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Size Specific Total Particulate Emission Factors for Mobile Sources

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by

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1. INTRODUCTION

The following material was developed to predict total particulate emission factors for gasoline and diesel fueled on-road vehicles, trucks and motorcycles at various vehicle speeds for particles in the respirable size range (less than 10 microns). Particulate emissions from these vehicles may also be determined at other size intervals less than 10 microns (e.g., less than 7.5, 5, or 2.5 microns).

User inputs to the equations to determine these emission factors include area travel fractions by vehicle class, vehicle miles traveled, vehicle speed, particle size limits of interest and calendar year.

This report presents particulate emission factor equations as the sum of individual masses of lead salt, organic and sulfate components for leaded and unleaded gasoline fueled vehicles. Composite (i.e., total particulate mass) equations are presented for diesel fueled vehicles and motorcycles, and tire and brake wear particulate. These equations are subsequently accompanied by tabulated emission factors which may be inserted into the appropriate particulate component equations. Fleet sales fractions and travel fractions by model year are included for each vehicle class. The fractions within each vehicle class that are equipped with different emission control systems also are provided. Cumulative distributions of particle size for leaded and unleaded gasoline and diesel fuel are presented both graphically and tabularly. Also, for the benefit of the user, an example calculation of particulate emissions from light-duty vehicles is provided.

The procedure herein can be used to project automotive particulate emissions by those agencies developing State Implementation Plans for particulate matter or by other interested parties within or outside the EPA concerned with size specific particulate emission factor projections for mobile sources.

This document is an updated version of an April 1984 report prepared by the Environmental Protection Agency, Office of Mobile Sources. It has been revised to include estimates of travel fractions and fleet characteristics from the June 1984 EPA report, User's Guide to MOBILE3 (Mobile Source Emissions Model), EPA 460/3-84-002.[44/] Revised estimates of emission control technology fractions also have been included. The methodology presented in this document is consistent with the procedure outlined in the April 15, 1983 EPA report, Supplementary Guidelines for Lead Implementation Plans -- Updated Projections for Motor Vehicle Lead Emissions[1/] which also was recently updated by Energy and Environmental Analysis, Inc.[45/] That report can be used to project the lead component of total particulate emissions for vehicles using leaded and unleaded gasoline. In addition to the lead component, the methodology outlined in this document can be used to develop estimates of three other components of particulate emission factors. Emission factors for organics, sulfates on the Federal Test Procedure (FTP) cycle, and heavy-duty gasoline trucks came from the Draft Study of Particulate Emissions From Motor Vehicles (for Section 214 of the Clean Air Act), by the Environmental Sciences Research Laboratory, Office of Research and Development, U.S. EPA, July 1983.[8/] Sulfates on the Sulfate Emission Test (SET) cycle and motorcycle emission factors came from the March 1981 EPA report, Compilation of Air Pollutant Emission Factors: Highway Mobile Sources EPA-460-3-81-005.[2/] Light- and heavy-duty diesel particulate emission factors are referenced

*/ = Reference at end of text.

from the Draft Diesel Particulate Study, Emission Control Technology Division, Office of Mobile Sources, Office of Air and Radiation, U.S. EPA, October 1983.[4/] Emission factor estimate updating is an ongoing process and, in many cases, these values are based on testing of only a few vehicles.

This document has been revised to reflect changes in the lead content of gasoline. On March 7, 1985, EPA issued regulations which require petroleum refiners to drop the average lead content of leaded gasoline to 0.5 g/gallon by July 31, 1985 and 0.1 g/gallon by January 1, 1986 to: 1) reduce the health hazards associated with lead, and 2) to discourage the practice of misfueling which deteriorates the efficiency of vehicle emission control systems. (See Federal Register, Volume 50, No. 45, March 7, 1985.)

2. PROJECTING SIZE SPECIFIC TOTAL PARTICULATE EMISSION FACTORS

This report provides a methodology to project areawide total particulate emissions from mobile sources in a given calendar year. Particulate emissions can consist of lead salts, organics and sulfate emissions. The relative amounts vary for different vehicle types, emission control strategies and vehicle operating modes. Analysis of lead particulate indicates that most of the exhausted lead appears as salts, PbClBr. Therefore, estimates of the mass of lead particulate will be considerably larger than those predicted by the lead document, which predicts the mass of lead alone. Organic emissions include both soluble organics and elemental carbon and are important contributors to total particulate emissions from all vehicles, especially diesels. Sulfate emissions, mostly from unleaded gasoline-fueled vehicles equipped with catalysts, also are important contributors to total vehicular particulate emissions.

Section 2.1 provides an overview of: 1) the methodology used to calculate total areawide particulate emissions, and 2) the computations required to estimate the individual emission factor components by vehicle category and type of particulate. The detailed emission factor component equations for light-duty vehicles and light-duty trucks are discussed in Section 2.2. Equations for heavy-duty vehicles are described in Section 2.3. Section 2.4 presents the calculations required for motorcycles and Section 2.5 provides brake and tire wear particulate emission factor components.

2.1 OVERVIEW OF METHODOLOGY

Areawide particulate emissions (shown in Equation (2-1)) are a function of calendar year, average vehicle speed, vehicle class travel fractions, the particle size range of interest and the vehicle class emissions associated with the calendar year and vehicle speed. With the exceptions of the vehicle class emission factors, all of the above parameters are inputs selected by the user on an areawide basis to obtain the desired output of mobile source particulate emissions for the area of interest.

$$EF_{pm,n,s} = \sum_{i=1}^{6} t_{i,n} EF_{i,n,s} + EF_{brakes} (M_B) + EF_{tires} \qquad (2\text{-}1)$$

where $EF_{pm,n,s}$ = size specific all-vehicle class total particulate emission factor on January 1 of calendar year n at vehicle speed s (g/mile)

i = vehicle class designator; 1 = light-duty vehicles (LDV), 2 = light-duty trucks I (LDT1), 3 = light-duty trucks II (LDT2), 4 = heavy-duty gas vehicles (HDGV), 5 = heavy-duty diesel vehicles (HDDV), 6 = motorcycles (MC)

s = vehicle speed; avg. Federal Test Procedure (FTP) = 19.6, avg. Sulfate Emissions Test (SET) = 34.8 (miles/hr); (Note: The FTP and SET are driving cycles used for the determination of emission factors.)

$t_{i,n}$ = area travel fraction of vehicle class i in calendar year n

$EF_{i,n,s}$ = particulate emission factor for vehicle class i in calendar year n at vehicle speed s (g/mile)

EF_{brakes} = airborne brake wear particulate emission factor component = 0.0128 grams/mile; this emission factor component is assumed to be the same for all vehicle classes, vehicle speeds and calendar years (all i, s, and n) due to lack of separate information for each i, s, and n

EF_{tires} = airborne tire wear particulate emission factor component = 0.002 grams/mile; this emission factor component is assumed to be the same for all vehicle classes, vehicle speeds and calendar years (all i, s, and n) due to lack of separate information for each i, s, and n

M_B = fraction of airborne particles less than a user-specified size cutoff (0.1-10 μ) that are attributable to vehicle brake wear, from Table 2-20 or Figure 2-4

The vehicle classes for which emission factor estimates may be obtained include: 1) light-duty vehicles (passenger cars), 2) light-duty trucks I (0-6000 lbs. GVWR), 3) light-duty trucks II (6001-8500 lbs. GVWR), 4) heavy-duty gas vehicles (greater than 8,501 lbs. GVWR), 5) heavy-duty diesel vehicles (greater than 8,501 lbs. GVWR), and 6) motorcycles.

The exhaust emission factors for each vehicle class for a given calendar year ($EF_{i,n,s}$) are broken down into component emission factors in Equation (2-2). The components represent the masses of lead salt, organic and sulfate emissions from both leaded and unleaded gasoline fueled vehicles and total particulate mass from diesel vehicles--all of which are multiplied by the fraction of total vehicles of a given model year designed for use on these three fuel types. The sum of these components for each model year is also multiplied by the fraction of the vehicle class travel (disaggregated by gasoline and diesel fuel types for all vehicle categories except light-duty vehicles) that is attributable to that model year in the calendar year of interest. For example, the component ($EF_{i,j,k,n,L}$) represents the emissions in grams per mile of lead salts (k=1) from vehicle class i emitted from model year j gasoline vehicles that are on the road in calendar year n and are designed for use on leaded fuel. These emission components must be summed up over the twenty model years prior to the calendar year of interest to include all the contributing fractions of emissions from vehicles on the road.

$$EF_{i,n,s} = \sum_{j=n-19}^{n} \Big[(EF_{i,j,k_1,n,L} + EF_{i,j,k_2,L} + EF_{i,j,k_3,L})(F_{L,i,j}) + (EF_{i,j,k_1,n,NL} + EF_{i,j,k_2,NL} + EF_{i,j,k_3,NL})(F_{NL,i,j}) \Big] m_{i,j,G} + (EF_{i,j,D})(F_{D,i,j})\, m_{i,j,D} \qquad (2\text{-}2)$$

M_B = fraction of airborne particles less than a user-specified size cutoff (0.1-10 μ) that are attributable to vehicle brake wear, from Table 2-20 or Figure 2-4

The vehicle classes for which emission factor estimates may be obtained include: 1) light-duty vehicles (passenger cars), 2) light-duty trucks I (0-6000 lbs. GVWR), 3) light-duty trucks II (6001-8500 lbs. GVWR), 4) heavy-duty gas vehicles (greater than 8,501 lbs. GVWR), 5) heavy-duty diesel vehicles (greater than 8,501 lbs. GVWR), and 6) motorcycles.

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$$EF_{i,n,s} = \sum_{j=n-19}^{n} \Big[(EF_{i,j,k_1,n,L} + EF_{i,j,k_2,L} + EF_{i,j,k_3,L})(F_{L,i,j}) + (EF_{i,j,k_1,n,NL} + EF_{i,j,k_2,NL} + EF_{i,j,k_3,NL})(F_{NL,i,j}) \Big] m_{i,j,G} + (EF_{i,j,D})(F_{D,i,j})\, m_{i,j,D} \qquad (2\text{-}2)$$

different for various conditions of vehicle driving cycle (speed) and load. For the purposes of this report, however, typical or average conditions are presented to facilitate the determination of vehicle particulate emissions versus particle size.

Particle size distributions for leaded, unleaded and diesel fueled vehicles and brake wear particles are contained in Table 2-20 and also in Figures 2-1, 2-2, 2-3, and 2-4 (no distributions are available for tire wear particulate). Typically, the average diameter of particles emitted from vehicles fueled with leaded gasoline are the largest, particles emitted from vehicles fueled with unleaded gasoline are somewhat smaller and particles emitted from diesel fueled vehicles are smaller yet. Some of the data for the size distribution of lead particles are conflicting (e.g., Moran et al, 1971 which shows a larger fraction of the lead in smaller size ranges than the other leaded gasoline references). Thus, these data are less certain than those for unleaded and diesel particles. References for those reports used in the determination of particle size distributions of leaded, unleaded and diesel fueled vehicle emissions and brake wear emissions are listed in Table 2-20.

Values for M_L, $M_{NL,C}$, $M_{NL,NC}$, M_D, and M_B should be expressed as dimensionless fractions of total particulate by weight emitted below a given size cutoff. Values may be read directly from Table 2-20 for the data points listed therein, or may be read off the graphs of continuous cumulative particle size distributions in Figures 2-1, 2-2, 2-3, and 2-4 for interpolated size cutoffs (e.g., 6.5 μ, 2.5μ).

2.2 LIGHT-DUTY VEHICLES AND LIGHT-DUTY TRUCKS I AND II

This section presents the lead, sulfate and organic emission factor equations for gasoline-fueled light-duty vehicles and light-duty trucks I and II. In addition, composite particulate emission factors are presented for light-duty diesel vehicles and light-duty diesel trucks. The fractions of light-duty vehicles and light-duty trucks by model year which operate on leaded or unleaded gasoline or diesel fuel are presented in Tables 2-4, 2-9, and 2-12. Tables 2-5, 2-10, 2-13, and 2-14 contain information on light-duty vehicle and light-duty truck travel fractions from model years n to n-19. To remain consistent with the data used in MOBILE3, travel fractions are assumed to be identical for gas and diesel light-duty vehicles; but separate travel fractions are used to characterize gasoline versus diesel light-duty trucks I and light-duty trucks II.

