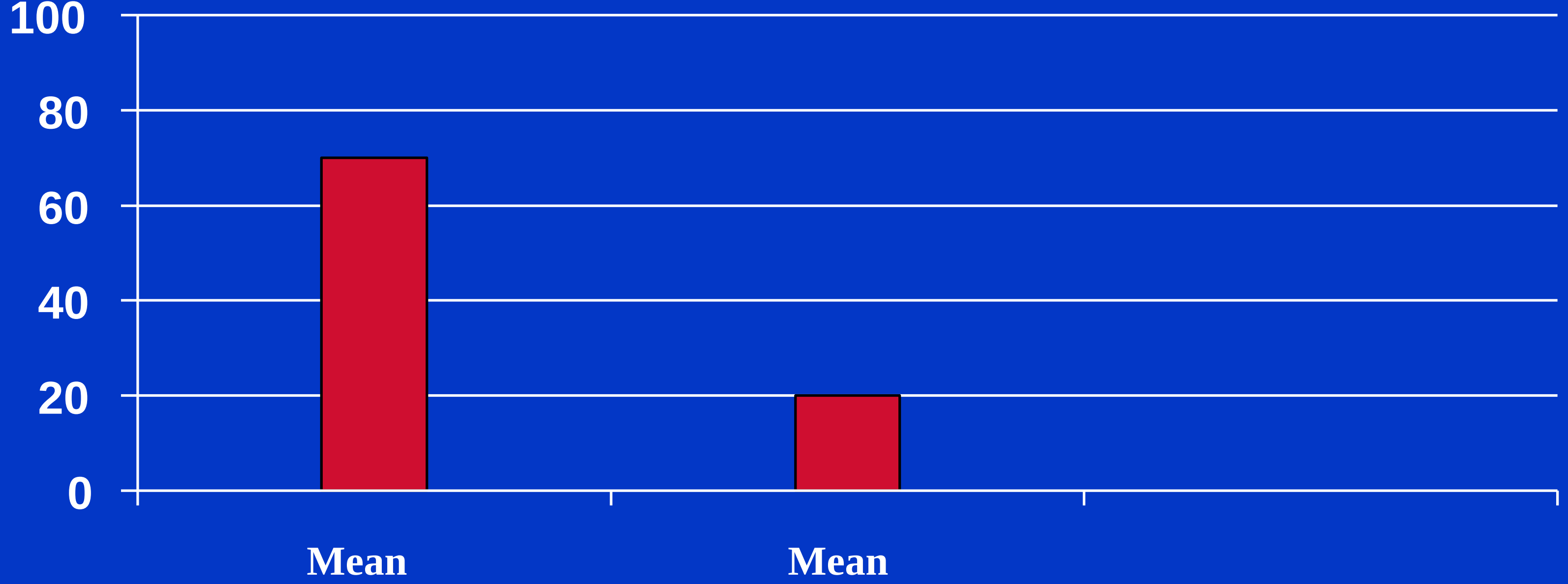
Smoke Reduction After Repair
ARB Pilot Repair Program (1989)



Sample Size: 58 Vehicles - Repaired to Manufacturers Specs

Smoke Reduction After Repair
ARB Pilot Repair Program (1989)

Peak Smoke Opacity (%)



Before Repair *After Repair*

Sample Size: 58 Vehicles - Repaired to Manufacturers Specs

California Environmental Protection Agency
AIR RESOURCES BOARD

Legal Framework for Programs

Health and Safety Code
Section 44011.6
Section 43701

Background Information for

HSVIP
PSIP
CCDET

January 2009

§ 44011.6. Test for smoke emissions; Advisory committee; Regulation and inspection; Criteria for compliance; Penalties; Administrative hearing

(a) The use of a heavy-duty motor vehicle that emits excessive smoke is prohibited.

(b) (1) As expeditiously as possible, the state board shall develop a test for the detection of excessive smoke emissions from heavy-duty diesel motor vehicles that is feasible for use in an intermittent roadside inspection program. During the development of the test procedure, the state board shall cooperate with the Department of the California Highway Patrol in conducting roadside inspections.

(2) The state board may also specify visual or functional inspection procedures to determine the presence of tampering or defective emissions control systems in heavy-duty diesel or heavy-duty gasoline motor vehicles. However, visual or functional inspection procedures for heavy-duty gasoline motor vehicles shall not be more stringent than those prescribed for heavy-duty gasoline motor vehicles subject to biennial inspection pursuant to Section 44013.

(3) The chairperson of the state board shall appoint an ad hoc committee which shall include, but not be limited to, representatives of heavy-duty engine manufacturers, carriers of property for compensation using heavy-duty gasoline or diesel motor vehicles, and the Department of the California Highway Patrol. The advisory committee shall cooperate with the state board to develop a test procedure pursuant to this subdivision and shall advise the state board in developing regulations to implement test procedures and inspection of heavy-duty commercial motor vehicles.

(c) Any smoke testing procedures or smoke measuring equipment, including any meter that measures smoke opacity or density and any recorder that stores or records smoke opacity or density measurements, used to test for compliance with this section and regulations adopted pursuant to this section, shall produce consistent and repeatable results. The requirements of this subdivision shall be satisfied by the adoption of Society of Automotive Engineers recommended practice J1667, “Snap-Acceleration Smoke Test Procedures for Heavy-Duty Diesel Powered Vehicles.”

(d) (1) The smoke test standards and procedures adopted and implemented pursuant to this section shall be designed to ensure that no engine will fail the smoke test standards and procedures when the engine is in good operating condition and is adjusted to the manufacturer's specifications.

(2) In implementing this section, the state board shall adopt regulations that ensure that there will be no false failures or that ensure that the state board will remedy any false failures without any penalty to the vehicle owner.

(e) The state board shall enforce the prohibition against the use of heavy-duty motor vehicles that are determined to have excessive smoke emissions and shall enforce any regulation prohibiting the use of a heavy-duty motor vehicle determined to have other emissions-related defects, using the test procedure established pursuant to this section.

(f) The state board may issue a citation to the owner or operator for any vehicle in violation of this section. The regulations may require the operator of a vehicle to submit to a test procedure adopted pursuant to subdivision (b) and this subdivision, and may specify that refusal to so submit is an admission consisting proof of a violation, and shall require that, when a citation has been issued, the owner of a vehicle in violation of the regulations shall, within 45 days, correct every deficiency specified in the citation.

(g) The department may develop criteria for one or more classes of smog check stations capable of determining compliance with regulations adopted pursuant to this section and may authorize those stations to issue certificates of compliance to vehicles in compliance with the regulations. The department may contract for the operation of smog check stations for heavy-duty motor vehicles pursuant to this subdivision, and only heavy-duty motor vehicles may be inspected at those stations.

(h) In addition to the corrective action required by this section, the owner of the motor vehicle in violation of this section is subject to a civil penalty of not more than one thousand five hundred dollars ($1,500) per day for each day that the vehicle is in violation. The state board may adopt a schedule of reduced civil penalties to be applied in cases where violations are corrected in an expeditious manner. However, the schedule of reduced civil penalties shall not apply where there have been repeated incidents of emissions control system tampering. All civil penalties imposed pursuant to this subdivision shall be collected by the state board and deposited in the Vehicle Inspection and Repair Fund. Funds in the Vehicle Inspection and Repair Fund, when appropriated by the Legislature, shall be available to the state board and the Department of the California Highway Patrol for the conduct of intermittent roadside inspections of heavy-duty motor vehicles pursuant to this section.

(i) Following the adoption of regulations pursuant to this section, the state board may commence inspecting heavy-duty motor vehicles. With the concurrence of the Department of the California Highway Patrol, these inspections may be conducted in conjunction with the safety and weight enforcement activities of the Department of the California Highway Patrol, or at other locations selected by the state board or the Department of the California Highway Patrol. Inspection locations may include private facilities where fleet vehicles are serviced or maintained. The state board and the Department of the California Highway Patrol may conduct these inspections either cooperatively or independently, and the state board may contract for assistance in the conduct of these inspections.

(j) The state board shall inform the Department of the California Highway Patrol whenever a vehicle owner cited pursuant to this section fails to take a required corrective action or to pay a civil penalty levied pursuant to subdivisions (h) and (k) in a timely manner. Following notice and opportunity for an administrative hearing pursuant to subdivision (n), the State board may request the Department of the California Highway Patrol to remove the vehicle from service and order the vehicle to be stored. Upon notification from the state board of payment of any civil penalties imposed under subdivision (h) and storage and related charges, the vehicle shall be released to the owner or designee. Upon release of the vehicle, the owner or designee shall correct every deficiency specified in any citation to that owner with respect to the vehicle.

(k) In addition to the corrective action required by subdivision (f), and in addition to the civil penalty imposed by subdivision (h), the owner of a motor vehicle cited by the state board pursuant to this section shall pay a penalty of three hundred dollars ($300) per citation; except that this penalty shall not apply to the first citation for any schoolbus. All civil penalties imposed pursuant to this subdivision shall be collected by the state board and deposited in the Diesel Emission Reduction Fund, which fund is hereby created. Funds in the Diesel Emission Reduction Fund, when appropriated by the Legislature, shall be available to the State Energy Resources Conservation and Development Commission for research, development, and demonstration programs undertaken pursuant to Section 25617 of the Public Resources Code.

(l) The state board shall adopt regulations that afford an owner cited under this section an opportunity for an administrative hearing consistant with, but not limited to all of the following: (1) any owner cited under this section may request an administrative hearing within 45 days following either personal receipt or certified mail receipt of the citation; (2)

if the owner fails to request an administrative hearing within 45 days, the citation shall be deemed a final order and not subject to review by any court or agency; (3) if the owner requests an administrative hearing and fails to seek review by administrative mandamus pursuant to Section 1094.5 of the Code of Civil Procedure within 60 days after the mailing of the administrative hearing decision, the decision shall be deemed a final order and not subject to review by any other court or agency; and (4) the 45-day period may be extended by the administrative hearing officer for good cause.

(m) Following exhaustion of the review procedures provided for in subdivision (l), the state board may apply to the Superior Court of Sacramento County for a judgment in the amunt of the civil penalty. The application, which shall include a certified copy of the final order of the administrative hearing officer, shall constitute a sufficient showing to warrant the issuance of the judgment.

Added Stats 1988 ch 1544 § 26. Amended Stats 1989 ch 940 § 2; Stats 1990 ch 1433 § 16 (SB 1874); Stats ch 578 § 1 (AB 584); Stats 1996 ch 292 § 1 (AB 1460). Amended Stats 2004 ch 644 § 21 (AB 2701).

HEALTH AND SAFETY CODE

§ 43701. Adoption of regulations; Emissions standards and procedures; Evidence that engine met federal standards at time of manufacture

(a) Not later than July 15, 1992, the state board, in consultation with the bureau and the review committee established pursuant to subdivision (a) of Section 44021, shall, after a public hearing, adopt regulations that require owners or operators of heavy-duty diesel motor vehicles perform regular inspections of their vehicles for excessive emissions of smoke. The inspection procedure, the frequency of inspections, the emission standards for smoke, and the actions the vehicle owner or operator is required to take to remedy excessive smoke emissions shall be specified by the state board. Those standards shall be developed in consultation with interested parties. The smoke standards adopted under this subdivision shall not be more stringent than those adopted under Chapter 5 (commencing with Section 44000).

(b) Not later than December 15, 1993, the state board shall, in consultation with the State Energy Resources Conservation and Development Commission, and after a public hearing, adopt regulations that require that heavy-duty diesel motor vehicles subject to subdivision (a) utilize emission control equipment and alternative fuels. The state board shall consider, but not be limited to, the use of cleaner burning diesel fuel, or other methods which will reduce gaseous and smoke emissions to the greatest extent feasible, taking into consideration the cost of compliance. The regulations shall provide that any significant modification of the engine necessary to meet these requirements shall be made during a regularly scheduled major maintenance or overhaul of the vehicle’s engine. If the state board requires the use of alternative fuels, it shall do so only to the extent those fuels are available.

(c) The state board shall adopt emissions standards and procedures for the qualification of any equipment used to meet the requirements of subdivision (b), and only qualified equipment shall be used.

(d) To the extent permissible under federal law, commencing January 1, 2006, the owner or operator of any commercial motor truck, as defined in Section 410 of the Vehicle Code, with a gross vehicle weight rating (GVWR) greater than 10,000 pounds that enters the state for purposes of operating in the state shall maintain and provide upon demand to enforcement authorities, evidence demonstrating that its engine met the federal emission standards applicable to commercial heavy-duty engines for that engine's model-year at the time it was manufactured, pursuant to the protocol and regulations developed and implemented pursuant to subdivision (e).

(3) The state board, not later than January 1, 2006, in consultation with the California Highway Patrol, shall develop, adopt, and implement regulations establishing an inspection protocol for determining whether the engine of a truck subject to the requirements of subdivision (d) met the federal emission standard applicable to heavy-duty engines for that engine's model-year at the time it was manufactured.

Added Stats 1990 ch 1453 § 1 (SB 2330). Amended Stats 1992 ch 674 § 5 (SB 1792); Stats 1995 ch 91 § 88 (SB 975); Stats 2004 ch 873 § 2 (AB 1009), effective September 29, 2004.

References at the time of publication (see page vii):

Regulations: 13, CCR, sections 1956.2, 2180.1, 2181, 2184, 2186, 2190, 2191, 2192, 2193, 2194

CALIFORNIA AIR RESOURCES BOARD

HEAVY-DUTY VEHICLE INSPECTION PROGRAM

(HDVIP)

I. LEGISLATIVE MANDATE

Due to public health concerns associated with the exposure to smoke emissions from heavy-duty vehicles, Senate Bill (SB) 1997 was enacted in 1998 to provide for the creation of Heavy-Duty Vehicle Inspection Program (HDVIP). Senate Bill 1997 required the creation of an “ad hoc advisory committee” [1] and gave it the mandate to develop an effective inspection program to curtail excessive smoke emissions from malmaintained or tampered heavy-duty vehicles. The bill also required the California Highway Patrol (CHP) to assist the Air Resources Board (ARB) in administering the HDVIP.

Senate Bill 1997 also authorized the ARB to issue citations and civil penalties to vehicles failing the prescribed test procedures and required cited vehicle owners to promptly correct deficiencies specified in the citation. If the required corrective action is not taken, violators can be assessed civil penalties up to $1500 per day. An addition, pursuant to Assembly Bill 1107 of 1989, a $300 civil penalty is assessed with each issued citation. These additional civil penalties are required, by AB 1107, to be deposited into a special “Diesel Emission Reduction Fund” intended to support diesel fuel research undertaken by the California Energy Commission (CEC). If a cited vehicle owner fails to take corrective action or pay the civil penalties levied, the CHP may remove the vehicle from service until the necessary corrective action is taken and/or the civil penalties are paid.

To complement SB 1997, the Legislature in 1990 enacted SB 1874 to provide a vehicle owner with recourse to contest a citation through an administrative hearing process. In conformance with SB 1874, the ARB has developed appropriate regulations to govern the administrative hearing process. These provisions can be found in the California Code of Regulations, Title 17, Article 5, Sections 60075.1 through 60075.47. Further details of the hearing process can be found in Section IV “Administrative Hearings”.

[1] The ad hoc advisory committee members consisted of representatives from the Air Resources Board (ARB), California Highway Patrol (CHP), South Coast Air Quality Management District (SCAQMD), heavy-duty vehicle engine manufactures (represented by the Engine Manufacturer’s Association (EMA)), and heavy-duty vehicle operation/carriers represented by the California Trucking Association (CTA)).

The provisions of SB 1997 and AB 1107, pertaining to the HDVIP, may be found in section 44011.6 et seq. of the California Health and Safety Code. (Please refer to Section III of this booklet for a copy of the Health and Safety Code, section 44011.6).

II. HEAVY-DUTY VEHICLE INSPECTION PROGRAM NEED

Since a significant number of in-use heavy-duty vehicles are diesel-fueled, their impact cannot be ignored. The following discussion highlights this impact.

A. TRUCK EMISSIONS

There are approximately 550,000 heavy-duty diesel vehicles registered in California (estimate for 1998). They are projected to travel approximately 36 million miles per day (135 miles/day/vehicle on average) and to consume 6.3 million gallons of diesel fuel each year.

On average, those vehicles emit: 49.32 tons per day (tpd) of reactive organic gases (ROG), 469.21 tpd of oxides of nitrogen (NOx), 23.44 tpd of oxides of sulfur (SOx), and 31.05 tpd of particulate matter (PM). These vehicles also emit carbon monoxide (CO), carbon dioxide (CO_2), and miscellaneous toxic compounds such as benzene, aldehydes, 1.3 butadiene, and xylene. Overall, heavy-duty vehicles account for approximately 30% of the NOx and 65% of the PM emissions from total on-road vehicles.

Although somewhat difficult to quantify directly, excessive smoke emissions from diesel trucks are a major public concern. Not only is excessive smoke emissions an indicator of possible engine problems and incomplete fuel combustion it is a major public health and nuisance concern. Every year government agencies receive thousands of complaints regarding smoking trucks.

B. SPECIFIC POLLUTANTS

The pollutants of most concern, due to their detrimental effect on public health, the environment, and agriculture, are: carbon monoxide and carbon dioxide, sulfur and nitrogen oxides, hydrocarbons, toxic air contaminants,
and particulates.

Carbon monoxide (CO) is an odorless gas that has numerous adverse public health effects. The most prevalent is its affect on displacing hemoglobin proteins in the bloodstream. This affect deprives oxygen to vital organs such as the brain. Exposure to high concentrations of CO can cause headaches, severe physiological distress, and even death under certain circumstances. Currently there are nine California cities which violate the federal CO standard.

Carbon dioxide (CO_2) is an odorless gas that has been identified as a "greenhouse" gas. Greenhouse gases are believed to contribute to global warming (i.e. the "greenhouse effect") which can affect global weather patterns.

Sulfur oxides (SO_x) and ***Nitrogen oxides (NO_x)*** are gaseous emissions which, when combined with moisture in the atmosphere, produce sulfuric and nitric acids. These acids are subsequently deposited in the environment via fog and rain. Acid rain and acid fog harms soil and water systems by altering their pH balance (i.e. causes excessive acidity). This pH imbalance damages California's agriculture, forests, and aquatic life. Many regions in California suffer from acid deposition exposure including the Lake Tahoe region and Yosemite National Park.

SO_x and NO_x are also responsible for sulfate and nitrate formation which reduces visibility and impairs respiration. NO_x enhances the formation of photochemical oxidants in sunlight as discussed below. NO_x and SO_x emissions are often associated with common brown haze observed in urban areas such as Los Angeles county, aggravated by surrounding mountains that contain these pollutants in an "air basin".

Reactive organic gases (ROG) and NO_x are gaseous emission which combine with sunlight in the atmosphere to form photochemical oxidants. A major oxidant is ozone, popularly known as Smog. Smog aggravates cardiovascular and respiratory systems and has been found to increase the incidence of bronchitis, emphysema, and cancer in various epidemiological (public health) studies.

Studies by the ARB and University of California have shown that smog exposure contributes to 80,000 deaths per year in California. In addition, due to high smog concentrations, outdoor exercise is canceled over 100 times per year for school children in the Los Angeles region.

Smog also harms vegetation by affecting respiration and photosynthesis and damaging leaves. These affects reduce the size, quality, yields of crops - in some instances plants can also die. Studies have also found that crops grown in the San Joaquin Valley (cotton, grapes, citrus, alfalfa, and tomatoes) are experiencing yield losses of 15-25% due to smog exposure. Annually, smog causes agricultural losses totaling over $300 million in California.

There are eleven California cities which exceed the federal ozone (smog) standard of 0.12 parts per million (ppm). The majority of California cities exceeds the more restrictive state ozone standard of 0.09 ppm. Over 50% of California's population is adversely affected by smog.

Toxic air contaminants (TAC) emissions pose a serious risk to public health, as well as diesel toxic air contaminants, such as benzene, have been found to contain numerous carcinogenic and mutagenic substances. The ARB is developing air toxic control measures on an on-going basis under the provisions of AB 1807 of 1983.

Particulate matter (PM) emissions are composed of very fine particles that can be readily inhaled and embedded in a person's respiratory system. Due to this tendency, particulate matter impairs a person's respiratory system and poses a serious threat to public health due to its carcinogenic and mutagenic toxic compounds. There are currently five areas in California which exceed the federal PM standard.

Particulate matter also adheres to the leaf surfaces of plants and impairs their ability to respire and photosynthesize. Particulate matter also contributes to poor visibility.

C. CAUSES of EXCESSIVE EMISSIONS

Engine malmaintenance and tampering are the primary causes of excessive diesel emissions - particularly smoke emissions. Examples of specific components or systems which are malmaintained or tampered are: fuel injection pump and seals, fuel injection timing, fuel injectors, smoke puff limiter, air filter, intercooler, turbocharger, exhaust gas recalculation valve, along with other internal engine components. Other causes of excessive diesel emissions are pressure leaks in the injection system or manifolds, excessive back pressure in the exhaust system, and fuel problems such as wrong fuel grade or water contamination.

D. CONTROLS METHODS

The primary means for controlling heavy-duty diesel engine emissions are:

1. **Technology-forcing emission standards.** Beginning with the 1991 model-year for transit bus engines and 1994 model-year for heavy-duty truck engines, heavy-duty engine manufacturers have been required to manufacture engines which meet a 5.0 grams per brake horsepower hour (g/bhp-hr) standard for NO_x and 0.1 g/bhp-hr standard for PM emissions. Beginning with the 1998 model-year, heavy-duty diesel engine manufacturers must meet a 4.0 g/bhp-hr standard for NO_x and a 2.0 g/bhp-hr (2.5 g/bhp-hr combined NO_x/ROG) NO_x standard in 2004. These standards lead to advanced engine designs, including: cylinder redesign and other internal engine modifications, turbocharger/supercharge redesign, intercooler applications, electronic fuel injection systems improvements, exhaust gas recirculation application, and catalytic trap oxidizer/particulate trap oxidizer development.

2. **Fuel regulations.** The ARB has implemented regulations that regulate the maximum allowable sulfur and aromatic hydrocarbon fraction of diesel fuel to 0.05% by weight and 10% by volume, respectively. Reductions in sulfur and aromatic hydrocarbon levels are expected to result in reductions of NO_x, SO_x, and PM emissions. Additionally, under the provisions of AB 1107 of 1989, further research is aimed at identifying additional means of reducing harmful emissions from diesel fuel combustion. Finally, heavy-duty engine manufacturers have introduced cleaner burning engines which operate on alternative fuels such as methanol, ethanol, natural gas (CNG/LPG), and liquefied petroleum gas (LPG).

3. **Inspection programs.** Inspection programs for in-use vehicles such as the HDVIP offer an effective means for identifying malmaintained or tampered heavy-duty vehicles. In recognition of this, other states, including Nevada, Colorado, Oregon, Arizona, and New Jersey, also operate heavy-duty vehicle inspection programs. With the standardization that the SAE J1667 smoke test procedures provides, the U.S. EPA to have a recommendation for other states to adopt similar programs such as the HDVIP in the future.

As it pertains to California, the legislature has mandated two additional inspection programs other than the HDVIP. First, the Periodic Smoke Inspection Program (PSIP) requires California based fleets to conduct annual self inspections. The PSIP complements the HDVIP and both share the same test and pass/fail criteria. More information on the PSIP can be found in this informational package.

Of particular note, however, the California legislature also provided for an additional inspection program that requires statewide law enforcement officials to issue citations to vehicles observed smoking for more than 10 seconds while in operation. The provisions for this program, commonly referred to as the "Vehicle Code Smoke Inspection Program", are found in Vehicle Code Section 27153.5[2]. The ARB does not administer this program.

III. HDVIP BACKGROUND

Since 1989, the ARB conducted numerous field studies in order to formulate an effective HDVIP. Through these studies, hundreds of vehicles were recruited and tested using various test methods. Many vehicles underwent extensive diagnostic and repair evaluations. Overall, three primary causes of excessive smoke emissions were identified. These are: improper transient air-fuel ratio control settings, fuel injection timing problems, and inadequate air intake (restricted air filters, etc.). These problems can generally be corrected for less than $500 per vehicle.

In addition, a smoke test procedure based on the rapid no-load accelerations (snap-accelerations) of the engine was found to be the most effective in determining excessive smoke emissions at roadside operations. During a snap-acceleration test the driver rapidly depresses the accelerator to the floorboard for a few seconds while the smoke is measured by an electronic smoke opacity meter. A smoke opacity meter monitors the smoke exiting the exhaust pipe.

[2] The Vehicle Code Smoke Inspection Program differs from the HDVIP program in that it features a visual ("Ringlemann") smoke emissions evaluation for the pass/fail evaluation. The visual readings are conducted while the vehicle is in operation. The smoke standards are either Ringlemann 1 or Ringlemann 2 - corresponding to 20% and 40% opacity, respectively.

