EVALUATION OF FUGITIVE DUST EMISSION DATA

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DRAFT REPORT

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NOTICE

This document is a preliminary draft. It has not been formally released by the U.S. Environmental Protection Agency and should not at this stage be construed to represent Agency policy. It is being circulated for comments on its technical merit and policy implications.

TABLE OF CONTENTS

LIST OF TABLES

SECTION 1

INTRODUCTION

The Joint Emissions Inventory Oversight Group (JEIOG) was formed to advise and coordinate the research plans and needs of the Air and Energy Engineering Research Laboratory (AEERL) and the Office of Air Quality Planning and Standards (OAQPS) related to the development of emissions inventory methodologies. The work detailed in this report is part of that coordination and needs effort.

One of the areas of high priority for JEIOG is area source emissions inventory methodologies for fugitive dust sources. Emission inventory methodologies for fugitive dust sources of PM_{10} have received little attention with regard to the availability of data sources, accuracy of emission factors used to develop inventories, frequency of updates to either emission factors or activity data, or an evaluation of alternative methods of determining emissions from these sources. As more local, state and regional agencies are required to submit regulatory plans for attainment of the PM_{10} ambient air quality standard, methods for accurately determining the emissions from fugitive dust sources will be crucial. As a consequence, EPA needs to have a definitive understanding of the current status of methodologies used to inventory these sources, so that guidance can be developed for the preparation of emissions inventories. In addition, EPA also needs to identify and prioritize appropriate research and development goals for the development of new, and enhancement of existing, fugitive dust emission estimation techniques. In order to help assess the current status of fugitive PM_{10} emissions estimation methodologies and to develop and prioritize the research and development goals for these sources, EPA issued E.H. Pechan and Associates, Inc. a work assignment to evaluate current fugitive PM_{10} emissions estimations methodologies and to provide an assessment of the research and development goals required for the development of new or the enhancement of existing methodologies.

The work carried out as part of this assignment was implemented in two broad tasks. These tasks were:

1. An evaluation of existing sources of field-gathered emissions data, for all fugitive dust area sources. This evaluation included assembly and documentation of currently available sources of data. Evaluation and discussion of the data included, but was not limited to, extent of data collection, type and extent of quality assurance utilized, documentation of raw data, and peer review procedure utilized. In addition, a specific subtask was to include a determination of the process necessary to fully document the

fugitive dust emissions data gathered during the NAPAP program. In particular, the NAPAP data evaluated was that concerning emissions from unpaved roads.

2. A subset of the fugitive dust sources examined as part of #1 above were examined to determine and document the methodologies currently used to estimate emissions. This subset included wind erosion, unpaved roads, agricultural tilling, construction/demolition activities, mining and quarrying, paved roads, and storage pile activities. Documentation of the current methodologies used to determine emissions included evaluation and discussion of the two principal inputs to an emissions estimation methodology, namely emission factors and source activity data. As part of this task, documentation of the currently used emission factor included the identification of which data summarized as part of #1 above was used to develop these emission factors. The evaluation of the source activity data included an examination of the completeness or extent of activity input, magnitude of the inventory area to which the activity data is applicable or available (i.e., local, regional, or national), accuracy of the data (if possible), and where appropriate, frequency and cost of updates required. Again, a specific subtask was the determination of the process necessary to document the source activity data gathered during the NAPAP program, in particular, that data that applies to the unpaved road emissions estimates

The results of this evaluation are presented below. Over 80 studies were evaluated to determine whether or not they were suitable for inclusion in this report. The studies presented in the review were selected based upon whether or not actual emissions measurements were made for that source. Normally, only emissions from uncontrolled sources were considered, however, a few sources were reviewed if we felt the results warranted inclusion from either a data quality perspective or from a historical development perspective. Some studies that are reviewed included emissions measurements from both controlled and uncontrolled sources.

The report is divided into four sections. Section one is this introduction. Section two details the emissions data, methodologies, equipment configurations, sampling sites, parameters measured, quality assurance aspects and findings of the studies reviewed. Section three examines the sources of activity data for the subset of sources considered in #2 above. Section four presents our evaluation of the reviewed studies and presents our comments and recommendations for future research and development activities.

The determination of the requirements for documenting the information from the 1985 NAPAP emissions measurements and activity data used to determine the emissions estimates from unpaved roads for the 1985 NAPAP emissions inventory are not included here. That information was provided to the Work Assignment Manager separately.

SECTION 2

EMISSIONS DATA ASSESSMENT

VEHICLE TRAVEL ON UNPAVED ROADS

Introduction

Unpaved roads are a significant source of particulate emissions in the United States. This category has received more attention by researchers than any other fugitive particulate source.

The majority of studies reviewed in this report used one of two approaches to estimate emissions: dispersion modeling or exposure profiling. The first technique generally involves measurement of dust concentrations upwind and downwind from the road, followed by solution of a generalized dispersion model to determine the source strength in units of mass of dust per unit of road length per unit time. This is in turn converted into an emission factor (mass per vehicle-mile or per vehicle-kilometer) by dividing by the number of vehicle passes.

Exposure profiling has been used to measure fugitive particulate emissions from several source categories. As it is applied in the case of roads (paved and unpaved), it involves measurement of the horizontal mass flux of dust downwind from the road by isokinetically sampling the air at several points over the height of the plume simultaneously. Background levels of dust are subtracted from the exposure calculated at each downwind sampling height. Exposure is then integrated with respect to height to obtain the mass emitted per unit of road length. Dividing this by the number of vehicle passes during the test gives the emission rate in mass per vehicle-mile (or per vehicle-kilometer).

Historical Development

According to Turner (1970), atmospheric dispersion modeling in general had its beginnings in the 1930's. Cowherd et al. (1974) found that the first application of dispersion modeling for determining particulate emissions from unpaved roads was by undergraduate students at the School of Engineering at the University of New Mexico in 1971. (No documentation for this study has been found). High volume (hi-vol) samplers were used then, and the most recent dispersion studies have also relied primarily on hi-vols to measure particulate concentrations. Of the studies which determined emission factors using dispersion modeling, only Jutze and Axetell's 1974 work used other equipment to measure concentrations. They used a beta gauge developed by GCA Corporation. The primary difference among the dispersion modeling studies has been in the number and placement of hi-vols used to estimate concentration. The most recent documented study which employed dispersion modeling to measure particulate emissions from vehicle travel on unpaved roads was performed in 1977 by McCaldin.

Exposure profiling is a much more recent development in the field of air pollution measurement than dispersion modeling. It was developed by the Midwest Research Institute (MRI) under a contract for EPA in 1973-74, specifically for the purpose of measuring fugitive particulate emissions. The first system consisted of several high-volume sampling "heads" mounted vertically on a profiler tower. The sampling heads were all attached to a single vacuum blower by flexible hosing. The orientation and intake velocity of the sampling heads were not adjusted during individual tests: the investigators noted that meteorological changes during individual tests were insignificant. Dust deposition between the road and the profile tower was considered part of vehicle emissions and, therefore, dustfall buckets were used to measure it.

This system has undergone several changes since its original development. For example, dust deposited between the road and the profiler is no longer measured or included in the emission factor. Suction at each sampling head is provided by independent blowers, facilitating variation in sampling speed between heads. Another refinement of the methodology is the use of warm-wire anemometers at each sampling intake to continuously monitor wind speed and adjust the sampling velocity to match it in order to maintain isokinetic conditions.

Several organizations have applied this methodology, each with its own variations in specific procedures or equipment configurations. MRI positions its profiler filters horizontally such that air is drawn in through a settling chamber (to catch particles larger than about 50 μm, since these are generally not suspended) before it passes up through the filter. Other organizations use vertically mounted filters in the profiler. Background dust levels are measured using a profiling tower in some cases and a standard hi-vol in others. Determination of particle size distribution has been performed in several ways: cascade impaction, scanning electron microscopy, and stacked filters. Between 1984-86 the Southern Research Institute (SoRI) evaluated this methodology by conducting a side-by-side comparison of five teams using the method but with variations in the specific implementation. This is the most recently documented application of exposure profiling in measuring particulate emissions from unpaved roads.

Several relevant studies did not employ either profiling or dispersion modeling methodologies. Rather than set up a plume sampler beside the road, Roberts (1973) towed it behind the car to measure the concentration of the plume and multiplied this by the estimated volume of the plume after traveling one mile to obtain the mass emitted per vehicle-mile. Handy et al. (1975) measured dust deposition near unpaved roads on a kilogram per month basis. Pinnick et al. (1985) measured particle concentrations and size distributions using a variety of optical particle measuring devices.

Organization

Reports that are of primary importance to the development of emission factors for vehicle travel on unpaved roads are reviewed in chronological order. The criteria for selecting these primary reports were as follows:

1. The study must attempt to measure dust emissions from unpaved roads.

2. The report must provide raw data (i.e. exposure of each filter for the profiling method or upwind and downwind concentrations for the modeling method).

3. Emissions from the test road must be uncontrolled (i.e. no dust suppressing treatments should be effecting emissions).

4. The test road must be authentic or very nearly so (i.e. the road must reflect typical unpaved road surface conditions).

The review of each primary report consists of a summary description of the methodology, test site(s), measured parameters, equipment configuration, sampling extent, quality assurance, findings, and publication outlet. Reports that are relevant to the development of emission factors but which fail one or more of the above criteria are considered of secondary importance and are briefly summarized in chronological order in the section following the primary study reviews.

Studies of Primary Importance

Study 1-- Jutze and Axetell, Investigation of Fugitive Dust Volume I - Sources, Emissions, and Control. EPA-450/3-74-036-a. 1974.

Methodology--A beta gauge was used to determine particulate concentrations at several heights and several distances from the road. These data points were substituted into the equation for a continuously emitting infinite line source (Turner, 1970), yielding an estimate for source strength (g/m/sec), which was converted to an emission factor (lb/veh-mile) by dividing by the rate at which vehicles pass the sampling point (veh/minute). It was assumed that a vehicle passage rate of 5 per minute was sufficient to qualify as a continuously emitting line source. Several sets of measurements were made with traffic traveling at different speeds for each test. Traffic flow for this study was regulated by the investigators.

Regression analysis was used to estimate the relationship between the measured emission factor and vehicle speed. Because the hi-vol is considered the standard equipment for measuring total suspended particulates, and it includes in its "catch" a much larger range of particle sizes than does the beta gauge, the average ratio of concentrations measured with the hi-vol sampler versus those obtained with the beta gauge was used as a multiplier for the estimated relationship.

Simple wind erosion of particulates from unpaved roads was then estimated using a model developed by Woodruff and Siddoway (1965). Emissions were estimated in tons/mile/year and divided by annual traffic volume (ADT * 365) to derive a factor in lbs/veh-mile. This wind erosion factor was then added to the factor representing vehicle travel on unpaved roads to obtain a total emission factor for unpaved roads.

Test Sites--Two pre-existing, unpaved roads in Sante Fe, New Mexico were the sites for measuring plume concentrations using the beta gauge. Other characteristics of the roads, such as percent silt or presence of gravel, were not documented.

Parameters and Equipment--Plume concentrations were estimated using both the beta gauge and the standard hi-vol sampler. Suspended particles were categorized as greater than or less than 3.3 μm in diameter using a hi-vol fitted with an Andersen impactor. The investigators did not specify whether this cut point was in aerodynamic or Stokes diameter. Vehicle speed was varied between sampling runs. Automatic counters tracked traffic volume. Wind speed and direction were monitored with continuous sensors.

Equipment Configuration--Beta gauge measurements were taken at 50, 75, 125, 200, and 300 feet downwind from the unpaved road. At each distance from the road, measures were taken at heights of 3, 6, and 10 feet. Hi-vol samplers, filtering air at 6 feet above ground, were also located at 75 and 200 feet from the road. There was apparently only one beta gauge instrument used in the study; therefore, measurements at the various distances from the road were not taken simultaneously.

Sampling Runs--Measurements were taken in six separate intervals over a two-day period. During each period, beta gauge measurements were taken at the three heights at several of the downwind stations (75 ft, 125 ft, etc.), and hi-vol samples were collected at the 75 and 200 foot stations. The number of vehicle passes varied between measurement periods. The beta gauge required between one and eight minutes to collect a sample and measure its concentration. Hi-vol samplers generally ran about one hour for each test.

Quality Assurance--Procedures for operating the hi-vol sampling equipment and collecting samples were fully documented. Careful attention was given to sample handling and transportation. However, detailed documentation of how the beta gauge was used and how the hi-vol filter samples were weighed was not provided. Consequently, this study is generally not reproducible.

Finally, although the investigators claimed to use the usual model for continuously emitting line sources, as found in the Workbook of Atmospheric Dispersion Estimates (Turner, 1970), their equation differs significantly from the model presented in that document. The equation as it appears in the workbook is

$$\chi\,(x,y,O;H) = \frac{2\,q}{\sin\phi\,\sqrt{2\,\pi}\;\sigma_z\,u}\;\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

The formula applied by the investigators was

$$\chi\,(x,y,O;H) = \frac{2\,q}{\sqrt{2\pi}\;\sigma_z\,u}\;\sin\phi\,\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

The ϕ represents the angle between the mean wind direction and the road.

Furthermore, contrary to Turner's (1970) recommendation, the investigators collected much of their data during periods in which ϕ was less than 45°.

Findings--The regression analysis mentioned above produced the following best fit line:

$$E = (0.16)(1.068)^{x}$$

where

E	=	dust emissions (lb/veh-mile)
x	=	vehicle speed (mph)

Evaluating this formula for x = 30 produces an emission factor of 1.15 lb/veh-mile.

The investigators found that plume concentration as measured by the standard hi-vol method averaged 1.68 times higher than the concentration estimated by the beta gauge, with a correlation of .87. Thus the coefficient in the above equation was multiplied by 1.68, and the equation was revised to be:

$$E = (0.27)(1.068)^{x}$$

Evaluating this formula for x = 30 results in E = 1.94 lb/veh-mile.

The estimated emission factor for wind erosion on unpaved roads was 1.54 lb/veh-mile. This was derived using a published wind erosion model; no field data on concentrations downwind from an unpaved road without traffic were collected. The sum of these two factors is 3.7 lb/veh-mile.

Publication--This study was conducted and documented under contract for the Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. It was published in 1974 as Publication No. EPA-450/3-74-036-a.

Study 2-- Cowherd et al. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037. 1974.

Methodology--Under a contract with the EPA the Midwest Research Institute (MRI) developed and applied its exposure profiling methodology for measuring emissions for certain fugitive dust sources. The basic procedure used to measure emissions from vehicle travel on unpaved roads is as follows:

1. Set up a vertical array of isokinetic filter samplers downwind from the unpaved road. Position a standard hi-vol sampler upwind from the road to measure the background dust level.

2. Collect filter samples of the dust plumes created when vehicles travel past the array. Operate the samplers

on the profile tower and the upwind, hi-vol samplers simultaneously.

3. Determine the mass of dust on the profiler filters and the upwind filter.

4. Subtract the background mass from the dust mass on each of the profiler filters.

5. Calculate the exposure (mass/area) of each sampling intake by dividing the dust mass on each filter (adjusted for background contribution) by the intake area.

6. Calculate the integral of exposure with respect to height. This is the plume mass per unit length of road during the test.

7. Divide by the number of vehicle passes to calculate the plume mass per vehicle mile.

Test Sites--Two gravel roads and two dirt roads in Kansas were used as sampling sites. These public roads were considered to be representative of the unpaved roads in the Dust Bowl area of the Great Plains.

Parameters and Equipment--Table 2.1 shows the parameters that were measured and the equipment used to measure them. All of these parameters were not measured in every sampling run.

TABLE 2.1. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameter	Equipment
Wind speed	Unspecified
Wind direction	Unspecified
Cloud cover	Direct observation
Temperature	Sling psychrometer
Relative humidity	Sling psychrometer
Road surface type	Direct observation
Road surface texture	Sieves, scales
Road surface moisture content	Oven, scales
Embankments	Direct observation
Traffic type	Direct observation
Traffic count	Direct observation
Plume dust exposure	Isokinetic exposure profiler

(continued)

TABLE 2.1. (continued)

Parameter	Equipment
Plume particle size distribution	Cascade impactor in standard hi-vol housing (Sierra impactor, Aerotec cyclone, or Anderson impactor, depending on the sampling run)
Plume concentration	Standard High-volume sampler
Background concentration	Standard high-volume sampler
Duration of sampling	Timer
Plume traveling time	Timer
Dust deposition	Dustfall buckets

Equipment Configuration--The exposure profiling tower was positioned at least 20 feet downwind from the road. Four isokinetic exposure profiling heads were attached to the tower at heights of 3, 5.5, 8, and 10 feet.

Dustfall buckets were positioned in a line perpendicular to the road at a height of one foot. Their distance from the downwind edge of the road varied between sampling runs and ranged from 9 to 100 feet. No more than three buckets were used in any one sampling run.

The upwind, background concentration was measured using a standard high-volume sampler, positioned 3 feet above the ground at an unspecified distance from the downwind edge of the road. For some of the sampling runs, another standard high-volume sampler was positioned 6 feet above the ground beside the exposure profiler so that the large-particle trapping efficiency of the standard high-volume sampler could be checked.

When the particle size classifier was used, it was located beside the exposure profiler at a height of 6 feet.

Meteorological conditions were deemed to be essentially constant during each sampling run. Wind direction and speed were measured by unspecified instrumentation at a height of 12 feet. Pasquill's Stability Classification was used to characterize the prevailing meteorological conditions during each sampling run.

Sampling Runs--A total of six one-hour sampling runs employing the exposure profiler were conducted. Three runs were performed on each of the two road types. The number of vehicle passes per sampling run ranged from 55 to 273. The total number of vehicle passes was 1,018.

Quality Assurance--In the use of standard high volume filtration, the investigators followed the procedures specified by EPA in "Reference Method for the Determination of Suspended Particulates in the Atmosphere (High Volume Method)," Federal Register, 36, 28 Appendix B, 22388-22390, 25 November 1971. For the measurement of dust deposition, the investigators followed the procedures set forth in "Standard Method for Collection and Analysis of Dustfall," ASTM Method D 1739-62.

Samples of the dust plume were collected only when the wind speed was less than 20 mph, the maximum speed under which samples could be collected isokinetically. As noted above, wind direction and speed were observed to be constant during each run. Likewise, the intake velocity and the directional orientation of the samplers in the exposure profiler were constant during each sampling run. Filter sampling under isokinetic conditions assures a more accurate measure of dust exposure (the mass of dust passing through a plane) than simple open-filter sampling.

Filters were conditioned in a controlled temperature and humidity environment before and after collection of dust samples. Filter samples were transported to the laboratory in individual folders. The interior surfaces of the sampler heads were rinsed, and the water was captured and later evaporated to determine the mass of dust on the interior surfaces.

The specific methodology followed in this study was documented in sufficient detail to permit reproduction of the study. Indeed, the exposure profiling technique has been utilized and adapted by several other organizations and investigators. However, documentation of quality assurance practices such as collocation of samplers, processing of blank profiler filters, and audits of profiler filter weights was not provided.

The investigators acknowledged two potential sources of small particle bias in their measurement of particle size distribution: 1) particles bouncing down through the cascade impactor to smaller particle stages; 2) non-isokinetic sampling which collects larger particles with lower efficiency than smaller particles.

Findings--The emissions data collected in this study are presented in Table 2.2.

The investigators developed the following equation for estimating emissions of particles smaller than 100 μm in Stokes diameter from vehicle travel on unpaved roads, based on the data collected in this study:

$$e = 0.81 \, s \, (S/30)$$

where

e = Emission factor (pounds per vehicle-mile)
s = Silt content of the road surface material (percent)
S = Average vehicle speed (miles per hour)

This equation applies only to days with rainfall less than 0.01 inches. Using this equation, the predictions for the six test conducted were within 10% of the actual lb/veh-mile.

Publication--This study was conducted and documented under a contract with the EPA Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. It was published in 1974 as Publication No. EPA-450/3-74-037.

TABLE 2.2. EXPOSURE DATA AND EMISSION FACTORS

Run	Height (ft)	Unit Exposure ($mg/in.^2$/ vehicle)	Emission Factors (lb/vehicle-mile)			
			Total Particulates (Integrated Unit Exposure)	$d^a > 30\ \mu m$	$2 < d^a < 30\ \mu m$	$d^a < 2\ \mu m$
1	10.5	0.082	10.0	4.0 (40%)	3.3 (33%)	2.7 (27%)
	8	0.289				
	5.5	0.591				
	3	0.619				
2	10.5	0.162	10.3	3.5 (34%)	3.7 (36%)	3.1 (30%)
	8	0.357				
	5.5	0.552				
	3	0.843				
3	10.5	0.172	13.9	6.0 (43%)	4.3 (31%)	3.6 (26%)
	8	0.459				
	5.5	0.753				
	3	1.158				
8	10.5	0.238	16.3	8.2 (50%)	4.4 (27%)	3.7 (23%)
	8	0.418				
	5.5	0.737				
	3	1.56				
10	10.5	0.150	6.0	2.1 (35%)	2.1 (35%)	1.8 (30%)
	8	0.242				
	5.5	0.281				
	3	0.511				
13	10.5	0.866	55.9	24.0 (43%)	18.8 (34%)	13.1 (23%)
	8	1.65				
	5.5	2.73				
	3	4.15				

a particle Stokes' diameter

Study 3-- Lemon et al. Derivation of Suspended Particulate Emission Factor for Motor Vehicle Use of Unpaved Roads. 1975.

Methodology--Dust emissions from vehicle travel on unpaved roads were estimated using dispersion modeling. Standard hi-vol samplers were used to measure upwind and downwind concentrations. The usual equation for a continuously emitting line source (Turner, 1970) was used to derive emission rates from the calculated concentrations and other relevant field data.

Test Site--An unpaved road in the Tucson metropolitan area was the site for this field study. The road was oriented east-west and was considered to be representative of the unpaved roads in the area in terms of emissions.

Parameters and Equipment--Two unmodified hi-vol samplers were used: one for measuring background concentration and one for measuring plume concentration. A hand held wind instrument was used to measure wind speed and direction. Plume height at the downwind sampler was estimated to be 3.05 meters (10 feet). Traffic speed was also estimated at 30 mph. The number and type of vehicles passing the sampler were also recorded.

Equipment Configuration--The upwind hi-vol was located 200 feet south of the road centerline. The downwind hi-vol was 30.5 feet north of the centerline. The wind instrument was held by the investigators; wind speed and direction were continuously monitored and recorded.

Sampling Runs--Four test runs, each approximately three hours long were conducted on separate days over a one week period. The number of vehicle passes per run ranged from 33 to 84, and the total number of passes was 260.

Quality Assurance--Quality assurance was lacking in this study. The specific procedures for sample handling and analysis were generally not documented. The investigators did not correctly apply the dispersion model for continuously emitting infinite line sources (Turner, 1970): they repeated the mistake made by Jutze and Axetell in 1974 (see review of that study). Furthermore, the angle between the wind direction and the road was less than 45° for a significant portion of the sampling time for three of the four tests. This is contrary to Turner's recommendation.

Findings--The investigators calculated emission factors of 8.14, 5.37, 6.81, and 3.25 lb/veh-mile.

Publication--This study was a follow-up of the field investigation and analysis performed by PEDCo Environmental Specialists, Inc. in 1974 (see Jutze and Axetell, 1974). It was conducted by researchers at the Pima County Air Quality Control District, based on their belief that PEDCo's findings were not accurate. No formal publication of this study has been found.

Study 4-- Struss and Mikucki, Fugitive Dust Emissions from Construction Haul Roads. 1977.

Methodology--Three different experiments were conducted. For the first phase a fully enclosed 25 foot diameter test track was used to evaluate the effect of soil type, soil moisture potential, vehicle speed, and vehicle weight on emissions. A cross-arm spanning the track held one tire at each end and was supported by a vertical center pole, which could be rotated at various speeds. The track was surfaced with gravel overlain with 6 inches of Gooselake clay. This arrangement provided a physical model for vehicle travel on unpaved roads. Soil psychrometers were placed 1/2 inch below the surface to measure soil water potential. Particulate concentration was measured using hi-vol samplers, which collected a fraction of the air being vented from the enclosure. The emission rate was calculated as the concentration times the flow rate divided by the tire speed.

For the second phase, three test roads, each 300 feet long and 10 feet wide, were constructed by plowing and tilling strips of land near Champaign, Illinois. No indication was given that the roads were compacted prior to testing. Soil psychrometers were placed beneath the surface at several places on each road. These roads all crossed at the middle and were arranged to allow for testing with nearly perpendicular winds under various mean wind directions. Once the appropriate road was selected, a single truck was driven back and forth on the track, while hi-vols were operated downwind. Vehicle speed and weight were varied between tests. The emission rate was calculated using the Gaussian model for a continuously emitting, infinite line source. The plume centerline height and the hi-vol sampling height were judged to be equal. Therefore, a simplified version of this model could be used:

$$\chi = \frac{2q}{\sqrt{2\pi}\, u \sigma_z \sin\phi}$$

where

q = source strength
u = wind speed
σ_z = standard deviation of the plume's vertical concentration distribution
ϕ = angle between wind direction and road

For the third phase, soil from the outdoor test roads was applied to the enclosed test track and tested in the same manner as described for the first phase. The soil type on the outdoor test track was Drummer silty clay loam.

Data from the third and first phases were compared to determine the effect of the change in soil type. Data from the third and second phases were compared to evaluate the model, i.e. the test track, relative to the process being modeled, the outdoor emission generation from outdoor haul roads. The authors felt that the outdoor test roads realistically represented construction haul roads. Emission rates were all expressed in terms of mass per tire-mile, for ease of comparison.

Test Sites--The indoor test track was at the University of Illinois at Champaign. The outdoor test roads were constructed in undeveloped land near Champaign.

Parameters and Equipment--In both cases high volume samplers were used to measure dust concentration. The soils' water potential was measure using soil psychrometers placed below the surface. Soil water potential was said to indicate how tightly water was held in the soil. The psychrometers were connected to an instrument which automatically displayed and recorded the data. Other soil parameters for which data was collected included soil plastic limit, liquid limit, silt content. The means for measuring these parameters were not documented.

One parameter was measured only for the indoor test track. The fraction of dust in the evacuation duct that was sampled by the hi-vols was determined by using a probe apparatus to sample the dust concentration at several points in the duct's cross section. The ratio of the probe concentration to the concentration measured by the hi-vol was found to be .9.

In the outdoor testing operation, wind speed and direction, atmospheric stability, and vehicle speed were also measured. A recording windvane anemometer provided data on wind speed and direction, whereas atmospheric stability was estimated using the method suggested by Pasquill (1968), which involves noting the frequency and magnitude of wind direction changes.

Equipment Configuration--For the indoor test track, hi-vol sampling heads were fixed in a box connected by a duct to the primary evacuation duct. The hi-vol heads were connected by more flexible ducts to their respective vacuum motors, which drew a portion of the air from the evacuation duct into the box and through the filters. The soil psychrometers were placed approximately one-half inch beneath the surface in the tire path.

The equipment configuration and the methodology for the third phase was identical to that of the first. The only difference was the soil type.

For the outdoor tests, three hi-vols were placed downwind from the road most suitable for testing based on wind conditions. Two were 50 feet downwind and the third was 100 feet. Three psychrometers were embedded in each of the roads in the tire paths.

Sampling Runs--Eighteen sampling runs were conducted in the first and third phases, randomly varying the tire speed and weight between tests. At high tire speeds the runs lasted roughly three hours, compared to about eight hours for slow speeds. Hi-vol filters were changed and psychrometer readings were taken every .5 to 2 hours. Thus, every run yielded multiple concentration measurements.

Nine one-hour runs were conducted at the outdoor test site. Again, vehicle speed and weight were varied between tests, but it was not practical in this instance to randomly vary the vehicle weight. Difficulties in weighting the tire arm prevented randomization of weights.

At the time this report was completed, only three sampling runs in the third phase were completed.

Quality Assurance--Quality assurance was not an important issue for the authors of this report. No documentation was provided for calibration of hi-vol samplers, auditing of sample weights, processing of blank filters, or other standard quality assurance procedures. However, documentation of raw data and methodological procedures was thorough.

Findings--The raw data generated by these three experiments are presented in order in Tables 2.3-2.5 below. Linear regression analysis of the data from the first phase yielded the following relationship, with an R^2 of 0.64:

$$\ln(D) = -5.37 + 0.12(T) + 0.21(S) + 0.90(W)$$

where

D	=	emission rate, grains/veh-mile
T	=	soil water potential, atmospheres of tension
S	=	vehicle speed, mph
W	=	vehicle weight, lb/tire

Each of the independent variables were significant at the .95 level.

The following equation was produced using linear regression analysis of the outdoor test road data:

$$\ln(D) = 5.28 + 0.01(T) + 0.06(S) + 0.50(W)$$

The R^2 value for this model was .66.

Data from the third phase was pooled with that from the first, and a regression analysis was again conducted, this time with the addition of another variable, soil plastic limit. Plastic limit, according to Struss and Mikucki, is "the percent moisture, by weight, contained in a soil when it passes from a plastic to a brittle state while drying." The resulting equation is shown below. The R^2 value of this equation was not documented.

$$\ln D = -13.05 + 0.12(T) + 0.21(S) + 0.90(W) + 0.48(P)$$

In this equation P is the plastic limit, and all the other variables are defined as before.

The only comparison between the second and third phase results was an acknowledgement that emissions from the outdoor test site were consistently higher than they were from the indoor test track. In fact, they were roughly an order of magnitude higher. The investigators surmised that this was due primarily to differences in the aerodynamics created by the moving vehicle and the rotating arm. Another factor which might lead to lower concentration measurements for the test track is the deposition of dust particles on the interior surfaces of the ventilation system before reaching the hi-vols.

Finally, data from all three phases were pooled and subjected to linear regression analysis. The resulting equation, for which no R^2 value was given, is shown below.

$$\ln D = -5.28 + 0.01(T) + 0.06(S) + 0.50(W) + 0.48(P)$$

<u>Publication</u>--These experiments were performed and documented by the U.S. Army Construction Engineering Research Laboratory (CERL). It is Special Report N-17, completed in February 1977.

TABLE 2.3. EMISSION FACTORS FOR FIRST PHASE

Run	Duration (hours)	Filter Weight Increase (grains)	Emission Rate (grains/tire-mile)
1	2	0.5386	1.42
	2	1.8102	4.85
	1.9	5.3333	15.1
	.9	4.0849	23.8
2	1	17.941	32.7
	.9	46.555	86.5
	.5	43.347	146
	.5	60.739	208
3	2.2	5.2314	8.60
	1.9	25.704	49.6
	1	32.244	121
	.75	28.322	139
4	1	0.9707	3.44
	1.1	3.7700	12.2
	.9	11.035	44.1
	.8	15.605	70.6
	1.05	24.268	87.2
5	.5	0.6713	2.35
	.55	3.6774	11.8
	.45	6.4382	25.4
	.5	14.043	50.5
	.45	18.847	76.3
	.55	26.157	87.8
	.25	19.065	137
6	1	1.2639	4.51
	1	1.8796	6.75
	.95	4.6157	17.2
	.8	7.4907	33.9
	1	14.954	54.5
	.4	9.8163	88.2
7	1	0.6157	2.23
	1	n.d.	n.d.
	1.05	1.6759	5.70
	.95	4.4182	16.3
	1	8.6234	30.4
	.4	5.1543	43.7
8	.95	0.2901	1.57
	.85	0.1096	0.66
	.9	0.1003	0.58
	.9	0.1111	0.64
	1.05	0.2407	1.20
	.9	0.3395	1.97
	1	0.3117	1.63
	1	0.8287	4.32
	.9	0.9861	5.75
	1.05	1.9089	9.61
	.5	1.0602	11.0
9	.35	0.5093	2.51
	.5	5.1512	17.8
	.45	13.785	53.6
	.5	29.586	106
	.5	35.418	131
10	.9	0.5447	3.14
	1	0.2207	1.14
	.9	0.3827	2.20
	.95	0.7701	4.23
	.95	3.7099	20.5
	1	3.3966	17.5

(continued)

TABLE 2.3. (continued)

Run	Duration (hours)	Filter Weight Increase (grains)	Emission Rate (grains/tire-mile)
11	.5	1.0725	3.75
	.5	n.d.	n.d.
	.5	3.3765	11.9
	.5	8.2253	29.2
	.45	13.475	52.4
	.55	20.000	64.9
	.45	22.741	88.4
12	1.05	0.875	29.2
	.95	2.6620	9.80
	.9	7.0169	27.8
	.95	14.400	53.0
	.9	22.125	58.5
	.5	13.048	87.3
	.5	19.952	136
13	1.05	0.5463	2.59
	1	0.4367	2.18
	1	1.0833	5.44
	.95	2.4846	13.4
	1	4.3410	22.2
	.5	3.0247	30.5
14	1	0.8318	2.78
	1	2.6836	9.15
	.95	7.8827	28.3
	.9	16.268	60.3
	.5	13.275	91.7
	.5	15.241	107
15	1.05	1.9568	6.16
	.95	8.4783	29.9
	1	16.378	56.2
	.45	11.497	85.5
16	1	0.3688	1.83
	1	0.1991	0.99
	.95	0.2562	1.34
	.95	0.5432	2.83
	1	1.3272	6.66
	.95	2.2700	12.0
	1	1.9630	9.67
17	1	0.4028	2.03
	1	0.2269	1.15
	1.1	0.2145	0.99
	.75	0.2160	1.45
	1.05	0.5000	2.42
	.95	0.5880	3.17
	1	1.0772	5.54
	.95	1.5555	8.27
18	.45	0.8750	3.21
	.5	1.4846	4.93
	.45	3.8287	14.3
	.5	7.2392	24.5
	.5	9.3194	31.6
	.55	14.992	46.5
19	1	0.8410	1.41
	.9	3.0802	5.72
	1.1	11.495	17.7

TABLE 2.4. TEST PARAMETERS AND EMISSION FACTORS FOR SECOND PHASE

Run	Duration (hours)	Concentration at 50′ (grain/ft³)	Concentration at 100′ (grain/ft³)	σ_z at 50′ (ft)	σ_z at 100′ (ft)	Wind speed (ft/sec)	Emission Factor[a] (grains/tire -mile)
1	1.5	.000262	.000154	4.6	8.5	10.5	599
2	1	.000571	.000342	4.6	8.5	9.5	1060
3	1	.00236	.00128	3.9	6.9	11.0	2600
4	1	.00151	.000910	6.2	13.1	7.5	2470
5	1	.00552	.00287	6.2	13.1	6.5	5830
6	1	.00142	.000941	4.6	8.5	11.0	2530
7	1	.000509	.000278	2.6	4.9	13.0	723
8	1	.00105	.000602	3.9	6.9	13.0	1720
9	1	.000802	.000633	2.3	4.3	19.0	1850
10	.9	.00148	.000833	2.3	4.3	14.0	1380
11	1	.00106	.000880	2.9	5.6	17.0	2270

a) Whether this rate is based on the measured concentration at 50 feet, 100 feet, or the average was not noted.

TABLE 2.5. EMISSION FACTORS FOR THIRD PHASE

Run	Duration (hours)	Filter Weight Increase (grains)	Emission Factor (grains/tire-mile)
1	1	0.9537	4.70
	1	1.7731	8.84
	1	2.8904	14.7
	.95	3.9815	21.3
	.95	5.1265	27.4
	.95	6.4382	34.7
2	.5	2.4737	16.8
	.5	3.3580	22.9
	.5	7.7762	53.0
	.45	6.8750	52.8
	.45	10.356	80.0
	.5	12.185	85.3
	.3	8.4922	97.8
3	.5	3.5123	11.6
	.5	9.1882	30.9
	.5	12.944	44.1
	.25	14.150	95.3

Study 5-- Axetell. Survey of Fugitive Dust from Coal Mines. EPA-908/1-78-003. 1978.

Methodology--Upwind-downwind dispersion modeling was used to measure emissions from haul roads at surface coal mines. Concentrations and other field parameters were used in the model shown below:

$$\chi = \frac{2q}{\sin\phi\sqrt{2\pi}\,\sigma_z u}$$

where

χ	=	plume centerline concentration at a distance x downwind from the source, g/m^3
q	=	source strength, g/sec-m
ϕ	=	angle between wind direction and line source
σ_z	=	the standard deviation of the plume's vertical concentration distribution at a downwind distance x, m
u	=	mean wind speed, m/sec

Following the example set by Turner (1970, problem 23), the investigators used a simplified version of the model for a continuously emitting, infinite line source. The effective height of emission was taken to be zero; consequently the expression

$$\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

always evaluated to one and could therefore be omitted from the equation. The emission factor was calculated by solving for source strength and dividing by the rate at which vehicles pass.

An effort was made to measure particle fallout rates. Concentrations at a series of downwind distances from the source were measured, and corresponding emission rates at the source were calculated using the above model, which assumes there is no particle fallout. Decreases in the "apparent emission rate" with increasing distance from the source would serve as a measure of fallout.

Test Sites--Unpaved, uncontrolled haul roads at two western surface coal mines were tested.

Parameters and Equipment--The parameters measured in this study are listed in Table 2.6, along with the tools used to collect the data.

TABLE 2.6. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameters	Equipment
Upwind concentration of TSP	Standard hi-vol
Downwind concentration of TSP	Standard hi-vol
Wind direction	Recording wind instrument
Wind speed	Recording wind instrument, hand-held anemometer
Other atmospheric stability parameters	Unspecified
Particle size distribution	Millipore filters on nuclepore filter holder and pump, microscope

Equipment Configuration--For each sampling run at the first mine, downwind hi-vols were set up at three downwind distances, 10, 20, and 30 meters; for two of the runs an additional sampler was operated 40 meters downwind. These all collected air 1.2 meters above the ground. A second hi-vol was placed at each of the first three downwind distances 2.4 meters above the ground. This configuration enabled the measurement of changes in concentration with downwind distance and height. Typically, a pair of hi-vols were placed together at a site upwind from the entire mine. This was preferred over placing samplers immediately upwind from the road because anticipated brief wind direction reversals would be less likely to effect upwind concentration measurements. Other hi-vols were placed at 10, 20, and 30 meters (or a similar series of distances) downwind from a particular source activity. For about half of the tests, downwind samplers were set up at both 1.2 and 2.4 meters above the ground at these downwind locations to provide information on the vertical dispersion of the plume.

Sampling Runs--Four sampling runs were conducted on uncontrolled haul roads at one mine; three runs were conducted at the other. The number of vehicle passes per run ranged from 32 to 46. During each sampling run, which lasted between 45 and 60 minutes, four or six downwind concentration measurements were taken, as described above.

Quality Assurance--The guidelines in the Quality Assurance Handbook for Air Pollution Measurement Systems (EPA, 1976) were followed in preparing filters, collecting and analyzing samples, and auditing the data. Hi-vol samplers were calibrated before field work began at each mine. One of every 25 filters was treated as a blank.

Findings--The measured concentrations and other field sampling data are shown in Table 2.7. As was the case with the other source activities in the mines, the apparent emission rate from haul roads did not generally decrease with downwind distance.

For those sampling runs which included concentration measurements at two consecutive downwind distances at the same height, the modeled apparent emission rates decreased with increasing distance in only about 35% of the sampling runs. For those tests in which concentrations were measured at downwind distances differing by 10 meters, the concentration **increased** an average of 19% between the two sampling points.

When measured at two heights, 1.4 meters and 2.4 meters, at the same downwind distance, the concentrations at the lower height averaged 14% higher than those at the samplers 2.4 meters above the ground.

Publication--This study was conducted and documented under a contract for the Environmental Protection Agency, Region VIII, Office of Energy Activities, Denver, Colorado. It was published in February of 1978 as Publication No. EPA-908/1-78-003.

TABLE 2.7. CONCENTRATION MEASUREMENTS AND ASSOCIATED FIELD DATA

Mine/ Sample	Wind Speed (m/sec)	Stability Class	Background Concentration (μg/m³)	Net Plume Concentration (μg/m³)	Downwind Distance (m)	Height (m)	Apparent Emission rate (lb/veh-mile)
B/1	3.7	C	152	1920	10	1.2	11.5
				1829	20	1.2	12.7
				1670	30	1.2	14.0
				1798	40	1.2	18.0
B/2	3.7	C	152	1767	10	1.2	10.6
				2034	20	1.2	14.2
				1504	30	1.2	12.6
				1773	10	2.4	8.5
				1584	20	2.4	9.9
				1156	30	2.4	8.7
B/3	4.7	C	152	3022	10	1.2	21.0
				2321	20	1.2	18.8
				1720	30	1.2	16.7
				1617	40	1.2	18.8

(continued)

TABLE 2.7 (continued)

Mine/ Sample	Wind Speed (m/sec)	Stability Class	Background Concentration (µg/m³)	Net Plume Concentration (µg/m³)	Downwind Distance (m)	Height (m)	Apparent Emission rate (lb/veh-mile)
B/4	4.7	C	152	3034	10	1.2	21.1
				2516	20	1.2	20.4
				1689	30	1.2	16.5
				2336	10	2.4	13.0
				1681	20	2.4	12.2
				1318	30	2.4	11.6
E/1	3.7	B	105	693	8	1.2	2.3
				794	17	1.2	3.7
				748	26	1.2	4.4
				427	8	2.4	1.6
				575	17	2.4	2.7
				571	26	2.4	3.4
E/2	3.7	B	105	500	8	1.2	1.7
				877	17	1.2	4.1
				619	26	1.2	3.7
				509	34	1.2	3.7
E/3	3.1	B	145	727	8	1.2	1.9
				788	17	1.2	2.8
				1051	26	1.2	4.7
				548	8	2.4	1.6
				711	17	2.4	2.5
				510	26	2.4	2.3

Study 6-- Bohn et al. Fugitive Emissions from Integrated Iron and Steel Plants. EPA-600/2-78-050. 1978.

Methodology--Exposure profiling, a technique originally developed by the Midwest Research Institute (MRI) in 1974, was the basic method used to measure emissions of particulates from vehicle travel on unpaved roads within integrated iron and steel plants.

Test Sites--Two plants provided sites for this investigation. One plant in the dry western U.S. was used for measuring emissions from vehicle travel on a road with a fine slag cover. The other plant was in the Great Lakes steel-producing area of the U.S. It was used for testing both paved roads and roads with a "hard-base" dirt cover.

Parameters and Equipment--Table 2.8 provides a list of parameters documented in the study and the corresponding equipment used to take the measurements.

Equipment Configuration--In each sampling run the exposure profiler was set up 5 meters from the edge of the unpaved road. For sites with light-duty traffic, sampling intakes were positioned at 1, 2, 3, and 4 meters above the ground. For heavy-duty traffic, they were set at 1.5, 3, 4.5, and 6 meters above the ground. A standard hi-vol sampler and a hi-vol cascade impactor with cyclone preseparator were placed beside the profiler at approximately 2 meters above the ground. The wind instrument was located 3 meters downwind from the edge of the road. Dustfall buckets were placed at 1 and 3 meters from the road's edge. Another standard hi-vol sampler was placed five meters upwind from the road.

Sampling Runs--A total of nine sampling runs, were conducted on unpaved roads, three on a road with fine slag cover and six on roads with a hard-based dirt cover. Each run lasted from 12 to 55 minutes. The investigators recorded 319 vehicle passes while sampling plumes on unpaved roads.

TABLE 2.8. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameter	Equipment
Wind speed	Anemometer
Wind direction	Anemometer
Cloud cover	Direct observation
Temperature	Sling psychrometer
Relative humidity	Sling psychrometer
Road surface condition	Direct observation
Dust loading	Dry vacuuming, scales
Dust texture	Sieves, standard shaker, scales
Traffic mix	Direct observation
Traffic count	Automatic counters
Plume exposure	Isokinetic hi-vol samplers on profiler tower
Plume particle size distribution	Hi-vol cascade impactor with cyclone preseparator
Downwind concentration	Hi-vol sampler
Background concentration	Hi-vol sampler
Duration of sampling	Timer
Deposition	Dustfall buckets

Quality Assurance--The extent to which methodological procedures were documented in this report is sufficient to permit their reproduction by other investigators. The manner in which exposed filters were collected and transported to the laboratory was described in some detail. However, documentation of specific quality assurance procedures, such as auditing filter weights, processing of blank filters, or calibration of sampling equipment, was generally not provided.

Findings--Exposure data and calculated emission factors for suspended particulates (less than 30 μm diameter) are presented in Table 2.9.

The predictive equation which was published in this study and which is based on the cumulative database gathered by Midwest Research Institute is shown below:

$$e = 5.9\ (s/12)\ (S/30)\ (W/3)^{0.8}\ (d/365)$$

where

e = suspended particulate emissions, lb/veh-mile
s = road surface silt content, %
S = average vehicle speed, mph
W = average vehicle weight, tons
d = dry days per year

Publication--This study was conducted and documented under a contract with the Environmental Protection Agency; Industrial Research Laboratory; Office of Energy, Minerals, and Industry; Research Triangle Park, North Carolina. It was published as Publication No. EPA-600/2-78-050 in March 1978.

TABLE 2.9. EXPOSURE DATA AND EMISSION FACTORS

Run	Sample Height (m)	Filter Exposure (mg/cm^2)	Integrated Filter Exposure (lb/mile)	Emission Factor[a] (lb/veh-mile) $d^b < 30$
A-7	1	5.34	5.6	4.9
	2	2.9		
	3	1.54		
	4	0.28		
A-14	1.5	17.9	16	27
	3	6.33		
	4.5	5.11		
	6	1.39		
A-15	1.5	12.5	16	29
	3	6.78		
	4.5	5.91		
	6	2.97		
E-1	1.5	4.53	18	17
	3	3.67		
	4.5	2.33		
	6	1.24		
E-2	1.5	4.43	19	16
	3	3.16		
	4.5	2.92		
	6	1.79		
E-3	1.5	5.76	16	19
	3	3.07		
	4.5	1.70		
	6	0.95		
E-4	1	4.24	7.7	13
	2	2.94		
	3	1.80		
	4	0.86		

(continued)

TABLE 2.9. (continued)

Run	Sample Height (m)	Filter Exposure (mg/cm²)	Integrated Filter Exposure (lb/mile)	Emission Factor[a] (lb/veh-mile) $d^b < 30$
E-5	1	5.70	11	11
	2	3.42		
	3	1.82		
	4	0.68		
E-6	1	8.15	14.2	19
	2	2.25		
	3	2.47		
	4	0.76		

a) isokinetic
b) particle Stokes diameter

Study 7-- Cowherd <u>et al.</u> <u>Iron and Steel Plant Open Source Fugitive Emission Evaluation</u>. EPA-600/2-79-103. 1979.

<u>Methodology</u>-- Exposure profiling was the primary technique used to estimate emissions of fugitive dust from unpaved roads. For a full description of this methodology, see the summary of Cowherd <u>et al.</u>, 1974.

<u>Test Sites</u>--Tests were conducted at two sites in unidentified iron and steel plants, one with a crushed slag road and the other with a mixed dirt-slag road.

Parameters and Equipment--

Table 2.10 lists the parameters measured and the equipment used to measure them.

Table 2.10. Parameters Measured and Corresponding Equipment

Parameters	Equipment
Wind speed	Recording anemometers
Wind direction	Unspecified
Cloud cover	Direct observation
Temperature	Sling psychrometer
Relative humidity	Sling psychrometer
Road surface condition	Direct observation
Road dust loading	Vacuum/broom
Road dust % silt	200-mesh screen, shaker
Traffic mix	Direct observation
Traffic count	Automatic counter
Exposure	Isokinetic hi-vol filtration (profiler)
Particle size distribution	Hi-vol cascade impactor & cyclone preseparator (directional)
Downwind concentration	Hi-vol sampler
Upwind concentration	Hi-vol sampler
Duration of sampling	Timer

Equipment Configuration--The exposure profiler was positioned 5 meters from the downwind edge of the road. Four sampler intakes were positioned at heights of 1.5, 3, 4.5, and 6 meters. A cascade impactor and a standard hi-vol sampler were placed beside the profiler two meters above the ground. For three of the tests, a second downwind standard hi-vol sampler was stationed about 17 meters from the edge of the road 2 meters above the ground. Wind measurements were taken between 7 and 14 meters upwind from the upwind edge of the road at two unspecified heights. A standard hi-vol sampler was also placed beside the wind station with its intake at a height of 2 meters.

Sampling Runs--Nine sampling runs were made on uncontrolled, unpaved roads. Three were on a mixed dirt-crushed slag surface, and 6 were on a crushed slag surface. The number of vehicle passes per sampling run ranged from 40 to 74. The total number of vehicle passes was 533.

Quality Assurance--An effort was made to apply or adapt the American Society of Testing and Materials (ASTM) Standards in the collection and analysis of road surface samples needed to quantify the silt content of the surface material. Except for the citation of this standard procedure, the authors documented no normal quality assurance procedures. However, documentation of the basic methodological procedures in field operations, sample handling, and data analysis was generally thorough.

Dust samples were transported to the laboratory in individual envelopes. Filter samples were conditioned at constant temperature and humidity for 24 hours before weighing. This same procedure was followed in weighing the filters prior to use.

Careful attention was given to sampling under isokinetic conditions. The intake velocity of each sampler was set to match the wind velocity prior to commencement of sampling. Wind speed was measured continuously during sample collection. Isokinetic correction factors were used to adjust exposures measured under non-isokinetic conditions.

An effort was also made to reduce small particle bias in characterizing the particle size distribution of the dust plume. One of the high volume cascade impactors was fitted with a cyclone preseparator to reduce small particle bias caused by large particles bouncing through the impactor stages to the back-up filter. The impactor/preseparator unit was calibrated to determine the 50% cutoff diameters of the cyclone inlet and the stages of the preseparator. The investigators found that the preseparator does eliminate much, but not all, of the small particle bias.

The procedure for accounting for background levels of dust was not adequately documented. Therefore, the emission factors presented in the study could not be reproduced from the data provided.

Findings--This study evaluated emissions from three source categories in iron and steel plants: vehicle travel on unpaved roads, vehicle travel on paved roads, and storage pile stacking. Data collected on unpaved road emissions, shown in Table 2.11, was added to MRI's database of field collected emissions data, and, using this larger database, the predictive emission factor equation for vehicle travel on unpaved roads was revised. A new variable, the average number of wheels per vehicle traveling the road segment, was added to the equation. The addition of this predictive variable is indicative of the fact that the emissions database collected by MRI was expanded under this study to include a wider range of test conditions. The revised equation is presented below.

$$e = 5.9\ (s/12)\ (S/48)\ (W/2.7)^{0.7}\ (w/4)^{0.5}\ (d/365)$$

where

e	=	Emission factor for particles < 30 µm in diameter, pounds per vehicle-mile
s	=	Silt content, %
S	=	Average vehicle speed, miles per hour
W	=	Average weight per vehicle, tons
w	=	Average number of wheels per vehicle
d	=	Dry days per year

Publication--This study was conducted and documented under a contract for EPA, Industrial Environmental Research Laboratory, Office of Energy, Minerals, and Industry, Research Triangle Park, North Carolina. It was published in 1979 as Publication No. EPA-600/2-79-103.

TABLE 2.11. EXPOSURE DATA AND EMISSION FACTORS

Run	Sampling Height (m)	Filter Exposure (mg/cm^2)	Integrated Filter Exposure (lb/mile)	Emission Factor[a] (lb/veh-mile)	
				d[b] < 30 µm	d[b] < 5 µm
F-21	1.5	0.79	123	3.0	1.0
	3.0	0.39			
	4.5	0.17			
	6.0	0.18			
F-22	1.5	0.60	98.3	1.7	0.53
	3.0	0.47			
	4.5	0.24			
	6.0	0.17			
F-23	1.5	1.01	168	2.3	0.75
	3.0	0.72			
	4.5	0.45			
	6.0	0.34			
G-27	1.5	4.69	901	12.0	3.1
	3.0	5.12			
	4.5	NA			
	6.0	1.07			
G-28	1.5	2.26	391	7.2	2.4
	3.0	1.60			
	4.5	NA			
	6.0	0.77			

(continued)

TABLE 2.11. (continued)

Run	Sampling Height (m)	Filter Exposure (mg/cm²)	Integrated Filter Exposure (lb/mile)	Emission Factor[a] (lb/veh-mile)	
				$d^b < 30$ µm	$d^b < 5$ µm
G-29	1.5	3.37	475	5.6	1.2
	3.0	1.83			
	4.5	NA			
	6.0	0.05			
G-30	1.5	1.98	317	8.7	1.5
	3.0	1.64			
	4.5	0.91			
	6.0	0.42			
G-31	1.5	1.71	244	5.1	1.1
	3.0	0.96			
	4.5	1.01			
	6.0	0.26			
G-32	1.5	5.06	845	16.0	3.4
	3.0	3.68			
	4.5	NA			
	6.0	1.39			

a) isokinetically corrected
b) particle Stokes' diameter

Study 8-- Cuscino. Taconite Mining Fugitive Emissions Study. 1979.

Methodology--Exposure profiling was used to measure particulate emissions from haul trucks traveling on unpaved roads at a taconite mine. As in the original exposure profiling study (Cowherd et al., 1974), point values of exposure were calculated as the dust mass per unit area of the sampler intake.

Test Sites--Tests were conducted on two different road surface types (sand/gravel and crushed rock) in the Erie Mining Company's operation in the Mesabi Iron range in Minnesota.

Parameters and Equipment--Several different pieces of equipment were employed in measuring plume dust. Exposure was measured using a profiler with four sampling heads. Air was drawn in isokinetically and routed up through the horizontal filter. The plume's particle size distribution was measured using a high volume cascade impactor with a cyclone preseparator (to remove very large particles which tend to bounce through the impaction substrates and cause fine particle measurement bias).

Standard hi-vol samplers measured total suspended particulate concentration at several downwind distances.

The number and type of vehicles passing during each sampling run were also documented. Data on many test site conditions were also collected: wind direction and speed, temperature, cloud cover, humidity, recent rainfall history, road surface material density, and silt content. The tools or methods of measuring these parameters was not documented.