2.2.1 Lead Emission Factors

Lead emission factors are calculated in the same manner as in the recent report entitled, Supplementary Guidelines for Lead Implementation Plans -- Updated Projections for Motor Vehicle Lead Emissions, hereinafter referred to as the "lead document."[1/] These lead emission estimates are multipled by a factor of 1.557 to account for the halogens, typically bromine and chlorine, which combine with lead to form total lead salt particulate emissions. This factor was obtained from a report by the Ethyl Corporation entitled Composition, Size, and Control of Automotive Exhaust Particulates, and is the ratio of PbClBr mass to Pb mass based on FTP results of 16 test vehicles.[22/]

LDV (Pre-1971) and LDT (Pre-1971): Leaded Fuel

For $i=1,2,3 \quad j=n-19,\ldots,1970 \quad k=1 \quad C_s=$from Table 2-7 $a_{s1,j}=(0.75)$:

$$EF_{i,j,k_1,n,L} = \left[Pb_{L,n}(0.887)(M_L) + Pb_{NL,n}(0.113)(M_{NL,NC}) \right] \frac{(0.75)(1.557)}{(E_{c,i,j})(C_s)} \qquad (2\text{-}3a)$$

where a_s = fraction of lead burned that is exhausted; for all non-catalyst vehicles and for catalyst vehicles using unleaded gasoline $a_{s1,j}$ = 0.75 (i.e., 75 percent); for catalyst vehicles using unleaded gasoline in 1975-1980, $a_{s2,j}$ = 0.40; for catalyst vehicles using leaded gasoline in 1981 and later, $a_{s2,j}$ = 0.44 (see Table 2-22)

C_s = speed-dependent fuel economy correction factor based on steady cruise or cyclic driving; available from Table 2-7 (nondimensional)

$Pb_{NL,n}$ = lead content of unleaded gasoline in calendar year n from Table 2-2 (g/gal)

$Pb_{L,n}$ = average lead content of leaded gasoline in calendar year n from Table 2-2 (g/gal)

$E_{c,i,j}$ = city/highway combined on-road fuel economy for model year j and vehicle class i from Table 2-6 (miles/gallon)

M_L = fraction of particles less than a user specifie size cutoff (0.1-10 μ) that are emitted from vehicles that are fueled with leaded gasoline, from Table 2-20 or Figure 2-1

$M_{NL,C}$ = fraction of particles less than a user specified size cutoff (0.1-10 μ) that are emitted from catalyst vehicles that are fueled with unleaded gasoline, from Table 2-20 or Figure 2-2

$M_{NL,NC}$ = fraction of particles less than a user specified size cutoff (0.1-10 μ) that are emitted from non-catalyst vehicles that are fueled with unleaded gasoline, from Table 2-19 or Figure 2-2

LDV (MY 1971-1974) and LDT (MY 1971-1978): Leaded Fuel

For i=1,2 j=1971,...,1974 k=1 C_s=from Table 2-7 $a_{s1,j}$=0.75:
and For i = 3 j=1971,...,1978

$$EF_{i,j,k_1 n,L} = \left[Pb_{L,n}(.916)(ML) + Pb_{NL,n}(0.084)(M_{NL,NC})\right] \frac{(0.75)(1.557)}{(E_{c,i,m})(C_s)} \qquad (2\text{-}3b)$$

LDV (MY 1975+) and LDT (MY 1979+): Leaded Fuel

For i=1,2 j=1975,...,n k=1 C_s=from Table 2-7 $a_{s1,j}$=0.75:
and For i=3 j=1979,...,n

$$EF_{i,j,k_1 n,L} = \left[Pb_{L,n}(0.724)(M_L) + Pb_{NL,n}(0.276)(M_{NL,NC})\right] \frac{(a_{s1,j})(1.5557)}{(E_{c,i,j})(C_s)} \qquad (2\text{-}4)$$

LDV (MY 1975+) and LDT (MY 1975+): Unleaded Fuel

For i=1,2,3 j=1975,...,n k=1 C_s=from Table 2-7 a_s=from Table 2-22:

$$EF_{i,j,k_1,n,NL} = \Big[(Pb_{NL,n})(1-r_i)(M_{NL,C})(a_{s1,j}) + \Big(Pb_{L,n}(r_i)(M_L)(F_{i,j,NL,NOCAT}) + P_i(F_{i,j,NL,CAT})(a_{s1,j})\Big) + Pb_{L,n}(r_i)(M_L)(1-P_i)(F_{i,j,NL,CAT})(a_{s,2,j})\Big] \frac{1.557}{E_{c,i,j}(C_s)} \qquad (2\text{-}5)$$

where r_i = misfueling rate for vehicle class i from Table 2-19

P_i = fraction of catalyst equipped vehicles with catalysts removed from Table 2-23

The calculation of area lead particulate emissions necessitates the determination of the percentage of burned lead exhausted (a_s). A value for a_s of 0.75 (i.e., 75 percent of the lead burned is exhausted) should be used for non-catalyst equipped, gasoline-powered vehicles. The 0.75 value is based on tests which measured exhaust emissions under cyclic driving conditions and found that 17 percent of the lead is retained by the engine (in the oil and combustion chamber) and 8 percent is retained by the muffler and exhaust pipes.[31/] For gasoline powered vehicles equipped with catalysts, a value of a_s=0.40 for 1975 to 1980 and a_s=0.44

for 1981 and later model year vehicles that have been misfueled, should be used. (For properly fueled catalyst vehicles the values of a_s for all model years is 0.75.) The value of a_s was computed from lead retention of monolithic and pelleted catalysts, respectively, and weighted for the sales mix of these catalysts in each time frame. The values of a_s are not assumed to vary with speed, since a_s is more correlated with driving mode, e.g., acceleration, cruise or deceleration, rather than speed alone, and little data is available to make a_s sensitive to all of these variables.

Combined city/highway fuel economy ($E_{c,i,j}$) is yet another factor affecting area lead particulate emissions. Fuel economy versus model year is provided in Table 2-6.

Lead particulate emissions can be determined at any speed by using Equations (2-3), (2-4), and (2-5) (for light-duty vehicles and trucks) and the appropriate value of the speed dependent fuel economy correction factor (C_s) for the vehicle speed of interest. Values of C_s at various speeds are provided in Table 2-7. It should be noted that average vehicle speed and C_s can be determined for an area by either of two approaches. One approach is to base C_s on the average vehicle speed for the area of concern. The average area vehicle speed should be a weighted average based on average speeds and VMT data for the various roadway classifications, such as limited access (greater than 5 mph), suburban roads (35 mph) and urban streets (25 mph or less). The other approach, which is considered more accurate, is to determine C_s and area emissions separately for each roadway classification (and average speed).

Area lead particulate emissions also are dependent upon the lead content of gasoline in a given calendar year. Values for the lead content of leaded ($Pb_{L,n}$) and unleaded gasoline ($Pb_{NL,n}$) are contained in Table 2-2. Values for future years will be updated as new information becomes available.

2.2.1.1 Misfueling and Fuel Switching

EPA has observed that misfueling rates (i.e., percentage of vehicles designed for use on unleaded gasoline that use leaded gasoline) are dependent on vehicle mileage and increase with vehicle mileage accumulation. Strictly speaking, this dependence on mileage should be reflected in the calculation of particulate emissions, with each model year receiving its own misfueling rate. However, this further complicates an already complex calculation. To give the user a choice, this report offers both the option of using a single average misfueling rate for all model years of a given vehicle class and exact misfueling rates for each vehicle class by vehicle age. The single average rates are determined for the weighted average mileage accumulated for each vehicle class and are listed in Table 2-19 for inspection and maintenance (I/M) and non-I/M areas. In other words, in the calculation of emission factors from 1975 on, the misfueling rate (r_i) depends only on which vehicle class (i) is being considered and whether the area of interest has an I/M program. As a result, misfueling rates and particulate emissions will be slightly overestimated, with the degree of overestimation declining with later evaluation years and essentially disappearing in 1995. For users who desire more accuracy, Table 2-19a gives exact misfueling rates for different vehicle ages and classes affected by misfueling.

The use of leaded gasoline on vehicles designed for unleaded fuel results in lead salt emissions. Since most of these vehicles have catalysts, the lead results in poisoning of the catalyst so that organic particulate emissions can be assumed to increase to the levels found with non-catalyst vehicles. Also, catalyst poisoning should result in no sulfur dioxide oxidation to sulfates. Sulfate levels are therefore assumed to be the same as those from non-catalyst vehicles.

Discretionary fuel switching (i.e., percentage of vehicles designed for use on leaded gasoline that use unleaded gasoline) is assumed to equal 11.3 percent of the leaded fleet prior to 1971, and 8.4 percent from 1971 to 1974 for the LDV and LDT I categories. The discretionary rate for the LDT II class is 8.4 percent from 1971 to 1978, and 27.6 percent thereafter. For the LDV and LDT1 classes, discretionary switching is assumed to be 27.6 percent after 1974. These discretionary rates apply only to the lead salt component of light-duty vehicle and light-duty truck I and II emissions. The misfueling rates employed here were used in the December 1983 EPA report, Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles, EPA-AA-TSS-83-10.[3/] The discretionary fuel switching rates were obtained from Energy and Environmental Analysis, Inc., Assessment of Current and Projected Trends in Light-Duty Vehicle Fuel Switching, June 1984.[7/]

2.2.2 Organic and Sulfate Emission Factors

2.2.2.1 Control System Fractions

Organic and sulfate emissions of gasoline-fueled vehicles depend on the type of vehicle emission control system in addition to the vehicle model year. The fraction of vehicles with different emission control systems to which different emission factors are applied are handled similarly to the fleet sales fractions for leaded, unleaded and diesel vehicles versus model year. The main difference is that these are fractions of the total number of vehicles designed for use of unleaded fuel and not the total number of vehicles in each vehicle class. These fractions are listed in Tables 2-3, 2-8, and 2-11 for light-duty vehicles and light-duty trucks I and II, respectively. These vehicle classes have a relatively wide range of control technology and, as a result, have a wide range of emission factor estimates. It should be noted that a small number of non-catalyst equipped vehicles have been certified for use on unleaded gasoline since 1975. These vehicles constitute a very small percentage of the total non-catalyst fleet, but are nonetheless considered in this report and have been given their own control system fraction category ($F_{i,j,NL,NOCAT}$).

The light-duty vehicle and truck emission control system fractions were obtained from the "sales-weighted" EPA emission factor in-use vehicle test data base. This data base contains gasoline-fueled vehicle mixes approximating the sales mixes for the 1975 through 1982 model years. All vehicles and trucks prior to 1975 models are assumed to be designed for use on leaded fuel (i.e., no diesel or catalyst vehicles). Emission control system fractions for 1983 and later LDVs are determined from recent projections by Energy and Environmental Analysis, Inc. in a report entitled, Forecasts of Emission Control Technology 1983-1990.[38/]

Data for 1975 through 1978 light-duty truck I technology fractions were obtained by combining EPA fuel economy data base sales figures by engine displacement and model type and Federal Certification Test Results for these years from the Federal Register, Volume 40, No. 48, March 11, 1975;[9/] Volume 41, No. 46, March 8, 1976;[10/] Volume 42, No. 110, June 8, 1977;[11/] and Volume 43, No. 181, September 18, 1978.[12/] The certification data provided emission control systems by model type and engine displacement which were matched with fuel economy sales fractions. These two data sources also served as the basis for deriving the 1979-1981 light-duty truck technology fractions.

Data for 1982 through 1984 light-duty trucks I and II technology fractions were obtained by subtracting California sales figures by engine family from Federal sales figures given in the EPA Certification data base for those years. Forecasts of post-1984 light-duty truck I and II technology fractions were developed internally and are consistent with data used for EPA emission factor projections.

2.2.2.2 Organic and Sulfate Emission Factor Components

Organic and sulfate emission factors for light-duty vehicles and light-duty trucks vary by model year, control system, vehicle speed and fuel type (leaded versus unleaded). These emission factors are derived from emission test data and are listed in Table 2-1 in terms of grams per mile. This table of emission factors is used in the following sets of equations to calculate LDV and LDT organic and sulfate emission factor components. (Table 2-1 also refers the user to the proper equation(s) listed below to which each emission factor should be applied.)

Organic Emission Factor Components

LDV and LDT (Pre-1970): Leaded Fuel, Avg. Speed = All

For i=1,2,3 j=n-19,...,1969 k=2:

$$EF_{i,j,k_2,L} = 0.193\ M_L \text{ (g/mile)} \qquad (2\text{-}6)$$

LDV AND LDT (1971-1974): Leaded Fuel, Avg. Speed = All

For i=1,2,3 j=1970,...,1974 k=2:

$$EF_{i,j,k_2,L} = 0.068\ M_L \text{ (g/mile)} \qquad (2\text{-}7)$$

LDV and LDT (1975+): Leaded Fuel, Avg. Speed = All

$$EF_{i,j,k_2,L} = 0.030\ M_L \text{ (g/mile)} \qquad (2\text{-}8)$$

LDV and LDT (1975+): Unleaded Fuel, Avg. Speed = All

$$EF_{i,j,k_2,NL} = (1-r_i)(F_{i,j,CAT})(0.017)(M_{NL,C}) \quad (2\text{-}9)$$

$$+ (r_i)(F_{i,j,CAT})(0.068)(M_L) + (F_{i,j,NL,NOCAT})(0.030)(M_{NL,NC})$$

where $F_{i,j,CAT}$ = fraction of the unleaded vehicle class i fleet equipped with a catalyst in model year j

$F_{i,j,NL,NOCAT}$ = fraction of the unleaded vehicle class i fleet without a catalyst in model year j

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Sulfate Emission Factor Components

LDV and LDT (All Model Years): Leaded Fuel, Avg. Speed = 19.6 mph

For i=1,2,3 j=n-19,...,n k=3 s=19.6:

$$EF_{i,j,k_3,L} = 0.002\ M_L\ (g/mile) \quad (2\text{-}10)$$

LDV and LDT (All Model Years): Leaded Fuel, Avg. Speed = 34.8 mph

For i=1,2,3 j=n-19,...,n k=3 s=34.8

$$EF_{i,j,k_3,L} = 0.001\ M_L\ (g/mile) \quad (2\text{-}11)$$

LDV and LDT (1975+): Unleaded Fuel, Avg. Speed = 19.6

For i=1,2,3 j=1975,...,n k=3 s=19.6

$$EF_{i,j,k_3,NL} = (1-r_i)\Big[(F_{i,j,CAT/NOAIR})(0.005)(M_{NL,C}) \tag{2-12}$$

$$+ (F_{i,j,CAT/AIR})(0.016)(M_{NL,C})$$

$$+ (F_{i,j,NL,NOCAT})(0.002)(M_{NL,NC})\Big]$$

$$+ (r_i)(0.002)(M_L)$$

where $F_{i,j,CAT/NOAIR}$ = fraction of the unleaded vehicle class i fleet equipped with a catalyst but no air pump in model year j; this includes oxidation catalyst ($F_{i,j,OXCAT}$) and three way catalyst ($F_{i,j,3WCAT}$) vehicles with no air pump

$F_{i,j,CAT/AIR}$ = fraction of the unleaded vehicle class i fleet equipped with a catalyst and an air pump in model year j; this includes oxidation catalyst ($F_{i,j,OCAT/AIR}$) and three-way plus oxidation catalyst ($F_{i,j,3WCAT/OXCAT}$) vehicles with air pumps

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LDV and LDT (1975+): Unleaded Fuel Avg. Speed = 34.8 mph

For i=1,2,3 j=1975,...,n k=3 s=34.8 r_i = from Table 2-19:

$$EF_{i,j,k_3NL} = (1-r_i)\Big[(F_{i,j,NL,NOCAT})(0.001)(M_{NL,NC}) \tag{2-13}$$

$$+ (F_{i,j,OXCAT})(0.005)(M_{NL,C}) + (F_{i,j,3WCAT})(0.001)(M_{NL,C})$$

$$+ (F_{i,j,OXCAT/AIR})(0.020)(M_{NL,C}) + (F_{i,j,3WCAT/OXCAT})$$

$$(0.025)(M_{NL,C})\Big] + (r_i)(0.001)(M_L)$$

where $F_{i,j,OXCAT}$ = fraction of the unleaded vehicle class i equpped with an oxidation catalyst but no air pump in model year j

$F_{i,j,3WCAT}$ = fraction of the unleaded vehicle class i equipped with a three-way catalyst in model year j; note these vehicles are sometimes equipped with air pumps that are usually only used during vehicle start-up; therefore, the vehicle category as a whole is assumed to emit sulfates at the same rate as non-air pump-equipped vehicles for emission factor consideration

$F_{i,j,OXCAT/AIR}$ = fraction of the unleaded vehicle class i equipped with an oxidation catalyst and an air pump in model year j

2.2.3 Diesel Emission Factors (Light-Duty)

Diesel particulate emission factors for different model years are listed separately for light-duty vehicles and light-duty trucks in Table 2-1. These emission factors are derived from test data and are used in the equations below to calculate total diesel particulate emission factor components for LDVs and LDTs. (Table 2-1 also refers the user to the proper equation below to which each emission factor should be applied.)