The snap-acceleration test is a quicker and safer test to perform than other test methods. It is particularly well suited for roadside inspections and periodic smoke inspections at fleet facilities.

The most recent study occurred in the winter and spring of 1996/97. This study served to evaluate, through a special truck repair study, a revised snap-acceleration smoke test procedure sponsored by the Society of Automotive Engineers (SAE J1667)[3]. As intended, the SAE J1667 test procedure proved to be effective in identifying trucks with excessive smoke emissions. The ARB incorporated the SAE J1667 into the HDVIP at the December 1997 board hearing. The ARB subsequently resumed the HDVIP with the revised snap acceleration test procedure on June 1, 1998.

A. KEY ELEMENTS

Under the HDVIP, inspections are conducted at CHP inspection and weigh stations, at random roadside locations, and at fleets statewide. California, out-of-state, and out-of-country registered heavy-duty vehicles are all subject to the HDVIP. Diesel-fueled vehicles are inspected for excessive smoke emissions and tampering of emission control systems. Gasoline-fueled vehicles are subject to a tampering inspection only. All inspections are entered into ARB field computers allowing easy tracking of citations.

The smoke opacity standards are 40% for trucks and buses with 1991 and newer model-year engines and 55% for those with model-year engines older than 1991. Under this latter category, however, a Notice of Violation (NOV) is issued to vehicles with smoke opacity levels between 55% and 69%[4]. If these vehicles are repaired to below 55% within the allowable 45-day time period, a citation is not issued.

Civil penalties for failing the prescribe standards range from $800 for the first level citation (i.e. the initial citation) to $1800 for second and subsequent level citations. A first level citation penalty can

3 The previous HDVIP snap-acceleration test procedure was incorporated onto the new SAE J1667 snap-acceleration test procedure by slightly revising the signal averaging characteristics of the previously required smoke meters and by incorporating correction factors for varying ambient conditions and altitude.

4 Under this NOV concept, a citation is issued if the vehicle exhibited smoke emissions 70% or greater or if the vehicle is not repaired to a level below 55% when a NOV is issued.

be reduced $300 if the cited vehicle is repaired within a 45-day period and if the repair documentation and post repair smoke test is provided. If a citation is not cleared, the ARB may recommend that the CHP remove a vehicle from service. Once impounded, a vehicle will not be released until all outstanding penalties are paid. Once paid, the vehicle will then be released for repairs. In order to clear the citation, the vehicle must be repaired and submitted to a retest within 15 days from the date of its release.

B. BENEFITS and COST-EFFECTIVENESS

Based on recent studies, it is anticipated that the implementation of the HDVIP[5] will provide 12.24 tpd of NO_x reduction; 6.37 tpd of ROG reduction, and 5.24 tpd of PM reduction in 1999. In 2010, the projected reductions are 14.03 of NO_x reduction, 5.30 tpd of ROG reduction, and 3.19 tpd of PM reduction. In addition, it is estimated that the HDVIP will reduce the number of on-road, excessively smoking heavy-duty vehicles by 29,000 in 1999 and 38,000 by 2010. With the combined effects of both the HDVIP and PSIP, approximately 625,000 excessively smoking heavy-duty vehicles will be reduced from 1999 through 2010. These values are applicable to only California. Values for other states in the nation will differ.

Through the promotion of better maintenance practices, the trucking industry is expected to realize a fuel savings. In 1999 and 2010 it is estimated that 16.7 million gallons and 19.2 million gallons, respectively, of diesel fuel will be saved by the trucking industry. This represents a reduction of fuel consumption of 0.69% and 0.66% in 1999 and 2010, respectively.

The cost effectiveness of these reductions are estimated to be $1.12 per pound in 1999 and $1.05 per pound in 2010. These estimates compare favorably to alternative emission control programs which typically cost between $2.50 and $5.00 per pound of emissions reduced.

[5] Note, the emission reduction benefits outlinerd in this section also take into account the projected benefits of the companion program - Periodic Smoke Inspection Program. The cost effectiveness figures represent the combined cost effectiveness of both the HDVIP and PSIP.

IV. ADMINISTRATIVE HEARINGS

In order to provide a cited vehicle owner with the recourse to contest a citation in an expeditious manner, Senate Bill 1874 required the ARB to enact an administrative hearing appeals process. Through the enacted process, a cited vehicle owner must first request a hearing within 45 days of receiving a citation. The hearing is conducted by an independent, in-house, administrative law judge who has broad authority to take any action necessary for a full and fair adjudication of a contested citation. At the hearing the vehicle owner is given the opportunity to present his/her case and to cross-examine any witnesses. Pursuant to the enacted hearing regulations, if an owner does not request a hearing within forty-five days, the issued citation is final and not subject to review by any court or agency. If the owner requests a hearing, the decision rendered pursuant to the proposed rules is final and not subject to review by any court or agency unless the owner seeks judicial review within sixty days of the mailing of the administrative hearing decision. The regulations to the HDVIP hearing process can be found in the California Code of Regulations, Title 17, Article 5, Sections 60075.1 through 60075.47.

CALIFORNIA AIR RESOURCES BOARD

PERIODIC SMOKE INSPECTION PROGRAM

(PSIP)

I. LEGISLATIVE MANDATE

To complement the effectiveness of the California Air Resources Board's mandate to curtail excessive smoke emissions from heavy-duty diesel vehicles, the California Legislature in 1992 mandated that owners or operators of heavy-duty diesel fleet vehicles perform periodic self inspections. Per Senate Bill (SB) 2330, the ARB was specifically directed to specify the inspection procedures, the inspection frequency, reference emissions standards, and the actions needed to conform to the established requirements.

In concert with the legislative mandate, the ARB consulted with the Bureau of Automotive Repair (BAR), the Inspection and Maintenance Review Committee, and industry representatives in developing the program's regulations. The enacted program is termed the "Periodic Smoke Inspection Program" (PSIP) and applies to California based fleet with two or more vehicles.

II. PSIP NEED

The PSIP is meant to complement the Heavy-Duty Vehicle Inspection Program (HDVIP). Although the HDVIP is effective in reducing excessive smoke emissions from heavy-duty diesel vehicles subject to random roadside locations, it is insufficient on its own to reduce the number of smoking trucks from the thousands of fleet vehicles based in California.

The HDVIP is conducted primarily at key interstate highway inspection stations along with intercity and rural random locations. However, since urban areas such as Los Angeles County are so large, additional strategies are needed in order to address the impact of all intercity vehicles. The PSIP is intended to fill this need by focusing on vehicles such as buses and trucks with more localized operations. In conjunction, both are expected to lower the emissions impact that malmaintained heavy-duty diesel vehicles have on California's air quality.

III. TRUCK EMISSIONS

Even though heavy-duty trucks and buses constitute only 2 percent of the total on-road motor vehicle fleet, they contribute approximately 30% of oxides of nitrogen emissions and 65% of the particulate matter emissions. On average, heavy-duty vehicles emit: 469.21 tpd of oxides of nitrogen (NO_x), 31.05 tpd of particulate matter (PM), 49.32 tons per day (tpd) of reactive organic gases (ROG), and 23.44 tpd of oxides of sulfur (SO_x). They also emit carbon monoxide (CO), carbon dioxide ($C0_2$), and miscellaneous toxic compounds such as benzene, aldehydes, 1.3 butadiene, and xylene.

Although somewhat difficult to quantify directly, excessive smoke emissions from diesel trucks are a major public concern. Not only is excessive smoke emissions an indicator of malmaintenance (which directly leads to incomplete fuel combustion and excessive particulate matter emissions), smoking trucks and buses are a major public health and nuisance concern. Every year government agencies receive thousands of complaints regarding smoking trucks[6].

Engine malmaintenance and tampering are the primary causes of excessive diesel emissions - particularly smoke emissions. Examples of specific components or systems which are malmaintained or tampered are: fuel injection pump and seals, fuel injection timing, fuel injectors, smoke puff limiter, air filter, intercooler, turbocharger, exhaust gas recirculation valve, along with other internal engine components. Other causes of excessive diesel emissions are pressure leaks in the injection system or manifolds, excessive back pressure in the exhaust system, and fuel problems such wrong fuel grade or water contamination.

IV. VEHICLES SUBJECT TO THE PSIP

The PSIP applies to all California based fleets which operate heavy-duty diesel vehicles with a GVWR of 6,001 pounds or more. Typical fleet vehicles include, pick-up trucks, flatbeds, semi-trucks, utility vehicles, vans, transit buses, and school buses.

The PSIP, however, does not apply to single vehicle operations. This qualification is needed in order to provide regulatory relief for economically-marginal small businesses which own a single heavy-duty diesel-powered vehicle. Many of these vehicles are privately owned, lighter duty, and are driven more

[6] Please refer to “Background Information of the Heavy-Duty Vehicle Inspection Program”, Section II, of this booklet for a discussion the emissions impact of heavy-duty vehicles on California’s public health and environment.

like passenger cars and light-duty trucks[7]. Large fleets, unlike single vehicle operations, can generally perform their own inspections or pool their inspections at common inspection facilities. It is estimated that about 20 percent of heavy-duty diesel vehicles registered in California operate as single (non-fleet) vehicles.

In addition, non-California based interstate vehicles are exempt since they are generally serviced and maintained outside of California. These types of vehicles include vehicles which:

(a) are registered under the International Registration Plan,

(b) operate in California under terms of Interstate Reciprocity Agreements,

(c) operate in California under the terms of any other apportioned registration, reciprocity, or bilateral prorate registration agreements between California and other jurisdictions, or

(d) operate in California under short-term vehicle registrations or permits of 90 days or less are also exempt from the PSIP.

These vehicles are generally in California on a temporary basis only and it would be inappropriate to subject them to the PSIP requirements. All heavy-duty diesel-powered vehicles operating in the state, however, are subject to the ARB's HDVIP. Interstate vehicles may, in fact, be more likely to be subject to a roadside inspection than a vehicle in a California urban fleet, since HDVIP enforcement operations are mostly located at the weigh stations along interstate highways. It is estimated that 19 percent of all heavy-duty vehicles operating in California are based outside California.

V. INSPECTION RESPONSIBILITIES

Section 2192 of Title 13 of the CCR sets forth the necessary vehicle inspection responsibilities to implement an effective PSIP. Owners of vehicles subject to the requirements of the regulations are required to periodically test their vehicles, repair their vehicles if smoke opacity standards are exceeded, re-test their vehicles once repaired, make additional repairs if necessary, record all test results and repair information, maintain records for two years, and permit an ARB inspector to review the inspection records at owner/operator designated fleet locations by appointment.

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[7] It may be more appropriate to inspect these vehicles in the biennial smog check program; to this extent, the Bureau of Automotive Repair is currently studying the feasibility of inspecting diesel vehicles at smog check stations.

A. INSPECTION INTERVALS

The established regulations require an initial “phase-in” inspection period in accordance to the established scheduled. Fleets of five or more vehicles are subject to the following inspection schedule:

* At least 25 percent of the fleet’s vehicles within 180 calendar days;
* At least 50 percent of the fleet’s vehicles within 270 calendar days;
* At least 75 percent of the fleet’s vehicles within 365 calendar days;
* The fleet’s remaining vehicles no later than 455 calendar days.

For fleets of 2 or 4 vehicles, at least one vehicle must be tested in the initial 180 day period, and in each subsequent 90 day period, until all vehicles are tested.

These testing intervals are applicable commencing on the effective date of the PSIP regulations (July 1, 1998) or whenever a new fleet becomes operable. Once a vehicle has been inspected, it is required to be tested annually thereafter.

Since it is unlikely that newer (post 1994) model year engines will smoke excessively during the first few years of use, the PSIP regulations allow a four year exemption for vehicles powered by 1994 or subsequent model-year engines. For these vehicles, the testing schedule begins on January 1 of calendar year that is four years after the model year of the engine, and are to be treated as having been acquired by the owner on January 1. For example, a 1995 model-year engine will be exempt until January 1, 1999.

VI. TEST PROCEDURE

Since the PSIP is meant to complement the HDVIP by promoting self compliance to the HDVIP, both employ the same test procedure and pass/fail criteria.

This procedure uses the SAE J1667snap-acceleration test method. During this test the driver rapidly depresses the accelerator to the floorboard for a few seconds while the smoke is measured. A smoke opacity meter monitors the smoke exiting the exhaust pipe.

This test was initially chosen because it is easy, quick and safe to perform and is particularly well suited for inspections at fleet facilities. Please refer to the PSIP testing regulations as contained in Title 13, section 2193 for the specific testing and equipment requirements.

VII. SMOKE OPACITY STANDARDS

A major legislative requirement for both the HDVIP and PSIP is that they be effective in identifying vehicles with excessive smoke emissions without causing any wrongful failures. The established HDVIP smoke opacity standards fulfill this mandate.

The smoke opacity standards are 40% for trucks with 1991 and newer model-year engines and 55% for those with model-year engines older than 1991. These standards are applicable to both the HDVIP and PSIP. Vehicles exceeding these standards will be cited under the HDVIP with one notable exception - for pre 1991 model-year engines a Notice of Violation (NOV) is issued for engines with smoke opacity levels between 55% and 69%[8]. If these vehicle are repaired to below 55% within the allowable 45 day time period, a citation is not issued.

To assure that wrongful failures do not occur under the HDVIP or the PSIP, certain engine families with unique operational characteristics have been granted exemptions from the above standards. Please refer to the attached technical bulletin at end of this summary for a list of exempt engine families and their assigned standards.

VIII. RECORD KEEPING REQUIREMENTS

The need to maintain records of the required inspections is an important element of the PSIP regulations. In particular, the record-keeping requirements allow the ARB to perform proper audits, and will assist the ARB in gathering information on the effectiveness of the program.

Per the PSIP requirements, vehicle owners/fleet operators must document:

* staff or contracted commercial entity responsible for PSIP testing,
* brand and model of the smoke testing equipment employed,
* date of the last smoke meter calibration,
* smoke meter operator,

[8] Under the NOV concept, a citation is issued if the vehicle exhibited smoke emissions are 70% or greater or of the vehicle is not repair to a level below 55% when a NOV is issued.

* specific vehicle identification,

* initial smoke test results and test dates,

* corrected action (i.e. repairs undertaken), if warranted, and

* post-repair smoke test results.

As noted, repair records must be maintained. These include repair receipts from a repair facility or a completed work order (if a fleet conducts its own repairs). Repair records need to also include the following information: name, address, and phone number of the facility conducting the repairs; name of the mechanic; date of repair(s), and/or adjustment(s); and an itemized list of replaced components, including description of replaced components; component part numbers, and cost.

To allow the trucking industry some flexibility, however, the required records may be maintained in any reasonable fashion, including electronic data files or hard copy files.

Please refer to section 2194, Title 13, Health and Safety Code of the enclosed PSIP regulations for a complete list of the record keeping requirements.

IX. PSIP INSPECTION RECORDS AUDITS

To effectively enforce the PSIP, the ARB needs to audit participating fleets. To this extent, the legislature has given the ARB the authority to review a fleet’s PSIP record keeping provisions at owner/operator designated fleet locations by appointment.

The ARB presently anticipates conducting audits in conjunction with the CHP’s Biennial Inspection of Terminals (BIT) program. The CHP currently administers this safety assurance program for trucks and buses that operate from California fleet facilities. A similar program exists for coach buses. An important feature of these CHP programs is the on-site audit of vehicle safety records. To prevent an undue regulatory burden on the owners and operators of heavy-duty diesel vehicles, the ARB anticipates coordinating its audits of the PSIP records with the CHP’s audit of safety records when feasible.

If a fleet owner fails to make available the PSIP records for review or if a review of the records indicate that some vehicles maybe in violation, the ARB may test a fleet’s vehicles at its premises. Under the Health and safety Code section 44011.6(f) the ARB can enforce the HDVIP at fleet facilities. Refusal to submit can be considered a HDVIP violation and can lead to the issuance of citations.

ENGINE FAMILY EXEMPTIONS

HDVIP and PSIP

Technical Bulletin
(As of April 22, 1998)

The following is a listing of approved exempted heavy-duty engines pursuant to section 2182(e) of Title 13 California Code of Regulations:

Engines Exempted to Higher Opacity Cutpoints

Manufacturer	No. Of Engine Families	Exempt/App. Opacity	Model Years
DDC (1)	6	75%	1987-90
Hypermax (2)	2	75%	1985-91
Caterpillar (3)	2	70%	1989-90
Cummins (4)	1	75%	1988-92

(1) Series 60 DDEC I and DDEC II engine families. DDC is upgrading these engines, by recalibrating the on-board electronic controls during routine maintenance, to comply with the applicable cutpoint.

(2) This exemption applies to an aftermarket parts turbo-charger installation.

(3) Selected Model 3176 electronic engines.

(4) L-10 engine family-CPL 1226.

For further information, contact the Northern Heavy-Duty Diesel Section office at (916) 322-7061, the Southern Heavy-Duty Diesel Section office at (626) 450-6161, or the Border Heavy-Duty Diesel Section office at (626) 350-6561 of the Air Resources Board.

DATA LOG SHEET SAMPLE

PERIODIC SMOKE INSPECTION PROGRAM (PSIP)

Date ______________ Time ______________

Test Facility : Facility Name ______________________________

Address ______________________________

____

Phone ______________________________

Operator Name : Smoke Meter ______________________________

Chart Recorder ______________________________

Throttle ______________________________

	Brand Name	Model	Date of Last Calibration
Smoke Meter :			
Chart Recorder :			

Vehicle : License ____________ Engine : Year ____________

VIN ____________ Make ____________

Facility ID ____________ Family ____________

CPL ____________

Smoke Test 1 : Date ____________________

Zero ____________ Span ________ Mid ________

Clean 1 ____________ Clean 2 ________ Clean 3 ________

Test 1 ____________ Test 2 ________ Test 3 ________

Avg. of 2 Closet Test Readings __________ Standard __________

Test Result : Pass - Fail Repair Needed : Yes - No

Smoke Test 2 : Date ____________________

Zero ____________ Span ________ Mid ________

Clean 1 ____________ Clean 2 ________ Clean 3 ________

Test 1 ____________ Test 2 ________ Test 3 ________

Avg. of 2 Closet Test Readings __________ Standard __________

Test Result : Pass - Fail Repair Needed : Yes - No

Suggested Format *

CALIFORNIA AIR RESOURCES BOARD

CALIFORNIA COUNCIL ON DIESEL EDUCATION AND TECHNOLOGY

(CCDET)

I. CALIFORNIA COUNCIL ON DIESEL EDUCATION AND TECHNOLOGY BACKGROUND

The California Council on Diesel Education and Technology (CCDET)was formed in the spring of 1992 to assist the trucking and transit industries and related repair industries in complying with the Heavy Duty Vehicle Inspection Program and the Periodic Smoke Inspection Program. The CCDET program is a coalition of government, industry, and academia established to develop and conduct training programs for service and repair personnel in the commercial truck and transit industries. Members of the CCDET program include the ARB and California Community Colleges with Diesel Technology Programs.

The CCDET coalition has selected six California Community Colleges (College of Alameda, San Joaquin Delta College, Golden West College, Los Angeles Trade Tech College, Palomar Community College, and Santa Ana College) to serve as lead institutions in developing the training program in cooperation with other CCDET members. All interested California Community Colleges or Technical Schools with Diesel Technology Programs will be invited to participate.

II. BENEFITS GAINED FROM THE CCDET PROGRAM

The CCDET program will benefit the trucking and transit industries by providing a higher quality of service available to the end users. The maintenance and repair facilities will receive an effective employee who has an understanding of air quality regulations and procedures. The CCDET program provides an enhanced education to the student as well as the community.

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California Environmental Protection Agency
AIR RESOURCES BOARD

Regulations for the

Heavy - Duty Vehicle Inspection Program (HDVIP)

and the

Periodic Smoke Inspection Program (PSIP)

January 2009

TITLE 13. MOTOR VEHICLES
DIVISION 3. AIR RESOURCES BOARD
CHAPTER 3.5. HEAVY-DUTY DIESEL SMOKE EMISSION TESTING, AND HEAVY-DUTY VEHICLE EMISSION CONTROL SYSTEM INSPECTIONS

§ 2180. Applicability.

Unless otherwise noted, this chapter applies to all diesel-powered and gasoline-powered heavy-duty vehicles, including pre-1974 model-year vehicles, operating in the State of California.

Note: Authority cited: Sections 39600, 39601, 43013, 43701 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43018, 43701 and 44011.6, Health and Safety Code; and Section 505, Vehicle Code.

§ 2180.1. Definitions.

(a) The definitions of this section supplement and are governed by the definitions set forth in Chapter 2 (commencing with section 39010), Part 1, Division 26 of the Health and Safety Code. The following definitions shall govern the provisions of this chapter.

(1) "Authorized dealer" means a group of independent service and repair facilities that are recognized by the motor vehicle or engine manufacturer as being capable of performing repairs to factory specifications; including warranty repair work.

(2) "ARB post-repair inspection" means a repeat emission control system inspection, conducted by the Air Resources Board at an Air Resources Board-specified site, for the purpose of clearing a Citation issued under section 2185(a)(1)(C).

(3) "ARB post-repair test" means a repeat test, conducted by the Air Resources Board at an Air Resources Board-specified site, for the purpose of clearing a Citation issued under section 2185(a)(1)(C).

(4) "Basic penalty" means the civil penalty of ($500) for a test procedure or emission control system inspection violation that is to be deposited in the Vehicle Inspection and Repair Fund.

(5) "Citation" means a legal notice issued by the Air Resources Board to the owner of a heavy-duty vehicle requiring the owner to repair the vehicle and to pay a civil penalty.

(6) "Day" means calendar day.

(7) "Defective" means a condition in which an emission control system or an emission control system component is malfunctioning due to age, wear, malmaintenance, or design defects.

(8) "Demonstration of correction" means the documents identified in section 2186.

(9) "Driver" has the same meaning as defined in California Vehicle Code section 305.

(10) "Emission control label" or "ECL" means the label required by the "California Motor Vehicle Emission Control Label Specifications", incorporated by reference in 13 CCR, section 1965, or Title 40, Code of Federal Regulations (CFR), Part 86, Subpart A.

(11) "Emission control system" means the pollution control components on an engine at the time its engine family is certified, including, but not limited to, the emission control label.

(12) "Executive Officer" means the Executive Officer of the Air Resources Board or his or her designee.

(13) "Federal emission standards" means the emission standards adopted by the U.S. Environmental Protection Agency, pursuant to Title 42 United States Code, section 7521(a), that are required to be met for the certification of heavy-duty vehicles or engines.

(14) "Fleet" means two (2) or more heavy-duty vehicles.

(15) "Heavy-duty commercial vehicle" means a "motor truck" designed, used, or maintained primarily for the transportation of property, as defined in section 410 of the Vehicle Code, and having a gross vehicle weight rating (GVWR) greater than 10,000 pounds.

(16) "Heavy-duty vehicle" means a motor vehicle having a manufacturer's maximum

gross vehicle weight rating (GVWR) greater than 6,000 pounds, except passenger cars.

(17) "Inspection procedure" means the test procedure specified in section 2182 and the emission control system inspection specified in section 2183.

(18) "Inspection site" means an area including a random roadside location, a weigh station, or a fleet facility used for conducting the heavy-duty vehicle test procedure, emission control system inspection, or both.

(19) "Inspector" means an Air Resources Board employee with the duty of enforcing Health and Safety Code sections 43701(a) and 44011.6 and title 13, CCR sections 2180 through 2194.

(20) "Issuance" means the act of mailing or personally delivering a Citation to the owner.

(21) "Minimum penalty" means the ($300) penalty that is to be deposited in the Diesel Emission Reduction Fund pursuant to Health and Safety Code section 44011.6(l).

(22) "Notice of Violation" means a legal notice issued to the owner of a heavy-duty vehicle powered by a pre-1991 model-year diesel engine with a measured smoke opacity exceeding 55 percent but not exceeding 69 percent, requiring the owner to repair the vehicle and submit a demonstration of correction.

(23) "Officer" means a uniformed member of the Department of the California Highway Patrol.

(24) "Opacity" means the percentage of light obstructed from passage through an exhaust smoke plume.

(25) "Owner" means either (A) the person registered as the owner of a vehicle by the California Department of Motor Vehicles (DMV), or its equivalent in another state, province, or country; or (B) a person shown by the registered owner to be legally responsible for the vehicle's maintenance. The person identified as the owner on the registration document carried on the vehicle at the time a Citation is issued shall be deemed the owner unless that person demonstrates that another person is the owner of the vehicle.

(26) "Removal from service" means the towing and storage of a vehicle under the auspices of the Department of the California Highway Patrol.

(27) "Repair facility" means any place where heavy-duty vehicles are repaired, rebuilt, reconditioned, or in any way maintained for the public at a charge, and fleet maintenance facilities.

