MIDWEST RESEARCH INSTITUTE

MRI REPORT

UPDATE OF FUGITIVE DUST EMISSION FACTORS IN AP-42 SECTION 11.2

FINAL REPORT

EPA Contract No. 68-02-3891
Assignment No. 19
MRI Project No. 8681-L(19)

July 14, 1987

For

Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Attn: Mr. Frank M. Noonan

MIDWEST RESEARCH INSTITUTE 425 VOLKER BOULEVARD KANSAS CITY, MISSOURI

UPDATE OF FUGITIVE DUST EMISSION FACTORS IN AP-42 SECTION 11.2

FINAL REPORT

EPA Contract No. 68-02-3891
Assignment No. 19
MRI Project No. 8681-L(19)

July 14, 1987

For

Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Attn: Mr. Frank M. Noonan

MIDWEST RESEARCH INSTITUTE 425 VOLKER BOULEVARD, KANSAS CITY, MISSOURI 64110 • 816 753-7600

PREFACE

This final report was prepared for the U.S. Environmental Protection Agency (EPA), Office of Air Quality Planning and Standards (OAQPS) under EPA Contract No. 68-02-3981, Assignment No. 19. Mr. Frank M. Noonan, Air Management Technology Branch, was the requestor of this work. The draft final report was prepared by Dr. Gregory E. Muleski with assistance from Dr. Chatten Cowherd and Mr. Phillip Englehart.

Approved for:

MIDWEST RESEARCH INSTITUTE

Chatten Cowherd, Director
Environmental Systems Department

July 14, 1987

CONTENTS

FIGURES

TABLES

SECTION 1

INTRODUCTION

In both the assessment of air quality and the design of control plans to achieve certain goals in terms of air quality, there is a critical need for reliable and consistent data on the quantity and physical characteristics of emissions from a variety of sources. The large number of individua release points and the diversity of source types make field measurements of emissions at every location impractical. Usually, the only feasible method of determining pollutant emissions for a given area is to make general emission estimates typical of each source type.

Calculation of the estimated emission rate for a given source requires data on source extent, uncontrolled emission factor, and control efficiency The mathematical expression for this calculation is as follows:

$$R = Me\ (1 - c) \qquad (1)$$

where:

R = mass emission rate

M = source extent

e = uncontrolled emission factor, i.e., rate of uncontrolled emissions per unit of source extent

c = fractional efficiency of control

The emission factor is an estimate of mass of pollutant released to the atmosphere per unit measure of source activity (e.g., vehicle miles traveled, tons of material transferred, etc.).

The document "Compilation of Air Pollutant Emission Factors" (commonly known as AP-42) has been published by the U.S. Environmental Protection Agency (EPA) since February 1972, and represents a compilation of emission factors for the most significant emission source categories. As more information about sources and control of emissions has become available, supplements to AP-42 have been issued for both new emission source categories and for updating existing emission source categories.

Because the national effort to control industrial sources of pollution has historically focused on discharge from stacks, ducts or flues, most of the emission factors reported in AP-42 apply to ducted emission sources. Over the past 15 years, however, it has become clear that fugitive (non-ducted) emissions contribute substantially to the impact of industrial operations and may, in some industries, be greater than the stack emissions.

Industrial sources of fugitive particulate emissions may be divided into the two classes of process and open dust sources. Process sources are fully or partially enclosed operations that alter the chemical or physical properties of a feed material. Examples of process sources are crushers, sintering machines, and metallurgical furnaces. Open dust sources are those that entail generation of emissions of solid particles by the forces of wind and machinery acting on exposed materials. These sources include open transport, storage and transfer of raw, intermediate, and waste aggregate materials. The remainder of this discussion focuses on the category of open dust sources.

Section 11.2 of AP-42 presents open dust emission factors for several generic source categories. These factors have been used extensively by industry and regulatory agency personnel during the past decade. Emission factors are presented for the following open dust sources:

Section	Source
11.2.1	Unpaved Roads
11.2.2	Agricultural Tilling
11.2.3	Aggregate Handling and Storage Piles
11.2.4	Heavy Construction Activities
11.2.5	Paved Urban Roads
11.2.6	Industrial Paved Roads

These factors, except that for heavy construction operations, are presented in the form of predictive equations which relate mass emissions to: (a) measures of source activity or energy expended; (b) properties of the material being disturbed; and (c) climatic parameters. As such, these factors become applicable to a wide range of source conditions, limited only by the extent of experimental verification.

As part of EPA's anticipated revision of the National Ambient Air Quality Standards (NAAQS) for particulate matter to address particles less than or equal to 10 μm in aerodynamic diameter (PM_{10}), the three sections concerning paved and unpaved roads were revised for inclusion in the Fourth Edition of AP-42 (September 1985). The three remaining sections were not updated.

Recent developments support the need for Section 11.2 to be revised and possibly expanded. First, revisions may be warranted simply because new test data are now available. The data generated in these new studies need to be reviewed in order to determine if revisions of Section 11.2 can be supported. For example, it is likely that recent field tests related to source categories already addressed in AP-42 may be used to broaden the applicability of the existing emission factors.

The second development involves increased interest in the control of fugitive dust emissions. Almost all field studies of road dust emissions during the 1980s have entailed evaluation of control techniques. As a result of these studies, considerably more data are now available to estimate the efficiency of certain control techniques (especially those for unpaved

roads). Revision of certain sections in Section 11.2 may be needed in light of these new results.

The particle size ranges of interest in this report are:

TP - Total airborne particulate matter.

TSP - Total suspended particulate matter, as determined by standard high volume air sampling.

SP - Particulate matter smaller than 30 μm in aerodynamic diameter. This fraction is often used to approximate TSP.

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

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

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

Particular attention is devoted to the TSP and SP fractions because of the current NAAQS and to PM_{10} because of the anticipated NAAQS revision pertaining to that fraction.

The purpose of this report is to present background information in support of new and revised AP-42 sections for open dust sources. This report is organized as follows:

Section 2 - Emission Factors Currently Reported in AP-42

Section 3 - Identification of Candidate Test Reports

Section 4 - Evaluation Criteria Test Reports

Section 5 - Candidate Emission Factors and Control Efficiency Data

Section 6 - Discussion and Recommendations

Both metric and English units are used in this report. The review of available test data (Section 5.0) uses the same set of units as does the test report being evaluated. If both sets are reported, preference is given to that set used during the original data reduction (if known).

SECTION 2.0

REVIEW OF AP-42

2.1 HISTORY OF AP-42

AP-42 presents data available on pollutant emissions for which adequate documentation exists to estimate emission factors. The factors given in AP-42 are based on emission data obtained by various methods, of which source testing, material balance studies, and engineering estimates are the most common. The primary purpose of the document is for use by individuals and groups responsible for developing air pollution emission inventories.

AP-42 was first published by the U.S. Public Health Service and, since 1972, by the EPA. The document has been revised on a periodic basis since that time. Supplements are issued either to revise existing emission factors or to present information regarding a source not previously included in AP-42. The Fourth Edition of AP-42 was issued in September 1985.

2.2 OPEN DUST SOURCE EMISSION FACTORS IN AP-42

In contrast to process sources of fugitive particulate emissions, open dust sources entail no change of material properties, either physical or chemical, of a feed material. Examples of open dust sources include materials transfer and storage piles. Operations which are not open dust sources include crushing, drying, and screening, all of which deal with a change in physical properties of a feed material.

Table 1 presents the open dust source emission factors given in AP-42 (Fourth Edition). Also given is the emission factor rating and the year that the AP-42 section was introduced or last revised. Ratings are described in Section 4.0 of this report.

TABLE 1. COMPILATION OF AP-42 OPEN DUST SOURCE EMISSION FACTORS

Industrial source category	Fugitive emission source	Emission factor (lb/ton)[a]	Emission factor rating	Year of latest revision	Comments
Adipic acid production	Drying, cooling, and storage	0.8	B	1977	A process source included in factor.
Carbon black manufacture	Fugitive emissions	0.20	C	1983	
Hydrofluoric acid production	Spar handling silos	60	D	1980	
	Spar transfer operations	6	E	1980	
Lead alkyl production	Sludge pits	1.2	B	1979	
Grain elevators	Receiving	0.6-1	B	1977	
	Shipping	0.3-1	B	1977	
Feed mills	Receiving	1.3	D	1977	
	Shipping	0.5	D	1977	
	Handling	3	D	1977	
Wheat milling	Receiving	1	D	1977	
	Precleaning and handling	5	D	1977	A process included in factor.
Durum milling	Receiving	1	D	1977	
	Precleaning and handling	5	D	1977	A process included in factor
Rye milling	Receiving	1	D	1977	
	Precleaning and handling	5	D	1977	A process included in factor
Dry corn milling	Receiving	1	D	1977	
	Precleaning and handling	5	D	1977	A process included in factor.
Rice milling	Receiving	0.64	D	1977	
	Precleaning and handling	5	D	1977	A process included in factor.
Soybean milling	Receiving	1.6	D	1977	
	Handling	5	D	1977	
	Bulk loading	0.27	D	1977	
Wet corn milling	Receiving	1	D	1977	
	Handling	5	D	1977	
Fermentation industry	Grain handling	3/3	E/D	1972/1982	Whiskey/beer making.
Ammonium nitrate fertilizer	Bulk loading	≤ 0.02	B	1984	
Phosphate fertilizer	Unloading	0.56	A	1980	
Triple superphosphate fertilizer	Unloading	0 14-0.18	A	1980	
Ammonium phosphates	Product sizing and material transfer	0.03	A	1980	Process included; factor represents one sample.

(Continued)

TABLE 1 (Continued)

Industrial source category	Fugitive emission source	Emission factor (lb/ton)[a]	Emission factor rating	Year of latest revision	Comments
Urea production	Bagging	0.19	C	1984	
Cattle feedlots	Unspecified	27 lb/day/10^3 head throughput	E	1979	Another factor given for lot capacity.
Cotton harvesting (picker)	Trailer loading	0.4 lb/mile[2]	C	1979	
	Field transport	2.5 lb/mile[2]	C	1979	
Cotton harvesting (stripper)	Trailer loading	0.32 lb/mile[2]	C	1979	
	Field transport	1.6 lb/mile[2]	C	1979	
Wheat harvesting	Truck loading	0.07 lb/mile[2]	D	1980	
	Field transport	0.65 lb/mile[2]	D	1980	
Sorghum harvesting	Truck loading	0.13 lb/mile[2]	D	1980	
	Field transport	1.2 lb/mile[2]	D	1980	
Primary aluminum	Materials handling	10	A	1973	
Metallurgical coke	Charging	0.85[b]	C	1982	
	Pushing	0.47[b]	A	1982	
Iron and steel	Varies	See comment	B-E	1983	Table 7.5-1 gives single-valued factor for several sources, reader is also refered to Chapter 11.2.
Primary lead smelters	Sinter transfer to dump	0.20	E	1980	
	Sinter product dump	0.01	E	1980	
	Slag cooling	0.47	E	1980	
	Materials handling	5.0	B	1981	
Gray iron foundries	Scrap and charge handling, heating	0.2[b]	D	1981	Process included in factor.
	Sand handling, preparation, mulling	3[b]	D	1981	Process included in factor.
Asphaltic concrete	Unloading coarse and fine aggregate	0.10[b]	E	1981	
	Aggregate elevator	0.20[b]	E	1981	
Brick manufacturing	Raw material storage	34	C	1973	
Calcium carbide manufacturing	Circular charging conveyor	(0.34)	C	1984	Controlled value.
Ceramic clay manufacturing	Storage	34	A	1972	
Clay/flyash sintering	Clay/coke crushing, screening and storage	15	C	1972	Processes included in factor.
	Natural clay crushing, screening, and storage	12	C	1972	Processes included in factor
Glass fiber manufacturing	Unloading and conveying	3	B	1985	
	Storage bins	0 2	B	1985	

(Continued)

TABLE 1 (Continued)

Industrial source category	Fugitive emission source	Emission factor (lb/ton)[a]	Emission factor rating	Year of latest revision	Comments
Phosphate rock processing	Storage and transfer	2	B	1980	
	Storage piles	40	B	1980	
Sand and gravel	Pile formation by stack	0.13	E	1985	
	Batch loading	0.056	E	1985	
	Storage piles	3.5-14.8	D	1985	
Crushed stone	Truck unloading	0.0003	D	1985	
	Truck loading	0.0003-0.06	E	1985	
	Conveying	0.0034	E	1985	
Taconite ore	Ore transfer	0.10	D	1983	
	Bentonite transfer	0.04	D	1983	
	Pellet handling	3.4	D	1983	
	Unpaved roads	9.3-11	C-D	1983	
Metallic minerals	Material handling and transfer	1.1	C	1982	Bauxite/alumina (low moisture ore).
	Material handling and transfer	0 01-0.12	C	1982	Other materials (low-high moisture ore).
Western surface coal mining	Truck loading, bulldozing, dragline, vehicular traffic, wind erosion	See comment	A-C	1983	Predictive equations
	Topsoil removal, overburden replacement, truck and train loading, truck and scraper unloading, wind erosion	See comment	C-E	1983	Single-valued emission factors.
Plywood veneer and layout	Sawdust handling	1.0	E	1980	
Woodworking waste collection	Storage bin vent	1	C	1979	
	Storage bin loadout	2	C	1979	
Unpaved roads	Vehicular traffic	Predictive eqn	A	1985	
Agricultural operations	Tilling	Predictive eqn.	A-B	1983	
Aggregate storage piles	Batch and continuous drop, wind erosion	Predictive eqn.	C	1983	
Heavy construction	Land cleaning, blasting, excavation, cut and fill, and construction	1.2 lb/acre/month	-	1975	
Paved urban roads	Vehicular traffic	Predictive eqn.	-	1985	
Industrial paved roads	Vehicular traffic	Predictive eqn	B-D	1985	A rating for separate PM-10 equation.

[a] Values in lb/ton except as noted

[b] Revisions made in Supplement A (October 1986).

For some open dust source categories described in AP-42, industry-specific emission factors are given, along with reference to generic emission factors presented in Section 11.2. For example, in Section 7.5.1 (Iron and Steel Production), it is stated that open dust sources contribute to the atmospheric particulate burden. It is later mentioned in this section that empirically derived predictive emission factor equations presented in Section 11.2 generally better quantify these sources than do the single-valued factors given.

SECTION 3.0

IDENTIFICATION OF CANDIDATE TEST REPORTS

3.1 REVIEW OF LITERATURE

As the result of a scoping study, Muleski (1986b) discussed recent fugitive emissions test data as well as recent citations of Section 11.2 that might support revisions and additions to that section of AP-42 leading to improved open dust source emission and control efficiency estimates. However, those reports had not undergone review to determine what effect the new test results might have on Section 11.2. In addition to the test data discussed in the scoping report, additional data were also identified by the EPA work assignment manager for consideration in this study.

3.2 SCREENING CRITERIA

In order to reduce the large amount of candidate literature to a final group of references pertinent to this update, five criteria were used:

1. The information in the reference document must deal with actual emission factor development and/or control efficiency measurement. Many documents discuss emission factors or control efficiencies but do not derive them.

2. Source testing must be part of the referenced study. Some reports develop emision factors or control efficiency estimates by applying assumptions to existing data.

3. The referenced study must deal with open dust source emissions of the types discussed in Chapter 11.2 of AP-42. Process fugitive emissions such as crushing, screening, and grinding are not pertinent to this investigation.

4. The document must constitute the original source of test data. For example, a convention or symposium paper was not included if the original study was already contained in a previous document referenced in the paper.

5. The results of the referenced study must not be presently incorporated in AP-42. The purpose of this study is to recommend updating AP-42 with research results not previously contained in AP-42. If possible, however, new test data are to be combined with previous data (used to develop the current AP-42 emission factor) in deriving an updated emission factor.

3.3 PRIMARY LIST OF TEST REPORTS

A set of reference materials, given as Table 2, was gathered using the criteria outlined above. These documents were then evaluated in terms of the material presented in the next section.

Note that while Reports 10a through 10f do present actual emission measurements, these reports were included primarily because they allow intercomparison of various source sampling methods that have been used to quantify open dust sources. This is discussed in greater detail in Section 5.0.

TABLE 2. PRELIMINARY LIST OF TEST REPORTS

1. T. Cuscino, Jr., et al., 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.

2. K. D. Rosbury, and R. A. Zimmer, Cost-Effectiveness of Dust Controls Used on Unpaved Haul Roads - Volume 1 of 2, Final Report for U.S. Bureau of Mines, Minneapolis, Minnesota, December 1983.

