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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
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Research Triangle Park, North Carolina 27711

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A LEAD EMISSION FACTOR FOR REENTRAINED DUST FROM A PAVED ROADWAY

by

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EPA Project Officer: Charles C. Masser

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PREFACE

This report was prepared for the Environmental Protection Agency under Contract No. 68-02-2609, Task Assignment No. 2. Mr. Charles Masser, Office of Air Quality Planning and Standards, was the requester of this work.

The work was performed in the Environmental and Materials Sciences Division of Midwest Research Institute under the supervision of Dr. Chatten Cowherd, Jr., Head, Air Quality Assessment Section. Mrs. Christine Maxwell, Principal Investigator, and Mr. Daniel Nelson were the authors of this report. Other MRI technical staff contributing to this project were Mr. Russel Bohn and Mrs. Carol Green.

Approved for:

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SUMMARY

The study reported herein is directed to the development of a lead emission factor for reentrained dust from paved roadways. With the impending adoption of an ambient air quality standard for lead, emission factors for major sources will be needed to pinpoint areas where emission control is required.

The results of this study indicate that the lead emission factor for reentrained dust is approximately 0.03 g per vehicle mile for the 1975-1976 sampling period. That approximation was calculated using the data from this study and from other investigations:

	Lead emission factor for 1975-1976 (g/vehicle mile)			
	Total (based on field measurements)		Dust reentrainment (based on MRI calculations)	
	Range	Average	Range	Average
MRI	0.03 to 0.11	0.06	0.01 to 0.06	0.03
PEDCo	0.005 to 0.319	0.07		0.03
Average		0.065		0.03

It is apparent that decreasing the lead content in gasoline will not only decrease the amount of airborne lead emitted from vehicle exhaust, but also will decrease the amount of lead-containing dust reentrained from paved roadways. With the reduction of lead in leaded gasoline and the continued introduction of catalyst equipped vehicles into the vehicle distribution, the lead emission factor for reentrained dust is expected to drop below 0.01 by 1980.

Analysis of airborne particulate samples for lead particle size distribution shows that the mass median diameter for particulate lead is about 1 μm as compared to a mass median diameter of about 5 μm for total airborne particulate.

This report documents the methodology used to develop the lead emission factor for reentrained dust. Samples of airborne particulate from two paved roadways in the Kansas City area, obtained by Midwest Research Institute under

the Environmental Protection Agency Contract No. 68-02-1403, were analyzed for lead content. The results of these analyses were used to derive the combined particulate lead emission factor for vehicle exhaust and reentrained dust. A separate calculation procedure was used to divide the combined particulate emission factor into the emission factors for vehicle exhaust and reentrained dust.

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SECTION 1.0

INTRODUCTION

This report presents the results of a program conducted by Midwest Research Institute (MRI) to characterize the amount of lead in road dust resuspended by the operation of vehicles on paved roadways. In this section, the background of the problem is reviewed and the study objective outlined.

1.1 BACKGROUND

The U.S. Environmental Protection Agency (EPA) has been given the task of developing an ambient air quality standard for lead. With the proposed air quality standard to be announced in the near future, the states will be required to start development of State Implementation Plans (SIP). An integral part of the SIP will be the lead emission inventory which will pinpoint areas where emission control is needed. One potentially significant source of airborne lead consists of lead in road dust resuspended by the operation of vehicles on a paved roadway.

1.2 OBJECTIVE

The objective of this investigation was to determine a lead emission factor for reentrained dust from paved roadways. To accomplish this objective, three major tasks were carried out, as summarized below:

Task 1 - Review Related Reports - Two specific reports were reviewed for useful information for the development of a lead emission factor for reentrained dust from paved roads. The reports were: "Lead Analysis for Kansas City and Cincinnati," (EPA Contract No. 68-02-2515)[1/] and "Particulate Study of the Philadelphia Air Quality Control Region," (EPA Contract No. 68-02-2345).[2/]

Task 2 - Analyze Selected Dust Samples for Lead - This task consisted of analysis for lead in samples of reentrained dust (i.e., airborne particulate) obtained by MRI at the 37th Street and Fairfax Trafficway sites in the Kansas City metropolitan area under EPA Contract No. 68-02-1403. Sample collection media from high-volume samplers were analyzed for lead. These samples included (a) high-volume filters, (b) impactor substrates, and (c) impactor preseparator washes. In order to calculate lead emission factors, samples of street dust loadings were obtained as part of this study, from the above sites and analyzed for lead.

Task 3 - Develop Emission Factor - Information gathered in Tasks 1 and 2 above, was compiled and a lead emission factor for reentrained dust from a paved roadway was developed. The methodology used is completely documented in this report. Since the vehicle mix is changing due to the introduction of the catalytic converter, the methodology can be expanded to account for decreases in lead content of gasoline for noncatalyst vehicles, and phase-in of catalyst vehicles.

The following sections of this report present (a) a description of the reentrained dust sampling methodology including field test locations and measurement techniques, (b) a summary of the lead analysis results, (c) the methodology for the development of a lead emission factor, (d) a summary of results and (e) comparisons with other studies.

SECTION 2.0

REENTRAINED DUST SAMPLING METHODOLOGY

2.1 FIELD TEST LOCATIONS

Under EPA Contract No. 68-02-1403, Tasks 7 and 25,[3/] field testing was conducted by MRI at several representative paved and unpaved road sites in the Kansas City area. Two of the paved road sites were selected for quantification of lead in reentrained dust: 37th Street and Fairfax Trafficway. Both sites are four-lane arterial streets in areas where attainment of particulate standards has been a problem. In addition, both sites have high traffic volume especially during shift changes at nearby automotive assembly plants. Table 1 summarizes the characteristics of each test site.

The 37th Street test roadway passes through a center-city residential neighborhood interspersed with light-to-medium industrial activity. The test pavement along 37th Street is asphalt and bordered by an unpaved parking area.

Medium industry surrounds the Fairfax Trafficway test site. This roadway is also surfaced with asphalt. Unpaved parking lots are located in several nearby areas. The traffic volume is heavy in both directions for the periods 6 to 9 AM and 2 to 4 PM. (Approximately 700 vehicles per hour were recorded for the 6 to 9 AM period and 1,400 vehicles per hour were recorded for the 2 to 4 PM period.)

2.2 FIELD MEASUREMENT METHODOLOGY

Field testing of airborne particulate emissions from paved roads was conducted at the 37th Street site in September and October 1975, and at the Fairfax Trafficway site in March 1976, under EPA Contract No. 68-02-1403.

To the extent possible, emission sampling was restricted to periods with moderate crosswinds (approximately 5 to 10 mph) and 3 or more days after significant rainfall (accumulation exceeding 0.5 in.). The ideal wind direction for exposure profiling is perpendicular to the road such that airborne particles flow directly away from the traffic and toward the sampling intakes. The ideal wind speed for the profiler is approximately 10 mph. This is in the middle of the range in which the profiler can be adjusted for isokinetic sampling.

TABLE 1. TEST SITE CHARACTERISTICS

Site	37th Street	Fairfax Trafficway
Location	Leeds Fire Station No. 26 6402 East 37th Street Kansas City, Missouri	Fire Station No. 15 5200 Fairfax Kansas City, Kansas
Land use	Residential (medium industry nearby)	Medium industry
Average daily traffic	7,870	8,360
Street characteristics		
Orientation	East-west	North-south
Surface type	Asphalt	Asphalt
Surface condition	Poorly maintained, cracked	Well maintained, smooth
Curbed	Yes	Yes
Ventilation	a/	a/
Air sampling station		
Operating agency	Kansas City, Missouri	Kansas City, Kansas-Wyandotte County Health Department
Geometric mean TSP ($\mu g/m^3$)		
1972	86	96
1973	101	86
1974	87	75
MRI runs	3, 5, 6	15 to 16

a/ Partial restriction caused by predominance of two- to three-story buildings in immediate area. Fairfax Trafficway area only restricted on west side of street.

Isokinetic sampling is achieved by adjusting the profiler flow rate such that when dividing the flow rate by the intake area, the result is equal to the mean wind speed. The lapse of several days after significant rainfall allows the particulate loading on the road surface to return to the equilibrium level.

Table 2 specifies the kinds and frequencies of field measurements that were conducted during each run. "Composite" samples denote a set of single samples taken from several locations in the area; "integrated" samples are those taken at one location for the duration of the run.

2.2.1 Sampling Equipment

The primary tool for quantification of emission rate was the MRI exposure profiler which was developed under EPA Contract No. 68-02-0619.[4/] The profiler has undergone design and operational changes since its original development. The profiler used for this study consists of a portable tower (4 meters in height) with four sampling heads (see Figure 1). The sampling heads were equipped with individual flow controllers to adjust to isokinetic conditions. New directional exposure intakes were added that automatically separate out the settleable particulates. Other mechanical hardware and flow indicators were attached to increase the ease of operation.

In addition to the profiler, high-volume samplers were set up to measure upwind and downwind suspended particulate concentrations and a cascade impactor was used for particle sizing. These samplers measured concentrations at breathing height (2 m above the ground). The impactor unit was equipped with a Sierra cyclone preseparator to remove coarse particles which otherwise would tend to bounce off of the glass fiber impaction substrates, causing fine particle measurement bias.

Figures 2 through 5 show the locations of sampling instruments at the 37th Street and Fairfax Trafficway sites. Distances from curbing are specified. For comparative purposes, the profiler, high-volume samplers and cascade impactor were placed approximately the same distance from the curb.

By means of a pivotal bearing and wind vane, the cyclone preseparator intake was continually directed into the wind. By having the flow controller set for 40 cfm and using a 3 in. diameter cyclone intake, the unit was set to isokinetic conditions for approximately a 10 mph wind.

Other site parameters that were mechanically recorded during each test included: wind speed, wind direction and vehicular traffic counts.

2.2.2 Sample Handling and Particulate Analysis

At the end of each run, the collected samples were carefully transferred to protective containers within the MRI instrument van to prevent dust losses.

