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Emission Control Technology Division
2565 Plymouth Road
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Supplementary Guidelines for Lead Implementation Plans — Updated Projections for Motor Vehicle Lead Emissions

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Supplementary Guidelines for Lead Implementation Plans — Updated Projections for Motor Vehicle Lead Emissions

by

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1. INTRODUCTION

The following material was developed to predict lead emission factors for gasoline fueled on-road vehicles and trucks at various vehicle speeds. User inputs to the equations to determine these emission factors include area travel fractions by vehicle class, vehicle miles traveled and vehicle speed. 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 catalysts also are provided. For the benefit of the user, an example calculation of lead emissions from light-duty vehicles is provided.

This document is an update to "Supplementary Guidelines for Lead Implementation Plans Updated Projections For Motor Vehicle Lead Emissions," U.S. EPA, EPA-450/2-83-002, Research Triangle Park, North Carolina, March 1983. This document provides updated projections for automotive lead emissions to be used by those agencies developing State Implementation Plans for lead. It has been revised to include estimates of travel fractions and fleet characterizations from the June 1984 EPA report, "User's Guide to MOBILE3 (Mobile Source Emissions Model)," EPA 460/3-84-002. It also reflects the final rulemaking recently issued by EPA which requires refiners to lower the lead content of leaded gasoline to 0.5 g/gallon on July 1, 1985 and 0.1 g/gallon by January 1, 1986 (Federal Register, Vol. 50, No. 45, March 7, 1985).

2. PROJECTING MOTOR VEHICLE LEAD EMISSIONS

Lead emissions from mobile sources are calculated based on the percentage of burned lead exhausted at different speeds, the lead content of gasoline, vehicle fuel economy and the model year mix of vehicles on the road. The lead content of gasoline and the model year vehicle mix are a function of the calendar year of interest. Fuel economy is averaged for all vehicles of the same model year in a given vehicle category.

2.1 OVERVIEW OF LEAD EMISSION CALCULATIONS

2.1.1 Individual Roadways or Areawide

For any given year subsequent to 1974, the total population of automobiles on the road consists of vehicles using either leaded or "non-leaded" (i.e., required to contain less than 0.050 gram/gallon lead) gasoline or diesel fuel. Diesel fuel is assumed to contain quantities of lead that are insignificant compared to gasoline fuel; therefore, only emissions from gasoline-powered vehicles are considered. The emission rate from automotive sources from an individual roadway (line source) is calculated by the following equation:

$$EF_{n,s} = \sum_{i=1}^{4} T(EF_{i,n,s}) \qquad (2\text{-}1)$$

where: $EF_{n,s}$ = total lead emission factor for calendar year n and speed s (g/road mile-day)

$EF_{i,n,s}$ = lead emission factor for vehicle class i in calendar year n and vehicle speed s (g/mi)

i = vehicle class designator; 1 = light-duty vehicles (LDV), 2 = light-duty trucks I (LDT1), 3 = light-duty trucks II (LDT2), and 4 = heavy-duty gas vehicles (HDGV)

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 = average daily traffic (vehicles/day)

To calculate the emission rate in units of grams/meter-second, $EF_{n,s}$ can be corrected by dividing by 1.39×10^8.

Equation (2-1) can be modified to calculate light-duty vehicle emissions as an area source rather than as specific line sources. The emission rate from automotive sources from an area source is calculated by the following equation:

$$EF_{n,s} = \sum_{i=1}^{4} V(EF_{i,n,s}) \qquad (2\text{-}2)$$

In equation (2-2), the term "T" was replaced by the term "V", the vehicle miles traveled in the area on a daily, monthly, or greater time basis. When VMT data are used, the emission rate, $EF_{n,s}$, will be expressed in grams per day, month, etc.