LDV (Pre-1981): Diesel Fuel

For i=1 j=n-19,...,1980:

$$EF_{i,j,D} = 0.700\ M_D \text{ (g/mile)} \qquad (2\text{-}14)$$

where M_D = fraction of particles less than a user-specified size cutoff (0.1-10 μ) that are emitted from vehicles that are fueled with diesel fuel, from Table 2-20 or Figure 2-3

LDV (1981-1986): Diesel Fuel

For i=1 j=1981,...,1986:

$$EF_{i,j,D} = 0.300\ M_D \text{ (g/mile)} \qquad (2\text{-}15)$$

LDV (1987+): Diesel Fuel

For i=1 j=1987,...,n:

$$EF_{i,j,D} = 0.200\ M_D\ \text{(g/mile)} \quad (2\text{-}16)$$

LDT (Pre-1981): Diesel Fuel

For i=1,2,3 j=n-19,...,1980:

$$EF_{i,j,D} = 0.800\ M_D\ \text{(g/mile)} \quad (2\text{-}17)$$

LDT (1981-1986): Diesel Fuel

For i=1,2,3 j=1981,...,1986:

$$EF_{i,j,D} = 0.300\ M_D\ \text{(g/mile)} \quad (2\text{-}18)$$

LDT (1987+): Diesel Fuel

For i=2,3 j=1987,...,n:

$$EF_{i,j,D} = 0.260\ M_D\ \text{(g/mile)} \quad (2\text{-}19)$$

2.3 HEAVY-DUTY VEHICLES

This section presents the lead, sulfate and organic emission factor component equations for gasoline-fueled heavy-duty vehicles. Composite particulate emission factor components for heavy-duty diesel vehicles also are provided. These emission factor components are then used in conjunction with estimates of sales fractions of heavy-duty vehicles by model year and fuel type (Table 2-15) and travel fractions by vintage (Tables 2-16 and 2-17) to calculate total emission factors. As shown in Table 2-15, heavy-duty gasoline vehicles use leaded gasoline prior to 1987. The fraction of unleaded vehicles from 1987 on represents the

8,501-14,000 lbs percentage of heavy-duty gasoline vehicles, and is based on the assumption that the more stringent emission standards currently proposed for 1987 and later heavy-duty gasoline vehicles in the 8,501 to 14,000 lbs range will require the use of oxidation catalysts and air injection. Heavy-duty gasoline vehicles above 14,000 lbs are assumed to consist entirely of leaded gasoline vehicles for all model years. The reader also should note that the travel fractions for heavy-duty diesel trucks in Table 2-17 are specific to calendar year 1987 and are therefore presented for example only. These fractions shift from one calendar year to the next due to the increasing penetration of diesels in the lower mileage, lighter weight categories of heavy-duty trucks (which consists of all vehicles over 8,500 lbs. GVW). To calculate heavy-duty diesel travel fractions in a particular year of interest other than 1987, the reader needs to use the projections of diesel heavy-duty vehicles in-use by GVW category and the estimates of diesel heavy-duty vehicle mileage accumulation by GVW category which are contained in Appendix A.

Table 2-6 presents data on heavy-duty truck fuel economy. Estimates of misfueling for heavy-duty gas vehicles under 14,000 lbs GVW (after model year 1986) are contained in Tables 2-19 and 2-19a. The effect of discretionary fuel switching has not been incorporated in the heavy-duty vehicle emission factor equations due to the lack of data on the current fuel purchase behavior of owners of heavy-duty vehicles. However, as new data become available these equations will be revised accordingly.

2.3.1 Lead Emission Factor Components

The following equations are used to derive lead emission factor components for heavy-duty gas vehicles operated on leaded and unleaded gasoline:

HDGV (Pre-1987): Leaded Fuel

For i=4 j=n-19,...,1986 k=1 a_s = from Table 2-22:

$$EF_{i,j,k_1 n,L} = \frac{(a_{s1,j})(Pb_{L,n})(1.557)}{E_{c,4,j}} (M_L) \qquad (2\text{-}20)$$

HDGV (1987+): Unleaded Fuel

For i=4 j=1987,...,n k=1 a_s = from Table 2-2 r_4 = from Table 2-19:

$$EF_{i,j,k_1,n,NL} = \frac{(1-r_4)(a_{s1,j})(Pb_{NL,n})(1.557)}{(E_{c,4a,j})^*} (M_{NL,C}) \qquad (2\text{-}21)$$

$$+ \frac{(r_4)(a_{s2,j})(Pb_{L,n})(1.557)}{E_{c,4a,j}} (M_L)$$

HDGV (1987+): Leaded Fuel

For i=4 j=1987,...,n k=1 a_s = from Table 2-22:

$$EF_{i,j,k_1,n,L} = \frac{(a_{s1,j})(Pb_{L,n})(1.557)}{(E_{c,4b,j})^{**}} (M_L) \qquad (2\text{-}22)$$

*4a represents the fuel economy for HDGV1 after 1986.

**4b represents the fuel economy for HDGV2 after 1986.

2.3.2 Organic Emission Factor Components

Organic emission factors for heavy-duty gasoline vehicles are listed in Table 2-1 in g/mile. These factors are used in the equations below to calculate the total HDG organic emission factor component. The reader should note that the HDG organic emission factors listed in Table 2-1 were derived assuming a constant 5.0 mpg for HDG vehicles of all model years. Therefore, the equations below have been adjusted by the factor $(5.0/E_{c,4,j})$ to account for the HDG fuel economy values currently used in MOBILE3.

HDGV (Pre-1987): Leaded Fuel

For i=4 j=n-19,...,1986 k=2:

$$EF_{i,j,k_2,L} = 0.370\ (M_L)\ (\frac{5.0}{E_{c,4,j}}) \quad (2\text{-}23)$$

HDGV (1987+): Unleaded Fuel

For i=4 j=1987,...,n k=2 r_4 = from Table 2-19:

$$EF_{i,j,k_2,NL} = \left[(1-r_4)(0.054)(M_{NL,C}) + (r_4)(0.163)(M_L)\right] (\frac{5.0}{E_{c,4a,j}}) \quad (2\text{-}24)$$

HDGV (1987+): Leaded Fuel

For i=4 j=1987,...,n k=2:

$$EF_{i,j,k_2,L} = 0.370\ (M_L)\ (\frac{5.0}{E_{c,4b,j}}) \quad (2\text{-}25)$$

2.3.3 Sulfate Emission Factor Components

Sulfate emission factors for HDG vehicles also are listed in Table 2-1 and are used in the following equations to produce HDG sulfate emission factor components. As with the HDG organic emisison factor components, the equations below contain the adjustment factor ($5.0/E_{c,4,j}$) to reflect the HDG fuel economy values currently used in MOBILE3.

HDGV (Pre-1987): Leaded Fuel

For i=4 j=n-19,...,1986 k=3:

$$EF_{i,j,k_3,L} = 0.006\ (M_L)\ (\frac{5.0}{E_{c,4,j}}) \quad (2\text{-}26)$$

HDGV (1987+): Unleaded Fuel

For i=4 j=1987,...,n k=3 r_4 = from Table 2-19:

$$EF_{i,j,k_3,L} \left[(1-r_4)(0.048)(M_{NL,C}) + (r_4)(0.006)(M_L)\right] (\frac{5.0}{E_{c,4a,j}}) \quad (2\text{-}27)$$

HDGV (1987+): Leaded Fuel

For i=4 j=1987,...,n k=3:

$$EF_{i,j,k_3,L} = 0.006\ (M_L)\ (\frac{5.0}{E_{c,4b,j}}) \qquad (2\text{-}28)$$

2.3.4 Diesel Particulate Emission Factors

Diesel particulate emission factors (measured in g/mile) for heavy-duty diesel vehicles are derived with the following equations:

HDDV (All Model Years): Diesel Fuel

For i=5 j=n-19,...,n:

$$EF_{5,j,D} = 0.7\ M_D\ (CF_{D,j}) \qquad (2\text{-}29)$$

where $CF_{D,j}$ = factor for converting gm/bhp-hr to gm/mi, from Table 2-21

2.4 MOTORCYCLE EMISSION FACTORS

This section presents the emission factors for motorcycles. Table 2-18 contains travel fractions for the motor vehicle fleet. Motorcycle sales are assumed to consist entirely of leaded gasoline vehicles for all model years. Therefore, misfueling rates for motorcycles are zero. Discretionary fuel switching rates are not incorporated into the equations due to the lack of data on the fuel purchasing habits of motorcycle owners.

Motorcycle fractions are based on 2-stroke versus 4-stroke emission factor estimates (see Table 2-1). Before 1978, most on-road motorcycle travel was done by 2-stroke vehicles (53.4 percent) and slightly less (46.6 percent) by 4-stroke vehicles according to sales figures in the 1983 Motorcycle Statistical Annual published by the Motorcycle Industry

Council, Inc.[13] In 1978, more stringent control of motorcycle emissions caused nearly all motorcycle manufacturers to build 4-stroke vehicles for on-road usage. Therefore, it is assumed that all motorcycles from 1978 on are 4-stroke vehicles since nearly all 2-stroke mileage is accumulated off-road.

The equations below present the lead emission factor component calculations for motorcycles. Due to the absence of catalyst emission controls on motorcycles, organic and sulfate emission factor components are not calculated.

<u>MC (Pre-1978): Leaded Fuel</u>

For i=6 j=n-19,...,1977:

$$EF_{6,j,L} = \left[(0.466)(0.046) + (0.534)(0.330)\right] (M_L) \qquad (2\text{-}30)$$

$$= 0.198\ M_L\ (\text{g/mile})$$

<u>MC (1978+): Leaded Fuel</u>

For i=6 j=1978,...,n:

$$EF_{6,j,L} = 0.046\ M_L\ (\text{g/mile}) \qquad (2\text{-}31)$$

2.5 BRAKE AND TIRE WEAR PARTICULATE EMISSION FACTOR COMPONENTS

Additional sources of motor vehicle particulate emissions include brake and tire wear emission components. Limited testing has been performed to estimate the contributions of brake and tire wear emissions to the total light-duty vehicle particulate emission rate. No data exist on the rate at which light-duty trucks, heavy-duty vehicles, or motorcycles emit brake and tire wear emissions. The user should be aware that brake and tire wear particulates are emitted from these vehicle classes at different rates than the light-duty vehicle rate, but since no data exists, the light-duty vehicle rate is used to estimate their contribution to total particulate emission rates.

Brake wear emissions from light-duty vehicles have been measured in a recent study and have been found to consist of significant quantities of particulate in the airborne particle size range. Airborne particulate emission rates for brake wear particles as measured on braking cycles representative of urban driving averaged 0.0128 grams per mile for light-duty gasoline vehicles.[40/] Particle size distribution for brake wear particulate (M_B) is included in this reference and is summarized in Table 2-20. The rate of 0.0128 g/mile times the appropriate fraction of M_B for the particle size cutoff of interest should be added to any calculation of particulate emissions less than 10 microns for all classes of vehicles. In the example calculation in Section 3-0 of this report, for example, M_B = 0.98, the brake wear particulate emission rate is therefore 0.0125 g/mile and the total light-duty vehicle particulate emission rate is 0.0726 g/mile. In this particular example, therefore, brake wear emissions account for 17 percent of the total particulate emission rate.

Tire wear particulate is generally larger in size than brake wear particulate and therefore consists of fewer particles in the airborne size range. Emission rates for airborne tire wear particulate for light-duty vehicles has been estimated at 0.002 g/mile.[41/ 42/] This rate should be added to calculations of particulate emissions less than 10 microns for all classes of vehicles. The addition of 0.002 g/mile in the example calculation in Section 3-0 indicates that airborne tire wear particulate accounts for about 3 percent of the total light-duty particulate emission rate.

No data on airborne particle size distribution are available for analyses of tire wear particulate emission rates at smaller particle size cutoffs (i.e., 2.5 microns or 7 microns). The user should either interpolate between zero and 10 microns to determine the appropriate emission rate for the distribution of tire wear particles below the desired size cutoff (e.g., at 7 microns tire wear emissions = 0.0014 g/mile and at 2.5 microns tire wear emissions = 0.0005 g/mile) or simply neglect tire wear particulate since it is likely to be negligible in these smaller particle size ranges.

Another source of particulate emissions for which emission factors could be developed is reentrained particulate from particles that have been deposited on road surfaces or possibly road material itself. While information is available on these reentrained particulates,[46/ 47/] they are not considered to be directly emitted by mobile sources and therefore are not included in this report.