TABLE 2. FIELD MEASUREMENTS--PAVED ROADS

Test Parameter	Units	Sampling Mode	Measurement Method
1. Meteorology			
a. Wind speed	mph	Continuous	Recording instrument at "background" station; sensors at reference height
b. Wind direction	Degree	Continuous	
c. Cloud cover	%	Single	Visual observation
d. Temperature	°F	Single	Sling psychrometer
e. Relative humidity	%	Single	Sling psychrometer
2. Road Surface			
a. Pavement type	-	Composite	Observation (photographs)
b. Surface condition	-	Composite	Observation
c. Dust loading	g/m^2	Multiple	Dry vacuuming
d. Dust texture	% silt	Multiple	Dry sieving
3. Vehicular Traffic			
a. Mix	-	Multiple	Observation (car, truck, number of axles, etc.)
b. Count	-	Cumulative	Automatic counters
4. Suspended Dust			
a. Exposure (versus height)	mg/cm^2	Integrated	Isokinetic high-volume filtration (MRI method)
b. Mass size distribution	μm	Integrated	High-volume cascade impaction
c. Downwind concentration	$\mu g/m^3$	Integrated	High-volume filtration (EPA method[5])
d. Background concentration	$\mu g/m^3$	Integrated	High-volume filtration (EPA method[5])
e. Duration of sampling	min	Cumulative	Timing

