Revision of Emission Factors for AP-42 Section 11.9
Western Surface Coal Mining

Revised Final Report

For U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Factor and Inventory Group
Research Triangle Park, NC 27711

Attn: Ron Myers (MD-14)

EPA Contract 68-D2-0159
Work Assignment No. 4-02

MRI Project No. 4604-02

September 1998

Revision of Emission Factors for AP-42 Section 11.9
Western Surface Coal Mining

Revised Final Report

For U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Factor and Inventory Group

EPA Contract 68-D2-0159
Work Assignment No. 4-02

MRI Project No. 4604-02

September 1998

NOTICE

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract No. 68-D2-0159 to Midwest Research Institute. It has been reviewed by the Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, and has been approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Office of Air Quality Planning and Standards (OAQPS), U. S. Environmental Protection Agency (EPA), under Contract No. 68-D2-0159, Work Assignment No.4-02. Mr. Ron Myers was the requester of the work.

Approved for:

MIDWEST RESEARCH INSTITUTE

Roy Neulicht
Program Manager
Environmental Engineering
Department

Jeff Shular, Director
Environmental Engineering
Department

July 1998

TABLE OF CONTENTS

Section 1
Introduction

The EPA's Office of Air Quality Planning and Standards (OAQPS), Emission Factor and Inventory Group (EFIG) develops and publishes emission factors for various applications. Factors are used by states, industry, consultants, and others in the air quality management process. The purpose of this work assignment is to assist EPA in the improvement and documentation of emission factors contained in AP-42, *Compilation of Air Pollutant Emission Factors*.

Section 234 of the Clean Air Act Amendments (CAAA) places certain responsibilities on EFIG to develop improved emission factors for activities at western surface coal mines. Over the past 3 years, a series of studies were undertaken first to review and then to expand/improve the measured emission factor data base for western surface coal mines. The objective of this work assignment was to incorporate the results of those studies in the AP-42 Section 11.9 on western surface coal mining.

The remainder of this report is structured as follows: Section 2 describes the revisions made to the surface coal mining section; References are given in Section 3; the appendices contain the revised AP-42 section and supporting information.

The principal pollutant of interest is particulate matter (PM), with special emphasis placed on PM-10--particulate matter equal to or less than 10 micrometers in aerodynamic diameter (µmA). PM-10 is the basis for the current NAAQS and thus represents the size range of the greatest regulatory interest. However, much of the historical surface coal mine field measurement data base predates promulgation of the PM-10 standard; thus, most of the test data reflect particulate sizes other than PM-10. Of these, the most important is TSP, or total suspended particulate, as measured by the standard high-volume (hi-vol) air sampler.

Section 2
Revision of AP-42 Section on Western Surface Coal Mining

Section 234 of the CAAA directed EPA to examine available emission factors and dispersion models to address potential overestimation of the air quality impacts of surface coal mining. Over the past 4 years, a series of studies have not only reviewed available emission factors but also collected new field measurements at a mine in Wyoming's Powder River Basin against which those factors could be compared and revised as necessary.

This section describes how AP 42 Section 11.9—"Western Surface Coal Mining"— has been revised in response to the newer studies. The section begins with a brief overview of the recent studies. Particular emphasis is placed on changes that have occurred in "typical operating practices" since the time that the original data base supporting the current AP-42 emission factors was assembled. For example, common haul truck capacities are now two to three times greater than those represented in the old emission factor data base.

2.1 Background

The current version of AP-42 Section 11.9 (included as Section 8.24 in earlier editions) was first drafted in 1983[4] and made use of field data collected during the late 1970s and early 1980s.[5,6] Minor changes to this section were subsequently made; the changes were related to (a) emissions from blasting and (b) estimating PM-10 emissions.

As noted above, Section 234 of the CAAA directed EPA to examine available emission factors and dispersion models to address potential overestimation of the air quality impacts of surface coal mining. An initial study[1] thoroughly reviewed emission factors either currently used for or potentially applicable to inventorying particulate matter emissions at surface coal mines. For each anthropogenic emission source, the current emission factor was reviewed. The report concluded that additional source testing was necessary to address major shortcomings in the data base. Table 1 summarizes recommendations made in Reference 1.

A second planning program[2] recommended an "integrated" approach to field measurements and combined extensive long-term air quality and meteorological monitoring with intensive short-term, source-directed testing. This approach would have effectively isolated separate steps in the emission factor/dispersion model methodology. As a practical matter, funding was inadequate to support the integrated approach. Under the revised multiyear approach, source-directed measurements were to be conducted first.

TABLE 1. RECOMMENDATIONS MADE IN REFERENCE 1

Source Category	Recommendations
General	• Recommended collection of field test data specific to the PM-10 size fraction. • Stressed need for independent test data against which the performance of various emission factors could be assessed.
Light- and medium-duty vehicular traffic	• Noted that, when applied to independent data, vehicular traffic the current emission factor could overpredict by an order of magnitude. • Recommended collection of newer, independent field data at surface coal mines.
Haul trucks	• Noted important changes in -- size of haul trucks commonly used -- degree of dust control/compaction of permanent haul roads since the time that the test data supporting AP42 were collected. • Recommended that collection of new haul truck emission data form a central focus of any field study.
Scrapers	• Stressed need for independent test data to assess emission factor performance.
Coal/overburden material transfers (e.g., shovel, truck unloading, dragline, etc.)	• Stressed need for independent test data to assess emission factor performance.

Testing occurred during the fall of 1992 at the Cordero Mine in Wyoming's Powder River Basin.[3] Thirty-six PM-10 emission tests, distributed over various sources and five test sites, were performed. In keeping with priorities established in the earlier emission factor review,[1] a majority of the field effort was devoted to emissions from haul truck traffic. A fairly broad spectrum of haul road dust control was tested, ranging from essentially unimproved overburden haul routes to extremely well-controlled coal haul roads. TSP emission tests were run concurrently with 22 of the PM-10 tests. In addition, three PM-10 and three TSP tests of light-duty captive traffic on permanent coal haul roads were completed. These tests were performed to quantify the importance of light-duty versus haul truck traffic on the roads. Finally, two tests of scraper travel also were conducted.

2.2 Recommended Changes to AP-42 Section

This section discusses how changes to Section 11.9 originated. In general, there were three sources of recommended changes:

A. **The 1992 field study[3] provided independent** test data and produced the following set of recommended changes in the AP-42 section for western surface coal mining:

A.1 The "generic" unpaved road emission factor equation in Section 13.2.2 was recommended for use in estimating emissions from light- to medium-duty vehicles at surface coal mines.

A.2 The current haul truck emission factor could not accurately predict the new emission test data. Consequently, revision of the haul truck emission factor was necessary.

B. The EPA EFIG staff requested that:

B.1 Quality ratings in Section 11.9 be thoroughly reviewed.

B.2 Typographical errors--which arose in January 1995 when Section 8.24 was reformatted for inclusion on the CHIEF web site as Section 11.9--be corrected.

B.3 A reference to the wind erosion emission estimation procedures included in Section 13.2.5 will be included in this section.

C. Early in the work assignment, MRI sent a summary of planned changes to Section 11.9 to a representative of the mining industry and that representative distributed the information to other parties. MRI received a response from one of those parties that specifically requested that:

C.1 Typographical errors and omissions involving the blasting emission factor be corrected.

C.2 The origin of the blasting emission factor be described.

As part of an update to AP-42 Section 13.2, “Miscellaneous Sources,” test data from the 1992 field study were combined with other unpaved road emission test data. The combined data set was used to develop a single revised generic predictive emission factor equation for vehicular traffic over unpaved surfaces. The source conditions for the new emission factor predictive equation spans more than two orders of magnitude in terms of mean vehicle weight and does not exhibit any systematic bias for the individual subsets (e.g., haul trucks at mines, light-duty vehicles on publicly accessible roads, scrapers in travel mode, etc.) that constitute the expanded data base. The background document (Ref 7) for the revised Section 13.2.2, “Unpaved Roads,” describes the development and validation of the unpaved road emission factor equation.

Also as part of the 1997 update to AP-42, EPA requested additional information on emission tests underlying the current version of Section 11.9. A series of appendices have been prepared to make this information available through the EPA’s Technology Transfer Network (TTN).

2.3 Revisions to AP-42 Section

The previous section discussed the origin of recommended changes to AP-42 Section 11.9. This section describes how each change was made.

Change A.1-Substitution of the generic unpaved road emission factor for the former light-/medium-duty vehicle frame emission factor. The 1992 field study provided new independent test data against which the recommended factor could be evaluated. Although in many cases, the AP-42 Section 8.24 model had been found to produce very accurate estimates the same model had been found to be capable of providing very unacceptable estimates in other cases. This variation is believed to have been the result of the model's dependence on the fourth power of moisture content.

Table 2 compares the 1992 test results to estimates obtained from the Section 13.2.2 "generic" model that is recommended in place of the Section 8.24 model.

Size range	Run		Measured emission factors (lb/VMT)	AP-42 Section 13.2.2 estimates (Ib/VMT)	Predicted to observed ratio
PM-10	BB-44		0.25	0.24	0.976
PM-10	BB-45		0.078	0.26	3.35
PM-10	BB-48		0.12	0.26	2.19
		Geometric mean	0.13	0.25	1.91
TSP	BB-44		1.3	0.54	0.426
TSP	BB-45		0.60	0.58	0.960
TSP	BB-48		0.49	0.58	1.19
		Geometric mean	0.72	0.57	0.786

Besides the 1992 test data, Reference 2 applied the generic unpaved road emission factor to the combined light- and medium-duty data sets. The following mean rations were obtained:

	Predicted-to-observed ratio		
Size range	No. of cases	Geometric mean ratio	Std. geometric deviation
PM-10	14	1.08	3.08
TSP	14	0.839	2.78

The comparisons indicate that the generic unpaved road emission factor model can provide very acceptable estimates for light- to medium-duty vehicle traffic at surface coal mines.

To complete this change, MRI deleted the light/medium duty vehicle entry in AP-42 Tables 11.9-1 and -2 and added footnote "g" to each table.

Change A.2-Revision of the haul truck emission factor equation. The 1992 field study[3] found none of the emission factor models available at that time to be fully capable of accurately estimating independent haul truck emission data. This was especially evident for the PM-10 size range.

Reference 3 presented new predictive PM-10 and TSP emission factor equations, based solely on the 1992 field test data. However, after the 1992 field study test report had been drafted, it was found that some surface loading values attributed to the old test data set were in error. (The error was corrected in the final version of the report.) After this mistake was corrected, the main reason for not combining the old and new data sets in Reference 3 was eliminated. As noted earlier, the haul truck test data from both the “old” (Ref 5) and “new” (Ref 3) surface coal mining field studies were combined in the expanded unpaved road data set (Ref 7). To direct readers to the revised and expanded unpaved road emission factor equation contained in Section 13.2.2, footnote "g" has been added to Tables 11.9-1 and -2.

Change B.1—Review of quality ratings. Another major portion of the work assignment concerned a thorough review of the quality ratings assigned to emission factors throughout Section 11.9. Tables 4 ant 5 present the quality rating schemes used for predictive equations and single-valued factors, respectively. In the review, emission factors and test data were traced to their original reports, and the rating scheme was applied. In addition, two other guidelines were followed:

1. If an emission factor for particle size range "X" is based on scaling of a factor for size range "Y", then X's rating is one letter lower than Y's.
2. The quality rating is not allowed to improve from a coarse to a finer particle size fraction.

The main result of the review was a general downgrading of quality ratings assigned to emission factors in Section 11.9.

TABLE 4. 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.

TABLE 5. 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.

Change B.2—Correction of typographical errors in Section 11.9. A variety of errors had been noted and were corrected.

Change B.3—Use of the generic wind erosion procedure. Much of the data base supporting AP-42 Section 13.2.5 ("Industrial Wind Erosion") pertains to coal surfaces. A new footnote has been added to AP-42 Tables 11.9-1 and -2 to direct readers to consider the use of Section 13.2.5 to estimate emissions from wind erosion.

Change C.1—Correction of typographical error and omissions in the blasting emission factor. As noted at the beginning of Section 2.1, AP-42 Section 8.24 was revised during the 1980s to change the predictive emission factor equation for blasting. (This revision is discussed in more detail below.) However, the metric and English versions of the equation did not correspond to one another, and no units were specified for the input variable. These errors were corrected.

Change C.2—Origin of the revised blasting emission factor predictive equation. As noted above, the blasting emission factor in Tables 8.24-1 and -2 was revised during the 1980s. When Section 8.24 was first drafted in 1983, it included TSP and PM-15 predictive emission factor equations for blasting, of the general form

$$e = k\,(A)^{a} / (D)^{b}\,(M)^{d} \qquad (2)$$

where:

e = emission factor, expressed in mass of emissions per blast
A = area blasted (area)
D = hole depth (length)
M = material moisture content (fraction)

and k, a, b, and c regression-based values, all greater than zero. In particular, the exponent for moisture was approximately 2. This functional form was first developed in Reference 1. In addition, a PM-2.5 emission factor was developed and was presented as 0.03 of the TSP emission factor. The PM-2.5 to TSP ratio was based upon the geometric mean of the 19 coal and overburden blasting tests that were conducted.

In September 1985, EPA included the unchanged Section 8.24 blasting equation in Section 8.18.2 ("Crushed Stone Processing"). By 1986, crushed stone industry representatives had raised concerns and questioned the appropriateness of the moisture term for stone. They noted that moisture values in the coal mining data set were easily an order of magnitude or greater than values for stone.

In 1986, EPA asked Midwest Research Institute under a level-of-effort contract to review available blasting emission test data. In June of 1986, MRI sent a letter to OAQPS that presented the results from that review. (A copy of that letter is contained in Appendix E.) This letter presented the following emission factor for use in the crushed stone industry, based on a reexamination of the original (surface coal mining) data set:

$$e = 0.00050\,(A)^{1.5} \qquad (3)$$

where:

e = TSP emission factor (lb/blast)
A = area blasted (m^2)

Later, MRI submitted draft interim guidance materials on estimating emissions from blasting at both surface coal mining and stone operations. (A copy of that material is also presented in Appendix E). Because equation (3) was developed from coal mining test data, that equation was recommended for use in estimating emissions at surface coal mines. In addition, a PM-10 to TSP ratio of 0.52 was suggested, based on the analogy with particle size data collected during emission tests of material handling operations. In the revisions to the section, the ratio of PM-2.5 to TSP of 0.03 was dropped from the blasting emission factor table.

A series of appendices are attached to this report to provide information on the test data that support the emission factors in Section 11.9. The information has been scanned for inclusion on the EPA's TTN. The appendices are as follows:

Appendix A	AP-42 Section
Appendix B	This appendix includes the report "Review of Surface Coal Mining Emission Factors," in entirety (Reference 1 of this background document).
Appendix C	This appendix contains the information on the sampling methodology especially as applied in Reference 5, which serves as the primary reference for Table 11.9-1 and -2 in the current AP-42 section.
Appendix D	Appendix D presents information on the sampling, handling, and analysis from Reference 5, which serves as the primary reference for Table 11.9-1 and -2 in the current AP-42 section.
Appendix E	This appendix presents information related to the blasting emission factor.
Appendix F	This appendix describes the test data collected for the truck loading, bulldozing, and dragline emission factor equations presented in AP-42 Tables 11.9-1 and -2.
Appendix G	This appendix describes the test data collected for the grading emission factor equation presented in AP-42 Tables 11.9-1 and -2. Note that the appendix also contains information related to the scrapers in travel mode. However, those emission tests were combined with other data in the expanded unpaved road data set used to support development of the revised AP-42 Section 13.2.2.
Appendix H	This appendix describes the test data collected for the active storage pile emission factor presented in AP-42 Tables 11.9-1 and -2.
Appendix I	This appendix presents information related to the stepwise linear regression analysis of emission test data to develop the predictive equations presented in AP-42 Tables 11.9-1 and -2. This appendix also contains background information on the correction factors presented in AP-42 Table 11.9-3.

Section 3
References

1. G. E. Muleski, *Review of Surface Coal Mining Emission Factors*, EPA-454/R-95-007, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1991.

2. G. E. Muleski and C. Cowherd, Jr., *Surface Cal Mine Study Plan*, EPA-454/R-95-009, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1992.

3. G. E. Muleski and C. Cowherd, Jr., *Surface Coal Mine Emission Factor Field Study*, EPA-454/R-95-010, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1994.

4. C. Cowherd, Jr., B. Petermann, and P. Englehart, Fugitive Dust Emission Factor Update for AP-42. EPA Contract 68-02-3177, Work Assignment 25, September 1983.

5. Improved Emission Factors for Fugitive Dust From Western Surface Coal Mines, EPA-600/7-84-048, U. S. Environmental Protection Agency, Volumes I and II, March 1984.

6. Shearer, D.L., R.A. Dougherty, and C.C. Easterbrook, Coal Mining Emission Factor Development and Modeling Study, TRC Environmental Consultants, July 1981.

7. Emission Factor Documentation for AP-42 Section 13.2.2, Unpaved Roads (Draft), Midwest Research Institute, EPA Contract 68-D2-0159, Work Assignment 4-02, September 1997.

Appendices

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (CONTINUED)

Page

Appendix A
Revised AP-42 Section 11.9
October 1997

This appendix contains revisions to AP-42 Section 11.9 "Western Surface Coal Mining." The purpose of the changes was to improve emission factors contained in AP-42, "Compilation of Air Pollutant Emission Factors." The revised AP-42 Section was removed from this file and is located in a seperate file.

Appendix B
"Review of Surface Coal Mining Emission Factors"

This appendix contains the interim EPA report "Review of Surface Coal Mining Emission Factors," in entirety. The report provides a review of held-measurement-based emission factors for surface coal mines and describes held testing needs to address gaps in the data base.

United States Environmental Protection Agency
Air

Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

EPA-454/R-95-007
July 1991

REVIEW OF SURFACE COAL MINING EMISSION FACTORS

Contains Data for
Postscript Only.

EPA-45/R-95-007

REVIEW OF SURFACE COAL MINING EMISSION FACTORS

Emission Factor And Inventory Group
Emissions, Monitoring, And Analysis Division
U. S. Environmental Protection Agency
Research Triangle Park, NC 27711

July 1991

EPA-45/R-95-007

PREFACE

This interim report was prepared by Midwest Research Institute under U.S. Environmental Protection Agency (EPA) Contract No. 68-DO-0137, Work Assignment No. 10. The principal author of this report is Dr. Greg Muleski; he was assisted by Mr. Robert Dobson and Ms. Karen Connery. Mr. Dennis Shipman of the Office of Air Quality Planning and Standards serves as the EPA's technical monitor of the work assignment.

Approved:

Charles F. Holt, Ph.D., Director
Engineering and Environmental
Technology Department

July 11, 1991

CONTENTS

SECTION 1

INTRODUCTION

As part of the Clean Air Act Amendments of 1990, the U.S. Environmental Protection Agency has the need to review and revise emission factors for criteria pollutants. Specifically, Section 234 of Title I requires field testing for emission factors for surface coal mines. This interim report provides a review of currently available, field-measurement-based emission factors for surface coal mines (SCMs) and describes field testing needs to address gaps in the data base.

A principal purpose of the review is to provide a common basis for discussion at a workshop to be held in Kansas City, Missouri, during August 1991. This report has been sent to interested parties who have been invited to participate at the workshop. These parties include coal and mining industry groups, environmental organizations, and state and federal agencies for mining activities and environmental protection.

Throughout the report, the review focuses on the strengths and weaknesses of the available data, thus identifying major gaps within the data base.

The remainder of this report is structured as follows. Section 2 presents a brief overview of the surface coal mining industry. Section 3 describes the types of emission sources found at SCMs, emphasizing operating characteristics that are potentially different between various parts of the country. In Section 4, the methods available to estimate emissions from SCM sources are discussed and major gaps within the data base are identified. Section 5 summarizes the results of the review and presents a series of recommendations. Section 6 lists the references cited in the report.

Emission factors relate the amount of mass emitted per unit activity of the source. For example, a common unit for travel related emissions is “lb/vmt,” or pounds emitted per vehicle mile traveled. Thus, the “source extent” on a road is measured in terms of the total miles traveled by vehicles over the road. Similarly, if a material handling emission factor is expressed in terms of pounds emitted per ton (or, cubic yard), then the source extent is measured in terms of the tons or cubic yards of material transferred.

The following discussion uses English—such as pounds and miles—rather than metric (Sl) units—such as kilograms and kilometers. This approach has been taken because it is believed that individuals taking part in the Kansas City workshop will be more familiar with common English units.

The principal pollutant of interest in this report is "particulate matter" (PM), with special emphasis placed on "PM-10" or (particulate matter no greater than 10 μma (microns in aerodynamic diameters). PM-10 is the basis for the current National Ambient Air Quality Standards (NAAQSs) for particulate matter as well as the EPA's Prevention of Significant Deterioration (PSD) increments.

PM-10 thus represents the size range of particulate matter that is of the greatest regulatory interest. Nevertheless, formal establishment of PM-10 as the standard basis is relatively recent, and virtually all surface coal mine field measurements reflect a particulate size other than PM-10. Other size ranges employed in this report are:

TSP Total Suspended Particulate, as measured by the standard high-volume (hi-vol) air sampler. TSP was the basis for the previous NAAQSs and PSD increments. TSP is a relatively coarse size fraction. While the capture characteristics of the hi-vol sampler are dependent upon approach wind velocity, the effective D50 (i.e., 50 percent of the particles are captured and 50 percent are not) varies roughly from 25 to 50 μma.

SP Suspended Particulate, which is used as a surrogate for TSP. Defined as PM no greater than 30 μma. Also denoted as "PM-30."

IP Inhalable Particulate, defined as PM no greater than 15 μma. Throughout the late 1970s and the early 1980s, it was clear that EPA intended to revise the NAAQSs to reflect a size range finer than TSP. What was not clear was the size fraction that would be eventually used, with values between 7 and 15 μma frequently mentioned. Thus, many field studies at SCMs were conducted using IP measurements because it was believed that would be the basis for the new NAAQS. IP may also be represented by "PM-15."

FP Fine Particulate, defined as PM no greater than 2.5 μma. Also denoted as "PM-2.5."

It is again emphasized that this is an interim report whose purpose is to provide a common basis for further discussion at the Kansas City workshop. It is probable that several issues in addition to those presented here will be raised at the workshop. This report, then, is an initial focus point for constructive discussions and, in that sense, represents very much a "work in progress."

SECTION 2

OVERVIEW OF THE SURFACE COAL MINING INDUSTRY

Coal is mined in 26 states. The leading coal producers are Kentucky, Wyoming, West Virginia, Pennsylvania, Illinois, Texas, Virginia, and Ohio; these states account for approximately 75% of U.S. coal production.[1]

United States coal reserves total approximately 490 billion tons. Of that total, 330 billion tons are estimated to be minable by underground methods and 160 billion tons by surface methods. Since the early 1970s surface mines have accounted for more than half of the total coal produced. In 1985 coal was produced by both underground and surface mining in 15 of the 26 coal-producing states, with the remaining 11 having surface mines only.

For discussion purposes in this report, the U.S. coal mining industry has been divided into three major regions:

- Appalachian Region
  - Northern Appalachia
  - Central Appalachia
  - Southern Appalachia
- Midwest Region
- West Region
  - Powder River
  - Rocky Mountain

(The small amount of coal mining in Alaska is not considered in this report.) Each region and subregion is briefly described in the following paragraphs.[2]

Northern Appalachia includes the states of Maryland, Pennsylvania, Ohio, and northern West Virginia. Coal production is largely high to medium sulfur bituminous coal. Eastern Pennsylvania is home to the only working anthracite mines in the United States. Bituminous coal production in the Northern Appalachian Region totaled 155.5 million tons in 1985 of which 62.2 million tons were surface mined and 93.4 were mined using underground methods (see Figure 1). Northern Appalachia is characterized by a small number of underground mines and a large number of very small surface operations.

Central Appalachia includes areas in Southern West Virginia, Virginia, the eastern half of Kentucky, and Northern Tennessee. The coal reserve base is approximately 52 billion tons of bituminous coal, of which 7.9 billion tons are minable by surface methods and 44.1 billion tons are recoverable by underground methods. Production in 1985 was 232.4 million tons of which 72.1 million tons were surface mined (see Figure 2).

Central Appalachia is characterized by a large number of “mom and pop” surface and underground mines. The mines are termed in this way due to the small, informal, family nature of most of the operations.

Southern Appalachia includes the mining areas of Alabama and southern Tennessee. The reserve base totals 4.9 billion tons of bituminous coal split equally between surface and underground mining methods. A 1-billion ton reserve of lignite is not presently mined. Production of bituminous coal in Southern Appalachia totaled 30.1 million tons in 1985 of which 13.9 million tons were surface mined. Southern Appalachia is characterized by a few producers with large capacity underground mines, and medium to small surface mines (see Figure 3).

The Midwest Region includes regions of Illinois, Indiana, and western Kentucky and is also known as the Illinois Coal Basin. The entire 110 billion ton reserve base is bituminous. Of this total, 21 billion tons are surface minable. Coal production in the Midwest totaled 131.4 million tons in 1985 (74.1 million tons surface mined).

The Midwest Region is characterized by large corporate mines. This is particularly true of underground mines. As shown in Figure 4, Midwest surface mines are quite uniformly distributed over a very broad range of annual production values.

Western coal mining is divided into two areas, the Rocky Mountain Region and the Powder River Basin. The Powder River Basin includes Montana and Wyoming. The reserve base ranges from lignite to reasonably high quality bituminous. The total reserve base is 189.4 billion tons, of which 168 billion tons is classified as subbituminous, 16 billion tons as lignite, and 6 billion tons as bituminous. Production in the Powder River Basin totaled 174 million tons in 1985, virtually all of which was surface mined (Figure 5). The Powder River Basin is characterized by very large surface mines, with the largest mines in the United States in this region.

The Rocky Mountain Region includes the states of Colorado, Utah, New Mexico, and Arizona. This region has reserves in four different classifications: anthracite, bituminous, subbituminous, and lignite. Recoverable reserves total 18.5 billion tons, of which 8 billion tons are considered minable by surface methods.

Coal production in the Rocky Mountain Region totaled 61.9 million tons in 1985 of which 42 million tons were surface mined. The total consisted of bituminous and subbituminous coal. Large surface operations and large underground operations characterize the region (see Figure 6).

Tables 1 and 2 provide summary information for the 1985 United States coal production in the Appalachian/Midwest and West regions, respectively.

In summary, the number of mines increases and the average size decreases as one considers U.S. surface coal mines from east to west. The Appalachian Region has many small surface operations while the relatively few western mines are almost all very large. The Midwest Region represents the transition between the two extremes, with surface mines in all size ranges relatively common.

Approximately 50% of the coal surface mined in the United States is from eastern regions, where mines tend to be relatively small. As will be seen in the next section, emissions from eastern SCMs have not been considered to any great extent. Consequently, potential differences in PM emissions due not only to the different size of mines, but also different climate factors in the east, have not been fully characterized.

SECTION 3

OVERVIEW OF EMISSION SOURCES AND MEASUREMENTS AT SURFACE COAL MINES

Throughout the surface mining process—from initial removal of topsoil until final reclamation—particulate matter (PM) may be emitted from a variety of operations. This Section (a) discusses major PM emission sources at surface coal mines and (b) provides a short history of field measurement of those emission sources.

IMPORTANT EMISSION SOURCES

Table 3 summarizes particulate matter emission sources typically found at surface coal mines; the operations listed in the Table are largely sequential. All sources may be present simultaneously throughout different areas at any one mine.

Clearly, PM sources vary in importance not only from one mine to another—depending on, say, strip ratios or the type of equipment used (power shovel, dragline, bucket wheel excavator [BWE])—but also from one time to another at the same mine—for example, when haul distances and hence haulage-related emissions are the greatest.

Several prior studies have examined, in general terms, the relative importance of different emission sources at SCMs. Inventories of hypothetical examples as well as of actual mines indicate that typically over half (roughly 60% to 90%) of the total suspended particulate (TSP) emission rate is due to the following four traffic-related sources:

- scraper travel
- coal haul trucks
- overburden haul trucks
- general (light and medium duty) traffic

Not all of the four sources are necessarily important at every mine. For example, overburden haul trucks are not used at a dragline mine; in that case, overburden removal by dragline becomes far more important. Also, general traffic might not be important at, say, small mines with deep coal seams.

In very general terms, the four traffic-related sources listed above plus overburden removal by dragline should account for roughly 70% of total TSP emissions at most large surface mines.[3]

FIELD MEASUREMENTS AT SURFACE COAL MINES

Since 1973, production in U.S. western mines has more than tripled.[1,2] The expansion is in large part the result of events during the early 1970s: the original Clean Air Act resulted in high demand for low-sulfur western coals, and the 1973 oil embargo stressed the importance of energy independence and spurred mining activities. Thus, the development of large western SCMs was accompanied by a more widespread interest in protecting the environment.

It is not surprising, then, that essentially all of the available field measurement data base (a) dates from the late 1970s and early 1980s and (b) primarily reflects western SCMs. Consequently, two limitations of available data become immediately apparent:

1. Eastern surface coal mines may not be well characterized in terms of emission characteristics. Recall that these mines tend to be substantially smaller in terms of production and disturbed area. In addition, there has long been a suspicion that open dust emission levels differ substantially between the eastern and western United States. This point is discussed further in the next section.
2. Throughout the country, available field measurements generally do not reference the particle size range of current regulatory interest, because of the relatively recent emergence of PM-10 as the basis for the PM NAAQSs. Furthermore, some field measurements have been found to be unreliable in terms of particle size characterization. This, too, is discussed in Section 4.0.

Table 4 summarizes major field measurement studies undertaken to determine emission factors generally applicable for SCMs.[5-8] Note that only two of the test programs considered mines east of the Mississippi River. The PEDCo/MRI study forms the principal basis for EPA's recommended emission factors for western surface coal. These factors are included in Section 8.24 of the EPA publication "Compilation of Air Pollutant Emission Factors," commonly referred to as "AP-42."[9]

Throughout the next section, it is assumed that the reader is familiar with common open dust source measurement techniques such as "upwind/ downwind" and "exposure profiling." Detailed descriptions of open source measurement methodologies are available elsewhere.[10]

The EDS study was conducted to develop PM emission factors for primary surface mining activities. Two mines in the Powder River Basin were considered, with tests conducted between fall 1978 and summer 1979. Emission factors are presented for the following sources:

trucks hauling coal or overburden (with and without watering as a control measure)

coal dumping

train loading

overburden replacement

topsoil removal by scrapers

wind erosion of stripped overburden and reclaimed land

With the exception of haul trucks, emissions were characterized using an upwind/downwind approach; haul truck tests employed exposure profiling. Results are summarized in Table 5. TSP was the particle size range of interest.

This industry-sponsored program paid particular attention to particle deposition and its implications for dispersion modeling. Emission factors are presented not only for at-source conditions, and "apparent" factors are given for distances of 500 and 1,000 m. At-source emission factors have largely been incorporated into AP-42 Section 8.24.

The PEDCo/MRI study was conducted with the express goal of developing emission factor equations for western SCM operations. TSP, IP, SP, and FP were the size ranges of interest. Three mines—in the Fort Union, the Powder River, and the San Juan Fields—were considered over the summer and fall of 1979 and the summer of 1980.

A combination of the exposure profiling, upwind/downwind, and portable wind tunnel sampling methodologies were employed to characterize emissions from the sources listed in Table 6, which summarizes the upwind/downwind and exposure profiling tests emissions testing conducted. Wind tunnel measurements and wind erosion emission factors are described later.

As noted earlier, this study provides most of the experimental basis for AP-42 Section 8.24.

The Skelly and Loy study, conducted as one part of an EPA contract, is the only field program in Table 4 devoted entirely to eastern surface coal mining. Upwind/downwind field measurements were collected over a short, 10-day period to determine TSP emission factors for

haul trucks

drilling/overburden removal/coal loading (considered as one source)

regrading of land where coal had been removed

See Table 7.

The scope and extent of this "screening type" study are much more limited than those for the other programs listed in Table 4. In addition, the authors noted that wind speeds and haul truck travel speeds were substantially higher than in the western studies. Consequently, it is very difficult to interpret the Skelly & Loy emission factors that are roughly an order of magnitude greater than corresponding western results. At the very least, however, this study indicates a need for further characterization of PM emissions at eastern SCMs.

The scope of the PEDCo/BuMines study was much more focused than the other studies in Table 4. While the other programs considered several emission sources, this program was undertaken to determine the efficiency and cost-effectiveness of dust controls applied to SCM haul roads. Tests were conducted at three mines—including one east of the Mississippi—during the summer and fall of 1982. Types of controls considered included: salts, surfactants, adhesives, bitumens, films, and plain water. Table 8 summarizes results of this test program.

Three points should be noted about this study. First, the report states that, because of the emphasis on control efficiencies, there was no attempt made to develop general emission factors for unpaved haul roads.

Second, exposure profiling measurements were made using stacked filtration units (SFUs). The SFUs were designed to produce data for the SP and FP size fractions. However, an independent contractor has found that the SFU collection media were selected on the basis of pore size and collection efficiency was not verified through calibration. A 1985 collaborative study of five different exposure profiling systems found that, as samples are collected, SFUs become more efficient. As a consequence, concentration and emission factors are systematically underestimated.[12,13] Overall, the independent evaluation concluded that SFUs could not be recommended for open dust emission characterization. As a result, this independent emissions data base is of little value in judging the "predictive accuracy" of haul road emissions factors.

Finally, much of the control efficiency data in the PEDCo/BuMines exhibit anomalous behavior, such as showing increased efficiency over time. It is believed that much of this is due to the fact that control efficiencies were not referenced to dry, uncontrolled emissions. A 1987 update to Section 11.2 of AP-42 demonstrated the regulatory importance of referencing unpaved road efficiency to worst-case conditions.[13]

Besides studies specifically directed toward surface coal mines, other field programs have produced emission factors that are applicable to a wide range of sources at SCMs. Field tests have been conducted on public roads as well as in various industries, including coal-fired power plants, iron and steel plants, stone quarrying, mining, and smelting operations. The results of these tests have been incorporated into "generic" emission factor models.

Section 11.2 of AP-42 presents generic open dust emission factors which can be applied to the following SCM sources

- scraper travel
- material handling activities for topsoil, overburden, and coal

- haul roads for both overburden and coal
- loading and unloading of trucks
- loadout for transit
- general traffic

Note that generic emission factors are available for the four or five most important emission sources identified earlier.

Finally, as part of a recently completed study for the State of Arizona, MRI conducted a critical review of unpaved road emission estimations.[14] The review encompassed the PEDCo/MRI data.[6] Pertinent results from this study are discussed in the next section.

SECTION 4

EMISSION FACTORS FOR USE AT SURFACE COAL MINES

The preceding Section described common PM emission sources and past field measurement efforts at SCMs. This Section first describes EPA guidance on emission estimation for SCMs and then presents a critical review of available emission factors.

AP-42 EMISSION FACTORS AND PREDICTIVE EQUATIONS

EPA publication AP-42, "Compilation of Air Pollutant Emission Factors," represents official agency guidance on the emission factors to be used for a wide variety of process, open, and mobile emission sources. Section 8.24 of AP-42, entitled "Western Surface Coal Mining," presents numerous predictive equations and single-valued emission factors for use at western SCMs. Figures 7 and 8 reproduce AP-42 Tables 8.24-2 and 8.24-4, respectively.

The western SCM emission factor equations presented for TSP and IP in Figure 7 are, almost without exception, the results from the PEDCo/MRI field study (Tables 4 and 7). Changes since the Section was originally prepared in 1983 have (a) revised the equation for blasting and (b) added PM-10 scaling factors for use with the IP emission equations. Quality ratings are generally high, with most equations rated "A" (excellent) or "B" (above average).[15]

The single-valued emission factors given in Figure 8 were developed from the data of three field studies: PEDCo/MRI, EDS, and an early screening study performed by PEDCo for EPA Region VIII. That screening study surveyed 12 operations at 5 different mines (denoted by Roman numerals in Table 8.24-4). Although that report presented emission factors, it made no attempt to develop generally applicable emission factors. Quality ratings for the single-valued emission factors are generally low; most factors are rated between "C" (average) and "E" (poor). For many of the sources, the reader is encouraged to use the "generic" emission factors found in Section 11.2 of AP-42.

Taken together, Figures 7 and 8 represent official EPA guidance on estimating particulate emissions at surface coal mines. Quality ratings are to be decreased one letter grade (e.g., from B to C) if the factors are applied to an eastern mine.

EVALUATION OF ALTERNATIVE EMISSION FACTORS

In this section, PM emission sources at SCMs are considered one by one, in the same order as Table 3. Emission factors available for each source are then discussed. Strengths and weaknesses of the factors emphasized, and implications for future testing are also discussed.

The emission factors and predictive equations have been assigned numbers for convenience; these are shown in Tables 9 and 10.

Topsoil Related Activities

Removal—The two emission factors identified for this operation (numbers 2.a and 2.b in Table 10) are already included in AP-42. Both factors have low quality ratings; in keeping with the general guidance given in Section 8.24, the value of 0.058 lb/ton is preferred because of fewer restrictions on its use.

All testing has been performed at western SCMs, and the applicability of the factor to eastern mines has not yet been established. However, because topsoil removal tends to be a relatively minor operation in terms of PM emissions—less than 1% of the total—it appears that further characterization of this source is not as critical as for other sources.

Scraper travel—Recall that this was earlier identified as one of the four or five most important emission sources at SCMs. The two emission factors available for this source are:

- the scraper equation (numbers 5.a and 5.b in Table 9) developed during the PEDCo/MRI study and included in Section 8.24
- the general unpaved road emission factor (number 5.c in Table 9) presented in Section 11.2.1 of AP-42

With the exception of an essentially linear dependence on silt content, the models bear little resemblance to one another. In general, the AP-42 emission factor model developed during the PEDCo/MRI study is recommended for use at western surface coal mines.

Note, however, that over the past 15 years numerous investigators have questioned the ability of unpaved road emission factors developed from tests in the eastern United States to adequately predict emissions in the west. A recent field study of unpaved roads in Arizona, however, found no evidence to support contentions that western unpaved travel emissions are systematically underpredicted.

In the case of scrapers, however, that question can be turned around to: Do tests conducted at western SCMs tend to adequately predict emissions at eastern mines? Although the applicability of the model to eastern mines has never been empirically demonstrated, the AP-42 model is also generally recommended for eastern mines.

In a larger sense, the AP-42 Section 8.24 emission factor models suffer from a lack of independent test data against which model performance can be assessed. In other words, all available test data were used to develop the emission factor models. As a result, there are no data available to compare measured emission factors against calculated values.

At a minimum, then, a limited field study of not only scraper but all other travel-related emissions at eastern mines is needed to gauge the applicability of the AP-42 emission factors. In the larger sense, however, the collection of independent test data (at both eastern and western mines) is important to assess model performance. The need for independent assessment grows as the relative importance of the emission source increases. Consequently, the theme of independent data will be repeated throughout this report for the four or five most important sources identified earlier.

Material handling, storage, and replacement activities—Only one emission factor (number 7.a in Table 10) specifically addressing topsoil handling was found. This factor dates from an early Region VIII screening study and is restricted in AP-42 as applicable to SCMs similar to a lignite mine in North Dakota. However, Table 8.24-4 suggests that the generic material handling predictive equation in Section 11.2.3 (number 2.c or 4.c in Table 9) should result in greater accuracy. The generic equation should also be more applicable to eastern mines, and is recommended for general use.

This source is a relatively minor contributor to PM emissions at SCMs and the need for further study is less critical than for other sources.

Overburden Related Activities

Drilling—In addition to the single-valued emission factors developed during the PEDCo/MRI study (number 1.a in Table 10), the Skelly & Loy study presents an emission factor for combined D/OR/CL—"drilling/overburden removal/coal loading" (number 2.d in Table 9). Because the Skelly & Loy value is for combined sources, the single-valued factor (number 1.a) for overburden drilling is recommended. Again, this factor has not been shown to be applicable to eastern mines. Drilling emissions are relatively small contributions to total PM emissions at surface mines, and further field study is not considered critically important at this time.

Blasting—Only a TSP emission factor for blasting is available at this time. This equation (number 1.b in Table 9) is the result of a 1987 reexamination of certain sources in AP-42 Section 8.24 and replaced the earlier expression (number 1.a in Table 9). The factor has not been shown to be applicable to eastern mines. The contribution of blasting to total PM emissions at surface mines is usually small, so use of a TSP factor to estimate PM-10 emissions should not be overly restrictive. Furthermore, blasting presents formidable logistical difficulties in sampling; consequently, further field study is not recommended at this time.

Removal—For overburden removal without draglines, two emission factors were identified (number 4.a in Table 10 and the combined D/OR/CL emission factor from Skelly & Loy). The Skelly & Loy value is, of course, combined with other sources and is based on removal by front-end loaders instead of power shovels. AP-42 restricts the use of the 0.037 lb/ton to specific mine locations. Again, Table 8.24-4 of AP-42 suggests that the generic material handling predictive equation in Section 11.2.3 (number 2.c in Table 9) should result in greater accuracy. The generic equation should also be more applicable to eastern mines, and is thus recommended for general use.

The AP-42 generic material handling equation was recently updated and the need for further study is not believed to be critical at present.

For dragline mines, there are two potentially available emission factors

- the dragline equation (number 4.b in Table 9) developed during the PEDCo/MRI and included in Section 8.24
- the general material handling emission factor (number 4.c in Table 9) presented in Section 11.2.3 of AP-42

In general, the AP-42 dragline emission factor is recommended for both western and eastern dragline mines. At a minimum, a limited field study is needed to assess the applicability of the emission factor to eastern mines. Because this can be one of the four or five most important PM sources at dragline mines, there is a need for additional field tests (at both eastern and western mines) to independently assess model performance.

Haul trucks—No fewer than four forms of emission factors (numbers 8.a through 8.e in Table 9) were found for this source. The interest in this PM source should not be particularly surprising because it is often one of the two most important PM contributors at truck-shovel mines. The two single-valued factors (8.c and 8.e) are not recommended for general use. Thus, the emission factors considered potentially applicable to this source are:

- the haul truck equation (numbers 8.a and 8.b in Table 9) developed during the PEDCO/MRI study and included in Section 8.24
- the general unpaved road emission factor (number 8.d in Table 9) presented in Section 11.2.1 of AP-42

As was the case with scrapers, the two models bear little functional resemblance to one another. The recent Arizona study found that the generic unpaved road equation tends to over predict haul truck emissions measured at western SCMs.[14] In general, then, the AP-42 Section 8.24 emission factor models developed are recommended for use at both eastern and western surface coal mines.

This recommendation is, however, provisional in that additional independent data are critically needed. That is, while something is known about the unpaved road equation, nothing is known about the performance of the Section 8.24 model when applied either to eastern mines or to independent data from western mines. (Because of problems noted earlier about sampler design, the PEDCo/BuMines study results do not provide reliable data for model validation purposes.) Because overburden and coal haul trucks can account for up to half of the total PM emissions at surface coal mines, independent quantitative assessment of the available models should be an important objective of any future field effort.

At a minimum, then, field study of haul truck emissions at eastern mines should be considered in future field efforts. In addition, collection of independent test data (at both eastern and western mines) is important to provide a gauge of model performance.

Material handling and storage activities—As with topsoil operations, the generic material handling equation (number 2.c in Table 9) should be more applicable to a broad range of SCMs and is recommended for general use. This source is a relatively minor contributor to PM emissions at SCMs and the need for further study is less critical than for other sources. Note, however, that overburden tends to have moisture contents outside the range of the generic equation. Some limited testing is suggested to determine the accuracy of the equation in those applications.

Replacement—For truck-shovel operations, this can be a relatively important PM emission source. Only one directly applicable factor (0.012 lb/ton, number 3.a in Table 10) was found; this value represents TSP results from western SCMs. In general, emissions from this source should be fairly accurately estimated using the generic material handling equation, which is potentially applicable to a wide range of mines and material characteristics. Because of the importance of this source at truck-shovel mines, further field characterization study is strongly suggested.

Dozer activities—Only the PEDCo/MRI study has tested emissions from dozers at SCMs. The results were combined into the predictive emission equation (numbers 3.a and 3.b in Table 9) presented in Section 8.24. Those models are recommended for both western and eastern mines.

The dozer equations result in emission rates (i.e., lb/hr) rather than emission factors. The use of a rate has hindered application of the equation to other types of particulate sources—most notably, landfills and remediation sites— which may not share the same dozer operating patterns with SCMs.[17]

Because dozers can account for a reasonably important fraction (approximately 1% to 3% each for overburden and coal) of emissions at SCMs, some additional field study is recommended. At a minimum, the applicability of the dozer equation to eastern mines should be addressed. It is recommended that field results be expressed in terms of emission factors (instead of rates) to facilitate transfer of the results to other emission sources.

Coal Activities

Drilling—Material presented earlier in connection with the drilling of overburden is equally applicable here. The single-valued factor for coal drilling (number 1.b in Table 10) is recommended. Although the factor has not been shown to be applicable to eastern mines, drilling can be expected to be a relatively small contributor to the total PM emission rate. Further field study is not considered critically important at this time.

Blasting—Again, material presented earlier for overburden is equally applicable here. The reexamined TSP equation (number 1.b in Table 9) is recommended. Because of logistical difficulties in sampler deployment, further field study is not recommended at this time.

Coal loading—Two emission factors pertaining specifically to SCMs were identified: the PEDCo/MRI equation presented in AP-42 and the Skelly & Lay combined "D/OR/CL" factor. The Skelly & Loy value is based on a screening study of several simultaneous sources; its general use is not recommended. In addition, the generic materials handling equation is potentially applicable to this source.

The similarity between the models numbered 2.a/2.b, and 2.c ends at their functional dependence on moisture. There is no overlap in the moisture values contained in the data bases supporting the two models; the generic factor is based on tests of dry materials (approximately 0.25% to 5% moisture) while the SCM data base has moisture contents ranging from 6.6% to 38%. Emission factors calculated from the two models can easily differ by an order of magnitude or more.

The difficulty in reliably estimating coal loading emissions should not be particularly surprising because that source exhibited high variability during the test program. The test report noted that coal loading data were more variable than the other data and that uncertainty in predictions is proportionately greater.[6] Over a total 25 tests at three mines, the relative standard deviation (or, coefficient of variation) was 210 percent, or roughly twice that of any other source tested. At one mine, the mean measured emission factor was an order of magnitude greater than the mean at the other two mines.

The generic materials handling equation (number 2.c in Table 9) was recently reexamined and was found to predict reasonably well TSP emissions from a rotary coal car dumper at a power plant.[13,18] That factor, on the other hand, is not based on any field tests conducted at SCMs; its applicability to coal loading at mines has not been demonstrated.

In general, it is recommended that an emission factor appropriate to a coal loading operation be based on the moisture content of the coal being loaded. For moisture contents greater than 5 %, models labeled as 2.a/2.b in Table 9 are recommended. For coals with lower moisture contents, the model 2.c in the Table is suggested. The reader is cautioned that the appropriate input value is surface moisture content, which can be determined by oven drying for approximately 1.5 hr at 110°C. Longer drying times for coal can result in the loss of bound moisture, yielding an overestimated surface moisture content.

Although coal loading tends to contribute only slightly to the total emissions at SCMs, there is often confusion and/or debate as to appropriate emission factors and input variables (i.e., surface versus bound moisture contents). Furthermore, emissions have been found to vary widely between mines. Reexamination of this source is recommended for any future field studies.

Truck haulage—The remarks about further study made in connection with overburden haul trucks are equally applicable here.

Truck unloading—Table 8.24-4 of AP-42 (see Figure 8) provides several factors for coal truck unloading, depending upon the type of truck dump or upon mine type (Roman numerals I through V). The table further suggests that the generic material handling predictive equation in Section 11.2.3 (number 2.c in Table 9) should result in greater accuracy. The generic equation should also be more applicable to eastern mines and is recommended for general use. Recall that the generic equation performed satisfactorily when applied to independent coal car dumping test data. Truck unloading tends to be a minor contributor to total mine emissions and further field study is not critically needed at this time. However, collection of some field data with higher moisture contents is recommended.

Material handling and storage activities—As with topsoil and overburden operations, the generic material handling equation (number 2.c in Table 9) should be more applicable to a broad range of SCMs and is recommended for any intermediate handling operations. This source is a relatively minor contributor to PM emissions at SCMs and the need for further study is less critical than for other sources.

Dozer activity—Remarks made earlier concerning this source and the need for further study are equally applicable here.

Loadout for train transit—Table 8.24-4 of AP-42 (see Figure 8) provides two factors for train loading. In general, however, the generic material handling predictive equation is recommended. Again, recall that the generic equation (a) should be more applicable to eastern mines and (b) satisfactorily predicted coal car dumping test results.

General Activities

General (medium/light-duty) vehicle travel—Three emission factor equations were identified as applicable for general vehicle travel:

- the general vehicle expressions developed during PEDCo/MRI and included in AP-42 Section 8.24 (numbers 7.a and 7.b in Table 9)
- the generic unpaved road emission factor included in AP-42 Section 11.2.1 (number 7.c in Table 9)
- recently developed models for light-duty (nominally 4 wheel, 35 to 55 mph, and 2 tons) vehicles on Arizona unpaved roads under dry conditions (numbers 7.d and 7.e in Table 9)

Unlike other travel-related sources under consideration here, independent emissions test data are available to examine the Section 8.24 model. When applied to the independent data from Arizona and Colorado (with average moisture contents around 0.2%), the Section 8.24 model overpredicted by two orders of magnitude. This is at least partially the result of the narrow range of moisture contents (0.9% to 1.7%) in Section 8.24 data base.

As part of the Arizona study, a review of historical data revealed no evidence on the part of the-Section 11.2.1 unpaved road model to systematically underpredict emissions from western roads.

Because of the demonstrated weakness of the Section 8.24 model, the following recommendations have been made for estimating emissions from general traffic at SCMs:

1. The "Arizona" models (numbers 7.d and 7.e in Table 9) are recommended for light vehicles (less than 3 tons) traveling at least 35 mph on unpaved roads in arid portions of the western United States.
2. For other situations, the generic unpaved road model (number 7.c in Table 9) is recommended.

Because general traffic can account for a large portion of the total PM emissions at a SCM, collection of additional field test data (at both eastern and western mines) should be an important objective of any future field effort.

Road grading—Two emission factors were found for this source: the model from the PEDCo/MRI study included in Section 8.24 (numbers 6.a/6.b in Table 9) and the single-valued factor of 54 lb/hr from the Skelly & Loy program (number 6.c in Table 9). The general use of the Section 8.24 model is recommended. Recall that these factors have not been shown to be applicable to eastern mines.

In addition, the generic unpaved road equation from AP-42 Section 11.2.1 has been shown to conservatively overestimate the measured grading emission factors. Because grading typically represents a minor contributor to total PM emissions, the overestimation is probably not overly restrictive. Further field study of grading emissions is not as critical as for other emission sources at present. Any future testing of graders should emphasize eastern mines.

Wind erosion (open areas, storage piles)—Wind erosion of particulate has been recently reexamined, and a new Section of AP-42 (Section 11.2.7, Industrial Aggregate Wind Erosion) prepared.[9] Because substantially over half of underlying data are from coal piles at SCMs, and at end-user locations, the need for future field study is not critical at this time. Any future testing should focus on eastern mines.

SECTION 5

SUMMARY AND RECOMMENDATIONS

Table 11 summarizes the results from a review of available field measurements from surface coal mines, and discusses suggested field testing. For each anthropogenic emission source, an emission factor is suggested.

Overall, the recommendations follow the guidelines presented in Section 8.24 of AP-42; the most notable exception is that for general light- to medium-duty traffic. For this source, independent test data allowed an objective evaluation and selection based on the performance of available emission models. For the reader's convenience, recommendations are either shown in boldface or are underlined.

Although a method has been recommended to estimate emissions for each major PM source at SCMs, additional testing should be considered necessary to address major shortcomings in the data base. The following paragraphs present general conclusions and recommendations.

1. Although mines in the east account for half of the coal surface mined in the United States, particulate emission sources at those mines have not been well characterized. In general, eastern surface coal mines are smaller but more numerous than mines west of the Mississippi. Eastern mines have only begun to be considered in terms of not only particulate emissions, but also operating characteristics that affect emission levels.

   There have long been suspicions that emission factors developed from eastern tests underestimate emissions in the west. In the case of SCMs, the question becomes turned around to: Can test results from western SCMs tend to adequately predict emissions at eastern mines? That is, how applicable are the AP-42 Section 8.24 emission factors to the eastern United States? At a minimum, then, some eastern field verification of the AP-42 SCM emission factors is necessary.

2. Applicability to eastern mines notwithstanding, it is unknown how well most of the AP-42 SCM factors perform in a general sense. Essentially all available test data were used in developing the Section 8.24 factors. Thus, there are no independent data against which calculated emission factors can be objectively compared. The lack of independent test data represents a limitation on the use of the SCM factors in both eastern and western mines.

The need for independent assessment grows as the relative importance of the emission source increases. Consequently, the theme of independent data is repeated throughout Table 11 for the most important (in terms of contribution to total emission levels) sources.

3. Because most SCM field measurements were made during the late 1970s and early 1980s, data generally reflect a particle size range other than PM-10. The PM-10 emission factors presented in AP-42 Section 8.24 are actually scaled IP factors, with the scaling based on size data presented for the generic emission factors presented in Section 11.2. At a minimum, limited field verification of PM-10 emission factors at eastern and western SCMs should be considered necessary.

4. In keeping with the guidance provided in AP-42 Section 8.24, the generic equation of Section 11.2.3 has been recommended for many of the materials handling operations. That equation has been recently updated and has been found to satisfactorily predict TSP emissions from coal dumping operations. Nevertheless, because so many of material handling operations at SCMs involve materials with surface moisture contents outside the range of the Section 11.2.3 factor, Table 11 suggests that additional field testing be conducted.

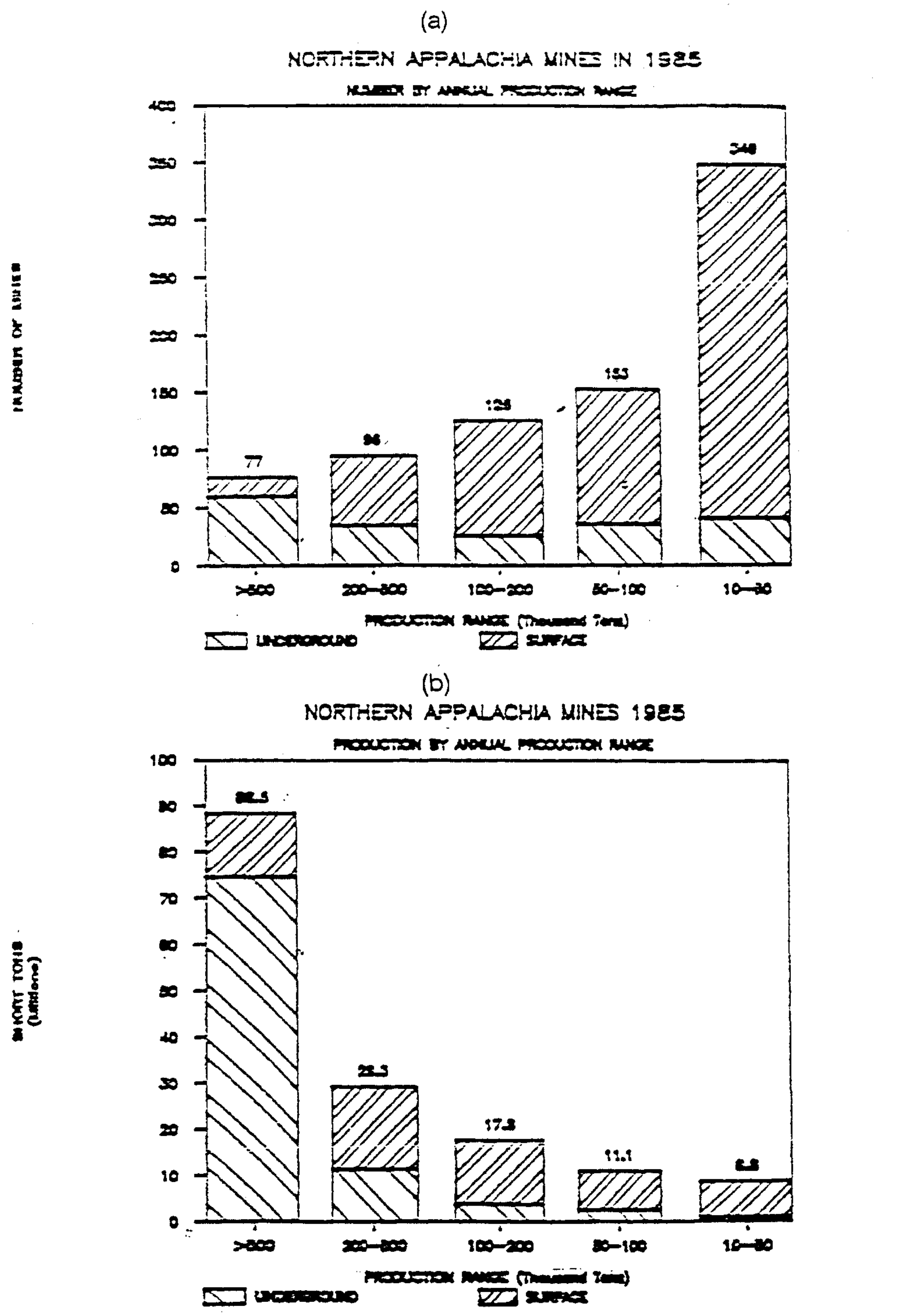


Figure 1. Histograms showing (a) number of mines and (b) total amount production as a function of mine size for the Northern Appalachia Region in 1985. From Reference 3.

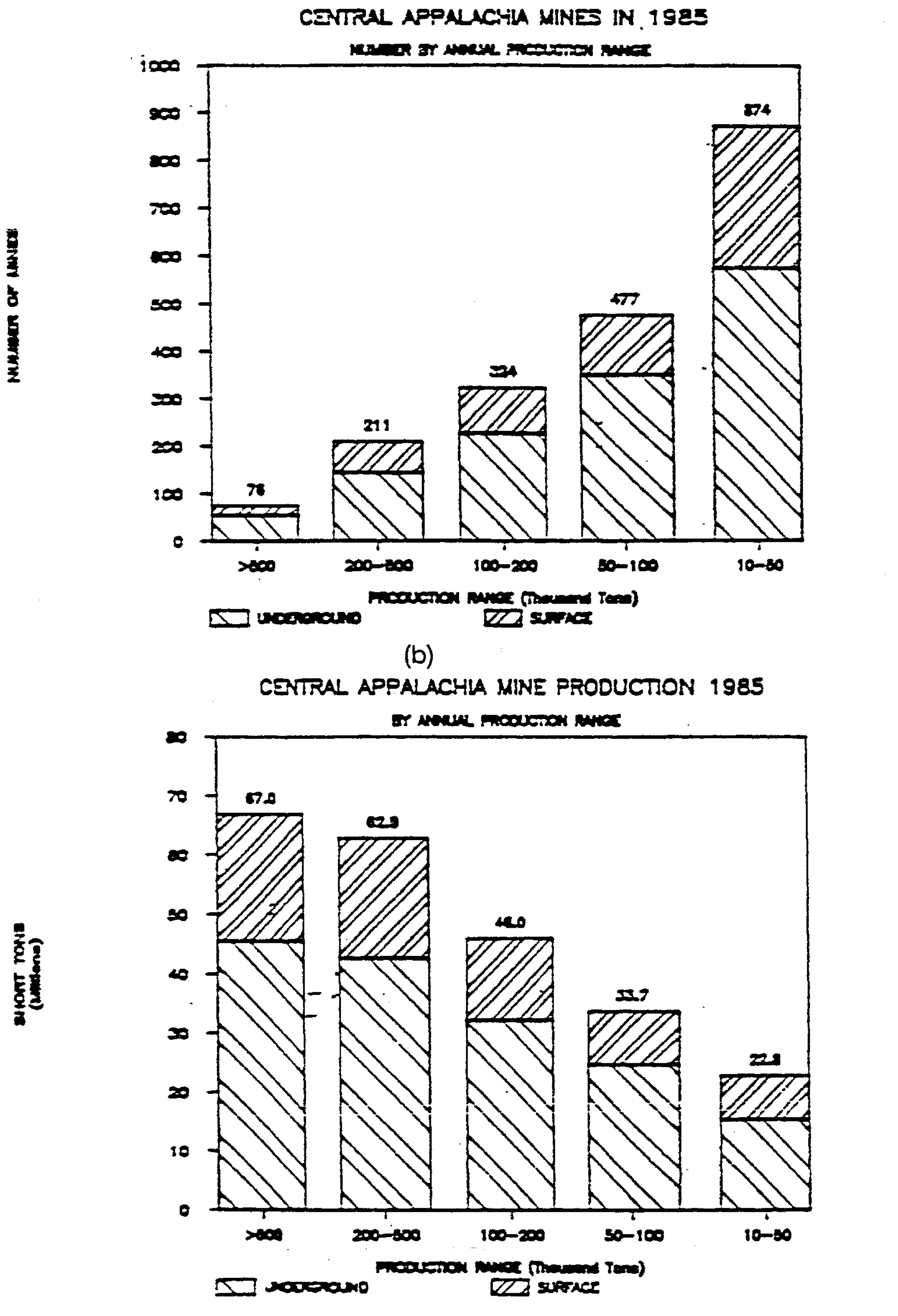
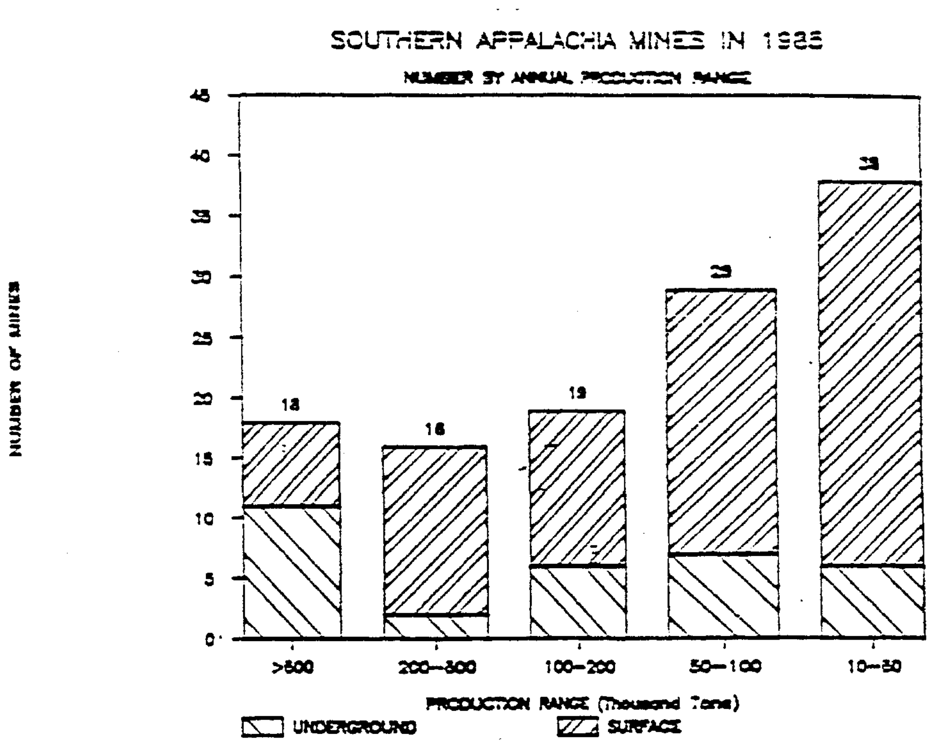


Figure 2. Histograms showing (a) number of mines and (b) total amount production as a function of mine size for the Central Appalachia Region in 1985. From Reference 3.