For both roadway and areawide emission calculations, the following generalized equation is used to compute emission factors for individual vehicle classes.

$$EF_{i,n,s} = \sum_{j=n-19}^{n} \left[(EF_{i,j,n,L})(F_{L,i,j}) + (EF_{i,j,n,NL})(F_{NL,i,j}) \right] m_{i,j} \qquad (2\text{-}3)$$

where: j = model year j = n-19, n-18,...,n-2, n-1, n

L = vehicles designed for use on leaded fuel

NL = vehicles designed for use on unleaded fuel

$F_{L,i,j}$ = fraction of the vehicle class i fleet designed for use on leaded gasoline in model year j

$F_{NL,i,j}$ = fraction of the vehicle class i fleet designed for use on unleaded gasoline in model year j

$m_{i,j}$ = travel fraction for all gasoline vehicles in class i in model year j

In the discussion which follows, specific emission component ($EF_{i,j,n,L}$ and $EF_{i,j,n,NL}$) factor equations are presented for each vehicle category.

2.2 EMISSION FACTORS FOR LIGHT-DUTY VEHICLES AND LIGHT-DUTY TRUCKS I AND II

To compute emission factors for leaded vehicles ($EF_{i,j,n,L}$) use equations (2-4), (2-5), and (2-6). For unleaded vehicles ($EF_{i,j,n,NL}$) use equation (2-7).

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

For i=1,2,3 j=n-19,...1970 C_s=from Table 2-1 $a_{s1,j}$=0.75

$$EF_{i,j,n,L} = \left[Pb_{L,n}(0.887) + Pb_{NL,n}(0.113)\right] \frac{0.75}{(E_{c,i,j})(C_s)} \qquad (2\text{-}4)$$

where: a_s = fraction of lead burned that is exhausted:

- for all non-catalyst vehicles and for catalyst vehicles using unleaded gasoline a_s = 0.75
- for catalyst vehicles using leaded gasoline in 1975-1980, $a_{s2,j}$ = .40
- for catalyst vehicles using leaded gasoline in 1981 and later, $a_{s2,j}$ = .44

C_s = speed-dependent fuel economy correction factor based on steady cruise or cyclic driving; available from Table 2-1 (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 2-9 (miles/gallon)

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

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

$$EF_{i,j,n,L} = \left[Pb_{L,n}(.916) + Pb_{NL,n}(0.084)\right] \frac{0.75}{(E_{c,i,j})(C_s)} \qquad (2\text{-}5)$$

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

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

$$EF_{i,j,n,L} = \left[Pb_{L,n}(0.724) + Pb_{NL,n}(0.276)\right] \frac{0.75}{(E_{c,i,j})(C_s)} \qquad (2\text{-}6)$$

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

For i=1,2 j=1975,...,n C_s=from Table 2-1 a_s=from Table 2-13
and For i=3 j=1979,...,n

$$EF_{i,j,n,NL} = \left[Pb_{NL,n}(1-r_i)(a_{s1,j}) + Pb_{L,n}(r_i)\left(F_{i,j,NL,NOCAT} + (P_i)(F_{i,j,CAT})\right)(a_{s1,j}) + Pb_{L,n}(r_i)(1-P_i)F_{i,j,CAT})(a_{s2,j})\right] \frac{1}{(E_{c,i,j})(C_s)} \qquad (2\text{-}7)$$

where: r_i = misfueling rate for vehicle class i from Table 2-12

P_i = fraction of catalyst equipped vehicle in class i with their catalysts removed, from Table 2-14