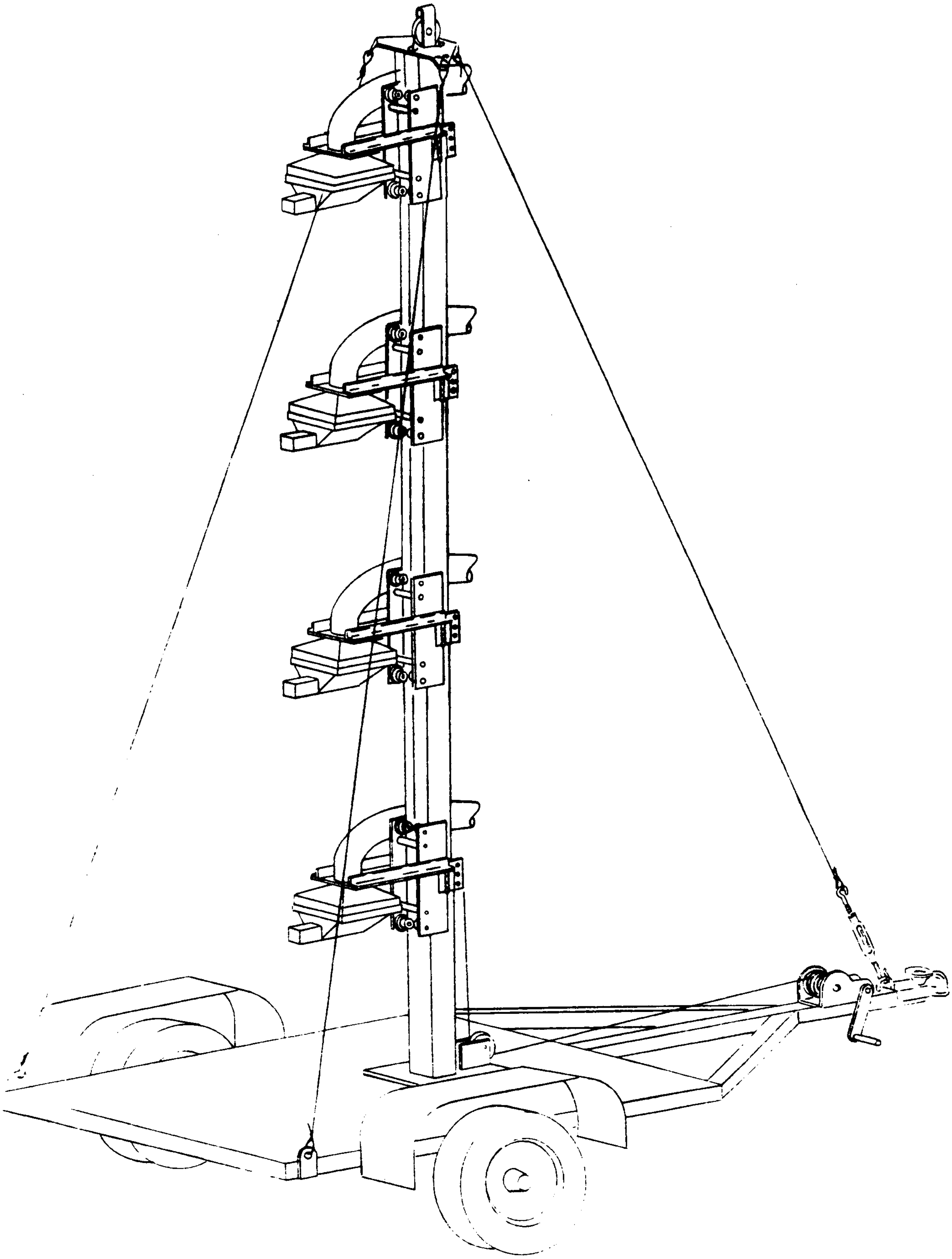


Figure 1. MRI Exposure Profiler

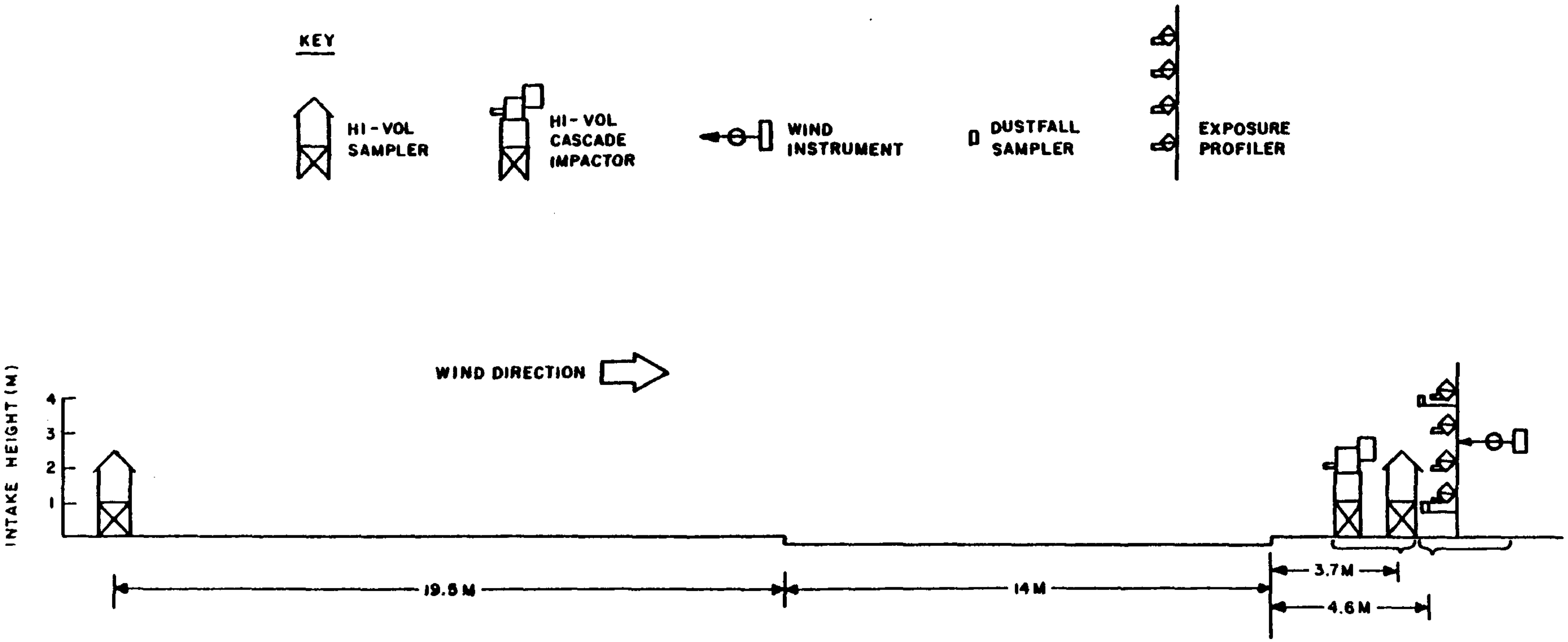


Figure 2. Location of Sampling Instruments at 37th Street Site--South Wind

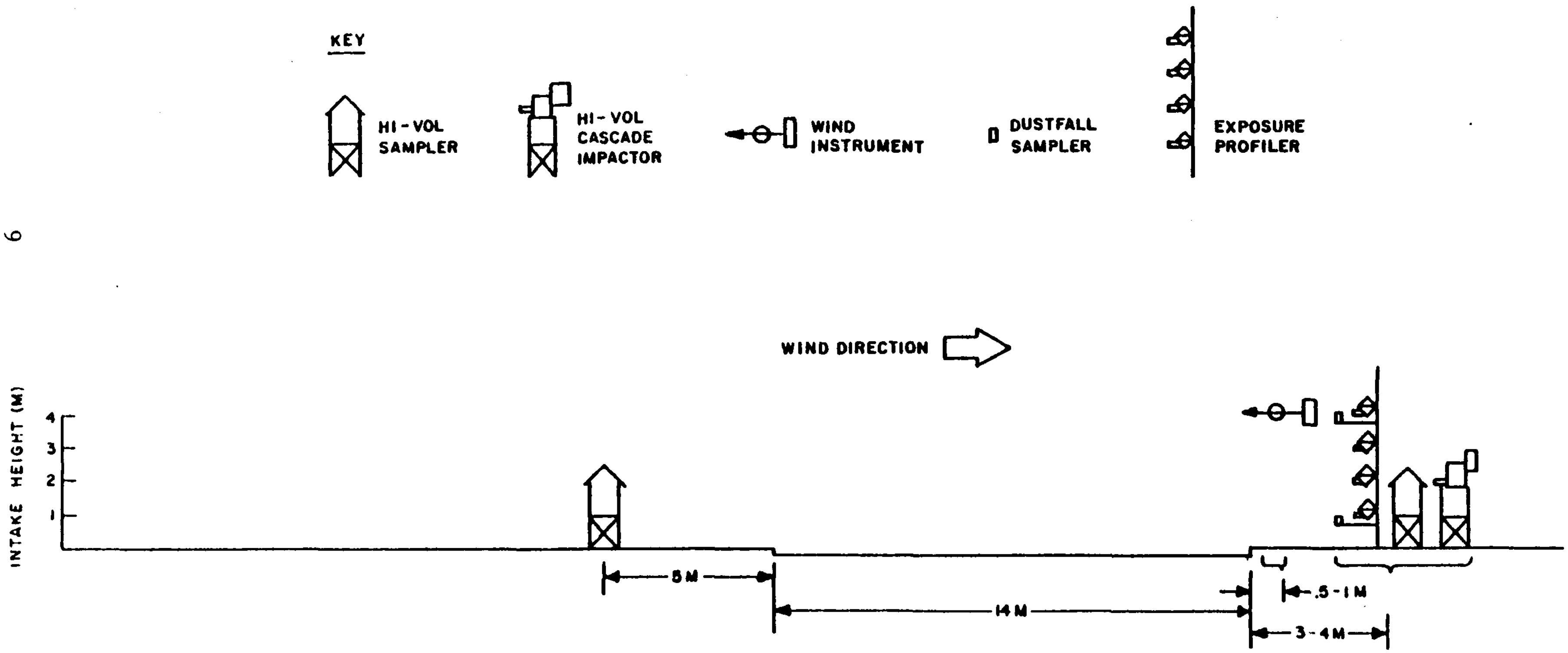


Figure 3. Location of Sampling Instruments at 37th Street Site--North Wind

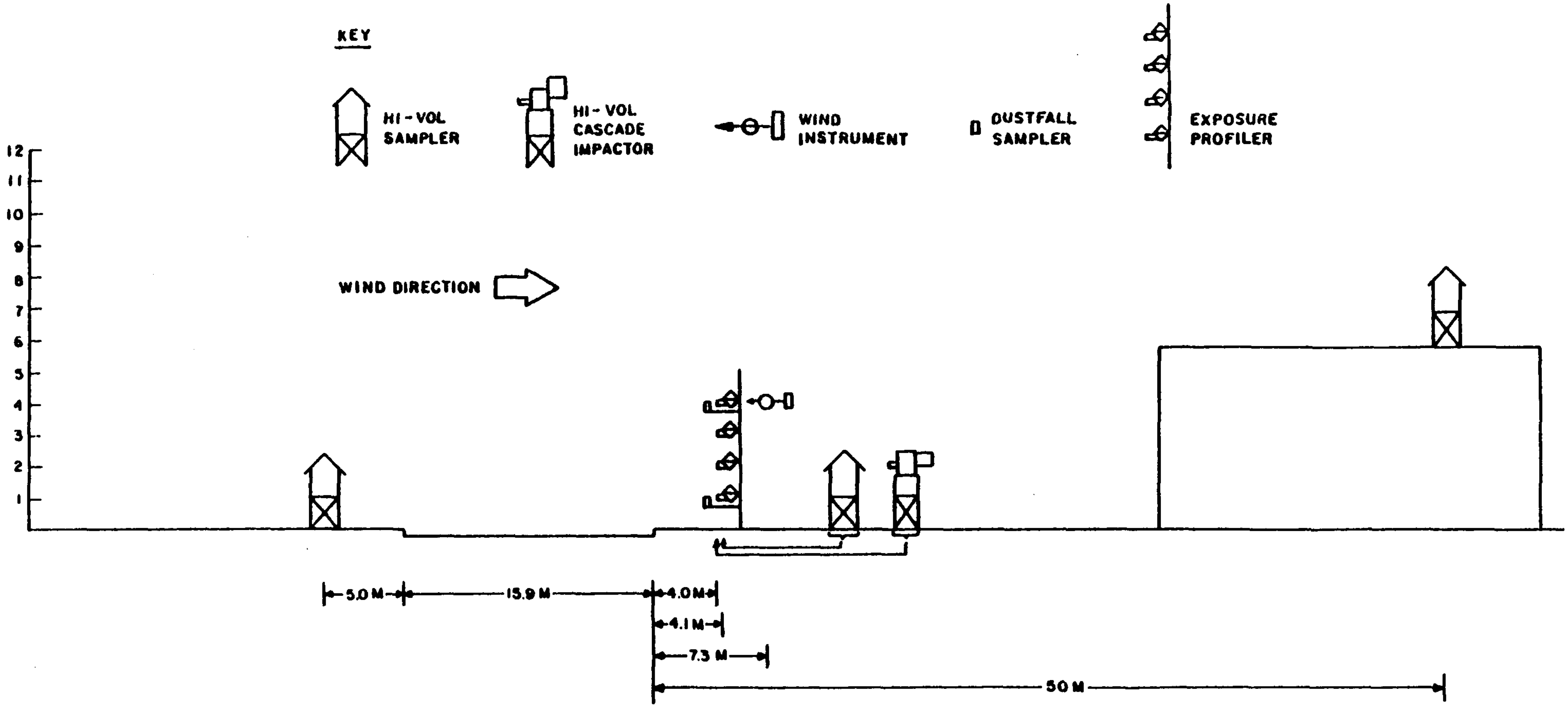


Figure 4. Location of Sampling Instruments at Fairfax Trafficway--Side View

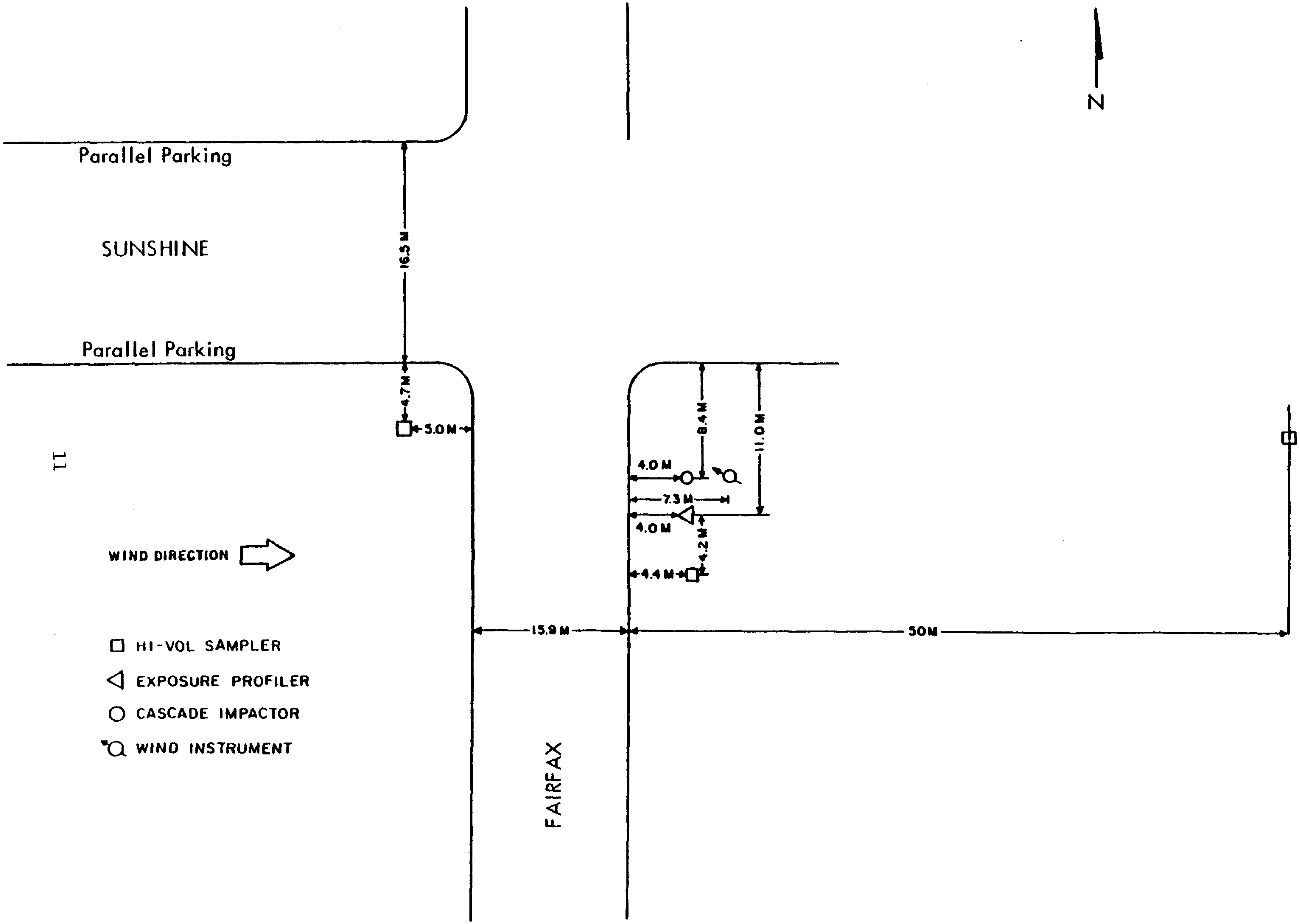


Figure 5. Location of Sampling Instruments at Fairfax Trafficway--Overhead View

High-volume filters (from the MRI exposure profiler and from standard high-volume units) and impaction substrates were folded and placed in individual envelopes. Particulate that collected on the interior surfaces of each exposure profiler intake and from the cyclone preseparator was rinsed with distilled water into separate glass jars.

Field testing samples were returned to MRI and analyzed in the laboratory. All filter types were conditioned in a controlled temperature and humidity room for a period of 24 hr before weighing. Several blank filters, taken to the field, were analyzed the same as the sample filters. The sample weights were corrected for any difference in blank tare weight and blank final weight.

Wash samples from the exposure profiler intakes and cyclone preseparator were obtained by filtering wash solution through Whatman No. 42 filters which were folded into a cone. The sample was drawn through the cone using a water aspirator for vacuum. The washed filters were dried at 110°C before being conditioned.

After the particulate analysis was completed, all filters were stored for future use. High-volume filters and impaction substrates were placed in individual glycene envelopes. All wash filters were placed in a common container.