3. G. E. Muleski et al., Extended Evaluation of Unpaved Road Dust Suppressants in the Iron and Steel Industry, EPA-600/2-84-027, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, February 1984.

4. E. T. Brookman et al., Determination of Fugitive Coal Dust Emissions from Rotary Railcar Dumping, TRC Project No. 1956-L81-00, May 1984.

5. G. E. Muleski, Measurement of Fugitive Dust Emissions from Prilled Sulfur Handling, Final Report, MRI Project No. 7995-L, Prepared for Gardinier, Inc., June 1984.

6. PEI Associates, Inc., Handbook - Dust Control at Hazardous Waste Sites, Draft Final Report prepared for U.S. Environmental Protection Agency, Cincinnati, Ohio, September 1984.

7. D. Russell and S. C. Caruso, "The Relative Effectiveness of a Dust Suppressant for Use on Unpaved Roads Within the Iron and Steel Industry," Presented at EPA/AISI Symposium on Iron and Steel Pollution Abatement, Cleveland, Ohio, October 1984.

8. T. F. Eckle and D. L. Trozzo, "Verification of the Efficiency of a Road-Dust Emission-Reduction Program by Exposure Profile Measurement, Presented at EPA/AISI Symposium on Iron and Steel Pollution Abatement Cleveland, Ohio, October 1984.

9. G. E. Muleski, Fugitive Emission Measurement of Fly Ash Loading at the River Rouge Power Plant, Final Report, MRI Project No. 8162-L, Prepared for Detroit Edison, March 1985.

10a. B. E. Pyle and J. D. McCain, Critical Review of Open Source Particulate Emission Measurements: Part II - Field Comparison, Final Report Southern Research Institute, Project No. 5050-4, prepared for the U.S Environmental Protection Agency, February 1986.

10b. Critical Review of Open Source Particulate Emission Measurements/Phase II - Field Tests, Field Data Analysis, and Report, Energy and Environmental Management, Inc., prepared for Southern Research Institute, Birmingham, Alabama, July 1984.

(Continued)

TABLE 2 (Continued)

10c. G. E. Muleski, Critical Review of Open Source Particulate Emission Measurements: Part II - Field Comparison, Final Report, MRI Project No. 7993-L, prepared for Southern Research Institute, Birmingham, Alabama, August 1984.

10d. K. D. Rosbury and R. A. Zimmer, Critical Review of Open Source Particulate Emission Measurements, Task 2 - Field Data Analysis and Report, PEDCo Environmental, Project No. 4181-67, prepared for Southern Research Institute, Birmingham, Alabama.

10e. E. T. Brookman, Critical Review of Open Source Particulate Emission Measurements: Part II - Field Comparison, TRC Environmental Consultants, Project No. 2681-L, prepared for Southern Research Institute, Birmingham, Alabama, July 1984.

10f. T. F. Eckle, Critical Review of Open Source Particulate Emission Measurements - Phase II - Field Test, United States Steel Corporation, September 1984.

11. G. E. Muleski and C. Cowherd, Jr., Evaluation of the Effectiveness of Chemical Dust Suppressants on Unpaved Roads, Final Report, MRI Project No. 8127-L, prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, November 1986.

SECTION 4

EVALUATION CRITERIA FOR THE TEST REPORTS

In selecting candidate open dust source factor and control efficiency emission data for inclusion in AP-42, primary consideration is given to the relative reliability of the new data compared to that currently contained in AP-42 for the same source. This section describes: EPA's quality rating system for AP-42 emission factors; methods for determining open dust source emission factors; the emission factor rating system used in this study; and the design and rating of sampling strategies used to determine control performance evaluation studies.

4.1 EPA'S EMISSION FACTOR QUALITY RATING SYSTEM

The emission factor rating system developed by the U.S. EPA, Office of Air Quality Planning and Standards (April 1980) is described in the following paragraphs.

Data obtained from source tests, material balance studies, and engineering estimates are used to calculate the emission factors presented in AP-42. These data are obtained from a variety of sources, including published technical papers and reports, documented emission testing results, and personal communications. Data provided by individual sources vary from single values, to ranges of minimum and maximum values, and finally to empirical formulas (predictive emission factor equations) which allow for correction of emission factors to specific source conditions. Some data sources provide complete details about collection and analysis procedures, whereas others may provide little information of this type.

The rating system for a particular emission factor data set is based on the following data standards:

A - Tests performed by a sound methodology and reported in enough detail for adequate validation. These tests are not necessarily EPA reference method tests, although such reference methods are certainly to be used as a guide.

B - Tests that are performed by a generally sound methodology but lack enough detail for adequate validation.

C - Tests that are based on an untested or new methodology or that lack a significant amount of background data.

D - Tests that are based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The following criteria are used to evaluate test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. Sampling procedures. If actual procedures deviated from standard methods, the deviations are well documented. Procedural alterations are often made in testing an uncommon type of source. When this occurs, an evaluation is made of how such alternative procedures could influence test results.

3. Sampling and process data. Many variations can occur without warning during testing, and sometimes without being noticed. Such variations can induce wide deviations in sampling results. If a large spread between test results cannot be explained by

information contained in the test report, the data are suspect and are given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used are compared to those specified by EPA, to establish equivalency. The depth of review of the calculations is dictated by the reviewers' confidence in the ability and conscientiousness of the tester, which in turn is based on factors such as consistency of results and completeness of other areas of the test report.

An A-rated test may be a source test, a material balance, or some other methodology, as long as it is generally accepted as a sound method or measuring emissions from that source.

In the ideal situation, a large number of A-rated source test sets representing a cross section of the industry are reduced to a single value for each individual source by computing the arithmetic mean of each test set. The emission factor is then computed by calculating the arithmetic mean of the individual source values. Alternatively, regression analysis is used to derive a predictive emission factor equation for the entire A-rated test set. No B-, C-, or D-rated test sets are used in the calculation of the emission factor because the number of A-rated tests is sufficient. This ideal method of calculating an emission factor is not always possible because of lack of A-rated data.

If the number of A-rated tests is so limited that inclusion of B-rated tests would improve the emission factor, then B-rated test data are included in the compilation of the arithmetic mean. No C- or D-rated test data are averaged with A- or B-rated test data. The rationale for inclusion of any B-rated test data is documented in the background information.

If no A- or B-rated test series are available, the emission factor is the arithmetic mean of the C- and D-rated test data. The C- and D-rated

test data are used only as a last resort, to provide an order-of-magnitude value.

In AP-42, the reliability of these emission factors is indicated by an overall Emission Factor Rating ranging from A (excellent) to E (poor). These ratings take into account the type and amount of data from which the factors were calculated.

The use of a statistical confidence interval may seem desirable as a more quantitative measure of the reliability of an emission factor. Because of the way an emission factor data base is generated, however, prudent application of statistical procedures precludes the use of confidence intervals unless the following conditions are met:

- The sample of sources from which the emission factor was determined is representative of the total population of such sources.

- The data collected at an individual source are representative of that source (i.e., no temporal variability resulting from source operating conditions could have biased the data).

- The method of measurement was properly applied at each source tested.

Because of the almost impossible task of assigning a meaningful confidence limit to the above variables and to other industry-specific variables, the use of a statistical confidence interval for an emission factor is not practical.

The following emission factor ratings are applied to the emission factor table.

A - Excellent. Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source

category is specific enough to minimize variability within the source category population.

B - Above average. Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A-rating, the source category is specific enough to minimize variability within the source category population.

C - Average. Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

D - Below average. The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

E - Poor. The emission factor was developed from C- and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There may be evidence of variability within the source category population. Limitations on the use of these factors are always footnoted.

Because the application of these factors is somewhat subjective, the reasons for each rating are documented in the background information.

4.2 METHODS OF EMISSION FACTOR DETERMINATION

Fugitive dust emission rates and particle size distributions are difficult to quantify because of the diffuse and variable nature of such sources and the wide range of particle size involved including particles which deposit immediately adjacent to the source. Standard source testing methods, which are designed for application to confined flows under steady-state, forced-flow conditions, are not suitable for measurement of fugitive emissions unless the plume can be drawn into a forced-flow system.

4.2.1 Mass Emissions Measurement

For field measurement of fugitive mass emissions from sources of interest in this report, basic techniques have been defined:

1. The quasi-stack method involves capturing the entire particulate emissions stream with enclosures or hoods and applying conventional source testing techniques to the confined flow.

2. The roof monitor method involves measurement of particulate concentrations and airflows across well defined building openings such as roof monitors, ceiling vents, and windows, followed by calculation of particulate mass flux exiting the building.

3. The upwind-downwind method involves measurement of upwind and downwind particulate concentrations, utilizing ground based samplers under known meteorological conditions, followed by calculation of source strength (mass emission rate) with atmospheric dispersion equations.

4. The exposure profiling method involves simultaneous, multipoint measurements of particulate concentration and wind speed over the effective cross-section of the plume, followed by calculation of net particulate mass flux through integration of the plume profiles.

Because it is usually impractical to enclose open dust sources or to capture the entire emissions plume, only the upwind-downwind and exposure profiling methods are suitable for measurement of particulate emissions from most open dust sources. These two methods are discussed separately below.

The basic procedure of the upwind-downwind method involves the measurement of particulate concentrations both upwind and downwind of the pollutant source. The number of upwind sampling instruments depends on the degree of isolation of the source operation of concern (i.e., the absence of interference from other sources upwind). Increasing the number of downwind instruments improves the reliability in determining the emission rate by providing better plume definition. In order to reasonably define the plume emanating from a point source, instruments need to be located at two downwind distances and three crosswind distances, at a minimum. The same sampling requirements pertain to line sources except that measurement need not be made at multiple crosswind distances.

Net downwind (i.e., downwind minus upwind) concentrations are used as input to dispersion equations (normally of the Gaussian type) to backcalculate the particulate emission rate (i.e., source strength) required to generate the pollutant concentration measured. Emission factors are obtained by dividing the calculated emission rate by a source activity rate (e.g., number of vehicles, or weight of material transferred per unit time). A number of meteorological parameters must be concurrently recorded for input to this dispersion equation. At a minimum the wind direction and speed must be recorded on-site.

While the upwind-downwind method is applicable to virtually all types of sources, it has significant limitations with regard to development of source-specific emission factors. The major limitations are as follows:

1. In attempting to quantify a large area source, overlapping of plumes from upwind (background) sources may preclude the determination of the specific contribution of the area sourc

2. Because of the impracticality of adjusting the locations of the sampling array for shifts in wind direction during sampling, it cannot be assumed that plume position is fixed in the application of the dispersion model.

3. The usual assumption that an area source is uniformly emitting does not allow for realistic representation of spatial variation in source activity.

4. The typical use of uncalibrated atmospheric dispersion models introduces the possibility of substantial error (a factor of three according to Turner, 1970) in the calculated emission rate, even if the stringent requirement of unobstructed dispersion from a simplified (e.g., constant emission rate from a single pint) source configuration is met.

The other measurement technique, exposure profiling, offers distinct advantages for source-specific quantification of fugitive emissions from open dust sources. The method uses the isokinetic profiling concept that is the basis for conventional (ducted) source testing. The passage of airborne pollutant immediately downwind of the source is measured directly by means of simultaneous multipoint sampling over the effective cross section of the fugitive emissions plume. This technique uses a mass-balance calculation scheme similar to EPA Method 5 stack testing rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model.

For measurement of nonbuoyant fugitive emissions, profiling sampling heads are distributed over a vertical network positioned just downwind (usually about 5 m) from the source. If total particulate emissions are measured, sampling intakes are pointed into the wind and sampling velocity is adjusted to match the local mean wind speed, as monitored by anemometers distributed over height above ground level.

The size of the sampling grid needed for exposure profiling of a particular source may be estimated by observation of the visible size of the plume or by calculation of plume dispersion. Grid size adjustments may be required based on the results of preliminary testing. Particulate sampling heads should be symmetrically distributed over the concentrated portion of the plume containing about 90% of the total mass flux (exposure). For example, assuming that the exposure from a point source is normally distributed, the exposure values measured by the samplers at the edge of the grid should be about 25% of the centerline exposure.

To calculate emission rates using the exposure profiling technique, a conservation of mass approach is used. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. The exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement. The steps in the calculation procedure are presented in the paragraphs below.

For directional samplers operated isokinetically, particulate exposures may be calculated by the following equation:

$$E = \frac{M}{a} = 2.83 \times 10^{-5} \frac{C_s Q_s t}{a} \qquad (2)$$

where:

E = particulate exposure, mg/cm^2

M = net particulate mass collected by sampler, mg

a = sampler intake area, cm^2

C_s = net particulate concentration, µg/m^3

Q_s = sampler flow rate, CFM

t = duration of sampling, min

The coefficient of Equation 2 is a conversion factor. Net mass or concentration refers to that portion which is attributable to the source being tested after subtraction of the contribution from background.

For nondirectional samplers (with size-specific inlets), exposure must be calculated by the following equation:

$$E = 3.05 \times 10^{-8} C_s U_s t \qquad (3)$$

where the symbols are defined as above and U_s is the approaching wind speed (in fpm). The resulting exposure values represent the specific particle size range sampled.

The integrated exposure for a given particle size range is found by numerical integration of the exposure profile over the effective area of the plume. Mathematically, this is stated as follows:

$$I = \int\int_{A} 10\ E\ dA = \int_{0-L}^{h}\int^{L} 10\ E\ dydz \qquad (4)$$

where:

I = integrated exposure, g

E = particulate exposure, mg/cm^2

A = effective area of plume aboveground, m

z = vertical coordinate measured from ground level, m

y = horizontal coordinate measured from center of plume, m

h = effective vertical extent, m

L = one-half of effective horizontal extent, m

Note that, for a line source, exposure is constant with respect to y and only a single integration over height is required. Physically, I represents the total passage of airborne particulate matter downwind of the source.

4.2.2 Particle Sizing

High-volume cascade impactors with glass fiber impaction substrates, which are commonly used to measure mass size distribution of atmospheric particulate, may be adapted for sizing of fugitive particulate emissions. A cyclone preseparator (or other device) is needed to remove coarse particles which otherwise would be subject to particle bounce within the impactor causing fine particle bias. Once again, the sampling intake should be pointed into the wind and the sampling velocity adjusted to the mean local wind speed by fitting the intake with a nozzle of appropriate size.

The size-selective inlet (SSI) for a standard high-volume sampler is also designed to capture particulate matter smaller than 15 μm in aerodynamic diameter. This unit is much less wind sensitive than dichotomous samplers, but it does not provide a cutpoint at 2.5 μm. However, it can be adapted for use with a high volume cascade impactor to define a mass size distribution of smaller than 15 μm in diameter. Recently, size-specific inlets with 10 μm cutpoints have become commercially available in anticipation of revision of the NAAQS for particulate matter.

Additional methods that have been used to obtain particle size distributions include stacked filtration units (Cahill et al., 1979) and both optical and electron microscopy. The relative merits of these techniques, as evaluated by an independent contractor in a collaborative field study, are discussed in Section 5.0.

4.2.3 Emission Factor Derivation

Usually the final emission factor for a given source operation, as presented in a test report, is derived simply as the arithmetic average of the individual emission factors calculated from each test of that source. Frequently the range of individual emission factor values is also presented.

As an alternative to the presentation of a final emission factor as a single-valued arithmetic mean, an emission factor may be presented in the form of a predictive equation derived by regression analysis of test data. Such an equation mathematically relates emissions to parameters which characterize source conditions. These parameters may be grouped into three categories:

1. Measures of source activity or energy expended (e.g., the speed and weight of a vehicle traveling on an unpaved road).

2. Properties of the material being disturbed (e.g., the content of suspendable fines in the surface material on an unpaved road).

3. Climatic parameters (e.g., number of precipitation-free days per year on which emissions tend to be at a maximum).

An emission factor equation is useful if it is successful in "explaining" much of the observed variance in emission factor values on the basis of corresponding variances in specific source parameters. This enables more reliable estimates of source emissions on a site-specific basis.

A generic emission factor equation is one that is developed for a source operation defined on the basis of a single dust generation mechanism which crosses industry lines. An example would be vehicular traffic on unpaved roads. To establish its applicability, a generic equation should be developed from test data obtained in different industries.

