DIVISION COPY

[redacted] Reference # 11

MIDWEST RESEARCH INSTITUTE

MRI REPORT

SIZE SPECIFIC PARTICULATE EMISSION FACTORS FOR UNCONTROLLED INDUSTRIAL AND RURAL ROADS

DRAFT FINAL REPORT
January 19, 1983

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

EPA Contract No. 68-02-3158
Technical Directive No. 12
MRI Project No. 4892-L(20)

EPA Project Officer: Dale Harmon
EPA Task Manager: William B. Kuykendal

Prepared for:

Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

SIZE SPECIFIC PARTICULATE EMISSION FACTORS FOR UNCONTROLLED INDUSTRIAL AND RURAL ROADS

DRAFT FINAL REPORT

January 19, 1983

by

J. Patrick Reider

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

EPA Contract No. 68-02-3158
Technical Directive No. 12

MRI Project No. 4892-L(20)

EPA Project Officer: Dale Harmon
EPA Task Manager: William B. Kuykendal

Prepared for:

Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Environmental Protection Agency's Industrial Environmental Research Laboratory under EPA Contract No. 68-02-3158, Technical Directive No. 12. Mr. William B. Kuykendal of the Particulate Technology Branch at Research Triangle Park, North Carolina, served as technical project officer for this study.

The field program was conducted in MRI's Air Quality Assessment Section under the supervision of Dr. C. Cowherd, Jr. The principal investigator for MRI and author of this report was Mr. J. Patrick Reider.

The author wishes to acknowledge the following field crew members for their contributions: Julia Poythress - sample filter preparation and laboratory analysis, computerized data analysis; Frank Pendleton - equipment preparation, maintenance, and calibration; Dave Griffin - road surface sampling and preparation and analysis of sampler washes; and Steve Cummins - soil sample analysis. Pat Reider and Frank Pendleton served as crew chiefs. Additional field crew members assisting with equipment deployment and traffic observations were James Knapp, Tim Arnold, and Phil Englehart. Greg Muleski assisted in developing the computerized particle size analysis procedure.

Approved for:

MIDWEST RESEARCH INSTITUTE

M. P. Schrag, Director
Environmental Systems Department

January 19, 1983

CONTENTS

1.0 INTRODUCTION

For years traffic-generated dust emissions from unpaved and paved industrial roads have been identified as a significant source of atmospheric particulate emissions, especially within those industries involved in the mining and processing of mineral aggregates. Typically, road dust emissions exceed emissions from other open dust sources associated with the transfer and storage of aggregate materials. For example, in western surface coal mines, dust emissions from uncontrolled unpaved roads usually account for more than three-fourths of the total particulate emissions, including typically controlled process sources, such as crushing operations.[1] Therefore, the quantification of this source is necessary for the development of effective strategies for the attainment and maintenance of the total suspended particulate (TSP) standard, as well as the anticipated particulate standard based on particle size.

Although a considerable amount of field testing of industrial roads has been performed, those studies have focused primarily on TSP emissions. Recently, the emphasis has shifted to the development of size-specific emission factors in the small particle range (< 15 μm aerodynamic diameter). The following particle size fractions were of primary interest in this study.

IP = Inhalable particulate matter consisting of particles smaller than 15 μm in aerodynamic diameter.

PM_{10} = Particulate matter consisting of particles smaller than 10 μm in aerodynamic diameter.

FP = Fine particulate matter consisting of particles smaller than 2.5 μm in aerodynamic diameter.

Two recent studies have provided size-specific emission factors for dust emissions from industrial paved and unpaved roads. In a study of fugitive dust sources in western surface coal mines, conducted by PEDCo Environmental and Midwest Research Institute,[1] emission factors were developed for haul trucks and for light and medium duty vehicles traveling on uncontrolled unpaved haul and access roads. A companion study conducted by Midwest Research Institute[2] was directed to the development of size-specific emission factors for dust emissions from uncontrolled paved and unpaved roads within iron and steel plants. Both of these studies employed the exposure profiling method coupled with the use of inertial particle sizing devices.

The objective of the field study described herein was to expand the emission factor data base by conducting field testing in other industries with significant road dust emissions. It was anticipated that the combined data base would include ranges of road and traffic conditions that encompass most industrial settings where road dust emissions are significant.

This document reports the results of a field testing program utilizing exposure profiling to develop quantitative emission factors for dust entrainment from vehicular traffic on uncontrolled industrial paved and unpaved roads as well as unpaved rural roads. Specific items discussed include field test sites, sampling equipment, field measurements, calculation procedures, and sampling and analysis results. Appendix A presents an example to demonstrate the emission factor calculation procedure. Appendix B reports the procedures for determining the silt content of the road surface particulate loading.

2.0 TEST SITE SELECTION

This testing program was designed to selectively increase the existing emission factor data base for industrial roads. Testing was conducted in four different industries under conditions sufficiently diverse to allow reliable application of the resulting emission factors within these industries.

This section discusses the sampling matrix for the field testing program, test site suitability for exposure profiling, site representativeness of industry, and industrial cooperation.

2.1 EXPERIMENTAL TEST MATRIX

An integrated sampling program was conducted at representative road sites distributed over four source category industries. The following industry categories were agreed upon for this task, to be supplemented by testing of rural unpaved roads:

- Cement and Lime Production
- Crushed Stone and Sand and Gravel Processing
- Primary Nonferrous Smelting
- Asphalt and Concrete Batching

These industries were believed to represent the largest sources of untested size-specific emissions from paved and unpaved roads. Triplicate tests of uncontrolled fugitive dust emissions were conducted at each site. The experimental design test matrix of industry sites originally proposed for this study is given in Table 1. The matrix of test conditions was sufficiently extensive to represent a wide range of conditions encountered in major

TABLE 1. EXPERIMENTAL DESIGN TEST MATRIX AND INDUSTRY SELECTION

Industry	Number of tests: Paved roads	Number of tests: Unpaved roads
Cement plant	3	3
Lime plant	3	3
Stone crushing operation	3	3
Sand and gravel processing	3	3
Asphalt batching	3	3
Concrete batching	3	3
Copper smelter	6	3
Rural roads		
Crushed stone	0	6
Dirt	0	3
Gravel	0	3
Totals	24	33

industries. Test sites were selected in each industry based upon the following criteria: suitability for exposure profiling; representativeness of the industrial category; and sufficiency of cooperation obtained from plant personnel. Each of these factors are discussed below.

2.2 SUITABILITY FOR EXPOSURE PROFILING

Three major criteria were used to determine the suitability of each candidate site for sampling of traffic-entrained road dust emissions by the exposure profiling technique.

1. Adequate space for sampling equipment with easy access to the area;

2. Sufficient traffic and/or surface dust loading so that adequate mass would be captured on the lightest loaded collection substrate during a reasonable sampling time period; and

3. A wide range of acceptable wind directions taking into account the test road orientation relative to the predominant wind direction and the possible effect of nearby structures on wind flow across the test road.

2.2.1 Adequate Space

Adequate space for equipment deployment and easy access to the area is required for fugitive road dust sampling. All sites were chosen to provide the necessary space, as well as, accessibility for the setup of the upwind and downwind sampling equipment and to ensure the safety of the field crew. Typically, exposure profiling equipment was deployed at a distance of 5 m from the downwind edge of the road. Background (upwind) samplers were usually located 5 m from the upwind edge of the roadway.

2.2.2 Sufficient Mass Catch

To provide for accurate determination of the fugitive dust emission rate from exposure profiling data, at least 5 mg of sample should be collected by each profiling head. Particulate concentration and sampling time must be sufficient to provide the 5 mg weight gain under isokinetic sampling conditions. This requirement is the most difficult to achieve for the highest sampling head (located at 5 m above ground) because of the significant decrease in particulate concentration with height. Traffic volume and/or road surface dust loadings should, therefore, be sufficient to provide a minimum sample at the top height.

During the site-survey of each candidate testing location, traffic was counted visually during a 15- to 30-min period. These traffic counts were then converted to an average hourly account by simple linear extrapolation with time. This, in conjunction with a visual estimate of emissions from each vehicle pass, was used to determine if an adequate sample could be obtained in a reasonable time period.

2.2.3 Acceptable Wind Directions

Wind directions that would successfully transport the traffic entrained dust from industrial roadways to the exposure profiler depend on the following factors:

- Road Orientation - the mean (15-min average) direction of the wind must lie within 45 degrees of the perpendicular to the road.