(28) "SAE J1667" means Society of Automotive Engineers (SAE) Recommended Practice SAE J1667 "Snap-Acceleration Smoke Test Procedure for Heavy-Duty Diesel Powered Vehicles," as issued February 1996 ("1996-02"), which is incorporated herein by reference.

(29) "Schoolbus" means the same as defined in California Vehicle Code section 545.

(30) "Smokemeter" means a detection device used to measure the opacity of smoke in percent opacity.

(31) "Tampered" means missing, modified, or disconnected, or, as it applies to emission control labels, permanently obscured.

(32) "Test procedures," for the purpose of chapter 3.5, means the test procedures set forth in SAE J1667.

(33) "Uncleared Citation" means a Citation for which demonstration of correction and, if required, payment of any civil penalty, has not been made.

Note: Authority cited: Sections 39600, 39601, 43013, 43701 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43018, 43701 and 44011.6, Health and Safety Code; Sections 410 and 505, Vehicle Code; title 42 United States Code, section 7521(a); and title 40, Code of Federal Regulations Part 86, Subpart A.

§ 2181. Responsibilities of the Driver and Inspector During the Inspection Procedure.

(a) Driver of heavy-duty diesel-powered vehicle. The driver of a heavy-duty diesel-powered vehicle selected to undergo the inspection procedure shall do all of the following:

(1) Drive the vehicle to the inspection site upon direction of an officer.

(2) Show proof of driver's license and vehicle registration to the inspector or officer upon request.

(3) Perform the test procedure upon request by an inspector.

(4) Open the vehicle door so that the inspector can observe the driver depress the accelerator pedal.

(5) Permit an emission control system inspection and open the hood of the vehicle upon the request of the inspector.

(6) As applicable, sign the Citation or Notice of Violation to acknowledge its receipt and sign the smoke test report to acknowledge performance of the test procedure.

(b) Driver of heavy-duty gasoline-powered vehicle. The driver of a heavy-duty gasoline-powered vehicle selected to undergo the inspection shall do all of the following:

(1) Drive the vehicle to the inspection site upon direction of an officer.

(2) Show proof of driver's license and vehicle registration to the inspector or officer upon request.

(3) Permit an emission control system inspection and open the hood of the vehicle upon request of the inspector.

(4) As applicable, sign the Citation or Notice of Violation to acknowledge its receipt.

(c) Inspector. The inspector in performing the inspection procedures shall do all of the following:

(1) Advise the driver that refusal to submit to the inspection procedure is a violation of these regulations.

(2) Obtain engine identification information from the vehicle when tested pursuant to section 2182 to determine which opacity standard specified in section 2182 applies.

(3) Except as otherwise provided in section 2181(c)(4), issue a Citation to the driver of a vehicle that fails the test procedure or the emission control system inspection.

(4) Issue a Notice of Violation to the driver of a vehicle powered by a pre-1991 model-year diesel engine with a measured smoke opacity exceeding 55 percent but not exceeding 69 percent, except where a Notice of Violation or Citation has been issued for the vehicle in the preceding 12 months.

(5) Issue a warning to the owner of a heavy-duty diesel-powered vehicle missing its emission control label that the label must be replaced and the engine number identification must be provided to the ARB within 45 days of written notification or receipt of a Citation under section 2183 from the ARB, or it will be conclusively presumed in any subsequent smoke opacity test where the emission control label remains missing that the vehicle is subject to the 40 percent smoke opacity standard in section 2182(a)(1), unless at the time of the subsequent test it is plainly evident from a visual inspection that the vehicle is powered by a pre-1991 model-year engine.

Note: Authority cited: Sections 39600, 39601, 43013, 43701 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43018, 43701 and 44011.6, Health and Safety Code; and Sections 260 and 305, Vehicle Code.

§ 2182. Heavy-Duty Diesel Vehicle Smoke Opacity Standards and Test Procedures; Excessive Smoke.

(a) Standards

(1) No heavy-duty vehicle powered by a 1991 or subsequent model-year diesel engine operating on the highways within the State of California shall exceed 40 percent smoke opacity when tested in accordance with this section unless its engine is exempted under subsection (c) or (d) below.

(2) No heavy-duty vehicle powered by a pre-1991 model-year diesel engine, operating on the highways within the State of California, shall exceed 55 percent smoke opacity when tested in accordance with this section unless its engine is exempted under subsection (c) or (d) below.

(b) Exemptions

(1) The Executive Officer shall exempt from subsections (a)(1) and (2) any engine

family that is shown by the engine manufacturer to the satisfaction of the Executive Officer to exhibit smoke opacity greater than 40 percent or 55 percent respectively when in good operating condition and adjusted to the manufacturer's specifications. Such engine family(s) must comply with any technologically appropriate less stringent opacity standard identified by the Executive Officer based on a review of the data obtained from engines in good operating condition and adjusted to manufacturer's specifications.

(2) The Executive Officer shall exempt from subsections (a)(1) and (2) any 1991 and earlier model-year heavy-duty diesel engines that are equipped with carryover add-on aftermarket turbocharger kits approved by the ARB, and are shown by the kit or engine manufacturer to the satisfaction of the Executive Officer to exhibit smoke opacity greater than 40 percent or 55 percent respectively when in good operating condition and adjusted to manufacturer's specifications. Such engines must comply with any technologically appropriate less stringent opacity standard identified by the Executive Officer based on a review of the data obtained from engines in good operating condition and adjusted to manufacturer's specifications.

(3) Exemptions previously issued and in effect on January 1, 1996 shall remain in effect under the amendments to this section adopted on March 2, 1998 and effective on May 4, 1998.

(4) A manufacturer seeking an exemption under subsection (b) shall provide the ARB with the engine emissions data needed to exempt the engine family and determine technologically appropriate less stringent opacity standards.

(c) Effect of missing emission control label on applicable standard. When the owner of a heavy-duty diesel-powered vehicle receives a Citation or written notification from the ARB that the emission control label was missing during an inspection, the owner must replace the emission control label and provide the engine number identification to the ARB within 45 days of receipt of the notification in addition to paying applicable penalties under section 2185(a)(3). If the owner fails to comply with this requirement, it will be conclusively presumed in any subsequent smoke opacity test where the emission control label remains missing that the vehicle is subject to the 40 percent smoke opacity standard in section 2182(a)(1), unless at the time of the subsequent test it is plainly evident from a visual inspection that the vehicle is powered by a pre-1991 model-year engine.

(d) Excessive Smoke. A heavy-duty vehicle has excessive smoke if it fails to comply with the smoke opacity standard applicable under this section 2182.

Note: Authority cited: Sections 39600, 39601, 43013, 43701 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43018, 43701 and 44011.6, Health and Safety Code.

§ 2183. Inspection of the Emission Control System on a Heavy-Duty Vehicle.

(a) Heavy-duty diesel-powered vehicles. No heavy-duty diesel-powered vehicle shall operate in California with tampered or defective emission control components. The ARB shall conduct a visual inspection of heavy-duty diesel-powered vehicles to determine whether emission control components have been tampered with or are defective. The inspection shall include, but is not limited to, the following:

(1) The engine governor.

(2) Any seals and/or covers protecting the air-fuel ratio adjustments.

(3) Any fuel injection pump seals and covers.

(4) The air cleaner and flow restriction indicator.

(5) The exhaust gas recirculation valve.

(6) The particulate matter trap system or catalytic converter system, including pipes and valves.

(7) Related hoses, connectors, brackets, and hardware for these components.

(8) Engine computer controls, related sensors, and actuators.

(9) Emission control label (ECL).

(10) Any other emissions-related components for a particular vehicle/engine as determined from the manufacturer's specifications, emission control label, certification data, or published vehicle parts manuals.

(b) Heavy-duty gasoline-powered vehicles. No heavy-duty gasoline-powered vehicle shall operate in California with tampered or defective emission control components. The ARB shall a conduct a visual inspection of heavy-duty gasoline-powered vehicles to determine whether emission control components have been tampered with or are defective. The inspection shall include, but is not limited to, the following:

(1) The air injection system.

(2) The positive crankcase ventilation system.

(3) The exhaust gas recirculation system.

(4) The catalytic converter, including pipes and valves.

(5) The evaporative emission control system.

(6) Related hoses, connectors, brackets, and hardware for these components.

(7) Engine computer controls, related sensors, and actuators.

(8) On-Board Diagnostic (OBD) systems for 1994 and subsequent model year vehicles, if so equipped.

(9) ECL.

(10) Any other emissions-related component for a particular vehicle/engine as determined from the manufacturer's specifications, emission control label, certification data, or published vehicle parts manuals.

(c) No 1974 or newer diesel powered heavy-duty commercial vehicle shall operate in California without evidence that, at the time of manufacture, the installed engine met emission standards at least as stringent as applicable federal emission standards for the model year of the engine. The ARB shall base its determination on whether an engine meets the above requirements by inspecting the ECL affixed to the vehicle's engine.

Note: Authority cited: Sections 39600, 39601, 43013, 43701 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43018, 43701 and 44011.6, Health and Safety Code.

§ 2184. Refusal to Submit to Inspection Procedure.

The refusal by an owner or driver of a vehicle to submit to the test procedure in section 2182 or to the emission control system inspection in section 2183 constitutes a failure of the test procedure or inspection, unless the driver is cited by the California Highway Patrol for a violation of California Vehicle Code section 2813.

Note: Authority cited: Sections 39600, 39601, 43013, 43701 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43018, 43701 and 44011.6, Health and Safety Code. Sections 305, 505 and 2813, Vehicle Code.

§ 2185. Civil Penalty Schedule.

(a) The owner of a heavy-duty vehicle that fails the test procedure or the emission controls system inspection, including by refusal to submit, is subject to the following penalty schedule:

(1) Heavy-Duty Vehicle Opacity and Tampering Penalties for Violating Sections 2182 and 2183(a) and (b), Except for Violations Involving a Tampered ECL.

(A) Except as provided below, the owner of a heavy-duty vehicle, that is cited for the first time pursuant to section 2182 or 2183 (a) and (b), other than for a tampered ECL, and for which demonstration of correction is provided and payment is made within 45 days from personal or certified mail receipt of the Citation, shall pay the minimum penalty of $300. An owner who fails to correct the vehicle or pay the minimum penalty within 45 days of receipt of the Citation shall be assessed a penalty of $800.

(B) The above penalty shall not apply to the first Citation received by an owner of a school bus, but the owner shall be subject to the penalty provisions of paragraphs 2185(a)(1)(A) and (C) respectively for second and any subsequent violations.

(C) The owner of a vehicle that is cited pursuant to section 2182 or 2183(a) and (b), other than for a tampered ECL, for a second time within a 12 month period for the same vehicle shall within 45 days from personal or certified mail receipt of the current Citation provide demonstration of correction and pay the penalty of $1,500 and the minimum penalty of $300 for a total of $1,800, notwithstanding section 2185(c).

(D) The owner of a heavy-duty vehicle that violates section 2184 by refusing to submit to an inspection conducted under sections 2182 or 2183(a) and (b), including inspections for a tampered ECL, shall be assessed a penalty of $800 for a first time violation. Subsequent violations of section 2184 for refusing to submit to an inspection under 2182 shall be subject to a penalty of $1800.

(2) Penalties for a Tampered ECL under section 2183.

(A) An owner of any heavy-duty vehicle shall receive a Citation each time that ARB finds that the vehicle has a tampered ECL. For the first year following the effective date of the amended regulation, February 15, 2007, if the owner demonstrates to ARB that a new label has been affixed to the vehicle's engine within 45-days of receipt of the Citation pursuant to section 2186(a)(3) below, no penalty shall be assessed. An owner of a heavy-duty vehicle who has been issued a Citation for a tampered ECL label and who has failed to have a replacement label affixed to the engine within 45-days of service of the Citation as set forth in section 2186(a)(3) below shall be subject to a $300 penalty.

(B) After the first year from the effective date of the amended regulation, February 15, 2007, the owner shall receive a citation assessing the owner a $300 penalty. The fine shall only be waived if, at the time of inspection, the owner provides other documentation from the engine manufacturer or an authorized dealer that demonstrates compliance with section 2183(c), and provided the ECL is replaced pursuant to paragraph (A) above. The documentation shall identify the engine by serial number.

(3) Penalties for Violations of Section 2183(c). The owner of a heavy-duty commercial vehicle that is cited for a violation of section 2183(c) shall be subject to the following penalties:

(A) The owner shall be subject to a penalty of $500 for each violation.

(B) For the purposes of section 2185(a)(3), it shall be presumed that a heavy-duty commercial vehicle with a tampered ECL is not in compliance with section 2183(c) and is subject to a $500 penalty for each violation in addition to the penalties provided for under section 2185(a)(2). If the owner demonstrates to ARB that a new ECL has been affixed to the vehicle's engine within 45-days of receipt of the Citation, pursuant to section 2186(a)(3) below, and the ECL demonstrates that the vehicle's engine was designed to at least meet U.S. EPA promulgated emission standards for the year of the engine's manufacture, the penalty for violation of section 2183(c) shall be waived.

(b)(1) No Citation shall be issued to the owner of a heavy-duty vehicle powered by a pre-1991 model-year diesel engine on the basis of a measured smoke opacity exceeding 55 percent but not exceeding 69 percent, unless:

(A) the owner fails to provide a demonstration of correction within 45 days from personal or certified mail receipt of the Notice of Violation, or

(B) a Notice of Violation or Citation has been issued for the vehicle in the preceding 12 months.

(2) The owner of a heavy-duty vehicle that is the subject of a Notice of Violation and for which demonstration of correction is provided within 45 days from personal or certified mail receipt of the Notice of Violation shall not be subject to a penalty for the violation.

(3) The owner of a heavy-duty vehicle that is initially subject to a Notice of Violation, but is cited after a demonstration of correction is not provided within 45 days from personal or certified mail receipt of a Notice of Violation, shall be subject to the penalty in section 2185(a)(1)(A).

(4)(A) Where a heavy-duty vehicle with a pre-1991 engine inspected in accordance with section 2181 has a measured opacity exceeding 55 percent but not exceeding 69 percent within 12 months of issuance of a Notice of Violation for which a demonstration of correction was timely provided within the applicable 45-day period, a Citation shall be issued and the owner shall be subject to the penalty in section 2185(a)(1)(A).

(B) Where a heavy-duty vehicle with a pre-1991 engine inspected in accordance with section 2181 has a measured opacity exceeding 55 percent but not exceeding 69 percent within 12 months of issuance of a Notice of Violation for which a demonstration of correction was not timely provided within the applicable 45- day period, a Citation shall be issued and the owner shall be subject to the penalty in section 2185(a)(1)(C).

(c) If a heavy-duty vehicle fails the test procedure or an emission control system inspection one year or more after the date of its most recent failure, the owner of that vehicle shall be subject to the penalty schedule in section 2185(a)(1)(A) and (a)(1)(C).

(d) When a heavy-duty vehicle is cited after a bona fide change of ownership between non-related persons or entities, the new owner shall not be subject to the penalty schedule in section 2185(a)(1)(A) and (C) if the only Citations issued for the vehicle within the previous 12 months were issued prior to the change of ownership to the new owner.

Note: Authority cited: Sections 39600, 39601, 43013, 43016, 43701 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43016, 43018, 43701 and 44011.6, Health and Safety Code. Sections 305, 505 and 545, Vehicle Code.

§ 2186. Demonstration of Correction and Post-Repair Test or Inspection.

(a) Demonstration of Correction. The owner must demonstrate correction of the vehicle by submitting to the Air Resources Board documents demonstrating compliance with (1) or (2) or (3):

(1) Where repairs are made at a repair facility, a repair receipt or a completed work order which contains the following information:

(A) Name, address, and phone number of the facility;

(B) Name of mechanic;

(C) Date of the repair;

(D) Description of component replacement(s), repair(s), and/or adjustment(s); and

(E) Itemized list of replaced component(s), including description of part, part number, and cost;

(2) Where the owner makes his or her own repairs outside of a repair facility,

(A) An itemized receipt for the parts used in the repair, and

(B) A statement identifying that date and nature of the repairs made;

(3) The owner of the heavy-duty vehicle who has received a Citation for a tampered ECL shall:

(A) Have the engine manufacturer through its authorized dealer, affix an emission control label identical to the label that was installed on the engine at the time of its original manufacturer;

(B) Provide written verification from the heavy-duty vehicle/engine manufacturer or its authorized dealer that the label has been replaced. The written verification must include identification of the engine serial number.

(b) Statement of Correction. The owner must also submit to the Air Resources Board documents demonstrating compliance with (1) or (2):

(1) Where the Citation or Notice of Violation was based on a failure to meet the opacity standard applicable under section 2182, a smoke test report from a subsequent test showing that the repaired vehicle passed the applicable section 2182 standard along with a statement to that effect made under penalty of perjury by the person who conducted the subsequent test;

(2) Where the Citation or Notice of Violation was based on a failure to pass an emission control system inspection as specified in section 2183, a statement by a person, under penalty of perjury, that the person has reinspected any components identified in the Citation or Notice of Violation as defective or tampered and has determined that these components are correct, are installed, and are in good working order; or

(c) The Air Resources Board shall require an ARB post-repair test or an ARB post-repair inspection whenever:

(1) a submitted repair receipt or work order does not comply with (a) above;

(2) a repair receipt, work order or authorized dealer verification appears to be falsified; or

(3) a second and subsequent failures of the test procedure or an emission control system inspection on the vehicle occur within a one year period.

Note: Authority cited: Sections 39600, 39601, 43013, 43701 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43018, 43701 and 44011.6, Health and Safety Code. Section 505, Vehicle Code.

§ 2187. Vehicles Removed from Service.

(a) Vehicles are subject to removal from service by the Department of the California Highway Patrol if requested by the Air Resources Board inspector, and if one or more uncleared Citations issued under section 2182 exist at the time of inspection.

(b) Upon payment by bank check, money order, or credit card of all unpaid penalties for a vehicle that has been removed from service, the Air Resources Board shall provide the owner, or designee, a release form for presentation to the Department of the California Highway Patrol.

(c) The release of the vehicle shall be subject to the condition that it be repaired and post-repair tested or inspected within 15 days.

Note: Authority cited: Sections 39600, 39601, 43013 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43018 and 44011.6, Health and Safety Code. Section 505, Vehicle Code.

§ 2188. Contesting a Citation.

The owner of a vehicle cited under these regulations may request a hearing pursuant to section 60075.1 et seq., title 17, California Code of Regulations.

Note: Authority cited: Sections 39600, 39601, 43013 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43018, 43701 and 44011.6, Health and Safety Code.

§ 2189. Severability of Provisions.

If any subsection, paragraph, subparagraph, sentence, clause, phrase, or portion of this Chapter is, for any reason, held invalid, unconstitutional, or unenforceable by any court of competent jurisdiction, such portion shall be deemed as a separate, distinct, and independent provision, and such holding shall not affect the validity of the remaining portions of the regulation.

Note: Authority cited: Sections 39600, 39601, 43013 and 44011.6, Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43013, 43018, 43701 and 44011.6, Health and Safety Code.

TITLE 13. MOTOR VEHICLES
DIVISION 3. AIR RESOURCES BOARD
CHAPTER 3.6. PERIODIC SMOKE INSPECTIONS OF HEAVY-DUTY DIESEL-POWERED VEHICLES

§ 2190. Vehicles Subject to the Periodic Smoke Inspection Requirements.

These regulations shall be applicable, operative July 1, 1998, as follows:
(a) Except as provided in subsections (b), (c), (d), (e) and (f), the requirements of this chapter apply to all heavy-duty diesel-powered vehicles with gross vehicle weight ratings greater than 6,000 pounds which operate on the streets or highways within the State of California.

(b) Heavy-duty diesel-powered vehicles which are not part of a fleet or are employed exclusively for personal use are excluded from the requirements of this chapter.

(c) Heavy-duty diesel-powered vehicles which are registered under the International Registration Plan as authorized by Article 4 (commencing with section 8050), Chapter 4, Division 3 of the Vehicle Code and which have established a base state other than California (non-California based vehicles) are excluded from the requirements of this chapter.

(d) Heavy-duty diesel-powered vehicles which operate in California under the terms of Interstate Reciprocity Agreements as authorized by Article 3 (commencing with section 8000), Chapter 4, Division 3 of the Vehicle Code and which belong to fleets that are not based in California are excluded from the requirements of this chapter.

(e) Heavy-duty diesel-powered vehicles operating in California under the terms of any other apportioned registration, reciprocity, or bilateral prorate registration agreement between California and other jurisdictions and which belong to fleets that are not based in California are excluded from the requirements of this chapter.

(f) Heavy-duty diesel-powered vehicles operating in California under short-term vehicle registrations or permits of 90 days or less (including but not limited to 90-day temporary registrations and 4-day permits under Vehicle Code section 4004) are excluded from the requirements of this chapter.

Note: Authority cited: Sections 39600, 39601 and 43701(a), Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43018, 43701(a), and 44011.6, Health and Safety Code.

§ 2191. Definitions.

(a) The definitions of this section supplement and are governed by the definitions set forth in Chapter 2 (commencing with Section 39010), Part 1, Division 26 of the Health and Safety Code. The provisions of this chapter shall also be governed by the definitions set forth in section 2180.1, Title 13, California Code of Regulations including the following modifications:

(1) "Fleet" means any group of 2 or more heavy-duty diesel-powered vehicles which are owned or operated by the same agency or entity.

(2) "Test opacity" means the opacity of smoke from a vehicle when measured in accordance section 2193(e).

Note: Authority cited: Section 39600, 39601 and 43701(a), Health and Safety Code. Reference: Sections 39002, 39003, 39010, 39033, 43000, 43018, 43701(a) and 44011.6, Health and Safety Code.

§ 2192. Vehicle Inspection Responsibilities.

(a) The owner of a heavy-duty diesel-powered vehicle subject to the requirements of this chapter shall do all of the following:

(1) Test the vehicle for excessive smoke emissions periodically according to the inspection intervals specified in section 2193(a), (b), and (c).

(2) Measure the smoke emissions for each test using the test procedure specified in section 2193(e).

(3) Record the smoke test opacity levels and other required test information as specified in section 2194.

(4) Have the vehicle repaired if it exceeds the applicable smoke opacity standard specified in section 2193(e).

(5) Record the vehicle repair information as specified in section 2194.

(6) Conduct a post-repair smoke test to determine if the vehicle complies with the applicable smoke opacity standard.

(7) Record the post-repair smoke test results as specified in section 2194.

(8) If the vehicle does not comply with the applicable smoke opacity standard after

the test required by section 2192(a)(7), make additional repairs to achieve compliance, and record the smoke test results as specified in section 2194.

(9) Keep the records specified in section 2194 for two years after the date of inspection.

(10) Permit an Air Resources Board inspector to review the inspection records specified in section 2194 at owner/operator designated fleet locations by appointment.

Note: Authority cited: Sections 39600, 39601 and 43701(a), Health and Safety Code. Reference: Sections 39002, 39003, 39033, 43000, 43016, 43018, 43701(a) and 44011.6, Health and Safety Code.

§ 2193. Smoke Opacity Inspection Intervals, Standards, and Test Procedures.

(a) Initial phase-in. Vehicles which are subject to the requirements of this chapter on the operative date of these regulations shall be tested for smoke opacity (and repaired if the applicable smoke opacity standard is exceeded) in accordance with the requirements of section 2192 pursuant to the applicable following schedule:

(1) Fleets of five or more vehicles subject to this chapter:

(A) At least 25 percent of the fleet's vehicles within 180 calendar days of the effective date of these regulations;

(B) At least 50 percent of the fleet's vehicles within 270 calendar days of the effective date of these regulations;

(C) At least 75 percent of the fleet's vehicles within 365 calendar days of the effective date of these regulations; and

(D) The fleet's remaining vehicles no later than 455 calendar days after the effective date of these regulations.

(2) For fleets of 2 to 4 vehicles, at least one vehicle must be tested in the initial 180 day period, and in each subsequent 90 calendar day period, until all vehicles in the fleet have been tested.

(b) New fleets. Fleets which first become subject to the requirements of this chapter subsequent to the effective date of these regulations must be tested in accordance with section 2192 within the applicable time intervals reflected in subsection (a) above, beginning on the date the fleet becomes subject to these regulations.

(c) Annual testing. Once a vehicle subject to the requirements of this chapter has been tested in accordance with subsection (a) or (b), or has been acquired by a fleet owner after the effective date of these regulations, the vehicle must periodically be tested for smoke opacity (and repaired if the applicable smoke opacity standard is exceeded) in accordance with the requirements of section 2192 within 12 months of the previous test conducted under this section 2193.

(d) Exemption for vehicles powered by 1994 or subsequent model-year engines. Any heavy-duty vehicle powered by a 1994 or subsequent model-year engine is exempt from the testing requirements of this section until January 1 of the calendar year that is four years after the model year of the engine, and is to be treated as having been acquired by the owner on that January 1. For example, 1995 model-year engine will be exempt until January 1, 1999.