4.3 EMISSION FACTOR QUALITY RATING SCHEME USED IN THIS STUDY

The uncontrolled emission factor quality rating scheme used in this study is identical to that used in an earlier update (Cowherd et al., 1983) and represents a refinement of the rating system developed by EPA for AP-42 emission factors, as described in Section 4.1. The scheme entails the rating of test data quality followed by the rating of the emission factor(s) developed from the test data.

Test data that were developed from well documented, sound methodologies were assigned an A rating. Data generated by a methodology that was generally sound but either did not meet a minimum test system requirements or lacked enough detail for adequate validation received a B rating.

In evaluating whether an upwind-downwind sampling strategy qualified as a sound methodology, the following minimum test system requirements were used. At least five particulate measuring devices must be operated during a test, with one device located upwind and the others located at two downwind and three crosswind distances. The requirements of measurements at crosswind distances is waived for the case of line sources. Also wind direction and speed must be concurrently on-site.

The minimum requirements for a sound exposure profiling program were the following. A vertical line grid of at least three samplers is sufficient for measurement of emissions from line or moving point sources while a two-dimensional array of at least five samplers is required for quantification of fixed virtual point source emissions. At least one upwind sampler must be operated to measure background concentration, and wind speed must be measured concurrently on-site.

Neither the upwind-downwind nor the exposure profiling method can be expected to produce A-rated emissions data when applied to large, poorly defined area sources, or under very light and variable wind flow conditions. In these situations, data ratings based on degree of compliance with minimum test system requirements were reduced one letter.

After the test data supporting a particular single-valued emission factor were evaluated, the criteria presented in Table 3 were used to assign a quality rating to the resulting emission factor. These criteria were developed to provide objective definition for: (a) industry representativeness; and (b) levels of variability within the data set for the source category. The rating system obviously does not include estimates of statistical confidence, nor does it reflect the expected accuracy of fugitive dust emission factors relative to conventional stack emission factors.

It does, however, serve as useful tool for evaluation of the quality of a given set of emission factors relative to the entire available fugitive dust emission factor data base.

TABLE 3. QUALITY RATING SCHEME FOR SINGLE-VALUED EMISSION FACTORS

Code	No. of test sites	No. of tests per site	Total No. of tests	Test data variability[a]	Adjustment for EF rating[b]
1	≥ 3	≥ 3	-	< F2	0
2	≥ 3	≥ 3	-	> F2	-1
3	2	≥ 2	≥ 5	< F2	-1
4	2	≥ 2	≥ 5	> F2	-2
5	-	-	≥ 3	< F2	-2
6	-	-	≥ 3	> F2	-3
7	1	2	2	> F2	-3
8	1	2	2	> F2	-4
9	1	1	1	-	-4

[a] Data spread in relation to central value. F2 denotes factor of two.

[b] Difference between emission factor rating and test data rating.

Minimum industry representativeness is defined in terms of number of test sites and number of tests per site. These criteria were derived from two principles:

1. Traditionally, three tests of a source represent the minimum requirement for reliable quantification.

2. More than two plant sites are needed to provide minimum industry representativeness.

The level of variability within an emission factor data set was defined in terms of the spread of the original emission factor data values about the mean or median single-valued factor for the source category. The fairly rigorous criterion that all data points must lie within a factor of two of the central value was adopted. It is recognized that this criterion is not insensitive to sample size in that for a sufficiently large test series, at least one value may be expected to fall outside the factor-of-two limits. However, this is not considered to be a problem because most of the current single-valued factors for fugitive dust sources are based on relatively small sample sizes.

Development of quality ratings for emission factor equations also required consideration of data representativeness and variability, as in the case of single-valued emission factors. However, the criteria used to assign ratings (Table 4) were different, reflecting the more sophisticated model being used to represent the test data. As a general principle, the quality rating for a given equation should lie between the test data rating and the rating that would be assigned to a single-valued factor based on the test data. The following criteria were established for an emission factor equation to have the same rating as the supporting test data:

1. At least three test sites and three tests per site, plus an additional three tests for each independent parameter in the equation.

2. Quantitative indication that a significant portion of the emission factor variation is attributable to the independent parameter(s) in the equation.

TABLE 4. QUALITY RATING SCHEME FOR EMISSION FACTOR EQUATIONS

Code	No. of test sites	No. of tests per site	Total No. of tests[a]	Adjustment for EF rating[b]
1	≥ 3	≥ 3	≥ (9 + 3P)	0
2	≥ 2	≥ 3	≥ 3P	-1
3	≥ 1	-	< 3P	-2

[a] P denotes number of correction parameters in emission factor equation.

[b] Difference between emission factor rating and test data rating.

Loss of quality rating in the translation of test data to an emission factor equation occurs when these criteria are not met. In practice, the first criterion was far more influential than the second in rating an emission factor equation, because development of an equation implies that a substantial portion of the emission factor variation is attributable to the independent parameter(s). As indicated in Table 4, the rating was reduced by one level below the test data rating if the number of tests did not meet the first criterion, but was at least three times greater than the number of independent parameters in the equation. The rating was reduced two levels if this supplementary criterion was not met.

The rationale for the supplementary criterion follows from the fact that the likelihood of including "spurious" relationships between the dependent variable (emissions) and the independent parameters in the equation increases as the ratio of number of independent parameters to sample size increases. For example, a four parameter equation based on five tests would exhibit perfect explanation (R^2=1.0) of the emission factor data, but the relationships contained in such an equation cannot be expected to hold true in independent applications.

4.4 DESIGN AND RATING OF CONTROL PERFORMANCE EVALUATION STUDIES

As noted above, control of open dust sources has recently attracted a great deal of attention. For instance, almost all field studies of paved and unpaved road dust emissions since 1980 have entailed the evaluation of some type of control technique. In general, however, this type of information is not included in the current version of AP-42.

Field evaluation of control efficiency requires that the study design include not only adequate emission measurement techniques (of the type discussed in Section 4.2) but also a proven "control application plan." In the past, two major types of plans have been used:

Type 1 - Controlled and uncontrolled emission measurements are obtained simultaneously.

Type 2 - Uncontrolled tests are performed initially, followed by controlled tests.

In order to ensure comparability between the operating characteristics of the controlled and uncontrolled sources, many evaluations are forced to employ Type 2 plans. An example would be a wet suppression system used on a primary crusher. One important exception to this, however, is unpaved road dust control. In this instance, under a Type 1 plan, testing is conducted on two or more contiguous road segments. One segment is left untreated and the others are treated with a separate dust suppressant.

Under a Type 2 plan, uncontrolled testing is initially performed on one or more road segments, generally under worst-case (dry) conditions. Each segment is then treated with a different chemical; no segment is left untreated as a reference. A normalization of emissions may be required to allow for differences in vehicle characteristics during the uncontrolled and controlled tests because they do not occur simultaneously. For example a change in vehicle mix should not be interpreted mistakenly as part of the efficiency of the control measure being tested.

The method used to normalize emission factors is generally based on the AP-42 predictive emission factor equation for the source under consideration. For example, for unpaved roads, emission factors are scaled by:

$$e_n = e_i \left(\frac{S_n}{S_i}\right)\left(\frac{W_n}{W_i}\right)^{0.7}\left(\frac{w_n}{w_i}\right)^{0.5} \quad (5)$$

where:

e_n = normalized value of the emission factor corresponding to run i

e_i = measured emission factor from run i

S_n = normalizing value for average vehicle speed

S_i = average vehicle speed during run i

W_n = normalizing value for average vehicle weight

W_i = average vehicle weight during run i

w_n = normalizing value for average number of wheels per vehicle pass

w_i = average number of wheels per vehicle pass during run i

Note that surface material properties (such as silt content) present in the AP-42 equations are not considered in the normalization process because the control measure affects these properties.

Regardless of the control plan selected, it is important that, for the purpose of estimating annual or seasonal controlled emissions from unpaved roads, average control efficiency values be based on worst-case (i.e., dry) uncontrolled emission levels. This is true simply because the AP-42 unpaved road predictive equation is based on source tests conducted under dry conditions. Extrapolation to annual average emissions estimates is accomplished by assuming that emissions are occurring at the estimated rate on days without measurable precipitation, and conversely are absent on days

with measurable precipitation. This assumption has never been verified in a rigorous manner; however, MRI's experience with hundreds of field tests indicate that it is a reasonable assumption if the source operates on a fairly "continuous" basis.

The uncontrolled emission factor for a specific unpaved road will increase substantially after a precipitation event as the surface dries. However, in the absence of data sufficient to describe this growth as a function of traffic parameters, amount of precipitation, time of day, season, cloud cover, and other variables, uncontrolled emissions are estimated using the simple assumption given above. Thus, in order to definitively estimate emission reductions attributable to a dust suppressant, control efficiency should be referenced to uncontrolled emissions under dry conditions. An extended discussion of the interrelationship of control and natural mitigation is provided elsewhere (Muleski, 1986a).

Finally, it is important that appropriate specification of an efficiency value depends on the nature of the control. In broad terms, control measures can be considered as either continuous or periodic, as the following examples illustrate:

Continuous Controls	Periodic Controls
Wet suppression for materials handling	Watering or chemical treatment of unpaved roads
Local exhaust hoods	Sweeping of paved travel surfaces
Enclosures	Chemical stabilization of exposed areas
Vegetation of exposed areas	

The major difference between the two types of controls is related to the time dependency of performance. For continuous controls, efficiency is essentially constant with respect to time. On the other hand, the efficiency associated with periodic controls tends to decrease (decay) with time. An example would be chemical treatment of an unpaved road; immediately after application, the road surface is thoroughly wetted and complete control is assumed. After curing, a generally high level of control is observed for approximately 1 week. Thereafter, the efficiency tends to decrease until the next application (at which time the cycle repeats).

In order to quantify the performance of a specific control, two measures of control efficiency are required. The first is "instantaneous" control and is defined by

$$c(t) = \left(1 - \frac{e_c(t)}{e_u}\right) \times 100\% \qquad (6)$$

where:

$c(t)$ = instantaneous control (percent) at t days after application

$e_c(t)$ = emission factor for the controlled source t days after application

e_u = uncontrolled emission factor

For a continuous control technique, the controlled emission factor, $e_c(t)$, is essentially independent of time. Consequently, the control c(t) in the above expression is also independent of time and is representative of a continuous technique. On the other hand, for a periodic control, the value of c(t) in Eq. (5) represents the (instantaneous) level of control over a specific test period and, hence, at a particular time after application.

The other important measure of control performance is average efficiency, defined as:

$$C(T) = \frac{1}{T} \int_0^T c(t)\, dt \qquad (7)$$

where:

C(T) = average control efficiency during period ending T days after application (percent)

c(t) = instantaneous control efficiency at t days after application (percent)

T = time period over which average control efficiency is desired (days)

Average control efficiency values are needed to estimate emission reductions due to periodic applications. Note, however, that if c(t) equals a constant, the two measures are identical.

The rating of reported control efficiency values presents numerous difficulties. As can be seen from Eq. (5), control efficiency values are defined as non-linear functions of two emission factors. Both the uncontrolled and controlled emission factors may carry their own ratings of A through E. However, in order to assign a rating to their ratio (i.e., control efficiency estimate), the interrelationship between the two ratings must be understood. At the present time, no attempt to investigate this relationship has been undertaken.

Additional complications arise if the control method being evaluated is periodic in nature. In this instance, any inherent variability (due to source conditions, measurement error, etc.) of emission levels about a mean value at a given point in time is confounded by the fact that the "mean" controlled emission level varies over time after application. Thus, a rating applied to a control estimate under these circumstances would involve not only the relative reliability of the ratio of controlled and uncontrolled emission factors (as discussed above) but also the temporal variation of the ratio's reliability.

As an example, suppose it is known that a control decays linearly from 100% at time zero to 0% at 30 days. Further assume that a sampling method measures a known unit emission factor as either 0.8 or 1.25 (with equal probability) and that a single controlled test is performed 15 days after application. Thus if the "true" uncontrolled emission level was 10 kg/VKT, then, with equal probability, this emission level would be measured as 8 or 12.5 kg/VKT. At 15 days, the "true" controlled value is 5 kg/VKT, but would be measured as 4 or 6.25 kg/VKT with equal probability. In this way, four separate outcomes are possible and each has a probability of one-fourth:

Outcome	Measured emission factor (kg/VKT)		Measured control efficiency (%)
	Uncontrolled	Controlled	
A	8	4	50
B	8	6.25	22
C	12.5	4	68
D	12.5	6.25	50

These four outcomes, as well as the linearly extrapolated lifetime estimated by each, are shown graphically in Figure 1.

Under this very idealized situation, there is a one-fourth probability that the 30-day lifetime of the control would be estimated as either 19 or 47 days, and only a one-half probability that the lifetime would be estimated as 30 days. Furthermore, if this experiment were repeated a large number of times, the mean lifetime would tend towards (1/4 x 19 + 1/4 x 47 + 1/2 x 30) = 31.5 days rather than the known value of 30 days.

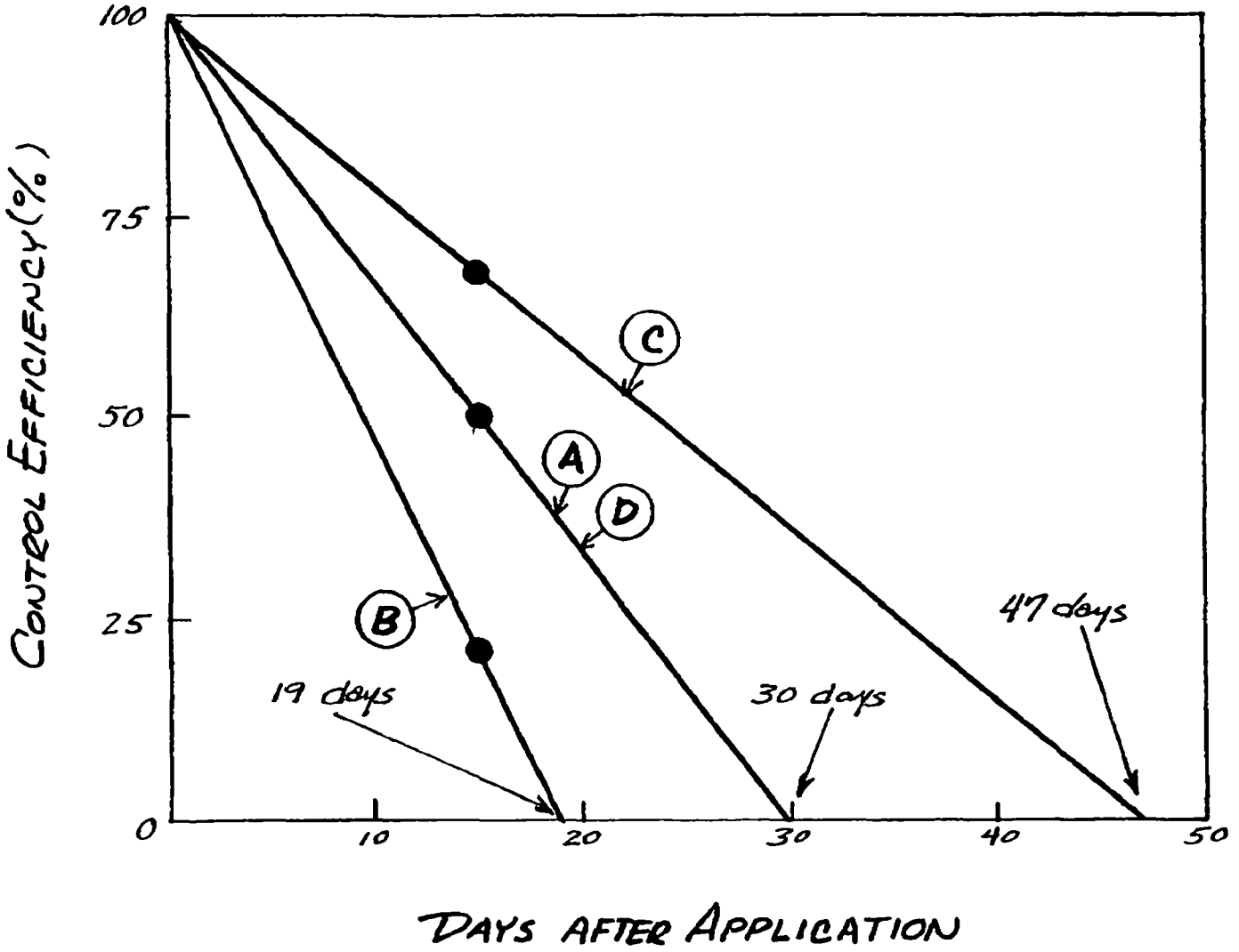

Figure 1. Hypothetical decay curves.