SECTION 3.0

ANALYSIS OF SELECTED SAMPLES FOR LEAD

Reentrained road dust samples obtained by MRI under EPA Contract No. 68-02-1403[3/] were analyzed for lead by flame atomic absorption spectroscopy in MRI's analytical chemistry laboratories. Sample collection media analyzed included: 36 Hi-Vol filters (Type A glass fiber), 25 Sierra impactor substrates, and 4 filtered intake wash samples (Whatman No. 42). The Sierra cascade impactor has 5 collection stages and a final 8 x 10 in. glass fiber backup filter.

Tables 3 and 4 for 37th Street and Fairfax Trafficway, respectively, summarize the lead content results for each sample. The results, given as "% Pb," are based on 100 times the total micrograms of lead in the sample divided by the sample (particulate) weight. All calculations were performed using three significant figures, but the results were rounded to two significant figures. Less the (<) values are listed as one significant figure. Because of the possibility of contamination stored in the common container, only a limited number of wash filters (Run 5) which appeared to be totally intact and uncontaminated, were analyzed for lead.

As part of the methodology for the development of the reentrained lead emission factor, it was necessary to obtain street dust loading samples. Samples from 37th Street and Fairfax Trafficway test sites were obtained in September 1977. One lane of each street segment was closed off at a time. Samples were collected for each of the four lane areas and two curb areas. Road surface areas with high particulate loading (near curbs) were manually swept with a whisk broom into a dustpan and collected in polyethylene bags. Subsequently, the entire roadway test surface area was thoroughly vacuumed with a generator-powered household vacuum cleaner. The vacuumed material was collected in disposable vacuum cleaner bags, which were secured and placed into polyethylene bags.

The street loading samples were labelled, stored and analyzed separately. This was done in case there was a need to look at individual lanes.

A portion of each street surface dust sample was analyzed for lead. Because of the large quantity of curb sweepings and the time required to do the analysis, only a small portion was actually analyzed. The lead content of this

TABLE 3. LEAD ANALYSIS OF REENTRAINED DUST (37TH STREET)

Run	Sample	Sampling height (m)	Concentration ($\mu g/m^3$)[a] TSP	Concentration ($\mu g/m^3$)[a] Pb	% Pb in filter catch
3	Upwind Hi-Vol	2	155	0.46	0.30
	Profiler 1	1	286	1.00	0.35
	Profiler 2	2	246	1.33	0.54
	Profiler 3	3	235	1.11	0.47
	Profiler 4	4	192	0.76	0.40
	Downwind Hi-Vol	2	271	1.82	0.67
	Sierra[b] Stage 1	2			0.69
	Stage 2	2			1.5
	Stage 3	2	164[c]	1.72[c]	2.2
	Stage 4	2			2.8
	Stage 5	2			3.3
	Backup	2			2.2
5	Upwind Hi-Vol		130	0.60	0.46
	Profiler 1 Filter	1	283	3.11	1.1
	Wash	1			0.19
	Profiler 2 Filter	2	223	1.87	0.84
	Wash	2			0.23
	Profiler 3 Filter	3	187	1.44	0.77
	Wash	3			0.31
	Profiler 4	4	140	0.95	0.68
	Downwind Hi-Vol	2	281	2.76	0.98
	Sierra[b] Cyclone Wash	2			0.26
	Stage 1	2			1.4
	Stage 2	2			1.6
	Stage 3	2	207[c]	3.05[c]	2.7
	Stage 4	2			2.6
	Stage 5	2			4.9
	Backup	2			2.4
6	Upwind Hi-Vol	2	137	0.56	0.41
	Profiler 1	1	254	4.06	1.6
	Profiler 2	2	206	4.50	2.2
	Profiler 3	3	169	2.70	1.6
	Profiler 4	4	136	2.98	2.2
	Downwind Hi-Vol	2	250	2.20	0.88
	Sierra[b,d] Stages 1 to 5	2	-	-	-

a/ Based on filter catch including background.

b/ Sierra cutoff diameter for lead density of 5 g/cm^3: Stage 1 - 2.5 μ
Stage 2 - 2.2 μ
Stage 3 - 1.2 μ
Stage 4 - 0.57 μ
Stage 5 - 0.28 μ

c/ Represents total concentration collected on all stages; the most meaningful value for comparison between TSP and lead since cutoff diameters based on different densities are not the same.

d/ Possible contamination of filters; values are suspect.

TABLE 4. LEAD ANALYSIS OF REENTRAINED DUST (FAIRFAX TRAFFICWAY)

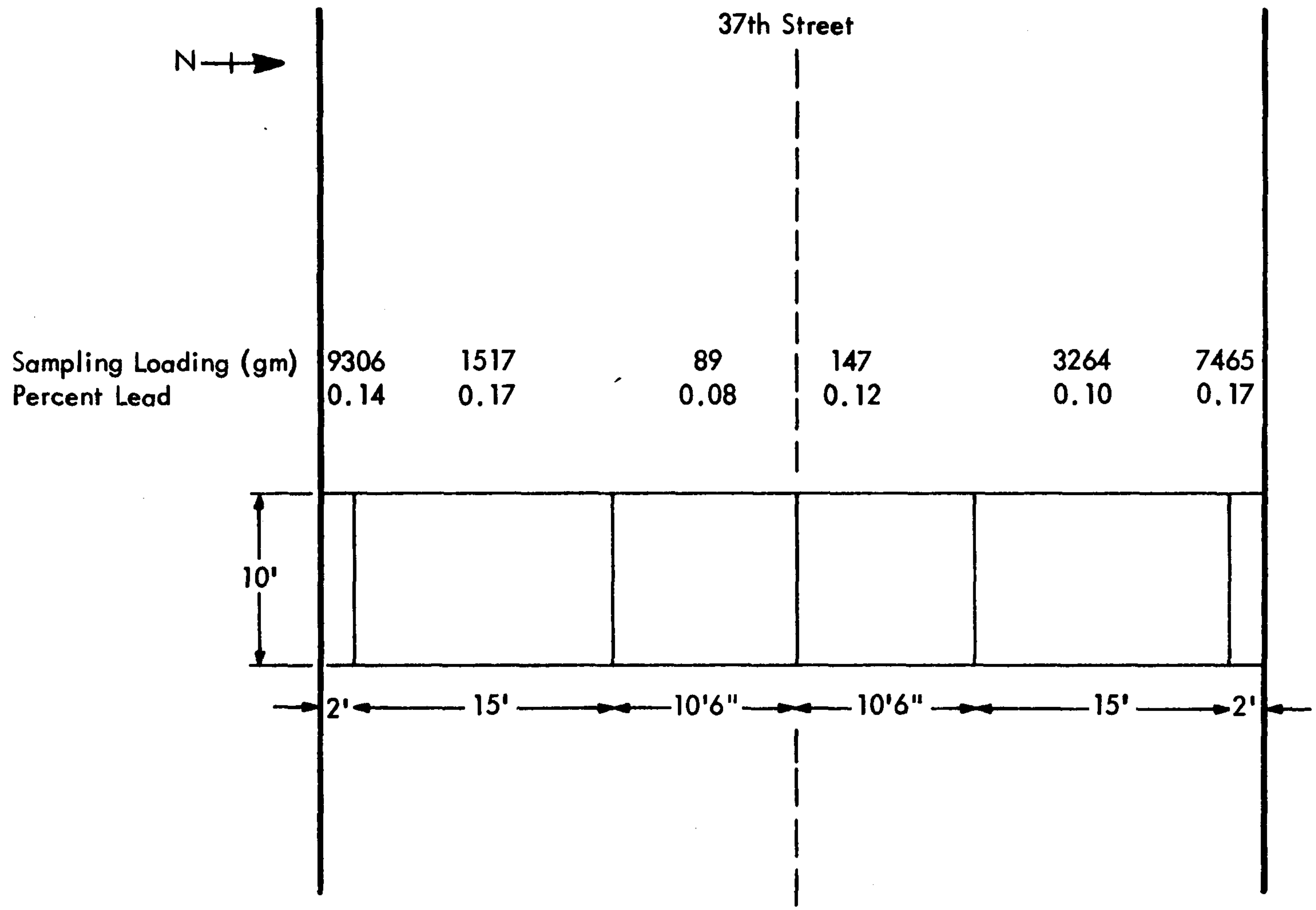
Run	Sample	Sampling height (m)	Concentration ($\mu g/m^3$)[a/] TSP	Concentration ($\mu g/m^3$)[a/] Pb	% Pb in filter catch
15	Upwind Hi-Vol	2	268	0.72	0.27
	Profiler 1	1	274	2.00	0.73
	Profiler 2	2	234	1.88	0.80
	Profiler 3	3	212	1.21	0.57
	Profiler 4	4	172	0.87	0.51
	Downwind Hi-Vol (4.4 m)	2	398	2.51	0.63
	Sierra[b/] Stage 1	2	234[c/] (Stage 1 – Backup)	1.60[c/] (Stage 1 – Backup)	0.94
	Stage 2	2			1.5
	Stage 3	2			1.6
	Stage 4	2			3.0
	Stage 5	2			2.8
	Backup	2			1.4
16	Upwind Hi-Vol	2	288	0.63	0.22
	Profiler 1	1	342	1.68	0.49
	Profiler 2	2	256	1.33	0.52
	Profiler 3	3	251	1.13	0.45
	Profiler 4	4	208	0.75	0.36
	Downwind Hi-Vol (4.4 m)	2	362	1.59	0.44
	Sierra[b/] Stage 1	2	232[c/] (Stage 1 – Backup)	1.15[c/] (Stage 1 – Backup)	0.74
	Stage 2	2			0.78
	Stage 3	2			1.2
	Stage 4	2			0.43
	Stage 5	2			1.7
	Backup	2			0.99

a/ Based on filter catch including background.

b/ Sierra cutoff diameter for lead density of 5 g/cm^3: Stage 1 - 2.5 μ
Stage 2 - 2.2 μ
Stage 3 - 1.2 μ
Stage 4 - 0.57 μ
Stage 5 - 0.28 μ

c/ Represents total concentration collected on all stages; the most meaningful value for comparison between TSP and lead since cutoff diameters based on different densities are not the same.