(e) Smoke opacity standards and test procedures.

(1) Except as otherwise provided in subsection (e)(2) below, the smoke opacity standards and test procedures are those specified in section 2182, Titled 13, California Code of Regulations.

(2) Prior to July 1, 1999, if a repair facility is not equipped with an operable SAE J1667 smokemeter, vehicles may be tested at the repair facility in accordance with the smoke opacity test procedures and opacity standards set forth in section (e)(3). These are the test procedures and opacity standards originally established for the heavy-duty diesel vehicle roadside inspection program in 1991.

(3) Optional smoke opacity test procedures and standards prior to July 1, 1999.

(A) Standards.

1. The maximum smoke opacity standard for a 1991 or subsequent model-year heavy-duty diesel-powered vehicle with a Federal peak smoke engine certification level of 35 percent peak opacity or less is 40 percent when tested in accordance with section 2193(e)(3)(B) and (C).

2. The maximum smoke opacity standard for any other heavy-duty diesel-powered vehicle is 55 percent when tested in accordance with section 2193(e)(3)(B) and (C).

3. The above standards do not apply to an engine exempted under section 2182(b).

(B) Equipment. The smoke opacity measurement equipment shall consist of a light extinction type smokemeter which includes an optical detection unit, a control/indicator unit, and a strip chart recorder.

1. The smokemeter shall comply with the specifications provided in the Society of Automotive Engineers (SAE) procedure J1243, "Diesel Emission Production Audit Test Procedure," May 1988, which is incorporated herein by reference, section 7.4 and shall be calibrated according to specifications in SAE procedure J1243, section 8.2.

2. The strip chart recorder shall comply with specifications in SAE procedure J1243, section 7.5, subsections 1-4 (May 1988).

(C) Procedure. The test procedure shall consist of preparation, preconditioning, and test phases:

1. In the preparation phase, the vehicle shall be placed at rest, the transmission shall be placed in neutral, and the vehicle wheels shall be properly restrained to prevent any rolling motion.

2. In the preconditioning phase, the vehicle shall be put through a snap-idle cycle two or more times until two successive measured smoke levels are within ten (10) opacity percent of each other. The smokemeter shall be rechecked prior to the preconditioning sequence to determine that its zero and span setting are adjusted according to specifications in SAE procedure J1243, section 8.1 (May 1988).

3. In the test procedure phase, the vehicle shall be put through the snap-idle cycle three times.

4. The opacity shall be measured during the preconditioning and test phases with a smokemeter and shall be recorded continuously on the chart recorder during each snap-idle cycle. The maximum instantaneous value recorded by the chart recorder shall be the opacity reading.

5. The test opacity to determine the compliance with (A)1. and (A)2. above shall be the average of the two meter readings with the least difference in opacity values. If all three readings have successive equivalent differences between them, the test opacity shall be the average of the three readings.

Note: Authority cited: Sections 39600, 39601, 43013, 43701(a), Health and Safety Code. Reference: Sections 39002, 39003, 39033, 43000, 43013, 43018, 43701(a) and 44011.6, Health and Safety Code.

§ 2194. Record Keeping Requirements.

(a) The owner of a vehicle subject to the requirements of this chapter shall record the following information when performing the smoke opacity testing:

(1) The brand name and model of the opacity meter.

(2) The dates of last calibration of the opacity meter and chart recorder.

(3) The name of the smoke meter operator who conducted the test.

(4) The name and address of the contracted smoke test facility or vehicle repair facility that conducted the test (if applicable).

(5) The applicable smoke opacity standard for the tested vehicle.

(6) Vehicle identification number, vehicle's engine year, engine make, and engine model, and test date. Fleet designated vehicle identification numbers are also acceptable.

(7) The initial smoke test opacity levels (for three successive test readings).

(8) An indication of whether the vehicle passed or failed the initial smoke test.

(9) The post-repair test date.

(10) The post-repair smoke test opacity levels (for three successive test readings).

(11) An indication of whether the vehicle passed or failed the post-repair smoke test.

(12) For vehicles that have failed the smoke test and have been repaired, the vehicle repair information specified in section 2186(a), Title 13, California Code of Regulations.

Note: Authority cited: Sections 39600, 39601 and 43701, Health and Safety Code. Reference: Sections 39002, 39003, 39033, 43000, 43018, 43701 and 44011.6, Health and Safety Code.

California Environmental Protection Agency
AIR RESOURCES BOARD

Common Causes of High Diesel Smoke Levels

And

Smoke Diagnostic Information

January 2009

COMMON CAUSES OF HIGH DIESEL SMOKE LEVELS:

Maintain your vehicles in accordance with manufacturers recommended maintenance schedules and repair procedures. Don’t tamper with the fuel settings. Use only replacement parts, which meet manufacturer’s specifications. High quality repairs and parts reduce fuel consumption, smoke problems, and downtime.

The following items are some of the more common causes of high levels:

- ✓ Maladjusted no – air pressure (Cummins)
- ✓ Maladjusted AFRC (CAT/Navistar)
- ✓ Maladjusted fuel rack (DDC and others)
- ✓ Defective or maladjusted puff limiter (Mack)
- ✓ Defective AFC plunger bellows (Cummins)
- ✓ Defective or maladjusted throttle delay (DDC)
- ✓ Restricted air filter
- ✓ Maladjusted injection timing
- ✓ Clogged, worn or mismatched injectors or nozzles
- ✓ Maladjusted or defective fuel injection pump
- ✓ Worn or incorrect fuel injector rocker arms and linkage parts
- ✓ Maladjusted valve lash
- ✓ Defective or maladjusted governor
- ✓ Low air box pressure
- ✓ Air manifold leaks
- ✓ Malfunctioning turbos and aftercoolers
- ✓ Poor fuel quality
- ✓ Improper driving gear

DIESEL SMOKE
DIAGNOSTIC INFORMATION

I. White Smoke

White Exhaust Smoke consists of a large number of particles of fuel oil larger than 1.0 microns in diameter. This indicates that the "Fuel is not Burning."

POSSIBLE CAUSE

1) faulty ignition pump
2) too high injectionpressure or faulty injection
3) improper grade/delivery of fuel
4) incorrect engine value timing
5) engine overheating or too cold, coolant entering combustion chamber and/or water in fuel
6) high exhaust back pressure

POSSIBLE REMEDY

1) set injection timing
2) check emission system operation
3) check fuel injection pump calibration
4) check injection nozzles
5) check fuel being used
6) check engine valve timing
7) check cooling system for overheating, head gasket leakage, and/or fuel tank and filters
8) check exhaust back pressure

II. Blue Smoke

Blue smoke consists of a large number of fuel oil particles about 0.5 microns in diameter or less. These particles are recondensed droplets of unburned fuel or incompletely burned fuel. This indicates that the engine burns excessive oil; and/or indication of "Lubricating Oil" being burned.

POSSIBLE CAUSE

1) engine crankcase oil level too high
2) wrong grade/type of fuel
3) oil level in air cleaner too high
4) air cleaner oil too light in viscosity
5) worn piston rings, valve guides or cylinders
6) turbocharger/blower defective

POSSIBLE REMEDY

1) check oil in crankcase and air cleaner
2) try another grade of fuel
3) perform compression test
4) check rings and/or valve seals
5) check turbocharger/blower

III. Black or Gray Smoke

Black or Gray Smoke consists of particles of carbon formed when fuel is heated in oxygen lean regions in the combustion chamber. Part of the fuel in the chamber is not being ignited or burned.

POSSIBLE CAUSE

1) faulty injection pump timing
2) too high injection pressure or faulty injection nozzles
3) clogged or damaged air intake filter
4) improper grade/delivery of fuel
5) incorrect engine valve timing
6) engine overheating
7) high exhaust back pressure
8) poor cylinder compression

POSSIBLE REMEDY

1) set injection pump timing
2) check emission system operation
3) check fuel injection pump
4) check injection nozzles
5) check fuel being used
6) check engine valve timing
7) check cooling system for overheating
8) check air intake filter
9) check exhaust back pressure
10) check compression

Source: DMC Inc., Placentia, California

GASOLINE SMOKE
DIAGNOSTIC INFORMATION

I. Black or Gray Smoke

Black or Gray Smoke consists of a large number of carbon particles that is found when the fuel is heated in oxygen lean regions in the combustion chamber. This is an indication that part of the fuel in the combustion chamber has not been ignited and/or indication of incomplete burning.

POSSIBLE CAUSE

1) clogged or damaged air intake filter
2) choke unloaded or controls malfunction
3) carburetor and/or choke malfunction
4) fuel injection system/electronic control/ECU malfunction
5) faulty injection nozzles
6) faulty ignition timing
7) ignition system malfunction
8) cooling system malfunction, engine too cold
9) intake manifold exhaust passage plugged
10) low cylinder compression
11) turbocharger controls malfunction and/or clogged air filter
12) emission system malfunction
13) high exhaust back pressure

Acceleration, may cause heavy black smoke on turbocharged engines.
Catalytic converters will have a strong sulfur odor.

POSSIBLE REMEDY

1) check air intake filter
2) check choke unloader and controls/intake manifold
3) check and/or repair carburetor
4) check fuel injection system and controls
5) perform tune-up
6) check cooling system
7) check exhaust system back pressure
8) check turbocharger controls and/or filter
9) check emission system
10) perform compression test

II. White Smoke

White Smoke consists of a large number of particles of coolant/water entering the combustion chamber and being vaporized.

POSSIBLE CAUSE

1) head gasket leaking
1) cylinder head or block cracked

POSSIBLE REMEDY

1) check compression
2) pressure test cooling system
3) test for combustion entering cooling system

III. Blue Smoke

Blue Smoke consists of recondensed droplets of unburned/incompletely burned oil which causes blue light to be scattered. This is an indication of excessive lubrication oil being burned.

POSSIBLE CAUSE

1) oil level too high or wrong viscosity
2) worn piston rings, valve guides or cylinder
3) leaking intake manifold gaskets
4) PCV system clogged
5) poor cylinder compression
6) turbocharger seals leaking
7) automatic transmission vacuum modulator defective

IV. External Engine Blue/Gray Smoke

Oil leaking onto the exhaust manifold or exhaust system will produce a light blue/gray smoke and will have an ordor of burning oil.

POSSIBLE CAUSE

1) engine seals or gaskets leaking
2) power steering seals or hoses leaking
3) transmission seals, gaskets or cooler lines leaking
4) PCV system clogged

POSSIBLE REMEDY

1) check all hydraulic systems
2) check/clean PCV system

V. External Engine White Smoke

POSSIBLE CAUSE

1) engine overheating (boiling)
2) coolant leaking onto hot engine or onto exhaust system

POSSIBLE REMEDY

1) check cooling system

California Environmental Protection Agency
AIR RESOURCES BOARD

Appendix A

Society of Automotive Engineers, Inc.

Snap-Acceleration Smoke Test Procedures for Heavy-Duty Diesel Powered Vehicles

January 2009

Society of Automotive Engineers (SAE)
J1667 Recommended Practice

Snap Acceleration Smoke Test Procedure for Heavy-Duty Powered Vehicles

The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J1667

ISSUED FEB96

Issued 1996-02

Submitted for recognition as an American National Standard

SNAP-ACCELERATION SMOKE TEST PROCEDURE FOR HEAVY-DUTY DIESEL POWERED VEHICLES

Foreword**—**This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

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1. Scope—This SAE Recommended Practice applies to vehicle exhaust smoke measurements made using the Snap-Acceleration test procedure. Because this is a non-moving vehicle test, this test can be conducted along the roadside, in a truck depot, a vehicle repair facility, or other test facilities. The test is intended to be used on heavy-duty trucks and buses powered by diesel engines. It is designed to be used in conjunction with smokemeters using the light extinction principle of smoke measurement.

This procedure describes how the snap-acceleration test is to be performed. It also gives specifications for the smokemeter and other test instrumentation and describes the algorithm for the measurement and quantification of the exhaust smoke produced during the test. Included are discussions of factors which influence snap-acceleration test results and methods to correct for these conditions. Unless otherwise noted, these correction methodologies are to be considered an integral part of the snap-acceleration test procedure.

1.1 Purpose—This document provides a procedure for assessing smoke emissions from in-use vehicles powered by heavy-duty diesel engines. Testing conducted in accordance with this procedure, in combination with reference smoke values, is intended to provide an indication of the state of maintenance and/or tampering of the engine and fuel system relative to the parameters which affect exhaust smoke. The procedure is expected to be of use to regulatory and enforcement authorities responsible for controlling smoke emissions from heavy-duty diesel-powered vehicles, and to heavy-duty vehicle maintenance and repair facilities. However, the procedure as written does not replicate the federal engine certification smoke cycle, and is intended to identify gross emitters. Regulatory agencies using this procedure must establish pass/fail criteria since SAE by-laws prohibit assignment of such criteria.

2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1349—Engine Power Test Code—Spark Ignition and Compression Ignition—Net Power Rating
SAE J1995—Engine Power Test Code—Spark Ignition and Compression Ignition—Gross Power Rating

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J255a—Diesel Engine Smoke Measurement
SAE J1243—Diesel Emission Production Audit Test Procedure

2.2.2 ISO PUBLICATION—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO CD 11614—Apparatus for the Measurement of the Opacity of the Light Absorption Coefficient of Exhaust Gas from Internal Combustion Engines

2.2.3 FEDERAL PUBLICATION—U. S. Government, DOD SSP, Subscription Service Division, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094

Code of Federal Regulations (CFR), Title 40, Part 86, Subpart I—Emission Regulation for New Diesel Heavy-Duty Engines: Smoke Exhaust Test Procedure

2.3 Other Publications

Procedures for Demonstrating Correlation Among Smokemeters

3. Definitions

3.1 Diesel Smoke—Particles, including aerosols, suspended in the exhaust stream of a diesel engine which absorb, reflect, or refract light.

3.2 Transmittance (T)—The fraction of light transmitted from a source which reaches a light detector.

3.3 Opacity (N)—The percentage of light transmitted from a source which is prevented from reaching a light detector. See Equation 1.

$$\text{Opacity \%} = 100*(1 - \text{Transmittance}) \quad \text{(Eq. 1)}$$

3.4 Effective Optical Path Length (L) or (EOPL)—The length of the smoke obscured optical path between the smokemeter light source and detector. Note that portions of the total light source to detector path length which are not smoke obscured do not contribute to the effective optical path length.

3.5 Smoke Density (K)—(also known as “Light Extinction Coefficient” and “Light Absorption Coefficient”) A fundamental means of quantifying the ability of a smoke plume or smoke containing gas sample to obscure light. By convention, smoke density is expressed on a per meter basis (m-1). The smoke density is a function of the number of smoke particles per unit gas volume, the size distribution of the smoke particles, and the light absorption and scattering properties of the particles. In the absence of blue or white smoke, the size distribution and the light absorption/scattering properties are similar for all diesel exhaust gas samples and the smoke density is primarily a function of the smoke particle density.

3.6 Beer-Lambert Law—A mathematical equation describing the physical relationships between the smoke density (K) and the smoke parameters of transmittance (T), and effective optical path length (L). Because smoke density (K) cannot be measured directly, the Beer-Lambert equation is used to calculate (K), when opacity (N) and EOPL (L) are known.

3.7 Smoke Opacimeter—A type of smokemeter designed to measure the opacity of a plume or sample of smoke by means of a light extinction principle.

3.8 Full-Flow End-of-Line Smokemeter—A smokemeter which measures the opacity of the full exhaust plume as it exits the tailpipe. The light source and detector for this type of smokemeter are located on opposite sides of the smoke plume and in close proximity to the open end of the tailpipe. When applying this type of smokemeter, the effective optical path length is a function of the tailpipe design.

3.9 Sampling Type Smokemeter (Also called Partial Flow Smokemeter)—A smokemeter which continually samples a representative portion of the total exhaust flow and directs it to a measurement cell. With this type of smokemeter, the effective optical path length is a function of the smokemeter design.

3.10 Smokemeter Measurement Zone—The effective length between the smokemeter light source and light detector through which exhaust gases pass and interact with the smokemeter light beam.

3.11 Smokemeter Response Time—See 6.3 and Appendix A.

3.12 Smokemeter Linearity—A measure of the maximum absolute deviation of values measured by the smokemeter from the reference values.

4. Special Notes and Conventions

4.1 The term smokemeter is a broad term which applies to all smoke-measuring devices regardless of the smoke-sensing technique employed. Throughout this document, the term smokemeter will refer only to opacimeter type smokemeters.

4.2 To fully describe the light obscuration properties of a smoke sample (i.e., smoke density), opacity (N) must always be associated with an EOPL. Whenever specific smoke opacity values are referenced in this document, the associated effective optical path length is understood to be 0.127 m (5 in).

5. Snap-Acceleration Test—The complete Snap-Acceleration process consists of five phases. These phases are:

a. Vehicle Preparation and Safety Check
b. Test Preparation and Equipment Set-up
c. Driver Familiarization and Vehicle Preconditioning
d. Execution of the Snap-Acceleration Test
e. Calculation and Reporting of Final Results

5.1 Vehicle Preparation and Safety Check—Prior to conducting the snap-acceleration test, the following items must be completed:

a. If the vehicle is equipped with a manual transmission, the transmission must be placed in neutral and the clutch must be released.
   If the vehicle is equipped with an automatic transmission, the transmission must be placed in the park position, if available, or otherwise in the neutral position.
b. The vehicle wheels must be chocked or the vehicle must be otherwise restrained to prevent the vehicle from moving during the testing.
c. Vehicle air conditioning should be turned off.
d. If the engine is equipped with an engine brake, it must be deactivated during the snap-acceleration testing.
e. All devices installed on the engine or vehicle which alter the normal acceleration characteristics of the engine and have the effect of temporarily lowering snap-acceleration test results, or preventing the test from being successfully completed, shall be deactivated prior to testing.
f. Verify the speed-limiting capability of the engine governor using the following procedure:
   With the engine at low idle, slowly depress the engine throttle and allow the engine speed to gradually increase toward its maximum governed high idle speed. As the engine speed increases, carefully note any visual or audible indications that the engine or vehicle may be of questionable soundness. If there are no indications of problems, allow the engine speed to increase to the point that it is possible to verify that the speed-limiting capability of the governor is functioning. Should there be any indication that the speed-limiting capability of the governor is not functioning, or that potential engine damage, or unsafe conditions for personnel or equipment may occur, the throttle should immediately be released and the snap-acceleration testing of the vehicle shall be aborted.
g. The vehicle should be inspected for exhaust leaks. Severe leaks in the system may cause the introduction of air into the exhaust stream which may cause erroneously low test results.
h. Users must be cautioned regarding the observance of blue or white smoke in the exhaust. Blue smoke can be an indicator of unburned hydrocarbons (possible oil burning or malfunctioning nozzle), and white smoke can be an indicator of water vapor (possible internal coolant leaking conditions).

5.2 Test Preparation and Equipment Set-up

5.2.1 AMBIENT AIR TEST CONDITIONS—Ambient air conditions can affect snap-acceleration smoke test results. To ensure reliable results, the correction factors in Appendix B should be applied to snap-acceleration testing results to account for normal changes in ambient conditions. However, these correction factors must be applied under the following conditions.

a. Altitude—Greater than 457 m (1500 ft) above sea level.
b. Air Temperature—Above or below the range of 2 to 30 x °C (36 to 86 x °F).
c. Wind—Excessively windy conditions should be avoided. Winds are excessive if they disturb the size, shape, or location of the vehicle exhaust plume in the region where exhaust samples are drawn or where the smoke plume is measured. The effect of wind may be eliminated or reduced by locating the vehicle in a wind-sheltered area or by using measuring equipment designs which preclude wind effects on the smoke in the measuring or sampling zones.
d. Dry Air Density—If the correction factors referenced in Appendix B are used, the useful range of dry air densities are: 0.908 to 1.235 kg/m^3 (0.0567 to 0.0771 lbm/ft^3). This range of dry air densities is based on air densities experienced during ambient conditions testing.
e. Humidity—No visible humidity (including fog, rain, and snow) in the region where exhaust samples are drawn or the smoke plume is measured. Some equipment designs preclude the effects of these conditions.

5.2.2 SMOKEMETER INSTALLATION—The smokemeter and other test equipment used for snap-acceleration tests shall meet the specifications of 6.1 through 6.5. The general installation procedures specified by the smokemeter manufacturer shall be followed when preparing to test a vehicle.

In addition, these special installation procedures shall be followed:

a. If the test results are to be reported in units of smoke opacity, the rated power of the engine should be determined. The rated power is needed to define the standard effective optical path length used to correct the as-measured smoke opacity to standard conditions as described in Appendix C. The rated power should be available from the tune-up label fixed to the engine or from literature supplied to the owner by the engine manufacturer. In some cases, particularly under roadside test conditions, it may not be possible to readily determine the rated engine power. In these cases, it is recommended that the OD of the vehicle tailpipe section be determined and used as the standard effective optical path length for the purposes of the Beer-Lambert corrections described in Appendix C. If the rated engine power becomes available after the test is run, the test result should be recorrected as necessary using Equation C3 and the appropriate standard effective optical path length from Table C1.
Sampling in or immediately downstream of bends such as curved stack outlets in the exhaust pipe may cause some variability between individual Snap-Acceleration cycle readings.
b. For Full Flow End-of-Line Type Smokemeters—The axis of the smokemeter light beam shall be perpendicular to the axis of the exhaust flow. The centerline of the light beam axis should be located as close as possible, but in no case further than 7 cm (2.76 in) from the exhaust outlet. Appendix D provides additional guidance for smokemeter replacement.
Determine the effective optical path length used to make the smoke measurements. For straight tailpipes of circular cross section, the effective optical path length is equal to the tailpipe ID, and for tubing construction can be reasonably approximated by the tailpipe OD. Appendix D provides guidance for determining the as-measured effective optical path length when irregular tailpipe configurations are encountered. The as-measured effective optical path length is required to convert measured smoke values to standard corrected smoke values using the procedures described in Appendix C.

c. For Sampling Type Smokemeters—The probe of the sampling type smokemeter shall be inserted into the exhaust tailpipe with the open end facing upstream and into the exhaust flow.
   The clearance between the inside edge of the open end of the sample probe and the tailpipe wall must be at least 5 mm (0.197 in).
   Only the probe and sampling pipe, or tubing, specified by the manufacturer of the smokemeter shall be used for the smoke sampling. Manufacturer's recommendations regarding the length of the sample line shall be adhered to.
d. Multiple Exhaust Outlets—When testing vehicles equipped with multiple exhaust outlets, such as dual exhaust systems originating from a single manifold or single pipe, it is normally not necessary to measure the smoke from each exhaust outlet. The following approach is suggested.
   If there is no discernible difference in the exhaust smoke exiting from each multiple exhaust outlet, the smoke should be measured from the exhaust outlet that provides the most convenient meter installation. A visual observation of one or more preliminary snap-acceleration test cycles should be sufficient to make this determination.
   Should there be a discernible difference in the smoke exiting from the multiple exhaust outlets, install the smokemeter and conduct the snap-acceleration test on the exhaust outlet that visually appears to have the highest smoke level.

5.2.3 A tachometer to measure the engine speed may be installed and calibrated per the manufacturer's recommendations. A tachometer provides useful data regarding idle RPM, maximum engine RPM, the time necessary for the operator to accelerate the engine from idle to maximum RPM, and the time the engine speed was held at maximum RPM. This information helps to ensure repeatability between test cycles.

5.3 Driver Familiarization and Vehicle Preconditioning

5.3.1 Prior to the preconditioning test, the vehicle should be operated under load for at least 15 min to ensure that the engine is warmed-up. Alternatively, vehicle water and oil temperature gages may be checked to verify that the engine is within its normal operating temperature range.

5.3.2 SNAP-ACCELERATION CYCLE—The vehicle operator shall be instructed on the proper execution of the snap-acceleration test sequence. It is of critical importance that the vehicle operator fully understand the proper movement of the vehicle throttle during the testing.

With the vehicle conditioned as in 5.1 and with the engine warmed-up and at low idle speed:

a. The operator shall move the throttle to the fully open position as rapidly as possible.
b. The operator shall hold the throttle in the fully open position until the time the engine reaches its maximum governed speed, plus an additional 1 to 4 s.
c. Upon completion of the 1 to 4 s with the engine at its maximum governed speed, the operator shall release the throttle and allow the engine to return to the low idle speed.
d. Once the engine reaches its low idle speed, the operator shall allow the engine to remain at idle for a minimum of 5 s, but no longer than 45 s, before initiating the next snap-acceleration test cycle.
   The time period at low idle allows the engine's turbocharger (if so equipped) to decelerate to its normal speed at engine idle. This helps to reduce the smoke variability between snap-acceleration cycles.
e. Steps (a) through (d) shall be repeated as necessary to complete the preliminary snap-acceleration cycles and the snap-acceleration test cycles described in 5.3.3 and 5.4.2.