The simple example above does not consider replicate tests at a given time, testing at various times after application, variation in source conditions, or any of the other complicating effects described earlier. However, the fact that an idealized situation can lead to such widely different estimates of control effectiveness does illustrate some of the difficulties in rating performance data collected in the "real world."

Consequently, no ratings are applied to control performance tests presented in this report. Rather, the recommendations made in Section 6.0 are based on qualitative judgment of the reliability and applicability of available data in estimating emission reductions with AP-42 methods.

SECTION 5

CANDIDATE EMISSION FACTORS AND CONTROL EFFICIENCY DATA

The test reports listed earlier in Table 2 were grouped by relevant subsections of AP-42 Section 11.2; the resulting list is given in Table 5. In this section, individual test reports are discussed in terms of: (a) field sampling methodology (including control efficiency evaluation, if applicable); (b) number of tests; and (c) location of tests. Quality ratings (based upon the schemes presented in Tables 3 and 4) are assigned to the emission factor data.

TABLE 5. LIST OF TEST REPORTS BY PERTINENT SUBSECTION

Subsection	Title	Test report
-	General Testing Methods	10a,b,c,d,e,f
11.2.1	Unpaved Roads	1,2,3,7,11
11.2.3	Aggregate Storage Piles	4,5,6,9
11.2.6	Industrial Paved Roads	1,5,8

Note that test reports 10a through 10f have not been assigned to a specific Section 11.2 subsection. As discussed in Section 3 above, these collaborative tests were more an examination of testing methodologies than an evaluation of any type of particulate emission source. Each of the testing organizations participating in this collaborative study also performed

field tests presented in Table 2. Because the implications of this critical review have direct bearing on the results from the other test reports, the collaborative studies will be discussed first.

5.1 GENERAL TESTING METHODOLOGIES

Test Report 10a

This report discusses the results of a collaborative field comparison of exposure profiling techniques. The field study compared the results obtained by five testing organizations for the same source (a "simulated" unpaved road formed by artificially loading a paved road at an integrated iron and steel plant in Indiana). All exposure profiling systems in this study met the minimum requirements of Section 4.3. Emission factors for total particulate (TP) as well as four smaller size fractions (less than or equal to 30, 15, 10, and 2.5 μm in aerodynamic diameter) were reported.

A total of 11 tests were performed during June 1984. Five testing locations were demarcated for use by different organizations. A different position was occupied by each testing group on a given day; during the week, each group conducted at least one test at each position. Note that, at the start of the week, each organization deployed a standard high-volume (hi-vol) sampler downwind of the simulated source. These samplers were not moved during the week of testing and were operated by the organization occupying the testing location on that day. Filters used in these hi-vols were supplied and analyzed by the independent contractor supervising the collaborative study.

At the start of testing, the road surface loading was estimated to be approximately 200,000 kg/km (600,000 lb/mile). Vehicle mixes during field sampling exhibited average weights between 6 and 30 Mg (7 and 33 tons) and average speeds between 26 and 40 kph (16 and 25 mph). This information is summarized in Table 6.

TABLE 6. SOURCE TESTING INFORMATION (Test Reports 10b to 10f)[a]

Operation	Equipment	Material[b]	Location	Test date	No. of tests
Vehicle traffic	Vehicle mix	Simulated unpaved road	Indiana	6/84	11

[a] Because this was a collaborative field test, source parameters were identical in all five test reports.

[b] In order to complete the comparative testing in reasonable time, a paved road was artificially loaded to increase mass emission levels.

Table 7 lists the average emission factors determined for this source by the different testing organizations and the range of conditions tested. Quality ratings were not assigned because a simulated source was evaluated, and results do not pertain to any actual source category. Additional results from the collaborative study are presented after individual discussions of the test reports submitted by the five testing organizations.

Test Report 10b

The sampling system for this study was composed of an upwind and downwind tower supporting three and five sampling heads, respectively. Each TP sampling head consisted of a high volume sampler motor, a vertically oriented filter, and a nozzle with a rectangular inlet. Intake flows were monitored using potentiometers and manometers. (Note that this is essentially the same profiling system used in Test Report 7.)

Additional equipment included: (a) a standard high volume (hi-vol) sampler (these samples were analyzed by the independent contractor supervising the field study); and (b) meteorological instruments for wind speed and direction. The latter equipment was used to manually set intake flow rates based on 15-min averages prior to testing. A uniform velocity distribution with height was assumed.

Particle sizing employed computer-controlled, scanning electron microscopy (CCSEM) which was performed for one of the six tests deemed valid. An additional test was also selected for analysis to estimate size distributions for tests conducted with wet road surfaces.

Test Report 10c

Major sampling equipment for this study included a five-head exposure profiling tower downwind of the source as well as cyclones at two heights both upwind and downwind of the source. The two downwind cyclones were fitted with five-stage cascade impactors and the lower upwind unit included a three-stage impactor. The cyclone and impactor units allowed particle

TABLE 7. RANGE OF CONDITIONS AND EMISSION FACTORS (Test Reports 10b to 10f)

Test report	No. of tests	Range of conditions					Suspended particulate emission factor[a,c]	PM_{10} Emission factor[b,c]	Emission factor units
		Silt (%)	Moisture (%)	Wind speed (mph)	Vehicle speed (mph)	Vehicle weight (ton)			
10b	11	6.4-21.0	0.2-1.5	3.6-12.6	20.4-28.0	6.3-32.4	6.56	1.92	kg/VKT
10c	11	6.9-11.1	-	4.8-14.0	16.0-25.0	7.1-33	3.58	1.88	kg/VKT
10d	11	3.9-10.8	2.9-15.2	3.6-11.5	20-30	7.0-34.0	2.37	1.16	kg/VKT
10e	11	6.39-13.69	-	5.06-11.81	20.19-27.94	7.46-34.98	5.3	1.8	kg/VKT
10f	11	11.0-16.0	-	6.26-15.26	17.89-24.35	6.5-24.26	7.1	2.6	kg/VKT

- Information not contained in test report.

[a] Particles < 30 μm aerodynamic diameter.

[b] Particles < 10 μm aerodynamic diamter.

[c] Emission factors are arithmetic mean of the 11 test runs. Values are also presented on pages 44 and 62 of Test Report 10a.

size distributions to be determined for individual tests. (Note that this is essentially the same profiling system employed in Test Reports 1, 3, 5, 9, and 11.)

Additional equipment included a standard hi-vol (again analyzed by the independent contractor) and wind speed and direction sensors mounted to the downwind profiling tower. Sampling intake rates were adjusted based on 10-min averages and an assumed logarithmic wind profile. Nozzles were employed on the cyclone preseparators to adjust intake velocities while maintaining a constant volumetric flow.

Test Report 10d

Identical upwind and downwind profiling towers were used in this study. Each tower supported four sampling heads which employed the stacked filtration concept (Cahill et al., 1979). The stacked filtration units (SFUs) simultaneously provide two separate particle size fractions: 30 and 2.5 μmA cutpoints are assigned to the stainless steel 400 mesh screen and 8.0 μm Nuclepore filter, respectively. A 0.8 μm Nucleopore filter is used as the backup filter. (Note that this is essentially the same sampling system used in Test Report 2.)

Additional equipment included a standard hi-vol analyzed by the independent contractor and a meteorological station to record wind speed and direction. The latter type of information was used (10-min averages) to adjust sampling intake rates for isokinesis. It should be noted that, although isokinetic sampling allows the determination of TP emission factors, this type of information is not typically reported.

Test Report 10e

The downwind profiling tower used in this study supported five sampling heads. An identical sampling head was deployed upwind of the test road. The flow rate for each head was servo-controlled, with adjustments made on the basis of wind speed anemometers located near the head. (Note that this is essentially the same sampling system used in Test Report 4.)

Additional equipment included standard hi-vols upwind and downwind of the test road (the downwind unit was analyzed by the independent contractor) as well as wind speed/direction systems both upwind and downwind.

Particle size distributions were obtained by CCSEM (using the same subcontractor as in Test Report 10b). A total of 26 filters were analyzed and reported.

Test Report 10f

The profiling system used in this study employed essentially the same type of sampling heads as in Test Report 10e. A total of four heads were supported by the downwind tower and a single head was deployed upwind. Additional equipment included a standard hi-vol (analyzed by the independent contractor) and a wind speed/direction system. Particle size distributions were obtained by an in-house CCSEM analysis. The development of this profiling is described in Test Report 8.

Results of the Collaborative Study

The five profiling systems evaluated during the collaborative study were all found to be capable of producing essentially equivalent results in terms of TP emissions. Note, however, that this statement is based on only three runs if Test Report 10d is included (as noted above, this organization does not usually report total particulate emissions). The other four organizations, using a variety of techniques (e.g., fixed versus variable flow rates, manual versus automatic adjustment, different integration schemes for exposure measurements, etc.), obtained equivalent results over all 11 tests.

For smaller particle size fractions, however, there was considerably less agreement among the results obtained by the five organizations. Figure 2 is a copy of Table 5 from Test Report 10a and presents the correlation matrix between emission factors over the span of the 11 tests.

CORRELATION COEFFICIENTS OF TP, TSP, PM_{10}, AND FP EMISSION FACTORS REPORTED BY TEST PARTICIPANTS

	TP					TSP (<30 μm)				
	USS	MRI	EEM	TRC	PEI	USS	MRI	EEM	TRC	PEI
USS	-	.770	.802	.787	-	-	.904	.772	.795	.504
MRI	.770	-	.584	.645	-	.904	-	.594	.705	.490
EEM	.802	.584	-	.728	-	.772	.594	-	.728	.486
TRC	.787	.645	.728	-	-	.795	.705	.728	-	.286
PEI	-	-	-	-	-	.504	.490	.464	.286	-

	PM_{10} (<10 μm)					F.P. (<2.5 μm)				
USS	-	.915	.669	.703	.625	-	.865	.472	.703	.224
MRI	.915	-	.636	.780	.566	.865	-	.612	.764	.434
EEM	.669	.636	-	.718	.564	.472	.612	-	.700	.520
TRC	.703	.780	.718	-	.251	.703	.764	.700	-	.124
PEI	.625	.566	.564	.251	-	.224	.434	.520	.124	-

Figure 2. Photocopy of Table 5 from Test Report 10a. Note that USS, MRI, EEM, TRC, and PEI correspond to Test Reports 10f, c, b, e, and d, respectively.

The particle sizing method, stack filtration units (SFUs), employed in Test Report 10d purportedly separated collected particulate matter into two size fractions, with nominal cutpoints of 30 and 2.5 μmA. The independent evaluation (Test Report 10a), however, noted that the 30 μmA collection medium described in Test Report 10d was selected on the basis of pore size and the collection efficiency was not verified by calibration. In addition it was noted that interception and impaction would probably result in a cut point substantially smaller than the 30 μmA assigned.

Furthermore, with the increased loading of the collection surface, the cutpoint would tend to decrease even more from the nominal value assigned. The latter point was supported by analysis of penetration versus both (a) hi-vol and (b) profiler catches. In each case, a negative correlation between penetration and sample catch was found. Thus, with the buildup of sample mass, the SFUs would tend to become more efficient filtration devices and, consequently, decreased values for particulate concentrations and emission factors would be obtained.

Additional substantiation of this behavior is provided in Figure 2. At the two nominal size fractions measured (2.5 and 30 μmA), neither emission factor presented in Test Report 10d shows a positive correlation with the other reported results that could be considered significant at the 5% level Thus, there is no significant tendency for Test Report 10d results to increase when results of the other organizations increase.

It was also noted in the independent evaluation that, because catch weights were quite close to detection limits in several cases, sampling time could not generally be shortened to avoid variation of cutpoints with loading. Finally, because the sizing system in Test Report 10d did not allow for a direct measurement of the 10 μmA fraction, two interpolation schemes were employed. Note, however, that the use of both schemes on the same data did not provide independent estimates, as implied in Test Report 10d. Because of the various problems noted above, the use of stack filtration units (SFUs) could not be recommended by the independent contractor monitoring the collaborative study.

The CCSEM technique was used by three (Test Reports 10a, 10e, and 10f) of the five contractors to provide particle size data. Aside from the difficulties that arise from assigning both volumes and equivalent aerodynamic diameters to the irregular, inhomogeneous particles encountered, the independent contractor also noted fundamental problems with both the upper and lower ends of the size spectrum. Based on these problems, the independent contractor found the CCSEM "methodology, as used by the participants of this test, unsuitable for applications of this type."

The only sizing technique recommended by the independent contractor was the inertial separation method by cyclone/impactor combinations (Test Report 10c). Although the independent contractor suggested some variations to the analysis procedure used in Test Report 10c, it was found that the results from either procedure were generally not significantly different from one another.

Figure 3 is a reproduction of Table 8 from Test Report 10a and presents size fractions for 30, 15, 10, and 2.5 μmA. The second entry for each test is the mass fraction contained in Test Report 10c while the first is the value recalculated by the independent contractor. A Wilcoxon signed rank test (McGhee, 1985) indicated that, of all size ranges considered, only the FP (2.5 μmA) fraction showed differences significant at the 10% level (but not at the 5% level). Consequently, there is no discernible difference between the two procedures over particle size ranges of current regulatory interest, although there is reason to suspect that the FP fractions may be different.

Additional comparisons presented in Test Report 10c indicate that (a) a 6-m profiling system gives results very comparable to a 7.5 m tower; (b) a three-stage impactor provides essentially identical 15 and 10 μmA size fractions as does a five-stage impactor (however, the 2.5 μmA fraction may be overestimated by a factor of approximately 1.2); and (c) sizing results obtained by either two- or one-step cyclone washes were essentially equivalent.

SIZE FRACTIONS OF PARTICULATE AS REPORTED BY MRI AND RECALCULATED BY SOUTHERN RESEARCH INSTITUTE

Test No.	Organization	Size Fraction as Percent Less Than				
		TP (total)	TSP (<30 μm)	PM_{15} (<15 μm)	PM_{10} (<10 μm)	FP (<2.5 μm)
1	SoRI	1.00	0.453	0.313	0.240	0.094
	MRI	1.00	0.395	0.284	0.216	0.066
2	SoRI	1.00	0.412	0.306	0.234	0.098
	MRI	1.00	0.427	0.263	0.202	0.064
3	SoRI	1.00	0.487	0.350	0.280	0.113
	MRI	1.00	0.374	0.243	0.183	0.058
4	SoRI	1.00	0.527	0.326	0.250	0.107
	MRI	1.00	0.448	0.303	0.236	0.077
5	SoRI	1.00	0.427	0.274	0.212	0.090
	MRI	1.00	0.689	0.547	0.449	0.170
6	SoRI	1.00	0.507	0.352	0.279	0.120
	MRI	1.00	0.439	0.294	0.230	0.078
7	SoRI	1.00	0.506	0.357	0.283	0.117
	MRI	1.00	0.567	0.405	0.320	0.105
8	SoRI	1.00	0.349	0.233	0.177	0.077
	MRI	1.00	0.318	0.212	0.164	0.056
9	SoRI	1.00	0.304	0.216	0.174	0.070
	MRI	1.00	0.373	0.196	0.152	0.054
10	SoRI	1.00	0.333	0.216	0.166	0.074
	MRI	1.00	0.419	0.294	0.230	0.076
11	SoRI	1.00	0.457	0.333	0.240	0.089
	MRI	1.00	0.480	0.332	0.253	0.072

Figure 3. Photocopy of Table 8 of Test Report 10a.

5.2 UNPAVED ROADS (SECTION 11.2.1)

Test Report 1

In this study, exposure profiling was used to quantify the performance of unpaved road dust controls. The control techniques evaluated included water and a petroleum resin product. Both controls were tested for heavy-duty traffic; only the petroleum resin was evaluated for light-duty vehicles. A Type 2 control application plan was employed.

Field tests were conducted at an integrated iron and steel plant in Ohio. Table 8 shows the number of tests conducted for each source/control combination.

Total particulate emission measurements were obtained during each test as part of the exposure profiling technique. Both four and five head profiling systems (4 to 5 m high) were used during this program. Cyclone/impactor combinations were used for particle size measurements at two downwind heights. Additional sampling equipment included: (a) standard hi-vols both upwind and downwind of the test road; (b) one or two size-selective inlets (15 μmA cutpoint) upwind of the source; and (c) recording instruments for wind speed and direction to adjust for isokinetic sampling. This meets the requirements of a sound, well-documented methodology in Section 4.3, and emission test data are rated A.