- Wind Fetch - the wind flowing toward the test roadway should not be blocked by obstacles in the upwind or downwind direction.

In order to evaluate the candidate sites for the wind fetch requirement, the arc of wind direction for which the wind would flow freely between the two nearest upwind obstacles (houses, buildings, or trees) can be calculated as follows:

$$\theta = \arctan \frac{b}{2a}$$

where θ represents the half angle of the arc, b is half the distance between the two blocking obstacles (fetch), and a is the perpendicular distance from the line joining the corners of the obstacles to the proposed location of the profiler (typically 5 m from the downwind edge of the roadway). Figure 1 illustrates these parameters.

2.3 SITE REPRESENTATIVENESS

Also of concern in site selection was the need to select a site that was representative of the test industry category. It was necessary (a) that the test roadways have surface characteristics similar to other sites in the respective industry category; (b) that the traffic on a test roadway be typical of that category; and (c) for industrial categories, that the site be located in a plant with a production rate representative of the plants within that industry.

2.3.1 Surface Characteristics

In previous emissions testing of road surfaces, MRI has demonstrated that surface characteristics play an important role in determining the emissions from a roadway source. For this reason, sites were chosen that visibly demonstrated road aggregate type, surface loadings, and surface texture that were typical of their industry category.

2.3.2 Vehicular Traffic

Also important in determining fugitive emissions from a roadway source are the characteristics of its vehicular traffic. Sites were, therefore, selected with vehicular traffic that was typical for the respective industry category. Important parameters in making this determination were traffic volume and the mixture of traffic vehicles (vehicle size, weight, and the number of wheels and axles).

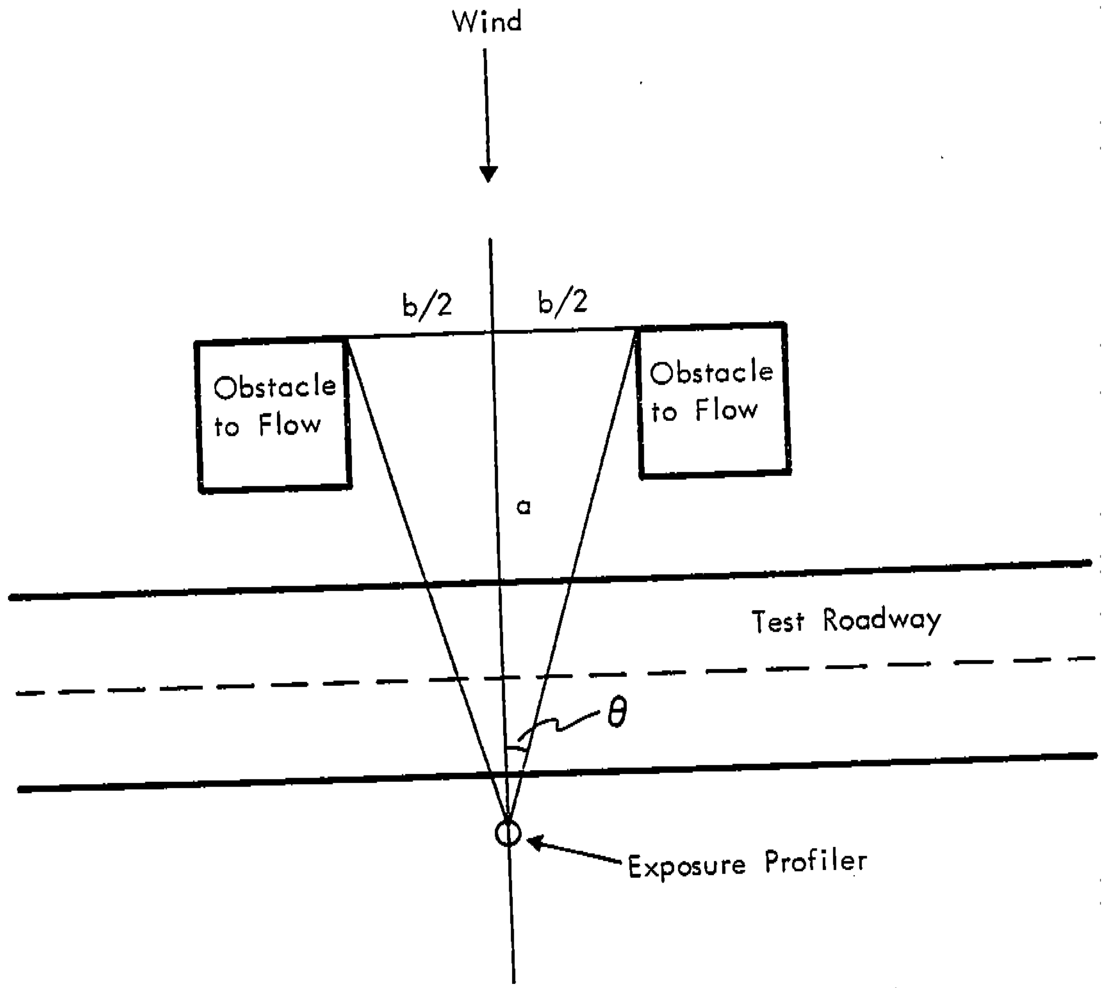

Figure 1. Parameters for calculations of angle of unobstructed wind flow.

2.4 INDUSTRIAL COOPERATION

Prior to any site selection, liaison was established with the appropriate corporate and plant personnel. During the initial contact, an explanation of the proposed work was presented. Later, site surveys were performed to determine the suitability of roads within candidate facilities for testing. If the plant was found suitable, permission for testing was requested. Further cooperation was also required once the testing began. Without permission to test and indication of substantial cooperation, plans for testing an otherwise good plant site were abandoned.

3.0 EXPOSURE PROFILING SAMPLING EQUIPMENT

A variety of sampling equipment was utilized in this study to measure particulate emissions, roadway surface particulate loadings, and traffic characteristics.

Table 2 specifies the kinds and frequencies of field instruments 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.

3.1 AIR SAMPLING EQUIPMENT

The primary sampling technique used in this sampling program for quantification of fugitive emissions was the MRI exposure profiler, which was developed under EPA Contract No. 68-02-0619.[3] The profiler as shown in Figure 2 consists of a portable tower (6 m height) supporting an array of five sampling heads. Each sampling head is operated as an isokinetic total particulate matter exposure sampler directing passage of the flow stream through a settling chamber (trapping particles larger than about 50 μm in diameter) and then upward through a standard 8 in. by 10 in. glass fiber filter positioned horizontally. Sampling intakes are pointed into the wind, and sampling velocity of each intake is adjusted to match the local mean wind speed, as determined prior to each test. Throughout each test, wind speed is monitored by recording anemometers at two heights, and the vertical wind profile of wind speed is determined by assuming a logarithmic distribution. The exposure profiler is positioned at a distance of 5 m from the downwind edge of the road.

TABLE 2. FIELD MEASUREMENTS FOR EXPOSURE PROFILE SAMPLING

Test Parameter	Units	Sampling Mode	Measurement/Instrument method	Manufacturer/Model
1. Meteorology				
a. Wind speed	m/s	continuous	warm wire anemometer	Kurz Model 410
b. Wind direction	deg	continuous	wind vane	Wong Eco-System III
c. Barometric pressure	"Hg	single	barometer	Thorman
d. Temperature	°C	single	sling psychrometer	Taylor cat. no. 146-761
e. Relative humidity	%	single	sling psychrometer	Taylor cat. no. 146-761
2. Road Surface				
a. Pavement type	-	composite	observation	-
b. Surface condition	-	composite	observation	-
c. Particulate loading	g/m^2	multiple	dry vacuuming/ broom sweeping	Hoover, Model S2015 Quick Broom
d. Silt content	% silt	multiple	dry sieving	Forney, Inc., LA-410 Sieve Shaker
3. Vehicular Traffic				
a. Mix	-	multiple	observation	-
b. Count	-	cumulative	observation	-
c. Weight	MG	multiple	gravimetric	-
d. Speed	K/H	multiple	observation	-
4. Atmospheric Particulate				
a. Total particulate	mass conc. ($\mu g/m^3$)	integrated	Iso-kinetic profiler	MRI developed under EPA Contract No. 68-02-0619
b. Total suspended particulate	mass conc. ($\mu g/m^3$)	integrated	Hi-Volume sampler	Sierra Instruments, Inc., Model 305
c. Inhalable particulate	mass conc. ($\mu g/m^3$)	integrated	size selective inlet	Sierra Instruments, Inc., Model 7000
d. Inhalable particulate	mass size dist. (μg)	integrated	cyclone precollector/ slotted high-volume cascade impactor	Sierra Instruments, Inc., Model 230