TABLE 2-1

EMISSION FACTORS OF MOTOR VEHICLE ENGINE TOTAL PARTICULATE EMISSIONS

Applicable Model Year(s)	Particulate Component	Control System	Type of Fuel Used	Vehicle Speed (MPH)	Emission Factor (grams/mile)	Equation Used In	Emission Factor Source Reference Number
Light-Duty Gasoline Vehicles and Trucks:							
Pre-1970	Organic	NOCAT	Leaded	All	0.193	(2-6)	8
1970-1974	Organic	NOCAT	Leaded	All	0.068	(2-7)	8
1975+	Organic	NOCAT	Leaded	All	0.030	(2-8)	8(a)
1975+	Organic	CAT	Unleaded	All	0.017	(2-9)	8(b)
1975+	Organic	CAT	Leaded	All	0.068	(2-9)	8(c)
1975+	Organic	NOCAT	Unleaded	All	0.030	(2-9)	8(a)(h)
All	Sulfate	NOCAT	Leaded	19.6	0.002	(2-10)(2-12)	8
1975+	Sulfate	CAT	Leaded	19.6	0.002	(2-12)	8(d)
Pre-1975	Sulfate	NOCAT	Leaded	34.8	0.001	(2-11)	2
1975+	Sulfate	CAT/NOAIR(f)	Unleaded	19.6	0.005	(2-12)	8
1975+	Sulfate	CAT/AIR(g)	Unleaded	19.6	0.016	(2-12)	8
1975+	Sulfate	NOCAT	Unleaded	19.6	0.002	(2-12)	8(e)
1975+	Sulfate	NOCAT	Leaded	34.8	0.001	(2-11)	2
1975+	Sulfate	NOCAT	Unleaded	34.8	0.001	(2-13)	2
1975+	Sulfate	OXCAT/NOAIR	Unleaded	34.8	0.005	(2-13)	2
1975+	Sulfate	3WCAT	Unleaded	34.8	0.001	(2-13)	2
1975+	Sulfate	OXCAT/AIR	Unleaded	34.8	0.020	(2-13)	2
1975+	Sulfate	3WCAT/AIR	Unleaded	34.8	0.025	(2-13)	2
1975+	Sulfate	CAT	Leaded	34.8	0.001	(2-13)	2(d)
Light-Duty Diesel Vehicles and Trucks:							
Pre-1981	All LDDV	-	Diesel	All	0.700	(2-14)	4
1981-1986	All LDDV	-	Diesel	All	0.300	(2-15)	4
1987+	All LDDV	-	Diesel	All	0.200	(2-16)	4
Pre-1981	All LDDV	-	Diesel	All	0.800	(2-17)	4
1981-1986	All LDDV	-	Diesel	All	0.300	(2-18)	4
1987+	All LDDV	-	Diesel	All	0.260	(2-19)	4

TABLE 2-1 (cont'd)

EMISSION FACTORS OF MOTOR VEHICLE ENGINE TOTAL PARTICULATE EMISSIONS

Applicable Model Year(s)	Particulate Component	Control System	Type of Fuel Used	Vehicle Speed (MPH)	Emission Factor (grams/mile)	Equation Used In	Emission Factor Source Reference Number
Heavy-Duty Gasoline Trucks:							
Pre-1987	Organic	NOCAT	Leaded	All	0.370	(2-23)	8
1987+	Organic	CAT/AIR	Unleaded	All	0.054	(2-24)	8
1987+	Organic	CAT/AIR	Leaded	All	0.163	(2-24)	(i)
1987+	Organic	NOCAT	Leaded	All	0.370	(2-25)	
Pre-1987	Sulfate	NOCAT	Leaded	All	0.006	(2-26)	8
1987+	Sulfate	CAT/AIR	Unleaded	All	0.048	(2-27)	8
1987+	Sulfate	NOCAT	Leaded	All	0.006	(2-27)	8
Heavy-Duty Diesel Trucks:							
All	All HDDT@	-	Diesel	All	0.700*	(2-29)	8
Motorcycles:							
All	4-Stroke	-	Leaded	All	0.046	(2-30)(2-31)	2
All	2-Stroke	-	Leaded	All	0.330	(2-30)	2

(a) Ratio 1.5/3.4 of 1970-74 organic value.
(b) Combined value of organic from catalyst/no air and catalyst/air vehicles.
(c) Same as 1970-74 no catalyst leaded organic value.
(d) Misfueled vehicles.
(e) Same as no catalyst leaded value.
(f) Includes oxidation catalyst vehicles and three-way catalyst vehicles without air pumpts.
(g) Includes oxidation catalyst vehicles and three-way plus oxidation catalyst vehicles with air pumps.
(h) Value should actually be higher for the light-duty truck II class (much like the 1970-74 organic value) but no data exist.
(i) Letter from Phil Lorang, July 12, 1984.

*g/Bhp-hr

TABLE 2-2

LEAD CONTENT OF GASOLINE

Year	Leaded Gasoline* (g/gal)	Unleaded Gasoline (g/gal)
1974	1.79	0.014
1975	1.82	0.014
1976	2.02	0.014
1977	2.03	0.014
1978	1.94	0.014
1979	1.85	0.014
1980	1.38	0.014
1981	1.15	0.014
1982	1.24	0.014
1983	1.14	0.014
1984	1.10	0.014
1985	0.50	0.014
1986	0.10	0.014
1987	0.10	0.014
1988	0.10	0.014
1989	0.10	0.014
1990	0.10	0.014

*1974-1982: Lead content based upon data submitted to EPA on historical sales data for leaded gasoline and data indicating the actual pooled average lead content. The value for unleaded gasoline is based on recent MVMA fuel surveys.

1983-1990: Lead content based upon requirements for average lead content of leaded gasoline. During the first half of 1983, small refineries were subject to a pooled average lead standard. Recent EPA regulations require refiners to reduce the lead content of leaded gasoline to 0.5 g/gal by July 31, 1985 and to 0.1 g/gal by January 1, 1986 and thereafter. (See Federal Register, Vol. 50, No. 45, March 7, 1985.)

TABLE 2-3

FRACTION OF LIGHT-DUTY VEHICLE MODEL YEAR SALES EQUIPPED WITH DIFFERENT EMISSION CONTROL SYSTEMS
(Low-Altitude Non-California)

System	Pre-1975	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988+
$F_{L,l,j}$	1.000	.128	.134	.158	.126	.097	0	0	0	0	0	0	0	0	0
$F_{l,j,NL,NOCAT}$	0	.081	.020	0	0	0	0	0	0	0	0	0	0	0	0
$F_{l,j,OXCAT/NOAIR}$	0	.597	.637	.650	.650	.640	.421	.033	0	0	0	0	0	0	0
$F_{l,j,OXCAT/AIR}$	0	.322	.343	.350	.350	.345	.514	.099	.142	.109	0	0	0	0	0
$F_{l,j,3WCAT}$	0	0	0	0	0	.015	.053	.263	.313	.244	.396	.532	.587	.641	.704
$F_{l,j,3WCAT/OXCAT}$	0	0	0	0	0	0	.012	.605	.545	.647	.604	.468	.414	.359	.296
$F_{D,l,j}$	0	.003	.003	.004	.009	.028	.034	.061	.046	.053	.060	.066	.073	.080	.090
$F_{l,j,CAT}$	0	.919	.980	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$F_{l,j,CAT/NOAIR}$	0	.597	.637	.650	.650	.655	.474	.296	.149	.194	.237	.381	.450	.518	.554
$F_{l,CAT/AIR}$	0	.322	.343	.350	.350	.345	.526	.704	.851	.806	.763	.691	.587	.482	.446

SOURCES: U.S. EPA Emission Factor In-Use Test Vehicle Data Base.
EEA Forecasts of Emission Control Technology 1982-1990 (used for years 1982-1988+).
U.S. EPA Fuel Economy Data Base.

NOTES: Model year columns do not add up to 1.000. Only $F_{L,l,j}$ and $F_{D,l,j}$ are fractions of all LDVs. All other systems are fractions of all unleaded LDVs.

TABLE 2-4

FLEET SALES FRACTIONS
Light-Duty Vehicles

Model Years	Nonleaded Gasoline Fraction of LDV Fleet, $F_{NL,1,j}$*	Leaded Gasoline Fraction of LDV Fleet, $F_{L,1,j}$	Diesel Fraction of LDV Fleet, $F_{D,1,j}$**
Pre-1975	0.000	1.000	0.000
1975	0.869	0.128	0.003
1976	0.863	0.134	0.003
1977	0.838	0.158	0.004
1978	0.865	0.126	0.009
1979	0.875	0.097	0.028
1980	0.966	0.000	0.034
1981	0.939	0.000	0.061
1982	0.954	0.000	0.046
1983	0.947	0.000	0.053
1984	0.940	0.000	0.060
1985	0.934	0.000	0.066
1986	0.927	0.000	0.073
1987	0.920	0.000	0.080
1988	0.910	0.000	0.090
1989	0.900	0.000	0.100
1990	0.887	0.000	0.113
1991	0.887	0.000	0.113
1992	0.886	0.000	0.114
1993	0.886	0.000	0.114
1994	0.885	0.000	0.115
1995+	0.885	0.000	0.115

Where $F_{NL,1}$ = Estimated fraction of the LDV model year fleet which use nonleaded gasoline

$F_{L,1}$ = Estimated fraction of the LDV model year fleet which use leaded gasoline

$F_{D,1}$ = Estimated fraction of the LDV model year fleet which use diesel fuel

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*Percentages of gasoline vehicles requiring leaded and nonleaded fuel obtained from Energy and Environmental Analysis, Inc., "The Highway Fuel Consumption Model: Tenth Quarterly Report," November 1983.

**Diesel and gasoline sales projections were made by EPA based on data obtained from Energy and Environmental Analysis, Inc., "The Highway Fuel Consumption Model: Tenth Quarterly Report," November 1983.

TABLE 2-5

TRAVEL WEIGHTING FACTOR CALCULATION*
Light-Duty Vehicles

Vehicle Age	(a) January 1 Fraction Total Registration	(b) Annual Mileage Accumulation Rate	(a)(b)	[(a)(b)/(SUM)] Fraction of LDV Travel by Model Year $m_{1,j,G}$ and $m_{1,j,D}$**
1	0.028	12,818	358.9	0.038
2	0.107	12,639	1,352.4	0.142
3	0.100	11,933	1,193.3	0.125
4	0.094	11,268	1,059.2	0.111
5	0.088	10,639	936.2	0.098
6	0.080	10,045	803.6	0.084
7	0.075	9,485	711.4	0.075
8	0.069	8,955	617.9	0.065
9	0.062	8,455	524.2	0.055
10	0.056	7,983	447.0	0.047
11	0.050	7,538	376.9	0.040
12	0.043	7,117	306.0	0.032
13	0.037	6,720	248.6	0.026
14	0.031	6,345	196.7	0.021
15	0.024	5,991	143.8	0.015
16	0.018	5,657	101.8	0.011
17	0.012	5,341	64.1	0.007
18	0.008	4,043	32.3	0.003
19	0.006	4,762	28.6	0.003
20+	0.008	4,496	36.0	0.004
		SUM:	9,538.9	

*Data derived from MOBILE3.

**Travel fractions are the same for diesel and gasoline fueled LDVs.

TABLE 2-6

CITY/HIGHWAY COMBINED ON-ROAD FUEL ECONOMY
(miles/gallon)

Model Year	Fuel Economy, $E_{c,i,j}$ LDV*	LDT1**	LDT2	HDGV1+	HDGV2	HDGV++
Pre-1970	13.9	10.6	7.9	-	-	6.5
1970	13.9	10.6	7.9	-	-	6.4
1971	13.2	10.4	7.7	-	-	6.4
1972	13.1	10.2	7.4	-	-	6.4
1973	12.9	9.9	7.0	-	-	6.5
1974	12.6	9.6	6.9	-	-	6.7
1975	13.5	11.6	8.8	-	-	6.8
1976	14.8	12.3	9.7	-	-	7.3
1977	15.5	13.0	9.4	-	-	7.7
1978	16.8	13.4	9.6	-	-	8.0
1979	17.2	14.2	9.8	-	-	8.2
1980	20.0	16.1	11.5	-	-	8.4
1981	21.4	17.7	13.3	-	-	8.6
1982	22.2	18.6	13.6	-	-	8.8
1983	22.2	19.2	13.7	-	-	8.9
1984	22.8	19.9	13.9	-	-	8.9
1985	23.2	20.7	14.0	-	-	9.0
1986	23.8	21.4	14.3	-	-	9.0
1987	24.3	23.0	14.5	9.5	5.6	9.0
1988	24.8	23.3	14.7	9.5	5.6	9.1
1989	25.2	23.1	14.9	9.6	5.6	9.2
1990	25.7	24.0	15.2	9.7	5.6	9.2
1991	26.2	24.5	15.4	9.7	5.7	9.3
1992	26.6	24.4	15.7	9.8	5.7	9.4
1993	27.2	25.3	15.9	9.8	5.7	9.4
1994	27.6	25.8	16.2	9.9	5.7	9.5
1995+	29.0	26.2	16.4	10.1	5.8	9.6

*Fuel economies for LDV's based on EPA memo from Karl H. Hellman to Ralph C. Stahman regarding Light-Duty MPG, June 15, 1984.

**Fuel economies for LDT's drawn from the input data used to generate "The Highway Fuel Consumption Model: Tenth Quarterly Report," prepared by Energy and Environmental Analysis, Inc.

+Fuel economies for Heavy-duty gasoline vehicles (HDGV) were derived from figure presented in an EPA memo to Mark Wolcott from Cooper Smith, dated July 2, 1984.

++Pre-1986 fuel economies are composites of HDGV1 and HDGV2.