$F_{i,j,CAT}$ = 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

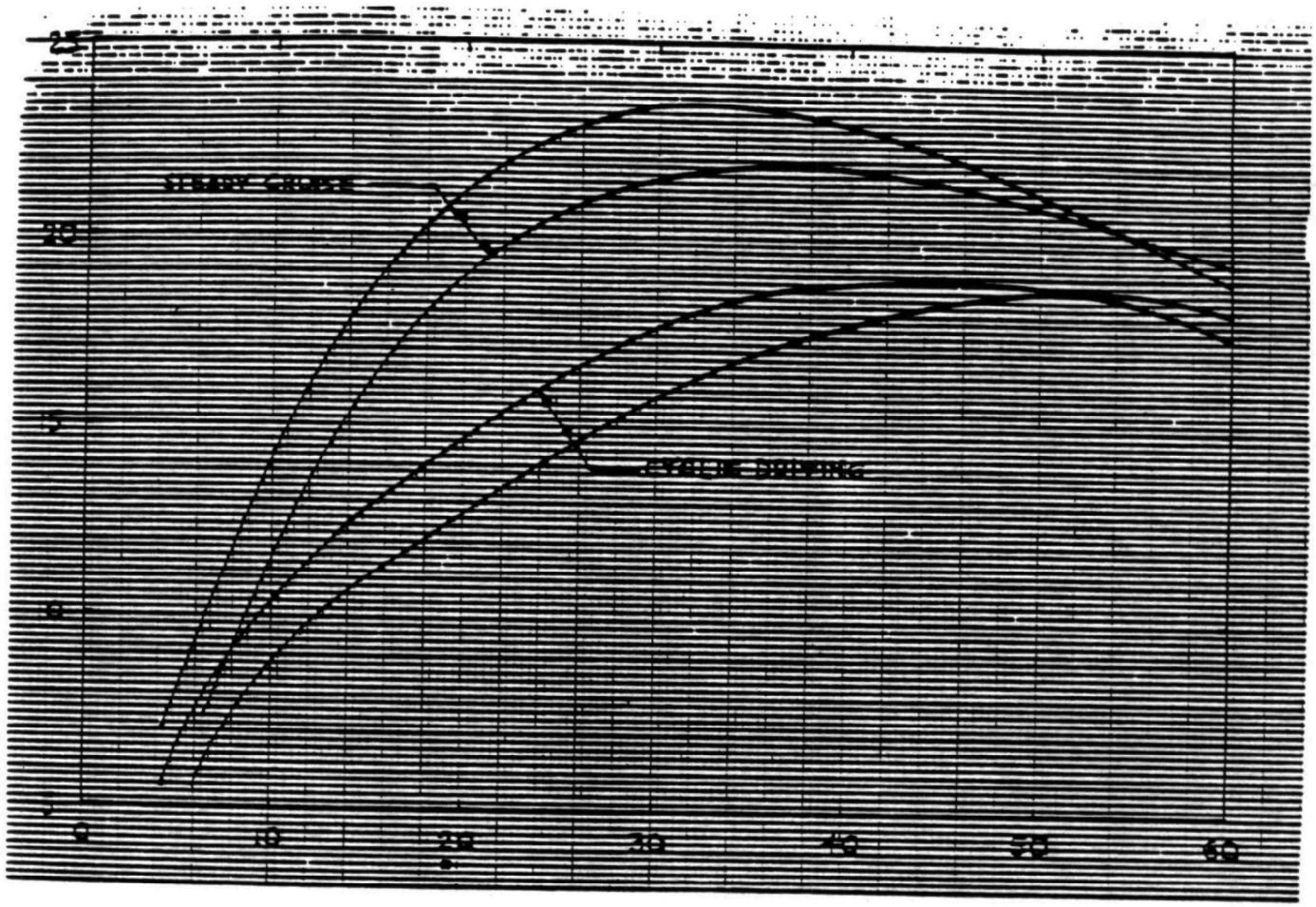
Equations (2-4), (2-5), and (2-6) collectively give the g lead/vehicle-road mile emitted by light-duty non-catalyst-equipped vehicles whereas equation (2-7) gives the g lead/vehicle-road mile emitted by catalyst-equipped vehicles. It should be noted that since 1975 a small number of non-catalyst-equipped vehicles ($F_{i,j,NL,NOCAT}$ from Table 2-15) have been certified for use on unleaded gasoline. Since these vehicles constitute such a small percentage of the total non-catalyst fleet, it will be assumed that the misfueling rate for these vehicles will be the same as that for catalyst equipped vehicles. Further discussion of selected variables used in the equations follows.