Equipment Configuration--The high volume cascade impactor, the profiler, and a standard high volume sampler were all set up five meters from the downwind edge of the road. The profiler had sampling heads at four heights: 1.5, 3, 4.5, and 6 meters. Anemometers were attached to the tower at heights of 1.5 and 4 meters. Two other standard hi-vol samplers were placed 20 and 50 meters from the downwind edge of the road. Wind speed and direction were also measured at two weather stations, one five meters upwind and the other 50 meters downwind. The measuring height of these weather stations was not documented.

Sampling Runs--Eight sampling runs, ranging in duration from 29 to 68 minutes, were conducted in which emissions from the road surface were not controlled. Sampling runs generally consisted of 15 haul trucks passing the sampling site where the fugitive emissions were measured. For two of the sampling runs, traffic consisted partially of pick-up trucks. Emissions from a total of 131 vehicle passes were measured.

Quality Assurance--In collecting and analyzing road surface samples for silt and moisture content, relevant standards set by the American Society of Testing and Materials were followed with some adaptation due to feasibility constraints. The methods were set forth in detail in an appendix.

To the extent practical, exposure samples were collected isokinetically. Otherwise, correction factors were used to adjust the sample to isokinetic conditions.

The following relevant quality assurance procedures were not documented for this study: calibration of air samplers, processing of blank filters, auditing of filter weights, and collocation of samplers.

It should also be noted that the haul road surfaced with sand/gravel was not in use prior to emissions testing. The investigators judged that the process of fine dust formation and subsequent emission into the atmosphere did not reach an equilibrium state until after the first two sampling runs (30 vehicle passes). Furthermore, three other tests were conducted on the day after a heavy rain.

Findings--The measured exposures and corresponding emission factors are shown in Table 2.12. A regression analysis was conducted on the data from this study and previous Midwest Research Institute studies of unpaved road emissions (Cowherd et al., 1974; Bohn, et al., 1978; and Cowherd et al., 1979). Runs I-1, I-2, I-6, I-7, and I-8, were excluded as they were believed to be not representative of dry, uncontrolled, unpaved roads (see discussion in Quality Assurance). The following equation was developed using this analysis:

TABLE 2.12. MEASURED EXPOSURES AND CALCULATED EMISSION FACTORS

Run	Sample Height (m)	Filter Exposure (mg/cm²)	Integrated Filter Exposure (lb/mile)	Emission Factor[a] (lb/veh-mile)
I-1[b]	1.5	0.76	138	9.2
	3.0	0.51		
	1.5	0.45		
	6.0	0.32		
I-2[b]	1.5	0.65	153	10.2
	3.0	0.55		
	1.5	0.54		
	6.0	0.46		
I-3	1.0	1.61	285	19.0
	3.0	1.18		
	1.5	0.91		
	6.0	0.54		
I-4	1.5	2.81	501	33.4
	3.0	2.35		
	1.5	1.60		
	6.0	0.76		
I-5	1.5	3.74	742.5	49.5
	3.0	2.72		
	1.5	2.55		
	6.0	1.64		
I-6[c]	1.5	0.19	69	2.3
	3.0	0.18		
	1.5	0.26		
	6.0	0.22		

(continued)

TABLE 2.12. (continued)

Run	Sample Height (m)	Filter Exposure (mg/cm²)	Integrated Filter Exposure (lb/mile)	Emission Factor[a] (lb/veh-mile)
I-7[c]	1.5	3.56	582	38.8
	3.0	2.45		
	1.5	1.76		
	6.0	0.98		
I-8[c]	1.5	1.70	260.7	23.7
	3.0	1.19		
	1.5	0.68		
	6.0	0.31		

a) for particles with aerodynamic diameter < 30 μm, before isokinetic correction
b) conducted on previously inactive road (see discussion in Quality Assurance)
c) conducted on day after heavy rains

$$EF = 0.00380\ s\ S\ W^{0.7}\ w^{0.5}$$

where

EF = Emission factor for particles with Stoke's diameter < 30 μm, lb/veh-mile
s = Silt content, %
S = Average vehicle speed, mph
W = Average vehicle weight, tons
w = Average number of wheels per vehicle

Publication--This study was conducted for the Minnesota Pollution Control Agency, Division of Air Quality, Roseville, Minnesota. It was apparently never published.

Study 9-- Reider. Size Specific Particulate Emission Factors for Uncontrolled Industrial and Rural Roads. January 1983.

Methodology--Exposure profiling was used to measure emissions from unpaved roads in both rural and industrial settings. An explanation of the specific procedures for calculating emission factors from the field data was not provided in the report.

Test Sites--In addition to public rural roads, tests were conducted on unpaved roads in facilities of three different industries: stone crushing, sand and gravel processing, and copper smelting. All of the industrial roads were two-lane, whereas some of the public, rural roads were one-lane and others were two-lane. For the industrial roads, test sites were selected according to three general criteria. Each test site needed to be: 1) suitable for the specific requirements of the exposure profiling methodology, 2) representative of most facilities in the industry, and 3) accessible via cooperation of the facility personnel.

Parameters and Equipment--The parameters measured in this study and the equipment used to take these measurements are shown in Table 2.13.

The procedures for calculating point values of exposure from these data were not included in this report. They are presumably similar to those discussed in Cowherd and Englehart, 1984, which is reviewed in the paved road section.

Equipment Configuration--Downwind air sampling equipment was set up five meters from the edge of the road. The exposure profiler had sampling heads at heights of 1, 2, 3, 4, and 5 meters. The wind speed is measured continuously at two sampling heights and a logarithmic distribution of the vertical wind speed profile is assumed in setting the sampling rates for the remaining sampler heads. A standard hi-vol sampler, a hi-vol fitted with a 15 µm size-selective inlet (SSI), and two cascade impactors with cyclone preseparators were also set up on the downwind side. The cascade impactors were positioned in a vertical array at heights of 1 and 3 meters. The hi-vols sampled air at a height of 2 meters.

Upwind sampling equipment was also generally set up five meters from the road. For all unpaved road tests, one of each of the following samplers was set up with intakes two meters above the ground: standard hi-vol, hi-vol with SSI, and cascade impactor with cyclone preseparator.

TABLE 2.13. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameter	Equipment
Wind speed	Warm wire anemometer
Wind direction	Wind vane
Atmospheric pressure	Barometer
Temperature	Sling psychrometer
Relative humidity	Sling psychrometer
Road surface condition	Direct observation
Road surface particulate loading	Dust pan, broom, scales
Road surface silt content	Sieves, scales
Traffic Mix	Direct observation
Traffic Count	Direct observation
Vehicle weight	Interview plant operators
Vehicle speed	Interview drivers
Plume total particulate concentration	Exposure profiler
Plume inhalable particulate concentration	Hi-vol with size-selective inlet
Size distribution of inhalable particulate	Cascade impactor with cyclone preseparator (impactor cutpoints of 10.2, 4.2, 2.1, 1.4, and 0.73 µm)

Sampling Runs--A total of 21 tests, ranging in duration between 12 and 203 minutes, were conducted on unpaved roads for this study. Sampling run time was sufficient to produce a filter weight gain of at least 5 mg on the top sampling head of the profiler. Tests were distributed among the various industries as shown in Table 2.14.

TABLE 2.14. EXTENT OF SAMPLING FOR VARIOUS INDUSTRIES

Industry	Number of Tests	Total Vehicle passes	Traffic Type
Stone crushing	5	225	Medium Duty
Sand and gravel processing	3	80	Heavy Duty
Copper smelting	3	151	Light Duty
Public roads			
crushed limestone	6	591	Light Duty
dirt	4	244	Light Duty
gravel	2	68	Light Duty

Quality Assurance--Except for the absence of an explanation of the manner in which values of concentration of IP and PM_{10} at each profile height were calculated, quality assurance for this study was good. Calibration of the profiler, hi-vols, and impactors was performed prior to testing at each site. Sampling filters and impactor substrates were equilibrated for 24 hours prior to weighing. Tare weights were given a 100% audit, and 10% of loaded weights were audited. Criteria for reweighing of the entire batch were provided. The orientation of the profile sampling heads were adjusted if the 15-minute average wind direction changed by more than 30 degrees. The sampling rate of the profile samplers was adjusted if the 15-minute average wind speed changed by more than 20%. Ten percent of all calculations were also audited.

Findings--The concentration measurements taken during the field tests are presented in Table 2.15. The investigators noted that the data from the profiler is net of background dust levels. The emission factors which were calculated from these data are shown in Table 2.16. Again, the specific procedures for calculating the emission factors are not described in this report.

Publication--This report has been completed only as a draft final report. It has not been published. However, it was cited in the AP-42 section on unpaved roads. The study was conducted under EPA Contract No. 68-02-3158.

TABLE 2.15. MEASURED DUST CONCENTRATIONS FOR TOTAL PARTICULATES AND PM_{10}

		Concentration (µg/m³)						
		Total Particulate					PM_{10}	
Run	Duration (minutes)	1 m	2 m	3 m	4 m	5 m	1 m	3 m
U-1	211	56890	27600	10230	7720	2180	6793	2903
U-2	79	32040	16080	6650	1660	810	4640	1803
U-3	119	54730	34380	18370	14940	7975	1165	766
U-4	196	31340	11380	5503	4440	1400	452	424
U-5	240	17740	8895	4324	1566	428	811	365
U-6	147	5680	2876	918	182	65	466	38
AA-1	65	15540	10290	8163	6964	5307	2313	1347
AA-2	58	20220	10320	4437	2003	305	212	293
AA-3	96	3695	1693	1081	556	400	346	146
AA-4	77	14290	9809	11510	7759	5654	4078	2244
AA-5	73	12280	8463	7239	5600	4070	2753	1675
AB-1	173	45410	15710	6766	3895	1918	2308	817
AB-2	266	121500	17800	5350	1167	162	827	100
AB-3	266	54580	16090	9700	2943	1354	2125	357
AB-4	162	15620	6253	a	890	175	2308	625
AC-1	143	11130	6534	4348	2422	1773	995	581
AC-2	143	6500	4912	3234	2276	1431	1156	317
AC-3	50	7802	3828	3525	1668	785	1542	546
AE-1	295	4288	2491	1189	b	355	571	138
AE-2	295	a	2193	793	141	c	502	299
AF-1	153	2487	a	1026	1138	c	130	146
AF-2	193	1338	a	826	506	318	317	131
AF-3	227	1290	a	1080	863	675	602	346

a) equipment malfunction or failure
b) torn filter
c) net concentration resulted in negative value

TABLE 2.16. EMISSION FACTORS FOR TOTAL PARTICULATES AND PM_{10}

Run	Total Particulate Emission Factor	PM_{10} Emission Factor
U-1	44.8	9.13
U-2	17.9	3.09
U-3	20.6	1.75
U-4	27.0	1.87
U-5	22.0	1.97
U-6	14.1	1.77
AA-1	9.36	2.15
AA-2	15.3	0.943
AA-3	4.83	0.903
AA-4	35.2	4.52
AA-5	30.3	5.83
AB-1	112.6	12.1
AB-2	42.1	0.951
AB-3	32.5	1.99
AB-4	11.1	1.86
AC-1	9.36	1.63
AC-2	7.62	1.46
AC-3	10.0	1.91
AE-1	5.43	0.713
AE-2	7.96	0.957
AF-1	15.3	2.60
AF-2	9.80	2.34
AF-3	8.28	3.26

Study 10-- Cuscino et al. Iron and Steel Plant Open Source Fugitive Emission Control Evaluation. EPA-600/2-83-110. 1983.

Methodology--Exposure profiling was used to measure emissions of particulate dust from vehicle travel on unpaved roads in iron and steel plants. The investigators made no changes in the basic methodology developed and applied in 1974 (see summary of Cowherd et al., 1974).

Test Sites--Tests of emissions from vehicular travel on unpaved, uncontrolled roads (i.e. not sprayed with a dust suppressant) were conducted at two different sites at Armco Steel, Incorporated's iron and steel works plant in Middletown, Ohio. Both sites were gravel roads. One was used primarily by heavy-duty vehicles, and the other was predominantly light-duty traffic.

Parameters and Equipment--Listed in Table 2.17 are the parameters measured and the equipment used to take the measurements in this study.

TABLE 2.17. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameter	Meteorology
Wind speed	Recording anemometer
Wind direction	Recording anemometer
Temperature	Unspecified
Road surface silt content	sieves, mechanical sieving device, scales
Road surface moisture content	Oven, scales
Traffic count	Direct observation
Plume exposure	Isokinetic hi-vol samplers (profiler)
Plume particle size distribution	Hi-vol cascade impactor with cyclone preseparator
Plume TSP concentration	Standard Hi-vol sampler
Plume IP concentration	Hi-vol sampler with size selective inlet
TSP background concentration	Standard Hi-vol sampler
Duration of sampling	Timer

Equipment Configuration--

Light-Duty Unpaved Road--The exposure profiler was located 5 meters from the downwind edge of the light-duty unpaved road. Sampling intakes were at heights of 1, 2, 3, and 4 meters. Several other instruments were positioned beside the profiler: a standard high-volume sampler at 2 meters above the ground, a high-volume sampler fitted with a size-selective inlet (designed to collect only particles less than 15 µm in aerodynamic diameter) at 2 meters height, and two high-volume samplers fitted with a cascade impactor and cyclone preseparator at 1 and 3 meters above the ground.

Three instruments were located 10 meters upwind from the upwind side of the road: a high-volume sampler with a 15 µm size-selective inlet 3 meters high, and two standard high-volume samplers, one 3 meters high and the other 1 meter high.

Heavy-Duty Unpaved Road--The equipment for the heavy-duty road site was configured the same as for the light-duty road with two exceptions: the profiler had a fifth sampler intake at 5 meters height, and there was no high volume sampler equipped with a size-selective inlet on the downwind side of the road.

Sampling Runs--Seven sampling runs were conducted on uncontrolled, unpaved roads in this study. Four were on light-duty roads, and three were on heavy-duty roads. Sampling run time ranged from 13 to 45 minutes, and the number of vehicle passes per run ranged from 10 to 101. The total number of passes was 276.

Quality Assurance--This study incorporated a rigorous quality control program. Procedures followed in collecting and analyzing samples were documented in considerable detail. Quality control measures were set forth for the sampling media, sampling flow rates, and sampling equipment (proper performance). Criteria for interrupting sample collection were also documented. Quality assurance practices included processing of blank samples, calibration of equipment, and auditing of sampling and analysis procedures.

The investigators note that their procedures met or surpassed the requirements set forth in the Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II - Ambient Air Specific Methods (U.S. EPA, 1977) and Ambient Monitoring Guidelines for Prevention of Significant Deterioration (U.S. EPA, 1978).

Careful attention was given to sampling under isokinetic conditions. Wind speed was monitored before and during sample collection. Fifteen minute averages of the wind speed at two monitoring heights and an assumed logarithmic vertical wind speed profile were used to set the intake velocity for each sampler on the profiler.

Findings--Because the purpose of this study was to evaluate various methods of controlling open source fugitive emissions from **iron** and steel plants, some experimental data was needed on particulate emissions from vehicle travel on **uncontrolled**, unpaved roads. Table 2.18 presents the primary emissions data collected for uncontrolled, unpaved roads in this study.

The investigators did not estimate a new predictive equation on the basis of their empirical findings. However, they did apply an equation estimated previously by MRI:

$$e = 5.9\ (s/12)\ (S/30)\ (W/3)^{0.7}\ (w/4)^{0.5}\ (d/365)$$

where

e	=	Mass of particulates < 30 µm in diameter lb/veh-mile
s	=	Silt content of road surface material %
S	=	Average vehicle speed mph
W	=	Average vehicle weight tons
w	=	Average number of vehicle wheels
d	=	Number of dry days per year

The investigators interpolated from the three size categories shown in Table 2.18 (assuming a log-normal distribution of particle sizes) to estimate an emission factor for particles less than 30 µm in diameter for each of the sampling runs. The ratio of predicted to actual (interpolated) emission factors ranged from .34 to 1.21 for the 7 sampling runs on uncontrolled, unpaved roads.

Publication--This study was conducted and documented for EPA, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. It was published in 1983 as Publication No. EPA-600/2-83-110.

TABLE 2.18. EXPOSURE DATA AND EMISSION FACTORS

Run	Traffic Type	Sample Height (m)	Net TP[a] Exposure (mg/cm²)	Emission Factors[b] (lb/veh-mile) TP[a]	d^c < 15 μm	d^c < 2.5 μm
F-28	Light Duty	1	3.52	10.7	1.05	0.245
		2	3.58			
		3	1.66			
		4	0.77			
F-29	Light Duty	1	5.20	14.2	4.25	1.27
		2	4.74			
		3	3.56			
		4	2.67			
F-30	Light Duty	1	4.20	9.98	2.99	0.898
		2	3.77			
		3	2.76			
		4	1.29			
F-31	Light Duty	1	3.01	12.4	3.90	1.02
		2	3.13			
		3	1.81			
		4	0.92			
F-68	Heavy Duty	1	12.0	129	33.5	7.74
		2	15.3			
		3	14.6			
		4	12.7			
		5	9.6			
F-69	Heavy Duty	1	10.7	133	25.9	8.84
		2	10.5			
		3	10.8			
		4	6.82			
		5	4.44			
F-70	Heavy Duty	1	8.60	133	32.8	8.52
		2	7.52			
		3	6.00			
		4	5.76			
		5	3.63			

a) total particulate, i.e. including mass in settling chamber
b) isokinetically corrected
c) particle aerodynamic diameter

Study 11-- Axetell and Cowherd. Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources. EPA-600/7-84-048. 1984.

Methodology--This study was conducted to develop emission factors for the various activities at surface coal mining operations in the Western U.S. The review will be limited to summarizing and discussing research on uncontrolled emissions from vehicle travel on unpaved roads. Emission factors were developed for four particle size categories: total particulates, particles with aerodynamic diameters less than 2.5 µm, those having diameters less than 15 µm, and total suspended particulates.

Two different testing set-ups were used in measuring emissions from this source. In the first, exposure profiling alone was employed. For the second, both the profiling method and the upwind-downwind method were used to determine the comparability of the findings from these two disparate techniques. The standard general equation for continuously emitting, infinite line sources (Turner, 1970) was used to estimate source strength from measured concentrations.

Three different tools for measuring the particle size distribution were also employed, evaluated, and compared in this second testing configuration: cascade impaction, dichotomous sampling, and microscopic examination of exposed millipore filters. Distribution data from the cascade impactors was corrected to adjust for the particle bounce problem (see reviews of Cowherd et al., 1974 and Cowherd et al., 1979). The effect of greasing the impaction substrates on particle bounce was also tested by operating impactors with grease for some tests and without grease for others. The investigators assumed that the true particle size distribution was lognormal and adjusted their experimental data to fit this form. The data generated by the dichotomous samplers was corrected based on findings by Wedding (1980) which indicate that the collection efficiency of the sampler depends on wind speed. The particle size measurements taken using microscopy were in terms of physical diameters. The investigators assumed an average particle density of 2.5 g/cm^3 and followed a procedure for converting these into aerodynamic diameters (U. S. Environmental Protection Agency, 1978).

Test Sites--Tests were conducted at three unspecified mines, one in each of the following Western coal fields: Powder River Basin, Fort Union, and San Juan River. These three fields were targeted for the study because they produce high volumes of strip-mined coal and because they are diverse in character. The investigator's intent with this selection was to maximize the representativeness of the findings while satisfying budget and time constraints.

Parameters and Equipment--Table 2.19 lists the parameters measured and the corresponding equipment employed during the field investigation of haul road emissions.

TABLE 2.19. PARAMETERS MEASURED AND EQUIPMENT EMPLOYED

Parameters	Equipment
Surface silt content	Oven, sieves, scales
Vehicle speed	Radar gun or timer
Vehicle weight	Truck scale
Total surface loading	Broom, scales
Surface moisture content	Oven, scales
Number of wheels	Direct observation
Solar intensity	Pyranograph
Atmospheric pressure	Barometer
Cloud cover	Direct observation
Temperature	Thermometer
Humidity	Sling psychrometer
Exposure (downwind)	Exposure profiler
Wind speed (upwind)	Continuous wind monitor
Wind speed (downwind)	Warm wire anemometers
Concentration of particles < 15 μm diameter (upwind and downwind)	Dichotomous sampler
Concentration of particles < 2.5 μm diameter (upwind and downwind)	Dichotomous sampler
Concentration of total suspended particulates (upwind and downwind)	Standard hi-vol
Particle size distribution (downwind)	1) Hi-vol with cascade impactor with cyclone preseparator 2) Dichotomous samplers 3) Optical microscope and millipore filters
Dust deposition	Dustfall buckets

Wind speed was monitored at two heights, and a logarithmic vertical distribution of the wind speed was assumed. The investigators noted that although dust exposure could be measured directly only with the profiler, it could also be determined using dichotomous samplers by multiplying concentration, wind speed, and sampling time.

Equipment Configuration--

Exposure Profiling Only--For all tests except those in which dispersion modeling and profiling techniques were used simultaneously, the following equipment was placed between five and ten meters downwind from the road: exposure profiler with sampling heads at 1.5, 3.0, 4.5, and 6 meters above the ground; a standard hi-vol sampler and a hi-vol fitted with a cascade impactor and cyclone preseparator, both having inlets 2.5 meters high; two dichotomous samplers with intakes 1.5 and 4.5 meters above the ground; two dustfall buckets at a height of 0.75 meters; and two warm wire anemometers at heights of 1.5 and 4.5 meters. The height of these instruments was reduced for cases in which the dust plume height was relatively low (e.g. for light- and medium-duty trucks). Pairs of dustfall buckets were also collocated 0.75 meters above the ground at 20 and 50 meters downwind, permitting measurement of deposition rates.

The following equipment was set up five meters upwind from the road: one dichotomous sampler 2.5 meters above the ground; one standard hi-vol sampler, also at a height of 2.5 meters; two dustfall buckets 0.75 meters above the ground; and one continuous wind monitor 4 meters high.

Exposure Profiling and Upwind-Downwind--The equipment configuration for those tests in which both exposure profiling and upwind-downwind modeling were used was very complex. Downwind air sampling was conducted primarily at three downwind distances: 5, 20, and 50 meters. Profiling towers were set up at each of these stations so plume mass depletion could be measured in addition to simple exposure. The closest tower consisted of four sampling heads at heights ranging from 1.5 to 6 meters. The towers at 20 and 30 meters downwind both had five sampling heads, with the highest heads at 9 and 12 meters, respectively. This was necessary due to the increased dispersion of the plume over longer distances. A vertical array of dichotomous samplers was also set up five meters downwind. The sampling heights matched those of the nearby exposure profiler. Two single dichotomous samplers were also set up on either side of the profiling towers at each of the three downwind monitoring distances. They had intakes 2.5 meters above the ground.

Two standard high volume samplers (all sampling at a height of 2.5 meters) were set up at each of the downwind distances: 5, 20, 50, and 100 meters. A third standard hi-vol was used five meters downwind. A total of three hi-vol cascade impactors were used, two were placed five meters from the road with intakes 1.5 and 4.5 meters above the ground, and one 20 meters from the road with its intake 2.5

meters high. Dustfall buckets were placed in pairs at each of the three downwind distances such that their sampling height was 0.75 meters.

Sampling Runs--Of a total of 29 sampling runs in which uncontrolled road emissions were measured, 19 had traffic dominated by haul trucks, and 10 were dominated by light- and medium-duty trucks. The number of vehicle passes per run was generally between 20 and 150. Exposure profiling was used for all sampling runs; for five of the haul truck runs, the upwind-downwind method was also used. Profile and hi-vol samplers were generally operated between 45 minutes and 1½ hours for each run.

Quality Assurance--This study included a thorough quality assurance program, which was subject to evaluation by a technical review group (including the two EPA project officers, representatives of the Bureau of Land Management, the Bureau of Mines, and the mining industry). Profilers, hi-vols, impactors, and dichotomous samplers were calibrated on a regular basis. Sampling media were conditioned under constant temperature and humidity prior to sampling. Seven percent of tare and final filter weights were audited. For every ten regularly processed filters and substrates, at least one was processed as a blank.

Regarding sampling isokineticity for the profiler, sampling intakes were reoriented if the 15 minute average wind direction changed by more than 30°, and the sampling rate was corrected when the 15 minute average wind speed changed by more than 20%.

The investigators recorded the total number of vehicle passes as well as the number of "bad" passes, in which the wind direction reversed and upwind filter weights were affected by road emissions. Data from one run had to be discarded because the number of bad passes far outweighed the number of good passes. Several other sampling runs had a significant percentage of bad passes. Most runs had no bad passes. For runs in which bad passes occurred, the upwind dust concentration was estimated by the average of the concentrations of the previous and following sampling runs. Bad passes were not counted when calculating the emission factor (i.e. when dividing the integrated exposure by the number of vehicle passes).

Despite the attention given to normal quality assurance practices in field data collection, the overall level of quality assurance for this study is compromised by the paucity of published raw field data. For instance, measured exposures at the various profiling heights were not reported. Because of this omission, the computations made by the investigators cannot be repeated and verified.

Findings--The emission factors measured for the uncontrolled sampling runs are presented in Table 2.20. Except where otherwise noted, data were collected using exposure profiling. The total particulate emission factor is based on the catch of each sampling head in the exposure profiler. The factor for particles smaller than 30 µm is based on an extrapolation of the fractions smaller than 15 µm and 2.5 µm, which were measured using the dichotomous sampler.

The particle size distribution data collected using the dichotomous sampler was found to be the most consistent of the three methods. The investigators cited three other reasons for using the dichotomous sampler data in calculating emission factors for the different particle size fractions: convenience of equipment, endorsement of dichotomous samplers by the EPA, and the greater availability of dichotomous sampler data from this particular equipment configuration.

Regression analysis was used to determine if the method of emissions measurement (profiling versus upwind-downwind modeling) is a significant predictor of the emission factor. Profiling was found to produce statistically higher factors for both total suspended particulates and inhalable particulates (< 15 µm aerodynamic diameter). The average differences were 24% and 52%, respectively.

Multiple regression analysis was used to develop predictive equations relating emission factors to various parameters. The estimated relationships for the different traffic types are shown in Table 2.21.

Publication--This study was conducted and documented under contract with the EPA Office of Air Quality Planning And Standards, Research Triangle Park, North Carolina, and the EPA Industrial Environmental Research Laboratory, Cincinnati, Ohio. It was published as Publication No. EPA-600/7-84-048 in March 1984.

TABLE 2.20. MEASURED EMISSION FACTORS

	-------Emission Factors (lb/veh-mile)-------			
Run	Total	d^a < 30 μm	d^a < 15 μm	d^a < 2.5 μm
J-9	51.4	15.2	7.4	0.41
J-9[b]		14.1		
J-10	54.1	33.0	17.7	0.54
J-10[b]		12.0		
J-11	67.2	30.2	15.4	0.69
J-12	16.5	12.9	7.9	0.26
J-12[b]		3.6		
J-20	36.6	12.3	5.4	0.14
J-20[b]		6.4		
J-21	76.4	14.2	6.0	0.21
J-21[b]		15.0		
K-1	23.2	8.2	3.3	0.05
K-6	8.0	2.2	1.1	0.07
K-7	4.6	3.9	2.5	0.07
J-13	7.0	5.5	4.5	0.50
J-18	9.5	8.2	6.6	1.5
J-19	7.1	6.7	5.2	0.22
K-2	5.0	0.64	0.33	0.03
K-3	3.1	0.76	0.39	0.03
K-4	3.0	0.60	0.34	0.04
K-5	2.7	0.93	0.52	0.05
P-11	12.8	8.5	4.5	0.10
P-12	12.8	9.0	5.1	0.13
P-13	9.7	7.8	4.1	0.15

a) aerodynamic particle diameter
b) upwind-downwind test for comparison

TABLE 2.21. EQUATIONS FOR PREDICTING MEDIAN EMISSION FACTORS[a]

Traffic Type	TSP (lb/veh-mile)	IP (lb/veh-mile)
Light- and Medium-Duty Vehicles	$5.79/M^{4.0}$	$3.72/M^{4.3}$
Haul Trucks	$0.0067\ w^{3.4}L^{0.2}$	$0.0051\ w^{3.5}$

a) variable definitions:
M = moisture content, %; w = number of wheels; L = silt loading, g/m^2

Study 12-- Pyle and McCain. Critical Review of Open Source Particulate Emission Measurements. Part II - Field Comparison. EPA-600/2-86-072. 1986.

Methodology--This document describes and evaluates a side-by-side field comparison of five organizations measuring emissions from vehicle travel on an unpaved road. The organizations were Energy & Environmental Management, Inc. (EEM), Midwest Research Institute (MRI), PEI Associates, Inc. (PEI), TRC Environmental Consultants, Inc. (TRC), and United States Steel Corporation (USS). All five organizations used the same basic methodology: exposure profiling. However, each organization chose its own sampling equipment, equipment configuration, and analytical procedures. Consequently, each organization's implementation of profiling differed in some ways from the others. Therefore, this study provided the opportunity for evaluation of the ease of implementation of the various procedures, their accuracy, and the comparability of the results.

Each testing position was equipped with a standard high-volume sampler set up three meters from the road's edge. These samplers were intended to serve as baseline monitors of conditions at each site and, therefore, did not rotate through the testing positions with the teams and the rest of the equipment.

Exposure and particle size distribution were measured using the specific equipment and procedures explained below for each group. Some of the procedures used were common to all groups. Every group recorded measurements for wind speed; temperature; silt content (the percent of road surface material less than 75 µm in diameter); and the number, type, and speed of the passing vehicles. For all teams, sampling runs were considered valid only when the ratio of mean sample inlet velocity to mean wind speed fell between 0.8 and 1.3 (inclusive).

Test Site--The test site was a paved slag haul road covered, for the purpose of this study, with 5 to 10 centimeters of aggregate. This aggregate was composed of clay, iron ore, and boiler ash, yielding an average silt content of 10%. The site was in a U.S. Steel facility in Gary, Indiana, about 50 meters south of Lake Michigan. Five test positions were established on each side of the road. Traffic on the road was a mixture of service vehicles and dump trucks.

Individual Group Implementation and Findings--

Energy & Environmental Management--EEM used a vertical array of 5 directional high-volume sampling heads on the downwind side of the road to measure exposure. Samplers were positioned at 2, 4, 6, 8, and 10 meters height. Background exposure was measured using a tower with three directional hi-vols at 2, 4, and 6 meters height. Filters for both profilers were vertically oriented.

Wind speed was measured at one meter above the ground. EEM assumed a uniform vertical distribution of wind speed; the intake velocity of each sampler on the profilers was set to match the wind speed measured prior to commencement of sampling. The sampling velocity was not adjusted during individual runs. Sampler intakes were kept within 20 degrees of pointing directly into the wind.

Particle size distribution in the dust plume was estimated using computer controlled scanning electron microscopy (CCSEM). Particulates from selected portions of profiler filters are removed and recollected on SEM sample stubs for analysis using a scanning electron microscope and an automated image analysis system. This system estimates a physical diameter - weight distribution curve for the sample. Portions of the specific procedures followed in using CCSEM were considered proprietary by the investigators and, therefore, were unavailable for review.

In addition to those parameters collected by all parties, as described above, EEM also measured the percent of road surface material less than 45 μm in diameter and the percent between 45 and 75 μm in diameter. Data was also collected on wind direction, humidity, and soil moisture. The equipment and procedures for measuring these parameters were not documented in the report.

EEM's exposure data and calculated emission factors are presented in Table 2.22.

Midwest Research Institute--MRI used a vertical array of 5 directional high-volume sampling heads positioned at 1.5, 3, 4.5, 6, and 7.5 meters above the ground to measure exposure downwind of the test road. Background exposure was measured using an array of 2 directional high-volume samplers at heights of 3 and 6 meters. Filters on both profilers were oriented horizontally above the intakes.

Wind speed was measured at heights of 1.5 and 4.5 meters. A logarithmic distribution of vertical wind speed was assumed in setting each of the sampler intake velocities equal to the wind speed. Intake velocities were adjusted every 10 minutes if measured wind speed changed substantially. The sampler intakes were kept within 20 degrees of the wind direction.

For measuring the size distribution of the particles in the dust plume, MRI used a high-volume sampler equipped with a cascade impactor and a cyclone. Two of these samplers were located beside the downwind profiling tower at 1.5 and 4.5 meters above the ground.

MRI's exposure data and calculated emission factors are presented in Table 2.23.

<u>PEI Associates, Inc.</u>--PEI used an array of 4 directional high-volume samplers to measure both particle size distribution and total exposure downwind from the road. Samplers were placed at heights of 1, 2.5, 5, and 9 meters. Filters were vertically oriented. For tests 1-7 and 11, the samplers on the profiler tower were fitted with a series of stacked filters designed to provide cut diameters of 30 and 2.5 μm. This equipment configuration was used to estimate particle size distribution and emission factors for particles less than 30 μm and for particles less than 2.5 μm. For tests 8-10 the stacked filters were removed, allowing measurement of total exposure and an emission factor for total particulates. An identical profiler was used to measured upwind, background exposure and particle size distribution.

Wind speed was measured at a height of 3 meters. The vertical change in wind speed was estimated by a power function, and the intake velocity of each profile sampler was set accordingly. Sampler inlets faced within 15 degrees of the wind direction.

In addition to the standard parameters, PEI also measured and recorded humidity and soil moisture.

PEI's exposure data and calculated emission factors are presented in Table 2.24.

<u>TRC Environmental Consultants, Inc.</u>--TRC used a vertical array of 5 directional high-volume samplers to measure exposure downwind from the road. Sampling intakes were set at heights of 1, 3, 5, 7, and 9 meters. Exposure upwind from the road was measured using a single directional high-volume sampler at 2 meters above the ground. Filters for the upwind and downwind samplers were oriented horizontally below the intakes.

Each sampler head was fitted with a thermal anemometer, providing continuous monitoring and automatic adjustment of intake velocity to match the wind velocity. Thus, there was no need to make assumptions regarding changes in wind speed with height. Sampler intakes faced within 30 degrees of the wind direction.

Like Energy & Environmental Management, Inc., TRC used computer controlled scanning electron microscopy to measure the particle size distribution of the filter samples.

TRC's exposure data and emission factors are presented in Table 2.25.

United States Steel Corporation--USS used a vertical array of 4 directional high-volume samplers to measure exposure downwind from the road. The samplers were positioned at 2, 4.5, 6.5, and 9 meters height. Upwind exposure was measured using a single, directional high-volume sampler 2 meters above the ground. Filters were oriented horizontally below the intakes.

Wind speed was monitored at each sampling head using a thermal anemometer, allowing continuous, automatic adjustment of the intake velocity to match the wind velocity. Therefore, assumptions regarding changes in wind speed with height were not necessary. Sampling intakes faced no more than 30 degrees from the wind direction. USS documented wind direction throughout the test runs.

Computer controlled scanning electron microscopy was used to measure the particle size distribution of the dust plume.

USS's exposure data and calculated emission factors are presented in Table 2.26.

Sampling Runs--Eleven sampling runs were conducted in which all five organizations simultaneously collected samples. The number of vehicle passes per sampling run averaged about 45. If one vehicle pass is defined as the passage of a vehicle in front of a single testing position, then a total of 2,321 vehicle passes were logged during this study. Sampling duration was not recorded.

Quality Assurance--Personnel from the Southern Research Institute (SoRI) supervised the field experiment and reviewed the analytical procedures which were documented in reports by each organization.

The organizations rotated through the test positions between sampling runs to reduce the possibility of bias arising from variations in the physical characteristics of the road.

SoRI used Lundgren cascade impactors as a basis for comparing the particle classifying devices used by the five organizations. For several tests the Lundgren impactors were collocated with these other samplers (i.e. MRI's cyclone and impactor).

Quality assurance practices implemented by each team were generally thorough and well documented. All groups calibrated their profiler heads before the field study began using various methods. TRC used a wind tunnel. Some form of audit of the filter weights was performed by each group. The notable example in this instance was MRI, who audited 10% of the tared filters and 100 % of the exposed filters. MRI and EEM also processed blank samples.

Findings--Findings of the individual organizations, in terms of emission factors for total particulates, are shown in Tables 2.22-2.26 at the end of the summary of this study. The SoRI investigators, having supervised the field study and reviewed the procedures and findings of the five organizations, came to the following conclusions concerning implementation of exposure profiling:

- Dust exposure is often significant as high as 9 meters above the ground; therefore, in future studies sampler intakes should be positioned at this height or higher.

- Dust exposure peaks at 1.5 to 2 meters above the ground; a sampler intake should be positioned at this level.

- Sampling isokineticity can be optimized using velocity sensors at each intake and a "servo system," enabling continuous adjustment of the intake velocity to match wind speed.

- The profiling systems used by the five organizations produced comparable results for total emission factors.
- The different techniques for measuring particle size distribution in the dust plume yield dissimilar results in terms of distribution curves and size-specific emission factors.

- The cyclone/impactor system, which MRI utilized, is recommended over CCSEM and the stacked filter method for measuring particle size distribution in the dust plume. (SoRI recommended several minor changes in the way MRI implemented the system.)

- Differences in the methods of graphical integration of exposure versus height are unimportant relative to other variations in implementation of the methodology.

Publication--This comparative review was prepared for the Technical Support Office of the Environmental Protection Agency, Air and Energy Engineering Research Laboratory, Research Triangle Park, North Carolina. It was published in 1986 as Publication No. EPA-600/2-86-072. It is Part II of a two-part study comparing the commonly used methods of measuring emissions and estimating emission factors for vehicle travel on unpaved roads.

Data Tables--

TABLE 2.22 EEM'S EXPOSURE DATA AND CALCULATED EMISSION FACTORS

EEM			
Run	Sampling Height (m)	Exposure mg/cm^2	Total Particulate Emission Factor (kg/VKT)
1	2	7.61	10.24
	4	5.15	
	6	1.98	
	8	0.16	
	9	0.35	
2	2	3.37	6.52
	4	2.89	
	6	1.10	
	8	0.46	
	9	0.05	
3	2	8.48	11.30
	4	4.42	
	6	2.35	
	8	0.93	
	9	0.21	
4	2	7.75	11.20
	4	6.57	
	6	2.77	
	8	1.58	
	9	0.58	
5	2	3.35	5.00
	4	2.20	
	6	1.44	
	8	0.71	
	9	0.43	
6	2	3.72	5.49
	4	3.15	
	6	2.15	
	8	1.06	
	9	0.45	

(continued)

TABLE 2.22 (continued)

EEM			
Run	Sampling Height (m)	Exposure mg/cm^2	Total Particulate Emission Factor (kg/VKT)
7	2	7.76	11.58
	4	5.71	
	6	2.78	
	8	1.46	
	9	0.88	
8	2	8.39	7.46
	4	5.89	
	6	2.54	
	8	0.47	
	9	0.03	
9	2	5.63	5.71
	4	3.05	
	6	1.35	
	8	0.25	
	9	0.14	
10	2	7.88	9.06
	4	6.39	
	6	2.95	
	8	0.67	
	9	0.08	
11	2	5.86	8.16
	4	3.69	
	6	2.06	
	8	0.64	
	9	0.08	

TABLE 2.23. MRI'S EXPOSURE DATA AND CALCULATED EMISSION FACTORS

MRI			
Run	Sampling Height (m)	Exposure mg/cm²	Total Particulate Emission Factor (kg/VKT)
1	1.5	8.12	9.33
	3	6.19	
	4.5	4.25	
	6	1.45	
	7.5	0.30	
2	1.5	3.22	4.26
	3	2.26	
	4.5	1.14	
	6	0.39	
	7.5	0.06	
3	1.5	9.89	12.20
	3	9.88	
	4.5	5.23	
	6	(3.1)	
	7.5	1.01	
4	1.5	13.50	15.90
	3	11.50	
	4.5	6.52	
	6	3.57	
	7.5	1.50	
5	1.5	0.60	2.54
	3	2.15	
	4.5	1.21	
	6	0.78	
	7.5	1.14	
6	1.5	5.08	11.50
	3	6.49	
	4.5	6.00	
	6	4.04	
	7.5	3.46	

(continued)

TABLE 2.23 (continued)

MRI			
Run	Sampling Height (m)	Exposure mg/cm²	Total Particulate Emission Factor (kg/VKT)
7	1.5	2.35	7.16
	3	5.77	
	4.5	3.56	
	6	2.91	
	7.5	2.33	
8	1.5	8.89	6.26
	3	7.73	
	4.5	4.44	
	6	1.73	
	7.5	0.55	
9	1.5	6.99	6.06
	3	5.88	
	4.5	3.58	
	6	2.50	
	7.5	0.40	
10	1.5	6.99	6.88
	3	5.88	
	4.5	3:78	
	6	2.50	
	7.5	0.40	
11	1.5	5.32	8.68
	3	6.52	
	4.5	5.19	
	6	2.40	
	7.5	0.74	

TABLE 2.24. PEI'S EXPOSURE DATA AND CALCULATED EMISSION FACTORS

PEI[a]			
Run	Sampling Height (m)	Exposure mg/cm^2	Total Particulate Emission Factor (kg/VKT)
8	1	10.40	7.81
	2.5	3.36	
	5	4.46	
	9	2.41	
9	1	5.23	4.16
	2.5	3.61	
	5	2.78	
	9	0.81	
10	1	5.23	5.56
	2.5	5.19	
	5	2.53	
	9	1.01	

a) PEI measured total particulate emissions only for these three tests.

TABLE 2.25. TRC'S EXPOSURE DATA AND CALCULATED EMISSION FACTORS

TRC			
Run	Sampling Height (m)	Exposure mg/cm^2	Total Particulate Emission Factor (kg/VKT)
1	1	5.21	7.11
	3	5.10	
	5	3.31	
	7	0.64	
	9	-0.10	
2	1	2.99	4.29
	3	2.06	
	5	0.95	
	7	0.33	
	9	-0.05	
3	1	6.02	6.67
	3	4.53	
	5	2.53	
	7	0.43	
	9	-0.06	
4	1	8.18	8.80
	3	4.50	
	5	3.93	
	7	1.28	
	9	0.21	
5	1	4.49	5.90
	3	3.92	
	5	2.56	
	7	1.02	
	9	0.34	
6	1	4.22	4.40
	3	3.11	
	5	2.19	
	7	0.57	
	9	-0.32	

(continued)

TABLE 2.25 (continued)

TRC			
Run	Sampling Height (m)	Exposure mg/cm^2	Total Particulate Emission Factor (kg/VKT)
7	1	4.18	5.85
	3	3.29	
	5	2.20	
	7	1.40	
	9	0.62	
8	1	5.50	4.54
	3	4.40	
	5	2.74	
	7	0.98	
	9	0.15	
9	1	3.57	4.06
	3	3.42	
	5	2.49	
	7	0.79	
	9	0.10	
10	1	5.45	5.65
	3	4.16	
	5	2.82	
	7	1.06	
	9	0.42	
11	1	4.78	5.74
	3	3.72	
	5	1.95	
	7	0.83	
	9	0.11	

TABLE 2.26. USS'S EXPOSURE DATA AND CALCULATED EMISSION FACTORS

USS			
Run	Sampling Height (m)	Exposure mg/cm^2	Total Particulate Emission Factor (kg/VKT)
1	2	6.35	8.56
	4.5	4.95	
	6.5	1.11	
	9	0.29	
2	2	3.15	5.29
	4.5	1.70	
	6.5	0.43	
	9	0.11	
3	2	6.88	9.20
	4.5	5.01	
	6.5	1.24	
	9	0.41	
4	2	11.74	15.92
	4.5	7.93	
	6.5	2.45	
	9	0.59	
5	2	3.51	4.84
	4.5	2.08	
	6.5	1.09	
	9	0.42	
6	2	5.67	7.79
	4.5	4.32	
	6.5	2.04	
	9	1.10	
7	2	7.49	12.28
	4.5	5.03	
	6.5	2.97	
	9	1.89	

(continued)

TABLE 2.26. (continued)

USS			
Run	**Sampling Height (m)**	**Exposure mg/cm²**	**Total Particulate Emission Factor (kg/VKT)**
8	2	6.99	6.59
	4.5	5.21	
	6.5	2.03	
	9	0.74	
9	2	3.53	4.19
	4.5	2.74	
	6.5	1.07	
	9	0.22	
10	2	6.69	8.22
	4.5	5.34	
	6.5	2.65	
	9	0.72	
11	2	7.14	9.61
	4.5	4.35	
	6.5	1.24	
	9	0.39	

Studies of Secondary Importance

Study 13-- Roberts. The Measurement, Cost and Control of Air Pollution from Unpaved Roads and Parking Lots in Seattle's Duwamish Valley. 1973.

The dust plume created by vehicle travel on a gravel road was sampled using a towed rack to which a cascade impactor was attached. The rack was designed as a vertical grid oriented perpendicular to the car's path; the impactor was rotated among the various positions between tests so that, after a series of tests, the average concentration of dust in the plume could be determined. In order to derive an emission factor in lb/veh-mile, the average plume concentration was multiplied by the volume of air into which it was emitted. This volume was estimated in the following manner. First, the area of the plume behind the car was estimated by towing a grid/rack of open impaction plates and examining the dust pattern on the plates. Second, this area -- 70 square feet -- was multiplied by 5,280 feet (1 mile) to obtain the air volume (36,960 ft^3) into which the dust was emitted after 1 mile of travel.

The impactor samples were also analyzed to determine the particle size distribution of the plume. This particle size breakdown was then used to estimate emission factors for various particle size categories based on the measured total particulate emission factors.

Sample collection, handling, and analysis procedures were not documented in detail. For example, specific procedures for handling the impactor plates were not documented. No mention was made of problems with particle bounce in the impactor; this problem has been documented by at least two other researchers (Cowherd et al., 1974 and McCaldin, 1977).

The distance between the vehicle and the towed rack was not documented. The investigator noted that it was difficult to certify that sampling was conducted under isokinetic conditions, due to turbulence in the wake behind the vehicle and changes in wind direction and speed.

Seventeen sampling runs were conducted at 20 mph on a gravel road in the Duwamish Valley in Seattle. Roberts noted that the test road had been sprayed with oil two years before, and that emissions from the road were still effectively suppressed at the time of the study. Consequently, the findings of this study are secondary in their importance to the development of emission factor equations.

For these 17 runs, the average concentration of total particulates in the air sampled by the cascade impactor was .133 grains/ft^3. Following the procedure explained above, the emission factor was calculated at 7 lb/veh-mile.

Limited testing was also conducted with vehicle speeds of 10 and 30 mph. The cascade impactor collected dust samples at only two grid positions on the sampling rack (as compared to 6 positions at 20 mph). The following proportional relationship was assumed in estimating an emission factor for the 10 mph tests:

$$D_2/D_1 = X/Y$$

where

D_2 = average concentration at grid sampling point D at 20 mph
D_2 = average concentration at grid sampling point D at 10 mph
X = total average (of all grid sampling points) at 20 mph
Y = total average (of all grid sampling points) at 10 mph

The same procedure was used to estimate an emission factor for 30 mph.

The calculated factors for the various speeds are shown below in Table 2.27. Roberts also presented emission factors for particles smaller than 10 µm and for particles smaller than 2 µm in diameter, though he did not explain how the fraction of the total particulate sample consisting of particles smaller than 10 µm was determined; i.e. he did not indicate whether the cascade impactor provided a cut point at that size.

TABLE 2.27. EMISSION FACTORS FOR VARIOUS SPEEDS

	Emission Factor (lb/veh-mile)		
Speed (mph)	Total Particulates	PM_{10}	d[a] < 2 µm
10	3.5	.58	.10
20	7.0	1.9	.24
30	22.2	9.0	.77
20	7.3	2.0	nd

a) particle diameter

This study was conducted and documented as partial fulfillment of requirements for a master's degree in engineering at the University of Washington. Portions of this work and some follow-up studies were published in the Journal of the Air Pollution Control Association in 1975.

Study 14-- Handy et al. "Unpaved Roads as Sources for Fugitive Dust." Transportation Research News. 1975.

Deposition of dust from ten unpaved roads was estimated using dustfall buckets mounted one meter above the ground in lines perpendicular to the road. The buckets were half filled with water to prevent resuspension of dust deposited in the bucket. Buckets were left in the field for 3 to 4 weeks before being sealed and brought to the laboratory for analysis. Contaminants such as insects and chaff were removed by hand before samples were dried and weighed. Particle size analysis was performed using sieves. Average deposition was plotted against distance from the road. Total dust deposited was calculated by integrating the area under this curve.

The dustfall buckets provided deposition data in terms of kg/hectare-month. The total dust mass deposited per road kilometer was calculated by integrating this with respect to distance from the road. Extrapolations were made from this field data to estimate kg/km/vpd/year, based on the estimated number of vehicles per day (vpd) traveling the road.

Deposited road dust was found to fall into two categories: roadside and distributed. The distinction is based on the change in the differential mass deposited as distance from the road is increased. The change occurs at about 10 meters from the centerline, roughly the same as the right-of-way for most secondary roads.

Total deposited dust ranged from 70 kg/km/month for a chemically treated surface to 56,640 kg/km/month for one untreated road. These numbers translated into 3.3 kg/km/vpd/year for the best road and 2185 kg/km/vpd/year for the worst.

The authors implied an assumption that dust deposition as measured with the dustfall buckets minus background deposition equals dust emitted from the road. Dust emission rates were not directly measured in this study. Traffic volume was estimated from a secondary data source, rather than measured precisely.

Study 15-- Dyck and Stukel, "Fugitive Dust Emissions from Trucks on Unpaved Roads." Environmental Science & Technology. 1976.

The upwind-downwind method was used to estimate emission factors for a truck traveling on unpaved roads in a construction access area. One upwind hi-vol sampler, 50 feet from the road, and four downwind hi-vol samplers, ranging from 50 to 250 feet from the road, were used to measure the road's contribution to dust concentration. This data was applied to a modification of the model for a continuously emitting, infinite line sources found in the Workbook of Atmospheric Dispersion Estimates (Turner, 1970) to yield estimated emission factors. The truck's weight and speed were varied by the investigators, as was the road surface type. Testing was conducted over several days. On each day, the choice for a test road was dictated by the prevailing wind direction. Each test lasted about one hour.

Measured emission factors for various combinations of vehicle weight, percent silt on the road surface, and road type (silty-sand and clay) were tabulated. The investigators used multiple linear regression to develop an equation for estimating the emission factor as a function of the experimental variables:

$$E = 5.286 - 3.599(R) + 0.00271(V)(W)(S)$$

subject to

$$10 \leq V \leq 25$$

where

E = emission factor, lb/veh-mile
R = road type, silty-sand or clay
V = velocity, mph
W = weight, thousands of pounds

The investigators did not document the specific analytic procedures followed in calculating the percent silt in the road surface material, conditioning and weighing filter samples, or measuring the moisture content of the road surface. Data on measured concentrations were not published.

The emission factor equation published in this article was an incorrect adaptation of the model cited in Turner, 1970. The model for a continuously emitting, infinite line source as it is presented by Turner (1970) and by the present study is

$$C(x,y,O,H) = \frac{2q}{\sin\phi \sqrt{2\pi}\, \sigma_z U} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

The investigators incorrectly solved this equation for source strength, q, as follows:

$$q = \frac{C \sin\phi \sqrt{2\pi}\ \sigma_z U}{2} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

The 'exp' term should be in the denominator in this equation. Because field data were not presented, it was not possible to determine whether this was a typographical error or a misapplication of the model.

Environmental Science & Technology (Volume 10, Number 10, October 1976, pp. 1046-48) is apparently the only outlet through which this study was published.

Study 16-- Cuscino et al. Fugitive Dust from Vehicles Travelling on Unpaved Roads. 1977.

The investigator proposed a refinement of the dispersion model for a continuously emitting infinite line source (Turner, 1970) to allow for dust deposition between the source and the location at which concentration is measured. A parameter representing the fraction of particles which touch the ground that are not deposited was added to the equation. This parameter is believed to be an unknown function of downwind distance, atmospheric conditions, and particle fall velocity.

Field experiments were conducted to determine the accuracy of the new model. Dust concentrations at several heights and distances downwind from an unpaved road on which vehicles traveled were measured using open-faced filters. Dust emissions were not measured. The source strength was taken from Roberts' (1973) estimates of emission factors for unpaved road. Measured concentrations were compared graphically with predicted concentrations.

Predicted concentrations were within a factor of 2 of the experimentally determined concentrations for most of the measurements, and within a factor of 3 for the remainder. No comparison was made between the accuracy of this proposed model and the accuracy of the standard model in the Workbook of Atmospheric Dispersion Estimates (1970).

This work was published in 1977 by the USDA Forest Service as General Technical Report NE-25, ODC907.3: 187: 111: 273: 425.1.

Study 17-- McCaldin. Fugitive Dust Study for Pima Country Air Quality Control District, Tucson, Arizona. 1977. Data on upwind and downwind dust concentrations and on mean wind speed and direction were collected and applied to a dispersion model to estimate an emission factor for vehicle travel on unpaved roads.

Five pre-existing dirt roads in Pima County, Arizona were the test sites for this study.

Upwind and downwind concentrations were measured using standard hi-vol samplers and "standard gravimetric methods." Sierra Impactors were used to measure particle size distribution. Vehicle speed was controlled by the investigator for most of the passes. The speed of the remainder were estimated visually. The number of passes was likewise controlled mostly by the investigator. Composite samples of road surface material were analyzed for percent silt using a 200 mesh screen. The Belfort Model 443 anemometer, held at 2 meters above the ground, was used to measure wind speed and direction.

Normally, two standard hi-vol samplers were located 50 feet from the center of the road, one on the upwind side and one on the downwind side. For some early tests two side-by-side hi-vols were placed at 50 feet upwind to determine the random variation in upwind concentration, and hi-vols were run at heights of 1, 2, 3, and 3.6 meters 50 feet on the downwind side to ascertain the plume's vertical concentration distribution. The investigator did not specify whether these downwind hi-vols were operated simultaneously in a vertical array. The sampling duration was between ten minutes and five hours for each run. For some of the final tests, Sierra Impactors were set up at the upwind station and at 50, 150, and 250 feet from the center of the road on the downwind side. They were operated for about four hours each test. The heights of the samplers were not specified.