(b)

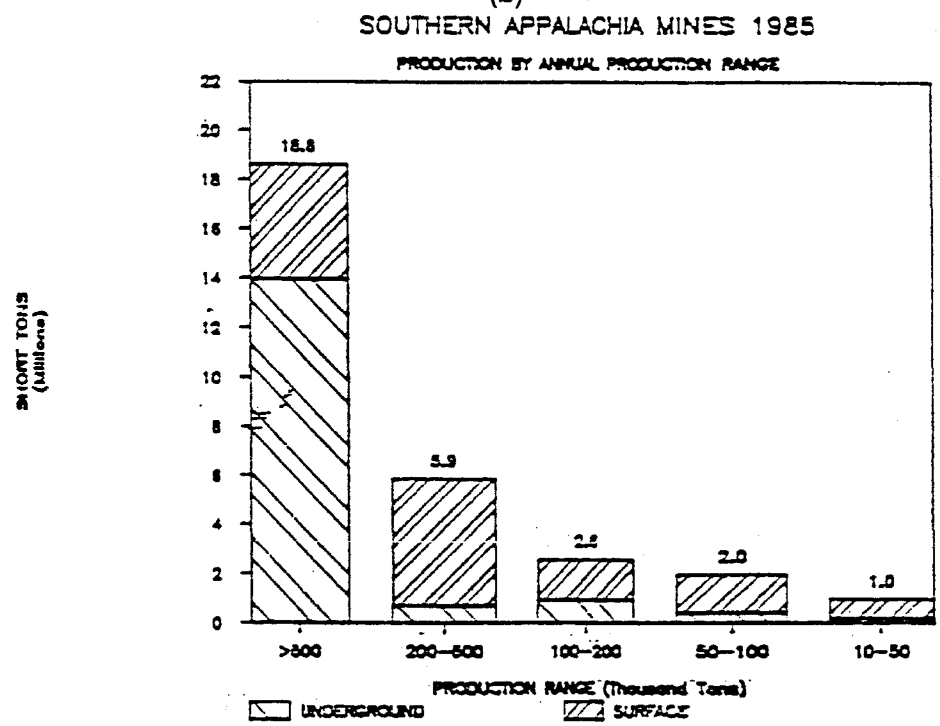
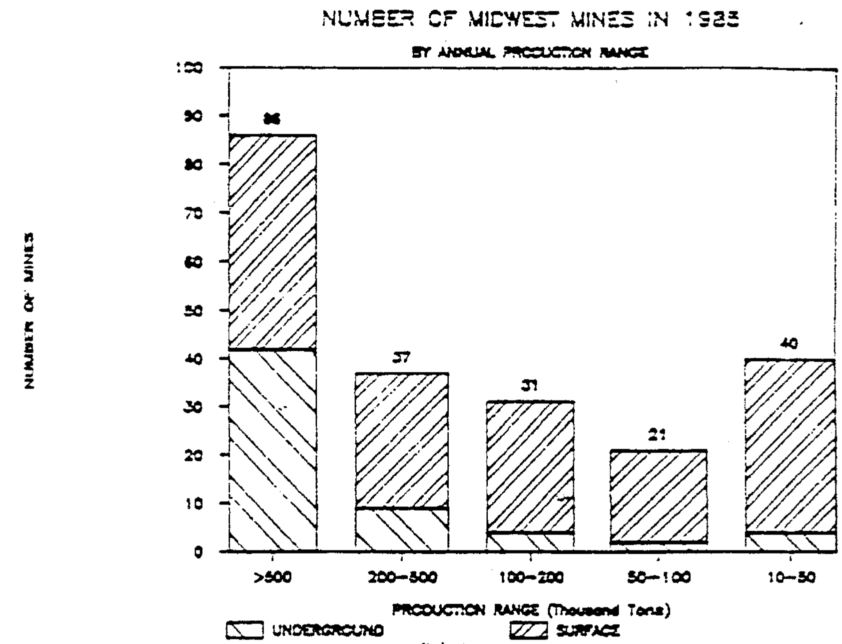


Figure 3. Histograms showing (a) number of mines and (b) total annual production as a function of mine size for the Southern Appalachia Region in 1985. From Reference 3.



(b)

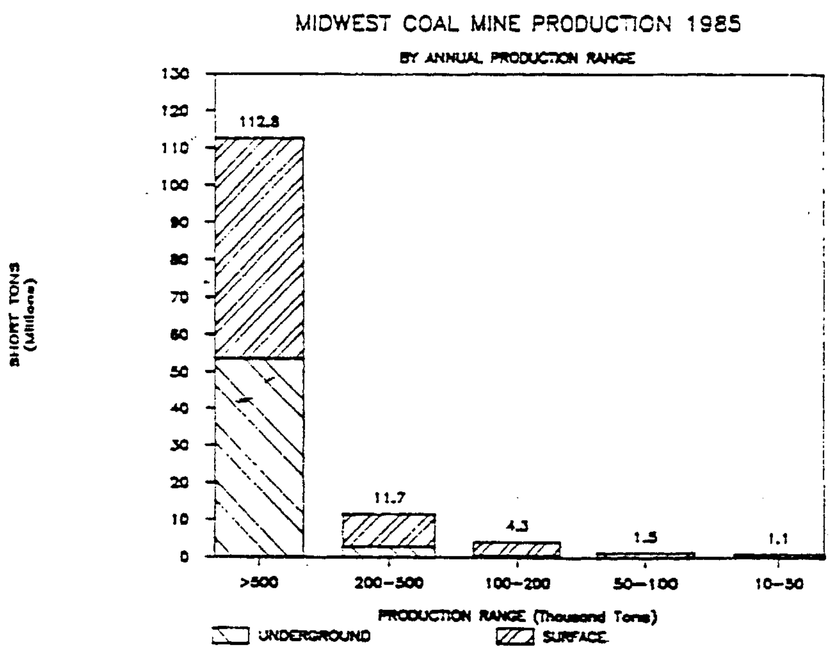


Figure 4. Histograms showing (a) number of mines and (b) total annual production as a function of mine size for the Midwest Region in 1985. From Reference 3.

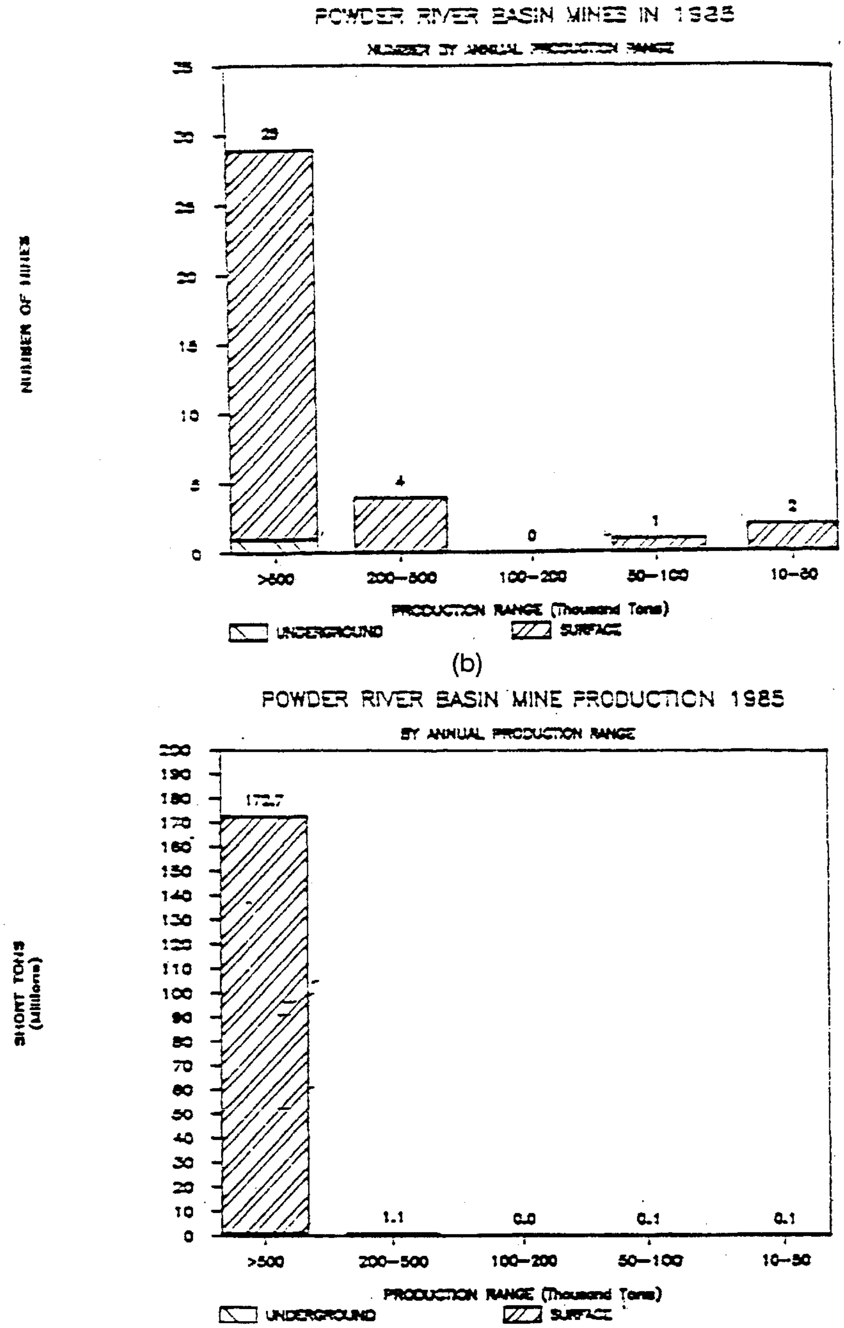
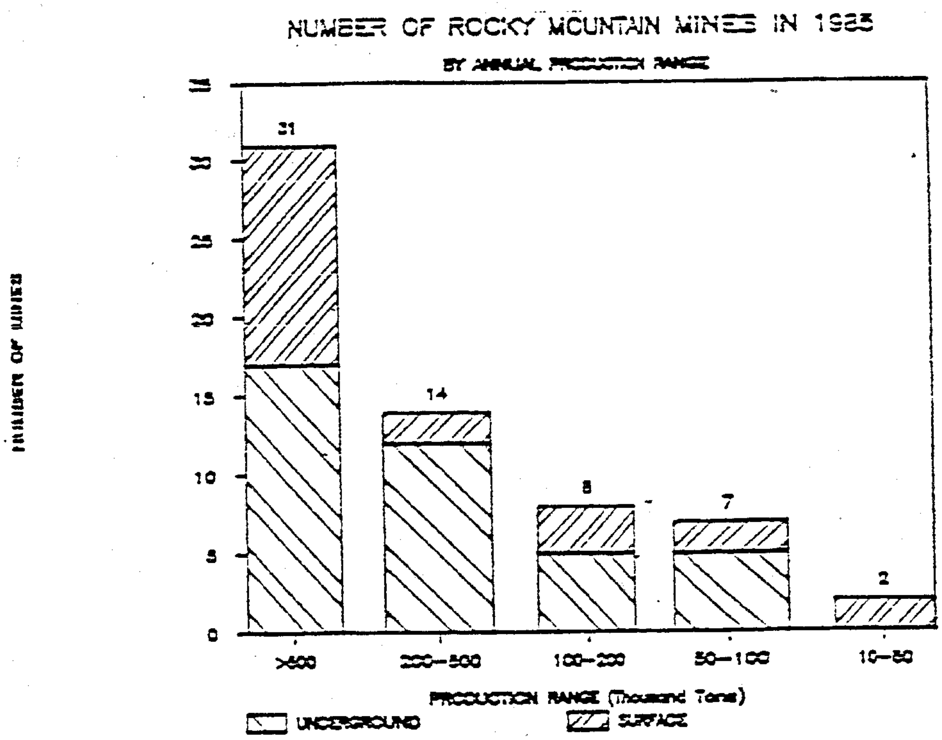


Figure 5. Histograms showing (a) number of mines and (b) total annual production as a function of mine size for the Powder River Basin in 1985. From Reference 3.



(b)

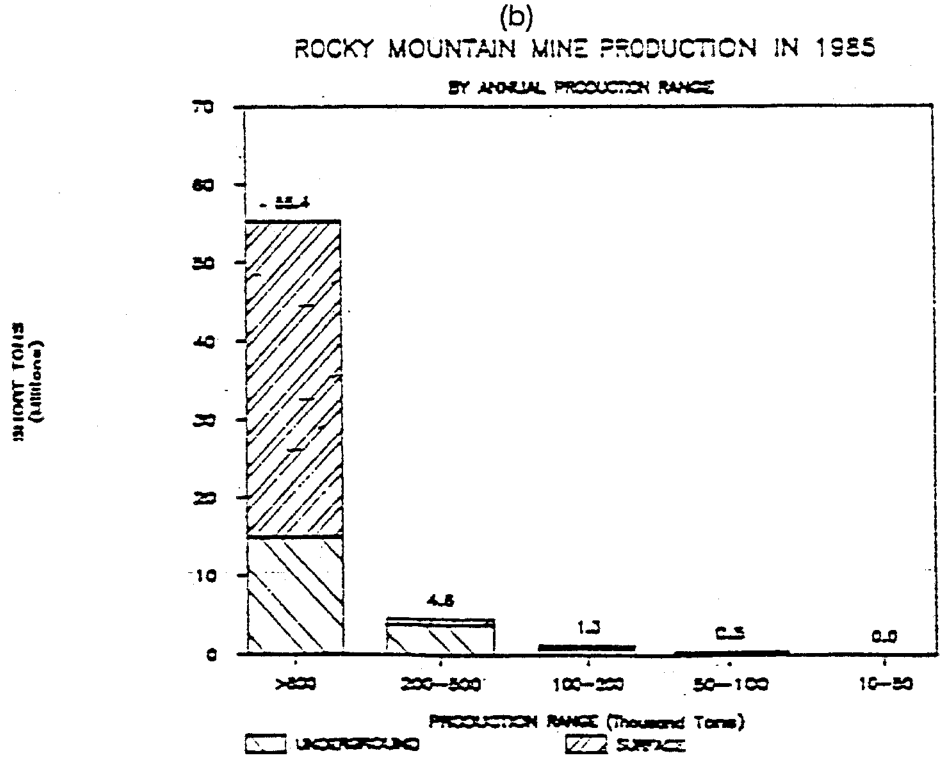


Figure 6. Histograms showing (a) number of mines and (b) total amount production as a function of mine size for the Rocky Mountain Region in 1985. From Reference 3.

TABLE 8.24-2. EMISSION FACTOR EQUATIONS FOR UNCONTROLLED OPEN DUST SOURCES AT WESTERN SURFACE COAL MINES (ENGLISH UNITS)[a]

Operation	Material	Emissions by particle size range (aerodynamic diameter)[b,c] TSP $\leq$30 um	$\leq$15 um	$\leq$10 um[d]	$\leq$2.5 um/TSP[e]	Units	Emission Factor Rating
Blasting	Coal or overburden	$0.0005A^{1.5}$	NA	0.52[e]	NA	lb/blast	C
Truck loading	Coal	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.75	0.019	lb/ton	B
Bulldozing	Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.75	0.022	lb/hr	B
	Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.75	0.105	lb/hr	B
Dragline	Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021\ (d)^{0.7}}{(M)^{0.3}}$	0.75	0.017	lb/yd^3	B
Scraper (travel model)		$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.60	0.026	lb/VMT	A
Grading		$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.60	0.031	lb/VMT	B
Vehicle traffic (light/medium duty)		$\frac{5.79}{(M)^{4.0}}$	$\frac{3.72}{(M)^{4.3}}$	0.60	0.040	lb/VMT	B
Haul truck		$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.60	0.017	lb/VMT	A
Active storage pile (wind erosion and maintenance)	Coal	1.6 u	NA	NA	NA	$\frac{lb}{(acre)(hr)}$	C[f]

[a]Reference 1, except for coal storage pile equation from Reference 4. TSP = total suspended particulate. VMT = vehicle miles traveled. NA = not available.
[b]TSP denotes what is measured by a standard high volume sampler (see Section 11.2).
[c]Symbols for equations:

- A = horizontal area, with blasting depth $\leq$70 ft. Not for vertical face of a bench
- M = material moisture content (%)
- s = material silt content (%)
- u = wind speed (m/sec)
- d = drop height (ft)
- W = mean vehicle weight (tons)
- S = mean vehicle speed (mph)
- w = mean number of wheels
- L = road surface silt loading (g/m^2)

[d]Multiply the $\leq$15 um equation by this fraction to determine emissions.
[e]Multiply the TSP predictive equation by this fraction to determine emissions in the $\leq$2.5 um size range.
[f]Rating applicable to Mine Types I, II and IV (see Tables 8.24-5 and 8.24-6).

Figure 7. Copy of the AP-42 Table 8.24-2, presenting emission factor equations for SCMs.

TABLE 8.24-4. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR OPEN DUST SOURCES AT WESTERN SURFACE COAL MINES

Source	Material	Mine location[a]	TSP emission factor[b]	Units	Emission Factor Rating
Drilling	Overburden	Any	1.3	lb/hole	B
			0.59	kg/hole	B
	Coal	V	0.22	lb/hole	E
			0.10	kg/hole	E
Topsoil removal by scraper	Topsoil	Any	0.058	lb/T	E
			0.029	kg/Mg	E
		IV	0.44	lb/T	D
			0.22	kg/Mg	D
Overburden replacement	Overburden	Any	0.012	lb/T	C
			0.0060	kg/Mg	C
Truck loading by power shovel (batch drop)[c]	Overburden	V	0.037	lb/T	C
			0.018	kg/Mg	C
Train loading (batch or continuous drop)[c]	Coal	Any	0.028	lb/T	D
			0.014	kg/Mg	D
		III	0.0002	lb/T	D
			0.0001	kg/Mg	D
Bottom dump truck unloading (batch drop)[c]	Overburden	V	0.002	lb/T	E
			0.001	kg/T	E
	Coal	IV	0.027	lb/T	E
			0.014	kg/Mg	E
		III	0.005	lb/T	E
			0.002	kg/Mg	E
		II	0.020	lb/T	E
			0.010	kg/Mg	E
		I	0.014	lb/T	D
			0.0070	kg/Mg	D
		Any	0.066	lb/T	D
			0.033	kg/Mg	D
End dump truck unloading (batch drop)[c]	Coal	V	0.007	lb/T	E
			0.004	kg/Mg	E
Scraper unloading (batch drop)[c]	Topsoil	IV	0.04	lb/T	C
			0.02	kg/Mg	C
Wind erosion of exposed areas	Seeded land, stripped overburden, graded overburden	Any	0.38	$\frac{T}{(acre)(yr)}$	C
			0.85	$\frac{Mg}{(hectare)(yr)}$	C

[a] Roman numerals I through V refer to specific mine locations for which the corresponding emission factors were developed (Reference 4). Tables 8.24-4 and 8.24-5 present characteristics of each of these mines. See text for correct use of these "mine specific" emission factors. The other factors (from Reference 5 except for overburden drilling from Reference 1) can be applied to any western surface coal mine.

[b] Total suspended particulate (TSP) denotes what is measured by a standard high volume sampler (see Section 11.2).

[c] Predictive emission factor equations, which generally provide more accurate estimates of emissions, are presented in Chapter 11.

8.24-8 EMISSION FACTORS 9/88

Figure 8. Copy .of AP-42 Table 8.24-4, presenting single-valued emissions factors for SCMs.

TABLE 1. EASTERN AND MIDWESTERN UNITED STATES COAL PRODUCTION STATISTICS

Eastern coal production (tons x 10^3)						Average mine size (tons/yr)	
Region	Total	Underground	Percent of total (%)	Surface	Percent of total (%)	Underground	Surface
Northern Appalachia	155,532	93,367	60.0	62,165	40.0	472,000	103,000
Central Appalachia	232,380	160,296	69.0	72,083	31.0	127,000	108,000
Southern Appalachia	30,122	16,233	53.9	13,889	46.1	507,000	158,000
Midwest	131,415	57,303	43.6	74,112	56.4	939,000	481,000
Pennsylvania Anthracite	4,281	440	10.3	3,841	89.7	49,000	55,000
Totals	553,730	327,639	59.2	226,091	40.8	--	--

TABLE 2. WESTERN UNITED STATES COAL PRODUCTION STATISTICS

Eastern coal production (tons x 10^3)						Average mine size (tons/yr)	
Region	Total	Underground	Percent of total (%)	Surface	Percent of total (%)	Underground	Surface
Rocky Mountain	61,876	19,925	32.2	41,951	67.8	510,000	1,824,000
Powder River Basin	173,997	1,058	0.6	172,939	99.4	1,058,000	4,941,000
Totals	235,873	20,983	8.8	214,890	91.2	--	--

TABLE 3. SUMMARY OF MAJOR EMISSION SOURCES AT SURFACE COAL MINES

Topsoil related activities ▸ Removal ▸ **Scraper travel** ▸ Material handling and storage activities ▸ Replacement
Overburden related activities ▸ Drilling ▸ Blasting ▸ **Removal** ▸ **Truck haulage** ▸ Material handling and storage activities ▸ Replacement ▸ Dozer activity
Coal seam activities ▸ Drilling ▸ Blasting ▸ Loading ▸ **Truck haulage** ▸ Truck unloading ▸ Processing (crushing, screening, etc.) ▸ Material handling and storage activities ▸ Dozer activity ▸ Loadout for transit
General activities ▸ **Vehicle travel** ▸ Road grading ▸ Wind erosion of open areas and materials in storage

TABLE 4. MAJOR FIELD TESTING PROGRAMS AT SURFACE COAL MINES

Name	Location (fields)	Sources	Comments	Reference No.
EDS Study	Powder River	Haul roads Coal dump Train loading Overburden Replacement Topsoil removal Wind erosion	Emphasis on source depletion, and "apparent emission factors" at various downwind distances; exposure profiling and upwind/downwind approaches	5
PEDCo/MRI	Fort Union Powder River San Juan	Coal loading dozers -- overburden -- coal Dragline Haul roads General traffic Scrapers Graders	Combination of exposure profiling and upwind/downwind tests; emission factors developed form the backbone of AP-42 Section 8.24	6
Skelly & Loy	Logan County, West Virginia	D/OR/CL[a] graders Haul roads	Upwind/downwind sampling over 10-day period; screening-type study	7
PEDCo/BuMines	Southern Illinois Southwestern Wyoming Northeastern Wyoming	Haul roads	Exposure profiling with stacked filtration units (SFUs); emphasis on haul road dust control efficiencies; no attempt made to develop general emission factor models	8

[a]Drilling, overburden replacement and coal loading treated as a single emission source.

TABLE 5. SUMMARY OF EDS RESULTS[a,5]

Source	Emission factor at source	Apparent emission factor at 500 m	Apparent emission factor at 1,000 m
Haul roads	22.0 lb/VMT	8.5 lb/VMT	7.8 lb/VMT
Coal dump	0.066 lb/ton	0.024 lb/ton	0.022 lb/ton
Train load	0.028 lb/ton	0.010 lb/ton	0.009 lb/ton
Overburden replacement	0.012 lb/ton	0.004 lb/ton	0.004 lb/ton
Topsoil removal	0.058 lb/ton	0.021 lb/ton	0.019 lb/ton
]Wind erosion	0.38 ton/acre-year @ 4.7 m/s mean wind speed	Not applicable	Not applicable

[a]Taken from Reference 11. Size range is TSP.

TABLE 6. SUMMARY OF EMISSIONS TESTING CONDUCTED BY PEDCo/MRI

Location[a]	Source	Control (C/U)[b]	No. of tests	Range	Units	Mean	Size
1 2 3	Coal loading[c]		2 8 15	0.004-0.031 0.002-0.121 0.005-1.271	lb/ton	0.010 0.025 0.135	TSP
1 2 3	Dozer overburden[c]		4 7 4	0.600-22.2 0.000-19.8 2.500-25.9	lb/hr	8.0 2.97 10.4	TSP
1 2 3	Dozer coal[c]		4 3 5	8.300-50.8 1.000-13.4 152-670	lb/hr	25.2 6.3 312	TSP
1 2 3	Dragline[c]		6 5 8	0.001-0.446 0.000-0.071 0.021-0.246	lb/yd^3	0.069 0.024 0.115	TSP
1 1W	Haul roads[c]		5 6	1.100-18.4 4.500-47.8	lb/vmt	8.2 19.4	TSP
1	Haul trucks[c]	U	6	12.90-33.0	lb/vmt	19.6	
2			10	0.600-8.2		4.2	
		U	6	3.900-8.2		5.6	
		C	4	0.600-3.4		2.2	
1W		U	3	0.710-73.1		47.0	
3			9	1.800-24.1		10.0	
		U	4	6.300-24.1		16.3	
		C	5	1.800-8.4		5.0	
1	Light-med. duty vehicles		5	0.350-0.82	lb/vmt	5.2	
		U	3	5.500-8.2		6.8	
		C	2	0.35		0.35	
2		U	4	0.600-0.93		0.73	
3		U	3	7.800-9.0		8.4	
1	Scrapers	U	5	3.900-50.2	lb/vmt	18.0	
2		U	6	10.30-74.3		32.9	
1W		U	2	163-355		259	
3		U	2	4.0		4.0	
2	Graders	U	5	1.800-7.3	lb/vmt	4.1	
3		U	2	8.600-34.0		21.3	

[a] 1 = Fort Union, 2 = Powder River Basin; 3 = San Juan River Fields; W = Winter tests.
[b] C/U: controlled/uncontrolled.
[c] Upwind/downwind tests.

TABLE 7. SUMMARY OF EMISSIONS TESTING CONDUCTED BY SKELLY AND LOY[7]

Operation	No. of samples	TSP emission factor	Units
Drilling/overburden removal/coal loading	33	339.6	lb/workday/acre
Regrading	7	442.2 54	lb/workday/acre[a] lb/hr[a]
Haul roads	8	246.8	lb/vehicle mile

[a]Regarding emission factor stated in two sets of units for comparison purposes.

TABLE 8. EMISSION FACTORS REPORTED BY THE PEDCo/BulMINES STUDY

Location[a]	Control method	No. of tests	Emission factors[b]	
			Range	Mean
1	Calcium chloride	6	0.12-4.65	2.00
	Acrylic	12	0.70-6.79	3.42
	Pertrotac	2	6.90-10.3	8.64
	Lignon	8	0.79-14.7	6.13
	Water	12	2.02-3.80	2.77
	No control	20	0.67-7.81	4.46
2	Calcium chloride	18	2.43-18.2	7.71
	Emulsified asphalt	16	4.73-25.2	13.84
	Acrylic	12	3.19-13.0	7.28
	Lignon	20	1.17-16.2	7.14
	Water	12	0.85-12.2	6.22
	No control	39	2.93-37.5	14.69
3	Calcium chloride	8	1.49-4.46	3.03
	Biocat	3	1.44-7.79	3.58
	Arco	4	1.46-2.42	1.79
	Lignon	8	0.78-2.76	1.84
	No control	17	1.41-6.84	3.36

[a]1 = Southern Illinois; 2 = Southwestern Wyoming; 3 = Northeastern Wyoming.
[b]TSP emission factors in units of lb/vmt.

TABLE 9. SUMMARY OF EMISSION FACTOR EQUATIONS FROM SCM's

No.	Source	Material[a]	Equation/Factor[b]	Particle size	Units	Reference
1.a	Blasting	C or O	$961\ A^{0.8}/D^{1.8}\ M$	TSP	lb/blast	PEDCo/MRI
1.b		C or O	$0.0005A^{1.5}$	TSP	lb/blast	AP-42 § 8.24[c]
2.a	Truck loading	C	$1.16/M^{1.3}$	TSP	lb/ton	PEDCo/MRI
2.b		C	$0.089/M^{0.9}$	PM-10	lb/ton	AP-42 § 8.24[d]
2.c		C or O	$k\ (0.0032)(U/5)^{1.3}/(M/2)^{1.4}$	e	lb/ton	AP-42 § 11.2.3
2.d		C	339.6	TSP	lb/workday/acre	Skelly & Loy
3.a	Bulldozing	C	$78.4\ s^{1.2}/M^{1.3}$	TSP	lb/hr	PEDCo/MRI
3.b		C	$14\ s^{1.5}/M^{1.4}$	PM-10	lb/hr	AP-42 § 8.24[d]
3.c		O	$5.7\ s^{1.2}/M^{1.3}$	TSP	lb/hr	PEDCo/MRI
3.d		O	$0.75\ s^{1.5}/M^{1.4}$	PM-10	lb/hr	AP-42 § 8.24[d]
3.e		O	54	TSP	lb/hr	Skelly & Loy
4.a	Dragline	O	$0.0021\ d^{1.1}/M^{0.3}$	TSP	lb/yd^3	PEDCo/MRI
4.b		O	$0.0016\ d^{0.7}/M^{0.3}$	PM-10	lb/yd^3	AP-42 § 8.24[d]
4.c		O	$k(0.0032)(U/5)^{1.3}/(M/2)^{1.4}$	e	lb/ton	AP-42 § 11.2.3
5.a	Scrapers in travel mode		$2.7 \times 10^{-5} s^{1.3}\ W^{2.4}$	TSP	lb/vmt	PEDCo/MRI
5.b			$3.7 \times 10^{-6}\ s^{1.4}\ W^{2.5}$	PM-10	lb/vmt	AP-42 § 8.24[d]
5.c			$k(5.9)(s/12)(S/30)(W/3)^{0.7}$ $(w/4)^{0.5} \left(\frac{365-p}{365} \right)$	f	lb/vmt	AP-42 § 11.2.1
6.a	Grading		$0.040\ S^{2.5}$	TSP	lb/vmt	PEDCo/MRI
6.b			$0.031\ S^{2.0}$	PM-10	lb/vmt	AP-42 § 8.24[d]
6.c			54	TSP	lb/hr	Skelly & Loy
7.a	General traffic		$5.79/M^{4.0}$	TSP	lb/vmt	PEDCo/MRI
7.b			$1.9/M^{4.3}$	PM-10	lb/vmt	AP-42 § 8.24[d]
7.c			$k(5.9)(s/12)(S/30)(W/3)^{0.7}$	f	lb/vmt	AP-42 § 11.2.1
7.d			$(w/4)^{0.5}(365\text{-}p)/365$			
7.e			$4.83(S/45)^{1.50}$	TSP	lb/vmt	Reference 14
			$1.22(S/45)^{1.89}$	PM-10	lb/vmt	Reference 14

TABLE 9. (continued)

No.	Source	Material[a]	Equation/Factor[b]	Particle size	Units	Reference
8.a	Haul trucks		$0.0067\ w^{3.4}\ L^{0.2}$	TSP	lb/vmt	PEDCO/MRI
8.b			$0.0031\ w^{3.5}$	PM-10	lb/vmt	AP-42 § 8.24[d]
8.c			246.8	TSP	lb/vmt	Skelly & Loy
8.d			$k(5.9)(s/12)(S/30)(W/3)^{0.7}(w/4)^{0.5}(365\text{-}p)/365$	f	lb/vmt	AP-42 § 11.2.1
8.e			22.0	TSP	lb/vmt	TRC/EDS

[a]C = coal O = overburden, T = topsoil.

[b]Symbols used:

A = area blasted, ft^2	W = mean vehicle weight, ton
M = moisture content, %	S = mean vehicle speed, mph
D = blasthole depth, ft	w = mean number of wheels
s = silt content, %	L = surface silt loading, g/m
U = mean wind speed, mph	p = mean annual number of days with at least 0.01 in. of precipitation

[c]Factor based on a reexamination of PEDCo/MRI study results.

[d]PM-10 factors based on IP emission factors developed in PEDCo/MRI study.

[e]For SP, k = 0.74; for PM-10, k = 0.35.

[f]For SP, k = 0.80; for PM-10, k = 0.36.

Table 10. AVAILABLE SINGLE-VALUED EMISSION FACTORS

No.	Source	Material[a]	TSP emission factor	Units
1.a	Drilling	O	1.3	lb/hole
1.b		C	0.22[b]	lb/hole
2.a.	Topsoil removal by scraper	T	0.058	lb/T
2.b		T	0.44[b]	lb/T
3.a	Overburden replacement	O	0.012	lb/T
4.a	Truck loading by power shovel (batch drop)	O	0.037[b]	lb/t
5.a.	Train loading (batch or continuous)	C	0.028	lb/T
5.b		C	0.0002[b]	lb/T
6.a	Dump truck unloading (batch)	O	0.002[b]	lb/T
6.b		C	0.027[b]	lb/T
6.c		C	0.005[b]	lb/T
6.d		C	0.020[b]	lb/T
6.e		C	0.014[b]	lb/T
6.f		C	0.066	lb/T
6.g		C	0.007[b]	lb/T
7.a	Scraper unloading (batch)	T	0.04[b]	lb/T
8.a	Wind erosion of exposed areas	S	0.38	T/acre-yr

[a]O = overburden; C = coal; T = topsoil; S = seeded land, stripped overburden, graded overburden.
[b]Factor restricted to use at certain types of mines (see Roman numerals I through V in Figure 8).

Table 11. SUMMARY OF RECOMMENDED EMISSION FACTORS AND FUTURE TESTING NEEDS

Source	Recommended emission factor[a]	Comments and recommendations for further field testing[b]
Topsoil--		
Removal	2.a in Table 10	Although the current need for further field testing is not critical, any subsequent field activities should emphasize eastern mines
Scraper travel	5.a/5.b in Table 9	The applicability of AP-42 emission factor models to eastern mines needs to be investigated. Of greater importance, independent test data (at both eastern and western mines) are critically needed to assess model performance.
Material handling	2.c in Table 10	Generic AP-42 Section 11.2.3 emission factor model was recently updated and is considered equally applicable to eastern and western mines. Surface moisture contents of interest are largely within range in data base underlying the generic emission factor. The need for further study is not considered critical at this time.
Overburden--		
Drilling	1.a in Table 10	Single-valued factor has not been shown to be applicable to eastern mines. Because drilling is relatively small contributor to overall emissions, further field study is not considered critically important at present. Future testing activities should include eastern mines.
Blasting	1.b in Table 9	Recommended factor is the result of 1987 reexamination of PEDCo/MRI data. Factor represents TSP only and has not been shown applicable to eastern mines. Although only a TSP value is available, its use is not believed to be overly conservative in overall inventorying process. Field testing for this source posses serious logistical challenges. Because blasting does not provide a large contribution to total emissions, further testing is not recommended at present.
Removal	4.c in Table 9	Generic materials handling emission factor recommended for truck-shovel mines. This model was revised in a recent update to AP-42 Section 11.2 and is considered equally applicable to eastern and western mines. In general, moisture contents of interest are likely to be outside the range in the data base underlying the generic factor. Limited study is recommended.
	4.a/4.b in Table 9	For dragline mines, the equation found in AP-42 Section 8.24 is recommended. At a minimum, a limited field study is needed to assess the applicability of the emission factor to eastern mines. Additional field test data (at both eastern and western mines) would permit independent assessment of model performance.

Table 11. (continued)

Source	Recommended emission factor[a]	Comments and recommendations for further field testing[b]
Haul trucks	8.a./8.b. in Table 9	Because overburden and coal haul trucks can account for up to half of the total PM emissions, it is important to have an independent assessment of model performance. Thus, collection of new field data at both eastern and western mines should be an important objective of any future field effort
Material handling	2.c in Table 10	Generic AP-42 Section 11.2.3 emission factor model was recently updated and is considered equally applicable to eastern and western mines. Moisture values are probably outside the range of the underlying data base, however. Limited field testing recommended, in conjunction with other overburden handling operations.
Dozer activity	4.a/4.b in Table 9	At a minimum, the applicability of the emission model to eastern mines should be field verified. To facilitate the transfer of results, it is recommended that results be expressed as emission factors rather than emission rates.
Replacement	2.c in Table 9	Because of the importance of this source at truck-shovel mines, further field characterization (at both eastern and western mines) study is strongly suggested.
Coal--		
Drilling	1.b in Table 10	Single-valued factor has not been shown to be applicable to eastern mines. Drilling is a relatively small contributor to overall emissions. Further field study is not considered critcally important at this time. Future testing activities should include eastern mines.
Blasting	1.b. in Table 9	TSP factor resulted from 1987 reexamination of PEDCo/MRI data. Has not been shown applicable to eastern mines. Although only a TSP value is available, its use is not believed to be overly conserative in overall inventorying process. Very difficult source for field testing. Further testing not recommended at present.
Coal loading	2.a./2.b or 2.c in Table 9	Model 2.a/2.b recommended for surface moisture contents greater than 4%, model 2.c recommended for surface moisture contents less than 5%. Because of confusion and/or debate as to appropriate emission factors and input variables (i.e., surface versus bound moisture contents) and because of high variability between mines, reexamination of this source is recommended in future field studies. This testing could be combined with testing of other handling activities (below).
Haul trucks	8.a/8.b in Table 9	Because overburden and coal haul trucks can account for up to half of the total PM emissions, it is important to have an independent assessment of model performance. Thus collection of new field data at both eastern and western mines should be an important objective of any future field effort.

Table 11. (continued)

Source	Recommended emission factor[a]	Comments and recommendations for further field testing[b]
Unloading	2.c in Table 10	Generic AP-42 Section 11.2.3 emission factor model was recently updated and is considered equally applicable to eastern and western mines. Moisture contents of interest for coal unloading, however, tend to be far greater than those in generic data base. Limited field testing effort, perhaps focused on eastern mines, is recommended.
Material handling	2.c. in Table 10	Same as previous comment.
Dozer activity	4.a/4.b in Table 9	At a minimum, the applicability of the emission model to eastern mines should be field verified. To facilitate the transfer of results, it is recommended that results be expressed as emission factors rather than emission rates.
Loadout for transit	2.c in Table 10	Same as comment for coal unloading.
General--		
General traffic	**7.c** or **7.d/7.e** in Table 9	Model 7.d/7.e recommended for light-duty, higher speed traffic in arid portions of the western United States. Because general traffic can account for a large portion of the total PM emissions at a SCM, collection of additional field test data (at both eastern and western mines) should be an important objective of any future field effort. Note that, when applied to independent data, the light- and medium-duty unpaved road emission model in Section 8.24 overpredicted by one or two orders of magnitude.
Road grading	6.a/6.b in Table 9	Generic unpaved road equation will conservatively overestimate the measured grading emission factors, and the overestimation is probably not overly restrictive in developing a mine-wide PM inventory. Further testing is not critical at present. Future testing of graders should emphasize eastern mines.

[a]Emission factors in **bold** differ from general guidelines given in Section 8.24 of AP-42.
[b]Suggested field testing underlined.

SECTION 6

REFERENCES

1. U.S. Environmental Protection Agency, *Non-Metallic Mineral Processing Plants*, Background Information for Proposed Standards.

2. Bureau of Mines, *Minerals Yearbook* (1986), Volume II.

3. Department of Commerce, Coal in the United States, Coal Exporters Association, U.S. Department of Commerce, International Trade Administration Office of Energy, March 1987.

4. Cole, C. F., B. L. Murphy, J. S. Evans, A. Garsd, *Quantification of Uncertainties in EPA's Fugitive Emissions and Modeling Methodologies at Surface Coa/Mines*, TRC Environmental Consultants, February 1985.

5. Shearer, D. L., R. A. Dougherty, C. C. Easterbrook, *Coal Mining Emission Factor Development and Modeling Study*, TRC Environmental Consultants, July 1981.

6. U.S. Environmental Protection Agency, *Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources*, EPA-600/7-84-048, Two Volumes, March 1984.

7. Ettinger, W. S., and R. E. McClure, *Fugitive Dust Generation on a Southern West Virginia Surface Coal Mine*, APCA Speciality Conference on Fugitive Dust Issues in the Coal Use Cycle, April 1983.

8. Rosenbury, K. D., and R. A. Zimmer, *Cost-Effectiveness of Dust Controls Used on Unpaved Haul Roads*, Two Volumes, Final Report for U.S. Bureau of Mines, Minneapolis, Minnesota, December 1983.

9. U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors (AP-42)*, Research Triangle Park, North Carolina, September 1985.

10. Cowherd, C., Jr., and J. S. Kinsey (1986), *Identification, Assessment, and Control of Fugitive Particulate Emissions*, EPA-600/8-86-023, U.S. Environmental Protection Agency, Washington, D.C.

11. Jacko, R. B., *Air Quality, in Surface Mining Environmental Monitoring and Reclamation Handbook*, Edited by L.V.A. Sendlein, H. Yazicigili, and C. L. Carlson, Elsevier; New York, 1983.

12. Pyle, B. E., 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.

13. Muleski, G. E., *Update of Fugitive Dust Emission Factors in AP-42 Section 11.2*, Report for U.S. Environmental Protection Agency, MRI Project No. 8681-L(19), July 1987.

14. Muleski, G. E., *Unpaved Road Emission Impact*, Report for Arizona Department of Environmental Quality, March 1991.

15. U.S. Environmental Protection Agency, *Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections*, April 1980.

16. U.S. Environmental Protection Agency, *Survey of Fugitive Dust from Coal Mines*, EPA-908/1-78-003, February 1978.

17. Muleski, G. E., *Update of Fugitive Dust Emission Factors in AP-42*, Report for U.S. Environmental Protection Agency, MRI Project No. 8481-L(11), August 1986.

18. Brookman, E. T., D. H. Carnes, P. A. Catizone, K. J. Kelley, *Determination of Fugitive Coal Dust Emissions from Rotary Railcar Dumping*, TRC Environmental Consultants, May 1984.

TECHNICAL REPORT DATA

(Please read Instructions on reverse before completing)

1. REPORT NO. EPA-454/R95-007	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Review of Surface Coal Mining Emission Factors		5. REPORT DATE July 11, 1991
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Midwest Research Institute Kansas City, Missouri		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Emission Factor and Inventory Group (MD-14) Emission Monitoring and Analysis Division Office of Air Quality Planning and Standards U. S. Environmental Protection Agency, RTP, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This report was generated as a first step in reviewing emission factors for western surface coal mines in response to Section 234 of the Clean Air Act of 1990.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT *	19. SECURITY CLASS *(Report)*	21. NO. OF PAGES 52
	20. SECURITY CLASS *(Page)*	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

Appendix C
Sampling Methodology

This appendix contains information on methods of sampling fugitive dust emissions. The information found in this appendix is from Section 4.2 of the EPA report “Fugitive Dust Emission Factor Update for AP-42 ” and Section 3 of the EPA report “Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources - Volume I - Sampling Methodology and Test Results.”

TABLE OF CONTENTS

C.1 Section 4.2 of Report: "Fugitive Dust Emission Factor Update for AP-42."

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 steadystate, forced-flow conditions, are not suitable for measurement of fugitive emissions unless the plume can be drawn into a forced-flow system.

Mass Emissions Measurement

For field measurement of fugitive mass emissions, three basic techniques have been defined (Development of Procedures for Measurement of Fugitive Emissions, EPA-600/2-76-284) which are summarized as follows:

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

2. The roof monitor method involves measurement of concentrations and airflows across well defined building openings such as roof monitors, ceiling vents, and windows.

3. The upwind-downwind method involves measurement of upwind and downwind air quality, utilizing ground based samplers under known meteorological conditions, and calculation of source strength with atmospheric dispersion equations.

Because it is impractical to enclose open dust sources or to capture the entire emissions plume, the upwind-downwind method is the only one of these three that is suitable for measurement of particulate emissions from open dust sources.

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 depend on the isolability 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.

After the concentration(s) measured upwind are subtracted from the downwind concentrations, the net downwind concentrations are then used as input to dispersion equations (normally of the Gaussian type) to back calculate the particulate emission rate required to generate the downwind pollutant concentration measured. 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 source.

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 source configuration is met.

Two additional measurement techniques, exposure profiling and the wind tunnel method offer distinct advantages for source-specific quantification of fugitive emissions from open dust sources.

The exposure profiling technique 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 distributed anemometers.

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:

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

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, ~g/m^3

U_s = approaching wind speed, sfpm

Q_s = sampler flow rate, CFM

t = duration of sampling, min

The coefficients of Equations 2 are conversion factors. Net mass or concentration refers to that portion which is attributable to the source being tested, after subtraction of the contribution from background.

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

where the symbols are defined as above. The resulting exposure values represent the specific

$$A = \int_{O}^{H} E dh \quad (4)$$

particle size range sampled.

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

where A = integrated exposure, m-mg/cm^2

E = particulate exposure, mg/cm^2

h = vertical distance coordinate, m

H = effective extent of plume above ground, m

Physically, A represents the total passage of airborne particulate matter downwind of the source, per unit length of line source.

The wind tunnel method utilizes a portable pull-through wind tunnel with an open-floored test section placed directly over the surface to be tested. Air is drawn through the tunnel at controlled velocities. The exit air stream from the test section passes through a circular duct fitted with an isokinetic probe at the downstream end. Air is drawn through the probe by a high-volume sampling train. This technique provides for precise study of the wind erosion process with minimal interference from background sources.

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 recently developed EPA version of the dichotomous sampler, which is virtually free of particle bounce problems is useful for quantification of fine particle mass concentrations. However, this device operates at a low flow rate (1 cu m/hr) yielding only 0.024 mg of sample in 24 hr for each 10 $\mu g/m^3$ of TSP concentration. Thus, an analytical balance of high precision is required to determine mass concentrations below and above the fine particulate (2.5 μm) cutpoint (the minimum in the typical bimodal size distribution of atmospheric particulate). In addition, the dichotomous sampler was designed to have a 15 μm cutpoint for capture of airborne particles (the upper size limit for inhalable particulate based on unit density); however, recent wind tunnel studies have shown that this cutpoint is wind sensitive (Wedding, 1980).

The size-selective inlet 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 the dichotomous sampler 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 available for both dichotomous samplers and high-volume samplers.

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 sources activity or energy expended (for example, the speed and weight of a vehicle traveling on an unpaved road).

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

3. Climatic parameters (for example, 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.

C.2 Section 3 of Report: "Improved Emission Factors for Fugitive Dust From Western Surface Coal Mining Sources--Volume 1 - Sampling Methodology and Test Results."

SECTION 3
SAMPLING METHODOLOGY

TECHNIQUES AVAILABLE TO SAMPLE FUGITIVE DUST EMISSIONS

Five basic techniques have been used to measure fugitive dust emissions. These are quasi-stack, roof monitor, exposure profiling, upwind-downwind and wind tunnel. Several experimental sampling methods are in developmental stages.

In the quasi-stack method of sampling, the emissions from a well-defined process are captured in a temporary enclosure and vented to a duct or stack of regular cross-sectional area. The emission concentration and the flow rate of the air stream in the duct are measured using standard stack sampling or other conventional methods.

Roof monitor sampling is used to measure fugitive emissions entering the ambient air from buildings or other enclosure openings. This type of sampling is applicable to roof vents, doors, windows, or numerous other openings located in such fashion that they prevent the installation of temporary enclosures.

The exposure profiling technique employs a single profile tower with multiple sampling heads to perform simultaneous multipoint isokinetic sampling over the plume cross-section. The profiling tower is 4 to 6 meters in height and is located downwind and as close to the source as possible (usually 5 meters). This method uses monitors located directly upwind to determine the background contribution. A modification of this technique employs balloon-suspended samplers.

With the upwind-downwind technique, an array of samplers is set up both upwind and downwind of the source. The source contribution is determined to be the difference between the upwind and downwind concentrations. The resulting contribution is then used in standard dispersion equations to back-calculate the source strength.

The wind tunnel method utilizes a portable wind tunnel with an open-floored test section placed directly over the surface to be tested. Air is drawn through the tunnel at controlled velocities. A probe is located at the end of the test section and the air is drawn through a sampling train.

Several sampling methods using new sampling equipment or sampling arrays are in various stages of development. These include tracer studies, lidar, acoustic radar, photometers, quartz crystal impactors, etc.

SELECTION OF SAMPLING METHODS

Each of the five basic techniques used to measure fugitive dust emissions has inherent advantages, disadvantages, and limitations to its use.

The quasi-stack method is the most accurate of the airborne fugitive emission sampling techniques because it captures virtually all of the emissions from a given source and conveys them to a measurement location with minimal dilution (Kalika et al. 1976). Its use is restricted to emission sources that can be isolated and are arranged to permit the capture of the emissions. There are no reported uses of this technique for sampling open sources at mines.

The roof monitor method is not as accurate as the quasi-stack method because a significant portion of the emissions escape through other openings and a higher degree of dilution occurs before measurement. This method can be used to measure many indoor sources where emissions are released to the ambient air at low air velocities through large openings. With the exception of the preparation plant and enclosed storage, none of the sources at mines occur within buildings.

The exposure profiling technique is applicable to sources where the ground-based profiler tower can be located vertically across the plume and where the distance from the source to the profiling tower can remain fixed at about 5 meters. This limits application to point sources and line sources. An example of a line source that can be sampled with this technique is haul trucks operating on a haul road. Sources such as draglines cannot be sampled using this technique because the source works in a general area (distance between source and tower cannot be fixed), and because of sampling equipment and personnel safety.

The upwind-downwind method is the least accurate of the methods described because only a small portion of the emissions are captured in the highly diluted transport air stream (Kalika et al. 1976). It is, however, a universally applicable method. It can be used to quantify emissions from a variety of sources where the requirements of exposure profiling cannot be met.

The wind tunnel method has been used to measure wind erosion of soil surfaces and coal piles (Gillette 1978; Cowherd et al. 1979). It offers the advantages of measurement of wind erosion under controlled wind conditions. The flow field in the tunnel has been shown to adequately simulate the properties of ambient winds which entrain particles from erodible surfaces (Gillette 1978).

Experimental sampling methods present at least three problems for coal mine applications. First, none have been used in coal mines to date. Second, they are still in experimental stages, so considerable time would be required for testing and development of standard operating procedures. Third, the per sample costs would be considerably higher than for currently available sampling techniques, thus reducing the number of samples that could be obtained. Therefore, these techniques were not considered applicable methods for this study.

After review of the inherent advantages, disadvantages and limitations of each of the five basic sampling techniques, the basic task was to determine which sampling method was most applicable to the specific sources to be sampled, and whether that method could be adapted to meet the multiple objectives of the study and the practical constraints of sampling in a surface coal mine.

Drilling was the only source which could be sampled with the quasi-stack method. No roof monitor sampling could be performed because none of the sources to be sampled occurs within a building. It was decided that the primary sampling method of the study would be exposure profiling. The decision was based primarily on the theoretically greater accuracy of the profiling technique as opposed to upwind-downwind sampling and its previous use in similar applications. Where the constraints of exposure profiling could not be met (point sources with too large a cross-sectional area), upwind-downwind would be used. The wind tunnel would be used for wind erosion sampling.

SAMPLING CONFIGURATIONS

Basic Configurations

Exposure Profiling--

Source strength--The exposure profiler consisted of a portable tower, 4 to 6 m in height, supporting an array of sampling heads. Each sampling head was operated as an isokinetic exposure sampler. The air flow stream passed through a settling chamber sampler. The air flow stream passed through a settling chamber (trapping particles larger than about 50 μm in diameter), and then flowed upward through a standard 8 in. x 10 in. glass fiber filter positioned horizontally. Sampling intakes were pointed into the wind, and the sampling velocity of each intake was adjusted to match the local mean wind speed as determined prior to each test. Throughout each test, wind speed was monitored by recording anemometers at two heights, and the vertical wind speed profile was determined by assuming a logarithmic distribution. This distribution has been found to describe surface winds under neutral atmospheric stability, and is a good approximation for other stability classes over the short vertical distances separating the profiler samples (Cowherd, Axetell, Guenther, and Jutze 1974). Sampling time was adequate to provide sufficient particulate mass ($\geq$10 mg) and to average over several units of cyclic fluctuation in the emission rate (e.g., vehicle passes on an unpaved road). A diagram of the profiling tower appears in Figure 3-1.

The devices used in the exposure profiling tests to measure concentrations and/or fluxes of airborne particulate matter are listed in Table 3-1. Note that only the (isokinetic) profiling samplers directly measure particulate exposure (mass per unit intake area) as well as particulate concentration (mass per unit volume). However, in the case of the other sampling devices, exposure may be calculated as the product of concentration, mean wind speed at the height of the sampler intake, and sampling time.

Two deployments of sampling equipment were used in this study: the basic deployment described in Table 3-2 and the special deployment shown in Table 3-3 for the comparability study.

Particle size--Two Sierra dichotomous samplers, a standard hi-vol, and a Sierra cascade impactor were used to measure particle sizes downwind. The dichotomous samplers collected fine and coarse fractions with upper cut points (50 percent efficiency) of 2.5 μm and approximately 15 μm. (Adjustments for wind speed sensitivity of the 15 μm cut point are discussed in Section 5; limitations of this sampling technique are described on Pages 12-4 and 12-5.)

The high-volume parallel-slot cascade impactor with a 20 cfm flow controller was equipped with a Sierra cyclone preseparator to remove coarse particles that otherwise would tend to bounce off the glass fiber impaction substrates. The bounce-through of coarse particles produces an excess of catch on the backup filter. This results in a positive bias in the measurement of fine particles (see Page 6-3). The cyclone sampling intake was directed into the wind and the sampling velocity adjusted to mean wind speed by fitting the intake with a nozzle of appropriate size, resulting in isokinetic sampling for wind speeds ranging from 5 to 15 mph.

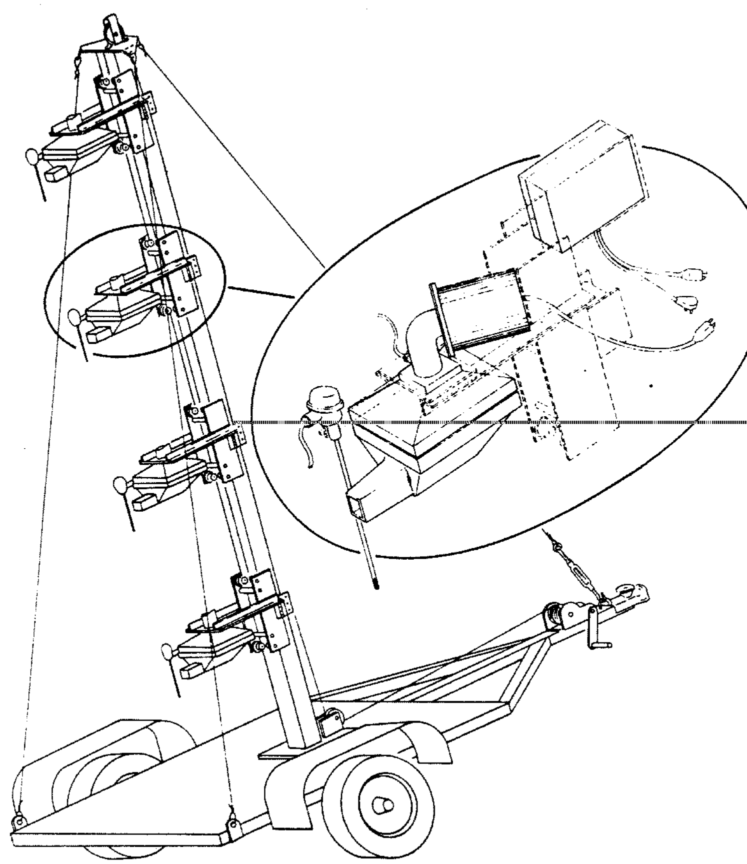


Figure 3-1. Exposure profiler.

TABLE 3-1. SAMPLING DEVICES FOR ATMOSPHERIC PARTICULATE MATTER--EXPOSURE PROFILING

Particulate Matter category[a]	Air Sampling Device			
	Type	**Quantity Measured**	**Operating Flow Rate**	**Flow Calibrator**
TP	Exposure profiler head	Exposure and concentration	Variable (10-50 SCFM) to achieve isokinetic sampling	Anemometer
	Cyclone with interchangeable probe tips and backup filter	Exposure and concentration	20 ACFM	Orifice calibrator
TSP	Standard hi-vol	Concentration	40-60 ACFM	Orifice calibrator
IP	Dichotomous sampler	Concentration	0.59 ACFM	Dry test meter
FP	Dichotomous sampler	Concentration	0.59 ACFM	Dry test meter

[a] TP = Total particulate = All particulate matter in plume
TSP = Total suspended particulate =Particulate matter in size range collected by hi-vol, estimated to be less than about μm diameter
IP = Inhalable particulate = Particulate less than 15 μm diameter
FP = Fine particulate = Particulate less than 2.5 μm diameter

TABLE 3-2. BASIC EQUIPMENT DEPLOYMENT FOR EXPOSURE PROFILING

Location	Distance from Source (m)	Equipment	Intake Height (m)[a]	
Upwind	5	1 Dichotomous sampler	2.5	
		1 Standard hi-vol	2.5	
		2 Dustfall buckets	0.75	
		1 Continuous wind monitor	4.0	
Downwind	5-10	1 MRI exposure profiler with 4 sampling heads	1.5	(1.0)
			3.0	(2.0)
			4.5	(3.0)
			6.0	(4.0)
		1 Standard hi-vol	2.5	(2.0)
		1 Hi-vol with cascade impactor	2.5	(2.0)
		2 Dichotomous samplers	1.5	
			4.5	(3.0)
		2 Dustfall buckets	0.75	
		2 Warm wire anemometers	1.5	(1.0)
			4.5	(3.0)
Downwind	20	2 Dustfall buckets	0.75	
Downwind	50	2 Dustfall buckets	0.75	

[a] Alternative heights for sources generating lower plume heights are given in parentheses.

TABLE 3-3. SPECIAL EQUIPMENT DEPLOYMENT FOR EXPOSURE PROFILING--COMPARABILITY TESTS

Location	Distance from Source (m)	Equipment	Intake Height (m)[a]
Upwind	5-10	1 Standard hi-vol	1.25
		1 Standard hi-vol	2.5
		2 Dustfall buckets	0.75
		1 Continuous wind monitor	4.0
Downwind	5	1 MRI exposure profiler with 4 sampling heads	1.5 3.0 4.5 6.0
		1 Standard hi-vol	2.5
		2 Hi-vols with cascade impactors	1.5
		4 Dichotomous samplers	1.5 3.0 4.5 6.0
		2 Dustfall buckets	0.75
		2 Warm wire anemometers	1.5 4.5
Downwind	20	1 Hi-vol with cascade impactor	2.5
		2 Dustfall buckets	0.75
Downwind	50	2 Dustfall buckets	0.75

Figure 3-2. Upwind-downwind sampling array.
Figure 3-3. Wind tunnel.
Figure 3-4. Quasi-stack sampling--temporary enclosure for drill sampling.

Deposition--Particle deposition was measured by placing dustfall buckets along a line downwind of the source at distances of 5 m, 20 m, and 50 m from the source. Greater distances would have been desirable for establishing the deposition curve, but measurable weights of dustfall could not be obtained beyond about 50 m during the 1-hour test periods. Dustfall buckets were collocated at each distance. The bucket openings were located 0.75 m above ground to avoid the impact of saltating particles generated by wind erosion downwind of the source.

Exposure Profiling Modification for Sampling Blasts--

Source strength--The exposure profiler concept was modified for sampling blasts. The large horizontal and vertical dimensions of the plumes necessitated a suspended array of samplers as well as ground-based samplers in order to sample over the plume cross-section in two dimensions. Five 47 mm PVC filter heads and sampling orifices were attached to a line suspended from a tethered balloon. The samplers were located at five heights with the highest at 30.5 m (2.5, 7.6, 15.2, 22.9, and 30.5 m). Each sampler was attached to a wind vane so that the orifices would face directly into the wind. The samplers were connected to a ground based pump with flexible tubing. The pump maintained an isokinetic flow rate for a wind speed of 5 mph. In order to avoid equipment damage from the blast debris and to obtain a representative sample of the plume, the balloon-suspended samplers were located about 100 m downwind of the blast area. This distance varied depending on the size of the blast and physical constraints. The distance was measured with a tape measure. The balloon-supported samplers were supplemented with five hi-vol/dichot pairs located on an arc at the same distance as the balloon from the edge of the blast area, and were spaced 20 m apart.

Particle size--The five ground-based dichotomous samplers provided the basic particle size information.

Deposition--There was no measurement of deposition with this sampling method. Dustfall samples would have been biased by falling debris from the blast.

Upwind-Downwind--

Source strength--The total upwind-downwind array used for sampling point sources included 15 samplers, of which 10 were hi-vols and 5 were dichotomous samplers. The arrangement is shown schematically in Figure 3-2. The downwind distances of the samplers from point sources were nominally 30 m, 60 m, 100 m, and 200 m. Frequently, distances in the array had to be modified because of physical obstructions (e.g., highwall) or potential interfering sources. A tape measure was used to measure source--to-sampler distances. The upwind samplers were placed 30 to 100 m upwind, depending on accessibility. The hi-vol and dichotomous samplers were mounted on tripod stands at a height of 2.5 m. This was the highest manageable height for this type of rapid-mount stand.

This array was modified slightly when sampling line sources. The array consisted of two hi-vol/dichot pairs at 5 m, 20 m, and 50 m with 2 hi-vols at 100 m. The two rows of samplers were normally separated by 20 m.