5.3.3 PRELIMINARY SNAP-ACCELERATION TEST CYCLES—The vehicle shall receive at least three preliminary snap-acceleration test cycles using the sequence described in 5.3.2. The preliminary cycles allow the vehicle operator to become familiar with the proper throttle movement, and also remove any loose soot which may have accumulated in the vehicle exhaust system during prior operation.

If smoke measurements are made during the preliminary cycles, the preliminary cycles can also provide the opportunity to check for proper operation of the smoke measurement system, and to check if the test validation criteria of 5.4.4 can be met. In this case, the data-processing unit and the smokemeter zero and full scale should first be set according to 5.4.1 and 5.4.2.

5.4 Execution of the Snap-Acceleration Test

5.4.1 DATA PROCESSING UNIT SET-UP—Before snap-acceleration testing can proceed, the smokemeter data processing unit must be properly set up. The operating instructions supplied by the processing unit manufacturer should be consulted for specific set-up procedures; however, the following functional steps must be accomplished.

a. If a multi-mode test system is used, the appropriate mode for snap-acceleration testing must be selected.
b. The desired smoke output units (opacity or smoke density) must be selected.
c. If the Beer-Lambert corrections as described in Appendix C are to be performed within the data-processing unit, values must be supplied for the standard and as-measured effective optical path lengths if opacity output is desired and for the as-measured effective optical path lengths if smoke density output is desired. Appendices C and D provide guidance in determining these input values.
d. If a red LED smokemeter light source is used and light source wavelength corrections are to be performed within the data-processing unit, the appropriate selections must be made to trigger these calculations (see Appendix C).
e. If the ambient condition corrections described in Appendix B are to be performed automatically by the data-processing unit, the appropriate ambient parameters must be input.
f. Any additional test identification information consistent with the needs of the test program and capabilities of the data-processing unit should be supplied at this time. Normally this would include the test date, test operator, vehicle identification, and other such information.

5.4.2 SMOKEMETER ZERO AND FULL SCALE—Prior to conducting smoke measurements, the zero and full scale readings of the smokemeter shall be verified. (Some meter systems may automatically perform the zero and full scale checks. For other meters, this sequence will need to be done manually.) Should optional recording devices be part of the test set-up, this equipment should also be checked for proper operation and calibration.

a. Smokemeter Warm-up—Prior to any zero and/or full-scale checks or adjustments, the smokemeter shall be warmed up and stabilized according to the manufacturer's recommendations. If the smokemeter is equipped with a purge air system to prevent sooting of the meter optics, this system should also be activated and adjusted according to the manufacturer's recommendations.
b. Smokemeter Zero—With the smokemeter in the Opacity readout mode, and with no blockage of the smokemeter light beam, adjust the readout to display 0.0% ± 1.0% opacity.
c. Smokemeter Full Scale—With the smokemeter in the Opacity readout mode, and all light prevented from reaching the detector, adjust the readout of the smokemeter to display 100.0% ± 1.0% opacity.
   NOTE—For Smokemeter readouts in units of Smoke Density (K).
   Smoke density (K) is a calculation based upon opacity and EOPL. The opacity scale offers two truly definable calibration points, namely 0% opacity and 100% opacity. The upper end of the smoke density scale is infinite, which makes this point on the K scale undefined. Because of this, the preferred method to set the zero and full scale of the meter when measuring in either smoke density (K) or opacity (N) units is to set the meter to the opacity readout mode and make the zero and full-scale adjustments as described in 5.4.2 (a) to (c). The smoke density would then be correctly calculated based upon the measured opacity and, of course, the EOPL, when the meter is returned to the smoke density readout mode for testing.
   However, if this technique is not possible, it is acceptable to set the zero and span of the smokemeter in units of smoke density (K) with the use of a neutral density filter of known value. Should this be the case, the smokemeter zero and span shall be set as follows:

d. Smokemeter Zero—With the smokemeter in the Smoke Density (K) readout mode, and with no blockage of the smokemeter light beam, adjust the readout to display 0.00 m^{-1} ± 0.10 m^{-1}.
e. Smokemeter Span (If required by the smokemeter manufacturer)—With the smokemeter in the Smoke Density (K) readout mode, place a neutral density filter of known value between the light emitter and detector. The neutral density filter shall meet the accuracy requirements of 6.2.10 and have a known nominal value in the range of 1.5 to 5.5 m^{-1}. Adjust the smokemeter readout to display the filter nominal value, ±0.10 m^{-1}.

NOTE—Neutral density calibration filters are precision devices and can easily be damaged during use. Handling should be minimized and, when required, should be done with care to avoid scratching or dirtying of the filter.

5.4.3 SNAP-ACCELERATION TEST CYCLES—Within 2 min of the execution of the preliminary snap-acceleration cycles, conduct three snap-acceleration test cycles, actuating the vehicle throttle in the manner and sequence described in 5.3.2 (a to e).

Determine the corrected maximum 0.5 s average smoke values for each of the three snap-acceleration cycles using the smoke data processing algorithms described in Appendices A and C.

At the conclusion of the test sequence, and where needed as per manufacturer's recommendation, determine the degree of smokemeter zero shift by eliminating all exhaust from between the smokemeter light source and detector and noting the smokemeter display.

5.4.4 TEST VALIDATION CRITERIA—The test results from 5.4.3 shall be considered valid only after the following criteria have been met.

a. The post-test smokemeter zero shift values shall not exceed:

   1. ±2.0% opacity—For smoke measurements made in opacity.
   2. ±0.15 m^{-1}—For smoke measurements made in smoke density (K).

b. The arithmetical difference between the highest and lowest corrected maximum 0.5 s average smoke values from the three test cycles shall not exceed:

   1. 5.0% opacity—For smoke measurements made in opacity.
   2. 0.50 m^{-1}—For smoke measurements made in smoke density (K).

5.4.5 INVALID TESTS—Should the smoke test data from 5.4.3 not meet the test validation criteria of 5.4.4, the following items should be checked as possible causes for the invalid test results:

a. If the engine did not meet the operating temperature requirements, run the engine/vehicle under load for at least 15 min or until the vehicle oil and water temperature gages indicate that normal engine operating temperatures have been achieved. Return to 5.2.2 (Smokemeter Installation) and repeat the test sequence.
b. If improper or inconsistent application of the vehicle throttle is suspected, re-instruct the vehicle operator as to the proper execution of the snap-acceleration test, especially the movement of the vehicle throttle, as detailed in 5.3.2. Continue on with the procedure at this point and repeat the preliminary test cycles and the snap-acceleration test sequence while observing the vehicle operator.
c. Check the smokemeter, its installation on the tailpipe, and any support instrumentation for possible malfunctions. Correct as necessary and then return to 5.3.3 (Preliminary Snap-Acceleration Test Cycles), and repeat the test sequence.

d. If the post-test smokemeter zero check was exceeded due to positive zero drift, the probable cause is soot accumulation on the smokemeter optics. It is recommended that the snap-acceleration test sequence be repeated and while doing so, the smokemeter zero may be readjusted during the low idle period between each of the snap-acceleration test cycles. If the measured low idle smoke level of the vehicle is less than 2.0% opacity or 0.20 m^{-1} smoke density, it is permissible to re-zero the meter while it remains exposed to the vehicle exhaust. If the idle smoke level exceeds these limits, it is necessary to discontinue exposure to exhaust before rezeroing the meter.
   It is not necessary to complete an invalid test before employing the rezeroing technique discussed previously. If comparison of the low idle smoke readings shows an increasing trend from one test cycle to the next, sooting of meter optics can be suspected and the rezeroing technique can immediately be used.
   If it is not possible to rezero the meter, the meter optics should be cleaned per the smokemeter manufacturer's recommended procedures and the test sequence should be repeated beginning at 5.3.3 (preliminary snap-acceleration test cycles). If zero drift and rezeroing difficulties persist, it is recommended that the meter purge air system (if so equipped) be checked for proper operation.
e. If the procedure has been repeated in accordance with the requirements stated in 5.4.5 (a to d), and the test results still cannot be obtained that conform with the test validation criteria, then it is likely that the engine is in need of service.

5.5 Calculation and Reporting of Final Test Result—If the validation criteria of 5.4.4 are met, the data shall be deemed valid and the test complete. The average of the corrected maximum 0.5 s average smoke values from the three snap-acceleration test cycles shall be computed and reported as the final test result. (See Appendix A.)

6. Test Instrumentation Specifications—This section provides specifications for the required and optional test equipment used in the snap-acceleration test.

6.1 General Requirements for the Smoke Measurement Equipment—The snap-acceleration smoke test requires the use of a smoke measurement and data-processing system which includes three functional units. These units may be integrated into a single component or provided as a system of interconnected components. The three functional units are:

a. A full-flow end-of-line or a sampling type smokemeter meeting the specifications of 6.2 through 6.4.
b. A data-processing unit capable of performing the functions described in Appendices A and C.
c. A printer and/or electronic storage medium to record and output the individual corrected maximum 0.5 s average smoke values from each snap-acceleration test cycle, and the final average snap-acceleration test result.

6.2 Specific Requirements for the Smoke Measurement Equipment

6.2.1 LINEARITY—±2% opacity or ±0.30 m^{-1} density.

6.2.2 ZERO DRIFT RATE—Not to exceed ±1% opacity/hour.

6.3 Instrument Response Time Requirements

6.3.1 OVERALL INSTRUMENT RESPONSE TIME REQUIREMENT—The overall instrument response time (t) shall be: 0.500 s ± 0.015 s. It is defined as the difference between the times when the output of the smokemeter reaches 10% and 90% of full scale when the opacity of the gas being measured is changed in less than 0.01 s.
It shall include all the physical, electrical, and filter response times. Mathematically, it is represented by Equation 2. (See Appendix A for a more detailed methodology and an example calculation.)

$$t = SQRT(t_p^2 + t_e^2 + t_F^2) \quad \text{(Eq. 2)}$$

where:

t_p = The physical response time
t_e = The electrical response time
t_F = The filter response time

6.3.2 PHYSICAL RESPONSE TIME (t_P)—This is the difference between the times when the output of a rapid response receiver (with a response time of not more than 0.01 s) reaches 10% and 90% of the full deviation when the opacity of the gas being measured is changed in less than 0.1 s.

The physical response time is defined for the smokemeter only and excludes the probe and sample line. However, on some in-use smokemeter systems, the probe and sample line may significantly affect the overall response time of the system. If necessary, this shall be taken into account for any particular smokemeter system.

For full-flow type smokemeters, the response time is a function of the velocity of flow in the vehicle exhaust pipe and the path length across the detector (detector diameter). It can be assumed equal to a negligible 0.01 s. For sampling type smokemeters where the measuring zone is a straight section of pipe of uniform diameter, the physical response can be estimated by Equation 3:

$$t = 0.8 * V / Q \quad \text{(Eq. 3)}$$

where:

Q = The rate of flow of gas through the measuring zone
V = The volume of the measuring zone

For such instruments, the speed of the gas through the measuring zone shall not differ by more than 50% from the average speed over 90% of the length of the measuring zone.

For all smokemeters, if the physical response calculates greater than 0.2 s, then the response time shall be measured.

6.3.3 ELECTRICAL RESPONSE TIME (t_e)—It is defined as the time needed for the recorder output to go from 10% of the maximum scale to 90% of the maximum scale value when a fully opaque screen is placed in front of the photo cell in less than 0.01 s, or the LED is turned off. This is to include all of the effects of recorder output response time.

6.3.4 FILTER RESPONSE TIME (t_f)—Filtering of the smoke signal will be necessary on most smokemeters to achieve an overall response time of 0.500 s ± 0.015 s. Most smokemeters have a very fast electrical response time, but physical response times will vary from one device to the next depending on design and gas flow.

Appendix A specifies the recommended second-order digital filtering algorithm to be used.

6.3.5 DETERMINATION OF THE PEAK SMOKE VALUE—An algorithm in Appendix A shall be used to determine the reported peak exhaust smoke levels.

6.4 Smokemeter Light Source and Detector

6.4.1 LIGHT SOURCE—The light source shall be an incandescent lamp with a color temperature in the range of 2800 to 3250 °K, or a green light emitting diode (LED) with a spectral peak between 550 and 570 nm.

Alternatively, a red LED may be used provided that the appropriate light wavelength correction is made as described in Appendix C.

6.4.2 LIGHT DETECTOR—The light detector shall be a photocell or a photodiode (with a filter, if necessary). In the case of an incandescent light source, the detector shall have a peak spectral response in the range of 550 to 570 nm, and shall have a gradual reduction in response to values of less than 4% of the peak response value below 430 nm and above 680 nm.

6.4.3 The rays of the light beam shall be parallel within a tolerance of 3 degrees of the optical axis. The detector shall be designed such that it is not affected by direct or indirect light rays with an angle of incidence greater than 3 degrees to the optical axis.

6.4.4 Any method such as purge air which is used to protect the light source and detector from direct contact with exhaust soot shall be designed to minimize any unknown effect on the effective optical path length of the measured smoke (see C.5.1). For full-flow end-of-line smokemeters, the protection feature must not cause the smoke plume to be distorted by more than 0.5 cm. For sampling type smokemeters, the meter manufacturer must account for any effect of the protection feature in specifying the effective optical path length of the meter.

6.4.5 The sampling and digitization rate of the data processing units shall be at least 20 Hz (i.e., at least 10 data samples per 0.5 s interval). Additionally, the product of the data sampling time increment (seconds) and one half the data sample rate (Hz) rounded to the next higher integer value must be within the range of 0.500 to 0.510 s.

6.5 Specifications for Auxiliary Test Equipment

6.5.1 NEUTRAL DENSITY FILTERS—Any neutral density filter used in conjunction with smokemeter calibration, linearity measurements, or setting span shall have its value known to within 0.5% opacity or 0.04 m^{-1}. The filter's named value must be checked for accuracy at least yearly using a reference traceable to a national standard.

6.5.2 If altitude correction (i.e., the altitude is greater than 457 m (1500 ft)) then:

a. Equipment used to measure barometric pressure must be accurate within ±0.30 kPa (±0.089 in-Hg)
b. Ambient dry bulb temperature must be accurate within ±2 °C (±3.6 °F)

6.5.3 Measurement of the following parameters is optional; however, if measured, the specified accuracy requirements should be met:

a. Ambient Dry Bulb Temperature—±2 °C (±3.6 °F)
b. Dew Point Temperature—±2 °C (±3.6 °F)
c. Engine Speed—±100 rpm

6.5.4 OPTIONAL RECORDING DEVICES—A supplemental chart recorder or other collection media may be used provided that the device(s) does not affect the smoke measurement.

7. Smokemeter Maintenance and Calibration—The smokemeter should be maintained and serviced per the manufacturer's recommendations. In addition to the zero and span adjustments to be made prior to each snap-acceleration test (5.4.2), the linearity of the meter response should be periodically checked as per manufacturer's recommendations in the range of measurement interest using neutral density filters meeting the requirements of 6.5.1. Non-linearities in excess of 2% opacity or 0.30 m^{-1} smoke density should be corrected prior to resuming testing with the meter.

PREPARED BY THE SAE HEAVY-DUTY IN-USE EMISSION STANDARDS COMMITTEE

APPENDIX A

SECOND-ORDER FILTER ALGORITHM USED TO CALCULATE A MAXIMUM 0.500 S AVERAGE SMOKE VALUE

A.1 Introduction—This appendix explains how to create and use the recommended Bessel low-pass digital filter algorithm in a smokemeter to filter out the high-frequency smoke readings which are produced during a snap-acceleration test. This appendix in particular describes the methodology used to design a low-pass second-order Bessel filter with a response time as needed for a particular smokemeter application. This appendix also describes the procedure for determining the final snap-acceleration test. Two example calculations detailing the selection of Bessel filter coefficients and their use are also provided in this appendix to illustrate the concepts more clearly.

The digital Bessel filter described in this appendix is a second-order (2-pole) low-pass digital filter algorithm. It is the recommended filter to be used for designing smokemeters with 0.500 s overall response times as required in 6.3. The Bessel filter type was chosen because it allows passage of all signals which do not change very much with time, but effectively blocks all signals with higher-frequency components. Its linear-phase characteristics also enable it to approximate a constant time delay over a limited frequency range. Transient waveforms can also be passed with minimal distortion when it is used as a running average type filter. A digital approach was chosen due to the relative ease of implementing a software algorithm in most smokemeters. However, analog Bessel filters using the appropriate electronic circuits may also be used.

A.2 Definitions

- B = Bessel parameter constant. It equals [Sqrt(5)-1]/2
- f_c = Bessel cutoff frequency used to control the filtered response
- t_e = Electrical response time of the smokemeter (seconds)
- t_F = Filter response time (seconds)
- t_{Fd} = Desired filter response time (seconds)
- t_p = Physical response time of the smokemeter (seconds)
- t_{10} = The test time when the output response to an input step response is equal to 10% of the step input
- t_{90} = The test time when the output response to an input step response is equal to 90% of the step input
- Δ_t = Time between two stored opacity values (i.e., sampling period (seconds))
- X_i = Bessel filter input at sample number (i)
- X_{i-1} = Bessel filter input at sample number (i-1)
- X_{1-2}= Bessel filter input at sample number (i-2)
- Y_i = Bessel filter output at sample number (i)
- Y_{i-1} = Bessel filter output at sample number (i-1)
- Y_{i-2}= Bessel filter output at sample number (i-2)

A.3 Designing a Bessel Low-Pass Filter—Designing the 0.500 s Bessel low-pass digital filter is a multistep process which may involve several iterative calculations to determine coefficients. This section provides a method for determining the desired amount of filtering for smokemeters with different electrical and physical response times, or different sample rates. Bessel filters can be designed to accommodate filter designs having response times ranging from 0.010 to 0.500 s, and digitization rates of 50 Hz and higher.

It is recommended that all Bessel filter calculations be performed in opacity units for the sake of consistency between smokemeters. If smokemeter output in units of density need to be reported, the Beer-Lambert law may be used to convert the final opacity results to density results, and perform any necessary stack size correction. This conversion should be done only after all Bessel filter equations have been performed due to the non-linearity of the Beer-Lambert law.

A.3.1 Calculating the Desired Filter Response Time (t_{Fd})—Prior to designing a digital Bessel filter, it is necessary to determine the physical response time (t_p) and the electrical response time (t_e) for the relevant smokemeter. These parameters are necessary in order to determine how much electronic filtering is necessary to achieve an overall 0.500 s response time. For some partial flow smokemeters this may require experimental data. For other smokemeters the procedures and equations in 6.3 may be used.

Once the values of t_p and t_e are known, the desired filter response time (t_{Fd}) can be determined by using Equation A1.

$$t_{Fd} = SQRT[0.500^2 - (t_p^2 + t_e^2)] \quad \text{(Eq. A1)}$$

A.3.2 Estimating Bessel Filter Cutoff Frequency (f_c)—The Bessel filter response time (t_F) is defined as the time in which the output signal (Y_i) reaches 10% (Y_{10}) and 90% (Y_{90}) of a full-scale input step (X_i) which occurs in less than 0.01 s. The difference in time between the 90% response (t_{90}) and the 10% response time (t_{10}) defines the response time (t_F). Thus,

$$(t_F) = (t_{90}) - (t_{10}) \quad \text{(Eq. A2)}$$

For the filter to operate properly, the filter response time (t_F) should be within 1% of the desired response time (t_{Fd}), that is, $[(t_F) - (t_{Fd})] < [0.01 * (t_{Fd})]$.

To create a filter where t_F approximates t_{Fd}, the appropriate cutoff frequency (f_c) must be determined. This is an iterative process of choosing successively better values of (f_c) until $[(t_F) - (t_{Fd})] < [0.01 * (t_{Fd})]$.

The first step in the process is to calculate a first guess value for f_c using Equation A3.

$$f_c = \pi/(10 * t_{Fd}) \quad \text{(Eq. A3)}$$

The values of B, Ω, C, and K are then calculated using Equation A4 through A7.

$$B = 0.618034 \quad \text{(Eq. A4)}$$

$$\Omega = 1/[\tan(\pi * \Delta t * f_c)] \quad \text{(Eq. A5)}$$

$$C = 1/[1 + \Omega * sqrt(3 * B) + B * \Omega^2] \quad \text{(Eq. A6)}$$

$$K = 2 * C * [B * \Omega^2 - 1] - 1 \quad \text{(Eq. A7)}$$

Δt = Time between two stored opacity values (i.e., sampling period (seconds)).

The values of K and C are then used in Equation A8 to calculate the Bessel filter response to the given step input. Because of the recursive nature of Equation A8, the values of X and Y listed as follows are used to begin the process.

$$Y_i = Y_{i-1} + C * [X_i + 2 * X_{i-1} + X_{i-2} - 4 * Y_{i-2}] + K * (Y_{i-1} - Y_{i-2}) \quad \text{(Eq. A8)}$$

where:

X_i = 100
X_{i-1} = 0
X_{i-2} = 0
Y_{i-1} = 0
Y_{i-2} = 0

As shown in the example (A.7.1), calculate Y_i for successive values of X_i = 100 until the value of Y_i has exceeded 90% of the step input (X_i). The difference in time between the 90% response (t_{90}) and the 10% response (t_{10}) defines the response time (t_F) for that value of (f_c). Since the data are digital, linear interpolation may be needed to precisely calculate t_{10} and t_{90}.

If the response time is not close enough to the desired response time {that is, if [(t_F)-(t_{Fd})] > [0.01*(t_{Fd})]}, then the iterative process must be repeated with a new value of (f_c). The variables (t_F) and (f_c) are approximately proportional to each other, so the new (f_c) should be selected based on the difference between (t_F) and (t_{Fd}) as shown in the example calculations (A.5.1).

A.4 Using the Bessel Filter Algorithm**—**The proper cutoff frequency (f_c) is the one that produces the desired filter response time (t_{Fd}). Once this frequency has been determined through the iterative process, the proper Bessel filter algorithm coefficients for Equation A4 through A7 are specified. Equation A8 and the coefficients can then be programmed into the smokemeter to produce the desired filter.

The Bessel filter equation (Equation A8) is recursive in nature. Thus, it needs some initial input values of X_{i-1} and X_{i-2} and initial output values Y_{i-1} and Y_{i-2} to get the algorithm started. These may be assumed to be 0% opacity. A detailed example calculation is shown in A.7.3.

A.5 Determining the Maximum 0.500 s Averaged Smoke Value**—**The maximum smoke value for a snap-acceleration test cycle (Y_{max}) is then selected from among the individual Y_i values computed using Equation A8 (after suitable Beer-Lambert and light source wavelength corrections are applied). This is the final test result for the test cycle and is used in combination with the results from the other snap-acceleration cycles in the test to determine a final snap-acceleration test result.

In equation form:

$$Y_{max} = \text{Maximum}(Y_i) \quad \text{(Eq. A9)}$$

A.6 Determination of the Final Test Result**—**If the test validation criteria of 5.4.4 have been met, the final snap-acceleration test result shall be computed by taking the simple average of the three corrected maximum 0.500 s averaged smoke values obtained from the three snap-acceleration test cycles.

$$A = (Y_{max,1} + Y_{max,2} + Y_{max,3})/3 \quad \text{(Eq. A10)}$$

A.7 A.7 Example of Incorporating a Bessel Filter Into a Smokemeter Design**—**This example illustrates how a full flow meter with a fast physical and electrical response time can implement the Bessel filter algorithm. The sample smokemeter has the following characteristics:

a. Physical Response Time = 0.020 s
b. Electrical Response Time = 0.010 s
c. Sampling Rate = 100 Hz
d. Sampling Period = 0.01 s

A.7.1 First Iteration to Estimate Bessel Function Cutoff Frequency (f_c)—This section displays the initial calculations which are performed to estimate the correct value of the cutoff frequency (f_c).

The results from Equation A1 indicate that the desired filter response (t_{Fd}) is 0.4995 (for simplicity, a value of 0.50 will be used in the sample calculations). This may be typical of a full flow meter with a very fast electrical and physical response time. It suggests that most of the desired 0.500 s filtering will be performed by the digital filter rather than the instrument.

$$t_{Fd} = 0.4995 = \text{SQRT}[0.500^2 - (0.020^2 + 0.010^2)] \quad \text{(Eq. A11)}$$

By inserting the correct values of Δt and t_F into Equations A2 through A7, the Bessel function coefficients are determined. These are shown in Table A1.