Data were collected on 46 sampling runs. Raw data for unpaved road emissions were not provided with this report.

Detailed documentation of sample collection and handling procedures was not provided. Data reduction could not be verified, as raw data was not included in the report. However, a sample calculation of an emission factor from concentration and wind data was provided.

Collocated hi-vol samples were collected, as noted above, but a comparison of the measured concentrations was not provided. Other quality assurance measures such as processing of blank samples and calibration of sampling equipment were not documented.

Emission rates were found to vary directly with percent silt and exponentially with vehicle speed. The average emission rate for vehicles traveling 30 mph on a road with a 10% silt surface was about 3 lb/veh-mile. An equation relating the emission rate to percent silt and vehicle speed was estimated from the collected data as follows:

$$E = (s)\ 0.035\ (S)^2$$

where

E	=	TSP emission factor, lb/veh-mile
s	=	mass percent silt
S	=	traffic speed, mph

Attempts to estimate particle size distribution failed due to particles bouncing down through the stages and dust settling on other surfaces within the hi-vol unit.

This study was conducted and documented under contract with the Pima County Air Quality Control District (AQCD). EPA Financial Grant Number A0090055-77-2, awarded to the Pima County AQCD, provided funding for the study.

Study 18-- Pinnick et al. "Dust Generated by Vehicular Traffic on Unpaved Roadways: Sizes and Infrared Extinction Characteristics." Aerosol Science and Technology. 1985.

This study is of secondary importance in the development of emission factors for vehicle travel on unpaved roads for three reasons: 1) no attempt was made to measure the total mass of dust emitted from the road or to measure emissions in mass/veh-mile 2) unusual vehicles (i.e. Army tanks) were used in the testing and 3) the test roads were constructed for this study and apparently did not reflect typical unpaved road conditions.

Two roads were constructed for this study of emissions from vehicle travel on unpaved roads. Army tanks, armored personnel carriers, and five-ton trucks served as the test vehicles. A battery of optical particle counters as well as a hi-vol sampler were used to estimate dust concentration in the plume of the passing vehicles.

A series of light-scattering aerosol counters and an optical array probe measured the mass and number of particles of several size categories, covering the range from sub-micron to 150 µm in diameter. These instruments measure particle size and number concentration. Considerable attention was given to calibrating these instruments.

The aerosol counters were mounted in a cage which was held up by a crane, enabling easy movement of the instruments from one side of the road to the other in the event of changes in wind direction. A series of hi-vol samplers were also stationed beside the road to measure aerosol "mass dosage."

Particle size distributions in the plume were found to be consistently bi-modal, with mass mean radii at 4 and 45 μm for roads made of sandy soil, and 10 μm and 35 μm for roads made of silty soil. For each test two separate concentrations were reported, one for each mode. Total measured concentrations ranged from .282 grams/m^3 for a single 5-ton truck, to 2.084 grams/m^3 for an armored personnel carrier.

VEHICLE TRAVEL ON PAVED ROADS

Introduction

The earliest field-measured emission factor for vehicle travel on paved roads was published in a master's thesis in 1973. Emissions from both paved and unpaved roads were measured in that study. The methodology, which consisted of towing a dust sampling rack behind a car to measure the plume concentration, was not utilized in any other field research.

From its beginning in this initial study, the historical development of field research on paved road emissions has closely paralleled that of unpaved roads. This, of course, is due to the similarity of the sources. Vehicle travel on paved roads has not received as much research attention as unpaved roads.

Most of the work falls into one of two methodological categories: upwind-downwind dispersion modeling or exposure profiling. For this particular source, the latter method has been utilized more than the former. The improvements in the exposure profiling methodology discussed in the section on unpaved roads are also true regarding its application to paved road emissions.

The reviews of field research reports are organized like those in the unpaved road section. Those reports which are of primary importance to the development of paved road emission factors are reviewed in chronological order. The review of each primary report consists of a summary description of the methodology, test site(s), measured parameters, equipment configuration, sampling extent, quality assurance, findings, and publication source.

Reports of secondary importance are briefly reviewed following the primary report reviews. Only two of the reviewed reports were considered secondary in importance: Roberts' 1973 master's thesis, and McCaldin's 1977 field study for the Pima County Air Quality Control District. Neither one of these documents provided raw field data or a detailed description of the field sampling or analysis procedures. However, because both of these studies involved the measurement of emissions from vehicle travel on paved roads, they were judged to be relevant to a review of the development of a paved road emission factor.

Studies of Primary Importance

Study 1-- Sehmel, G.A. "Particle Resuspension from an Asphalt Road Caused by Car and Truck Traffic." Atmospheric Environment. Vol. 7. 1973.

Methodology--This study employed a methodology similar to that used in the original Midwest Research Institute (MRI) profiling study (Cowherd et al., 1974). A known mass of zinc sulfide (ZnS) particles was applied to one lane of a paved road. Vehicles were driven either through or beside the ZnS at speeds ranging from 5 to 50 mph. Vertical filter arrays were set up downwind from the road to measure particle exposure at various heights and distances from the road. Point values for exposure were calculated as the mass of ZnS per unit filter area. Deposition was also measured. The fraction of ZnS emitted (or "resuspended") from the road was measured as the integrated exposure at a particular downwind distance plus the integrated deposition between the road and that distance. The following assumed mass balance relationship was the basis for this calculation:

$$ZnS_{lost} = ZnS_{exp} + ZnS_{dep}$$

where

ZnS_{lost} = mass of ZnS lost from road surface

ZnS_{exp} = mass of ZnS passing through a vertical plane parallel to the road at a given downwind distance

ZnS_{dep} = mass of ZnS deposited between the road and thesame downwind distance

The emitted mass was expressed as a fraction of the ZnS particle mass on the road prior to the vehicle pass. This fraction was called the resuspension rate.

Test Site--An asphalt road was used as the test site. The road did not appear dusty, but it was not cleaned prior to this experiment. The ZnS dust was screened such that particles applied to the road would be generally smaller than 25 µm. Cylindrical particle generators were used to apply about 0.5 gram of material per square foot of road.

Parameters and Equipment--The two principal parameters measured were exposure and deposition. The exposure samplers used were described not explicitly but by reference to previous published studies by the same author. He did note that the flow rate was controlled by a one cfm critical orifice, and that the exposed membrane filter had a diameter of 1.6 inches. Special real time samplers were also used to sample ZnS at 2 feet above the ground. These samplers enabled the investigator to know when sufficient mass was collected on the filters.

Deposition was measured using membrane filters mounted on filter holders; these were recessed into the ground so that the filter was approximately level with the surface.

Three-cup anemometers were used to measure wind speed at two heights; a vector vane indicated the wind direction. Friction velocity was calculated using the wind speed profile, as measured with the anemometers.

Equipment Configuration--Exposure samplers were attached to towers at heights of one, three, six, and eight feet. The towers were set up in a square matrix on the downwind side of the road. Three towers were placed 10 feet apart at each of 3 perpendicular distances downwind: 10, 20, and 30 feet. For a portion of the study, similar towers, with added filters at 11 feet above the ground, were also placed at the edge of the road.

Deposition samplers were placed at the base of every exposure sampler tower and at downwind distances of 3.5, 60, and 100 feet. Three samplers were placed at each of these distances, each sampler being 10 feet apart.

The anemometers were attached to a tower at heights of one and seven feet, and the vector vane was attached at three feet above the ground. The tower was positioned approximately three feet away from the road on the downwind side.

Sampling Runs--Twenty-one sampling runs were documented in this report. Vehicle type (car versus 3/4 ton truck), vehicle pass type (driving through the ZnS versus driving in the lane beside the ZnS) and speed were held constant during individual runs and varied between runs. The number of vehicle passes per sampling run was not documented.

Quality Assurance--Quality assurance for this study was poor. As the author noted, wind erosion losses from the road surface between tests were not measured; therefore, the actual mass of ZnS on the road prior to each test was not known with certainty. Consequently, calculated resuspension rates (mass suspended/source mass prior to test) could be lower than the true rate.

The description of equipment employed and procedures followed was very general. The interval at which vehicles passed the test area was not indicated. The manner in which filters were handled, transported, conditioned, and weighed was not discussed.

Exposure samples were not collected isokinetically, nor were any corrections made to the data to adjust them to isokinetic conditions.

The investigator's data reductions could not be checked because raw data, including measured exposures or deposited masses, were not published.

Findings--As noted above, emissions were expressed as a fraction of the total source mass prior to each run that was "resuspended" per vehicle pass; it was referred to as the "resuspension rate". This fraction was found to increase with vehicle speed. More particularly, it increased with the square of vehicle speed for those tests in which the car drove **through** the ZnS. On the first day of testing (on which the ZnS was originally applied), vehicle speeds through the ZnS ranged from 5 to 50 mph, and the corresponding resuspension rate ranged from 0.000019 to 0.0109. A similar relationship was apparent for those runs in which vehicles passed **by** the ZnS, except the resuspension rate was about an order of magnitude smaller.

Truck passes through the ZnS at five mph produced a higher resuspension rate than cars; at 50 mph, cars produced a higher resuspension rate than trucks. Sehmel suspected that this reversal might be due to inaccurate sampling.

The resuspension rate for the ZnS particles was found to decline over time. The investigator noted that this could be due to losses of the source ZnS due to wind erosion (as discussed under Quality Assurance).

Dust deposition between the road and any of the downwind sampling distances was maximized in tests with cars traveling at 15 mph.

Publication--This study was documented in an article in the journal Atmospheric Environment, Volume 7, pages 291-309.

Study 2-- Cowherd et al. Quantification of Dust Entrainment from Paved Roadways. EPA-450/3-77-027. 1977.

Methodology--Exposure profiling was used to measure emissions from paved roads. Standard high volume (hi-vol) samplers were also used to measure the decrease in suspended dust concentration with increasing distance downwind from the road. For one of the three sites at which emissions were measured, pulverized soil and gravel were applied to the road in measured amounts.

Test Sites-- Three test sites were selected in the Kansas City Area. Two of the sites were four-lane roads in areas known to have problems with particulate levels. Both of these sites were bordered by unpaved parking lots. One was surfaced with asphalt and the other was concrete. The third site, at which dust was artificially applied, was also a four-lane road. It was in an undeveloped portion of an industrial park, and was closed to public traffic during emissions testing. All three roads had curbs.

Parameters and Equipment--Table 2.28 lists the parameters measured and corresponding equipment employed in this study.

Equipment Configuration--Certain aspects of the equipment configuration varied between the test sites. The basic configuration, common to all three sites, was as follows. The exposure profiler consisted of four isokinetic sampling heads positioned on the tower at heights of one, two, three, and four meters. For all three sites the profiler was set back three to five meters from the edge of the road. Dustfall buckets were attached to the profile tower at heights of one and four meters. A hi-vol cascade impactor with its intake at 2 meters above the ground was placed beside the profiler. Except where otherwise noted, all standard hi-vol samplers had intake heights of two meters.

The placement of the standard hi-vol samplers, the wind instrument, and dustfall buckets varied from site to site and, in some instances, from one test to the next. These variations are explained below.

TABLE 2.28. MEASURED PARAMETERS AND CORRESPONDING EQUIPMENT

Parameter	Equipment
Wind speed	Unspecified
Wind direction	Unspecified
Cloud cover	Direct observation
Temperature	Sling psychrometer
Relative Humidity	Sling psychrometer
Pavement Type	Direct observation
Road surface condition	Direct observation
Road surface dust loading[a]	Vacuum, scales
Road surface dust texture[a]	Sieves, scales
Traffic mix	Direct observation
Traffic count	Automatic counters, direct observation
Plume exposure	Isokinetic hi-vol samplers (on profile tower)
Plume particle size distribution	Hi-vol cascade impactor, cutpoints at 0.4, 0.8, 1.8, and 3 μm
Downwind concentration	Standard hi-vol sampler
Background concentration	Standard hi-vol sampler
Sampling duration	Timer
Dust deposition	Dustfall buckets

a) Measured only for site at which dust was artificially applied

At the first site (37th Street), when the wind was from the south, background dust concentration was measured with a standard hi-vol sampler 19.9 meters from the upwind curb, with its intake at a height of 2 meters. Downwind concentration was sampled from beside the profiler at the same height. Wind speed and direction were measured on the downwind side 4.6 meters from the curb at a height of about 2.5 meters.

When the wind was from the north during sampling at the first site, upwind dust concentration was measured at five meters from the curb. Downwind concentration was measured with the standard hi-vol sampler beside the profiler. Wind speed and direction were measured at 0.5 to 1 meter downwind from the road and 4 meters above the ground.

At the test site in the industrial park (Stillwell site), the configuration did not depend on the wind direction. The upwind standard hi-vol sampler was positioned four meters from the curb.

Wind speed and direction were also measured here, at a height of 4 meters. During each test at this site, a standard hi-vol sampler and a dustfall bucket were placed 20 meters downwind. For some tests concentration and deposition were also measured at 10 or 50 meters downwind. Some tests at this site included dustfall measurements at one meter from the downwind curb.

At the third site (Fairfax Trafficway) dustfall measurements were not taken, except for the two buckets attached to the profile tower. Wind speed and direction were monitored at 7.3 meters downwind, 4 meters above the ground. Background concentration was sampled five meters upwind from the road. Downwind concentration was sampled at two positions: beside the profile tower at the usual height and 50 meters downwind at approximately 7 meters above the ground.

Sampling Runs--Emission factors were collected for 13 sampling runs: 3 at 37th Street, 8 at the industrial park, and 2 at Fairfax Trafficway. The industrial park was the site at which the dust on the road was artificially controlled. Pulverized topsoil was applied before the first four runs at this site, and gravel was used for the last four. At the 37th Street site the number of vehicle passes per 4½-hour run ranged from 1,880, to 2,440. At the industrial park each run lasted between 30 and 90 minutes and included from 100 to 600 passes. At Fairfax Trafficway one run had 3,791 passes, and the other had 4,146 passes. Both of these were four-hour sampling runs. A total of 16,331 vehicle passes were logged during this study.

Quality Assurance--The guidelines set forth in the "Reference Method for the Determination of Suspended Particulates in the Atmosphere (High Volume Method)" (1971) were followed in measuring dust concentrations with the standard hi-vol sampler. The "Standard Method for Collection and Analysis of Dustfall" (American Society of Testing and Materials) was followed in collecting dust deposition data. The methods of handling, transporting, and processing exposed filters were thoroughly documented; sample integrity was assured to the extent practical.

In the exposure profiling operation quality assurance measures such as processing of blank filters, collocation of samplers, calibration of exposure profiling equipment, or auditing of tared or exposed filter weights were not documented.

The methods of measuring wind speed and direction and for setting the sampling rate and direction were not documented. The investigators noted that for the test site on 37th Street, the isokinetic flow ratio (sampling intake velocity divided by wind velocity) was much greater than one. Tabular data indicate ratios of 5, 6, and 7.5 for the three tests at this site. Sampling under these conditions was necessary due to light wind conditions and low dust concentrations. Isokinetic correction factors were used to adjust the measured exposures and concentrations to isokinetic conditions.

Findings--Data on exposure of each filter on the profiler were not published. Concentrations at the different profiler heights were published only in graphic form. Emission factors calculated from field measurements of exposure are shown below in Table 2.29. Runs 3, 5, and 6 were performed on 37th Street; runs 7 through 14 were from the industrial park, at which the surface loading was artificially controlled; and runs 15 and 16 were from Fairfax Trafficway.

TABLE 2.29. CALCULATED EMISSION FACTORS

	Emission Factors[a] (lb/veh-mile)		
Run	Total[b]	$d^c < 30\ \mu m$	$d^c < 5\ \mu m$
3	0.015	0.013	0.007
5	0.020	0.019	0.013
6	0.012	0.012	0.008
7	34.7	19.4	6.2
8	26.7	9.6	3.2
9	12.2	3.7	1.1
10	6.9	2.1	0.62
11	10.0	4.8	1.6
12	6.8	3.7	0.95
13	5.3	2.2	0.74
14	1.1	0.46	0.14
15	0.019	0.017	0.008
16	0.010	0.0092	0.0042

a) corrected to isokinetic conditions
b) based on total "catch" by each sampling head on the profiler
c) particle Stokes' diameter

Data from both dustfall buckets and standard hi-vol samplers positioned at various distances downwind from the road indicate that the rate of dust deposition decreases very rapidly with increasing distance from the road.

The investigators developed the following linear relationship between emission factors and silt loadings less than 20 g/m^2 (280 kg/km, upper limit of typical loading range) based on a scatter plot of the data from the eight sampling runs in which surface loading was controlled artificially:

$$e = KLs$$

where

e	=	Emission factor, kg/veh-km
K	=	Proportionality constant, $vehicle^{-1}$
L	=	Surface loading excluding curb area, kg/km
s	=	Silt content, fraction

The value for K was estimated from this graph at 0.00098. This number was then used to estimate silt loadings at the other two test sites based on the measured emission factors. The estimates were compared with measurements made in a previous study on the same streets: Sartor and Boyd (1972) measured total loading as part of a water pollution study. To make the comparison, Cowherd et al. assumed that 10% of the total loading was silt. The resulting numbers were within about 37% of the values estimated by Cowherd et al.

Publication--This study was conducted and documented under contract for the Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. It was published as Publication No. EPA-450/3-77-020 in July 1977.

Study 3-- Axetell and Zell. Control of Reentrained Dust from Paved Streets. EPA-907/9-77-007. 1977.

The primary purpose of this report was to document methods of controlling dust emissions from paved roads. Several field studies were conducted in support of this objective, three of which pertain to uncontrolled emissions from paved roads. Only one actually estimates emission rates from paved roads. It is reviewed below, whereas the other two are considered of secondary importance and are therefore discussed briefly at the end of the paved road section.

Methodology--Normal upwind-downwind dispersion modeling was used to estimate emission rates from traffic on paved streets. The model used is shown below.

$$\chi = \frac{2q}{\sin\phi\sqrt{2\pi}\,\sigma_z u}$$

where

χ	=	plume centerline concentration at ground level at distance x downwind from the source, g/m^3
q	=	line source strength, g/sec-m
ϕ	=	angle between wind direction and the road
σ_z	=	the standard deviation of the vertical distribution of the plume concentration at a distance x downwind from the source, m
u	=	mean wind speed, m/sec

It is a simplified version of the standard model for a continuously emitting, infinite line source (Turner, 1970). As in the example set by Turner (p. 53), the term

$$\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

was omitted because the effective height of emission, H, was taken to be zero; thus, the 'exp' term always evaluated to be one. Also, the researchers estimated an initial σ_z (i.e. σ_z when x = 0) according to the recommendation by Turner (1970). This initial σ_z was estimated at 1.5 meters.

Test Sites--Four separate test sites in unspecified locations were used. Each site was located within a different land use area: undeveloped, park, residential/commercial, and extensive commercial/campus.

Parameters and Equipment--Upwind and downwind concentration of total suspended particulates was measured using standard high-volume samplers. Wind speed and direction were also recorded every two minutes during sampling; the type of equipment was not specified. An automatic counter was used to measure traffic volume for each test. The average traffic speed was determined by driving a vehicle with the flow of the traffic and noting the speedometer reading.

Equipment Configuration--Three standard high volume samplers were placed downwind 10, 20, and 30 meters from the street. One background hi-vol was placed 10 meters from the upwind edge of the road.

Sampling Runs--A total of 60 runs were conducted at the four different sites. Of these, 35 were performed under stable wind conditions. Each run lasted one to two hours. The traffic volume per run was not documented.

Quality Assurance--The documentation for this field study was particularly scant. No indication was given that any published quality assurance guidelines (e.g. Quality Assurance Handbook for Air Pollution Measurement Systems. Volume II - Ambient Air Specific Methods [U.S. EPA, 1977], or Ambient Monitoring Guidelines for Prevention of Significant Deterioration [U.S. EPA, 1978]) were followed. Documentation was not provided for such quality assurance measures as auditing of filter weights or data reduction calculations, calibration of equipment, processing of blank samples, or collocation of samplers.

Furthermore, data for the other dispersion modeling parameters such as wind speed and atmospheric stability were not included in the report.

Samples collected during periods of widely variable wind direction were not considered valid; the results of these, however, were listed in a separate table.

Findings--The average TSP emission factor for the 35 test runs was 3.7 g/veh-mile. The standard deviation was 3.3 g/veh-mile. A comparison of emission factors for streets in areas of differing land uses did not indicate a strong relationship between land use and emission factors. The data collected during periods of consistent wind direction are presented in Table 2.30.

TABLE 2.30. PARTICULATE CONCENTRATIONS AND EMISSION FACTORS

	Net downwind concentration µg/m³			Apparent Emission Factor g/veh-mi		
	--Distance from Downwind Edge of Street--					
Run No.	10m	20m	30m	10m	20m	30m
3	76.9	40.5	33.3	2.98	2.10	2.16
4	46.7	40.6	59.7	2.83	3.27	5.98
7	85.3	59.3	35.0	1.65	1.54	1.13
10	90.5	54.4	39.6	7.99	6.41	5.83
12	34.1	7.8	2.1	2.13	0.64	0.21
13	40.2	5.7	0	3.38	0.64	-
16	35.9	20.9	20.2	1.99	1.54	1.87
18	16.8	5.5	2.9	1.32	0.58	0.38
20	9.6	1.6	16.6	0.42	0.09	1.20
22	62.9	37.8	32.0	1.62	1.30	1.37
23	42.9	37.0	41.2	6.66	7.66	10.66
25	48.7	48.4	15.3	1.10	1.45	0.57
26	72.3	40.7	24.5	5.36	4.03	3.04
27	73.2	59.9	36.8	2.87	3.13	2.42
28	132.1	119.7	61.2	16.67	20.16	12.88
29	36.5	23.7	22.4	5.86	5.06	5.99
30	80.3	71.3	68.5	6.44	7.62	9.15
31	62.1	53.4	41.6	1.46	1.68	1.63
34	30.1	2.7	0	1.54	0.19	-
37	46.1	27.6	10.9	5.15	4.12	2.04
38	85.5	62.5	26.9	4.31	4.18	2.25
39	44.8	28.9	6.9	3.15	2.72	0.81
40	166.1	132.4	74.4	3.38	3.95	2.52
41	54.7	20.9	38.8	7.84	4.00	9.28
42	30.7	15.9	9.6	2.38	1.64	1.24
43	73.3	44.0	30.2	5.68	4.57	3.90
45	61.2	39.8	43.4	5.01	4.33	5.92
47	64.6	29.5	9.5	1.84	1.12	0.45
49	71.0	29.6	22.5	6.88	3.84	3.63
50	76.4	58.0	33.4	1.23	1.25	0.90
51	90.4	57.7	13.3	4.45	3.79	1.09
52	90.3	58.4	36.8	1.89	1.63	1.29
54	148.6	95.7	75.4	8.12	6.98	6.87
56	99.1	51.5	38.1	7.69	5.33	4.93
57	98.5	81.0	36.5	4.34	4.76	2.68
avg.	67.9	44.7	30.3	4.21	3.63	3.26

Publication--Preparation of this document and the supporting field work described above were sponsored by the Environmental Protection Agency, Region VII - Air Support Branch, Kansas City, Missouri. It was published as Publication No. EPA-907/9-77-007 in July of 1977.

Study 4-- Bohn et al. Fugitive Emissions from Integrated Iron and Steel Plants. EPA-600/2-78-050. 1978.

Methodology--Exposure profiling, a technique originally developed by the Midwest Research Institute (MRI) in 1974, was the basic method used to measure emissions of particulates from various specific activities within integrated iron and steel plants.

Test Sites--Paved road emissions were measured at an unidentified iron and steel plant in the Great Lakes steel-producing area of the U.S.

Parameters and Equipment--Table 2.31 provides a list of parameters documented in the study and the corresponding equipment used to take the measurements.

TABLE 2.31. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameters	Equipment
Wind speed	Unspecified
Wind direction	Unspecified
Cloud cover	Direct observation
Temperature	Sling psychrometer
Relative humidity	Sling psychrometer
Road surface condition	Direct observation
Dust loading	Dry vacuuming, scales
Dust texture	Sieves, standard shaker, scales
Traffic mix	Direct observation
Traffic count	Automatic counters
Plume exposure	Isokinetic hi-vol samplers on profiler tower
Plume particle size distribution	Hi-vol cascade impactor with cyclone preseparator
Downwind concentration	Hi-vol sampler
Background concentration	Hi-vol sampler
Duration of sampling	Timer
Deposition	Dustfall buckets

Equipment Configuration--In each sampling run the exposure profiler was set up 5 meters from the edge of the road. For sites with light-duty traffic, sampling intakes were positioned at 1, 2, 3, and 4 meters above the ground. For heavy-duty traffic, they were set at 1.5, 3, 4.5, and 6 meters above the ground. A standard hi-vol sampler and a hi-vol cascade impactor with cyclone preseparator were placed beside the profiler at approximately two meters above the ground. The wind instrument was located three meters downwind from the edge of the road at a height of about 5 meters. Dustfall buckets were placed one and three meters from the road's edge. Another standard hi-vol sampler was placed five meters upwind from the road.

Sampling Runs--Three, one-hour sampling runs were conducted on paved roads. However, emissions data were provided for only two of these tests. Winds were apparently too light to collect valid data for the third test. For the two valid tests, the number of vehicle passes was 127 and 104; most of these were light-duty vehicles.

Quality Assurance--The issue of quality assurance was not directly addressed in this report. Documentation of specific quality assurance procedures, such as auditing filter weights, processing of blank filters, or calibration of sampling equipment was not provided.

The extent to which methodological procedures were documented in this report is sufficient to permit their reproduction by other investigators. The manner in which exposed filters were collected and transported to the laboratory was described in some detail.

Findings--Exposure data and calculated emission factors for suspended particulates (less than 30 µm diameter) are presented in Table 2.32. Based on the data collected during this and a previous study of emissions from paved roads (Cowherd et al., 1977), a predictive equation for paved road emissions was developed:

$$e = 0.45\ (s/10)\ (L/5000)\ (W/3)^{0.8}$$

where

e	=	suspended particulate emissions, lb/veh-mile
s	=	road surface silt content, %
L	=	dust loading on traveled part of road, lb/mile
W	=	average vehicle weight, tons

The specific procedures followed in developing this equation were not specified. The coefficient was based on test results from traffic on paved arterial highways with assumed values for percent silt and surface dust loading. The first two correction parameters, (i.e. s/10 and L/5000) were derived from data collected in Cowherd et al., 1977. The $(W/3)^{0.8}$ was added by analogy to the unpaved road emission factor. No precision factor value was provided for this formula.

TABLE 2.32. EXPOSURE DATA AND EMISSION FACTORS

Run	Sample Height (m)	Filter Exposure (mg/cm^2)	Integrated Filter Exposure (lb/mile)	Emission Factor[a] (lb/veh-mile) $d^b < 30$ µm
E-7	1	0.22	0.42	0.8
	2	0.15		
	3	0.24		
	4	0.20		
E-8	1	0.30	1.1	1.1
	2	0.28		
	3	0.41		
	4	0.37		

a) isokinetic
b) particle Stokes' diameter

Publication--This study was conducted and documented under a contract with the Environmental Protection Agency; Industrial Research Laboratory; Office of Energy, Minerals, and Industry; Research Triangle Park, North Carolina. It was published as Publication No. EPA-600/2-78-050 in March 1978.

Study 5-- Cowherd, et al. Iron and Steel Plant Open Source Fugitive Emission Evaluation. EPA-600/2-79-103. 1979.

Methodology--Exposure profiling was used to measure emissions from paved road traffic.

Test Sites--Two paved roads at unidentified iron and steel plants were the sites for these measurements.

Parameters and Equipment--Table 2.33 lists the parameters measured and the equipment used to measure them.

Equipment Configuration--The sampling configuration was different for each of the two sites. They are explained separately below.

First Site--For one of the sites, the exposure profiler was set up four meters from the downwind edge of the road with sampler heads at 1, 2, 3, and 4 meters above the ground. A cascade impactor was positioned beside the profiler. Three downwind hi-vol samplers were set up, one each at 5, 20, and 50 meters from the road. Two wind stations were set up, one on each side of the road, to monitor wind conditions at a height of four feet. The upwind station was about 15 meters from the road, and the downwind station was placed beside the farthest downwind hi-vol, about 20 meters from the road. Upwind dust concentration was measured by a standard hi-vol placed beside the upwind wind station.

Second Site--For the other site a taller profile tower was set up four meters from the road with sampler heads at heights of 1.5, 3, 4.5, and 6 meters. A cascade impactor was placed beside the profiler. Hi-vols were placed 3 and 20 meters from the road on the downwind side. Upwind concentration was measured at 10 to 15 meters from the road with a hi-vol sampler. Two wind stations were set up on the upwind side of the road, one at about 5 meters and the other at about 12 meters from the road. They also monitored wind conditions at four meters above the ground.

TABLE 2.33. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameters	Equipment
Wind speed	Recording anemometers
Wind direction	Unspecified
Cloud cover	Direct observation
Temperature	Sling psychrometer
Relative humidity	Sling psychrometer
Road surface condition	Direct observation
Road dust loading	Vacuum/broom
Road dust % silt	200-mesh screen, shaker
Number of traffic lanes	Direct observation
Traffic mix	Direct observation
Traffic count	Automatic counter
Exposure	Isokinetic hi-vol exposure profiler
Particle size distribution	Hi-vol cascade impactor & cyclone preseparator (directional)
Downwind concentration	Hi-vol sampler
Upwind concentration	Hi-vol sampler
Duration of sampling	Timer

All hi-vol samplers and cascade impactors had sampling heights of two meters.

Sampling Runs--Six sampling runs were conducted, three at each of the two sites. The number of vehicle passes per run ranged from 47 to 123. A total of 481 passes were logged.

Quality Assurance--An effort was made to apply or adapt the American Society of Testing and Materials (ASTM) Standards in the collection and analysis of road surface samples needed to quantify the silt content of the surface material. Except for the citation of this standard procedure, the authors documented no normal quality assurance procedures. However, documentation of the specific methodological procedures in field operations, sample handling, and data analysis was generally thorough.

Dust samples were transported to the laboratory in separate envelopes. Filter samples were conditioned at constant temperature and humidity for 24 hours before weighing. This same procedure was followed in weighing the filters prior to use.

Careful attention was given to sampling under isokinetic conditions. The intake velocity of each sampler was set to match the wind velocity prior to commencement of sampling. Wind speed was measured continuously during sample collection. Isokinetic correction factors were used to adjust exposures measured under non-isokinetic conditions.

An effort was also made to reduce small particle bias in characterizing the particle size distribution of the dust plume. One of the high volume cascade impactors was fitted with a cyclone preseparator to reduce small particle bias caused by large particles bouncing through the impactor stages to the back-up filter. The impactor/preseparator unit was calibrated to determine the 50% cutoff diameters of the cyclone inlet and the stages of the preseparator. The investigators found that the preseparator does eliminate much, but not all, of the small particle bias.

Findings--The emission factors measured in this study are presented in Table 2.34.

A predictive equation was developed from the findings of this study and previous research by the Midwest Research Institute (Cowherd et al., 1977; Bohn et al., 1978).

$$e = 0.090\ I\ (4/n)\ (s/10)\ (L/1000)\ (W/3)^{0.7}$$

where

e	=	Mass of suspended particulates, lb/veh-mile
I	=	industrial road factor
n	=	number of traffic lanes
s	=	road surface silt content, %
L	=	road surface dust loading, lb/mile
W	=	average vehicle weight

The precision factor for this equation when predicting the emission factors measured during these three studies was 3.31. The precision factor (f) is defined such that the 68% confidence interval for each predicted emission factor (P) is bounded by the values P/f and Pf.

Publication--This study was conducted and documented under a contract for EPA, Industrial Environmental Research Laboratory, Office of Energy, Minerals, and Industry, Research Triangle Park, North Carolina. It was published in 1979 as Publication No. EPA-600/2-79-103.

TABLE 2.34. EXPOSURE DATA AND EMISSION FACTORS

Run	Sample Height (m)	Filter Exposure[a] (mg/cm^2)	Integrated Filter Exposure (lb/mile)	Emission Factors[b] (lb/veh-mile)	
				d^c < 30 μm	d^c < 5 μm
F-13	1	0.24	37.2	0.58	0.16
	2	0.17			
	3	0.16			
	4	0.16			
F-14	1	0.18	21.8	0.20	0.11
	2	0.12			
	3	0.10			
	4	0.08			
F-15	1	0.12	14.7	0.16	0.66
	2	0.04			
	3	0.02			
	4	0.07			
F-16	1.5	1.57	244	2.5	0.78
	3.0	1.09			
	4.5	0.66			
	6.0	0.33			
F-17	1.5	1.29	209	1.7	0.24
	3.0	0.98			
	4.5	0.60			
	6.0	0.27			
F-18	1.5	0.30	67.0	0.48	0.17
	3.0	0.29			
	4.5	0.23			
	6.0	0.20			

a) net of background dust
b) isokinetically corrected
c) particle Stokes' diameter

Study 6-- Reider. Size Specific Particulate Emission Factors for Uncontrolled Industrial and Rural Roads. January 1983.

Methodology--Exposure profiling was used to measure emissions from paved roads in industrial settings. An explanation of the specific procedures for calculating emission factors from the field data was not provided in the report.

Test Sites--Tests were conducted on paved roads in facilities of four different industries: asphalt batching, concrete batching, sand and gravel processing, and copper smelting. The test sites for the asphalt batching and the sand and gravel processing facilities were one-lane roads, whereas two-lane roads were tested for the concrete batching and the copper smelting facilities. Test sites were selected according to three general criteria; each test site was found to be: 1) suitable for the specific requirements of the exposure profiling methodology, 2) representative of most facilities in the industry, and 3) accessible via cooperation of the facility personnel.

Parameters and Equipment--The parameters measured in this study and the equipment used to take these measurements are shown in Table 2.35.

TABLE 2.35. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameter	Equipment
Wind speed	Warm wire anemometer
Wind direction	Wind vane
Atmospheric pressure	Barometer
Temperature	Sling psychrometer
Relative humidity	Sling psychrometer
Road surface condition	Direct observation
Road surface particulate loading	Dust pan, broom, scales
Road surface silt content	Sieves, scales
Traffic Mix	Direct observation
Traffic Count	Direct observation
Vehicle weight	Interview plant operators
Vehicle speed	Interview drivers
Plume total particulate concentration	Exposure profiler
Plume inhalable particulate concentration	Hi-vol with size-selective inlet
Size distribution of inhalable particulate	Cascade impactor with cyclone preseparator (impactor cutpoints of 10.2, 4.2, 2.1, 1.4, and 0.73 μm)

The procedures for calculating point values of exposure from these data were not included in this report. They are presumably similar to those discussed in Cowherd and Englehart, 1984, which is also reviewed in this section.

Equipment Configuration--Downwind air sampling equipment was set up five meters from the edge of the road. The exposure profiler had sampling heads at heights of 1, 2, 3, 4, and 5 meters. The wind speed is measured continuously at two sampling heights and a logarithmic distribution of the vertical wind speed profile is assumed in setting the sampling rates for the remaining sampler heads. A standard hi-vol sampler, a hi-vol fitted with a size-selective inlet (SSI), and two cascade impactors with cyclone preseparators were also set up on the downwind side. The cascade impactors were positioned in a vertical array at heights of 1 and 3 meters. The hi-vols sampled air at a height of 2 meters.

Upwind sampling equipment was also generally set up five meters from the road. For most of the tests, one of each of the following samplers was set up with intakes two meters above the ground: standard hi-vol, hi-vol with SSI, and cascade impactor with cyclone preseparator. Background dust levels at the concrete and asphalt operations were judged to be too low to collect sufficient mass on the different stages of the cascade impactor, so the upwind impactor was not used in tests at these facilities.

Sampling Runs--A total of 13 tests, ranging in duration between 13 and 344 minutes, were conducted on paved roads for this study. Sampling run time was sufficient to produce a filter weight gain of at least 5 mg on the top sampling head of the profiler. These tests were distributed among the various industries as shown in Table 2.36.

TABLE 2.36. EXTENT OF SAMPLING FOR VARIOUS INDUSTRIES

Industry	Number of Tests	Total Vehicle passes	Traffic Type
Asphalt batching	4	373	Medium Duty
Concrete batching	3	372	Medium Duty
Copper smelting	3	123	Medium Duty
Sand and gravel processing	3	47	Heavy Duty

Quality Assurance--The investigator noted that the sampling and analysis procedures met or surpassed the guidelines set forth in the Quality Assurance Handbook for Air Pollution Measurement Systems, Vol. II - Ambient Air Specific Methods (U.S. EPA, 1977) and the Ambient Monitoring Guidelines for Prevention of Significant Deterioration (U.S. EPA, 1978). Except for the lack of a description of some data reduction procedures, quality assurance for this study was good. The profiler sampling heads, hi-vols, and impactors were calibrated prior to testing at each site. Sampling filters and impactor substrates were equilibrated for 24 hours prior to weighing. Tare weights were given a 100% audit, and 10% of loaded filter weights were audited. Criteria for reweighing of the entire batch were provided. The orientation of the profile sampling heads were adjusted if the 15-minute average wind direction changed by more than 30 degrees. The sampling rate of the profile samplers was adjusted if the 15-minute average wind speed changed by more than 20%. Ten percent of all calculations were also audited.

Findings--The concentration measurements taken during the field tests are presented in Table 2.37. The investigator noted that the data from the profiler is net of background dust levels.

The emission factors which were calculated from these data were shown in Table 2.38. Again, the specific procedures for calculating the emission factors are not described in this report.

Publication--This report has been completed only as a draft final report. It has not been published. However, it was cited in the AP-42 section on paved industrial roads. The study was conducted under EPA Contract No. 68-02-3158.

TABLE 2.37. MEASURED DUST CONCENTRATIONS FOR TOTAL PARTICULATES AND PM_{10}

		Concentration (μg/m³)						
		Total Particulate (Exposure Profiler)					PM_{10} (Cascade Impactor)	
Run	Duration (minutes)	1 m	2 m	3 m	4 m	5 m	1 m	3 m
Y-1	367	432	118	99	a	37	18	16
Y-2	443	411	223	112	77	b	58	51
Y-3	200	1698	791	562	355	156	82	52
Y-4	192	7992	2753	1638	1001	490	292	191
Z-1	348	1352	806	454	366	215	425	252
Z-2	313	3214	1775	1364	919	641	520	285
Z-3	313	4214	2409	1750	1256	711	810	404
AC-4	76	7226	5893	4812	2755	1863	2399	599
AC-5	58	3261	1864	1644	1007	857	1567	591
AC-6	74	6746	5314	4144	a	1524	1367	367
AD-1	103	1273	1036	974	720	588	251	110
AD-2	71	832	1173	600	347	177	165	82
AD-3	41	1065	788	504	b	b	80	57

a) torn filter
b) net concentration resulted in negative value

TABLE 2.38. EMISSION FACTORS FOR TOTAL PARTICULATES AND PM_{10}

Run	Total Particulate Emission Factor (lb/veh-mile)	PM_{10} Emission Factor (lb/veh-mile)
Y-1	1.43	0.257
Y-2	1.48	0.401
Y-3	0.75	0.0801
Y-4	3.65	0.441
Z-1	2.25	0.699
Z-2	7.23	1.63
Z-3	17.5	4.01
AC-4	15.74	3.86
AC-5	10.8	3.13
AC-6	7.07	1.35
AD-1	19.3	3.27
AD-2	6.64	0.753
AD-3	4.35	0.513

Study 7-- Cuscino _et al._ _Iron and Steel Plant Open Source Fugitive Emission Control Evaluation_. EPA-600/2-83-110. 1983.

Methodology--Exposure profiling was used to measure emissions from vehicle travel on paved roads in iron and steel plants. The method of calculating exposure at the various profile sampler heights differs significantly from that used in previous Midwest Research Institute (MRI) profiling studies. Prior to this study, exposure was calculated as the dust mass on the filter divided by the intake area. For this study the equation below was used to compute exposures for particle size categories of interest:

$$E = 10^{-7}\ C\ U\ t$$

where

E = exposure (mg/cm^2) for particle size of interest
C = concentration ($\mu g/m^3$) of same particle size
U = mean wind speed (m/s)
t = sampling duration (s)

No explanation was given for this change in methodology.

Test Site--Tests of emissions from vehicular travel on paved, uncontrolled roads (i.e. not sprayed with a dust suppressant) were conducted at six different sites at Armco Steel, Incorporated's iron and steel works plant in Middletown, Ohio.

Parameters and Equipment--Listed in Table 2.39 are the parameters measured and the equipment used to take the measurements in this study.

Equipment Configuration--For each test all downwind monitoring equipment were placed five meters from the edge of the road, and all upwind samplers were placed ten meters from the road. Four or five isokinetic sampling heads, depending on the expected plume height, were attached to the profiling tower at one meter intervals. Two hi-vol impactors with cyclone preseparators were set up beside the profile tower one meter and three meters above the ground. A standard hi-vol sampler was also placed beside the profile tower with its intake two meters above the ground. For some of the tests, a hi-vol with a size-selective inlet (SSI) was also stationed on the downwind side.

TABLE 2.39. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameter	Equipment
Wind speed	Recording anemometer
Wind direction	Recording anemometer
Temperature	Unspecified
Road width	Unspecified
Number of lanes in Road	Direct observation
Road surface silt loading	Broom, vacuum
Road surface silt content	Sieves, mechanical sieving device, scales
Road surface moisture content	Oven, scales
Traffic count	Direct observation
Plume exposure	Isokinetic hi-vol samplers (profiler)
Plume particle size distribution	Hi-vol cascade impactor with cyclone preseparator (cutpoints not provided)
Plume TSP concentration	Standard Hi-vol sampler
Plume IP concentration	Hi-vol sampler with size selective inlet
TSP background concentration	Standard Hi-vol sampler
Duration of sampling	Timer

A standard hi-vol sampler was placed with its intake two meters above the ground on the upwind side for each test. Hi-vols with SSIs were also used on the upwind side; for some of the tests two were set up with intakes at heights of one and three meters, and for others, a single hi-vol/SSI was set up with its intake at two meters above the ground.

Sampling Runs--Eleven sampling runs were conducted on uncontrolled, paved roads in this study. Most samples were collected over one or two hours, but one run lasted over four hours. The number of vehicle passes per run ranged from 79 to 301. The total number of passes was 1,279.

Quality Assurance--This study incorporated a rigorous quality control program. Procedures followed in collecting and analyzing samples were documented in considerable detail. Quality control measures were set forth for the sampling media, sampling flow rates, and equipment maintenance. Criteria for interrupting sample collection were also documented. Quality assurance practices included processing of blank samples, calibration of equipment, and auditing of sampling and analysis procedures.

The investigators note that their procedures met or surpassed the requirements set forth in Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II - Ambient Air Specific Methods (U.S. EPA, 1977) and Ambient Monitoring Guidelines for Prevention of Significant Deterioration (U.S. EPA, 1978).

Careful attention was given to sampling under isokinetic conditions. Wind speed was monitored before and during sample collection. Fifteen minute averages of the wind speed at two monitoring heights and an assumed logarithmic vertical wind speed profile were used to set the intake velocity for each sampler on the profiler.

Findings--Because the purpose of this study was to evaluate various methods of controlling open source fugitive emissions from iron and steel plants, some experimental data was needed on particulate emissions from vehicle travel on **uncontrolled**, paved roads. Table 2.40 presents the primary emissions data collected for this source.

The investigators did not estimate, in this report, a new predictive equation on the basis of their empirical findings. However, they did test predictions of the equation which was developed from field data collected by MRI prior to this study (Cowherd et al., 1977; Bohn et al., 1978); and Cowherd et al., 1979). The equation is presented in the review of Cowherd et al., 1979. The precision factor of this equation when predicting emissions for sampling runs conducted in the present study and the study by Cowherd et al. (1979) was 2.14.

Publication--This study was conducted and documented for EPA, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. It was published in 1983 as Publication No. EPA-600/2-83-110.

TABLE 2.40. EXPOSURE DATA AND EMISSION FACTORS

			Emission Factors[b] (lb/veh-mile)		
Run	Sample Height (m)	Net TP[a] Exposure (mg/cm²)	Total[a] Particulates	d[c] < 15 µm	d[c] < 2.5 µm
F-27	1	1.14	0.848	0.357	0.106
	2	0.94			
	3	0.66			
	4	0.00			
F-32	1	0.683	0.292	0.144	0.0503
	2	0.523			
	3	0.385			
	4	0.346			
F-34	1	1.24	1.73	0.536	0.147
	2	0.82			
	3	0.66			
	4	0.42			
F-35	1	3.18	2.18	0.849	0.207
	2	2.02			
	3	1.12			
	4	0.00			
F-45	1	3.44	2.75	0.608	0.173
	2	2.50			
	3	2.01			
	4	1.41			
	5	1.45			
F-57	1	1.18	2.86	0.554	0.148
	2	1.39			
	3	1.09			
	4	0.605			
	5	0.439			
F-58	1	2.00	2.90	1.08	0.197
	2	0.569			
	3	0.805			
	4	0.431			
	5	0.300			

(continued)

TABLE 2.40 (continued)

Run	Sample Height (m)	Net TP[a] Exposure (mg/cm^2)	Emission Factors[b] (lb/veh-mile) Total[a] Particulates	d^c < 15 μm	d^c < 2.5 μm
B-59	1	1.93	2.95	0.993	0.334
	2	0.597			
	3	0.887			
	4	0.433			
	5	0.379			
B-60	1	1.34	3.72	1.18	0.432
	2	1.51			
	3	0.803			
	4	0.603			
	5	0.430			
B-61	1	2.95	4.65	1.35	0.327
	2	2.60			
	3	1.97			
	4	1.66			
	5	0.987			
B-62	1	2.66	3.50	0.929	0.245
	2	2.58			
	3	2.07			
	4	1.29			
	5	0.00			

a) total particulate, i.e. including mass in settling chamber
b) isokinetically corrected
c) particle aerodynamic diameter

Study 8-- Cowherd and Englehart. Paved Road Particulate Emissions: Source Category Report. EPA-600/7-84-077. 1984.

Methodology--Exposure profiling was used to measure particulate emissions from paved roads.

Test Sites--Tests were conducted at three sites in the Kansas City area during the winter of 1980 and at five sites in the St. Louis / Granite City, Illinois area the following spring. Streets in these areas were selected on the basis of the following criteria:

- traffic volume and road surface particulate mass must be sufficient to generate adequate filter loading within a four-hour test run
- space must be available for upwind and downwind sampling equipment and for staff
- expected wind direction must be within 45° of perpendicular to the road
- wind fetch upwind from the road should be large

Each test site was on one of the following four road types: commercial/industrial, commercial/residential, expressway, and rural town.

Parameters and Equipment--The parameters for which direct field measurements were available (i.e. no extrapolation or interpolation of data needed) and the equipment used to collect the data are listed in Table 2.41.

The concentration of particles with aerodynamic diameters less than 2.5 µm and of those smaller than 10 µm was estimated in the following manner:

1. The measured concentrations of each of the particle size categories listed in Table 2.41 were converted to percentages of the total suspended particulate concentration.

2. These data points were graphed with particles sizes in logarithmic scale on the Y-axis and the corresponding percent of the total particulate mass smaller than the given size in probability scale on the X-axis.

TABLE 2.41. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameter	Equipment
Wind speed	Warm wire anemometer
Wind direction	Wind vane
Cloud cover	Direct observation
Temperature	Sling psychrometer
Relative humidity	Sling psychrometer
Pavement type	Direct observation
Road surface condition	Direct observation
Surface particulate loading	Dry vacuum, scales
Surface particulate texture	Sieves, scales
Vehicle mix	Direct observation
Vehicle count	pneumatic tube axle counters
Plume total particulate concentration	Profiler
Plume total suspended particulate concentration	Standard high volume sampler
Plume concentration of particles < 15 µm in aerodynamic diameter	High volume with size-selective inlet
Plume concentration of particles in the categories: < 7.2 µm aerodynamic diameter < 3.0 µm " < 1.5 µm " < 0.95 µm " < 0.49 µm "	Cascade impactor with greased substrates attached to the above hi-vol sampler

3. Graphic interpolation is used to derive percentages of the total particulate mass smaller than 2.5 µm and 10 µm.

The equation below was used to compute point values of exposure at the sampling heads for any of the particle size categories:

$$E = 10^{-7}\ C\ U\ t$$

where

E = exposure for particle size of interest, mg/cm^2
C = concentration ($\mu g/m^3$) (measured or interpolated) of same particle size, $\mu g/m^3$
U = mean wind speed, m/s
t = sampling duration, s

Equipment Configuration--The sampling equipment configuration varied in some details over the course of the study. The basic arrangement is described below, and the components which did change are described in the following paragraphs.

The downwind configuration was the same throughout the study. The exposure profiler, which was placed about 2.5 meters from the downwind edge of the road, consisted of four isokinetic sampling heads fixed at heights of one, two, three, and four meters. A standard hi-vol sampler and two hi-vols with attached size-selective inlets (SSI) and cascade impactors were placed beside the profile tower at respective heights of two, one, and three meters. Also in every test, an upwind standard hi-vol sampler was positioned about four meters from the road with its intake at the usual height of two meters.

For the tests in the Kansas City area, two hi-vols with SSIs were set up at heights of two and four meters. For some of the tests in the St. Louis/Granite City area, a single upwind hi-vol fitted with attached SSI and cascade impactor was set up 2 meters above the ground. For the remainder of the tests, two upwind hi-vols with SSIs (but no cascade impactors) were placed at one and three meters above the ground. All upwind air samplers were about four meters from the road.

Sampling Runs--Nine sampling runs were conducted at the three sites in the Kansas City area. Seven of these runs passed the investigators' quality control criteria (see discussion under Quality Assurance). Of the ten tests conducted in the St. Louis/Granite City area, only three passed the quality control criteria. Runs which failed these criteria were not included in the multiple regression analysis. Most samples were collected over a period of two to four hours, but one rural road test lasted almost six hours. The number of vehicle passes per sampling run ranged from about 1,900 to about 15,000.

Quality Assurance--Quality assurance was thorough and well documented. Calibration schedules and acceptable variations were presented for air samplers and laboratory balance. Exposed filters were conditioned for 24 hours prior to weighing. Some of each type of filter or substrate were processed as blanks to determine necessary corrections for the effects of filter handling. Filter weights were audited regularly. To assure isokinetic sampling, the orientation of the intake direction was adjusted when the 15-minute average wind direction changed by more than 30°, and the sampling velocity was adjusted any time the wind speed (15 minute average) changed by more than 20%. These quality assurance procedures met or surpassed applicable requirements found in EPA's Quality Assurance Handbook for Air Pollution Measurement Systems Volume II - Ambient Air Specific Methods (U.S. EPA, 1977), and Ambient Monitoring Guidelines for

Prevention of Significant Deterioration (U.S. EPA, 1978). In addition, the investigators specified the following conditions under which sampling results were excluded from regression analysis:

- Mean angle between wind direction and profiler orientation ≥ 20°
- Mean angle between profiler orientation and road orientation ≥ 45°
- Wind speed < 4 mph
- Background concentration relative to downwind measurements deemed "acceptable"
- Results not based on average of data from other runs

Findings--Except for a sample calculation in an appendix, data were not published on concentrations or exposures at individual profile sampler heads. The calculated emission factors for those sampling runs which were included in a multiple regression analysis are listed in Table 2.42.

TABLE 2.42. CALCULATED EMISSION FACTORS

		Emission Factors (lb/veh-mile * 10^4) by Particle Size Category		
Site	Road Type	d^a < 15 μm	d^a < 10 μm	d^a < 2.5 μm
M-1	Commercial/ Industrial	125.0	110.0	63.2
M-2	Commercial/ Industrial	35.7	34.0	30.4
M-3	Commercial/ Industrial	84.8	78.1	52.0
M-9	Commercial/ Industrial	99.3	71.2	40.5
M-6	Commercial/ Residential	32.9	30.4	20.9
M-7	Commercial/ Residential	117.0	92.8	36.8
M-15	Commercial/ Residential	35.8	32.3	22.0
M-11	Expressway	7.8	7.0	3.4
M-12	Expressway	2.1	1.9	1.4
M-8	Rural Town	311.0	247.0	50.4

a) aerodynamic diameter

As can be seen from the Table 2.42, the expressway had the lowest emissions, and the rural town road had the highest emissions.

The fraction of the total suspended particulate mass in particles smaller than 15 μm was found to be greater on the upwind side of the road than the downwind side. The same was true for PM_{10} and fine particulates.

Stepwise linear regression was used to build predictive models for emissions of total suspended particulates (TSP), inhalable particulates (IP), PM_{10}, and fine particulates (FP). The candidate predictor variables were total loading (g/m^2), silt loading (g/m^2), average vehicle speed (kph), and average vehicle weight (Mg). The resulting equations are shown below:

$$e_{TSP} = 5.87\ (sL/0.5)^{0.9}$$
$$e_{IP} = 2.54\ (sL/0.5)^{0.8}$$
$$e_{PM10} = 2.28\ (sL/0.5)^{0.8}$$
$$e_{FP} = 1.02\ (sL/0.5)^{0.6}$$

where

e_i = Emission factor for particle size category i, g/veh-km
sL = Silt loading, g/m^2

Speed was not selected as a predictor variable because of its high correlation with silt loading. The precision factors for these equations when predicting emissions in the ten sampling runs which passed the QA screening are, respectively, 2.4, 2.0, 2.2, and 2.2.

Publication--This study was published as Publication No. EPA-600/7-84-077 in July of 1984. It was conducted and documented under contract for the Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina.