2.2.1 Speed Correction Factor

Figure 2-1 compares steady cruise fuel economy and generalized cyclic driving fuel economy to vehicle speed. Figure 2-1 was generated using data from 1973, 1974, and 1975 model year vehicles. Using the cyclic driving fuel economy at 32.7 miles per hour as the basis for comparison (since this speed is the average speed for the EPA combined city/highway fuel economy), fuel economy correction factors (C_s) for both steady cruise and cyclic driving can be calculated at various speeds. These calculations have been made and are presented in Table 2-1. Table 2-1 should be used to interpolate C_s for those speeds not listed in Table 2-1. The fuel economy correction factor for cyclic driving should be used for roadways that do not have steady speed. (The determination of how much variation in speed constitutes cyclic driving is judgmental. Questionable cases should be analyzed both ways.) Likewise, the fuel economy correction factor for steady cruise driving should be used if

Figure 2-1

FUEL ECONOMY AT VARIOUS SPEEDS*



SPEED, MPH

* Passenger Car Fuel Economy: EPA and Road, September 1980, [EPA-460/3-80-010].

free-flow, steady speed driving is indicated (e.g., along a highway at a relatively constant speed). The correction factors for cyclic and steady cruise driving become similar at high speeds as the number of stops, accelerations, and decelerations during cyclic driving decrease.

2.2.2 Fleet Travel and Fleet Sales Fractions

The fraction of annual travel by model year j ($m_{i,j}$) can be found in the last column of Tables 2-3, 2-5, and 2-7 for light-duty vehicles, light-duty trucks I, and light-duty trucks II. These values for ($m_{i,j}$) are EPA's estimates of the national values. Local values should be used where available. The term, "$m_{i,j}$" accounts for all light-duty vehicles in a given model year. The travel weighting fractions were taken from EPA's Mobile Sources Inventory Model, MOBILE3. (It should be noted that the travel weighting fractions reflect a January 1 evaluation date.)

The fractions of the model year j fleet using unleaded and leaded gasoline, $F_{NL,i,j}$ and $F_{L,i,j}$, respectively, are given in Table 2-4. Values for $F_{NL,i,j}$ and $F_{L,i,j}$ account for the increasing dieselization of the light-duty vehicle fleet. Diesel-powered vehicles are assumed to emit quantities of lead that are insignificant compared to gasoline-powered vehicles; therefore, sales fractions for diesel-powered vehicles are not included. Latest sales projections for diesel-powered vehicles were derived from MOBILE3 data. Estimates of the percentages of gasoline vehicles requiring leaded and unleaded fuel were obtained from Energy and Environmental Analysis, Inc., "The Highway Fuel Consumption Model: Tenth Quarterly Report," November 1983.

2.2.3 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 lead 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 2-12 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 lead 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 2-12a gives exact misfueling rates for different vehicle ages and classes affected by misfueling. For misfueled vehicles with their catalysts removed, the fraction (P_i) in Table 2-14 is applied to the fraction of vehicles with catalysts ($F_{l,j,CAT}$) in Table 2-15. These misfueling rates have been derived from the December 1983 EPA Report, Anti-Tampering and Anti-Misfueling Programs to Reduce In-Use Emissions From Motor-Vehicles, EPA-AA-TSS-83-10.

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. 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.

The effect of discretionary fuel switching for vehicles designed for use on leaded fuel has been incorporated into equations (2-4), (2-5), and (2-6).

2.2.4 Fuel Economy and Fuel Lead Content

Fuel economy is yet another factor affecting lead emission levels. The city/highway combined on-road fuel economies, $E_{c,i,j}$ for model years 1970 to 1988 are given in Table 2-9. LDV fuel economy estimates were taken from an internal EPA memorandum by Karl Hellman to Ralph Stahman dated June 5, 1984. LDT fuel economies were obtained from Energy and Environmental Analysis, (EEA) Inc., "The Highway Fuel Consumption Model - Tenth Quarterly Report," November 1983. HDGV mpg estimates were drawn from an EPA memo to Mark Wolcott from Cooper Smith dated July 2, 1984.