TABLE 2-7

FUEL ECONOMY CORRECTION FACTORS AT VARIOUS SPEEDS, C_s
(Normalized to 32.7 miles/hour-cyclic driving)

	Speed (mph)	C_s Cyclic Driving	C_s Steady Cruise
	5	0.323	0.467
	10	0.553	0.709
	15	0.692	0.997
(FTP)	20	0.790	1.153
	25	0.885	1.248
	30	0.963	1.294
	32.7	1.000	1.303
(SET)	35	1.022	1.303
	40	1.053	1.288
	45	1.073	1.256
	50	1.078	1.210
	55	1.063	1.159
	60	1.023	1.104

TABLE 2-8

FRACTION OF LIGHT-DUTY TRUCK I MODEL YEAR SALES EQUIPPED WITH DIFFERENT EMISSION CONTROL SYSTEMS (LOW-ALTITUDE NON-CALIFORNIA)

System	Pre-1975	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988+
$F_{L,2,j}$	1.000	.188	.088	.038	.027	.03	.021	.026	.021	.022	0	0	0	0	0
$F_{2,j,NL,NOCAT}$	0	.123	.225	.083	.069	.034	.027	.011	0	0	0	0	0	0	0
$F_{2,j,OXCAT/NOAIR}$	0	.570	.504	.596	.605	.561	.564	.574	.066	.092	.003	0	0	0	0
$F_{2,j,OXCAT/AIR}$	0	.307	.271	.321	.325	.405	.409	.415	.887	.687	.595	.550	.550	.150	.150
$F_{2,j,3WCAT}$	0	0	0	0	0	0	0	0	.027	.054	.126	.150	.150	.350	.350
$F_{2,j,3WCAT/OXCAT}$	0	0	0	0	0	0	0	0	.021	.167	.276	.300	.300	.500	.500
$F_{D,2,j}$	0	.002	.003	.005	.009	.028	.034	.060	.080	.100	.130	.160	.180	.210	.240
$F_{2,j,CAT}$	0	.877	.775	.917	.930	.966	.973	.989	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$F_{2,j,CAT/NOAIR}$	0	.570	.504	.596	.605	.561	.564	.574	.069	.073	.056	.080	.080	.200	.200
$F_{2,CAT/AIR}$	0	.307	.271	.321	.325	.405	.409	.415	.931	.927	.944	.920	.920	.800	.800

Sources: U.S. EPA Emission Factor In-Use Test Vehicle Data Base.
U.S. EPA Fuel Economy Data Base.
U.S. EPA Federal Register: Federal Certification Test Results 1975-78 and 1982-84.
EEA Estimates of Emission Control Systems Projections.

Note: Model year columns do not add up to 1.000. Only $F_{L,2,j}$ and $F_{D,2,j}$ are fractions of all LDTIs. All other systems are fractions of all unleaded LDTIs.

TABLE 2-9

FLEET SALES FRACTIONS
Light-Duty Trucks I

Model Years	Unleaded Gasoline Fraction of LDT1 Fleet, $F_{NL,2,j}$*	Leaded Gasoline Fraction of LDT1 Fleet, $F_{L,2,j}$	Diesel Fraction of LDT1 Fleet, $F_{D,2,j}$**
Pre-1975	0.000	1.000	0.000
1975	0.810	0.188	0.002
1976	0.909	0.088	0.003
1977	0.957	0.038	0.005
1978	0.964	0.027	0.009
1979	0.942	0.030	0.028
1980	0.945	0.021	0.034
1981	0.914	0.026	0.060
1982	0.899	0.021	0.080
1983	0.878	0.022	0.100
1984	0.870	0.000	0.130
1985	0.840	0.000	0.160
1986	0.820	0.000	0.180
1987	0.790	0.000	0.210
1988	0.760	0.000	0.240
1989	0.730	0.000	0.270
1990	0.706	0.000	0.294
1991	0.697	0.000	0.303
1992	0.688	0.000	0.312
1993	0.679	0.000	0.321
1994	0.670	0.000	0.330
1995+	0.661	0.000	0.339

Where $F_{NL,2}$ = Estimated fraction of the LDT1 model year fleet which use nonleaded gasoline.

$F_{L,2}$ = Estimated fraction of the LDT1 model year fleet which use leaded gasoline.

$F_{D,2}$ = Estimated fraction of the LDT1 model year fleet which use diesel fuel.

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*Percentages of gasoline vehicles requiring leaded and unleaded fuel obtained from Energy and Environmental Analysis, Inc., "The Highway Fuel Consumption Model: Tenth Quarterly Report," November 1983.

**Diesel and gasoline sales projections were derived from MOBILE3.

TABLE 2-10

TRAVEL WEIGHTING FACTOR CALCULATION*
Light-Duty Gas Trucks I**

Vehicle Age	(a) January 1 Fraction Total Registration	(b) Annual Mileage Accumulation Rate	(a)(b)	[(a)(b)/(SUM)] Fraction of LDV Travel by Model Year, $m_{2,j,G}$
1	0.023	17,394	400.1	0.036
2	0.089	17,079	1,520.0	0.135
3	0.085	15,839	1,346.3	0.120
4	0.081	14,690	1,189.9	0.106
5	0.076	13,624	1,035.4	0.092
6	0.072	12,636	909.8	0.081
7	0.068	11,719	796.9	0.071
8	0.064	10,868	695.6	0.062
9	0.060	10,080	604.8	0.054
10	0.055	9,348	514.1	0.046
11	0.050	8,670	433.5	0.039
12	0.046	8,041	369.9	0.033
13	0.042	7,457	313.2	0.028
14	0.038	6,916	262.8	0.023
15	0.034	6,415	218.1	0.019
16	0.029	5,949	172.5	0.015
17	0.025	5,517	137.9	0.012
18	0.021	5,117	107.5	0.009
19	0.017	4,746	80.7	0.007
20	0.025	4,402	110.1	0.010
		SUM:	11,219.1	

*Data derived from MOBILE3.

**Light-duty trucks I have a gross vehicle weight (GVW) rating of 6,000 pounds or less.

TABLE 2-11

FRACTION OF MODEL YEAR SALE OF LIGHT-DUTY TRUCKS II
BY EMISSION CONTROL SYSTEMS

System	Pre-1975	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
$F_{L,3,j}$	1.000	1.000	1.000	1.000	.988	0	0	0	0	0	0	0	0	0	0
$F_{3,j,NL,NOCAT}$	0	0	0	0	0	.008	0	0	0	0	0	0	0	0	0
$F_{3,j,OXCAT}$	0	0	0	0	0	.496	.500	.500	.222	.284	0	0	0	0	0
$F_{3,j,OXCAT/AIR}$	0	0	0	0	0	.496	.500	.500	.704	.577	.823	.800	.800	0	0
$F_{3,j,3WCAT}$	0	0	0	0	0	0	0	0	0	.012	.003	0	0	.020	.020
$F_{3,j,3WCAT/OXCAT}$	0	0	0	0	0	0	0	0	.074	.127	.174	.200	.200	.980	.980
$F_{D,3,j}$	0	0	0	0	.012	.025	.050	.050	.080	.113	.147	.180	.194	.208	.222
$F_{3,j,CAT}$	0	0	0	0	0	.992	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
$F_{3,j,CAT/NOAIR}$	0	0	0	0	0	.496	.500	.500	.222	.293	0	0	0	.020	.020
$F_{3,CAT/AIR}$	0	0	0	0	0	.496	.500	.500	.778	.707	1.000	1.000	1.000	.980	.980

Sources: U.S. EPA Emission Factor In-Use Test Vehicle Data Base.
U.S. EPA Federal Register: Federal Certification Test Results 1982-84.
EEA Estimates of Emission Control Systems Projections.

Note: Model year columns do not add up to 1.000. Only $F_{L,3,j}$ and $F_{D,3,j}$ are fractions of all LDT2s. All other systems are fractions of all unleaded LDT2s.

TABLE 2-12

FLEET SALES FRACTIONS
Light-Duty Trucks II

Model Years	Unleaded Gasoline Fraction of LDT2 Fleet, $F_{NL,3,j}$*	Leaded Gasoline Fraction of LDT2 Fleet, $F_{L,3,j}$**	Diesel Fraction of LDT2 Fleet, $F_{D,3,j}$**
Pre-1975	0.000	1.000	0.000
1975	0.000	0.998	0.002
1976	0.000	0.997	0.003
1977	0.000	0.995	0.005
1978	0.000	0.991	0.009
1979	0.972	0.000	0.028
1980	0.966	0.000	0.034
1981	0.940	0.000	0.060
1982	0.920	0.000	0.080
1983	0.900	0.000	0.100
1984	0.870	0.000	0.130
1985	0.840	0.000	0.160
1986	0.820	0.000	0.180
1987	0.790	0.000	0.210
1988	0.760	0.000	0.240
1989	0.730	0.000	0.270
1990	0.706	0.000	0.294
1991	0.697	0.000	0.303
1992	0.688	0.000	0.312
1993	0.679	0.000	0.321
1994	0.670	0.000	0.330
1995+	0.661	0.000	0.339

WHERE $F_{NL,3}$ = Estimated fraction of the LDT2 model year fleet which use nonleaded gasoline.

$F_{L,3}$ = Estimated fraction of the LDT2 model year fleet which use leaded gasoline.

$F_{D,3}$ = Estimated fraction of the LDT2 model year fleet which use diesel fuel.

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*Percentages of gasoline vehicles requiring leaded and nonleaded fuel obtained from Energy and Environmental Analysis, Inc., "The Highway Fuel Consumption Model: Tenth Quarterly Report," November 1983.

**Diesel and gasoline sales projections were derived from MOBILE3.

TABLE 2-13

TRAVEL WEIGHTING FACTOR CALCULATION*
Light-Duty Gas Trucks II**

Vehicle Age	(a) January 1 Fraction Total Registration	(b) Annual Mileage Accumulation Rate	(a)(b)	[(a)(b)/(SUM)] Fraction of LDT2 Travel by Model Year, $m_{3,j,G}$
1	0.023	18,352	422.1	0.036
2	0.089	18,001	1,602.1	0.138
3	0.085	16,622	1,412.9	0.122
4	0.081	15,348	1,243.2	0.107
5	0.076	14,172	1,077.1	0.093
6	0.072	13,087	942.3	0.081
7	0.068	12,084	821.7	0.071
8	0.064	11,158	714.1	0.062
9	0.060	10,303	618.2	0.053
10	0.055	9,514	523.3	0.045
11	0.050	8,785	439.3	0.038
12	0.046	8,112	373.2	0.032
13	0.042	7,491	314.6	0.027
14	0.038	6,917	262.8	0.023
15	0.034	6,386	217.1	0.019
16	0.029	5,897	171.0	0.015
17	0.025	5,446	136.2	0.012
18	0.021	5,028	105.6	0.009
19	0.017	4,643	78.9	0.007
20+	0.025	4,287	107.2	0.009
		SUM:	11,582.9	

*Data derived from MOBILE3.

**Light-duty trucks II have a gross vehicle weight (GVW) rating of 6,001 to 8,500 pounds.

TABLE 2-14

TRAVEL WEIGHTING FACTOR CALCULATION*
Light-Duty Diesel Trucks I and II**

Vehicle Age	(a) January 1 Fraction Total Registration	(b) Annual Mileage Accumulation Rate	(a)(b)	[(a)(b)/(SUM)] Fraction of LDDT I & II Travel by Model Year, $m_{i,j,D}$
1	0.023	17,552	403.7	0.035
2	0.087	17,230	1,499.0	0.129
3	0.083	15,964	1,325.0	0.114
4	0.079	14,791	1,168.5	0.101
5	0.075	13,705	1,027.9	0.088
6	0.071	12,699	901.6	0.078
7	0.066	11,766	776.6	0.067
8	0.062	10,901	675.9	0.058
9	0.058	10,101	585.9	0.050
10	0.054	9,359	505.4	0.043
11	0.049	8,671	424.9	0.037
12	0.045	8,035	361.6	0.031
13	0.041	7,444	305.2	0.026
14	0.037	6,897	255.2	0.022
15	0.033	6,391	210.9	0.018
16	0.029	5,921	171.7	0.015
17	0.025	5,487	137.2	0.012
18	0.020	5,084	101.7	0.009
19	0.016	4,710	75.4	0.006
20+	0.025	4,364	109.1	0.009
		SUM:	11,622.4	

*Data derived from MOBILE3.

**Light-duty trucks I and II have a gross vehicle weight (GVW) rating of 0-8,500 pounds.

TABLE 2-15

FLEET SALES FRACTIONS
Heavy-Duty Gasoline Vehicles (HDGV)*

Model Years	Unleaded Fraction of HDGV Fleet $F_{NL,4,j}$**	Leaded Fraction of HDGV Fleet $F_{L,4,j}$
Pre-1977	0.000	1.000
1977	0.000	1.000
1978	0.000	1.000
1979	0.000	1.000
1980	0.000	1.000
1981	0.000	1.000
1982	0.000	1.000
1983	0.000	1.000
1984	0.000	1.000
1985	0.000	1.000
1986	0.000	1.000
1987	0.823	0.177
1988	0.824	0.176
1989	0.825	0.175
1990	0.826	0.174
1991	0.828	0.172
1992	0.829	0.171
1993	0.833	0.167
1994	0.837	0.163
1995	0.840	0.160

*Heavy-duty gasoline vehicles have a gross vehicle weight (GVW) rating greater than 8,501 pounds.

*The estimated fractions of the HDGV model year fleets which are gasoline-powered are consistent with figures from M.C. Smith, "Heavy-Duty Vehicle Emission Conversion Factors: 1962-1997," EPA-AA/SDSB-84-1, Office of Mobile Sources, August 1984.

TABLE 2-16

TRAVEL WEIGHTING FACTOR CALCULATION*
Heavy-Duty Gasoline Vehicle (HDGV)**

Vehicle Age	(a) January 1 Fraction Total Registration	(b) Annual Mileage Accumulation Rate	(a)(b)	[(a)(b)/(SUM)] Fraction of HDGT Travel by Model Year, $m_{4,j,G}$
1	0.000	0	0.0	0.000
2	0.148	19,967	2,955.1	0.227
3	0.126	18,077	2,277.7	0.175
4	0.107	16,365	1,751.1	0.134
5	0.092	14,815	1,363.0	0.105
6	0.078	13,413	1,046.2	0.080
7	0.067	12,143	813.6	0.062
8	0.058	10,993	637.6	0.049
9	0.049	9,952	487.6	0.037
10	0.041	9,010	369.4	0.028
11	0.036	8,156	293.6	0.023
12	0.030	7,384	221.5	0.017
13	0.026	6,685	173.8	0.013
14	0.022	6,052	133.1	0.010
15	0.020	5,479	121.0	0.009
16	0.016	4,960	79.4	0.006
17	0.014	4,490	62.9	0.005
18	0.012	4,065	48.8	0.004
19	0.010	3,680	36.8	0.003
20+	0.049	3,332	163.3	0.013
		SUM:	13,035.5	

*Data derived from MOBILE3.