Studies of Secondary Importance

Study 9-- Roberts. The Measurement, Cost and Control of Air Pollution from Unpaved Roads and Parking Lots in Seattle's Duwamish Valley. 1973.

The dust plume created by a vehicle traveling on a paved road was sampled using a towed rack to which a cascade impactor was attached. The rack was designed as a vertical grid oriented perpendicular to the car's path; the impactor was rotated among the various positions between tests so that, after a series of tests, the average concentration of dust in the plume could be determined. In order to derive an emission factor in lb/veh-mile, the average plume concentration was multiplied by the volume of air into which it was emitted. This volume was estimated in the following manner. First, the area of the plume behind the car was estimated by towing a grid/rack of open impaction plates and examining the dust pattern on the plates. Second, this area, 70 square feet, was multiplied by 5,280 feet (1 mile) to obtain the air volume (36,960 ft^3) into which the dust was emitted after 1 mile of travel.

The impactor samples were also analyzed to determine the particle size distribution of the plume. This particle size breakdown was then used to estimate emission factors for various particle size categories.

Sample collection, handling, and analysis procedures were not documented in detail. For example, specific procedures for handling the impactor plates were not documented. No mention was made of problems with particle bounce in the impactor; this problem has been documented by at least two other researchers (Cowherd et al., 1974 and McCaldin, 1977).

The distance between the vehicle and the towed rack was not documented. The investigator noted that it was difficult to certify that sampling was conducted under isokinetic conditions, due to turbulence in the wake behind the vehicle and changes in wind direction and speed.

An unspecified number of sampling runs were conducted on two paved roads in the Duwamish Valley in Seattle. One of the roads had curbs and was regularly swept, and the other had no curbs and was visibly dusty. Following the procedure explained above, total emissions were measured at an average of 0.14 lb/veh-mile for the clean road and 0.83 lb/veh-mile for the dusty road. For particles smaller than 10 µm, emissions were measured at 0.0055 lb/veh-mile and 0.17 lb/veh-mile for the clean and dusty road, respectively. A factor for particles with diameter less than two µm was also measured for the dusty paved road: 0.022 lb/veh-mile. The investigator did not explain how the fraction of the total particulate sample consisting of particles smaller than 10 µm was determined; i.e. he did not indicate whether the cascade impactor provided a cut point at that size.

This study was conducted and documented as partial fulfillment of requirements for a master's degree in engineering at the University of Washington. Portions of this work and some follow-up research were published in the Journal of the Air Pollution Control Association in 1975.

Study 10-- Axetell and Zell. Control of Reentrained Dust From Paved Streets. EPA-907/9-77-007. 1977.

Of the several field studies which were documented in this publication, two were considered secondary in importance to the development of reliable emission factors for vehicle travel on uncontrolled paved roads. They were carried out in support of the primary purpose of this report, which was to document methods of controlling dust emissions from paved roads. One involved measurement of TSP concentrations near the mud carry-out area associated with a building construction site, and in the other zinc sulfide dust was distributed in the same mud carry-out area to trace the distance mud is tracked away from a construction site. These two studies are described briefly below.

In the first study, four high volume samplers were set up adjacent to the mud carry-out area associated with a single access point for a construction site in Kansas City. Separate mean concentrations were calculated and presented for each of four different road cleaning programs. One of these was essentially no control at all. Mean concentrations for the four cleaning programs were also compared with the mean TSP concentrations of 15 regional monitoring sites. This regional average was used as a measured of background TSP concentration. For the no-control tests, the concentrations were roughly 20 to 40 $\mu g/m^3$ higher than the regional background level of 84.1 $\mu g/m^3$. Corresponding emission rates were not estimated from these concentration measurements.

The second study was conducted at this same site. Zinc sulfide (ZnS) mixed with sand was sprinkled on the mud track-out area. Samples of street dust were collected at several distances from the site entrance one day and again eight days after the ZnS was applied. On the first day after the application, increased ZnS levels were detected along 1500 feet of the access road. On the eighth day higher than normal levels of ZnS were detected up to 2000 feet from the entrance.

No indication was given that any normal quality assurance procedures were followed for either of these studies. The authors acknowledged that concentration measurements could have been effected by activities within the construction site itself. The duration of each hi-vol sample was not documented. Raw data were not published.

Preparation of this document, and the supporting field work described above, were sponsored by the Environmental Protection Agency, Region VII - Air Support Branch, Kansas City, Missouri. It was published as Publication No. EPA-907/9-77-007 in July of 1977.

Study 11-- McCaldin. Fugitive Dust Study for Pima County Air Quality Control District, Tucson, Arizona. 1977.

The investigator used upwind-downwind dispersion modeling to measure emissions from vehicular traffic on paved roads. Two types of paved roads were tested: one with dirt shoulders and no curbs, and one with curbs. Upwind and downwind dust concentrations were measured using one standard high volume sampler on each side of the road, 50 feet from the centerline.

The road without curbs had four lanes and about 45 feet of shoulder on either side. Traffic on the paved lanes varied from 500 to 700 vehicles per hour, and vehicles using the shoulders passed at a rate of 6 to 12 per hour. Thus, traffic on the unpaved portion ranged approximately from 0.8% to 2.3% of the total traffic volume on the roadway. Six tests, each lasting between three and four hours, were conducted at this site over a period of 21 days. Calculated emission factors, as well as measured upwind and downwind concentrations, were documented in this report. Emission factors for the uncurbed road were calculated at .003, .006, .007, .022, .026 and .068 lb/veh-mile.

The three curbed road test sites had traffic volumes of about 650, 130, and 220 vehicles per hour. Each test road had identifiable sources of road dust nearby. A total of seven tests, each lasting from three to five hours, were conducted on these three roads. One emission factor was reported for each curbed road test site: 0.004, 0.02, and 0.05 lb/veh-mile. Upwind and downwind concentrations at this site were not published.

No quality assurance procedures were documented for the paved roads field research. Details regarding the manner in which filters were tared, transported, and equilibrated (if at all), were not given. The measured angle between the wind and the road, a key parameter for the model, was not published.

This study was conducted and documented under contract with the Pima County Air Quality Control District (AQCD). EPA Financial Grant Number A0090055-77-2, awarded to the Pima County AQCD, provided funding for the study.

MINING

Introduction

Mining and quarrying activities are significant sources of fugitive dust in some areas. Four studies have been conducted to measure emission rates in this source category, two at western surface coal mines and two at quarries. In the first mining study (Axetell, 1978), upwind-downwind dispersion modeling was used to estimate emission rates for several activities at five strip mines. In the other mining study (Axetell and Cowherd, 1984), the different mining activities were tested using the upwind-downwind method, the quasi-stack method, or the exposure profiling method, depending on the character of the source. In both of the quarry studies, emissions were estimated using the upwind-downwind method. These four studies are reviewed in chronological order.

Two additional field studies involved measurement of dust concentration and other parameters in western strip mines. Because they did not measure emission rates, they are considered secondary in importance. In one of these (Cook et al., 1980), the relationship between dust concentration and other variables, including activity type and intensity near the sampler, was examined statistically. In the other (Marple et al., 1980), the performance of a mobile air sampling and analysis vehicle was documented, and the findings from the collected data were discussed. These two studies are summarized following the review of the primary studies.

Studies of Primary Importance

Study 1-- Axetell. Survey of Fugitive Dust from Coal Mines. EPA-908/1-78-003. 1978.

Methodology--The investigators used upwind-downwind dispersion modeling to measure emission factors for several mining operations: topsoil removal, drilling, blasting, dragline, shoveling/truck loading, and fly-ash dumping. The following area source model, from Turner, 1970, was used:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

where

χ	=	plume centerline concentration at a distance x downwind from the source, g/m^3
Q	=	source strength, g/sec
σ_y	=	the standard deviation of the horizontal distribution of the plume concentration at a distance x downwind from the source, m
σ_z	=	the standard deviation of the vertical distribution of the plume concentration at a distance x downwind from the source, m
u	=	mean wind speed, m/sec
y	=	horizontal distance from the sampler to the plume centerline, m
H	=	average vertical distance from plume centerline to samplers, m

An effort was made to measure particle fallout rates. Concentrations at a series of downwind distances from the source were measured, and corresponding emission rates at the source were calculated using the above model, which assumes there is no particle fallout. Decreases in the "apparent emission rate" with increasing distance from the source would serve as a measure of fallout.

Test Sites--Operations at five western coal mines were tested. Except for one lignite mine, all of the operations extracted sub-bituminous coal.

Parameters and Equipment--Most of the parameters measured in this study are listed in Table 2.43, along with the tools used to collect the data. In addition, estimates were made for the initial dimensions and dispersion of the dust plume, the receptor's distance from the source, the receptor's vertical and horizontal distance from the plume centerline, and the length of time the receptor is in the plume. These estimates were all made visually.

TABLE 2.43. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameters	Equipment
Upwind concentration of TSP	Standard hi-vol
Downwind concentration of TSP	Standard hi-vol
Wind direction	Recording wind instrument
Wind speed	Recording wind instrument, hand-held wind speed anemometer
Other atmospheric stability parameters	Unspecified
Particle size distribution	Millipore filters on nuclepore filter holder and pump, microscope

Equipment Configuration--The equipment configuration varied between sources and mines. It was not completely described for each test run. Typically, a pair of hi-vols were placed together at a location upwind from the entire mining operation. This was preferred over placing samplers immediately upwind from the activity because anticipated brief wind direction reversals would be less likely to effect upwind concentration measurements. Other hi-vols were placed at 10, 20, and 30 meters (or a similar series of distances) downwind from a particular source activity. For about half of the tests, downwind samplers were set up at both 1.2 and 2.4 meters above the ground at these downwind locations to provide information on the vertical dispersion of the plume.

Sampling Runs--The number of sampling runs conducted on each activity is indicated in Table 2.44. Each sampling run consisted of several concentration measurements, which ranged in duration primarily between 30 and 90 minutes.

TABLE 2.44. EXTENT OF SAMPLING AT VARIOUS MINING ACTIVITIES

Activity	Number of Sampling Runs	Activity	Number of Sampling Runs
Topsoil removal	10	Shovel/Truck loading	26
Drilling	5	Front-end loader	1
Blasting	13	Train loading	9
Dragline	30	Total	89

Quality Assurance--The guidelines in the Quality Assurance Handbook for Air Pollution Measurement Systems (U.S. EPA, 1976) were followed in preparing filters, collecting and analyzing samples, and auditing the data. Hi-vol samplers were calibrated before field work began at each mine. One of every 25 filters was treated as a blank.

The investigators listed several problems experienced in the field sampling program which indicate a decrease in the reliability of the field data. Foremost was the fact that much of the data collected in the field was subject to the ability of the field staff to make visual estimates. Plume dimensions and distance from the plume centerline are two examples of this. In addition, one avoidable problem greatly decreased the integrity of the data: the two separate field crews did not follow the same procedures in collecting samples in several critical respects. There was no way to fully correct the data for these differences.

Findings--The measured concentrations and other field sampling data are shown in Table 2.45. Emission factors for these sampling runs were presented separately in the report. Average emission factors by operation and mine are shown in Table 2.46.

The empirical data collected in this study did not support the supposition that the apparent emission rate decreases with distance due to particle fallout. For those sampling runs which included concentration measurements at two consecutive downwind distances at the same height, the modeled apparent emission rates decreased with increasing distance in only about 35% of the sampling runs. For those tests in which concentrations were measured at downwind distances differing by 10 meters, the concentration **increased** an average of 19% between the two sampling points.

When measured at two heights, 1.4 meters and 2.4 meters, at the same downwind distance, the concentrations at the lower height averaged 14% higher than those at the samplers 2.4 meters above the ground.

Publication--This study was conducted and documented under a contract for the Environmental Protection Agency, Region VIII, Office of Energy Activities, Denver, Colorado. It was published in February of 1978 as Publication No. EPA-908/1-78-003.

TABLE 2.45. DISPERSION MODELLING DATA

Source	Mine/ Sample	Wind Speed (m/sec)	Stability Class	Back-ground Concentr. (µg\m³)	Net Plume Concentr. (µg/m³)	Downwind Distance (m)	Vertical Distance from Plume Centerline (m)	Horizontal Distance from Plume Centerline (m)
Drag-line	A/1	.4	B	88	1476 825 1376 1324 1247 1020	30 40 50 30 40 50	5.0 5.0 5.0 6.3 6.3 6.3	5.5 8.9 12.3 4.5 7.9 11.3
	A/2	.4	B	88	1658 1145 1234	30 40 50	5.0 5.0 5.0	3.5 6.9 10.3
	A/3	.4	B	88	500 303 322	50 60 70	5.0 5.0 5.0	11.3 16.7 23.6
	A/4	.4	B	88	408 337 416 466 337 305	50 60 70 50 60 70	5.0 5.0 5.0 6.3 6.3 6.3	9.3 14.7 21.6 10.3 15.7 22.6
	A/5	1.8	B	64	954 828 1155 795 351	40 55 70 40 55	-3.0 -3.0 -3.0 -1.8 -1.8	3.0 3.0 3.0 2.0 2.0
	A/6	1.8	B	64	990 569 944	40 55 70	-3.0 -3.0 -3.0	1.0 1.0 1.0
	A/7	.4	B	64	414 272 258 174 290 334	75 90 105 75 90 105	11.0 11.0 11.0 12.2 12.2 12.2	46.0 55.0 64.0 45.0 54.0 63.0
	A/8	.4	B	64	38 52 83 47 0 51	75 90 105 75 90 105	11.0 11.0 11.0 12.2 12.2 12.2	46.0 55.0 64.0 45.0 54.0 63.0
	B/1	3.6	C	131	20154 18010 15633 21087 3935 20542	50 65 80 50 65 80	-1.3 -1.3 -1.3 -.1 -.1 -.1	0 0 0 0 0 0
	B/2	3.6	C	131	24846 19034 17520	50 65 80	-1.3 -1.3 -1.3	0 0 0
	B/3	5.8	D	131	23216 27025 26753 7429 22000 25867	70 80 90 70 80 90	-1.3 -1.3 -1.3 -.1 -.1 -.1	0 0 0 0 0 0
	B/4	5.8	D	131	21860 26017 7476	70 80 90	-1.3 -1.3 -1.3	0 0 0
	B/5	5.4	D	131	7594 18664 17497	70 85 100	-1.3 -1.3 -1.3	0 0 0

(continued)

TABLE 2.45. (continued)

Source	Mine/ Sample	Wind Speed (m/sec)	Stability Class	Back-ground Concentr. (µg\m³)	Net Plume Concentr. (µg/m³)	Downwind Distance (m)	Vertical Distance from Plume Centerline (m)	Horizontal Distance from Plume Centerline (m)
Drag-line	B/6	5.4	D	131	7722 12809 18765 7197 12686 14131	70 85 100 70 85 100	-1.3 -1.3 -1.3 -.1 -.1 -.1	0 0 0 0 0 0
	B/7	3.1	C	125	5184 3304 5222 6564 4899 3681	70 80 90 70 80 90	-3.8 -3.8 -3.8 -2.6 -2.6 -2.6	0 0 0 0 0 0
	B/8	3.1	C	125	5848 4574 4449 4769	70 80 90 100	-3.8 -3.8 -3.8 -3.8	0 0 0 0
	B/9	3.6	C	125	12853 3499 3509 3619	70 80 90 100	-3.8 -3.8 -3.8 -3.8	0 0 0 0
	B/10	3.6	C	125	4393 3266 3396 3090 3982 3180	70 80 90 70 80 90	-3.8 -3.8 -3.8 -2.6 -2.6 -2.6	0 0 0 0 0 0
	C/1	3.6	B	89	96 0 210 125 133 89	70 70 79 79 87 87	-6.5 -5.0 -6.5 -5.0 -6.5 -5.0	0 0 0 0 0 0
	C/2	3.6	B	89	37 78 127	70 79 87 96	-6.5 -6.5 -6.5 void	0 0 0
	C/3	4.0	B	89	208 262 287 72 12 170	70 79 87 70 79 87	-6.5 -6.5 -6.5 -5.0 -5.0 -5.0	0 0 0 0 0 0
	C/4	4.0	B	89	113 100 161 128	70 79 87 96	-6.5 -6.5 -6.5 -6.5	0 0 0 0
	C/5	5.4	C	89	139 236 297 323 144 217	70 79 87 70 79 87	-6.5 -6.5 -6.5 -5.0 -5.0 -5.0	0 0 0 0 0 0
	C/6	5.4	C	89	241 287 394 289	70 79 87 96	-6.5 -6.5 -6.5 -6.5	0 0 0 0
	D/1	6.3	D	94	1475 1585 1577 1631	75 84 92 100	-3.8 -3.8 -3.8 -3.8	0 0 0 0

(continued)

TABLE 2.45. (continued)

Source	Mine/ Sample	Wind Speed (m/sec)	Stability Class	Back-ground Concentr. (μg\m³)	Net Plume Concentr. (μg/m³)	Downwind Distance (m)	Vertical Distance from Plume Centerline (m)	Horizontal Distance from Plume Centerline (m)
Drag-line	D/2	7.2	D	94	898 1498 1095 1389 763 1258	75 75 84 84 92 92	-3.8 -2.6 -3.8 -2.6 -3.8 -2.6	0 0 0 0 0 0
	D/3	7.2	D	94	1047 1062 608 610	75 84 92 100	-3.8 -3.8 -3.8 -3.8	0 0 0 0
	D/4	7.2	D	101	808 911 892 914 1128 1821	75 75 84 84 92 92	-3.8 -2.6 -3.8 -2.6 -3.8 -2.6	0 0 0 0 0 0
	D/5	6.3	D	101	925 1078 1082 838	75 84 92 100	-3.8 -3.8 -3.8 -3.8	0 0 0 0
	D/6	5.8	D	101	672 1475 668 756	75 84 92 100	-3.8 -3.8 -3.8 -3.8	0 0 0 0
Shovel/ Truck Loading	A/1	.5	B	88	660 1273 583 786 643 618	30 45 60 30 45 60	-2.3 -2.3 -2.3 -1.1 -1.1 -1.1	-3.0 -3.0 -3.0 -2.0 -2.0 -2.0
	A/2	.5	B	88	980 705 528	30 45 60	-2.3 -2.3 -2.3	-1.0 -1.0 -1.0
	A/3	.4	B	88	3104 1217 790	15 30 45	-2.3 -2.3 -2.3	-1.0 -1.0 -1.0
	A/4	.4	B	88	1786 1965 1477 3528 1916 1227	15 30 45 15 30 45	-2.3 -2.3 -2.3 -1.1 -1.1 -1.1	-3.0 -3.0 -3.0 -2.0 -2.0 -2.0
	A/5	1.3	A	87	4135 2449 1699 1399	16 26 36 46	-2.3 -2.3 -2.3 -2.3	0 0 0 0
	A/6	1.3	A	87	1940 1474 1562 1268	16 26 36 46	-2.3 -2.3 -2.3 -2.3	0 0 0 0
	B/1	.6	B	153	5276 3706 2766 2149	35 45 55 65	-2.8 -2.8 -2.8 -2.8	3.5 3.5 3.5 3.5
	B/2	.6	B	153	4924 3910 2662 4763 3712 2576	35 45 55 35 45 55	-2.8 -2.8 -2.8 -1.6 -1.6 -1.6	3.5 3.5 3.5 3.5 3.5 3.5

(continued)

TABLE 2.45. (continued)

Source	Mine/ Sample	Wind Speed (m/sec)	Stability Class	Back- ground Concentr. (µg\m³)	Net Plume Concentr. (µg/m³)	Downwind Distance (m)	Vertical Distance from Plume Centerline (m)	Horizontal Distance from Plume Centerline (m)
Shovel/ Truck Loading	B/3	.4	B	153	1449	30	-2.8	3.5
					2607	40	-2.8	3.5
					2185	50	-2.8	3.5
					3337	30	-1.6	3.5
					2194	40	-1.6	3.5
					1806	50	-1.6	3.5
	B/4	.4	B	153	3907	30	-2.8	3.5
					2223	40	-2.8	3.5
					2096	50	-2.8	3.5
					1859	60	-2.8	3.5
	B/5	np[a]	np	np	1569	40	1.7	
					2351	50	1.7	b
					1743	60	1.7	b
					1470	40	2.9	b
					554	50	2.9	b
					1466	60	2.9	b
	B/6	np	np	np	1739	40	1.7	b
					1410	50	1.7	b
					2450	60	1.7	b
					1516	70	1.7	b
	C/1	3.6	C	59	341	50	-3.8	1.0
					320	50	-2.6	0
					293	59	-3.8	1.0
					296	59	-2.6	0
					287	67	-3.8	1.0
					183	67	-2.6	0
	C/2	3.6	C	59	184	50	-3.8	1.0
					244	59	-3.8	1.0
					269	67	-3.8	1.0
					290	76	-3.8	1.0
	C/3	3.6	C	59	226	50	-3.8	1.0
					130	50	-2.6	0
					192	59	-3.8	1.0
					134	59	-2.6	0
					238	67	-3.8	1.0
					164	67	-2.6	0
	C/4	3.6	C	59	141	50	-3.8	1.0
					120	59	-3.8	1.0
					44	67	-3.8	1.0
					154	76	-3.8	1.0
Shovel/ Truck Loading - Coal	E/1	2.5	B	64	1191	20	6.3	1.0
					1031	20	5.1	0
					1059	28	6.3	1.0
					655	28	5.1	0
					954	37	6.3	1.0
					311	37	5.1	0
	E/2	2.5	B	64	652	20	6.3	1.0
					1163	28	6.3	1.0
					911	37	6.3	1.0
					537	46	6.3	1.0
	E/3	2.3	B	64	855	20	6.3	1.0
					822	20	5.1	0
					806	28	6.3	1.0
					817	28	5.1	0
					859	37	6.3	1.0
					762	37	5.1	0
	E/4	2.3	B	64	880	20	6.3	1.0
					558	28	6.3	1.0
					1061	37	6.3	1.0
					735	46	6.3	1.0

(continued)

TABLE 2.45. (continued)

Source	Mine/ Sample	Wind Speed (m/sec)	Stability Class	Back-ground Concentr. (μg\m^3)	Net Plume Concentr. (μg/m^3)	Downwind Distance (m)	Vertical Distance from Plume Centerline (m)	Horizontal Distance from Plume Centerline (m)
Shovel/ Truck Loading - Over-burden	E/1	3.6	B	112	2569	20	-1.3	2.7
					2510	20	-.1	3.7
					1232	25	-1.3	4.1
					2426	25	-.1	5.1
					1361	30	-1.3	5.6
					1825	30	-.1	6.6
					679	142[b]	-1.3	16.0
					317	142[b]	-1.3	41.0
	E/2	3.6	B	112	2255	20	-1.3	4.7
					2633	25	-1.3	6.1
					2676	30	-1.3	7.6
					2668	35	-1.3	9.0
					646	142[b]	-1.3	66.0
	E/3	3.1	B	112	4572	20	-1.3	1.2
					2298	20	-.1	2.2
					3406	25	-1.3	2.2
					2263	25	-.1	3.2
					2841	30	-1.3	3.4
					2802	30	-.1	4.4
					262	142[b]	-1.3	5.0
					205	142[b]	-1.3	30.0
	E/4	3.1	B	112	4117	20	-1.3	3.2
					2369	25	-1.3	4.2
					4427	30	-1.3	5.4
					3231	35	-1.3	6.4
					308	142[b]	-1.3	55.0
	E/5	2.7	B	112	2739	22	-1.3	6.3
					2106	22	-.1	7.3
					1548	28	-1.3	8.6
					1839	28	-.1	9.6
					1172	33	-1.3	11.0
					1558	33	-.1	12.0
					267	158[b]	-1.3	41.0
					240	158[b]	-1.3	66.0
	E/6	2.7	B	112	2531	22	-1.3	8.3
					2053	28	-1.3	10.6
					2730	33	-1.3	13.0
					2178	39	-1.3	15.3
					403	158[b]	-1.3	91.0
Over-burden Blast	A/1	2.4	B	88	5340	100	-47.6	0
					3222	110	-47.6	0
					2002	120	-47.6	0
	C/1	3.6	B	61	9085	30	-3.8	0
					8799	39	-3.8	0
					5782	47	-3.8	0
					5751	56	-3.8	0
	C/2	3.6	B	61	9930	30	-3.8	0
					7810	30	-2.6	0
					6297	39	-3.8	0
					4503	39	-2.6	0
					5924	47	-3.8	0
					5531	47	-2.6	0
	E/1	3.7	C	77	1094	74	-16.3	29.0
					1502	81	-16.3	31.0
					1359	89	-16.3	34.0
					740	96	-16.3	36.0
					394	197[b]	-16.3	78.0

(continued)

TABLE 2.45. (continued)

Source	Mine/ Sample	Wind Speed (m/sec)	Stability Class	Back-ground Concentr. (µg\m^3)	Net Plume Concentr. (µg/m^3)	Downwind Distance (m)	Vertical Distance from Plume Centerline (m)	Horizontal Distance from Plume Centerline (m)
Over-burden Blast	E/2	3.7	C	77	1327	74	-16.3	24.0
					1064	81	-16.3	26.0
					1097	89	-16.3	29.0
					1265	74	-15.1	19.0
					1323	81	-15.1	21.0
					616	89	-15.1	24.0
					479	197[b]	-16.3	64.0
					445	197[b]	-16.3	53.0
Coal Blast	B/1	3.0	B	153	-	11	0	0
					66611	22	0	0
					76174	33	0	0
					5448	11	0	0
					50274	22	0	0
					67913	33	0	0
	B/2	3.0	B	153	59125	11	0	0
					67093	22	0	0
					74570	33	0	0
	C/1	5.4	C	89	3079	111	-3.8	-.5
					1137	111	-2.6	.5
					2721	121	-3.8	-.5
					3307	121	-2.6	.5
					2669	130	-3.8	-.5
					2189	130	-2.6	.5
	C/2	5.4	C	89	2967	111	-3.8	1.5
					3156	121	-3.8	1.5
					2381	130	-3.8	1.5
					2254	139	-3.8	1.5
	D/1	4.0	B	115	1186	100	-13.8	0
					668	100	-12.6	0
					1149	109	-13.8	0
					733	109	-12.6	0
					1340	117	-13.8	0
	D/2	4.0	B	115	1004	100	-13.8	0
					810	109	-13.8	0
					628	117	-13.8	0
					469	126	-13.8	0
	E/1	2.6	B	128	2289	200	-3.8	43.0
					2194	208	-2.6	44.0
					1456	217	-3.8	46.0
					1851	200	-2.6	42.0
					1939	208	-3.8	43.0
					1587	217	-2.6	45.0
	E/2	2.6	B	128	2627	100	-13.8	21.0
					3347	108	-13.8	23.0
					2203	117	-13.8	25.0
					2485	126	-13.8	27.0
Drilling	A/1	.9	B	88	146	16	.2	c
					292	26	.2	c
					247	36	.2	c
					29	16	1.4	c
					39	26	1.4	c
					-	36	1.4	c
	C/1	3.6	C	89	461	6	1.0	.3
					244	6	2.2	1.3
					403	15	1.0	4.2
					222	15	2.2	5.2
					274	24	1.0	8.2
					129	24	2.2	9.2
	C/2	3.6	C	89	269	6	1.0	2.3
					171	15	1.0	6.2
					175	24	1.0	10.2
					214	34	1.0	14.2

(continued)

TABLE 2.45. (continued)

Source	Mine/ Sample	Wind Speed (m/sec)	Stability Class	Back-ground Concentr. (μg\m^3)	Net Plume Concentr. (μg/m^3)	Downwind Distance (m)	Vertical Distance from Plume Centerline (m)	Horizontal Distance from Plume Centerline (m)
Drilling	E/1	4.1	C	676	2723	5	.7	1.0
					1862	14	.7	1.0
					1127	22	.7	1.0
					717	30	.7	1.0
	E/2	4.1	C	676	2116	5	.7	1.0
					1049	14	.7	1.0
					255	22	.7	1.0
					1307	5	1.9	0
					132	14	1.9	0
					0	22	1.9	0
Train Loading	C/1	4.9	B	89	457	12	-3.4	1.0
					167	12	-2.2	2.0
					50	21	-3.4	1.0
					48	21	-2.2	2.0
					221	29	-3.4	1.0
					11	29	-2.2	2.0
	C/2	4.9	B	89	77	12	-3.4	3.0
					172	21	-3.4	3.0
					103	29	-3.4	3.0
					25	38	-3.4	3.0
	C/3	4.5	B	89	404	12	-3.4	1.0
					186	12	-2.2	2.0
					158	21	-3.4	1.0
					119	21	-2.2	2.0
					328	29	-3.4	1.0
					220	29	-2.2	2.0
	C/4	4.5	B	89	115	12	-3.4	3.0
					132	21	-3.4	3.0
					76	29	-3.4	3.0
					84	38	-3.4	3.0
	E/1	n.d.	n.d.	28	3136	10	-1.3	n.d.
					1474	20	-1.3	n.d.
					943	30	-1.3	n.d.
					1919	40	-1.3	n.d.
	E/2	n.d.	n.d.	28	1416	10	-1.3	n.d.
					2050	20	-1.3	n.d.
					383	30	-1.3	n.d.
					1041	40	-1.3	n.d.
	E/3	n.d.	n.d.	28	2047	10	-1.3	n.d.
					2022	10	-.1	n.d.
					1340	20	-1.3	n.d.
					1155	20	-.1	n.d.
					1041	30	-1.3	n.d.
					1223	30	-.1	n.d.
	E/4	n.d.	n.d.	43	281	10	-1.3	n.d.
					372	10	-.1	n.d.
					127	20	-1.3	n.d.
					105	20	-.1	n.d.
					123	30	-1.3	n.d.
					117	30	-.1	n.d.
	E/5	n.d.	n.d.	43	329	10	-1.3	n.d.
					254	20	-1.3	n.d.
					263	30	-1.3	n.d.
					150	40	-1.3	n.d.
Topsoil Removal (scraper)	D/1	5.8	C	158	1704	30	-.3	np
					2310	34	-.3	np
					1583	38	-.3	np
					466	30	.9	np
					2035	34	.9	np
					1390	38	.9	np

(continued)

TABLE 2.45. (continued)

Source	Mine/ Sample	Wind Speed (m/sec)	Stability Class	Back-ground Concentr. (µg\m³)	Net Plume Concentr. (µg/m³)	Downwind Distance (m)	Vertical Distance from Plume Centerline (m)	Horizontal Distance from Plume Centerline (m)
Topsoil Removal (scraper)	D/2	6.2	C	158	6914 3055 7075 8363	30 34 38 42	-.3 -.3 -.3 -.3	np np np np
	D/3	7.2	C	158	12149 11800 16507 5944 7385 7672	30 34 38 30 34 38	-.3 -.3 -.3 .9 .9 .9	np np np np np np
	D/4	7.2	C	158	5415 7556 6178 8107	30 34 38 42	.3 -.3 -.3 -.3	np np np np
	D/5	7.6	C	158	4797 5925 5658 4597	30 37 41 45	-.3 -.3 -.3 -.3	np np np np
Front-end Loader	D/1	2.7	B	122	1812 2149 2539 1972	80 88 97 106	-1.3 -1.3 -1.3 -1.3	0 0 0 0

[a] np = not published
[b] Sampled by mining company
[c] Samplers not in plume
[d] n.d. = not determined

TABLE 2.46. AVERAGE EMISSION RATES BY OPERATION AND MINE[a]

Operation	Units	Mine				
		A N.W. Colorado	B S.W. Wyoming	C S.E. Montana	D Central N. Dakota	E. N.E. Wyoming
Dragline	lb/yd^3	.0056	.053	.0030	.021	
Shovel/Truck loading	lb/ton					
coal		.014	.007	.002		.0035
overburden						.037
Blasting	lb/blast					
coal				25.1	78.1	72.4
overburden		1690		14.2		85.3
Truck dump	lb/ton					
bottom dump		.014	.020	.005	.027	
end dump						.007
overburden						.002[b]
Drilling	lb/hole					
coal						.22
overburden				1.5		
Fly-ash dump	lb/hr	3.9				
Train loading	lb/ton			.0002		
Topsoil removal	lb/yd^3					
scraping					.35	
dumping					.03	
Front-end loader	lb/ton				.12	

a) The authors advise that these factors should be used only in conjunction with theoretical fallout factors.

Study 2-- Chalekode et al. Emissions from the Crushed Granite Industry: State of the Art. EPA-600/2-78-021. 1978.

Methodology--The investigators used upwind-downwind dispersion modeling to estimate emission factors for several quarrying and rock processing operations. Only two of these operations, drilling and blasting, are pertinent to the "mining and quarrying" category. Turner's (1970) equation for a ground level source with no plume rise was used to model the source strength from drilling:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z}$$

For blasting, the following model was used to estimate the total mass emitted:

$$D_T = \frac{Q_T}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

where

D_T = total dose, g-sec/m^3
Q_T = total release, grams and all other variables are defined as normal

The source strength for each sampling run was calculated as the average of the emission rates calculated from concentration measurements at several downwind stations. This was then divided y the production rate to give an emission factor in mass emitted per unit mass of product.

Test Sites--Two granite quarrying and processing facilities served as test sites for this study. The operations were said to be representative of the granite industry.

Parameters and Equipment--The report only partially documents the use of field equipment, particularly instruments which measure dust concentration. The summary below is based on limited textual explanation as well as tabular data on sampling durations.

A GCA portable respirable dust monitor, which uses "electronic measurement of the beta absorption of the collected sample" of air, was used to measure dust concentrations downwind from the drilling operations. The monitor, which normally captures particles smaller than 50 µm in diameter, was equipped with a cyclone separator, providing a cut point of 10 µm. Wind speed was recorded automatically every 15 seconds by an anemometer attached to the respirable dust monitor. Mean wind speed for each sample was computed by averaging the 15 second readings.

High volume samplers were used to measure concentrations upwind and downwind from quarry blasts and apparently some drilling operations. Wind speed, wind direction and temperature were measured from a meteorological station. An average wind speed was computed at the end of each 15 minutes. These values were then averaged to yield an average wind speed for the sampling run. Stability class was determined on the basis of cloud cover, wind speed, and time of day. Sampler positions relative to the source were estimated by pacing.

Equipment Configuration--Again, documentation of equipment deployment was inadequate. The authors did not describe how the portable dust monitor was positioned in the field. For blasting, five hi-vols were used, one upwind and four downwind. Three downwind samplers were configured in an arc of roughly equal distance from the source, and the fourth was closer to the source and near the plume centerline (i.e. $y \approx 0$). The distances of all of these samplers from the source were not published.

Sampling Runs--Only one concentration measurement from downwind of the blasting operation was reported. It was a 45 minute sample. The remaining seven published concentrations were from four-minute samples taken downwind of drilling activities. Water was applied to the drill face in six of these. The number of blasts, the number of holes drilled, and the depth of the holes drilled during sampling were not documented.

Quality Assurance--The issue of quality assurance was not addressed in this report. No documentation was provided for calibration of sampling equipment, auditing of filter weights, or use of reference methods.

The explanation of field sampling procedures and conditions was unclear. Although the authors noted that the hi-vols were used for all concentration measurements, use of the respirable dust monitor was also mentioned. It was capable of collecting samples over a short time period. Thus, for this review it was assumed that the four minute samples were taken using the respirable dust monitor and that the 45 minute blasting sample was collected with the hi-vol. It should be noted that although five hi-vols were employed, only one concentration reading for the blasting was published. The hi-vol sampler from which it was derived was not reported.

The method used to measure emissions from blasting may have been inappropriate for the source. It is likely that the dust plume from a single blast would remain in the vicinity for only a fraction of the 45 minutes during which the air sample was collected, especially given the measured wind speed of 7 mph. As was noted earlier, the number of blasts set off during the sampling time was not reported. However, it seems unlikely that multiple blasts could be set off at the same distance upwind from the sampler during a 45 minute period, particularly given the authors' indication that a single blast typically provided enough raw material for the processing facility for several days. Consequently, the available evidence indicates that a significant portion of the air sampled by the downwind hi-vol was not from the blast plume. If this was the case, then the measured downwind concentration would not have been representative of the average concentration **in the plume**, resulting in an inaccurate estimate of the emission factor.

The investigators did not use an appropriate model to estimate emissions from drilling. Their reported modeling parameters indicate that downwind concentration measurements were not made on the plume centerline. In the modeling framework presented by Turner (1970), such a source should be modeled using an equation which includes the following correction factor to adjust for concentration measurements taken away from the plume centerline:

$$\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

where

- y = distance between plume centerline and receptor
- σ_y = standard deviation of the plume's crosswind concentration distribution

Findings--The published dispersion modeling data and the resulting source strengths are shown in Table 2.47. Note that the source strength, even for blasting, is given in mass per unit time. In the text of the report, the authors noted that the tabulated emission from blasting was actually mass per blast. This is yet another discrepancy in the report.

The investigators learned from plant personnel that one blast typically provides material for 26,250 tons of product. The resulting emission factor, after converting to metric tons, was .0796 kg of "total particulate" (< 100 µm in diameter) per metric ton of product. Based on the findings of Blackwood et al., 1978, which indicate that the average ratio between respirable particulates and total particulates in (traprock) quarrying emissions is 0.169, the emission factor for respirable particulates (< 10 µm) was calculated as .0135 kg/metric ton.

The investigators averaged the four wet drilling, total particulate emission rates to derive a single source strength: 0.015 grams/sec. In converting this to an emission factor, it was assumed that most plants use wet drilling and that the drilling time averages 176 hours per blast. The resulting factor for total particulates was 3.99×10^{-4} kg/metric ton. The average of the two respirable emission rates 0.0015 grams/sec, or 10% of the average total particulate source strength. Therefore, the emission factor for respirable particulates was taken to be 10% of the factor for total particulates: 3.99×10^{-5} kg/metric ton.

TABLE 2.47. DISPERSION MODELING DATA

Activity	Wind Speed (mph)	Monitoring Position (feet)			Concentration[a] (μg/m³)	Source Strength (grams/sec)	Stability Class
		X	Y	Z			
Blasting	7	2300	0	230	763.4 total	1908000	D
Drilling, Dry	2	78	20	0	1540 respire	.3562	C
Drilling, Wet	2	90	22	0	70 total	.01159	D
Drilling, Wet	2	90	22	0	130 total	.02152	D
Drilling, Wet	2	90	0	0	560 total	.006728	D
Drilling, Wet	2	90	22	0	130 total	.02152	D
Drilling, Wet	2	90	0	0	120 respire	.001442	D
Drilling, Wet	2	90	0	0	130 respire	.001562	D

a) some measurements were for total particulates and others were for respirable particulates (i.e. smaller than 10 μm in diameter)

Publication--This study was conducted and documented under contract for the EPA, Industrial Environmental Research Laboratory, Cincinnati, Ohio. It was published as Publication No. EPA-600/2-78-021 in February of 1978.

Study 3-- Blackwood and Chalekode. Source Assessment: Crushed Stone. EPA-600/2-78-004L. 1978.

Methodology--This study was very similar to the source assessment of crushed stone production (Chalekode et al., 1978). In fact, much of the documentation was identical to that of Chalekode et al., 1978. It should be noted that this report was published about two months after Chalekode et al., and that Chalekode and Blackwood were co-authors of both reports.

As in the earlier study, the investigators used upwind-downwind dispersion modeling to estimate emission factors for rock excavation operations. Blasting and quarrying (i.e. gathering and loading blasted material into haul trucks) were monitored, and Turner's (1970) equation for a ground level point source with no plume rise was used to model the source strength:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

Test Sites--Field monitoring was conducted at two unidentified stone quarry and processing operations. Both produced crushed traprock. They were considered representative of the crushed stone industry, particularly because 68% of crushed stone produced (in 1978) was traprock.

Parameters and Equipment--High volume samplers were used to test emissions from blasting and quarrying. They collected particles smaller than 100 µm in diameter. Wind speed, wind direction, and temperature were measured from a meteorological station. An average wind speed was computed at the end of each 15 minutes. These 15-minute averages were then averaged to give a mean wind speed for the sampling run. Stability class was determined and reevaluated every two or three hours on the basis of cloud cover, wind speed, and time of day.

Equipment Configuration--Five hi-vols were distributed in the same manner described for Chalekode et al., 1978. The distances of all of these samplers from the source were not published. In fact, the reported field data only provide concentrations at one, or at most two, monitoring stations, which were identified by their coordinates relative to the source. Neither the sampling height of the monitor nor the location of the wind or temperature measurements were documented.

Sampling Runs--The extent of sampling conducted for this study is unclear. Two concentration measurements were presented for blasting and two for quarrying. The two blasting samples were collected over 16 and 55 minute periods. Both quarrying samples were collected over 45 minute periods. Concentration measurements were not reported for all of the downwind monitoring sites. The authors did not indicate which, if any, of the tabulated concentration measurements were made simultaneously.

Quality Assurance--The documented quality assurance practices for this study are limited. The hi-vols were calibrated prior to sampling, and filters were inspected and desiccated prior to weighing.

A lack of clear documentation of the methodology and findings brings the quality of the published data into question. As was noted under "Sampling Runs," the tabulated findings do not coincide with the described methodology. The applied dispersion model assumes that monitors are at ground level. However, one of the samples was given a z-coordinate (height) of 30 feet.

Findings--The dispersion modeling parameters for the blasting and quarrying operations are presented below in Table 2.48.

TABLE 2.48. DISPERSION MODELING PARAMETERS

Activity	Wind Speed (mph)	Monitoring Position (feet)			Concentration ($\mu g/m^3$)	Source Strength	Stability Class
		X	Y	Z			
Blasting	8	204	0	0	393	179.8 grams	C
Blasting	8	204	0	0	678	1066 grams	C
Quarrying	17	615	0	30	169	1.602 grams/sec	C
Quarrying	17	791	0	0	135	1.595 grams/sec	C

The emission factors for blasting were reported at 8.8 mg/metric ton for "respirable particulates" (< 10 µm in diameter) and 52.2 mg/metric ton for "total particulates" (< 100 µm). For quarrying, the respective factors are 1,050 mg/metric ton and 10,500 mg/metric ton. The method of deriving these factors was not described.

Publication--This report is Publication No. EPA-600/2-78-004L, prepared for EPA's Industrial Environmental Research Laboratory in Cincinnati, Ohio. It was published in May of 1978.

Study 4-- Axetell and Cowherd. Improved Emission Factors for Fugitive Dust From Western Surface Coal Mining Sources. EPA-600/7-84-048. 1984.

Methodologies--Seven different mining operations were tested to determine emission factors for fugitive dust. The sampling/measurement method depended upon the character of the source. Upwind-downwind dispersion modeling was used for dozer, scraper, dragline, and coal loading (with shovels or front-end loaders) operations. The investigators used the same dispersion models as were described in the review of Axetell, 1978. The scraper was tested as a captive line source. It was driven back and forth along a test strip without scraping or dumping, because emissions from these two actions were judged to be insignificant when compared to emissions from the movement of the vehicle across the ground. The dozer was treated as a line source when it could be found operating in that mode; when it could not it was tested as a captive area source. The dragline and coal loading operations were modeled as area sources.

Normal exposure profiling was used for grader and scraper operations. These sources were considered line sources, and, as such, a horizontal array of plume samplers was not needed. Sample masses were converted to concentration by dividing by the flow rate and the sampling duration. Exposure at each intake is then calculated as the product of concentration, sampling rate, and duration, divided by the area of the sampler intake.

The scraper operation was tested using both profiling and modeling to determine the comparability of the results of these two methods. The results of this comparability study, which also included testing of unpaved road emissions using the two methods and an evaluation of several particle sizing devices, are described in the review of this document in the unpaved roads section.

Blasting of overburden was tested using a variation of exposure profiling which merits elaboration here. An array of five samplers was suspended from a tethered balloon to enable sampling over the vertical extent of the plume. Each sampler was fitted with a wind vane which kept the intake pointing into the wind. Flexible tubing ran from each sampler to a pump on the ground. The samplers operated isokinetically at a wind speed of 5 mph. Sampler pairs consisting of a standard hi-vol and a dichotomous sampler were distributed in an arc at the same distance from the blast area as the balloon. They provided data on concentration across the horizontal extent of the plume. Plume boundaries were determined from these measured concentrations and photographs. The mass of dust passing the downwind sampling location was calculated by integrating measured concentrations with respect to horizontal position and height and multiplying by the wind speed and sampling time.

Emissions from the drilling operation were measured using the quasi-stack method. A temporary enclosure was placed over the drill and hole, and dust emissions were vented through a single outlet. The outlet area was divided evenly into four equal parts. The wind velocity was measured and air samples were collected at the center of each of these areas simultaneously. To approximate isokinetic conditions, the intake velocity of the samplers was adjusted every two to three minutes. The mass emitted was calculated using the following equation:

$$E = \sum_{i=1}^{4} V_i \chi_i$$

where

E = emitted mass, g
χ_i = concentration measured at sampler i, g/m^3
V_i = total volume of air filtered through sampler i, m^3

This mass was then converted to an emission factor by dividing by the number of holes drilled.

Test Sites--Tests were conducted at three unspecified mines, one in each of the following Western coal fields: Powder River Basin, Fort Union, and San Juan River. These three fields were targeted for the study because they produce high volumes of strip-mined coal and because they are diverse in character. The investigator's intent with this selection was to maximize the representativeness of the findings while satisfying budget and time constraints.

Parameters and Equipment--The plume sampling parameters measured for each operation are discussed in the following section. Those source characterization and meteorological parameters which were monitored for each operation are listed in Table 2.49.

TABLE 2.49. SOURCE CHARACTERIZATION AND METEOROLOGICAL PARAMETERS

Operation	Parameter	Equipment/Source
Drilling	Silt content Moisture content Depth of hole	Oven, sieves, scales Oven, scales Given by drill operator
Blasting	Number of holes Size of blast area Moisture content	Direct observation Direct observation Given by mining company

(continued)

TABLE 2.49. (continued)

Operation	Parameter	Equipment/Source
Coal loading	Silt content Moisture content Bucket capacity Equipment operation	Oven, sieves scales Oven, scales From equipment specifications Field notes on variations
Dozer	Silt content Moisture content Speed Blade size	Oven, sieves, scales Oven, scales Time/distance From equipment specifications
Dragline	Silt content Moisture content Bucket capacity Drop distance	Oven, sieves, scales Oven, scales From equipment specifications Direct observation
Scraper & Grader	Surface silt content Vehicle speed Vehicle weight Total surface loading Surface moisture content Number of wheels	Oven, sieves, scales Radar gun Truck scale Broom, scales Oven, scales Direct observation
All sources	Wind speed Wind direction Temperature Solar intensity Humidity Atmospheric pressure Cloud cover	Anemometer Anemometer Thermometer Pyranograph Sling psychrometer Barometer Direct observation

Equipment Configuration--

Quasi-Stack Method--The equipment configuration for the drilling operation was relatively simple. A wooden enclosure was constructed with 4 X 6 foot openings at two ends. This enclosure was set up on the downwind side of the drill base. Four profile samplers were fixed horizontally across the downwind outlet of the enclosure. No other air sampling equipment was used for this operation. Deposition was not monitored.

Exposure Profiling Using Tethered Balloon--A vertical array of samplers was suspended from a balloon about 100 meters downwind from the edge of the blast zone. Five sampler heads were positioned at heights of 2.5, 7.6, 15.2, 22.9, and 30.5 meters. Five hi-vol/dichot sampler pairs were each

20 to 30 meters apart. The dichot samplers provided data on the particle size distribution of the plume. Dust deposition was not measured for this operation.

Standard Exposure Profiling--For those tests which employed exposure profiling as the only emissions measurement technique, the following equipment was placed between five and ten meters downwind from the source: exposure profiler with sampling heads at 1.5, 3.0, 4.5, and 6 meters above the ground; a standard hi-vol sampler and a hi-vol fitted with a cascade impactor and cyclone preseparator, both having inlets 2.5 meters high; two dichot samplers with intakes 1.5 and 4.5 meters above the ground; two dustfall buckets at a height of 0.75 meters; and two warm wire anemometers at heights of 1.5 and 4.5 meters. Pairs of dustfall buckets were also collocated 0.75 meters above the ground at 20 and 50 meters downwind, permitting measurement of dust deposition rates.

The following equipment was set up five meters upwind from the road: one dichot sampler 2.5 meters above the ground; one standard hi-vol sampler, also at a height of 2.5 meters; two dustfall buckets 0.75 meters above the ground; and one continuous wind monitor 4 meters high.

Upwind-Downwind Method--The configuration of equipment for this method depended on whether the mining operation was treated as a line source or a area source. For area sources an array of about 14 air samplers, 9 hi-vol and 5 dichot, was set up on the downwind side. Each sampler was mounted on a tripod stand such that it sampled at a height of 2.5 meters. Two hi-vol/dichot sampler pairs were placed about 30 meters downwind. Three of these pairs were placed in an arc about 60 meters downwind. Three hi-vols were distributed at a downwind distance of about 100 meters. When the layout of the field sites permitted, one or two hi-vols were placed about 200 meters from the source. Upwind air samples were collected with a hi-vol and a dichot sampler placed between 30 and 100 meters from the source. They also sampled at a height of 2.5 meters.

For line sources, two hi-vol/dichot sampler pairs were placed about 20 meters apart at each of the following downwind distances: 5, 20, and 50 meters. Two hi-vols were placed 100 meters downwind. These all sampled air 2.5 meters above the ground.

In addition to the dichot samplers, millipore filters were used to provide a measure of particle size distribution. The height and downwind distance at which these filters were exposed were not documented.

Simultaneous Exposure Profiling and Upwind-Downwind--The equipment configuration for those tests in which both exposure profiling and upwind-downwind modeling were used was very complex. Downwind air sampling was conducted primarily at three downwind distances: 5, 20, and 50 meters. Profiling towers were set up at each of these stations so plume mass depletion could be measured in addition to simple exposure. The closest tower consisted of four sampling heads at heights ranging from 1.5 to 6 meters. The towers at 20 and 30 meters downwind both had five sampling heads, with the highest heads at 9 and 12 meters, respectively. This was necessary due to the increased dispersion of the plume over longer distances from the source. A vertical array of dichot samplers was also set up five meters downwind. The sampling heights matched those of the nearby exposure profiler. Two single dichot samplers were also set up on either side of the profiling towers at each of the three downwind monitoring distances. They had intakes 2.5 meters above the ground.

Two standard high volume samplers (all sampling at a height of 2.5 meters) were set up at each of the downwind distances: 5, 20, 50, and 100 meters. A third standard hi-vol was used five meters downwind. A total of three hi-vol cascade impactors were used, two 5 meters from the road with intakes 1.5 and 4.5 meters above the ground, and one 20 meters from the road with its intake 2.5 meters high. Dustfall buckets were placed in pairs at each of the three downwind distances such that their sampling height was 0.75 meters.

Sampling Runs--The number of sampling runs and the sampling method(s) for each operation are listed in Table 2.50.

TABLE 2.50. SAMPLING RUNS FOR EACH OPERATION

Source	Method(s)	Sampling Runs	Approximate Duration per Run (min)
Drilling (overburden)	Quasi-stack	30	15-90
Blasting	Exposure profiling with tethered balloon	18	3-30
Coal loading	Upwind-downwind	25	15-90
Dozers	Upwind-downwind	27	15-145
Dragline	Upwind-downwind	19	30-75
Scraper	Exposure profiling and Upwind-downwind	5	15-110
Grader	Exposure profiling	7	30-120
Total		131	

Quality Assurance--This study included a thorough quality assurance program, which was subject to evaluation by a technical review group (including the two EPA project officers, and representatives of the Bureau of Land Management, the Bureau of Mines, and the mining industry). Profilers, hi-vols, impactors, and dichot samplers were calibrated on a regular basis. Sampling media were conditioned at constant temperature and humidity prior to weighing. Seven percent of tare and final filter weights were audited. For every ten regularly processed filters and substrates, at least one was processed as a blank.

Regarding sampling isokineticity of the profiler, sampling intakes were reoriented if the 15 minute average wind direction changed by more than 30°, and the sampling rate was corrected when the 15 minute average wind speed changed by more than 20%.

For tests of scraper and grader emissions, the investigators recorded the total number of passes as well as the number of "bad" passes, in which the wind direction reversed and upwind filter weights were affected by road emissions. For one of the scraper tests, only about half of the passes were judged to be good. There were no bad passes for the grader tests. For runs in which bad passes occurred, the upwind dust concentration was estimated by the average of the concentrations of the previous and following sampling runs. Bad passes were not counted when calculating the emission factor (i.e. when dividing the integrated exposure by the number of vehicle passes).

Despite the attention given to normal quality assurance practices in field data collection, the overall level of quality assurance for this study is compromised by the paucity of published raw field data. For instance, measured exposures at the various profiling heights were not reported. Because of this omission, the calculations of base emission factors made by the investigators cannot be repeated and verified.

Findings--The emission factors measured for each sampling run are shown in the Tables 2.51-2.55. Multiple linear regression analysis yielded the predictive equations for TSP and IP emissions shown in Table 2.56. With the exception of four predictor variables, all are significant at the 0.05 level. For the drilling operation, the only variable which proved useful in predicting TSP was % silt. However, contrary to expectations, the relationship between % silt and TSP was inverse; therefore, it was eliminated from the equation, leaving only the geometric mean as the emission factor.

Publication--This study was conducted and documented under contract with the EPA Office of Air Quality Planning And Standards, Research Triangle Park, North Carolina, and the EPA

Industrial Environmental Research Laboratory, Cincinnati, Ohio. It was published as Publication No. EPA-600/7-84-048 in March 1984.