TABLE A1—INITIAL BESSEL COEFFICIENTS

Equation A1	t_F	0.500
Equation A2	f_c	0.6283
Equation A4	B	0.618
Equation A5	Ω	50.6555063
Equation A6	C	0.00060396
Equation A7	K	0.91427037
	Δt	0.01

The Bessel coefficients can now be inserted into Equation A8 along with the step input function (i.e., an input of 0% opacity to 100% opacity in 0.01 s) to illustrate the effect of the Bessel filter on the step response as a function of time. The input step function is shown as X_i in Table A2. To simulate the step response, input X_I = 100. This will create the sudden jump from 0 to 100%.

The Bessel filtered output is shown as Y_i in Table A2. The two output points which are of interest are the 10% response point and the 90% response point. These are the values where Y_i first exceeds 10% and 90%. Since the output Y_i is digital, the exact 10% and 90% points must be interpolated from Table A2. The four points which bound the 10% and 90% points are indicated by an “X” in the Index column of Table A2. These are index numbers 9, 10, and 64, 65.

For this specific case, the following interpolation formulas are used to calculate the values of $t_{10\%}$ and $t_{90\%}$.

$$t_{10\%} = 0.01*[9 + (10 - 8.647)/(10.260 - 8.647)] = 0.0984 s \quad \text{(Eq. A12)}$$

$$t_{90\%} = 0.01*[64 + (90 - 89.834)/(90.427 - 89.834)] = 0.6428 s \quad \text{(Eq. A13)}$$

Now calculate the difference between $t_{90\%}$ and $t_{10\%}$ and see if it is close enough to t_F (close enough means within 1% or in this case 0.005).

$$0.6428 - 0.0984 = 0.5444 s \quad \text{(Eq. A14)}$$

The calculation shows that the response time of the filter is 0.5444 s using a value of f_c of 0.6283. The difference between this value and the desired value of 0.50 is 0.0444 which is about 10% greater than desired. Thus, another attempt to reach the desired response time will have to be made. Since 0.5444 is about 10% too high, use a cutoff frequency (f_c) which is 10% larger for the second iteration.

A.7.2 **Second Iteration to Estimate Bessel Function Cutoff Frequency (f_c)—**For the second iteration, a value of 0.690 is chosen for the value of f_c. This is approximately 10% higher than the value previously used. When this value is used, the Bessel function coefficients in Table A3 are obtained.

The filter responses Y_i were also recalculated for the step input X_i. The entire table of inputs (X_i) and responses (Y_i) (analogous to Table A2) is not shown. However, the values of t_{10} and t_{90} and the difference between were calculated and are shown in Table A4. In this case, the difference between the filter response time and the desired filter response time of 0.50 s is 0.0049. This is less than the 1% difference criteria (0.005 s). Thus, the value of 0.692 for the frequency cutoff (f_c) is the correct one for this smokemeter application.

A.7.3 Sample Calculation of the Bessel Filter Opacity Response—Once the appropriate value for the cutoff frequency (f_c) has been determined, then Equations A4 through A8 are used to calculate the Bessel filtered opacity values (Y_i) for any given input opacity values (X_i). The maximum filtered response is then selected and reported as the smoke reading for that particular snap-acceleration cycle.

TABLE A2—INITIAL SIMULATION OF THE BESSEL FILTER EFFECT (USED TO DETERMINE f_c)

	Index	Time	X_i	X_{i-1}	X_{i-2}	Y_i	Y_{i-1}	Y_{i-2}
	0	0.00	100	0	0	0.060	0.000	0.000
	1	0.01	100	100	0	0.297	0.060	0.000
	2	0.02	100	100	100	0.754	0.297	0.060
	3	0.03	100	100	100	1.414	0.754	0.297
	4	0.04	100	100	100	2.256	1.414	0.754
	5	0.05	100	100	100	3.264	2.256	1.414
	6	0.06	100	100	100	4.423	3.264	2.256
	7	0.07	100	100	100	5.715	4.423	3.264
	8	0.08	100	100	100	7.128	5.715	4.423
X	9	0.09	100	100	100	8.647	7.128	5.715
X	10	0.10	100	100	100	10.260	8.647	7.128
	11	0.11	100	100	100	11.956	10.260	8.647
	12	0.12	100	100	100	13.723	11.956	10.260
	13	0.13	100	100	100	15.552	13.723	11.956
	14	0.14	100	100	100	17.432	15.552	13.723
	15	0.15	100	100	100	19.355	17.432	15.552
	16	0.16	100	100	100	21.312	19.355	17.432
	17	0.17	100	100	100	23.297	21.312	19.355
	18	0.18	100	100	100	25.301	23.297	21.312
	19	0.19	100	100	100	27.319	25.301	23.297
	20	0.20	100	100	100	29.344	27.319	25.301
	21	0.21	100	100	100	31.372	29.344	27.319
	22	0.22	100	100	100	33.396	31.372	29.344
	23	0.23	100	100	100	35.413	33.396	31.372
	24	0.24	100	100	100	37.417	35.413	33.396
	25	0.25	100	100	100	39.406	37.417	35.413
	26	0.26	100	100	100	41.375	39.406	37.417
	27	0.27	100	100	100	43.322	41.375	39.406
	28	0.28	100	100	100	45.244	43.322	41.375
	29	0.29	100	100	100	47.138	45.244	43.322
	30	0.30	100	100	100	49.001	47.138	45.244
	31	0.31	100	100	100	50.833	49.001	47.138
	32	0.32	100	100	100	52.631	50.833	49.001
	33	0.33	100	100	100	54.394	52.631	50.833
	34	0.34	100	100	100	56.119	54.394	52.631
	35	0.35	100	100	100	57.807	56.119	54.394
	36	0.36	100	100	100	59.457	57.807	56.119
	37	0.37	100	100	100	61.067	59.457	57.807
	38	0.38	100	100	100	62.637	61.067	59.457
	39	0.39	100	100	100	64.166	62.637	61.067
	40	0.40	100	100	100	65.654	64.166	62.637
	41	0.41	100	100	100	67.102	65.654	64.166
	42	0.42	100	100	100	68.508	67.102	65.654

TABLE A2—INITIAL SIMULATION OF THE BESSEL FILTER EFFECT (USED TO DETERMINE f_c) (CONTINUED)

	Index	Time	X_i	X_{i-1}	X_{i-2}	Y_i	Y_{i-1}	Y_{i-2}
	43	0.43	100	100	100	69.873	68.508	67.102
	44	0.44	100	100	100	71.198	69.873	68.508
	45	0.45	100	100	100	72.481	71.198	69.873
	46	0.46	100	100	100	73.724	72.481	71.198
	47	0.47	100	100	100	74.927	73.724	72.481
	48	0.48	100	100	100	76.090	74.927	73.724
	49	0.49	100	100	100	77.215	76.090	74.927
	50	0.50	100	100	100	78.300	77.215	76.090
	51	0.51	100	100	100	79.348	78.300	77.215
	52	0.52	100	100	100	80.358	79.348	78.300
	53	0.53	100	100	100	81.331	80.358	79.348
	54	0.54	100	100	100	82.269	81.331	80.358
	55	0.55	100	100	100	83.171	82.269	81.331
	56	0.56	100	100	100	84.039	83.171	82.269
	57	0.57	100	100	100	84.872	84.039	83.171
	58	0.58	100	100	100	85.673	84.872	84.039
	59	0.59	100	100	100	86.442	85.673	84.872
	60	0.60	100	100	100	87.180	86.442	85.673
	61	0.61	100	100	100	87.887	87.180	86.442
	62	0.62	100	100	100	88.564	87.887	87.180
	63	0.63	100	100	100	89.213	88.564	87.887
X	64	0.64	100	100	100	89.834	89.213	88.564
X	65	0.65	100	100	100	90.427	89.834	89.213
	66	0.66	100	100	100	90.994	90.427	89.834
	67	0.67	100	100	100	91.536	90.994	90.427
	68	0.68	100	100	100	92.053	91.536	90.994
	69	0.69	100	100	100	92.546	92.053	91.536
	70	0.70	100	100	100	93.016	92.546	92.053

TABLE A3—FINAL BESSEL COEFFICIENTS

Equation A1	t_F	0.500
Equation A2	f_c	0.6292
Equation A4	B	0.618000
Equation A5	Ω	45.991292
Equation A6	C	0.000729
Equation A7	K	0.905717
	Δt	0.01

TABLE A4—BOUNDARY RESPONSE TIMES (SECOND ITERATION)

$t_{10\%}$	0.09145
$t_{90\%}$	0.5856
$\Delta\ t_{90\%} - t_{10\%}$	0.4951

Table A5 shows a sample calculation for an actual snap-acceleration smoke event collected at 100 Hz. Only 100 (1 s) readings and calculated values are shown so as to reduce the length of the table. The Bessel coefficients shown in Table A3 are used with Equation A8 to calculate the Bessel filter responses (Y_i) to the raw smoke inputs (X_i).

TABLE A5—BESSEL FILTER EXAMPLE

Time	X_i	X_{i-1}	X_{i-2}	Y_i	Y_{i-1}	Y_{i-2}
0.00	0.00	0.00	0.00	0.000	0.000	0.000
0.01	0.00	0.00	0.00	0.000	0.000	0.000
0.02	0.30	0.00	0.00	0.000	0.000	0.000
0.03	0.60	0.30	0.00	0.001	0.000	0.000
0.04	0.50	0.60	0.30	0.004	0.001	0.000
0.05	0.40	0.50	0.60	0.007	0.004	0.001
0.06	0.30	0.40	0.50	0.012	0.007	0.004
0.07	0.10	0.30	0.40	0.017	0.012	0.007
0.08	0.00	0.10	0.30	0.021	0.017	0.012
0.09	0.00	0.00	0.10	0.026	0.021	0.017
0.10	0.00	0.00	0.00	0.029	0.026	0.021
0.11	0.00	0.00	0.00	0.033	0.029	0.026
0.12	0.00	0.00	0.00	0.036	0.033	0.029
0.13	0.20	0.00	0.00	0.039	0.036	0.033
0.14	0.40	0.20	0.00	0.042	0.039	0.036
0.15	0.40	0.40	0.20	0.045	0.042	0.039
0.16	0.30	0.40	0.40	0.049	0.045	0.042
0.17	0.30	0.30	0.40	0.054	0.049	0.045
0.18	0.70	0.30	0.30	0.059	0.054	0.049
0.19	0.80	0.70	0.30	0.066	0.059	0.054
0.20	0.70	0.80	0.70	0.073	0.066	0.059
0.21	0.40	0.70	0.80	0.082	0.073	0.066
0.22	0.20	0.40	0.70	0.091	0.082	0.073
0.23	0.20	0.20	0.40	0.100	0.091	0.082
0.24	0.30	0.20	0.20	0.108	0.100	0.091
0.25	0.50	0.30	0.20	0.116	0.108	0.100
0.26	0.40	0.50	0.30	0.124	0.116	0.108
0.27	0.20	0.40	0.50	0.133	0.124	0.116
0.28	0.00	0.20	0.40	0.140	0.133	0.124
0.29	0.40	0.00	0.20	0.147	0.140	0.133
0.30	0.30	0.40	0.00	0.154	0.147	0.140
0.31	0.20	0.30	0.40	0.161	0.154	0.147
0.32	0.20	0.20	0.30	0.167	0.161	0.154
0.33	0.10	0.20	0.20	0.172	0.167	0.161
0.34	0.10	0.10	0.20	0.177	0.172	0.167
0.35	0.30	0.10	0.10	0.182	0.177	0.172
0.36	0.70	0.30	0.10	0.186	0.182	0.177
0.37	1.10	0.70	0.30	0.192	0.186	0.182
0.38	2.60	1.10	0.70	0.200	0.192	0.186
0.39	3.50	2.60	1.10	0.215	0.200	0.192
0.40	7.10	3.50	2.60	0.239	0.215	0.200
0.41	10.20	7.10	3.50	0.281	0.239	0.215
0.42	15.90	10.20	7.10	0.350	0.281	0.239
0.43	21.80	15.90	10.20	0.458	0.350	0.281

TABLE A5—BESSEL FILTER EXAMPLE (CONTINUED)

Time	X_i	X_{i-1}	X_{i-2}	Y_i	Y_{i-1}	Y_{i-2}
0.44	28.10	21.80	15.90	0.619	0.458	0.350
0.45	34.40	28.10	21.80	0.846	0.619	0.458
0.46	39.90	34.40	28.10	1.149	0.846	0.619
0.47	44.80	39.90	34.40	1.537	1.149	0.846
0.48	50.30	44.80	39.90	2.016	1.537	1.149
0.49	52.70	50.30	44.80	2.590	2.016	1.537
0.50	56.40	52.70	50.30	3.259	2.590	2.016
0.51	58.80	56.40	52.70	4.020	3.259	2.590
0.52	61.50	58.80	56.40	4.873	4.020	3.259
0.53	63.40	61.50	58.80	5.812	4.873	4.020
0.54	64.70	63.40	61.50	6.832	5.812	4.873
0.55	65.00	64.70	63.40	7.928	6.832	5.812
0.56	66.20	65.00	64.70	9.091	7.928	6.832
0.57	66.40	66.20	65.00	10.313	9.091	7.928
0.58	68.30	66.40	66.20	11.589	10.313	9.091
0.59	67.00	68.30	66.40	12.911	11.589	10.313
0.60	66.30	67.00	68.30	14.271	12.911	11.589
0.61	66.40	66.30	67.00	15.659	14.271	12.911
0.62	65.90	66.40	66.30	17.068	15.659	14.271
0.63	66.10	65.90	66.40	18.491	17.068	15.659
0.64	63.50	66.10	65.90	19.921	18.491	17.068
0.65	63.40	63.50	66.10	21.349	19.921	18.491
0.66	61.20	63.40	63.50	22.768	21.349	19.921
0.67	59.90	61.20	63.40	24.170	22.768	21.349
0.68	59.40	59.90	61.20	25.549	24.170	22.768
0.69	58.20	59.40	59.90	26.900	25.549	24.170
0.70	56.60	58.20	59.40	28.218	26.900	25.549
0.71	54.70	56.60	58.20	29.499	28.218	26.900
0.72	53.80	54.70	56.60	30.737	29.499	28.218
0.73	53.40	53.80	54.70	31.930	30.737	29.499
0.74	51.70	53.40	53.80	33.075	31.930	30.737
0.75	50.80	51.70	53.40	34.171	33.075	31.930
0.76	48.80	50.80	51.70	35.214	34.171	33.075
0.77	48.30	48.80	50.80	36.203	35.214	34.171
0.78	45.80	48.30	48.80	37.135	36.203	35.214
0.79	45.30	45.80	48.30	38.009	37.135	36.203
0.80	44.30	45.30	45.80	38.823	38.009	37.135
0.81	42.00	44.30	45.30	39.579	38.823	38.009
0.82	42.20	42.00	44.30	40.274	39.579	38.823
0.83	39.90	42.20	42.00	40.910	40.274	39.579
0.84	39.20	39.90	42.20	41.485	40.910	40.274
0.85	39.10	39.20	39.90	42.002	41.485	40.910
0.86	36.90	39.10	39.20	42.462	42.002	41.485
0.87	36.50	36.90	39.10	42.865	42.462	42.002
0.88	35.20	36.50	36.90	43.211	42.865	42.462
0.89	34.50	35.20	36.50	43.503	43.211	42.865
0.90	34.90	34.50	35.20	43.743	43.503	43.211
0.91	32.70	34.90	34.50	43.934	43.743	43.503
0.92	32.10	32.70	34.90	44.075	43.934	43.743
0.93	31.50	32.10	32.70	44.169	44.075	43.934
0.94	30.50	31.50	32.10	44.216	44.169	44.075

TABLE A5—BESSEL FILTER EXAMPLE (CONTINUED)

Time	X_i	X_{i-1}	X_{i-2}	Y_i	Y_{i-1}	Y_{i-2}
0.95	30.70	30.50	31.50	44.220	44.216	44.169
0.96	30.20	30.70	30.50	44.184	44.220	44.216
0.97	29.30	30.20	30.70	44.110	44.184	44.220
0.98	26.90	29.30	30.20	43.999	44.110	44.184
0.99	25.80	26.90	29.30	43.848	43.999	44.110
1.00	25.30	25.80	26.90	43.660	43.848	43.999

APPENDIX B

CORRECTIONS FOR AMBIENT TEST CONDITIONS

B.1 Introduction—Adjustment of snap-acceleration smoke values for the influence of ambient measurement conditions is an important and integral part of the SAE J1667 smoke measurement procedure. Testing has shown at-site ambient environmental conditions to be among the most influential testing factors that affect as-measured snap-acceleration smoke results. The ambient environmental factors incurred at the point of measurement in the form of altitude, barometric pressure, air temperature, and humidity have been combined into the single parameter of dry air density in order to provide a means of accounting for the influence of these factors on snap-acceleration test results. This appendix details procedures and offers guidelines for performing this important adjustment to snap-acceleration smoke values.

As will be summarized in Section B.7, the adjustment equations provided in this appendix were derived from an extensive snap-acceleration smoke test program involving a wide variety of heavy-duty diesel powered vehicles. One of the main conclusions of this test program was that each of the engines powering the test vehicles displayed different degrees of sensitivity to changes in air density. These differences were likely due to the different combustion and smoke control technologies employed by these engines at the time of their manufacture.

The air density adjustment equations provided in this appendix reflect the best fit nominal sensitivity of the sample of engines/vehicles evaluated. Some engines were more sensitive, and some were less sensitive, to the air density changes than predicted by the adjustment equations. In light of this, applying the correction equations to specific engines/vehicles of unknown air density sensitivity, the adjustment equations can only be considered approximate. It is recommended that regulatory agencies adopting this procedure in enforcement programs make some allowance for the fact that the air density sensitivity of individual vehicles tested in the program will, in general, not be known precisely and may be different than indicated by the nominal adjustment.

B.1.1 Reference Conditions—To perform an air density adjustment to an observed smoke value, it is necessary to define a reference air density which is used as the basis for the adjustment. The reference dry air density which was selected is:

$$1.1567 \text{ kg/m}^3 \ (0.0722 \text{ lbm/ft}^3)$$

This dry air density is the reference density specified in SAE J1349 and J1995, which specify the net and gross power rating conditions for diesel engines.

B.1.2 Precautions

a. The air density extremes encountered during the smoke test program (see Section B.7) used to derive the adjustment equations ranged from a low of 0.908 kg/m^3 (0.0567 lbm/ft^3) to a high of 1.235 kg/m^3 (0.0771 lbm/ft^3). The adjustment equations provided in this appendix should not be used outside of this range of air density.
b. The results from the study used to develop these correction factors suggested that at high temperatures above 32 °C (90 °F) and at low altitude sites around 412 m (1350 ft) in elevation there appeared to be a systematic temperature effect present that may not be accounted for by these correction factors. Residuals (the difference between measured values and calculated values) at these sites tend to decrease in value with increasing temperature. This may suggest the need for further adjustments to the equations to account for these temperature trends.
c. The air density adjustment equations presented here were developed specifically for use with snap-acceleration smoke values obtained using the procedures, equipment, and analysis techniques described in this document. The adjustment equations are not recommended for use with snap-acceleration smoke values obtained using peak-reading type smokemeters, or other smoke measurement procedures.

B.2 Symbols

A = Final avg. snap-acceleration test result, in units of opacity (%) or smoke density K(m^{-1}), from Equation A4. "A" is equivalent to N_t or K_t, depending on the smoke units being used.
BARO = Barometric pressure, absolute, kPa (in-Hg).
c = Regression coefficient for ambient condition adjustment equation.
DBT = Dry bulb temperature, ambient temperature measured in conjunction with WBT, °C (°F).
DPT = Dew point temperature, °C (°F).
F = Ferrel's equation, saturation pressure adjustment factor.
K = Smoke density (extinction coefficient), per meter (m^{-1}).
N = Smoke opacity, in percent (%).
r = Air density (dry), kg/m^3 (lbm/ft^3).
Dr = Dry air density differential between actual test conditions or reference conditions, and base conditions.
RH = Relative humidity, percent (%).
SPT = Water saturation pressure at the ambient temperature, kPa (in-Hg).
SPWBT= Water saturation pressure at the wet bulb temperature, kPa (in-Hg).
T = Ambient temperature, if different from the DBT, °C (°F).
WBT = Wet bulb temperature, °C (°F).
WVP = Water vapor pressure, kPa (in-Hg).

NOTE—Pressure units given in in-Hg are referenced to 0 °C.

subscripts
abs = absolute temperature. T + 273.15 Kelvin (T + 459.67 °R)
base = base dry air density. The air density upon which the ambient conditions correction regression efficients are based.
ref = at reference dry air density conditions, 1.1567 kg/m^3 (0.0722 lbm/ft^3).
t = at non-reference dry air density, usually actual test dry air density.

B.3 Snap-Acceleration Smoke Adjustment Methods—This appendix contains snap-acceleration adjustment equations that account for the air density effects on snap-acceleration smoke. The measured vehicle smoke value (A) is adjusted to the reference air density (ρ_{ref}). The measured smoke value (A), along with the actual dry air density (ρ_t) at the time of the test, are used in Section B.4 for opacity units or Section B.5 for smoke density units to compute the smoke level (N_{ref} or K_{ref}) at the reference air density (ρ_{ref}).

B.4 Adjustment of Snap-Acceleration Smoke Opacity (N) Values for the Effects of Changes in the Dry Air Density—The approach for adjusting smoke opacity values for the effects of changes in the dry air density is to convert the smoke opacity value, N_t, to smoke density units (K), adjust the smoke density value according to the procedures described in Section B.5, and then re-convert the adjusted smoke density value back into smoke opacity units as N_{ref}.

To adjust a snap-acceleration smoke opacity value for the effects of changes in the dry air density:

a. Convert the smoke opacity value to the equivalent smoke density units using the following equation:

$$K = (-1/L) * 1n(1-(N/100)) \quad \text{(Eq. B1)}$$

where:

K = Smoke density (m-1).
L = Optical path length of the smoke measurement, in meters (m). If L is not known, assume a value of 0.127 m.
N = Smoke opacity value to be converted, usually Nt.

b. Adjust the resulting smoke density value, calculated in step 1, according to the procedures described in Section B.5 to produce K_{ref}.

c. Convert the resulting adjusted smoke density value calculated in Section B.5 to equivalent smoke opacity units according to the following equation:

$$N = (1 - e^{-KL})^{*}100 \qquad \text{(Eq. B2)}$$

where:

N = Ambient conditions adjusted smoke opacity value, N_{ref}.
K = Ambient conditions adjusted smoke density value, K_{ref}, determined in Section B.5.
L = Optical path length value used in Equation B1.

NOTE—It is important to use the same value of L (optical path length) for the conversion to smoke density units and for the re-conversion back to smoke opacity units. The actual value of L is not critical; however, it must be a positive non-zero value.

B.5 Adjustment of Snap-Acceleration Smoke Density (K) Values for the Effects of Changes in the Dry Air Density—The base air density (ρ_{base}) parameter used in this section should not be confused with the reference air density (ρ_{ref}). The base air density is the ambient condition used to develop the adjustment regression coefficient used in this section. The adjustment equations in this section provide for the reference air density to be different from the base air density used in the regression analysis of the ambient conditions test data.

To adjust a measured snap-acceleration smoke density value to reference air density conditions:

a. Calculate the air density differences using ρ_{ref} and ρ_{base}:

$$\Delta\rho_1 = \rho_{ref} - \rho_{base} \qquad \text{(Eq. B3)}$$

$$\Delta\rho_2 = \rho_t - \rho_{base} \qquad \text{(Eq. B4)}$$

b. Calculate the adjusted snap-acceleration smoke density value, K_{ref}, at the reference dry air density, using Equation B5, and the appropriate values for coefficient c and r from Table B1.

$$K_{ref} = K_t{}^{*}\frac{(c^{*}\Delta\rho_1{}^2 + 1)}{(c^{*}\Delta\rho_2{}^2 + 1)} \qquad \text{(Eq. B5)}$$

TABLE B1—SMOKE DENSITY ADJUSTMENT CONSTANTS

Air Density Units	c	ρ_{base}	
kg/m^3	21.1234	1.2094	(metric)
lbm/ft^3	5420.0671	0.0755	(English)

c. Substituting the values in Table B1 for c and ρ into Equation B3 through B5 produces Equation B6 and B7 for K_{ref}.