**Heavy-duty gasoline vehicles have a gross vehicle weight (GVW) rating greater than 8,500 pounds.

TABLE 2-17

TRAVEL WEIGHTING FACTOR CALCULATION*
For Heavy-Duty Diesel Vehicles in Calendar Year 1987

Vehicle Age	(a) January 1 Fraction Total Registration	(b)** Annual Mileage Accumulation Rate	(a)(b)	[(a)(b)/(SUM)] Fraction of HDTT 1 Travel by Model Year, $m_{5,j,D}$
1	0.000	0	0.0	0.000
2	0.166	67,910	11,273.1	0.241
3	0.13	61,749	8,521.4	0.182
4	0.115	56,155	6,457.8	0.138
5	0.097	51,073	4,954.1	0.106
6	0.080	46,457	3,716.6	0.079
7	0.067	42,260	2,831.4	0.060
8	0.056	38,447	2,153.0	0.046
9	0.047	34,982	1,644.2	0.035
10	0.040	31,832	1,273.3	0.027
11	0.033	28,968	955.9	0.020
12	0.027	26,363	711.8	0.015
13	0.023	23,995	551.9	0.012
14	0.019	21,43	415.0	0.009
15	0.015	19,883	298.2	0.006
16	0.013	18,101	235.3	0.005
17	0.011	16,41	181.3	0.004
18	0.009	15,007	135.1	0.003
19	0.008	13,665	109.3	0.002
20+	0.034	12,444	423.1	0.009
		SUM:	46,841.8	

*Data derived from MOBILE3.

**The tabulated annual mileage accumulation rate is specific to CY 1987 only. The rate shifts from one year to the next due to the increasing penetration of diesels in the lower mileage, lighter weight classes of the heavy-duty truck category (which contains all vehicles with a GVW rating over 8,500 pounds).

TABLE 2-18

TRAVEL WEIGHTING FACTOR CALCULATION*
Motorcycles

Vehicle Age	(a) January 1 Fraction Total Registration	(b) Annual Mileage Accumulation Rate	(a)(b)	[(a)(b)/(SUM)] Fraction of MC Travel by Model Year, $m_{6,j,G}$
1	0.000	0	0.0	0.000
2	0.167	4,100	685.7	0.356
3	0.159	2,800	445.7	0.232
4	0.134	2,100	281.0	0.146
5	0.142	1,600	227.0	0.118
6	0.131	1,200	157.8	0.082
7	0.080	800	63.7	0.033
8	0.051	600	30.4	0.016
9	0.028	400	11.1	0.001
10	0.010	200	2.1	0.010
11	0.098	200	19.6	0.000
12	0.000	200	0.0	0.000
13	0.000	0	0.0	0.000
14	0.000	0	0.0	0.000
15	0.000	0	0.0	0.000
16	0.000	0	0.0	0.000
17	0.000	0	0.0	0.000
18	0.000	0	0.0	0.000
19	0.000	0	0.0	0.000
20+	0.000	0	0.0	0.000
		SUM:	1,924.0	

*Data derived from MOBILE3.

TABLE 2-19

RATES OF MISFUELING (r_i)

FOR DIFFERENT VEHICLE CLASSES*

	I/M	Non-I/M
Light-Duty Vehicles (i=1)	0.09	0.20
Light-Duty Trucks I (i=2)	0.20	0.46
Light-Duty Trucks II (i=3)	0.21	0.47
Heavy-Duty Gasoline Vehicles (i=4)**	0.19	0.40
Motorcycles (i=6)	0	0

*Values in this table are expressed as fractions of the total number of vehicles in each class. Misfueling rates are determined for the weighted average mileage accumulated for each vehicle class.

**Misfueling rates for Heavy-Duty Gasoline Vehicles pertain only to heavy-duty gasoline vehicles 1 made after model year 1986.

SOURCES: The equations used to estimate misfueling as a function of mileage for I/M and non-I/M areas are drawn from "Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles," EPA-AA-TSS-83-10, Office of Mobile Sources, December 31, 1983.

Weighted average mileages by vehicle category are calculated from data contained in MOBILE3.

TABLE 2-19a

RATES OF MISFUELING (r_i) FOR DIFFERENT VEHICLE AGES AND CLASSES*

Vehicle Age	LDV Non-I/M	LDV I/M	LDTI Non-I/M	LDTI I/M	LDTII Non-I/M	LDTII I/M	HDGV1 Non-I/M	HDGV1 I/M
1	.04	.04	.22	.13	.23	.13	.18	.12
2	.07	.05	.27	.14	.27	.15	.23	.13
3	.10	.06	.31	.16	.32	.16	.28	.15
4	.13	.07	.35	.17	.36	.17	.32	.16
5	.16	.08	.38	.18	.39	.18	.36	.17
6	.18	.09	.42	.19	.43	.19	.39	.18
7	.21	.09	.45	.20	.46	.20	.42	.19
8	.23	.10	.47	.21	.49	.21	.45	.20
9	.25	.11	.50	.21	.51	.22	.48	.21
10	.27	.11	.52	.22	.54	.23	.50	.22
11	.29	.12	.55	.23	.56	.23	.52	.22
12	.31	.12	.57	.24	.58	.24	.54	.23
13	.33	.13	.59	.24	.60	.25	.56	.23
14	.34	.13	.60	.25	.62	.25	.57	.24
15	.36	.14	.62	.25	.63	.26	.59	.24
16	.37	.14	.64	.26	.65	.26	.60	.25
17	.39	.15	.65	.26	.66	.26	.61	.25
18	.40	.15	.66	.26	.68	.27	.62	.25
19	.41	.15	.68	.27	.69	.27	.63	.25
20+	.42	.16	.69	.27	.70	.28	.64	.26

*Values in this table are expressed as fractions of the total number of vehicles in each class. Misfueling rates are determined for the average mileage in each class. Misfueling rates are determined for the average mileage accumulated by each vehicle class of each vehicle age group.

**Misfueling rates for Heavy-Duty Gasoline Vehicles 1 (HDGV1) are estimates for 1987 and later calendar years. Currently all HDGV1s use leaded fuel. (For example, for the year 1990, use the first three values in either the non-I/M or I/M HDGV1 column. All HDGV1s greater than 3 years old in this case (i.e., pre-1987 vehicles) would have a misfueling rate of zero since they do not require use of unleaded fuel.

SOURCES: The equations used to estimate misfueling as a function of mileage for I/M and non-I/M areas are drawn from "Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions from Motor Vehicles," EPA-AA-TSS-83-10, Office of Mobile Sources, December 31, 1983.

Weighted average mileages by vehicle category are calculated from data contained in MOBILE3.

TABLE 2-20

AVERAGE DATA ON PARTICLE SIZE DISTRIBUTION

Leaded Fuel, M_L	Cumulative Fraction of Particulate Mass Smaller Than Diameter		
	0.2 μ	2 μ	10 μ
Median Particle Fractions, M_L	0.23	0.43	0.64
Ranges of M_L Values*	0.18-0.28	0.28-0.58	0.45-0.84

References: (author summary of) Ninomiya et al, 1970; Moran et al, 1971; Gental et al, 1973; Cantwell et al, 1972; Boyer and Laitiner, 1975; Habibi et al, 1970; Hirschler and Gilbert, 1964.

Unleaded Fuel, M_{NL}	Cumulative Fraction of Particulate Mass Smaller Than Diameter		
	0.2 μ	2 μ	10 μ
$M_{NL,C}$	0.87	0.89	0.97
Ranges of $M_{NL,C}$ Valves**	0.86-0.88	0.84-0.94	0.84-1.00
$M_{NL,NC}$	0.42	0.66	0.90
Ranges of $M_{NL,C}$ Valves	0.29-0.55	0.52-0.80	0.63-1.00

References: (author summary of) Foster et al, 1976; Trayser et al, 1976; Foster et al, 1974; Melton et al, 1973; Habibi, 1973; Gental et al, 1973.

*95 percent confidence intervals on mean of data.

**95 percent confidence intervals by "t" statistics.

TABLE 2-20

AVERAGE DATA ON PARTICLE SIZE DISTRIBUTION (cont'd)

Diesel Fuel, M_D	Cumulative Fraction of Particulate Mass Smaller Than Diameter				
	0.2 μ	1.0 μ	2.0 μ	2.5 μ	10 μ
M_D	0.73	0.86	0.90	0.92	1.00
Ranges of M_D Values+	0.69-0.75	0.76-0.93	0.86-0.95	0.88-0.95	0.97-1.00

References: Breslin, et al, 1976; Hare, 1979, Bykowski, 1981; Bykowski, 1983; McCain and Faulkner, 1979; Vuk, et al, 1976; Begeman, 1979; Carpenter and Johnson, 1979; Verrant and Kittelson, 1977.

Brake Wear Particulate, M_B	Cumulative Fraction of Particulate Mass Smaller Than Diameter				
	0.43 μ	1.1 μ	4.7 μ	7 μ	10 μ
Median Particle Fractions, M_B++	0.09	0.16	0.82	0.90	0.98
Ranges of M_B Values	Not available				

Reference: Cha et al, 1983.

+Intermediate speed, no load, prechamber engine, 2D fuel.

++Samples for determining particle size distribution were collected by running about 20 braking cycles weighted to be representative of urban driving conditions.

TABLE 2-21

LOW ALTITUDE HDDV CONVERSTION FACTORS*

Model Year	Conversion Factor (CF_j)
1951-1962	2.7420
1963-1965	2.7307
1966-1968	2.8267
1969-1971	3.0080
1972-1974	3.1917
1975-1979	3.1420
1980-1981	2.7780
1982-1984	2.5580
1985	2.4700
1986	2.4260
1987-1992	2.3600
1993-1996	2.3175
1997-2000	2.3100

*These factors are used to convert emissions in g/Bhp-hr to g/mile. They are consistent with those contained in M.C. Smith, "Heavy-Duty Vehicle Emission Conversion Factors: 1962-1977," EPA-AA-SDSB-84-1, Office of Mobile Sourcs, August 1984.

TABLE 2-22

FRACTION OF LEAD BURNED THAT IS EMITTED, a_s

	$a_{s1,j}$*		$a_{s2,j}$**
All years	.75	1975-1980	.40
		1981+	.44

*$a_{s1,j}$ is used for all vehicles using unleaded gasoline and for vehicles without catalysts using leaded gasoline.

**$a_{s2,j}$ is used for catalyst equipped vehicles using leaded gasoline.

TABLE 2-23

FRACTION OF CATALYST EQUIPPED VEHICLES WITH CATALYST REMOVED, P_i*

	P_1	P_2 and P_3
I/M	.017	.050
Non-I/M	.045	.195

*Fractions obtained from "Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions From Motor Vehicles," U.S. EPA, December 1983.