TABLE 2.51. EMISSION FACTORS DERIVED USING EXPOSURE PROFILING: SCRAPER AND GRADER

		Emission Factor (lb/veh-mile)			
Source	Run	Total[a]	d[b] < 30 μm	d[b] < 15 μm	d[b] < 2.5 μm
Scraper	J-1	41.4	8.6	4.2	0.27
	J-2	66.5	9.4	4.0	0.19
	J-3	125	50.2	26.1	1.5
	J-4	27.5	3.9	1.7	0.09
	J-5	96.7	17.7	10.0	1.4
	K-15	126	16.2	7.2	0.39
	K-16	206	29.2	15.6	1.8
	K-17	232	74.3	35.6	1.6
	K-18	179	43.0	19.3	0.81
	K-22	58.4	10.3	4.8	0.29
	K-23	118	24.5	11.1	0.54
	L-5	360[c]	355[c]	217[c]	0.72[c]
	L-6	184	163	94	1.0
	P-15	383	d	d	d
	P-18	18.8[e]	4.0[e]	1.4[e]	0.02[e]
Grader	K-19	31.3	4.0	2.3	0.33
	K-20	29.0	4.3	1.7	0.46
	K-21	22.5	1.8	0.89	0.08
	K-24	13.1	3.2	1.9	0.29
	K-25	19.5	7.3	4.1	0.38
	P-16	53.2	34.0	15.4	0.09
	P-17	73.9	8.6	2.9	0.04

a) total particulates (i.e. all sizes)
b) aerodynamic diameter
c) profiler samplers malfunctioned
d) only one dichot sampler and only four good passes
e) only two profilers operational

TABLE 2.52. EMISSION FACTORS DERIVED FROM QUASI-STACK TESTING: DRILLING

	Emission Factor (lb/hole)			Emission Factor (lb/hole)	
Mine/Run	Filter[a]	Total[b]	Mine/Run	Filter[a]	Total[b]
1/1	1.18	6.75	1W/5	2.54	111.72
1/2	0.20	0.75	1W/6	2.91	44.34
1/3	0.24	0.81	1W/7	3.35	68.50
1/4	0.04	0.28	1W/8	3.05	40.71
1/5	0.17	0.47	1W/9	2.23	34.86
1/6	0.11	1.92	1W/10	0.53	2.09
1/7	0.33	7.61	1W/11	0.06	1.04
1/8	1.56	24.31	1W/12	0.45	3.89
1/9	1.98	50.31	3/1	3.06	21.07
1/10	2.43	41.01	3/2	7.29	35.23
1/11	0.95	12.69	3/3	4.65	12.72
1W[c]/1	0.76	5.80	3/4	6.48	22.18
1W/2	3.38	43.46	3/5	4.04	15.92
1W/3	2.57	144.3	3/6	1.79	9.96
1W/4	1.95	23.52	3/7	5.84	26.47

a) calculated using only the mass collected on the filter
b) calculated using mass on the filter and in the settling chamber
c) winter sampling at mine 1

TABLE 2.53. EMISSION FACTOR DERIVED USING EXPOSURE PROFILING WITH TETHERED BALLOON: BLASTING

Mine/Material	Run	Emission factor (lb/blast)		
		$d^a < 30$ µm	$d^a < 15$ µm	$d^a < 2.5$ µm
1/Coal	1	32.5	44.9[b]	3.62
1/Coal	2	2.7	1.56	0.32
1/Coal	3	51.7	17.3	1.23
1/Overburden	1	40.4	32.9	0.79
1/Overburden	2	79.4	48.9	0.09
2/Coal	1	8.8	1.55	0.10
2/Coal	2	1.1	0.62	0.06
2/Coal	3	10.7	3.57	0.80

(continued)

TABLE 2.53. (continued)

Mine/Material	Run	Emission factor (lb/blast)		
		d[a] < 30 μm	d[a] < 15 μm	d[a] < 2.5 μm
2/Coal	4	1.6	0.45	0.10
2/Coal	5	40.3	15.30	1.27
2/Coal	6	11.8	1.99	0.01
3/Coal	2	401	123.4	10.4
3/Coal	3	514	142.8	12.3
3/Coal	4	148	87.9	13.0
3/Coal	5	113	35.3	2.1
3/Coal	6	206	71.3	19.8
3/Overburden	1	35.2	16.9	3.5
3/Overburden	2	270	93.9	16.2

a) aerodynamic diameter
b) this value represents mass of particles with aerodynamic diameter < 20.5 μm.

TABLE 2.54. EMISSION FACTORS DERIVED FROM UPWIND DOWNWIND MODELING: COAL LOADING

	Emission Factor (lb/ton)				Emission Factor (lb/ton)		
Mine/Run	TSP	IP	FP	Mine/Run	TSP	IP	FP
1/1	0.0069	.002	.0001	3/4	0.0105	.002	.0002
1/2	0.0100	.003	.0002	3/5	0.0087	.001	.0001
2/1	0.044	.005	.0002	3/6	0.0140	.006	.0001
2/2	0.068	.022	.0008	3/7	0.035	.008	.0012
2/3	0.0147	.003	.0001	3/8	0.062	.012	.0012
2/4	0.0134	.005	.0018	3/9	0.058	.014	.0005
2/5	0.0099	.004	.0007	3/10	0.193	.038	.0033
2/6	0.0228	.017	.0029	3/11	0.095	.020	.0005
2/7	0.0206	.008	.0008	3/12	0.042	.011	.0021
2/8	0.0065	.004	.0002	3/13	1.09	.378	.0054
3/1	0.120	.044	.0038	3/14	0.358	.121	.0035
3/2	0.082	.008	.0005	3/15	0.188	nd	nd
3/3	0.051	.016	.0022				

TABLE 2.55. EMISSION FACTOR DERIVED FROM UPWIND-DOWNWIND METHOD: DOZER, DRAGLINE, AND SCRAPER

		Emission Factor						Emission Factor			
Mine/Source	Run	TSP	IP	FP	Units	Mine/Source	Run	TSP	IP	FP	Units
1/Dozer (Over-burden)	1	16.2	3.18	.436	lb/hr	3/Dozer (Coal)	5	224	82.2	3.50	lb/hr
	2	12.6	2.18	.322	lb/hr	1/Dragline	1	.024	.006	.0009	lb/yd^3
	3	2.6	2.85	1.01	lb/hr		2	.029	.012	.0002	lb/yd^3
	4	3.0	c	c	lb/hr		3	.004	.002	.0001	lb/yd^3
2/Dozer (Over-burden)	1	0.9	2.12	.583	lb/hr		4	.048	.006	.0001	lb/yd^3
	2	1.8	5.88	.091	lb/hr		5	.070	.0165	.0009	lb/yd^3
	3	2.6	1.00	.790	lb/hr		6	.400	.061	.0087	lb/yd^3
	4	1.3	0.48	.065	lb/hr	2/Dragline	1	.042	.003	.0002	lb/yd^3
	5	9.2	1.14	.680	lb/hr		2	.026	.007	.0008	lb/yd^3
	6	1.0	0.68	.421	lb/hr		3	.003	.001	.0003	lb/yd^3
	7	1.0	1.22	.536	lb/hr		4	.016	.015	.0010	lb/yd^3
3/Dozer (Over-burden)	1	5.4	.98	.356	lb/hr		5	.068	.035	.0110	lb/yd^3
	2	5.2	.781	.089	lb/hr	3/Dragline	1	.184	.018	.0017	lb/yd^3
	3	18.0	4.57	.925	lb/hr		2	.133	.016	.0011	lb/yd^3
	4	20.7	32.6	1.73	lb/hr		3	.192	.058	.006	lb/yd^3
1/Dozer (Coal)	1	16.1	4.49	.243	lb/hr		4	.099	.043	.005	lb/yd^3
	2	40.1	39.9	.730	lb/hr		5	.060	.038	.0001	lb/yd^3
	3	19.0	4.73	1.00	lb/hr		6	.068	.028	.0017	lb/yd^3
	4	21.3	13.0	2.68	lb/hr		7	.104	.024	.0023	lb/yd^3
2/Dozer (Coal)	1	9.1	2.26	.252	lb/hr		8	.105	.017	.0004	lb/yd^3
	2	6.2	2.26	.199	lb/hr	1/Scraper	J1	10.6			lb/veh-mile
	3	3.0	0.92	.138	lb/hr		J2	18.6			lb/veh-mile
3/Dozer (Coal)	1	289	177	3.50	lb/hr		J3	35.6			lb/veh-mile
	2	222	178	2.25	lb/hr		J4	5.7			lb/veh-mile
	3	439	236	4.49	lb/hr		J5	20.0			lb/veh-mile
	4	323	176	3.28	lb/hr						

TABLE 2.56. PREDICTIVE EQUATIONS DEVELOPED THROUGH REGRESSION ANALYSIS OF FIELD DATA[a]

Operation	TSP	IP	Units
Drilling	1.3	NA	lb/hole
Blasting	$(961\ A^{0.8})/(D^{1.8}\ M^{1.9})$	$(2550\ A^{0.6})/(D^{1.5}\ M^{2.3})$	lb/blast
Coal loading	$1.16/M^{1.2}$	$0.119/M^{0.9}$	lb/ton
Dozer, coal	$78.4\ s^{1.2}/M^{1.3}$	$18.6\ s^{1.5}/M^{1.4}$	lb/hour
Dozer, overburden	$5.7\ s^{1.2}/M^{1.3}$	$1.0\ s^{1.5}/M^{1.4}$	lb/hour
Dragline	$0.0021\ d^{1.1}/M^{0.3}$	$0.0021\ d^{0.7}/M^{0.3}$	lb/yd^3
Scraper	$(2.7 * 10^{-5})\ s^{1.3}\ W^{2.4}$	$(6.2 * 10^{-6})\ s^{1.4}\ W^{2.5}$	lb/veh-mile
Grader	$0.040\ S^{2.5}$	$0.051\ S^{2.0}$	lb/veh-mile

a) A = area blasted, ft^2; D = depth of holes, ft; M = moisture content, %; s = silt content, %; d = drop distance, ft; W = vehicle weight, tons; S = vehicle speed, mph

Studies of Secondary Importance

Study 5-- Cook et al. Fugitive Dust from Western Surface Coal Mines. EPA-600/7-80-158. 1980.

The methodology for this study was relatively straight-forward. Data were collected on a series of environmental parameters at several strip mines in the Western U.S.: total suspended particulate (TSP) concentration, duration of mining operation (for 12 different operations), wind speed, and precipitation. An analysis of variance (ANOVA) and regression analysis were conducted to determine which variables are statistically related to TSP. Emission factors for the various activities were not calculated.

Measurements were collected at four mines in three separate visits per mine. These visits took place during late spring, fall, and winter. Two of the mines had rolling terrain with predominantly grassland vegetation, and two had semi-rugged terrain with sagebrush vegetation.

The field sampling program was performed by a subcontractor. Four high volume samplers fitted with Anderson heads were used to measure TSP. The investigators noted that the hi-vols (General Metal Works GMWL 2000) collected particles smaller than 100 μm in diameter. The mass on each filter was combined to give the TSP mass. The samplers were set up between 250 and 500 meters downwind of each operation. Sampling periods corresponded roughly with the eight-hour work shifts at the mines. It should be noted that the wind direction sometimes changed, causing nominal downwind samplers to be outside of the plume for a period.

Detailed procedures for filter and dust sample handling were well-documented. Plastic gloves were always used when handling filters to prevent changes in weight due to contamination. Filters were individually packed in plastic bags before and after sample collection.

The relationship between TSP and the predictor variables was estimated by the equation below:

$$TSP = 30.3\ Q_1^{0.13}\ Q_2^{0.10}\ Q_8^{0.10}\ S^{0.40}$$

where

TSP	=	average concentration of particles with diameter < 100 μm, $\mu g/m^3$
Q_1	=	dragline operating minutes per shift
Q_2	=	coal truck hauling trips per shift
Q_8	=	number of vehicle passes on nearby public road per shift
S	=	wind speed, mph

The investigators noted that of the four predictor variables, wind speed had the strongest influence on TSP, as indicated by the fact that doubling S would increase TSP by 32%, whereas doubling each of the other variables individually would increase TSP by no more than 10%.

This study was published in August of 1980 as Publication No. EPA-600/7-80-158. It was conducted for the Environmental Protection Agency, Industrial Environmental Research Laboratory in Cincinnati, Ohio.

Study 6-- Marple et al. Fugitive Dust Study of an Open Pit Coal Mine with the University of Minnesota Mobile Laboratory. 1980.

The emphasis of this study was on determining what instruments could feasibly be used in monitoring fugitive dust from a mobile laboratory. The concentration and particle size distribution of dust from the mine were the main parameters of interest. The report consists primarily of 1) documentation of the contents and design capabilities of the University of

Minnesota Mobile Laboratory (UMML), 2) a description of the field sampling activities, 3) data analysis and findings, and 4) conclusions and recommendations.

Field experimentation was conducted at several sites in a strip mine in the western United States. The mining activities occurring during the field tests were similar to those described in Axetell et al., 1984, which is also summarized in this section.

Particle size distribution was measured in parts with several different instruments. An electrical aerosol analyzer (EAA) counted particles in the size range 0.01 µm to 1 µm. A modified optical particle counter (OPC) measured the concentration of particles in the 0.5 to 5.6 µm range, and a second modified OPC measured particles from 5.6 µm to 15 µm in diameter. In addition, an Aitken nuclei counter (General Electric GE-1) and a rate meter attached to the large particle OPC provided real time data on the concentration of particles in the respective ranges 0.01 µm to 1.0 µm and larger than 5.6 µm. The measurement height for all of these instruments was about 3 meters. Open faced Millipore filters were exposed and analyzed microscopically as a check on the ability of the above equipment to detect very large particles. A special cascade impactor was used in the field tests, though it was not part of the UMML. The impaction plates rotated during sample collection so that dust was distributed evenly around the impaction substrates.

In addition to dust particle size and concentration, data were collected for meteorological parameters, gas concentrations, and aerosol chemistry from instruments on the UMML.

Conclusions regarding plume dust which were drawn by the investigators as a result of this study are listed below:

- The instruments in the UMML could be used to study and measure dust plumes in any location the UMML could access.

- For plumes from passing vehicles, the concentration increased as vehicle size increased, as vehicle speed increased, and as the distance from the road decreased.

- Dust emissions were measured in terms of mass per unit length of road per unit of plume height. Plume height was never measured or estimated, so emission factors could not be calculated.

This study was conducted for the U.S. Department of Interior, Bureau of Mines, under contract J0295071. The researchers worked under the auspices of the University of Minnesota, Particle Engineering Laboratory, Minneapolis, Minnesota. The report date is August, 1980. It was apparently never published.

STORAGE PILES

Introduction

The transfer of aggregate material into and out of storage piles and the maintenance of those storage piles generates fugitive dust. Emissions have been measured or modeled in five field studies, four of which were performed by the Midwest Research Institute. The first two, which were documented in the original exposure profiling report (Cowherd et al., 1974), examined emissions from a sand and gravel storage area and from one particular operation, load out of aggregate into dump trucks. The third study (Bohn et al., 1978) measured emissions from several types of aggregate transfer operations at two iron and steel facilities. The study by Blackwood and Chalekode (1978) involved upwind-downwind dispersion modeling of emissions from the dumping of traprock gravel in a quarry storage area. In the fourth study (Cowherd et al., 1979) emissions were measured from the loading of iron pellets and coal into storage piles using long conveyor stackers. Each of these studies is reviewed here in chronological order.

A sixth study (Vekris, 1971) included measurement of emissions from a heavy duty vehicle traveling across a large coal storage pile at a power plant. Although the fugitive dust source was not the transfer of material into or out of the storage area, but rather the action of the vehicle against the pile surface, it is reviewed briefly at the end of this section because it involves a storage pile and it fits into no other defined category.

A study by Axetell (1978) included measurement of dust downwind from storage piles. However, because the emission rate from this source was expressed as a function of wind speed, and because the intensity of activity in the storage pile was not recorded, it is reviewed in the section on wind erosion.

Studies of Primary Importance

Study 1-- Cowherd et al., Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037. 1974.

This report documented two distinct field studies on dust emissions from storage piles. These two studies are reviewed separately below. Conclusions from the findings of both studies are then summarized.

Total Emissions from Aggregate Storage Operations--

Methodology--The mass of dust emitted from a storage operation was measured using a rather simple methodology. The site's contribution to the downwind ambient dust concentration was estimated using upwind and downwind hi-vol samplers. The mass of dust emitted per unit time was calculated as the average net concentration times the atmospheric ventilation rate (which is in this case the volumetric rate at which air passes through the cross-sectional area defined by the width and height of the storage area).

Sampling runs were conducted during 12- and 24-hour periods. Four parameters were evaluated as possible factors influencing the dust emission rate: rainfall, wind speed, aggregate size, and intensity of activity. For the rainfall factor, sampling results were divided into two groups: dry period results and wet period results. Runs were deemed wet if any precipitation occurred during sampling or if more than a trace occurred on the day before. The average net concentration and emission rate for each group was compared to determine if emissions were higher during dry periods than wet periods.

To check for effects of wind speed and aggregate size, these variables were each plotted against downwind concentration. For aggregate size, this was accomplished by matching storage piles of various sizes of aggregate with particular samplers downwind from the piles.

Accurate data were not available on the level of activity in the storage area during each sampling run. Thus, it was not possible to estimate a relationship between the intensity of activity and concentration. However, after some manipulation of the data, it was possible to compare concentrations corresponding to periods when the storage area was active with those for non-working periods. The 12-hour sampling runs were conducted exclusively during non-working hours, and most 24-hour samples were conducted during periods including both working and non-working hours. (The rest covered exclusively non-working periods.) A concentration for working hours was calculated using the following relationship, in which A is the 24-hour average concentration for a day including 8 to 12 hours of activity, B is the average concentration during hours of activity in the storage area, and C is the average concentration for inactive hours:

$$A = (B + C)/2$$

Test Sites--Tests were conducted at a sand and gravel quarry and processing center near Cincinnati, Ohio. The investigators considered it representative of operations at many medium and large aggregate sites. Although the gravel pit was adjacent to the storage area, the samplers used in this study were judged to be sufficiently isolated from any dust generated in the pit itself by the difference in elevation between the pit and the storage area. Fifteen storage piles, ranging in height from 5 to 30 feet, were maintained in this area. The investigators computed an average pile height, weighted on the basis of the pile surface area, of 23 feet. Each pile was for a different size aggregate. The turnover rate for these piles was said to be high. No processing of aggregate was conducted in this area.

Parameters and Equipment--Upwind and downwind concentration of total suspended particulates was measured using standard hi-vol samplers. These were automatically activated by wind sensors when the wind direction was within 90° of South. They were also equipped with timers to record the duration of the sample. A high volume cascade impactor was used to measure the particle size distribution of the dust downwind from the storage area. Meteorological data, including cloud cover, temperature, and precipitation, were acquired from a nearby Federal Aviation Administration Weather Station. The size of the aggregate in each pile was noted so the effect of aggregate size on downwind concentration could be analyzed. Data were also collected on the height and configuration of each pile. The equipment operator's records documented the tonnage of material excavated, sized, and loaded onto trucks for transport. This provided only a very rough indication of the level of activity at the site during a given day.

Equipment Configuration--The five downwind samplers were scattered on the downwind side of the storage area. Three of them were set up among the storage piles, and two were immediately downwind of the entire storage area. The intake height of these samplers ranged from 3 to 20 feet. The height and upwind distance of the background sampler was not documented, nor was the position of the cascade impactor. Wind speed and direction were measured continuously on a pole about 25 feet above the ground.

Sampling Runs--Eleven 24-hour and seven 12-hour sampling runs were conducted. Four of the 24-hour runs were on weekends when there was no activity at the storage area. The remainder ran from noon one work day until noon the next. All of the 12-hour samples ran from 6:00 p.m. until 6:00 a.m. the next day.

Quality Assurance--None of the normal quality assurance procedures, such as processing of blank samples, calibration of equipment, or auditing of measurements or calculations, were documented for this field study.

Presentation of raw field data was complete. Measured upwind concentrations and net downwind concentration for each site and sampling period were documented. Evidence that the net downwind concentration measured the full contribution of the storage area alone was presented in three separate comparisons: the upwind concentration was in line with typical regional ambient levels, the upwind concentration was less than the downwind concentrations in almost every instance, and the average upwind concentrations during working periods were close to those of non-working periods.

Findings--The concentrations measured for each sampling run are shown in Table 2.57. The run time for each sampler is also shown for every test.

The average concentration for working days and non-working days was 182.7 $\mu g/m^3$ and 47.4 $\mu g/m^3$, respectively. Using the methodology described above, corresponding emission rates were calculated at 103 and 26.8 kg/day. The concentration calculated for working hours was 318 $\mu g/m^3$, which converts to an emission rate of 7.5 kg/hr.

Neither the calculations for converting these numbers into emission factors nor the activity rate (e.g. tons stored per day) were presented in the report. The factor for an active storage area with eight to twelve hours of activity per 24 hours was given as 0.42 lb/ton placed in storage (13.2 lb/storage acre/day). For periods of inactivity, the emission factor was calculated as 3.5 lb/storage acre/day (0.11 lb/ton placed in storage). For a normal mix of five workdays per week, the emission factor was calculated as 0.33 lb/ton placed in storage.

Rainfall, as recorded in the manner described above, was found to reduce emissions by roughly 50%. Neither the size of the aggregate in the storage piles nor the wind speed was found to have a significant influence on TSP emissions.

The particle size distribution of dust downwind from the storage area was not discussed, although the cascade impactor was listed as an instrument used in the field study.

TABLE 2.57. CONCENTRATION MEASUREMENTS AND SAMPLE RUN TIMES

			Net Downwind Concentration ($\mu g/m^3$) / Sampling Time (minutes)					
Date	Test Period (hr)	Upwind Concent. ($\mu g/m^3$) / Sample Time (min)	Hi-vol 2	Hi-vol 3	Hi-vol 4	Hi-vol 5	Hi-vol 6	Average[a]
6/9	24	94/1130	8/1140	23/1082	49/1074	13/1165	4/1064	19
6/11	12	95/484	107/403	152/415	184/413	172/423	76/355	138
6/12	24	60/1009	85/1074	113/1103	252/1039	208/1073	147/1090	161
6/13	12	65/276	215/70	125/73	15/80	0[b]/280	125/62	96
6/14	24	139/695	575/424	134/347	239/360	175/661	259/285	276
6/16	24	75/1126	3/1192	0[b]/1128	0[b]/1082	7/1168	26/378	7
6/18	12	71/532	21/340	16/381	37/406	42/619	Void[c]	29
6/19	24	49/1149	93/1127	57/1160	105/1134	74/1440	170/940	100
6/20	12	61/410	Void[c]	Void[c]	48/201	2/719	Void[c]	25
6/21	24	7/1205	152/1032	140/1301	249/940	154/1423	108/1009	161
6/23	24	67/1087	8/1011	6/1440	Void[c]	9/1352	27/1024	12
6/25	12	86/586	55/578	19/721	89/301	33/719	210/510	81
6/26	24	58/1181	121/1440	134/1365	50/1290	202/240	Void[c]	127
6/30	24	61/1233	16/1119	31/1066	0[b]/1190	31/982	42/1032	24
7/2	12	64/611	20/613	17/620	11/596	71/378	Void[c]	30
7/3	12	50/1139	28/1058	24/1031	28/869	22/1249	19/1054	24
7/5	24	95/770	231/508	138/420	146/1311	150/1280	40/375	141
7/6	24	124/1093	362/734	170/842	332/751	183/1432	241/706	258

a) Average downwind sampling time was not calculated
b) A net concentration of zero was assumed when the upwind concentration was slightly higher than the downwind
c) No explanation was given for the voided samples

Emissions from Aggregate Load Out--

Methodology--Exposure profiling was used to measure dust generated by a high loader dropping aggregate into a dump truck. A vertical, two-dimensional matrix of isokinetic high volume samplers was positioned downwind from the truck being loaded. The dust emitted when the aggregate was dumped passed through the sampling array. Total exposure was calculated by integrating the mass collected per unit area with respect to height and horizontal position.

Test Site--An asphalt producing facility in Kansas City provided the site for this study. The operation used four different types of aggregate in producing asphalt. Testing was conducted on a weekend when the plant was not in operation.

Parameters and Equipment--The profiler consisted of six hi-vol sampling heads with vertically oriented filters. The samplers were pre-set to operate isokinetically with wind speeds of 10 mph. A high volume cascade impactor was used to collect data on plume particle size distribution. It provided cut points at diameters of approximately 0.7, 1.25, 2.1, and 4.4 µm. Upwind and downwind TSP concentrations were measured with standard hi-vol samplers.

Meteorological parameters for which data were recorded included wind speed and direction, cloud cover, temperature, relative humidity, and atmospheric stability. Several source characterization parameters were recorded. The size distribution of aggregate in the pile was determined by scooping 12 samples from the pile and dry sieving them. Moisture content was determined by measuring the sample weight loss after oven drying. The age and configuration of the storage pile, and the load capacity of the high loader, about 15 tons, were also recorded.

Equipment Configuration--The distance between the dump truck and the profile grid was not documented. From a figure depicting the sampling configuration, it appears to be roughly five meters. The profiler sampling heads were arranged as follows: one each at the top and bottom of a vertical support pole, and four others spaced evenly on a horizontal support pole, which bisected the vertical one. This structure was fixed on the top of a van. The top sampler was about 12.5 feet above the ground over the center of the truck. The two samplers on both sides of the horizontal support were 1.5 and 4.5 feet from the vertical support. They were about 9.5 feet above the ground. The bottom sampler was approximately 6.5 feet high. Thus, the profiler spanned about nine feet horizontally and six feet vertically, with its center roughly 9.5 feet above the ground.

The cascade impactor was also on top of the truck, about 8 feet above the ground and 1 foot from the vertical support pole of the profiler. The positions of the two standard hi-vol samplers were not documented in this report. Wind speed and direction were continuously monitored at a height of 12 feet.

<u>Sampling Runs</u>--Only two sampling runs were conducted in this field experiment. One run consisted of 86 dumps, and the other 80. In both cases about 150 tons of aggregate were loaded.

<u>Quality Assurance</u>--In the use of standard high volume filtration, the investigators followed the procedures specified by EPA in "Reference Method for the Determination of Suspended Particulates in the Atmosphere (High Volume Method)" (1971). For the measurement of dust deposition, the investigators followed the procedures set forth in "Standard Method for Collection and Analysis of Dustfall," ASTM Method D 1739-62.

The wind speeds for the two tests were 12.6 and 14.0 mph. Thus the isokinetic ratios were, respectively, .79 and .71. No corrections were made to the calculated emission factors to account for the sub-isokinetic sampling.

Filters were conditioned in a controlled temperature and humidity environment prior to weighing both before and after collection of dust samples. Filter samples were transported to the laboratory in individual folders. The interior surfaces of the sampler heads were rinsed, and the water was captured and later evaporated to determine the mass of dust on the interior surfaces.

The investigators acknowledged two potential sources of small particle bias in their measurement of particle size distribution: 1) particles bouncing down through the cascade impactor to smaller particle stages; 2) non-isokinetic sampling which collects larger particles with lower efficiency than smaller particles.

It should be noted that, although this work was described as determining an emission factor for the aggregate load out process, emissions were measured only from the dropping of aggregate from the high loader into the dump truck. Emissions generated when the loader scooped the aggregate from the pile or when it moved between the pile and the truck were not measured or discussed.

<u>Findings</u>--The exposure measurements and calculated emission factors for the two sampling runs are presented in Table 2.58. The investigators concluded that an average TSP emission factor for this operation was about 0.05 lb/ton based on the following:

1. The TSP emission factor for these two tests were 0.053 and 0.063 lb/ton.

2. Emissions from these particular tests were thought to be near the maximum for this type of operation because the tested aggregate had been crushed less than one week earlier and had remained dry, the wind velocity was high, the aggregate sizes tested were small, and the amount of fines in the piles was substantial.

TABLE 2.58. MEASURED EXPOSURES AND CALCULATED EMISSION FACTORS

Run	Sample Time (min)	Sampler Position: Height Above Grade (feet)	Sampler Position: Distance from Center of Truck (feet)	Exposure ($mg/in^2/ton$)	Emission Factors (lb/ton): Total	Emission Factors (lb/ton): $d^a > 30$ µm	Emission Factors (lb/ton): $2 < d^a < 30$ µm	Emission Factors (lb/ton): $d^a < 2$ µm
15	61.2	6.5	0	2.59	0.11	0.057	0.018	0.035
		9.5	4.5	2.75				
		9.5	1.5	2.92				
		9.5	1.5	3.74				
		9.5	4.5	2.60				
		12.5	0	1.64				
16	59.1	6.5	0	1.07	0.11	0.047	0.021	0.042
		9.5	4.5	1.48				
		9.5	1.5	2.66				
		9.5	1.5	3.32				
		9.5	4.5	2.28				
		12.5	0	3.68				

a) particle Stokes diameter

<u>Conclusions From The Two Studies</u>--The investigators assumed that the total emissions from an aggregate storage pile area equaled the sum of the emissions from the following four sources:

1. Loading of aggregate into storage piles
2. Equipment travel in the storage area
3. Wind erosion
4. Load out of aggregate for shipment

The first study measured the total emissions from the storage area (0.33 lb/ton) and emissions produced by wind erosion (0.11 lb/ton); the second study measured emissions from aggregate load out (0.05 lb/ton). Emissions from source #1 were apparently assumed to be similar to those from source #4: the factor for loading aggregate into storage piles was taken to be 0.04 lb/ton. Thus, estimates were available for the total operation and every component except equipment travel. It was calculated by subtraction as 0.13 lb/ton.

The precipitation-evaporation index was found to be the most useful parameter in characterizing regional variability in total emissions from aggregate storage operations. The corrected emission factor for each ton of aggregate placed in storage was presented as

$$e = \frac{0.33}{(PE/100)^2}$$

where

e	=	TSP emission factor, lb/ton placed in storage
PE	=	precipitation index

The method of estimating this relationship between the emission factor and the PE index was not discussed.

Publication--These two field studies were conducted and documented under a contract with the EPA Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. The report was published in 1974 as Publication No. EPA-450/3-74-037.

Study 2-- Bohn et al. Fugitive Emissions From Integrated Iron and Steel Plants. EPA-600/2-78-050. 1978.

Methodology--An exposure profiler similar to the one used by Cowherd et al. (1974) was used to measure the mass flux of dust downwind from two operations related directly to aggregate storage piles. A third source, the transfer of aggregate between perpendicular conveyor belts, was also tested. Although this source is not directly associated with storage piles, the action is very similar to that seen in storage pile operations.

Test Sites--Sampling was conducted at two integrated iron and steel plants. One was in the dry western U.S. It included tests of emissions from the load-out of slag from a storage pile into a dump truck, and from the addition of pelletized or lump iron ore to existing storage piles by a mobile stacking conveyor belt. At the second facility, in the eastern steel producing region of the country, tests were conducted on emissions from a transfer point between two perpendicular conveyor belts carrying sinter.

Parameters and Equipment--The exposure profiling grid employed two different types of air filtering devices. Most prevalent was the isokinetic high volume sampler developed by Midwest Research Institute. This sampler differed slightly from the kind employed in 1974 (Cowherd et al.) in that the filter was positioned horizontally and air was drawn in through a settling chamber and up through the filter. The settling chamber captured particles larger than about 50 µm in diameter. Smaller, lower capacity ("auxiliary") samplers were used at the two ends of the horizontal rod. These also had intakes facing into the wind to allow isokinetic sampling, but they did not have settling chambers.

Standard hi-vol samplers were used to determine upwind and downwind concentrations of TSP. A high volume cascade impactor with a cyclone preseparator provided data on the plume's particle size distribution. It sampled isokinetically at a wind speed of 10 mph. The cut points for this impactor were not specified.

The transferred aggregate was characterized by recording the material type, its moisture content, its texture (including percent silt), and the throughput rate. Moisture content was determined by weight loss after oven drying, and the texture was measured by dry sieving.

Meteorological parameters for which data was collected included wind speed and direction, cloud cover, temperature, and relative humidity. Anemometers monitored wind speed and direction prior to commencement of testing and continuously recorded wind conditions during the runs; thus, the intake velocity of the samplers could be set to match the wind speed and, after testing was completed, exposures could be corrected for deviations from isokinetic sampling.

Equipment Configuration--For the storage pile load-out operation, the profiling grid was placed two meters downwind from the dump truck. The grid consisted of a vertical array of two isokinetic hi-vol samplers and a horizontal array of two isokinetic hi-vols (closest to the vertical support) and two auxiliary isokinetic samplers (at each end of the horizontal support). The vertical boundaries of the grid were typically 2.5 meters high on the bottom and 6.25 meters high on the top; the width of the grid was normally 4.2 meters (i.e. 2.1 meters on each side of the vertical support). The horizontal array of samplers had intakes 4.5 meters above the ground.

For the conveyor belt stacking operation, the profiling grid was about five meters from the center of the pile on the downwind side. The vertical array consisted of four isokinetic hi-vol samplers fixed at heights of 1, 2, 3, and 4 meters. The horizontal support had only two auxiliary isokinetic samplers with lateral displacements from the center support of 1.4 meters.

Emissions from the conveyor transfer station were measured using a smaller scale sampling grid placed an unspecified distance downwind from the transfer point. This grid had three profiling samplers 1.6 meters above the ground and one each at heights of 1.1 and 2.2 meters. The two outside samplers on the horizontal support were about one meter from the center support. Only auxiliary type samplers were used on this profiler.

For all three of these operations, the hi-vol cascade impactor and a standard hi-vol were attached to the horizontal support. The upwind hi-vol sampled at a height of 2 meters; its upwind distance was not noted. Anemometers measured wind speed at two heights on the profile grid. Any assumptions regarding the vertical distribution of wind speed were not made explicit.

Sampling Runs--Three sampling runs were conducted for the conveyor transfer station, and six each were conducted for the aggregate load out and conveyor stacking operations. Each 30- to 40-minute test of the load out operation was conducted while about 150 tons of material were loaded. During each 15-minute test of the conveyor transfer process, 52 tons of sinter were transferred between the two belts. The mass stacked by the conveyor stacker per sampling run ranged from 216 to 500 tons. The run time for testing of this operation was between 13 and 30 minutes.

Quality Assurance--The issue of quality assurance was not explicitly addressed in this report. Standard quality assurance procedures such as calibration of air samplers, processing of blank filters, and auditing of sample weights were not documented.

Field data presentation was complete. The procedures for determining the dust mass on the filters were described in detail. Air filters and impaction substrates were stored and transported in separate envelopes and were allowed to equilibrate in a constant temperature and humidity environment before weighing.

Some of the computational procedures employed were not described in detail and, therefore, could not be repeated. The authors did not explain how they integrated the point values of exposure when there were two different types of exposure samplers measuring two different particle size ranges. Recall that the isokinetic hi-vol samplers have a settling chamber, whereas the auxiliary samplers do not. Thus, the filters in the hi-vol heads collect dust particles smaller than about 50 µm, while the filters in the auxiliary samplers collect particles with no maximum particle diameter. No indication was given that these disparate sample types were treated any differently in computing what the investigators refer to as the "integrated filter exposure."

Findings--The measured point values of exposure and the calculated emission factors for material load-out, conveyor stacking, and conveyor transferring are shown respectively in Tables 2.59, 2.60, and 2.61. Those sampling heads for which no filter exposure is given are the smaller capacity auxiliary samplers. Again, the method used to integrate exposure with respect to horizontal position is unclear, due to the lack of "filter exposures" for each sampling head. Hence, it is unclear how the values for "integrated filter exposure" were calculated.

Two predictive equations were developed from this data and the findings of a field study of emissions from a sand and gravel storage area (Cowherd et al., 1974). The model developed for the conveyor stacker is

$$EF = 0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2}$$

where

EF	=	emission factor for suspended particulates, lb/ton transferred
s	=	aggregate silt content, %
U	=	wind speed, mph
M	=	aggregate moisture content, %

The model for aggregate load-out from a high loader to a dump truck is basically the same, except for the addition of a new correction factor: Y is the effective capacity of the loader in cubic yards. The equation is

$$EF = 0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2\left(\frac{Y}{6}\right)}$$

The method used to develop these equations was not described.

Publication--This study was conducted and documented under a contract with the Environmental Protection Agency; Industrial Research Laboratory; Office of Energy, Minerals, and Industry; Research Triangle Park, North Carolina. It was published as Publication No. EPA-600/2-78-050 in March 1978.

TABLE 2.59. MEASURED EXPOSURES AND CALCULATED EMISSION FACTORS FOR MATERIAL LOAD-OUT

Run	Duration (min)	Height (meters)	Distance from Centerline (meters)	Total Exposure (mg/cm^2)	Filter Exposure (mg/cm^2)	Integrated Filter Exposure[a] (lb/ton)	Emission Factor[b] (lb/ton)
A1	30	3	0	274	51.0	0.15	0.056
		4.5	2.1 R	41.2			
		4.5	0.7 R	99.1	22.7		
		4.5	0.7 L	182	40.4		
		4.5	2.1 L	76.0			
		6	0	74.1	23.8		
A2	40	2.5	0	88.8	14.09	0.062	0.028
		4.37	2.4 R	16.4			
		4.37	0.7 R	77.8	14.7		
		4.37	0.7 L	80.9	25.5		
		4.37	2.4 L	12.5			
		6.25	0	34.0	12.3		
A3	30	2.5	0	454	52.2	0.16	0.059
		4.37	2.4 R	51.6			
		4.37	0.7 R	169	29.5		
		4.37	0.7 L	285	47.6		
		4.37	2.4 L	104.7			
		6.25	0	134	27.2		
A4	30	2.5	0	63.4	8.0	0.032	0.030
		4.37	2.4 R	23.9			
		4.37	0.7 R	31.4	4.4		
		4.37	0.7 L	35.9	3.1		
		4.37	2.4 L	24.2			
		6.25	0	10.8	3.1		
A5	40	2.5	0	20.5	3.7	0.013	0.011
		4.37	2.4 R	9.1			
		4.37	0.7 R	13.0	1.9		
		4.37	0.7 L	12.0	2.9		
		4.37	2.4 L	7.3			
		6.25	0	n.d.	n.d.		

(continued)

TABLE 2.59. (continued)

Run	Duration (min)	Height (meters)	Distance from Centerline (meters)	Total Exposure (mg/cm^2)	Filter Exposure (mg/cm^2)	Integrated Filter Exposure[a] (lb/ton)	Emission Factor[b] (lb/ton)
A6	40	2.5	0	61.2	9.0	0.017	0.011
		4.37	2.4 R	14.9			
		4.37	0.7 R	21.7	5.5		
		4.37	0.7 L	41.0	11.0		
		4.37	2.4 L	32.7			
		6.25	0	5.9	3.0		

a) corrected to isokinetic sampling conditions
b) for particles with Stokes' diameters < 30 μm

TABLE 2.60. MEASURED EXPOSURES AND CALCULATED EMISSION FACTORS FOR CONVEYOR STACKING

Run	Duration (min)	Sampling Height (meters)	Distance from Centerline (meters)	Total Exposure (mg/cm^2)	Filter Exposure (mg/cm^2)	Integrated Filter Exposure[a] (lb/ton)	Emission Factor[b] (lb/ton)
A8	30	1	0	113	25.5	0.0041	0.0040
		2	1.4 R	18.1			
		2	0	21.7	5.8		
		2	1.4 L	12.6			
		3	0	11	2.4		
		4	0	3	0.8		
A9	15	1	0	51	19.7	0.024	n.d.
		2	0	48	14.6		
		3	1.4 L	45.0			
		3	0	62	16.7		
		3	1.4 R	46.8			
		4	0	26	6.2		

(continued)

TABLE 2.60. (continued)

Run	Duration (min)	Sampling Height (meters)	Distance from Centerline (meters)	Total Exposure (mg/cm^2)	Filter Exposure (mg/cm^2)	Integrated Filter Exposure[a] (lb/ton)	Emission Factor[b] (lb/ton)
A10	13	1	0	70	20.6	0.038	0.010
		2	0	61	12.6		
		3	1.4 R	31.0			
		3	0	58	15.7		
		3	1.4 L	30.3			
		4	0	8	8.5		
A11	22	1	0	38.5	5.4	0.0038	0.00099
		2	1.4 L	15.1			
		2	0	14.7	2.1		
		2	1.4 R	9.9			
		3	0	11.5	1.3		
		4	0	4.0	0.8		
A12	25	1	0	10.5	0.9	0.00058	0.00066
		2	1.4 R	8.0			
		2	0	5.5	0.6		
		2	1.4 L	1.7			
		3	0	3.72	0.4		
		4	0	1.78	0.4		
A13	28	1	0	1.39	0.3	0.00031	0.00046
		2	0	1.65	0.5		
		3	1.4 L	2.09			
		3	0	2.05	0.5		
		3	1.4 R	3.62			
		4	0	1.59	0.3		

a) corrected to isokinetic sampling conditions
b) for particles with Stokes' diameters < 30 μm

TABLE 2.61. MEASURED EXPOSURES AND CALCULATED EMISSION FACTORS FOR CONVEYOR TRANSFER

Run	Duration (min)	Sample Height (meters)	Distance from Centerline (meters)	Total Exposure (mg/cm^2)	Integrated Filter Exposure[a] (lb/ton)	Emission Factor[b] (lb/ton)
E10	15	2.2	0	16.8	0.043	0.036
		1.6	1	17.2		
		1.6	0	39.5		
		1.6	1	51.0		
		1.1	0	32.2		
E11	15	2.2	0	45.6	0.084	0.064
		1.6	1	26.8		
		1.6	0	31.2		
		1.6	1	57.1		
		1.1	0	30.4		
E12	15	2.2	0	16.1	0.038	0.037
		1.6	1	31.2		
		1.6	0	20.3		
		1.6	1	14.6		
		1.1	0	18.6		

a) corrected to isokinetic sampling conditions
b) for particles with Stokes' diameters < 30 μm

Study 3-- Blackwood and Chalekode. Source Assessment: Crushed Stone. EPA-600/2-78-004L. 1978.

Methodology--The investigators used upwind-downwind dispersion modeling to estimate emission factors for unloading of processed rock from trucks into storage piles. Turner's (1970) equation for a ground level source with no plume rise was used to model the source strength:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

The source strength for the activity was calculated as the average of those emission rates calculated at several downwind stations.

Test Sites--Field monitoring was conducted at two unidentified stone quarry and processing operations. Both produced crushed traprock. They were considered representative of the crushed stone industry, particularly because 68% of crushed stone produced (in 1978) was traprock.

Parameters and Equipment--A GCA portable respirable dust monitor was used to measure concentrations downwind from the loadout site. When used with a cyclone separator, it measured concentration of "respirable" (i.e. smaller than 10 µm) particles. The equipment used to monitor upwind concentration was not noted. Wind speed as measured by an anemometer was recorded automatically every 15 seconds. The average wind speed during each sampling run was calculated as the average of these 15-second averages. The downwind distance from the source was estimated by pacing between the source and the monitor. Stability class was determined and reevaluated every two or three hours on the basis of cloud cover, wind speed, and time of day.

Equipment Configuration--Little documentation is provided regarding the manner in which the respirable dust monitor was deployed. When used for testing various rock processing operations, it was used to collect several concentration measurements in a traverse downwind from the source. Although this was probably not possible for a quick batch operation like truck unloading, no explanation was given for the positioning of the sampler downwind from this activity. However, tabulated field data indicate that the sampler's downwind distance ranged from 40 to 210 feet. The sampling height of the monitor was not published.

Sampling Runs--A total of 13 concentration measurements for truck unloading operations were reported in this document. The number of dumps was not recorded. Sampling duration was four minutes for each run, except one eight minute test.

Quality Assurance--No documentation was provided for calibration of the dust monitor or the cyclone separator that was used with it. Field procedures were not thoroughly explained. As was noted earlier, the method of measuring the upwind concentration was not discussed.

The method of measuring emissions is clearly inappropriate for the source, because unloading of a truck only requires a fraction of the time required to collect the air sample. Consequently, concentration measurements are biased low. This issue was not addressed by the authors, and it was in effect hidden by the lack of documentation of activity level during each sample collection.

Findings--The dispersion modeling data published in this report is shown in Table 2.62. Note that source strength is sometimes given as a dose and sometimes as an emission rate. No justification was given for this. The respirable particulate emission factors calculated for plants B and A, respectively, were 0.0746 and 0.033 g/metric ton transferred. The mean emission factor of 0.0538 g/metric ton was given a 95% confidence interval of ± 0.264 g/metric ton. The total particulate emission factors for plants B and A were 0.209 and 0.0442 g/metric ton, respectively. The mean total particulate factor, 0.127 g/metric ton, was given a 95% confidence interval of ± 1.05 g/metric ton. The method of deriving the emission factors for each plant was not described.

Publication--This report is Publication No. EPA-600/2-78-004L, prepared for EPA's Industrial Environmental Research Laboratory in Cincinnati, Ohio. It was published in May of 1978.

TABLE 2.62. DISPERSION MODELING DATA FOR UNLOADING TRUCK

Plant	Wind Speed (mph)	Monitoring Position (feet)			Concentration (μg/m³)	Source Strength	Stability Class
		X	Y	Z			
B	5.3	123	0	0	140	8.0 g	B
B	5.3	70	0	0	10	.2043 g	B
B	5.3	90	0	0	25	.8081 g	B
B	5.3	100	0	0	28	2.194 g	B
B	5.3	90	0	0	20	.6465 g	B
B	5.3	70	0	0	22	.4495 g	B
B	5.3	90	0	0	672	21.72 g	B
B	5.3	100	0	0	27	2.116 g	B
B	5.3	90	0	0	72	2.327 g	B
A	8	210	0	0	10	.005021 g/sec	C
A	8	70	0	0	80	.005511 g/sec	C
A	8	70	0	0	204	.01405 g/sec	C
A	8	210	0	0	4	.002008 g/sec	C

Study 4-- Cowherd _et al._ _Iron and Steel Plant Open Source Fugitive Emission Evaluation_. EPA-600/2-79-103. 1979.

Methodology--Dust emissions from a mobile conveyor stacker were measured using the exposure profiling methodology. Because the source was treated as a moving point rather than a fixed source, there was no need to measure exposure at several points in the horizontal plane. Total exposure was calculated as the mass emitted per stacker-mile. This was then converted to an emission factor by multiplying by the stacker's velocity (i.e m/sec) and the inverse of the stacking rate (hr/ton).

Test Site--The stacker was used to form elongated storage piles of iron pellets and coal. The length of the conveyor stacker boom was about ten meters for the coal stacking operation and 67 meters for the iron pellet stacking operation. The drop distance for the iron pellets ranged from 9 to 12 meters; for the coal it was 5 meters. The facility at which these tests were conducted was not identified.

Parameters and Equipment--Upwind and downwind concentrations of total suspended particulates were measured using standard hi-vol samplers. A high volume cascade impactor was used to measure the particle size distribution of the dust downwind from the storage area. A profiling tower consisting of four isokinetic hi-vol samplers was used to measure point values of exposure at a series of heights above the ground.

Wind speed and direction were continuously monitored with recording anemometers. In setting the sampling velocity to match the local wind speed, the vertical distribution of the wind speed was assumed to be logarithmic. Other meteorological parameters for which data was collected included cloud cover, temperature, precipitation, and relative humidity.

In order to characterize the stored material, data on several relevant parameters was collected. The material type (coal versus iron pellets) and the throughput rate were noted. Aggregate samples were taken and analyzed using the usual methods to determine the moisture and silt content.

Equipment Configuration--For each sampling run the profiler was placed between 4.5 and 11.5 meters downwind from the pile being formed. The sampling heads had intakes 1.5, 3, 4.5, and 6 meters above the ground. A high volume cascade impactor and a standard hi-vol were set up beside the profiler; they both sampled at a height of 2 meters. For some tests additional downwind standard hi-vols were placed 20 and 50 meters from the source. The upwind hi-vol, which also sampled air two meters above the ground, was placed 30 to 50 meters upwind or crosswind from the source. Only one measurement height was given for wind speed, four meters. For some tests this was done 10 meters upwind from the source and in others 50 meters downwind.

Sampling Runs--Emission factors were calculated for four sampling runs, three of which were for iron pellet stacking, and the fourth was for coal stacking. For iron pellets, the number of stacker passes in front of the profiler varied between 7 and 11. Thirty passes were logged in the coal stacking test.

Quality Assurance--An effort was made to apply or adapt the American Society of Testing and Materials (ASTM) Standards in the collection and analysis of samples needed to quantify the silt content of the surface material. Except for the citation of this standard procedure, the authors documented no normal quality assurance procedures. Documentation of the basic methodological procedures involved in field operations, sample handling, and data analysis was generally thorough.

Dust samples were transported to the laboratory in individual envelopes. Filter samples were conditioned at constant temperature and humidity for 24 hours before weighing. This same procedure was followed in weighing the filters prior to use.

The procedure for accounting for background levels of dust was not adequately documented. Therefore, the emission factors presented in the study could not be reproduced from the data provided.

Findings--Table 2.63 shows the measured exposures and resulting emission factors for each sampling run. The duration of the runs was not documented.

TABLE 2.63 EXPOSURE MEASUREMENTS AND CALCULATED EMISSION FACTORS

Run	Sample Height (meters)	Total Exposure (mg/cm²)	Filter Exposure (mg/cm²)	Integrated Filter Exposure (lb/mile)	TSP Emission Factor (lb/ton)	FP Emission Factor (lb/ton)
H-10	1.5	12.1	2.43	319	0.0023	0.00012
	3	5.88	1.43			
	4.5	3.18	0.89			
	6	4.13	2.56			
H-11	1.5	0.92	0.42	90.8	0.0029	0.00087
	3	0.74	0.62			
	4.5	0.50	0.46			
	6	0.10	0.09			
H-12	1.5	3.45	1.38	202	0.0023	0.00069
	3	1.15	0.35			
	4.5	1.11	0.80			
	6	1.82	1.59			
F-19	1.5	0.82	0.42	65.6	0.00014	0.000011
	3	0.34	0.21			
	4.5	0.35	0.19			
	6	0.27	0.15			

A revised predictive equation for continuous stacking was developed from this field study and previous research (Bohn et al., 1978):

$$EF = 0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{3}\right)}{\left(\frac{M}{2}\right)^2}$$

where

EF = TSP emission factor, lb/ton of aggregate transferred
s = silt content, %
M = moisture content, %
U = mean wind speed, mph
H = drop height, meters

The equation is the same as the one published in the earlier report except for the addition of the correction factor for drop height.

Publication--This study was conducted and documented under a contract for EPA, Industrial Environmental Research Laboratory, Office of Energy, Minerals, and Industry, Research Triangle Park, North Carolina. It was published in 1979 as Publication No. EPA-600/2-79-103.

Studies of Secondary Importance

Study 5-- Vekris. "Dispersion of Coal Particles from Storage Piles." Hydro Research Quarterly. Vol. 23. No. 2. 1971.

The emission rate from a heavy duty vehicle moving across a coal storage pile was calculated using the equation

$$Q = \frac{wuhs}{nV}$$

where

Q	=	mass emitted per unit time
w	=	weight gain of high volume filter
u	=	wind speed
h	=	height of the dust plume
s	=	vehicle speed
n	=	number of vehicle passes
V	=	volumetric flow rate of sampler

No explanation was given for how this equation was developed.

A high volume sampler was positioned at the edge of the pile, downwind from the vehicle, and three feet above grade. A total of six samples were collected. The duration of these samples was not published. Calculated dust generation rates ranged from 13.42 g/sec to 66.38 g/sec.

The source studied in this work does not strictly fit the definition of the storage pile source category. The author noted that the emissions are from the action of the vehicle against the surface of the storage pile, rather than from the transfer of material into or out of the pile. Neither does it fit the definition of the unpaved road source category. However, it was felt that the study is worthy of mention in this report.

CONSTRUCTION ACTIVITIES

Introduction

Field measurement of particulate emissions related to construction activities has been performed at three sites. Dust emissions from two building construction sites and a road construction site were modeled using the upwind-downwind dispersion modeling method. Two different reports (Jutze and Axetell, 1974; Cowherd et al., 1974) document the field research and findings for the building construction sites. Both reports cover both sites, but, because they do not provide the same documentation and data analysis, they are reviewed separately. The report on road construction emissions (Kinsey and Englehart, 1983) included, in addition to upwind-downwind dispersion modeling of emission rates, a regression analysis relating TSP concentration to other field variables. These three reports are reviewed here in chronological order.

Studies of Primary Importance

Study 1-- Jutze and Axetell. Investigation of Fugitive Dust Volume I: Sources, Emissions, and Control. EPA-450/3-74-036-a. 1974.

Methodology--Upwind-downwind dispersion modeling was used to estimate emissions from building construction sites. Individual construction operations, such as grading or materials unloading, were not tested separately. The investigators used the Gaussian dispersion model for concentrations along a plume centerline from a ground level source with no effective plume rise:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u}$$

Two adjustments were made to this equation. First, because the construction sites were considered area sources, the initial standard deviation of the crosswind distribution of the plume concentration, σ_{yo}, was assumed to be equal to the length of the side of the construction area divided by 4.3. Second, because the sampling time was longer than three minutes, the above formula for concentration was multiplied by 0.36. Both of these adjustments follow the recommendation of Turner (1970). The resulting formula for source strength, Q (g/sec), is shown below:

$$Q = 2.78 \pi \sigma_y \sigma_z u \chi$$

where

σ_y	=	standard deviation of the crosswind distribution of the plume's concentration at the downwind measurement site (a function of atmospheric stability, downwind distance, and the assumed initial standard deviation, σ_{yo}).
σ_z	=	standard deviation of the vertical distribution of the plume's concentration at the downwind measurement site (a function of the atmospheric stability and downwind distance), m
u	=	mean wind speed, m/sec
χ	=	measured concentration of particulates at the downwind measurement site (minus the background concentration), g/m^3

Calculated source strengths were converted into tons/year and into tons/acre-month.

Test Sites--Data were collected from two building construction sites: a 100 acre site in Las Vegas, and a 90 acre site in Maricopa County (Phoenix), Arizona.

Parameters and Equipment--Standard high volume samplers were used to measure concentration of TSP both upwind and downwind of the construction sites. Wind velocity and direction were measured using continuous windvane/anemometer sensors.