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.

2.2.5 Percent of Fuel Burned That is 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 operating on leaded fuel, and for all vehicles using unleaded fuel. 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. 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. These values of a_s do not vary with speed, since a_s is more correlated with driving mode, e.g., acceleration, cruise or deceleration, rather than speed alone.

2.3 LEAD EMISSIONS FROM OTHER GASOLINE-POWERED VEHICLES

In addition to light-duty gasoline-powered vehicles, other vehicles to consider include heavy-duty gasoline-powered trucks. (Motorcycles are assumed to emit quantities of lead that are insignificant compared to other gasoline-powered vehicles.)

Heavy-duty gasoline-powered trucks are assumed to burn leaded gasoline until 1987. It is assumed that emission standards effective in 1987 will require all new heavy-duty gasoline-powered trucks under 14,001 lbs GVW to use catalytic converters and thereby burn unleaded fuel. The emission rate for heavy-duty gasoline powered trucks prior to 1987 is calculated by using the following modification of equation (2-4):

HDGV (Pre MY 1987): Leaded Fuel

For $i=4$ $j=n-19,\ldots,1986$ C_s=from Table 2-1 $a_{sl,j}=0.75$

$$EF_{i,n,s} = \frac{a_{sl,j}\ Pb_{L,n}}{E_{c,i,j}\ C_s} \qquad (2\text{-}8)$$

HDGV (Post MY 1986): Leaded Fuel

For $i=4$ $j=1987,\ldots,n$ C_s=from Table 2-1 a_s=from Table 2-13

$$EF_{i,n,s} = \frac{Pb_{NL,n}\, m_{i,j}(1-r_i)(a_{sl,j})}{E_{c,4a,i}^{*}\ (C_s)} + \frac{Pb_{L,n}\, m_{i,j}(r_i)(a_{s2,j})}{E_{c,4b,i}^{**}\ (C_s)} \qquad (2\text{-}9)$$

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

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

Values for the variables used in equations (2-8) and (2-9) are given in the following tables/figures:

Variable	HDGV
a_s	Table 2-13
C_s	Table 2-1
$Pb_{NL,n}$; $Pb_{L,n}$	Table 2-2
$m_{i,j}$	Table 2-10
$E_{c,i,j}$	Table 2-9
R_i	Table 2-12

Fleet sales fractions for heavy-duty gasoline vehicles projected to 1995, are given in Table 2-11. Heavy-duty gasoline vehicles have a gross vehicle weight (GVW) rating of greater than 8,500 lbs GVW. The fleet sales fractions are decreasing with model year, reflecting the increasing dieselization of the heavy-duty fleet. These estimated fleet sales fractions can be used when projecting T, the average daily traffic (heavy-duty gasoline trucks/day), for future years.

TABLE 2-1

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 2-2

LEAD CONTENT OF GASOLINE

Year	Leaded Gasoline* (g/gal) Pb_L	Unleaded Gasoline (g/gal) Pb_{NL}
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 which were recently revised by EPA for 1985 and beyond and published in the Federal Register (Federal Register, Vol. 50, No. 45, March 7, 1985).

TABLE 2-3

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, $m_{l,j}$
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.

TABLE 2-4

FLEET SALES FRACTIONS
Light-Duty Vehicles*

Model Years	Nonleaded Gasoline Fraction of LDV Fleet, $F_{NL,l,j}$**	Leaded Gasoline Fraction of LDV Fleet, $F_{L,l,j}$
Pre-1975	0.000	1.000
1975	0.869	0.128
1976	0.863	0.134
1977	0.838	0.158
1978	0.865	0.126
1979	0.875	0.097
1980	0.966	0.000
1981	0.939	0.000
1982	0.954	0.000
1983	0.947	0.000
1984	0.940	0.000
1985	0.934	0.000
1986	0.927	0.000
1987	0.920	0.000
1988	0.910	0.000
1989	0.900	0.000
1990	0.887	0.000
1991	0.887	0.000
1992	0.886	0.000
1993	0.886	0.000
1994	0.885	0.000
1995+	0.885	0.000

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

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

*Percentages of gasoline vehicles requiring leaded and nonleaded fuel obtained from EPA Certification Data Base.