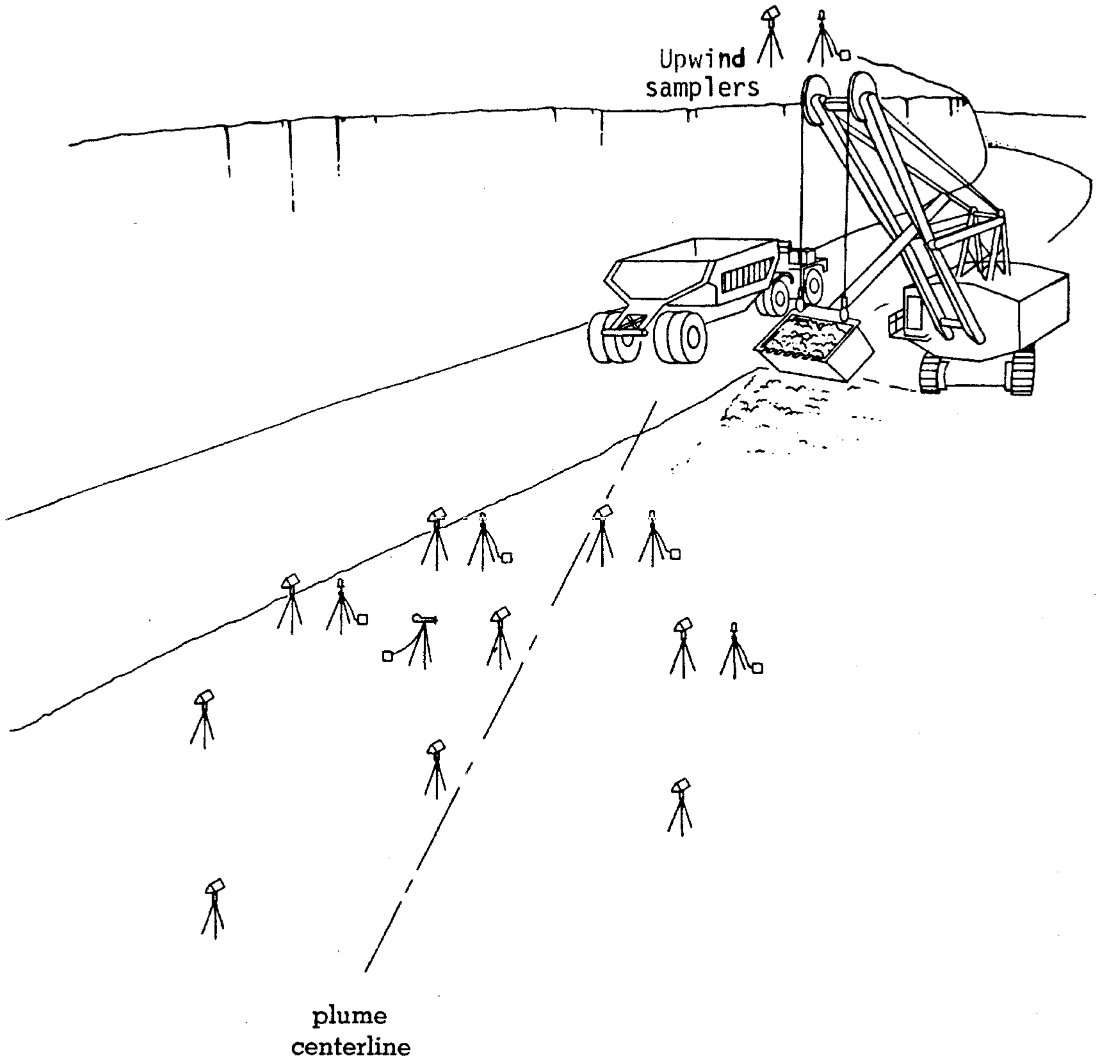


Figure 3-2. Upwind-downwind sampling array.

Particle size--In addition to the dichotomous samplers located upwind of the source and at 30 m and 60 m distances downwind of the source, millipore filters were exposed for shorter time periods during the sampling at different downwind distances. These filters were to be subjected to microscopic examination for sizing, but most of this work was suspended because of poor agreement of microscopy with aerodynamic sizing methods in the comparability study.

Deposition--The upwind-downwind method allows indirect measurement of deposition through calculation of apparent emission rates at different downwind distances. The reduction in apparent emission rates as a function of distance is attributed to deposition. At distances beyond about 100 m, deposition rates determined by this method would probably be too small to be detected separate from plume dispersion.

Wind Tunnel--

Source strength--For the measurement of dust emissions generated by wind erosion of exposed areas and storage piles, a portable wind tunnel was used. The tunnel consisted of an inlet section, a test section, and an outlet diffuser. As a modification to previous wind tunnel designs, the working section had a 1 foot by 1 foot cross section. This enlargement was made so that the tunnel could be used with rougher surfaces. The open-floored test section of the tunnel was placed directly on the surface to be tested (1 ft x 8 ft), and the tunnel air flow was adjusted to predetermined values that corresponded to the means of the upper NOAA wind speed ranges. Tunnel wind speed was measured by a pitot tube at the downstream end of the test section. Tunnel wind speeds were related to wind speed at the standard 10 m height by means of a logarithmic profile.

An airtight seal was maintained along the sides of the tunnel by rubber flaps attached to the bottom edges of the tunnel sides. These were covered with material from areas adjacent to the test surface to eliminate air infiltration.

To reduce the dust levels in the tunnel air intake stream, testing was conducted only when ambient winds were well below the threshold velocity for erosion of the exposed material. A portable high-volume sampler with an open-faced filter (roof structure removed) was operated on top of the inlet section to measure background dust levels. The filter was vertically oriented parallel to the tunnel inlet face.

An emission sampling module was used with the pull-through wind tunnel in measuring particulate emissions generated by wind erosion. As shown in Figure 3-3, the sampling module was located between the tunnel outlet hose and the fan inlet. The sampling train, which was operated at 15-25 cfm, consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, backup filter, and high-volume motor. Interchangeable probe tips were sized for isokinetic sampling over the desired tunnel wind speed range. The emission sampling train and the portable hi-vol were calibrated in the field prior to testing.

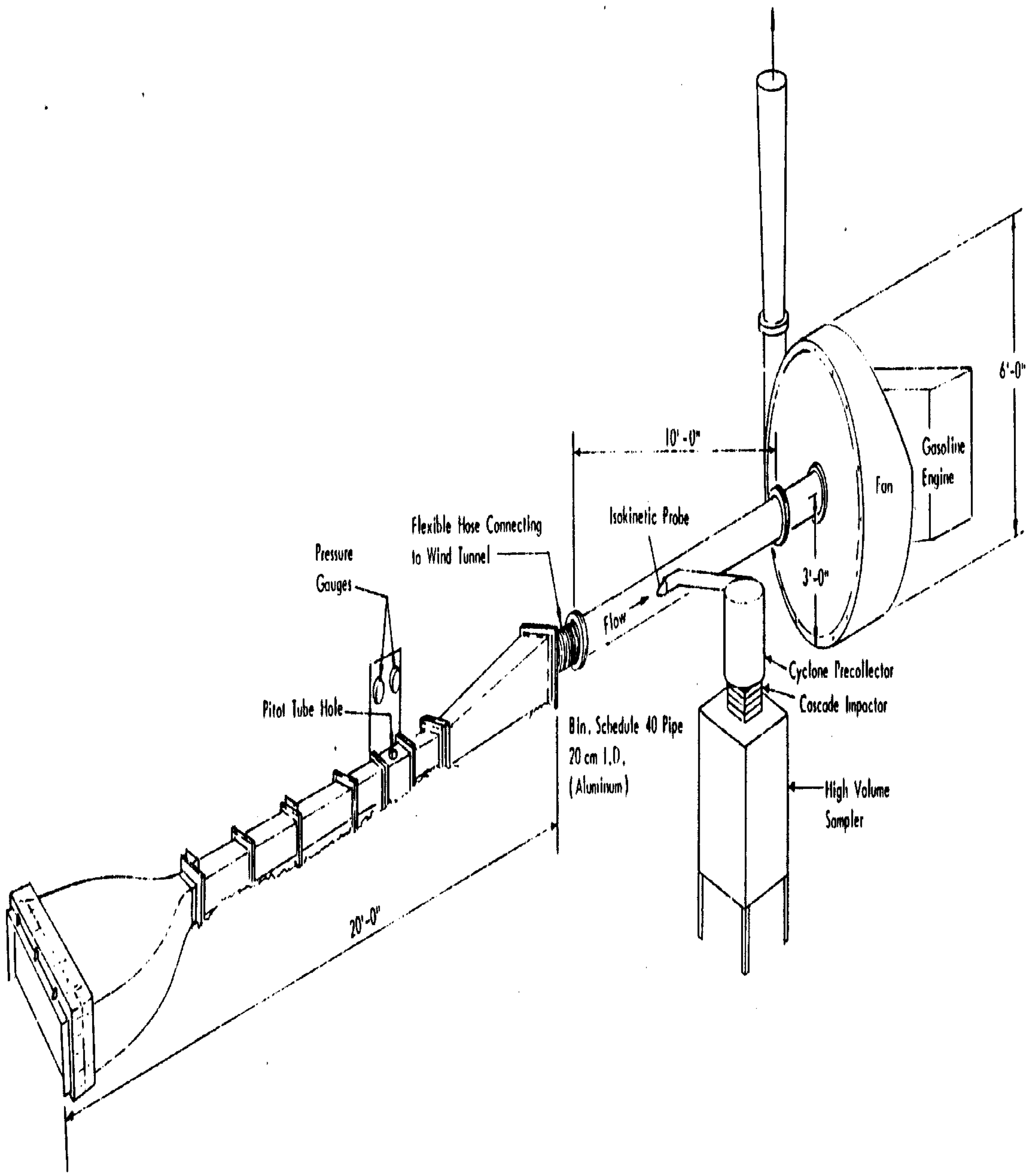


Figure 3-3. Wind tunnel.

Particle size--The size distribution for 30 μm and smaller particles was generated from the cascade impactor used as the total particulate sampler. The procedure for correction of the size data to account for particle bounce-through is described in Section 5.

Deposition--No method of measuring the deposition rate of particles suspended by wind erosion in the test section could be incorporated into the design of the wind tunnel.

Quasi-Stack--

Source strength--An enclosure was fabricated consisting of an adjustable metal frame covered with plastic. The frame was 6 feet long with maximum openings at the ends of 5 x 6 feet. Due to problems with the plastic during high winds, the original enclosure was replaced with a wood enclosure with openings 4 x 6 feet, as shown in Figure 3-4. For each test, the enclosure was placed downwind of the drill base. The outlet area was divided into four rectangles of equal area, and the wind velocity was measured at the center of each rectangle with a hot wire anemometer to define the wind profile inside the frame.

Four exposure profiler samplers with flow controllers were used to sample the plume. Using the wind profile data, the sampler flow rates were adjusted at 2 to 3 minute intervals to near-isokinetic conditions.

Particle size--The only particle size measurements made with this sampling method was the split between the filter catch and settling chamber catch in the profiler heads.

Deposition--There was no direct measurement of deposition with this sampling method.

Sampling Configurations by Source

The basic sampling configurations were adapted to each source to be tested. Sampling configurations used for each source are indicated in Table 3-4 and described below.

Overburden Drilling--

This activity was sampled using the quasi-stack configuration.

Blasting--

The plume from a blast is particularly difficult to sample because of the vertical and horizontal dimensions of the plume and the inability to place sampling equipment near the blast. Further, the plume is suspected to be non-Gaussian because of the way in which the plume is initially formed. Therefore, upwind-downwind sampling is not appropriate. To sample blasts, a modification of the exposure profiling technique was developed. This modification was discussed previously. A typical sampling array is shown in Figure 3-5. The same sampling procedure was used for overburden blasts and coal blasts.

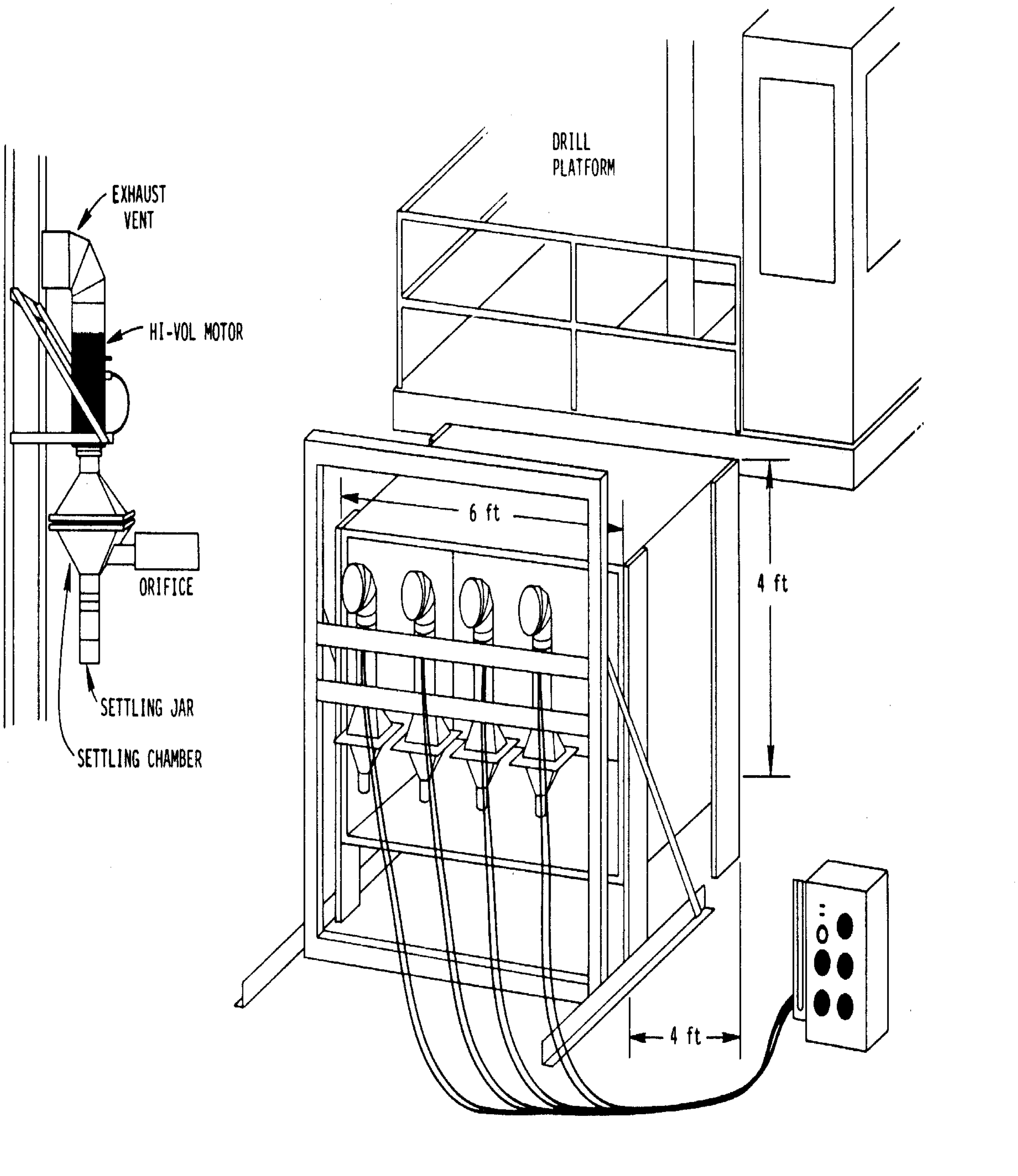


Figure 3-4. Quasi-stack sampling--temporary enclosure for drill sampling.

TABLE 3-4. SAMPLING CONFIGURATIONS FOR SIGNIFICANT SOURCES

Source	Point, Line, or Area[a]	Sampling Configuration
Drilling (overburden)	Point	Quasi-stack
Blasting (coal and overburden)	Area	Exposure profiling (modification
Coal loading (shovel/truck and front-end loader)	Point or area	Upwind/downwind
Dozer (coal and overburden)	Line or point	Upwind/downwind
Dragline	Point or area	Upwind/downwind
Haul truck	Line	Exposure profiling
Light- and medium-duty vehicles	Line	Exposure profiling
Scraper	Line	Exposure profiling
Grader	Line	Exposure profiling
Wind erosion of exposed areas	Area	Wind tunnel
Wind erosion of storage piles	Area	Wind tunnel

[a] Several of these sources could be operated as a line, point, or area source. Where possible, the predominant method of operation was used. In other cases, sampling requirements dictated the type of operation.

Figure 3-5. Blast sampling with modified exposure profiling configuration.

Coal Loading with Shovels or Front-End Loaders-

The exposure profiler could not be used for this source because of movement of the plume origin. Therefore, the upwind-downwind configuration for point sources was used. There are many points at which dust is emitted during truck loading--pulling the truck into position, scooping the material to be loaded, lifting and swinging the bucket, dropping the load, driving the truck away, and cleanup of the area by dozers or front-end loaders. Dropping of the load into the truck was generally the largest emission point so its emissions were used as the plume centerline for the sampling array, with the array spread wide enough to collect emissions from all the dust-producing points. Bucket size was recorded for each test, as well as the number of bucket drops.

Wind conditions and the width of the pit dictated the juxtaposition of the source and sampler array. When the winds channeled through the pit and the pit was wide enough to set up the sampling equipment out of the way of haul trucks, the samplers were set up downwind and in the pit. When winds were perpendicular to the pit, the sampling array was set up on a bench if the bench was not more than 5 to 7 meters high. With this configuration, the top of the haul truck was about even with the height of the bench; emissions from the shovel drop point could be very effectively sampled in this manner. Two coal loading sampling arrays are shown in Figure 3-6.

Dozers--

Dozers are difficult to test because they may operate either as a line source or in a general area as large as several acres over a 1-hour test period. When a dozer operated as a line source, the upwind-downwind configuration for a line source was used. The samplers were located with the assumed plume center-line perpendicular to the line of travel for the dozer. The number of times the dozer passed the samplers was recorded for each test. Since dozers could not always be found operating as a line source, captive dozers were sometimes used so that test conditions could be more accurately controlled. To sample dozers working in an area, the upwind-downwind pint source configuration was used. The location and size of the area was recorded along with dozer movements.

Dragline--

Sampling of this source was performed with the upwind-downwind configuration because of the large initial dimensions of the plume and because of the impossibility of placing samplers near the plume origin. There are three emission points--pickup of the overburden material, material lost from the bucket during the swing, and overburden drop. It was not always possible to position samplers so they were downwind of all three points. Therefore, sketches were made of each setup and field notes were recorded as to which points were included in the test. The number of drops, average drop distance, and size of the dragline bucket were also recorded.

Location of the samplers relative to the dragline bucket was determined by wind orientation, size of the pit (width and length) and pit accessibility. When winds were parallel to the pit, the array was set up in the pit if there was sufficient space and the floor of the pit was accessible. This setup usually resulted in the plumes from all three emission points passing over the samplers. When winds were perpendicular to the pit, draglines were only sampled if samplers could be placed on a bench downwind at approximately the same height as the spoils pile where the overburden was being dropped. Figure 3-7 shows the two typical dragline sampling configurations.

Sampling array in the pit

Sampling array on a bench

Figure 3-6. Coal loading with upwind-downwind configuration.

Sampling array in the pit

Sampling array at about the same height as the spoils pile

Figure 3-7. Dragline sampling with upwind-downwind concentration.

Haul Trucks--

Most sampling periods for haul trucks at the first mine were performed as part of the comparability study (see Section 6), employing both exposure profiling and upwind-downwind configurations. Haul trucks were used to perform the comparative study because they are a uniformly-emitting line source and because haul road traffic is the largest particulate source in most mines. At subsequent mines, exposure profiling was used to sample this source. For each test, the wind was approximately perpendicular to the road, the air intakes of the samplers were pointed directly into the wind, and the samplers extended to a height of 6 m to capture the vertical extent of the plume. In a few cases, more than <U10 of the plume mass extended above the top sampler because of a combination of light winds, unstable atmospheric conditions, and large vehicles. Consistent travel speed and diversion of watering trucks was requested during each sampling period. A haul truck sampling array in shown in Figure 3-8.

Light- and Medium-Duty Vehicles--

The sampling methodology for this category of vehicles was nearly identical to the haul truck procedures. The only exceptions were that: (l) a 4 m sampler height was adequate to sample the plume from the smaller vehicles and (2) pickup trucks belonging to the contractor were used for better control of vehicle speed and weight. In most cases, access roads specifically for lighter vehicles were used for testing. However, some sampling for light- and medium-duty vehicles was done on haul roads. Samples of the road surfaces were taken so that differences due to road properties could be evaluated (a full discussion of source characterization is included in the next subsection). A light- and medium-duty vehicle sampling array is shown in previously cited Figure 3-8.

Scraper--

This source was sampled by the exposure profiling method. Scrapers were sampled while traveling on a temporary road so that the emissions could be tested as a line source. Neither the loading nor the emptying operations were sampled, since both had been estimated to have insignificant emissions compared to scraper travel. The profiler was extended to 6 m to sample the vertical extent of the plume. In order to secure a suitable setup in a location without interference from other sources, it was often necessary to use captive equipment. A typical sampling array for scrapers IS shown in Figure 3-9.

Graders--

Exposure profiling was used to sample graders. Graders operate in a fairly constant manner; only the speed and travel surface (on road/off road) vary over time. It was assumed that the travel surface could be considered as a correction factor rather than requiring two separate emission factors. As with dozers, captive equipment was sometimes necessary to sample this source because graders did not normally drive past the same location repetitively. Even if they were regrading a short stretch of road, they would be at a different location on the road cross section with each pass, making it difficult to reposition the profiler. Therefore, captive equipment allowed better control of test variables.

Haul truck level

Light- and medium-duty truck

Figure 3-8. Haul road sampling with exposure profiling configuration.

Figure 3-9. Scraper sampling with exposure profiling configuration.

Wind Erosion of Exposed Areas and Storage Piles--

The wind tunnel was used to sample these two sources. In measuring emissions with the portable wind tunnel, it was necessary to place the tunnel on a flat, nearly horizontal section of surface. Care was taken not to disturb the natural crust on the surface, with the exception of removing a few large clumps that prevented the tunnel test section from making an airtight seal with the surface.

The threshold velocity for wind erosion and emission rates at several predetermined wind speeds above the threshold were measured on each test surface. Wind erosion of exposed surfaces had been shown to decay in time for velocities well above the threshold value for the exposed surface. Therefore, some tests of a given surface were performed sequentially to trace the decay of the erosion rate over time at high test velocities. A typical wind tunnel sampling configuration is shown in Figure 3-10.

Changes Made in Response to Comments

The basic sampling designs presented above represent the combined efforts of the two contractors as well as comments received from the technical review group. Specific changes made in response to technical review group comments are summarized below.

1. Dichotomous samplers were added to the exposure profiling sampling method. They were placed at four heights corresponding to the isokinetic sampling heights during the comparability study, and at two heights for the remainder of the tests. With this arrangement, dichotomous samplers replaced the cascade impactor as the primary particle size sampler in exposure profiling.

2. A fourth row of downwind samplers was added to the upwind-downwind array. Two hi-vole were placed at 200 m from the source to aid in the measurement of deposition.

3. The quasi-stack sampling method was adopted for sampling overburden drilling and an enclosure was designed and fabricated.

4. The modification of the exposure profiling method to sample blasts was devised.

5. Provisions were made to sample scrapers, and other sources as required, as captive equipment in locations not subject to other dust interferences.

SOURCE CHARACTERIZATION PROCEDURES

In order to determine the parameters that affect dust generation from an individual source, the suspected parameters must be measured at the time of the emission test. These parameters fall into three categories: properties of the materials being disturbed by wind or machinery, operating parameters of the mining equipment involved, and meteorological conditions. Table 3-5 lists the potential parameters by source that were quantified during the study.

Figure 3-10. Wind erosion sampling with wind tunnel.

TABLE 3-5. SOURCE CHARACTERIZATION PARAMETERS MONITORED DURING TESTING

Source	Parameter[a]	Quantification Technique
All tests	Wind speed and direction	Anemometer
	Temperature	Thermometer
	Solar intensity	Pyranograph
	Humidity	Sling psychrometer
	Atmospheric pressure	Barometer
	Percent cloud cover	Visual estimate
Overburden drilling	Silt content	Dry sieving
	Moisture content	Oven drying
	Depth of hole	Drill operator
Blasting	Number of holes	Visual count
	Size of blast area	Measurement
	Moisture content	From mining company
Coal loading	Silt content	Dry sieving
	Moisture content	Oven drying
	Bucket capacity	Equipment specifications
	Equipment operation	Record variations
Dozer	Silt content	Dry sieving
	Moisture content	Oven drying
	Speed	Time/distance
	Blade size	Equipment specifications
Dragline	Silt content	Dry sieving
	Moisture content	Oven drying
	Bucket capacity	Equipment specifications
	Drop distance	Visual estimate
Haul truck	Surface silt content	Dry sieving
	Vehicle speed	Radar gun
	Vehicle weight	Truck scale
	Surface loading	Mass/area of collected road sample
	Surface moisture content	Oven drying
	Number of wheels	Visual observation
Light- and medium-duty vehicles	Same parameters and quantification techniques as for haul trucks	
Scraper	Same parameters and quantification techniques as for haul trucks	
Grader	Same parameters and quantification techniques as for haul trucks	
Wind erosion of exposed areas	Surface erodibility	Dry sieving
	Surface silt content	Dry sieving, before and after test
	Surface moisture content	Oven drying, before and after test
	Surface roughness height	Measurement
Wind erosion of storage piles	Same parameters and quantification techniques as for wind erosion of exposed areas	

[a] Most of the meteorological parameters monitored during all tests are needed to estimate emission rates, and are not considered to be potential correction parameters in the emission factor equations.

Representative samples of materials (topsoil, overburden, coal, or road surface) were obtained at each test location. Unpaved and paved roads were sampled by removing loose material (by means of vacuuming and/or broom sweeping) from lateral strips of road surface extending across the travel portion. Loose aggregate materials being transferred were sampled with a shovel to a depth exceeding the size of the largest aggregate pieces. Erodible surfaces were sampled to a depth of about 1 centimeter. The samples were analyzed to determine moisture and silt content.

Mining equipment travel speeds were measured by radar gun or with a stop watch over a known travel distance. Equipment specifications and traveling weights were obtained from mine personnel. For several sources, it was necessary to count vehicle passes, bucket drops, etc. These counts were usually recorded by two people during the test to ensure the accuracy of the results. Frequent photographs were taken during each test to establish the sampling layout (to supplement the ground-measured distances), source activity patterns, and plume characteristics.

Micro-meteorological conditions were recorded for each test. Most of these data were used in the calculation of concentrations or emission rates rather than as potential correction factors for the emission factor equations. During the test, a recording wind instrument measured wind direction and wind speed at the sampling site. A pyranograph was used to measure solar intensity. Humidity was determined with a sling psychrometer. A barometer was used to record atmospheric pressure. The percent of cloud cover was visually estimated.

In addition to monitoring micro-meteorological conditions, a fixed monitoring station at the mine monitored parameters affecting the entire area. Data were recorded on temperature, humidity, wind speed and direction, and precipitation.

ADJUSTMENTS MADE DURING SAMPLING

The sampling configurations detailed in this section were the result of a careful study design process completed prior to actual field sampling. Actual field conditions forced changes to elements of the study design.

A modification to the upwind-downwind sampling array was required. Whereas the study design called for two hi-vole at 200 m downwind of the source, this setup could not be adapted to field conditions. Three major reasons for the deviation from the study designs were: (a) the difficulty of locating the samplers where they were not subjected to other dust interferences; (b) the difficulty of extending power to the samplers; and © in many sampling locations, there was not 200 m of accessible ground downwind of the source. Therefore, only 1 hi-vol was routinely placed at the 200 m distance and in some cases no sampler was located at that distance.

Four modifications were made to the exposure profiling sampling array. First, it was impractical to mount dichotomous samplers at all four heights on the profiling tower as called for in the original study design. Dichotomous samplers were placed at two heights. Second, the study design called for an exposure profiling test to be terminated if the standard deviation of the wind direction exceeded 22.5° during the test period. Because unstable atmospheric conditions were encountered at Mine 1 during the summer season, it was necessary to relax this restriction. However, this change had no effect on the direction-insensitive dichotomous sampler which served as the primary sizing device. At the third mine, a second cascade impactor and hi-vol were added alongside the profiler at the height of the third profiling head. This was to provide backup data on particle size distribution in the upper portion of the plume and on the TSP concentration profile. Finally, greased substrates were used with the cascade impactors at the third mine to test whether particle bounce-through observed at the first two mines would be diminished.

A modification was required to the balloon sampling array. The study design specified that the five ground-based sampler pairs be located 10 m apart and that the balloon samplers be located on the blast plume centerline. This was found to be impractical under field conditions. The location of the plume centerline was very dependent on the exact wind direction at the time of the blast. Because the balloon sampling array required at least one hour to set up, it was impossible to anticipate the exact wind direction one hour hence. Therefore, the ground-based samplers were placed 20 to 30 m apart when the wind was variable so that some of the samplers were in the plume. The balloon sometimes could not be moved to the plume centerline quickly enough after the blast. Rapid sequence photography was used during the test to assist in determining the plume centerline) the emission factor calculation procedure was adjusted accordingly.

ERROR ANALYSES FOR SAMPLING METHODS

Separate error analyses were prepared for the exposure profiling and upwind-downwind sampling methods. These analyses were documented in interim technical reports and will only be summarized here (Midwest Research Institute 1979; PEDCo Environmental 1979).

A summary of potential errors (lσ) in the exposure profiling method initially estimated by MRI is shown in Table 3-6. Potential errors fall in the categories of sample collection, laboratory analysis, and emission factor calculation. For particles less than 15 μm, the error in the technique was estimated by MRI to range from -14 percent to +8 percent. Subsequent field experience on this project indicated that actual error was 30 to 35 percent in that size range and higher for the less than 30 μm (suspended particulate) size range.

Potential errors initially estimated by PEDCo for the upwind-downwind sampling method are summarized in Table 3-7. A delineation was made between errors associated with line sources and point/area sources. The estimated errors were ±30.5 percent and ±50.1 percent, respectively.

SUMMARY OF TESTS PERFORMED

Sampling performed is shown in Table 3-8. The number of samples are shown by source and mine. A total of 265 tests were completed.

TABLE 3-6. SUMMARY OF POTENTIAL ERRORS IN THE EXPOSURE PROFILING METHOD

Source of Error	Error Type	Action to Minimize Error	Estimated Error
Sample Collection			
1. Instrument error	Random	Planned maintenance, periodic calibration and frequent flow checks	5%[a]
2. Anisokinetic sampling			
a. Wind direction fluctuation	Systematic	σ_θ<22.5°	<10%
b. Non-zero angle of intake to wind	Systematic	θ<30°	<10%
c. Sampling rate does not match wind speed	Systematic	0.8 < IFR <1.2	<5%
3. Improper filter loading	Systematic	Decrease or increase sampling duration	2% for fibrous media; 10% for non-fibrous media
4. Particle bounce	Systematic	Use dichotomous sampler	Negligible
Laboratory Analysis			
5. Instrument error	Random	Planned maintenance, periodic calibration and frequent weight checks	Negligible
6. Filter handling	Random	Use blanks for each test. Control weighing environment for humidity and temperature	2% for hi-vol filters; 5% for lo-vol filters
Emission Factor Calculation			
7. Poor definition of profile	Random	Sample at 4 or more points over plume dimension of 10 m; 90% of plume mass defined by sampling points	10%
8. Extrapolation of particle size distribution	Random	Assume log-normal particle size distribution	20% for extrapolation to 30 µm. See text.
Total (particles less than 15 µm)			-14% to + 8%[a]

[a] Subsequent field experience in this project (see Section 6) indicated that the dichotomous sampler instrument error was at least 25 percent, producing a total error (for particles less than 15 µm) of 30 to 35 percent.

TABLE 3-7. SUMMARY OF POTENTIAL ERRORS IN THE UPWIND-DOWNWIND SAMPLING METHOD

		Estimated Error	
Source of Error	**Data Restraints to Limit Error**	**Line Source**	**Point/Area Source**
<u>Measurement</u>			
1. High volume sampler measurements	Orientation of roof within average wind direction	18.8%	18.8%
2. Wind speed measurement	Average wind speed >1.0 mph	4.6%	4.6%
3. Location relative to the source			
a. Distance from source	Measure from downwind edge of source	1.7%	1.7%
b. Distance from plume ℄ in y dimension	Samplers should be within $2\sigma_y$ of centerline	-	5.8°
c. Distance from plume ℄ in z dimension	Samplers should be within $2\sigma_z$ of centerline	0.5 m	1.0 m
<u>Atmospheric Dispersion Equation</u>			
4. Initial plume dispersion			
Horizontal		-	0.2 m
Vertical		0.2 m	0.5 m
5. Dispersion coefficients			
Empirical values		3.2%	5.8/3.2%
Estimation of stability class		15.9%	21.1/15.9%
6. Subtraction of a background concentration	This error will be higher when the wind reverses briefly or upwind samplers are biased by nearby sources	18.8%	18.8%
7. Gaussian plume shape		cannot quantify	
8. Steady state dispersion	Marginal passes <12% of good passes	6.0%	6.0%
Total		30.5%	50.1%

TABLE 3-8. SUMMARY OF TESTS PERFORMED

Sources	Mine 1	Mine 2	Mine 1W[a]	Mine 3	Total
Drill (overburden)	11	-	12	7	30
Blasting (coal)	3	6		7	16
Blasting (overburden)	2			3	5
Coal loading	2	8		15	25
Dozer (overburden)	4	7		4	15
Dozer (coal)	4	3		5	12
Dragline	6	5		8	19
Haul truck	7[b]	9	10	9	35[c]
Light- and medium-duty truck	5	5		3	13[d]
Scraper	5[b]	5	2	2	14
Grader		6		2	8
Exposed area (overburden)	11	14	3	6	34[e]
Exposed area (coal)	10	7	6	16	39
Total	70	75	33	87	265

[a]Winter sampling period.
[b]Five of these tests were comparability tests.
[c]Nine of these were for controlled sources.
[d]Two of these were for controlled sources.
[e]Three of these were for controlled sources.

Appendix D
Sample Handling and Analysis

This appendix contains information on the handling and analysis of fugitive dust emission samples. All information found in this appendix, is from section 4 of the EPA report "Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources - Volume I -Sampling Methodology and Test Results."

TABLE OF CONTENTS

D.1 Section 4 of Report: "Improved Emission Factors for Fugitive Dust From Western Surface Coal Mining Sources--Volume 1 - Sampling Methodology and Test Results.

SECTION 4
SAMPLE HANDLING AND ANALYSIS

SAMPLE HANDLING

Several different types of particulate samples were collected during the field work: hi-vol glass filters, filters and settling chamber catches from exposure profilers, cascade impactor stages, cyclone precollector catches, Teflon filters from dichotomous samplers, millipore filter cartridges for microscopic analysis, PVC filters from the balloon sampling system, and dustfall samples. These samples all required slightly different handling procedures.

At the end of each run, the collected samples were transferred carefully to protective containers. All transfer operations except removal of cartridges from the instruments were done in a van or in the field lab to minimize sample losses and contamination. Sample media were carried and transported locally in an upright position, and covered with temporary snap-on shields or covers where appropriate. Hi-vol and profiler filters were folded and placed in individual envelopes. Dust collected on interior surfaces of profiler probes and cyclone precollectors was rinsed with distilled water into containers with the settling chamber catches.

In order to reduce the amount of material dislodged from the taut dichotomous filters during handling, the preweighed filters were placed in plastic holders that were then kept in individual petri dishes throughout the handling process. The petri dishes were sealed with tape before being returned to the laboratory and stacked in small carrying cases so that they would not be inverted. Many of the dichotomous filters were hand-carried back to the laboratory by air travel rather than returning with the sampling equipment and other samples in the van.

In spite of the special handling procedures adopted for the dichotomous filters, loose particulate material was observed in some of the petri dishes and material could be seen migrating across the filter surfaces with any bumping of the filter holder. Several corrective actions were investigated by PEDCo and

MRI throughout the study, but this remained an unresolved handling problem. First, ringed Teflon filters were substituted for the mesh-backed filters initially used in an attempt to reduce movement or vibration of the exposed filters. Next, the possibility of weighing the filters in the field was reviewed. However, a sensitive microbalance and strict filter equilibration procedures were required because of the small weights involved--filter tare weights less than 100 mg and many upwind and fine particle fraction sample weights less than 50 μg. (See Pages 12-4 and 12-5 for further discussion of dichotomous samplers.)

PVC filters for the balloon samplers and millipore filters for particle size analysis were sent to the field in plastic cartridges. These cartridges were uncapped and affixed to the air pumps during sampling, then resealed and returned to the laboratory for gravimetric or microscopic analysis. Loss of material from these filter surfaces was not observed to be a problem as it was with the Teflon filters.

All samples except the dichotomous filters were labeled with the name of the mine, date, operation, sampler, and a unique sample number (dichotomous sample holders had only the sample number). This same information was also recorded on a field data sheet at the time of sampling. Copies of the field data sheets were shown in the study design report.

To minimize the problem of particle bounce, the glass fiber cascade impactor substrates were greased for use at Mine 3. The grease solution was prepared by dissolving 100 grams of stopcock grease in 1 liter of reagent grade toluene. A low pressure spray gun was used to apply this solution to the impaction surfaces. No grease was applied to the borders and backs of the substrates. After treatment, the substrates were equilibrated and weighed using standard procedures. The substrates were handled, transported and stored in specially designed frames which protected the greased surfaces.

After samples were taken at the mines, they were kept in the field lab until returned to the main laboratory. All samples were accounted for by the field crew by checking against the field data sheet records prior to leaving the field location. Photocopies of the data sheets were made and transported separately from the samples. Upon reaching the lab, the chain of custody was maintained by immediately logging in the sample numbers of all samples received. No samples were known to have been lost through misplacement or inadequate labeling during the entire study.

Non-filter (aggregate) samples were collected during or immediately following each sampling period and labeled with identifying information. The samples were kept tightly wrapped in plastic bags until they were split and analyzed for moisture content. Dried samples were then repackaged for shipment to the main laboratories for sieving.

ANALYSES PERFORMED

Laboratory analyses were performed on particulate samples and on aggregate samples. All monitoring of source activities and meteorological conditions was done with on-site measurements and did not result in the collection of samples for later analysis. The analyses performed are summarized in Table 4-1.

All particulate samples were analyzed in the lab of the contractor who took the samples. However, almost all of the aggregate sample analyses were done in the MRI lab because of their extensive past experience with aggregate analyses and to maintain consistency in methods. Aggregate samples for PEDCo's tests were taken by their field crew and moisture contents were determined in the field lab. Most of the labeled, dried aggregate samples were then turned over to MRI for all other analyses.

PEDCo performed all microscopy analyses. Initially, microscopy samples were to be used to determine full particle size distributions. After the comparability study results showed that microscopy data did not agree with that obtained from sampling devices that measured aerodynamic particle sizes, the microscopy work was limited to determination of largest particles in the plume downwind of sources.

LABORATORY ANALYSIS PROCEDURES

Filters

Particulate samples were collected on four different types of filters: glass fiber, Teflon, polyvinyl chloride (PVC) and cellulose copolymer (millipore). The procedure for preparing and analyzing glass fiber filters for high volume air sampling is fully described in Quality Assurance Handbook for Air Pollution Measurement Systems--Volume II, Ambient Air Specific Methods (U.S. Environmental Protection Agency 1977b). Nonstandardized methods were used for the other three filter types. The procedures for each type are described below.

TABLE 4-1. LABORATORY ANALYSES PERFORMED

Sample	Analysis Performed
Particulate	
Hi-vol filter	Weigh, calculate concentration
Exposure profiler filter	Weigh
Settling chamber catch	Filter, dry, weigh
Cyclone precollector catch	Filter, dry, weigh
Cascade impactor stages	Weigh
Quasi-stack filter	Weigh
Settling chamber catch	Transfer, dry, weigh
Teflon filter	Weigh, calculate concentration
PVC filter	Weigh
Millipore filter	Microscopic examination for size distribution and max size
Dustfall	Filter, dry, weigh
Aggregate	
Raw soil sample	Moisture content
Dried sample	Mechanical sieving

Glass fiber filters were numbered and examined for defects, then equilibrated for 24 hours at 70°F and less than 50 percent relative humidity in a special weighing room. The filters were weighed to the nearest 0.1 mg. The balance was checked at frequent intervals with standard weights to assure accuracy. The filters remained in the same controlled environment for another 24 hours, after which a second analyst reweighed 10 percent of them as a precision check. All the filters in each set in which check weights varied by more than 3.0 mg from initial weights were reweighed. After weighing, the filters were packed flat, alternating with onionskin paper, for shipment to the field.

When exposed filters were returned from the field, they were equilibrated under the same conditions as the initial weighing. They were weighed and check weighed in the same manner.

Teflon filters from dichotomous samplers were desiccated for 24 hours over anhydrous calcium sulfate (Drierite) before weighing, both before and after use. The filters were weighed in the same constant temperature and humidity room as the glass fiber filters. They were weighed to the nearest 0.01 mg and the check weighing had to agree within 0.10 mg or all filters in the set were reweighed. The filters themselves were not numbered, but were placed in numbered petri dishes for handling and transport. Plastic filter holders were also placed on the filters in the lab so they could be inserted directly into the dichotomous samplers in the field.

PVC filters were treated in exactly the same manner as the Teflon filters, with the exception that they were placed in plastic cartridges rather than petri dishes.

The millipore filters used for microscopic analysis were not weighed to determine the amount of material collected. After they were exposed and returned to the lab in a plastic cartridge, a radial section of the filter was cut and mounted on a glass microscope slide. The filter section was then immersed in an organic fluid that rendered it invisible under the microscope, and a cover slip was placed over it. The slide was examined under a light microscope at 100 power using phase contrast illumination. The particles were sized by comparison with a calibrated reticle in the eyepiece. Ten different fields and at least 200 particles were counted on each slide. Also, the diameters of the three largest individual particles observed were recorded.

Settling Chamber Catches and Dustfall Samples

Laboratory grade dionized distilled water was used in the field laboratory to recover samples from settling chambers and dustfall buckets. Each unit was thoroughly washed five to eight separate times. A wash consisted of spraying 15 to 25 ml of water into the unit, swirling the unit around, and then quantitatively pouring the water into a sample jar. After the last wash, the sample jar (holding 150 ± 50 ml of wash water) was sealed and packed for shipping to MRI for sample recovery.

At the MRI laboratory, the entire wash solution was passed through a 47 mm Buchner type funnel holding a Type AP glass fiber filter under suction. The sample jar was then rinsed twice with 10 to 20 ml of dionized water. This water was passed through the Buchner funnel ensuring collection of all suspended material on the 47 mm filter. The tared filter was then dried in an oven at 100°C for 24 hours. After drying, the filters were conditioned at constant temperature 24 ± 2°C and constant humidity 45 ± 5 percent relative humidity for 24 hours.

All filters, both tared and exposed, were weighed to ±5 μg with a 10 percent audit of tared and exposed filters. Audit limits were ±100 μg. Blank values were determined by washing "clean" (unexposed) settling chambers and dustfall buckets in the field and following the above procedures.

Aggregate Samples

Samples of road dust and other aggregate materials were collected in 20 to 25 kg quantities for analysis of moisture and silt content. The samples were stored briefly in airtight plastic bags, then reduced with a sample splitter (riffle) or by coning and quartering to about 1 kg (800 to 1600 g).

The final split samples were placed in a tared metal pan, weighed on a balance, and dried in an oven at 110°C overnight. Laboratory procedures called for drying of materials composed of hydrated minerals or organic materials like coal and certain soils for only 2 hours. The samples were then reweighed and the moisture content calculated as the weight loss divided by the original weight of the sample alone. This moisture analysis was done in the field lab.

Dried samples were placed in plastic containers and sealed for shipment to main laboratories for determination of silt contents. This was done by mechanical dry sieving, with the portion passing a 200-mesh screen constituting the silt portion. The nest of sieves was placed on a conventional sieve shaker for 15 min. The material passing the 200-mesh screen, particles of less than 75 μm diameter, constituted the smallest particles which could be accurately determined by dry sieving according to ASTM methods.

More detailed sample collection and laboratory procedures for the moisture and silt analyses were presented in an appendix to the study design report.

QUALITY ASSURANCE PROCEDURES AND RESULTS

Quality assurance was an important concern from the beginning of this field study because of its size, complexity, and importance. Several special activities were instituted as part of the overall quality assurance effort. The primary one was delineation of specific quality assurance procedures to be followed throughout the study. This list of procedures was subjected to review by the technical review group; a revised version is presented in Table 4-2. It covers sampling flow rates, sampling media, sampling equipment and data calculations.

In addition to the quantitative checks listed in Table 4-2, many nonquantifiable procedures related to sample handling and visual inspection of equipment were adopted. Some of these were based on standard practices but others were set more stringent than normal requirements. No quality assurance procedures for operating or maintaining dichotomous samplers had been recommended yet by EPA, so considerable project effort was expended in developing and testing these procedures.

Meteorological equipment and monitoring procedures are not covered in Table 4-2. Approved equipment was used and it was operated and maintained according to manufacturer's instructions. Meteorological instruments had been calibrated in a laboratory wind tunnel prior to the field work.

Adherence to the specified quality assurance procedures was checked periodically by the Project Officer and other members of the technical review group, by intercontractor checks, and by external independent audits. Results of the quality assurance program for flow rates and weighing are summarized in Table 4-3. Results of the audits are described in the following section.

TABLE 4-2. QUALITY ASSURANCE PROCEDURES FOR MINING EMISSION FACTOR STUDY

Activity	QA Check/Requirement
Sampling flow rates	
Calibration	
Profilers, hi-vols, and impactors	Calibrate flows in operating ranges using calibration orifice, once at each mine prior to testing.
Dichotomous samplers	Calibrate flows in operating ranges with displaced volume test meters once at each mine prior to testing.
Single-point checks Profilers, hi-vols, and impactors	Check 25% of units with rotameter, calibration orifice, electronic calibrator once at each site prior to testing (different units each time). If any flows deviate by more than 7%, check all other units of same type and recalibrate non-complying units. (See alternative check below).
Dichotomous samplers	Check 25% of units with calibration orifice once at each site prior to testing (different units each time). If any flows deviate by more than 5%, check all other units and recalibrate non-complying units.
Alternative	If flows cannot be checked at test site, check all units every two weeks and recalibrate units which deviate by more than 7% (5% for dichots).
Orifice calibration	Calibrate against displaced volume test meter annually.
Sampling media	
Preparation	Inspect and imprint glass fiber media with ID numbers.
	Inspect and place Teflon media (dichot filters) in petri dishes labeled with ID numbers.
Conditioning	Equilibrate media for 24 hours in clean controlled room with relative humidity of less than 50% (variation of less than ±5%) and with temperature between 20°C and 25°C (variation of less than ±3%).
Weighing	Weigh hi-vol filters and impactor substrates to nearest 0.1 mg and weigh dichot filters to nearest 0.01 mg.
Auditing of weights (tare and final)	Independently verify weights of 7% of filters and substrates (at least 4 from each batch). Reweigh batch if weights of any hi-vol filters or substrates deviate by more than ±3.0 mg or if weights of any dichot filters deviate by more than ±0.1 mg.
Correction for handling effects	Weigh and handle at least one blank for each 10 filters or substrates of each type for each test.
Prevention of handling losses	Transport dichot filters upright in filter cassettes placed in protective petri dishes.

TABLE 4-2. (continued)

Activity	QA Check/Requirement
Calibration of balance	Balance to be calibrated once per year by certified manufacturers representative. Check prior to each use with laboratory Class S weights.
<u>Sampling equipment</u>	
Maintenance	
All samplers	Check motors, gaskets, timers, and flow measuring devices at each mine prior to testing.
Dichotomous samplers	Check and clean inlets and nozzles between mines.
Equipment sitting	Separate collocated samplers by 3-10 equipment widths.
Operation	
Isokinetic sampling (profilers only)	Adjust sampling intake orientation whenever mean (15 min average) wind direction changes by more than 30 degrees.
	Adjust sampling rate whenever mean (15 min average) wind speed approaching sampler changes by more than 20%.
Prevision of static mode deposition	Cap sampler inlets prior to and immediately after sampling.
<u>Data calculations</u>	
Data recording	Use specifically designed data forms to assure al necessary data are recorded. All data sheets must be initial and dated.
Calculations	Independently verify 10% of calculations of each type. Recheck all calculations if any value audited deviates by more ±3%.

TABLE 4-3. QUALITY ASSURANCE RESULTS

Activity	QA Check/Requirement
Calibration	
Profilers, hi-vols, and impactors	PEDCo calibrated hi-vols a total of 6 times in the 4 visits.
	MRI had flow controllers on all 3 types of units. These set flows were calibrated a total of 4 times for profilers, 7 times for hi-vols and impactors.
Dichotomous samplers	PEDCo and MRI calibrated their 9 dichots a total of 6 times, at least once at each mine visit. Actual flow rates varied as much as 9.1% between calibrations.
Single point checks	
Profilers, hi-vols, and impactors	Out of a total of 29 single point checks, only 2 PEDCo hi-vols were found to be outside the 7% allowable deviation, thus requiring recalibration. For MRI, 20 single point checks produced no units out of compliance.
Dichotomous samplers	The dichotomous samplers were recalibrated with a test meter each time rather than checking flow with a calibrated orifice.
Weighings	
Tare and final weights	PEDCo reweighed a total of 250 unexposed and exposed hi-vol filters during the study. Three of the reweighings differed by more than 3.0 mg. For 238 dichot filter reweighings, only four differed by more than 0.1 mg.
	MRI reweighed a total of 524 unexposed and exposed glass fiber filters during the study. Four of the reweighings differed by more than 3.0 mg. For 43 dichot filter reweighings, only one differed by more than 0.1 mg.
Blank filters	PEDCo analyzed 88 blank hi-vol and 69 blank dichot filters. The average weight increase was 3.4 mg (0.087%) for hi-vols, 0.036 mg (0.038%) for dichots. The highest blanks were 26.3 and 0.22 mg, respectively.
	MRI analyzed 67 hi-vol and dichot filter blanks. The highest blanks were 7.05 mg and 0.52 mg, respectively.

AUDITS

In addition to the rigorous internal quality assurance program and the review procedures set up with the technical review group, several independent audits were carried out during this study to further increase confidence in results. Two different levels of audits were employed:

Intercontractor - MRI audited PEDCo and vice versa

External - Performed by an EPA instrument or laboratory expert or a third EPA contractor

The audit activities and results of audits are summarized in Table 4-4.

Although there are no formal pass/fail criteria for audits such as these, all of the audits except the collocated samplers in the comparability study and filter weighings seemed to indicate that measurements were being made correctly and accurately. The collocated sampler results are discussed further in Sections 6 and 12. All the filters that exceeded allowable tolerances upon reweighing (10 percent of audited filters) lost weight. In the case of the hi-vol filters, loose material was observed in the filter folders and noted on the MRI data sheet. The amounts lost from the dichot filters would not be as readily noticeable in the petri dishes. The several extra handling steps required for auditing the filters, including their transport from Cincinnati to Kansas City, could have caused loss of material from the filters.

In addition to the external flow calibration audit at the third mine (shown in Table 4-4), another one was conducted at the second mine. However, results of this earlier audit were withdrawn by the contractor who performed it after it was learned that some critical steps, such as the auditee being present and current calibration curves being provided at the time of the audit, had not been followed. However, the preliminary results of that withdrawn audit showed generally acceptable performance of almost all the sampling equipment.

Some of the calculations of each contractor were repeated by the other as an audit activity. In general, the data were found to be free of calculation errors, but differences in assumptions and values read from curves led to frequent differences in final emission rates. No effort was made to estimate the average difference in independently calculated emission rates.

TABLE 4-4. AUDITS CONDUCTED AND RESULTS

Activity	Inter-Contractor or External Audit	Contractor Audited	Date	No. and Type of Units	Results
Flow Calibration	I	PEDCo	8-22-79	2 hi-vol	Each 4% from cal. curve
		MRI	8-27-79	1 hi-vol 1 impactor 2 dichot	Hi-vol and impactor within 4% of curve; dichot within 2%
		PEDCo	10-12-79	2 hi-vol	One within 1%, other out by 12.6%
		MRI	10-12-79	2 hi-vol 1 dichot	Both within 7% Within 5%
	E (EPA, OAQPS)	PEDCo	8-01-79	7 dichot	All set 5 to 11% high
		MRI	8-01-79	2 dichot	One within 1%, other out by 10%
	E (contractor)	MRI	8-06-80		
		PEDCo	8-05-80	10 hi-vol	7 within 5%, 2 within 7%, one 8.3% from cal. curve
		PEDCo	8-06-80	5 dichot	Total flows all within 5%, 2 coarse flows differed by 6.2 and 9.2%
Filter weighing	I	PEDCo	1-02-80	39 hi-vol 31 dichot	Three hi-vol filters varied by more than 5.0 mg; all lost weight and loose material in folder was noted. Four dichots exceeded the 0.10 mg tolerance and all lost weight
		MRI	-		Filters not submitted yet
Laboratory procedures	E (EPA, EMSL)	PEDCo	10-30-79	Compreh. review	No problems found
		MRI	11-13-79	Compreh. review	No problems found
Collocated samplers	I	Both	7-26-79 to 8-09-79	18 hi-vol 10 dichot	Paired hi-vol values differed by an avg. of 34%; IP values by 35%
Systems audit	E (EPA, OAQPS)	Both	8-01-79	All	Checked siting, calibration, filter handling, and maintenance procedures. Few minor problems found but concluded that operations should provide reliable data

Appendix E

Materials Related to Blasting Emission Factor

This appendix contains information related to emission factors for blasting. The information contained in the appendix includes four items: Section 5.5 and 8.5 of "Fugitive Dust Emission Factor Update for AP-42 "; memorandum from Chatten Cowherd, MRI, to James Southerland, EPA, June 1986; memorandum from Greg Muleski, MRI, to Frank Noonan, EPA, April 1987; and Section 9 of "Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources--Volume I -Sampling Methodology and Test Results."

TABLE OF CONTENTS

E.1 Section 5.5 and 8.5 of "Fugitive Dust Emission Factor Update for AP-42

5.5 Section 8.24 - Western Surface Coal Mining and Processing

5.5.1 Test Report 4 (1977)

This study developed an emission factor for coal storage only. Four tests at one coal storage pile (location not given) were conducted using the upwind-downwind technique. Table 23 presents the source testing information fo r this study.

TABLE 23. COAL STORAGE SOURCE TESTING INFORMATION (Test Report 4)

Operation	Equipment	Material	Site	Test date	No. of tests
Wind erosion	Storage pile	Coal	Plant 1	3/74	2
				8/74	2

High-volume samplers were used to collect the airborne particulates from one upwind and four downwind positions. The wind parameters were recorded at 15-min intervals. A sampling array similar to that described in Section 5.3.2 (Test Report 6) was employed in this study. This sampling system meets the minimum requirements of the upwind-downwind sampling technique. Optical microscopy was employed to determine a particle size distribution. However, the particle size distribution for the emission factor was determined from particle counting only (not-mass fraction), which is unrepresentative of a mass size distribution.

This methodology is of generally sound quality; and emission rates were determined in a similar manner to that described in Section 5.3.2 (Test Report 6). However, the report lacks sufficient detail for adequate validation. For example, no indication is given as to sampling height. Also the field data recorded at the sampling stations are not presented. The test data are therefore rated B.

Table 24 presents the developed emission factor, conditions tested and the appropriate rating. Only one pile was sampled, although it was two different sizes during testing. The rating code refers to Table 4.

TABLE 24. COAL STORAGE EMISSION FACTOR, RANGE OF TEST CONDITIONS, AND RATING (Test Report 4)

		Range of Conditions				
Operation	**No. of tests**	**Wind speed, m/s**	**Moisture content, %**	**Emission factor[a,b]**	**Rating code**	**Rating**
Wind erosion of coal storage pile	4	1.5-2.7	2.2-11	0.013 lb/T/yr	5	D

[a]For particles <10 μm (physical diameter).
[b]Emission factor is arithmetic mean of test runs C1, C2, CS-3 and CS-5 from page 30, Table A1 of test report.

5.5.2 Test Report 5 (1978)

This study was directed to the development of emission factors for the surface coal mining industry. Testing was conducted at five Western coal mines (Mines A through E). Table 25 presents the distribution of tests performed.

The upwind-downwind method was used with standard high-volume samplers for particulate collection. Wind parameters were continuously measured at a fixed location within each mine. A hand-held wind speed indicator was used when possible to record data at the exact test site. Optical microscopy was employed to determine particle size distribution.

The upwind-downwind sampler deployment used in this study generally employed six samplers for each test; additionally, six more samplers were operated at a second height in half the tests to determine a vertical plume gradient. Two instruments were located upwind of a source to measure background concentrations while four instruments were located downwind. These downwind samplers were deployed along a straight line (the assumed plume centerline) at four different distances.

TABLE 25. COAL MINING SOURCE TESTING INFORMATION (Test Report 5)

Operation	Equipment	Material	No. of Tests at Mine A	B	C	D	E	Test Date
Overburden removal	Dragline	Overburden	6	10	6	6	0	-
Vehicle traffic	Haul truck[b]	Unpaved road	0	4	0	[c]	[c]	-
Loading	Shovel/truck	Coal	6	4	4	0	4	-
		Overburden	0	0	0	0	6	-
Blasting	NA	Overburden	1	0	2	0	2	-
		Coal	0	0	2	2	2	-
Dumping[a]	Truck	-	6	2	2	4	0	-
Storage pile wind erosion[d]	-	Coal	6	6	0	4	0	-
Drilling	NA	Overburden	0	0	2	0	0	-
		Coal	0	0	0	0	2	-
Dumping[a]	-	Fly ash	2	0	0	0	0	-
Loading[a]	Train	Coal	0	0	4	0	0	-
Topsoil removal	Scraper	Topsoil	0	0	0	5	0	-
Topsoil dumping	Scraper	Topsoil	0	0	0	5	0	-
-[a]	Front-end loader	-	0	0	0	1	0	-

- = Information not contained in test report.
NA = Not applicable.
[a]Details as to specific operation sampled for are not stated in text.
[b]Size not given.
[c]Unable to determine if tests were under controlled or uncontrolled states.
[d]Includes pile maintenance (unspecified equipment).

The determination of emission rates involved back calculation using dispersion equations after subtraction of the background from the downwind concentration. The following dispersion equation was used to calculate emission rates for area sources.

$$C = \frac{Q}{\pi \sigma_y \sigma_z u} \quad (6)$$

where:

C = concentration

Q = emission rate

σ_y, σ_z = horizontal and vertical dispersion coefficients

u = wind speed

Line source emission rates were determined by use of this dispersion equation:

$$C = \frac{2\,Q}{\sin\,\phi\,\sqrt{2\pi}\,\sigma_z\,u} \quad (7)$$

where:

C = concentration

Q = emission rate

ϕ = angle between line source and wind direction

σ_z = vertical dispersion coefficient

u = wind speed

The predictive emission factor equation for wind erosion of active storage piles was developed by plotting the emission rates against the wind speeds recorded during testing. The resulting linear function was described by the equation:

$$e = 15.83\,u \quad (8)$$

where e = emission rate (lb/hr)

u = wind speed (m/sec)

This equation was then converted to one with units of $\frac{\text{lb}}{(\text{acre})(\text{hr})}$ by assuming storage pile surface areas of 10 acres.

This upwind-downwind sampling system does not meet the minimum requirements for point sources as set forth in Section 4.3 since particulate concentrations at only one crosswind distance were observed. Also details on the operations tested are frequently sketchy. Therefore, with three exceptions the test data are rated B. The test data for haul roads are rated A, because sampling at multiple crosswind distances is not required when testing line sources. The test data for storage pile wind erosion (and maintenance) are rated C because of: (a) the very light winds encountered; (b) the large size of the piles; and (c) the lack of information on pile maintenance activities. The test data for blasting are rated C because of the difficulty of quantifying the plume with ground based samplers.

The report indicates that emission factor variation between mines for the same operation is relatively high; therefore, it was recommended (in the report) that the factors be mine (type) specific. The following list describes the location of the five mines. The report gives a more in-depth description of each mine including production rate, stratigraphic data, coal analysis data, surface deposition, storage capacity, and blasting data.

Mine	Area
A	Northwest Colorado
B	Southwest Wyoming
C	Southeast Montana
D	Central North Dakota
E	Northeast Wyoming

Tables 26 through 30 present the average emission factors determined at each mine along with the ranges of conditions tested and the associated emission factor ratings. The text indicates the emission factors should be used with a fallout function for distances closer than 5 km; however, the text does not explicitly state what particulate size range is represented by the emission factors.

The rating codes in Tables 26 through 30 refer to Table 5 (wind erosion) and Table 4 (all other sources). Because the single-valued factors were intended to apply only to the specific mine types, the requirement for more than one test site was waived. The rating for the equation developed for storage pile wind erosion (and maintenance) is applicable when the equation is applied to mine types A, B, or D.

5.5.3 Test Report 14 (1981)

This study was conducted to determine improved fugitive dust emission factors for Western surface coal mines. Field testing was conducted in three coal fields; Powder River Basin (Mine 1), North Dakota (Mine 2), and Four Corners (Mine 3). The testing was performed during 1979 and 1980. Table 31 lists the testing information for this study.

The primary sampling method was exposure profiling. When source configuration made it necessary, alternate methods were used, including upwind-downwind, balloon, and quasi-stack sampling. Particle size distributions were determined by use of dichotomous samplers. Other equipment utilized were: (a) high volume samplers for determining upwind concentrations; (b) dustfall buckets for determining downwind particulate deposition; and (c) recording wind instruments to determine mean wind speed and direction for adjusting the exposure profiler to isokinetic sampling conditions and for use in upwind-downwind calculations.

Exposure profiling was used to measure emissions from moving point sources (see Table 31). The exposure profiling sampling system was similar to that described in Section 5.1.1 and therefore meets the minimum system design requirements. The upwind-downwind sampling system consisted generally of 15 particulate collection devices; 5 dichotomous samplers and 10 Hi-Vols.

One Hi-Vol and one dichotomous sampler were placed upwind while the remaining instruments were placed at multiple downwind and crosswind distances. This system also meets the minimum upwind-downwind requirements as described in Section 4.3.

TABLE 26. COAL MINING EMISSION FACTORS (MINE TYPE A), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	0.4-1.8	-	0.0056 lb/yd^3	4	D
Shovel/truck loading (coal)	6	0.4-1.3	10	0.014 lb/T	4	D
Blasting (overburden)	1	2.4	-	1,690[c] lb/blast	9	E
Truck dump[d] (bottom)	6	0.4-2.7	-	0.014 lb/T	4	D
Storage pile erosion[e]	6	0.5-2.6	10	$1.6\ u\ \frac{lb}{(acre)(hr)}$	1[f]	C[f]
Fly ash dump	2	1.5	-	3.9 lb/hr	7/8	E

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.
[c]Text indicates this value represents a maximum rate.
[d]Material not given.
[e]u = Wind speed in m/sec. This factor includes emissions from pile maintenance.
[f]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 27. COAL MINING EMISSION FACTORS (MINE TYPE B), RANGE OF TEST CONDITIONS, AND RATINGS
(Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	10	3.1-5.8	-	0.053 lb/yd^3	4	D
Haul road	4	3.7-4.7	-	17.0 lb/VMT	5	C
Shovel/truck loading (coal)	4	0.4-0.6	18	0.007 lb/T	5	D
Truck dump (bottom)	2	3.7	-	0.020 lb/T	7	E
Storage pile erosion[c]	6	0.8-7.6	18	$1.6\ u\ \frac{lb}{(acre)(hr)}$	1[d]	C[d]

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.
[c]u = Wind speed in m/sec. This factor includes emissions from pile maintenance.
[d]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 28. COAL MINING EMISSION FACTORS (MINE TYPE C), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	3.6-5.4	-	0.0030 lb/yd^3	3	C
Shovel/truck loading (coal)	4	3.6	24	0.002 lb/T	5	D
Blasting						
Coal	2	5.4	24	25.1 lb/blast	7	E
Overburden	2	3.6	-	14.2 lb/blast	7	E
Truck dump (bottom)	2	3.6	-	0.005 lb/T	7	E
Drilling (overburden)	2	3.6	-	1.5 lb/hole	8	
Train loading	4	4.5-4.9	24	0.0002 lb/T	5	D

\- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.