Table 9 presents the average emission factors determined during the study and the range of test conditions. Note that, because this study was directed to control performance evaluation rather than emission factor development, no quality ratings are assigned.

Chemically controlled unpaved roads were tested during the first 2 days after application; consequently, no long-term average control efficiency values were obtained during this study. In addition, the control efficiency data obtained for chemically treated heavy-duty unpaved roads should be considered less reliable because controlled and uncontrolled

TABLE 8. SOURCE TESTING INFORMATION (Test Report 1)

Operation	Equipment	Material	Location	Test dates	No. of tests
Vehicle traffic	Heavy-duty vehicles	Unpaved roads uncontrolled	Ohio	11/80	3
Vehicle traffic	Ligh-duty vehicles	Unpaved roads uncontrolled	Ohio	7/80	4
Vehicle traffic	Light-duty vehicles	Upaved roads controlled	Ohio	10/80	5
Vehicle traffic	Heavy-duty vehicles	Unpaved roads concontrolled	Ohio	11/80	7
Vehicle traffic	Medium-duty vehicles	Paved roads uncontrolled	Ohio	7/80, 10/80 11/80	7
Vehicle traffic	Medium-duty vehicles	Paved roads controlled	Ohio	7/80, 10/80 11/80	5
Vehicle traffic	Medium-duty vehicles	Paved roads uncontrolled	Texas	7/80	4
Vehicle traffic	Medium-duty vehicles	Paved roads concontrolled	Texas	6/80	7

TABLE 9. RANGE OF CONDITIONS AND EMISSION FACTORS (Test Report 1)

Material/equipment/ operation	Location	No. of tests	Range of conditions: Silt (%)	Moisture (%)	Wind speed (mph)	Vehicle speed (mph)	Vehicle weight (ton)	Inhalable particulate emission factor[a]	PM_{10} Emission factor	Emission factor units
Light-duty unpaved road/uncontrolled[b]	Ohio	4	-	-	1.6-6 2	15	3	3.05	-	lb/VMT
Light-duty unpaved road/Coherex®[c]	Ohio	5	0 015-1.8	-	4.0-9.1	25	3	0.27	-	lb/VMT
Heavy-duty unpaved road/uncontrolled[d]	Ohio	3	14-16	-	7.4-9 5	20	22-53	8.37	-	lb/VMT
Heavy-duty unpaved road/watering[e]	Ohio	3	4.5-5.1	-	5.5-6.4	20-25	53-54	2.24	-	lb/VMT
Heavy-duty unpaved road/Coherex®[f]	Ohio	4	2.5-5.4	-	5.2-9.3	15-22	19-54	0.53	-	lb/VMT
Paved road/uncontrolled[g]	Ohio	7	10 4-35.7	-	4.0-12	-	14-40	0.68	-	lb/VMT
Paved road/vacuum sweeping[h]	Ohio	4	18.3-27.9	-	4.5-6.4	-	8.3-18	0.37	-	lb/VMT
Paved road/water flushing[i]	Ohio	1	9.45	-	9.0	-	29	1.32	-	lb/VMT
Paved road/water flushing and broom sweeping[j]	Texas	4	28.2-34.3	-	3 0-5.7	-	9.4-11	0.23	-	lb/VMT
Paved road/water flushing[k]	Texas	3	11 2-22.6	-	5 4-8.6	-	9.2-11	0.41	-	lb/VMT
Paved road/uncontrolled[l]	Texas	4	6 45-14.0	-	3.6-6.6	-	11-12	0.95	-	lb/VMT

- = Information not contained in test report

[a] Particles < 15 μm aerodynamic diameter.

[b] Emission factor is the arithmetic mean of test runs F-59, F-60, F-63, and F-64 from page 48, Table 3-11 of test report.

[c] Emission factor is the arithmetic mean of test runs F-65, F-66, and F-67 from page 48, Table 3-11 of test report.

[d] Emission factor is the arithmetic mean of test runs F-68, F-69, and F-70 from page 50, Table 3-12 of test report.

[e] Emission factor is the arithmetic mean of test runs F-65, F-66, and F-67 from page 50, Table 3-12 of test report.

[f] Emission factor is the arithmetic mean of test runs F-59, F-60, F-63, and F-64 from page 50, Table 3-12 of test report.

[g] Emission factor is the arithmetic mean of test runs F-34, F-35, F-61, F-62, F-27, F-45, and F-32 from page 74, Table 3-27 of test report.

[h] Emission factor is the arithmetic mean of test runs F-36, F-37, F-38, and F-39 from page 74, Table 3-27 of test report.

[i] Emission factor is the value obtained from test run F-74 on page 74, Table 3-27 of test report.

[j] Emission factor is the arithmetic mean of test runs B-50, B-51, B-52, and B-53 from page 74, Table 3-27 of test report.

[k] Emission factor is the arithmetic mean of test runs, B-54, B-55, and B-56 from page 74, Table 3-27 of test report.

[l] Emission factor is the arithmetic mean of test runs B-57, B-58, B-59, and B-60 from page 74, Table 3-27 of test report.

tests were not conducted at the same site. Watering tests of a heavy-duty, unpaved road, as presented in Figure 3-7 of the test report, imply a control efficiency decay rate of approximately 9%/hr over all size ranges considered.

Test Report 2

This study evaluated the performance of several unpaved road dust controls under heavy-duty traffic at three surface coal mines. Results were obtained using exposure profiling with a Type 1 control application plan.

Tests were conducted at mines in southern Illinois and in southwestern and northeastern Wyoming. Dust suppressants evaluated included: a salt; an acrylic cement; two emulsified asphalts; an enzyme; a lignon sulfonate; and water. With the exception of the last three, controls were generally evaluated using both topical and incorporated applications.

Air sampling was primarily accomplished using an exposure profiling tower which employed SFUs of the type discussed earlier. Consequently, 30 and 2.5 μmA emission factors and control efficiencies are presented in the report. Additional instruments deployed included: (a) dustfall buckets; (b) a RAM-1 aerosol monitor; (c) a quartz crystal cascade analyzer (QCCA); and (d) wind speed/direction recording equipment. The QCCA was not found to be suitable for the field tests; as a result, 15 μmA SSIs were substituted at the second and third mines. The test report states that IP control efficiencies were based on measured concentrations (rather than mass emission rates used for TSP and FP); however, no summary information about IP control is provided in the report.

The profiling system employed meets the minimum requirements of Section 4.3. General documentation is adequate. However, in light of the findings by the independent contractor in Test Report 10a, the SFUs employed in this study cannot be expected to yield reliable measurements for emissions in the two nominal particle size fractions. Consequently, the emissions data obtained in this study should be downgraded from a rating of A to C. Although the emission measurements cannot be considered reliable, the

ratio of controlled and uncontrolled emission levels might be expected to provide control efficiency values of greater reliability.

Table 10 identifies the number of tests and source/control combinations evaluated at each mine. Average emission factors and range of source conditions are presented in Table 11.

Control efficiency values over time were reported for each mine/control combination. However, many of these combinations exhibit apparent increases in efficiency over time. This anomalous behavior is possibly due to the fact that efficiency values were not referenced to dry, uncontrolled emissions (cf. Section 4.4).

Test Report 3

This study represents a continuation of the control performance evaluations begun in Test Report 1. Three unpaved road dust controls were evaluated: an emulsified asphalt; a petroleum resin; and water. The evaluations were conducted under medium to heavy duty traffic at two steel plants in Indiana and Missouri. Unlike Test Report 1, the primary focus in this study was the long-term decay of chemical dust suppressants applied to unpaved roads. Table 12 summarizes the source testing information presented in the report. A Type 2 control plan was employed.

The primary sampling equipment for this study included a four-head (6 m tall) exposure profiling tower with cyclone/impactor combinations at two downwind heights. Total particulate concentrations upwind of the source were measured using a cyclone/impactor combination. An additional cyclone was deployed upwind for controlled tests. Wind speed and direction were continuously monitored, and 10 min averages were used to maintain isokinetic sampling. As in Test Report 1, the test data are rated A. Table 13 presents average emission factors and ranges of source conditions.

TABLE 10. SOURCE TESTING INFORMATION (Test Report 2)

Operation	Equipment	Material[a]	Location	Test dates	No. of tests
Vehicle traffic	Heavy-duty vehicles	Unpaved road with $CaCl_2$[b]	Southern Illinois	6/83-7/83	6
Vehicle traffic	Heavy-duty vehicles	Unpaved road with acrylic[b]	Southern Illinois	6/83-7/83	12
Vehicle traffic	Heavy-duty vehicles	Unpaved road with emulsified asphalt[b]	Southern Illinois	7/83	2
Vehicle traffic	Heavy-duty vehicles	Unpaved road with lignon[b]	Southern Illinois	6/83-7/83	8
Vehicle traffic	Heavy-duty vehicles	Unpaved road with water	Southern Illinois	6/83-7/83	12
Vehicle traffic	Heavy-duty vehicles	Unpaved road uncontrolled[c]	Southern Illinois	6/83-7/83	20
Vehicle traffic	Heavy-duty vehicles	Unpaved road with $CaCl_2$[d]	Southwest Wyoming	8/83	18
Vehicle traffic	Heavy-duty vehicles	Unpaved road with emulsified asphalt[d]	Southwest Wyoming	8/83	16
Vehicle traffic	Heavy-duty vehicles	Unpaved road with acrylic[d]	Southwest Wyoming	8/83	16
Vehicle traffic	Heavy-duty vehicles	Unpaved road with lignon[d]	Southwest Wyoming	8/83	20
Vehicle traffic	Heavy-duty vehicles	Unpaved road with water[d]	Southwest Wyoming	8/83-9/83	12
Vehicle traffic	Heavy-duty vehicles	Unpaved road uncontrolled[c]	Southwest Wyoming	8/83-9/83	41

(Continued)

TABLE 10. (Continued)

Operation	Equipment	Material[a]	Location	Test dates	No. of tests
Vehicle traffic	Heavy-duty vehicles	Unpaved road with $CaCl_2$[f]	Northeast Wyoming	10/83-11/83	8
Vehicle traffic	Heavy-duty vehicles	Unpaved road with biocat[g]	Northeast Wyoming	10/83	5
Vehicle traffic	Heavy-duty vehicles	Unpaved road with emulsified asphalt[b]	Northeast Wyoming	10/83	4
Vehicle traffic	Heavy-duty vehicles	Unpaved road with lignon sulfonate	Northeast Wyoming	10/83	8
Vehicle traffic	Heavy-duty vehicles	Unpaved road, uncontrolled[h]	Northeast Wyoming	10/83	19

[a] Dust suppressants were applied to unpaved roads to determine the control effectiveness.

[b] The dust suppressant was applied in two sections of the unpaved road using different application techniques. See Table 6.2, page 6-5 of test report for dust suppressent application.

[c] After each dust suppressant was applied to the unpaved road, a section was left for no control.

[d] The dust suppressant was applied in two sections of the unpaved road using different application techniques. See Table 6.7, page 6-13 of test report for dust suppressant application.

[e] After each dust suppressant was applied to the unpaved road, a section was left for no control.

[f] The dust suppressant was applied in two sections of the unpaved road using different application techniques. See Table 6.12, page 6-21 of test report for dust suppressant application.

[g] Dust suppressant was applied in one section of the unpaved road using one application technique. See Table 6.12, page 6-21 of test report for dust suppressant application.

[h] After each dust suppressant was applied to the unpaved road, a section was left for no control.

TABLE 11. RANGE OF CONDITIONS AND EMISSION FACTORS (Test Report 2)

Material/equipment/ operation	Location	No. of tests	Range of conditions					Suspended particulate emission factor[a,c]	Fine particulate emission factor[b,c]	Emission factor units
			Silt (%)	Moisture (%)	Wind speed (mph)	Vehicle speed (mph)	Vehicle weight (ton)			
Unpaved road/ with $CaCL_2$	Southern Illinois	6	2 20-5.32	0 16-3 07	-	33 9-40.3	28.2-65.9	2.01	0 12	lb/VMT
Unpaved road/with acrylic	Southern Illinois	12	1.64-3.59	0.06-0.55	-	20 8-41.1	22.2-88.7	3.42	0 68	lb/VMT
Unpaved road/with emulsified asphalt	Southern Illinois	2	-	-	-	33 6	60.8	8.65	0 62	lb/VMT
Unpaved road/with lignon	Southern Illinois	8	3.0-5.45	0.31-1.23	-	32 4-43.2	16 0-65 2	6 08	0.48	lb/VMT
Unpaved road/water water	Southern Illinois	12	2.05-3.89	0.08-0.17	-	37.1-49.3	38.6-61.6	2.77	0.64	lb/VMT
Unpaved road/uncon- trolled	Southern Illinois	20	1.29-8.21	0.17-0.79	-	20.8-49.3	16.0-88.7	4.47	0.80	lb/VMT
Unpaved road/with $CaCl_2$	Southwest Wyoming	18	1 82-8.03	0 2-2.2	-	27.0-38.3	43.6-83.3	7.71	0.66	lb/VMT
Unpaved road/with emulsified asphalt	Southwest Wyoming	16	3.37-6.0	0.4-4.80	-	25.0-36.9	18.1-67.4	13.84	1.32	lb/VMT
Unpaved road/with acrylic[d]	Southwest Wyoming	16	2.06-4.28	1 0-4.6	-	34.9-45.1	37.5-87.4	7.28	0.89	lb/VMT
Unpaved road/with lignon	Southwest Wyoming	20	2 16-4 92	0 8-3.4	-	37.8-48.9	51.3-69.2	7.14	0.82	lb/VMT
Unpaved road/with water	Southwest Wyoming	12	5.69	1.0	-	29 2-40.0	13.5-89.9	6.22	0.74	lb/VMT
Unpaved road/uncon- trolled	Southwest Wyoming	41	2.33-13.6	0.4-5.4	-	25.0-48.9	13.5-82.4	14.42	1.27	lb/VMT

(Continued)

TABLE 11. (Continued)

Material/equipment/ operation	Location	No. of tests	Range of conditions					Suspended particulate emission factor[a,c]	Fine particulate emission factor[b,c]	Emission factor units
			Silt (%)	Moisture (%)	Wind speed (mph)	Vehicle speed (mph)	Vehicle weight (ton)			
Unpaved road/with $CaCl_2$	Northeast Wyoming	8	2.0-5.3	1.0-2 80	-	29.4-36.6	47.2-155.0	3.03	0.53	lb/VMT
Unpaved road with/ biocat[e]	Northeast Wyoming	5	-	-	-	23.1	13.4-169.9	3.58	0.29	lb/VMT
Unpaved road/with emulsified asphalt	Northeast Wyoming	4	6.7-8.3	0.4-0.8	-	20.2	76.4-132.9	1.79	0.16	lb/VMT
Unpaved road/with ligon	Northeast Wyoming	8	2.6-4.8	0.8-1.6	-	23.0-36.6	17.0-157.0	1.84	0.23	lb/VMT
Unpaved road/un-controlled[f]	Northeast Wyoming	19	4.5-5.7	0.4-1.4	-	20.0-48.9	13.4-169.9	3.36	0.45	lb/VMT

- = Information not contained in test report.

[a] Particles < 30 μm aerodynamic diameter See discussion in Section 5 1.

[b] Particles < 2.5 μm aerodynamic diameter. See discussion in Section 5.1

[c] Emission factors are arithmetic mean of the test runs from Tables B-1, B-2, and B-3 of test report.

[d] Emission factors are the arithmetic mean from 12 of the 16 test runs. Data were missing for the four test runs as found in Table B-2 of test report.

[e] Emission factors are the arithmetic mean from three of the five test runs. Data were missing for the two test runs as found in Table B-3 of test report.

[f] Emission factors are the arithmetic mean from 17 of the 19 test runs. Data were missing for the two test runs as found in Table B-3 of test report.