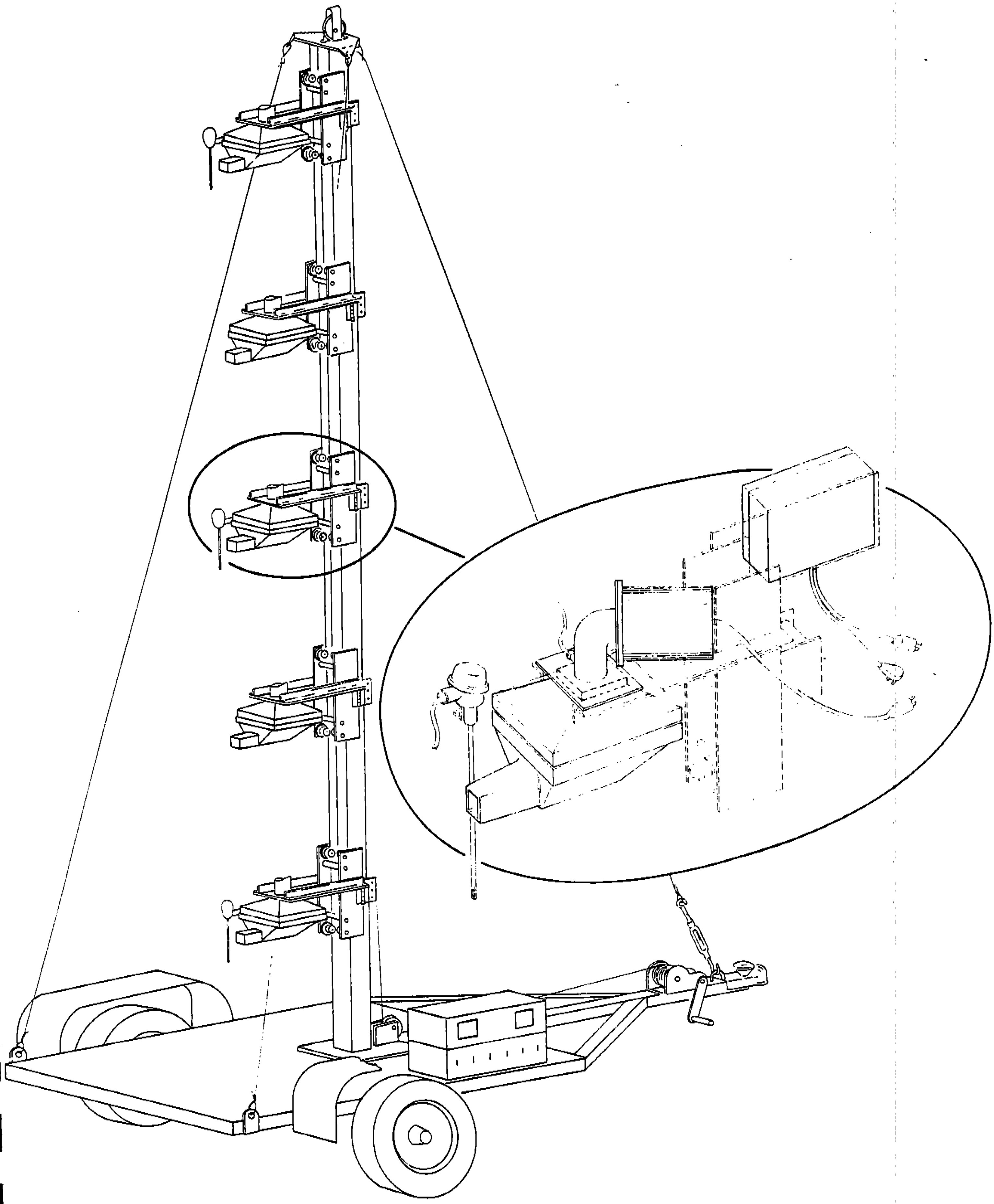

Figure 2. MRI exposure profile tower and equipment.

The recently developed EPA version of the size selective inlet (SSI) for the high-volume air sampler was used to determine IP concentrations. To obtain the particle size distribution of IP, a high-volume parallel-slot cascade impactor (CI) with greased substrates was positioned beneath a cyclone precollector. The five-stage cascade impactor, operating at a flow rate of 20 SCFM, has 50% efficiency cutpoints of 10.2, 4.2, 2.1, 1.4, and 0.73 μm in aerodynamic diameter. Since the last two stages were below the particle size range of interest, they were not used in this study.

Other air sampling instrumentation used included standard high-volume air samplers to measure total suspended particulate matter (TSP) consisting of particles smaller than about 30 μm in aerodynamic diameter.

3.2 SAMPLING EQUIPMENT DEPLOYMENT

For each test of a road, the downwind equipment included an exposure profiling system with five sampling heads positioned at 1, 2, 3, 4, and 5 m heights. A standard high-volume air sampler plus another high-volume sampler equipped with an SSI were operated at a height of 2 m. Additionally, high-volume samplers fitted with cyclone/cascade impactors were placed at 1 m and 3 m heights to determine IP, PM_{10}, and FP mass fractions of the total particulate emissions.

The basic upwind equipment were three high-volume air samplers all deployed at a height of 2 m. One sampler was equipped with an SSI, another was fitted with a cyclone/cascade impactor, and the third was operated as a standard high-volume sampler.

Two variations in profiling equipment deployment were used in this study. The deployment of samplers for each exposure profiling test is shown in Figure 3. However, the upwind cyclone/impactor was omitted for the asphalt and concrete industry testing. The background particulate levels for those sites were anticipated to be insufficient to fractionate and have adequate mass on each substrate to accurately measure.