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

TABLE 2-5

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, $m_{2,j}$
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 2-6

FLEET SALES FRACTIONS
Light-Duty Trucks I*

Model Years	Unleaded Gasoline Fraction of LDT1 Fleet, $F_{NL,2}$**	Leaded Gasoline Fraction of LDT1 Fleet, $F_{L,2}$
Pre-1975	0.000	1.000
1975	0.810	0.188
1976	0.909	0.088
1977	0.957	0.038
1978	0.964	0.027
1979	0.942	0.030
1980	0.945	0.021
1981	0.914	0.026
1982	0.899	0.021
1983	0.878	0.022
1984	0.870	0.000
1985	0.840	0.000
1986	0.820	0.000
1987	0.790	0.000
1988	0.760	0.000
1989	0.730	0.000
1990	0.706	0.000
1991	0.697	0.000
1992	0.688	0.000
1993	0.679	0.000
1994	0.670	0.000
1995+	0.661	0.000

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.

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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 2-7

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, $m_{3,j}$
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 2-8

FLEET SALES FRACTIONS
Light-Duty Trucks II*

Model Years	Unleaded Gasoline Fraction of LDT2 Fleet, $F_{NL,3}$**	Leaded Gasoline Fraction of LDT2 Fleet, $F_{L,3}$
Pre-1975	0.000	1.000
1975	0.000	0.998
1976	0.000	0.997
1977	0.000	0.995
1978	0.000	0.991
1979	0.972	0.000
1980	0.966	0.000
1981	0.940	0.000
1982	0.920	0.000
1983	0.900	0.000
1984	0.870	0.000
1985	0.840	0.000
1986	0.820	0.000
1987	0.790	0.000
1988	0.760	0.000
1989	0.730	0.000
1990	0.706	0.000
1991	0.697	0.000
1992	0.688	0.000
1993	0.679	0.000
1994	0.670	0.000
1995+	0.661	0.000

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.

---

*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 2-9

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 and later	29.0	26.2	16.4	10.1	5.8	9.6

*Fuel economies for LDV's from MOBILE3 data 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 2-10

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, $m_{4,j}$
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 2-11

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

Model Years	Unleaded Fraction of HDGV Fleet $F_{L,4,j}$**	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	0.159

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

**The estimated fractions of the HDGV model year fleets which are unleaded are based on figures from "Historical and Projected Emissions Conversion Factor and Fuel Economy for Heavy-Duty Trucks 1962-2002," prepared for MVMA by Energy and Environmental Analysis, Inc., December 1983. These estimates are consistent with the data presented in "Heavy-Duty Vehicle Emission Conversion Factors: 1962-1997 prepared by M.C. Smith IV, U.S. Environmental Protection Agency, August, 1984.

TABLE 2-12

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 (i=4)**	0.19	0.40

*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 those trucks 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 2-12a

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

Vehicle Age	LDV		LDTI		LDTII		HDGV1 **	
	Non-I/M	I/M	Non-I/M	I/M	Non-I/M	I/M	Non-I/M	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 2-13

FRACTION OF LEAD BURNED THAT IS EXHAUSTED, 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 2-14

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.