Metric Units ρ (kg/m^3)

$$K_{ref} = \frac{K_t}{19.952\ \rho_t{}^2 - 48.259\ \rho_t + 30.126} \qquad \text{(Eq. B6)}$$

English Units ρ (lbm/ft³)

$$K_{ref} = \frac{K_t}{5119.55\ \rho_t^2 - 773.05\ \rho_t + 30.126} \qquad \text{(Eq. B7)}$$

B.6 Calculation of Dry Air Density—In order to correct the smoke values using the equations in Sections B.4 or B.5, it is first necessary to determine the dry air density at the test conditions. This can be done by measuring the barometric pressure (BARO), the ambient air temperature (T or DBT), and either the dew point temperature (DPT), or the wet and dry bulb temperatures (WBT and DBT), or the relative humidity (RH). From these measurements the dry air density may be determined from the following equation.

$$\rho = (u*(BARO - WVP))/(T_{abs}) \qquad \text{(Eq. B8)}$$

where:

TABLE B2—

	Metric	English
ρ, Air Density (dry)	kg/m^3	lbm/ft^3
Units conversion (u)	3.4836	1.3255
Barometric Pressure (BARO)	kPa	in-Hg
Water Vapor Pressure (WVP)	kPa	in-Hg
Ambient Temperature (T_{abs})	Kelvin	°R

The barometric pressure and the ambient temperature must be measured at the test conditions of interest. The water vapor pressure may be calculated as described in B.6.1, or obtained from a psychrometric chart.

NOTE—Exclusion of the water vapor pressure term in Equation B8 (calculation of dry air density) is permissible, thus eliminating the need to measure DPT, WBT, or RH and calculate the WVP. However, the user should be aware that this results in a bias error, usually towards a smaller adjustment factor applied to the smoke values. In addition, it should be noted that as the ambient temperature increases, the amount of water the air can hold increases rapidly, and thus, the potential impact of this error also increases. The examples in Section B.6 illustrate the impact of ignoring the water vapor pressure in the adjustment equations.

B.6.1 Calculation of Water Vapor Pressure (WVP)—The method of calculating the water vapor pressure is dependent upon the instrumentation used to determine the moisture in the ambient air. The most common methods utilized are by the measurement of the dew point temperature (DPT), the measurement of the wet bulb/dry bulb temperatures, and by the measurement of the relative humidity (RH). From these measurements, the vapor pressure of the air may be determined.

B.6.1.1 CALCULATION OF WVP FROM DEW POINT TEMPERATURE—This procedure uses a dimensionless (normalized) polynomial for the vapor pressure calculation. This allows calculations to be performed in any units, utilizing the same polynomial coefficients. In using this technique, the input and output parameters to the polynomial are normalized and un-normalized, respectively, with the supplied support equations.

a. Calculate the normalized dew point temperature (NT) from the measured dew point temperature (DPT).

$$NT = (DPT - TL)/(TH - TL) \qquad \text{(Eq. B9)}$$

TABLE B3—

Temperature Units	TL	TH
°C	-30.0	+40.0
°F	-22.0	+104.0

NOTE—DPT, TL, and TH must be in the same temperature units. Equation B9 applies over a dew point temperature range of -30 to +40 °C (-22 to +104 °F).

b. Calculate the normalized water vapor pressure (NP) at the normalized dew point temperature (NT).

$$NP = -4.959658E\text{-}5 + (4.956773E\text{-}2*NT) + (9.455172E\text{-}2*NT^2) + (4.199096E\text{-}1*NT^3) + (-7.549164E\text{-}2*NT^4) + (5.114628E\text{-}1*NT^5) \quad \text{(Eq. B10)}$$

c. Un-normalize the saturation pressure (NP) to produce the WVP at the dew point temperature, DPT, in the units of choice.

$$WVP = PL + (NP*(PH - PL)) \quad \text{(Eq. B11)}$$

TABLE B4—

Pressure Units	PL	PH
kPa	5.0951E-2	7.375
in-Hg	1.5046E-2	2.178

NOTE—WVP, PL, and PH must be in the same pressure units.

B.6.1.2 CALCULATION OF WVP FROM WET BULB/DRY BULB TEMPERATURES—This procedure uses a dimensionless (normalized) polynomial for the vapor pressure calculation. This allows calculations to be performed in any units, utilizing the same polynomial coefficients. In using this technique, the input and output parameters to the polynomial are normalized and un-normalized, respectively, with the supplied support equations.

a. Calculate the normalized wet bulb temperature (NT) from the measured wet bulb temperature (WBT).

$$NT = (WBT - TL)/(TH - TL) \quad \text{(Eq. B12)}$$

TABLE B5—

Temperature Units	TL	TH
°C	-30.0	+40.0
°F	-22.0	+104.0

NOTE—WBT, TL, and TH must be in the same temperature units. Equation B12 applies over a wet bulb temperature range of -30 to +40 °C (-22 to +104 °F).

b. Calculate the normalized saturation pressure (NP) at the normalized wet bulb temperature (NT).

$$NP = -4.959658E\text{-}5 + (4.956673E\text{-}2*NT) + (9.455172E\text{-}2*NT^2) + (4.199096E\text{-}1*NT^3) + (-7.549164E\text{-}2*NT^4) + (5.114628E\text{-}1*NT^5) \quad \text{(Eq. B13)}$$

c. Un-normalize the saturation pressure (NP) to produce the saturation pressure at the wet bulb temperature, SPWBT, in the units of choice.

$$SPWBT = PL + (NP*(PH - PL)) \quad \text{(Eq. B14)}$$

TABLE B6—

Pressure Units	PL	PH
kPa	5.0951E-2	7.375
in-Hg	1.5046E-2	2.178

NOTE—SPWBT, PL, and PH must be in the same pressure units.

d. Using Ferrel's equation, calculate the adjustment factor (F).
Metric Units—WBT in °C

$$F = 3.67E\text{-}4*(1 + (1.152E\text{-}3*WBT)) \quad \text{(Eq. B15)}$$

English Units—WBT in °F

$$F = 3.67E\text{-}4*(1 + (6.4E\text{–}4*(WBT - 32))) \quad \text{(Eq. B16)}$$

e. Calculate the Water Vapor Pressure (WVP).

Metric Units—SPWBT, BARO in kPa; DBT, WBT in °C.

$$WVP = SPWBT - (1.8*F*BARO*(DBT - WBT)) \quad \text{(Eq. B17)}$$

English Units—SPWB, BARO in in-Hg; DBT, WBT in °F.

$$WVP = SPWBT - (F*BARO*(DBT - WBT)) \quad \text{(Eq. B18)}$$

B.6.1.3 CALCULATION OF WVP FROM RELATIVE HUMIDITY AND AMBIENT TEMPERATURE—This procedure uses a dimensionless (normalized) polynomial for the vapor pressure calculation. This allows calculations to be performed in any units, utilizing the same polynomial coefficients. In using this technique, the input and output parameters to the polynomial are normalized and un-normalized, respectively, with the supplied support equations.

a. Calculate the normalized ambient temperature (NT) from the measured ambient temperature (T).

$$NT = (T - TL)/(TH - TL) \quad \text{(Eq. B19)}$$

TABLE B7—

Temperature Units	TL	TH
°C	-30.0	+40.0
°F	-22.0	+104.0

NOTE—T, TL, and TH must be in the same temperature units. Equation B19 applies over an ambient temperature range of -30 to +40 °C (-22 to +104 °F).

b. Calculate the normalized saturation pressure (NP) at the normalized ambient temperature (NT).

$$NP = -4.959658E\text{-}5 + (4.956673E\text{-}2*NT) + (9.455172E\text{-}2*NT^2) + (4.199096E\text{-}1*NT^3) + (-7.549164E\text{-}2*NT^4) + (5.114628E\text{-}1*NT^5) \quad \text{(Eq. B20)}$$

c. Un-normalize the saturation pressure (NP) to produce the saturation pressure at the ambient temperature, SPT, in the units of choice.

$$SPT = PL + (NP*(PH - PL)) \quad \text{(Eq. B21)}$$

TABLE B8—

Pressure Units	PL	PH
kPa	5.0951E-2	7.375
in-Hg	1.5046E-2	2.178

NOTE—SPT, PL, and PH must be in the same pressure units.

d. Calculate the WVP at the measured relative humidity, RH. WVP will be in the same units as SPT.

$$WVP = SPT*(RH/100) \quad \text{(Eq. B22)}$$

B.7 Examples of Adjustments to Ambient Smoke Values—The following hypothetical examples may assist in applying the ambient correction equations. Both metric and English unit based examples are provided. Also included for reference are the applicable equation numbers used in this appendix.

Example 1

Situation—A vehicle tested for smoke at a moderate elevation produces an average snap-acceleration smoke value of 60% opacity (the (A) value reported from Equation B3).

Task—From the ambient conditions measurements, determine the adjusted smoke opacity (N_{ref}) at the reference air density (ρ_{ref}).

Ambient measurements	Equation Constants
Smoke (A)= 60% opacity	c = 54.200671
(BARO)= 27.00 in-Hg	TL = -22 x °F
(T)= 77 x °F	TH = 104 x °F
(RH)= 50%	PL = 1.5046E-2 in-Hg
	PH = 2.178 in-Hg
	EOPL = 0.127 m
	(ρ_{ref}) = 0.0722 lbm/ft^3
	(ρ_{base}) = 0.0755 lbm/ft^3

Calculations:

(Eq.B19)	NT	=	(77 - (-22))/(104 - (-22)) = 0.785714
(Eq.B20)	NP	=	0.425334 (polynomial)
(Eq.B21)	SPT	=	1.5046E-2 + 0.425334 * (2.178 - 1.5046E-2)
		=	0.935024
(Eq.B22)	WVP	=	0.935024 * (50.0/100)
		=	0.4675
(Eq.B8)	ρ_{dry}	=	(1.3255 * (27.0 - 0.4675))/(77 + 459.67)
		=	0.06553
(Eq.B1)	K_t	=	7.215
(Eq.B3)	$\Delta \rho 1$	=	0.0722 - 0.0755 = -0.0033
(Eq.B4)	$\Delta \rho 2$	=	0.06553 - 0.0755 = -0.00996
(Eq.B5)	K_{ref}	=	4.966
(Eq.B2)	N_{ref}	=	46.8%

Result—A vehicle with a snap-acceleration smoke level of 60% opacity at a dry air density of 0.0655 lbm/ft^3 would be projected to produce a smoke value of 46.8% opacity at the reference dry air density of 0.0722 lbm/ft^3.

It should be noted that if the RH measurement had not been performed and the effect of WVP ignored, the resulting impact would have changed N_{ref} from 46.8% to 49.5% opacity.

Example 2

Situation—A vehicle tested for smoke at a moderate elevation produces an average snap-acceleration smoke density of 7.2 m^{-1} (the (A) value reported from Equation B3).

Task—From the ambient conditions measurements, determine the adjusted smoke density (K^{ref}) at the reference air density (ρ_{ref}).

Ambient measurements		Equation Constants		
Smoke (A)	= 7.2 m^{-1}	c	=	0.211234
(BARO)	= 88.50 kPa	TL	=	-30 °C
(T)	= 20 °C	TH	=	40 °C
(DPT)	= 10 °C	PL	=	5.0951E-2 kPa
		PH	=	7.375 kPa
		(ρ_{ref})	=	1.1567 kg/m^3
		(ρ_{base})	=	1.2094 kg/m^3

Calculations:

(Eq.B9)	NT	= (10 – (–30))/(40 – (–30)) = 0.571428
(Eq.B10)	NP	= 0.160612 (polynomial)
(Eq.B11)	WVP	= 5.0951E-2– (0.160612 * (7.375 – 5.0951E-2))
		= 1.2272
(Eq.B8)	ρ_{dry}	= (3.4836 * (88.5 – 1.227))/(20 + 273.15)
		= 1.0370
(Eq.B3)	$\Delta\rho_1$	= 1.1567– 1.2094 = –0.0527
(Eq.B4)	$\Delta\rho_2$	= 1.0370 – 1.2094 = –0.17230
(Eq.B5)	K_{ref}	= 4.684 m-^{1}

Result—A vehicle with a snap-acceleration smoke density of 7.2 m^{-1} at a dry air density of 1.0370 kg/m^3 would be projected to produce a smoke density of 4.684 (m^{-1}) at the reference dry air density of 1.1567 kg/m^3.

B.8 Snap-Acceleration/Air Density Field Test Program—The snap-acceleration smoke adjustment equations of this appendix were derived using data from a smoke test program designed to study the effects of ambient conditions on snap-acceleration smoke levels. The test program was conducted during the summer of 1993 and involved measuring the snap-acceleration levels of several heavy-duty diesel-powered vehicles, as the vehicles traveled an out and back route over a wide range of elevations on Interstate 80, in California. The vehicles were tested for snap-acceleration smoke with several types of smokemeters using the SAE J1667 test procedures and data analysis algorithm. Eight tests were performed at six different elevations along the route. At two of the elevations, tests were performed on both the outbound and return legs of the test route. The range of the ambient test conditions encountered during the test program are shown in Table B9.

TABLE B9—TEST PROGRAM AMBIENT EXTREMES

Units	min	max
Metric		
Elevation	12 m	2207 m
Air Density (dry)	0.906 kg/m^3	1.235 kg/m^3
Air Density (wet)	0.915 kg/m^3	1.240 kg/m^3
Barometer	78.3 kPa	101.7 kPa
Ambient Temp.	11.7 °C	37.2 °C
Specific Humidity	0.6 gm/kg	12.7 gm/kg
English		
Elevation	40 ft	7240 ft
Air Density (dry)	0.0567 lbm/ft^3	0.0771 lbm/ft^3
Air Density (wet)	0.0571 lbm/ft^3	0.0774 lbm/ft^3
Barometer	23.11 in-Hg	30.03 in-Hg
Ambient Temp.	53 °F	99 °F
Specific Humidity	4 grains	89 grains

A total of 24 diesel-powered vehicles were tested in the program, with the number, type, and manufacturer of the diesel engines powering these vehicles providing a fairly representative sample of the engines in the general U.S. heavy-duty vehicle population. Engines manufactured by Caterpillar, Cummins, Detroit Diesel (both 2 and 4 cycle), and Mack were included in the test sample, as were engines with both mechanical and electronic injection control systems. There was one naturally aspirated engine in the test sample with the rest being turbocharged. The manufacturing dates of the engines covered a range from 1971 to 1993 with about 46% of the engines manufactured in the 1985-1989 period and about 33% manufactured between 1990 and 1993.

Four different manufacturers of smokemeters (Bosch, Caltest, Sun, and Wager) participated in the test program. The smokemeters included full flow end-of-line (EOL) and sampling type smokemeters. Both peak-reading meters and prototype meters which were programmed to perform the SAE J1667 half-second averaging algorithm were included in the testing.

The data from the testing program were assembled into a single data base so that standard mathematical and statistical procedures could be utilized to query for relationships among the various test parameters. Data from the peak-reading meters and data which did not meet the SAE J1667 test validation criteria, as given in 5.4.4, were excluded from the analyses. Dry air density, barometric pressure, and altitude all produced significant correlations with the snap-acceleration smoke values, with dry air density providing the better correlation.

The data from this test program were also used to quantify the repeatability of the test procedure. This was done in two ways. In the first method, the average of the ambient condition corrected smoke values was computed for each vehicle, test day and smokemeter combination. The deviations of the individual corrected smoke values from this average were then computed and used to provide a measure of the repeatability of the test procedure over the full range of ambient conditions encountered in the test program and allowed by the procedure. When this was done for all the data in the test program data base, 91% of the deviations from average were less than 6% opacity.

In the second method, only the data taken at the two elevations where repeat tests were run were utilized. For each vehicle/meter combination the two test results obtained at these test locations created a data pair which differed only slightly in ambient dry air density. (Since the elevation was the same for both points in the data pair, the only source of air density differences was the change in ambient conditions which occurred in the few hours between the two tests.) All these smoke values were corrected to the standard reference air density using the methods described in this appendix and the deviation of the corrected smoke values was noted for each data pair. For 90% of the pairs, the deviations were less than 3% opacity.

The difference in the repeatabilities quantified by the two methods reflects the imprecision of applying the ambient condition corrections to specific vehicles over wide ranges of air density.

APPENDIX C

APPLICATION OF CORRECTIONS TO MEASURED SMOKE VALUES

***C.1 Introduction*—**Fundamentally, all smoke opacimeters measure the transmittance of light through a smoke plume or a sample of gas which contains smoke particles. Typically, however, it is desired to quantify and report the exhaust smoke emissions in units of either smoke opacity (N) or smoke density (k). Furthermore, if the smoke level is reported as smoke opacity, then is it also necessary to report the associated effective optical path length to fully specify the smoke level of the vehicle. This is because measured smoke opacity is a function of the effective optical path length (EOPL) used to make the measurement. For example, an engine that yielded a 20% opacity when tested with a tailpipe which caused the EOPL to be 76 mm would have measured opacities of 26%, 31%, and 36%, respectively, when tested with larger tailpipes which caused the EOPL to be 102, 127, and 152 mm. Therefore, to facilitate comparisons of smoke opacity data from different sources and with smoke standards which may be developed, opacity values must be reported at standard effective optical path lengths.

When smoke is measured using an effective optical path length which is different than the standard path length, the measured smoke values must be converted to opacity at the standard path length using the appropriate Beer-Lambert relationship. Similarly, if it is desired to report the test results in units of smoke density, it is necessary to use the Beer-Lambert relationship to convert the measured opacity results to smoke density.

Finally, if smoke measurements are made using a smokemeter having a red LED light source, a wavelength correction is necessary to account for the fact that the ability of diesel smoke to absorb light depends on the wavelength of the light.

This appendix describes how measured smoke values are to be corrected to the desired reporting units using the Beer-Lambert relationships and how the light source wavelength corrections are to be made.

C.2 Definitions and Symbols

C.2.1 Diesel Smoke—Particles, including aerosols, suspended in the exhaust stream of a diesel engine which absorb, reflect, or refract light.

C.2.2 Transmittance (T)—The fraction of light transmitted from a source which reaches a light detector.

C.2.3 Opacity (N)—The percentage of light transmitted from a source which is prevented from reaching a light detector.

C.2.4 Effective Optical Path Length (L)—The length of the smoke obscured optical path between the smokemeter light source and light detector. Note that portions of the total light source to detector path length which are not smoke obscured do not contribute to the effective optical path length.

C.2.5 Smoke Density (k)—A fundamental means of quantifying the ability of a smoke plume or a smoke-containing gas sample to prevent the passage of light. By convention, smoke density is expressed on a per meter basis (m^{-1}).

C.2.6 W—The wavelength of the smokemeter light source.

C.2.7 Subscripts

C.2.7.1 m—Refers to the as-measured condition

C.2.7.2 s—Refers to values corrected to a standard condition

C.3 Beer-Lambert Relationships—The Beer-Lambert Law defines the relationship between transmittance, smoke density, and effective optical path length as shown in Equation C1.

$$T = e^{-kL} \quad \text{(Eq. C1)}$$

From the definitions of transmittance and opacity, the relationship between these parameters may be defined as shown in Equation C2.

$$N(\%) = 100 * (1 - T) \quad \text{(Eq. C2)}$$

From Equations C1 and C2 the following important relationships can be derived:

$$N_s = 100 * (1 - ((1 - (N_m / 100))(L_s / L_m))) \quad \text{(Eq. C3)}$$

$$k = -(1 / L_m) * (1n(1 - (N_m / 100))) \quad \text{(Eq. C4)}$$

To achieve proper results in applying Equations C1 and C4, the effective optical path lengths (L and L_m) must be expressed in units of meters (m). It is recommended that the effective optical path lengths used in Equation C3 also be expressed in meters (m); however, any length unit may be used as long as L_s and L_m are expressed in the same measurement unit.

C.4 Use of Beer-Lambert Relationships—Conversion from as-measured smoke values to appropriate reporting units is a two-step process. Since, as noted in Section C.1, the basic measurement unit of all smokemeters is transmittance, the first step in all cases is to convert from transmittance (T) to opacity at the as-measured effective optical path length (N_m) using Equation C2. Since all opacimeters do this internally, this step is transparent to the user.

The second step of the process is to convert from N_m to the desired reporting units as follows:

a. If the test results are to be reported in opacity units, Equation C3 must be used to convert from opacity at the as-measured effective optical path length to opacity at the standard effective optical path length. (In the event that the measured and standard effective optical path lengths are identical, N_s is equal to N_m and this secondary conversion step is not required.)
b. If the test results are to be reported in units of smoke density, then Equation C4 must be applied.

C.5 Effective Optical Path Length Input Values—In order to apply conversion Equation C4, it is necessary to input the as-measured effective optical path length (L_m). To use Equation C3, values must be input both for L_m and for L_s, the standard effective optical path length. This section provides guidance on the determination of these input values.

C.5.1 Determination of L_m—For full-flow end-of-line type smokemeters, L_m is a function of the vehicle tailpipe design. For straight tailpipes with a circular cross section, L_m is equal to the tailpipe ID. For tailpipes constructed of common tubing, the tubing OD may be used to approximate the tubing ID. Appendix D provides guidance in determining L_m for other tailpipe configurations.

For sampling type smokemeters, L_m is a fixed function of the meter measurement cell and purge air system design. Specification data supplied by the meter manufacturer should be consulted to determine the appropriate value for L_m when this type of smokemeter is used.

Typically, it is necessary to determine L_m within ±5 mm to achieve corrected smoke results that are accurate within ±2% opacity or ±0.2 m^{-1} smoke density.

C.5.2 Determination of L_s—To ensure meaningful smoke data comparisons, smoke opacity results should be reported at the standard effective optical path lengths, L_s shown in Table C1. Table C1 is constructed such that the standard effective optical path length increases with the engine power rating and approximates exhaust tailpipe sizes commonly used in vehicle applications. In cases where the engine rated power cannot be determined, the actual tailpipe OD usually provides a good approximation of L_s and may be used in lieu of Table C1.

TABLE C1—STANDARD EFFECTIVE OPTICAL PATH LENGTHS

Related Engine Power kW	Rated Engine Power BHP	Standard Effective Optical Path length mm	Standard Effective Optical Path Length in
Less than 75	Less than 101	51	2
75 to 149	101 to 200	76	3
150 to 224	201 to 300	102	4
225 or More	301 or more	127	5

When testing vehicles with multiple exhaust outlets, the total rated engine power must be used with Table C1 to determine the standard effective optical path length. The rated engine power must not be divided by the number of exhaust outlets when using Table C1. If this error is made, it will result in reported smoke opacity values which are erroneously low.

C.6 Sequencing of Beer-Lambert Corrections

C.6.1 Preferred Method—To achieve the highest degree of accuracy, the Beer-Lambert conversion calculations described in Section C.4 should be performed on each instantaneous measured smoke value before any further data-processing takes place. To perform the calculations in this manner during snap-acceleration testing requires significant data-processing capacity since the minimum smoke data-processing rate is 20 Hz. In addition, the ability to input values for L_m and L_s to the data-processing unit is required.

C.6.2 Alternate Methods—In some cases, users may wish to use data-processing systems which are not capable of performing the Beer-Lambert corrections using the preferred method in C.6.1. In these cases, either of the following alternate techniques may be employed; however, users are cautioned that there will be some loss of accuracy.

a. The appropriate Beer-Lambert conversion equations as defined in Section C.4 may be applied after instantaneous smoke values have been averaged using the procedures described in Appendix A. The snap-acceleration test error that results from the use of this method will, in most cases, be less than 1% opacity or 0.15 m^{-1} smoke density, but could be somewhat higher when the snap-acceleration test generates a very high and sharp smoke spike.
b. Appropriate Beer-Lambert conversions may be performed manually on as-measured average smoke values by using the alignment chart shown in Figure C1. In this method, an as-measured smoke opacity (N_m) is located on the vertical column which most closely represents the as-measured effective optical path length (L_m). The user then reads horizontally across the chart to the column which represents the standard effective optical path length (L_s) if a smoke opacity output is desired, or to the smoke density column if a density output is desired. The user then reads the desired output by interpolating the scale of the target column. For example, if an opacity value of 40% were measured using an effective optical path length of 102 mm (4 in), the chart could be used to determine that the equivalent opacity at a path length of 127 mm (5 in) is approximately 47% and that the associated smoke density is about 5.0 m^{-1}.

Since the alignment chart was developed using Equations C3 and C4, the fundamental accuracy of this method is the same as alternate method (a). However, when the as-measured effective optical path length is not equal to one of the values which appear as one of the vertical chart scales the utility and/or accuracy of this method is reduced. This method also introduces the potential for small errors due to resolution and readability of the non-linear chart scales.

C.7 Smokemeter Light Source Wavelength Corrections**—**The ability of diesel smoke to absorb light is wavelength dependent (i.e., diesel smoke does not have neutral spectral density). For this reason, smokemeters using different light sources will respond differently to the same smoke sample, and corrections are required to achieve comparable results.

Since most smokemeters today use either a green LED or an incandescent light source, with an equivalent peak spectral emissivity, this will be the standard for reporting snap-acceleration test results. Smoke measurements made with meters using red LED light sources must be corrected using the following equations.

$$N_s = 100*(1-((1-(N_m/100))(w_m/w_s))) \qquad \text{(Eq. C5)}$$

$$K_s = (-1/L)*1n((1-(N_m/100))(w_m/w_s)) \qquad \text{(Eq. C6)}$$

where:

Ws = the wavelength of a standard green LED light source = 570 nm
Wm= the wavelength of a red LED light source = 660 nm

It is preferred that the wavelength corrections, like the Beer-Lambert corrections, be applied to each instantaneous measured smoke value. However, if this is not possible, and if small errors are acceptable, the wavelength corrections may be applied after average smoke values are obtained as described in Appendix A.