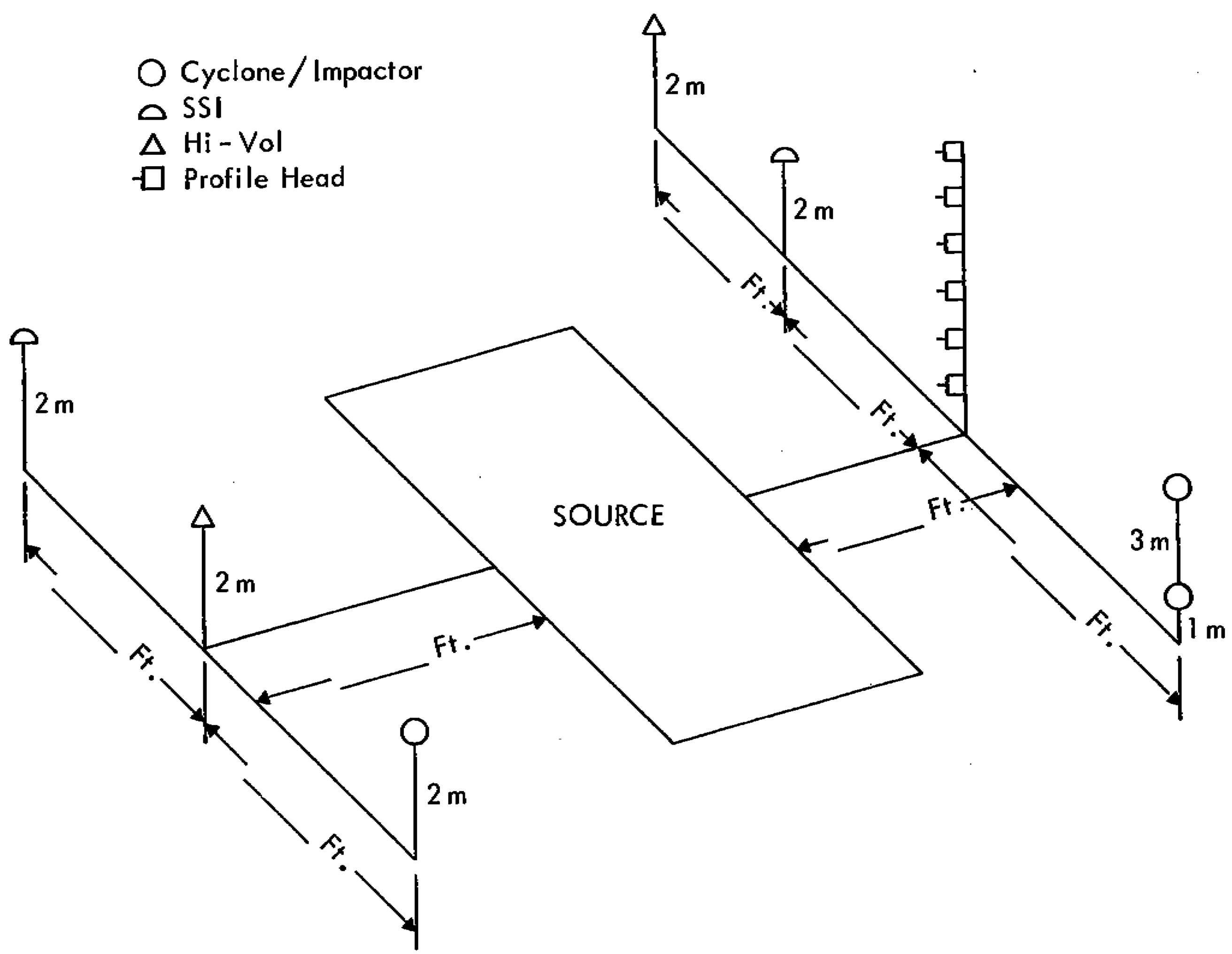

Figure 3. Exposure profiling equipment deployment diagram.

3.3 ROADWAY DUST SAMPLING EQUIPMENT

Samples of the dust found on paved roadway surfaces were collected during the source tests. In order to collect this surface dust, it was necessary to close each traffic lane for a period of approximately 15 min. Normally, an area that was 12 to 15 in. by the width of a road was sampled. A hand-held portable vacuum cleaner was used to collect the roadway dust. The attached brush on the collection inlet was used to abrade surface compacted dust and to remove dust from the crevices of the road surface. Vacuuming was preceded by broom sweeping if large aggregate was present.

Unpaved roadway dust samples were collected by sweeping the loose layer of soil or crushed rock from the hardpan road base with a broom and dust pan. Sweeping was performed so that the road base was not abraded by the broom, and so that only the naturally occurring loose dust was collected. The sweeping was performed slowly so that dust was not entrained into the atmosphere. From these samples, the silt content and moisture content of the surface materials were measured. Recording the sample area provides information to determine the total particulate loading and the silt loading.

3.4 VEHICLE CHARACTERIZATION EQUIPMENT

The vehicular characteristics monitored during each test included: (a) total traffic count, (b) mean traffic speed, (c) mean vehicle weight, and (d) vehicle mix.

Total vehicle count, vehicle speed, and vehicle mix were determined by manual observations. The speed of the traveling vehicles was verified by consulting with drivers at the test sites. The weights of the vehicle types were obtained by consulting plant operators at industrial sites and automobile literature concerning curb weights of vehicles for rural roads.

4.0 SAMPLING AND ANALYSIS PROCEDURES

The sampling and analysis procedures employed in this study were subject to the Quality Control guidelines summarized in Tables 3 to 6. These procedures met or exceeded the requirements specified by EPA.[4,5]

As part of the QC program for this study, routine audits of sampling and analysis procedures were performed. The purpose of the audits was to demonstrate that measurements were made within acceptable control conditions for particulate source sampling and to assess the source testing data for precision and accuracy. Examples of items audited include gravimetric analysis, flow rate calibration, data processing, and emission factor calculation. The mandatory use of specially designed reporting forms for sampling and analysis data obtained in the field and laboratory aided in the auditing procedure. Further detail on specific sampling and analysis procedures are provided in the following sections.

4.1 PREPARATION OF SAMPLE COLLECTION MEDIA

Particulate samples were collected on Type A slotted glass fiber impactor substrates and on Type AE (8 in. x 10 in.) glass fiber filters. To minimize the problem of particle bounce, the glass fiber cascade impactor substrates were greased. The grease solution was prepared by dissolving 140 g of stopcock grease in 1 liter of reagent grade toluene. No grease was applied to the borders and backs of the substrates. The substrates were handled, transported and stored in specially designed frames which protected the greased surfaces.

TABLE 3. QUALITY CONTROL PROCEDURES FOR SAMPLING FLOW RATES

Activity	QC check/requirement
Calibration • Profilers, hi-vols, and impactors	Calibrate flows in operations ranges using calibration orifice or anemometer type calibrator prior to testing each site.
Orifice calibrator	Calibrate against displaced volume test meter annually.
	Audit calibration using a reference flow calibrator provided by local air quality agency.
Anemometer calibrator	Calibrate against a pitot tube in a laboratory wind tunnel.

TABLE 4. QUALITY CONTROL PROCEDURES FOR SAMPLING DATA

Activity	QC check/requirement
Preparation	Inspect and imprint glass fiber media with ID numbers.
Conditioning	Equilibrate media for 24 hr in clean controlled room with relative humidity of less than 50% (variation of less than ± 5%) and with temperature between 20° ± and 25°C (variation of less than ± 3%).
Weighing	Weigh hi-vol filters and impactor substrates to nearest 0.05 mg.
Auditing of weights (tare and final)	Independently verify weights of 100% of tare weights and 10% of final weights on filters and substrates. Reweigh batch if weights of any hi-vol filters (8 x 10 in.) or substrates deviate by more than ± 1.0 and ± 0.5 mg, respectively.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 filter substrates, profiler inlets, and cyclones for each industry.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative check prior to each use with laboratory Class S weights.

TABLE 5. QUALITY CONTROL PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QC check/requirement
Maintenance	
• All samplers	Check motors, gaskets, timers, and flow measuring devices at each regional site prior to testing.
Operation	
• Timing	Start and stop all samplers during time spans not exceeding 1 min.
• Isokinetic sampling (profilers only)	Adjust sampling intake orientation whenever mean (15 min average) wind direction changes by more than 30 degrees.
	Adjust sampling rate whenever mean (15 min average) wind speed approaching sampler changes by more than 20%.
• Prevention of static mode deposition	Cap sampler inlets prior to and immediately after sampling.
	Remove all inlets and filters immediately after the test and transfer to specially designed containers.

TABLE 6. QUALITY CONTROL PROCEDURES FOR DATA PROCESSING AND CALCULATIONS

Activity	QA check/requirements
Data recording	Use specially designed data forms to assure all necessary data are recorded. All data sheets must be initialed and dated.
Calculations	Independently verify 10% of calculations of each type. Recheck all calculations if any value audited deviates by more than ± 3%.

Prior to the initial weighing, the greased substrates and filters were equilibrated for 24 hr at constant temperature and humidity in a special weighing room. During weighing, the balance was checked at frequent intervals with standard weights to assure accuracy. The substrates and filters remained in the same controlled environment for another 24 hr, after which a second analyst reweighed them as a precision check. Substrates or filters that could not pass audit limits were discarded. Ten percent of the substrates and filter taken to the field were used as blanks.

4.2 PRE-TEST PROCEDURES/EVALUATION OF SAMPLING CONDITIONS

Prior to equipment deployment, a number of decisions were made as to the potential for acceptable source testing conditions. These decisions were based on forecast information obtained from the local U.S. Weather Service office. A specific sampling location was identified based on the prognosticated wind direction. Sampling would ensue only if the wind speed forecast was between 3 and 20 mph. Sampling was not planned if there was a high probability of measurable precipitation (normally > 20%) or if the road surface was damp.

If conditions were considered acceptable, the sampling equipment was transported to the site, and deployment was initiated. This procedure normally took 1 to 2 hr to complete. During this period, the samples of the road surface particulate were collected at a location within 100 m of the air sampling site.

4.3 AIR SAMPLING

Once the source testing equipment was set up and filters put in place, air sampling commenced. Information recorded for each test included: (a) exposure profiler - start/stop times, wind speed profiles and sampler flow rates (determined every 15 min) and wind direction (relative to roadway perpendicular); (b) SSI, Hi-Vols - start/stop times, and sampler flow rates; (c) vehicle traffic - total count, vehicle mix count, and speed; and (d) general meteorology - wind speed and direction, temperature, and relative humidity.

Sampling usually lasted 1 to 3 hr. Occasionally, sampling was interrupted due to occurrence of unacceptable meteorological conditions and then restarted when suitable conditions returned. Table 7 presents the criteria used for suspending or terminating a source test.