TABLE 2-15

FRACTION OF CATALYST AND NON-CATALYST VEHICLES BUILT TO USE UNLEADED FUEL

	LDV		LDTI		LDTII	
	$F_{1,i,CAT}$	$F_{1,i,NL,NOCAT}$	$F_{2,i,CAT}$	$F_{2,i,NL,NOCAT}$	$F_{3,i,CAT}$	$F_{3,i,NL,NOCAT}$
1975	0.919	0.081	0.877	0.123	-	-
1976	0.980	0.020	0.775	0.225	-	-
1977	1.000	-	0.917	0.083	-	-
1978	1.000	-	0.930	0.069	-	-
1979	1.000	-	0.966	0.034	0.992	0.008
1980	1.000	-	0.973	0.027	1.000	-
1981	1.000	-	0.989	0.011	1.000	-
1982	1.000	-	1.000	-	1.000	-
1983	1.000	-	1.000	-	1.000	-
1984	1.000	-	1.000	-	1.000	-
1985	1.000	-	1.000	-	1.000	-
1986	1.000	-	1.000	-	1.000	-
1987	1.000	-	1.000	-	1.000	-
1988+	1.000	-	1.000	-	1.000	-

Sources: U.S. EPA Federal Register: Federal Certification Test Results 1975-78 and 1982-84.
EEA Estimates of Emission Control Systems Projections.

3. EXAMPLE CALCULATION OF LIGHT-DUTY VEHICLE LEAD EMISSIONS

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 areawide lead emission rate for the year 1985. Assume an inspection and maintenance program has been implemented in this area. The simplified misfueling rates from Table 2-12 will be used.

SOLUTION

Use equations (2-4), (2-5), (2-6), and (2-7) to plug into equation (2-3) to get emission factors by vehicle class. Use individual class factors to plug into equation (2-2) for total areawide lead emissions in 1985.

$$T1,1985 = 1.0$$

$$n = 1985$$

$$i = 1 = LDV$$

$$s = 19.6 \text{ mph}$$

$$Pb_{L,1985} = 1.1 \text{ g/gal} \quad \text{(Table 2-2)}$$

$$Pb_{NL,1985} = 0.014 \text{ g/gal} \quad \text{(Table 2-2)}$$

$$a_{s1,1966-1985} = 0.75 \quad \text{(Table 2-13)}$$

$$a_{s2,1975-1980} = 0.40 \quad \text{(Table 2-13)}$$

$$a_{s2,1981-1985} = 0.44 \quad \text{(Table 2-13)}$$

$$C_s = 0.79 \quad \text{(Table 2-1)}$$

$$P_1 = 0.017 \quad \text{(Table 2-14)}$$

$$r_1 = 0.09 \quad \text{(Table 2-12)}$$

$$EF_{n,s} = \sum_{i=1}^{4} T\,(EF_{i,n,s}) \qquad (3\text{-}1)$$

$$EF_{1,1985,19.6} = \sum_{j=1966}^{1985} \Big[(EF_{1,j,1985,L}) \times (F_{L,1,j}) + (EF_{1,j,1985,NL}) \times (F_{NL,1,j}) \Big] \times m_{1,j} \qquad (3\text{-}2)$$

Use the following equations to plug into equation (3-2) and sum over the appropriate model years.

For j=1966-1970

$$EF_{1,j,1985,L} = \Big(1.1(0.887) + 0.014(0.113)\Big) \times \frac{.75}{E_{c,1,j}^{(0.79)}} = \frac{.928}{E_{c,1,j}} \qquad (3\text{-}3)$$

For j=1971-1974

$$EF_{1,j,1985,L} = \Big(1.1(0.916) + 0.014(0.084)\Big) \times \frac{.75}{E_{c,i}^{(0.79)}} = \frac{.958}{E_{c,i}} \qquad (3\text{-}4)$$

For j=1975-1985

$$EF_{1,j,1985,L} = \Big(1.1(0.724) + 0.014(0.276)\Big) \times \frac{.75}{E_{c,1,j}^{(0.79)}} = \frac{.776}{E_{c,1,j}} \qquad (3\text{-}5)$$