Equipment Configuration--The specific positioning of the samplers was not documented, except that the downwind measurement distance was given in a table showing the dispersion model parameters. At the Las Vegas construction site, concentration measurements were made at downwind distances of 650 and 525 meters. At the Maricopa County site, concentration measurements were made at three downwind distances, 315, 758, and 1575 meters. The upwind distance of the background sampler(s) was not published.

Sampling Runs--Four concentration measurements were taken for the Las Vegas site, two at each of the downwind distances. For the Maricopa County site, 12 concentration measurements were taken, five at the closest sampling distance, 3 at the intermediate distance, and 4 at the farthest distance. Samples were collected over 24-hour periods.

Quality Assurance--The investigators provided little assurance of the quality of the data collected for this study. Although the procedures for operating the hi-vol samplers and for handling and transporting the filters were thoroughly documented, the procedures used to determine the filtered dust mass were not described. Normal quality assurance procedures, such as calibration of samplers, processing of blank filters, or auditing of weight measurements or data reduction calculations, were not documented for this study.

Findings--The field data collected in the study of fugitive dust emissions from construction sites is shown in Table 2.64. The average emission rate for the Las Vegas site was 1162 tons/year, which converts into about 1 ton/acre/month. The average for the Maricopa County site was 1970 tons/year; this is equivalent to 1.8 tons/acre/month.

TABLE 2.64. DISPERSION MODELING DATA AND CALCULATED SOURCE STRENGTHS

Site	Downwind distance (meters)	Stability Class	σ_y[a] (m)	σ_z (m)	Wind Speed (m/sec)	Concentration (mg/m^3)	Source Strength (g/sec)
Las Vegas	650	C	118	69	3.6	.092	23.6
Las Vegas	650	B	152	107	2.7	.122	46.8
Las Vegas	525	C	107	63	3.6	.162	34.3
Las Vegas	525	C	107	63	5.4	.091	28.9
Maricopa	315	B	159	112	2.7	.180	75.6
Maricopa	315	B	159	112	2.7	.220	92.3
Maricopa	315	B	159	112	1.2	.130	24.2
Maricopa	315	B	159	112	0.9	.090	12.6
Maricopa	345	B	159	112	0.9	.155	21.7
Maricopa	758	B	223	170	2.7	.140	125.0
Maricopa	758	B	223	170	2.7	.215	192.0
Maricopa	758	B	223	170	0.9	.100	29.8
Maricopa	1575	B	300	240	1.2	.040	30.2
Maricopa	1575	B	300	240	0.9	.020	11.3
Maricopa	1575	B	300	240	0.9	.065	36.7
Maricopa	1575	B	300	240	2.2	.020	27.6

a) σ_y is a function of downwind distance, stability class, and the assumed standard deviation of the crosswind distribution of the plume concentration at the point of release ($x = 0$).

Publication--This study was conducted and documented under contract for the Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and

Standards, Research Triangle Park, North Carolina. It was published in 1974 as Publication No. EPA-450/3-74-036-a.

Study 2-- Cowherd et al. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037. 1974.

Methodology--This report documents the field research and findings of the same study described by Jutze and Axetell (EPA-450/3-74-036a, 1974). However, more concentration measurements were available to Cowherd et al. for analysis and modeling than were included in that report. It should be noted that both Jutze and Axetell were also co-authors of this document (EPA-450/3-74-037). This report sheds additional light on the positions of the high volume samplers relative to the construction sites and to the wind direction. It also includes more extensive data analysis and interpretation than Jutze and Axetell, 1974.

Prior to using the dispersion model, the investigators prepared and analyzed pollution roses for each of the hi-vol stations to determine if the receptors were being influenced by other local dust sources. Some receptors were excluded from formal analysis on the basis of this cursory evaluation. Source strengths were modeled separately for several different wind directions and compared subjectively before a final emission factor was selected.

The dispersion modeling approach employed in this report is similar to that used by Jutze and Axetell. It includes the same assumptions regarding initial plume dispersion and concentrations for long sampling periods. The primary difference between the method used by Jutze and Axetell and that of Cowherd et al. is that Cowherd et al. averaged net downwind concentrations for a particular wind direction prior to calculating a corresponding average source strength.

Test Sites--Emissions were modeled for a 100 acre building construction site in Las Vegas and for a 80 acre building construction site in Maricopa County, Arizona. Note that the size of the Maricopa site is ten acres less than the size stated in Jutze and Axetell's report. Both of these sites were watered on most air sampling days.

Parameters and Equipment--Upwind and downwind concentrations of total suspended particulates were measured with standard hi-vol samplers. Wind direction and velocity were monitored using a continuous windvane/anemometer. Atmospheric stability was not recorded or discussed. Construction activity levels were subjectively rated as "no activity," "light to moderate activity," or "heavy activity" for each sampling period.

Equipment Configuration--For the Maricopa County site, six standard high volume samplers were distributed as follows. One sampler was placed adjacent to the construction site on the east side (typically the downwind side). This was about 315 meters from the center of the construction site. Three others were set up in the northeast quadrant (relative to the construction site), in anticipation of predominantly southwesterly winds. One of these samplers was later judged to provide an unrepresentative sample, and measurements collected with it were excluded from the analysis. The downwind distances from the center of the construction site to the remaining samplers were 731 meters and 1021 meters.

Two samplers were set up on the anticipated upwind side of the site, but one of these was also judged to provide a poor measure of background dust levels and was consequently excluded from the analysis. The remaining upwind sampler was roughly 1520 meters from the center of the site. The intake height of the hi-vols was not noted.

Five hi-vols were used for the Las Vegas site. One was adjacent to the southwest corner of the site. The other four were distributed to the north and east of the site at distances ranging from about 8.1 km to 13 km from the center of the site. They were intended to measure downwind concentration. The placement of the wind instruments was not documented for either site.

Sampling Runs--Each sample was collected over a 24-hour period. For the Maricopa County site, 24 sampling runs were conducted over a 7½ week period. A total of 88 concentration measurements made during these sampling runs were published, including 24 background samples. For the Las Vegas construction site, 30 sampling runs were conducted, from which 125 concentration measurements were published. These samples spanned a nine week period.

The term sampling run should be considered loosely for this report, because concentrations measured on a given day were not always used to generate a single corresponding source strength from the model. Rather, average net downwind concentrations were calculated for various wind directions and converted into corresponding emission factors using the dispersion model described above.

Quality Assurance--The investigators provided little assurance of the quality of the data collected for this study. Although, the procedures for operating the hi-vol samplers and for handling and transporting the filters were thoroughly documented in the report by Jutze and Axetell, the methods used to determine the filtered dust mass were not described. Normal quality assurance procedures, such as calibration of samplers, processing of blank filters, or auditing of weight measurements or data reduction calculations were not documented for this study. As was noted earlier, not all of the data needed for the dispersion equation were presented in this report.

Several problems regarding the configuration of the samplers diminish the quality of the data gathered in the project. No information was given on the intake height of the samplers. They could have been on roof-tops or on the ground. It is apparent that the hi-vols did not always collect samples from the plume centerline; this is contrary to the assumptions of the dispersion model applied. The report also indicates that other significant dust sources between the upwind and downwind samplers probably affected the concentration measurements, particularly at the Las Vegas site.

Findings--During the field work at the Maricopa County site the winds were generally from the south, west, or southwest. Recall that the three downwind samplers were all northeast of the site. To determine which wind direction yielded the most accurate measure of source strength, the investigators used the data presented in Table 2.65. They concluded that, because the two estimates of source strength for southwesterly winds were closest together, they must be closer to the true source strength. Thus, the emission factor for this site was taken to be 1.4 tons/acre/month.

TABLE 2.65. SOURCE STRENGTHS CALCULATED FOR VARIOUS WIND DIRECTIONS

	Modeled Source strength (tons/acre/month)	
Wind direction	Based on only one downwind sampler, adjacent to the site on the east side	Based on average of all three downwind samplers
Southwest	1.37	1.41
South	1.13	1.51
West	0.42	0.65

For the Las Vegas site separate source strengths were calculated for southwest winds and for north winds. They were, respectively, 0.6 and 0.96 tons/acre/month. The investigators judged that the receptors were affected least by other local dust sources during north winds, and concluded that emissions from the construction site were about 1.0 tons/acre/month.

For neither site was a strong correlation detected between source strength and intensity of construction activity.

Publication--This study was conducted and documented under a contract with the EPA Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. It was published in 1974 as Publication No. EPA-450/3-74-037.

Study 3-- Kinsey and Englehart. Study of Construction Related Dust Control. 1983.

Methodology--Dust concentration measurements were taken upwind and downwind from a road construction operation. This data was used in two different analytical frameworks. For one, several other variables for which field data was collected were regressed on concentration to estimate the relationship between these variables and concentration. This procedure was performed for measured concentrations of several particle size categories. In the second framework, a generalized atmospheric dispersion model was applied to the data to estimate TSP emission factors for each set of upwind and downwind measurements. The equation used to calculate source strength is shown below. It was derived from the model for a continuously emitting, infinite line source (Turner, 1970).

$$q = \frac{0.5\chi \sin\phi \, (2\pi)^{0.5} \sigma_z u}{\exp\left[-1/2\left(\frac{z}{\sigma_z}\right)^2\right]}$$

where

q	=	line source strength, g/m-sec
χ	=	plume centerline concentration for TSP measured 50 meters downwind from the source, g/m^3
ϕ	=	angle between the wind direction and the road
σ_z	=	standard deviation of the plume's vertical concentration distribution, a function of downwind distance, stability, and an assumed initial plume dispersion, σ^{zo}, m
u	=	mean wind speed, m/sec
z	=	vertical distance of sampler inlet from the ground, m

The initial standard deviation of the plume's vertical concentration distribution was assumed to be 4 meters.

Test Site--Field data were collected at an active road construction site in a rural area near Minneapolis/St. Paul, Minnesota. The road was oriented east to west; prevailing winds were from the north. The land on both sides of the road were in cover crops. Separate tests were conducted for three different construction operations: 1)topsoil removal, 2) cut and fill operations, and 3) final grading and preparation of the road base.

Parameters and Equipment--Two types of air filtering equipment were used for this study: a standard high volume sampler and a hi-vol fitted with a size-selective inlet (SSI) and a cascade impactor. The standard hi-vol measured TSP concentration. The SSI had a theoretical cut point of 15 µm, and the cascade impactor measured particles in the size range between 0.5 µm and 7 µm. The PM-10 and IP concentrations were determined by interpolation or extrapolation of data points derived from these devices.

Two "automated meteorological stations" collected data on wind speed and direction (at two heights, 5 and 8 meters), temperature, and precipitation. Atmospheric stability was also evaluated and recorded. Records were kept on the number and type of vehicles passing the monitoring stations. The predominant vehicle type for each operation is shown in Table 2.66. In addition, the quality of each pass was rated "good," "marginal," or "bad," depending on the wind/road angle and the presence or absence of a visible dust plume impacting the downwind samplers. Soil moisture and silt content were also measured in the normal manner.

TABLE 2.66. PRIMARY EQUIPMENT FOR EACH OPERATION OF ROAD CONSTRUCTION PROJECT

Operation	Primary Vehicles
Site Clearing & Topsoil Removal	Bulldozer, Scraper Pan
Cut & Fill	Bulldozer, Scraper Pan
Final Grading & Preparation of Road Base	Vibratory Drum Roller Road Grader Dump Truck

Equipment Configuration--Four dust monitoring stations were set up, two on the north side at perpendicular distances of 25 and 50 meters, and two on the south side at the same distances. Each monitoring station consisted of a standard hi-vol sampler and a hi-vol cascade impactor, as described above. Intake heights of these samplers were normally two meters above the ground; however, toward the end of the sampling program, the downwind samplers had to be elevated because the cover crop, corn, would have otherwise effected concentration measurements. Two directional wind activators and event recorders were set up, one on each side of the road, about half way between the two monitoring stations, to turn off all the dust monitoring equipment when the wind direction shifted to within 67.5° of north or south.

Sampling Runs--A total of 12 sampling runs were conducted during this study. The number of vehicle passes per run ranged from 16 to 105. The sample run time ranged from 14 to 116 minutes, except for one run which lasted 742 minutes.

Quality Assurance--The quality assurance for this study was generally good. One out of every ten filters was processed as a blank. All of the filter tare weights and 20% of final filter weights were audited by a second analyst. The hi-vol samplers were calibrated before and after each sampling run. Before weighing, filters were equilibrated at a constant temperature and humidity. The accuracy of the balance was checked with Class S weights before each weighing.

Findings--The data for the dispersion modeling calculations are shown in Table 2.67. Raw upwind and downwind concentrations were not published. The computed emission factors for each sampling run and the construction activity occurring are also presented in this table. Calculated emission factors are based on the concentration measurement 50 meters downwind, because the plume was believed to be better defined at greater distances. Topsoil removal was found to produce more TSP emissions than the other activities.

Multiple regression analysis of the data yielded the equations shown in Table 2.68. The amount of variation in field-measured concentrations that is explained by each formula is indicated by the R^2 value.

Publication--This study was conducted for the Minnesota Pollution Control Agency, Roseville, Minnesota. The report was prepared in April of 1983. It has not been published.

TABLE 2.67. DISPERSION MODELING PARAMETERS AND RESULTS

Run	Stability Class	σ_z[a] (m)	Mean Wind Speed (m/sec)	Net Downwind Concentr. ($\mu g/m^3$)	Passes Per Minute	TSP Emission Factor (lb/veh-mile)	Activity
AH-1	D	6.01	4.4	13292	1.03	75.5	Topsoil removal
AH-2	D	6.01	5.1	16996	1.57	73.4	Topsoil removal
AH-3	C	7.49	4.1	595	0.47	8.41	Pan scraper traffic (empty)
AH-4	B	9.12	3.1	7642	1.12	41.5	Cut/Fill
AH-5	D	6.01	3.8	3281	1.26	13.2	Cut/Fill
AH-6	D	6.01	8.0	292	0.94	3.31	Earth Hauling
AH-7	C	7.49	4.9	124	0.07	14.1	Cut/Fill
AH-9	B	9.12	2.8	676	0.86	4.29	Earth Hauling
AH-10	D	6.01	6.7	977	0.88	9.86	Cut/Fill
AH-11	C	7.49	5.5	604	0.21	25.8	Aggregat e Hauling
AH-12	C	7.49	5.8	2448	0.38	61.0	Aggregat e Hauling
AH-14	C	7.49	3.4	845	0.68	6.88	Aggregat e Hauling

a) standard deviation of the plume's vertical concentration distribution at the downwind measurement distance

TABLE 2.68. FINDINGS OF REGRESSION ANALYSIS

	Formula[a] for Predicted Concentration (µg/m³)	
Particle Size Category (µg/m³)	25 meters downwind	50 meters downwind
TSP	$575(s)^{0.87}(Td)^{0.89}(M)^{-0.66}$ $R^2 = 0.81$	$374(s)^{0.80}(Td)^{0.97}(M)^{-0.47}$ $R^2 = 0.74$
IP	$142(s)^{0.88}(Td)^{0.93}(M)^{-0.55}$ $R^2 = 0.78$	$87(s)^{0.86}(Td)^{1}(M)^{-0.44}$ $R^2 = 0.76$
PM_{10}	$112(s)^{0.87}(Td)^{0.95}(M)^{-0.52}$ $R^2 = 0.78$	$60(s)^{0.88}(Td)^{1.04}(M)^{-0.40}$ $R^2 = 0.75$

a) variable definitions:
s = surface silt content, %
Td = traffic density, vehicle passes per minute
M = surface moisture, %

AGRICULTURAL ACTIVITIES

Introduction

Agricultural operations have received limited attention regarding the fugitive dust emissions they produce. Emission rates have been measured in two field studies, both conducted by the Midwest Research Institute using the exposure profiling methodology. They are reviewed here in chronological order.

Studies of Primary Importance

Study 1-- Cowherd et al. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037. 1974.

Methodology--This field research was part of the original study which used exposure profiling to measure fugitive dust emissions. The methodology is explained fully in the section on unpaved roads under this same reference. The only difference is that the emission factor is expressed as mass per unit area (e.g. lb/acre) rather than mass per unit length (e.g. lb/veh-mile). To derive these units, the mass generated per unit length of tilling (which is measured the same as in the case of unpaved roads) is multiplied by the number of passes required to till an acre of land.

Test Sites--A total of four sites, two each in Morton County and Wallace County, Kansas were tested. The soils at the sites in Morton County, referred to as sites A1 and A2, were Dalhart/Richfield fine sandy loam and Ulysses/Richfield silt loam, respectively. Site A1, fallow prior to tilling, had a slight vegetative cover. Site A2 had no vegetation; it was also fallow. The soils at sites A3 and A4 in Wallace County were respectively Ulysses/Colby silt loam and Keith/Colby silt loam. Both of these were fallow with light vegetative cover. The land at all of these sites was level to gently sloping (up to 2%).

Parameters and Equipment--Table 2.69 lists the parameters measured and the corresponding equipment used in studying emissions from tilling.

For each test the tilling equipment was either a one-way disk plow or a sweep-type plow. These were considered representative of the equipment widely used in dry land farming in the Great Plains. The width of the equipment ranged from 12 to 30 feet. Equipment speed ranged from four to seven mph. Soil samples were collected to depths between four and six inches.

Emission factors were calculated for three particle size categories: larger than 30 μm, between 2 and 30 μm, and smaller than 2 μm. According to Muleski et al. (1983), these categories were based on Stokes' diameter. Though not detailed explicitly, the percentage of the emission plume which fell into the less-than-2 μm category was apparently determined by translating the cascade impactor cut points (see footnote for Table 2.69) into equivalent Stokes' diameters and interpolating.

TABLE 2.69. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameters	Equipment
Wind speed	Unspecified
Wind direction	Unspecified
Cloud cover	Direct observation
Temperature	Sling psychrometer
Relative humidity	Sling psychrometer
Soil texture	Hydrometer
Soil moisture	Oven, scales
Vegetative cover	Direct observation
Tillage equipment type	Direct observation
Tillage equipment width	Direct observation
Tillage equipment speed	Timer, reference points
Tillage equipment passes	Direct observation
Plume total dust exposure/concentration	Isokinetic exposure profiler
Plume particle size distribution	High volume cascade impactor (Anderson impactor, Sierra Impactor[a])
Plume TSP concentration	Standard high volume sampler
Background concentration	Standard high volume sampler
Sampling duration	Timer
Dust deposition	Dustfall buckets
Dust saltation	Saltation catcher

a) An Aerotec cyclone was used for one test. Particle size data were presented only for the Anderson impactor, which had aerodynamic cut diameters at 0.17, 1.25, 2.1, and 4.5 μm.

Equipment Configuration--All downwind sampling equipment was placed about 20 feet from the downwind edge of the tilling path. The exposure profiler was set up with sampling heads 3, 5.5, 8, and 10.5 feet above the ground. The particle size classifier (Anderson impactor, Sierra impactor, or Aerotec cyclone, depending on the sampling run) had its intake six feet above the ground. Dustfall buckets were used in only two of the seven sampling runs. Saltation catchers sampled at heights ranging from 1 to 2.5 feet. The downwind standard hi-vol sampler was used in only one of the seven tests; it sampled at a height of six feet. The position of the upwind standard hi-vol was not documented. Wind speed and direction were measured at a height of 12 feet.

Sampling Runs--A total of seven sampling runs were conducted on tilling operations. The number of machinery passes per run ranged from 10 to 16. Sampling runs lasted between 13 and 35 minutes. Plumes from a total of 87 passes were sampled.

Quality Assurance--In the use of standard high volume filtration, the investigators followed the procedures specified by EPA in "Reference Method for the Determination of Suspended Particulates in the Atmosphere (High Volume Method)," (1971). For the measurement of dust deposition, the investigators followed the procedures set forth in "Standard Method for Collection and Analysis of Dustfall," ASTM Method D 1739-62.

Samples of the dust plume were collected only when the wind speed was less than 20 mph, the maximum speed under which samples could be collected isokinetically. As noted above, wind direction and speed were observed to be constant during each run. Likewise, the intake velocity and the directional orientation of the samplers in the exposure profiler were constant during each sampling run.

Filters were conditioned in a controlled temperature and humidity environment before and after collection of dust samples. Filter samples were transported to the laboratory in individual folders. The interior surfaces of the sampler heads were rinsed, and the water was captured and evaporated to determine the mass of dust on the interior surfaces.

Documentation of quality assurance practices such as collocation of samplers, processing of blank profiler filters, and audits of profiler filter weights was not provided.

The investigators acknowledged two potential sources of small particle bias in the measurement of particle size distribution: 1) particles bouncing down through the cascade impactor to smaller particle stages; 2) non-isokinetic sampling which collects larger particles with lower efficiency than smaller particles.

Findings--The exposures and emission factors measured in this study are presented in Table 2.70. A predictive equation was developed based on the limited data collected in this study:

$$e = \frac{1.4\, s\, (S/5.5)}{(PE/50)^2}$$

where

e = emission factor, lb/acre
s = silt content (i.e. percent between 2 and 50 μm in diameter)
S = implement speed, mph
PE = Thornthwaite's precipitation-evaporation index

The predictions of this model were within 16% of the measured lb/acre for these seven tests.

TABLE 2.70. EXPOSURE DATA AND EMISSION FACTORS

Run	Ht (ft)	Unit Exposure (mg/in.^{2}/ equivalent pass[a])	Integrated Exposure (lb/mile[b])	Emission Factors (lb/acre)			
				Total	$d^c > 30$ μm	$2 < d^c < 30$ μm	$d^c < 2$ μm
5	10.5 8 5.5 3	0.804 1.23 3.77 7.27	81.4	55.9	5.6 (10%)	28.2 (50%)	22.1 (40%)
6	10.5 8 5.5 3	0.537 1.92 3.60 10.8	75.4	51.9	5.2 (10%)	26.2 (50%)	20.5 (40%)
7	10.5 8 5.5 3	0.256 1.24 3.60 10.8	86.6	59.6	6.0 (10%)	30.0 (50%)	23.6 (40%)
9	10.5 8 5.5 3	1.30 1.91 2.96 4.29	50.5	41.6	4.2 (10%)	21.0 (50%)	16.4 (40%)
11	10.5 8 5.5 3	1.76 2.35 4.35 6.53	92.4	63.6	15.9 (25%)	27.7 (44%)	20.0 (31%)
12	10.5 8 5.5 3	2.31 3.34 5.35 9.06	124	85.2	21.3 (25%)	31.9 (37%)	32.0 (38%)
14	10.5 8 5.5 3	2.53 3.74 5.59 8.38	114	78.1	19.5 (25%)	36.3 (46%)	22.3 (29%)

a) In order to facilitate comparison with data from unpaved roads, which generally have lanes about 12 feet wide, data describing exposures from 12-, 20-, and 30-foot wide tillers were normalized to represent the mass per square inch per 12-ft wide tilling pass.
b) i.e. per mile of 12-foot wide tilling
c) particle Stokes' diameter

Publication--This study was conducted and documented under a contract with the EPA Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. It was published in 1974 as Publication No. EPA-450/3-74-037.

Study 2: Cuscino et al. The Role of Agricultural Practices in Fugitive Dust Emissions. 1981.

Methodology--The investigators used exposure profiling to measure fugitive dust emissions from several agricultural operations. The equation $E = C\ U\ t$, where E is the exposure (mass/area), C is the concentration (mass/volume), U is the wind speed (length/time), and t is the sampling time, was used to calculate exposure at each sampling height.

Test Sites--Sampling was conducted at three sites in California. Several soil preparation and maintenance operations were tested at the Norman Clark Farm in Fresno County in the San Joaquin Valley, at which hay and alfalfa were being grown, and at the Rice Experimental Station in Butte County in the Sacramento Valley. Sugar beet harvesting operations were tested at the Hamatani Farm in Sacramento County in the Sacramento Valley.

Parameters and Equipment--Table 2.71 below lists the parameters which were measured and the equipment employed in making those measurements. Exposures for various particle size categories were calculated using the method described in Cowherd, et al. (1984); an explanation of this method is provided in the review of that report in the section on paved roads.

Equipment Configuration--The exposure profiler was kept five meters from the downwind edge of the equipment path. Sampling heads on the profiler were fixed at heights of 1, 2, 3, and 4 meters. The cassette-mounted filter was positioned five meters downwind and two meters above the ground. Wind direction and speed were measured four meters above the ground at an unspecified distance upwind. A standard hi-vol sampler and a hi-vol cascade impactor were also operated on the upwind side at an unspecified distance.

For the tests of soil preparation and maintenance operations, downwind inhalable particulates (IP, particles with aerodynamic diameter less than 15 µm) concentration was measured at distances of 5, 50, and 100 meters with the intakes 2 meters above the ground. For some tests this series was duplicated at another height, 1 or 3 meters, to measure the change in IP concentration with height.

Sampling Runs--A total of 17 sampling runs were conducted to measure emissions from agriculture operations. Eleven of these were soil preparation or maintenance activities. Emissions were

TABLE 2.71. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameters	Equipment
Wind speed	Recording anemometer
Wind direction	Unspecified
Soil moisture	Oven, scales
Soil erodibility	Oven, sieves, scales
Soil silt content	Oven, sieves, mechanical sieving device
Equipment type	Direct observation
Equipment width	Unspecified
Concentration of TSP upwind	Standard hi-vol sampler
Plume concentration of TSP	Standard hi-vol sampler
Plume concentration of particles with aerodynamic diameter < 15 µm	Hi-vol with size-selective inlet
Plume concentration of particles in the categories: < 7.2 µm aerodynamic diameter < 3 µm " < 1.5 µm " < 0.95 µm " < 0.49 µm "	Cascade impactor with greased substrates attached to the above hi-vol sampler
Plume concentration of total particulates	Exposure profiler
Decay in plume IP concentration with downwind distance[a]	Hi-vol/SSI in series of increasing downwind distance
Largest particle size	Cassette-mounted 37 mm filter, microscope

a) Measured only for soil preparation / maintenance operations

measured from the towed implement and the towing tractor, which was either on tracks or on six wheels. Of the five runs at the Norman Clark Farm, three tested emissions for land planing (using an implement to level the land), and two were a disc operation. All of the runs at the Rice Experimental Station measured emissions from the disc operation.

Six sampling runs were conducted on a beet harvesting operation at Hamatani Farm. This harvest consisted of two separate field operations: leaf beating (removal of tops of plants) and beet digging. Both operations were tested in three sampling runs. Both implements were on two wheels and where towed behind a four-wheel tractor. During the digging operation an 18-wheel truck followed beside the digger. The duration of each sampling run was not reported; however, it was long enough to collect a measurable mass of dust and allow the averaging of the emitted dust mass over several implement passes.

Quality Assurance--Ample assurance was provided for the quality of the data gathered in this study.

The quality of each machine pass was judged according to the angle between the wind direction and the machine's path. The vast majority of the runs were of good quality.

The procedures for collecting and analyzing soil samples for moisture content, erodibility, and silt content were presented in detail; the laboratory scale's zero was checked prior to each measurement. All filter tare weights were audited. The measured weights of ten percent of the used filters were audited. Equipment was calibrated before testing at each site and at two week intervals.

Exposure samples were considered isokinetic if the ratio of sampling velocity over wind velocity was within the range of 0.8 to 1.2. Most samples met this criteria. Those samples which were not collected isokinetically were corrected to isokinetic conditions.

Findings--Field emissions data and calculated emission factors are shown in Table 2.72. Data on wind speed and sampling duration were not published. Runs with an "N" in the run identification column were conducted during soil preparation and maintenance operations, whereas those with an "R" were conducted on harvesting operations.

In developing predictive equations for the two kinds of operations tested, the investigators considered two variables: soil silt content, and soil moisture content. To develop an equation for total particulate emissions from soil preparation and maintenance operations, data from the tests at the Norman Clark Farm and the Rice Experimental Station (runs N-3 through N-13) and from 7 tests conducted in Kansas in 1974 (Cowherd et al., 1974) were used in a regression analysis. For equations for inhalable and fine particulate emissions, only data from those tests conducted in this study could be used, because these parameters were not measured in the 1974 study.

Inclusion of moisture content did not improve the predictive accuracy of the equation. To explain this the investigators theorized that moisture content effects emissions only when the moisture content was near a critical level, above which emissions would be greatly reduced, and that the farmers were all tilling when soil moisture was below that level. Table 2.73 shows the relationships estimated for each of the particle size categories, as well as some summary statistics. Due to the limited number of sampling runs conducted on beet harvesting (including leaf beating and beet digging), only a very limited statistical analysis was possible. Both silt content and moisture content were found useful in predicting emission factors. However, specific predictive equations were not published.

Publication--This study was prepared for the California Air Resources Board (CARB) in Sacramento, California. It was published in June of 1981 as (CARB's) Report No. ARB/r-81/138.

TABLE 2.72. EMISSION MEASUREMENTS AND CALCULATED EMISSION FACTORS

Run	Ht (m)	Concentr.[a] (μg/m³)	Integrated Exposure (mg/cm)			Emission Factor (kg/km²)		
			Total	IP[b]	FP[c]	Total	IP[b]	FP[c]
N-3	1	8504	1700	226	59	2320	309	80.5
	2	7195						
	3	4023						
	4	2564						
N-4	1	8113	1900	213	85	2600	291	116
	2	7960						
	3	4594						
	4	3388						
N-5	1	5293	1840	169	100	2520	231	137
	2	4544						
	3	3588						
	4	2373						
N-6	1	5806	1440	299	106	2960	613	217
	2	2310						
	3	806						
	4	184						
N-7	1	10417	1060	313	78.4	2720	797	200
	2	5130						
	3	1642						
	4	1359						
N-8	1	3036	382	48.5	17.9	522	66.2	24.4
	2	1462						
	3	581						
	4	293						

(continued)

TABLE 2.72. (continued)

Run	Ht (m)	Concentr.[a] (μg/m³)	Integrated Exposure (mg/cm)			Emission Factor (kg/km²)		
			Total	IP[b]	FP[c]	Total	IP[b]	FP[c]
N-9	1	2405	591	251	94.0	865	379	138
	2	1060						
	3	363						
	4	127						
N-10	1	3621	1120	442	214	1630	646	314
	2	1597						
	3	579						
	4	216						
N-11	1	5692	1180	395	182	1610	540	249
	2	2124						
	3	598						
	4	187						
N-12	1	6710	953	264	125	1300	361	170
	2	2051						
	3	552						
	4	213						
N-13	1	5303	764	282	137	1120	412	200
	2	2207						
	3	687						
	4	193						
R-1	1	2833	590	21.1	11.1	3940	141	74.3
	2	6064						
	3	1164						
	4	1482						
R-2	1	3539	322	149	66.3	2150	997	444
	2	2054						
	3	1203						
	4	707						

(continued)

TABLE 2.72. (continued)

Run	Ht (m)	Concentr.[a] (μg/m³)	Integrated Exposure (mg/cm)			Emission Factor (kg/km²)		
			Total	IP[b]	FP[c]	Total	IP[b]	FP[c]
R-3	1	6615	512	122	59.2	3430	816	396
	2	2703						
	3	1645						
	4	1149						
R-4	1	3220	816	160	74.3	3560	699	325
	2	1147						
	3	966						
	4	782						
R-5	1	2178	366	103	43.9	11.40	321	137
	2	1796						
	3	1316						
	4	1292						
R-6	1	3285	454	200	108	3300	1460	786
	2	2955						
	3	2518						
	4	1647						

a) gross measurements, i.e. including background
b) inhalable particulates
c) fine particulates

TABLE 2.73. PREDICTIVE EMISSION FACTOR EQUATIONS FOR SOIL PREPARATION AND MAINTENANCE OPERATIONS

Emission Factor Equation	R-squared	One-sigma precision factor
kg/km² of TP[a] = 538 (% silt)$^{0.6}$	.88	1.29
kg/km² of IP[b] = 135 (% silt)$^{0.6}$	not published	2.17
kg/km² of FP[c] = 53.8 (% silt)$^{0.6}$	not published	2.33

a) Total particulates; i.e., no limit on particle size
b) Inhalable particulates; i.e., particles with aerodynamic diameter < 15 μm
c) Fine particulates; i.e., particles with aerodynamic diameter < 2.5 μm

LANDFILLS

Particulate emission rates from sanitary landfills have not been field measured. An emission inventory was prepared by Muleski and Hecht (1987) for two landfills near Chicago. Field data on soil silt and moisture content, vehicle weight, number of wheels, travel distance, and speed, and traffic density were applied to the AP-42 emission factor for unpaved roads to estimate emissions from the haul road within the landfills. The AP-42 emission factor for a bulldozer working coal mine overburden was used to estimate emissions from a dozer and a compactor operating in the landfill. The old AP-42 factor for batch drop operations was used to estimate emissions from materials handling at the landfill. The three emission factor equations are shown below:

Haul Roads

$$e = 2.1\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-P}{365}\right)$$

where

e	=	PM_{10} emission factor, lb/veh-mile
s	=	silt content, %
S	=	vehicle speed, mph
W	=	vehicle weight, tons
w	=	number of wheels per vehicle
p	=	number of day with more than 0.1 inches of precipitation

Dozer and Compactor Operation

$$e = 5.69\,\frac{(s)^{1.2}}{(M)^{1.3}}$$

where the variables are defined as above, except e is the TSP emission factor in lb/veh-mile.

Materials Handling

$$e = 0.00065\,\frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{5}\right)}{\left(\frac{M}{2}\right)^{2}\left(\frac{Y}{6}\right)^{0.33}}$$

where

U	=	mean wind speed, mph
H	=	drop height, ft
Y	=	dumping device capacity, yd^3

and the other variables are as defined above.

Total calculated PM_{10} emissions from the two landfills were 37 tons/year and 13 tons/year.

CATTLE FEEDLOTS

Very little field data is available on dust emissions from cattle feedlots. The source assessment conducted by Peters and Blackwood (1977) found only two studies, both sponsored by the California Cattle Feeders Association, in which particulate concentrations at cattle feedlots were measured (Elam et al., 1971; Elam et al., 1972). However, emission rates were not measured or modeled in either of these two studies. In fact, data on other field parameters, such as upwind and downwind sampling distance, wind speed, atmospheric stability, or feedlot size, were not collected.

Peters and Blackwood took the 24-hour concentration data reported by Elam et al. (1972), corrected it to a 10 minute sampling time using the method described by Turner (1970), made assumptions for each of the deficient parameters, and modeled an emission rate for each measured concentration. The downwind edge of the feedlot was treated as an apparent line source; thus the equation for a continuously emitting line source (Turner, 1970) was used:

$$\chi = \frac{2Q_L}{\sqrt{2\pi}\,\sigma_{zu}} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

where

χ	=	concentration at downwind distance x, g/m^3
Q_L	=	emission rate per length of a line source, g/s-m
u	=	average wind speed, m/s
H	=	effective height of emission, m
σ_z	=	standard deviation of the plume's vertical concentration distribution, m

The downwind distance was taken to be 50 meters. The national average wind speed of 4.47 m/s and the average stability class, C, were assumed. The emission height was assumed to be 3.05 meters, and σ_z was assumed to be 4 meters. Table 2.74 shows the field measured concentrations, the corrected concentrations, and the modeled source strengths. The average source strength was 0.0361 g/s-m.

Additional data were collected on the average size and density of California cattle feedlots to permit conversion of the average source strength to units of mass emitted per second for the average California feedlot, which was found to contain 8,000 head on 27.5 acres. The resulting rate, 11.9 g/s, was then converted to 36.7 $\mu g/s\text{-}m^2$. As presented in AP-42, 11.9 g/s also equates to 128 kg/day/1,000 head capacity.

TABLE 2.74. CONCENTRATIONS AND CORRESPONDING SOURCE STRENGTHS

Feedlot Number	Measured Concentration (μg/m3)	Corrected Concentration (μg/m3)	Source Strength (g/s-m)
19	453.3	1056.2	0.0256
25	977.9	2278.5	0.0553
4	418.3	974.6	0.0237
8	1034.8	2411.1	0.0585
9	108.6	253.0	0.0061
12	348.4	811.8	0.0197
13	534.5	1245.4	0.0302
15	959.8	2236.3	0.0543
17	716.0	1668.3	0.0405
20	53.7	125.1	0.0030
2	1046.4	2438.1	0.0592
3	379.8	884.9	0.0215
5	1184.7	2760.4	0.0670
6	660.3	1538.5	0.0373
7	860.3	2004.5	0.0487
10	1267.8	2954.0	0.0717
14	703.6	639.4	0.0398
22	268.5	625.6	0.0152
23	1161.0	2705.1	0.0657
24	276.1	643.3	0.0156
1	279.4	651.0	0.0158
11	263.7	614.4	0.0149
16	1129.8	2632.4	0.0639
26	216.2	503.7	0.0122
18	660.6	1539.2	0.0373

Documentation of the absence or presence of dust control techniques at these feedlots was not provided. The field testing occurred exclusively during California's dry season.

UNPAVED PARKING LOTS

McCaldin (1977) attempted to measure emissions from vehicle travel in an unpaved parking lot using the upwind-downwind method. Four 1.5 to 3 hour tests were conducted at an unpaved parking lot in Tucson, Arizona. Standard high volume samplers were used to measure dust concentration. There was no significant difference in background and downwind concentrations The number of "vehicle movements" in the lot during sampling totaled 38.

McCaldin estimated emissions from a hypothetical one-acre parking lot using the emission factor equation he developed from unpaved road field test results:

$$E = (s)\ 0.035\ (S)^2$$

where

E	=	TSP emission factor, lb/veh-mile
s	=	mass percent silt
S	=	traffic speed, mph

He assumed a vehicle speed of 15 mph and a resulting emission factor of 1 lb/mile. The assumed percent silt was not given. The total travel distance for a vehicle entering and exiting the parking lot was taken to be 300 feet. The resulting emission factor was 0.05 lb/use of the lot.

In a similar manner, the Midwest Research Institute (1988) used the AP-42 emission factor equation for unpaved roads and several large assumptions to calculate the mass emitted per use of a parking lot. However, the emission rate was expressed as a function of the dimensions of the parking lot:

$$E_{10} = 0.2\,\frac{365-p}{365}\,(L+W)$$

where

E_{10}	=	PM_{10} emissions, g/use of the lot
p	=	number of days/year with rain
L	=	dimension of parking lot perpendicular to aisles, m
W	=	dimension of parking lot parallel to aisles, m

In developing the above equation from the unpaved road emission factor, the following assumptions were made:

1) silt content is 12%
2) average number of wheels per vehicle is 4
3) average weight of vehicles is 3 tons
4) vehicles travel at 10 mph in parking lots

WIND EROSION

Introduction

Emissions estimates for wind erosion have typically dealt with either emissions from open areas (such as agricultural fields) or from storage piles during periods when they are not actively being utilized.

Development of wind erosion emissions estimates in early emission inventory efforts typically involved using an equation developed from data collected in the late 1940s and early 1950s that was not intended for use in evaluating suspended particulate emissions estimates, but rather was developed for evaluating strategies for minimizing the horizontal flux (translational movement) of particulates from field to field. This early work was performed by Dr. W.S. Chepil. The majority of this early work reflected measurements made using wind tunnels. The early form of the wind erosion equation was a simple exponential expressing the amount of soil loss in a wind tunnel as a function of soil cloddiness, amount of surface residue and degree of surface roughness. This equation has been continuously modified as new research data has become available, and is now a complex equation indicating the relation between potential soil loss from a field and a number of primary field and climatic variables. The form of the wind erosion equation most commonly utilized in developing TSP emission inventories was proposed in 1965 by Woodruff and Siddoway. As put forward in their 1965 publication, the wind erosion equation can only be utilized to develop wind erosion soil loss estimates on an annual basis, and as previously stated is not intended to produce estimates of the vertical flux of particles, but rather total soil loss from an upwind field to some downwind location.

In utilizing the wind erosion equation for determining wind erosion particulate emission estimates, an assumption regarding the fraction of the horizontal material that is actually suspended has been made. Typically, this value (for TSP) has been chosen to be 2.5%, however, the range has been indicated as between 2-10%.

There are few actual emission measurement studies from wind erosion sources. Typically, the measurements that have been made can be grouped into one of three types. First, measurements of aerosol particle numbers were taken at two or more heights above ground in order to determine the vertical flux of particles. Second, measurements of wind erosion emissions from a variety of surface types were made using wind tunnels (either by bringing into the lab samples of the material, or utilizing portable wind tunnels in the field). Finally, a few emissions measurements were made in fields using upwind-downwind sampling techniques to try and determine the emissions from a particular field.

Details of those studies that did report emissions data of one of the three types indicated above are reported below. The studies evaluated include wind erosion emissions measured for open areas as well as wind erosion emissions measurements determined for sources such as aggregate storage piles, mining and quarrying and other fugitive sources considered in the previous sections.

Studies of Primary Importance

Study 1-- Gillette et al. "Measurements of Aerosol Size Distributions and Vertical Fluxes of Aerosols on Land Subject to Wind Erosion." Journal of Applied Meteorology. Vol. 11. pp. 977-987. 1972.

Methodology--Vertical fluxes of aerosol particulates were determined based on considerations of both the aerosol and momentum fluxes and by making some simplifications concerning the coefficient of exchange for aerosols and the eddy viscosity. In practice, the vertical flux of particles was determined using the following equation:

$$F_a=-pCu_1^2(n_2-n_1)/u_2-u_1$$

where F_a is the vertical aerosol flux, p is the density of air, C is the drag coefficient, u_1 is the wind speed taken at height z_1, u_2 is the wind speed taken at height z_2, and n_1 and n_2 are the number of particles measured at heights z_1 and z_2 respectively. In practice, aerosols within the size range 0.3-6 microns were measured, and the resulting particle fluxes as functions of size were expressed in the conventional dN/d log r notation where N(r) is the total number of particles having radii $\leq$ r.

Test Site--All samples were taken in an eroding field at the University of Nebraska Northwest Experimental Laboratory located near Alliance, Nebraska.

Parameters and Equipment--Aerosol samples were collected using single-stage jet impactors. The aerosol impaction surface was a microscope cover slip coated with filtered silicone oil and mounted on a standard microscope slide. Size distributions of the collected aerosol were determined from photomicrographs taken using a Zeiss TGC-3 particle sizer and counter. All samples were collected isokinetically.

In addition to the aerosol collection, wind speed was determined using a three cup Belfort anemometer. Soil erosion parameters were also measured. Soil particle creep was measured using 15 cm long cylinder buried flush with the soil surface. Total soil flow (soil creep and saltation) was measured using a Bagnold catcher. Soil condition parameters were also measured. These parameters included water content, cloddiness, clod stability, crop residue and ridge roughness. Water content was measured by drying containers of soil at 120 C until three successive weights were the same. Soil cloddiness was determined as the percentage of soil passing through a rotary sieve with 0.84 mm square openings. Clod stability was also determined using the rotary sieve. Crop residue was measured using standard USDA methods. Ridge roughness was measured by comparison to photographs. The particle size distribution of the soil particles were determined by wet sieving and scanning electron microscopy.

Equipment and Configuration--Aerosol samples collected using the jet impactors were collected at two heights, 1.5 and 6 meters above the ground. The wind speed was measured at 1.5, 3, and 6 meters above the ground.

Sampling Runs--A total of thirteen samples were obtained, however, several of the experiments were repeated twice. The data for the duplicates was not presented. Samples were obtained on March 17, 18 and 31, April 1,4,15,28-30, May 13, and July 12, 1971. Sampling times ranged from 30 minutes to 2 hours.

Quality Assurance--As indicated above, duplicate aerosol size distributions were obtained for use in determining the aerosol size flux. The results of these duplicate samples were used as an indicator of the sensitivity of the technique. The error associated with the particle size counting was determined using a standard Poisson distribution. Variability resulting from the laboratory procedure was determined by examining the results for laboratory repeatability. Two independent determinations were made on three aerosol collections, and the percentage standard deviations for the four particle size classes used in the field data were calculated. The results of these standard deviation calculations were presented.

Findings--Of the thirteen samples taken, only four indicated positive vertical fluxes (i.e., emissions of particles for the conditions examined in the study). For those samples indicating positive fluxes, the number fluxes were converted to mass fluxes by assuming that the soil and aerosol bulk densities were the same and that the particles were spherical. The results indicated that the vertical flux of aerosols $\leq$ 10 microns were between 0.6×10^{-5} and 1×10^{-4} micrograms/cm^2/sec.

Horizontal fluxes were also determined using the wind erosion equation and the actual measured flux determined by summing soil creep and saltation measurements. These measurements were in rough agreement. One interesting point in these measurements is that it provides an indication of the actual percentage of the total horizontal flux that is represented by the vertical (suspended) flux. As noted above, for most previous TSP wind erosion emission inventories, it was assumed that 2.5% of the total wind erosion flux was the suspended component. However, the ratio of the vertical fluxes determined in this study to the horizontal fluxes measured yields values between 0.0067 and 0.01%, values that are much lower than the 2.5% that has been utilized in the past.

Publication--This study was documented in the Journal of Applied Meteorology, Volume 11, pages 977-987, 1972.

Study 2-- Jutze and Axetell. Investigation of Fugitive Dust Volume I - Sources, Emissions, and Control. EPA-450/3-74-036-a. 1974.

Methodology--Upwind-downwind sampling using directional hi-vol samplers was carried out to measure emissions from agricultural sites at two locations. A diffusion equation for ground-level sources with no effective plume rise was used to estimate the source strength from measured concentrations.

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u}$$

The resulting formula for source strength, Q (g/sec), is shown below:

$$Q = 2.78 \pi \sigma_y \sigma_z u \chi$$

where

σ_y = standard deviation of the crosswind distribution of the plume's concentration at the downwind measurement site (a function of atmospheric stability, downwind distance, and the assumed initial standard deviation, σ_{yo}).

σ_z = standard deviation of the vertical distribution of the plume's concentration at the downwind measurement site (a function of the atmospheric stability and downwind distance), m

u = mean wind speed, m/sec

χ = measured concentration of particulates at the downwind measurement site (minus the background concentration), g/m^3

Test Site--Two sites located in agricultural areas were utilized to try and determine the emissions resulting from wind erosion of agricultural land. One of the test sites was located near the University of Arizona in Mesa, Arizona. The second site was located in the San Joaquin Valley of California, close to the University of California Westside Agricultural Field Station.

Parameters and Equipment--Equipment utilized in this study included directional hi-vols, hi-vols equipped with Andersen cascade impactors, standard hi-vols and a meteorological tower. However, even though all of these samplers were utilized at the two test sites, only the information from the directional hi-vols was utilized to develop the emissions estimates. Wind velocity and direction were measured using continuous windvane/anemometer sensors.

Equipment and Configuration--No detailed information was given concerning the location of the sampling equipment. Maps showing the locations of samplers were provided, but didn't differentiate between the different types of samplers. The downwind measurement distance used in the dispersion modeling was given in a table in the report. At the Mesa site this distance was 30 meters and 315 meters for the two sampler locations for which measurements were made. Two sets of measurements were made for each of the sampler locations at the Mesa site. For the San Joaquin site, the distances for the four measurements were 250, 150, 150, and 250 meters downwind. A single sample was obtained at each downwind distance at the San Joaquin site.

Sampling Runs--Four concentration measurements were taken for each of the two sites. Samples were collected over either a 24-hour or 48- hour period.

Quality Assurance--The investigators provided little assurance of the quality of the data collected for this study. Although, the procedures for operating the hi-vol samplers and for handling and transporting the filters were thoroughly documented, the procedures used to determine the filtered dust mass were not described. Normal quality assurance procedures, such as calibration of samplers, processing of blank filters, or auditing of weight measurements or data reduction calculations, were not documented for this study.

Findings--The field data collected in this study of fugitive dust emissions from agricultural wind erosion is shown in Table 2.75. The emission rate calculated for the San Joaquin valley agricultural area was 0.6 tons/acre/year. For the Mesa agricultural site, the emission rate was determined to be 2.1 tons/acre/year. The investigators calculated emissions using these emission factors and compared those emissions with those calculated from the wind erosion equation. The results showed that emissions calculated using the wind erosion equation would only be 22 and 21 percent of the San Joaquin and Mesa emissions calculated using the emission rates determined from the field studies. The investigators attributed this overprediction using the developed emission factors to the fact that the emission factors do not account for the fact that some of the acreage used to develop the total emissions estimates had continuous ground cover, which is accounted for in the wind erosion equation, but not in the emission factors developed in this study. In spite of the fact that emission factors were developed using field information, the actual emissions estimates produced for this study were made using the wind erosion equation (with the assumption that 2.5% of the total mass eroded was emitted vertically).

TABLE 2.75. DISPERSION PARAMETERS - AGRICULTURAL SITES

Site	x (m)	Stability Class	σ_y (m)	σ_z (m)	Wind Speed (m/sec)	Concentr. (mg/m^3)	Source Strength (g/sec)
San Joaquin	250	B	125	87	3.1	.039	11.8
San Joaquin	150	B	116	75	2.2	.026	5.0
San Joaquin	150	B	116	75	3.1	.029	7.9
San Joaquin	250	C	115	67	4.0	.035	9.5
Mesa	30	C	186	108	3.1	.019	10.3
Mesa	30	C	186	108	3.6	.037	23.3
Mesa	315	B	228	172	2.7	.023	21.3
Mesa	315	B	228	172	2.7	.072	66.6

Publication--This study was conducted and documented under contract for the Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. It was published in 1974 as Publication No. EPA-450/3-74-036-a.

Study 3-- Cowherd et al., Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037. 1974.

This report documented two distinct field studies on dust emissions from storage piles: total emissions from aggregate storage operations and emissions generated during aggregate load-out operations. However, emissions measurements made during the total emissions monitoring program could be further subdivided into two components: measurements made during active operations within the storage area and measurements made during non-active periods. The investigators considered the measurements made during the non-active periods to be indicative of wind erosion emissions from storage piles.

Methodology--The mass of dust emitted from a storage operation was measured using a rather simple methodology. The site's contribution to the downwind ambient dust concentration was estimated using upwind and downwind hi-vol samplers. The mass of dust emitted per unit time was calculated as the average net concentration times the atmospheric ventilation rate (which is in this case the volumetric rate at which air passes through the cross-sectional area defined by the width and height of the storage area).

Sampling runs were conducted during 12- and 24-hour periods. Four parameters were evaluated as possible factors influencing the total dust emission rate for aggregate storage operations: rainfall, wind speed, aggregate size, and intensity of activity. For the rainfall factor, sampling results were divided into two groups: dry period results and wet period results. Runs were deemed wet if any precipitation occurred during sampling or if more than a trace occurred on the day before. The average net concentration and emission rate for each group was compared to determine if emissions were higher during dry periods than wet periods.

To check for effects of wind speed and aggregate size, these variables were each plotted against downwind concentration. For aggregate size, this was accomplished by matching storage piles of various sizes of aggregate with particular samplers downwind from the piles.

Accurate data were not available on the level of activity in the storage area during each sampling run. Thus, it was not possible to estimate a relationship between the intensity of activity and concentration. However, after some manipulation of the data, it was possible to compare concentrations corresponding to periods when the storage area was active with those for non-working periods. The 12-hour sampling runs were conducted exclusively during non-working hours, and most 24-hour samples were conducted during periods including both working and non-working hours. (The rest covered exclusively non-working periods.) A concentration for working hours was calculated using the following relationship, in which A is the 24-hour average concentration for a day including 8 to 12 hours of activity, B is the average concentration during hours of activity in the storage area, and C is the average concentration for inactive hours:

$$A = (B + C)/2$$

<u>Test Site</u>--Tests were conducted at a sand and gravel quarry and processing center near Cincinnati, Ohio. The investigators considered it representative of operations at many medium and large aggregate sites. Although the gravel pit was adjacent to the storage area, the samplers used in this study were judged to be sufficiently isolated from any dust generated in the pit itself by the difference in elevation between the pit and the storage area. Fifteen storage piles, ranging in height from 5 to 30 feet, were maintained in this area. The investigators computed an average pile height, weighted on the basis of the

pile surface area, of 23 feet. Each pile was for a different size aggregate. The turnover rate for these piles was said to be high. No processing of aggregate was conducted in this area.

Parameters and Equipment--Upwind and downwind concentration of total suspended particulates was measured using standard hi-vol samplers. These were automatically activated by wind sensors when the wind direction was within 90° of south. They were also equipped with timers to record the duration of the sample. A high volume cascade impactor was used to measure the particle size distribution of the dust downwind from the storage area. Meteorological data, including cloud cover, temperature, and precipitation, were acquired from a nearby Federal Aviation Administration Weather Station. The size of the aggregate in each pile was noted so the effect of aggregate size on downwind concentration could be analyzed. Data were also collected on the height and configuration of each pile. The equipment operator's records documented the tonnage of material excavated, sized, and loaded onto trucks for transport. This provided only a very rough indication of the level of activity at the site during a given day.

Equipment Configuration--The five downwind samplers were scattered on the downwind side of the storage area. Three of them were set up among the storage piles, and two were immediately downwind of the entire storage area. The intake height of these samplers ranged from 3 to 20 feet. The height and upwind distance of the background sampler was not documented, nor was the position of the cascade impactor. Wind speed and direction were measured continuously on a pole about 25 feet above the ground.

Sampling Runs--Eleven 24-hour and seven 12-hour sampling runs were conducted. Four of the 24-hour runs were on weekends when there was no activity at the storage area. The remainder ran from noon one work day until noon the next. All of the 12-hour samples ran from 6:00 p.m. until 6:00 a.m. the next day. For the purposes of estimating the wind erosion component of the storage pile emissions, the samples collected on the weekends and from 6:00 p.m. until 6:00 a.m. were considered inactive and thus representative of the wind erosion component.

Quality Assurance--None of the normal quality assurance procedures, such as processing of blank samples, calibration of equipment, or auditing of measurements or calculations, were documented for this field study.

Presentation of raw field data was complete. Measured upwind concentrations and net downwind concentration for each site and sampling period were documented. Evidence that the net downwind concentration measured the full contribution of the storage area alone was presented in three separate comparisons:

the upwind concentration was in line with typical regional ambient levels, the upwind concentration was greater than the downwind concentrations in almost every instance, and the average upwind concentrations during working periods were close to those of non-working periods.