The upwind-background samplers were normally operated concurrent with the downwind samplers. Whenever possible, care was taken to position the upwind samplers away from any influencing particulate emission source.

4.4 SAMPLE HANDLING AND ANALYSIS

To prevent particulate losses, the exposed media were carefully transferred at the end of each run to protective containers within the MRI instrument van. Exposed filters and substrates were placed in individual glassine envelopes and numbered file folders, and then returned to the MRI laboratory. Particulate that collected on the interior surfaces of each exposure profiling head was rinsed with distilled water into separate jars.

TABLE 7. CRITERIA FOR SUSPENDING OR TERMINATING AN EXPOSURE PROFILING TEST

A test will be suspended or terminated if:[a]

1. Rainfall ensues during equipment setup or when sampling is in progress.
2. Mean wind speed during sampling moves outside the 3 to 20 mph acceptable range for a substantial portion of the test.
3. The angle between mean wind direction and the perpendicular to the path of the moving point source during sampling exceeds 45 degrees.
4. Mean wind direction during sampling shifts by more than 30 degrees from profiler intake direction and profiler can not be adjusted without violating number 3 above.
5. Daylight is insufficient for safe equipment operation.
6. Source condition deviates from predetermined criteria (e.g., occurrence of truck spill).

[a] "Mean" denotes a 15-min average.

When exposed substrates and filters (and the associated blanks) were returned from the field, they were equilibrated under the same conditions as the initial weighing. After reweighing, 20% were audited to check precision.

The vacuum bags were weighed to determine total net mass collected. Then the dust was removed from the bags and was dry sieved. The screen sizes used for the dry sieving process were the following: 3/8 in., 4, 10, 20, 40, 100, 140, and 200 mesh. The material passing a 200 mesh screen is referred to as silt content.

4.5 EMISSION FACTOR CALCULATION

The primary quantities used in obtaining emission factors in this study were the concentrations measured by the cyclone/cascade impactor sampler combinations. This combination provides a total particulate value but also permits the determination of concentrations in other particle size ranges. The MRI exposure profiler collects total particulate matter and enables one to determine the plume height. A knowledge of the vertical distributions of plume concentration is necessary in the numerical integration required to calculate emission factors. The emission factor calculation procedure is presented in Appendix A.

5.0 TEST RESULTS

5.1 TEST SITE CONDITIONS

The field tests for this study were conducted in the fall of 1981 and during the spring and summer of 1982. As indicated in the test matrix, Table 8, field sampling sites can be classified into five different industry types as well as rural nonindustrial roads. As shown in Table 8, field tests were conducted in three different geographical regions, Rocky Mountain region (sand and gravel processing, gravel rural road), Great Plains region (stone crushing, asphalt and concrete batching, and rural roads), and the southwestern region of the United States (copper smelter).

Table 9 presents the sampling parameters for each test conducted including deployment locations for the equipment and road orientation. The arithmetic mean and standard deviation for the wind speed and direction are given to indicate the variability of the wind. The zero degree orientation defined for the wind direction is perpendicular to the roadway.

The primary considerations for the selection of an industrial test site were industrial cooperation, which was most essential, suitability for exposure profiling, and sufficient traffic for adequate mass on collection substrates. It was desirable during pretest surveys to gain access to industrial plants in the Kansas City region that were of representative size and/or traffic conditions for the respective industrial category. Plant operating conditions, which were supplied by plant personnel for each test site, are included in Table 8.

Testing at the copper smelter occurred shortly before a scheduled maintenance shutdown of the plant. Testing of the sand and gravel operation in Colorado occurred before the actual production season started but during the

TABLE 8. FIELD TEST MATRIX

Industrial category	Test site location	Operating conditions	No. of tests conducted: Paved roads	No. of tests conducted: Unpaved roads	Sampling period
Stone crushing	Kansas	425 T/hr	0	5	Dec. 81
Sand and gravel processing	Colorado	a	3	0	Apr. 82
	Kansas	225 T/hr	0	3	July 82
Asphalt batching	Missouri	150 T/hr	4	0	Oct. 81
Concrete batching	Missouri	88,500 T/yr	3	0	Nov. 81
Copper smelting	Arizona	b	3	3	Apr. 82
Rural roads					
Crushed limestone road	Kansas	c	0	6	Aug. 81 Sept. 81
Dirt road	Missouri	c	0	4	Mar. 82
Gravel road	Colorado	c	0	2	Apr. 82
Total			18	21	

[a] Process not operating during testing; however, 600 T/hr was the typical rate for 1982.

[b] Source operating rate not available.

[c] Not applicable.

TABLE 9. SAMPLING PARAMETERS

Run No.	Industrial category	Test date	Sampling duration (min)	Road orientation	Distance from source: Upwind (m)	Distance from source: Downwind (m)	Wind speed (m/s): $\bar{X}$	Wind speed (m/s): σ	Wind direction (degrees): $\bar{X}$	Wind direction (degrees): σ
U-1	Rural Roads	8/18/81	62	N-S	8.6	6.2	3.7	0.6	-20.9	23.3
U-2		8/19/81	46	N-S	8.6	6.2	3.4	0.5	-41.0	17.4
U-3		9/4/81	60	N-S	8.6	6.2	1.1	0.2	4.51	20.0
U-4		9/9/81	63	E-W	11.2	7.1	3.2	0.6	0.31	6.50
U-5		9/10/81	62	E-W	11.2	7.1	5.2	0.7	-21.1	-
U-6		3/24/82	55	E-W	6.7	5.2	5.9	0.6	-15.3	7.13
Y-1	Asphalt Batching	10/28/81	274	E-W	5.8	3.7	2.4	3.3	-19.5	19.4
Y-2		10/29/81	344	E-W	5.8	3.7	2.1	0.5	-12.4	6.42
Y-3		10/30/81	95	E-W	6.7	4.6	2.7	0.6	2.7	6.60
Y-4		10/30/81	102	E-W	6.7	4.6	2.5	0.7	3.5	4.75
Z-1	Concrete Batching	11/10/81	170	E-W	7.9	5.8	3.0	0.6	-3.5	7.90
Z-2		11/18/81	143	E-W	7.9	5.8	4.4	0.7	-17.2	-
Z-3		11/18/81	109	E-W	7.9	5.8	4.3	0.8	-22.7	6.50
AA-1	Stone Crushing	12/4/81	65	E-W	7.6	5.1	2.1	0.4	-26.7	10.2
AA-2		12/4/81	59	E-W	7.6	5.1	1.1	0.3	-61.3	6.0
AA-3		12/7/81	51	N-S	5.3	6.1	2.2	0.8	24.1	34.9
AA-4		12/10/81	72	E-W	5.5	6.9	3.6	0.3	-32.0	3.6
AA-5		12/10/81	65	E-W	5.5	6.9	4.2	0.2	-34.2	3.0
AB-1	Rural Roads	3/29/82	109	-	10.5	7.1	5.9	1.3	-51.5	-
AB-2		3/31/82	22	N-S	11.0	4.9	2.9	1.0	8.7	21.7
AB-3		3/31/82	22	N-S	11.0	4.9	3.8	0.4	-9.0	29.3
AB-4		4/1/82	22	WSW-ENE	5.8	4.2	5.0	0.6	3.8	17.9
AC-1	Copper Smelting	4/12/82	50	N-S	2.9	4.1	1.9	0.2	-8.6	22.8
AC-2		4/13/82	45	N-S	2.9	4.1	2.4	0.5	0.67	7.8
AC-3		4/14/82	42	N-S	4.6	4.6	3.1	0.4	7.9	2.9
AC-4		4/15/82	38	N-S	4.9	11.9	3.9	0.7	42.1	-
AC-5		4/15/82	36	N-S	4.7	11.9	4.3	1.0	44.6	-
AC-6		4/16/82	33	N-S	4.9	11.9	2.2	0.9	-27.4	-
AD-1	Sand and Gravel Processing	4/22/82	110	E-W	4.6	6.6	3.4	0.8	-1.58	14.6
AD-2		4/22/82	69	E-W	4.6	6.6	2.3	0.5	-2.20	19.4
AD-3		4/23/82	76	E-W	4.6	6.6	1.4	0.7	-34.6	-
AE-1	Rural Roads	4/24/82	24	E-W	4.9	5.2	4.3	0.6	13.0	25.2
AE-2		4/24/82	15	E-W	4.9	5.2	5.0	1.1	28.9	14.7
AF-2	Sand and Gravel Processing	7/29/82	154	E-W	5.2	5.5	1.0	0.2	-28.1	28.2
AF-2		7/30/82	190	E-W	5.2	5.5	1.4	0.3	-31.7	20.4
AF-3		8/2/82	203	E-W	5.2	5.5	2.1	0.4	-27.9	8.43

material stockpiling activities prior to equipment shakedown operations. In both cases, plant personnel indicated the traffic observed was typical for their operations.