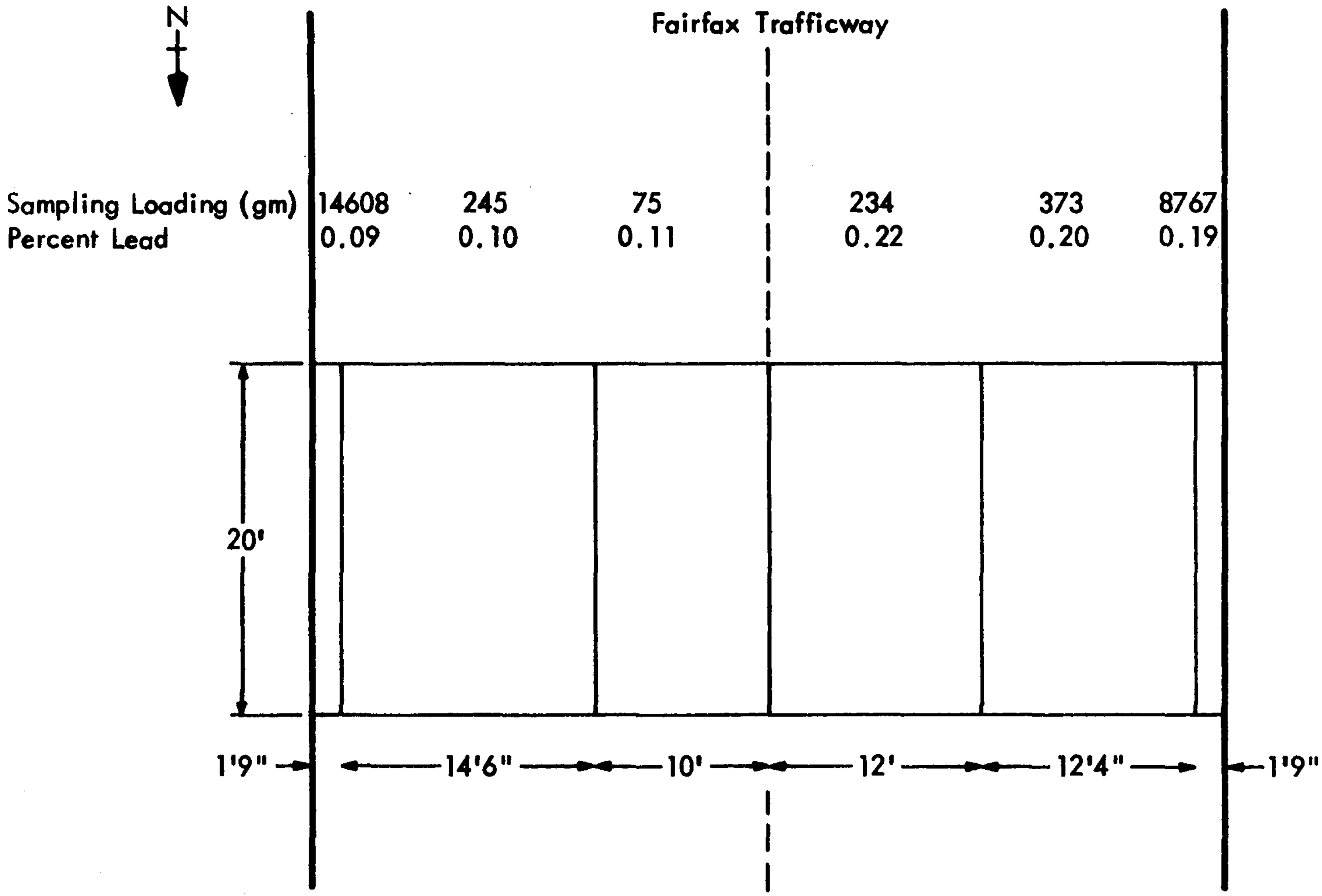
small portion was assumed to be representative. Figures 6 and 7 show the distribution of street dust loading and corresponding percent lead for the 37th Street and Fairfax Trafficway sites, respectively. As indicated, the percent lead in the street dust loading samples ranged from 0.08 to 0.22%. This compares well with other studies which report values in the range of 0.02 to 0.3% lead.[6]



37th Street (Excluding Curb) = 1,650 kg/km
= 5,830 lb/mile

37th Street (Including Curb) = 7,150 kg/km
= 25,300 lb/mile

Figure 6. Distribution of Street Dust - 37th Street



Fairfax Trafficway (Excluding Curb) = 152 kg/km
= 539 lb/mile

Fairfax Trafficway (Including Curb) = 3,990 kg/km
= 14,100 lb/mile

Figure 7. Distribution of Street Dust - Fairfax Trafficway

SECTION 4.0

DEVELOPMENT OF TOTAL LEAD EMISSION FACTOR

Dust entrainment from a paved road was quantified by measuring the total passage of airborne dust (after subtraction of background) at some downwind distance. The calculation procedure for lead exposure and corresponding emission factor for suspended particulate lead is presented and a sample calculation is documented in the Appendix. Exposure is defined as the horizontal flux of airborne dust (mass per time per sampling intake area) integrated over the time of measurement.

4.1 UNCORRECTED TEST RESULTS

Tables 5 through 7 summarize the particulate emission test parameters for the 37th Street and Fairfax Trafficway sites.[3/] Table 5 presents data on the time of each run, prevailing meteorological conditions, and vehicular traffic volume. Table 7 gives the results of particulate exposure and concentration measurements for each run. Table 8 presents the total particulate lead concentrations calculated by the methodology given in the Appendix. Background (upwind) lead concentrations are in the range of 0.46 to 0.63 $\mu g/m^3$, which agree well with other measured ambient concentrations.[7/]

The following subsections describe in more detail the corrections (a) to isokinetic sampling conditions and (b) for particles smaller than 30 µm in diameter.

4.2 ISOKINETIC CORRECTION

It was sometimes necessary to sample at a nonisokinetic flow rate. For example, to obtain sufficient sample under light wind conditions, the sampling intake velocity was higher than the mean wind velocity. The following multiplicative factors were used to correct both measured exposures and concentrations to corresponding isokinetic values.

TABLE 5. EMISSIONS TEST PARAMETERS

Run	Date	Time		Duration of exposure sampling (min)	Ambient temperature (°F)	Wind		Wind direction angle to road (°)	No. of vehicle passes	No. of vehicle passes/hr
		Start	Finish			Speed (mph)	Direction[a] (°)			
3	9/17/75	1115	1545	270	68	2.0	140	40	1,880	418
5	9/23/75	1500	1930	270	78	3.0	340	20	2,260	502
6	10/9/75	1400	1830	270	75	2.5	340	20	2,440	542
15	3/16/76	1330	1730	240	40	7.1	290	20	3,791	948
16	3/24/76	1200	1600	240	66	7.3	280	10	4,146	1,040

a/ Magnetic reading.

TABLE 6. SUSPENDED PARTICULATE CONCENTRATION AND EXPOSURE MEASUREMENTS

Run	Particulate concentration (µg/m^3) at 2 m above ground					Isokinetic ratio for profiler, u/U	Integrated exposure [d] (lb/vehicle-mile)
		Downwind, including background					
		Profiler[b]		Standard	Cascade		
	Background[a]	Total	< 30 µm	Hi-Vol[a]	Impactor[c]		
3	155	295	257	271	164	7.5	0.015[b]
5	130	293	284	281	207	5.0	0.020[b]
6	137	261	257	250	230	6.0	0.012[b]
15	268	336	292	398	234	1.4	0.019
16	288	327	301	362	232	1.6	0.010

a/ Hi-vol measurement.
b/ Isokinetic.
c/ Total concentration measured by Sierra impactor substrates and backup filter.
d/ Calculated by procedure described in Appendix.

TABLE 7. LEAD CONCENTRATION AND EXPOSURE MEASUREMENTS

	Lead concentration ($\mu g/m^3$) at 2 m above ground					
		Downwind, including background			Isokinetic ratio for profiler,	Integrated exposure[d/]
Run	Background[a/]	Profiler[b/]	Standard Hi-Vol[a/]	Cascade Impactor[c/]	u/U	(g/vehicle-mile)
3	0.46	1.42	1.82	1.7	7.5	0.03
5	0.60	2.03	2.76	3.0	5.0	0.09
6	0.56	4.62	2.20	e/	6.0	0.13
15	0.72	2.08	2.51	1.6	1.4	0.07
16	0.63	1.47	1.59	1.2	1.6	0.05

a/ Hi-Vol measurement.

b/ Isokinetic.

c/ Total concentration measured by Sierra impactor substrates and backup filter.

d/ Calculated by procedure described in Appendix.

e/ Possible sample contamination.

	Fine particles ($d < 5$ µm)	Coarse particles ($d > 50$ µm)
Exposure multiplier	U/u	1
Concentration multiplier	1	u/U

where u = Sampling intake velocity at a given elevation
U = Wind velocity at same elevation as u
d = Aerodynamic (equivalent sphere) particle diameter

For a particle size distribution containing a mixture of fine, intermediate, and coarse particles, the isokinetic correction factor is an average of the above factors, weighted by the relative proportion of coarse and fine particles. For example, if the mass of fine particles in the distribution equals twice the mass of the coarse particles, the weighted isokinetic correction for exposure would be:

$$1/3\ [2(U/u) + 1]$$

4.3 PARTICLE SIZE ADJUSTMENT

A particle size adjustment factor is used for determining an emission factor representing specific particle size ranges, such as particles smaller than 30 µ or 5 µ. As stated earlier, a cyclone preseparator was used in conjunction with a high-volume cascade impactor to measure airborne particle size distribution. The purpose of the preseparator was to remove coarse particles which otherwise would tend to bounce through the impactor to the backup filter, thereby causing fine-particle measurement bias.

Table 8 presents a comparison of the particle sizing results for total particulate and lead particulate. The effective cutoff diameter of the impactor stages was calculated on the basis of density of 2.5 g/cm^3 for particulate and 5 g/cm^3 for lead. The data given in Table 8 are from plots of particle diameter (µm) versus percent less than stated size on log-probability scale graph paper.