TABLE 12. SOURCE TESTING INFORMATION (Test Report 3)

Operation	Equipment	Material	Location	Test dates	No. of tests
Vehicle traffic	Medium-duty vehicles	Uncontrolled unpaved road	Indiana	6/82	3
Vehicle traffic	Medium-duty vehicles	Unpaved road with asphalt emulsion	Indiana	6/82-10/82	8
Vehicle traffic	Medium-duty vehicles	Uncontrolled unpaved road	Missouri	9/82	3
Vehicle traffic	Medium-duty vehicles	Unpaved road with water	Missouri	9/82	3
Vehicle traffic	Medium-duty vehicles	Unpaved road with petroleum resin	Missouri	9/82-11/82	8
Vehicle traffic	Medium to heavy-duty vehicles	Unpaved road with petroleum resin reapplied	Missouri	11/82-12/82	4

TABLE 13. RANGE OF CONDITIONS AND EMISSION FACTORS (Test Report 3)

Material/equipment/ operation	Location	No of tests	Range of conditions: Silt (%)	Moisture (%)	Wind speed (mph)	Vehicle speed (mph)	Vehicle weight (ton)	Total particulate emission factor[c]	PM_{10} Emission factor[d]	Emission factor units
Uncontrolled unpaved road[e]	Indiana	3	5.8-7.5	-	4.2-5.8	15-17	25-28	18.9	3.5	lb/VMT
Unpaved road with asphalt emulsion[f]	Indiana	8	0.28-13	-	2.2-6.6	13-15	23-34	4.13	0 50	lb/VMT
Uncontrolled unpaved road[g]	Missouri	3	6.3-7.7	-	2.0-4.2	15	50-54	16.7	2.98	lb/VMT
Unpaved road with water[h]	Missouri	3	4.9-5.3[a]	-	4.4-6.1	15	48-50	3.27	0.37	lb/VMT
Unpaved road with petroleum resin[i]	Missouri	8	1.5-7.1	-	2.8-12	15-22	27-56	8.97	1.03	lb/VMT
Unpaved road with petroleum resin reapplied[j]	Missouri	4	0.034-1.7[b]	-	4.9-8.8	28-49	31-54	1.53	0.22	lb/VMT

- = Information not contained in test report.

[a] One sample missing.

[b] The mass of one sample was so small as to be undetectable.

[c] Airborne particles regardless of size.

[d] Particles < 10 μm aerodynamic diameter.

[e] Emission factors are arithmetic mean of test runs AG-1, AG-2, and AG-3 from page 53, Table 3-6 of test report.

[f] Emission factors are arithmetic mean of test runs AG-4 through AG-11 from page 53, Table 3-6 of test report.

[g] Emission factors are arithmetic mean of test runs AJ-1, AJ-2, and AJ-3 from page 53, Table 3-6 of test report.

[h] Emission factors are arithmetic mean of test runs AJ-4, AJ-5, and AJ-6 from page 53, Table 3-6 of test report.

[i] Emission factors are arithmetic mean of test runs AJ-7 through AJ-12 from page 53, Table 3-6 of test report. Tests AJ-16, -17 excluded because of high moisture contents.

[j] Emission factors are arithmetic mean of test runs AJ-13, -14, -15, and -18 from page 53, Table 3-6 of test report.

Efficiency decay rates were obtained for each control application. The decay rate for watering was found to be comparable to that in Test Report 1 despite differences in ambient temperature and application intensity.

Test Report 7

This paper was primarily directed to a discussion of a generic unpaved road dust suppressant that could be produced on-site at iron and steel plants. Exposure profiling of both controlled and uncontrolled emissions from unpaved roads is also described; however, little information about the field tests is presented. Profiling was conducted under subcontract by the same testing organization in Test Report 10b. Because no reference to an earlier test report is given in the paper, it is assumed that this paper represents the original source of the test data. Test data are rated B because of the lack of adequate documentation and because individual test results are not presented.

Both commercially available and generic petroleum resin products were evaluated in this study. Testing took place at a coke and iron facility in Pennsylvania during the fall of 1983. Available testing information and test results are presented in Tables 14 and 15, respectively. For both suppressants, the test report presented control efficiency values for three times after an initial application and once after a repeat application.

Test Report 11

Largely representing a continuation of the control evaluations conducted in Test Reports 1 and 3, this study discussed the long-term performance of five unpaved road dust suppressants used in the iron and steel industry. Field tests were conducted at the same test sites as in Test Report 3.

The suppressants evaluated were: an emulsified asphalt; an acrylic cement; both commercial and generic petroleum resin products; and a salt.

TABLE 14. SOURCE TESTING INFORMATION (Test Report 7)

Operation	Equipment	Material	Location	Test dates	No. of tests
Vehicle traffic	Heavy-haul trucks	Unpaved road with oil resin/water emulsion[a]	Pennsylvania	10/83-11/83	4[c]
Vehicle traffic	Heavy-haul trucks	Unpaved road with commercial product[b]	Pennsylvania	10/83-11/83	4[c]
Vehicle traffic	Heavy-haul trucks	Uncontrolled unpaved road	Pennsylvania	10/83	9

[a] Dust suppressant is the generic formula developed for the study.

[b] Commercial petroleum resin dust suppressant.

[c] Four controlled emission factors were reported. However, report states that each is based on two tests where possible.

TABLE 15. RANGE OF CONDITIONS, EMISSION FACTORS, AND RATINGS
(Test Report 7)

Material/equipment/ operation	No. of tests	Range of conditions					Emission factor	Emission factor units
		Silt (%)	Moisture (%)	Wind speed (mph)	Vehicle speed (mph)	Vehicle weight (ton)		
Unpaved road with oil resin/water emulsion	4	-	-	-	-	-	0.69[a]	-
Unpaved road with commercial product	4	-	-	-	-	-	0.37[a]	-
Uncontrolled unpaved road	9	-	-	-	-	-	5.99[b]	-

- Information not contained in report.

[a] Emission factor is arithmetic mean of four test runs from Table 5. See footnote c in Table 14. Units not given but believed to be lb/VMT.

[b] Uncontrolled emission factor based on nine test runs. Units not stated but believed to be lb/VMT.

The report used code letters for each suppressant to discourage selective citation of test results.

The basic study design incorporated exposure profiling with a Type 1 control application plan. Because of difficulties encountered at the Indiana site, however, a Type 2 plan was later adopted. Testing information is presented in Table 16.

The primary sampling equipment included four-head profiling towers (6 m height), a downwind cyclone/impactor combination, and an upwind standard hi-vol fitted with a cascade impactor. The height at which downwind particle size measurements were obtained was selected on the basis of prior testing and approximated the point in the dust plume at which half the mass emissions pass above and half below. Additional instrumentation included recording wind speed and direction sensors used to maintain isokinetic sampling.

The profiling tests used a sound methodology and were well documented. As noted above, results from the Indiana site were potentially influenced by upwind sources and nearby structures. For this reason, exposure profiling test data from plant AP are rated B while data from plant AQ are rated A. Test results and ranges of source conditions are presented in Table 17.

Additional studies were conducted prior to field testing in order to characterize both unpaved road traffic and dust suppressant usage in the iron and steel industry. The results of these surveys were used to evaluate the suppressants under service conditions representative of unpaved roads in the iron and steel industry. In addition, the test report combines control efficiency decay rates obtained during the field study with earlier results to develop a control performance model for petroleum resin products.

5.3 AGGREGATE STORAGE PILES (SECTION 11.2.3)

Three test reports were identified that pertain to the source activities currently discussed in Section 11.2.3 of AP-42. In contrast to the

TABLE 16. SOURCE TESTING INFORMATION (Test Report 11)

Operation	Equipment	Material	Location	Test dates	No. of tests
Vehicle traffic	Medium to heavy-duty vehicles	Unpaved road with Coherex®	Indiana	5/85-8/85	6
Vehicle traffic	Medium to heavy-duty vehicles	Unpaved road with Petro Tac®	Indiana	5/85-8/85	6
Vehicle traffic	Medium to heavy-duty vehicles	Unpaved road with calcium chloride	Indiana	5/85-8/85	3
Vehicle traffic	Medium to heavy-duty vehicles	Uncontrolled unpaved road	Indiana	5/85-8/85	5
Vehicle traffic	Medium to heavy-duty vehicles	Unpaved road with Coherex®	Missouri	9/85-11/85	9
Vehicle traffic	Medium to heavy-duty vehicles	Unpaved road with Soil Sement®	Missouri	9/85-11/85	11
Vehicle traffic	Medium to heavy-duty vehicles	Unpaved road with Generic 2	Missouri	9/85-11/85	11
Vehicle traffic	Medium to heavy-duty vehicles	Unpaved road with Petro Tac®	Missouri	9/85-11/85	5
Vehicle traffic	Medium to heavy-duty vehicles	Unpaved road with calcium chloride	Missouri	9/85-11/85	6
Vehicle traffic	Medium to heavy-duty vehicles	Uncontrolled unpaved road	Missouri	9/85-11/85	2

TABLE 17. RANGE OF CONDITIONS, EMISSION FACTORS, AND RATINGS
(Test Report 11)

Material/equipment/ operation	Location	No. of tests	Range of conditions					Total particulate emission factor[a]	PM_{10} Emission factor[a]	Emission factor units
			Silt (%)	Moisture (%)	Wind speed (mph)	Vehicle speed (mph)	Vehicle weight (ton)			
Unpaved road/ with Coherex®	Indiana	6[b]	< 0.05-12	0.08-1.4	1.6-8.5	15	26-29	2,570[c]	349[c]	g/VKT
Unpaved road/with Petro Tac®	Indiana	6[b]	1.9-11	0.12-0.46	0.92-11	15	26-30	1,000[d]	94[d]	g/VKT
Unpaved road/with calcium chloride	Indiana	3[b]	2.7-4.3	1.2-1.4	4.2-8.5	15	29-28	355[e]	e	g/VKT
Unpaved road/uncontrolled	Indiana	5[b]	6.0-8.3	0.1-1 1	1.6-6.2	15	35-37	5,020[f]	808[f]	g/VKT
Unpaved road/with Coherex®	Missouri	9	1.1-15	0.78-1.6	5.0-12.0	15	6.5-24	1,340[g]	128[g]	g/VKT
Unpaved road/with Soil Sement®	Missouri	11	0.6-4.4	0.77-1.1	5.0-10.0	15	6.5-24	730[h]	829[h]	g/VKT
Unpaved road/with Generic 2	Missouri	11	0.76-10	0.95-1.5	5.0-11.0	15	6.5-24	1,250[i]	189[i]	g/VKT
Unpaved road/with Petro Tac®	Missouri	5	3.1-5 0	1.1-1.8	5.0-11.0	15	9.7-24	1,590[j]	201[j]	g/VKT
Unpaved road/with calcium chloride	Missouri	6	1.6-12	1.4-2.1	5 0-13	15	6.5-24	2,030[k]	277[k]	g/VKT
Unpaved road/uncontrolled	Missouri	2	7.0	1.5	8.4-8.7	15	9.8-10	1,900[l]	286[l]	g/VKT

[a] Emission factors at each plant normalized to common source conditions. Tests with no net mass detected not included in emission factors presented.

[b] One test other than exposure profiling was also conducted.

[c] Arithmetic mean of X- suffix tests in Table 3-13, page 55, of test report.

[d] Arithmetic mean of P- suffix tests in Table 3-13, page 55 of test report.

[e] Values from test AP-3C in Table 3-13, page 55 of test report. No net PM_{10} mass detected.

[f] Arithmetic mean of U- suffix tests in Table 3-13, page 55, of test report.

[g] Arithmetic mean of X- suffix tests in Table 3-14, page 56, of test report.

[h] Arithmetic mean of S- suffix tests in Table 3-14, page 56, of test report.

[i] Arithmetic mean of G- suffix tests in Table 3-14, page 56, of test report.

[j] Arithmetic mean of P- suffix tests in Table 3-14, page 56, of test report.

[k] Arithmetic mean of C- suffix tests in Table 3-14, page 56, of test report.

[l] Arithmetic mean of U- suffix tests in Table 3-14, page 56, of test report.

studies discussed above, these reports largely deal with emission factor development. These reports are discussed below.

Test Report 4

This report presents the results of field tests conducted on dust emissions from rotary coal car dumping at a power plant in Maryland. The car dumper is enclosed in an east-west shed and thus should be considered at least partially controlled. Source testing information is provided in Table 18.

Mass flux measurements were taken at both the entrance and exit doors to characterize mass emissions leaving the shed. However, only one doorway was sampled during the first phase of the program. Additional upwind/downwind and dustfall measurements were taken within the shed. Sampling equipment/operation met the requirements of Section 4.3.

The mass flux samplers were the same isokinetic units described in Test Report 10e. Particle size measurements were obtained for most tests which exhibited westerly winds; measurements were made using five-stage cascade impactors at three of the sampling locations. These units were also fitted with preseparating settling chambers (which are referred to as horizontal elutriators in Brookman, 1983). The preseparator cutpoints are given as 30 and 42 μm for 20 and 40 cfm flow rates, respectively.

During Phase I, the impactors units were operated at 20 cfm. However, because difficulties were encountered in maintaining that flow rate, Phase II employed a 40 cfm flow rate. Additional problems were reported involving particle bounce through the impactor. It should be noted that the choice of preseparator in this study actually compounded particle bounce problems because it allowed larger particles to enter (and potentially bounce through) the impactor at higher flow rates. For this reason, particulate emissions data for the smaller size ranges should be downgraded to a B rating.

Final size distributions reported were obtained by multiplying the average impactor data obtained during Phase II by the ratio of optical

TABLE 18. SOURCE TESTING INFORMATION (Test Report 4)

Operation	Equipment	Material	Location	Test date	No. of tests
Batch-drop	Rotary railcar dumper	Coal	Maryland	7/83-11/83	62

microscopy to impaction results for one test. Results of testing are presented in Table 19.

Additional regression analysis was performed on the test results, with separate predictive models, based on moisture content, developed for washed and unwashed coal. However, the relationships were considered weak and unsuitable for prediction purposes. Average suspended particulate emission factors for washed and unwashed coal were 0.0006 and 0.0016 lb/ton, respectively.

Test Report 5

This report describes the results of field tests conducted at a prilled sulfur facility in California. Particulate emissions from the batch drop of prill into a partial enclosure were quantified. The enclosure was constructed to simulate a melter feed hopper. This simulation was necessary because the client did not use prill at its facility; consequently, testing was performed at a prill production plant.

Freshly produced wet prill was allowed to dry prior to testing. The same batch of sulfur was dropped repeatedly to simulate various handling operations and to determine any increase in emissions with increased fines content. Over six tests, the material was transferred a total of 18 times. Additional source testing information is presented in Table 20.

Total particulate mass measurements were obtained using profiling heads of the type discussed in Test Report 10c. A total of six units were arranged in a two-dimensional array 2 m downwind of the hopper. Cyclone/impactor combinations were used both upwind and downwind of the source. Additional equipment included wind speed/direction instruments used to maintain isokinetic sampling. The test data are rated A.

Test results, range of source conditions, and quality ratings assigned are given in Table 21. Note that the tests were undertaken to extend the applicability of current AP-42 estimation methods and not to develop single-valued emission factors for the source.

TABLE 19. RANGE OF CONDITIONS, EMISSION FACTORS, AND RATINGS
(Test Report 4)

Material/equipment/ operation	No. of tests	Range of conditions			Suspended particulate emission factor[c]	PM_{10} Emission factor	Emission factor units
		Silt (%)	Moisture (%)	Wind speed (mph)			
Coal batch-drop railcar dumper	62	0.7-4.8[d]	2.7-7.4[c]	0.5-2.9[a] 1.0-3.4[b]	0.0011[e]	0.00024[f]	lb/ton

NA = Not applicable.
- = Information not found in test report.

[a] Wind speed at exit doorway of dumper shed from page 47-49, Table 5-3 of test report.

[b] Wind speed at entrance doorway of dumper shed from page 47-49, Table 6-3 of test report.

[c] Average moisture content from page 55-56, Table 5-6 of test report.

[d] Average silt content from page 55-56, Table 5-6 of test report.

[e] Emission factor is arithmetic mean for 62 test runs from Table 5-8, page 59-60 of test report. Value is also given on page 72 of test report. Emission factor rated D, based on Table 3. See discussion in text for additional emission factors for washed and unwashed coal.

[f] Individual factors not presented; mean PM_{10} fraction reported as 0.22 on page 72. Emission factor rated E, based on Table 3.

TABLE 20. SOURCE TESTING INFORMATION (Test Report 5)

Operation	Equipment	Material	Location	Test dates	No. of tests
Batch drop[a]	Front-end loader[b]	Wet formed prilled sulfur	California	4/84	6
Loader travel	Ford CL65 front-end loader	Paved surface within plant	California	4/84	3

[a] Prilled sulfur was dumped at a constant height of 5 ft.