TABLE 29. COAL MINING EMISSION FACTORS (MINE TYPE D), RANGE OF TEST CONDITIONS, AND RATINGS
(Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	5.8-7.2	-	0.021 lb/yd^3	3	C
Blasting (coal)	2	4.0	38	78.1 lb/blast	7	E
Truck dump (bottom)	4	4.5-6.7	-	0.027 lb/T	6	E
Storage pile erosion[c]	4	0.9-1.3	38	$1.6\ u\ \frac{\text{lb}}{(\text{acre})(\text{hr})}$	1[d]	C[d]
Topsoil removal						
Scraping	5	5.8-7.6	-	0.35 lb/yd^3	4	D
Dumping	5	2.2-3.6	-	0.03 lb/yd^3	3	C
Front-end loader	1	2.7	-	0.12 lb/T	9	E

\- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.
[c]u = Wind speed in m/sec.
[d]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 30. COAL MINING EMISSION FACTORS (MINE TYPE E), RANGE OF TEST CONDITIONS, AND RATINGS
(Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Shovel/truck loading						
Coal	4	2.3-2.5	30	0.0035 lb/T	5	D
Overburden	6	2.7-3.6	30	0.037 lb/T	3	C
Blasting						
Coal	2	2.6	30	72.4 lb/blast	7	E
Overburden	2	3.7	-	85.3 lb/blast	7	E
Truck dump						
Overburden	2	6.2	-	0.002 lb/T	8	E
Coal (end dump)	4	2.7-3.1	30	0.007 lb/T	6	E
Drilling (coal)	2	4.1	30	0.22 lb/hole	8	E

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.

TABLE 31. COAL MINING SOURCE TESTING INFORMATION (Test Report 14)

Operation	Equipment	Material	Test Method[a]	Site (mine)	Test Dates	No. of Tests
Drilling	NA	Overburden	Quasi-stack	1, 3	7/79, 8/79, 12/79, 7/80	30
Blasting	NA	Coal	Balloon[b]	1, 2, 3	8/79,10/79, 7/80, 8/80	14
		Overburden	Balloon[b]	1, 3	8/79, 8/80	4
Loading	Shovel/truck	Coal	Uw-Dw	1, 2	8/79, 10/79	10
	Front-end loader/truck	Coal	Uw-Dw	3	7/80, 8/80	15
Dozing	Dozer	Coal	Uw-Dw	1, 2, 3	8/79, 10/79, 8/80	12
		Overburden	Uw-Dw	1, 2, 3	8/79, 10/79, 7/80, 8/80	15
Dragline	Dragline	Overburden	Uw-Dw	1, 2, 3	8/79, 10/79, 7/80, 8/80	19
Vehicle traffic	Haul truck	Unpaved road	Uw-Dw	1	8/79, 12/79	11
		Unpaved road	Profiling	1, 2 ,3	7/79, 8/79, 12/79	21
	Light-medium duty	Unpaved road	Profiling	1, 2, 3	8/79, 10/79, 8/80	10
Scrapers[c] (travel mode)	Scraper	Unpaved surface	Uw-Dw	1	7/79	5
		Unpaved surface	Profiling	1, 2, 3	7/79, 10/79, 12/79, 8/80	15
Grading	Grader	Unpaved surface	Profiling	2, 3	10/79, 8/80	7

- = Information not contained in test report.
NA = Not applicable.
[a]Uw-Dw = Upwind-downwind.
[b]This is actually a modified version of exposure profiling.
[c]Loading and dumping not tested.

The test data were collected using a well documented sound methodology and, therefore, are rated A for line sources and for drilling. The test data for coal loading, dozing, and dragline operations are rated B because of the poorly defined plume characteristics and the interference of the pit areas with plume dispersion. For blasting the test data are rated C because of the difficulty of quantifying the large plume with a single line of samplers.

Table 32 presents the average emission factors, range of test conditions, and ratings assigned for Test Report 14. These single-valued factors were determined by substituting geometric means of the test conditions into a set of predictive emission factor equations also developed in the study. The equations are listed in Table 33. The rating codes in Table 32 refer to Table 4, and the codes in Table 33 refer to Table S.

5.5.4 Test Report 15 (1981)

A portion of this study was devoted to the development of surface coal mining emission factors. Field testing was performed from August 1978 through the summer of 1979 at two surface coal mines located in the Powder River Basin of Wyoming. Table 34 presents the source testing information for this study.

The test methods employed to develop emission factors were: upwind-downwind, profiling, and a tracer technique. Particle sizing was performed by optical microscopy of exposed Millipore filters.

The profiling technique employed in this study was actually a variation of the exposure profiling procedure described in Section 5.1.1 (Test Report 7). High volume samplers were used instead of directional isokinetic intakes; therefore, the emission rates determined by profiling were for TSP (total suspended particulate).

The tracer technique utilized arrays of both high-volume samplers and tracer samplers with a straightforward calculation scheme. These sampling systems meet the minimum requirements as set forth in Section 4.3; therefore; the test data are rated A.

TABLE 32. COAL MINING EMISSION FACTORS, RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 14)

Operation	No. of Tests	Range of Conditions								Particulate Emission Factor[a]			Units	Rating Code	Rat-ing
		Mat'l Moisture Content (%)	Mat'l Silt Content (%)	Surface Silt Loading (g/m^2)	Vehicle Speed (mph)	Vehicle Weight (tons)	No. of Wheels	Wind Speed (mph)	Other	TSP	< 15 μm	< 25 μm			
Drilling	30	6.9-9.0	5.2-26.8	NA	NA	NA	NA	0.9-6.3	[b]	1.3	-	-	lb/hole	2	B
Blasting															
Coal	14	11.1-38.0	-	NA	NA	NA	NA	2.2-12.1	[c]	35.4[d]	13.2[d]	1.10[d]	lb/blast	2	D
Overburden	4	7.2-8.0	-	NA	NA	NA	NA	2.2-11.4	[e]					2	C
Coal loading	25	6.6-38.0	3.6-4.2	NA	NA	NA	NA	2.2-11.2	[f]	0.037	0.008	0.0007	lb/ton	2	C
Dozing															
Coal	12	4.0-22.0	6.0-11.3	NA	5-12	-	NA	3.4-13.4	None	46.0	20.0	1.0	lb/hr	2	C
Overburden	15	2.2-16.8	3.8-15.1	NA	2-7	-	NA	2.5-19.0	None	3.7	0.88	0.39	lb/hr	2	C
Dragline	19	0.2-16.3	4.6-14.0	NA	NA	NA	NA	2.2-16.6	g	0.059	0.013	0.001	lb/hr	2	C
Vehicle traffic															
Light-medium duty	10	0.9-1.7	4.9-10.1	5.9-48.2	24.8-42.9	2.0-2.6	4.0-4.1	6.5-13.0	None	2.9	1.8	0.12	lb/VMT	2	B
Haul truck	27	0.3-8.5	2.8-18.0	3.8-254	14.9-36.0	24-138	4.9-10.0	1.8-15.4	None	17.4	8.2	0.30	lb/VMT	2	B
Scrapers	15	0.9-7.8	7.2-25.2	8.0-96.8	9.9-31.7	36-70	4.0-4.1	2.5-21.0	None	13.2	6.0	0.34	lb/VMT	2	B
Grading	7	1.0-9.1	7.2-29.0	76-190	5.0-11.8	13-14	5.9-6.0	4.3-11.6	None	5.7	2.7	0.18	lb/VMT	4	C

- = Information not contained in test report.

NA = Not applicable.

[a]ISP and < 15 μm emission factors were determined by applying the mean correction correlation parameters in Table 13-9 (page 13-15 of test report) to the equation in Table 15-1 (page 15-2 of test report). The less than 2.5 μm emission factors were determined by applying the appropriate fraction found in Table 15-1 (page 15-2 of test report) to the ISP emission factors.

[b]Depth of drilling = 30 to 100 ft.

[c]No. of holes = 6 to 750; blast area - 100 to 6,800 m^2; depth of holes = 20 to 70 ft.

[d]The results of coal and overburden blasting were combined in the test report to form a single emission factor.

[e]No. of holes = 20 to 60; blast area = 2,200 to 9,600 m^2; depth of holes = 25 to 135 ft.

[f]Bucket capacity = 14 to 17 $yards^3$.

[g]Bucket capacity = 32 to 65 $yards^3$; drop distance = 5 to 100 ft.

TABLE 33. COAL MINING EMISSION FACTOR EQUATIONS AND RATINGS

Operation	Particulate Emission Factor Equation[a] TSP	< 15 μm	< 2.5 μm/TSP[b]	Units	Rating Code	Rating
Blasting (coal or overburden)	$\frac{961\ (A)^{0.8}}{(D)^{1.8}\ (M)^{1.9}}$	$\frac{2,550\ (A)^{0.6}}{(D)^{1.5}\ (M)^{2.3}}$	0.030	lb/blast	1	C
Coal loading	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.019	lb/ton	1	B
Dozing Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.022	lb/hr	1	B
Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.105	lb/hr	1	B
Dragline Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021\ (d)^{0.7}}{(M)^{0.3}}$	0.017	lb/yard^3	1	B
Scrapers (Travel mode)	$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.026	lb/VMT	1	A
Grading	$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.031	lb/VMT	2	B
Vehicle traffic Light-medium duty	$\frac{5.79}{(M)^{4.0}}$	$\frac{3.22}{(M)^{4.3}}$	0.040	lb/VMT	2	B
Haul trucks	$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.017	lb/VMT	1	A

Note: The range of test conditions are as stated in Table 32. Particle diameters are aerodynamic.

[a]From page 15-2, Table 15-1 of test report.

[b]Multiply this fraction by the TSP predictive equation to determine emissions in the < 2.5 μm size range.

A = area blasted (ft^2)
M = moisture content (%)
D = hole depth (ft)
s = silt content (%)
d = drop height (ft)
W = vehicle weight (tons)
S = vehicle speed (mph)
w = number of wheels
L = silt loading (g/m^2)

TABLE 34. COAL MINING SOURCE TESTING INFORMATION (Test Report 15)

Operation	Equipment	Material	Test Method[a]	Site No. (mine)	Test Dates	No. of Tests
Vehicle traffic	Haul trucks	Coal, overburden	Profiling	2	Winter, spring, summer	26[b]
Dumping	-	Coal	Tracer	1, 2	Fall, winter	3
Loading	Train	Coal	Tracer	1, 2	Fall	2
Overburden replacement	-	Overburden	Uw-Dw	1, 2	Winter, spring, summer	7
Topsoil removal	(Scraper)[c]	Topsoil	Uw-Dw	1	Summer	2
Exposed Area	NA	Seeded land, stripped overburden, graded overburden	Uw-Dw	1, 2	Spring, summer	18

- = Information not contained in test report.
NA = Not applicable.
[a]Uw-Dw = Upwind-downwind.
[b]This series of tests involved a wide variety of road conditions ranging from total control (wet) to totally uncontrolled (dry). An emission factor equation was derived which takes the amount of control present into account (see Table 33, footnote a).
[c]Although scrapers are most often used in this operation the test report did not explicitly state that scrapers were being used.

The upwind-downwind sampling system consisted of 10 Hi-Vols of which two were placed upwind and eight were placed at multiple downwind and crosswind distances. Wind direction and speed were concurrently measured at an on-site station for all test periods. This sampling system meets the minimum requirements set forth in Section 4.3. However, the emission factors are rated B because these operations tested (overburden replacement, coal dumping, and top soil removal) were not described as to the equipment employed (see Table 34).

The calculated TSP emission rates were modified with a depletion factor, as follows. A deposition velocity was determined from dustfall bucket measurements:

$$V_d = 1.51 \ (x)^{-0.588} \qquad (9)$$

where:

V_d = deposition velocity

x = distance downwind of source

This velocity was combined with stability class and wind speed to derive a depletion factor in terms of distance downwind of a particulate source. The actual emission rate for an operation was then calculated through division of the apparent emission rate (measured at a particular distance downwind) by the appropriate depletion factor.

Table 35 gives the range of test conditions, emission factors, and applicable ratings for Test Report 16. The rating codes refer to Table 4. These ratings overlook the particle size incompatibility between the Hi-Vol measurements of particulate flux and the dustfall measurements of deposition velocity.

TABLE 35. COAL MINING EMISSION FACTORS, RANGE OF TEST CONDITIOINS, AND RATINGS (Test Report 15)

Operation	Number of Tests	Mat'l Mois-ture Content (%)	Mat'l Silt Conent (%)	Veh-icle Speed (mph)	Vehicle Weight (tons)	Wind Speed (mph)	Total Particu-late Emission Factor	Units	Rat-ing Code	Ra-ting
Vehicle traffic[a]	26	Dry-wet	8.3-11.2	22-24	-	3.6-19.2	22.0	lb/VMT	4	C
Coal dumping[b]	3	-	-	NA	NA	2.9-6.0	0.066	lb/T	6	D
Train loading[c]	2	-	-	NA	NA	4.0-11.4	0.027	lb/T	7	D
Overburden replacement[d]	7	-	-	-	-	3.8-19.9	0.012	lb/T	3	C
Topsoil removal[a]	2	-	-	-	-	10.1	0.058	lb/T	8	E
Exposed areas[f]	18	-	-	NA	NA	5.4-17.4	0.38	ton/acre-year	2	C

- = Information not contained in test report.
NA = Not applicable.
[a]The emission factor equation derived for this source is from page 35 of test report. It was evaluated at zero wettings per hour.
[b]Emission factor is from page 46, Table 5.1 of test report.
[c]Emission factor is from page 47, Table 5.2 of test report.
[d]Emission factor is from page 52, Table 6.1 of test report.
[e]Emission factor is from page 52, Table 6.2 of test report.
[f]Emission factor is from page 55, Table 7.1 of test report.

8.5 Western Surface Coal Mining and Processing

Since no emission factors are currently presented in AP-42 for coal mining. The predictive emission factor equations presented in Table 49 are recommended for inclusion in AP-42 under a section named “Western Surface Coal Mining.” Table 50 presents the single-valued emission factors for western surface coal mining. It is recommended that for any source operation not covered by the equations in Table 49, the highest rated single valued factors from Table 50 be incorporated in AP-42.

All of the recommended factors may be applied to Eastern surface coal mining. However, each should then be aerated one letter value (e.g., C to D).

TABLE 49. WESTERN SURFACE COAL MINING PREDICTIVE EMISSION FACTOR EQUATIONS

(Test Reports 5 and 14)

Operation	Material	Particulate Emission Factor Equation: TSP	Particulate Emission Factor Equation: < 15 μm	Particulate Emission Factor Equation: < 2.5 μm/TSP[a]	Units	Test Report	Rating
Blasting	Coal or overburden	$\frac{961\ (A)^{0.8}}{(D)^{1.8}\ (M)^{1.9}}$	$\frac{2{,}550\ (A)^{0.6}}{(D)^{1.5}\ (M)^{2.3}}$	0.030	lb/blast	14	C
Truck loading	Coal	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.019	lb/ton	14	B
Dozing	Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.022	lb/hr	14	B
	Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.105	lb/hr	14	B
Dragline	Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021\ (d)^{0.7}}{(M)^{0.3}}$	0.017	$lb/yard^3$	14	B
Scrapers (travel mode)		$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.026	lb/VMT	14	A
Grading		$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.031	lb/VMT	14	B
Vehicle traffic (light-medium duty)		$\frac{5.79}{(M)^{4.0}}$	$\frac{3.72}{(M)^{4.3}}$	0.040	lb/VMT	14	B
Haul trucks		$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.017	lb/VMT	14	A
Storage pile (Wind erosion and maintenance)	Coal	1.6 u	-	-		5	C[b]

- = Unable to be determined from informaiton continaed in test report.

[a]Multiply this fraction by the TSP predictive equation to detemrine emissions in the < 2.5 μm size range.

[b]Rating applicable to Mine Types A, B, and D (see p 61).

A = area blasted (ft^2)
M = moisture content (%)
D = hole depth (ft)
s = silt content (%)
μ = wind speed (m/sec)
d = drop height (ft)
W = vehicle weight (tons)
S = vehicle speed (mph)
w = number of wheels
L = silt loading (g/m2)

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS
(Test Report 4, 5, 14, and 15)

		Emission Factor by Aerodynamic Diameter									
Operation	**Source (Material)**	**Total**	**TSP**	**< 30 (μm)**	**< 15 (μm)**	**< 10 (μm)**	**< 5 (μm)**	**< 2.5 (μm)**	**Units**	**Test Report**	**Rating**
Drilling											
	(Overburden) (mine type C)	-	1.3	-	-	-	-	-	lb/hole	14	B
	(Coal) (mine type E)	-	0.22	-	-	-	-	-	lb/hole	5	E
Blasting	(Overburden)										
	(mine type A)	-	1,690	-	-	-	-	-	lb/blast	5	E
	(mine type C)	-	14.2	-	-	-	-	-	lb/blast	5	E
	(mine type E)	-	85.3	-	-	-	-	-	lb/blast	5	E
	(Coal)										
	(mine type C)	-	25.1	-	-	-	-	-	lb/blast	5	E
	(mine type D)	-	78.1	-	-	-	-	-	lb/blast	5	E
	(mine type E)	-	72.4	-	-	-	-	-	lb/blast	5	E
Dragline	(Overburden)										
	(mine type A)	-	0.0056	-	-	-	-	-	lb/yd^3	5	D
	(mine type B)	-	0.053	-	-	-	-	-	lb/yd^3	5	D
	(mine type C)	-	0.0030	-	-	-	-	-	lb/yd^3	5	C
	(mine type D)	-	0.021	-	-	-	-	-	lb/yd^3	5	C
Top soil removal	Scraper										
	(mine type D)	-	0.44	-	-	-	-	-	lb/T	5	D
	Unspecified equipment	-	0.058	-	-	-	-	-	lb/T	15	E
Overburden replacement	Unspecified equipment	-	0.012	-	-	-	-	-	lb/T	15	C

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS (Test Report 4, 5, 14, and 15) (cont.)

		Emission Factor by Aerodynamic Diameter									
Operation	**Source (Material)**	**Total**	**TSP**	**< 30 (μm)**	**< 15 (μm)**	**< 10 (μm)**	**< 5 (μm)**	**< 2.5 (μm)**	**Units**	**Test Report**	**Rating**
Batch-drop	Dumping via truck (Overburden-bottom)										
	(mine type E)	-	0.002	-	-	-	-	-	lb/T	5	E
	(Coal-end)										
	(mine type E)	-	0.007	-	-	-	-	-	lb/T	5	E
	(Material not specified-bottom)										
	(mine type A)	-	0.014	-	-	-	-	-	lb/T	5	D
	(mine type B)	-	0.020	-	-	-	-	-	lb/T	5	E
	(mine type C)	-	0.005	-	-	-	-	-	lb/T	5	E
	(mine type D)	-	0.027	-	-	-	-	-	lb/T	5	E
	Dumping via scraper (top soil)										
	(mine type D)	-	0.04	-	-	-	-	-	lb/T	5	C
	Dumping via unspecified equipment or process										
	(Coal)	-	0.066	-	-	-	-	-	lb/T	15	D
	(Fly-ash)										
	(mine type A)	-	3.9	-	-	-	-	-	lb/hr	5	E
	Front-end loader/truck (Material unspecified)										
	(mine type D)	-	0.12	-	-	-	-	-	lb/T	5	E
	Power shovel/truck (Overburden)										
	(mine type E)	-	0.037	-	-	-	-	-	lb/T	5	C

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS
(Test Report 4, 5, 14, and 15) (cont.)

Operation	Source (Material)	Emission Factor by Aerodynamic Diameter: Total	TSP	< 30 (μm)	< 15 (μm)	< 10 (μm)	< 5 (μm)	< 2.5 (μm)	Units	Test Report	Rating
	(Coal)										
	(mine type A)	-	0.014	-	-	-	-	-	lb/T	5	D
	(mine type B)	-	0.007	-	-	-	-	-	lb/T	5	D
	(mine type C)	-	0.002	-	-	-	-	-	lb/T	5	D
	(mine type E)	-	0.0035	-	-	-	-	-	lb/T	5	D
	Loading train via unspecified equipment and process (Coal)	-	0.027	-	-	-	-	-	lb/T	15	D
	(mine type C)	-	0.0002	-	-	-	-	-	lb/T	5	D
Storage pile	Wind erosion (Coal)	-	0.013	-	-	-	-	-	lb/T/yr	4	D
Vehicle traffic on unpaved road	Haul truck (unspecified size)	-	17.0	-	-	-	-	-	lb/VMT	5	C
	(mine type B)	-	22.0	-	-	-	-	-	lb/VMT	15	C
Wind erosion	Exposed areas	-	0.38	-	-	-	-	-	$\frac{T}{(acre)(yr)}$	15	C

\- = Unable to be determined from informaiton continaed in test report.
= Not recommended for inclusion into AP-42.

E.2 Memorandum from Chatten Cowherd, MRI, to James Southerland, EPA, June 1986.

MIDWEST RESEARCH INSTITUTE
425 Volker Boulevard
Kansas City, Missouri 64 (cut off)
Telephone (816) 753-(cut off)

June 2, 1986

Mr. James H. Southerland
U.S. Environmental Protection Agency
Office of Air Quality Planning
and Standards
Research Triangle Park, NC 27711

Dear Mr. Southerland:

In response to your recent inquiry, this letter presents our opinion regarding the appropriateness of the emission factor for blasting as presented in AP-42 Section 8.19.2, Crushed Stone Processing. As noted in the footnote to Table 8.19.2-2, the subject emission factor was adapted from Table 8.24-2 in the section on Western Surface Coal Mining, based on tests of coal and overburden blasting at three mines.

A major concern regarding the derivation of this blasting emission factor equation has to do with the moisture data used to characterize coal. There are only three moisture values (11, 22, 38%) used to represent conditions for 14 tests at the three mines, and these high values are believed to include bound as well as unbound moisture. The moisture values of 7.2 and 8.0% used for the our tests of overburden appear to be reasonable.

Another potential concern relates to the fact that the equation was derived mostly from tests of coal. At first glance, it would seem likely that the techniques for blasting unfractured stone might vary considerably from

those used for unfractured coal. For example, limited data from Mine 1 indicate that about five times more explosive is used to blast a given area of overburden as compared to the same area of coal.
In reexamining the original data underlying the equation, we have uncovered a simple relationship between TSP mass emissions (per blast) and area blasted, as depicted in the attached figure. Except for one overburden data point for a 135-ft depth of blast, all the coal and overburden data fit this correlation reasonably well. The depth of blast for coal is consistently about 20 ft. but the depth of blast for overburden ranges from 20 ft to 70 ft (excluding the outlier point). Although more explosive is required to blast a given area of overburden (at a typical depth), there appears to be an offsetting effect of lower friability, so that both overburden and coal fit the same relationship.

Finally, although data on area blasted from the two Monsanto tests of granite and traprock are not available, we have estimated these values based on Monsanto's calculated quantities of rock blasted and an assumed depth of 20 ft. As shown on the attached figure the two Monsanto values, which are based on a much less accurate measurement method, bracket the overall range of mining emission factors for blasting.

Based on the results of this new review of the blasting emission factor equation, we do not recommend that the emission factor equation originally developed for western surface coal mines be used for stone quarries. The moisture content data base is inadequate and the values for coal are suspect. Moreover, no significant dependence of emissions on either moisture content or depth fo blasting (up to 70 ft) is evident.

To estimate TSP emissions from blasting of unfractured stone (assuming the blasting depth does not exceed 70 ft), we recommend the following equation:

$$e = 0.00050\ A^{1.5}$$

where:

e = TSP emission factor (lb/blast)

A = area blasted ($m^{2)}$

If the exposed frontal face of the blasted area is of the same magnitude as the top face, it may be appropriate to use the sum of the frontal and top areas. Note that for relatively small blast areas typical of rock quarries (<1000 m^2), there is more scatter in the supporting data, as shown on the attached figure.

Please contact me or Dr. Greg Muleski if you have questions about this information.

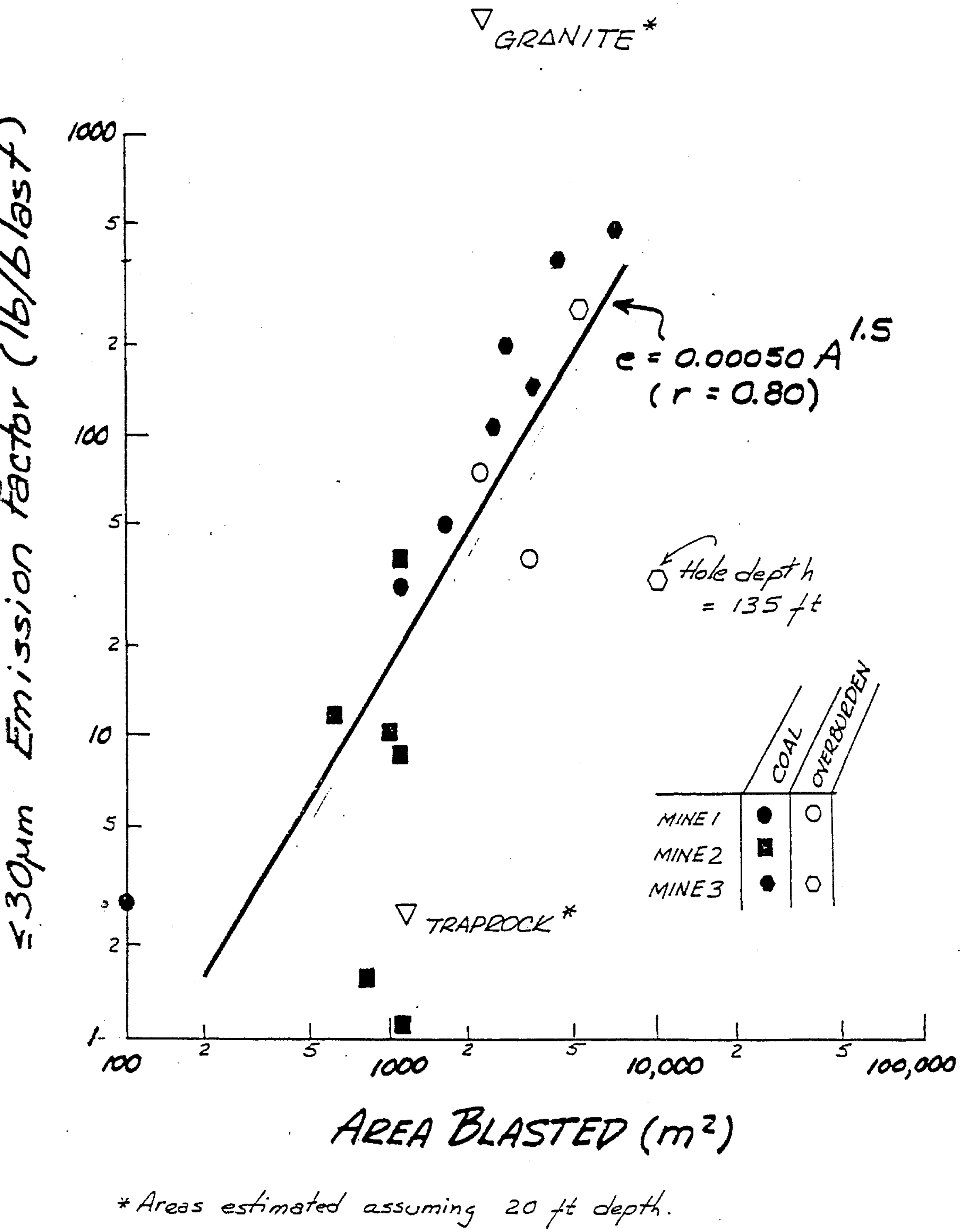
Sincerely,

MIDWEST RESEARCH INSTITUTE

Chatten Cowherd, Director
Environmental Systems Department

CC/jer

Enclosure


GRANITE *
≤30μm Emission factor (lb/blast)
1000
5
2
100
5
2
10
5
2
1
100
2
5
1000
2
5
10,000
2
5
100,000
e = 0.00050 A 1.5
(r = 0.80)
Hole depth = 135 ft
COAL
OVERBURDEN
MINE 1
MINE 2
MINE 3
TRAPROCK *
AREA BLASTED (m²)
* Areas estimated assuming 20 ft depth.

E.3 Memorandum from Greg Muleski, MRI, to Frank Noonan, EPA, April 1987

April 3, 1987

Mr. Frank Noonan (MD-14)
Criteria Emissions Section, AMTB, MDAD
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Dear Frank:

Enclosed are the revised copies of the interim guidance and test design drafts we discussed last week.

Please call if you have any questions.

Sincerely,

MIDWEST RESEARCH INSTITUTE

Gregory E. Muleski, Ph.D.
Senior Environmental Engineer

GEM/jer

Enclosure

DRAFT

INTERIM GUIDANCE FOR ESTIMATING PARTICULATE EMISSIONS FROM BLASTING OPERATIONS

The U.S. Environmental Protection Agency (EPA) has determined that the AP-42 particulate emission factor equation for blasting should no longer be applied to coal mines (AP-42 Section 8.24) or stone quarries (AP-42 Section 8.19.2). The purpose of this document is to provide interim guidance on the estimation of emissions from blasting operations conducted at western surface coal mines and from operations involving the blasting of unfractured stone.

Western Surface Coal Mining

The particulate emission factor equation for blasting, which appears in Table 8.24-2, was originally derived based on 14 tests of coal and 4 tests of overburden at three western surface coal mines. It contains a strong dependence on moisture content of material blasted. A major concern regarding the derivation of the equation has to do with the moisture data used to characterize coal. First, problems in obtaining representative samples of in-place coal were encountered. Second, there are only three moisture values (11, 22, and 38%) used to represent conditions for 14 tests at the three mines, and these high values are believed to include bound as well as unbound moisture. The moisture values of 7.2 and 8.0% used for the four tests of overburden appear to be reasonable.

In reexamining the original data underlying the equation, a simple relationship between TSP mass emissions (per blast) and area blasted was uncovered, as depicted in Figure 1. Except for one overburden data point for a 135-ft depth of blast, all the coal and overburden data fit this correlation reasonably well. The depth of blast for coal is consistently about 20 ft, but the depth of blast for overburden ranges from 20 to 70 ft (excluding the outlier point). Although more explosive is required to blast a given area of overburden (at a typical depth), it appears that there may be an offsetting effect of lower friability, so that both overburden and coal fit the same relationship.

Therefore, to estimate the TSP emissions from blasting of coall or overburden (assuming the blasting depth does not exceed 70 ft), the following equation is recommended:

$$e = 0.00050\ A^{1.5}$$

where:

e = TSP emission factor (lb/blast)

A = area blasted ($m^{2)}$

The area blasted (A) refers to the horizontal area and does not include the vertical face of a bench. For example, if a blast employs M rows (separated by a distance x meters) of N holes separated by a distance y meters, then the area blasted by the (M N) holes is (M N x y) square meters.

In order to estimate PM_{10} emissions (10µmA) from blasting, the value obtained from Equation 1 for TSP emissions (30µmA) should be multiplied by 0.5. This value represents and average PM_{10}/PM_{30} ratio derived from teh materials handling particle size data currently presented in Section 11.2.3 of AP-42. The PM_{10} size fraction was not quantified directly in the study of blasting emissions from western surface coal mines.

The quality rating for the new emission factor equation may be derived in the same manner as was done for the quation for blasting currently given in Section 8.24, Western Surface Coal Mining. As stated in the supporting background document (EPA-450/4-83-003), the blasting test data from teh western suface coal mines are rated C. According t the quality rating criteria for emission factor equations, there is no reduction of qualty rating (i.e., the equation is also rated C) if used to estimate blasting emissions in western surface coal mines.

<u>Crushed Stone Processing</u>

Only two single-valued emission factors for blasting of unfractured stone appear in the literature. As indicated in the background document for Section 8.19, Construction Aggregate (EPA-450/4-83-007), the single-valued emission factors for blasting of granite and traprock are both rated E (poor). The principal reason for the low rating of these factors is the small number of supporting tests (one or two) for each factor, even though the test data from these “screening studies” are rated B in both cases.

The new emission factor equation presented above for coal and over-burden blasting at western surface coal mines provides a possible alternative to the single-valued emission factors for estimation of particulate emissions from blasting operation at stone quarries. As stated above, the emission factor equation carries a C quality rating if applied to western surface coal mines. For application to similar blasting operations in other industries, the equation would be rated D provided that: (a) reliable values of the correction parameters have been determined for the specific sources of interest; and (b) the correction parameter values are with in ranges tested in developing the equation. Because of typical dissimilarities in the techniques used for blasting in western surface coal mines as compared to stone quarries, there is ample reason for further reducing the rating of the emission factor equation to E for application to blasting of unfractured stone. In particular most stone quarries involve relatively small blast areas ($A < 1000\ m^2$), which bracket the lower end of the range shown in Figure 1 for western surface coal mines. Moreover, it can be seen in Figure 1 that the scatter in the data for blast areas smaller than about 2000 m^2 indicate a decrease in reliability of the equation even when applied to western surface coal mines.

Therefore, it is concluded that for a wide range of industrial applications involving blasting of unfractured stone, the single-valued emission factors as well as the newly develop emission factor equation yield only crude estimates (E-rated) of particulate emissions. At this low degree of quantitation, it is difficult to reason as to which estimate is more reliable. Unfortunately, in the absence of much needed additional test data, the investigator must deal with the problem of selecting the most appropriate emission factor on a case-by-case basis.

It is strongly recommended that reliable emission factors for estimated particulate emissions from blasting of unfractured stone be based on site specific field testing. The attachment Design of Field Studies of Blasting Emissions, presents applicable guidance on available sampling methods, sampling devices, and test design considerations.

E.4 Section 9 of "Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources--Volume I - Sampling methodology and Test Results."

SECTION 9
RESULTS FOR SOURCE TESTED BY BALLOON SAMPLING

SUMMARY OF TESTS PERFORMED

Blasting was the only source tested by the balloon sampling method. Overburden and coal blasts were both sampled with the same procedure, but the data were kept separate during the data analysis phase so that the option of developing separate emission factors was available. A total of 18 successful tests were completed--14 for coal blasts and 4 for overburden blasts. Three more blasts were sampled, but the balloon was hit and broken in one and the plumes missed the sampler arrays in two others; no attempt was made to calculate emission rates for these three tests.

The overburden was not blasted at the mine in North Dakota (second mine), so overburden blast tests were confined to the first and third mines. The resulting sample size of four is not large enough for development of a-statistically sound emission factor.

The sampling array consisted of balloon-supported samplers at five heights plus five pairs of ground-based hi-vols and dichots to establish the horizontal extent of the plume. No measure of deposition rate was made with this configuration because all samplers were at the same distance from the source.

Samplers at Mine 2 were located in the pit for coal blasts, but samplers at Mines 1 and 3 were located on the highwall above the pit. Therefore, some (prior) deposition is included in the emission rate measured at the latter mines. These are the only emission rates in the study that are not representative of emissions directly from the source.

Test conditions for the blasting tests are summarized in Table 9-1. An extremely wide range of blast sizes was sampled--from 6 to 750 holes and from 100 to 9600 m^2. The variation in moisture contents was also quite wide. The only potential correction factor with a limited range during testing was the depth of the holes. All the holes for coal blasts were about 20 ft deep. Overburden holes had a range of 25 to 135 ft. but there are not enough data points to develop a correction factor.

TABLE 9-1. TEST CONDITIONS FOR BLASTING

Sampling Conditions						Source Characteristics			Soil Properties	Meteorological Conditions		
Test	**Date**	**Start Time**	**Duration, Minutes**	**Samplers In or Out of Pit**	**No. of Holes**	**Area m²**	**Tons of Explosive**	**Depth of Holes, ft.**	**Moisture, %**	**Temp., °F**	**Wind Speed, m/s**	**Stab Class**
Mine 1												
Coal 1	8/10/79	15:00	5	out	33	1100	1.0	22	22	82	1.1	A
2	8/10/79	15:30	3	out	6	100	0.2	22	22	82	1.0	A
3	8/14/79	12:00	7	out	42	1600	1.3	20	22	62	1.4	B
Ovb 1	8/14/79	14:30	16	out	33	3400	12.0	70	7.2	66	5.1	D
2	8/20/79	14:45	8	out	20	2200	10.0	60	7.2	76	2.0	A
Mine 2												
Coal 1	10/25/79	11:28	6	in	195	1100		20	38	45	2.6	C
2	10/26/79	11:00	8	in	210	1100		20	38	43	1.6	C
3	10/29/79	9:33	3	in	180	1000		20	38	43	1.8	C
4	10/29/79	12:07	6	in	150	800		20	38	43	1.0	B
5	10/29/79	14:30	7	in	110	1100		20	38	38	3.2	D
6	10/30/79	14:35	6	in	96	600		20	38	47	5.4	D
Mine 3												
Coal 2	7/28/80	14:20	13	out	250	4100		20	11.1	99	1.7	B
3	7/29/80	14:10	21	out	750	6800		20	11.1	104	1.2	B
4	8/01/80	13:10	25	out	200	3400		20	11.1	90	2.0	A
5	8/04/80	14:15	7	out	150	2400		20	11.1	95	2.7	C
6	8/06/80	10:45	12	out	160	2700		20	11.1	82	1.3	B
Ovb 1	8/06/80	14:35	10	out	50	9600		135	8.0	93	1.7	A
2	8/12/80	15:05	10	out	60	5000		25	8.0	95	1.0	A

RESULTS

TSP emission rates are shown in Table 9-2. The emission rates varied over a wide range, from 1.1 to 514 lb/blast. Blasting emissions at the first two mines were relatively low; those at the third mine were quite high. Some of these differences are expected to be explained by test conditions, which also varied over a correspondingly wide range. The values in Table 9-2 are as measured, and have not been adjusted for any potential correction factors.

The data subsets by mine were too small for statistics such as standard deviation to be meaningful. If the data are divided into subsets of coal and overburden blasts, the TSP emission rates are as follows:

Type blast	No. samples	Mean, lb	Std dev	Range
Coal	14	110.2	161.2	1.-1-514
Overburden	4	106.2	110.9	35.2-270

The only sample that was more than two standard deviations away from the mean was the 514 lb value. However, this blast had more than three times as many holes as any other blast sampled, so it would not be considered an outlier.

Inhalable and fine particulate emission rates are presented in Table 9-3. The IP emission rates ranged from 0.5 to 142.8 lb/blast and from 17 to 138 percent of TSP. The IP emission rates for blasts averaged 46 percent of the TSP rates, about the same ratio as for haul roads. Fine particulate averaged 5.0 percent of TSP, higher than for any other source. Coal blasts and overburden blasts did not have any obvious distinctions in their respective particle size distributions.

PROBLEMS ENCOUNTERED

Balloon sampling represented a substantial modification of the exposure profiling method and therefore a somewhat experimental technique. It was particularly difficult to apply to blasting because technical limitations of the technique combined with the infrequency of blasting resulted in very few opportunities to perform the sampling.

TABLE 9-2. APPARENT EMISSION RATES FOR BLASTING
High-Volume (30 μm)

Test No.	Pound/Blast	Distance from Source, m	Test No.	Pound/Blast	Distance from Source, m
Mine 1 Coal			Mine 1 Overburden		
1	32.5	96	1	40.4	100
2	2.7	96	2	79.4	100
3	51.7	37			
Mine 2 Coal					
1	8.8	130			
2	1.1	213			
3	10.7	130			
4	1.6	160			
5	40.3	170			
6	11.8	180			
Mine 3 Coal			Mine 3 Overburden		
2	401	90	1	35.2	110
3	514	160	2	270	200
4	148	128			
5	113	53			
6	206	82			

TABLE 9-3. APPARENT EMISSION RATES FOR BLASTING
Dichotomous (15 μm, 2.5 μm)

Test No.	Pound/Blast IP	Pound/Blast FP	Distance from Source, m	Test No.	Pound/Blast IP	Pound/Blast FP	Distance from Source, m
Mine 1 Coal				Mine 1 Overburden			
1	44.9[a]	3.62	96	1	32.9	0.79	100
2	1.56	0.32	96	2	48.9	0.09	100
3	17.3	1.23	37				
Mine 2 Coal							
1	1.55	0.10	130				
2	0.62	0.06	213				
3	3.57	0.80	130				
4	0.45	0.10	160				
5	15.30	1.27	170				
6	1.99	0.01	180				
Mine 3 Coal				Mine 3 Overburden			
2	123.4	10.4	90	1	16.9	3.5	110
3	142.8	12.3	160	2	93.9	16.2	200
4	87.9	13.0	128				
5	35.3	2.1	53				
6	71.3	19.8	82				

[a]Dichotomous concentrations are greater than hi-vol, value represents 20.5µm cut point for IP.

This sampling method could not be used when ground level winds were greater than about 6 m/s because the balloon could not be controlled on its tether. At wind speeds less than about 1 m/s, wind direction tended to vary and the sampling array could not be located with any confidence of being in the plume. Also, at low wind speeds, the plume from the blast frequently split or rose vertically from the blast site. Therefore, sampling was constrained to a fairly narrow range of wind speeds.

For safety reasons, a source-sampler distance of 100 m or more was usually required. At this distance, the plume could disperse vertically above the top sampler inlet under unstable atmospheric conditions.

Even though sampling was done at very large mines, only one or two blasts per day were scheduled. This often created difficulties in obtaining the prescribed number of blasting tests at each mine.

Since blasting was not a continuous operation, there was no continuous plume to provide assistance in locating the samplers. For coal blasts in particular, the portion of the plume below the high wall usually was channeled parallel to the pit but any portion rising above the high wall was subject to ambient winds and often separated from the plume in the pit.

Finally, representative soil samples could not be obtained for this source because of the abrupt change in the characteristics of the soil caused by the blast. The moisture contents reported in Table 9-1 were for samples of coal in place and overburden from drilling tests (both prior to blasting).

Appendix F
Materials Related to Truck Loading, Bulldozing, and Dragline Emission Factors

This appendix contains information related to truck loading, bulldozing and dragline emission factors. The information is from Sections 5.5 and 8.5 of EPA report “Fugitive Dust Emission Factor Update for AP42 ” and Section 8 of EPA report “Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources - Volume I - Sampling Methodology and Test Results.”

TABLE OF CONTENTS

F.1 Sections 5.5 and 8.5 of EPA report "Fugitive Dust Emission Factor Update for AP-42"

5.5 Section 8.24 - Western Surface Coal Mining and Processing

5.5.1 Test Report 4 (1977)

This study developed an emission factor for coal storage only. Four tests at one coal storage pile (location not given) were conducted using the upwind-downwind technique. Table 23 presents the source testing information for this study.

TABLE 23. COAL STORAGE SOURCE TESTING INFORMATION
(Test Report 4)

Operation	Equipment	Material	Site	Test Date	No. of Tests
Wind erosion	Storage pile	Coal	Plant 1	3/74	2
				8/74	2

High-volume samplers were used to collect the airborne particulates from one upwind and four downwind positions. The wind parameters were recorded at 15-min intervals. A sampling array similar to that described in Section 5.3.2 (Test Report 6) was employed in this study. This sampling system meets the minimum requirements of the upwind-downwind sampling technique. Optical microscopy was employed to determine a particle size distribution. However, the particle size distribution for the emission factor was determined from particle counting only (not mass fraction), which is unrepresentative of a mass size distribution.

This methodology is of generally sound quality; and emission rates were determined in a similar manner to that described in Section 5.3.2 (Test Report 6). However, the report lacks sufficient detail for adequate validation. For example, no indication is given as to sampling height. Also the field data recorded at the sampling stations are not presented. The test data are therefore rated B.

Table 24 presents the developed emission factor, conditions tested and the appropriate rating. Only one pile was sampled, although it was two different sizes during testing. The rating code refers to Table 4.

TABLE 24. COAL STORAGE EMISSION FACTOR, RANGE OF TEST CONDITIONS, AND RATING (Test Report 4)

Operation	No. of Tests	Range of Conditions: Wind Speed (m/S)	Range of Conditions: Moisture Content (%)	Emission Factor[a,b]	Rating Code	Rating
Wind erosion of coal storage pile	4	1.5-2.7	2.2-111	0.013 lb/T/yr	5	D

[a]For particles < 10 μm (physical diameter).

[b]Emission factor is arithmetic mean of test runs C1, C2, CS-3 and CS-5 from page 30, Table A1 of test report.

5.5.2 Test Report 5 (1978)

This study was directed to the development of emission factors for the surface coal mining industry. Testing was conducted at five Western coal mines (Mines A through E). Table 25 presents the distribution of tests performed.

The upwind-downwind method was used with standard high-volume samplers for particulate collection. Wind parameters were continuously measured at a fixed location within each mine. A hand-held wind speed indicator was used when possible to record data at the exact test site. Optical microscopy was employed to determine particle size distribution.

The upwind-downwind sampler deployment used in this study generally employed six samplers for each test; additionally, six more samplers were operated at a second height in half the tests to determine a vertical plume gradient. Two instruments were located upwind of a source to measure background concentrations while four instruments were located downwind. These downwind samplers were deployed along a straight line (the assumed plume centerline) at four different distances.

TABLE 25. COAL MINING SOURCE TESTING INFORMATION (Test Report 5)

Operation	Equipment	Material	No. of Tests at Mine A	B	C	D	E	Test Date
Overburden removal	Dragline	Overburden	6	10	6	6	0	-
Vehicle traffic	Haul truck[b]	Unpaved road	0	4	0	[c]	[c]	-
Loading	Shovel/truck	Coal	6	4	4	0	4	-
		Overburden	0	0	0	0	6	-
Blasting	NA	Overburden	1	0	2	0	2	-
		Coal	0	0	2	2	2	-
Dumping[a]	Truck	-	6	2	2	4	0	-
		Overburden	0	0	0	0	4	-
		Coal	0	0	0	0	2	-
Storage pile wind erosion[d]	-	Coal	6	6	0	4	0	-
Drilling	NA	Overburden	0	0	2	0	0	-
		Coal	0	0	0	0	2	-
Dumping[a]	-	Fly ash	2	0	0	0	0	-
Loading[a]	Train	Coal	0	0	4	0	0	-
Topsoil removal	Scraper	Topsoil	0	0	0	5	0	-
Topsoil dumping	Scraper	Topsoil	0	0	0	5	0	-
-[a]	Front-end loader	-	0	0	0	1	0	-

- = Information not contained in test report.
NA = Not applicable.
[a]Details as to specific operation sampled for are not stated in text.
[b]Size not given.
[c]Unable to determine if tests were under controlled or uncontrolled states.
[d]Includes pile maintenance (unspecified equipment).

The determination of emission rates involved back calculation using dispersion equations after subtraction of the background from the downwind concentration. The following dispersion equation was

$$C = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad (6)$$

where:

C = concentration

Q = emission rate

σ_y, σ_z = horizontal and vertical dispersion coefficients

u = wind speed

Line source emission rates were determined by use of this dispersion equation:

$$C = \frac{2\ Q}{\sin\ \phi\ \sqrt{2\pi}\ \sigma_z\ u} \qquad (7)$$

where:

C = concentration

Q = emission rate

ϕ = angle between line source and wind direction

σ_z = vertical dispersion coefficient

u = wind speed

The predictive emission factor equation for wind erosion of active storage piles was developed by plotting the emission rates against the wind speeds recorded during testing. The resulting linear function was described by the equation:

$$e = 15.83\ u \qquad (8)$$

where:

e = emission rate (lb/hr)

u = wind speed (m/sec)

This equation was then converted to one with units of $\frac{\text{lb}}{(\text{acre})(\text{hr})}$ by assuming storage pile surface areas of 10 acres.

This upwind-downwind sampling system does not meet the minimum requirements for point sources as set forth in Section 4.3 since particulate concentrations at only one crosswind distance were observed. Also details on the operations tested are frequently sketchy. Therefore, with three exceptions the test data are rated B. The test data for haul roads are rated A, because sampling at multiple crosswind distances is not required when testing line sources. The test data for storage pile wind erosion (and maintenance) are rated C because of: (a) the very light winds encountered; (b) the large size of the piles; and (c) the lack of information on pile maintenance activities. The test data for blasting are rated C because of the difficulty of quantifying the plume with ground based samplers.

The report indicates that emission factor variation between mines for the same operation is relatively high; therefore, it was recommended (in the report) that the factors be mine (type) specific. The following list describes the location of the five mines. The report gives a more in-depth description of each mine including production rate, stratigraphic data, coal analysis data, surface deposition, storage capacity, and blasting data.

Mine	Area
A	Northwest Colorado
B	Southwest Wyoming
C	Southeast Montana
D	Central North Dakota
E	Northeast Wyoming

Tables 26 through 30 present the average emission factors determined at each mine along with the ranges of conditions tested and the associated emission factor ratings. The text indicates that the emission factors should be used with a fallout function for distances closer than 5 km; however, the text does not explicitly state what particulate size range is represented by the emission factors.

The rating codes in Tables 26 through 30 refer to Table 5 (wind erosion) and Table 4 (all other sources). Because the single-valued factors were intended to apply only to the specific mine types, the requirement for more than one test site was waived. The rating for the equation developed for storage pile wind erosion (and maintenance) is applicable when the equation is applied to mine types A, B. or D.

5.5.3 Test Report 14 (1981)

This study was conducted to determine improved fugitive dust emission factors for Western surface coal mines. Field testing was conducted in three coal fields; Powder River Basin (Mine 1), North Dakota (Mine 2), and Four Corners (Mine 3). The testing was performed during 1979 and 1980. Table 31 lists the testing information for this study.

The primary sampling method was exposure profiling. When source configuration made it necessary, alternate methods were used, including upwind-downwind, balloon, and quasi-stack sampling. Particle size distributions were determined by use of dichotomous samplers. Other equipment utilized were: (a) high volume samplers for determining upwind concentrations; (b) dustfall buckets for determining downwind particulate deposition; and © recording wind instruments to determine mean wind speed and direction for adjusting the exposure profiler to isokinetic sampling conditions and for use in upwind-downwind calculations.

Exposure profiling was used to measure emissions from moving point sources (see Table 31). The exposure profiling sampling system was similar to that described in Section 5.1.1 and therefore meets the minimum system design requirements. The upwind-downwind sampling system consisted generally of 15 particulate collection devices; 5 dichotomous samplers and 10 Hi-vols.

One Hi-Vol and one dichotomous sampler were placed upwind while the remaining instruments were placed at multiple downwind and crosswind distances. This system also meets the minimum upwind-downwind requirements as described in Section 4.3.

TABLE 26. COAL MINING EMISSION FACTORS (MINE TYPE A), RANGE OF TEST CONDITIONS, AND RATINGS
(Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	0.4-1.8	-	0.0056 lb/yd^3	4	D
Shovel/truck loading (coal)	6	0.4-1.3	10	0.014 lb/T	4	D
Blasting (overburden)	1	2.4	-	1,690[c] lb/blast	9	E
Truck dump[d] (bottom)	6	0.4-2.7	-	0.014 lb/T	4	D
Storage pile erosion[e]	6	0.5-2.6	10	$1.6\ u\ \frac{lb}{(acre)(hr)}$	1[f]	C[f]
Fly ash dump	2	1.5	-	3.9 lb/hr	7/8	E

\- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.
[c]Text indicates this value represents a maximum rate.
[d]Material not given.
[e]u = Wind speed in m/sec. This factor includes emissions from pile maintenance.
[f]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 27. COAL MINING EMISSION FACTORS (MINE TYPE B), RANGE OF TEST CONDITIONS, AND RATINGS
(Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	10	3.1-5.8	-	0.053 lb/yd^3	4	D
Haul road	4	3.7-4.7	-	17.0 lb/VMT	5	C
Shovel/truck loading (coal)	4	0.4-0.6	18	0.007 lb/T	5	D
Truck dump (bottom)	2	3.7	-	0.020 lb/T	7	E
Storage pile erosion[c]	6	0.8-7.6	18	$1.6\ u\ \frac{lb}{(acre)(hr)}$	1[d]	C[d]

- = Information not contained in test report.

[a]Particle size not explicitly stated in test report.

[b]Emission factors are from page 2, Table 1 of test report.

[c]u = Wind speed in m/sec. This factor includes emissions from pile maintenance.

[d]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 28. COAL MINING EMISSION FACTORS (MINE TYPE C), RANGE OF TEST CONDITIONS, AND RATINGS
(Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	3.6-5.4	-	0.0030 lb/yd^3	3	C
Shovel/truck loading (coal)	4	3.6	24	0.002 lb/T	5	D
Blasting						
Coal	2	5.4	24	25.1 lb/blast	7	E
Overburden	2	3.6	-	14.2 lb/blast	7	E
Truck dump (bottom)	2	3.6	-	0.005 lb/T	7	E
Drilling (overburden)	2	3.6	-	1.5 lb/hole	8	
Train loading	4	4.5-4.9	24	0.0002 lb/T	5	D

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.

TABLE 29. COAL MINING EMISSION FACTORS (MINE TYPE D), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	5.8-7.2	-	$0.021\ lb/yd^3$	3	C
Blasting (coal)	2	4.0	38	78.1 lb/blast	7	E
Truck dump (bottom)	4	4.5-6.7	-	0.027 lb/T	6	E
Storage pile erosion[c]	4	0.9-1.3	38	$1.6\ u\ \frac{lb}{(acre)(hr)}$	1[d]	C[d]
Topsoil removal						
Scraping	5	5.8-7.6	-	$0.35\ lb/yd^3$	4	D
Dumping	5	2.2-3.6	-	$0.03\ lb/yd^3$	3	C
Front-end loader	1	2.7	-	0.12 lb/T	9	E

- = Information not contained in test report.

[a]Particle size not explicitly stated in test report.

[b]Emission factors are from page 2, Table 1 of test report.

[c]u = Wind speed in m/sec.

[d]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 30. COAL MINING EMISSION FACTORS (MINE TYPE E), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Shovel/truck loading						
Coal	4	2.3-2.5	30	0.0035 lb/T	5	D
Overburden	6	2.7-3.6	30	0.037 lb/T	3	C
Blasting Coal	2	2.6	30	72.4 lb/blast	7	E
Overburden	2	3.7	-	85.3 lb/blast	7	E
Truck dump Overburden	2	6.2	-	0.002 lb/T	8	E
Coal (end dump)	4	2.7-3.1	30	0.007 lb/T	6	E
Drilling (coal)	2	4.1	30	0.22 lb/hole	8	E

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.

TABLE 31. COAL MINING SOURCE TESTING INFORMATION
(Test Report 14)

Operation	Equipment	Material	Test Method[a]	Site (mine)	Test Dates	No. of Tests
Drilling	NA	Overburden	Quasi-stack	1, 3	7/79, 8/79, 12/79, 7/80	30
Blasting	NA	Coal	Balloon[b]	1, 2, 3	8/79,10/79, 7/80, 8/80	14
		Overburden	Balloon[b]	1, 3	8/79, 8/80	4
Loading	Shovel/truck	Coal	Uw-Dw	1, 2	8/79, 10/79	10
	Front-end loader/truck	Coal	Uw-Dw	3	7/80, 8/80	15
Dozing	Dozer	Coal	Uw-Dw	1, 2, 3	8/79, 10/79, 8/80	12
		Overburden	Uw-Dw	1, 2, 3	8/79, 10/79, 7/80, 8/80	15
Dragline	Dragline	Overburden	Uw-Dw	1, 2, 3	8/79, 10/79, 7/80, 8/80	19
Vehicle traffic	Haul truck	Unpaved road	Uw-Dw	1	8/79, 12/79	11
		Unpaved road	Profiling	1, 2 ,3	7/79, 8/79, 12/79	21
	Light-medium duty	Unpaved road	Profiling	1, 2, 3	8/79, 10/79, 8/80	10
Scrapers[c] (travel mode)	Scraper	Unpaved surface	Uw-Dw	1	7/79	5
		Unpaved surface	Profiling	1, 2, 3	7/79, 10/79, 12/79, 8/80	15
Grading	Grader	Unpaved surface	Profiling	2, 3	10/79, 8/80	7

\- = Information not contained in test report.
NA = Not applicable.
[a]Uw-Dw = Upwind-downwind.
[b]This is actually a modified version of exposure profiling.
[c]Loading and dumping not tested.

The test data were collected using a well documented sound methodology and, therefore, are rated A for line sources and for drilling. The test data for coal loading, dozing, and dragline operations are rated B because of the poorly defined plume characteristics and the interference of the pit areas with plume dispersion. For blasting the test data are rated C because of the difficulty of quantifying the large plume with a single line of samplers.

Table 32 presents the average emission factors, range of test conditions, and ratings assigned for Test Report 14. These single-valued factors were determined by substituting geometric means of the test conditions into a set of predictive emission factor equations also developed in the study. The equations are listed in Table 33. The rating codes in Table 32 refer to Table 4, and the codes in Table 33 refer to Table 5.

5.5.4 Test Report 15 (1981)

A portion of this study was devoted to the development of surface coal mining emission factors. Field testing was performed from August 1978 through the summer of 1979 at two surface coal mines located in the Powder River Basin of Wyoming. Table 34 presents the source testing information for this study.

The test methods employed to develop emission factors were: upwind-downwind, profiling, and a tracer technique. Particle sizing was performed by optical microscopy of exposed Millipore filters.

The profiling technique employed in this study was actually a variation of the exposure profiling procedure described in Section 5.1.1 (Test Report 7). High volume samplers were used instead of directional isokinetic intakes; therefore, the emission rates determined by profiling were for TSP (total suspended particulate).

The tracer technique utilized arrays of bcch high-volume samplers and tracer samplers with a straightforward calculation scheme. These sampling systems meet the minimum requirements as set forth in Section 4.3; therefore; the test data are rated A.

TABLE 32. COAL MINING EMISSION FACTORS, RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 14)

Operation	No. of Tests	Range of Conditions								Particulate Emission Factor[a]			Units	Rating Code	Rat-ing
		Mat'l Moisture Content (%)	Mat'l Silt Content (%)	Surface Silt Loading (g/m^2)	Vehicle Speed (mph)	Vehicle Weight (tons)	No. of Wheels	Wind Speed (mph)	Other	TSP	< 15 μm	< 25 μm			
Drilling	30	6.9-9.0	5.2-26.8	NA	NA	NA	NA	0.9-6.3	b	1.3	-	-	lb/hole	2	B
Blasting															
Coal	14	11.1-38.0	-	NA	NA	NA	NA	2.2-12.1	c	35.4[d]	13.2[d]	1.10[d]		2	D
Overburden	4	7.2-8.0	-	NA	NA	NA	NA	2.2-11.4	e				lb/blast	2	C
Coal loading	25	6.6-38.0	3.6-4.2	NA	NA	NA	NA	2.2-11.2	f	0.037	0.008	0.0007	lb/ton	2	C
Dozing															
Coal	12	4.0-22.0	6.0-11.3	NA	5-12	-	NA	3.4-13.4	None	46.0	20.0	1.0	lb/hr	2	C
Overburden	15	2.2-16.8	3.8-15.1	NA	2-7	-	NA	2.5-19.0	None	3.7	0.88	0.39	lb/hr	2	C
Dragline	19	0.2-16.3	4.6-14.0	NA	NA	NA	NA	2.2-16.6	g	0.059	0.013	0.001	lb/hr	2	C
Vehicle traffic															
Light-medium duty	10	0.9-1.7	4.9-10.1	5.9-48.2	24.8-42.9	2.0-2.6	4.0-4.1	6.5-13.0	None	2.9	1.8	0.12	lb/VMT	2	B
Haul truck	27	0.3-8.5	2.8-18.0	3.8-254	14.9-36.0	24-138	4.9-10.0	1.8-15.4	None	17.4	8.2	0.30	lb/VMT	2	B
Scrapers	15	0.9-7.8	7.2-25.2	8.0-96.8	9.9-31.7	36-70	4.0-4.1	2.5-21.0	None	13.2	6.0	0.34	lb/VMT	2	B
Grading	7	1.0-9.1	7.2-29.0	76-190	5.0-11.8	13-14	5.9-6.0	4.3-11.6	None	5.7	2.7	0.18	lb/VMT	4	C

- = Information not contained in test report.
NA = Not applicable.
[a]ISP and < 15 μm emission factors were determined by applying the mean correction correlation parameters in Table 13-9 (page 13-15 of test report) to the equation in Table 15-1 (page 15-2 of test report). The less than 2.5 μm emission factors were determined by applying the appropriate fraction found in Table 15-1 (page 15-2 of test report) to the ISP emission factors.
[b]Depth of drilling = 30 to 100 ft.
[c]No. of holes = 6 to 750; blast area - 100 to 6,800 m^2; depth of holes = 20 to 70 ft.
[d]The results of coal and overburden blasting were combined in the test report to form a single emission factor.
[e]No. of holes = 20 to 60; blast area = 2,200 to 9,600 m^2; depth of holes = 25 to 135 ft.
[f]Bucket capacity = 14 to 17 $yards^3$.
[g]Bucket capacity = 32 to 65 $yards^3$; drop distance = 5 to 100 ft.

TABLE 33. COAL MINING EMISSION FACTOR EQUATIONS AND RATINGS (Test Report 14)

Operation	Particulate Emission Factor Equation[a] TSP	< 15 µm	< 2.5 µm/TSP[b]	Units	Rating Code	Rating
Blasting (coal or overburden)	$\frac{961\ (A)^{0.8}}{(D)^{1.8}\ (M)^{1.9}}$	$\frac{2{,}550\ (A)^{0.6}}{(D)^{1.5}\ (M)^{2.3}}$	0.030	lb/blast	1	C
Coal loading	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.019	lb/ton	1	B
Dozing Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.022	lb/hr	1	B
Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.105	lb/hr	1	B
Dragline Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021\ (d)^{0.7}}{(M)^{0.3}}$	0.017	lb/yard³	1	B
Scrapers (Travel mode)	$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.}$	0.026	lb/VMT	1	A
Grading	$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.031	lb/VMT	2	B
Vehicle traffic Light-medium duty	$\frac{5.79}{(M)^{4.0}}$	$\frac{3.22}{(M)^{4.3}}$	0.040	lb/VMT	2	B
Haul trucks	$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.017	lb/VMT	1	A

Note: The range of test conditions are as stated in Table 32. Particle diameters are aerodynamic.

[a]From page 15-2, Table 15-1 of test report.

[b]Multiply this fraction by the TSP predictive equation to determine emissions in the < 2.5 µm size range.

A = area blasted (ft^2)
M = moisture content (%)
D = hole depth (ft)
s = silt content (%)
d = drop height (ft)
W = vehicle weight (tons)
S = vehicle speed (mph)
w = number of wheels
L = silt loading (g/m^2)

TABLE 34. COAL MINING SOURCE TESTING INFORMATION (Test Report 15)

Operation	Equipment	Material	Test Method[a]	Site No. (mine)	Test Dates	No. of Tests
Vehicle traffic	Haul trucks	Coal, overburden	Profiling	2	Winter, spring, summer	26[b]
Dumping	-	Coal	Tracer	1, 2	Fall, winter	3
Loading	Train	Coal	Tracer	1, 2	Fall	2
Overburden replacement	-	Overburden	Uw-Dw	1, 2	Winter, spring, summer	7
Topsoil removal	(Scraper)[c]	Topsoil	Uw-Dw	1	Summer	2
Exposed Area	NA	Seeded land, stripped overburden, graded overburden	Uw-Dw	1, 2	Spring, summer	18

- = Information not contained in test report.
NA = Not applicable.
[a]Uw-Dw = Upwind-downwind.
[b]This series of tests involved a wide variety of road conditions ranging from total control (wet) to totally uncontrolled (dry). An emission factor equation was derived which takes the amount of control present into account (see Table 33, footnote a).
[c]Although scrapers are most often used in this operation the test report did not explicitly state that scrapers were being used.