The particle size distributions indicate that the lead particles are essentially all less than 30 µm in diameter; thus, the particle size adjustment factor is approximately equal to 1. Table 8 also indicates that the mass median diameter for lead is less than 1 µm. This agrees with a study in the Cincinnati area indicating mass median diameters in the range of 0.18 to 0.42 µ.[8/]

TABLE 8. PARTICLE SIZE DATA

		Particulate[a]				Lead[b]			
Run	Site	MMD[c] (μm)	Weight % < 30 μm	Weight % < 5 μm	Fine particle ratio[d]	MMD[c] (μm)	Weight % < 30 μm	Weight % < 5 μm	Fine particle ratio[d]
3	37th Street	5.5	87	48	0.55	0.6	98	87	0.89
5	37th Street	3.3	97	64	0.66	0.2	98	90	0.92
6	37th Street	2.8	99	70	0.71	< 0.1	> 99	98	~0.98
15	Fairfax	6.5	87	41	0.47	1	93	76	0.82
16	Fairfax	5.3	92	42	0.46	1	88	74	0.84

a/ Based on density of 2.5 g/cm^3.

b/ Based on density of 5 g/cm^3.

c/ MMD = Mass Median Diameter.

d/ Ratio = (weight % < 5 μm) ÷ (weight % < 30 μm).

4.4 TOTAL LEAD EMISSION FACTOR

The total lead emission factors developed in this study are summarized in Table 9. These emission factors represent particles smaller than 30 μm in diameter. These are the same values presented in Table 7 for integrated exposure.

Total lead is comprised of lead from vehicle exhaust and from dust reentrainment. A description of the calculation procedures used in determining the total lead emission factor is given in the Appendix. The vehicle exhaust portion of the emission factor was calculated as described in Section 5.2 and the dust reentrainment emission factor was calculated by difference.

TABLE 9. MEASURED TOTAL PARTICULATE LEAD EMISSION FACTORS

Run	Location	Total lead emission factor[a/] (g/vehicle mile)	Total lead emission factor[a/] (g/vehicle km)
3	37th Street (midday)	0.03	0.02
5	37th Street (rush hour)	0.09	0.06
6	37th Street (rush hour)	0.13	0.08
15	Fairfax Trafficway	0.07	0.04
16	Fairfax Trafficway	0.05	0.03

a/ Measured total particulate lead emissions are the sum of vehicle exhaust and reentrained dust.

SECTION 5.0

EMISSION FACTOR CONTRIBUTIONS

5.1 MRI SAMPLING SITE CHARACTERISTICS

The following paragraphs describe the differences in the MRI sampling locations which may explain the variation in the measured total particulate lead emission factor. This information is helpful in the determination of the contributions of lead from vehicle exhaust and lead from reentrained dust.

37th Street (midday) - Sampling for run 3 was performed during early afternoon (nonrush hour). The wind conditions were extremely light. Vehicle speed may be assumed to have been close to the speed limit of 30 mph (assume 25 mph). Vehicle mix was primarily older cars. Sampling was performed near an intersection controlled by a traffic light.

37th Street (rush hour) - For runs 5 and 6, sampling was performed during the afternoon (including rush hour). Wind conditions were light (less than 5 mph). Vehicle speed was approximately 20 mph. Change of shift for a major assembly plant (located 3 blocks east) provided a high percentage of the traffic. Vehicle mix was 70% automobiles plus buses and trucks.

Fairfax Trafficway - Street dust loadings were lighter for this site than for 37th Street; however, background levels were extremely high due to interference from a merging street and various industrial sources. Sampling was performed during afternoon rush hour which consisted of traffic in both directions for shift changes. Vehicle speed was considerably less than the speed limit (assume an average of 15 mph).

5.2 LEAD FROM VEHICLE EXHAUST

An average lead emission factor for lead in vehicle exhaust was derived from information presented in Reference 9. The following paragraphs describe vehicle exhaust emissions for (a) composite vehicle operation, and (b) constant cruise speeds.

Table 10 summarizes vehicle exhaust lead emission factors based on composite operation (i.e., includes speed correction, temperature, and hot/cold weighting correction) for 1974 through 1995, based on an average vehicle speed of 30 mph.[9/]

TABLE 10. PROJECTED VEHICLE EXHAUST LEAD EMISSION FACTORS (COMPOSITE OPERATION)[9]

Year	Emission factor[a] (g/vehicle mile)
1974	0.131
1975	0.08[b]
1976	0.07[b]
1977	0.062
1978	0.047
1979	0.028
1980	0.026
1981	0.024
1983	0.011
1985	0.006
1990	0.002
1995	0.002

a/ For typical driving patterns: Composite of interrupted and freely flowing traffic.

b/ Estimated value.

Since during the MRI emission testing program, the vehicles were operating at nearly steady speeds, it was necessary to determine lead emission factors at constant cruise speeds.

Based on previously reported data[9/] Figure 8 shows worst-case curve of the percentage of burned lead exhausted versus vehicle cruise speed. These data can be used in the following equation to derive an emission factor for lead from vehicle exhaust:

$$EF = \frac{(PE/100)\ LC}{MPG} \qquad \text{Eq. (1)}$$

where

EF = Worst-case lead emission factor for vehicle exhaust at a constant speed in grams per vehicle mile.

PE = Percentage of burned lead that is exhausted as derived from Figure 8.

LC = Lead content in gasoline, in grams per gallon.

MPG = Fuel economy, in miles per gallon of gasoline consumed.

From Figure 8, one can determine for constant vehicle speeds of 15 to 40 mph, the percentages of burned lead exhausted are approximately 10 to 32%, respectively.

The average lead content of leaded gasoline during the periods of sampling (Fall 1975 and Spring 1976) is stated to be 1.72 g of lead per gallon of gasoline.[9/] This figure will be reduced to approximately 0.5 g of lead per gallon of gasoline by October 1, 1979.

Assuming fuel economy of 15 mpg (estimate) and lead content equal to 1.7 g/gal., the vehicle exhaust lead emission factors are given in Table 11. The emission factors in Table 11 are based on constant cruise speeds.

TABLE 11. VEHICLE EXHAUST LEAD EMISSION FACTORS (CONSTANT CRUISE SPEEDS)

Vehicle speed (mph)	Lead emission factor for vehicle exhaust[a/] (g/vehicle/mile)
15	0.011
20	0.018
25	0.022
30	0.025
35	0.031
40	0.036

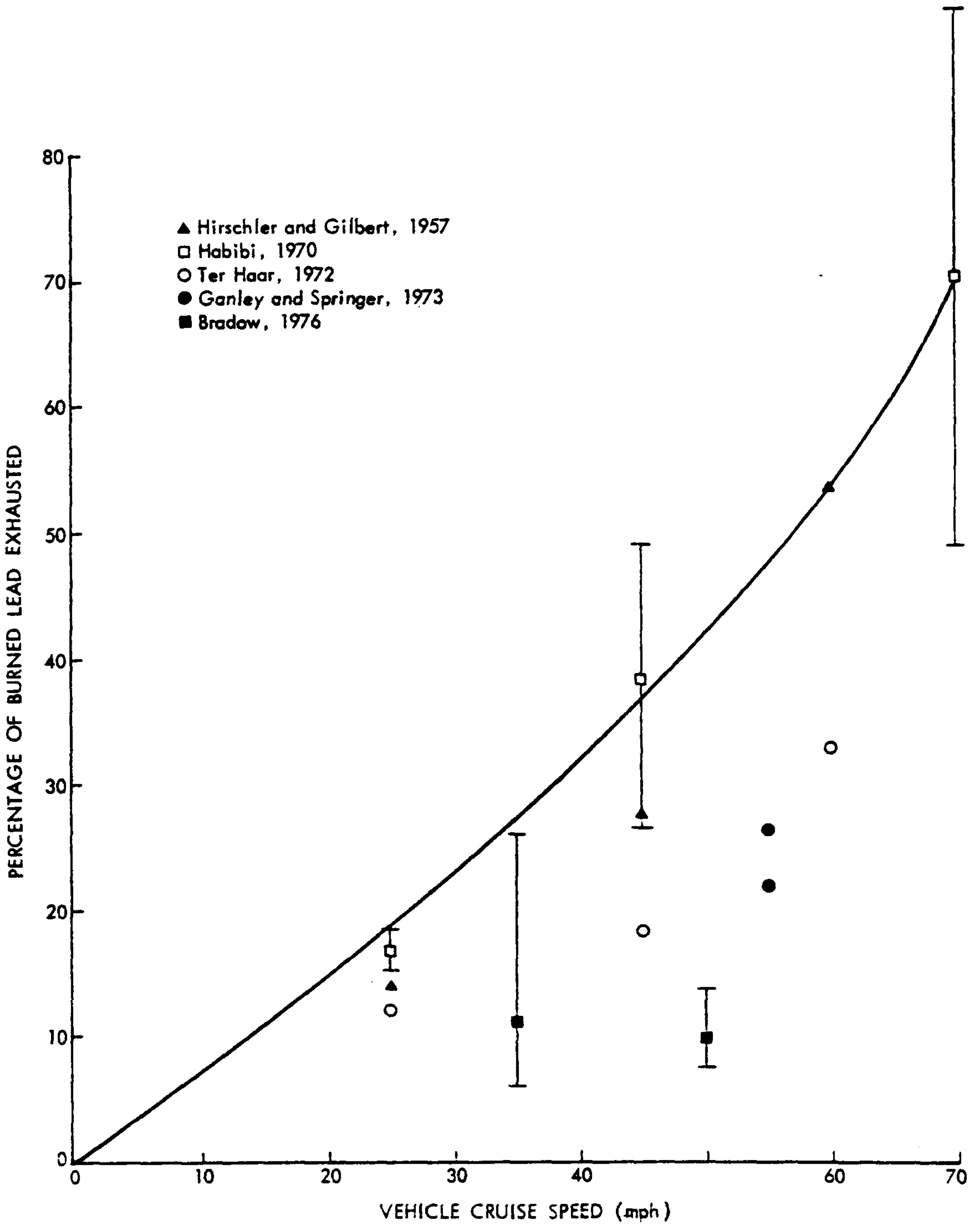


Figure 8. Percentage of Burned Lead Exhausted Versus Vehicle Cruise Speed

Lead emissions from vehicle exhaust increase rapidly during vehicle acceleration, deceleration, cold engine operation, and high vehicle speed. This is evident by comparison of equivalent lead vehicle exhaust emission factors for composite operation versus constant cruise speed. For 1975-1976 and 30 mph vehicle speed, the composite operation factor is approximately 0.075 g/vehicle mile (see Table 10) and the constant cruise speed factor is 0.025 g/vehicle mile (see Table 11). This gives a factor of three correction for stop and go traffic. In addition, the mass median diameter of lead emissions increases with vehicle age.[10/]

The emission factor for lead from vehicle exhaust can be calculated for each MRI run using the data in Table 11, and if applicable, a factor of three adjustment for stop and go traffic. The resulting vehicle exhaust lead emission factors are given in Table 12.