[b] One cubic yard front-end loader.

TABLE 21. RANGE OF CONDITIONS, EMISSION FACTORS, AND RATINGS
(Test Report 5)

Material/equipment/ operation	No. of tests	Range of conditions					Suspended particulate emission factor[c]	PM_{10} Emission factor	Emission factor units
		Silt (%)	Moisture (%)	Wind speed (mph)	Vehicle speed (mph)	Vehicle weight (ton)			
Prilled surface/ batch-drop[d]	6	0.44-2.5[a]	1.1-2.7[a]	5.1-17.5	NA	NA	0.040	-	lb/ton
Paved surface/ loader travel[e]	3	5.2-48[a]	NA	9.8-13.4	5[b]	3.2[b]	0.77	-	lb/VMT

NA = Not applicable.
- = Information not contained in test report.

[a] Average of two values.

[b] All three tests had the same value.

[c] Particles < 30 μm aerodynamic diameter.

[d] Emission factor is the arithmetic mean of test runs AK1 to AK6 from page 26, Table 3-5 of test report. Single-valued factor rated D on basis of Table 3. See discussion in text.

[e] Emission factor is the arithmetic mean of test runs AK7, AK8, and AK9 from page 26, Table 3-5 of test report. Single-valued factor rated D on basis of Table 3. See also discussion in text.

Test Report 6

This report presents dust control efficiency values for materials handling operations involving a front endloader and dump trucks. However, only control efficiency values are presented; no mass emission rates or factors are given. A subsequent telephone conversation with the testing organization indicated that the efficiency values were based on relative measures of emissions. Because the study design did not concern absolute measurement of emissions, such as relating total suspended emissions to a unit activity level, this report was deleted from consideration.

Test Report 9

This study presented size-specific particulate emission factors for the loading of fly ash into open trucks. Tests were conducted at a coal-fired power plant in Michigan. Load-out was from an enclosed loading bay below a silo used to store ash collected by an ESP. Because the truck/trailer combinations used to haul the fly ash were slightly longer than the loading bay, the bay doorways were alternately open and blocked by the vehicle during loading operations.

To facilitate testing, a slight modification to the operation was made to ensure that the downwind doorway was continuously blocked during the loading process. The only additional modification involved keeping the bay's overhead door at a constant 12 ft height. This change reduced the necessary height of the downwind sampling array and avoided any difficulty in isokinetically sampling particulate mass through a flexible plastic curtain at the bay doors. Because none of these changes altered the physical operation of the load-out process, mass emissions were said to be unaffected and merely rerouted through the open areas of the doorway. A summary of the testing information is provided in Table 22.

Downwind mass flux measurements were obtained using TP samplers of the type used in Test Report 10c. A total of six downwind samplers of this type were used to quantify mass flux values. Particle size measurements were

TABLE 22. SOURCE TESTING INFORMATION (Test Report 9)

Operation	Equipment	Material	Location	Test date	No. of tests
Batch loading	Truck/trailer combination	Fly ash	Michigan	9/84	4

made using cyclone/impactor combinations at two locations (which were co-located with TP samplers). Upwind concentration and size distribution measurements were obtained with another cyclone/impactor combination.

Additional instrumentation included anemometers at five of the six downwind sampling locations as well as a wind vane at the sixth point. Oner to five-minute averages from these instruments were used to maintain isokinetic sampling. All downwind air sampling and ancillary equipment were mounted in the plane of the doorway and were rotated into fixed locations after the truck/trailer entered the bay. A two-parameter wind station was deployed outside of the loading bay to record ambient wind speed and direction.

The sampling methodology was sound and well-documented; because the source modifications were not considered to affect mass emissions, the test data are rated A. Test results, ranges of conditions, and quality ratings assigned to the data are presented in Table 23.

5.4 INDUSTRIAL PAVED ROADS (SECTION 11.2.6)

Three test reports dealing with Section 11.2.6 of AP-42, Industrial Paved Roads, were identified. Those reports are discussed below.

Test Report 1

This study evaluated paved road control techniques at two integrated iron and steel plants in Ohio and Texas. Sampling methodologies used were identical to those discussed earlier in the section on unpaved roads. Source testing information and test results were given previously as Tables 8 and 9, respectively. Control efficiencies are presented for vacuum sweeping, water flushing, and flushing with broom sweeping. Reported efficiencies for the latter two should be considered less reliable because controlled and uncontrolled tests were not always performed on the same road because of meteorological and logistical constraints.

TABLE 23. RANGE OF CONDITIONS, EMISSION FACTORS, AND RATINGS
(Test Report 9)

Material/equipment/ operation	No. of tests	Range of conditions			Suspended particulate emission factor[a]	PM_{10} Emission factor[b]	Emission factor units
		Silt (%)	Moisture (%)	Wind speed (mph)			
Fly ash batch loading[c]	4	25-40[d]	26-30	4-6	0.0044	0.0017	lb/ton

[a] Particles < 30 μm aerodynamic diameter.

[b] Particles < 10 μm aerodynamic diameter.

[c] Emission factors are arithmetric mean of test runs AN-1, AN-2, AN-3, and AN-4 from page 22, Table 3-4 of test report. Factors rated D on basis of Table 3.

[d] Report states on page 18 that silt contents are believed to be lower bounds on material finer than 200 mesh.

Test Report 5

In addition to the materials handling tests described earlier, this study also quantified particulate emissions from vehicle travel on paved surfaces. A total of three tests were performed. The first two were conducted on the rather heavily loaded surface resulting from the repeated transfer of prill during the handling tests. The final test was conducted after the surface had been manually cleaned by flushing and sweeping. Source testing information was given previously in Table 20.

A five-head profiling tower (5 m tall) was used to sample total mass flux. Additional concentration and particle size measurements were obtained from cyclone/impactor combinations at two downwind and one upwind heights. As before, test data are rated A. Testing results were given earlier in Table 21.

Test Report 8

This paper discusses the development of an exposure profiling system as well as an evaluation of the effectiveness of paved road vacuum sweeping. Note that, because no reference is given to an earlier test report, this paper is considered to be the original source of the test data.

The exposure profiling and particle sizing systems used in the study were essentially identical to those discussed in Test Report 10f. Test data are B-rated because of inadequate detail in the report. Source testing information and results of the tests are presented in Tables 24 and 25, respectively.

TABLE 24. SOURCE TESTING INFORMATION (Test Report 8)

Operation	Equipment	Material	Location	Test dates	No. of tests
Vehicle traffic	Average vehicle mix	Paved road uncontrolled	Pennsylvania	-	10
Vehicle traffic	Average vehicle mix	Paved road controlled[a]	Pennsylvania	-	5

- = Information not contained in Test Report.

[a] Control of the paved road was a twice per week vacuum sweeping program.

TABLE 25. RANGE OF CONDITIONS AND EMISSION FACTORS (Test Report 8)

Material/equipment/ operation	No. of tests	Range of conditions: Silt[c] (%)	Moisture (%)	Wind speed (mph)	Vehicle speed (mph)	Vehicle weight (ton)	SP Emission factor	PM_{10} Emission factor	Emission factor units
Uncontrolled paved road/vehicle mix[a]	10	8.95	-	-	-	0.5-35	0.18	-	lb/VMT
Controlled paved road/vehicle mix[b]	5	16.2	-	-	-	0.5-35	0.096	-	lb/VMT

NA = Not applicable
- = Information not contained in test report.

[a] Emission rate is the area under the exposure profile curve from Figure 2, page 5 of test report divided by the average number of vehicles for six of the 10 test runs.

[b] Emission rate is the area under the exposure profile curve from Figure 3, page 8 of test report divided by the average number of vehicles for four of the five test runs.

[c] Values are the average silt content of the test runs.

SECTION 6

DISCUSSION AND RECOMMENDATIONS

The preceding section discussed available test reports. The test report results are used in this section to assess AP-42 Section 11.2 This assessment can be divided into three main categories: (a) use of the test results as independent data in order to measure the accuracy of the current AP-42 predictive emission factor equations; (b) use of the test data to expand the range of source conditions underlying the current AP-42 equations and possibly recommend revised equations; and (c) use of the test data to expand the current AP-42 discussions of control methods.

6.1 UNPAVED ROADS (SECTION 11.2.1)

The particle size data in Test Report 1 was employed in preparing Section 11.2.1 for inclusion in the Fourth Edition of AP-42. Consequently, the uncontrolled emission factors given in that report cannot be used to assess the performance of the current AP-42 unpaved road equations when applied to independent data sets.

The uncontrolled emission factors in Test Reports 2 and 7 were not considered for further evaluation. As discussed in Section 5.1, an independent evaluation found that the SFUs used in Test Report 2 are incapable of providing reliable emission factors for the size ranges assigned to the device Furthermore, Test Report 7 provides only TP emission factors; because this size range is not included in Section 11.2.1, no comparisons are possible.

General agreement between predicted (using the current AP-42 equation) and observed emissions was found to be good for the 10 tests of uncontrolled

emissions in Test Reports 3 and 11. Summary statistics for the ratio of predicted to observed emissions are presented below:

	< 30 μmS[a]	< 15 μmA	< 10 μmA	< 2.5 μmA
Geometric mean	1.01	1.65	1.55	2.51
Standard geometric deviation	1.65	1.78	1.73	1.90

[a] Stokes diameter based on a particle density of 2.5 g/cm³. Results for the six tests in Test Report 3 only; Test Report 11 did not present emission factors in this size range.

In terms of particle size ranges of current regulatory interest, it would appear that independent applications of the current AP-42 unpaved road equation yield estimates within acceptable limits.

While the travel surfaces described in Test Reports 10a through 10f and 5 were paved, surface loadings were far above (from 3 to 80 times greater) those underlying the current AP-42 paved road equations. As reported in Test Reports 5 and 10c, in those instances where loose material essentially covers a paved surface, the travel surface is perhaps better characterized as unpaved than paved in terms of particulate emissions. Although it is unlikely that this type of source is of common importance, slight revisions to AP-42 Sections 11.2.1 and 11.2.6 to incorporate this finding may be warranted. Section 6.3 of this report provides an additional discussion of emissions from heavily loaded paved surfaces.

As noted throughout this report, the control of unpaved road dust emissions has attracted considerable attention during the 1980s. Many industries have implemented plant-wide dust control programs for unpaved roads. Independent applications of the unpaved road equation have indicated that estimates of the emission factor (e in Eq. (1)) are generally quite good; however, the lack of guidance on estimating the effective control term in that equation has hindered reliable unpaved road emission estimates for

many industries. Note that, because most control measures applied to unpaved roads are periodic in nature (as discussed in Section 4.3), use of the time-averaged value of efficiency given in Eq. (6) is appropriate.

Owing to the wide range of: (a) available dust suppressants; (b) application parameters (such as the intensity, dilution, and frequency of chemical application) used for these suppressants; and (c) service environments including traffic parameters (such as average vehicle weight or daily number of passes) and meteorological parameters (such as rainfall), it is often very difficult to transfer prior field test results obtained under one set of conditions to estimate average control efficiency values for another set of conditions. To date, only one attempt has been made to develop a model of average control performance. This model was developed in Test Report 11 and is presented below.

It is important to realize that any given test series can provide only one estimate of average control efficiency. This is true simply because the various values of instantaneous control efficiency obtained at different times after application must be combined to obtain an effective decay rate. For example, although there may be a data base of 100 controlled tests, this data base may provide only 10 average control values.

As discussed in Test Report 11, only petroleum resin products have been evaluated in enough detail to warrant an attempt at a control performance model. Many suppressants (such as asphalt emulsions and acrylic cements) have been evaluated under only two or three very different sets of conditions.

Test Report 11 combined the results of seven long-term field evaluations of petroleum resins to obtain the following models of average control efficiency:

Size fraction	Nominal averaging period	Sample size	Estimated average efficiency (%)[a]	Correlation coefficient
TP	14 day	7	37 + 44 g	0.948
	30 day	5	28 + 52 g	0.939
PM_{10}	14 day	6	64 + 23 g	0.755
	30 day	4	50 + 36 g	0.915

[a] The variable "g" represents ground inventory (L/m^2). See text for a discussion of g. The slopes and intercepts for each of the models were obtained from a least-squares, linear regression analysis of seven long-term field studies.

The TP models all show correlations significant at the 2% level, while for PM_{10}, the corresponding level is only 10%.

The factor, g, is termed the (cumulative) ground inventory and is found by adding together the total volume (per unit area) of chemical concentrate (not solution) applied since the start of the dust control season. For example, if a plant originally applied 2 L/m^2 of a 20% solution on April 1, and followed with 1.5 L/m^2 of a 16% solution on the first of each following month, then after the June 1 application, g = 0.88 L/m^2. In this example, because applications occur once a month, the nominal averaging period is 30 days. Thus, between June 1 and July 1, an average TP control of 28 + 52 (0.88) = 74% and PM_{10} control of 50 + 36 (0.88) = 82% are estimated by the models given above.

The average TP and PM_{10} control performance models for petroleum resins presented above were designed to meet typical needs in the iron and steel industry. Application (intensity and frequency of treatment) and traffic parameters inherent in the model reasonably span common conditions in that industry. How well the model performs under different service conditions (e.g., rural roads) cannot be assessed at this time. However, because roughly two-thirds of the field tests supporting the current unpaved road equation were conducted in the iron and steel industry, it is reasonable to include this model in Section 11.2.1.

It is recommended that AP-42 Section 11.2.1.3 (Control Methods) be revised in order to include this average control performance model. Because so many industrial unpaved roads are currently controlled, it is important that users of AP-42 be able to estimate control efficiency values. In addition, it is recommended that any revision also include numerous references to test reports and manuals that contain data on other control techniques (e.g., Cowherd and Kinsey, 1986).

6.2 AGGREGATE STORAGE PILES (SECTION 11.2.3)

Unlike the case of unpaved roads, the recent test data that pertain to this section of AP-42 Section 11.2 potentially represent a substantial increase to the data base underlying current AP-42 predictive equations. However, only the results of Test Report 5 could be used in a reexamination of the predictive equations for materials handling. Note that run AK-5 was excluded because the test report stated that there was strong evidence that test was biased by wind erosion.

The results from Test Reports 4 and 9 were not included for several reasons. The material of interest in Test Report 9--fly ash--is not generally considered an aggregate material because it consists of fine particles of relatively uniform size. The test report discussed problems encountered in the size classification of this material by dry sieving. Reported silt contents were said to represent lower bounds on the fraction of material that would pass a 200 mesh screen during the sieving procedure discussed in Section 11.2.3. In addition, the source operation was enclosed and partially controlled by water. Because of these differences in both material and source operation parameters, the results from the test report were not included.

Results from Test Report 4 were excluded for a variety of reasons. As in Test Report 9, the source was enclosed. An additional consideration is related to the problems encountered with particle size measurements. As discussed in Section 5.0, particle bounce problems were compounded by the choice of preseparation device, and results from impaction were essentially

changed to results from optical microscopy. Because the independent contractor in Test Report 10a could recommend only impaction for exposure profiling particle size measurements and because of the obvious need for reliable particle size information in light of the anticipated NAAQS revision, it was believed that problems encountered with sizing, in addition to the difference in source operation, made this data set unsuitable for inclusion. (Note, however, that these test results are employed later as independent data to assess the predictive accuracy of a revised emission factor equation.)

A preliminary step in incorporating results from Test Report 5 into the materials handling data base involved correction to identical size fractions. This step was necessary because the current AP-42 equations are based on particles ≤ 30 μmS (Stokes diameter based on a density of 2.5 g/cm^3), and results in Test Report 5 are for 30 μmA. Correction of results from Test Report 5 to 30 μmS (or 50 μmA) was accomplished using a log-normal size distribution and the data contained in the test report. The results are given below:

Data base	Ratio for stated size[a]				
	30 μmA	15 μmA	10 μmA	5 μmA	2.5 μmA
Current batch drop[b]	0.73	0.48	0.36	0.23	0.13
Current continuous drop[b]	0.77	0.49	0.37	0.21	0.11
Test Report 5, Runs AK-1 and -2[c]	0.73	0.49	0.36	0.22	0.11
Test Report 5, Runs AK-3 through-6[c]	0.70	0.41	0.23	0.11	0.06

[a] Ratio of stated size fraction to fraction ≤ 50 μmA.

[b] Values taken from current AP-42 Section 11.2.3.