Findings--The concentrations measured for each of the sampling runs made during inactive periods are shown in Table 2.76. The run time for each sampler is also shown for every test.

The average concentration on non-working days was 47.4 $\mu g/m^3$. Using the methodology described above, the corresponding emission rate for the wind erosion component of storage piles was calculated to be 26.8 kg/day.

Neither the calculations for converting these numbers into emission factors nor the activity rate (e.g. tons stored per day) were presented in the report. For periods of inactivity, the emission factor was calculated as 3.5 lb/storage acre/day (0.11 lb/ton placed in storage).

Rainfall, as recorded in the manner described above, was found to reduce total aggregate storage pile emissions by roughly 50%. However, when the data for inactive periods only was examined, the reduction due to precipitation was slightly less than 25%. Neither the size of the aggregate in the storage piles nor the wind speed was not found to have a significant influence on wind erosion emissions from storage piles.

The particle size distribution of dust downwind from the storage area was not discussed, although the cascade impactor was listed as an instrument used in the field study.

Wind erosion emissions from storage piles were found to contribute approximately 25% of the total emissions from aggregate storage piles based on the data collected as part of this study. The investigators also presented a procedure for estimating windblown dust as an appendix to this report. In that appendix they detailed how to use the USDA wind erosion equation and indicate that the fraction of total eroded material that is suspended is 2.5%. They also indicated that one of the drawbacks of using the wind erosion equation is the assumption of a constant percentage of total soil losses becoming suspended and that this assumption was made without any substantiating data.

Publication--This field study was conducted and documented under a contract with the EPA Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. The report was published in 1974 as Publication No. EPA-450/3-74-037.

TABLE 2.76. CONCENTRATION MEASUREMENTS AND SAMPLE RUN TIMES

			Net Downwind Concentration (µg/m³) / Sampling Time (minutes)					
Date	Test Period (hr)	Upwind Concent. (µg/m³) / Sample Time (min)	Hi-vol 2	Hi-vol 3	Hi-vol 4	Hi-vol 5	Hi-vol 6	Avg[a]
6/9	24	94/1130	8/1140	23/1082	49/1074	13/1165	4/1064	19
6/11	12	95/484	107/403	152/415	184/413	172/423	76/355	138
6/13	12	65/276	215/70	125/73	15/80	0[b]/280	125/62	96
6/16	24	75/1126	3/1192	0[b]/1128	0[b]/1082	7/1168	26/378	7
6/18	12	71/532	21/340	16/381	37/406	42/619	Void[c]	29
6/20	12	61/410	Void[c]	Void[c]	48/201	2/719	Void[c]	25
6/23	24	67/1087	8/1011	6/1440	Void[c]	9/1352	27/1024	12
6/25	12	86/586	55/578	19/721	89/301	33/719	210/510	81
6/30	24	61/1233	16/1119	31/1066	0[b]/1190	31/982	42/1032	24
7/2	12	64/611	20/613	17/620	11/596	71/378	Void[c]	30
7/3	12	50/1139	28/1058	24/1031	28/869	22/1249	19/1054	24

a) Average downwind sampling time was not calculated
b) A net concentration of zero was assumed when the upwind concentration was slightly higher than the downwind
c) No explanation was given for the voided samples

Study 4-- Axetell. Survey of Fugitive Dust from Coal Mines. EPA-908/1-78-003. 1978.

Methodology--The investigators used upwind-downwind dispersion modeling to measure emission factors for several mining operations: topsoil removal, drilling, blasting, dragline, shoveling/truck loading, and fly-ash dumping. Concentrations resulting from emissions from exposed areas were also measured. However, emission rates were not determined for exposed areas. During most of the sampling periods for exposed areas, the particulate concentrations increased with distance downwind from the source. These values would have produced highly variable emission rates at the various downwind distances, using the area source dispersion model employed in this study.

Test Sites--Operations at five western coal mines were tested. Except for one lignite mine, all of the operations extracted sub-bituminous coal.

Parameters and Equipment--Most of the parameters measured in this study are listed in Table 2.77 along with the tools used to collect the data. In addition, estimates were made for the initial dimensions and dispersion of the dust plume, the receptor's distance from the source, the receptor's vertical and horizontal distance from the plume centerline, and the length of time the receptor is in the plume. These estimates were all made visually.

TABLE 2.77. PARAMETERS MEASURED AND CORRESPONDING EQUIPMENT

Parameters	Equipment
Upwind concentration of TSP	Standard hi-vol
Downwind concentration of TSP	Standard hi-vol
Wind direction	Recording wind instrument
Wind speed	Recording wind instrument, hand-held wind speed anemometer
Other atmospheric stability parameters	Unspecified
Particle size distribution	Millipore filters on nuclepore filter holder and pump, microscope

Equipment Configuration--The equipment configuration varied between sources and mines. It was not completely described for each test run. Typically, a pair of hi-vols were placed together at a location upwind from the exposed area. This was preferred over placing samplers immediately upwind from the activity because anticipated brief wind direction reversals would be less likely to effect upwind concentration measurements. Other hi-vols were placed at 10, 20, and 30 meters (or a similar series of distances) downwind from the exposed area activity. Downwind samplers were set up at both 1.2 and 2.4 meters above the ground at these downwind locations to provide information on the vertical dispersion of the plume.

Sampling Runs--The number of sampling runs and the measured concentrations for the exposed areas measured are in Table 2.78. Each sampling run consisted of several concentration measurements.

Quality Assurance--The guidelines in the Quality Assurance Handbook for Air Pollution Measurement Systems (U.S. EPA, 1976) were followed in preparing filters, collecting and analyzing samples, and auditing the data. Hi-vol samplers were calibrated before field work began at each mine. One of every 25 filters was treated as a blank.

The investigators listed several problems experienced in the field sampling program which indicate a decrease in the reliability of the field data. Foremost was the fact that much of the data collected in the field was subject to the ability of

TABLE 2.78. MEASURED CONCENTRATIONS DOWNWIND OF EXPOSED AREAS

Mine	Sampling period	Downwind concentrations, μg/m³							Background concentration	Wind Speed (m/sec)
		At 1.2 m ht				At 2.4 m ht				
	Dist	10m	20m	30m	40m	10m	20m	30m		
A	1	103	253	171					64	.8
	2	377	603	313					64	1.0
	3	423	322	347	349				88	.4
	4	490	240	338	297				88	.4
B	1	1376	1865	1979	2431				84	7.2
	2	1480	1944	2139		689	742	1111	84	7.2
	3	3846	4716	9309		815	1325	1640	84	8.2
	4	4842	6199	6433	6407				84	8.2
	5	1398	2310	2565		398	850	991	84	7.5
	6	1602	2203	2446	2771				84	7.5
	Dist	Samplers within exposed area								
C	1	82	77	109		120	32	74	32	2.2
	2	86	111	171	81				32	2.2
	3	99	168	117	134				32	2.2
	4	106	117	165		64	42	117	32	2.2
	Dist	0m	10m	20m	30m	0m	10m	20m		
D	1	213	100	172	109				87	5.7
	2	457	317	474		429	409	1705	105	9.7
	3	598	567	270	559				105	8.8
E	1		298	143	228	91	74	110	a	4.8
	2	119	134	153	153				a	4.8
	3	144	66	104		98	105	66	a	6.2
	4	65	92	94	117				a	6.2

[a] Wind reversal at start of sampling period; no upwind samplers.

the field staff to make visual estimates. Plume dimensions and distance from the plume centerline are two examples of this. In addition, one avoidable problem greatly decreased the integrity of the data: the two separate field crews did not follow the same procedures in collecting samples in several critical respects. There was no way to fully correct the data for these differences.

Findings--As indicated above, the data did not allow for the calculation of emission rates due to wind erosion of exposed areas. In fact the data indicated that the concentrations increased downwind of the exposed areas.

The investigators initially assumed that the emission rates would decrease with distance downwind due to particle deposition. However, despite the fact that emission rates were not calculated for exposed areas, the empirical data collected in this study did not support the supposition that the apparent emission rate decreases with distance due to particle fallout. This is readily apparent from examination of the concentration information which shows an increase in concentration with distance downwind.

The data also indicate that, when measured at two heights (1.4 meters and 2.4 meters) at the same downwind distance, the concentrations at the lower height were generally 20-50% higher than those measured at the sampler highest above ground.

Publication--This study was conducted and documented under a contract for the Environmental Protection Agency, Region VIII, Office of Energy Activities, Denver, Colorado. It was published in February of 1978 as Publication No. EPA-908/1-78-003.

Study 5-- Cowherd et al., Iron and Steel Plant Open Source Fugitive Emission Evaluation. EPA-600/2-79-103. 1979.

Methodology--Wind erosion emissions were generated using a portable wind tunnel outfitted with a sampling train that consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, back-up filter, and high-volume sampler motor. Interchangeable probe tips were utilized on the probe to facilitate isokinetic sampling.

Emission factors developed from the data collected as part of this study were presented, but the methodology used to calculate the emission factors was not documented.

Test Sites--Preliminary tests were conducted on disturbed prairie land and a coal storage pile to determine the threshold friction velocities for wind erosion and to gather other data required to design the sampling module.

Emissions tests were made a total of 12 times. Eight of these tests were conducted on the upper flat surface of an inactive coal storage pile. These eight tests were subdivided into five tests of undisturbed (crusted) areas and three tests of disturbed areas. In addition to these eight tests, two tests were performed on a flat undisturbed area adjacent to a dolomite storage pile and two tests were conducted on disturbed prairie soil.

Parameters and Equipment--A portable wind tunnel with an open-floored test section measuring 15 cm x 2.4 m was utilized to generate wind erosion emissions on a coal storage pile, ground adjacent to a dolomite storage area, and disturbed prairie soil within iron and steel plants.

In addition to the wind tunnel, particulate samples were collected using an isokinetic probe attached to a cyclone precollector mounted to a cascade impactor.

Soil parameters were also determined. Samples were obtained both prior to and subsequent to sampling using a small broom. These samples were analyzed gravimetrically in the laboratory. In addition, the moisture content and the silt content were also determined. The silt content was determined using a conventional shaker.

Dust that collected in the probe tip and in the cyclone precollector were also collected by rinsing the probe and collector with distilled water and then drying until a dry residue remained.

Equipment Configuration--A sampling train that consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, back-up filter, and high-volume sampler motor was mounted so that the probe was oriented at right angles to the flow in the tunnel and along the centerline. Interchangeable probe tips to facilitate isokinetic sampling were utilized on the probe. These tips enabled isokinetic sampling at average cross-sectional velocities of 7, 12, 17, and 27 m/sec.

Sampling Runs--One sampling run was conducted for each test site detailed above, resulting in a total of 12 sampling runs.

Quality Assurance--A minimal amount of information concerning the handling of filters and dust samples collected in the field was provided, however, detailed procedures concerning data manipulation, emission factor calculations, treatment of blanks, calibration of samplers and other similar items was not provided.

Findings--Table 2.79 details the emissions data collectfed as part of this study. As can be seen from this table, emission rates ranged from 0.023 to 6.5 g/sec/m^2. Undisturbed surfaces emitted much lower levels than did disturbed surfaces of the same material, verifying the capability of surface crusts to inhibit wind erosion. In addition, the authors note that wind erosion emissions tend to decay over the collection period. No effort was made to develop emission factors from this data.

Publication--This study was conducted and documented under a contract for the Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. It was published in May of 1979 as Publication No. EPA-600/2-79-103.

TABLE 2.79. WIND EROSION SAMPLING PARAMETERS

Run	Surface Type	Cross-Sectional Average Velocity (m/sec)	Volume Sampled (m^3)	Total Mass Collected (g)	Suspended Particulate Emission Factor ($g/sec/m^2$)
C-1	Undisturbed coal	15.6	5.66	0.8680	0.12
C-2	Undisturbed coal	25.0	2.83	2.7565	1.2
C-3	Undisturbed coal	25.0	5.23	0.2176	0.053
C-4	Disturbed coal	8.49	5.66	0.2995	0.023
C-5	Disturbed coal	16.1	1.13	2.4418	1.7
C-6	Disturbed coal	16.1	3.40	0.4106	0.097
C-7	Disturbed coal	19.2[a]	0.850	2.6867	3.1
C-8	Disturbed coal	15.6[a]	0.378	3.0931	6.5
C-9	Undisturbed dolomite	10.3	5.66	0.3773	0.035
C-10	Undisturbed dolomite	14.8	5.66	4.2370	0.56
C-11	Disturbed prairie soil	9.83	5.66	0.6034	0.052
C-12	Disturbed prairie soil	10.7	1.08	8.1764	4.1

[a] Estimated value

Study 6-- Cuscino <u>et al.</u>, <u>Iron and Steel Plant Open Source Fugitive Emission Control Evaluation</u>. EPA-600/2-83-110. 1983.

<u>Methodology</u>--Wind erosion emissions were generated using a portable wind tunnel outfitted with a sampling train that consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, back-up filter, and high-volume sampler motor. Interchangeable probe tips were utilized on the probe to facilitate isokinetic sampling.

Particulate emission rates were determined using the following equation:

$$E = \frac{C_n Q_t}{A}$$

where

E = particulate emission rate, g/m^2-sec
C_n = net particulate concentration, g/m^3
Q_t = tunnel flow rate, m^3/sec
A = exposed test area, m^2 = 0.918

No attempt was made to determine emission factors based on the soil properties measured as part of this study and the emission rates determined.

Test Sites--Test sites were formed by plant personnel at two facilities. Test sites were prepared by either a front-end loader or a bulldozer. Tests were performed on coal storage piles or on coal yard exposed areas. Preliminary tests were conducted to determine the threshold friction velocities for wind erosion and to gather other data required to design the sampling module.

Emissions tests were made a total of 29 times. Fourteen of these tests were conducted on uncontrolled surfaces of coal storage areas, twelve on controlled coal storage piles, two on active exposed areas, and one test on an inactive exposed area.

Parameters and Equipment--A portable wind tunnel with an open-floored test section was utilized to generate wind erosion emissions on a coal storage pile, or on exposed areas within iron and steel plants. Tunnel wind speed was measured using a pitot tube at the downstream end of the working section and was related to wind speed at the standard 10 meter height by means of a logarithmic profile.

In addition to the wind tunnel, particulate samples were collected using an isokinetic probe attached to a cyclone precollector mounted to a cascade impactor.

Soil parameters were also determined. Soil samples were obtained both prior to and subsequent to air sampling using a small broom. These samples were analyzed gravimetrically in the laboratory. In addition, the moisture content and the silt content were also determined. The silt content was determined using a conventional shaker.

Dust that collected in the probe tip and in the cyclone precollector were also collected by rinsing the probe and collector with distilled water and then drying until a dry residue remained.

Equipment Configuration--A sampling train that consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, back-up filter, and high-volume sampler motor was mounted so that the probe was oriented at right angles to the flow in the tunnel and along the centerline. Interchangeable probe tips were utilized on the probe. These tips enabled isokinetic sampling over the desired tunnel wind speed range.

Sampling Runs--One sampling run was conducted for each test site detailed above, resulting in a total of 29 sampling runs.

Quality Assurance--The sampling and analysis procedures utilized in this study were subject to certain quality control guidelines. Procedures followed in collecting and analyzing samples were documented in considerable detail. Quality control measures were set forth for the sampling media, sampling flow rates, and sampling equipment (proper performance). Criteria for interrupting sampling were also documented. Quality assurance practices included processing blank samples, calibration of equipment, and auditing of sampling and analysis procedures.

The investigators note that their procedures met or exceeded the requirements set forth in Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II - Ambient Air Specific Methods (U.S. EPA, 1077) and Ambient Monitoring Guidelines for Prevention of Significant Deterioration (U.S. EPA, 1978).

Filter substrates were coated with grease to help eliminate known particle bounce problems associated with cascade impactors. However, correction routines were still necessary to try and correct for particle bounce problems.

Findings--Table 2.80 details the emissions data collected as part of this study. Only emissions data collected for uncontrolled tests are presented in this table. Emission rates range from less than 0.1 mg/m^2/sec to 288 mg/m^2/sec. This entire range was found for the three tests on exposed areas and encompasses the results for coal storage piles. The authors note that wind erosion emissions tend to decay over the collection period. For those results where the emission rates were found to decay by more than 20% during back-to-back tests, an additional calculation was performed in order to determine the erosion potential. They proposed a technique for determining the erosion potential. The calculation technique assumes that there is an exponential decay in the emission rate that is based upon the material available for erosion. The erosion potential was calculated from the measured loss rates for two different erosion tests of the same surface. The equation for determining the erosion potential is:

$$\frac{\ln\frac{(M_o-L_1)}{M_o}}{\ln\frac{(M_o-L_2)}{M_o}} = \frac{t_1}{t_2}$$

where:

M_o = Erosion potential (quantity of erodible material present on the surface before onset of erosion), g/m^2

L_1 = measured loss rate during time period 0 to t_1, $g/m^2 = E_1t_1$

L_2 = measured loss rate during time period 0 to t_2, $g/m^2 = L_1 + E_2(t_2-t_1)$

Although emission rates were determined in this study, no emission factor for wind erosion was developed.

TABLE 2.80. WIND EROSION PARAMETERS

Run	Material	Flow Rate (m^3/hr)	Volume Sampled (m^3)	Total Mass Collected (mg)	Net Emission Rate		
					TP ($mg/m^2/s$)	IP ($mg/m^2/s$)	FP ($mg/m^2/s$)
F-46	Exp. area	3,570	13.0	4.72	0.0843	-	-
F-47	Exp. area	2,800	6.60	309	39.1	5.19	1.75
F-48	Exp. area	3,890	1.68	413	288	17.0	5.31
F-49	Coal	2,030	12.6	5.06	0.215	0.0685	0.0238
F-50	Coal	2,790	5.15	22.6	3.65	0.489	0.163
F-51	Coal	2,790	20.6	38.2	5.14	0.569	0.179
F-52	Coal	3,740	10.4	82.9	9.06	0.0543	0.0181
F-53	Coal	3,740	41.5	73.7	2.01	0.0806	0.0161
F-54	Coal	1,840	10.4	5.30	0.258	0.163	0.0635
F-55	Coal	2,760	14.3	13.2	0.753	0.166	0.0516
H-20	Coal	3,220	9.85	232	2.14	0.265	0.125
H-21	Coal	4,180	13.1	459	43.9	3.42	1.01
H-22	Coal	4,320	13.4	105	9.96	0.911	0.303
H-23	Coal	2,770	0.889	9.43	8.89	1.51	0.308
H-24	Coal	2,820	8.00	43.0	4.47	0.113	0.0844
H-25	Coal	3,710	12.1	135	12.4	0.285	0.140
H-26	Coal	4,390	14.2	1,770	166	2.64	0.319

Publication--This study was conducted and documented under a contract for the Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research

Laboratory, Research Triangle Park, North Carolina. It was published in October of 1983 as Publication No. EPA-600/2-79-103

Study 7-- Axetell and Cowherd. Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources. EPA-600/7-84-048. 1984.

Methodology--Wind erosion emissions were generated using a portable wind tunnel outfitted with a sampling train that consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, back-up filter, and high-volume sampler motor. Interchangeable probe tips to facilitate isokinetic sampling were utilized on the probe.

Particulate emission rates were determined using the same methodology described above for the Cuscino et al., 1983.

Test Sites--A total of 37 wind tunnel tests were conducted as part of this study. Tests were performed on either coal storage piles or on exposed ground areas. 27 tests were performed on coal storage piles and 10 tests were performed on exposed ground areas at three different mines. Emissions tests on exposed surfaces were made on topsoil, subsoil, overburden and scoria.

Parameters and Equipment--A portable wind tunnel with an open-floored test section was utilized to generate wind erosion emissions on coal storage piles, or on exposed areas within western surface coal mines. Tunnel wind speed was measured using a pitot tube at the downstream end of the working section and was related to wind speed at the standard 10 meter height by means of a logarithmic profile.

In addition to the wind tunnel, particulate samples were collected using an isokinetic probe attached to a cyclone precollector mounted to a cascade impactor. Particle size distributions were determined for particles less than or equal to 30 microns in diameter.

Soil parameters were also determined. Soil samples were obtained both prior to and subsequent to air sampling using a small broom. These samples were analyzed gravimetrically in the laboratory. In addition, the moisture content and the silt content were also determined. The silt content was determined using a conventional shaker.

Dust that collected in the probe tip and in the cyclone precollector were also collected by rinsing the probe and collector with distilled water and then drying until a dry residue remained.

Equipment Configuration--A sampling train that consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, back-up filter, and high-volume sampler motor was mounted so that the probe was oriented at right angles to the flow in the tunnel and along the centerline. Interchangeable probe tips were utilized on the probe. These tips enabled isokinetic sampling over the desired tunnel wind speed range.

Sampling Runs--One sampling run was conducted for each test site detailed above, resulting in a total of 37 sampling runs. However, because many of the samples exhibited decaying emission rates, several of these runs represent a second run on the same surface so that the erosion potential could be calculated.

Quality Assurance--This study included a thorough quality assurance program, which was subject to evaluation by a technical review group (including the two EPA project officers, and representatives of the Bureau of Land Management, the Bureau of Mines, and the mining industry). All samplers were calibrated on a regular basis. Sampling media were conditioned at constant temperature and humidity prior to weighing. Seven percent of tare and final filter weights were audited. For every ten regularly processed filters and substrates, at least one was processed as a blank.

The investigators note that their procedures met or exceeded the requirements set forth in Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II - Ambient Air Specific Methods (U.S. EPA, 1977).

Filter substrates were coated with grease to help eliminate known particle bounce problems associated with cascade impactors only at the third mine sampled. However, correction routines were still necessary to try and correct for particle bounce problems even for samples obtained using coated filters. In tests conducted for other fugitive sources at the mines, dichotomous samplers were also utilized, and it was determined from collocated samplers that the dichotomous samplers yielded more reproducible results than cascade impactors for determining the particle size distribution. Unfortunately, for wind erosion, the experimental setup did not include dichotomous samplers.

Despite the attention given to normal quality assurance practices in field data collection, the overall level of quality assurance for this study is compromised by the paucity of published raw field data. For instance, measured exposures at the various profiling heights were not reported. Because of this omission, the calculations of base emission factors made by the investigators cannot be repeated and verified.

Findings--Table 2.81 details the emission rates determined for this study. Unfortunately, the actual mass catch on the filters was not presented in this report and thus is not reported in the table. Emission rates were determined for both suspended particulates (≤ 30 μm) and inhalable particulates (≤ 15 μm). Emission rates ranged from approximately 1 $mg/m^2/sec$ to 254

TABLE 2.81. WIND TESTING DATA

Surface Type	Run	Wind speed at tunnel centerline (m/s)	Emission Rate	
			Suspended particulate (mg/m^2-sec)	Inhalable particulate (mg/m^2-sec)
Coal Storage Piles	J-24	14.3	3.40	2.26
	J-25	14.2	5.20	3.44
	J-26	11.7	254	157
	J-27	15.6	74.8	47.2
	K-39	16.7	170	119
	K-40	15.0	111	72.2
	K-41	14.8	4.54	2.96
	K-42	16.9	93.1	62.6
	K-43	16.9	4.36	2.79
	K-45	13.6	59.8	43.6
	K-46	13.6	7.41	5.48
	P-20	11.6	12.7	8.11
	P-21	13.1	9.66	4.14
	P-22	13.1	1.08	0.597
	P-23	14.2	2.32	1.39
	P-24	14.8	1.76	1.07
	P-25	16.0	3.92	2.31
	P-26	16.2	9.48	5.33
	P-27	16.0	38.6	20.2
	P-28	15.8	5.78	3.43
	P-29	17.3	16.1	11.2
	P-30	16.9	1.68	0.97
	P-31	11.8	19.1	10.1
	P-32	12.0	2.31	0.943
	P-33	14.5	27.4	15.7
	P-34	14.4	6.05	3.03
	P-35	14.5	2.78	1.85
Exposed Ground Areas	J-29	18.1	1.60	1.08
	J-30[a]	16.6	-	-
	K-35	15.1	36.8	24.5
	K-36	14.8	1.20	0.822
	K-37	15.1	6.93	4.58
	K-49	15.8	33.7	22.2
	K-50	15.8	0.782	0.652
	P-36	10.3	16.1	10.1
	P-37	10.3	30.5	19.0
	P-38	10.3	60.2	37.7
	P-39[b]	6.3	-	-
	P-40	8.1	116	7.55
	P-41[b]	10.7	-	-

a) No particle size data available
b) Emissions consisted entirely of particles larger than 11.6 μm aerodynamic diameter.

$mg/m^2/sec$ for suspended particulates for coal piles. The range for inhalable particulates was from approximately 0.6 $mg/m^2/sec$ to 157 $mg/m^2/sec$. For exposed areas the ranges for suspended and inhalable particulates were from 0.8-116 $mg/m^2/sec$ and 0.6-25 $mg/m^2/sec$, respectively.

Although emission factors for other fugitive dust sources were determined in this study using multiple linear regression analysis, the authors decided not to perform this analysis on the data for wind erosion. This decision was based largely on the fact that there were a number of samples that indicated emission rates that decayed with time (i.e. the soils tested displayed erosion potential). As a consequence, sequential tests on the same surface were required which had the effect of reducing the number of independent data points from 32 to 16. The authors felt that, because of the large number of potentially significant correction parameters in relation to the total number of independent samples, regression analysis should not be conducted. As a consequence, no attempt was made to determine emission factors based on the soil properties measured as part of this study and the emission rates determined.

Publication--This study was conducted and documented under a contract for the Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati, Ohio. It was published in March of 1984 as Publication No. EPA-600/7-84-048

Study 8-- Connor et al., Wind Erosion Testing by Portable Wind Tunnel at an Iron and Steel Plant. Paper 86-22.1, 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, MN. 1986.

Methodology--Wind erosion emissions were generated using a portable wind tunnel outfitted with a sampling train that consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, back-up filter, and high-volume sampler motor. Interchangeable probe tips to facilitate isokinetic sampling were utilized on the probe.

Particulate emission rates were determined using the same equation utilized by Cuscino et al., 1983.

No attempt was made to determine emission factors based on the soil properties measured as part of this study and the emission rates determined, although the relationships between the erosion potential and several of the soil properties measured were examined.

Test Sites--Tests were performed at the Dofasco iron and steel plant in Hamilton, Ontario, Canada. Tests were performed on coal storage piles or on exposed areas.

Emissions tests were made a total of 24 times. Twelve of these tests were conducted on uncontrolled surfaces of coal storage areas, six on controlled coal storage piles, and six on exposed areas.

Parameters and Equipment--A portable wind tunnel with an open-floored test section was utilized to generate wind erosion emissions on a coal storage pile, or on exposed areas within the iron and steel plant. Tunnel wind speed was measured, but the method used to measure it was not detailed.

Soil parameters were also determined. Samples were analyzed to determine the soil moisture, silt content and surface compaction, but the details of the sampling and analysis procedures were not published.

Equipment Configuration--A sampling train that consisted of a tapered probe connected to a high-volume sampler was mounted so that the probe was oriented at right angles to the flow in the tunnel and along the centerline. Interchangeable probe tips to facilitate isokinetic sampling were utilized on the probe. These tips enabled isokinetic sampling over the desired tunnel wind speed range.

Sampling Runs--It was not clear how many sampling runs were conducted for each sample. Since the erosion potential requires a minimum of two samples back-to-back at the same site, it would seem logical that a minimum of two sampling runs/sample were conducted.

Quality Assurance--With the exception of stating that all filters were conditioned at constant temperature and humidity for 24 hours both prior to and following sampling, quality assurance procedures were not detailed in this study.

Findings--Only a limited amount of emission rate information was presented in this paper. The data presented was utilized to compare the results of this study with that of earlier work conducted at iron and steel facilities by Midwest Research Institute. The authors indicated that the data were largely not comparable due to differences in the test conditions. Only two of the six measurements compared were similar. The other measurements exhibited large differences.

The authors did determine the erosion potential for each of the test sites. In addition, they examined the relationship to the erosion potential of the silt content and the wind speed. Graphs of these relationships were presented and indicated that the erosion potential was roughly exponentially related to both the silt content and the wind speed.

Publication--This study was conducted by personnel employed by Dofasco, Inc. and was published in June of 1986 as Paper number 86-22.1 in the Proceedings of the 79th Annual Meeting of the Air Pollution Control Association.

Studies of Secondary Importance

As indicated earlier in this section, the wind erosion equation as described by Woodruff and Siddoway (1965) has typically been the "emission factor" utilized for the development of emission inventory estimates for wind erosion. Despite the number of studies examined above that made direct field measurements, no emission factor has been developed as a direct result of the those studies. However, this has not prevented the development of additional emission factors for calculating emissions from wind erosion.

Cowherd et al. (1977) propose a method for estimating particulate emissions generated by wind erosion in an appendix to their report. The emission factor equation suggested is a hybridization of the Woodruff and Siddoway wind erosion equation coupled with some information obtained from work performed by Dale Gillette. The equation proposed is as follows:

$$E = 0.0089 \frac{esr}{(PE/50)^2} f$$

where

E = emissions of suspended dust, tons/acre/year
e = soil erodibility, tons/acre/year
s = silt content of surface soil, %
f = fraction of time wind exceeds the threshold value for wind erosion, assumed to be 12 mph
r = mitigative fractional reduction in wind erosion due to vegetative cover, derived from a graph
PE= Thornwaite's Precipitation-Evaporation index

As indicated above, this equation is based solely on analogy to the wind erosion equation, and has no reliance upon any measured data.

Bohn et al. (1978) further perpetuate this equation and the utilization of analogy in building emission factor equations in their assessment of fugitive emissions from integrated iron and steel plants. In that report, they present two emission factor equations for wind erosion. One for storage pile wind erosion emissions and one for wind erosion of exposed areas. The equation presented for wind erosion of exposed areas is of the same basic form as that presented in Cowherd et al., 1977 with the exception that the emission factor is now in lbs/acre/year, the coefficient is now 3400 instead of 0.0089, the erodibility term is now e/50 rather than e, the silt term is now s/15 rather than s, the fraction of time that the wind exceeds the threshold is now f/25 rather than f, and the vegetative cover term r is eliminated altogether. No explanation of the process used to make these modifications was given. Additionally, even though the authors note that "it is known that above the wind speed threshold of 12 mph for wind erosion, the erosion rate increases with the cube of the wind speed, the wind speed correction term was simplified to reflect an average value of 15 mph for periods of erosion."

The equation given by Bohn et al. (1978) for wind erosion of storage piles is as follows:

$$EF = 0.05\left(\frac{s}{1.5}\right)\left(\frac{D}{90}\right)\left(\frac{d}{365}\right)\left(\frac{f}{15}\right)$$

where

EF= suspended particulate emissions, lb/ton material stored
s = silt content of aggregate, %
D = duration of storage, days
d = dry days per year
f = percentage of time wind speed exceeds 12 mph

With the exception of the coefficient, none of the corrective parameters are based on measured data. The coefficient is based on the measurements made during the Bohn et al. study. However, it has been adjusted to one half the measure value based on the authors' estimate that the average wind speed through the emission layer was only half the value measured above the top of the piles.

By 1984, the equation proposed above for storage pile wind erosion emissions had been replaced by a new equation which relates the wind erosion emissions to the erosion potential corresponding to the fastest mile of wind for the period between disturbances and the frequency of disturbances. The equation is:

$$EF = fP(u^{+}_{15})$$

where

f = frequency of disturbance per month

$P(u^{+}_{15})$ = erosion potential corresponding to the observed (or probable) fastest mile of wind, lb/acre

The fastest mile must be corrected to a height of 15 cm in order to utilize this equation. As before, no data analysis was utilized to justify the proposal of this equation. An equation of similar form (and also without data analysis to justify its adoption) is published in AP-42. It is used to predict industrial wind erosion emissions.

The latest equation proposed for evaluating wind erosion emissions was developed by Gillette and Passi (1988). Their equation was utilized to develop wind erosion emissions estimates for the 1985 National Acid Precipitation Assessment Program (NAPAP). In their work, they proposed the following equation for estimating wind erosion emissions:

$$E = C \sum_{i=1}^{N} R_i g(L_i) A_i \Delta T \int_{U_{ti}}^{\infty} G(U) p_i(U)\, dU$$

where E is the mass of dust emitted in the time period ΔT; C is a constant determined by calibration; i is the index of summation over N different erodible areas within the region of interest; R_i is the effect of soil roughness; $g(L_i)$ is the effect of field length, L_i; A_i is the area of land being considered; G(U) is the vertical mass flux of dust as a function of wind speed, U; $p_i(U)$ is the probability density function of the wind speed during the time period of interest, and U_{ti} is the ith threshold wind speed for dust emission. Details of how each of the above terms are obtained are given in the authors paper (Gillette and Passi, 1988). The dust emission data used to calibrate the model was that obtained by Gillette et al., 1978.

SECTION 3

ACTIVITY DATA AND EMISSION FACTORS USED FOR INVENTORY PURPOSES

INTRODUCTION

The following is an evaluation of the source activity data for agricultural tilling, wind erosion, unpaved roads, paved roads construction/demolition, mining and quarrying, and storage piles. The criteria used in this evaluation were completeness and extent of activity input data, magnitude of the inventory area to which the activity data was applicable or available for (i.e., local, regional, or national), accuracy of data (when possible), frequency of updates and cost.

GENERAL INFORMATION

The first approach use to locate sources of activity data was to examine existing PM_{10} fugitive dust emissions inventories. Individuals listed on the SCRAM bulletin board as the EPA regional office contacts for PM_{10} inventories were contacted first. After speaking with individuals from each of the 10 EPA regional offices, the general consensus was that a region only maintained a fugitive dust PM_{10} emissions inventory if there were nonattainment area(s) within the region. If an inventory was prepared, it was prepared by the State or local air pollution agency. When the State and local air pollution agencies (a least one or more from half the EPA regions were contacted) discussed their inventories many had divided the above source categories into either point or area source emissions. Point sources would be unpaved and paved roads, storage piles, construction/demolition and mining and quarrying activities. Area sources would include paved and unpaved roads not covered as point sources, wind erosion and agricultural tilling. Many of the nonattainment areas are urban, therefore agricultural tilling is frequently not a factor. In some states the activity levels are maintained in permit files; however most inventories are for SIPs and the activity data is site specific and has to be obtained by the air agencies. Only in a few instances (such as VMT for area source paved roads) were federal, state, or local non-air pollution agencies contacted by the states air pollution agencies to obtain activity data.

The second approach used to locate activity data sources was a literature search of previously developed PM_{10}/TSP fugitive dust emission inventories. These documents were searched for federal, state, or local agencies that were contacted to provide activity data for these emission inventories. From the list of agencies developed (DOT, DOC, USDA, FHWA, DOL, etc.), a phone survey was conducted starting at the federal level. The federal agencies were questioned as to activity availability using evaluation criteria listed above. For many of the source categories, the activity data (when available) was available at both the national and state level. Very few agencies maintain data at the county or local level and were unable to confirm if the states or county agencies gather these statistics. As a consequence the next step was to contact the state agencies to request the availability of activity and emission factor correction parameters information. At least one state per EPA region was contacted for many different state agencies such as DOT, DOC, SCS, and DOL.

As a result of the telephone and literature surveys a couple of common emission factor correction parameter and activity data sources were located. For the source categories examined all the required meteorological data was available from the National Climatic Data Center (NCDC) in the form of either the monthly or annual Local Climatological Data summaries (NCDC,1991). An example of these summaries can be found in Appendix A. These reports are available directly from NCDC at an approximate cost of $1 per month per station or $180 per diskette. (The price per diskette is based on an estimate to receive the fastest mile per day for six years of data at one location). The Local Climatological Data Summaries can also be located in many libraries. There are approximately eight to nine thousand substations in the U.S. These substations collect at a minimum the minimum and maximum daily temperatures and daily precipitation amounts. Most cities and major airports will maintain all statistics. The Climatological Data for each of the 50 states contains an index of the stations in that state. The data element, fastest mile (which is used in calculating wind erosion emissions) is being phased out at many locations and is being replaced by peak wind statistics. The publication of monthly reports generally have a three month lag time and the annual summaries have a lag time of about six months.

A second source of general information is the County Statistic Tape File 3 (CO-STAT 3) which is available from the U.S. Bureau of Census. The data found in the County Statistic Tape File 3 (CO-STAT 3) pertains to agricultural, business, construction, education, housing, labor, population, and service industries. The cost of the tape is $175. The data is based on 1980 data plus other Census sources and other Census years up to 1987. The data is national, state, and county or county equivalent (Alliance 1990). This source would probably be most useful for developing a national PM_{10} fugitive dust emission inventory at a county level when activity data is not available and surrogate activity indicators are needed, i.e., state VMT for unpaved roads is estimated by the FHWA but a surrogate either (housing or population) might be necessary to distribute the VMT to a county level.

As will be illustrated in the following source category subsections, data availability is dependent on several factors. Air pollution agencies will have very source specific data on emission factor correction parameters or activity data for a limited area. The federal non-air pollution agencies maintain activity data (VMT, acres of land planted, etc.) for sources on either a national and/or state level. Finally the data is sometimes collected but is very difficult to extract in the necessary format or the data is simply not available. An example of this is that most states take traffic counts on state roads. The problems in converting these counts to VMT include not including counts for all roads systems within a county and associating these counts to a road segment within the county. The second example is that the U.S. Bureau of Mines survey all the nonfuel mines in the U.S. each year to gather several types of data including production figures. The problem is that these mines are promised total confidentiality in exchange for their cooperation, thus the data, although collected cannot be used. Individuals at both the U.S. BOM and U.S. Mineral Survey were rather certain that the U.S. BOM was the only agency to collect production figures.

The following subsections detail the activity data requirements of each of the fugitive dust source categories. The activity data and emission factor correction parameters required to develop emissions estimates are discussed according to the source of information be it EPA, State, or local air pollution agencies, federal/State non-air pollution agencies, or PM_{10} fugitive dust emission inventory documents. All contacts made with the Federal, State, and local agencies were personal telecommunications with individuals at these agencies.

AGRICULTURAL TILLING

The following is the AP-42 emission factor equation for determining the quantity of dust emissions from agricultural tilling per acre of land tilled.

$$E=k(4.80)s^{0.6} \text{ (lbs/acre)}$$

where:

- E = emission factor
- k = particle size multiplier (dimensionless, aerodynamic particle size multiplier are given in AP-42 for [total particulate, <30, <15, <10, <5 and <2.5 microns])
- s = silt content of surface soil (%)

Both studies reviewed in section two, (Cuscino, et al., 1981 and Cowherd et al.,1974) for agricultural tilling are cited as references in AP-42. The particle size multiplier (k) values given in AP-42 are the only source found for this correction parameter. The other correction parameter, silt content of surface soil (s), along with the acres of land tilled, and how many tillings per year were surveyed.

Non EPA Federal, State, and Local Agencies

Silt content--

A national map of soils types is available from the USDA, Soil Conservation Service (SCS) dated 1988. Personnel at the National Agricultural Statistics Service (NASS) indicated that state SCS can provide county level maps of soil types. Apparently a National Soil Survey for each county in the U.S. was conducted and most have been completed. One should contact the state SCS office and talk to the soil scientist regarding the availability of the data.

Number of tillings and acres of land planted--

The acres planted for each crop by state for each year can be obtained from the USDA. The delay on the annual state summary is approximately four months. NASS currently does not have the data but are working on a central database. This data is available currently by contacting the state Soil Conservation Service.

EPA regional office or state or local air pollution agencies

The state air pollution agencies also indicated that activity data and emission factor correction parameters were obtained from the county SCS. Other sources mentioned were aerial photos to estimate acreage of farm land, site-specific silt measurements (as in Arizona), and use of state permit information (as in Ohio).

Emission inventory documents

Silt content--

Examples of silt content sources from PM_{10} fugitive dust emission inventories are as follows. In developing an old TSP inventory, Vermont used the U.S. SCS estimate of an average silt content for Vermont agricultural soils and an average P.E. index (State of Vermont, 1979). Other documents suggested using soil types obtained from soil survey reports published by the SCS, county or state agricultural departments, and farmers or growers trade associations (Jutze et al., 1974). Silt content may be obtained from the state conservationist at the SCS through the use of Land Use Maps (Cowherd and Guenther, 1976). The soil types for California (CARB, 1987) were obtained from the University of California Division of Agricultural Sciences generalized soil map of California developed in 1980. CARB obtained the climatic factor from the USDA SCS Annual Wind Erosion Climatic factor, 1986 interim map.

Number of tillings and acres of cropland --

Tillings and acres of cropland sources were also cited in several PM_{10}/TSP emission inventories. Vermont's 1979 SIP indicated that tilled acreage was estimated by planimeter measurement of cropland area from state Land Use Maps and multiplied by the county ratio of tilled land to total cropland obtained from the Vermont Census of Agriculture (State of Vermont, 1979). Crop acreage statistics by county can be found in annual bulletins published jointly by USDA's Statistical Reporting Service and the State university system except in California where the data comes from individual county agricultural reports (Jutze et al., 1974). The Census of Agriculture publishes harvested cropland by county (Cowherd and Guenther, 1976). For California the acreage of crops can be obtained from each of the 58 counties' 1987 county crop reports prepared by the county agricultural commissioner (CARB, 1987).

WIND EROSION

Emission factors

For wind erosion three emission factor equations, the associated correction factors, and activity data were investigated. These emission factors equations are Woodruff and Siddoway (1965), Gillette and Passi (1988), and AP-42 industrial wind erosion.

The modified Woodruff and Siddoway windblown dust equation cited in Cowherd et al. (1974) is of the form:

$$E_s = AIKCL'V' \text{ (tons/acre/year)}$$

where:

E_s	=	suspended particulate fraction of wind erosion losses of tilled fields
A	=	portion of total wind erosion losses that would be measured as suspended particulate, (estimated to be 0.025)
I	=	soil erodibility, (tons/acre/year)
K	=	surface roughness factor, (dimensionless)
C	=	climatic factor
L'	=	unsheltered field width, (dimensionless)
V'	=	vegetative cover factor, (dimensionless)

Cowherd et al. (1974) provides soil erodibility (I) values based on the predominate soil texture class. Soil types can be obtained from the USDA (see agricultural tilling). Values of K, L, and V for common field crops are also presented in Cowherd et al. (1974). The climatic factor (C) can be calculated as follows:

C = 0.345W^3/(PE)^2

where:

W = mean annual wind velocity (mph) corrected to a standard height of 30 feet
PE = Thornthwaite's precipitation-evaporation index (sum of 12 monthly ratio's of precipitation to actual evap-transpiration).

The climatic factor can also be obtained from maps that use the Weather Bureau data to calculate monthly climatic factors (NCDC, 1991).

The second emission factor equation (Gillette and Passi, 1988) is as follows:

$$E = C\sum_{i=1}^{N} R_i g(L_i) A_i \Delta T \int_{U_i}^{\infty} G(U) P_i(U) dU$$

where:

E = mass of dust emitted in the time period delta T
C = constant, determined by calibration
N = number of different erodible areas within the region of interest
R_i = effect of soil roughness
$g(L_i)$ = effect of field length (L_i)
A_i = area of land being considered
G(U) = is the vertical mass flux (mass/unit area/time) as a function of wind speed (U)
$P_i(U)$ = probability density function of wind speed during the period of interest
U_i = i^{th} threshold wind speed for dust emission.

With knowledge of soil types and Land Use Maps (see agricultural tilling), wind speed statistics, and several tables from Gillette and Passi (1988) the above equation can be solved.

The third emission factor equation is the industrial wind erosion equation obtained from AP-42. It can be used to estimate wind generated particulate emissions from mixtures of erodible and nonerodible surface materials subject to disturbances in units of grams/meter/year as follows:

$$E = k\sum_{i=1}^{N} P_i$$

where:

E	=	emission factor
k	=	particle size multiplier (aerodynamic particle size multipliers for 30, <15, <10 and <2.5 microns are presented in AP-42)
N	=	number of disturbances per year
P_i	=	erosion potential corresponding to the observed (or probable) fastest mile of wind from the i^{th} period between disturbances.

Correction parameters are needed to determine P_i. These include the type of material, the shape and size of any piles, and fastest mile of wind. With this data and the help of other AP-42 tables in the industrial wind erosion section, the above equation can be solved.

State Agencies

The state Soil Conservation Service provide data for soil characteristics (number of disturbed/undisturbed acres, mass fraction of surface soil particles smaller than 50 microns, fraction of soil that can be suspended, soil erodibility and surface roughness). The soil types can be obtained from the same sources as for agricultural tilling. There is county data from state conservation agencies for mass fractions of surface soil particles smaller than 50 microns. The seasonal planting that could be used to determine when and how often agricultural lands are disturbed can be obtained from the USDA which provides usual planting and harvesting dates by crop and state (some states are broken down in smaller areas or to county levels). The most recent document containing this information was published in April 1984 and the previous publication date was August of 1972. The only other source of data found was that the state of Ohio uses permit information to determine wind erosion estimates of storage piles.

CONSTRUCTION

Two sources of emission factors for construction/demolition activities were investigate. The first was the PM_{10} gap filling document (MRI, 1988) which contains a construction site preparation and a demolition of structures emission factor equation. The gap filling document sites the Kinsey et al, (1983) report in its references. The demolition of structures equation is the same emission factor as that found in AP-42 for storage pile drop operations and the discussion on it can be found in the storage piles. The construction site emission factor is as follows:

$$E = E_t + E_e + E_h$$

where:

E = emission factor
E_t = topsoil emission factor (20lbs/VMT)
E_e = earthmoving emission factor (4.3 lbs/VMT)
E_h = hauling emission factor (10 lb/VMT).

A source for construction VMT was not located. Those places contacted were the State Department of Motor Vehicles, the State Information Processing Center, Highway Registration, Highway Building Department, R.L. Polk, Transportation Data Center, Construction Equipment and Leasing, Caterpillar Equipment and Automotive News.

The other emission factor equation is the AP-42 heavy construction emission factor of 1.2 tons/acre of construction/month of activity. The emissions document in support of this emission factor is Cowherd et al. (1974). A discussion of the AP-42 heavy construction emission factor activity data follows. However, construction dollars were also investigated since both Cowherd et al. (1974) and Heisler (1988) have utilized construction dollars by SIC construction type as a factor to determine the acres of construction.

Non EPA Federal, State, and Local Agencies

At the federal level there are three agencies that publish the value of construction. F.W. Dodge Division of McGraw Hill Information Systems Company reports the monthly value of construction contracts for privately and publicly owned new and major alteration projects in the U.S. by their regional division (since January 1985 all F.W. Dodge regions conform to Census regions with the exception of the west region). They also publish national monthly value of construction contracts for privately and publicly owned projects for the following categories: housekeeping residential, nonhousekeeping residential, commercial, manufacturing, educational and science, hospital and other health treatment, public building and nonbuilding construction. The federal highway administration publishes in its annual Highway Statistics (FHWA, 1990) state construction dollars spent by agency (federal, state, local). The Census Bureau (U.S. DOC, 1987) publishes every five years (last published in 1987) construction value by state and by SIC (1521, 1522, 1531, 1541, 1542, 1611, 1622, 1623, and 1629). The building permit section of the Bureau of Census provides county, monthly construction values through three formats, diskette and hardcopy which contains the county information and printed publication. There is also a annual report that summarizes the data from the previous 12 months. The monthly reports are available with approximately a one month delay and the annual report is generally available May of the following year. There is a cost to the general public but these reports are free to other federal agencies.

The NC Department of Labor (DOL) maintains statistics on building permits (from counties/cities) by residential, nonresidential or commercial building type. Cost of the building is estimated at the time the permit is acquired and published in the Division of Statistics monthly reports. We were also informed by the NC DOL that F.W. Dodge estimates use a ceiling. The NC report has a few months time lag.

Several states contacted used the above data sources. Illinois Commerce Research Department releases F.W. Dodge bimonthly summaries. The Texas Real Estate Research facility and the Kansas Department of Commerce obtain data from the U.S. DOC monthly construction permit data.

The Georgia Economic Development Department maintains only the number of permits. Both the Pennsylvania and Massachusetts DOL have historical construction statistics but because of state budget cuts no longer maintain these statistics.

EPA regional office or state and local air pollution agencies

In Indiana building permits contain estimates on dollar value and acres of construction. At the county air agencies in Arizona, the construction permits contain duration information.

Emission inventory documents

Acres of active construction can be obtained from Public Works or building department construction permit files (Jutze et al., 1974). Other places suggested were the county or state planning departments, building or trade associations, county APCD permit files, and bank published economic revenues for metropolitan areas. Amick et al. (1974) suggests the land planning council, county engineers and county assessors for obtaining the acreage under construction for residential, industrial and commercial construction. In California the Statistical Abstract published by the Department of Finance contains data on residential building (CARB, 1987). The California Department of Finance, Financial and Economic Research unit maintains data on commercial, industrial and institutional building valuation.

MINING AND QUARRYING

For mining and quarrying operations, there is no one single emission factor equation. In fact, U.S. EPA (1990) separates this category by commodity (metal, minerals, coal and tailing piles [Evans and Cooper, 1980]) and further by processing activity (vehicle loading/unloading, blasting, crushing, drilling, overburden removal and unpaved road travel). Most of these emission factors are single factors i.e., lbs/unit. The complexity is compounded since each mining commodity and process has a different unit. Several of the possible units for mining and quarrying activities are tons of crushed stone processed, tons of coal, number of blasts, cubic yards of overburden removal, VMT, number of holes drilled, tons of coal loaded, tons of overburden, tons of ore processed, or amount of land in use for disposal of mill and processing wastes.

Because of the variety in the above emission factors, all the emission studies reviewed in section two apply (Cook et al, 1980: Marple et al., 1980: Axetell, 1978: Axetell and Cowherd, 1984).

Non EPA Federal, State, and Local Agencies

From the U.S. Bureau of Mines (BOM) and the Mineral Information section of the U.S. Geological Survey it was determined that the BOM sends a yearly survey to all mines (nonfuel). The U.S. BOM collects this data with the help of the states. In return the states coauthor the state chapters of the annual minerals yearbook. The BOM is the sole collector of production data surveys. Data is published with a two year lag time in the yearbook on a national commodity level. State and/or county level data retrievals are made by special request of the mining and quarrying statistical department. Production numbers are confidential therefore, at the state or county level the data is often unavailable for confidential reasons. To determine whether a state would release the confidential information each state would have to be individually contacted. The individuals spoken to at the federal level were unaware of any state that would provide this information. The U.S. DOE publishes annual coal production and number of mines by state and type of mining (surface or underground) with a one year lag time. This information is obtained from the Energy Information Administration, Form EIA-7A, "Coal Production Report". These production figures excludes mines producing less than 10,000 short tons of coal during the year. When speaking with the EIA National energy information center they were unable to locate a publication which presents county level coal production figures.

Several state Geological Survey and Department of Labor (KS, PA, IL and CO) publish reports on mineral and coal statistics. However, no state agency questioned released mineral production figures due to the confidentiality of the data.

<u>EPA regional office or state and local air pollution agencies</u>

The county air agencies within Arizona maintain permits on sand and gravel activities. Other states also use permit information.

<u>Emission inventory documents</u>

Jutze <u>et al</u>. (1974) suggests obtaining total acreage, surface condition and size of different sections of tailings piles from state agencies or departments of mining and minerals, the minerals yearbook, the state mining association or individual mining companies.

UNPAVED ROADS

The following AP-42 equation is use to estimate the quantity of size specific particulate emissions from unpaved roads per vehicle mile traveled.

$$E=k(5.9)(s/12)(S/30)(W/3^{0.7}(w/4)^{0.5}([365-p]/365) \quad \text{(lb/VMT)}$$

where:

- E = emission factor
- k = particle size multiplier (dimensionless, values for k are presented in AP-42 for the following aerodynamic particle size ranges [<30, <15, <10, <5, <2.5 microns])
- s = silt content of road surface material (%)
- S = mean vehicle speed (mph)
- W = mean vehicle weight (ton)
- w = mean number of wheels
- p = number of days with at least 0.01 inch of precipitation per year.

It is recommended that site specific values for silt be used but if not available AP-42 provides typical silt content values of surface material on industrial and rural unpaved roads. As a conservative approximation, the silt content of the parent soil in the area can be used. Caution should be used when applying these values since tests show that road silt content is normally lower than that in the surrounding parent soil. AP-42 does not suggest default values for speed, vehicle weight or number of wheels.

The emissions studies reviewed in section two that are cited in AP-42 includes: Cowherd et al. (1974), Dyck and Stukel (1976), Bohn et al. (1978), Cowherd et al. (1979), Cuscino et al. (1983), Reider (1983) and Axetell and Cowherd (1984).

Non EPA Federal, State, and Local Agencies

Vehicle Speeds--

An agency that determined vehicle speeds on all road surface types and functional class systems was not found. Federal Highway Statistics does supply some speed data per state by functional road class for roads with posted 55 mph speed limits. NC DOT has some published and available speed data through libraries but the extent of this data is unknown.

Vehicle weight, wheels and distribution--

Estimates of national vehicle weight, the number of wheels per vehicle and travel activity by vehicle type can be obtained from the U.S. Department of Transportation (DOT). Some state DOT's (NC, KS, and IL) maintain vehicle distribution and vehicle weights (usually trucks) in their files.

Vehicle miles travelled (VMT) and road mileage--

VMT on the state level is obtained from two sources. The annual Highway Statistics (FHWA, 1990) reports the rural and urban mileage by surface type and functional classification, but does not include the local functional class unpaved road mileage. Local functional class rural and urban unpaved road mileage by average daily traffic volume (ADTV) ranges in a spreadsheet format can be obtained from the U.S.DOT. County level road mileage by functional system is also available from the U.S.DOT approximately every two years but no distinction is made as to surface type.