The upwind-downwind sampling system consisted of 10 Hi-Vols of which two were placed upwind and eight were placed at multiple downwind and crosswind distances. Wind direction and speed were concurrently measured at an on-site station for all test periods. This sampling system meets the minimum requirements set forth in Section 4.3. However, the emission factors are rated B because these operations tested (overburden replacement, coal dumping, and top soil removal) were not described as to the equipment employed (see Table 34).

The calculated TSP emission rates were modified with a depletion factor, as follows. A deposition velocity was determined from dustfall bucket measurements:

$$V_d = 1.51\ (x)^{-0.588} \tag{9}$$

where V_d = deposition velocity

x = distance downwind of source

This velocity was combined with stability class and wind speed to derive a depletion factor in terms of distance downwind of a particulate source. The actual emission rate for an operation was then calculated through division of the apparent emission rate (measured at a particular distance downwind) by the appropriate depletion factor.

Table 35 gives the range of test conditions, emission factors, and applicable ratings for Test Report 16. The rating codes refer to Table 4. These ratings overlook the particle size incompatibility between the Hi-Vol measurements of particulate flux and the dustfall measurements of deposition velocity.

8.5 Western Surface Coal Mining and Processing

Since no emission factors are currently presented in AP-42 for coal mining. The predictive emission factor equations presented in Table 49 are recommended for inclusion in AP-42 under a section named "Western Surface Coal Mining." Table 50 presents the single-valued emission factors for western surface coal mining. It is recommended that for any source operation not covered by the equations in Table 49, the highest rated single-valued factors from Table 50 be incorporated in AP-42.

All of the recommended factors may be applied to Eastern surface coal mining. However, each should then be aerated one letter value (e.g., C to D).

TABLE 35. COAL MINING EMISSION FACTORS, RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 15)

Operation	Number of Tests	Mat'l Mois-ture Content (%)	Mat'l Silt Content (%)	Veh-icle Speed (mph)	Vehicle Weight (tons)	Wind Speed (mph)	Total Particu-late Emission Factor	Units	Rat-ing Code	Ra-ting
Vehicle traffic[a]	26	Dry-wet	8.3-11.2	22-24	-	3.6-19.2	22.0	lb/VMT	4	C
Coal dumping[b]	3	-	-	NA	NA	2.9-6.0	0.066	lb/T	6	D
Train loading[c]	2	-	-	NA	NA	4.0-11.4	0.027	lb/T	7	D
Overburden replacement[d]	7	-	-	-	-	3.8-19.9	0.012	lb/T	3	C
Topsoil removal[a]	2	-	-	-	-	10.1	0.058	lb/T	8	E
Exposed areas[f]	18	-	-	NA	NA	5.4-17.4	0.38	ton/acre-year	2	C

- = Information not contained in test report.
NA = Not applicable.
[a]The emission factor equation derived for this source is from page 35 of test report. It was evaluated at zero wettings per hour.
[b]Emission factor is from page 46, Table 5.1 of test report.
[c]Emission factor is from page 47, Table 5.2 of test report.
[d]Emission factor is from page 52, Table 6.1 of test report.
[e]Emission factor is from page 52, Table 6.2 of test report.
[f]Emission factor is from page 55, Table 7.1 of test report.

TABLE 49. WESTERN SURFACE COAL MINING PREDICTIVE EMISSION FACTOR EQUATIONS
(Test Reports 5 and 14)

Operation	Material	Particulate Emission Factor Equation: TSP	Particulate Emission Factor Equation: < 15 μm	Particulate Emission Factor Equation: < 2.5 μm/TSP[a]	Units	Test Report	Rating
Blasting	Coal or overburden	$\frac{961\ (A)^{0.8}}{(D)^{1.8}\ (M)^{1.9}}$	$\frac{2{,}550\ (A)^{0.6}}{(D)^{1.5}\ (M)^{2.3}}$	0.030	lb/blast	14	C
Truck loading	Coal	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.019	lb/ton	14	B
Dozing	Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.022	lb/hr	14	B
	Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.105	lb/hr	14	B
Dragline	Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.017	lb/yard^3	14	B
Scrapers (travel mode)		$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.026	lb/VMT	14	A
Grading		$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.031	lb/VMT	14	B
Vehicle traffic (light-medium duty)		$\frac{5.79}{(M)^{4.0}}$	$\frac{3.72}{(M)^{4.3}}$	0.040	lb/VMT	14	B
Haul trucks		$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.017	lb/VMT	14	A
Storage pile (Wind erosion and mainten-ance	Coal	1.6 u	-	-	$\frac{lb}{(acre)(hr)}$	5	C[b]

\- = Unable to be determined from information contained in test report.
[a]Multiply this fraction by the TSP predictive equation to determine emissions in the < 2.5 μm size range.
[b]Rating applicable to Mine Types A, B, and D (see p 61).

A = area blasted (ft^2)
M = moisture content (%)
D = hole depth (ft)
s = silt content (%)
μ = wind speed (m/sec)
d = drop height (ft)
W = vehicle weight (tons)
S = vehicle speed (mph)
w = number of wheels
L = silt loading (g/m2)

F-22

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS
(Test Report 4, 5, 14, and 15)

		Emission Factor by Aerodynamic Diameter									
Operation	**Source (Material)**	**Total**	**TSP**	**< 30 (μm)**	**< 15 (μm)**	**< 10 (μm)**	**< 5 (μm)**	**< 2.5 (μm)**	**Units**	**Test Report**	**Rating**
Drilling											
	(Overburden) (mine type C)	-	1.3	-	-	-	-	-	lb/hole	14	B
	(Coal) (mine type E)	-	0.22	-	-	-	-	-	lb/hole	5	E
Blasting	(Overburden)										
	(mine type A)	-	1,690	-	-	-	-	-	lb/blast	5	E
	(mine type C)	-	14.2	-	-	-	-	-	lb/blast	5	E
	(mine type E)	-	85.3	-	-	-	-	-	lb/blast	5	E
	(Coal)										
	(mine type C)	-	25.1	-	-	-	-	-	lb/blast	5	E
	(mine type D)	-	78.1	-	-	-	-	-	lb/blast	5	E
	(mine type E)	-	72.4	-	-	-	-	-	lb/blast	5	E
Dragline	(Overburden)										
	(mine type A)	-	0.0056	-	-	-	-	-	lb/yd^3	5	D
	(mine type B)	-	0.053	-	-	-	-	-	lb/yd^3	5	D
	(mine type C)	-	0.0030	-	-	-	-	-	lb/yd^3	5	C
	(mine type D)	-	0.021	-	-	-	-	-	lb/yd^3	5	C
Top soil removal	Scraper										
	(mine type D)	-	0.44	-	-	-	-	-	lb/T	5	D
	Unspecified equipment	-	0.058	-	-	-	-	-	lb/T	15	E
Overburden replacement	Unspecified equipment	-	0.012	-	-	-	-	-	lb/T	15	C

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS
(Test Report 4, 5, 14, and 15) (cont.)

		Emission Factor by Aerodynamic Diameter									
Operation	**Source (Material)**	**Total**	**TSP**	**< 30 (μm)**	**< 15 (μm)**	**< 10 (μm)**	**< 5 (μm)**	**< 2.5 (μm)**	**Units**	**Test Report**	**Rating**
Batch-drop	Dumping via truck (Overburden-bottom)										
	(mine type E)	-	0.002	-	-	-	-	-	lb/T	5	E
	(Coal-end)										
	(mine type E)	-	0.007	-	-	-	-	-	lb/T	5	E
	(Material not specified-bottom)										
	(mine type A)	-	0.014	-	-	-	-	-	lb/T	5	D
	(mine type B)	-	0.020	-	-	-	-	-	lb/T	5	E
	(mine type C)	-	0.005	-	-	-	-	-	lb/T	5	E
	(mine type D)	-	0.027	-	-	-	-	-	lb/T	5	E
	Dumping via scraper (top soil)										
	(mine type D)	-	0.04	-	-	-	-	-	lb/T	5	C
	Dumping via unspecified equipment or process										
	(Coal)	-	0.066	-	-	-	-	-	lb/T	15	D
	(Fly-ash)										
	(mine type A)	-	3.9	-	-	-	-	-	lb/hr	5	E
	Front-end loader/truck (Material unspecified)										
	(mine type D)	-	0.12	-	-	-	-	-	lb/T	5	E
	Power shovel/truck (Overburden)										
	(mine type E)	-	0.037	-	-	-	-	-	lb/T	5	C

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS (Test Report 4, 5, 14, and 15) (cont.)

		Emission Factor by Aerodynamic Diameter									
Operation	**Source (Material)**	**Total**	**TSP**	**< 30 (μm)**	**< 15 (μm)**	**< 10 (μm)**	**< 5 (μm)**	**< 2.5 (μm)**	**Units**	**Test Report**	**Rating**
	(Coal)										
	(mine type A)	-	0.014	-	-	-	-	-	lb/T	5	D
	(mine type B)	-	0.007	-	-	-	-	-	lb/T	5	D
	(mine type C)	-	0.002	-	-	-	-	-	lb/T	5	D
	(mine type E)	-	0.0035	-	-	-	-	-	lb/T	5	D
	Loading train via unspecified equipment and process										
	(Coal)	-	0.027	-	-	-	-	-	lb/T	15	D
	(mine type C)	-	0.0002	-	-	-	-	-	lb/T	5	D
Storage pile	Wind erosion (Coal)	-	0.013	-	-	-	-	-	lb/T/yr	4	D
Vehicle traffic on unpaved road	Haul truck (unspecified size)	-	17.0	-	-	-	-	-	lb/VMT	5	C
	(mine type B)	-	22.0	-	-	-	-	-	lb/VMT	15	C
Wind erosion	Exposed areas	-	0.38	-	-	-	-	-	$\frac{T}{(acre)(yr)}$	15	C

- = Unable to be determined from information contained in test report.
= Not recommended for inclusion into AP.

F.2 Section 8 of EPA report "Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources--Volume I - Sampling Methodology and Test Results

SECTION 8

RESULTS FOR SOURCES TESTED BY UPWIND-DOWNWIND SAMPLING

SUMMARY OF TESTS PERFORMED

Five different sources were tested by the upwind-downwind method--coal loading, dozers, draglines, haul roads, and scrapers. However, haul roads and scrapers were tested by upwind-downwind sampling only as part of the comparability study, with the exception of six additional upwind-downwind haul road tests during the winter sampling period. Test conditions, net concentrations, and calculated emission rates for the comparability tests were presented in Section 6. Test conditions and emission rates for haul road tests are repeated here for easier comparison with winter haul road tests, but scraper data are not shown again. Haul roads were tested by the upwind-downwind method during the winter when limited operations and poor choices for sampling locations precluded sampling of dozers or draglines, the two primary choices.

A total of 87 successful upwind-downwind tests were conducted at the three mines/four visits. They were distributed by source and by mine as follows:

	Number of tests			
Source	Mine 1	Mine 2	Mine 1W	Mine 3
Coal loading	2	8		15
Dozer, overburden	4	7		4
Dozer, coal	4	3		5
Draglines	6	5		8
Haul roads	5		6	
Scrapers	5			

Test conditions for the coal loading tests are summarized in Table 8-1. Correction factors for this source may be difficult to develop: bucket capacities and silt contents did not vary significantly during the tests, nor did drop distances (not shown in the table). One variable not included in the table was type of coal loading equipment. At the first two mines, shovels were used; at the third mine, front-end loaders were used.

Test conditions for dozers are summarized in Tables 8-2 and 8-3 for dozers working overburden and coal, respectively. These two source categories exhibited a wide range of operating and soil characteristics in their tests--speed varied from 2 to 10 mph, silt contents from 3.8 to 15.1 percent, and moisture contents from 2.2 to 22 percent. This indicates a good potential for correction factors. Also, there is a possibility of producing a single emission factor for the two dozer operations.

Dragline test conditions are shown in Table 8-4. Bucket sizes for the different tests were all nearly the same, but large differences in drop distances (5 to 100 ft), silt contents (4.6 to 14 percent), and moisture contents (0.2 to 16.3 percent) were obtained. One dragline variable used in the preliminary data analysis for the statistical plan, operator skill, was not included in Table 8-4 because it was judged to be too subjective and of little value as a correction factor for predicting emissions from draglines. Also, it was not found to be a significant variable in the preliminary data analysis.

Test conditions for haul roads tested by upwind-downwind sampling are summarized in Table 8-5. Most of the tests for this source were done by exposure profiling, so this subset of tests was not analyzed separately to develop another emission factor. Instead, the calculated emission rates and test conditions for these tests were combined with the exposure profiling test data in the data analysis and emission factor development phase.

RESULTS

The apparent TSP emission rates calculated from the concentrations at each hi-vol sampler are shown in Tables 8-6 through 8-10 for coal loading, dozers (overburden), dozers (coal), draglines, and haul roads, respectively. These reported emission rates have not been adjusted for any potential correction factors. The individual emission rates are shown as a function of source sampler distances in these tables. Distance is an important factor in the evaluation of deposition.

TABLE 8-1. TEST CONDITIONS FOR COAL LOADING

Test	Date	Start Time	Sampling Duration, Minutes	Source Characteristics: No. of Trucks	Source Characteristics: Bucket Capacity, Yd^3	Soil Properties: Silt, %	Soil Properties: Moisture, %	Meteorological Conditions: Temp., F	Meteorological Conditions: Wind Speed, m/s	Meteorological Conditions: Stab Class
Mine 1										
1	8/11/79	12:35	43	10	17	No	22	87	1.0	A
2	8/11/79	13:45	39	3	17	data	22	91	1.0	A
Mine 2										
1	10/16/79	9:45	72	4	14	No	38	46	4.3	C
2	10/16/79	12:45	80	4	14	data	38	55	4.3	C
3	10/16/79	16:00	45	4	14		38	56	2.9	C
4	10/16/79	17:00	30	3	14		38	56	2.6	C
5	10/18/79	9:40	42	3	14		38	50	2.1	C
6	10/18/79	12:50	40	2	14		38	57	4.8	D
7	10/18/79	15:30	36	2	14		38	60	4.9	D
8	10/30/79	16:00	35	5	16		38	38	5.0	C
Mine 3										
1	7/26/80	8:34	35	2	16	3.6	11.9	74	1.7	C
2	7/26/80	9:26	44	3	16	3.6	11.9	80	1.0	A
3	7/26/80	10:27	24	2	16	3.6	11.9	82	1.0	A
4	7/30/80	10:35	23	4	16	4.2	18.0	94	1.1	A
5	7/30/80	11:50	52	10	16	4.2	18.0	95	1.1	A
6	7/30/80	12:58	65	8	16	4.2	18.0	95	2.9	B
7	8/05/80	10:15	54	2	16	3.9	12.2	93	1.3	B
8	8/07/80	9:17	34	3	16	4.0	11.1	82	1.0	C
9	8/07/80	10:02	46	2	16	4.0	11.1	83	1.3	D
10	8/07/80	12:00	28	3	16	4.0	11.1	100	1.2	B
11	8/07/80	12:48	47	4	16	4.0	11.1	100	1.9	A
12	8/12/80	8:42	22	4	16	3.7	6.6	79	2.0	C
13	8/12/80	10:03	18	2	16	3.7	6.6	89	1.9	C
14	8/12/80	10:42	13	3	16	3.7	6.6	89	1.8	C
15	8/12/80	11:30	22	3	16	3.7	6.6	89	2.5	D

TABLE 8-2. TEST CONDITIONS FOR DOZER (OVERBURDEN)

Test	Date	Start Time	Sampling Duration, Minutes	Source Characteristics: Speed, mph	Source Characteristics: Passes	Soil Properties: Silt, %	Soil Properties: Moisture, %	Meteorological Conditions: Temp., F	Meteorological Conditions: Wind Speed, m/s	Meteorological Conditions: Stab Class
Mine 1										
1	8/22/79	13:10	59	4	30	15.1	8.8	79	2.9	B
2	8/22/79	14:30	63	4	32	15.1	8.8	86	1.8	A
3	8/22/79	16:15	71	2	17	15.1	8.8	79	3.2	B
4	8/23/79	13:25	133	2	33	7.5	8.2	80	2.0	A
Mine 2										
1	10/15/79	11:00	46	7	20	4.1	16.8	65	5.0	D
2	10/20/79	12:45	64	7	42	3.8	15.6	44	8.5	D
3	10/23/79	13:00	97	7	52	4.4	15.3	42	4.9	C
4	10/23/79	15:05	54	7	22	4.4	15.3	51	3.2	B
5	10/23/79	16:20	55	7	7	4.4	15.3	52	1.8	C
6	10/27/79	12:50	145	7	82	5.4	13.6	53	3.3	C
7	10/27/79	16:08	55	7	60	5.4	13.6	65	2.7	C
Mine 3										
1	7/29/80	8:28	60	2	30	7.0	3.6	78	1.5	A
2	7/29/80	9:54	43	2	21	7.0	3.6	85	1.3	B
3	8/11/80	9:24	49	2	14	6.9	2.2	83	1.1	A
4	8/11/80	12:30	23	2	10	6.9	2.2	85	1.9	B

TABLE 8-3. TEST CONDITIONS FOR DOZER (COAL)

Test		Date	Start Time	Sampling Duration, Minutes	Source Characteristics: Speed, mph	Source Characteristics: Passes	Source Characteristics: No. of Dozers	Soil Properties: Silt, %	Soil Properties: Moisture, %	Meteorological Conditions: Temp., F	Meteorological Conditions: Wind Speed, m/s	Meteorological Conditions: Stab Class
Mine	1											
	1	8/18/79	10:15	60	8	n/a	2	8.0	20.0	83	1.5	A
	2	8/18/79	12:45	46	8	n/a	2	8.0	20.0	86	3.4	B
	3	8/18/79	13:50	37	8	n/a	1	8.0	20.0	88	2.3	B
	4	8/18/79	14:50	30	8	n/a	1	8.0	20.0	85	2.2	B
Mine	2											
	1	10/26/79	14:20	25	7	24	2	6.0	22.0	53	3.6	C
	2	10/26/79	15:00	47	7	22	1	6.0	22.0	53	4.1	D
	3	10/26/79	16:08	43	7	26	1	6.0	22.0	54	2.7	C
Mine	3											
	1	8/10/80	16:02	15	8	17	1	11.3	4.0	92	5.7	C
	2	8/10/80	16:40	17	10	21	1	11.3	4.0	93	6.0	D
	3	8/10/80	17:25	12	12	19	1	11.3	4.0	95	5.2	D
	4	8/10/80	18:05	18	5	19	1	11.3	4.0	91	3.8	C
	5	8/10/80	18:45	14	5	15	1	11.3	4.0	90	3.0	C

TABLE 8-4. TEST CONDITIONS FOR DRAGLINES

Test		Date	Start Time	Sampling Duration, Minutes	Buckets	Bucket Capacity, Yd^3	Drop Dist., Ft.	Silt, %	Moisture, %	Temp., F	Wind Speed, m/s	Stab Class
					Source Characteristics			**Soil Properties**		**Meteorological Conditions**		
Mine	1											
	1	8/08/79	11:15	49	32	60	10	6.4	8.4	78	2.4	B
	2	8/08/79	14:09	62	46	60	32	6.4	8.4	83	3.1	B
	3	8/08/79	16:40	60	44	60	20	6.4	8.4	88	3.9	C
	4	8/17/79	11:00	44	54	60	28	6.4	8.4	84	2.0	A
	5	8/17/79	14:40	49	49	60	30	6.4	8.4	86	1.0	A
	6	8/17/79	16:00	31	5	60	82	6.4	8.4	84	1.8	A
Mine	2											
	1	10/13/79	12:15	68	63	32	40	11.4	15.6	47	4.7	D
	2	10/13/79	14:28	72	71	32	40	11.4	15.6	52	4.1	C
	3	10/13/79	16:00	74	66	32	5	11.4	15.6	53	3.6	C
	4	10/21/79	12:48	52	46	32	10	12.6	16.3	38	3.9	D
	5	10/24/79	14:45	83	6	32	30	5.0	14.9	54	2.7	C
Mine	3											
	1	7/31/80	10:19	41	30	55	100	14.0	2.7	85	1.0	A
	2	7/31/80	11:35	53	37	55	60	14.0	2.7	93	1.9	A
	3	7/31/80	12:40	35	40	55	100	14.0	2.7	94	2.2	B
	4	7/31/80	13:28	55	22	55	30	4.6	1.2	96	2.1	B
	5	8/02/80	10:30	29	22	65	10	5.0	0.2	88	6.2	D
	6	8/02/80	11:35	40	24	65	20	5.0	0.2	88	7.4	D
	7	8/02/80	12:34	26	18	65	25	5.0	0.2	88	4.1	C
	8	8/02/80	13:45	55	23	65	25	5.0	0.2	90	3.6	C

TABLE 8-5. TEST CONDITIONS FOR HAUL ROADS

Test		Date	Start Time	Sampling Duration, Minutes	Source Characteristics			Soil Properties		Meteorological Conditions		
					Passes	Mean Speed, mph	Mean Weight, ton	Silt, %	Moisture, %	Temp., F	Wind Speed, m/s	Stab Class
Mine	1											
	J9	8/01/79	10:21	59	44	19	72	9.4	3.4	83	3.8	B
	J10	8/01/79	14:02	47	43	19	66	9.4	2.2	89	4.8	C
	J12	8/02/79	10:47	49	20	15	109	14.2	6.8	81	1.1	A
	J20	8/09/79	14:10	46	23	17	138	11.6	8.5	73	2.1	B
	J21	8/09/79	16:52	21	13	15	121	11.6	8.5	77	2.2	B
Mine	1W											
	1	12/04/79	10:54	64	14					64	5.7	D
	2	12/08/79	12:40	38	28	24	106	15.9[a]	5.0[a]	53	6.2	D
	3	12/08/79	13:50	54	24	20	118	13.8	4.9	56	5.8	D
	4	12/08/79	15:00	52	31	20	95	18.0	5.1	56	5.4	D
	5	12/09/79	9:15	55	25					52	2.0	C
	6	12/09/79	10:30	63	22					59	5.0	D

[a]Average of other samples this day.

TABLE 8-6. APPARENT EMISSION RATES FOR COAL LOADING
High Volume (30 μm)

Test No.		Apparent Emission Rates at Specified Distances, lb/ton								Distances from Source, m			
	First		Second			Third			Fourth				
Mine 1													
1	0.006	0.005	0.005	0.005	0.006	0.008	0.010	0.010		25	50	80	
2	0.005	0.004	0.010	0.008	0.010	0.017	0.016	0.031		20	45	75	
Mine 2													
1	0.030	0.057	0.050	0.048	0.034	0.043[a]	0.081[a]	0.045[a]		34	65	131	
2	0.043	0.089	0.071	0.121	0.067					65	96	162	
3	0.014	0.023	0.019	0.017	0.011	0.017	0.045	0.002		57	82	183	
4	0.013	0.018	0.013	0.012	0.010	0.016	0.026	0.012		80	105	206	
5	0.005	0.007	0.007	0.008	0.015	0.004	0.013	0.017	0.013	30	62	101	
6	0.022	0.025	0.039	0.012	0.021		0.013	0.017	0.033	10	28	62	199
7	0.030	0.008	0.011	0.018	0.038		0.012		0.027	10	28	62	170
8	0.005	0.004	0.005	0.004	0.005	0.009	0.010	0.010		30	60	110	170
Mine 3													
1	0.128	0.113	0.168	0.038	0.072	0.088		0.015	0.025	111	132	148	166
2	0.115	0.049	0.008	0.061	0.043	0.053	0.036	0.043	0.055	31	58	96	150
3	0.060	0.067	0.055	0.038	0.035	0.056	0.057	0.051	0.042	29	56	94	148
4	0.005		0.016	0.011	0.012	0.019		0.009	0.010	12	24	31	45
5	0.006	0.005	0.007	0.007	0.013	0.014			0.019	16	27	34	50
6	0.008	0.014	0.010	0.016[a]	0.021	0.015			0.029	16	27	34	50
7		0.005	0.026	0.070	0.041	0.036	0.056	0.017		10	20	35	
8	0.041	0.051	0.069	0.064		0.079	0.104			60	90	130	
9	0.042	0.047	0.059	0.133		0.066	0.070			45	75	115	
10	0.194	0.100	0.200	0.045		0.214	0.222			45	65	105	
11	0.041	0.029	0.130	0.051		0.191	0.134			29	49	89	
12	0.039	0.034	0.049	1.271		0.036	0.077			35	65	95	
13	0.364	0.842	0.912	0.356		1.218	1.214			35	65	95	
14	0.165	0.282	0.291	0.128		0.352	0.507			35	62	92	
15	0.177	0.161	0.131			0.265	0.267			35	62	92	

[a]Interference from truck trafic.

TABLE 8-7. APPARENT EMISSION RATES FOR DOZER (OVERBURDEN)
High Volume (30 μm)

		Apparent Emission Rates at Specified Distances, lb/h													
Test No.		First		Second			Third			Fourth		Distance from Source, m			
Mine	1														
	1	14.3	18.2	11.6	9.0	7.8	10.3	10.5	[a] 8.9	4.5		15	44	78	180
	2	12.0	13.0	17.0	17.9	7.9	22.2	15.7[a]	2.4	8.2		20	49	83	185
	3	2.5	2.6	2.3	0.8	3.2	1.8	[a]	8.1	1.5		25	54	88	190
	4	3.4	5.5	4.9	1.3	2.3	0.6			13.1		25	52	78	138
Mine	2														
	1	0.8	0.3	2.0[a]	0.6	6.1									
	2	2.1	0.6	2.3	0.7		3.0	2.4	1.8	5.3		25	56		
	3	1.8	2.2	0.8	1.8	2.1	3.7	3.5	3.5	6.3		20	46	81	151
	4	3.0	2.9	4.8	0.0	1.9	0.0	0.0	0.0	3.2		25	58	100	162
	5		1.6	0.8	0.0	3.6	8.6	17.3	19.8	17.6		25	58	100	162
	6	0.8	0.7	0.7	0.4		1.2			2.4	2.7	8	23	100	162
	7	1.0	1.5		1.3		1.5	3.5		0.0	1.0	31	66	53	103
														90	146
Mine	3														
	1	4.5	5.2	4.6	5.5	8.0	3.8	7.0	8.8	4.8		25	45	75	115
	2	2.5	4.8	5.0	4.3	5.0	6.4	4.9	5.0	6.3		20	40	70	110
	3	21.0	14.9	18.0	17.8		14.4	16.7				25	41	63	
	4	25.9		20.1	15.9		17.7	23.9				43	59	81	

[a]Used as upwind concentration.

TABLE 8-8. APPARENT EMISSION RATES FOR DOZER (COAL)
High-Volume (30 μm)

Test No.		Apparent Emission Rates at Specified Distances, lb/h													
		First		Second			Third			Fourth		Distance from Source, m			
Mine	1											125	155	193	292
	1	13.4	16.7	12.1	15.4	20.1	16.8	14.1	23.5	20.4		125	155	193	292
	2	47.1	34.9	40.9	34.3	23.1	34.8	50.8	37.9	[a]		125	155	193	292
	3	8.3	38.5	12.1	12.5	19.0	[b]	31.2	45.0	11.6		125	155	193	292
	4	11.9	22.0	16.5	25.0	30.8	[b]	18.4	46.8	24.3					
Mine	2														
	1	9.7	8.0	10.4	8.6	6.4	11.5	13.4				30	42	53	
	2	3.0	5.8	5.2	6.6	8.4	4.6	9.5				40	67	78	
	3	1.6	2.5	3.8	3.4	4.2	1.0	4.4				40	67	78	
Mine	3														
	1	281		284	303		229	340		283	300	30	60	91	133
	2	298	234	217	153		164	217		250	242	30	60	91	133
	3	300	453	533	427		540	540		526	670	30	60	91	133
	4	255	255	324	368		306	414		366	293	30	60	91	133
	5	160	152	243	193		239	245		300	261	30	60	91	133

[a]Less than upwind concentration.
[b]Used as upwind concentration.

TABLE 8-9. APPARENT EMISSION RATES FOR COAL DRAGLINE
High Volume (30 μm)

Test No.	Apparent Emission Rates at Specified Distances, lb/yd^3									Distances from Source, m			
	First		Second			Third			Fourth				
Mine 1													
1	0.023	0.023	0.023	0.021	0.021	0.023	0.028	0.039	0.028	60	90	130	220
2	0.009	0.010	0.021	0.022	0.023	0.050	0.043	0.054	0.068	20	50	90	180
3	0.003	0.005	0.001	0.007	0.003	0.003	0.003	0.009	0.007	20	50	90	180
4	0.042	0.055	0.032	0.051	0.051	0.016	0.031	0.060	0.007	90	122	156	246
5	0.074	0.067	0.073	0.074	0.074	0.046	0.062	0.107	0.026	140	172	206	296
6	0.355	0.446	0.314	0.302	0.442	0.047	0.049	0.179	[a]	80	112	146	236
Mine 2													
1	0.034	0.052	0.043			0.068	0.025	0.024	0.046	40	67	97	203
2	0.019	0.026	0.031	0.016	0.024	0.039	0.017	0.035	0.027	31	61	89	168
3	0.001	0.002	0.004	0.001	0.001	0.005	0.003	0.002	0.005	31	61	89	168
4	0.012	0.012	0.019	0.016	0.019	0.021	0.017	0.013	0.025	150	177	216	310
5	0.065	0.071	0.061	0.035	0.014	0.025	0.033	0.030	0.000	110	139	172	230
Mine 3													
1	0.188	0.181	0.142	0.138	0.138	0.120		0.077	0.067	94	121	148	
2	0.122	0.142	0.102	0.120	0.202	0.204	0.181	0.130		94	121	148	
3	0.196	0.205	0.185	0.179	0.191	0.246	0.194	0.192		94	121	148	
4	0.080	0.062	0.111	0.102	0.115	0.157	0.021	0.125		94	121	148	
5	0.063	0.057	0.064	0.053	0.066	0.056	0.052	0.067		140	166	196	
6	0.081	0.070	0.065	0.049	0.072	0.069	0.069	0.134	0.138	98	124	154	234
7	0.122	0.075	0.079	0.131	0.087	0.101	0.088	0.114	0.136	98	124	154	234
8	0.101	0.097	0.103	0.113	0.106	0.101	0.111	0.105	0.104	140	166	196	276

[a]Concentration less than upwind.

TABLE 8-10. APPARENT EMISSION RATES FOR HAUL ROADS
High Volume (30 μm)

		Apparent Emission Rates at Specified Distances, lb/VMT											
Test No.		First		Second		Third		Fourth		Distances from Source, m			
Mine	1												
	J9	16.1	12.1	10.8	16.5	12.3	10.3	3.8	6.4	5	20	50	100
	J10	13.0	11.1	9.3	8.2	3.2	3.3	a	a	5	20	50	100
	J12	3.5	3.5	4.3	4.4	3.1	2.7	1.1	a	5	20	50	100
	J20	5.1	7.7	4.0	4.6	2.8	2.8	a	a	5	20	50	100
	J21	11.7	18.4	11.8	15.8	8.7	16.8	6.8	10.2	5	20	50	100
Mine	1W												
	1	11.6	11.6	12.1	9.6	13.6	13.1	13.9	14.6	5	20	50	100
	2	19.1	13.1	13.3		13.3	11.2	8.5	10.6	5	20	50	100
	3	28.3	21.8	15.6	15.2		7.7	4.5	4.8	5	20	50	100
	4	36.0	38.3	32.8	21.6	29.8	25.6	20.0	21.7	5	20	50	100
	5	11.5	15.1	9.3	14.4		13.9	6.3		5	20	50	100
	6	47.8	40.9	31.1	31.0		31.5	28.8	40.6	5	20	50	100

[a]Downwind concentration less than calculated upwind.

When the samples were evaluated for deposition as described in Section 5, only 21 out of the 87 upwind-downwind samples (including scrapers) demonstrated distinct fallout over the three or four distances. The percentage of tests showing fallout was much higher for sources sampled as line sources than for sources sampled as point sources: 13 out of 25 (52 percent) for line sources compared to 8 out of 62 (12.g percent) for point sources.

It was concluded that some problem exists with the point source dispersion equation because its results rarely indicate deposition, although the same type and size distribution of emissions are involved as with the line source dispersion equation. The sensitivity of calculated emission rates to several inputs to the point source equation (such as initial plume width, initial horizontal dispersion, distance from plume centerline, and stability class) were examined, but no single input parameter could be found that would change the emission data by distance to show deposition.

The single-value TSP emission rates for each test determined from the multiple emission rate values are summarized in Table 8-11. The means and standard deviations for these tests are shown below:

Source	No. Tests	Units	Mean	Std Dev	Range
Coal loading	25	lb/ton	0.105	0.220	0.0069-1.09
Dozer, overburden	15	lb/h	6.8	6.9	0.9-20.7
Dozer, coal	12	1b/h	134.3	155.6	3.0-439
Dragline	19	lb/yd^3	0.088	0.093	0.003-0.400
Haul road	11	lb/VMT	17.4	10.9	3.6-37.2
Scraper	5	1b/VMT	18.1	11.4	5.7-35.6

It should be emphasized that the mean values reported here are not emission factors; they do not have any consideration of correction factors included in them.

Emission rates for coal loading varied over a wide range, from 0.0069 to 1.09 lb/ton. Rates at the third mine averaged an order of magnitude higher than at the first two mines. Since a front-end loader was used at the third mine and shovels at the first two, the wide differences in average emission rates may indicate that separate emission factors are required for these two types of coal loading.

TABLE 8-11. EMISSION RATES FOR UPWIND-DOWNWIND TESTS

Coal Loading		**Dozer, Overburden**		**Dozer, Coal**		**Dragline**		**Haul Road/Scraper**	
Test No.	**Emission Rate, lb/ton**	**Test No.**	**Emission Rate, lb/h**	**Test No.**	**Emission Rate, lb/h**	**Test No.**	**Emission Rate, lb/yd^3**	**Test No.**	**Emission Rate, lb/VMT**
								Haul Road	
Mine 1		Mine 1		Mine 1		Mine 1		Mine 1	
1	0.0069	1	16.2	1	16.1	1	0.024	J9	14.1
2	0.0100	2	12.6	2	40.1	2	0.029	J10	12.0
		3	2.6	3	19.0	3	0.004	J12	3.6
Mine 2		4	3.0	4	21.3	4	0.048	J20	6.4
1	0.044					5	0.070	J21	15.0
2	0.068	Mine 2		Mine 2		6	0.400		
3	0.0147	1	0.9	1	9.1			Mine 1W	
4	0.0134	2	1.8	2	6.2	Mine 2		1	12.9
5	0.0099	3	2.6	3	3.0	1	0.042	2	16.1
6	0.0228	4	1.3			2	0.026	3	25.0
7	0.0206	5	9.2	Mine 3		3	0.003	4	37.2
8	0.0065	6	1.0	1	289	4	0.016	5	12.8
		7	1.0	2	222	5	0.068	6	36.0
Mine 3				3	439				
1	0.120	Mine 3		4	323	Mine 3		Scraper	
2	0.082	1	5.4	5	224	1	0.184	Mine 1	
3	0.051	2	5.2			2	0.133	J1	10.6
4	0.0105	3	18.0			3	0.192	J2	18.6
5	0.0087	4	20.7			4	0.099	J3	35.6
6	0.0140					5	0.060	J4	5.7
7	0.035					6	0.104	J5	20.0
8	0.062					7	0.105		
9	0.058					8			
10	0.193								
11	0.095								
12	0.042								
13	1.09								
14	0.358								
15	0.188								

Emissions from dozers working overburden varied over a moderate range. Much of that variation can probably be explained by the soil characteristics of the overburden being regraded: soil at the second mine, which in general had the lowest emission rates, had the highest moisture contents and lowest silt contents; soil at the third mine, which had the highest emission rates, was driest. The evaluation of these two correction parameters is described in Section 13.

Coal dozer emissions were grouped very tightly by mine. The averages, standard deviations, and ranges by mine show this:

Mine	Mean	Std Dev	Range
1	24.1	10.9	16.1-40.1
2	6.1	3.0	3.0-9.1
3	299	89.2	222-439

Coal characteristics are also expected to explain part of this variation, but it is doubtful that the very high emission rates at the third mine can be explained with just those parameters. Dozers working coal had considerably higher emission rates than dozers working overburden. The two sources probably cannot be combined into a single emission factor with available data unless some correction parameter reflecting the type of material being worked is incorporated.

Dragline emissions had greater variation within each mine than between mine averages. As with several of the other sources, emission rates at the third mine were highest and moisture contents of soil samples were the lowest. The only sample more than two standard deviations away from the mean was a 0.400 value obtained at the first mine. This potential outlier (its high value may be explained by correction parameters) was more than twice the next highest emission rate.

Haul roads had relatively little variation in emission rates for the tests shown. However, all these tests were taken at the same mine during two different time periods. For a more comprehensive listing of haul road emission rates from all three mines/ four visits, the exposure profiling test data in Section 7 should be reviewed.

Average IP and FP emission rates for each test, along with IP emission rates calculated from each sampler, are presented by source in Tables 8-12 through 8-16. The values could be averaged without first considering deposition because dichotomous samplers were only located at the first two distances from the source (leaving only about a 30 m distance in which measurable deposition could occur) and because smaller particles do not have significant deposition. Although the IP data from the upwind-downwind tests have a large amount of scatter, no reduction in emission rates with distance is evident.

The average ratios of IP and FP to TSP emission rates are:

Source	Avg. Ratio of IP to TSP Emission Rates	Avg. Ratio of FP to TSP Emission Rates
Coal loading	0.30	0.030
Dozer, overburden	0.86	0.196
Dozer, coal	0.49	0.031
Dragline	0.32	0.032
Haul road	0.42	0.024

These values are different than the average ratios of net concentrations because of the effect of deposition on calculation of the single-value TSP emission rates.

The overburden dozer IP/TSP ratios are much higher than for other sources because five of the 15 tests had IP concentrations much higher than TSP concentrations. When the IP concentration exceeds the TSP concentration, correction of the IP value to 15 μm size from the actual (wind speed dependent) cut point cannot be performed by the method described on Page 5-36. For such cases in Table 8-13 (and Table 8-14 through 8-16), the uncorrected IP values were reported along with their estimated cut points. If the five tests with uncorrected IP data were eliminated, the average IP/TSP ratio would be 0.28, much closer to that of the other sources. No explanation was found for the high IP concentrations compared to TSP concentrations for overburden dozers.

For all sources except overburden dozers, the IP and FP emission rate variabilities (as measured by the relative standard deviation) were about the same as TSP emission rate variabilities. Due to the four high dichotomous sample values, the IP and FP emission rates for overburden dozers had about twice the relative standard deviation as the TSP emission rates.

TABLE 8-12. EMISSION RATES FOR COAL LOADING
Dichotomous (15 μm, 2.5 μm)

Test No.	Apparent IP Emission Rates at Specified Distances, lb/ton					Avg. IP Emission Rate, lb/ton	Avg. FP Emission Rate, lb/ton	Distances from Source, m	
	First		Second						
Mine 1									
1	0.002	0.001	0.002	0.001	0.002	0.002	0.0001	25	50
2	0.001	0.001	0.002	0.007	0.006	0.003	0.0002	20	45
Mine 2									
1	0.005	0.006	0.002	0.005		0.005	0.0002	34	65
2	0.013	0.050	0.018	0.009		0.022	0.0008	65	96
3	0.003	0.002	0.005	0.003		0.003	0.0001	57	82
4	0.002	0.008	0.005	0.005		0.005	0.0018	80	105
5	0.001	0.004	0.002		0.008	0.004	0.0007	30	62
6	0.005	0.011	0.039		0.014	0.017	0.0029	10	28
7	0.013	0.001	0.005		0.011	0.008	0.0008	10	28
8	0.004	0.003			0.005	0.004	0.0002	30	60
Mine 3									
1	0.112	0.035	0.023	0.006	0.004	0.044	0.0038	111	132
2			0.011		0.005	0.008	0.0005	31	58
3	0.003	0.008	0.039			0.016	0.0022	29	56
4	0.001		0.001	0.004	0.001	0.002	0.0002	12	24
5	0.001	0.001	0.001		0.003	0.001	0.0001	16	27
6	0.002	0.009	0.011		0.003	0.006	0.0001	16	27
7		0.002	0.011		0.012	0.008	0.0012	10	20
8	0.011	0.000	0.018	0.020		0.012	0.0012	60	90
9	0.012	0.012	0.021	0.013		0.014	0.0005	45	75
10	0.051	0.029	0.040	0.036		0.038	0.0033	45	65
11	0.003	0.011	0.056	0.009		0.020	0.0005	29	49
12	0.012	0.006	0.015	0.010		0.011	0.0021	35	65
13	0.575	0.182	0.404	0.352		0.378	0.0054	35	65
14	0.116	0.093	0.152	0.122		0.121	0.0035	35	62
15	No dichotomous data for test								

TABLE 8-13. EMISSION RATES FOR DOZER (OVERBURDEN)
Dichotomous (15 μm, 2.5 μm)

Test No.	Apparent IP Emission Rates at Specified Distances, lb/h — First		Apparent IP Emission Rates at Specified Distances, lb/h — Second			Avg. IP Emission Rate, lb/h	Avg. FP Emission Rate, lb/h	Distances from Source, m		
Mine 1										
1	3.39	1.75	2.43	2.71	5.66	3.18	0.436	15	44	
2	1.68	2.78	2.02	2.22		2.18	0.322	20	49	
3	3.86[a]	1.58	3.18[a]	3.17[a]	2.48	2.85	1.010	25	54	
4	[b]	[b]	[b]	[b]	[b]	[c]	[c]	25	52	
Mine 2										
1	0.0	0.91[d]	1.13		6.43[d]	2.12	0.583	25	56	
2	3.74[e]	13.9[e]			0.0	5.88	0.091	20	46	
3	2.39[f]	0.0	1.62		0.0	1.00	0.790	25	58	
4	0.846	0.0	0.561		0.521	0.48	0.065	25	58	
5	0.0	4.19[g]	0.375		0.0	1.14	0.680	25	58	
6	1.00[h]	0.922[h]	0.632	0.129		0.68	0.421	8	23	
7	0.885	0.513	2.82	0.646		1.22	0.536	31	66	
Mine 3										
1	0.488	0.679	0.842		1.91	0.98	0.356	25	45	
2	0.701	0.912	0.600		0.913	0.781	0.089	20	40	
3	6.48		5.22		2.00[j]	4.57	0.925	25	41	63
4[k]	33.4		32.6		31.8	32.6	1.73	43	59	81

[a]This dichotomous sampler value could not be corrected to a 15 μm cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 16.2 μm.
[b]Downwind concentration less than upwind
[c]Insufficient data.
[d]See footnote a; represents 13.4 μm cut point.
[e]See footnote a; represents 10.4 μm cut point.
[f]See footnote a; represents 13.5 μm cut point.
[g]See footnote a; represents 20.2 μm cut point.
[h]See footnote a; represents 16.0 μm cut point.
[i]See footnote a; represents 17.4 μm cut point.
[j]Actually at 63 m distance.
[k]See footnote a; represents 19.8 μm cut point
[l]Actually at 8 m distance.

TABLE 8-14. EMISSION RATES FOR DOZER (COAL)
Dichotomous (15 μm, 2.5 μm)

Test No.		Apparent IP Emission Rates at Specified Distances, lb/h					Avg. IP Emission Rate, lb/h	Avg. FP Emission Rate, lb/h	Distances from Source, m	
		First		Second						
Mine	1									
	1	3.94	3.94	4.18	3.89	6.97	4.49	0.243	125	155
	2	38.0	42.0[a]	67.2[a]	21.1	31.2[a]	39.9	0.730	125	155
	3	7.91	1.49	2.44	3.89	7.94	4.73	1.000	125	155
	4	6.49	6.48	11.5	13.4	27.0	13.0	2.68	125	155
Mine	2									
	1	1.73	3.58	1.02		2.71	2.26	0.252	30	42
	2	2.08	1.03	2.94		2.98	2.26	0.199	40	67
	3	0.82	0.43	0.57		1.86	0.92	0.138	40	67
Mine	3									
	1	214		96	222		177	3.50	30	60
	2	254	223	119	113		178	2.25	30	60
	3	229	273	259	185		236	4.49	30	60
	4	161	157	183	204		176	3.28	30	60
	5	70	78	109	72		82.2	3.50	30	60

[a]This dichotomous sampler value could not be corrected to a 15 μm cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 15.8 μm.

TABLE 8-15. EMISSION RATES FOR DRAGLINE
Dichotomous (15 μm, 2.5 μm)

Test No.	Apparent IP Emission Rates at Specified Distances, lb/h — First		Second			Avg. IP Emission Rate, lb/yd^3	Avg. FP Emission Rate, lb/yd^3	Distances from Source, m	
Mine 1									
1	0.008	0.004	0.002	0.066	0.010	0.006	0.0009	60	90
2	0.008	0.004	0.008	0.021	0.021	0.012	0.0002	20	50
2	0.001	0.001	0.002	0.004	0.002	0.002	0.0001	20	50
4	0.007	0.007	0.003	0.008	0.007	0.006	0.0001	90	120
5	0.010	0.006	0.016	0.025	0.021	0.016	0.0009	140	170
6	0.060	0.038	0.060	0.042	0.104	0.061	0.0087	80	110
Mine 2									
1	0.002	0.003	0.003			0.003	0.0002	40	67
2	0.009	0.009	0.002		0.008	0.007	0.0008	31	61
3	0.001	0.001	0.002		0.001	0.001	0.0003	31	61
4	0.026	0.010	0.005		0.020	0.015	0.0010	150	177
5	0.022	0.028	0.038		0.052[a]	0.035	0.0110	110	139
Mine 3									
1	0.008	0.028	0.015		0.024	0.018	0.0017	94	121
2	0.013	0.017	0.017		0.017	0.016	0.0011	94	121
3	0.058	0.052[b]			0.063	0.058	0.006	94	121
4	0.044	0.063	0.039		0.026	0.043	0.005	94	121
5	0.038	0.055	0.034		0.025	0.038	0.0001	140	166
6	0.034	0.029	0.011		0.040	0.028	0.0017	98	124
7	0.036	0.022	0.019		0.020	0.024	0.0023	98	124
8	0.028	0.003	0.014		0.023	0.017	0.0004	140	166

[a] This dichotomous sampler value could not be corrected to a 15 μm cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 17.4 μm.
[b] See footnote a; represents 19.0 μm cut point.

TABLE 8-16. EMISSION RATES FOR HAUL ROADS
Dichotomous (15 μm, 2.5 μm)

Test No.	Apparent IP Emission Rates at Specified Distances, lb/VMT						Avg. IP Emission Rate, lb/VMT	Avg. FP Emission Rate, lb/VMT	Distances from Source, m		
	First		Second		Third						
Mine 1											
J9	8.71	5.61	5.65	12.13	3.74	5.08	6.82	0.141	5	20	50
J10	7.42	4.50	7.91	7.24	3.55[a]	6.17[a]	6.13	0.300	5	20	50
J12	0.74	0.52	1.50	0.96	0.00	0.53	0.71	0.095	5	20	50
J20	3.81	3.80	5.63[b]	5.83[b]	5.37[b]	8.92[b]	5.56	0.401	5	20	50
J21	5.22	7.41	5.26	5.72	5.65	7.01	6.04	0.758	5	20	50
Mine 1W											
1	4.28	5.91	7.32	6.59			6.02	0.192	5	20	
2	7.18	11.69	9.11				9.33	0.062	5	20	
3	17.12	13.33	8.57	8.97			12.00	0.804	5	20	
4	5.41	3.80	8.06	4.62			5.47	0.620	5	20	
5	2.26	1.57	1.00	1.42			1.56	0.217	5	20	
6	10.78	12.36	10.25	14.36			11.94	0.165	5	20	

[a] This dichotomous sampler value could not be corrected to a 15 μm cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 13.6 μm.
[b] See footnote a; represent 19.0 μm cut point.

PROBLEMS ENCOUNTERED

The most common problem associated with upwind-downwind sampling was the long time required to set up the complex array of 16 samplers and auxiliary equipment. On many occasions, the wind direction would change or the mining operation would move while the samplers were still being set up.

Another frequent problem was mining equipment breakdown or reassignment. At various times, the sampling team encountered these situations: power loss to dragline; front-end loader broke down while loading first truck; dozer broke down, 2 hours until replacement arrived; dozer operator called away to operate frontend loader; and brief maintenance check of dragline leading to shutdown for the remainder of shift for repair.

A third problem was atypical operation of the mining equipment during sampling. One example was the noticeable difference in dragline operators' ability to lift and swing the bucket without losing material. Sampling of a careless operator resulted in emission rates two to five times as high as the previous operator working in the same location.

The dragline presented other difficulties in sampling by the upwind-downwind method. For safety reasons or because of topographic obstructions, it was often impossible to place samplers in a regular array downwind of the dragline. Therefore, many samples were taken well off the plume centerline, resulting in large adjustment factor values in the dispersion equation calculations and the potential for larger errors. Estimating average source-to-sampler distances for moving operations such as draglines was also difficult.

Sampling of coal loading operations was complicated by the many related dust-producing activities that are associated with it. It is impossible to sample coal loading by the upwind-downwind method without also getting some contributions from the haul truck pulling into position, from a front-end loader cleaning spilled coal from the loading area, and from the shovel or frontend loader restacking the loose coal between trucks. It can be argued that all of these constitute necessary parts of the overall coal loading operation and they are not a duplication of emissions included in other emission factors, but the problem arises in selecting loading operations that have typical amounts of this associated activity.

Adverse meteorology also created several problems in obtaining samples. Weather-related problems were not limited to the upwind-downwind sampling method or the five sources sampled by this method, but the large number of upwind-downwind tests resulted in more of these test periods being impacted by weather. Wind speed caused problems most frequently. When wind speeds were less than 1 m/s or greater than about 8 m/s, sampling could not be done. Extremely low and high winds occurred on a surprisingly large number of days, causing lost work time by the field crew, delays in starting some tests, and premature cessation of others. Variable wind directions and wind shifts were other meteorological problems encountered. In addition to causing extra movement and set up of the sampling equipment, changes in wind direction also ruined upwind samples for some sampling periods in progress. Finally, several sampling days were lost due to rain.

Appendix G
Materials Related to Scraper and Grading Emission Factors

This appendix contains information related to scraper and grading emission factors. The information is from Sections 5.5 and 8.5 of EPA report “Fugitive Dust Emission Factor Update for AP-42” and Section 7 of EPA report “Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources - Volume I - Sampling Methodology and Test Results.”

TABLE OF CONTENTS

G.1 Sections 5.5 and 8.5 of EPA report "Fugitive Dust Emission Factor Update for AP-42"

5.5 Section 8.24 - Western Surface Coal Mining and Processing

5.5.1 Test Report 4 (1977)

This study developed an emission factor for coal storage only. Four tests at one coal storage pile (location not given) were conducted using the upwind-downwind technique. Table 23 presents the source testing information for this study.

TABLE 23. COAL STORAGE SOURCE TESTING INFORMATION
(Test Report 4)

Operation	Equipment	Material	Site	Test Date	No. of Tests
Wind erosion	Storage pile	Coal	Plant 1	3/74	2
				8/74	2

High-volume samplers were used to collect the airborne particulates from one upwind and four downwind positions. The wind parameters were recorded at 15-min intervals. A sampling array similar to that described in Section 5.3.2 (Test Report 6) was employed in this study. This sampling system meets the minimum requirements of the upwind-downwind sampling technique. Optical microscopy was employed to determine a particle size distribution. However, the particle size distribution for the emission factor was determined from particle counting only (not mass fraction), which is unrepresentative of a mass size distribution.

This methodology is of generally sound quality; and emission rates were determined in a similar manner to that described in Section 5.3.2 (Test Report 6). However, the report lacks sufficient detail for adequate validation. For example, no indication is given as to sampling height. Also the field data recorded at the sampling stations are not presented. The test data are therefore rated B.

Table 24 presents the developed emission factor, conditions tested and the appropriate rating. Only one pile was sampled, although it was two different sizes during testing. The rating code refers to Table 4.

TABLE 24. COAL STORAGE EMISSION FACTOR, RANGE OF TEST CONDITIONS, AND RATING (Test Report 4)

Operation	No. of Tests	Range of conditions		Emission Factor[a,b]	Rating Code	Rating
		Wind Speed (m/s)	Moisture Content (T)			
Wind erosion of coal storage piles	4	1.5-2.7	2.2-11	0.013 lb/T/yr	5	D

[a]For particles < 10 μm (physical diameter).

[b]Emission factor is arithmetic mean of test runs C1, C2, CS-3 and CS-5 from page 30, Table A1 of test report.

5.5.2 Test Report S (1978)

This study was directed to the development of emission factors for the surface coal mining industry. Testing was conducted at five Western coal mines (Mines A through E). Table 25 presents the distribution of tests performed.

The upwind-downwind method was used with standard high-volume samplers for particulate collection. Wind parameters were continuously measured at a fixed location within each mine. A hand-held wind speed indicator was used when possible to record data at the exact test site. Optical microscopy was employed to determine particle size distribution.

The upwind-downwind sampler deployment used in this study generally employed six samplers for each test; additionally, six more samplers were operated at a second height in half the tests to determine a vertical plume gradient. Two instruments were located upwind of a source to measure background concentrations while four instruments were located downwind. These downwind samplers were deployed along a straight line (the assumed plume centerline) at four different distances.

TABLE 25. COAL MINING SOURCE TESTING INFORMATION
(Test Report 5)

			No. of Tests at Mine					
Operation	**Equipment**	**Material**	**A**	**B**	**C**	**D**	**E**	**Test Date**
Overburden removal	Dragline	Overburden	6	10	6	6	0	-
Vehicle traffic	Haul truck[b]	Unpaved road	0	4	0	[c]	[c]	-
Loading	Shovel/truck	Coal	6	4	4	0	4	-
		Overburden	0	0	0	0	6	-
Blasting	NA	Overburden	1	0	2	0	2	-
		Coal	0	0	2	2	2	-
Dumping[a]	Truck	-	6	2	2	4	0	-
		Coal	0	0	0	0	4	-
		Overburden	0	0	0	0	2	-
Storage pile wind erosion[d]	-	Coal	6	6	0	4	0	-
Drilling	NA	Overburden	0	0	2	0	0	-
		Coal	0	0	0	0	2	-
Dumping[a]	-	Fly ash	2	0	0	0	0	-
Loading[a]	Train	Coal	0	0	4	0	0	-
Topsoil removal	Scraper	Topsoil	0	0	0	5	0	-
Topsoil dumping	Scraper	Topsoil	0	0	0	5	0	-
-[a]	Front-end loader	-	0	0	0	1	0	-

- = Information not contained in test report.
NA = Not applicable.
[a]Details as to specific operation sampled for are not stated in text.
[b]Size not given.
[c]Unable to determine if tests were under controlled or uncontrolled states.
[d]Includes pile maintenance (unspecified equipment).

The determination of emission rates involved back calculation using dispersion equations after subtraction of the background from the downwind concentration. The following dispersion equation was used to calculate emission rates for area sources.

$$C = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad (6)$$

where:

- C = concentration
- Q = emission rate
- σ_y, σ_z = horizontal and vertical dispersion coefficients
- u = wind speed

Line source emission rates were determined by use of this dispersion equation:

$$C = \frac{2\,Q}{\sin\phi \sqrt{2\pi}\; \sigma_z\; u} \qquad (7)$$

where:

- C = concentration
- Q = emission rate
- ϕ = angle between line source and wind direction
- σ_z = vertical dispersion coefficient
- u = wind speed

The predictive emission factor equation for wind erosion of active storage piles was developed by plotting the emission rates against the wind speeds recorded during testing. The resulting linear function was described by the equation:

$$e = 15.83\; u \qquad (8)$$

where:

e = emission rate (lb/hr)

u = wind speed (m/sec)

This equation was then converted to one with units of $\frac{lb}{(acre)(hr)}$ by assuming storage pile surface areas of 10 acres.

This upwind-downwind sampling system does not meet the minimum requirements for point sources as set forth in Section 4.3 since particulate concentrations at only one crosswind distance were observed. Also details on the operations tested are frequently sketchy. Therefore, with three exceptions the test data are rated B. The test data for haul roads are rated A, because sampling at multiple crosswind distances is not required when testing line sources. The test data for storage pile wind erosion (and maintenance) are rated C because of: (a) the very light winds encountered; (b) the large size of the piles; and (c) the lack of information on pile maintenance activities. The test data for blasting are rated C because of the difficulty of quantifying the plume with ground based samplers.

The report indicates that emission factor variation between mines for the same operation is relatively high; therefore, it was recommended (in the report) that the factors be mine (type) specific. The following list describes the location of the five mines. The report gives a more in-depth description of each mine including production rate, stratigraphic data, coal analysis data, surface deposition, storage capacity, and blasting data.

Mine	Area
A	Northwest Colorado
B	Southwest Wyoming
C	Southeast Montana
D	Central North Dakota
E	Northeast Wyoming

Tables 26 through 30 present the average emission factors determined at each mine along with the ranges of conditions tested and the associated emission factor ratings. The text indicates that the emission factors should be used with a fallout function for distances closer than 5 km; however, the text does not explicitly state what particulate size range is represented by the emission factors.

TABLE 26. COAL MINING EMISSION FACTORS (MINE TYPE A), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	0.4-1.8	-	0.0056 lb/yd^3	4	D
Shovel/truck loading (coal)	6	0.4-1.3	10	0.014 lb/T	4	D
Blasting (overburden)	1	2.4	-	1,690[c] lb/blast	9	E
Truck dump[d] (bottom)	6	0.4-2.7	-	0.014 lb/T	4	D
Storage pile erosion[e]	6	0.5-2.6	10	$1.6\ u\ \frac{\text{lb}}{(\text{acre})(\text{hr})}$	1[f]	C[f]
Fly ash dump	2	1.5	-	3.9 lb/hr	7/8	E

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.
[c]Text indicates this value represents a maximum rate.
[d]Material not given.
[e]u = Wind speed in m/sec. This factor includes emissions from pile maintenance.
[f]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 27. COAL MINING EMISSION FACTORS (MINE TYPE B), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	10	3.1-5.8	-	0.053 lb/yd^3	4	D
Haul road	4	3.7-4.7	-	17.0 lb/VMT	5	C
Shovel/truck loading (coal)	4	0.4-0.6	18	0.007 lb/T	5	D
Truck dump (bottom)	2	3.7	-	0.020 lb/T	7	E
Storage pile erosion[c]	6	0.8-7.6	18	$1.6\ u\ \frac{lb}{(acre)(hr)}$	1[d]	C[d]

- = Information not contained in test report.

[a]Particle size not explicitly stated in test report.

[b]Emission factors are from page 2, Table 1 of test report.

[c]u = Wind speed in m/sec. This factor includes emissions from pile maintenance.

[d]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 28. COAL MINING EMISSION FACTORS (MINE TYPE C), RANGE OF TEST CONDITIONS, AND RATINGS
(Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	3.6-5.4	-	0.0030 lb/yd^3	3	C
Shovel/truck loading (coal)	4	3.6	24	0.002 lb/T	5	D
Blasting						
Coal	2	5.4	24	25.1 lb/blast	7	E
Overburden	2	3.6	-	14.2 lb/blast	7	E
Truck dump (bottom)	2	3.6	-	0.005 lb/T	7	E
Drilling (overburden)	2	3.6	-	1.5 lb/hole	8	
Train loading	4	4.5-4.9	24	0.0002 lb/T	5	D

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.

TABLE 29. COAL MINING EMISSION FACTORS (MINE TYPE D), RANGE OF TEST CONDITIONS, AND RATINGS
(Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	5.8-7.2	-	$0.021\ lb/yd^3$	3	C
Blasting (coal)	2	4.0	38	78.1 lb/blast	7	E
Truck dump (bottom)	4	4.5-6.7	-	0.027 lb/T	6	E
Storage pile erosion[c]	4	0.9-1.3	38	$1.6\ u\ \frac{lb}{(acre)(hr)}$	1[d]	C[d]
Topsoil removal						
Scraping	5	5.8-7.6	-	$0.35\ lb/yd^3$	4	D
Dumping	5	2.2-3.6	-	$0.03\ lb/yd^3$	3	C
Front-end loader	1	2.7	-	0.12 lb/T	9	E

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.
[c]u = Wind speed in m/sec.
[d]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 30. COAL MINING EMISSION FACTORS (MINE TYPE E), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Shovel/truck loading						
Coal	4	2.3-2.5	30	0.0035 lb/T	5	D
Overburden	6	2.7-3.6	30	0.037 lb/T	3	C
Blasting Coal	2	2.6	30	72.4 lb/blast	7	E
Overburden	2	3.7	-	85.3 lb/blast	7	E
Truck dump Overburden	2	6.2	-	0.002 lb/T	8	E
Coal (end dump)	4	2.7-3.1	30	0.007 lb/T	6	E
Drilling (coal)	2	4.1	30	0.22 lb/hole	8	E

\- = Information not contained in test report.

[a]Particle size not explicitly stated in test report.

[b]Emission factors are from page 2, Table 1 of test report.

The rating codes in Tables 26 through 30 refer to Table 5 (wind erosion) and Table 4 (all other sources). Because the single-valued factors were intended to apply only to the specific mine types,- the requirement for more than one test site was waived. The rating for the equation developed for storage pile wind erosion (and maintenance) is applicable when the equation is applied to mine types A, B. or D.

5.5.3 Test Report 14 (1981)

This study was conducted to determine improved fugitive dust emission factors for Western surface coal mines. Field testing was conducted in three coal fields; Powder River Basin (Mine 1), North Dakota (Mine 2), and Four Corners (Mine 3). The testing was performed during 1979 and 1980. Table 31 lists the testing information for this study.

The primary sampling method was exposure profiling. When source configuration made it necessary, alternate methods were used, including upwind-downwind, balloon, and quasi-stack sampling. Particle size distributions were determined by use of dichotomous samplers. Other equipment utilized were: (a) high volume samplers for determining upwind concentrations; (b) dustfall buckets for determining downwind particulate deposition; and (c) recording wind instruments to determine mean wind speed and direction for adjusting the exposure profiler to isokinetic sampling conditions and for use in upwind-downwind calculations.

Exposure profiling was used to measure emissions from moving point sources (see Table 31). The exposure profiling sampling system was similar to that described in Section 5.1.1 and therefore meets the minimum system design requirements. The upwind-downwind sampling system consisted generally of 15 particulate collection devices; 5 dichotomous samplers and 10 Hi-vols.

One Hi-vol and one dichotomous sampler were placed upwind while the remaining instruments were placed at multiple downwind and crosswind distances. This system also meets the minimum upwind-downwind requirements as described in Section 4.3.