Figure 2-1

LEADED GASOLINE PARTICULATE SIZE DISTRIBUTION

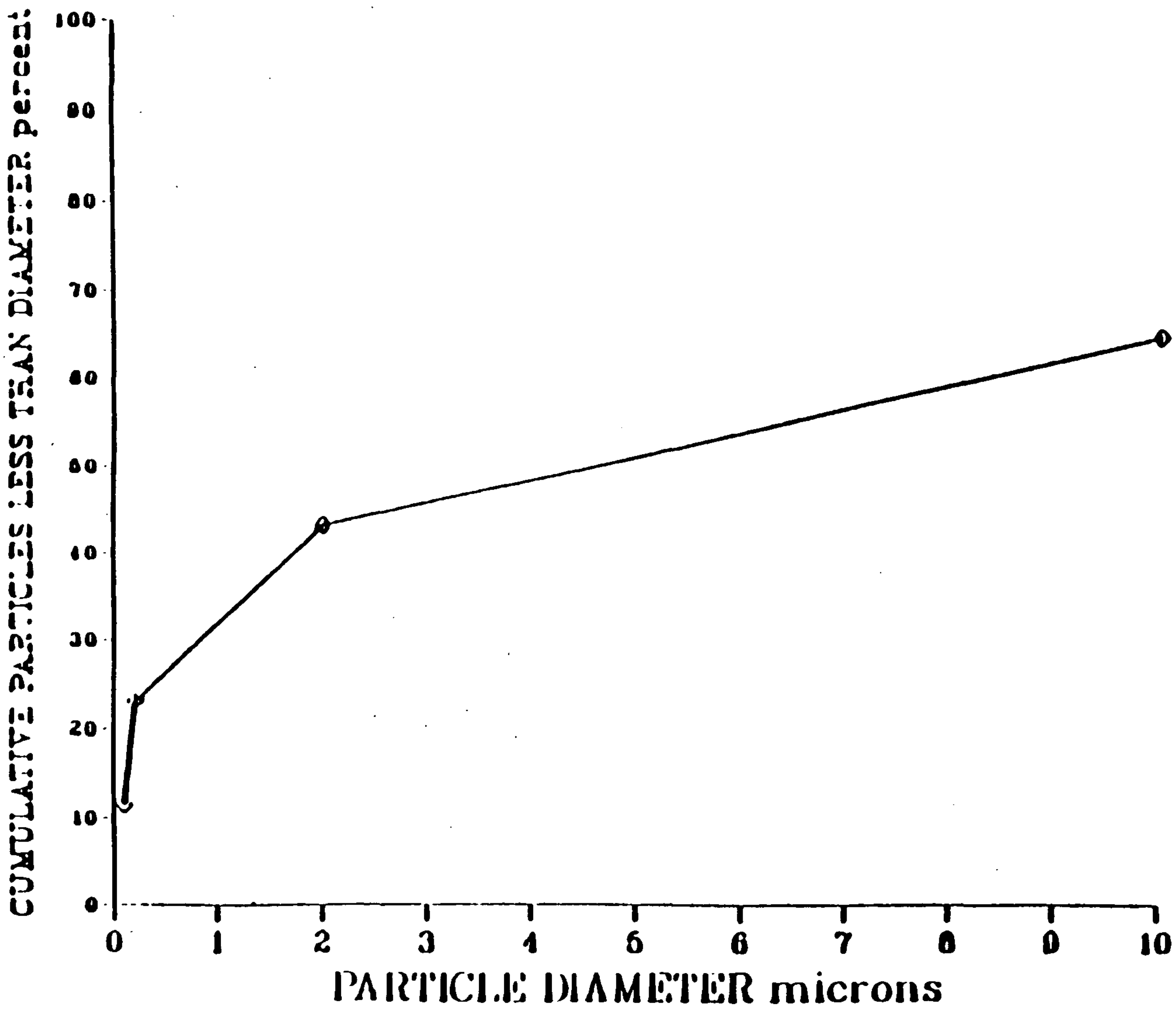
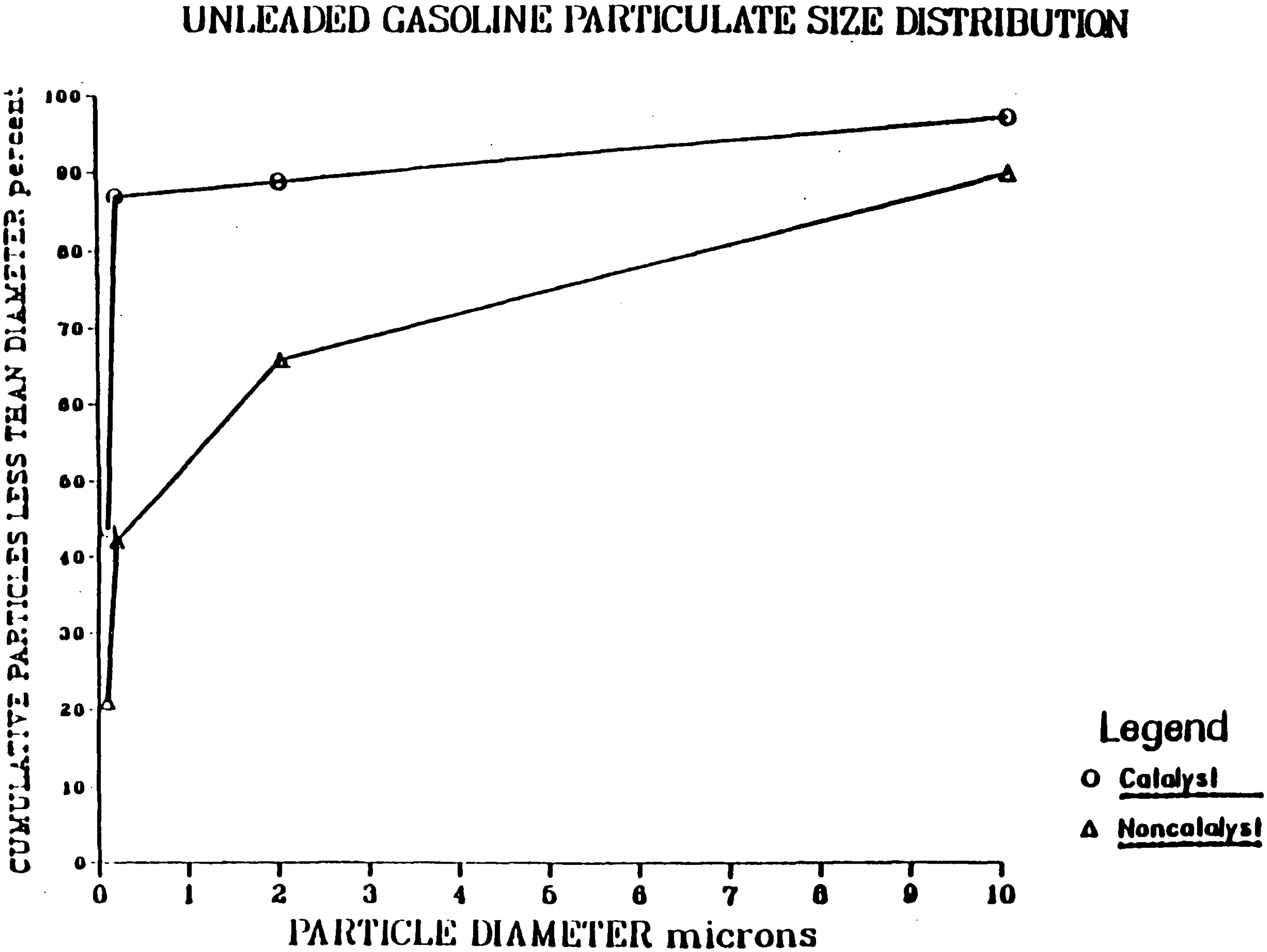
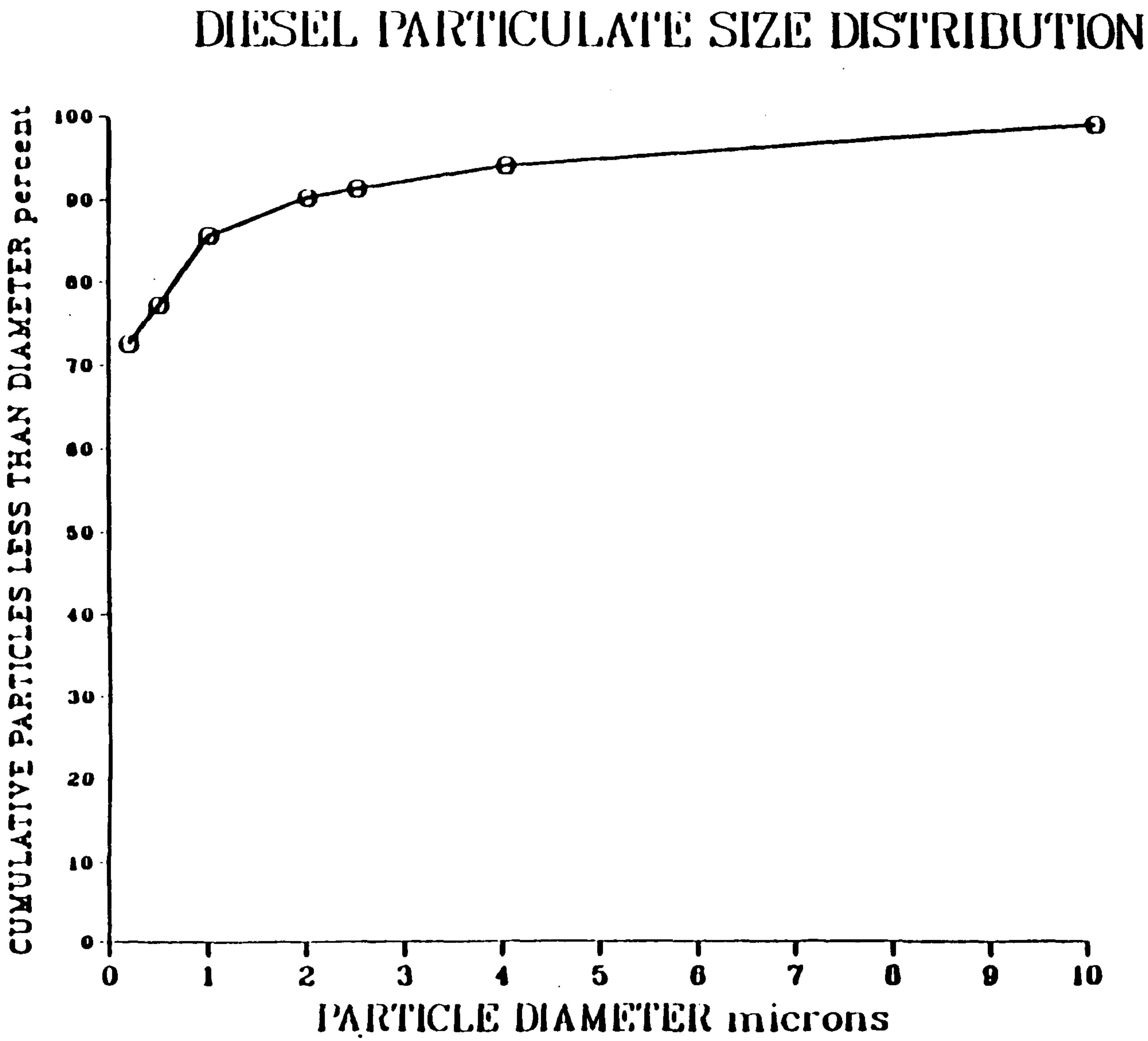


Figure 2-2



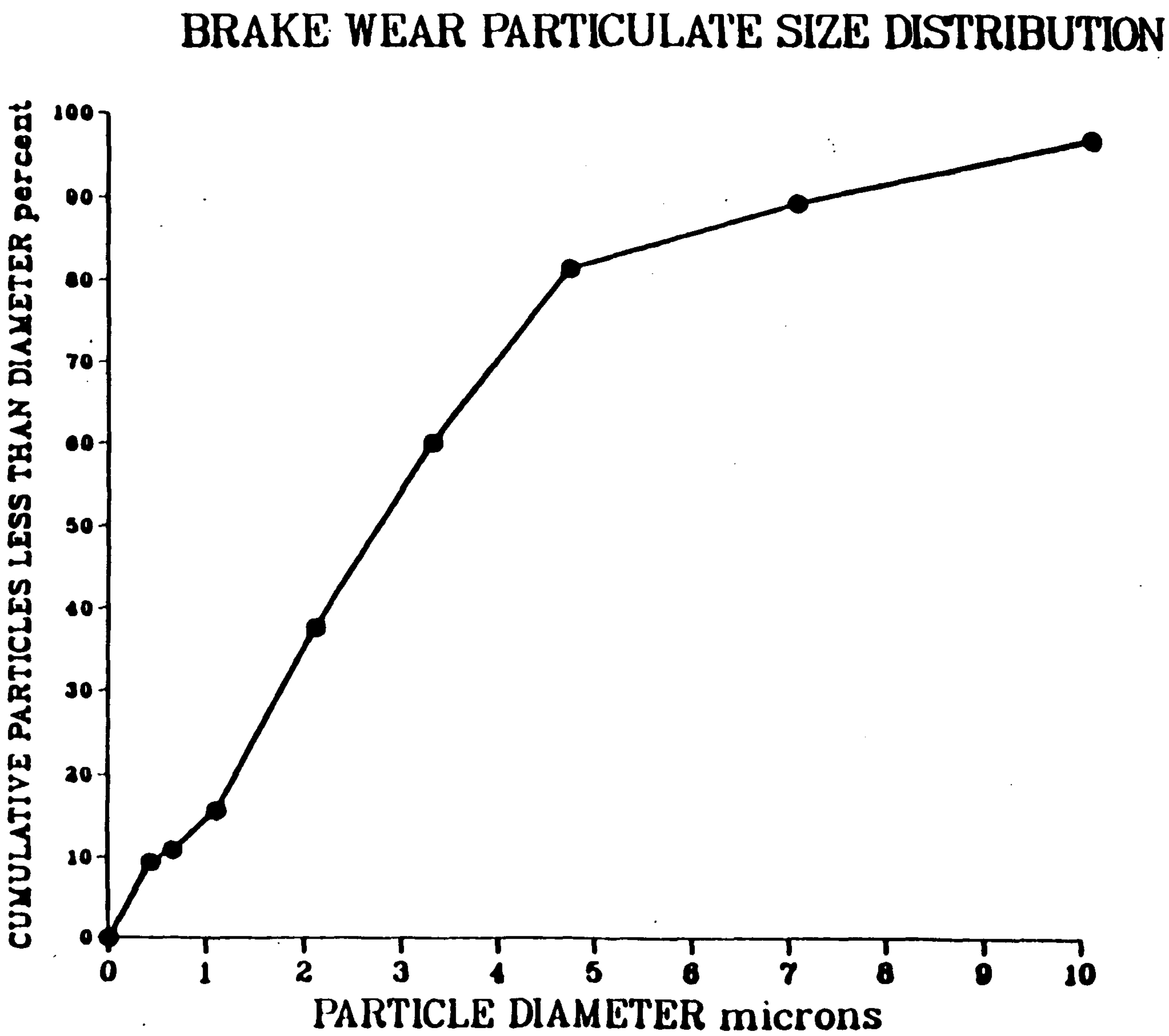
UNLEADED GASOLINE PARTICULATE SIZE DISTRIBUTION
CUMULATIVE PARTICLES LESS THAN DIAMETER percent
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
PARTICLE DIAMETER microns
Legend
Catalyst
Noncatalyst

Figure 2-3



DIESEL PARTICULATE SIZE DISTRIBUTION
CUMULATIVE PARTICLES LESS THAN DIAMETER percent
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
PARTICLE DIAMETER microns

Figure 2-4


BRAKE WEAR PARTICULATE SIZE DISTRIBUTION
CUMULATIVE PARTICLES LESS THAN DIAMETER percent
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
PARTICLE DIAMETER microns

3. EXAMPLE CALCULATION OF AUTOMOBILE PARTICULATE EMISSIONS LESS THAN 10 MICRONS

PROBLEM

For an area characterized by light-duty vehicles driving under cyclic conditions with an average speed of 19.6 miles per hour, calculate the particulate emission rate of particles less than 10 μ in diameter for the year 1985. Assume an inspection and maintenance program has been implemented in this area. The simplified misfueling rates from Table 2-19 will be used.

SOLUTION

Use equations (2-1), (2-2), (2-3), (2-4), (2-5), (2-6), (2-7), (2-8), (2-9), (2-10), (2-12), (2-14), and (2-15).

Particulate Matter Size Cutoff = 10 μ

$n=1985 \quad i=1=LDV \quad s=19.6$ mph $\quad M_B=0.98$

$t_{1,1985} = 1.0 \quad r_i$ (from Table 2-19) = 0.09

Base Equation (2-1): Total Particulate Emission Factors Vehicle Exhaust Particulate Component and Airborne Brake Wear Component and Airborne Tire Wear Component

$$EF_{PM10,1985,19.6} = (1.0)(EF_{1,1985,19.6}) + (0.0128)(0.98) + (0.002)$$

Total Vehicle Exhaust Particulate Emission Component (2-2)*:

$$EF_{1,1985,19.6} = \sum_{j=1966}^{1985} \Big[(EF_{1,1985,19.6}) + EF_{1,j,k_2,L} + EF_{1,j,k_3,L})$$

$$\times (F_{L,1,j}) + (EF_{1,j,k_1,1985,NL} + EF_{1,j,k_2,NL} + EF_{1,j,k_3,NL})$$

$$\times (F_{NL,1,j})\Big] M_{i,j,G} + (EF_{1,j,D})(F_{D,1,j})\, m_{1,j,D}$$

where $Pb_{L,1985} = 1.1$ (g/gal)

$Pb_{NL,1985} = 0.014$ (g/gal)

$M_{L,10} = 0.64$

$M_{NL,C,10} = 0.97$

$M_{NL,C,10} = 0.90$

$M_D = 1.00$

a_s = from Table 2-22

$C_s = 0.79$

$P_i = 0.017$

Using the following equations to plug into Equation (2-2) and sum over the appropriate model years:

Lead Emission Factor Component (2-3a): Leaded Fuel

For j=1966-1970 k=1

$$EF_{1,j,k_1,1985,L} = \Big[(1.1)(.887)(0.64) + (0.014)(0.113)(0.90)\Big]$$

$$\times \frac{(0.75)(1.557)}{(E_{c1,j})(0.79)} = \frac{.925}{E_{c,i,j}}$$

---

*The numbers in ( ) in equation titles refer to the equations presented in Section 2.