Light source wavelength corrections using Equations C5 and C6 should be applied when the meter is used to measure diesel smoke, but should not be used when the meter is being calibrated using a neutral density filter.

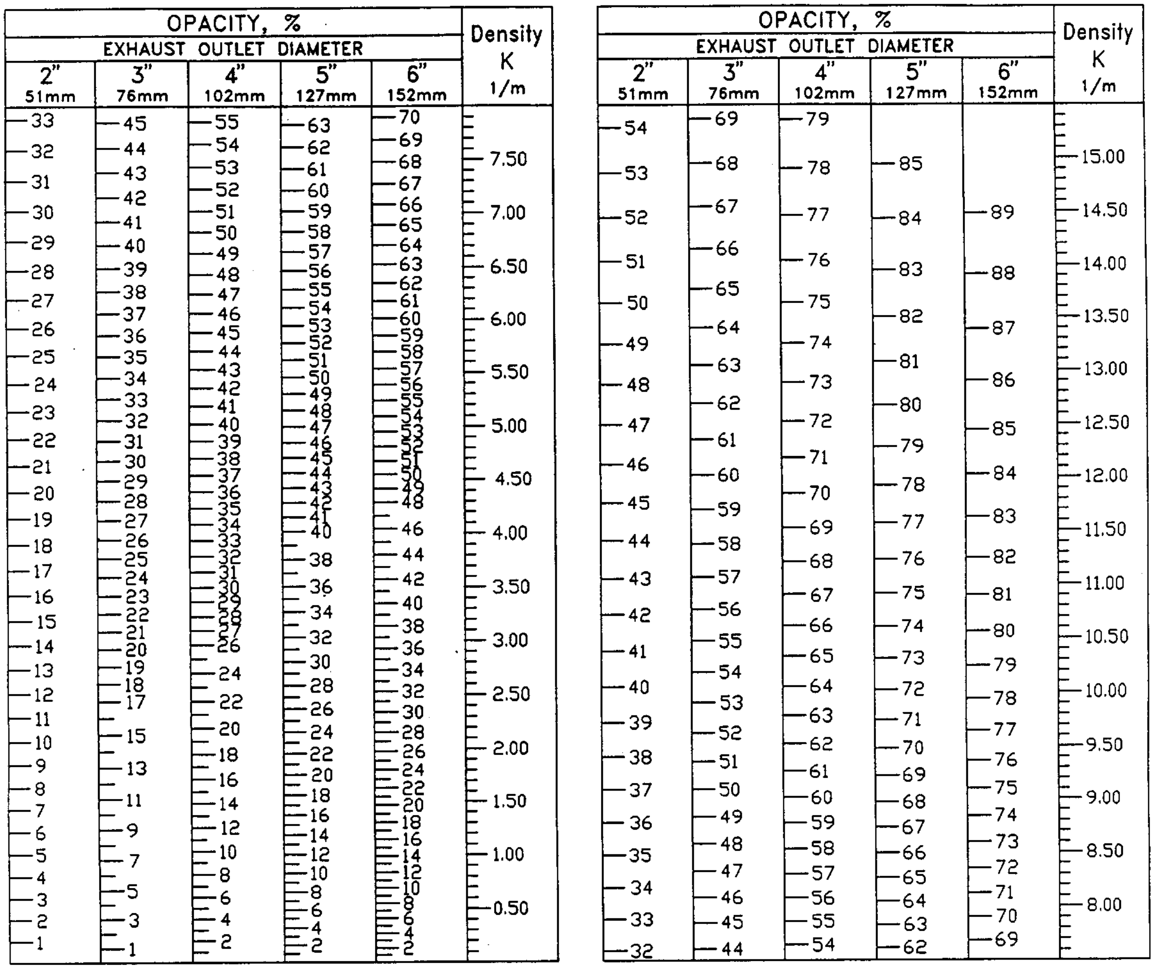

FIGURE C1—ALIGNMENT CHART

APPENDIX D

EXHAUST SYSTEMS AND SPECIAL APPLICATIONS

***D.1 Introduction*—**In order to report snap-acceleration test results at standard conditions, the Beer-Lambert effective optical path length corrections described in Appendix C must be applied to the as-measured smoke values. A required input for the Beer-Lambert corrections is the as-measured effective optical path length (L_m). When a sampling type smokemeter is used, L_m is a function of the meter design and is expected to be supplied by the meter manufacturer. When a full-flow end-of-line smokemeter is used, L_m is a function of the vehicle exhaust system and the way the meter is mounted on the tailpipe. Users of full-flow smokemeters must, therefore, determine L_m for each test conducted on a case by case basis.

Recognizing the wide variety of exhaust systems that may be encountered when conducting vehicle tests, this appendix provides guidelines which will assist full-flow smokemeter users in determining L_m. This appendix also includes suggestions for mounting full-flow meters on specific types of vehicular exhaust systems. Following these suggestions will facilitate the determination of L_m and will insure that proper smoke measurement principles are adhered to.

D.2 Determination of the As-Measured Effective Optical Path Length (L_m)

D.2.1 General Comments—The effective optical path length has been defined as “the length of the smoke obscured path between the smokemeter light source and detector.” Portions of the light source to detector path length which are not smoke obscured do not contribute to the effective optical path length. If the smokemeter light beam is located sufficiently close to the exhaust outlet (within 7 cm or 2.76 in) the cross section of the smoke plume as it passes by the smokemeter is essentially the same as the tailpipe outlet and the effective optical path length is equal to the internal distance across the tailpipe outlet along the line of orientation of the smokemeter light beam. In general, this distance should be determined by direct measurement of the tailpipe outlet, and to achieve corrected smoke results which are within ±2% opacity or ±0.2 m^{-1} smoke density, this measurement should be made within ±5 mm (±0.197 in).

It is often difficult, particularly in roadside testing applications, to gain access to and obtain direct measurements of the tailpipe outlets on many vehicles. Fortunately, for many common tailpipe designs L_m can be determined with sufficient accuracy from external exhaust system dimensions which are more easily measured. The remainder of this section describes these cases and the principles and procedures that should be adhered to in determining L_m.

D.2.2 External Versus Internal Tailpipe Dimensions—Most tailpipes encountered on vehicles are constructed from metal tubing of various standard nominal sizes. Nominal tubing sizes are based on the tubing OD whereas it is the internal dimension of the tailpipe that dictates L_m. The difference between the external and internal tailpipe dimension is twice the tubing wall thickness which is typically about 1.5 mm (0.060 in).

Use of the external tailpipe dimension as the as-measured effective optical path length results in corrected smoke values which are slightly less than the true corrected smoke values (~1% opacity or 0.01 m^{-1} smoke density). In most cases, this small error is acceptable. However, in cases where extreme accuracy is required or where the tailpipe wall thickness is unusually large, the material thickness should be accounted for in determining L_m.

D.2.3 Straight Circular Non-Beveled Tailpipes—This is the simplest tailpipe design that may be encountered and is illustrated in Figure D1. In this case, the smokemeter light beam should be oriented such that it is perpendicular to and passes through the central axis of the smoke plume and is within 70 mm (2.76 in) of the tailpipe exit. If these guidelines are followed, L_m is equal to the tailpipe ID and can usually be adequately approximated by the tailpipe OD (see D.2.2).

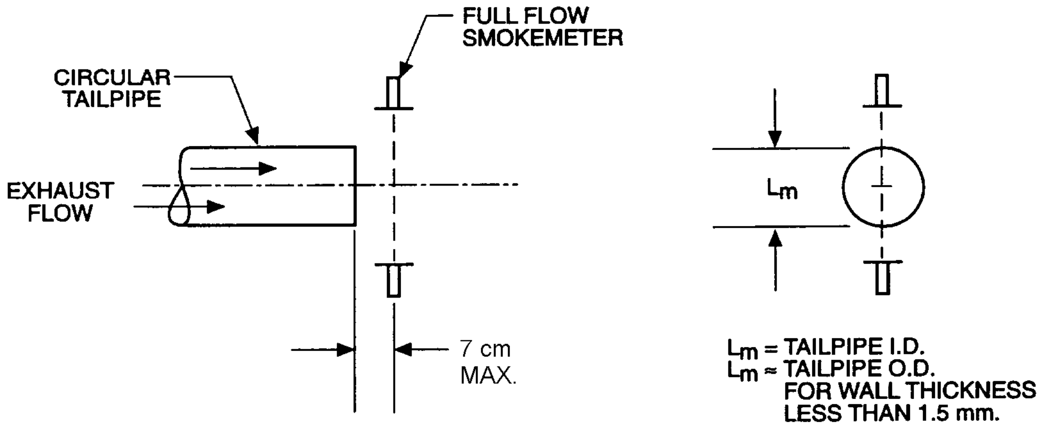

FIGURE D1—STRAIGHT CIRCULAR NON-BEVELED TAILPIPE

D.2.4 Straight Circular Beveled Tailpipes—A beveled tailpipe is formed when the outlet of the tailpipe is not cut off square (perpendicular) to the axis of the exhaust flow. When this type of tailpipe is encountered, there is only one recommended smokemeter mounting orientation. The axis of the smokemeter light beam should be perpendicular to and passing through the central axis of the smoke plume and should be parallel to the minor axis of the elliptical shape of the tailpipe exit. The smokemeter light beam must also be within 70 mm (2.76 in) of the tailpipe outlet (Figure D2). If these guidelines are followed, L_m is equal to the tailpipe ID and can usually be adequately approximated by the tailpipe OD (see D.2.2).

D.2.5 Curved Circular Tailpipes—When the central axis of the tailpipe is curved at the approach to the exit, the tailpipe is said to be curved and the cross section of the tailpipe outlet is non-circular. To avoid erroneously low readings when this type of tailpipe is encountered, the smokemeter should be mounted such that the axis of the smokemeter light beam is perpendicular to and passing through the central axis of the smoke plume (not necessarily the centerline of the pipe) and is parallel to the minor axis of the tailpipe exit. The smokemeter light beam must also be within 70 mm (2.76 in) of the tailpipe exit (Figure D3). If these guidelines are followed, L_m is equal to the tailpipe ID and can usually be adequately approximated by the tailpipe OD (see D.2.2).

Smokemeter orientations in which the smokemeter light beam is not parallel to the minor axis of the tailpipe exit may be used, but in these cases it will be necessary to determine L_m by direct measurement.

D.2.6 Non-Circular Tailpipe—If the tailpipe cross section is non-circular, the smokemeter should be mounted such that the smokemeter light beam is perpendicular to and passes through the central axis of the smoke plume and is within 70 mm (2.76 in) of the tailpipe exit. For these cases, L_m will need to be determined by direct measurement. If the tailpipe cross section is an oval or ellipse, it is recommended that the smokemeter light beam be aligned with either the major or minor axis of the tailpipe cross section in order to facilitate the measurement of L_m (Figure D4).

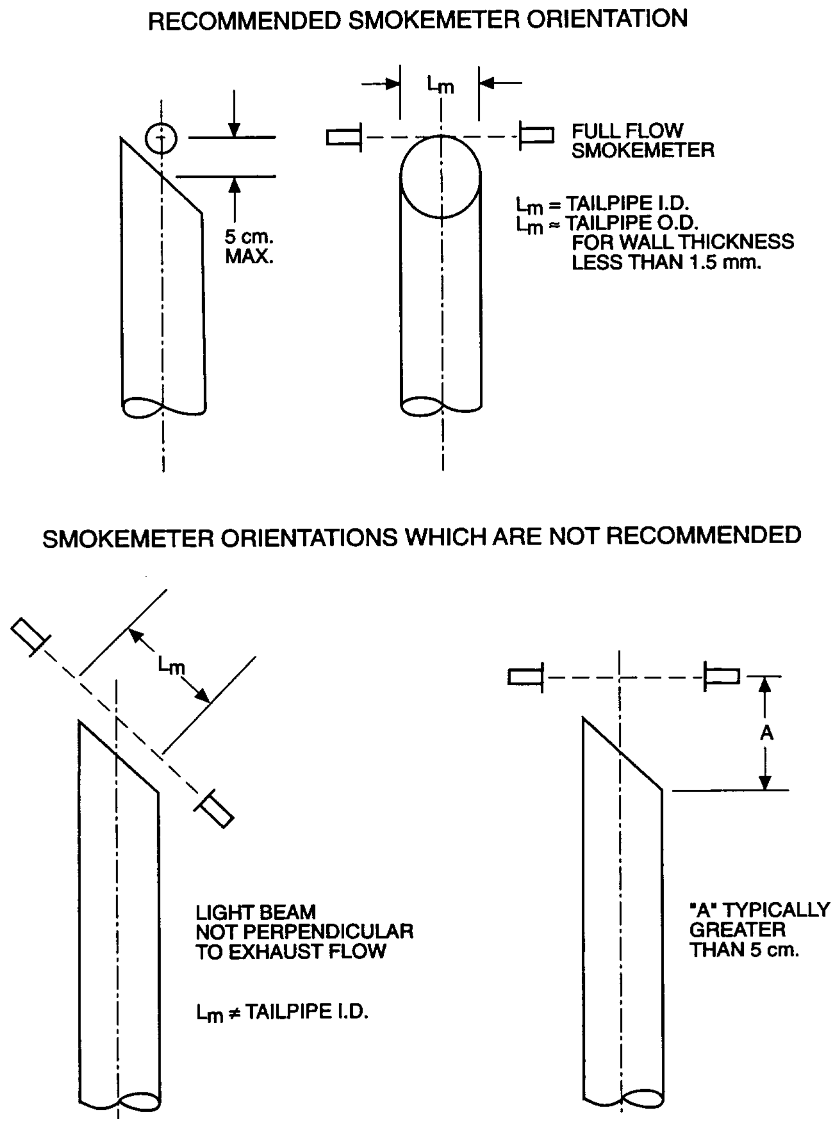

FIGURE D2—STRAIGHT CIRCULAR BEVELED TAILPIPE

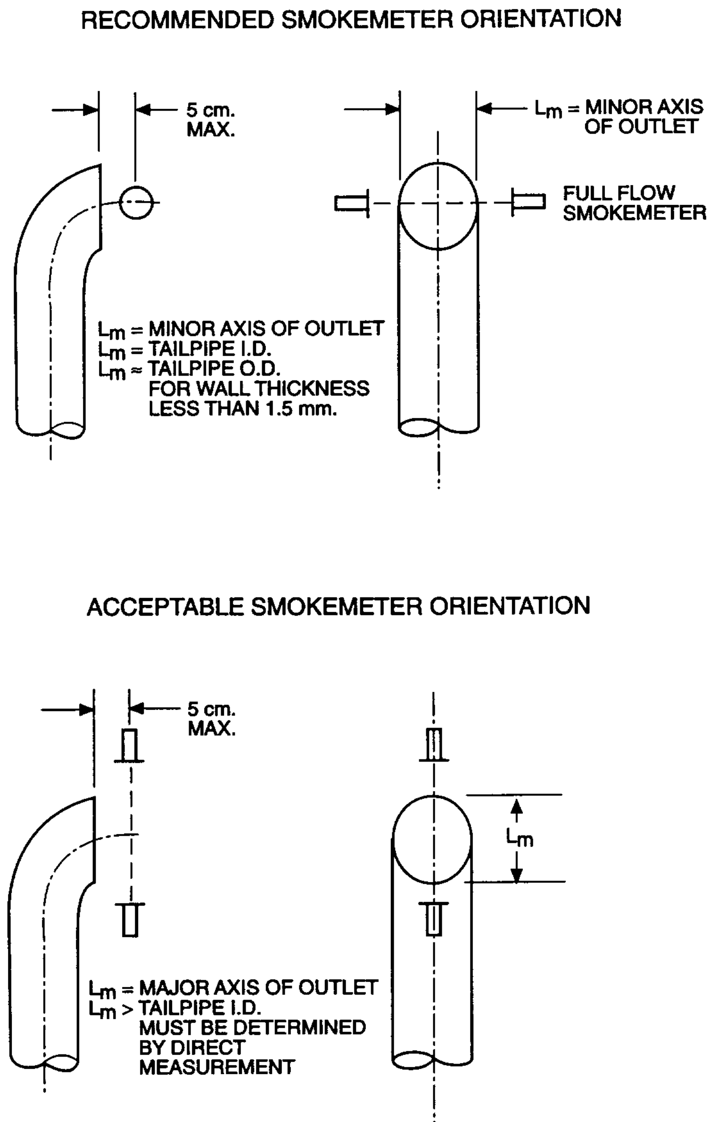

FIGURE D3—CURVED CIRCULAR TAILPIPE

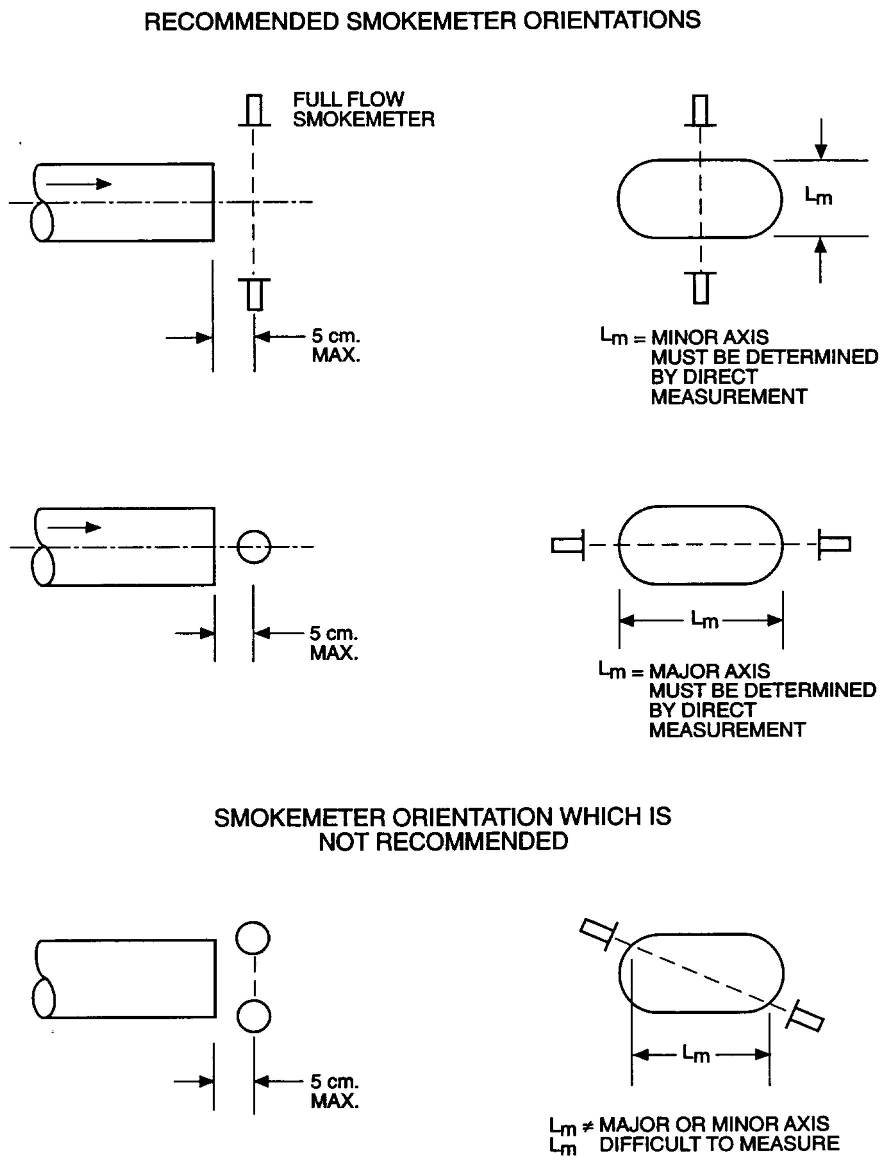

FIGURE D4—NON-CIRCULAR TAILPIPE

D.3 Other Conditions

D.3.1 Rain Caps—Smoke measurements cannot be performed using a full-flow end-of-line smokemeter when a tailpipe rain cap is operational. If present, rain caps must be removed or secured in the fully open position prior to smoke testing. If the smokemeter is installed without removing the rain cap, the meter must be oriented so that the cap does not interfere with the smoke plume or block any portion of the smokemeter light beam (Figure D5).

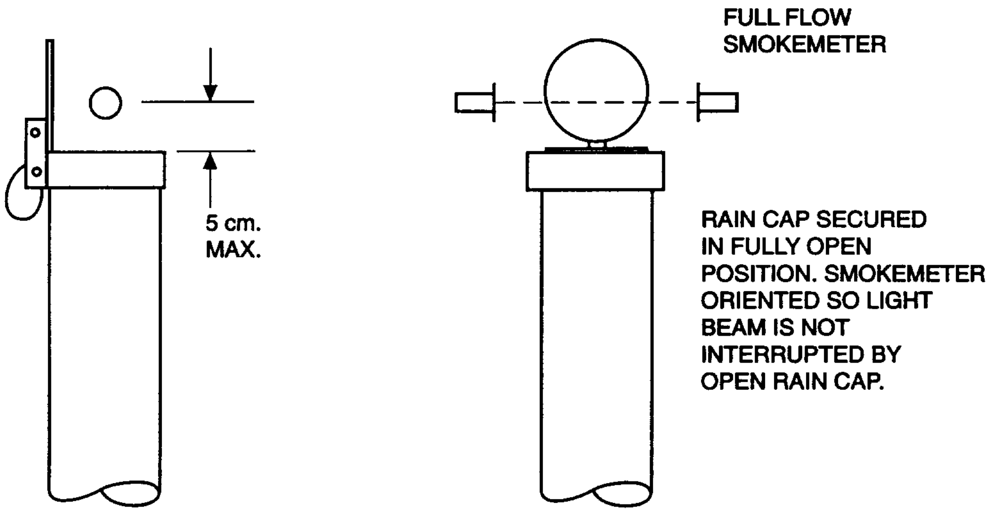

FIGURE D5—RAIN CAP

D.3.2 Downward Directed Exhaust—Many vehicles have horizontal exhaust systems affixed to the underside of the vehicle chassis. Typically these exhaust systems have a curved tailpipe which directs the exhaust flow down against the surface of the roadway.

Care should be exercised when using a full-flow end-of-line smokemeter with vehicles having this type of exhaust system. In some cases, exhaust gases can “rebound” off the roadway surface and recirculate through the smokemeter light beam causing erroneously high smoke measurements. This condition can be aggravated if road dust becomes entrained in the recirculating exhaust flow.

In most cases, little can be done to prevent this condition; however, it is recommended that testing personnel attempt to observe whether recirculation is occurring when testing vehicles with downward directed exhaust systems. If recirculation appears to be influencing the smoke measurement, the test results should be considered unreliable (too high) and should be used with caution.

Rationale—Not applicable.

Relationship of SAE Standard to ISO Standard—Not applicable.

Application—This SAE Recommended Practice applies to vehicle exhaust smoke measurements made using the Snap-Acceleration test procedure. Because this is a non-moving vehicle test, this test can be conducted along the roadside, in a truck depot, a vehicle repair facility, or other test facilities. The test is intended to be used on heavy-duty trucks and buses powered by diesel engines. It is designed to be used in conjunction with smokemeters using the light extinction principle of smoke measurement.

This procedure describes how the snap-acceleration test is to be performed. It also gives specifications for the smokemeter and other test instrumentation and describes the algorithm for the measurement and quantification of the exhaust smoke produced during the test. Included are discussions of factors which influence snap-acceleration test results and methods to correct for these conditions. Unless otherwise noted, these correction methodologies are to be considered an integral part of the snap-acceleration test procedure.

Reference Section

SAE J255a—Diesel Engine Smoke Measurement

SAE J1243—Diesel Emission Production Audit Test Procedure

SAE J1349—Engine Power Test Code—Spark Ignition and Compression Ignition—Net Power Rating

SAE J1995—Engine Power Test Code—Spark Ignition and Compression Ignition—Gross Power Rating

ISO CD 11614—Apparatus for the Measurement of the Opacity of the Light Absorption Coefficient of Exhaust Gas from Internal Combustion Engines

Code of Federal Regulations (CFR), Title 40, Part 86, Subpart I—Emission Regulation for New Diesel Heavy-Duty Engines: Smoke Exhaust Test Procedure

Procedures for Demonstrating Correlation Among Smokemeters

Developed by the SAE Heavy-Duty In-Use Emission Standards Committee

California Environmental Protection Agency
AIR RESOURCES BOARD

HDVIP/PSIP Contact List

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CALIFORNIA AIR RESOURCES BOARD

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Thank you