5.2 ROAD SURFACE PARTICULATE LOADINGS

During each fugitive emissions sampling run, samples of roadway surface particulate were collected to determine total particulate loadings, silt loadings, silt content (i.e., silt percentage of total loading), and the moisture content of surface loading.

Silt loading was calculated as the product of total loading and fractional silt content. To obtain the total loading, the mass of road surface particulate sample was divided by the surface area from which the sample was obtained. The tare weights of sample containers were subtracted from the total weights to obtain the sample weights. Appendix B gives the procedure for determination of silt content.

Table 10 presents the source parameters for the test roads. As indicated in Tables 10 and 11, a wide range of road surface and traffic conditions were tested. Mean vehicle weights were calculated as the arithmetic average of the weights of vehicles passing over the test road segment during the emissions sampling period. Vehicle weights were assigned to vehicle types as described in the body of this report.

Emission factors developed from this study represent a wide range of road surface loadings as presented in Table 10. The range of total loadings found for paved industrial roads was 189 (Z-1) to 4,197 g/m^2 (Y-3). An obvious comparison of total loading indicates that the Z runs and AD runs are paved road surfaces characterized by relatively low loading values. Additional industrial paved roads were tested in the Y runs and runs AC-4, -5, and -6; however, for these tests, the surfaces were very heavily loaded with levels comparable to those determined for unpaved roads.

TABLE 10. SOURCE PARAMETER DESCRIPTION

Run No.	Industrial category	No. of lanes	Lane width (m)	Total loading (g/m^2)	Moisture content (%)	Silt loading (g/m^2)	Silt content (%)
U-1	Rural Roads	2	2.3	3,841	0.25	365	9.5
U-2	(unpaved)	2	2.3	4,889	0.30	445	9.1
U-3		2	2.3	3,405	0.27	262	7.7
U-4		2	2.3	2,136	0.40	184	8.6
U-5		2	2.3	2,774	0.37	255	9.2
U-6							
Y-1	Asphalt Batching	1	4.2	3,490	0.22	91	2.6
Y-2	(paved)	1	4.3	2,819	0.51	76	2.7
Y-3		1	4.3	4,197	0.32	193	4.6
Y-4		1	4.3	4,197	0.32	193	4.6
Z-1	Concrete Batching	2	3.7	189	a	11.3	6.0
Z-2	(paved)	2	3.8	239	a	12.4	5.2
Z-3		2	3.8	239	a	12.4	5.2
AA-1	Stone Crushing	2	3.8	3,531	0.40	484	13.7
AA-2	(unpaved)	2	3.8	3,363	0.34	515	15.3
AA-3		2	4.0	7,188	0.84	755	10.5
AA-4		2	2.9	5,837	2.1	911	15.6
AA-5		2	2.9	5,837	2.1	911	15.6
AB-1	Rural Roads	1	3.6	7,822	3.9	2,745	35.1
AB-2	(unpaved)	1	3.7	2,478	4.5	414	16.7
AB-3		1	3.7	2,285	3.2	384	16.8
AB-4		1	4.3	2,287	3.1	133	5.8
AC-1	Copper Smelting	2	4.3	2,302	0.07	440	19.1
AC-2	(unpaved)	2	4.3	2,478	0.07	394	15.9
AC-3		2	4.0	3,488	0.03	558	16.0
AC-4	(paved)	2	5.3	1,448	0.43	287	19.8
AC-5		2	5.3	1,221	0.43	188	15.4
AC-6		2	5.3	1,841	0.53	400	21.7
AD-1	Sand and Gravel	1	3.7	1,481	a	94.8	6.4
AD-2	Processing	1	3.7	805	a	63.6	7.9
AD-3	(paved)	1	3.7	755	a	52.6	7.0
AE-1	Rural Roads	2	3.6	1,206	0.26	60.3	5.0
AE-2	(unpaved)	2	3.6	1,206	0.26	60.3	5.0
AF-1	Sand and Gravel	2	4.9	12,979	0.23	545	4.2
AF-2	Processing	2	4.9	15,142	0.17	908	6.0
AF-3	(unpaved)	2	4.9	14,224	0.15	583	4.1

[a] No moisture determination made on paved road sample.

1 m = 3.281 ft

TABLE 11. SOURCE TEST VEHICLE CHARACTERISTICS

Run No.	Industrial category	No. of vehicle passes	Type of traffic	Mean vehicle weight (tonnes)	Mean wheels	Mean vehicle speed (mph)
U-1	Rural Roads	125	Light duty	1.9	4	35
U-2		105	Light duty	1.9	4	35
U-3		101	Light duty	1.9	4	35
U-4		102	Light duty	1.9	4	25
U-5		107	Light duty	2.3	4	25
U-6		51	Light duty	1.9	4	30
Y-1	Asphalt Batching	47	Med. duty	3.6	6	10
Y-2		76	Med. duty	3.7	7	10
Y-3		100	Med. duty	3.8	6.5	10
Y-4		150	Med. duty	3.7	6	10
Z-1	Concrete Batching	149	Med. duty	8.0	10	10
Z-2		161	Med. duty	8.0	10	15
Z-3		62	Med. duty	8.0	10	15
AA-1	Stone Crushing	55	Med. duty	11	5	15
AA-2		24	Med. duty	13	4.4	15
AA-3		34	Med. duty	10	4	10
AA-4		56	Med. duty	14	5.6	10
AA-5		56	Med. duty	13	5	10
AB-1	Rural Roads	94	Light duty	2.3	4	25
AB-2		50	Light duty	2.3	4	25
AB-3		50	Light duty	2.3	4	25
AB-4		50	Light duty	2.3	4	25
AC-1	Copper Smelting	51	Light duty	2.2	4.8	10
AC-2		49	Light duty	2.1	4	10
AC-3		51	Light duty	2.4	4.3	10
AC-4		45	Med. duty	5.7	7.4	10
AC-5		36	Med. duty	7.0	6.2	15
AC-6		42	Med. duty	3.1	4.2	20
AD-1	Sand and Gravel Processing	11	Hvy. duty	42	11	23
AD-2		16	Hvy. duty	39	17	23
AD-3		20	Hvy. duty	40	15	23
AE-1	Rural Roads	46	Light duty	2.1	4	40
AE-2		22	Light duty	1.8	4	35
AF-1	Sand and Gravel Processing	18	Hvy. duty	29	14.5	5
AF-2		28	Hvy. duty	27	16.6	5
AF-3		34	Hvy. duty	27	12.5	5

Tests conducted at the copper smelter (AC runs) show a distinct difference in loadings considering the road types. Two different sites were tested at the same facility. The unpaved road surface loadings (AC-1, -2, and -3) are generally within a factor of 2 higher when compared to the paved road tests (AC-4, -5, and -6). Another parameter that can be used to distinguish the two types of road surfaces is the silt loading found in Table 10. Except for runs Y-3 and Y-4, the silt loading is below 100 g/m^2. The matrix of test conditions for industrial roads encompass roadways and industrial settings where traffic-entrained road dust emissions were most significant.

5.3 AIRBORNE PARTICULATE CONCENTRATIONS

The upwind particulate mass concentrations, used for background particulate levels, are listed in Table 12. The data listed in Table 12 include the duration of each sample, a TSP value measured using the standard high-volume sampler, an IP concentration using a high-volume sampler equipped with an SSI, and the isokinetically corrected total particulate (TP) concentrations from the cyclone precollector and cascade impactor (C/I) combination sampler. The various particulate size data results from the C/I are also presented.

Table 13 presents the downwind net TP concentrations (background subtracted) at the five exposure profiler heights; the standard hi-vol sampler concentrations; the SSI equipped hi-vol concentrations; and the IP, PM_{10}, and FP particulate concentrations at the 1- and 3-m heights. The data follow the expected trends of total particulate and size-specific concentrations which decreases with height. The concentrations for paved roads (i.e., Y; Z; AC-3, -4, -5; and AD runs) are generally orders of magnitude lower than the unpaved road tests. The hi-vol (TSP) concentration is usually higher than the SSI (IP) concentration, as would be expected considering the size fractions measured with each instrument.