All states are required to provide data to the U.S. DOT in order to collect federal aid. The data provided is part of the Highway Performance Monitoring System (HPMS). A copy of the data ele-ents requested can be found in the Appendix A. This data con .ns traffic counts for various state roads throughout each sta

-affic counts are made in most states on state maintained roads. For some states distinction is made by road surface types (NC, KS, and Texas), while other state Department of

Transportations differentiate by functional class only. Most counts are not annual, they maybe updated every two (NC) to 5 (IL) years. Most of these counts are available on county maps for a fee. The exception is Texas which publishes annual tables of county VMT by highway system and surface type.

EPA regional office or state and local air pollution agencies

Silt content--

Average state silt content values were developed as part of the 1985 National Acid Precipitation Assessment Program (NAPAP). It was developed by the Illinois State Water Survey. The database contains the silt content of over 200 unpaved roads from over thirty states. Average silt content of unpaved roads in a state were calculated for each state that had three or more samples for that state. For states that did not have the required number of samples, the average for all samples from all states was substituted.

VMT--

Surveys and questionnaires are sent by states agencies or the data are available in their permit files on facility unpaved road VMT or emission factor correction factor parameters. The area source estimates for VMT are often obtained from state and federal highway maps. Arizona estimates ADTV on unpaved roads since traffic counters have become buried under dust.

Emission inventory documents

Silt content--

Vermont's 1979 SIP used an average silt content obtained from direct testing for the state and used the state highway departments estimate of average vehicle speed.

VMT and mileage--

Vermont's 1979 SIP used the state highway department town maps to obtain road mileage and coupled with an estimate of 11 miles per vehicle per day. Exact mileage by county for different types of unpaved roads can be obtained from state or county Highway Department's annual reports on the status of highway statistics (Jutze et al., 1974). Traffic flow and road surface type maps were obtained from the planning department of the Illinois State DOT and the Mapping Department of the Missouri State Highway Commission by Cowherd and Guenther (1976). California draft inventory guidance does not use the AP-42 emission factor for unpaved roads (CARB, 1987). The windblown dust equation they used requires acres of land which they estimate by obtaining the unpaved road mileage from the

California Highway System Engineering Branch and multiplying by 25 feet (the assumed width of the street).

PAVED ROADS

Emission factors

AP-42 divides paved roads into two subsections: paved urban roads and industrial paved roads. Dust emissions from vehicle traffic on a paved roadway may be estimated using the following equation:

$$E=k(sL/0.7)^p \text{ lb/VMT}$$

where:

E	=	emission factor
L	=	total road surface dust loading (grains/sq ft)
s	=	surface silt content
k	=	base emission factor (lb/VMT)'
p	=	exponent (dimensionless)

The base emission factor coefficient (k) and exponent (p) in the above equation for each size fraction (TSP, <15, <10, and <2.5 microns) are listed in AP-42. The two terms s and L when combined are referred to as the silt loading parameter. Default silt loading values for a select number of cities by roadway category are presented in AP-42. Using all the defaults from AP-42 yields the recommended particulate emission factors for specific roadway categories and particle size fractions. Therefore only VMT for each roadway category is needed.

The emission studies reviewed that are references for the AP-42 paved urban road emission factors are Axetell and Zell (1977), Cowherd and Englehart (1984), and Cowherd et al. (1977).

The quantity of total suspended particulate emissions generated by vehicle traffic on dry industrial paved roads per VMT may be estimated by using the following AP-42 equation:

$$E=0.077I(4/n)(s/10)(L/1000)(W/3)^{0.7} \text{ (lb/VMT)}$$

where:

E	=	emission factor
I	=	industrial augmentation factor (dimensionless)
n	=	number of traffic lanes
s	=	surface material silt content (%)
L	=	surface dust loading (lb/mile)
W	=	average vehicle weight (ton)

The guideline for industrial road augmentation factor (I) suggest I=7.0 for a paved industrial roadway with traffic entering from unpaved areas. I=3.5 for an industrial roadway with unpaved shoulders where 20 percent of the vehicles are forced to travel temporarily with one set of wheels on the shoulder. I=1.0 for cases where traffic travels only on paved areas.

Typical silt content and loading values for paved roads at industrial facilities are presented in AP-42.

An alternate industrial paved road emission factor for traffic consisting predominately of medium and heavy duty vehicles follows:

$$E=k(3.5)(sl/0.35)^{0.3} \text{ lb/VMT}$$

where:

sL = road surface silt loading (oz/sq yd)

The particle size multiplier (k) values are given for various aerodynamic size ranges (<15, <10, <2.5 microns). This alternative equation can be replaced by a single valued emission factor for light duty vehicles on heavily loaded roads for <15 or < 10 microns (0.41 or .33 lb/VMT).

The emission studies reviewed in section one that are references for the AP-42 industrial paved road emission factors are Bohn et al. (1978), Cowherd et al. (1979), Cowherd and Englehart (1984), Cuscino et al. (1983) and Reider (1983).

Non EPA Federal, State, and Local Agencies

VMT--

VMT on all road surface types by functional class for each state can be obtained from Highway Statistics (FHWA, 1990). By special request, the VMT for all surface types by rural and urban classes for each state for each month may be obtained.

Other--

Traffic lane mileage by rural and urban functional classifications for each state can be obtained from FHWA (1990). Information on where to obtain vehicle weights and vehicle distributions can be found in the unpaved road activity data section. A federal, state or local agency that publishes silt loading values was not found.

EPA regional office or state and local air pollution agencies

Silt--

The state of Maine collected site specific silt loading values for sanding/salting of paved roads for their 1991 PM_{10} SIP. Some site-specific silt content and size distribution data was collected for Arizona's inventory.

Other--

Locally derived paved road capacity, number of lanes, and ADTV values were obtained for Arizona's inventory. Details on EPA agencies obtaining VMT data can be found in the unpaved road activity data section.

Emission inventory documents

In CARB's draft inventory guidance they suggest obtaining VMT from California DOT division of Highway and Programming for arterial and collector highways based on HPMS data and CALTRANS which estimates 1987 VMT by county.

STORAGE PILES

Total dust emissions from aggregate storage piles are contributed by several distinct source activities within the storage cycle:

1. Loading of aggregate onto storage piles (batch or continuous drop operations)
2. Equipment traffic in storage area
3. Wind erosion of pile surfaces and ground areas around piles
4. Loadout of aggregate for shipment or for return to the process stream (batch or continuous drop operations).

For equipment traffic in storage areas the recommended emission factor equation is that for vehicle traffic on unpaved roads. The emissions from wind erosion of pile surfaces and ground areas around piles are best estimated using the industrial wind erosion equation (see wind erosion section). The storage pile drop operation (loading or loadout) emission factor equation obtained from AP-42 is as follows:

$$E = k(0.0032)[(U/5)^{1.3}/(M/2)^{1.4}]$$

where:

E = emission factor

k = particle size multiplier (dimensionless) [aerodynamic particle size multipliers for <30, <15, <10, <5 and <2.5 microns found in AP-42]
U = mean wind speed (mph)
M = material moisture content (%)

AP-42 provides a table of typical silt and moisture content values of materials at various industries.

The emission reports reviewed earlier that resulted in the above emission factor equations are Bohn et al. (1978), Cowherd et al. (1974), and Cowherd et al. (1979).

The state air pollution agencies gathered storage pile statistics by three methods. These methods were aerial photos, (Illinois in 1988) to estimate the size of stock piles, permit information, and surveys (Wayne County, Michigan).

Amick et al. (1974) suggested contacting the plant operators to obtain storage pile activity data. A federal, state or local non-air pollution agency that gathers statistics on storage piles was not found.

SECTION 4

EVALUATION AND RECOMMENDATIONS

Field studies in which data was collected to develop emission factors were reviewed in Section 2. In Section 3, the activity data required to develop emissions estimates from these emission factors were identified, and sources from which this data can be obtained were noted. This section presents an evaluation of the field studies, the resulting data, and the availability of the requisite activity data. Recommendations for future research and development efforts based on this evaluation are then presented.

EVALUATION

Several broad areas have been identified for evaluation:

1. Methodology
2. Sampling equipment
3. Quality assurance
4. Emission factor development
5. Documentation
6. Activity data requirements

Evaluations of each of the above areas are detailed below.

Methodology

In general, two main methodologies have been utilized to develop fugitive emissions data: exposure profiling and upwind-downwind modeling. As documented in Section 2, other methods have been used, but not nearly to the extent of these two. Therefore, most comments presented here will concern one or both of these two methods. Several important problems with their implementation have been identified.

Lack of Statistical Design--

Very few of the reviewed field study reports documented a statistically based experimental design. In only one study (Cook *et al.*, 1980) was a thorough statistical analysis utilized to determine the number of samples necessary to assure adequate data collection *prior* to the field sampling phase.

Lack of Procedural Standardization--

Despite the number of experiments performed to determine the emissions from fugitive dust sources, few experiments were conducted identically even within individual studies designed to sample the same source. Some examples will serve to illustrate this point. In the initial study conducted by MRI in 1974 (Cowherd et al.) in which exposure profiling was first utilized, the filters in the profiler sampling heads were oriented vertically. In subsequent studies by MRI, the filters were mounted horizontally. No reason or justification was ever given for this.

To further illustrate this point of non-standardized procedures, in the 1986 comparability study by Pyle and McCain, the heights and numbers of exposure profiler heads for each group differed, even though the source being measured was the same and the samplers were located side-by-side.

Other non-standard items noted in the reviewed studies include the distance downwind from the source that the exposure profiler is located, the number and types of ancillary samplers (i.e. particle sizing devices) located with the profiler tower, and the methods used to maintain the orientation of the samplers into the wind and to correct the collected samples to isokinetic conditions after sampling.

No detailed procedural method has been developed for fugitive dust sampling similar to that for Method 5 stack testing or for locating and operating ambient particulate monitors.

Potential Background Sampling Problems--

Typically, when exposure profiling has been utilized to determine emissions from fugitive dust sources, the background correction has been made using the data from one sampler, usually located at a lower height than most of the exposure profiling sampler heads. Since the majority of the data collected and utilized has been for TSP rather than PM_{10}, the possibility exists that there is a change in the particle concentration with height above the ground. Thus, correcting an exposure profiler head located at 12 feet above the ground with the background levels determined using a sampler with an inlet height of 2.5 feet above the ground could lead to errors in the determination of exposures.

Furthermore, the background samples were not collected isokinetically. Because the efficiency of the hi-vol depends on ambient particle size and meteorological conditions, measured background levels may be biased downward.

Potential Particle Size Distribution Sampling Problems--

Most determinations of the particle size distribution have been made using either a single instrument or two particle size sampling devices located at two heights. Typically, the device used to determine the particle size distribution has been a high volume cascade impactor. The assumption in this approach is that the particle size distribution does not vary with height and that estimation of particle-size specific emissions can be made from the integrated exposure sample coupled with information on the particle size distribution. However, if the particle size distribution varies with height, this method could result in erroneous emission factor development. Indeed, the study by Axetell and Cowherd (1984) indicated that there was a difference in the particle size distribution with height.

Unisolated or Incompletely Measured Dust Sources--

Isolating a particular dust source from others and completely measuring it are critical steps in developing an accurate emission factor. Difficulty with this issue was alluded to or detected in several reports. Most noteworthy are Cowherd et al., 1974 and Axetell, 1978. Cowherd et al. estimated emissions from building construction sites using the upwind-downwind method. Wind roses presented in the report indicated that the source was not isolated from neighboring dust sources. Thus, the modeled emission rate may not be reliable. Axetell noted problems with wind direction reversals which effectively placed downwind dust mass on the nominal upwind filter. Although most of the other reviewed field study reports did not indicate any problems of this nature, few presented evidence that this issue was not a problem. The researchers who use upwind-downwind modeling are more likely to encounter this problem than those using profiling because the former is the most appropriate method of estimating emissions from widely dispersed, less easily isolated sources.

Incorrect Solution of the Dispersion Model Equation--

As indicated in the reviews presented in Section 2, especially those for unpaved roads, the investigators have frequently rearranged the dispersion equation incorrectly and have then proceeded to solve the equation in its incorrect form. Three of the six unpaved road studies employing upwind-downwind dispersion modeling did not correctly apply the model. Jutze and Axetell (1974) claimed to use the equation for a continuously emitting, infinite line source in Turner's Workbook of Atmospheric Dispersion Estimates (1970). However, as is explained in the summary of that study, they misplaced the term which accounts for the angle between the wind direction and the road, sin ϕ. Furthermore, attempts to reproduce their calculations for source strength, q, were unsuccessful. Three examples of these discrepancies are shown in Table 4.1.

TABLE 4.1. EVALUATION OF COMPUTATIONS BY JUTZE AND AXETELL, 1974

height (m)	vert. disp. coefficient (meters)	concentr. (mg/m^3)	wind speed (m/sec)	wind angle (degr)	sin of angle	q^a (mg/m/sec)	q^b (mg/m/sec)	q^c (mg/m/sec)
2	2.9	0.196	3.1	45	0.71	2.77	3.97	1.39
2	2.9	0.216	3.1	45	0.71	3.06	4.85	1.53
2	4.4	0.272	2.7	45	0.71	5.44	6.31	2.72

a) source strength using investigators' formula
b) published source strength
c) source strength using model as in Turner, 1970

Lemon et al. (1975) made the same mistake in their study. Table 4.2 shows discrepancies similar to those found in Jutze and Axetell's work. The discrepancies are much smaller in this instance because sin ϕ is very close to one. In neither case was an explanation found for the differences between the published source strengths and those calculated using the investigators' formula.

TABLE 4.2. EVALUATION OF COMPUTATIONS BY LEMON ET AL., 1974.

ht (m)	vert. disp. coefficient (meters)	concentr. ($\mu g/m^3$)	wind speed (m/sec)	wind angle (degr)	sin of angle	q^a (mg/m/sec)	q^b (mg/m/sec)	q^b (mg/m/sec)
2.134	1.56	1425	3.08	74	0.96	22.75	21.19	21.02
2.134	1.56	725	3.69	78	0.98	13.63	13.50	13.04
2.134	1.56	1756	1.85	70	0.94	17.23	17.16	15.21
2.134	1.56	588	2.46	61	0.87	8.24	8.19	6.30

a) source strength using investigators' formula
b) published source strength
c) source strength using model as in Turner, 1970

Dyck and Stukel (1976) also incorrectly solved the same model for source strength, but their field data was not published.

Incorrect Use of Dispersion Models--

Besides not solving the dispersion model equation correctly, several investigators have utilized the dispersion model equations incorrectly. These incorrect uses include using the equation for a continuously emitting line source when the wind/road angle was less than the 45° minimum requirement specified by Turner (1970). Another example is the frequent use of continuously emitting source models to estimate emissions from sources that are clearly not continuous. This situation was evident in some studies of unpaved road mining activity emissions. In those cases, a puff model would probably be more appropriate. Incidentally, this is yet another example of incomplete measurement of the source.

Other studies that have utilized dispersion models have ignored terms that must be included in the equation when the sampler is not at ground level. One study (Blackwood and Chalekode, 1978) utilized the point source dispersion model in the form that the equation takes for ground level monitors ($z = 0$), despite the fact that it was clearly indicated in the data presented that the monitor was located well above ground level.

Sampling Equipment

Use of Outmoded Equipment--

Although some new measurement technologies have been field tested (i.e. Pinnick et al., 1985), only rarely have proven, state-of-the-art samplers been utilized in developing emission factors for fugitive dust sources. Typically, the only EPA-verified sampler that has been utilized in these studies is the standard high volume sampler. In those cases where dichotomous samplers have been used, they were the early versions with the 15 µm inlet heads. However, when the dichotomous samplers have been utilized, the results have been consistent, especially with regard to particle size information.

Indirect Measurement of PM_{10} Concentration--

No studies examined in this report determined PM_{10} emissions directly. Estimates of PM_{10} emissions were made by either interpolating or extrapolating from data on particle size distributions without direct measurements of 10 µm particles. Sampling equipment which does directly sample PM_{10} has been wind tunnel and field tested and found to be reliable in 1982 (Wedding et al.).

Particle Bounce in Measurement of Particle Size Distribution--

The majority of the information collected on particle size distributions was collected using high volume cascade impactors. These samplers are known to have particle bounce problems resulting in an overestimation of the fine particle contribution. Additionally, even though attempts were made to correct for these particle bounce problems by using greased substrates, the particle bounce problems still existed. Early studies which did not employ greased substrates, utilized a calculational method to "redistribute" the particle mass by assuming a lognormal particle size distribution. However, even some later studies that utilized greased substrates found it necessary to utilize this calculational method to redistribute this mass. This could have been caused by high filter loadings on the filters. Aerosol scientists have known for a long period of time that a heavily loaded filter (even if treated to avoid particle bounce) can still exhibit particle bounce problems, since once the filter becomes loaded, the additional particles bounce off of the previously collected particles, despite the treatment to prevent particle bounce.

Despite the knowledge that particle bounce problems existed with these samplers and that the problem could be attenuated by treating the filters, some studies still continued to use the samplers without treating the filters.

Perhaps the most damaging evidence of the particle size distribution problem associated with using high volume cascade impactors was found in the study by Axetell and Cowherd (1984) where dichotomous samplers and cascade impactors with greased substrates were operated side-by-side. The results showed that the dichotomous samplers yielded the most reliable results.

Poorly Characterized Samplers--

Although EPA has been scrupulous in its development and characterization of samplers designed for the determination of ambient pollutant concentrations and for stack testing purposes, no rigorous testing results have ever been published for exposure profiler heads. Although these samplers were typically based on high volume sampler motors and filter holders, several firms utilizing this technology have added components to the system that potentially modify the flow and capture characteristics of the samplers. For instance, MRI utilized a roof-shaped cover with a square inlet fitted with an isokinetic probe tip in several of its exposure profile experiments. The purpose of this cover was to serve as a settling chamber in order to eliminate or reduce the number of particles larger than 50 µm in diameter. However, the attributes of this sampler concerning flow characteristics and whether or not this configuration actually served to remove particles larger than 50 µm has never been tested rigorously, at least not so far as can be ascertained in the publications examined for this report.

Quality Assurance

General quality assurance (QA) practices varied widely between the studies reviewed. Certain aspects of the sampling programs had good to excellent QA. The aspects of the sampling programs that were most frequently subject to some form of QA were maintenance and calibration of samplers; attention to isokinetic sampling; preparation, handling, and weighing of filters; and standard procedures for the sampling, handling, and analysis of surface material samples.

Reports from the initial and other early profiling studies provided substantial detail on the procedures followed in the methodology. However, quality assurance measures such as processing of blank profiler filters, collocation of profile sampler intakes, or auditing of profile filter weights were generally not documented.

The studies which utilized dispersion modeling were generally of lower documented quality than those using exposure profiling. For the modeling studies, documentation of quality assurance procedures and even detailed methodological procedures was generally lacking.

In those studies that demonstrated the best quality assurance programs, additional quality assurance protocols were delimited for blank evaluations, auditing of filter weights, statistical analysis to determine the number of samples necessary to assure an adequate sampling of the source and collocation of samplers. Few studies utilized these additional quality assurance procedures, however, and those that did have higher quality assurance were typically the later studies.

Several aspects concerning quality assurance were never addressed in any of the studies. Collocation of exposure profiling arrays to try and determine the reproducibility of the methodology was never assessed. Variability and reproducibility of methods used to ascertain the silt content of various materials by obtaining duplicate samples was never performed.

Audits of data reduction calculations were rarely documented. As is indicated in Tables 4.1 and 4.2 in the methodology evaluation above, calculational errors do occur. The need for more audits in data reduction procedures is also demonstrated in Table 4.3. Note that Cowherd et al., 1974 was a report written under contract for EPA. The investigators' calculation of particulate concentrations from exposure measurements could not be duplicated. To derive concentration from exposure, the requisite additional data are the area of the intake, the rate at which air is sampled, and the duration of sampling. Table 4.3 shows comparisons of the results of attempts to reproduce the published data for several profile samplers.

TABLE 4.3. EVALUATION OF COMPUTATIONS BY COWHERD ET AL., 1974.

ht (ft)	sample rate (m^3/sec)	plume concentr. (mg/m^3)	back-ground concentr. (mg/m^3)	corrected plume concentr. (mg/m^3)	# of passes	inlet area (in^2)	sample time (sec)	MRI's exposure (mg/in^2/veh.)	Pechan[a] exposure (mg/in^2/veh)
10.5	0.0137	0.9	0.0469	0.8531	168	4	3600	0.082	0.06
8	0.0130	3.33	0.0469	3.2831	168	4	3600	0.289	0.23
5.5	0.0123	7.2	0.0469	7.1531	168	4	3600	0.591	0.47
3	0.0114	8.13	0.0469	8.0831	168	4	3600	0.629	0.49

a) Pechan formula: unit exposure = concentration * sampling rate * sampling time / intake area / # passes

Sampling isokineticity is also an issue of quality assurance. Studies varied widely in their attention this issue and in their methods of addressing it. Cowherd et al., 1974, noted that changes in wind speed during sampling were insignificant. However, some of the exposures were isokinetically corrected. The field comparison study supervised by Pyle and McCain (1986) is noteworthy for its application (by some of the participants) of servo systems for continuous monitoring and adjustment of sampling velocity to match wind velocity. Pyle and McCain found that the servo system can maintain isokineticity at each profiler head, thus eliminating the need to correct the measured exposures.

Emission Factor Development

Several major problems exist in the development of emission factors from the data reviewed above. These problems are listed and discussed in the paragraphs below.

Lack of Data--

Perhaps the biggest problem is the paucity of data utilized to develop the emission factors currently used for several sources. Emissions from cattle feedlots, landfills, and unpaved parking lots have not been field measured at all. Very limited testing has been conducted for agricultural tilling, construction of buildings and roads, and wind erosion.

Lack of Thorough Statistical Analysis--

Many of the studies (especially the earlier ones) provided little statistical analysis of the data collected. Means and standard deviations of the results were frequently not calculated. Even those studies that did provide detailed data analysis, either in the form of analysis of variance or multiple linear regression, often omitted crucial details. For instance, several studies which indicated that they used multiple linear regression analysis to determine the coefficients associated with correction parameters in the emission factor equations provided no theoretical or empirical basis for the selection of those correction parameters over other potential correction parameters. In some of the studies, the statistical analysis was presented, but the underlying data was not presented.

Capricious Selection of Correction Parameters--

In many instances, a correction parameter was chosen without empirical data indicating a relationship between it and the emission rate. Correction parameters were added on the basis of theory with no data at all, either supporting or contradicting. This was sometimes done on the basis of analogy to other sources which were believed to be similar in some regard. For example, because the average number of wheels per vehicle was found to be a useful predictor of emissions from unpaved roads, it was assumed that the same correction parameter should be used for paved road emissions. Without any statistical basis, the wheels correction parameter was added to the proposed predictive emission factor equation for paved roads (Cowherd et al., 1979). In fact, Cowherd and Englehart, in their 1985 source category report on industrial and rural roads, found that wheels was not a useful predictor of emissions from industrial paved roads.

In that same report, Cowherd and Englehart recommended the use of silt content (i.e. percent silt) in place of silt loading (i.e. mass of silt per unit area) as a correction parameter in the unpaved road emission factor equation, despite data analysis showing that silt loading explained more of the variance in the emissions data. Their recommendation was based on two considerations. First, limited tests indicated that silt loading was a less reproducible parameter than silt content, a finding which was attributed to those relatively few cases in which no well defined hard pan had formed beneath the loose surface material. Second, existing field data was found to be more abundant for silt content of industrial roads than for silt loading. In response to the first consideration, after careful comparison of the methodologies used to collect data on both parameters, no substantial difference in difficulty of sample collection was noted. The improved predictive ability of the equation utilizing silt loading over the one using silt content would be well worth any possible slight increase in sampling difficulty. Regarding the second consideration, the survey of available correction parameter and activity data in Section 3 found significant sources for neither one of the correction parameters in question.

Empirically unjustified modifications were also made to the wind erosion emission factor. As was noted in the review of Bohn et al., 1978 in the wind erosion section, several correction parameters were added without reference to any supporting data.

Documentation

Many of the problems noted above may be attributed at least in part to poor documentation. This includes documentation of both sampling and analytical procedures, as well as raw field data. A lack of documentation frequently prohibited attempts to reproduce the results. The problem of undocumented raw data speaks for itself, but the issue of procedural documentation warrants some elaboration here. Three key areas were often poorly documented.

Method of Correcting Plume Exposure for Background Levels--

Prior to the 1986 study by Pyle and McCain, the method of correcting plume exposure for background dust was poorly defined. In the study by Cowherd et al. (1974), an upwind hi-vol sampler was used to measure the background dust level. It is unclear from the report if the adjustment to measured plume dust level was made via concentration or exposure. If the samples were collected isokinetically, it would not matter; but, since they often were not, the exact procedure for correcting for background dust levels was ambiguous.

All of the other profiling studies prior to 1986 employ either the standard hi-vol sampler or the hi-vol with a size-selective inlet (SSI) to measure background dust levels. None of these other studies clearly document the manner in which background dust is accounted for. All of the participants in the side-by-side field study supervised and documented by Pyle and McCain (1986) used isokinetically sampling hi-vols to measure background dust (most participants used a profile tower of two or more sampling heads).

Method of Calculating Integrated Exposure From Sampler Data--

There were several reports in which this process was not clearly documented. In cases in which two different types of sampling heads were used on a single profiler (e.g. Bohn et al., 1978), no indication was given that differences in the sampling characteristics of the heads were accounted for in the integration process. In many instances, the method of integration was not even discussed. Again, omissions such as these make it impossible to reproduce the results.

Method of Deriving Emission Factor Equations--

Particularly for storage pile emissions, but also to a lesser extent for other source categories, the method or logic used to develop emission factor equations was not fully documented. This problem was discussed above in the section on emission factor development.

Activity Data Requirements

In evaluating and determining the types and availability of activity data and/or correction parameters for PM_{10} fugitive dust emission factors, it became clear that the availability of data necessary is clearly influenced by the scale of the emission inventory being developed. Conversations with air pollution agency personnel responsible for developing inventories for nonattainment areas indicated that either default parameters were utilized or the agency personnel either went to the facility and collected the information or a survey was sent to the facility requesting that they provide the information. While this approach is adequate for small scale inventories covering a limited area or number of facilities, for an inventory the scale of the 1985 NAPAP inventory, such an approach would be impossible. The reason that these air pollution agencies must utilize this approach however, is that the information needed either as activity data or as a correction parameter in the emission factor equation is not information that the facility typically reports to or is collected by a federal agency or to a trade association. Several examples will serve to illustrate this problem.

The original TSP emission factor developed for estimating construction emissions required activity information on the acres of construction and the number of months of activity. Typically, the information reported on a routine basis for construction activities has been the number of permits issued or construction dollars spent. In some areas, the acres of construction are available, but there was no instance where the months of activity were maintained as a data element found in our examination of sources of activity data.

The EPA recommended PM_{10} emission factor for construction activities requires activity data on the VMT for various types of construction vehicles. This information is not available at any level and can only be obtained by making site-specific measurements. Thus, use of this emission factor to develop a state or national level inventory would be impossible.

The paved road emission factor requires knowledge of the silt loading for use as a correction parameter in determining emissions estimates from paved roads. The database readily available for use by most personnel involved in emission inventory development for silt loading is AP-42, which contains a very limited number of measurements from an even more limited number of sites. An equation has been suggested for estimating the silt loading on public paved roads based on ADTV. However, since the emission factor is given in lbs/VMT and ADTV is directly related to VMT, why not develop an emission factor that only requires ADTV to begin with.

The unpaved road emission factor requires correction parameter information on silt content, number of wheels, vehicle weight and vehicle speed. While there is limited information at the national and state level on the distribution of vehicles by weight and number of wheels, it is not broken down by type of surface and cannot be obtained at the county level. Detailed information on silt content (especially at the county level), like the silt loading for paved roads, is virtually non-existent.

Further examples of this problem of availability of activity data necessary for development of emissions inventories at anything other than a very localized inventory scale include industrial wind erosion (the fastest mile statistic necessary to calculate emissions is being phased out and replaced in NCDC summaries) and surface mining operations (15 different types of activity data including VMT, holes drilled, blasts, VMT by scrapers, hours of bulldozer use and tons of coal mined are required). Other fugitive dust sources have similar problems.

RECOMMENDATIONS

The following ten recommendations are based on the evaluations of the studies in which fugitive emissions were field measured, the activity data and correction parameters required to utilize emission factors to develop emission inventories, and the availability of that data.

1) Additional field testing should be conducted on the source categories with the following order of priority: construction, wind erosion, paved roads, storage piles, agricultural tilling, mining and quarrying (especially quarrying), and unpaved roads.

Testing of construction emissions is needed because only two field studies of that source have been conducted and because of the expected relative contribution of that source, particularly in urban areas. Many of the PM_{10} Group I and II areas are urban areas where construction activities are likely to be found and to be contributors to PM_{10}.

Wind erosion is high on the list because the empirical data on dust emissions due to wind erosion is very limited and because wind influences all of the other sources. Additionally, work on wind erosion may be required to determine how to evaluate wind erosion in urban areas. "Street canyon" effects for mobile source emissions have been recognized for some time. Do these same "street canyon" effects influence wind erosion from exposed areas within cities because of a channeling effect? Questions such as these need research and investigation.

The other categories listed above were placed in the priority list according to the extent and quality of field data currently available, and the potential magnitude of the source in inventories. The other source categories, landfills, feedlots, and unpaved parking lots, are of lower priority regarding development. However, in certain areas and at certain inventory scales, these sources may be important and will require a significant development effort to determine adequate emission factors.

2) Standardized procedures should be developed for conducting and documenting fugitive emissions field tests, resulting data analysis, and emission factor development.

There are currently no such standard procedures available for the measurement of fugitive dust emissions. A procedures manual would eliminate much of the often unnecessary variation in sampling equipment configuration, analytical procedures, and quality assurance. An emissions database generated from generally consistent field testing projects will have less variability and will permit more meaningful analysis than a database built on many dissimilar or non-comparable projects.

The procedures manual should include guidelines for the following areas:

- equipment configuration, including the distance of downwind samplers from the source, the number of sampling heads as a function of estimated plume height (for profiling), and the number and type of ancillary samplers.
- method of correcting for background dust levels
- necessary testing conditions, particularly regarding meteorological parameters
- method of acquiring isokinetic exposures (for profiling)
- selection of the appropriate dispersion model (for modeling)

In addition, or as an alternative, to the last item, investigators could be required to justify their choice of a dispersion model.

Many of the remaining recommendations could also be incorporated into the procedures manual.

3) Emphasis should be placed on utilization of state-of-the-art, well characterized sampling equipment.

A primary example of this is the dichotomous sampler. The great advantage of the dichotomous sampler concerning particle size distribution is that it operates as a virtual impactor. As a consequence, it does not suffer from the particle bounce problems associated with the high volume cascade impactors, since there is no physical surface on which the particles can bounce. There are a few drawbacks to the use of dichotomous samplers in determining emissions from fugitive dust sources. The main drawback is the low sampling rate associated with this sampler. This is especially true for the fine particle ($\leq$ 2.5 µm) flow, which is only 0.1 that of the total sampler flow. As a consequence, it can be difficult to obtain enough mass on the fine fraction filter to measure above the noise level associated with the balance. An additional problem area is that the cut-point for the inlet is wind speed sensitive. Thus the upper limit for the particle size cut-point varies with the wind speed. However, this does not apply to the fine fraction, since typically the material in the $\leq$ 2.5 µm fraction is not affected by the sampler cut-point. Despite these limitations, the dichotomous sampler represents a well classified, state-of-the-art particle sampler.

Perhaps EPA should give some thought to development of a "trichotomous" sampler having two virtual impactor stages, one at the current fine particle cut point and one at the 10 µm cut point. The upper limit could then be wind speed sensititve, and it would not matter, since the internal flow dynamics would then handle the PM_{10} fraction.

Optical particle sizing devices should also be carefully considered for characterizing the particle size distribution of the dust plume. In some circumstances, the relatively short run time needed to collect a sample permits multiple samples to be taken at several heights in the plume before the character of the plume changes substantially.

The use of hot wire anemometers and automatically adjusting flow controllers should be encouraged, if not required, when conducting exposure profiling. This will help to insure that samples are collected isokinetically. This may not be feasible with dichotomous samplers, however.

4) Statistical methods should always be employed in both the experimental design and the field data analysis.

Field experiments should be designed such that the results will generate relatively certain (e.g. 95% confidence) conclusions regarding the relationships between the monitored variables over the ranges experienced in the test. Similarly, specific statistical criteria should be used in determining the utility of a particular variable in explaining variation in emissions. Statistics should at least play a key role in determining which variables are used in a predictive equation. Furthermore, summary statistics that reflect the amount of variability in the measured emissions which is explained by the predictor variables should be reported with each revision of the equation.

5) Insure the use and documentation of quality assurance practices in emissions measuring projects.

Development of a Quality Assurance Project Plan (QAPP) for each environmental monitoring and measurement effort has been a requirement of the Office of Research and Development (ORD) since May 30, 1979. Interim guidelines for preparation of QAPPs were published in 1980 (U.S. EPA). These guidelines specify that the following items must be addressed in the QAPP:

- QA procedures for measurement data in terms of precision, accuracy, completeness, representativeness, and comparability
- sampling procedures
- sample custody
- calibration procedures and frequency
- analytical procedures
- data reduction, validation, and reporting
- internal quality control checks and frequency
- performance and systems audits and frequency
- preventive maintenance procedures and schedules
- specific routine procedures to be used to assess data precision, accuracy, and completeness of specific measurement parameters involved
- corrective action
- quality assurance reports to management

Clearly, many of the reviewed field studies, including those done after 1980, have not addressed all of the above items. If every future field measurement project conforms to these guidelines, the collected data will be of a much greater quality and value. For very large emissions testing projects, it may be advisable to have an organization other than the one performing the sampling conduct the QA audit.

6) Whenever exposure profiling is chosen as the method of choice, require that dispersion modeling of the emission rate be conducted also.

In other words, measurements taken for exposure profiling could also be utilized in dispersion modeling. Since exposure profilers also could be utilized to determine concentration, the dispersion model could be solved for the various heights of the profiler heads to determine the source strength of the source. This would serve as a check on the results of exposure profiling. When the emission rates calculated by the two different methods are in significant disagreement, the investigators would be alerted to possible problems in their equipment configuration. Additional data requirements would be minimal.

7) Explore emissions modeling alternatives to the framework described in the Workbook of Atmospheric Dispersion Estimates (1970).

The models described and discussed by Turner are, with few exceptions, intended for use with continuously emitting sources or sources from which pollutant releases last longer than the travel time between the source and the receptor. Many of the fugitive dust sources discussed here are sometimes, if not always, intermittent. For example, depending on the traffic density, paved and unpaved roads are sometimes more aptly described as intermittent rather than continuous. Models designed specifically to estimate pollutant releases which occur in short intervals have been developed in recent years. These are typically referred to as puff models. Adaptation of these models to line-type sources may be required.

8) The availability of activity data and data on correction parameters should be considered when developing predictive emission factors.

The issue of inventory scale is critical here. As was pointed out in the evaluation of activity data above, many of the correction parameters required for use in the emission factors available now require data that have not, are not, and probably will not ever be collected by a state, regional, or national agency or trade association. The only way of obtaining much of this information is to perform a site visit and collect it or to send out surveys to individual facilities to collect it. If EPA still wants to pursue development of activity-specific emission factors, it should also consider one of the following options.

- Undertake a parallel emission factor development effort oriented towards both larger scale inventories in which activity-specific emission factors are still developed, and emission factors for the facility requiring activity data based upon routinely reported and published information. An example would be surface coal mining. Develop activity-specific emission factors that require VMT for hauling vehicles, but also develop an emission factor for total mining activity based on tons of coal produced for utilization in developing state, regional or national level emissions estimates.

- Perform an evaluation using robust statistical analyses to determine appropriate surrogate indicators that can be used as a basis for developing estimates of the activity-specific correction parameters currently utilized in emission factors. For example, determine if there is a significant statistical correlation between construction dollars spent and construction vehicle VMT upon which estimates of construction VMT can be made using reported information on construction dollars.

- Try to establish inter-agency agreements between EPA and other agencies such as DOT, DOL, etc., to make the necessary information a required piece of information in their standard reports.

9) Encourage individuals, organizations, and government agencies which have collected data on correction parameters or activity levels to submit it to the Clearing House for Inventories and Emission Factors (CHIEF).

Having adequate emission factors and activity data developed is a major first step towards improvements in estimating emissions from fugitive dust sources. However, if the information is unavailable or it takes a long time to distribute it, its value is greatly diminished. Having the data available on the CHIEF bulletin board would greatly facilitate the dissemination of the most recent information.

10) Determine the relative importance of temporal activity data to PM_{10} emission inventory development.

Temporal information concerning activity data for PM_{10} fugitive dust sources is virtually non-existent, especially at the hourly or daily level. For a very limited number of activity data types, monthly information is available, but typically, only annual data is available. If hourly or daily information is of a high priority (as it is for ozone inventories), then a significant research and development effort will be required to develop the information.

Finally, EPA must realize that institution of these recommendations will not be inexpensive. In many respects, development of emission factors for these sources will be almost like starting at the beginning. The majority of the emissions testing for these sources was performed from the late 1970s to the mid 1980s. No direct measurements of PM_{10} for these sources have been made. Although adequate funding will go a long way towards improving and developing emission factors for fugitive dust sources, without a well thought out program of research and development, the results will not be adequate to meet the requirements of fugitive PM_{10} emission inventory development efforts.

SECTION 5

REFERENCES

Alliance. Improved Emission Inventory Methodology for Other Stationary Source Fuel Combustion Categories Draft Summary Report. EPA contract number 68-D9-0173, September 1990.

American Society of Testing and Materials. "Standard Method for Collection and Analysis of Dustfall." Method D 1739-62.

Amick, R.S., K. Axetell, D. Wells. Fugitive Dust Emission Inventory Techniques. 67th Annual AWMA Meeting, Denver, CO. June 9-13, 1974.

Axetell, Kenneth, Jr. and Chatten Cowherd, Jr. Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources. EPA-600/7-84-048. U.S. Environmental Protection Agency, Cincinnati, Ohio. March 1984.

Axetell, Kenneth, Jr. Survey of Fugitive Dust from Coal Mines. EPA-908/1-78-003. U.S. Environmental Protection Agency, Denver, Colorado. February 1978.

Axetell, Kenneth, and Joan Zell. Control of Reentrained Dust From Paved Streets. EPA-907/9-77-007. U.S. Environmental Protection Agency. July 1977.

Blackwood, T. R., P. K. Chalekode, and R. A. Wachter. Source Assessment: Crushed Stone. EPA-600/2-78-004L. U.S. Environmental Protection Agency, Cincinnati, Ohio. May 1978.

Bohn, Russel, Thomas Cuscino, Jr., and Chatten Cowherd, Jr. Fugitive Emissions from Integrated Iron and Steel Plants. EPA-600/2-78-050, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. March 1978.

Chalekode, P. K., J. A. Peters, T. R. Blackwood, and S. R. Archer. Emissions from the Crushed Granite Industry: State of the Art. EPA-600/2-78-021. U.S. Environmental Protection Agency, Cincinnati, Ohio. February 1978.

Connor, Andrew D., Thomas E. McGuire, and Murray S. Greenfield. Wind Erosion Testing by Portable Wind Tunnel at an Iron and Steel Plant. 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, Minnesota. Paper No. 86-22.1. June 22-27, 1986.

Cook, Frank, Arlo Hendrikson, L. Daniel Maxim, and Paul R. Saunders. Fugitive Dust From Western Surface Coal Mines. EPA-600/7-80-158. U.S. Environmental Protection Agency, Cincinnati, Ohio. August 1980.

Cowherd, Chatten, Jr., Russel Bohn, and Thomas Cuscino, Jr. Iron and Steel Plant Open Source Fugitive Emission Evaluation. EPA-600/2-79-103, Environmental Protection Agency, Research Triangle Park, North Carolina. May 1979.

Cowherd, C.C. Jr., C. Guenther. Development of a Methodology and Emission Inventory for Fugitive Dust for Regional Air Pollution Study. EPA-450/3-76-003. Prepared for U.S. EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. 1976.

Cowherd, Chatten, Jr., Kenneth Axetell, Jr., Christine M. Guenther, and George A. Jutze. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. June 1974.

Cowherd, Chatten, Jr., Christine M. Maxwell, and Daniel W. Nelson. Quantification of Dust Entrainment from Paved Roadways. EPA-450/3-77-027. U.S. Environmental Protection Agency. July 1977.

Cowherd, Chatten, Jr. and Phillip J. Englehart. Paved Road Particulate Emissions--Source Category Report. EPA-600/7-84-077. U.S. Environmental Protection Agency. July 1984.

Cuscino, Thomas, Jr., Gregory E. Muleski, and Chatten Cowherd, Jr. Iron and Steel Plant Open Source Fugitive Emission Control Evaluation. EPA-600/2-83-110, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. October 1983.

Cuscino, Thomas A., John S. Kinsey, Richard Hackney, Russel Bohn, and R. Michael Roberts. The Role of Agricultural Practices in Fugitive Dust Emissions. Contract report for the California Air Resources Board. June 1981.

Cuscino, Thomas A., Robert Jennings Heinsohn, and Clotworthy Birnie, Jr. Fugitive Dust from Vehicles Travelling on Unpaved Roads. General Technical Report NE-25, ODC 907.3; 187: 111: 273: 425.1, USDA Forest Service. 1977.

Dyck, Rodney I. J. and James J. Stukel. "Fugitive Dust Emissions from Trucks on Unpaved Roads." Environmental Science and Technology. Vol. 10. No. 10. October 1976. pp. 1046-48.

Elam, C. J., J. W. Algeo, T. Westing, and A. Martinez. Bulletin D. California Cattle Feeders Association. Bakersfield, California. June 1972.

Elam, C. J., T. Westing, J. W. Algeo, and L. Hokit. Measurement and Control of Feedlot Particulate Matter. California Cattle Feeders Association. Bakersfield, California. February 1971.

Evans, J.S. and D.W. Cooper. An Inventory of Particulate Emissions from Open Sources. Journal Air Pollution Control Association, Vol. 30, #12,pp. 1298-1303. December, 1980.

Gillette, D.A., and R. Passi. Modeling Dust Emission Caused by Wind Erosion.. Journal of Geophysical Research, Vol. 93, NO. D11, pp. 14,233-14,242. November, 1988.

Handy, R. L., J. M. Hoover, K. L. Bergeson, and Darwin E. Fox. "Unpaved Roads as Sources for Fugitive Dust." Transportation Research News. 1975. pp. 6-9.

Heisler, S.L. Interim Emissions Inventory for Regional Air Quality Studies. Electric Power Research Institute Report, EPRI EA-6070. November, 1988.

Jutze, George, and Kenneth Axetell. Investigation of Fugitive Dust Volume I - Sources, Emissions, and Control. EPA-450/3-74-036-a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. June 1974.

Kinsey, John Scott, Phillip Englehart, and Alan L. Jirik. Study of Construction Related Dust Control. Contract No. 32200-07976-01. Minnesota Pollution Control Agency, Roseville, Minnesota. April 1983.

Lemon, Richard W., Richard W. Bloomingdale, and Karen J. Heidel. Derivation of Suspended Particulate Emission Factor for Motor Vehicle Use of Unpaved Roadways. unpublished study by the Pima County Air Quality Control District. February 1975.

Marple, Virgil, Kenneth Rubow, and Orville Lantto. Fugitive Dust Study of an Open Pit Coal Mine. Contract No. USDI/BOM J0295071. U.S. Department of Interior, Bureau of Mines, Washington, D.C. September 1980.

McCaldin, Roy O. Fugitive Dust Study for Pima County Air Quality Control District, Tucson, Arizona. AQ-91A. Air Quality Control District of Pima County. October 1977.

Midwest Research Institute. Gap Filling PM_{10} Emission Factors for Selected Open Area Dust Sources. EPA-450/4-88-003. U.S. Environmental Protection Agency. Research Triangle Park, North Carolina. February 1988.

Muleski, G. E., C. Cowherd, Jr. and T. Cuscino, Jr. Current Procedures for Open Source Particulate Emission Measures. Midwest Research Institute. December 1983.

Muleski, G., and D. Hecht. PM_{10} Emission Inventory of Landfills in the Lake Calumet Area. Contract No. 68-02-3891. U.S. Environmental Protection Agency. September 1987.

National Climatic Data Center. Local Climatological Data. 1991.

Pasquill, F. Meteorology and Atomic Energy 1968. U.S. Atomic Energy Commission. 1968.

Peters, J. A. and T. R. Blackwood. Source Assessment: Beef Cattle Feedlots. EPA-600/2-77-107. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. June 1977.

Pinnick, R. G., G. Fernandez, B. D. Hinds, C. W. Bruce, R. W. Schaefer, and J. D. Pendleton. "Dust Generated by Vehicular Traffic on Unpaved Roadways: Sizes and Infrared Extinction Characteristics." Aerosol Science and Technology. Vol. 4. 1985. pp. 99-121.

Pyle, Bobby E. and Joseph D. McCain. Critical Review of Open Source Particulate Emission Measurements. Part II - Field Comparison. EPA-600/2-86-072, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. August, 1986.

"Reference Method for the Determination of Suspended Particulates in the Atmosphere (High Volume Method)," Federal Register, 36, 28, Appendix B, 22388-22390, 25 November 1971.

Reider, J. Patrick. Size Specific Particulate Emission Factors for Uncontrolled Industrial and Rural Roads. Draft Final Report. EPA Contract No. 68-02-3158. January 1983.

Roberts, John Warren. The Measurement, Cost and Control of Air Pollution From Unpaved Roads and Parking Lots in Seattle's Duwamish Valley. Thesis for Master of Science in Engineering, University of Washington. 1973.

Roberts, John W., Harry A. Watters, Carl A. Mangold, and August T. Rossano. "Costs and Benefits of Road Dust Control in Seattle's Industrial Valley." Journal of the Air Pollution Control Association. Vol. 25. No. 9. September 1975. pp. 948-52.

Sartor, J. D. and G. B. Boyd. "Water Pollution Aspects of Street Surface Contaminants." U.S. Environmental Protection Agency, Publication No. EPA-R2-72-081. November 1972.

Sehmel, G. A. "Particle Resuspension from an Asphalt Road Caused by Car and Truck Traffic." Atmospheric Environment. Vol. 7. pp.291-309. July 1973.

State of California Air Resource Board. CARB Draft Inventory Report. Sacramento, CA. 1987.

State of Vermont, Agency of Natural Resources, Department of Environmental Conservation. State of Vermont Implementation Plan Revision, Appendix A. January 1979.

Struss, S. R. and W. J. Mikucki. Fugitive Dust Emissions From Construction Haul Roads. Special Report N-17. U.S. Army Construction Engineering Research Laboratory. February 1977.

Turner, D. Bruce. Workbook of Atmospheric Dispersion Estimates. Publication Number AP-26. U.S. Environmental Protection Agency. Research Triangle Park, North Carolina. Revised 1970.

U.S. DOE. Coal Production (Annual), DOE/EIA-0118. November, 1990.

U.S. DOC, Bureau of Census. Industrial Series Census of Construction. Table 10, Value of Construction Work for Establishments with Payroll by Location of Construction Work. 1987.

U.S. DOT, FHWA. Highway Statistics, 1989 (Annual). October, 1990.

U.S. Environmental Protection Agency. "Reference Method for the Determination of Suspended Particulates in the Atmosphere (High Volume Method)." Federal Register. 36, 28. Appendix B. pp. 22388-22390. November 1971.

U.S. Environmental Protection Agency. Quality Assurance Handbook for Air Pollution Measurement Systems. Volume II: Ambient Air Specific Methods. Research Triangle Park, North Carolina. November 1976.

U.S. Environmental Protection Agency. Cascade Impactor Data Reduction with SR-52 and TI-59 Programmable Calculators. Research Triangle Park, North Carolina. Publication No. EPA-600/7-78-226. November 1978.

U.S. Environmental Protection Agency. Quality Assurance Handbook for Air Pollution Measurement Systems Volume II: Ambient Air Specific Methods. EPA-600/4-77-027a. May 1977.

U.S. Environmental Protection Agency. Ambient Monitoring Guidelines for Prevention of Significant Deterioration Research Triangle Park, North Carolina. 1978.

U.S. Environmental Protection Agency. Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans. QAMS-005/80. Washington, D.C. December 1980.

USDA Statistical Reporting Service, Agricultural Handbook Number 628, Usual Planting and Harvesting Dates for U.S. Field Crops, April, 1984.

Vekris, S. L. "Dispersion of Coal Particles from Storage Piles." Hydro Research Quarterly. Vol. 23. No. 2. 1971.

Wedding, J. B., A. W. Weigand, and T. C. Carney. "A 10 µm Cutpoint Inlet for the Dichotomous Sampler." Environmental Science and Technology. Vol. 16, pp. 602-06.

Woodruff, N.P. and F. H. Siddoway. "A Wind Erosion Equation." Soil Science Society of America Proceedings. Vol. 29. No. 5, September-October 1965.

APPENDIX A

NOTES AND INFORMATION CONCERNING ACTIVITY DATA SOURCES

The state of Virginia does not have a PM_{10} nonattainment area and therefore has never developed a PM_{10} fugitive dust inventory.

Region I said that the region collects emission estimates from the states with nonattainment areas. For Region I these states are Maine and Connecticut.

The PM_{10} nonattainment area in Maine is Presque Isle. They prepared a 1991 SIPs on sanding/salting of paved roads. They collected site specific counts, mileage and silt loading values. Some of their traffic counts were obtained from Maine's DOT.

In Region VII there are not any nonattainment areas so no information on PM_{10} fugitive dust is collected nor is a PM_{10} SIP developed. The states in region VII are Iowa, Kansas, Missouri and Nebraska.

Bob Judge of Region I stated that attainment states in his region do a point source inventory only and therefore do not collect fugitive dust activity data.

Region V stated only nonattainment areas collected fugitive dust inventories and they are done by the state or local agencies.

In 1988 MRI performed a PM_{10} study on Illinois's two nonattainment areas, Chicago and Granite city. MRI sent companies surveys for VMT, used monitoring data for background emission. They took aerial photo to estimate sizes of stock piles and parking lots.

In Indiana they use AP-42 emission factors for paved and unpaved roads, storage piles, open sources and wind erosion. To obtain VMT they sent questionnaires to facilities and asked for surface loading and if not provided they use the AP-42 defaults. For agricultural tilling they obtained county-level data from the county soil conservation services. For area source paved and unpaved roads, they obtained state and federal highway maps of ADTV, and from county/metro roads they obtained traffic counts. They do not do a mining and quarrying PM_{10} emission estimate. For construction they used building permits which contain the estimated acres and cost of the construction.

Region IX stated that the state and local air agencies did the inventory work. In Arizona the state performed the inventory and in California and Nevada local agencies estimated the emissions.

In Arizona, Engineering Science developed a base inventory for modeling work. They performed paved road sampling, size distribution, and silt content. The traffic data was locally generated data from paved road traffic tapes which contain capacity, number of lanes, and ADTV. For unpaved roads the ADTV was estimated. For Yuma county, the use of a traffic counter is impossible since the counters become buried within minutes in dust. For determining activity levels for construction, storage piles and sand/gravel they obtained county air pollution permit files. For agricultural tilling they took aerial photos to estimate acreage and took silt measurements.

Within Nevada the permits call for all fugitive dust to be suppressed or a facility is in violation. VMT is developed from hydrographic basis or some actual Nevada DOT data.

From U.S. EPA, National Air Data Branch (NADB) it was learned that to determine PM_{10} fugitive emissions in AMS the truck VMT is obtained from the Truck Inventory and Use Survey and county level registration is obtained from R.L. Polk. In their files are county level paved road VMT for 1985 for the following states: California, Delaware, District of Columbia, Georgia, Illinois, Iowa, Kansas, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, Texas, Utah, West Virginia, and Wyoming. AMS also states that at present, no methodology to estimate activity levels on a county basis nor emission factors are available for miscellaneous wind erosion. They also state that at present, no methodology is available to estimate activity level at the county level.

Ohio uses their permits to obtain activity data,they inventory paved and unpaved roads, mining, storage piles and wind erosion. They use AP-42 emission factors with the exception of wind erosion where they use an older AP-42 emission factor equation. The original area source inventory was developed by PEI for Ohio SIP during the late 1970's and is currently updated by population.

Region I stated that Connecticut adjusted street data to fit monitoring data. New Haven is the only nonattainment area and the modeling group is presently investigating the problems. In 1979 an attempt at a construction inventory was made.

In 1982 a fugitive dust inventory for Massachusetts was estimated. Presently there is no methodology.

There are no nonattainment areas in New Hampshire, but they do inventory PM_{10} for all their SO_2 sources.

There are also no nonattainment areas in Rhode Island, but they do some monitoring.

In Michigan, the Wayne County Pollution Agency sent out surveys to collect VMT and storage pile data. For an area source paved road inventory, the VMT projections were made by Southeastern Michigan Council of Government (SEMCG). The SEMCG also periodically does traffic counts for Detroit.

West Virginia has presently sent surveys to industries for the November 15, 1991 PM_{10} SIP.

The Allegheny County, Pennsylvania Air Agency is presently sending surveys to industries. Their last fugitive dust emission report was prepared by TRC.

The state of Vermont did a 1979 SIP inventory. They sent a copy of the Appendix A: Non-Attainment Area Emission Inventory.

New Jersey uses ambient monitoring data to derive PM_{10} emissions for the State.

New York goes to a specific area that has been identified as having potential fugitive dust problems. New York then evaluates the potential emissions and then proceeds with the permitting process (a site specific basis) if necessary. Examples of these specific sources include quarries, sanding operations, and road dust. New York goes to DOT for actual highway information. New York monitors especially dusty areas to determine the significance of the problem. No estimation of fugitive PM_{10} for construction/demolition, wind erosion or agricultural tilling is done.