TABLE 31. COAL MINING SOURCE TESTING INFORMATION (Test Report 14)

Operation	Equipment	Material	Test Method[a]	Site (mine)	Test Dates	No. of Tests
Drilling	NA	Overburden	Quasi-stack	1, 3	7/79, 8/79, 12/79, 7/80	30
Blasting	NA	Coal	Balloon[b]	1, 2, 3	8/79,10/79, 7/80, 8/80	14
		Overburden	Balloon[b]	1, 3	8/79, 8/80	4
Loading	Shovel/truck	Coal	Uw-Dw	1, 2	8/79, 10/79	10
	Front-end loader/truck	Coal	Uw-Dw	3	7/80, 8/80	15
Dozing	Dozer	Coal	Uw-Dw	1, 2, 3	8/79, 10/79, 8/80	12
		Overburden	Uw-Dw	1, 2, 3	8/79, 10/79, 7/80, 8/80	15
Dragline	Dragline	Overburden	Uw-Dw	1, 2, 3	8/79, 10/79, 7/80, 8/80	19
Vehicle traffic	Haul truck	Unpaved road	Uw-Dw	1	8/79, 12/79	11
		Unpaved road	Profiling	1, 2 ,3	7/79, 8/79, 12/79	21
	Light-medium duty	Unpaved road	Profiling	1, 2, 3	8/79, 10/79, 8/80	10
Scrapers[c] (travel mode)	Scraper	Unpaved surface	Uw-Dw	1	7/79	5
		Unpaved surface	Profiling	1, 2, 3	7/79, 10/79, 12/79, 8/80	15
Grading	Grader	Unpaved surface	Profiling	2, 3	10/79, 8/80	7

- = Information not contained in test report.
NA = Not applicable.
[a]Uw-Dw = Upwind-downwind.
[b]This is actually a modified version of exposure profiling.
[c]Loading and dumping not tested.

The test data were collected using a well documented sound methodology and, therefore, are rated A for line sources and for drilling. The test data for coal loading, dozing, and dragline operations are rated B because of the poorly defined plume characteristics and the interference of the pit areas with plume dispersion. For blasting the test data are rated C because of the difficulty of quantifying the large plume with a single line of samplers.

Table 32 presents the average emission factors, range of test conditions, and ratings assigned for Test Report 14. These single-valued factors were determined by substituting geometric means of the test conditions into a set of predictive emission factor equations also developed in the study. The equations are listed in Table 33. The rating codes in Table 32 refer to Table 4, and the codes in Table 33 refer to Table 5.

5.5.4 Test Report 15 (1981)

A portion of this study was devoted to the development of surface coal mining emission factors. Field testing was performed from August 1978 through the summer of 1979 at two surface coal mines located in the Powder River Basin of Wyoming. Table 34 presents the source testing information for this study.

The test methods employed to develop emission factors were: upwind-downwind, profiling, and a tracer technique. Particle sizing was performed by optical microscopy of exposed Millipore filters.

The profiling technique employed in this study was actually a variation of the exposure profiling procedure described in Section 5.1.1 (Test Report 7). High volume samplers were used instead of directional isokinetic intakes; therefore, the emission rates determined by profiling were for TSP (total suspended particulate).

The tracer technique utilized arrays of Bach high-volume samplers and tracer samplers with a straightforward calculation scheme. These sampling systems meet the minimum requirements as set forth in Section 4.3; therefore; the test data are rated A.

TABLE 32. COAL MINING EMISSION FACTORS, RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 14)

Operation	No. of Tests	Range of Conditions								Particulate Emission Factor[a]			Units	Rating Code	Rat-ing
		Mat'l Moisture Content (%)	Mat'l Silt Content (%)	Surface Silt Loading (g/m^2)	Vehicle Speed (mph)	Vehicle Weight (tons)	No. of Wheels	Wind Speed (mph)	Other	TSP	< 15 μm	< 25 μm			
Drilling	30	6.9-9.0	5.2-26.8	NA	NA	NA	NA	0.9-6.3	[b]	1.3	-	-	lb/hole	2	B
Blasting															
Coal	14	11.1-38.0	-	NA	NA	NA	NA	2.2-12.1	[c]	35.4[d]	13.2[d]	1.10[d]	lb/blast	2	D
Overburden	4	7.2-8.0	-	NA	NA	NA	NA	2.2-11.4	[e]					2	C
Coal loading	25	6.6-38.0	3.6-4.2	NA	NA	NA	NA	2.2-11.2	[f]	0.037	0.008	0.0007	lb/ton	2	C
Dozing															
Coal	12	4.0-22.0	6.0-11.3	NA	5-12	-	NA	3.4-13.4	None	46.0	20.0	1.0	lb/hr	2	C
Overburden	15	2.2-16.8	3.8-15.1	NA	2-7	-	NA	2.5-19.0	None	3.7	0.88	0.39	lb/hr	2	C
Dragline	19	0.2-16.3	4.6-14.0	NA	NA	NA	NA	2.2-16.6	[g]	0.059	0.013	0.001	lb/hr	2	C
Vehicle traffic															
Light-medium duty	10	0.9-1.7	4.9-10.1	5.9-48.2	24.8-42.9	2.0-2.6	4.0-4.1	6.5-13.0	None	2.9	1.8	0.12	lb/VMT	2	B
Haul truck	27	0.3-8.5	2.8-18.0	3.8-254	14.9-36.0	24-138	4.9-10.0	1.8-15.4	None	17.4	8.2	0.30	lb/VMT	2	B
Scrapers	15	0.9-7.8	7.2-25.2	8.0-96.8	9.9-31.7	36-70	4.0-4.1	2.5-21.0	None	13.2	6.0	0.34	lb/VMT	2	B
Grading	7	1.0-9.1	7.2-29.0	76-190	5.0-11.8	13-14	5.9-6.0	4.3-11.6	None	5.7	2.7	0.18	lb/VMT	4	C

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

[a]ISP and < 15 μm emission factors were determined by applying the mean correction correlation parameters in Table 13-9 (page 13-15 of test report) to the equation in Table 15-1 (page 15-2 of test report). The less than 2.5 μm emission factors were determined by applying the appropriate fraction found in Table 15-1 (page 15-2 of test report) to the ISP emission factors.

[b]Depth of drilling = 30 to 100 ft.

[c]No. of holes = 6 to 750; blast area - 100 to 6,800 m^2; depth of holes = 20 to 70 ft.

[d]The results of coal and overburden blasting were combined in the test report to form a single emission factor.

[e]No. of holes = 20 to 60; blast area = 2,200 to 9,600 m^2; depth of holes = 25 to 135 ft.

[f]Bucket capacity = 14 to 17 $yards^3$.

[g]Bucket capacity = 32 to 65 $yards^3$; drop distance = 5 to 100 ft.

TABLE 33. COAL MINING EMISSION FACTOR EQUATIONS AND RATINGS (Test Report 14)

Operation	Particulate Emission Factor Equation[a] TSP	< 15 μm	< 2.5 μm/TSP[b]	Units	Rating Code	Rating
Blasting (coal or overburden)	$\frac{961\ (A)^{0.8}}{(D)^{1.8}\ (M)^{1.9}}$	$\frac{2{,}550\ (A)^{0.6}}{(D)^{1.5}\ (M)^{2.3}}$	0.030	lb/blast	1	C
Coal loading	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.019	lb/ton	1	B
Dozing Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.022	lb/hr	1	B
Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.105	lb/hr	1	B
Dragline Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021\ (d)^{0.7}}{(M)^{0.3}}$	0.017	lb/yard^3	1	B
Scrapers (Travel mode)	$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.026	lb/VMT	1	A
Grading	$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.031	lb/VMT	2	B
Vehicle traffic Light-medium duty	$\frac{5.79}{(M)^{4.0}}$	$\frac{3.22}{(M)^{4.3}}$	0.040	lb/VMT	2	B
Haul trucks	$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.017	lb/VMT	1	A

Note: The range of test conditions are as stated in Table 32. Particle diameters are aerodynamic.

[a]From page 15-2, Table 15-1 of test report.

[b]Multiply this fraction by the TSP predictive equation to determine emissions in the < 2.5 μm size range.

A = area blasted (ft^2)

M = moisture content (%)

D = hole depth (ft)

s = silt content (%)

d = drop height (ft)

W = vehicle weight (tons)

S = vehicle speed (mph)

w = number of wheels

L = silt loading (g/m^2)

TABLE 34. COAL MINING SOURCE TESTING INFORMATION (Test Report 15)

Operation	Equipment	Material	Test Method[a]	Site No. (mine)	Test Dates	No. of Tests
Vehicle traffic	Haul trucks	Coal overburden	Profiling	2	Winter, spring, summer	26[b]
Dumping	-	Coal	Tracer	1, 2	Fall, winter	3
Loading	Train	Coal	Tracer	1, 2	Fall	2
Overburden replacement	-	Overburden	Uw-Dw	1, 2	Winter, spring, summer	7
Topsoil removal	(Scraper)[c]	Topsoil	Uw-Dw	1	Summer	2
Exposed Area	NA	Seeded land, stripped overburden, graded overburden	Uw-Dw	1, 2	Spring, summer	18

- = Information not contained in test report.
NA = Not applicable.
[a]Uw-Dw = Upwind-downwind.
[b]This series of tests involved a wide variety of road conditions ranging from total control (wet) to totally uncontrolled (dry). An emission factor equation was derived which takes the amount of control present into account (see Table 33, footnote a).
[c]Although scrapers are most often used in this operation the test report did not explicitly state that scrapers were being used.

The upwind-downwind sampling system consisted of 10 Hi-Vols of which two were placed upwind and eight were placed at multiple downwind and crosswind distances. Wind direction and speed were concurrently measured at an on-site station for all test periods. This sampling system meets the minimum requirements set forth in Section 4.3. However, the emission factors are rated B because these operations tested (overburden replacement, coal dumping, and top soil removal) were not described as to the equipment employed (see Table 34).

The calculated TSP emission rates were modified with a depletion factor, as follows. A deposition velocity was determined from dustfall bucket measurements:

$$V_d = 1.51 \; (x)^{-0.588} \qquad (9)$$

where:

V_d = deposition velocity

x = distance downwind of source

This velocity was combined with stability class and wind speed to derive a depletion factor in terms of distance downwind of a particulate source. The actual emission rate for an operation was then calculated through division of the apparent emission rate (measured at a particular distance downwind) by the appropriate depletion factor.

Table 35 gives the range of test conditions, emission factors, and applicable ratings for Test Report 16. The rating codes refer to Table 4. These ratings overlook the particle size incompatibility between the Hi-Vol measurements of particulate flux and the dustfall measurements of deposition velocity.

TABLE 35. COAL MINING EMISSION FACTORS, RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 15)

Operation	Number of Tests	Mat'l Moisture Content (%)	Mat'l Silt Content (%)	Vehicle Speed (mph)	Vehicle Weight (tons)	Wind Speed (mph)	Total Particulate Emission Factor	Units	Rating Code	Rating
Vehicle traffic[a]	26	Dry-wet	8.3-11.2	22-24	-	3.6-19.2	22.0	lb/VMT	4	C
Coal dumping[b]	3	-	-	NA	NA	2.9-6.0	0.066	lb/T	6	D
Train loading[c]	2	-	-	NA	NA	4.0-11.4	0.027	lb/T	7	D
Overburden replacement[d]	7	-	-	-	-	3.8-19.9	0.012	lb/T	3	C
Topsoil removal[a]	2	-	-	-	-	10.1	0.058	lb/T	8	E
Exposed areas[f]	18	-	-	NA	NA	5.4-17.4	0.38	ton/acre-year	2	C

- = Information not contained in test report.
NA = Not applicable.
[a]The emission factor equation derived for this source is from page 35 of test report. It was evaluated at zero wettings per hour.
[b]Emission factor is from page 46, Table 5.1 of test report.
[c]Emission factor is from page 47, Table 5.2 of test report.
[d]Emission factor is from page 52, Table 6.1 of test report.
[e]Emission factor is from page 52, Table 6.2 of test report.
[f]Emission factor is from page 55, Table 7.1 of test report.

8.5 <u>Western Surface Coal Mining and Processing</u>

Since no emission factors are currently presented in AP-42 for coal mining. The predictive emission factor equations presented in Table 49 are recommended for inclusion in AP-42 under a section named "Western Surface Coal Mining." Table SO presents the single-valued emission factors for western surface coal mining. It is recommended that for any source operation not covered by the equations in Table 49, the highest rated single valued factors from Table 50 be incorporated in AP-42.

All of the recommended factors may be applied to Eastern surface coal mining. However, each should then be aerated one letter value (e.g., C to D).

TABLE 49. WESTERN SURFACE COAL MINING PREDICTIVE EMISSION FACTOR EQUATIONS
(Test Reports 5 and 14)

Operation	Material	Particulate Emission Factor Equation: TSP	Particulate Emission Factor Equation: < 15 μm	Particulate Emission Factor Equation: < 2.5 μm/TSP[a]	Units	Test Report	Rating
Blasting	Coal or overburden	$\frac{961\ (A)^{0.8}}{(D)^{1.8}\ (M)^{1.9}}$	$\frac{2,550\ (A)^{0.6}}{(D)^{1.5}\ (M)^{2.3}}$	0.030	lb/blast	14	C
Truck loading	Coal	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.019	lb/ton	14	B
Dozing	Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.022	lb/hr	14	B
	Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.105	lb/hr	14	B
Dragline	Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021\ (d)^{0.7}}{(M)^{0.3}}$	0.017	lb/yard^3	14	B
Scrapers (travel mode)		$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.026	lb/VMT	14	A
Grading		$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.031	lb/VMT	14	B
Vehicle traffic (light-medium duty)		$\frac{5.79}{(M)^{4.0}}$	$\frac{3.72}{(M)^{4.3}}$	0.040	lb/VMT	14	B
Haul trucks		$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.017	lb/VMT	14	A
Storage pile (Wind erosion and maintenance)	Coal	1.6 u	-	-	$\frac{lb}{(acre)(hr)}$	5	C[b]

- = Unable to be determined from information contained in test report.

[a]Multiply this fraction by the TSP predictive equation to determine emissions in the < 2.5 μm size range.

[b]Rating applicable to Mine Types A, B, and D (see p 61).

A = area blasted (ft^2)
M = moisture content (%)
D = hole depth (ft)
s = silt content (%)
μ = wind speed (m/sec)
d = drop height (ft)
W = vehicle weight (tons)
S = vehicle speed (mph)
w = number of wheels
L = silt loading (g/m2)

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS (Test Report 4, 5, 14, and 15)

Operation	Source (Material)	Total	TSP	Emission Factor by Aerodynamic Diameter < 30 (μm)	< 15 (μm)	< 10 (μm)	< 5 (μm)	< 2.5 (μm)	Units	Test Report	Rating
Drilling											
	(Overburden) (mine type C)	-	1.3	-	-	-	-	-	lb/hole	14	B
	(Coal)										
	(mine type E)	-	0.22	-	-	-	-	-	lb/hole	5	E
Blasting	(Overburden)										
	(mine type A)	-	1,690	-	-	-	-	-	lb/blast	5	E
	(mine type C)	-	14.2	-	-	-	-	-	lb/blast	5	E
	(mine type E)	-	85.3	-	-	-	-	-	lb/blast	5	E
	(Coal)										
	(mine type C)	-	25.1	-	-	-	-	-	lb/blast	5	E
	(mine type D)	-	78.1	-	-	-	-	-	lb/blast	5	E
	(mine type E)	-	72.4	-	-	-	-	-	lb/blast	5	E
Dragline	(Overburden)										
	(mine type A)	-	0.0056	-	-	-	-	-	lb/yd^3	5	D
	(mine type B)	-	0.053	-	-	-	-	-	lb/yd^3	5	D
	(mine type C)	-	0.0030	-	-	-	-	-	lb/yd^3	5	C
	(mine type D)	-	0.021	-	-	-	-	-	lb/yd^3	5	C
Top soil removal	Scraper										
	(mine type D)	-	0.44	-	-	-	-	-	lb/T	5	D
	Unspecified equipment	-	0.058	-	-	-	-	-	lb/T	15	E
Overburden replacement	Unspecified equipment	-	0.012	-	-	-	-	-	lb/T	15	C

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS (Test Report 4, 5, 14, and 15) (cont.)

		Emission Factor by Aerodynamic Diameter									
Operation	**Source (Material)**	**Total**	**TSP**	**< 30 (μm)**	**< 15 (μm)**	**< 10 (μm)**	**< 5 (μm)**	**< 2.5 (μm)**	**Units**	**Test Report**	**Rating**
Batch-drop	Dumping via truck (Overburden-bottom)										
	(mine type E)	-	0.002	-	-	-	-	-	lb/T	5	E
	(Coal-end)										
	(mine type E)	-	0.007	-	-	-	-	-	lb/T	5	E
	(Material not specified-bottom)										
	(mine type A)	-	0.014	-	-	-	-	-	lb/T	5	D
	(mine type B)	-	0.020	-	-	-	-	-	lb/T	5	E
	(mine type C)	-	0.005	-	-	-	-	-	lb/T	5	E
	(mine type D)	-	0.027	-	-	-	-	-	lb/T	5	E
	Dumping via scraper (top soil)										
	(mine type D)	-	0.04	-	-	-	-	-	lb/T	5	C
	Dumping via unspecified equipment or process										
	(Coal)	-	0.066	-	-	-	-	-	lb/T	15	D
	(Fly-ash)										
	(mine type A)	-	3.9	-	-	-	-	-	lb/hr	5	E
	Front-end loader/truck (Material unspecified)										
	(mine type D)	-	0.12	-	-	-	-	-	lb/T	5	E
	Power shovel/truck (Overburden)										
	(mine type E)	-	0.037	-	-	-	-	-	lb/T	5	C

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS (Test Report 4, 5, 14, and 15) (cont.)

		Emission Factor by Aerodynamic Diameter									
Operation	Source (Material)	Total	TSP	< 30 (μm)	< 15 (μm)	< 10 (μm)	< 5 (μm)	< 2.5 (μm)	Units	Test Report	Rating
	(Coal)										
	(mine type	-	0.014	-	-	-	-	-	lb/T	5	D
	A)	-	0.007	-	-	-	-	-	lb/T	5	D
	(mine type B)	-	0.002	-	-	-	-	-	lb/T	5	D
	(mine type C) (mine type E)	-	0.0035	-	-	-	-	-	lb/T	5	D
	Loading train via	-	0.027	-	-	-	-	-	lb/T	15	D
	unspecified equipment and process (Coal) (mine type C)	-	0.0002	-	-	-	-	-	lb/T	5	D
Storage pile	Wind erosion (Coal)	-	0.013	-	-	-	-	-	lb/T/yr	4	D
Vehicle traffic on unpaved road	Haul truck (unspecified size)	-	17.0	-	-	-	-	-	lb/VMT	5	C
	(mine type B)	-	22.0	-	-	-	-	-	lb/VMT	15	C
Wind erosion	Exposed areas	-	0.38	-	-	-	-	-	$\frac{T}{(acre)(yr)}$	15	C

- = Unable to be determined from information contained in test report.
= Not recommended for inclusion into AP-42.

G.2 Section 7 of EPA report "Improved Emission Factors for Fugitive Dust From Western Surface Coal Mining Sources--Volume I - Sampling Methodology and Test Results"

SECTION 7
RESULTS FOR SOURCES TESTED BY EXPOSURE PROFILING

SUMMARY OF TESTS PERFORMED

As previously discussed, exposure profiling was used to test particulate emissions from haul trucks, light-duty and medium-duty vehicles, scrapers (travel mode) and graders. These sources were tested at three mines during the period July 1979 through August 1980.

A total of 63 successful exposure profiling tests were conducted at the three mines/four visits. They were distributed by source and by mine as follows:

		Number of Tests			
Source	**Controlled/ Uncontrolled**	**Mine 1**	**Mine 2**	**Mine 1W**	**Mine 3**
Haul trucks	U	6	6	3	4
	C	0	4	0	5
Light- and med.- duty vehicles	U	3	4	0	3
	C	2	0	0	0
Scrapers	U	5	6	2	2
Graders	U	0	5	0	2

Light and variable wind conditions were encountered at Mine 1 during the test period July-August 1979, with winds occasionally reversing and traffic-generated emissions impacting on the upwind sampling station. These events were termed “bad passes.”

Table 7-1 lists the site conditions for the exposure profiling tests of dust emissions generated by haul trucks. The comparability tests are indicated by an asterisk after the run number. In addition to the testing of uncontrolled sources, watering of haul roads was tested as a control measure.

Table 7-2 gives the road and traffic characteristics for the exposure profiling tests of haul trucks. This source category exhibited a wide range of road and traffic characteristics, indicating a good potential for identifying and quantifying correction parameters. Most tests involved a blend of vehicle types dominated by haul trucks. Silt and moisture values were determined by laboratory analysis of road surface aggregate samples obtained from the test roads. Mean vehicle speeds and weights are arithmetic averages for the mixes of vehicles which passed over the test roads during exposure profiling.

Table 7-3 lists the site conditions for the exposure profiling tests of dust emissions generated by light- and medium-duty vehicles. In addition to the testing of uncontrolled roads, the application of calcium chloride to an access road was tested as a control measure.

Table 7-4 gives the road and traffic conditions for the exposure profiling tests of light- and medium-duty vehicles. Small variations in mean vehicle weight and mean number of vehicle wheels were observed for this source category. No access roads were available at Mine 2, so light-duty vehicles were tested at a haul road site.

Table 7-5 lists the site conditions for the exposure profiling tests of dust emissions generated by scrapers (travel mode). Table 7-6 gives the road and traffic conditions for the exposure profiling tests of scrapers. All scrapers tested were four-wheeled vehicles, which excluded this parameter from consideration as a correction factor.

Table 7-7 lists the site conditions for the exposure profiling tests of dust emissions generated by graders. Table 7-8 gives the road and traffic conditions for the exposure profiling tests of graders. All graders tested were six-wheeled vehicles and weighed 14 tons. Therefore, mean vehicle weight and mean number of vehicle wheels were excluded from consideration as correction factors.

TABLE 7-1. EXPOSURE PROFILING SITE CONDITIONS - HAUL TRUCKS

	Profiler						Meteorology	
					Vehicle Passes			
Mine/Site[a]	Run[b]	Date	Start Time	Sampling Duration (min)	Good	Bad	Temp (°C)	Wind Speed[c] (m/s)
Mine 1/Site 2	J-6	7/30/79	16:06	67	2	37	24.5	0.9
	J-9*	8/01/79	10:21	51	41	0	28.3	4.8
	J-10*	8/01/79	14:08	52	43	2	31.0	4.4
	J-11[d]	8/01/79	17:39	48	40	0	30.5	4.2
	J-12*	8/02/79	10:50	49	18	1	26.7	0.8
	J-20*	8/09/79	14:10	49	23	0	23.0	2.5
	J-21*	8/09/79	16:51	26	13	1	25.0	1.6
Mine 2/Site 1	K-1	10/11/79	10:21	86	65	0	14.6	6.2
Mine 2/Site 3 (Watered)	K-6	10/15/79	11:03	177	84	0	17.8	3.4
Mine 2/Site 3	K-7	10/15/79	14:50	53	57	0	23.5	2.6
Mine 2/Site 3 (Watered)	K-8	10/16/79	11:02	105	43	0	10.3	5.7
Mine 2/Site 3	K-9	10/16/79	13:18	89	63	0	12.0	5.0
	K-10	10/17/79	10:37	65	40	0	10.6	5.0
	K-11	10/17/79	12:05	64	50	0	12.5	5.2
	K-12	10/17/79	13:38	58	43	0	15.5	5.4
Mine 2/Site 3 (Watered)	K-13	10/23/79	10:47	73	78	0	4.0	3.7
Mine 1/Site 5	L-1	12/07/79	14:04	92	57	0	0.7	1.9
Mine 1/Site 6	L-2	12/08/79	13:12	4[e]	23[f]	0	12.2	6.9
	L-3	12/08/79	13:45	48	26	0	13.2	6.5
	L-4	12/08/79	15:04	47	32	0	13.6	6.1
Mine 3/Site 1	P-1	7/25/80	16:28	57	15	0	35	3.8
Mine 3/Site 2	P-2	7/26/80	10:25	95	10	2	27	1.8
	P-3	7/27/80	9:10	89	18	0	27	3.8
Mine 3/Site 2 (Watered)	P-4	7/28/80	8:41	135	48	0	27	3.7
Mine 3/Site 2	P-5	7/29/80	7:32	108	38	0	32	2.8

TABLE 7-1. (CONTINUED)

Mine 3/Site 2 (Watered)	P-6	7/30/80	7:12	112	48	0	29	2.2
	P-7	7/31/80	7:27	95	35	0	29	2.5
	P-8	7/31/80	9:22	103	49	0	29	3.0
	P-9	8/01/80	7:51	142	48	0	27	3.7

[a] Mine 1/Site 2 - Mine B tipple road (haul road to crusher).
Mine 2/Site 1 - 250m west of haul truck unloading station.
Mine 2/Site 3 - 1 mile west of haul truck unloading station.
Mine 1/Site 5 - About 100m east of haul road sites for summer testing.
Mine 1/Site 6 - About 250m northeast of haul road sites for summer testing.
Mine 2/Site 1 - Near Ramp 5 east of lake.
Mine 2/Site 2 - Between Ramps 2 and 3.
[b]Asterisk indicates comparability test.
[c]Value at 3m above the ground, interpolated from 1.5 and 4.5m warm wire anemometer data using a logarithmic profile.
[d]MRI comparative equipment run; PEDCO did not test.
[e]Represents total time that the profiler ran properly; there was a prior period for which isokinetic flows could not be obtained.
[f]Represents the total number of passes during the attempted run (while the equipment, other than the profiler, was operating).

TABLE 7-2. ROAD AND TRAFFIC CHARACTERISTICS - HAUL TRUCKS

	Road Surface Properties						
Run	Loading (g/m^2)	Silt (%)	Moist. (%)	Vehicle Mix	Mean Vehicle Speed (km/h)	Mean Vehicle Weight (tons)	Mean No. of Vehicle Wheels
J-6		7.9[a]	5.4[a]	----------	--	--	--
J-9*	40	9.4	3.4	About 2/3 haul trucks; rest light duty trucks	31	65	8.0
J-10*	130	9.4	2.2	About 2/3 haul trucks; rest light duty trucks	31	60	7.7
J-11	82	8.2	4.2	Mostly unloaded haul trucks	32	60	9.9
J-12*	235	14.2	6.8	Mostly haul trucks	24	99	9.5
J-20*	330	11.6	8.5	Mostly loaded haul trucks	27	125	10.0
J-21*	330	b	b	Mostly haul trucks	24	110	9.3
K-1	780	7.7	2.2	Combination of heavy and light duty trucks	53	63	6.1
K-6	354	2.2	7.9	Combination haul trucks and light duty trucks	56	89	7.4
K-7	361	2.8	0.9	Mostly light duty trucks	55	24	4.9
K-8	329	3.1	1.7	Combination haul trucks and light duty trucks	58	65	6.3
K-9	470	4.7	1.5	Combination haul trucks and light duty trucks	47	74	6.7
K-10	290	7.7	2.0	Combination haul trucks and light duty trucks	58	69	6.6
K-11	290	8.9	2.0	Combination haul trucks and light duty trucks	48	73	6.5
K-12	290	11.8	2.3	Combination haul trucks and light duty trucks	58	95	7.3
K-13	67	1.8	2.7	Combination haul trucks and light duty trucks	51	64	6.6
K-26	67	[b]	[b]	Combination haul trucks and light duty trucks	51	84	6.8
L-1	450	13.0	7.7	Mostly haul trucks	42	95	8.8
L-2	104	b	b	Mostly haul trucks	39	96	9.8
L-3	550	13.8	4.9	Mostly haul trucks	32	107	9.3
L-4	1410	18.0	5.1	Mostly haul trucks	32	86	8.3
P-1	489	4.7	0.4	Mostly haul trucks	43	79	8.5
P-2	489	4.7	0.4	About ½ haul trucks; rest light/ medium vehicles	42	42	7.2
P-3	580	4.1	0.3	Haul trucks	50	94	9.7

TABLE 7-2. (CONTINUED)

	Road Surface Properties						
Run	Loading (g/m^2)	Silt (%)	Moist. (%)	Vehicle Mix	Mean Vehicle Speed (km/h)	Mean Vehicle Weight (tons)	Mean No. of Vehicle Wheels
P-4	200	2.0	0.3	About ½ haul trucks; rest light/ medium vehicles	51	55	7.6
P-5	131	3.1	c	About ½ haul trucks; rest light/ medium vehicles	50	47	7.1
P-6	489	2.8	2.9	Mostly light/medium vehicles	51	25	5.6
P-7	458	2.4	1.5	About ½ haul trucks; rest light/ medium vehicles	50	61	7.6
P-8	680	7.7	15.3	About ½ haul trucks; rest light/ medium vehicles	47	47	7.5
P-9	438	1.6	20.1	About ½ haul trucks; rest light/ medium vehicles	50	58	8.7

[a]Average of more than one sample.
[b]No sample taken.
[c]Moisture below detectable limits.

TABLE 7-5. EXPOSURE PROFILING SITE CONDITIONS - SCRAPERS

	Profiler				Vehicle Passes		Meteorology	
Mine/Site[a]	Run[b]	Date	Start Time	Sampling Duration (min)	Good	Bad	Temp (°C)	Wind Speed[c] (m/s)
Mine 1/Site 1	J-1*	7/26/79	16:49	87	63[d]		23.3	2.8
	J-2*	7/27/79	13:45	34	18	15[e]	25.0	1.4
	J-3*	7/27/79	16:38	51	35		29.4	1.3
	J-4*	7/28/79	11:22	52	25	5	20.0	1.1
	J-5*	7/28/79	14:24	60	12	2	29.5	1.4
Mine 2/Site 4	K-15	10/25/79	11:54	13	6	0	5.0	3.9
	K-16	10/26/79	11:07	41	10	0	8.8	2.6
	K-17	10/26/79	15:22	18	31	0	12.0	4.0
	K-18	10/26/79	15:59	37	30	0	13.1	2.6
	K-22	10/29/79	9:08	110	20	0	5.0	3.0
	K-23	10/29/79	13:23	43	20	0	6.1	4.6
Mine 1/Site 7	L-5	12/12/79	10:40	14	20	0	3.5	8.6
	L-6	12/12/79	11:22	22	15	0	4.2	9.4
Mine 3/Site 4	P-14	8/06/80	Aborted test					
	P-15	8/08/80	14:02	43	4	1	32	1.6
	P-18	8/10/80	16:18	33	18	0	27	3.9

[a]Mine 1/Site 1 - Temporary scraper road at reclamation site.
Mine 2/Site 4 - 250 m north of north pit area.
Mine 1/Site 7 - About 1 mile northeast of haul road sites for summer testing.
Mine 3/Site 4 - 100 m south of pit.
[b]Asterisk indicates comparability test.
[c]Value at 3 m above the ground, interpolated from 1.5 and 4.5 m warm wire anemometer data using a logarithmic profile.
[d]Represents total passes; pass quality was not recorded.
[e]Combination of marginal and bad passes.

TABLE 7-6. ROAD AND TRAFFIC CHARACTERISTICS - SCRAPERS

	Road Surface Properties						
Run	Loading (g/m^2)	Silt (%)	Moist. (%)	Vehicle Mix	Mean Vehicle Speed (km/h)	Mean Vehicle Weight (tons)	Mean No. of Vehicle Wheels
J-1*	121	8.9[a]	5.7[a]	Mostly scrapers	31	50	4.1
J-2*	313	23.4[a]	2.3[a]	Mostly scrapers	31	53	4.0
J-3*	310	15.8	4.1	Mostly scrapers	39	54	4.1
J-4*	55	14.6[a]	1.5[a]	Unloaded scrapers	32	36	4.0
J-5*	310	10.6[a]	0.9[a]	Loaded scrapers	29	70	4.0
K-15	[b]	[b]	[b]	Mostly unloaded scrapers[c]	45	46	4.0
K-16	384	25.2[d]	6.0	All scrapers	48	64	4.0
K-17	384	25.2[d]	6.0	Mostly scrapers	37	57	4.1
K-18	384	25.2[d]	6.0	All scrapers	40	66	4.0
K-22	301	21.6	5.4	All unloaded scrapers	51	45	4.0
K-23	318	24.6	7.8	All scrapers	45	54	4.0
L-5	238	21.0	[e]	All scrapers	34	53	4.0
L-6	238	21.0	[e]	All scrapers	32	50	4.0
P-15	[f]	7.2	1.0	Mostly scrapers	26	42	4.0
P-18	[f]	7.2	1.0	Scrapers	16	64	4.0

[a]Average of more than one sample.
[b]No sample taken.
[c]Test stopped prematurely; scraper drivers quit for lunch.
[d]Average silt of Runs K-19 to K-23.
eUnrepresentative sample taken after grader pass; sample not analyzed.
[f]Sample not analyzed for loading.

TABLE 7-7. EXPOSURE PROFILING SITE CONDITIONS - GRADERS

	Profiler						Meteorology	
					Vehicle Passes			
Mine/Site[a]	Run[b]	Date	Start Time	Sampling Duration (min)	Good	Bad	Temp (°C)	Wind Speed[c] (m/s)
Mine 2/Site 4	K-19	10/27/79	10:24	57	40	0	10.2	5.2
	K-20	10/27/79	11:46	59	40	0	13.4	4.5
	K-21	10/27/79	13:34	49	40	0	17.4	4.3
Mine 2/Site 5	K-24	10/30/79	10:16	35	30	0	6.5	4.4
	K-25	10/30/79	11:16	39	30	0	7.8	4.6
Mine 3/Site 4		8/10/80	17:45	129	9	0	27	3.5
	P-17	8/10/80	13:28	67	15	0	27	1.9

[a]Mine 2/Site 4 - 250 m north of north pit area.
Mine 2/Site 5 - 250 m northwest of haul truck unloading station.
Mine 3/Site 4 - 100 m south of pit.
[b]Value at 3 m above the ground, interpolated from 1.5 and 4.5 m warm wire anemometer data using a logarithmic profile.

TABLE 7-8. ROAD AND TRAFFIC CHARACTERISTICS - GRADERS

	Road Surface Properties						
Run	**Loading (g/m^2)**	**Silt (%)**	**Moist. (%)**	**Vehicle Mix**	**Mean Vehicle Speed (km/h)**	**Mean Vehicle Weight (tons)**	**Mean No. of Vehicle Wheels**
K-19	328	23.1	9.1	All graders	8	14	6.0
K-20	535	29.0	8.8	All graders	10	14	6.0
K-21	495	27.8	7.2	All graders	10	14	6.0
K-24	597	17.6	4.0	Mostly graders	10	13	5.9
K-25	776	24.5	5.4	All graders	10	14	6.0
P-16	[a]	7.2	1.0	Graders	19	14	6.0
P-17	[a]	7.2	1.0	Graders	16	14	6.0

[a]Sample not analyzed for loading.

RESULTS

The measured emission rates are shown in Tables 7-9 through 7-12 for haul trucks, light- and medium-duty vehicles, scrapers, and graders, respectively. In each case, emission rates are given for TP, SP, IP, and FP.

For certain runs, emission rates could not be calculated. For haul truck run L-2, the profiler samples did not maintain a consistent flow rate. Haul truck run J-6 was not analyzed because of the predominance of bad passes. The emissions from run J-7, the access road treated with calcium chloride, were too low to be measured. Scraper run P-15 produced only a TP emission factor; questionable results from a single dichotomous sampler prevented calculation of reliable emission rates for SP, IP, and FP.

The means, standard deviations, and ranges of SP emission rates for each source category are shown below:

Source	No. Tests	SP Emission Rate (lbs/VMT)		
		Mean	**Std. Dev.**	**Range**
Haul trucks				
Uncontrolled	19	18.8	20.2	0.71-67.2
Controlled	9	4.88	3.44	0.60-8.4
Light- and medium-duty vehicles				
Uncontrolled	10	4.16	3.73	0.64-9.0
Controlled	2	0.35[a]	[a]	[a]
Scrapers				
Uncontrolled	14	57.8	95.3	3.9-355
Graders				
Uncontrolled	7	9.03	11.2	1.8-34.0

[a] On one of two tests, the emissions were below detectable limits.

As expected, the SP emission rates for controlled road sources were substantially lower than for uncontrolled sources. The mean emission rate for watered haul roads was 26 percent of the mean for uncontrolled haul roads. For light- and medium-duty vehicles, the mean emission rate for roads treated with calcium chloride was 8 percent of the mean for uncontrolled roads.

TABLE 7-10. TEST RESULTS FOR LIGHT- AND MEDIUM-DUTY VEHICLES

	Particulate Emissions Rates			
Run	**TP, lb/VMT**	**SP, lb/VMT**	**IP, lb/VMT**	**FP, lb/VMT**
J-7	[a]	[a]	[a]	[a]
J-8	0.55	0.35[a]	0.34[b]	0.09[b]
J-13	7.0	5.5[b]	4.5[b]	0.50[b]
J-18	9.5	8.2[b]	6.6[b]	1.5[b]
J-19	7.1	6.7[b]	5.2[b]	0.22[b]
K-2	5.0	0.64	0.33	0.03
K-3	3.1	0.76	0.39	0.03
K-4	3.0	0.60	0.34	0.04
K-5	2.7	0.93	0.52	0.05
P-11	12.8	8.5	4.5	0.10
P-12	12.8	9.0	5.1	0.13
P-13	9.7	7.8	4.1	0.15

[a]Emissions too low to be measured.
[b]ERC dichotomous samplers.

TABLE 7-11. TEST RESULTS FOR SCRAPERS

	Particulate Emission Rates			
Run[a]	TP, lb/VMT	SP, lb/VMT	IP, lb/VMT	FP, lb/VMT
J-1*	41.4	8.6	4.2	0.27
J-2*	66.5	9.4	4.0	0.19
J-3*	125	50.2	26.1	1.5
J-4*	27.5	3.9	1.7	0.09
J-5*	96.7	17.7	10.0	1.4
K-15	126	16.2	7.2	0.39
K-16	206	29.2	15.6	1.8
K-17	232	74.3	35.6	1.6
K-18	179	43.0	19.3	0.81
K-22	58.4	10.3	4.8	0.29
K-23	118	24.5	11.1	0.54
L-5	360[b]	355[b]	217[b]	0.72[b]
L-6	184	163	94.0	1.0
P-15	383	[c]	[c]	[c]
P-18	18.8[d]	4.0[d]	1.4[d]	0.02[d]

[a]Asterisk indicates comparability test.
[b]Profiler samplers malfunctioned.
[c]Only one dichotomous sampler and only four good passes.
[d]Only two profilers operational.

TABLE 7-12. TEST RESULTS FOR GRADERS

	Particulate Emission Rates			
Run	**TP, lb/VMT**	**SP, lb/VMT**	**IP, lb/VMT**	**FP, lb/VMT**
K-19	31.3	4.0	2.3	0.33
K-20	29.0	4.3	1.7	0.46
K-21	22.5	1.8	0.89	0.08
K-24	13.1	3.2	1.9	0.29
K-25	19.5	7.3	4.1	0.38
P-16	53.2	34.0	15.4	0.09
P-17	73.9	8.6	2.9	0.04

The average ratios of IF and FP to SP emission rates are:

Source	Average Ratio of IP to SP Emission Rates	Average Ratio of FP to SP Emission Rates
Haul trucks	0.50	0.033
Light- and medium-duty vehicles	0.63	0.112
Scrapers	0.49	0.026
Graders	0.48	0.055

As indicated, SP emissions from light- and medium-duty vehicles contained a much larger proportion of small particles than did the other source categories.

The measured dustfall rates are shown in Tables 7-13 through 7-16 for haul trucks, light- and medium-duty vehicles, scrapers, and graders, respectively.

Flux data from collocated samplers are given for the upwind sampling location and for three downwind distances. The downwind dustfall fluxes decay sharply with distance from the source.

PROBLEMS ENCOUNTERED

Adverse meteorology created the most frequent difficulties in sampling emissions from unpaved roads. Isokinetic sampling cannot be achieved with the existing profilers when wind speeds are less than 4 mph. Problems of light winds occurred mostly during the summer testing at Mine 1. In addition, wind direction shifts resulted in source plume impacts on the upwind samplers on several occasions. These events, termed "bad passes," were confined for the most part to summer testing at Mine 1.

Bad passes were not counted in determining source impact on downwind samplers. Measured upwind particulate concentrations were adjusted to mean observed upwind concentrations for adjoining sampling periods at the same site when no bad passes occurred.

Another problem encountered was mining equipment breakdown or reassignment. On several occasions sampling equipment had been deployed but testing could not be conducted because the mining vehicle activity scheduled for the test road did not occur.

TABLE 7-13. DUSTFALL RATES FOR TESTS OF HAUL TRUCK

		Flux (mg/m²-min.)		
		Downwind		
Run	Upwind	5m	20 m	50 m
J-6	16	[a]	6.1	[a]
	17	[a]	[d]	[a]
J-9	4.0	131	29	13
	3.9	91	36	6.7
J-10	7.5	126	54	5.2
	5.9	126	45	8.9
J-11	3.3	274	75	16
	1.9	285	56	27
J-12	0.9	19	8.2	1.4
	6.4	14	9.2	3.4
J-20	0.8	31	8.1	10.0
	1.2	33	9.1	7.9
J-21	7.1	19	17	2.0
	19	22	7.6	30
K-1	2.5	34[b]	16	8.0
	3.5	25[b]	51	17
K-6	0.7	12	3.0	2.9
	0.6	12	3.0	4.1
K-7	0.6	12	11	7.2
	0.5	16	12	8.0
K-8	1.6	7.1	8.1	3.7
	5.3	14	1.1	3.1
K-9	2.0	21	6.1	5.2
	6.6	16	7.0	6.2
K-10	0. 7[c]	25	25	8.1
	0.8[c]	34	18	8.1
K-11	0.7[c]	33	26	8.2
	0.8[c]	42	18	8.1

TABLE 7-15. DUSTFALL RATES FOR TESTS OF SCRAPERS

		Flux (mg/m^2-min.)		
		Downwind		
Run	Upwind	5m	20 m	50 m
J-1	4.8	33	8.5	[a]
	3.4	32	8.2	[a]
J-2	51	26	13	[b]
	54	34	1.3	[b]
J-3	27	39	b	7.9
	7.1	39	2.7	b
J-4	5.8	14	6.4	1.3
	6.0	12	6.3	6.5
J-5	2.0	16	3.0	2.0
	2.9	12	3.3	1.3
K-15	3.6	84	69	34
	3.9	180	24	360[c]
K-16	11	44	16	52
	9.2	46	13	52
K-17	4.2	3100	370	40
	3.5	2800	490	40
K-18	4.1	860	171	25
	3.5	760	140	25
K-22	0.9	39	21	11
	1.3	34	30	7.3
K-23	0.9	99	53	26
	1.3	87	74	19
L-5	8.1	200	33	6.2
L-6	8.2	100	69	40
P-15	[a]	[a]	[a]	[a]
P-18	[a]	[a]	[a]	[a]

[a]Sample not taken.
[b]Negative net weight when blank was included.
[c]Sample included nondust material.

TABLE 7-16. DUSTFALL RATES FOR TESTS OF GRADERS

		Flux (mg/m^2-min.)		
		Downwind		
Run	Upwind	5m	20 m	50 m
K-19	2.5	46	52	28
	2.6	75	36	18
K-20	2.6	20	53	28
	2.7	25	37	19
K-21	2.6	65	62	34
	2.7	56	43	22
K-24	2.7	64	49	23
	4.5	48	40	16
K-25	2.8	61	46	22
	4.7	46	39	15
P-16	[a]	22	2.9	0.2
	[a]	22	9.8	6.6
P-17	[a]	21	6.1	6.6
	[a]	27	10	9.9

[a]Sample not taken

Appendix H

Materials Related to Active Storage Pile Emission Factor

This appendix contains information related to emission factors for active storage piles. The information is from Sections 5.5 and 8.5 of EPA report "Fugitive Dust Emission Factor Update for AP42" and Section 10 of EPA report "Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources - Volume I - Sampling Methodology and Test Results."

TABLE OF CONTENTS

H.1 Section 5.5 of EPA report "Fugitive Dust Emission Factor Update for AP-42"

5.5 Section 8.24 - Western Surface Coal Mining and Processing

5.5.1 Test Report 4 (1977)

This study developed an emission factor for coal storage only. Four tests at one coal storage pile (location not given) were conducted using the upwind-downwind technique. Table 23 presents the source testing information for this study.

High-volume samplers were used to collect the airborne particulates from one upwind and four downwind positions. The wind parameters were recorded at 15-min intervals. A sampling array similar to that described in Section 5.3.2 (Test Report 6) was employed in this study. This sampling system meets the minimum requirements of the upwind-downwind sampling technique. Optical microscopy was employed to determine a particle size distribution. However, the particle size distribution for the emission factor was determined from particle counting only (not mass fraction), which is unrepresentative of a mass size distribution.

This methodology is of generally sound quality; and emission rates were determined in a similar manner to that described in Section 5.3.2 (Test Report 6). However, the report lacks sufficient detail for adequate validation. For example, no indication is given as to sampling height. Also the field data recorded at the sampling stations are not presented. The test data are therefore rated B

Table 24 presents the developed emission factor, conditions tested and the appropriate rating. Only one pile was sampled, although it was two different sizes during testing. The rating code refers to Table 4.

5.5.2 Test Report 5 (1978)

This study was directed to the development of emission factors for the surface coal mining industry. Testing was conducted at five Western coal mines (Mines A through E). Table 25 presents the distribution of tests performed.

The upwind-downwind method was used with standard high-volume samplers for particulate collection. Wind parameters were continuously measured at a fixed location within each mine. A hand-held wind speed indicator was used when possible to record data at the exact test site. Optical microscopy was employed to determine particle size distribution.

The upwind-downwind sampler deployment used in this study generally employed six samplers for each test; additionally, six more samplers were operated at a second height in half the tests to determine a vertical plume gradient. Two instruments were located upwind of a source to measure background concentrations while four instruments were located downwind. These downwind samplers were deployed along a straight line (the assumed plume centerline) at four different distances.

The determination of emission rates involved back calculation using dispersion equations after subtaction of the background from the downwind concentration. The following dispersion equation was used to calculate emission rates for area sources.

$$C = \frac{Q}{\pi \sigma_y \sigma_z u} \quad (6)$$

where C = concentration

Q = emission rate

σ_y, σ_z = horizontal and vertical dispersion coefficients

u = wind speed

Line source emission rates were determined by use of this dispersion equation:

$$C = \frac{2\ Q}{\sin\ \phi\ \sqrt{2\pi}\ \sigma_z\ u} \quad (7)$$

where C = concentration

Q = emission rate

ϕ = angle between line source and wind direction

σ_z = vertical dispersion coefficient

u = wind speed

The predictive emission factor equation for wind erosion of active storage piles was developed by plotting the emission rates against the wind speeds recorded during testing. The resulting linear function was described by the equation:

$$e = 15.83\ u \quad (8)$$

where e = emission rate (lb/hr)

u = wind speed (m/sec)

This equation was then converted to one with units of lb/(acre) (hr) by assuming storage pile surface areas of 10 acres.

This upwind-downwind sampling system does not meet the minimum requirements for point sources as set forth in Section 4.3 since particulate concentrations at only one crosswind distance were observed. Also details on the operations tested are frequently sketchy. Therefore, with three exceptions the test data are rated B. The test data for haul roads are rated A, because sampling at multiple crosswind distances is not required when testing line sources. The test data for storage pile wind erosion (and maintenance) are rated C because of: (a) the very light winds encountered; (b) the large size of the piles; and (c) the lack of information on pile maintenance activities. The test data for blasting are rated C because of the difficulty of quantifying the plume with ground based samplers.

The report indicates that emission factor variation between mines for the same operation is relatively high; therefore, it was recommended (in the report) that the factors be mine (type) specific. The following list describes the location of the five mines. The report gives a more in-depth description of each mine including production rate, stratigraphic data, coal analysis data, surface deposition, storage capacity, and blasting data.

Mine	Area
A	Northwest Colorado
B	Southwest Wyoming
C	Southeast Montana
D	Central North Dakota
E	Northeast Wyoming

Tables 26 through 30 present the average emission factors determined at each mine along with the ranges of conditions tested and the associated emission factor ratings. The text indicates that the emission factors should be used with a fallout function for distances closer than 5 km; however, the text does not explicitly state what particulate size range is represented by the emission factors.

The rating codes in Tables 26 through 30 refer to Table 5 (wind erosion) and Table 4 (all other sources). Because the single-valued factors were intended to apply only to the specific mine types, the requirement for more than one test site was waived. The rating for the equation developed for storage pile wind erosion (and maintenance) is applicable when the equation is applied to mine types A, B. or D.

5.5.3 Test Report 14 (1981)

This study was conducted to determine improved fugitive dust emission factors for Western surface coal mines. Field testing was conducted in three coal fields; Powder River Basin (Mine 1), North Dakota (Mine 2), and Four Corners (Mine 3). The testing was performed during 1979 and 1980. Table 31 lists the testing information for this study.

The primary sampling method was exposure profiling. When source configuration made it necessary, alternate methods were used, including upwinddownwind, balloon, and quasi-stack sampling. Particle size distributions were determined by use of dichotomous samplers. Other equipment utilized were: (a) high volume samplers for determining upwind concentrations; (b) dustfall buckets for determining downwind particulate deposition; and (c) recording wind instruments to determine mean wind speed and direction for adjusting the exposure profiler to isokinetic sampling conditions and for use in upwind-downwind calculations.

Exposure profiling was used to measure emissions from moving point sources (see Table 31). The exposure profiling sampling system was similar to that described in Section 5.1.1 and therefore meets the minimum system design requirements. The upwind-downwind sampling system consisted generally of 15 particulate collection devices; 5 dichotomous samplers and 10 Hi-vols.

One Hi-Vol and one dichotomous sampler were placed upwind while the remaining instruments were placed at multiple downwind and crosswind distances. This system also meets the minimum upwind-downwind requirements as described in Section 4.3.

The test data were collected using a well documented sound methodology and, therefore, are rated A for line sources and for drilling. The test data for coal loading, dozing, and dragline operations are rated B because of the poorly defined plume characteristics and the interference of the pit areas with plume dispersion. For blasting the test data are rated C because of the difficulty of quantifying the large plume with a single line of samplers.

Table 32 presents the average emission factors, range of test conditions, and ratings assigned for Test Report 14. These single-valued factors were determined by substituting geometric means of the test conditions into a set of predictive emission factor equations also developed in the study. The equations are listed in Table 33. The rating codes in Table 32 refer to Table 4, and the codes in Table 33 refer to Table 5.

5.5.4 Test Report 15 (1981)

A portion of this study was devoted to the development of surface coal mining emission factors. Field testing was performed from August 1978 through the summer of 1979 at two surface coal mines located in the Powder River Basin of Wyoming. Table 34 presents the source testing information for this study.

The test methods employed to develop emission factors were: upwinddownwind, profiling, and a tracer technique. Particle sizing was performed by optical microscopy of exposed Millipore filters.

The profiling technique employed in this study was actually a variation of the exposure profiling procedure described in Section 5.1.1 (Test Report 7). High volume samplers were used instead of directional isokinetic intakes; therefore, the emission rates determined by profiling were for TSP (total suspended particulate).

The tracer technique utilized arrays or both high-volume samplers and t lacer samplers with a straightforward calculation scheme. These sampling systems meet the minimum requirements as set forth in Section 4.3; therefore; the test data are rated A.

The upwind-downwind sampling system consisted of 10 Hi-Vols of which two were placed upwind and eight were placed at multiple downwind and crosswind distances. Wind direction and speed were concurrently measured at an on-site station for all test periods. This sampling system meets the minimum requirements set forth in Section 4.3. However, the emission factors are rated B because these operations tested (overburden replacement, coal dumping, and top soil removal) were not described as to the equipment employed (see Table 34).

The calculated TSP emission rates were modified with a depletion factor, as follows. A deposition velocity was determined from dustfall bucket measurements:

$$V_d = 1.51 \ (x)^{-0.588} \tag{9}$$

where V_d = deposition velocity
x = distance downwind of source

This velocity was combined with stability class and wind speed to derive a depletion factor in terms of distance downwind of a particulate source. The actual emission rate for an operation was then calculated through division of the apparent emission rate (measured at a particular distance downwind) by the appropriate depletion factor.

Table 35 gives the range of test conditions, emission factors, and applicable ratings for Test Report 16. The rating codes refer to Table 4. These ratings overlook the particle size incompatibility between the Hi-Vol measurements of particulate flux and the dustfall measurements of deposition velocity.

TABLE 23. COAL STORAGE SOURCE TESTING INFORMATION (Test Report 4)

Operation	Equipment	Material	Site	Test Date	No. of Tests
Wind erosion	Storage pile	Coal	Plant 1	3/74 8/74	2

TABLE 24. COAL STORAGE EMISSION FACTOR, RANGE OF TEST CONDITIONS, AND RATING (Test Report 4)

		Range of Conditions				
Operation	No. of Tests	Wind Speed (m/s)	Moisture Content (%)	Emission Factor[a,b]	Rating Code	Rating
Wind erosion of coal storage pile	4	1.5-2.7	2.2-11	0.013 lb/T/yr	5	D

[a]For particles < 10, μm (physical diameter).
[b]Emission factor is arithmetic mean of test runs C1, C2, CS-3 and CS-S from page 30, Table A1 of test report.

TABLE 25. COAL MINING SOURCE TESTING INFORMATION
(Test Report 5)

			No. of Tests at Mine					
Operation	**Equipment**	**Material**	**A**	**B**	**C**	**D**	**E**	**Test Date**
Overburden removal	Dragline	Overburden	6	10	6	6	0	-
Vehicle traffic	Haul truck[b]	Unpaved road	0	4	0	[c]	[c]	-
Loading	Shovel/truck	Coal	6	4	4	0	4	-
		Overburden	0	0	0	0	6	-
Blasting	NA	Overburden	1	0	2	0	2	-
		Coal	0	0	2	2	2	-
Dumping[a]	Truck	-	6	2	2	4	0	-
		Overburden	0	0	0	0	4	-
		Coal	0	0	0	0	2	-
Storage pile wind erosion[d]	-	Coal	6	6	0	4	0	-
Drilling	NA	Overburden	0	0	2	0	0	-
		Coal	0	0	0	0	2	-
Dumping[a]	-	Fly ash	2	0	0	0	0	-
Loading[a]	Train	Coal	0	0	4	0	0	-
Topsoil removal	Scraper	Topsoil	0	0	0	5	0	-
Topsoil dumping	Scraper	Topsoil	0	0	0	5	0	-
-[a]	Front-end loader	-	0	0	0	1	0	-

- = Information not contained in test report.
NA = Not applicable.
[a]Details as to specific operation sampled for are not stated in text.
[b]Size not given.
[c]Unable to determine if tests were under controlled or uncontrolled states.
[d]Includes pile maintenance (unspecified equipment).

TABLE 26. COAL MINING EMISSION FACTORS (MINE TYPE A), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	0.4-1.8	-	0.0056 lb/yd^3	4	D
Shovel/truck loading (coal)	6	0.4-1.3	10	0.014 lb/T	4	D
Blasting (overburden)	1	2.4	-	1,690[c] lb/blast	9	E
Truck dump[d] (bottom)	6	0.4-2.7	-	0.014 lb/T	4	D
Storage pile erosion[e]	6	0.5-2.6	10	$1.6\ u\ \frac{lb}{(acre)(hr)}$	1[f]	C[f]
Fly ash dump	2	1.5	-	3.9 lb/hr	7/8	E

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.
[c]Text indicates this value represents a maximum rate.
[d]Material not given.
[e]u = Wind speed in m/sec. This factor includes emissions from pile maintenance.
[f]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 27. COAL MINING EMISSION FACTORS (MINE TYPE B), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	10	3.1-5.8	-	0.053 lb/yd^3	4	D
Haul road	4	3.7-4.7	-	17.0 lb/VMT	5	C
Shovel/truck loading (coal)	4	0.4-0.6	18	0.007 lb/T	5	D
Truck dump (bottom)	2	3.7	-	0.020 lb/T	7	E
Storage pile erosion[c]	6	0.8-7.6	18	$1.6\ u\ \frac{lb}{(acre)(hr)}$	1[d]	C[d]

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.
[c]u = Wind speed in m/sec. This factor includes emissions from pile maintenance.
[d]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 28. COAL MINING EMISSION FACTORS (MINE TYPE C), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	3.6-5.4	-	0.0030 lb/yd^3	3	C
Shovel/truck loading (coal)	4	3.6	24	0.002 lb/T	5	D
Blasting						
Coal	2	5.4	24	25.1 lb/blast	7	E
Overburden	2	3.6	-	14.2 lb/blast	7	E
Truck dump (bottom)	2	3.6	-	0.005 lb/T	7	E
Drilling (overburden)	2	3.6	-	1.5 lb/hole	8	
Train loading	4	4.5-4.9	24	0.0002 lb/T	5	D

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.

TABLE 29. COAL MINING EMISSION FACTORS (MINE TYPE D), RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Dragline	6	5.8-7.2	-	0.021 lb/yd^3	3	C
Blasting (coal)	2	4.0	38	78.1 lb/blast	7	E
Truck dump (bottom)	4	4.5-6.7	-	0.027 lb/T	6	E
Storage pile erosion[c]	4	0.9-1.3	38	$1.6\ u\ \frac{lb}{(acre)(hr)}$	1[d]	C[d]
Topsoil removal						
Scraping	5	5.8-7.6	-	0.35 lb/yd^3	4	D
Dumping	5	2.2-3.6	-	0.03 lb/yd^3	3	C
Front-end loader	1	2.7	-	0.12 lb/T	9	E

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.
[c]u = Wind speed in m/sec.
[d]Rating code refers to Table 5. Rating based on combined data Mines A, B, and D.

TABLE 30. COAL MINING EMISSION FACTORS (MINE TYPE E), RANGE OF TEST CONDITIONS, AND RATINGS
(Test Report 5)

Operation	Number of Tests	Range of Conditions: Wind Speed (mph)	Range of Conditions: Moisture (%)	TSP Emission Factor[a,b]	Rating Code	Rating
Shovel/truck loading						
Coal	4	2.3-2.5	30	0.0035 lb/T	5	D
Overburden	6	2.7-3.6	30	0.037 lb/T	3	C
Blasting Coal	2	2.6	30	72.4 lb/blast	7	E
Overburden	2	3.7	-	85.3 lb/blast	7	E
Truck dump Overburden	2	6.2	-	0.002 lb/T	8	E
Coal (end dump)	4	2.7-3.1	30	0.007 lb/T	6	E
Drilling (coal)	2	4.1	30	0.22 lb/hole	8	E

- = Information not contained in test report.
[a]Particle size not explicitly stated in test report.
[b]Emission factors are from page 2, Table 1 of test report.

TABLE 31. COAL MINING SOURCE TESTING INFORMATION (Test Report 14)

Operation	Equipment	Material	Test Method[a]	Site (mine)	Test Dates	No. of Tests
Drilling	NA	Overburden	Quasi-stack	1, 3	7/79, 8/79, 12/79, 7/80	30
Blasting	NA	Coal	Balloon[b]	1, 2, 3	8/79,10/79, 7/80, 8/80	14
		Overburden	Balloon[b]	1, 3	8/79, 8/80	4
Loading	Shovel/truck	Coal	Uw-Dw	1, 2	8/79, 10/79	10
	Front-end loader/truck	Coal	Uw-Dw	3	7/80, 8/80	15
Dozing	Dozer	Coal	Uw-Dw	1, 2, 3	8/79, 10/79, 8/80	12
		Overburden	Uw-Dw	1, 2, 3	8/79, 10/79, 7/80, 8/80	15
Dragline	Dragline	Overburden	Uw-Dw	1, 2, 3	8/79, 10/79, 7/80, 8/80	19
Vehicle traffic	Haul truck	Unpaved road	Uw-Dw	1	8/79, 12/79	11
		Unpaved road	Profiling	1, 2 ,3	7/79, 8/79, 12/79	21
	Light-medium duty	Unpaved road	Profiling	1, 2, 3	8/79, 10/79, 8/80	10
Scrapers[c] (travel mode)	Scraper	Unpaved surface	Uw-Dw	1	7/79	5
		Unpaved surface	Profiling	1, 2, 3	7/79, 10/79, 12/79, 8/80	15
Grading	Grader	Unpaved surface	Profiling	2, 3	10/79, 8/80	7

- = Information not contained in test report.
NA = Not applicable.
[a]Uw-Dw = Upwind-downwind.
[b]This is actually a modified version of exposure profiling.
[c]Loading and dumping not tested.

TABLE 32. COAL MINING EMISSION FACTORS, RANGE OF TEST CONDITIONS, AND RATINGS (Test Report 14)

		Range of Conditions								Particulate Emission Factor[a]					
Operation	No. of Tests	Mat'l Moist-ure Content (%)	Mat'l Silt Content (%)	Surface Silt Loading (g/m^2)	Vehicle Speed (mph)	Vehicle Weight (tons)	No. of Wheels	Wind Speed (mph)	Other	TSP	<15 μm	<25 μm	Units	Rating Code	Rating
Drilling	30	6.9-9.0	5.2-26.8	NA	NA	NA	NA	0.9-6.3	b	1.3	-	-	lb/hole	2	B
Blasting															
Coal	14	11.1-38.0	-	NA	NA	NA	NA	2.2-12.1	c	35.4[d]	13.2[d]	1.10[d]		2	D
Overburden	4	7.2-8.0	-	NA	NA	NA	NA	2.2-11.4	e				lb/blast	2	C
Coal loading	25	6.6-38.0	3.6-4.2	NA	NA	NA	NA	2.2-11.2	f	0.037	0.008	0.0007	lb/ton	2	C
Dozing															
Coal	12	4.0-22.0	6.0-11.3	NA	5-12	-	NA	3.4-13.4	None	46.0	20.0	1.0	lb/hr	2	C
Overburden	15	2.2-16.8	3.8-15.1	NA	2-7	-	NA	2.5-19.0	None	3.7	0.88	0.39	lb/hr	2	C
Dragline	19	0.2-16.3	4.6-14.0	NA	NA	NA	NA	2.2-16.6	g	0.059	0.013	0.001	lb/hr	2	C
Vehicle traffic															
Light-medium duty	10	0.9-1.7	4.9-10.1	5.9-48.2	24.8-42.9	2.0-2.6	4.0-4.1	6.5-13.0	None	2.9	1.8	0.12	lb/VMT	2	B
Haul truck	27	0.3-8.5	2.8-18.0	3.8-254	14.9-36.0	24-138	4.9-10.0	1.8-15.4	None	17.4	8.2	0.30	lb/VMT	2	B
Scrapers	15	0.9-7.8	7.2-25.2	8.0-96.8	9.9-31.7	36-70	4.0-4.1	2.5-21.0	None	13.2	6.0	0.34	lb/VMT	2	B
Grading	7	1.0-9.1	7.2-29.0	76-190	5.0-11.8	13-14	5.9-6.0	4.3-11.6	None	5.7	2.7	0.18	lb/VMT	4	C

- = Information not contained in test report.
NA = Not applicable.
[a]ISP and < 15 μm emission factors were determined by applying the mean correction correlation parameters in Table 13-9 (page 13-15 of test report) to the equation in Table 15-1 (page 15-2 of test report). The less than 2.5 μm emission factors were determined by applying the appropriate fraction found in Table 15-1 (page 15-2 of test report) to the ISP emission factors.
[b]Depth of drilling = 30 to 100 ft.
[c]No. of holes = 6 to 750; blast area - 100 to 6,800 m^2; depth of holes = 20 to 70 ft.
[d]The results of coal and overburden blasting were combined in the test report to form a single emission factor.
[e]No. of holes = 20 to 60; blast area = 2,200 to 9,600 m^2; depth of holes = 25 to 135 ft.
[f]Bucket capacity = 14 to 17 $yards^3$.
[g]Bucket capacity = 32 to 65 $yards^3$; drop distance = 5 to 100 ft.