TABLE 12. UPWIND DATA

Run No.	Sampling duration (min)	Hi-vol conc. (μg/m³)	SSI conc. (μg/m³)	Cyclone and cascade impactor results: TP conc. (μg/m³)	TP size distribution: % < 15 μm	% < 10 μm	% < 2.5 μm	Conc. < 15 μm (μg/m³)
U-1	211	59	21	107	74	64	33	79
U-2	79	78	66	204	97	87	46	199
U-3	119	350	225	311	52	41	17	161
U-4	196	47	23	70	55	41	2	39
U-5	240	44	38	131	44	34	11	58
U-6	147	17	1.0	39	65	57	40	25
Y-1	367	41	18	a	a	a	a	a
Y-2	443	51	38	a	a	a	a	a
Y-3	200	74	49	a	a	a	a	a
Y-4	192	67	49	a	a	a	a	a
Z-1	348	167	68	a	a	a	a	a
Z-2	313	b	913	a	a	a	a	a
Z-3	313	b	913	a	a	a	a	a
AA-1	65	5,087	1,823	6,110	25	15	3	1,530
AA-2	58	4,391	1,121	10,250	13	6	1	1,358
AA-3	96	c	6,717	6,728	97	96	95	6,511
AA-4	77	3,479	1,596	3,855	45	30	5	1,733
AA-5	73	2,467	1,089	2,549	38	24	5	960
AB-1	173	195	150	122	28	18	5	34
AB-2	266	25	15	28	16	11	11	4
AB-3	266	25	15	28	16	11	11	4
AB-4	162	77	c	105	45	41	37	47
AC-1	143	537	337	625	38	26	7	239
AC-2	143	537	337	625	38	26	7	239
AC-3	50	676	320	1,199	35	25	13	415
AC-4	76	350	264	489	32	19	3	155
AC-5	58	638	440	332	33	22	6	111
AC-6	74	342	371	625	30	21	10	190
AD-1	103	894	567	450	23	15	7	103
AD-2	71	463	122	450	23	15	7	103
AD-3	41	279	877	1,195	22	14	5	268
AE-1	295	45	143	72	49	36	14	35
AE-2	295	45	143	72	49	36	14	35
AF-1	153	946	583	1,366	36	25	8	485
AF-2	193	443	271	419	49	38	13	206
AF-3	227	40	30	26	29	21	9	8

[a] No cascade impactor sampler used for this test.

[b] Tear in collection substrate.

[c] Equipment malfunction.

TABLE 13. DOWNWIND NET CONCENTRATIONS (μg/m³)

Run No.	Exposure profilers (TP) 1 m	2 m	3 m	4 m	5 m	Hi-vol (TSP), 2 m	SSI (IP), 2 m	Cyclone/impactors IP (1 m/3 m)	PM_{10} (1 m/3 m)	FP (1 m/3 m)
U-1	56,890	27,600	10,230	7,720	2,180	17,423	6,480	10,628/4,382	6,793/2,903	1,481/538
U-2	32,040	16,080	6,650	1,660	810	11,429	4,887	7,554/2,688	4,640/1,803	671/334
U-3	54,730	34,380	18,370	14,940	7,975	a	a	2,166/1,328	1,165/766	222/141
U-4	31,340	11,380	5,503	4,440	1,400	5,286	1,866	934/718	452/424	76/71
U-5	17,740	8,895	4,324	1,566	428	5,053	1,717	1,474/650	811/365	136/76
U-6	5,680	2,876	918	182	65	2,333	1,422	755/66	466/38	68/8
Y-1	432	118	99	b	37	84	45	30/22	18/16	9/9
Y-2	411	223	112	77	c	179	92	79/65	58/51	28/29
Y-3	1,698	791	562	355	156	535	240	130/78	82/52	41/29
Y-4	7,992	2,753	1,638	1,001	490	1,832	1,046	529/312	292/191	65/58
Z-1	1,352	806	454	366	215	591	309	611/347	425/252	49/77
Z-2	3,214	1,775	1,364	919	641	c	c	761/406	520/285	158/104
Z-3	4,241	2,409	1,750	1,256	711	2,470	223	1,207/591	810/404	192/119
AA-1	15,540	10,290	8,163	6,964	5,307	4,502	1,614	3,734/2,180	2,313/1,347	343/217
AA-2	20,220	10,320	4,437	2,003	305	771	835	492/545	212/293	29/34
AA-3	3,695	1,693	1,081	556	400	1,484	241	595/244	346/146	40/18
AA-4	14,290	9,809	11,510	7,759	5,654	10,699	3,968	6,815/3,785	4,078/2,244	479/334
AA-5	12,280	8,463	7,239	5,600	4,070	8,154	3,657	4,425/2,730	2,753/1,675	338/221
AB-1	45,410	15,710	6,766	3,895	1,918	9,914	1,060	4,032/1,421	2,308/817	519/142
AB-2	121,500	17,800	5,350	1,167	162	10,915	3,588	2,228/910	827/100	152/b
AB-3	54,580	16,090	9,700	2,943	1,354	14,325	3,965	4,124/834	2,125/357	326/48
AB-4	15,620	6,253	a	890	175	9,522	2,837	3,540/881	2,308/625	649/211
AC-1	11,130	6,534	4,348	2,422	1,773	4,233	1,793	1,579/884	995/581	175/115
AC-2	6,500	4,912	3,234	2,276	1,431	3,289	1,315	1,739/475	1,156/317	189/85
AC-3	7,802	3,828	3,525	1,668	785	4,563	1,738	2,366/863	1,542/546	265/118
AC-4	7,226	5,893	4,812	2,755	1,863	a	929	3,422/906	2,399/599	527/122
AC-5	3,261	1,864	1,644	1,007	857	2,454	1,127	2,243/831	1,567/591	330/148
AC-6	6,746	5,314	4,144	b	1,524	2,761	1,012	1,984/561	1,367/367	297/100
AD-1	1,273	1,036	974	720	588	477	336	381/175	251/110	57/28
AD-2	832	1,173	600	347	177	264	137	279/136	165/82	32/26
AD-3	1,065	788	504	c	c	230	c	129/84	80/57	30/25
AE-1	4,288	2,491	1,189	b	355	a	a	849/217	571/138	172/61
AE-2	a	2,193	793	141	c	709	827	755/379	502/299	217/212
AF-1	2,487	a	1,026	1,138	c	159	21	213/222	130/146	33/35
AF-2	1,338	a	826	506	318	833	230	453/188	317/131	80/37
AF-3	1,290	a	1,080	863	675	1,028	477	834/463	602/346	133/105

[a] Equipment malfunction or failure.

[b] Torn filter.

[c] Net concentration resulted in negative value.

5.4 CALCULATED EMISSION FACTORS

Tables 14 and 15 present the emission factors (TP, IP, PM_{10}, and FP) determined for each test. The source characterization parameters which are considered to have an effect on the quantity of dust emissions from industrial roads are presented in Table 10 in Section 5.2. Appendix A describes the procedures used to calculate the emission factors from field test data.

Tables 16 and 17 summarize the TP, IP, PM_{10}, and FP emissions for paved and unpaved roads sampled in this study. The arithmetic mean standard deviation and range of values for each set of tests are presented in these tables. Table 18 tabulates the ratios of particle size-specific emission factors. Taking into account the grinding action that occurs on paved surfaces, the emission factor ratios are generally higher for the paved road tests.

As stated previously, the primary objective of this study was to expand the existing data base of known size-specific particulate emissions data. The resulting data base from this study and other existing data from surface coal mines and the integrated iron and steel industry should be sufficient to develop reliable emission factors to provide estimates of source conditions (industries) not actually tested but lying within the matrix of conditions that have been tested.