For j=1975-1985

$$EF_{1,j,1985,NL} = \Big[0.014(0.91)(0.75) + 1.1(0.09)(F_{1,j,NL,NOCAT} + (0.017)(F_{1,j,CAT})(0.75) + 1.1(0.09)(0.983)(F_{1,j,CAT})(a_{s,1,j})\Big] \quad (3\text{-}6)$$

$$x \frac{1}{E_{c,1,j}^{(0.79)}} = \frac{X_{1,j}}{E_{c,1,j}}$$

	$X_{1,j}$
1975	.0665
1976	.06389
1977	.06303
1978	.06303
1979	.06303
1980	.06303
1981	.06795
1982	.06795
1983	.06795
1984	.06795
1985	.06795

Plugging the appropriate values into equation (3-1), we arrive at the values shown in Section C of Table 3-1. Adding summation (1) and summation (2) we get: $EF_{1,85,19.6} = 0.0132$ (g/mi).

Note: This example is an estimate of lead 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	$m_{1,j}$	$F_{NL,1,j}$	$F_{L,1,j}$	$E_{c,1,j}$	$F_{1,j,CAT}$	$F_{1,j,NL,NOCAT}$	$\frac{(F_{NL,1,j})(m_{1,j})}{E_{c1,j}}$	$\frac{(F_{L,1,j})(m_{1,j})}{E_{c1,j}}$
1985	1	0.038	0.934	-	24.6	1.000	-	.00144	-
1984	2	0.142	0.940	-	23.8	1.000	-	.00561	-
1983	3	0.125	0.947	-	23.2	1.000	-	.00510	-
1982	4	0.111	0.954	-	22.9	1.000	-	.00462	-
1981	5	0.098	0.939	-	21.5	1.000	-	.00428	-
1980	6	0.084	0.966	0.000	19.6	1.000	-	.00414	-
1979	7	0.075	0.875	0.097	17.8	1.000	-	.00369	.00041
1978	8	0.065	0.865	0.126	16.6	1.000	-	.00339	.00049
1977	9	0.055	0.838	0.158	15.5	1.000	-	.00297	.00056
1976	10	0.047	0.863	0.134	14.8	0.980	0.020	.00274	.00043
1975	11	0.040	0.869	0.128	13.8	0.919	0.081	.00252	.00037
1974	12	0.032	-	1.000	12.6	-	-	-	.00254
1973	13	0.026	-	1.000	12.9	-	-	-	.00202
1972	14	0.021	-	1.000	13.1	-	-	-	.00160
1971	15	0.015	-	1.000	13.2	-	-	-	.00114
1970	16	0.011	-	1.000	13.9	-	-	-	.00079
1969	17	0.007	-	1.000	13.9	-	-	-	.00050
1968	18	0.003	-	1.000	13.9	-	-	-	.00022
1967	19	0.003	-	1.000	13.9	-	-	-	.00022
1966-	20+	0.004	-	1,000	13.9	-	-	-	.00029

TABLE 3-1

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

B. Emission Factor Summation Description

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

Summation (2) calculates the emission factor component in Equation (3-5) that is used in Equation (3-1).

TABLE 3-1

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

C. Emission Factor Calculations

Year, j	1 $(EF_{1,j,1985,L})(F_{L,1,j})(m_{1,j})$	2 $(EF_{1,j,1985,NL})(F_{NL,1,j})(m_{1,j})$
1985	-	0.0001
1984	-	0.0004
1983	-	0.0003
1982	-	0.0003
1981	-	0.0003
1980	-	0.0003
1979	0.0003	0.0002
1978	0.0004	0.0002
1977	0.0004	0.0002
1976	0.0003	0.0002
1975	0.0003	0.0002
1974	0.0024	-
1973	0.0019	-
1972	0.0015	-
1971	0.0011	-
1970	0.0007	-
1969	0.0005	-
1968	0.0002	-
1967	0.0002	-
1966-	0.0003	-
SUM:	0.0105	0.0027

$EF_{1,1985,19.6} = 0.0132$ (g/mi)