[c] Values obtained from test report size data and assumed log-normal distribution.

Note that the size distributions for the data sets are very comparable.

Three predictive equations (for emissions ≦ 50 μmA) were obtained by stepwise linear regression (Nie et al., 1975), corresponding to the three data subsets:

A. Current batch drop data base supplemented with Test Report 5 results (13 data points).

B. Current continuous drop data base (9 data points).

C. A and B combined (22 data points).

Potential correction parameters included:

- Silt content, s (%)
- Moisture content, M (%)
- Wind speed, U (mph)
- Drop height, h (ft)
- Dumping device capacity, Y (yd^3)

Note that the last parameter pertains only to batch drop tests. The dependent variable was the ≦ 50 μmA emission factor in pounds of emissions per thousand tons of material transferred. All variables were log transformed in order to obtain a multiplicative model.

Resulting equations are presented in Table 26. Note that moisture content appears in each model; in fact, moisture was the first variable to enter in each of the three stepwise linear regression analyses.

An analysis of variance indicated that the regression results for data sets A and C are both significant at the 0.01% level; the corresponding level for set B is 2.3%. Each equation obtained was further examined using a standard cross-validation (CV) technique (Mosteller and Tukey, 1977). Using this technique, each point in the underlying data base is excluded one at a time, and the equation generated from the reduced data base is used to estimate the missing value.

TABLE 26. REGRESSION EQUATIONS OBTAINED FOR MATERIALS HANDLING DATA SETS[a]

Data set	Sample size	Predictive equation	Multiple R^2
A	13	$0.74(s)^{0.64}(U)^{1.4}/(M)^{1.0}$	0.896
B	9	$0.14(h)^{1.2}/(M)^{1.6}$	0.716
C	22	$1.0(U)^{1.3}/(M)^{1.4}$	0.858

[a] See text for data set and variable identification.

In this way, n quasi-independent estimates are obtained from a data base of n tests, and the validity of using stepwise regression to obtain a model is evaluated. Summary information on this process is provided below:

	Ratio of quasi-independent Estimate to observed emission factor		
Data set/equation	Range	Geometric mean	Geometric std. dev.
A (13 tests)	0.35-2.54	0.96	1.79
B (9 tests)	0.12-12.6	0.91	4.55
C (22 tests)	0.15-4.38	1.01	2.48

The most important results from the cross-validation analysis pertain to the model for continuous drop operations (Data Set B). In addition to its poor performance in generating quasi-independent estimates for the missing data points, the equations obtained from the reduced data base were largely "unstable." From the nine reduced data sets, equations involving six different sets of correction parameters were obtained. For example,

silt content entered six of the nine equations with exponents ranging from -0.953 to 1.07; height, on the other hand, entered only three equations. Because the elimination of only one data point results in such drastic changes in the predictive model, it can be concluded that the equation for Data Set B in Table 26 is of little merit.

The cross-validation results for Data Sets A and C are much more favorable. For Set A, all three variables in Table 26 (s, U, and M) entered into each equation obtained from the 13 reduced data bases; in addition, all exponents obtained showed relatively little variation. For Set C, the two variables in Table 26 (U and M) entered each equation generated from the reduced data sets; additionally, silt entered once and drop height seven times during the 22 trials.

The predictive equations for Data Sets A and C may be said to be fairly stable and, as shown earlier, are of relatively high accuracy in providing quasi-independent estimates of missing data. Although the equation for Set A exhibits less variation in terms of predictive accuracy, the equation for C encompasses far greater source and material property variation (e.g., both batch and continuous drop operations, wider range of moisture contents etc.). Furthermore, a Kruskal-Wallis analysis of variance (McGhee, 1985) indicated no significant difference in residuals as a function of the three data subsets (i.e., current AP-42 batch and continuous drop bases and Test Report 5).

Consequently, it is recommended that the equation developed for Data Set C replace the two materials handling equations currently contained in Section 11.2.3. Thus, a single equation is recommended in the form:

$$E = k(0.0016) \frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \text{ (kg/Mg)}$$

$$E = k(0.0032) \frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \text{ (lb/ton)} \quad (8)$$

where:

E = emission factor

k = particle size multiplier (dimensionless)

U = mean wind speed, m/s (mph)

M = material moisture content (%)

Note that this equation is identical to that given earlier in Table 26. The particle size multiplier k varies with aerodynamic particle diameter as shown below:

Aerodynamic particle size multiplier (k)				
< 30 μm	< 15 μm	< 10 μm	< 5 μm	< 2.5 μm
0.74	0.48	0.35	0.20	0.11

These size fractions represent averages of the data given earlier weighted by the number of tests in Data Set C. Based on the criteria presented in Table 4, the above equation would be rated A.

Note that Eq. (7), unlike the current expressions in Section 11.2.3, does not include silt as a correction parameter. There are a number of reasons why this parameter is excluded. In Data Set C, there is a negative (but insignificant) correlation between silt and emission factor. Although it is reasonable to expect an increase in emissions as silt increases, this

was not found in the data set. It is presumed that this can be attributed to high correlation between silt and wind speed, and between wind speed and emission factor (with both correlations significant at the 5% level). The second correlation is expected; the first intercorrelation, however, is not supported by any physical reason, but rather is largely due to the fact that most tests with high silt contents in the data set were conducted under lower wind speeds. This confounding of test conditions is the cause of the probably spurious relationship between silt and emissions.

In addition, it is possible that there is an important relationship between the silt and moisture contents for aggregate materials. The tests supporting the current AP-42 batch drop equation yield a negative correlation between these two parameters which is significant at the 10% level. However, as other tests (with different materials under consideration) are included, silt and moisture exhibit insignificant, positive intercorrelations. At present, it cannot be said with any degree of certainty whether silt and moisture, for a given material or aggregates in general, are interrelated, and additional experimentation is needed. With the data currently available, however, the high degree of intercorrelation between silt and wind speed precludes silt content as a correction parameter.

As a final remark in this regard, it should be noted that the relationships expressed in Eq. (7) are generally comparable to those in the current AP-42 batch and continuous drop equations. The recommended equation is based on a reexamination of the relationship between the emission factor and independent source parameters using stepwise linear regression. As noted in Cowherd et al. (1983), the current AP-42 predictive equations for batch and continuous drop operations were developed by fitting available test data to a functional relationship. Because only relatively few data were available, relationships for these particular equations were not developed by regression analysis (as were the equations for paved and unpaved roads). The form of the relationships underlying the current equations was based on analogy with those for other fugitive dust sources. In addition, the batch drop equation was further modified in Cowherd et al. (1983) prior to inclusion in AP-42.

An additional examination of the recommended equation employed the data contained in Test Report 4. Of the 62 emissions tests conducted, 45 were associated with moisture and wind speed data. The equation recommended above was used to estimate the reported emission factor, and results are presented below.

	Ratio of predicted to reported emission factors	
Size range[a]	Geometric mean	Geometric standard deviation
Suspended particulate	1.51	2.53
≤ 30 μmA	1.45	-
≤ 10 μmA	2.40	-

[a] Particle size data shown on page 72 of Test Report 4. Because only suspended values are reported for each test, only the mean ratio can be compared for smaller size ranges. Estimate for suspended particulate assumes a size multiplier k equal to 1.

Several items about this comparison should be noted. First, only one significant figure was used to report emission factors in about 70% of the 45 tests. If the additional digits were truncated rather than rounded (which may be more likely if the data were generated by a computer), the ratio of predicted to reported emissions would be systematically biased toward higher values. In addition, the source evaluated in Test Report 4 was enclosed while Eq. (7) is based only on open tests, and the dumping capacity of the railcar is roughly one order of magnitude greater than the largest value for the batch drop tests supporting Eq. (7). Finally, as noted earlier, that test report discussed several problems encountered with particle sizing, and test data for smaller size ranges are B rated. Despite these problems, the above comparison indicates that the estimated emission factors agree fairly well with the reported values. This is especially true for the suspended particulate and 30 μmA size fractions. The

agreement for the PM_{10} is not as good, although it is unknown what effect the problems encountered with particle sizing in the test report have on the ratio.

6.3 INDUSTRIAL PAVED ROADS (SECTION 11.2.6)

The uncontrolled tests of particulate emissions from paved roads presented in Test Report 1 were included in the data base used in developing the current AP-42 emission factor equations for IP, PM_{10}, and FP. Consequently, results from that test report cannot provide information on the relative accuracy in independent applications of the current predictive equations.

Test Report 5, however, does present independent applications of the TSP predictive equation. Three tests of emissions from traffic on paved surfaces were conducted. The first two tests were performed with heavily loaded surfaces and the third was conducted after the surface had been cleaned. None of the loading values fall into the range of (149 to 7,100 lb/mile) of the tests supporting the current TSP equation. Comparisons of predicted to observed emissions (taken from page 31 of the report) are summarized below:

Run	Loading (lb/mile)	Ratio of predicted to actual emission factors
AK-7	48,000	8.70
AK-8	23,000	1.44
AK-9	90	1.23

The test report noted that the agreement between predicted and observed emissions was generally good and became better as source conditions approached the conditions of the tests used to develop the predictive equation. The report also suggested that heavily loaded paved surfaces may be better considered as unpaved in terms of emission estimates. Note that, had

the unpaved road equation been used to estimate runs AK-7 and AK-8, measured emission levels would be underestimated by a mean factor of 2.2, while the paved road equation overpredicts by a mean factor of 3.5. The difficulty of estimating emissions from heavily loaded paved surfaces was also addressed in Test Report 10c.

In order to assess the current single-valued PM_{10} emission factor for light duty traffic on heavily loaded roads, emission factors for this size range were generated using the data and calculation scheme presented in Test Report 5. The results of the comparison are presented below:

Run	PM_{10} emission factor (lb/VMT)		Predicted ÷ actual
	Predicted	Actual[a]	
AK-7	0.33	0.17	1.94
AK-8	0.33	0.67	0.49

[a] Values determined using size data presented in Test Report 5 with calculation scheme described.

Although only two runs are available for comparison, agreement is generally acceptable. Finally, note that Run AK-9 could not be used to assess the current PM_{10} equation in AP-42 Section 11.2.6 because: (a) the vehicle weight in this test was far below the range used in developing the equation; and (b) adjustment of the loading value 90 lb/mile to a mass per unit area would require information not contained in the test report. Recall, however, that the earlier comparison between predicted and observed SP emissions showed good agreement for this test.

In general, although there are few independent data available to assess the accuracy of the current AP-42 paved road estimates, the comparison presented in this section would indicate good agreement in cases where source conditions are comparable to those in the underlying data bases. Additional

data (Test Report 8) also showed good agreement between predicted and observed emissions. This report is discussed later in this section in connection with control methods used for industrial paved roads.

As is the case for unpaved roads, many industries have recently instituted plant-wide control programs for paved roads. However, various paved road control techniques have not been studied in as much detail as those for unpaved roads. This limitation is not as restrictive as it may first appear because available paved road control measures reduce (silt) loading on the travel surface. Thus, controlled emission factors can be estimated by substituting these reduced loading values in the current AP-42 predictive equations.

The results of controlled paved road tests in Test Report 1 were estimated using the current paved road equations; the results of this comparison are summarized below:

Control method	Sample size	Ratio of predicted to observed emission factors[a]		
		IP	PM_{10}[b]	FP
Vacuum sweeping[c]	4	1.31/1.92	1.02/1.97	1.24/2.07
Water flushing	4	1.67/1.84	1.38/2.00	2.05/3.22
Flushing and broom sweeping	3	5.61/1.95	4.34/1.83	9.54/4.25

[a] First entry is geometric mean ratio, second is standard geometric deviation.

[b] Observed PM_{10} obtained using log-normal interpolation between reported IP and FP emission factors.

[c] All silt loading values for vacuum sweeping are well below values in data base supporting AP-42 equation.

Agreement between estimated and observed emissions is quite good for both vacuum sweeping and water flushing. For these controls, the limited data

available would indicate that controlled emission estimates can be obtained using the current AP-42 (uncontrolled) predictive equations. For flushing and broom sweeping, however, the industrial paved road equation tends to substantially overpredict observed emission levels.

A similar comparison for suspended particulate emissions from paved roads was presented in Test Report 8. Measured emissions from a paved road both before and after vacuum sweeping were compared to estimates obtained from an earlier version of the current AP-42 equation for TSP. This version, originally presented in Supplement 14 (May 1983), differs from the current version only in that the constant term was changed from 0.090 to 0.077 lb/VMT. Emission rates presented in Test Report 8 are summarized below:

	Emission rate (lb/mile/hr)		
		Estimated	
	Measured[a]	Previous equation	Current equation[b]
Before vacuum sweeping	8.43	8.46	7.24
After vacuum sweeping	4.54	4.44	3.80

[a] Measured emissions reflect particles smaller than 30 μm as determined by CCSEM. Before and after measurements based on average from 6 and 4 tests, respectively. Test Report 8 does not present results for individual tests.

[b] Obtained by multiplying results in Test Report 8 by (0.077/0.090). See discussion in text.

Although only average emission levels can be compared, the limited data available support the contention that controlled TSP emissions may be estimated within acceptable limits by the current AP-42 uncontrolled emission factor equation.

It is recommended that Section 11.2.6.4 be revised to reflect the findings that, based on the available data, emissions from certain controlled

industrial paved roads can be estimated using the equations currently presented in AP-42. Although the underlying data base is limited, adequate estimates were obtained for vacuum sweeping, over all particle size ranges of interest in Section 11.2.6, and for water flushing, over the IP, PM_{10}, and FP size fractions. The results for vacuum sweeping are particularly noteworthy because all controlled (silt) loading values used in the comparisons presented earlier were considerably lower than the values supporting the predictive equations for uncontrolled emissions.

6.4 SUMMARY

An important shift in emphasis has been noted in fugitive dust studies over the past 5 or 6 years compared to those performed in the 1970s. The previous decade witnessed numerous field studies yielding results that formed the basis of most open dust emission factors presented in AP-42. When these emission factors were used to inventory particulate emissions in various industries, it became apparent that open dust sources in general (and traffic on paved and unpaved roads in particular) often account for a considerable portion of the total release of particulate emissions at a facility. Recognition of the importance of major open dust sources in turn led to interest in the control of these sources, and field studies were undertaken to quantify the effectiveness of various control techniques.

The revisions to AP-42 Section 11.2 that are recommended in this report mirror the developments discussed above. Although there were relatively few new, independent data for uncontrolled paved and unpaved road emissions, the data available indicated that the current AP-42 methods yield estimates with acceptable accuracy. The majority of new data for these types of sources pertain to control performance evaluation. Consequently, the revisions recommended for AP-42 Sections 11.2.1 and 11.2.6 address the new area of interest.

The only exception is the recommended revision to AP-42 Section 11.2.3 for aggregate storage piles. Here, new data were available that extended the range of silt and moisture contents and source operation parameters.

These additional data allowed a reexamination of the current AP-42 estimation procedures, and the revised equation presented in Section 6.2 is the result of this reexamination.

7.0 REFERENCES

Brookman, E. T. 1983. Critical Review of Open Source Particulate Emission Measurements - Current Procedures. TRC Environmental Consultants.

Cahill, T. A., et al. 1979. Ambient Aerosol Sampling with Stacked Filter Units. FHWA-RD-78-178, Federal Highway Administration, Washington, D.C.

Cowherd, C., et al. 1983. Fugitive Dust Emission Factor Update for AP-42. EPA Contract No. 68-02-3177, Assignment 25, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Cowherd, C., and J. S. Kinsey. 1986. Identification, Assessment, and Control of Fugitive Particulate Emissions. EPA-600/8-86-023, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

McGhee, J. W. 1985. Introductory Statistics. West Publishing, St. Paul, Minnesota.

Mostfeller, F., and J. W. Tukey. 1977. Data Analysis and Regression. Addison-Wesley, Reading, Massachusetts.

Muleski, G. E. 1986a. Estimation of Unpaved Road Emission Reductions at Iron and Steel Plants. Draft Supplemental Report. Midwest Research Institute.

Muleski, G. E. 1986b. Update of Fugitive Emission Factors in AP-42. EPA Contract No. 68-02-3891, Assignment 11, Final Report prepared for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Nie, N. H., et al. 1975. Statistical Package for the Social Sciences, Second Edition. McGraw-Hill, New York, New York.

Turner, D. B. 1970. Workbook of Atmospheric Dispersion Estimates. AP-26, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.