TABLE 14. EMISSION FACTORS FOR UNPAVED ROADS

Run No.	Industrial category	Total particulate emission factor (g/VKT)	Total particulate emission factor (lb/VMT)	Inhalable particulate emission factor (g/VKT)	Inhalable particulate emission factor (lb/VMT)	PM_{10} particulate emission factor (g/VKT)	PM_{10} particulate emission factor (lb/VMT)	Fine particulate emission factor (g/VKT)	Fine particulate emission factor (lb/VMT)
U-1	Rural Roads	12,600	44.8	3,980	14.1	2,570	9.13	513	1.82
U-2		5,050	17.9	1,410	4.99	871	3.09	115	0.407
U-3		5,810	20.6	894	3.17	493	1.75	85.7	0.304
U-4		13,300	27.0	1,010	3.56	527	1.87	91.3	0.324
U-5		6,200	22.0	1,020	3.63	555	1.97	84.6	0.300
U-6		3,980	14.1	851	3.02	499	1.77	70.5	0.250
AA-1	Stone Crushing Operation	2,640	9.36	902	3.20	606	2.15	80.9	0.285
AA-2		4,310	15.3	538	1.91	266	0.943	33.0	0.117
AA-3		1,360	4.83	429	1.52	255	0.903	30.7	0.109
AA-4		9,920	35.2	2,380	8.44	1,270	4.52	110	0.389
AA-5		8,540	30.3	2,730	9.67	1,640	5.83	151	0.537
AB-1	Rural Roads	31,700	112.6	5,980	21.2	3,410	12.1	699	2.48
AB-2		11,900	42.1	919	3.26	268	0.951	25.3	0.0899
AB-3		9,160	32.5	1,180	4.18	561	1.99	79.2	0.281
AB-4		3,130	11.1	798	2.83	524	1.86	143	0.507
AC-1	Copper Smelting	2,640	9.36	716	2.54	460	1.63	79.8	0.283
AC-2		2,150	7.62	623	2.21	412	1.46	83.7	0.297
AC-3		2,820	10.0	837	2.97	538	1.91	104	0.370
AE-1	Rural Roads	1,530	5.43	310	1.10	201	0.713	70.8	0.251
AE-2		2,240	7.96	392	1.39	270	0.957	136	0.481
AF-1	Sand and Gravel Processing	4,310	15.3	1,120	3.97	733	2.60	176	0.624
AF-2		2,760	9.80	944	3.35	660	2.34	175	0.620
AF-3		2,330	8.28	1,250	4.44	919	3.26	277	0.982

TABLE 15. EMISSION FACTORS FOR PAVED ROADS

Run No.	Industrial category	Total particulate emission factor (g/VKT)	Total particulate emission factor (lb/VMT)	Inhalable particulate emission factor (g/VKT)	Inhalable particulate emission factor (lb/VMT)	PM_{10} particulate emission factor (g/VKT)	PM_{10} particulate emission factor (lb/VMT)	Fine particulate emission factor (g/VKT)	Fine particulate emission factor (lb/VMT)
Y-1	Asphalt Batching	403	1.43	100	0.358	72.5	0.257	39.2	0.139
Y-2		417	1.48	148	0.525	113	0.401	60.3	0.214
Y-3		211	0.75	86.2	0.124	22.6	0.0801	12.0	0.427
Y-4		1,030	3.65	209	0.741	124	0.441	35.0	0.124
Z-1	Concrete Batching	634	2.25	275	0.976	197	0.699	56.4	0.200
Z-2		2,040	7.23	660	2.34	460	1.63	158	0.562
Z-3		4,930	17.5	1,640	5.82	1,130	4.01	307	1.09
AC-4	Copper Smelting	4,430	15.7	1,570	5.56	1,090	3.86	239	0.846
AC-5		3,040	10.8	1,250	4.44	882	3.13	202	0.716
AC-6		1,990	7.07	570	2.02	381	1.35	73.3	0.260
AD-1	Sand and Gravel Processing	5,440	19.3	1,440	5.10	922	3.27	80.4	0.285
AD-2		1,870	6.64	355	1.26	212	0.753	54.7	0.194
AD-3		1,230	4.35	221	0.783	145	0.513	59.5	0.211

TABLE 16. SUMMARY OF UNPAVED ROAD EMISSION FACTORS (lb/VMT)

Industrial category	TP			IP			PM_{10}			FP		
	$\bar{X}$	σ	Range	$\bar{X}$	σ	Range	$\bar{X}$	σ	Range	$\bar{X}$	σ	Range
Rural Roads	21.9	3.80	17.9-27.0	3.84	0.790	3.17-4.99	2.17	0.620	1.75-3.09	0.334	0.050	0.300-0.407
Stone Crushing	25.0	13.7	9.36-35.2	7.10	3.44	3.20-9.67			2.15-5.83	4.17	1.87	2.15-5.83
Rural Roads	28.6	15.9	11.1-42.1	3.42	0.690	2.83-4.18	1.60	0.566	0.951-1.99	0.293	0.209	0.090-0.507
Copper Smelter	8.99	1.23	7.62-10.0	2.57	0.381	2.21-2.97	1.67	0.227	1.46-1.91	0.317	0.047	0.283-0.370
Rural Roads	6.70	1.79	5.43-7.96	1.25	0.205	1.10-1.39	0.835	0.173	0.713-0.957	0.366	0.163	0.251-0.481
Sand and Gravel Processing	11.1	3.69	8.28-15.3	3.92	0.547	3.35-4.44	2.73	0.474	2.34-3.26	0.742	0.208	0.620-0.982

TABLE 17. SUMMARY OF PAVED ROAD EMISSION FACTORS (lb/VMT)

Industrial category	TP			IP			PM_{10}			FP		
	$\bar{X}$	σ	Range	$\bar{X}$	σ	Range	$\bar{X}$	σ	Range	$\bar{X}$	σ	Range
Asphalt Batching	1.83	1.26	0.750-3.65	0.437	0.261	0.124-0.741	0.295	0.163	0.0801-0.441	0.130	0.070	0.0427-0.214
Concrete Batching	4.74	3.52	2.25-7.23	1.66	0.964	0.976-2.34	1.17	0.658	0.699-1.63	0.381	0.256	0.200-0.562
Copper Smelting	11.2	4.33	7.07-15.7	4.01	1.81	2.02-5.56	2.78	1.29	1.35-3.86	0.607	0.308	0.260-0.846
Sand and Gravel Processing	5.50	1.62	4.35-6.64	1.02	0.337	0.783-1.26	0.633	0.170	0.513-0.753	0.203	0.012	0.194-0.211

TABLE 18. SUMMARY OF EMISSION FACTOR RATIOS

Industrial category	IP/TP		PM_{10}/TP		FP/TP		PM_{10}/IP		FP/IP		FP/PM_{10}	
	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
Unpaved roads												
Rural Roads	0.183	0.066	0.104	0.047	0.0158	0.0048	0.560	0.041	0.0878	0.0069	0.158	0.020
Stone Crushing	0.300	0.054	0.183	0.052	0.0197	0.098	0.604	0.068	0.0636	0.0226	0.104	0.026
Rural Roads	0.154	0.091	0.084	0.075	0.0188	0.0235	0.475	0.183	0.0913	0.0785	0.170	0.092
Copper Smelting	0.286	0.014	0.186	0.010	0.0354	0.0046	0.649	0.011	0.123	0.0116	0.190	0.015
Rural Roads	0.189	0.020	0.126	0.008	0.0533	0.0100	0.669	0.029	0.287	0.0834	0.428	0.107
Sand and Gravel Processing	0.379	0.142	0.268	0.115	0.0744	0.0403	0.696	0.040	0.188	0.0321	0.269	0.031
Paved roads												
Asphalt Batching	0.243	0.082	0.170	0.075	0.0833	0.0487	0.681	0.075	0.327	0.110	0.472	0.128
Concrete Batching	0.379	0.078	0.268	0.061	0.0833	0.0079	0.707	0.013	0.223	0.025	0.316	0.042
Copper Smelting	0.350	0.063	0.242	0.050	0.0523	0.0148	0.689	0.019	0.147	0.017	0.214	0.019
Sand and Gravel Processing	0.185	0.007	0.116	0.004	0.0369	0.0109	0.627	0.040	0.201	0.067	0.318	0.085

REFERENCES

1. Axetell, K., Jr., and C. Cowherd, Jr. Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources - Vol. II: Emission Factors. U.S. Environmental Protection Agency, Cincinnati, Ohio, November 1981.

2. Cuscino, T., Jr., G. Muleski, and C. Cowherd, Jr. Iron and Steel Plant Open Source Fugitive Emission Control Evaluation. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1982.

3. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. U.S. Environmental Protection Agency Report No. EPA 450/3-74-037, June 1974.

4. Quality Assurance Handbook for Air Pollution Measurement Systems, Vol. II - Ambient Air Specific Methods. EPA 600/4-77-027a. May 1977.

5. Ambient Monitoring Guidelines for Prevention of Significant Deterioration. EPA 450/2-78-019. May 1978.