TABLE 33. COAL MINING EMISSION FACTOR EQUATIONS AND RATINGS (Test Report 14)

Operation	Particulate Emission Factor Equation[a] TSP	< 15 μm	< 2.5 μm/TSP[b]	Units	Rating Code	Rating
Blasting (coal or overburden)	$\frac{961\ (A)^{0.8}}{(D)^{1.8}\ (M)^{1.9}}$	$\frac{2,550\ (A)^{0.6}}{(D)^{1.5}\ (M)^{2.3}}$	0.030	lb/blast	1	C
Coal loading	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.019	lb/ton	1	B
Dozing Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.022	lb/hr	1	B
Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.105	lb/hr	1	B
Dragline Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021\ (d)^{0.7}}{(M)^{0.3}}$	0.017	$lb/yard^3$	1	B
Scrapers (Travel mode)	$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.026	lb/VMT	1	A
Grading	$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.031	lb/VMT	2	B
Vehicle traffic Light-medium duty	$\frac{5.79}{(M)^{4.0}}$	$\frac{3.22}{(M)^{4.3}}$	0.040	lb/VMT	2	B
Haul trucks	$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.017	lb/VMT	1	A

Note: The range of test conditions are as stated in Table 32. Particle diameters are aerodynamic.
[a]From page 15-2, Table 15-1 of test report.
[b]Multiply this fraction by the TSP predictive equation to determine emissions in the < 2.5 μm size range.

A = area blasted (ft^2)
M = moisture content (%)
D = hole depth (ft)
s = silt content (%)
d = drop height (ft)
W = vehicle weight (tons)
S = vehicle speed (mph)
w = number of wheels
L = silt loading (g/m^2)

TABLE 34. COAL MINING SOURCE TESTING INFORMATION
(Test Report 15)

Operation	Equipment	Material	Test Method[a]	Site No. (mine)	Test Dates	No. of Tests
Vehicle traffic	Haul trucks	Coal overburden	Profiling	2	Winter, spring, summer	26[b]
Dumping	-	Coal	Tracer	1, 2	Fall, winter	3
Loading	Train	Coal	Tracer	1, 2	Fall	2
Overburden replacement	-	Overburden	Uw-Dw	1, 2	Winter, spring, summer	7
Topsoil removal	(Scraper)[c]	Topsoil	Uw-Dw	1	Summer	2
Exposed Area	NA	Seeded land, stripped overburden, graded overburden	Uw-Dw	1, 2	Spring, summer	18

- = Information not contained in test report.
NA = Not applicable.
[a]Uw-Dw = Upwind-downwind.
[b]This series of tests involved a wide variety of road conditions ranging from total control (wet) to totally uncontrolled (dry). An emission factor equation was derived which takes the amount of control present into account
(see Table 33, footnote a).
[c]Although scrapers are most often used in this operation the test report did not explicitly state that scrapers were being used.

TABLE 35. COAL MINING EMISSION FACTORS, RANGE OF TEST CONDITIONS, AND RATINGS
(Test Report 15)

Operation	No. of Tests	Mat'l Moisture Content (%)	Mat'l Silt Content (%)	Veh-icle Speed (mph)	Vehicle Weight (tons)	Wind Speed (mph)	Total Particu-late Emission Factor	Units	Rating Code	Rating
Vehicle traffic[a]	26	Dry-wet	8.3-11.2	22-24	-	3.6-19.2	22.0	lb/VMT	4	C
Coal dumping[b]	3	-	-	NA	NA	2.9-6.0	0.066	lb/T	6	D
Train loading[c]	2	-	-	NA	NA	4.0-11.4	0.027	lb/T	7	D
Overburden replacement[d]	7	-	-	-	-	3.8-19.9	0.012	lb/T	3	C
Topsoil removal[a]	2	-	-	-	-	10.1	0.058	lb/T	8	E
Exposed areas[f]	18	-	-	NA	NA	5.4-17.4	0.38	ton/acre-year	2	C

- = Information not contained in test report.
NA = Not applicable.
[a]The emission factor equation derived for this source is from page 35 of test report. It was evaluated at zero wettings per hour.
[b]Emission factor is from page 46, Table 5.1 of test report.
[c]Emission factor is from page 47, Table 5.2 of test report.
[d]Emission factor is from page 52, Table 6.1 of test report.
[e]Emission factor is from page 52, Table 6.2 of test report.
[f]Emission factor is from page 55, Table 7.1 of test report.

8.5 Western Surface Coal Mining and Processing

Since no emission factors are currently presented in AP-42 for coal mining. The predictive emission factor equations presented in Table 49 are recommended for inclusion in AP-42 under a section named "Western Surface Coal Mining." Table 50 presents the single-valued emission factors for western surface coal mining. It is recommended that for any source operation not covered by the equations in Table 49, the highest rated singlevalued factors from Table 50 be incorporated in AP-42.

All of the recommended factors may be applied to Eastern surface coal mining. However, each should then be aerated one letter value (e.g., C to D).

TABLE 49. WESTERN SURFACE COAL MINING PREDICTIVE EMISSION FACTOR EQUATIONS (Test Reports 5 and 14)

Operation	Material	Particulate Emission Factor Equation[a]: TSP	Particulate Emission Factor Equation[a]: < 15 μm	Particulate Emission Factor Equation[a]: < 2.5 μm/TSP[a]	Units	Test Report	Rating
Blasting	Coal or overburden	$\frac{961\ (A)^{0.8}}{(D)^{1.8}\ (M)^{1.9}}$	$\frac{2,550\ (A)^{0.6}}{(D)^{1.5}\ (M)^{2.3}}$	0.030	lb/blast	14	C
Truck loading	Coal	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.019	lb/ton	14	B
Dozing	Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.022	lb/hr	14	B
	Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.105	lb/hr	14	B
Dragline	Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021\ (d)^{0.7}}{(M)^{0.3}}$	0.017	lb/yard^3	14	B
Scrapers (travel mode)		$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.026	lb/VMT	14	A
Grading		$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.031	lb/VMT	14	B
Vehicle traffic (light-medium duty)		$\frac{5.79}{(M)^{4.0}}$	$\frac{3.72}{(M)^{4.3}}$	0.040	lb/VMT	14	B
Haul trucks		$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.017	lb/VMT	14	A
Storage pile (Wind erosion and mainten-ance	Coal	16 u	-	-	$\frac{lb}{(acre)(hr)}$	5	C[b]

- = Unable to be determined from information contained in test report.
[a]Multiply this fraction by the TSP predictive equation to determine emissions in the < 2.5 μm size range.
[b]Rating applicable to Mine Types A, B, and D (see p 61).

A	=	area blasted (ft^2)	d	=	drop height (ft)
M	=	moisture content (%)	W	=	vehicle weight (tons)
D	=	hole depth (ft)	S	=	vehicle speed (mph)
s	=	silt content (%)	w	=	number of wheels
μ	=	wind speed (m/sec)	L	=	silt loading (g/m2)

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS (Test Report 4, 5, 14, and 15)

Operation	Source (Material)	Emission Factor by Aerodynamic Diameter: Total	TSP	< 30 (μm)	< 15 (μm)	< 10 (μm)	< 5 (μm)	< 2.5 (μm)	Units	Test Report	Rating
Drilling											
	(Overburden) (mine type C)	-	1.3	-	-	-	-	-	lb/hole	14	B
	(Coal) (mine type E)	-	0.22	-	-	-	-	-	lb/hole	5	E
Blasting	(Overburden)										
	(mine type A)	-	1,690	-	-	-	-	-	lb/blast	5	E
	(mine type C)	-	14.2	-	-	-	-	-	lb/blast	5	E
	(mine type E)	-	85.3	-	-	-	-	-	lb/blast	5	E
	(Coal)										
	(mine type C)	-	25.1	-	-	-	-	-	lb/blast	5	E
	(mine type D)	-	78.1	-	-	-	-	-	lb/blast	5	E
	(mine type E)	-	72.4	-	-	-	-	-	lb/blast	5	E
Dragline	(Overburden)										
	(mine type A)	-	0.0056	-	-	-	-	-	lb/yd^3	5	D
	(mine type B)	-	0.053	-	-	-	-	-	lb/yd^3	5	D
	(mine type C)	-	0.0030	-	-	-	-	-	lb/yd^3	5	C
	(mine type D)	-	0.021	-	-	-	-	-	lb/yd^3	5	C
Top soil removal	Scraper										
	(mine type D)	-	0.44	-	-	-	-	-	lb/T	5	D
	Unspecified equipment	-	0.058	-	-	-	-	-	lb/T	15	E
Overburden replacement	Unspecified equipment	-	0.012	-	-	-	-	-	lb/T	15	C

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS (Test Report 4, 5, 14, and 15) (cont.)

		Emission Factor by Aerodynamic Diameter									
Operation	Source (Material)	Total	TSP	< 30 (μm)	< 15 (μm)	< 10 (μm)	< 5 (μm)	< 2.5 (μm)	Units	Test Report	Rating
Batch-drop	Dumping via truck (Overburden-bottom)										
	(mine type E)	-	0.002	-	-	-	-	-	lb/T	5	E
	(Coal-end)										
	(mine type E)	-	0.007	-	-	-	-	-	lb/T	5	E
	(Material not specified-bottom)										
	(mine type A)	-	0.014	-	-	-	-	-	lb/T	5	D
	(mine type B)	-	0.020	-	-	-	-	-	lb/T	5	E
	(mine type C)	-	0.005	-	-	-	-	-	lb/T	5	E
	(mine type D)	-	0.027	-	-	-	-	-	lb/T	5	E
	Dumping via scraper (top soil)										
	(mine type D)	-	0.04	-	-	-	-	-	lb/T	5	C
	Dumping via unspecified equipment or process										
	(Coal)	-	0.066	-	-	-	-	-	lb/T	15	D
	(Fly-ash)										
	(mine type A)	-	3.9	-	-	-	-	-	lb/hr	5	E
	Front-end loader/truck (Material unspecified)										
	(mine type D)	-	0.12	-	-	-	-	-	lb/T	5	E
	Power shovel/truck (Overburden)										
	(mine type E)	-	0.037	-	-	-	-	-	lb/T	5	C

TABLE 50. WESTERN SURFACE COAL MINING SINGLE-VALUED EMISSION FACTORS (Test Report 4, 5, 14, and 15) (cont.)

Operation	Source (Material)	Total	TSP	< 30 (μm)	< 15 (μm)	< 10 (μm)	< 5 (μm)	< 2.5 (μm)	Units	Test Report	Rating
		Emission Factor by Aerodynamic Diameter									
	(Coal)										
	(mine type A)	-	0.014	-	-	-	-	-	lb/T	5	D
	(mine type B)	-	0.007	-	-	-	-	-	lb/T	5	D
	(mine type C)	-	0.002	-	-	-	-	-	lb/T	5	D
	(mine type E)	-	0.0035	-	-	-	-	-	lb/T	5	D
	Loading train via unspecified equipment and process										
	(Coal)	-	0.027	-	-	-	-	-	lb/T	15	D
	(mine type C)	-	0.0002	-	-	-	-	-	lb/T	5	D
Storage pile	Wind erosion (Coal)	-	0.013	-	-	-	-	-	lb/T/yr	4	D
Vehicle traffic on unpaved road	Haul truck (unspecified size)	-	17.0	-	-	-	-	-	lb/VMT	5	C
	(mine type B)	-	22.0	-	-	-	-	-	lb/VMT	15	C
Wind erosion	Exposed areas	-	0.38	-	-	-	-	-	$\frac{T}{(acre)(yr)}$	15	C

- = Unable to be determined from information contained in test report.
= Not recommended for inclusion into AP.

H.2 Section 10 of EPA report "Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources --Volume I - Sampling Methodology and Test Results"

SECTION 10

RESULTS FOR SOURCES TESTED BY WIND TUNNEL METHOD

SUMMARY OF TESTS PERFORMED

As discussed previously, the wind tunnel method was used to test particulate emissions generated by wind erosion of coal storage piles and exposed ground areas. These sources were tested at three mine sites during the period October 1979 through August 1980.

A total of 37 successful wind tunnel tests were conducted at the three mines. Tests at Mine 1 took place in late autumn, with below normal temperatures and snowfall being encountered. Emissions tests were distributed by source and by mine as follows:

	Number of Tests		
Source	**Mine 1**	**Mine 2**	**Mine 3**
Coal storage piles	4	7	16
Exposed ground piles	1	5	4

The decision of when to sample emissions from a given test surface was based on the first observation of visible emissions as the tunnel flow rate was increased. At Mines 1 and 2, if visible emissions in the blower exhaust were not observed at a particular tunnel flow rate, no air sampling was performed, but a velocity profile was obtained. Then the tunnel flow rate was increased to -he next level and the process repeated. When visible emissions were observed, emission sampling was performed and then repeated at the same wind speed (but for a longer sampling time) to measure the decay in the erosion rate. At Mine 3, particle movement on the test surface was used as the indicator that the threshold velocity had been reached and that emission sampling should be performed. Five tests on coal piles and seven tests on exposed ground areas were conducted on surfaces where no erosion was visually observed, and in these cases no emissions sampling was performed.

Table 10-1 lists the test site parameters for the wind tunnel tests conducted on coal pile surfaces. The ambient temperature and relative humidity measurements were obtained just above the coal surface external to the tunnel.

Table 10-2 gives the tunnel test conditions for the wind erosion emission tests on coal surfaces. The equivalent speed at 10 m was determined by extrapolation of the logarithmic velocity profile measured in the wind tunnel test section above the eroding surface. The friction velocity, which is a measure of the wind shear at the eroding surface, was determined from the velocity profile.

Table 10-3 gives the erosion-related properties of the coal surfaces from which wind-generated emissions were measured. The silt and moisture values were determined from laboratory analysis of aggregate samples taken from representative undisturbed sections of the erodible surface ("before" erosion) and from the actual test surface after erosion; therefore, only one "before" condition and one "after" condition existed for each test site. The roughness height was determined from the velocity profile measured above the test surface at a tunnel wind speed just below the threshold value.

Table 10-4 lists the test site parameters for the wind tunnel tests conducted on exposed ground areas. The surfaces tested included topsoil, subsoil (with and without snow cover), overburden and scoria. For Runs J-28, K-31 through K-34, K-47 and K-48, no air sampling was performed, but velocity profiles were obtained.

Table 10-5 gives the tunnel test conditions for the wind erosion emission tests on exposed ground areas. Table 10-6 gives the erosion-related properties of the exposed ground surfaces from which wind-generated emissions were measured.

RESULTS

Table 10-7 and 10-8 present the wind erosion emission rates measured for coal pile surfaces and exposed ground areas, respectively. Emission rates are given for suspended particulate matter (particles smaller than 30 μm in aerodynamic diameter) and inhalable particulate matter (particles smaller than 15 μm in aerodynamic diameter).

For certain emission sampling runs, emission rates could not be calculated. No particle size data were available for run J-30. For exposed ground area runs P-37 and P-41, measured emissions consisted entirely of particles larger than 11.6 μm aerodynamic diameter (the cyclone cut point).

The means, standard deviations, and ranges of SP emission rates for each source category are shown below:

Source	No. Tests	SP Emission Rate (lbs/acre-s)		
		Mean	Std. Dev.	Range
Coal piles				
On pile, uncrusted	16	0.318	0.439	0.0150-1.52
On pile, crusted	7	0.0521	0.0415	0.00964-0.113
Surrounding pile	4	0.754	1.054	0.0303-2.27
Exposed ground areas				
Soil, dry	4	0.264	0.195	0.104-0.537
Soil, wet	1	0.0143		0.0143
Overburden	5	0.142	0.160	0.00698-0.329

It can be seen that natural surface crusts on coal piles are effective in mitigating wind-generated dust emissions. In addition, emissions from areas surrounding piles appear to exceeed emissions from uncrusted pile surfaces but are highly variable.

With reference to the rates measured for exposed ground areas, emissions from more finely textured soil exceed emissions from overburden. As expected, the presence of substantial moisture in the soil is effective in reducing emissions.

Examination of the conditions under which tests were conducted indicates (1) an increase in emission rate with wind speed and (2) a decrease in emission rate with time after onset of erosion. This must be considered in comparing emission rates for different source conditions.

PROBLEMS ENCOUNTERED

The only significant problem in this phase of the study was the unforeseen resistnace of selected test surfaces to wind erosion. Threshold velocities were unexpectedly high and occasionally above the maximum tunnel wind speed. This occurred primarily because of the presence of natural surface crusts which protected against erosion. As a result, the testing of many surfaces was limited to determination of surface roughness heights.

Although testing of emissions was intended to be restricted only to dry surfaces, the occurrence of snowfall at Mine 1 provided an interesting test condition for the effect of surface moisture. This helps to better quantify the seasonal variation in wind-generated emissions.

TABLE l0-1. WIND EROSION TEST SITE PARAMETERS - COAL STORAGE PILES

Mine/Site[a]	Run	Date	Start Time (hr:sec)	Sampling Duration (min:sec)	Ambient Meterology	
					Temp. (C)	R.H. (%)
Mine 1/Site A	J-22	11/9/79	-	-	-2.8	-
Mine 1/Site B	J-23	11/9/79	-	-	-2.8	-
	J-24	11/9/79	1330:00	5:30	-1.1	79
	J-25	11/9/79	1413:00	30:00	-1.1	79
Mine 1/Site C	J-26	11/9/79	1606:30	1:00	-1.1	79
	J-27	11/9/79	1620:15	8:15	-1.1	79
Mine 2/Site A	K-30	10/31/79	-	-	3.3	75
Mine 2/Site E	K-38	11/3/79	-	-	-1.1	100
	K-39	11/3/79	1417:25	6:00	2.8	61
Mine 2/Site F	K-40	11/3/79	1550:05	6:49	4.4	60
	K-41	11/3/79	1635:25	30:00	2.8	65
Mine 2/Site G	K-42	11/4/79	1120:00	5:50	2.8	64
	K-43	11/4/79	1156:20	30:00	3.9	70
Mine 2/Site H	K-44	11/4/79	-	-	2.2	-
	K-45	11/4/79	1652:40	3:35	2 8	51
	K-46	11/4/79	1717:40	30:00	24	29
Mine 3/Site A	P-20	8/12/80	0848:00	30:00	24	39
	P-21	8/12/80	0946:00	10:00	29	26
	P-22	8/12/80	1014:00	40:00	29	26
	P-23	8/12/80	1114:00	10:00	33	21
	P-24	8/12/80	1222:00	40:00	33	21
	P-25	8/12/80	1538:00	10:00	37	12
	P-26	8/12/80	1617:00	10:00	37	12

TABLE 10-1. (continued)

Mine/Site[a]	Run	Date	Start Time (hr:sec)	Sampling Duration (min:sec)	Ambient Meterology	
					Temp. (C)	R.H. (%)
Mine 3/Site B	P-27	8/12/80	1813:00	2:00	37	12
	P-28	8/13/80	1017:00	8:00	28	35
	P-29	8/13/80	1134:00	2:00	34	24
	P-30	8/13/80	1146:00	8:00	34	24
Mine 3/Site C	P-31	8/13/80	1546:00	2:00	34	19
	P-32	8/13/80	1601:00	8:00	34	19
	P-33	8/13/80	1649:00	2:00	34	19
	P-34	8/13/80	1704:00	8:00	34	19
	P-35	8/13/80	1738:00	26:00	34	19

[a] Mine 1/Site A - Base of pile.
Mine 1/Site B - Traveled area (dozer track) surrounding pile.
Mine 1/Site C - Traveled area (light duty vehicle track) surrounding pile.
Mine 2/Site A - Raw coal surge pile.
Mine 2/Site E - Raw coal surge pile.
Mine 2/Site F - Raw coal surge pile.
Mine 2/Site G - Raw coal surge pile.
Mine 2/Site H - Along dozer track on raw coal surge pile.
Mine 3/Site A - Approximately 1 kilometer east of power plant on crusted vehicle track.
Mine 3/Site B - Twenty-five meters south of Site A on furrow in coal pile.
Mine 3/Site C - Seventy-five meters west of Site B on uncrusted haul truck track.

TABLE 10-2. WIND TUNNEL TEST CONDITIONS - COAL STORAGE PILES

	Wind Speed at Tunnel Centerline		Friction Velocity		Equivalent Speed at 10 m	
Run	**(m/s)**	**(mph)**	**(m/s)**	**(mph)**	**(m/s)**	**(mph)**
J-24	14.3	32.1	0.97	2.17	25.0	56.0
J-25	14.2	31.8	0.96	2.15	25.0	56.0
J-26	11.7	26.2	0.63	1.41	18.8	42.0
J-27	15.6	35.0	0.94	2.10	25.9	58.0
K-39	16.7	37.3	1.46	3.27	32.2	72.0
K-40	15.0	33.5	1.46	3.27	29.1	65.0
K-41	14.8	33.2	1.44	3.22	29.1	65.0
K-42	16.9	37.9	1.73	3.87	33.5	75.0
K-43	16.9	37.9	1.73	3.87	33.5	75.0
K-45	13.6	30.4	1.32	2.95	27.3	61.0
K-46	13.6	30.4	1.32	2.95	27.3	61.0
P-20	11.6	25.9	0.44	0.984	16.8	37.5
P-21	13.1	29.2	0.60	1.34	19.2	43.0
P-22	13.1	29.2	0.60	1.34	19.2	43.0
P-23	14.2	31.8	0.64	1.43	21.9	49.0
P-24	14.8	33.2	0.61	1.36	20.3	45.5
P-25	16.0	35.8	0.66	1.48	22.4	50.0
P-26	16.2	36.3	0.71	1.59	23.7	53.0
P-27	16.0	35.7	1.00	2.24	26.4	59.0
P-28	15.8	35.4	1.20	2.68	30.6	68.5
P-29	17.3	38.6	1.31	2.93	>31.3	>70.0
P-30	16.9	37.7	1.08	2.42	26.4	59.0
P-31	11.8	26.3	0.91	2.04	21.5	48.0
P-32	12.0	26.8	0.95	2.12	24.6	55.0
P-33	14.5	32.4	1.15	2.57	26.6	59.5
P-34	14.4	32.2	1.25	2.80	31.3	70.0
P-35	14.5	32.4	1.25	2.80	>31.3	>70.0

TABLE l0-3. WIND EROSION SURFACE CONDITIONS - COAL STORAGE PILES

Run	Silt Before (%)	Silt After (%)	Moisture Before (%)	Moisture After (%)	Roughness Height (cm)	Threshold Speed at Tunnel Centerline (m/s)	Threshold Speed at Tunnel Centerline (mph)
J-24	16.4	-	2.5	-	0.04	9.52	21.3
J-25	16.4	6.8	2.5	3.3	0.04	9.52[a]	21.3[a]
J-26	16.4	-	2.5	-	0.008	9.52[a]	21.3[a]
J-27	16.4	-	2.5	-	0.02	9.52[a]	21.3[a]
K-39	5.1	4.2	20.2	19.9	0.16	14.1	31.6
K-40	5.1	-	20.2	-	0.25	14.1	31.6
K-41	5.1	6.8	20.2	10.5	0.25	14.1	31.6
K-42	3.4	-	6.8	-	0.30	14.1	31.6
K-43	3.4	2.3	6.8	6.4	0.30	14.1	31.6
K-45	11.6	-	2.8	-	0.25	11.1	24.8
K-46	11.6	10.0	2.8	2.1	0.25	11.1	24.8
P-20	3.8	4.1	4.6	3.4	0.0005	8.76	19.6
P-21	3.8	4.1	4.6	3.4	0.0024	8.76	19.6
P-22	3.8	4.1	4.6	3.4	0.0024	8.76	19.6
P-23	3.8	4.1	4.6	3.4	0.0022	8.76	19.6
P-24	3.8	4.1	4.6	3.4	0.0009	8.76	19.6
P-25	3.8	4.1	4.6	3.4	0.0009	8.76	19.6
P-26	3.8	4.1	4.6	3.4	0.0017	8.76	19.6
P-27	4.0	3.8	7.8	5.1	0.025	14.6	32.6
P-28	4.0	3.8	7.8	5.1	0.078	14.6	32.6
P-29	4.0	3.8	7.8	5.1	0.078	14.6	32.6
P-30	4.0	3.8	7.8	5.1	0.030	14.6	32.6
P-31	4.4	-	3.4	-	0.085	8.32	18.6
P-32	4.4	-	3.4	-	0.10	8.32	18.6
P-33	4.4	-	3.4	-	0.10	8.32	18.6
P-34	4.4	-	3.4	-	0.15	8.32	18.6
P-35	4.4	-	3.4	-	0.15	8.32	18.6

[a]Assumed the same as J-24.

TABLE 10-4. WIND EROSION TEST SITE PARAMETERS - EXPOSED GROUND AREAS

Mine/Site[a]	Run	Date	Start time (hr:sec)	Sampling duration (min:sec)	Ambient meteorology	
					Temp. (C)	R.H. (%)
Mine 1/Site D	J-28	11/10/79	---	---	0.6	---
	J-29	11/10/79	1141:00	30:00	0.6	91
	J-30	11/10/79	1342:30	30:10	2.8	87
Mine 2/Site B	K-31	11/1/79	---	---	2.2	60
	K-32	11/1/79	---	---	2.2	60
	K-33	11/1/79	---	---	2.2	60
Mine 2/Site C	K-34	11/2/79	---	---	-1.7	80
	K-35	11/2/79	1454:00	3:21	-1.7	80
	K-36	11/2/79	1536:00	30:36	-1.7	80
Mine 2/Site D	K-37	11/2/79	1704:17	11:43	-1.7	80
Mine 2/Site I	K-47	11/5/79	---	---	-1.1	---
Mine 2/Site J	K-48	11/5/79	---	---	-1.1	---
	K-49	11/5/79	1515:00	5:00	0.6	63
Mine 2/Site J	K-50	11/5/79	1555:30	28:00	0.0	75
Mine 3/Site D	P-36	8/14/80	1012:00	2:00	---	---
	P-37	8/14/80	1026:00	4:00	---	---
	P-38	8/14/80	1042:00	4:00	---	---
Mine 3/Site E	P-39	8/14/80	1212:00	4:00	---	---
Mine 3/Site E	P-40	8/14/80	1225:00	4:00	---	---
	P-41	8/14/80	1240:00	4:00	---	---

[a] Mine 1/Site D - Subsoil covered with one-half inch of snow, which melted prior to Run J-30.
Mine 2/Site B - Exposed soil near pit.
Mine 2/Site C - Dragline access road recently cut down; road surface represented disturbed overburden.
Mine 2/Site D - Adjacent to Site C and in same material.
Mine 2/Site I - Small bank made of overburden and left by grader on side of unpaved road.
Mine 2/Site J - Scoria haul road.
Mine 3/Site D - Exposed topsoil. Two hundred meters south of pit.
Mine 3/Site E - Five meters west of Site D.

TABLE 10-5. WIND TUNNEL TEST CONDITIONS - EXPOSED GROUND AREAS

Run	Wind speed at tunnel centerline (m/s)	Wind speed at tunnel centerline (mph)	Friction velocity (m/s)	Friction velocity (mph)	Equivalent speed at 10 m (m/s)	Equivalent speed at 10 m (mph)
J-29	18.1	40.5	1.96	4.38	38.0	85.0
J-30	16.6	37.1	1.62	3.62	32.6	73.0
K-35	15.1	33.7	1.54	3.44	30.9	69.0
K-36	14.8	33.1	1.51	3.38	30.0	67.0
K-37	15.1	33.7	1.54	3.44	30.9	69.0
K-49	15.8	35.4	1.56	3.49	30.4	68.0
K-50	15.8	35.4	1.56	3.49	30.4	68.0
P-36	10.3	19.6	0.87	1.95	15.7	35.0
P-37	10.3	19.6	0.87	1.95	15.7	35.0
P-38	10.3	19.6	0.87	1.95	15.7	35.0
P-39	6.3	14.0	0.33	0.738	10.3	23.0
P-40	8.1	18.0	0.44	0.984	13.0	29.0
P-41	10.7	23.9	1.00	2.24	20.1	45.0

TABLE 10-6. WIND EROSION SURFACE CONDITION - EXPOSED GROUND AREAS

Run	Silt		Moisture		Roughness Height (cm)	Threshold speed at tunnel centerline	
	Before (%)	After (%)	Before (%)	After (%)		(ms/)	(mph)
J-29	--	--	--	--	0.38	>18.3	>41
J-30	--	--	--	--	0.25	>18.3	>41
K-35	21.1	18.8	6.4	5.6	0.30	10.5	23.4
K-36	21.1	18.8	6.4	5.6	0.30	10.5	23.4
K-37	21.1	22.7	6.4	5.6	0.30	10.5	23.4
K-49	18.8	--	4.1	--	0.26	13.5	30.1
K-50	18.8	15.1	4.1	2.7	0.26	13.5	30.1
P-36	5.1	--	0.8	--	0.13	4.65	10.4
P-37	5.1	--	0.8	--	0.13	4.65	10.4
P-38	5.1	--	0.8	--	0.13	4.65	10.4
P-39	5.1	--	--	--	0.0075	5.14	11.5
P-40	5.1	--	--	--	0.01	5.14	11.5
P-41	5.1	--	--	--	0.21	5.14	11.5

TABLE 10-7. WIND EROSION TEST RESULTS - COAL STORAGE PILES

	Emission Rate			
	Suspended Particulate		Inhalable Particulate	
	(g/m²-s)	(lb/acre-s)	(g/m²-s)	(lb/acre-s)
J-24	0.00340	0.0303	0.00226	0.0202
J-25	0.00520	0.0464	0.00344	0.0307
J-26	0.254	2.27	0.157	1.40
J-27	0.0748	0.668	0.0472	0.421
K-39	0.170	1.52	0.119	1.06
K-40	0.111	0.991	0.0722	0.644
K-41	0.00454	0.0405	0.00296	0.0264
K-42	0.0961	0.831	0.0626	0.559
K-43	0.00436	0.0389	0.00279	0.0249
K-45	0.0598	0.534	0.0436	0.389
K-46	0.00741	0.0661	0.00548	0.0489
P-20	0.0127	0.113	0.00811	0.0724
P-21	0.00966	0.0862	0.00414	0.0369
P-22	0.00108	0.00964	0.000597	0.00533
P-23	0.00232	0.0207	0.00139	0.0124
P-24	0.00176	0.0157	0.00107	0.00955
P-25	0.00392	0.0350	O.C0231	0.0206
P-26	0.00948	0.0846	0.00533	0.0476
P-27	0.0386	0.344	0.0202	0.180
P-28	0.00578	0.0516	0.00343	0.0306
P-29	0.0161	0.144	0.0112	0.100
P-30	0.00168	0.0150	0.000970	0.00866
P-31	0.0191	0.170	0.0101	0.0901
P-32	0.00231	0.0206	0.000943	0.00842
P-33	0.0274	0.245	0.0157	0.140
P-34	0.00605	0.0540	0.00303	0.0270
P-35	0.00278	0.0248	0.00185	0.0165

TABLE l0-8. WIND EROSION TEST RESULTS - EXPOSED GROUND AREAS

	Emission Rate			
	Suspended Particulate		Inhalable Particulate	
	(g/m^2-s)	(lb/acre-s)	(g/m^2-s)	(lb/acre-s)
J-29	0.00160	0.0143	0.00108	0.00964
J-30[a]	-	-	-	-
K-35	0.0368	0.329	0.0245	0.219
K-36	0.00120	0.0107	0.000822	0.00734
K-37	0.00693	0.0618	0.00458	0.0409
K-49	0.0337	0.301	0.0222	0.198
K-50	0.000782	0.00698	0.000652	0.00582
P-36	0.0161	0.144	0.0101	0.0901
P-37	0.0305	0.272	0.0190	0.170
P-38	0.0602	0.537	0.0377	0.336
P-39[b]	-	-	-	-
P-40	0.116	0.104	0.00755	0.0674
P-41[b]	-	-	-	-

[a] No particle size data available.
[b] Emissions consisted entirely of particles larger than 11.6 μm aerodynamic diameter.

Appendix I

Development of Correction Factors and Emission Factor Equations

This appendix contains information on the development of correction factors and emission factor equations for fugitive dust emissions. The information is from Sections 5 and 13, and Appendices A and B of the EPA report “Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources - Volume I and 11.”

TABLE OF CONTENTS

SECTION 5
CALCULATION AND DATA ANALYSIS METHODOLOGY

NUMBER OF TESTS PER SOURCE

The study design proposed the number of samples to be collected for each operation, but these initial numbers were based primarily on available sampling time and the relative importance of each operation as a dust source. Several members of the technical review group requested a statistical analysis to determine the appropriate number of samples to be taken.

After sampling data were obtained from the first two mines/three visits, the total sample size needed to achieve a specified margin of error and confidence level could be calculated by knowing the variability of the partial data set. This method of estimating required sample size, in which about half of the preliminarily-estimated sample size is taken and its standard deviation is used to provide a final estimate of sample size, is called the two-stage or Stein method. The two-stage method, along with two preliminary data evaluations, constituted the statistical plan finally prepared for the study.

The steps in estimating total sample sizes and remaining samples in the statistical plan were:

1. Determine (by source) whether samples taken in different seasons and/or at different mines were from the same population. If they were, total sample size could be calculated directly.
2. Evaluate potential correction factors. If samples were not from a single distribution, significant correction factors could bring them into a single distribution. If they were from populations with the same mean, correction factors could reduce the residual standard deviation.
3. Calculate required sample sizes using residual standard deviations.
4. Calculate remaining samples required to achieve the desired margin of error and confidence level and recommend the number of samples for each source to be taken at the third mine.

<u>Two-Stage Method for Estimating Sample Size</u>

If samples are to be taken from a single normal population, the required total sample size can be calculated with the following equation based on the two-stage sampling method (Natrella 1963):

$$n = \frac{t^2 s_1^2}{d^2} \qquad \text{(Eq.1)}$$

where
- n = number of samples required for first and second stages combined
- s_1 = estimate of population standard deviation based on n_1 samples
- t = tabled t-value for risk $\propto$ and n_l^{-1}degrees of freedom
- d = margin of error in estimating population mean

The margin of error, d, and the risk, α, that the estimate of the mean will deviate from the population mean by an amount d or greater are specified by the user. A relative error $(d/\bar{x})$ of 25 percent and a risk level of 20 percent have been specified for the calculations presented herein based on the intended use for the results, the measurement errors involved in obtaining the samples, and the accuracy of emission factors currently being used for other sources. Having specified d (or $d/\bar{x}$) and α, the only additional value needed to calculate n for each source is the estimate of population standard deviation, s_1 (or $s_1/\bar{x}$), based on the partial sample obtained to date, n_l.

Samples from the Same Normal Population

One important restriction on the use of Equation 1, as noted above, is that samples (from different mines) must be from a single normal distribution. If average emission rates for a specific source at three different mines are 2, 10, and 50 lb/ton, and the three samples have relatively low variability, the combined data cannot be assumed to be normally distributed with a common mean. Regardless of how many samples were taken at each mine, the data would be trimodally distributed.

Therefore, before Equation 1 can be used to calculate the total sample size, a check should be performed to determine whether the available data from different mines are from populations with the same mean and variance. If not, the mines would need to be treated separately and thus require a calculation of required sample size for each mine, using the analogue of Equation 1 (n = number of samples at a single mine). The total sample size would then be the total of the three sample sizes calculated for the respective mines.

A statistical test can be performed on the data to evaluate whether two or more sets of samples taken at different mines or in different seasons are from distributions (populations) having the same means and variances (Natrella 1963; Hald 1952).* This test was performed in the statistical plan and indicated that all sources at the first two mines/three visits except coal dozers, haul roads, and overburden drills were from the same populations. Therefore, with the exceptions noted, total sample sizes could be determined directly.

Correction Factors

The approach on which this study has been based is that the final emission factors will be mean emission rates with correction factors attached to adequately account for the wide range of mining and meteorological conditions over which the emission factors must be applied. The use of correction factors may affect required sample sizes, in that correction factors which reduce the uncertainty (standard deviation) in estimating an emission factor also reduce the sample size necessary to attain a desired

---

* Another test, the x^2 test for goodness of fit, may be more appropriate for determining whether data are from a population with a normal distribution, but it was not used in the original statistical plan.

precision with a specified confidence. Therefore, the partial data from two mines were analyzed for significant correction factors that could reduce the sample standard deviations and thus possibly reduce required sample sizes. It should be pointed out that some additional samples are needed to adequately quantify the effect of each correction factor on the emission factor, so a small reduction in sample size due to the use of a correction factor would be offset by this need for extra data.

Independent variables thought to be candidates for correction factors were measured or monitored with each sample of emission rate. The potential correction factors were listed in Table 3-5.

The approach for evaluation of correction factors described later in this section, multiple linear regression, was used to identify significant correction factors in the partial data set. However, analysis was not as thorough (e.g., did not include transformations) because it was being done only to get a slightly better estimate of the optimum sample size.

The independent variables considered and their effects on standard deviation are summarized in Table 5-1. Using appropriate values of s (standard deviation) in Equation 1, the sample sizes consistent with the previously-discussed relative error of 25 percent and risk level of 20 percent were calculated. These numbers are shown in Table 5-2, which was taken from the statistical plan. Some $\overline{x}$ and s values in this table may not agree exactly with values reported later in the results sections because of minor changes in calculation procedures between the time the statistical plan (e.g., method of extrapolating to 30 μm SP emission rate) was released and the final report was prepared.

These sample sizes were calculated after 2 mines/3 visits, leaving only one mine visit to obtain all the additional samples. It was not possible to complete the sampling requirements specified in Table 5-2 at the third mine within available project resources. Therefore, an attempt was made to get relative errors for all sources down to 0.31 and major sources (haul trucks, scrapers, and draglines) down to 0.25 by slightly reallocating the number of samples required for several of the sources. Table 5-3 compares four different sets of sample sizes:

1. Originally proposed in study design.
2. Calculated after 2 mines/3 visits to achieve a relative error of 25 percent at risk level of 0.20.
3. Proposed in statistical plan as feasible totals after third mine.
4. Actually collected at 3 mines/4 visits.

CALCULATION PROCEDURES

Exposure Profiling

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.

Step 1 Calculate Weights of Collected Sample--In order to calculate the total weight of particulate matter collected by a sampler, the weights of air filters and of intake wash filters (profiler intakes and cyclone precollectors only) are determined before and after use. The weight change of an unexposed filter (blank) is used to adjust for the effects of filter handling. The following equation is used to calculate the weight of particulate matter collected.

$$\text{Particulate sample weight} = \text{Final filter weight} - \text{Tare filter weight} - \left(\text{Final blank weight} - \text{Tare blank weight} \right) \quad \text{(Eq. 2)}$$

Because of the typically small fractions of fines in fugitive dust plumes and the low sampling rate of the dichotomous sampler, no weight gain may be detected on the fine filter of this instrument. This makes it necessary to estimate a minimum detectable FP concentration corresponding to the minimum weight gain which can be detected by the balance (0.005 mg). Since four individual tare and final weights produce the particulate sample weight (Equation 2), the minimum detectable weight on a filter is 0.01 mg.

To calculate the minimum FP concentration, the sampling rate (1 m^3/h) and duration of sampling must be taken into account. For example, the minimum concentration which can be detected for a one-hour sampling period is 10 $\mu g/m^3$. The actual sampling time should be used to calculate the minimum concentration.

Step 2 Calculate Particulate Concentrations--The concentration of particulate matter measured by a sampler, expressed in units of micrograms per standard cubic meter (μg/som), is given by the following equation:

$$c_s = 3.53 \times 10^4 \frac{m}{Q_s t} \quad \text{(Eq. 3)}$$

where C_s = particulate concentration, μg/scm

m = particulate sample weight, mg

Q_s = sampler flow rate, SCFM

t = duration of sampling, min

The coefficient in Equation 3 is simply a conversion factor. To be consistent with the National Ambient Air Quality Standard for TSP, all concentrations are expressed in standard conditions (25°C and 29.92 in. of Hg).

The specific particulate matter concentrations are determined from the various particulate catches as follows:

TP - { Profiler: filter catch + intake catch
or
Cyclone/cascade impactor: cyclone catch + substrate catches + backup filter catch }

TSP - Hi-vol sampler: filter catch

SP - Calculated: sub-30 μm fraction determined by extrapolation of sub-2.5 and sub-15 μm fractions assuming a lognormal size distribution

IP - Size-selective inlet: filter catch
Dichotomous sampler: coarse particulate filter catch + fine particulate filter catch

FP - Dichotomous sampler: fine particle filter catch multiplied by 1.11

The dichotomous sampler total flow of l m^3/h is divided into a coarse particle flow of 0.1 m^3/h and a fine particle flow of 0.9 m^3/h. The mass collected on the fine particle filter is adjusted for fine particles which remain in the air stream destined for the coarse particle filter.

Upwind (background) concentrations of TP or any of the respective size fractions are subtracted from corresponding downwind concentrations to produce "net" concentrations attributable to the tested source. Upwind sampling at one height (2.5 meters) did not allow determination of vertical variations of the upwind concentration. Because the upwind concentration at 2.5 meters may be greater than at the 4 to 6 meter height of the downwind profiling tower, this may cause a downward bias of the net concentration. Upwind TP is preferably obtained with an isokinetic sampler, but should be represented well by the upwind TSP concentration measured by a standard hi-vol, if there are no nearby sources that would have a coarse particle impact on the background station.

Step 3 Calculate Isokinetic Flow Ratios--The isokinetic flow ratio (IFR) is the ratio of the sampler intake air speed to the wind speed approaching the sampler. It is given by:

$$IFR = \frac{Q}{aU} = \frac{Q_S}{aU_s} \qquad \text{(Eq. 4)}$$

where Q = sampler flow rate, ACFM

Q_s = sampler flow rate, SCFM

a = intake area of sampler, ft^2

U = approaching wind speed, fpm

U_s = approaching wind speed, sfpm

IFR is of interest in the sampling of TP, since isokinetic sampling assures that particles of all sizes are sampled without bias.

Step 4 Calculate Downwind Particle Size Distributions--The downwind particle size distribution of source-contributed particulate matter at a given height may be calculated from net TP, IP, and FP concentrations at the same height (and distance from the source). Normally, the TP value from the exposure profiler head would be used, unless a cascade impactor operates much closer to isokinetic sampling conditions than the exposure profiler head.

The proper inlet cut-point of each dichotomous sampler must be determined based on the mean wind speed at the height of the sampler. The concentration from a single upwind dichotomous sampler should be adequately representative of the background contribution to the downwind dichotomous sampler concentrations. The reasons are: (a) the background concentration should not vary appreciably with height; (b) the upwind sampler, which is operated at an intermediate height, is exposed to a mean wind speed which is within about 20 percent of the wind speed extremes that correspond to the range of downwind sampler heights; and (c) errors resulting from the above conditions are small because of the typically small contribution of background in comparison to the source plume.

Independent particle size distributions may be determined from a cascade impactor using the proper 50 percent cutoff diameters for the cyclone precollector and each impaction stage. Corrections for coarse particle bounce are recommended.

If it can be shown that the FP and apparent IP fractions of the net TP concentrations do not vary significantly with height in the plume, i.e., by more than about 10 percent, then the plume can be adequately characterized by a single particle size distribution. This size distribution is developed from the dichotomous sampler net concentrations. The fine particle cutpoint of the dichotomous sampler (2.5 μm) corresponds to the midpoint of the normally observed bimodel size distribution of atmospheric aerosol. The coarse mode represents particles produced by a single formation mechanism and can be expected to consist of particles of lognormally distributed size. The best fit lognormal line through the data points (mass fractions of TP) is determined using a standard linear regression on transformed data points as described by Reider and Cowherd (1979). This best fit line is extrapolated or interpolated to determine SP and IP fractions of TP.

Step 5 Calculate Particulate Exposures and Integrate Profiles--For directional samplers operated isokinetically, particulate exposures may be calculated by the following equation:

$$E = \frac{M}{a} = 2.83 \times 10^{-5} \frac{C_s Q_s t}{a} \quad \text{(Eq. 5)}$$

$$= 3.05 \times 10^{-8} C_s U_s T \quad \text{(Eq. 6)}$$

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/sm3

U_s = approaching wind speed, sfpm

Q_s = sampler flow rate, SCFM

t = duration of sampling, min

The coefficients of Equations 5 and 6 are conversion factors. Net mass or concentration refers to that portion which is attributable to the source being tested, after subtraction of the contribution from background.

Note that the above equations may also be written in terms of test parameters expressed in actual rather than standard conditions. As mentioned earlier, the MRI profiler heads and warm-wire anemometers give readings expressed at standard conditions.

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

$$A = \int_O^H E dh \quad \text{(Eq. 7)}$$

where A = integrated exposure, m-mg/cm^2

E = particulate exposure, m-mg/cm^2

h = vertical distance coordinate, m

H = effective extent of plume above ground, m

Physically, A represents the total passage of airborne particulate matter downwind of the source, per unit length of line source.

The net exposure must equal zero at the vertical extremes of the profile, i.e., at the ground where the wind velocity equals zero and at the effective height of the plume where the net concentration equals zero. The maximum TP exposure usually occurs below a height of 1 m, so that there is a sharp decay in TP exposure near the ground. The effective height of the plume is determined by extrapolation of the two uppermost net TSP concentrations.

Integration of the portion of the net TP exposure profile that extends above a height of 1 m is accomplished using Simpson's Rule on an odd number of equally spaced exposure values. The maximum error in the integrated exposure resulting from extrapolation above the top sampler is estimated to be one-half of the fraction of the plume mass which lies above the top sampler. The portion of the profile below a height of 1 m is adequately depicted as a vertical line representing uniform exposure, because of the offsetting effects of the usual occurrence of maximum exposure and the decay to zero exposure at ground level (see Figure 5-1).

<u>Step 6 Calculate Particulate Emission Rates</u>--The TP emission rate for airborne particulate of a given particle size range generated by vehicles traveling along a straight-line road segment, expressed in pounds of emissions per vehicle-mile traveled (VMT), is given by:

$$e = 35.5 \frac{A}{N} \qquad \text{(Eq. 8)}$$

where e = particulate emission rate, lb/VMT

A = integrated exposure, m-mg/cm^2

N = number of vehicle passes, dimensionless

The coefficient of Equation 8 is simply a conversion factor. The metric equivalent emission rate is expressed in kilograms (or grams) of particulate emissions per vehicle-kilometer traveled (VKT)

The SP, IP, and FP emission rates for a given test are calculated by multiplying the TP emission rate by the respective size fractions obtained in Step 4.

Dustfall flux decays with distance downwind of the source, and the flux distribution may be integrated to determine the portion of the TP emission which settles out near the source. Although this effect has been analyzed in previous studies, it is not essential to the reduction of profiling data. Consequently, no such analysis is being performed in the present study as part of the profiling calculations.

Upwind-Downwind

The basis for calculation of emission rates in the upwind-downwind sampling method is conversion of ambient concentration data into corresponding emission rates by use of a Gaussian dispersion equation. Two different forms of the Gaussian dispersion equation were used--one for line sources and the other for point sources. In both cases, net downwind (downwind minus upwind) concentrations were substituted into the equation along with appropriate meteorological and distance data to calculate apparent source strengths. The eight to 10 samplers in the downwind array resulted in that number of estimates of source strength being produced for each sampling period.

In an interim technical report, the calculation procedures for the upwind-downwind method were explained in slightly greater detail than has been allocated in this report. A step-by-step calculation procedure was presented in the interim report and is summarized below:

1. Determine stability class by σ_θ method.
2. Calculate initial plume dispersion, σ_{yo} and σ_{zo}.
3. Determine virtual distance x_o.
4. Determine source-to-sampler distances.
5. Calculate plume dispersion (σ_y and σ_z) at each downwind sampling distance.
6. Correct measured concentrations for distance of sampler away from plume centerline (for point sources only).
7. Calculate source strength with Gaussian dispersion equation.
8. Convert source strength to an emission rate.

These steps are discussed briefly below.

Step 1 Determine the Stability Class--Stability class was calculated using the σ_θ method. A σ_θ value was determined for each test period by the method described on the following page. Stability class was then estimated as presented in Table 5-4. An alternate method of estimating stability, based on wind speed and cloud cover, always agreed within half a stability class with the σ_θ method value.

Steps 2 through 5 Calculate Plume Dispersion Coefficients (σ_y and σ_z)--Values of σ_y and σ_z are a function of downwind distance, x, and stability class. For distances greater than 100 m, Pasquill's dispersion curves can be used to determine values of σ_y and σ_z (Turner 1970, pp 8-9). For distances less than 100 m, the following equations were utilized:

$$\sigma_y = \frac{\sigma_\theta}{57.3}(x) + \sigma_{yo} \qquad \text{(Eq. 9)}$$

$$\sigma_z = a(x + x_o)^b \qquad \text{(Eq. 10)}$$

The variables in Equations 9 and 10 were determined as follows:

σ_θ - The σ_θ value is the standard deviation of horizontal wind direction and was obtained by dividing the wind direction strip chart recording for the test period into increments of 1 min each, specifying an average direction for each increment, and calculating the standard deviation of the resulting set of readings. The upper limit of σ_θ for use in Equation 18 is 32°.

χ - The source-to-sampler distance was measured in the field and later obtained from the sketch of the sampling setup for each test. It is the straight line distance from the source to the sampler rather than the perpendicular distance from the source to a row of samplers.

σ_{yo} - Initial horizontal plume dispersion is the initial plume width divided by 4.30 (Turner 1970). The average initial plume width was observed and recorded during sampling. Photographs were also taken.

a,b - These are empirically-derived dispersion coefficients that are only applicable within 100 m of a ground-level source (Zimmerman and Thompson 1975). The coefficients are a function of stability class:

Stability class	a	b
A	0.180	0.945
B	0.145	0.932
C	0.110	0.915
D	0.085	0.870

x_o - The virtual distance term, x_o, is used to simulate the effect of initial vertical plume dispersion. It is estimated from the initial vertical plume dispersion value, σ_{zo}, which in turn is the observed initial plume height divided by 2.15 (Turner 1970):

$$x_o = b\sqrt{\sigma_{zo}/a}$$

Step 6 Correct Concentrations for Distance of Sampler Away from Plume Centerline--The dispersion equations assume that sampling is done along the plume centerline. For line sources, this is a reasonable assumption because the emissions occur at ground level and have an initial vertical dispersion (σ_{zo}) of 3 to 5 m. Therefore, the plume centerline is at about 2.5 m height, the same as the sampler heights.

Field personnel attempted to position samplers so that this relationship was maintained even in rough terrain. Horizontal dispersion does not enter into the calculation for line sources.

For point sources, it is not possible to sample continuously along the plume centerline because of varying wind directions and possibly because of varying emission heights (e.g., shovels and draglines). The problem of varying wind direction was accounted for by first determining the resultant wind direction relative to the line of samplers, trigonometrically calculating the horizontal distance from the sampler to the plume centerline (y), and then determining the reduction from centerline concentration with the following equation:

$$\text{reduction factor}_y = e^{-\frac{1}{2}\left[\left(\frac{y}{\sigma_y}\right)^2\right]} \qquad \text{(Eq. 11)}$$

Differences in the height of sampling and height of emission release were accounted for in the point source dispersion equation with an additional exponential expression when the average difference in height could be determined. Field personnel noted heights of emission release on data sheets for later use in dispersion calculations. The exponential expression used to determine the reduction from centerline concentration is:

$$\text{reduction factor}_z = e^{-\frac{1}{2}\left[\left(\frac{H}{\sigma_z}\right)^2\right]} \qquad \text{(Eq. 12)}$$

where H = average vertical distance from plume centerline to samplers, m

Step 7 Calculate Source Strength with Gaussian Dispersion Equation--The line source equation was used for haul road, scraper, and some dozer sources. The equation is:

$$\chi = \frac{2q}{\sin\phi \sqrt{2\pi}\, \sigma_z\, u} \qquad \text{(Eq. 13)}$$

where χ = plume centerline concentration at a distance x downwind from the mining source, g/m^3

q = line source strength, g/s-m

ϕ = angle between wind direction and line source

σ_z = the vertical standard deviation of plume concentration distribution at the downwind distance x for the prevailing atmospheric stability, m

u = mean wind speed, m/s

The point source dispersion equation was used in conjunction with dragline, coal loading, and other dozer operations. This equation is:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad \text{(Eq. 14)}$$

where Q = point source strength, g/s

σ_y = the horizontal standard deviation of plume concentration distribution at the downwind distance x for the prevailing atmospheric stability, m

χ, σ_z, u = same as Equation 14

Step 8 Convert Source Strength to an Emission Rate--The calculated values of q were converted to an emission rate per vehicle (haul roads and scrapers) or per hour. For the per vehicle unit, the q value in g/s-m was divided by the traffic volume during the sampling period. For the per hour unit, the q value was converted to lb/h at normal operating speed. Similarly, point source Q values were converted to emission rates per ton of material handled or per hour.

In summary, upwind-downwind emission rates were calculated using either a point source or line source version of the Gaussian dispersion equation. The point source equation utilized two additional factors to account for inability to sample on the plume centerline in the horizontal and vertical dimensions. Each sampler produced a separate estimate of emission rate for the test, so 8 to 10 values associated with different downwind distances were generated for each test.

IP and FP emission rates could have been calculated by using the procedure described above. However, at any specified point within the plume, the calculated emission rate is directly proportional to measured concentration. Therefore, ratios of measured IP and FP concentrations to TSP concentrations were calculated for each pair of dichotomous and hi-vol samplers. The resulting fractions were multiplied by the calculated TSP emission rate for the corresponding point in the plume to get IP and FP emission rates.

If particle deposition is significant over the distance of the downwind sampler array, apparent emission rates should decrease with distance from the source. Therefore, upwind-downwind sampling provided an implicit measure of the rate of deposition. In addition, the possible decrease in apparent emission rate with distance meant that the eight to 10 different values for a test could not simply be averaged to obtain a single emission rate for the test. The procedure for combining the values is explained in a following subsection.

Balloon Sampling

This calculation procedure combines concepts used in quasi-stack and exposure profiling sampling. However, it is less accurate than either of these two methods because the sampling equipment does not operate at isokinetic flow rates.

The balloon samplers were preset to a flow rate that was isokinetic at a wind speed of 5 mph. Since wind speed only approached this speed in two of the 18 tests, the sampling rates were normally super-isokinetic. The other two types of equipment in the array, hi-vols and dichotomous samplers, sample at a relatively constant air flow. In spite of this limitation, it was judged that a calculation involving integration of concentrations would yield better results than could be obtained by using a dispersion equation.

Step 1. Plot Concentration Data in Horizontal and Vertical Dimensions--Concentration data from the ground-based hi-vols and balloon-suspended samplers yield a concentration profile of the plume in both the horizontal and vertical directions. By combining these profiles with visual observations and photographs, it was possible to determine the plume boundaries. Conceptually, the next step was to approximate the volume of air that passed the sampling array by multiplying the product of wind speed and sampling duration by the cross-sectional area of the plume. This concept is similar to the procedures used in the quasi-stack calculations. Quasi-stack calculations are discussed in the next subsection.

The calculation procedure is essentially a graphical integration technique. Concentrations measured by the ground-level hi-vols (2.5 m height) were plotted against their horizontal spacing. By using visual observations, photographs taken in the field, and the curve itself, the profile was extrapolated to zero concentration at both edges of the plume. The resulting curve was assumed to represent the concentration profile at ground level and was graphically integrated. This concept is demonstrated in Figure 5-2.

Step 2 Estimate the Volume Formed by the Two Profiles--The balloon samplers were suspended at five specific heights of 2.5, 7.6, 15.2, 22.9, and 30.5 m. Since concentrations measured by these samplers were not directly comparable to those from hi-vols, concentrations at the four heights above 2.5 m were expressed as ratios of the 2.5 m concentration. The resulting curve of relative concentration versus height was extrapolated to a height of zero concentration, as shown in Figure 5-3. The next step was to multiply each of the ratios by the area under the ground-level concentration profile. This produced an approximation of the relative integrated concentration at each of the five heights. By using a trapezoidal approximation technique, an estimate of the volume formed by the two profiles was obtained.

Step 3 Calculate the TSP Emission Rate--The final emission rate calculation was made with the following equation:

$$E = 60\ V(u)t \qquad \text{(Eq. 15)}$$

where E = total emissions from blast, mg

V = volume under the two profiles, mg/m

u = wind speed, m/s

t = sampling duration, min

The final result was then converted to lb/blast. This value was recorded as the TSP emission rate.

Step 4 Calculate IP and FP Emission Rates--The next step was to calculate IP and FP emission rates. The unadjusted IP and FP concentrations for each dichot were expressed as fractions of their associated hi-vol concentrations. Then, the averages of the five unadjusted IP fractions and the five FP fractions were calculated and the 50 percent cut point for IP was adjusted to account for the inlet's dependence on wind speed. A more detailed discussion of the correction for wind speed is presented in a later subsection. The resulting fractions were multiplied by the TSP emission rate and the results reported as IP and FP emission rates.

The procedure outlined above incorporates a critical assumption concerning particle size distribution. Due to a lack of particle size data at each height, the assumption has been made that the fractions of the concentration less than 15 and 2.5 μm are the same throughout the plume as they are at 2.5 m height. Since particle size distribution measured at ground level was applied to the entire plume, the reported IP and FP emission rates are probably underestimates.

Wind Tunnel

To calculate emission rates from wind tunnel data, a conservation of mass approach is used. The quantity of airborne particulate generated by wind erosion of the test surface equals the quantity leaving the tunnel minus the quantity (background) entering the tunnel. Calculation steps are described below.

Step 1 Calculate Weights of Collected Sample--The samples are all collected on filters. Weights are determined by subtracting tare weights from final filter weights.

Step 2 Calculate Particulate Concentrations--The concentration of particulate matter measured by a sampler, expressed in units of micrograms per cubic meter (μg/m^3), is given by the following equation:

$$C = 3.53 \times 10^4 = \frac{m}{Q_s t} \qquad \text{(Eq.16)}$$

where: C = particulate concentration, μg/m^3

m = particulate sample weight, mg

Q_s = sampler flow rate, ACFM

t = duration of sampling, min

The coefficient in Equation 16 is simply a conversion factor.

The specific particulate matter concentrations determined from the various sampler catches are as follows:

TP - Cyclone/cascade impactor: cyclone catch + substrate catches + backup filter catch

TSP - Hi-Vol sampler: filter catch

To be consistent with the National Ambient Air Quality Standard for TSP, concentrations should be expressed at standard conditions (25°C and 29.92 in. of Hg.).

Tunnel inlet (background) concentrations of TP or any of the respective particulate size fractions are subtracted from corresponding tunnel exit concentrations to produce "net" concentrations attributable to the tested source. The tunnel inlet TP concentration is preferably obtained with an isokinetic sampler, but should be represented well by the TSP concentration measured by the modified hi-vol, if there are no nearby sources that would have a coarse particle impact on the tunnel inlet air.

Step 3 Calculate Tunnel Volume Flow Rate--During testing, the wind speed profile along the vertical bisector of the tunnel working section is measured with a standard pitot tube and inclined manometer, using the following equation:

$$u(z) = 6.51 \frac{H(z)\ T}{P} \qquad \text{(Eq.17)}$$

where $u(z)$ = wind speed, m/s

$H(z)$ = manometer reading, in. H_2O

z = height above test surface, cm

T = tunnel air temperature, °K

P = tunnel air pressure, in. Hg

The values for T and P are equivalent to ambient conditions.

A pitot tube and inclined manometer are also used to measure the centerline wind speed in the sampling duct, at the point where the sampling probe is installed. Because the ratio of the centerline wind speed in the sampling duct to the centerline wind speed in the test section is independent of flow rate, it can be used to determine isokinetic sampling conditions for any flow rate in the tunnel.

The velocity profile near the test surface (tunnel floor) and the walls of the tunnel is found to follow a logarithmic distribution (Gillette 1978):

$$u(z) \frac{u*}{0.4} \ln \frac{z}{z_o} \qquad \text{(Eq.18)}$$

where $u*$ = friction velocity, cm/s

z_o = roughness height, cm

The roughness height of the test surface is determined by extrapolation of the velocity profile near the surface to z=0. The roughness height for the plexiglas walls and ceiling of the tunnel is 6×10^{-4} cm. These velocity profiles are integrated over the cross-sectional area of the tunnel (30.5 cm x 30.5 cm) to yield the volumetric flow rate through the tunnel for a particular set of test conditions.

Step 4 Calculate Isokinetic Flow Ratio--The isokinetic flow ratio (IFR) is the ratio of the sampler intake air speed to the wind speed approaching the sampler. It is given by:

$$IFR = \frac{Q_s}{aU_s} \qquad \text{(Eq.19)}$$

where Q_s = sampler flow rate, ACFM

a = intake area of sampler, ft^2

U_s = wind speed approaching the sampler, fpm

IFR is of interest in the sampling of TP, since isokinetic sampling assures that particles of all sizes are sampled without bias.

Step 5 Calculate Downstream Particle Size Distribution--

The downstream particle size distribution of source-contributed particulate matter may be calculated from the net TP concentration and the net concentrations measured by the cyclone and by each cascade impactor stage. The 50 percent cutoff diameters for the cyclone precollector and each impaction stage must be adjusted to the sampler flow rate. Corrections for coarse particle bounce are recommended. The corrections are described on Page 5-36.

Because the particle size cut point of the cyclone is about 11 μm, the determination of suspended particulate (SP, less than 30 μm) concentration and IP concentration requires extrapolation of the particle size distribution to obtain the percentage of TP that consists of SP (or IP). A log normal size distribution is used for this extrapolation.