Lead Emission Factor Component (2-3b): Leaded Fuel

For j=1971-1974 k=1

$$EF_{1,j,k_1,1985,L} = \left[(1.1)(.916)(0.64) + (0.014)(0.084)(0.90)\right] \times \frac{(0.75)(1.557)}{(E_{c,i,j})(0.79)} = \frac{.955}{E_{c,i,j}}$$

Lead Emission Factor Component (2-4): Leaded Fuel

For j=1975-1985 k=1

$$EF_{1,j,k_1,1985,L} = \left[(1.1)(0.724)(0.64) + (0.014)(0.276)(0.90)\right] \times \frac{(0.75)(1.557)}{(E_{c,i,j})(0.79)} = \frac{.7586}{E_{c,i,j}}$$

Lead Emission Factor Component (2-5): Unleaded Fuel

For j=1975-1985 k=1

$$EF_{1,j,k_1,1985,NL} = \Big[(0.014)(0.91)(0.97)(0.75) + (1.1)(0.09)(0.64)\Big(F_{i,j,NL,NOCAT} + (0.17)(F_{i,j,NL,CAT})\Big)(0.75) + (1.1)(0.09)(0.64)(.983)(F_{i,j,NL,CAT})(a_{s2,j})\Big] \times \frac{1.557}{E_{c,1,j}(0.79)}$$

$$= 1.557\left[\frac{(.009) + F_{i,j,NL,NOCAT} + (.017)(F_{i,j,NL,CAT})(.048) + (.062)F_{i,j,NL,CAT}(a_{s2,j})}{E_{c,1,j}(0.79)}\right]$$

$$= \frac{X_{,j}}{E_{c,i,j}}$$

	$X_{,j}$
1985	.0731
1984	.0731
1983	.0731
1982	.0731
1981	.0731
1980	.0682
1979	.0682
1978	.0682
1977	.0682
1976	.0694
1975	.0717

Organic Emission Factor Component (2-6): Leaded Fuel

For j=1966-1969 k=2

$$EF_{1,j,k_2,L} = (0.193)(0.64) = 0.124 \text{ (g/mile)}$$

Organic Emission Factor Components (2-7): Leaded Fuel

For j=1970-1974 k=2

$$EF_{1,j,k_2,L} = (0.068)(0.64) = 0.044 \text{ (g/mile)}$$

Organic Emission Factor Component (2-8): Leaded Fuel

For j=1975-1985 k=2

$$EF_{1,j,k_2L} = (0.030)(0.64) = 0.019 \text{ (g/mile)}$$

Organic Emission Factor Component (2-9): Unleaded Fuel

For j=1975-1985 k=2

$$EF_{1,j,k_2,NL} = (0.91)(F_{i,j,CAT})(0.017)(0.97)$$

$$+ (0.09)(F_{1,j,CAT})(0.068)(0.64)$$

$$+ (F_{1,j,NL,NOCAT})(0.030)(0.90)$$

$$= (0.019)(F_{1,j,CAT}) + (0.027)(F_{1,j,NL,NOCAT})$$

Sulfate Emission Factor Component (2-10): Leaded Fuel

For j=1966-1985 k=3

$$EF_{1,j,k_3,L} = (0.002)(0.64) = 0.001 \text{ (g/mile)}$$

Sulfate Emission Factor Component (2-12): Unleaded Fuel

For j=1975-1985 k=3

$$EF_{1,j,k_3,NL} = (0.91)\Big[(F_{1,j,CAT/NOAIR})(0.005)(0.97)$$

$$+ (F_{1,j,CAT/AIR})(0.016)(0.97)$$

$$+ (F_{1,j,NL,NOCAT})(0.002)(0.90)\Big] + (0.09)(0.002)(0.64)$$

$$= \Big[(F_{1,j,CAT/NOAIR})(0.004) +)F_{1,j,CAT/AIR})(0.016)$$

$$+ (F_{1,j,NL,NOCAT})(0.002)\Big] + 0.0001$$

Diesel Particulate Emission Factor Component (2-14)

For j=1966-1980

$$EF_{1,j,D} = (0.700)(1.00) = 0.700 \text{ (g/mile)}$$

Diesel Particulate Emission Factor Component (2-15)

For j=1981-1985

$$EF_{1,j,D} = (0.300)(1.00) = 0.300 \text{ (g/mile)}$$

Table 3-1 presents the inputs and the sequence of calculations necessary to derive the LDV exhaust particulate emission factor components (using the above equations) and the total LDV exhaust particulate emission rate, $EF_{1,1985,19.6}$. This estimate is then combined with the airborne brake wear and airborne tire wear particulate components to obtain the total LDV particulate emission rate:

$$EF_{PM10,1985,19.6} = (1.0)(0.0581) + 0.0125 + 0.002 = 0.0726 \text{ (g/mile)}$$

This example is an estimate of particulate emissions from light-duty vehicles only. Therefore, the total emission rate from all vehicle classes for an area in calendar year 1985 can be expected to be considerably higher.

TABLE 3-1

EXAMPLE CALCULATIONS
LIGHT-DUTY VEHICLE PARTICULATE EMISSION RATE
LESS THAN 10 MICRONS FOR THE YEAR 1985

A. Emission Factor Component Calculation Inputs

Model Year$_j$	Age	$m_{l,j}$	$F_{NL,l,j}$	$F_{L,l,j}$	$E_{cl,j}$	$F_{D,l,j}$	$F_{l,j,}$CAT	$F_{l,j,NL,}$NOCAT	$F_{l,j,}$CAT/NOAIR	$F_{l,j,}$CAT/AIR
1985	1	0.038	0.934	-	24.6	0.066	1.000	-	0.381	0.691
1984	2	0.142	0.940	-	23.8	0.060	1.000	-	0.237	0.763
1983	3	0.125	0.947	-	23.2	0.053	1.000	-	0.194	0.806
1982	4	0.111	0.954	-	22.9	0.046	1.000	-	0.149	0.851
1981	5	0.098	0.939	-	21.5	0.061	1.000	-	0.296	0.704
1980	6	0.084	0.966	0.000	19.6	0.034	1.000	-	0.474	0.526
1979	7	0.075	0.875	0.097	17.8	0.028	1.000	-	0.655	0.345
1978	8	0.065	0.865	0.126	16.6	0.009	1.000	-	0.650	0.350
1977	9	0.055	0.838	0.158	15.5	0.004	1.000	-	0.650	0.350
1976	10	0.047	0.863	0.134	14.8	0.003	0.980	0.020	0.637	0.343
1975	11	0.040	0.869	0.128	13.8	0.003	0.919	0.081	0.597	0.322
1974	12	0.032	-	1.000	12.6	-	-	-	-	-
1973	13	0.026	-	1.000	12.9	-	-	-	-	-
1972	14	0.021	-	1.000	13.1	-	-	-	-	-
1971	15	0.015	-	1.000	13.2	-	-	-	-	-
1970	16	0.011	-	1.000	13.9	-	-	-	-	-
1969	17	0.007	-	1.000	13.9	-	-	-	-	-
1968	18	0.003	-	1.000	13.9	-	-	-	-	-
1967	19	0.003	-	1.000	13.9	-	-	-	-	-
1966-	20+	0.004	-	1.000	13.9	-	-	-	-	-

TABLE 3-1 (cont'd)

EXAMPLE CALCULATIONS
LIGHT-DUTY VEHICLE PARTICULATE EMISSION RATE
LESS THAN 10 MICRONS FOR THE YEAR 1985

B. Emission Factor Component Summation Descriptions

Summation (1) calculates the emission factor component in Equations (2-3a), (2-3b), and (2-4) that are used in Equation (2-2).

Summation (2) calculates the emission factor component in Equation (2-5) that is used in Equation (2-2).

Summation (3) calculates the emission factor component in Equations (2-6), (2-7), and (2-8) that are used in Equation (2-2).

Summation (4) calculates the emission factor component in Equation (2-9) that is used in Equation (2-2).

Summation (5) calculates the emission factor component in Equation (2-10) that is used in Equation (2-2).

Summation (6) calculates the emission factor component in Equation (2-12) that is used in Equation (2-2).

Summation (7) calculates the emission factor component in Equations (2-14) and (2-15) that are used in Equation (2-2).

TABLE 3-1

EXAMPLE CALCULATIONS
LIGHT-DUTY VEHICLE PARTICULATE EMISSION RATE
LESS THAN 10 MICRONS FOR THE YEAR 1985 (cont'd)

C. Emission Factor Component Calculations

Model Year, j	(1) $(EF_{1,j,k_1,1985,L})$ $(F_{L,1,j})(m_{1,j})$		(2) $(EF_{1,j,k_1,1985,NL})$ $(F_{NL,1,j})(m_{1,j})$		(3) $(EF_{1,j,k_2,L})$ $(F_{L,1,j})(m_{1,j})$		(4) $(EF_{1,j,k_2,NL})$ $(F_{NL,1,j})(m_{1,j})$		(5) $(EF_{1,j,k_3,L})$ $(F_{L,1,j})(m_{1,j})$		(6) $(EF_{1,j,k_3,NL})$ $(F_{NL,1,j})(m_{1,j})$		(7) $(EF_{1,j,D})$ $(F_{D,1,j})(m_{1,j})$
1985	-		0.0001		-		0.0007		-		0.0004		0.0008
1984	-		0.0004		-		0.0025		-		0.0017		0.0026
1983	-		0.0004		-		0.0022		-		0.0016		0.0020
1982	-		0.0003		-		0.0020		-		0.0015		0.0015
1981	-		0.0003		-		0.0017		-		0.0011		0.0018
1980	-		0.0003		-		0.0015		-		0.0008		0.0020
1979	0.0003		0.0003		0.0001		0.0012		0.00001		0.0005		0.0015
1978	0.0004		0.0002		0.0002		0.0011		0.00001		0.0005		0.0004
1977	0.0004		0.0002		0.0002		0.0009		0.00001		0.0004		0.0001
1976	0.0003		0.0002		0.0001		0.0008		0.00001		0.0003		0.0001
1975	0.0003		0.0002		0.0001		0.0007		0.00001		0.0003		0.0001
1974	0.0024		-		0.0014		-		0.00003		-		-
1973	0.0019		-		0.0011		-		0.00003		-		-
1972	0.0015		-		0.0009		-		0.00002		-		-
1971	0.0010		-		0.0007		-		0.00002		-		-
1970	0.0007		-		0.0004		-		0.00001		-		-
1969	0.0005		-		0.0009		-		0.00001		-		-
1968	0.0002		-		0.0004		-		0.00000		-		-
1967	0.0002		-		0.0004		-		0.00000		-		-
1966-	0.0003		-		0.0005		-		0.00000		-		-
SUM:	0.0104	+	0.0029	+	0.0074	+	0.0153	+	0.00017	+	0.0091	+	0.0129

= .0581 (g/mile) = $EF_{1,1985,19.6}$

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APPENDIX A

TABLE A-1

AVERAGE ANNUAL MILEAGE BY VINTAGE FOR HEAVY-DUTY TRUCKS

Age	Class 2-B	Light HDDV	Medium HDDV	Heavy HDDV
1	18,352	45,544	53,370	82,288
2	16,946	39,671	46,901	74,984
3	15,648	34,558	41,190	68,328
4	14,449	30,092	36,206	62,263
5	13,342	26,213	31,812	56,737
6	12,320	22,834	27,948	51,700
7	11,376	19,898	24,556	47,111
8	10,504	17,332	21,575	42,930
9	9,700	15,098	18,956	39,119
10	8,956	13,152	16,655	35,647
11	8,270	11,456	14,632	32,483
12	7,637	9,979	12,856	29,599
13	7,052	8,693	11,296	26,972
14	6,511	7,572	9,925	24,578
15	6,012	6,596	8,719	22,396
16	5,552	5,746	7,661	20,408
17	5,126	5,005	6,728	18,597
18	4,734	4,360	5,913	16,946
19	4,371	3,798	5,196	15,442
20+	4,036	3,308	4,565	14,071

Source: MOBILE3.

TABLE A-2

PROJECTIONS OF HEAVY-DUTY VEHICLES IN OPERATION

Year	Class 2-B	Light HDDV	Medium HDDV	Heavy HDDV
1980	0.000	0.006	0.112	1.521
1981	0.000	0.006	0.124	1.581
1982	0.049	0.009	0.135	1.599
1983	0.014	0.013	0.141	1.592
1984	0.185	0.022	0.153	1.641
1985	0.274	0.037	0.166	1.719
1986	0.370	0.053	0.177	1.816
1987	0.475	0.071	0.185	1.927
1988	0.588	0.089	0.193	2.041
1989	0.707	0.106	0.201	2.151
1990	0.831	0.122	0.208	2.258
1991	0.960	0.137	0.215	2.362
1992	1.092	0.151	0.222	2.471
1993	1.225	0.165	0.229	2.581
1994	1.354	0.178	0.237	2.693
1995	1.480	0.190	0.245	2.807
1996	1.600	0.202	0.253	2.914
1997	1.712	0.212	0.261	3.015
1998	1.816	0.222	0.269	3.108
1999	1.912	0.230	0.276	3.194
2000	1.999	0.238	0.283	3.273

Source: MOBILE3.