For Run 3, the vehicle exhaust emission factor represents constant speed driving. The value of 0.02 g/vehicle mile is taken directly from Table 11, using an average vehicle speed of 25 mph. Runs 5 and 6 are based on 20 mph and Runs 15 and 16 are based on 15 mph. However, for these latter vehicle exhaust emission factors, the factor of three correction was applied to adjust the emission factors for stop and go traffic.

5.3 LEAD FROM DUST REENTRAINMENT

The emission factor for lead from dust reentrainment was calculated in this study as the difference between the total lead emission factor and the vehicle exhaust lead emission factor. This section provides a description of another method for determining lead from dust reentrainment which serves as a cross-check.

A functional relationship between the computed total reentrained particulate emission factor and the measured silt loading (excluding curbs) is defined in the following equation:[3/]

$$e = KLs \qquad \text{Eq. (2)}$$

where
- e = Particulate emission factor (kg/vehicle kilometers)
- K = Proportionality constant (vehicle^{-1})
- L = Surface loading excluding curbs (kg/km)
- s = Silt content of the surface material (fraction)

As an example, substitution of appropriate data into Eq. (2) for Fairfax Trafficway gives the following emission factor for total reentrained particulates:

$$e = 91 \times 10^{-5} \times (152) \times (0.06) = 13.4 \text{ g/vehicle mile}$$

TABLE 12. SUMMARY OF VEHICLE EXHAUST LEAD EMISSION FACTORS

Run	Site	Traffic speed (mph)	characteristics	Vehicle exhaust lead emission factor (gm/veh-mile)
3	37th Street (midday)	25	Light, steady	0.02[a]
5, 6	37th Street (rush hour)	20	Steady, stop and go	0.05[b]
15, 16	Fairfax Trafficway	15	Heavy, steady	0.03[b]

a/ From Table 11.

b/ From Table 11 using a correction factor for stop and go traffic equal to 3.

The emission factor for lead can be calculated as the product of the particulate emission factor and lead content of the surface material. From Figure 7, the weighted average lead content of street loading excluding curbs for Fairfax Trafficway is 0.17%. Thus, the lead emission factor from the reentrained dust would be (13.4) x (0.17/100) = 0.02 g/vehicle-mile.

5.4 MRI RESULTS

Table 13 presents the total particulate lead emission factors developed by MRI. In addition, proposed factors for particulate lead reentrainment by traffic are presented.

The vehicle exhaust lead emission factor was determined using the methodology described in Section 5.2. Specifically, average vehicle speed and assumed fuel economy can be substituted into Eq. (1). Since Eq. (1) assumes a constant cruise speed, the resulting emission factor should then be multiplied by the exhaust multiplier which is based on specific site and traffic characteristics. The exhaust multiplier increases the emission factors to values comparable to 1974 to 1977 data presented in Table 10.

The lead emission factor for reentrained dust is the difference between the measured total emission factor (given in the last column of Table 13) and the vehicle exhaust emission factor. As indicated in Table 13, the lead reentrainment factor seems to be approximately equivalent to the vehicle exhaust factor.

It is clear from Table 10 that the projected lead emissions from vehicle exhaust on a year-by-year basis will decrease in direct proportion to the reduction in the lead content of gasoline burned. It is also reasonable to assume that lead emissions from dust will decrease in the same way, because the source of lead in road surface dust is vehicle combustion of leaded gasoline.

TABLE 13. SUMMARY OF PARTICULATE LEAD EMISSION FACTORS

Run	Lead emission factor (g/vehicle mile)		
	Vehicle exhaust	Dust reentrainment	Measured total
3	0.02	0.01	0.03
5	0.05	0.04	0.09
6	0.05	0.08	0.13
Average	0.05	0.06	0.11
15	0.03	0.04	0.07
16	0.03	0.02	0.05
Average	0.03	0.03	0.06

SECTION 6.0

COMPARISON OF RESULTS

Table 14 presents a comparison of lead data presented in this report, with equivalent data contained in reports prepared by PEDCo Environmental[1/] and by GCA/Technology Division.[2/]

Figure 9 presents a plot of ambient lead concentrations versus sampling height for the MRI, PEDCo and GCA studies. The profiles measured by MRI at a distance of 3 m from the curb show a more pronounced effect of the traffic sources, in comparison with the profiles measured by PEDCo and GCA at greater distances from the curb.

6.1 PEDCo STUDY

A study performed by PEDCo Environmental[1/] used hi-vol measurements of ground-level lead concentrations (i.e., concentrations at various distances downwind from each road) to determine total lead emission factors. This study included analysis of filters for 35 runs at four locations (undeveloped area, park, residential, and commercial).

Total lead emission factors were calculated by PEDCo for 10, 20 and 30 m distances from the road. The results are as follows:

Distance downwind (m)	Total lead emission factor (g/vehicle mile)	
	Range	Average
10	0.016-0.201	0.068
20	0.007-0.319	0.068
30	<0.005-0.154	0.072

In order to calculate, by difference, an average lead emission factor for dust reentrainment from the PEDCo data, the vehicle exhaust emission factor was calculated by MRI assuming constant cruise speeds. The procedure used was that given in Section 5.2.

TABLE 14. COMPARISON OF LEAD RESULTS

	MRI	PEDCo[1]	GCA[2]
I. % lead in particulate samples			
A. Upwind hi-vol	0.22-0.46	0.0-2.64[b]	
B. Street loading	0.09-0.22	1.3-2.7 (<44 μm)	
C. Downwind hi-vol	0.44-0.98	0.13-3.43	0.6-1.8
II. Lead concentrations ($\mu g/m^3$) - see Figure 9			
A. Upwind hi-vol	0.46-0.72	0.00-2.04[b]	
B. Downwind hi-vol	1.59-2.76	0.39-5.75[b]	1-4
III. Particle size	Fine (see Table 8)	Fine[a]	
IV. Lead emission factors (g/veh. mi.)	Site[e] A, B, C		
A. Total	0.03, 0.11, 0.06	0.069[b]	
B. Vehicle exhaust	0.02, 0.05, 0.03	0.036[c]	
C. Road dust reentrainment	0.01, 0.06, 0.03	0.033[d]	

a/ Horizontal measurements taken at various distances downwind from the road resulted in increases in % lead.

b/ Based on average of 35 runs.

c/ Calculated using methodology described in Section 5.2 (average vehicle speed = 40 mph; and constant cruise speed).

d/ Calculated by difference; i.e., total emission factor minus vehicle exhaust emission factor.

e/ Site A - 37th Street (midday)
Site B - 37th Street (rush hour)
Site C - Fairfax Trafficway

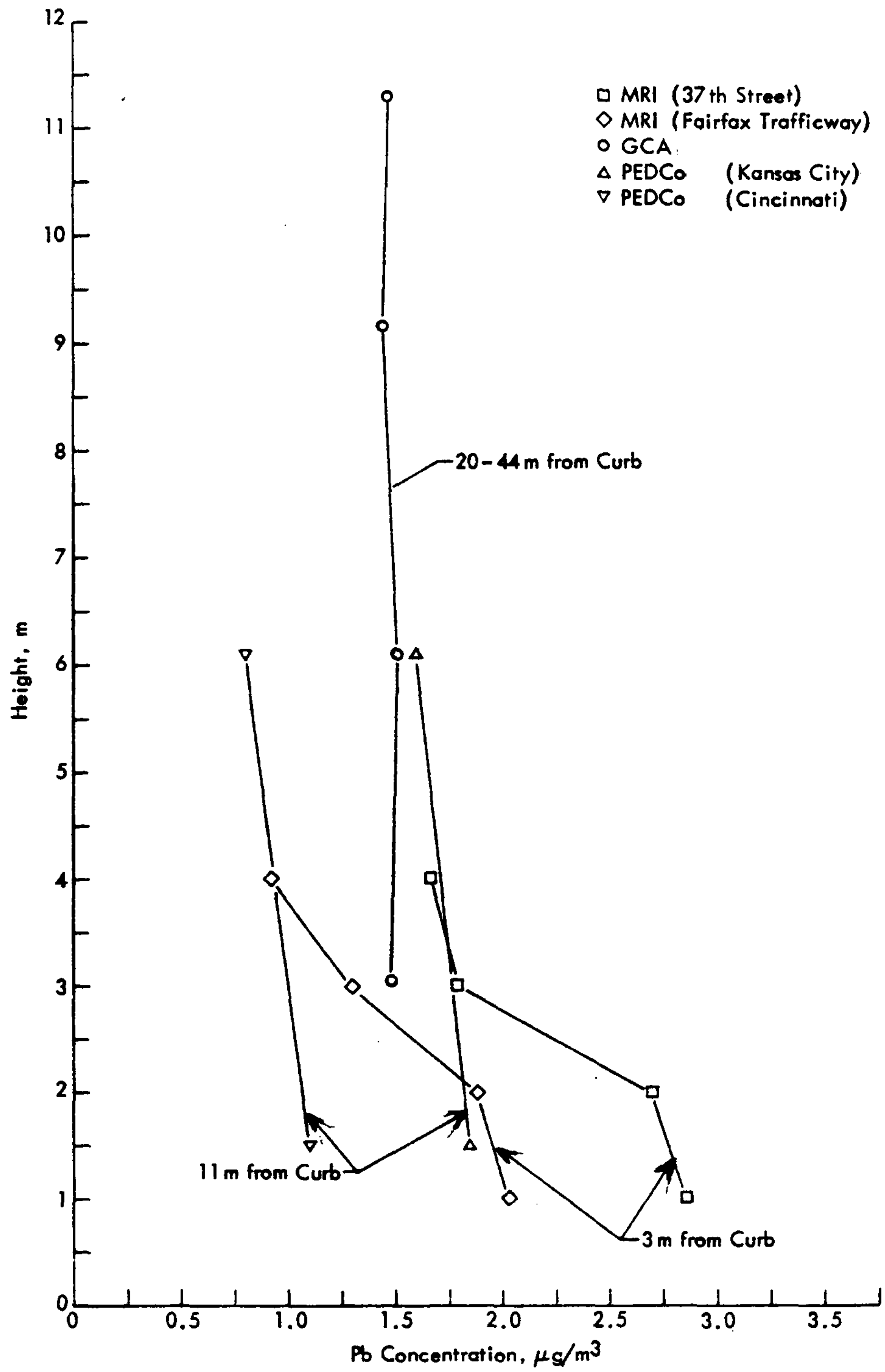


Figure 9. Comparison of Lead Concentrations at Various Sampling Heights

Twenty-seven out of the 35 PEDCo runs were conducted at locations with an average traffic speed of 39 mph. The remaining eight tests were conducted at a commercial site with some stop and go traffic. The average total lead emission factor for the 27 runs was 0.068 g/vehicle mile. The vehicle exhaust emission factor is 0.036 g/vehicle mile for 40 mph (Table 11). This gives an average dust reentrainment emission factor of 0.068 minus 0.036, or 0.032 g/vehicle mile.

The PEDCo study also showed increased lead content of particulates at further distances from the road. This indicates that the lead consists primarily of fine particles, which is also indicated by the MRI results (see Table 8).

6.2 GCA STUDY

A study performed by GCA[2/] used high-volume samplers mounted on a 40-ft tower at heights of 10, 20, 30, and 37 ft. Thirteen 24-hr samples were made at the intersection of two major downtown streets in Philadelphia.

The study indicated that there was no relationship between sampler height and lead concentrations (see Figure 9). This appears to be due to the enhanced vertical dispersion and due to the elevated sampling heights. The GCA study, too, indicates that lead is concentrated in fine particles.

6.3 SUMMARY OF RESULTS

The results of this study plus other studies indicate that the lead emission factor for reentrained dust is approximately 0.03 g/vehicle mile for the 1975-1976 sampling period. It is apparent that decreasing the lead content in gasoline will not only decrease the amount of airborne lead emitted from vehicle exhaust, but also will decrease the amount of lead-containing dust reentrained from paved roadways. With the reduction of lead in leaded gasoline and the continued introduction of catalyst equipped vehicles into the vehicle distribution, the lead emission factor for reentrained dust is expected to drop below 0.01 by 1980.

The following emission factors were calculated using the results of this study and the data from other investigations:

	Lead emission factor for 1975-1976 (g/vehicle mile)			
	Total		Dust reentrainment	
	Range	Average	Range	Average
Midwest Research Institute	0.03 to 0.11	0.06	0.01 to 0.06	0.03
PEDCo Environmental	0.005 to 0.319	0.07		0.03
Average		0.065		0.03

Analysis of airborne particulate samples for lead particle size distribution shows that lead is concentrated in fine particles. The mass median diameter for particulate lead is about 1 μm as compared to a mass median diameter of about 5 μm for total airborne particulate. This result is substantiated by results reported elsewhere which indicate that the lead content of airborne particulate increases with distance from the curb.

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GLOSSARY

Dry Sieving - The sieving of oven-dried aggregate by passing it through a series of screens of descending opening size.

Enclosure - A structure which either partially or totally surrounds a fugitive emissions source thereby reducing the amount of emissions.

Exposure - The point value of the flux (mass/area-time) of airborne particulate passing through the atmosphere, integrated over the time of measurement.

Exposure, Integrated - The result of mathematical integration of partially distributed measurements of airborne particulate exposure downwind of a fugitive emissions source.

Exposure Profiling - Direct measurement of the total passage of airborne particulate immediately downwind of the source by means of simultaneous multipoint isokinetic sampling over the effective cross section of the fugitive emissions plume.

Particle Diameter, Aerodynamic - The diameter of a hypothetical sphere of unit density (1 g/cm^3) having the same terminal settling velocity as the particle in question, regardless of its geometric size, shape and true density.

Particle Diameter, Stokes - The diameter of a hypothetical sphere having the same density and terminal settling velocity as the particle in question, regardless of its geometric size and shape.

Particle Drift Distance - Horizontal distance from point of particle injection into the atmosphere to point of removal by contact with the ground surface.

Particulate, Fine - Airborne particulate smaller than 5 μm in Stokes diameter.

Particulate, Suspended - Airborne particulate smaller in Stokes diameter than 30 μm, the approximate cut-off diameter for the capture of particulate matter by a standard high-volume sampler, based on particle density of 2 to 2.5 g/cm^3.

Road, Paved - A roadway constructed of rigid surface materials, such as asphalt, cement, concrete and brick.

Road Surface Dust Loading - The mass of loose surface dust on paved roadway, per length of roadway, as determined by dry vacuuming.

Silt Content - The mass portion of an aggregate sample smaller than 75 μm in diameter as determined by dry sieving.

APPENDIX

EXAMPLE CALCULATION OF LEAD EMISSION FACTOR
(Run 5)

A. CALCULATION OF TOTAL LEAD EXPOSURE

The purpose of this subsection is to show the procedures for calculating total lead exposure. Exposure is the flux (mass/area-time) of airborne particulate passing through the atmosphere, integrated over the time of measurement. The basic data used in this calculation is the net filter and net wash sample weights collected at sampling heights of 1, 2, 3, and 4 m by the MRI exposure profiler.

		RESULT
STEP 1	Compute Filter Pb Net Weight (μg)	
	= Filter Particulate Net Weight (μg) x % Lead on Filter/100	
	Profiler 1 = 61,250 x (1.1/100) =	674
	Profiler 2 = 55,600 x (0.84/100) =	467
	Profiler 3 = 50,950 x (0.77/100) =	392
	Profiler 4 = 40,350 x (0.68/100) =	274
STEP 2	Compute Wash Sample Pb Net Weight (μg)	
	= Wash Sample Particulate Net Weight (μg) x % Lead in Wash Sample/100	
	Profiler 1 = 17,900 x (0.19/100) =	34
	Profiler 2 = 17,350 x (0.23/100) =	40
	Profiler 3 = 11,000 x (0.31/100) =	34
	Profiler 4 = 12,950 x (0.30/100) =	39

		RESULT
STEP 3	Determine Total Pb Sample Weight (μg)	
	= Filter Pb Net Weight (μg) from Step 2 + Wash Sample Pb Net Weight from Step 2	
	Profiler 1 = 674 + 34 =	708
	Profiler 2 = 467 + 40 =	507
	Profiler 3 = 392 + 34 =	426
	Profiler 4 = 274 + 39 =	313
STEP 4	Calculate Pb Concentration (μg/m^3)	
	= Total Pb Sample Weight (μg) from Step 3 ÷ Volume of Air Sampled (m^3)	
	Profiler 1 = 708/217	3.27
	Profiler 2 = 507/249	2.03 (see Table 7)
	Profiler 3 = 426/272	1.56
	Profiler 4 = 313/288	1.09
STEP 5	Hi-Vol Pb Concentration (μg/m^3) Excluding Background	
	= Subtract Upwind (Background) Hi-Vol Pb Concentration (μg/m^3) given in Table 7 from Profiler Concentrations (μg/m^3) given in Step 4	
	Profiler 1 = 3.27 - 0.60 =	2.67
	Profiler 2 = 2.03 - 0.60 =	1.43
	Profiler 3 = 1.56 - 0.60 =	0.96
	Profiler 4 = 1.09 - 0.60 =	0.49
STEP 6	Compute Total Pb Net Mass (μg)	
	= Hi-Vol Pb Concentration, Excluding Background (μg/m^3) given in Step 5 x Volume Air Samples (m^3)	
	Profiler 1 = 2.67 x 217 =	578
	Profiler 2 = 1.43 x 249 =	356
	Profiler 3 = 0.96 x 272 =	261
	Profiler 4 = 0.49 x 288 =	141

		RESULT
STEP 7	Determine Area Under Exposure Profile (mg-ft)	
	Plot Total Pb Net Mass (μg) Versus Sampling Height (m) Graphically Integrate	
	Area = 1,637 μg-m x 0.00328 mg-ft/μg-m	5.37
STEP 8	Calculate Total Pb Exposure (g/veh. mi.)	
	= Area (mg-ft) given in Step 7 ÷ No. of Vehicle Passes given in Table 5 x 5280 (ft/mi.) x 36 (intake conversion) x 10^{-3} (g/mg)	0.452
	= (5.37 ÷ 2260) x 5280 x 36 x 10^{-3}	

B. CALCULATION OF TOTAL LEAD EMISSION FACTOR

The purpose of this subsection is to present the procedure for converting total lead exposure to an isokinetic emission factor representing particles smaller than 30 μm in diameter.

STEP 1	Calculate Isokinetic Emission Factor (g/veh. mi.)	
	Correct Total Pb Exposure to Isokinetic Conditions Using MRI Procedures (see Section 4.2)	
	= 0.452 x (U/u) = 0.452 x 0.2 =	0.090 (see Table 7)
STEP 2	Calculate Total Pb Emission Factor (Smaller than 30 μm in diameter)	
	= Isokinetic Emission Factor (g/veh. mi.) x Fraction < 30 μm (from Table 8)	
	= 0.090 x 0.98 =	0.09

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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7. AUTHOR(S) Christine M. Maxwell and Daniel W. Nelson		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Midwest Research Institute 425 Volker Boulevard Kansas City, MO 64110		10. PROGRAM ELEMENT NO.
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15. SUPPLEMENTARY NOTES

Project Officer - Charles C. Masser

16. ABSTRACT

The results of this study indicate that the lead emission factor for reentrained dust is approximately 0.03 g per vehicle mile for the 1975-1976 sampling period. That approximation was calculated using the results of this study and the data from other investigations.

It is apparent that decreasing the lead content in gasoline will not only decrease the amount of airborne lead emitted from vehicle exhaust, but also will decrease the amount of lead-containing dust reentrained from paved roadways. With the reduction of lead in leaded gasoline and the continued introduction of catalyst equipped vehicles into the vehicle distribution, the lead emission factor for reentrained dust is expected to drop below 0.01 by 1980.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Lead Emissions Emission Factor		

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