Step 6 Calculate Particulate Emission Rates--The emission rate for airborne particulate of a given particle size range generated by wind erosion of the test surface is given by:

$$e = \frac{C_n Q_t}{A} \qquad \text{(Eq.20)}$$

where e = particulate emission rate, g/m^2-s

C_n = net particulate concentration, g/m^3

Q_t = tunnel flow rate, m^3/s

A = exposed test area = $0.918 m^2$

Step 7 Calculate Erosion Potential--If the emission rate is found to decay significantly (by more than about 20 percent) during back-to-back tests of a given surface at the same wind speed, due to the presence of non-erodible elements on the surface, then an additional calculation step must be performed to determine the erosion potential of the test surface. The erosion potential is the total quantity of erodible particles, in any specified particle size range, present on the surface (per unit area) prior to the onset of erosion. Because wind erosion is an avalanching process, it is reasonable to assume that the loss rate from the surface is proportional to the amount of erodible material remaining:

$$M_t = M_o e^{-kt} \qquad \text{(Eq. 21)}$$

where M_t = quantity of erodible material present on the surface at any time, g/m^2

M_o = erosion potential, i.e., quantity of erodible material present on the surface before the onset of erosion, g/m^2

k = constant, s^{-1}

t = cumulative erosion time, s

Consistent with Equation 21, the erosion potential may be calculated from the measured losses from the test surface for two erosion times:

$$\frac{\ln\left(\frac{M_o - L_1}{M_o}\right)}{\ln\left(\frac{M_o - L_2}{M_o}\right)} = \frac{t_1}{t_2} \qquad \text{(Eq. 22)}$$

where L_l = measured loss during time period 0 to t_l, g/m^2

L_2 = measured loss during time period 0 to t_2, g/m^2

The loss may be back-calculated as the product of the emission rate from Equation 20 and the cumulative erosion time.

Quasi-Stack

The source strengths of the drill tests are determined by multiplying the average particulate concentration in the sampled volume of air by the total volume of air that passed through the enclosure during the test. For this calculation procedure, the air passing through the enclosure is assumed to contain all of the particulate emitted by the source. This calculation can be expressed as:

$$E = \chi V \qquad \text{(Eq. 23)}$$

where E = source strength, g

χ = concentration, g/m^3

V = total volume, m^3

Step 1 Determine Particle Size Fractions--As described in Section 3, isokinetic samplers were used to obtain total concentration data for the particulate emissions passing through the enclosure. Originally, these data were to be related to particle size, based on the results of microscopic analyses. However, the inconsistent results obtained from the comparability tests precluded the use of this technique for particle sizing. Consequently, the total concentration data were divided into suspended and settleable fractions. The filter fraction of the concentration was assumed to be suspended particulate and the remainder was assumed to be settleable particulate.

Step 2 Determine Concentration for Each Sampler--Rather than traverse the enclosure, as is done in conventional source testing, four separate profiler samplers were used during each test. These samplers were spaced at regular intervals along the horizontal centerline of the enclosure. Each sampler was set to the approximate isokinetic sampling rate. This rate was determined from the wind velocity measured at each sampler with a hot-wire anemometer. The wind velocity was checked at each sampler every 2 to 3 minutes and the sampling rates were adjusted as necessary.

Step 3 Calculate Volume of Air Sampled by Each Profiler--In order to simplify the calculation of source strength, it was assumed that the concentration and wind velocity measured at each sampler were representative of one-fourth the cross-sectional area of the enclosure. Thus, the total volume of air associated with each profiler concentration was calculated as follows:

$$V_i = (u_i)\ (a/4)(t) \qquad \text{(Eq. 24)}$$

where V_i = total volume of air associated with sampler i, m^3

u_i = mean velocity measured at sampler i, m/min

a = cross-sectional area of enclosure, m^2

t = sampling duration, min

Step 4 Calculate the Total Emissions as Sum of Four Partial Emission Rates--Separate source strengths, E, are calculated for the total concentration and the fraction captured on the filter. The equation is:

$$E = \sum_{i=1}^{4} v_i\ \chi_i \qquad \text{(Eq. 25)}$$

These source strengths, in grams, were converted to pounds per hole drilled and are reported in Section 11.

PARTICLE SIZE CORRECTIONS

Several different size fraction measurements require a mathematical calculation to correct for some deficiency in the sampling equipment from ideal size separation. Three of the calculation procedures are described here:

Correction of dichotomous samples to 15 μm values

Conversion of physical diameters measured microscopically to equivalent aerodynamic diameters

Correction of cascade impactor data to account for particle bounce-through.

Correction of Dichotomous Data

Recent research indicates that the collection efficiency of the dichotomous sampler inlet is dependent on wind speed (Wedding 1980). As shown in Figure 5-4, the 50 percent cut point that is nominally 15 μm actually varies from 10 to 22 μm over the range of wind speeds tested.

The procedure developed in the present study to correct dichot concentrations to a 15 μm cut point was to:

1. Determine the average wind speed for each test period.
2. Estimate the actual cut point for the sample from Figure 5-4.
3. Calculate net concentrations for each stage by subtracting upwind dichot concentrations.
4. Calculate the total concentration less than the estimated cut point diameter by summing the net concentrations on the two stages.
5. Adjust the fine fraction (<2.5 μm) concentration by multiplying by 1.11 to account for fine particles that remain in the portion of the air stream that carries the coarse fraction particles.
6. Calculate the ratio of fine fraction to net TSP concentration and the ratio of total net dichot concentration to net TSP concentration.
7. Plot (on log-probability paper) two data points on a graph of particle size versus fraction of TSP concentration. The two points are the fraction less than 2.5 μm and the fraction less than the cut point determined in step 2.
8. Draw a straight line through the two points and interpolate or extrapolate the fraction less than 15 μm. (Steps 7 and 8 are a graphical solution that may be replaced by a calculator program that can perform the linear interpolation or extrapolation with greater precision.)
9. Calculate the net concentration less than 15 μm from this fraction and the known net TSP concentration.

A relatively small error is involved in the assumption of a log linear curve between the two points because the 15 μm point is so near the point for the actual upper limit particle size. The largest uncertainty in applying this correction is probably the accuracy of the research data in Figure 5-4.

Conversion of Microscopy Data to Aerodynamic Diameters

Three calculation procedures for converting physical particle diameters into equivalent aerodynamic diameters were found in the literature (Hesketh 1977; Stockham 1977; and Mercer 1973). One of these was utilized in calculations in a recent EPA publication, so this procedure was adopted for the present project (U.S. Environmental Protection Agency 1978b). The equation relating the two measurements of particle size is:

$$d_a = d \sqrt{\frac{\rho C}{C_a}} \qquad \text{(Eq. 26)}$$

where d_a = particle aerodynamic diameter, μm

d = particle physical diameter, μm

ρ = particle density

C = Cunningham factor

= 1 + 0.000621 T/d

T = temperature, °K

C_a = Cunningham correction for d_a

This equation requires a trial-and-error solution because C_a is a function of d_a. The multiple iterations can be performed by a computer or calculator program (EPA 1978b).

In practice, C_a is approximately equal to C so the aerodynamic diameter (d_a) is approximately the physical diameter (d) times ρ. An average particle density of 2.5 was assumed with the microscopy data from this study, thus yielding conversion factors of about 1.58. It is questionable whether the trial-and-error calculation of C_a in Equation 26 is warranted when density values are assumed.

Correction of Cascade Impactor Data

To correct for particle bounce-through, MRI has developed a procedure for adjusting the size distribution data obtained from its cascade impactors, which are equipped with cyclone precollectors. The true size distribution (after correction) is assumed to be lognormal as defined by two data points: the corrected fraction of particulate penetrating the final impaction stage (less than 0.7 μm) and the fraction of particulate caught by the cyclone (greater than about 10 μm). The weight of material on the backup stage was replaced (corrected) by the average of weights caught on the two preceding impaction stages if the backup stage weight was higher than this average.

Because the particulate matter collected downwind of a fugitive dust source is produced primarily by a uniform physical generation mechanism, it was judged reasonable to assume that the size distribution of airborne particulate smaller than 30 μm is lognormal. This in fact is suggested by the uncorrected particle size distributions previously measured by MRI.

The isokinetic sampling system for the portable wind tunnel utilizes the same type of cyclone precollector and cascade impactor. An identical particle bounce-through correction procedure was used with this system.

COMBINING RESULTS OF INDIVIDUAL SAMPLES AND TESTS

Combining Samples

In the quasi-stack and exposure profiling sampling methods, multiple samples were taken across the plume and the measurements were combined in the calculations to produce a single estimate of emission rate for each test. However, in the upwind-downwind method, several (eight to 10) independent estimates of emission rate were generated for a single sampling period. These independent estimates were made at different downwind distances and therefore had differing amounts of deposition associated with them.

The procedure for combining upwind-downwind samples was based on comparison of emission rates as a function of distance. If apparent emission rates consistently decreased with distance (not more than two values out of progression for a test), the average from the front row samplers was taken as the initial emission rate and deposition at succeeding distances was reported as a percent of the initial emission rate. If apparent emission rates did not have a consistent trend or increased with distance, then all values were averaged to get an emission rate for the test and deposition was reported as negligible. Since deposition cannot be a negative value, increases in apparent emission rates with distance were attributed to data scatter, non-Gaussian plume dispersion, or inability to accurately locate the plume centerline (for point sources).

The amount of deposition from the front row to the back row of samplers is related to the distance of these samplers from the source, i.e., if the front samplers are at the edge of the source and back row is 100 m downwind (this was the standard set-up for line sources), a detectable reduction in apparent emission rates should result. However, if the front row is 60 m from the source and back row is 100 m further downwind (typical set-up for point sources due to safety considerations), the reduction in apparent emission rates with distance is likely to be less than the average difference due to data scatter.

These dual methods of obtaining a single estimate of emission rate for each test introduce an upward bias into the data; high levels on the front row in general lead to their retention as the final values, while low levels in general lead to averaging with higher emission rates from subsequent rows. This bias is thought to be less than the errors that would result in applying either of these methods universally for the different deposition situations described above. It should also be noted that other types of deposition measurements are possible.

Any single estimate more than two standard deviations away from the average of the remaining samples was considered an outlier and not included in calculating the average emission rate.

Combining Tests

Emission rates for three particle size ranges were reported for all tests, along with data on the conditions under which the tests were taken. These data were first subjected to multiple linear regression (MLR) analysis, as described below. Of the three size ranges, only the TSP and IP data were used in the MLR analysis. This analysis identified significant correction parameters for each source.

Next, adjusted emission rates were calculated for each test with the significant correction parameters. From this data set, average emission rates (base emission factors) and confidence intervals were calculated. The emission factor equation is this average emission rate times the correction factors determined from the MLR analysis.

PROCEDURE FOR DEVELOPMENT OF CORRECTION FACTORS

The method used to evaluate independent variables for possible use as correction factors was stepwise MLR. It was available as a computer program as part of the Statistical Package for the Social Sciences (SPSS). The MLR program outputs of interest in evaluating the data sets for each source were the multiple regression coefficient, significance of the variable, and reduction in relative standard deviation due to each variable. The stepwise MLR technique is described in moderate detail in Appendix A. Further information on it can be found in the following references: Statistical Methods, Fourth Edition (Snedecor 1946); Applied Regression Analysis (Draper 1965); and SPSS, Second Edition (Nie 1975).

Because of the high relative standard deviations $(s/\bar{x})$ for the data sets and the desire to have correction factors in the emission factor equations multiplicative rather than additive, all independent and dependent variable data were transformed to natural logarithms before being entered in the MLR program.

The stepwise regression program first selected the potential correction factor that was the best predictor of TSP emission rate, changed the dependent variable values to reflect the impact of this independent variable, then repeated this process with remaining potential correction factors until all had been used in the MLR equation or until no improvement in the predictive equation was obtained by adding another variable. Not all variables included in the MLR equation were necessarily selected as correction factors.

A detailed description of correction factor development procedures is given in Section 13 of Volume II.

TABLE 5-1. EVALUATION OF CORRECTION FACTORS WITH PARTIAL DATA SET

Source/Samples	Potential Correction Factor	Mult. R	Significance	Relative Std. Deviation
				0.838
Overburden drilling/23	Silt	0.58	0.004	0.699
	Depth of hole	0.63	0.161	0.681
	% moisture	0.63	0.809	0.697
				1.037
Blasting (coal)/9	No. of holes	0.47	0.199	0.977
	% moisture	0.48	0.860	1.053
				1.149
Coal loading/10	Bucket capacity	0.39	0.264	1.122
				0.784
Dozer (ovbd)/11	Speed	0.61	0.048	0.657
	Silt	0.69	0.239	0.636
	% moisture		Did not improve regression	
				0.695
Dozer (coal)/7	Speed	0.84	0.019	0.416
	Silt		Did not improve regression	
	% moisture		Did not improve regression	
				1.446
Dragline/11	Drop distance	0.88	0.000	0.733
	% moisture	0.91	0.120	0.662
	Bucket capacity	0.92	0.334	0.659
	Operation	0.96[a]	0.048[a]	0.500
	Silt		Did not improve regression	
				1.470
Haul truck/18	Silt	0.40	0.048	1.377
	No. of passes	0.46	0.074	1.364
	Control	0.47	0.148	1.387
	Moisture	0.48	0.258	1.419
Lt.- and med.-duty vehicles/6	Veh. weight (added to above)	0.54[b]	0.280	1.076[b]
				0.888
Scraper/ 12	Silt	0.15	0.649	0.922
	% moisture	0.20	0.827	0.961
	No. of passes	0.28	0.877	1.000
Grader/5	Not enough data			

[a]Interrelated with drop distance, so not used as a correction factor.
[b]The four variables for haul roads all explained more variance than vehicle weight, and it did not reduce residual coefficient of variation for combined haul road/access road data set.

TABLE 5-2. CALCULATED SAMPLE SIZES USING TWO-STAGE METHOD

Source	Single Pop.	First Est.	n_1	$t_{0.8}$[a]	s[b]	$\bar{x}$	$s/\bar{x}$	n, per mine	n, total
Drilling	no	40	11	1. 383	From Table 5-1		0.70	15	45
			12	1.372	From Table 5-1		0.70	15	
Blasting (coal)	yes	12	9	1.397	18.7	18.0	1.04		34
Coal loading	yes	30	10	1.383	0.031	0.027	1.15		41
Dozer (ovbd)	yes	18	11	1. 383	From Table 5-1		0.66		14
Dozer (coal)	no	18	4	1.638	8.97[b]	25.4	0.35	6[b]	27
			3	1.886	3.01[b]	6.54	0.46	12[b]	
Dragline	yes	18	11	1. 383	From Table 5-1		0.73		17
Haul truck (PEDCo est.)	no	30	5	1.533	4.54	9.67	0.47	9	30
			6	1.476	10.37	19.20	0.54	11	
Haul truck IP (MRI est.)	no	30	6	1.476	3.99	6.68	0.60	13	29
			6	1.476	0.62	1.56	.40	6	
Lt.- and med.- duty vehicles	yes	15	5	1.533	3.30	2.87	1.15		50
Scraper	yes	18	12	1.363	13.99	15.75	0.89		24
Grader	?	9	5	1.533	0.90	1.7	.53		11

[a] Degrees of freedom (d.f.) for calculating t are n_1-1 unless there are correction factors, in which case d.f. are reduced by 1 for each correction b factor.

[b] Smaller sample sizes are required without use of correction factor for speed.

TABLE 5-3. SAMPLE SIZES PROPOSED AND OBTAINED

Source	Samples Proposed in Study dsn	Samples Required by 2-Stage Method	Samples Proposed in Stat Plan	Rel. Error for Samples in Stat Plan	Samples Actually Collect
Drilling	40	45	30	0.20	30
Blasting (coal)	12	34	16	0.36	16
Coal loading	30	41	24	0.32	25
Dozer (ovbd)	18	14	16	0.31	15
Dozer (coal)	18	27	10	0.31	12
Dragline	18	17	19	0.21	19
Haul truck	30	30	40	0.19	36
Lt.- and med. - duty vehicles	15	50	12[a]	0.45[a]	12
Scrapers	18	24	24	0.24	15
Graders	9	11	8	0.27	7

[a]Expected to be combined with haul roads in a single emission factor.

TABLE 5-4. σ_θ METHOD OF DETERMINING ATMOSPHERIC STABILITY CLASS

σ_θ	Stability Class
σ_θ >22.5°	A
17.5 <σ_θ <22.5	B
12.5 <σ_θ <17.5	C
σ_θ <12.5	D

(σ_θ <7.5° would be E stability, but D would be used because all sampling occurred during daytime and E is only a nighttime stability class)

Source: Mitchell 1979.

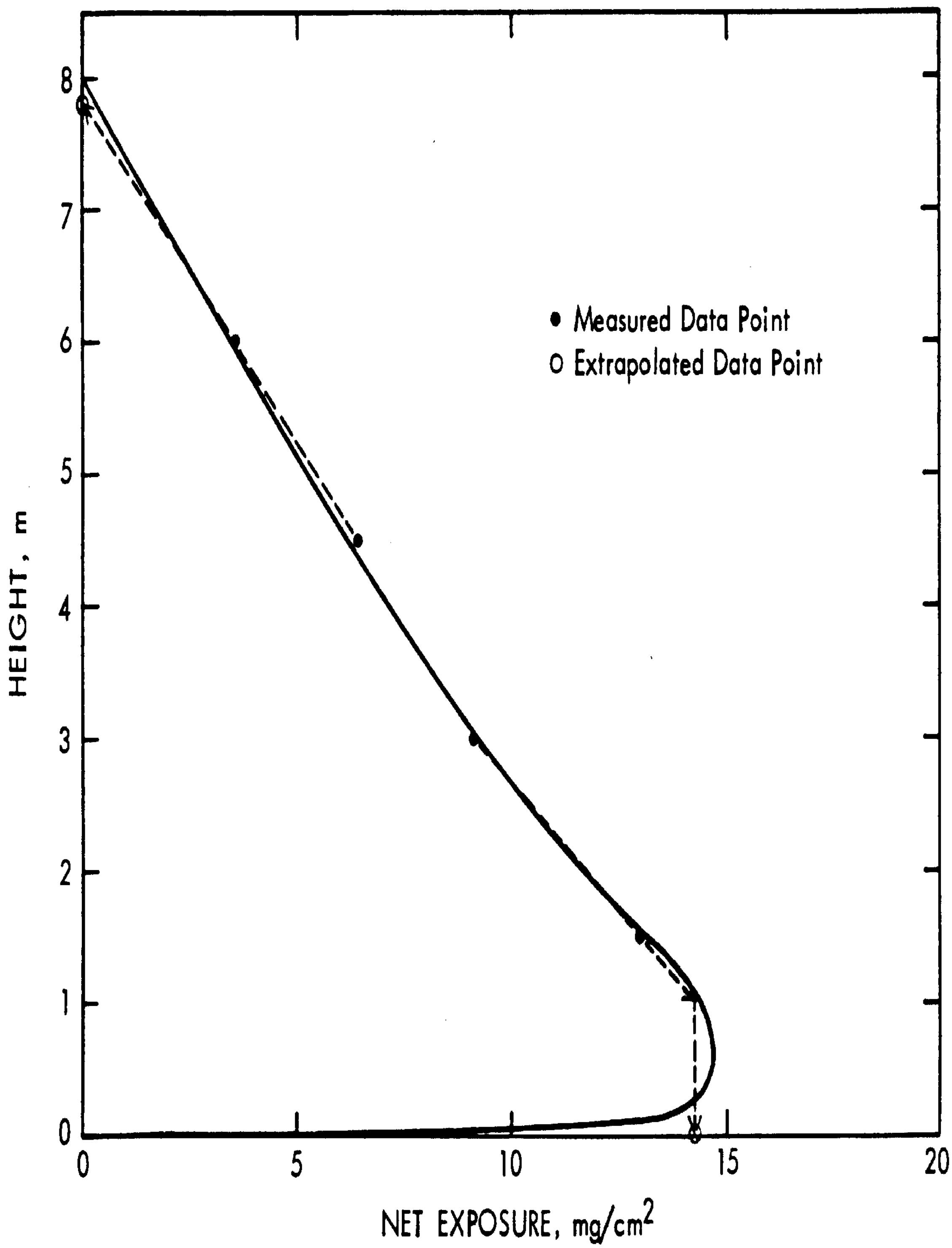


Figure 5-1. Illustration of exposure profile extrapolation procedures (haul truck J-9).

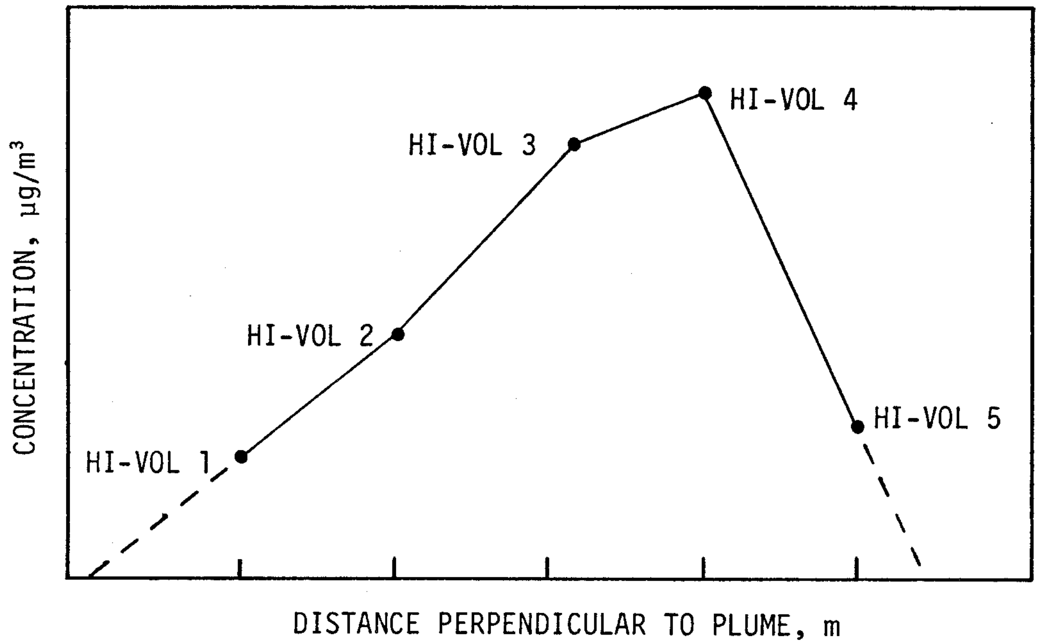


Figure 5-2. Example ground-level concentration profile.

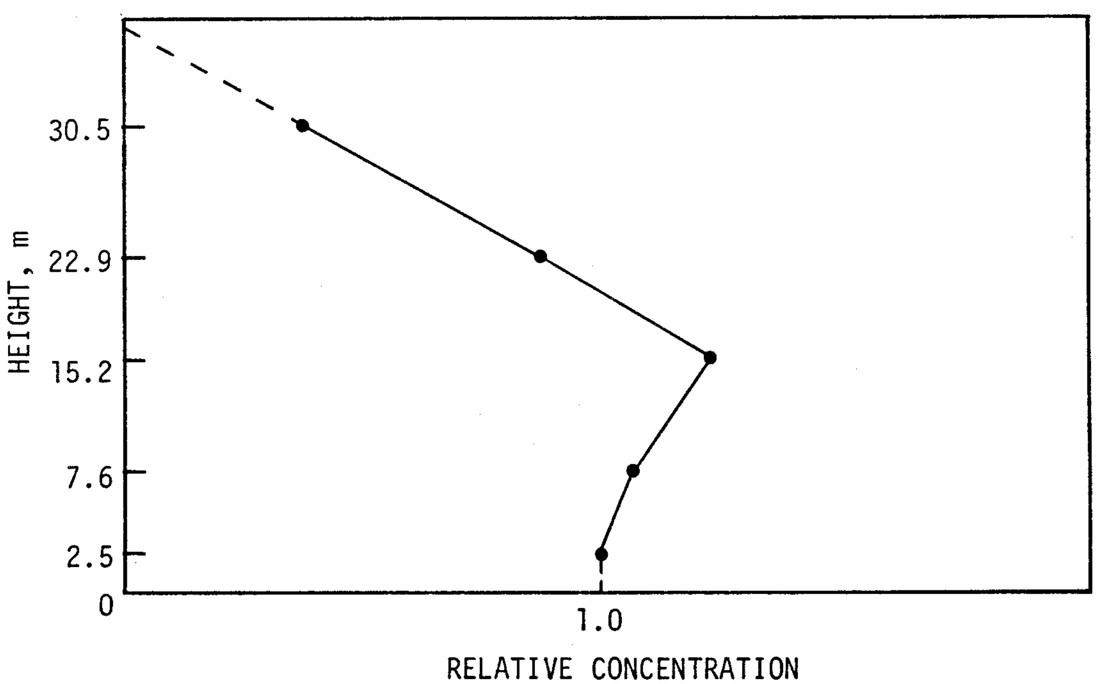


Figure 5-3. Example vertical concentration profile.

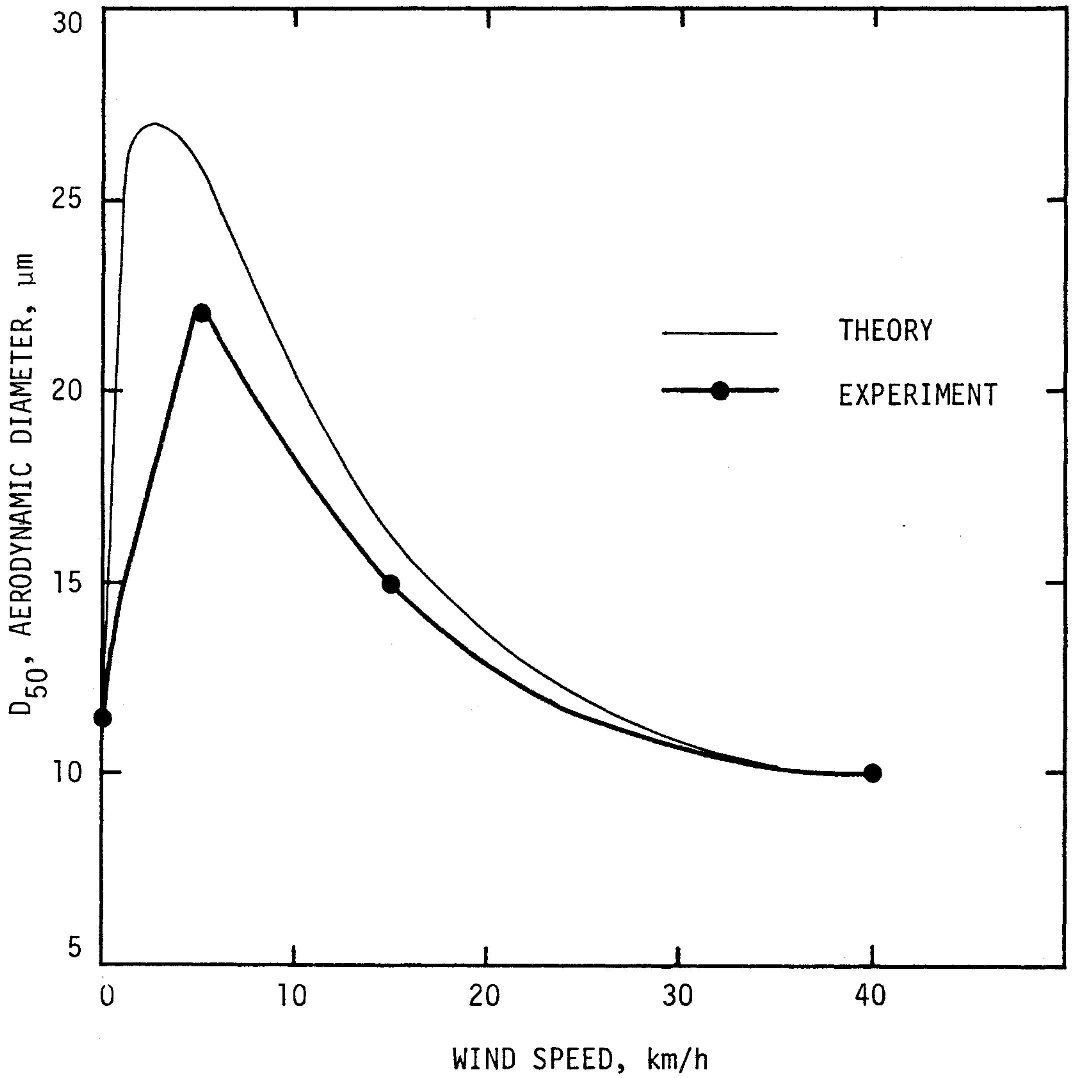


Figure 5-4. Plot of the 50 percent cut point of the inlet versus wind speed.

SECTION 13
DEVELOPMENT OF CORRECTION FACTORS AND EMISSION FACTOR EQUATIONS

The method for developing correction factors was based on multiple linear regression (MLR), as described in Section 5 (Page 5-32). To summarize the method briefly, values for all variables being considered as possible correction factors were tabulated by source with the corresponding TSP emission rates for each test, then the data were transformed to their natural logarithms. The transformed data were input to the MLR program, specifying the stepwise option and permitting entry of all variables that increased the multiple regression coefficient (initially allowing the program to determine the order of entry of the variables).

The MLR output of greatest interest was the significance of each variable. In nontechnical terms, significance is the probability that the observed relationship between the independent and dependent variables is due to chance. If the significance was less than 0.05, the variable was included as a correction factor; if it was between 0.05 and 0.20, its inclusion was discretionary; and if above 0.20, the variable was not included. The correction factors were multiplicative because of the ln transformation; the power for each significant correction factor was specified in the MLR output as the coefficient (B value) for that variable in the linear regression equation.

This MLR analysis could not be employed with data from the wind erosion sources because sequential tests were found to be related and were grouped, thus reducing the number of independent data points. With the large number of potential correction parameters in relation to data points, regression analysis was not feasible.

MULTIPLE LINEAR REGRESSION ANALYSIS

The stepwise multiple linear regression program that is the nucleus of the correction factor development procedure is explained in moderate detail in Appendix A. Further information on it can be found in the following three references: Statistical Methods, Fourth Edition (Snedecor 1946); Applied Regression Analysis (Draper and Smith 1965); and SPSS, Second Edition (Nie 1975).

The independent variables that were evaluated as possible correction factors are listed in Table 13-1. An assessment was made during the MLR analysis to determine the portion of the total variation in the emission factors explained by the correction factors (multiple regression coefficient squared) and whether additional variables should have been considered. The data for each of these variables were presented in tables throughout Sections 7 through 11 (Volume I), and have not been repeated here.

The data were all transformed to their natural logarithms prior to running MLR. The presumption that the ln transformation would provide better final emission factor equations was based on three considerations: the data sets all had high relative standard deviations indicating that the distributions of the emission factor were skewed to the right (i.e., a long upper tail); the homogeneity of variances (a condition for any least squares analysis) was increased; and multiplicative correction factors were preferable to additive ones.

More than one MLR run was usually required to obtain the final MLR equation, with its associated significance and regression coefficients (B values). Second and third runs were needed to eliminate a data point shown to be an outlier, to remove a variable highly correlated with another, to remove a variable with significance of 0.05 to 0.20 that entered the stepwise regression ahead of another variable still being evaluated, or to eliminate a dummy variable (such as a source subcategory or control/no control) after its significance had been determined. The sequence of MLR runs with the TSP data for each source is documented by presenting in Table 13-2 the results of the first run for each source (with all the variables included), a description in Table 13-3 of all changes made to get to the final run, and in Table 13-4 the results of the final run.

The multiple regression (correlation) coefficient, R. is a measure of how well the variables in the equation explain variations in emission rate. (Actually, R^2 is the portion of the total variation explained by the use of the specified variables). Significance, the second reported statistic, estimates the chance that the observed correlation for a particular variable is due to random variation. Finally, the residual relative standard deviation measures the amount of variability left in the transformed data set after adjustment as indicated by the regression equation. In the transformed data set, the mean logarithmic values can be quite small. Consequently, the relative standard deviations are larger than normally encountered in regression analysis.

Several independent variables were fairly significant (less than 0.20) when they entered the regression equations, but were not included as correction factors in the final emission factors. The reasons for omitting these potential correction factors are explained below, by source:

Drills/Silt -This variable was highly significant but was inversely rather than directly related to emission rate. Therefore, the last potential correction factor for this source is eliminated; the reported emission factor is simply the geometric mean of the observed values.

Blasts/No. of holes -This variable was highly correlated with another independent variable, area blasted, which entered the regression equation before number of holes.

Coal loading/Bucket size -Bucket size was related to emission rate by a power of -12.3 in the regression equation, primarily because of the very narrow range of bucket sizes tested--14 to 17 yd^3 . Also, bucket size only had a correlation of 0.05 with emission rate.

Dozer, all/Dozer speed - Although equipment speed was significant in the combined data set, it was not significant in either of the subsets (coal dozers or overburden dozers).

Dragline/Silt - In the first run, silt was not a significant variable. However, when an outlier was removed, it became highly significant but was inversely rather than directly related to emission rate.

Scrapers/Vehicle speed - This parameter was significant at the 0.111 level, in the discretionary range. It was omitted because of its high correlation with silt which entered the equation earlier.

Light- and medium-duty vehicles/Weight - This was omitted to preserve the simplicity of the resulting equation in light of the high correlation between emission factor and moisture, the first parameter entered.

Haul trucks/Vehicle speed - Inverse relationship with emission rate was inconsistent with all previous studies.

Haul trucks/Weight - This parameter was omitted because its coefficient was negative, which is difficult to justify from the physics of the problem.

These relationships conflicted with previous experience in fugitive dust testing. While the actual relationship may be similar to that indicated by the MLR equation, some confirmation in the form of additional data was thought to be needed before including these dubious parameters as correction factors.

The transformations, initial MLR runs, adjustments, and additional MLR runs were done by the same procedures with the IP emission data as with the TSP data, using the same values of the independent variables. The results are summarized in an analogous series of three tables—Tables 13-5, 13-6, and 13-7. As indicated in Table 13-6, very few changes were required from the initial runs of the IP data, with the benefit of the prior TSP runs. For every source, the same independent variables were highly significant for IP as for TSP.

EMISSION FACTOR PREDICTION EQUATIONS

The prediction equations obtained from the MLR analyses are summarized in Table 13-8. These equations were taken directly from the MLR runs described in Tables 13-4 and 13-7, with the coefficients in the Table 13-8 equations being the exponentials of the MLR equation constant terms and the exponents for each term being the B values. These equations give estimates of the median value of the emission factors for given value(s) of the correction factor(s). (The coefficients and exponents are from the intermediate MLR step that includes only the significant variables that appear in the final equation.) All but four of the independent variables in the equations in Table 13-8 are significant at the 0.05 level or better. The four variables in the discretionary range (0.05 to 0.20) that were included are: L in haul truck TSP equation, $\propto = 0.146$; A in the coal blasting IP equation, $\propto = 0.051$; M in the overburden IP equation, $\propto = 0.071$; and S in the grader IP equation, $\propto = 0.078$. The geometric mean values and ranges of the correction factors are summarized in Table 13-9.

CONFIDENCE AND PREDICTION INTERVALS

A computational procedure for obtaining confidence and prediction intervals for emission factors is described in Appendix B at the end of this volume of the report. An example of this computation is given here for coal loading emission data versus the moisture content correction factor.

Figure 13-1 summarizes the results of this example and also includes the observed emission factors. The line in the center of the graph is the predicted median emission rate estimated by the geometric mean. The inside set of curves give the confidence interval for the "true median" as a function of moisture content (M), and the outside set of curves give the prediction interval for an individual emission factor. The intervals vary in length as a function of M. The widths of the intervals are measures of the precision of the estimated factors. These precisions are comparable to those of existing emission factors as illustrated in Section 14.

To summarize the information contained in these curves for confidence intervals, the following information is presented:

1. Prediction equation for the media emission factor from Table 13-8: TSP, lb/ton = $1.16/M^{1.2}$.

2. Geometric mean and range (maximum and minimum values) of moisture content correction factor from Table 13-9: GM = 17.8 percent, 6.6 to 38 percent.

3. Estimated median emission factor at the geometric mean (GM) of the correction factor from Table 13-10: 0.034 lb/ton.

4. Ninety-five percent confidence intervals for the median emission factor (the median value for a large number of tests over one year) at the GM of each correction factor from Table 13-10: 0.023 lb/ton to 0.049 lb/ton.

5. Ninety-five percent prediction intervals for an individual emission factor (approximately one hour) at the GM of the correction factor from Table 13-10: 0.005 lb/ton to 0.215 lb/ton.

The confidence and prediction interval data are given only for one value of the correction factor(s) in order to simplify the presentation. The widths of the intervals at the GM are indicative of the widths at other values provided one uses a percentage of the median value in deriving the confidence and prediction limits. For example, for the coal loading data the lower confidence limits are approximately 50 to 70 percent of the median value, the upper limits are 140 to 170 percent of the median value; the lower prediction limits are 15 percent of the median value and the upper limits are 630 percent (or 6.3 times) of the median value. The coal loading data are slightly more variable than data for other sources and hence the limits are proportionately wider than for the other sources.

Fine particulate (FP) emission factors were not developed by the same series of steps as were the TSP and IP factors, because of the larger variances expected in these data sets and the many tests with negligible readings. However, the relative standard deviations calculated from data in Table 12-2 indicate variability approximately the same as for TSP and IP data. The geometric mean ratios of FP to TSP presented in Table 13-8 are proposed for use with the TSP emission factor equations to derive FP emission factors. The FP emission factor is obtained by multiplying the median FP/TSP ratio times the calculated TSP emission factor for each source.

EMISSION FACTORS FOR WIND EROSION SOURCES

In nearly all of the tests of wind erosion emissions from the surfaces of coal piles and exposed ground areas, the SP and IP emission rates were found to decay sharply with time. An exception was the sandy topsoil tested at Mine 3; in that case, an increase in emission rate was observed, probably because of the entrainment effect of infiltration air as the loose soil surface receded below the sides of the wind tunnel. The concept of erosion potential was introduced in Section 5 to treat the case of an exponentially decreasing quantity of erodible material on the test surface. The erosion potential is the total quantity of particles, in any specified particle size range, present on the surface (per unit area) that can be removed by erosion at a particular wind speed.

The calculation of erosion potential necessitated grouping of sequential tests on the same surface. In effect, this reduced the number of independent data points for coal and overburden emissions from 32 to 16. As a result, the decision was made not to subject these data to regression analysis because of the large number of potentially significant correction parameters in relation to the number of emission measurements for any given surface type and condition.

Table 13-11 lists the calculated values of erosion potential classified by erodible surface type and by wind speed at the tunnel centerline. For the most part, the test wind speeds fit into 3-mph increments; values of erosion potential for the few runs performed at other wind speeds are listed under the nearest wind speed category. Whenever erosion potential is given as a range, the extremes represent two data points obtained at nominally the same conditions.

Erosion potential was calculated using Equation 22 (Chapter 5), which is repeated here:

$$\frac{\ln\left(\frac{M_o - L_1}{M_o}\right)}{\ln\left(\frac{M_o - L_2}{M_o}\right)} = \frac{t_1}{t_2} \qquad \text{(Eq. 22)}$$

where M_o = erosion potential, i.e., quantity of erodible material present on the surface before the onset of erosion, g/m^2

t = cumulative erosion time, s

L_1 = measured loss during time period 0 to t_1, g/m^2

L_2 = measured loss during time period 0 to t_2, g/m^2

Alternatively, Equation 22 can be rewritten as follows:

$$\left(1 - \frac{L_2}{M_o}\right) = \left(1 - \frac{L_1}{M_o}\right)^{\frac{t_2}{t_1}} \qquad \text{(Eq. 22a)}$$

An iterative calculation procedure was required to calculate erosion potential from Equation 22 or 22a. Further, two cumulative loss values and erosion times obtained from back-to-back testing of the same surface were required. Each loss value was calculated as the product of the emission rate and the erosion time.

For example, Runs P-27 and P-28 took place on a coal pile furrow at a tunnel centerline wind speed of 36 mph. The incremental losses were calculated as follows:

P-27: 0.0386 g/m^2-s x 120 s = 4.63 g/m^2

P-28: 0.00578 g/m^2-s x 480 s = 2.77 g/m^2

Thus the values substituted into Equation 22 for this test series were:

L_1 = 4.63 g/m^2

t_1 = 120 s

L_2 = 4.63 + 2.77 = 7.40 g/m^2

t_2 = 120 + 480 = 600 s

A value of M_o = 10 was selected and substituted into the right-hand side of Equation 22a and the left-hand side was solved for M_o. The resulting value of 7.75 was then substituted back into the right-hand side to obtain a new solution--7.48. Additional substitutions were made and the iteration procedure converged quickly to 7.46 for erosion potential (M_o), indicating that only a small additional loss (0.06 g/m^2)

would have occurred if the tunnel had been operated beyond the 600-s time period at the same wind speed. The corresponding nonmetric value for the erosion potential is 67 lb/acre, which rounds to 70 lb/acre.

Data from unpaired runs (J-26, J-27, K-39, P-20, and K-37) were used to derive estimated values of erosion potential. Except for J-26, the erosion times were long enough so that the measured losses approximated the corresponding erosion potentials.

Note that whenever a surface was tested at sequentially increasing wind speeds, the measured losses from the lower speeds were added to the losses at the next higher speeds and so on. This reflects the hypothesis that, if the lower speeds had not been tested beforehand, correspondingly greater losses would have occurred at the higher speeds.

The emissions from the coal pile at Mine 3 appear to be significantly lower than the coal pile emissions measured at Mines 1 and 2. The coal pile at Mine 3, which had been inactive for a period of days, was noticeably crusted; but attempts were made to test areas where relatively fresh vehicle tracks were present. It is not known what percentage of the erosion potential of these test areas may have been lost because of brief periods of high winds which typically occurred with the evening wind shift. The coal pile furrow tested at Mine 3 had a much greater portion of large chunks of coal (exceeding 1 inch in size) on the surface, in comparison with the scraper and truck tracks.

The uncrusted overburden and scoria surfaces tested at Mine 2 exhibited emission rates that were much lower than the coal surfaces tested, except for the coal pile furrow. This reflects the larger portion of nonerodible coarse aggregates present on these non-coal surfaces.

The wind speeds that were used in the testing (Table 13-11), which exceeded the threshold for the onset of visually observable emissions, corresponded to the upper extremes of the frequency distributions of hourly mean wind speeds observed (at a height of 5-10 m) for most areas of the country. For flat surfaces, the wind speed at the centerline of the wind tunnel, 15 cm above the surface, is about half the value of the wind speed at the 10 m reference height. However, for elevated pile surfaces, particularly on the windward faces, the ratio (u_{15}+/u_{ref}) may approach and even exceed unity. It should be noted that smart but measurable erosion may have occurred at the threshold velocity.

In estimating the magnitude of wind generated emissions, wind gusts must also be taken into account. For the surfaces tested, typically about three-fourths of the erosion potential was emitted within 5 min of cumulative erosion time. Therefore, although the mean wind speeds at surface coal mines will usually not be high enough to produce continuous wind erosion, gusts may quickly deplete the erosion potential over a period of a few hours. Because erosion potential increases rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable which best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement which has passed by the 1-mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 min (for a fastest mile of 30 mph), matches well with the half life of the erosion process, which ranges between 1 and 4 min.

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action which results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed ground area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

Although vehicular traffic alters the surface by pulverizing surface material, this effect probably does not restore the full erosion potential, except for surfaces that crust before substantial wind erosion occurs. In that case, breaking of the crust over the area of the tire/surface contact once again exposes the erodible material beneath.

The emission factor for wind generated emissions of a specified particle size range may be expressed in units of lb/acre month as follows:

$$\text{Emission Factor} = f \cdot P(u_{15}^{+}) \qquad \text{(Eq. 29)}$$

where f = frequency of disturbance, per month

$P(u_{15}^{+})$ = erosion potential corresponding to the observed (or probable) fastest mile of wind for the period between disturbances, after correcting the fastest mile to a height of 15 cm (as described below), lb/acre.

$P(u_{15}^{+})$ is taken directly from Table 13-ll for the type of surface being considered. Interpolation or limited extrapolation of erosion potential data may be required.

When applying Equation 29 to an erodible surface, a modified form of Equation 18 (Page 5-23) is used to correct the fastest mile of wind from the reference anemometer height at the reporting weather station to a height of 15 cm. The correction equation is as follows:

$$u_{15}^{+} = u_{ref}^{+} \frac{\ln\left(\frac{15}{z_o}\right)}{\ln\left(\frac{h_{ref} - h_{surf}}{z_o}\right)} \qquad \text{(Eq. 30)}$$

where u_{15}^{+} = corrected value of the fastest mile, mph

u_{ref}^{+} = value of the fastest mile measured at the reference height, mph

h_{ref} = height of the reference anemometer above ground, cm

h_{surf} = height of the eroding surface above ground, cm

z_o = roughness height of the eroding surface, cm

An estimated value of the roughness height for the surface being considered may be obtained from Table 13-12.

Equation 30 is restricted to cases for which h_{ref} - h_{surf} $\geq$ 15 cm. Because the standard reference height for meteorological measurement is 10 m, this restriction generally allows for piles with flat upper surfaces as high as about 9.85 m and conical piles as high as 19.7 m. However, there may be situations which do not conform to the above restriction; for example, when the meteorological measurement height is as low as 5m. As a default value for these cases, u_{15}^{+} is set equal to u_{ref}^{+} i.e., no height correction is made for the measured fastest mile.

Values of h_{surf} in Equation 30 reflect the extent to which the eroding surf contour penetrates the surface wind layer. Clearly for flat ground surfaces, h_{surf} = 0. For an elevated storage pile with a relatively flat upper surface, h_{surf} represents the height of the upper surface above ground. For conical shaped piles, one-half the pile height is used as a first approximation for h_{surf}. In the case of elevated storage pile surfaces, the emission factor equation (Equation 29) is expressed per unit area of contact between the pile and the ground surface.

To illustrate the application of Equation 29, the following hypothetical example is offered. A coal surge pile planned for a new mine development will have a relatively flat upper surface with an average height of 6 m. The pile will be disturbed at nearly regular intervals every 3 months by adding coal to or removing coal from the surface using trucks and front-end loaders. During periods between disturbance, it is anticipated that light crusting will occur. The fastest mile data for the nearest weather station is shown in Table 13-13, representing a 5-year length of record. The height of the reference meteorological instrument is 8.0 m above the ground.

To derive the annual average emission factor, the year is divided into quarterly periods. The fastest mile for each period is determined, and the average value is calculated. From Table 13-13, the 3-month fastest mile values of 47, 38, 45, and 41 mph yield an average of 43 mph. Next, Equation 30 is used to correct the average fastest mile from the reference height of 8 m to 15 cm above the 6-m height of the upper pile surface. A value of 0.06 cm is used as the roughness height for a lightly crusted coal pile surface, as taken from Table 13-12. Substitution of these data into Equation 30 yields:

$$u_{15}^{+} = 43 \frac{\ln \frac{15}{0.06}}{\ln \frac{800-600}{0.06}} = 29 \text{ mph}$$

From Table 13-11, the SP erosion potential for 29 mph on a lightly crusted coal pile is 140 lb/acre. Substitution into Equation 29 yields:

$$\text{SP emission factor} = \frac{0.33}{\text{mo}} \times 140 \frac{\text{lb}}{\text{acre}} = 46 \frac{\text{lb}}{\text{acre-mo}}$$

Using the appropriate IP/SP ratio from Table 13-12, the corresponding IP emission factor is 46 x 0.55 = 25 lb/acre-mo.

One notable limitation in the use of Equation 29 is its application to active storage piles. Because the fastest mile is recorded only once per day, use of the daily fastest mile to represent a surface disturbed more than once per day will result in an over-estimate of emissions.

The approach outlined above for calculation of emission factors appears to be fundamentally sound, but data limitations produce a large amount of uncertainty in the calculated factors. Even though the erosion potential values are judged to be accurate to within a factor of two or better for the surfaces tested, it is not known how well these surfaces represent the range of erodible surface conditions found at Western surface coal mines. Additional uncertainty results from the use of Equation 30 to correct the fastest mile values to a height of 15 cm above the erodible surface. Taking all the sources of uncertainty into account, it is thought that the wind erosion emission factors derived for surfaces similar to those tested are accurate to within a factor of about three.

The levels of uncertainty in SP and IP emission factors derived by the technique outlined in this section could be reduced substantially by gathering more data to better define:

1. Relationship of erosion potential to wind speed.
2. Relationship between approach wind speed and the distribution of surface wind speed around basic pile shapes of varying size.
3. Relationship of erosion potential to surface texture.
4. Effect of crusting.

Previous research on wind erosion of natural surfaces could provide some insight into the nature of these effects. Soil loss resulting from wind erosion of agricultural land has been the subject of field and laboratory investigation for a number of years. This research has focused on the movement of total soil mass, primarily sand-sized aggregates, as a function of wind and soil conditions (Bagnold 1941; Chepil and Woodruff 1963). Only relatively recently, however, have field measurements been performed in an effort to quantify fine particle emissions produced during wind erosion of farm fields (Gillette and Blifford 1972; Gillette 1978).

Until further research is accomplished, it is recommended that wind erosion factors be used with full consideration of their uncertainty and preliminary nature. It is recommended that their use be restricted to estimates of emissions relative to other mine sources and that they not be used for estimating the ambient air impact of wind erosion at surface coal mines.

TABLE 13-1. VARIABLES EVALUATED AS CORRECTION FACTORS

Source	Sample Size[a]	Variables Evaluated	Units
Drill, overburden	30	Silt	%
		Moisture	%
		Depth of drilling	ft
Blasting	18	Material blasted (coal	-
		or overburden)	-
		No. of holes	ft^2[b]
		Area blasted	ft
		Depth of holes	%
		Moisture	m
		Distance to samplers	m/s
		Wind speed	-
		Stability class	
Coal loading	25	Equipment type	-
		Bucket size	yd^3
		Moisture	%
Dozer	27	Material worked	-
		Dozer speed	mph
		Silt	%
		Moisture	%
		Wind speed	m/s
Dragline	19	Drop distance	ft
		Bucket size	yd^3
		Silt	%
		Moisture	%
Scrapers	15	Silt	%
		Weight	tons
		Vehicle speed	mph[b]
		Wheels	-
		Silt loading	g/m^2
		Moisture	%
		Wind speed	m/s
Graders	7	c	c
Light- and medium duty vehicles	10	c	c
Haul trucks	27	c	c

[a]Uncontrolled runs only.

[b]Originally reported in metric units in Volume I; the variable values were c converted to English units.

[c]Same as for scrapers.

TABLE 13-2. RESULTS OF FIRST MULTIPLE LINEAR REGRESSION RUNS (TSP)

Source	Variable (in order of MLR output)	Multiple R	Significance	Rel. Std. Dev.
				9.54
Drill	Silt	0.51	0.004	8.35
	Moisture	0.53	0.421	8.40
	Depth	0.53	0.719	8.54
				0.515
Blasting, all	Area blasted	0.73	0.001	0.363
	Moisture	0.79	0.077	0.337
	Depth of holes	0.90	0.002	0.246
	Wind speed	0.91	0.248	0.242
	No. of holes	0.93	0.163	0.232
	Material blasted	0.93	0.300	0.230
	Dist. to samplers	0.94	0.589	0.238
	Stability class	0.94	0.910	0.250
				0.596
Blasting, coal[a]	Moisture	0.82	0.000	0.353
	Areas blasted	0.90	0.022	0.287
	Wind speed	0.92	0.143	0.269
	No. of holes	0.94	0.123	0.247
	Depth of holes	0.94	0.608	0.257
	Stability class	0.94	0.523	0.267
	Dist. to samplers	0.95	0.662	0.283
				0.414
Coal loading, all	Equipment type	0.74	0.000	0.287
	Moisture	0.77	0.097	0.275
	Bucket size	0.89	0.000	0.203
				0.492
Coal loading, front-end loaders[a]	Moisture	0.80	0.000	0.306
	Watering	0.90	0.001	0.230
				0.762
Dozer, all	Material worked	0.66	0.000	0.582
	Moisture	0.91	0.000	0.331
	Silt	0.92	0.040	0.308
	Dozer speed	0.95	0.004	0.260
	Wind speed	0.95	0.477	0.263
				0.458
Dozer, coal[a]	Silt	0.97	0.000	0.112
	Moisture	0.98	0.139	0.103
	Dozer speed	0.98	0.625	0.108

TABLE 13-2 (continued)

Source	Variable (in order of MLR output)	Multiple R	Significance	Rel. Std. Dev.
				0.867
Dozer, overburden[a]	Moisture	0.78	0.001	0.566
	Silt	0.87	0.029	0.471
	Dozer speed	0.91	0.072	0.417
				0.416
Dragline	Drop distance	0.74	0.000	0.288
	Moisture	0.85	0.004	0.229
	Silt	0.86	0.365	0.230
	Bucket size	0.87	0.147	0.236
				0.526
Scrapers (all uncontrolled)	Weight	0.68	0.022	0.407
	Moisture	0.80	0.076	0.350
	Wheels	0.85	0.232	0.336
	Silt	0.94	0.028	0.235
	Vehicle speed	0.96	0.187	0.212
	Silt loading	0.97	0.318	0.206
	Wind speed	0.97	0.794	0.235
				16.933
Graders (all uncontrolled)[b]	Silt loading	0.40	0.500	17.909
	Vehicle speed	0.63	0.471	18.614
	Wheels	0.96	0.226	9.144
				6.562
Light- and medium-duty vehicles (all uncontrolled)[c]	Moisture	0.97	0.000	1.741
	Weight	0.99	0.005	1.019
	Wheels	0.99	0.349	1.017
	Silt	0.99	0.681	1.093
	Silt loading	1.00	0.133	0.890
	Wind speed	1.00	0.202	0.749
				0.788
Haul trucks (includes uw. -dw. tests, all uncontrolled)	Vehicle speed	0.51	0.011	0.693
	Wind speed	0.72	0.003	0.573
	Moisture	0.89	0.000	0.390
	Silt loading	0.91	0.039	0.357
	Wheels	0.91	0.701	0.365
	Weight	0.92	0.318	0.364
	Silt	0.92	0.886	0.375

[a] This source was evaluated initially as a subset of the entire data set and was not carried through the subsequent data analyses.

[b] Weight, moisture, silt, and wind speed were rejected in the first MLR because of an insufficient tolerance level.

[c] Vehicle speed was rejected because of an insufficient tolerance level.

TABLE 13-3. CHANGES MADE IN MULTIPLE LINEAR REGRESSION RUNS (TSP)

Source	Change Made	Run No.	Reason
Drill	Remove two data points	2	Outliers
Blasting, all	Specify moisture as first variable	2	Moisture had R = 0.72 vs. variable area with R = 0.73
Coal loading, all	Eliminate bucket size, add control	2	Bucket size was to the 12.3 power
	Remove one data point	3	Outlier
Dozer, all	Remove one data point	2	Outlier
Dragline	Remove one data point	2	Outlier
Scraper	Drop wheels, moisture, and silt loading	2	Wheels did not vary appreciably, moisture and silt loading difficult to quantify
	Add moisture; remove anisokinetic runs; drop wind	2	Moisture needs to explain low emissions at mine. Four anisokinetic runs (low winds) eliminated
Graders	Drop wheels, weight, moisture, and silt loading	2	Wheels and weight did not vary appreciably, moisture and silt loading difficult to quantify
Light- and medium-duty vehicles			
Haul trucks	Drop wind speed, vehicle speed, anisokinetic runs	2	Three anisokinetic runs (low winds) eliminated, vehicle speed correlation inconsistent with previous studies
	Remove K-7 and L-1	3	Outlier and run unrepresented by vehicle mix

TABLE 13-4. RESULTS OF FINAL MULTIPLE LINEAR REGRESSION RUNS (TSP)

Source	Variable	Multiple R	Significance	Rel. Std. Dev.
				5.30
Drill	Silt	0.59	0.001	4.36
				0.515
Blasting, all	Moisture	0.72	0.001	0.367
	Depth	0.84	0.009	0.300
	Area	0.90	0.012	0.246
				0.341
Coal loading, all	Moisture	0.67	0.000	0.258
	Control	0.77	0.012	0.227
				0.774
Dozer, all	Material worked	0.67	0.000	0.587
	Moisture	0.93	0.000	0.298
	Silt	0.95	0.005	0.253
	Dozer speed	0.97	0.003	0.210
				0.389
Dragline	Drop distance	0.80	0.000	0.241
	Moisture	0.91	0.001	0.172
	Silt	0.93	0.043	0.153
				0.647
Scrapers	Silt	0.70	0.036	0.494
	Weight	0.93	0.006	0.271
	Vehicle speed	0.96	0. 111	0. 225
	Moisture	0.96	0.634	0.243
				2.013
Graders	Vehicle speed	0.83	0.022	1.237
	Wind speed	0.87	0.333	1.212
	Silt	0.90	0.451	1.252
				6.562
Light- and medium-duty vehicles	Moisture	0.97	0.000	1.741
	Weight	0.99	0.005	1.019
	Wheels	0.99	0.349	1.017
	Silt	0.99	0.681	1.093
	Silt loading	1.00	0.133	0.890
	Wind speed	1.00	0.202	0.749
				0.540
Haul trucks	Wheels	0.66	0.002	0.416
	Silt loading.	0.72	0.146	0.400
	Weight	0.80	0.036	0.355
	Silt	0.82	0.324	0.355
	Moisture	0.82	0.458	0.360

TABLE 13-5. RESULTS OF FIRST MULTIPLE LINEAR REGRESSION RUNS (IP)

Source	Variable (in order of MLR output)	Multiple R	Significance	Rel. Std. Dev.
Drill	N/A			9.54
				0.753
Blasting, all	Moisture	0.81	0.015	0.367
	Depth of holes	0.88	0.040	0.330
	Area blasted	0.92	0.000	0.451
	Wind speed	0.93	0.210	0.321
	No. of holes	0.94	0.225	0.312
	Material blasted	0.95	0.272	0.307
	Dist. to samplers	0.95	0.313	0.305
	Stability class	0.95	0.841	0.323
				0.933
Blasting, coal[a]	Moisture	0.86	0.000	0.490
	Areas blasted	0.91	0.050	0.421
	No. of holes	0.93	0.146	0.392
	Wind speed	0.94	0.202	0.373
	Dist. to samplers	0.96	0.248	0.360
	Stability class	0.96	0.489	0.373
				0.235
Coal loading, all	Moisture	0.49	0.017	0.210
	Control	0.66	0.017	0.185
	Equipment type	0.67	0.576	0.189
				1.569
Dozer, all	Material worked	0.71	0.000	1.132
	Moisture	0.91	0.000	0.683
	Silt	0.94	0.006	0.579
	Dozer speed	0.97	0.001	0.449
				0.682
Dozer, coal[a]	Moisture	0.91	0.000	0.291
	Silt	0.96	0.012	0.213
	Dozer speed	0.96	0.420	0.216
				8.262
Dozer, overburden[a]	Silt	0.77	0.004	5.550
	Moisture	0.85	0.071	4.830
	Dozer speed	0.87	0.290	4.756
				0.259
Dragline	Moisture	0.49	0.032	0.232
	Drop distance	0.69	0.015	0.197
	Silt.72	0.72	0.281	0.196
	Bucket size	0.73	0.582	0.200

[a] This source was evaluated initially as a subset of the entire data set and was not carried through the subsequent data analyses.

TABLE 13-5 (continued)

Source	Variable (in order of MLR output)	Multiple R	Significance	Rel. Std. Dev.
				0.987
Scrapers (all uncontrolled)	Weight	0.71	0.015	0.735
	Moisture	0.81	0.094	0.647
	Wheels	0.86	0.173	0.600
	Silt	0.93	0.058	0.469
	Vehicle speed	0.96	0.086	0.371
	Silt loading	0.98	0.238	0.341
	Wind speed	0.98	0.737	0.386
				0.906
Graders (all uncontrolled)	Silt	0.30	0.626	0.998
	Wheels	0.65	0.397	0.975
	Silt loading	0.87	0.442	0.883
				1.977
Light- and medium-duty vehicles (all uncontrolled)	Silt loading	0.97	0.000	0.526
	Silt	0.98	0.043	0.410
	Vehicle speed	0.99	0.010	0.243
	Wind speed	1.00	0.044	0.170
				1.991
Haul trucks (includes uw.-dw. tests, all uncontrolled)	Vehicle speed	0.40	0.046	1.861
	Wind speed	0.64	0.006	1.600
	Moisture	0.84	0.000	1.153
	Silt loading	0.84	0.695	1.177
	Wheels	0.84	0.754	1.205
	Weight	0.85	0.609	1.228
	Silt	0.85	0.724	1.259

[a] This source was evaluated initially as a subst of the entire data set and was not carried through the subsequent data analyses.

TABLE 13-6. CHANGES MADE IN MULTIPLE LINEAR REGRESSION RUNS (IP)

Source	Change Made	Run No.	Reason
Blasting, all	None		
Coal loading, all	None		
Dozer, all	Remove one data point	2	Outlier
Dragline	None		
Scrapers	Drop wheels, silt loading, wind speed; remove anisokinetic runs	2	Wheels did not vary appreciably, silt loading difficult to quantify; four anisokinetic runs (low winds) eliminated
Graders	Drop wheels, weight, moisture, and silt loading	2	Wheels and weight did not vary appreciably; moisture and silt loading difficult to quantify
Light- and medium-duty vehicles	None		
Haul trucks	Drop wind speed, vehicle speed; remove anisokinetic runs plus K-7 and L-1	2	Three anisokinetic runs (low winds) eliminated. Vehicle speed correlation inconsistent with previous studies. L-1 is outlier and K-7 had unrepresentative vehicle mix

TABLE 13-7. RESULTS OF FINAL MULTIPLE LINEAR REGRESSION RUNS (IP)

Source	Variable	Multiple R	Significance	Rel. Std. Dev.
				0.753
Blasting, all	Moisture	0.81	0.000	0.451
	Depth of holes	0.88	0.015	0.376
	Area blasted	0.92	0.040	0.330
				0.235
Coal loading, all	Moisture	0.49	0.017	0.210
	Control	0.66	0.017	0.185
				1.676
Dozer, all	Material worked	0.70	0.000	1.230
	Moisture	0.92	0.000	0.696
	Silt	0.95	0.006	0.583
	Dozer speed	0.98	0.000	0.405
				0.259
Dragline	Moisture	0.49	0.032	0.232
	Drop distance	0.69	0.015	0.197
				1.706
Scrapers	Silt	0.67	0.046	1.346
	Weight	0.90	0.015	0.856
	Vehicle speed	0.96	0.036	0.580
				3.439
Graders	Vehicle speed	0.70	0.078	2.680
	Wind speed	0.81	0.246	2.478
	Silt	0.89	0.254	2.220
				1.977
Light- and medium-duty vehicles	Moisture	0.95	0.000	0.667
	Weight	0.99	0.005	0.389
	Silt	0.99	0.084	0.321
	Vehicle speed	0.99	0.217	0.298
	Silt loading	1.00	0.161	0.253
	Wind speed	1.00	0.216	0.216
				1.043
Haul trucks	Wheels	0.65	0.003	0.816
	Weight	0.68	0.272	0.809
	Silt loading	0.72	0.198	0.790
	Silt	0.73	0.617	0.810
	Moisture	0.74	0.473	0.823

TABLE 13-8. PREDICTION EQUATIONS FOR MEDIAN EMISSION RATES

Source	Prediction Equations: TSP	Prediction Equations: IP	FP/TSP Ratios Median Value	Units
Drill	1.3	None[a]	None[a]	lb/hole
Blasting, all	$\frac{961\ A^{0.8}}{D^{1.8}\ M^{1.9}}$	$\frac{2550\ A^{0.6}}{D^{1.5}\ M^{2.3}}$	0.30	lb/blast
Coal loading	$1.16/M^{1.2}$	$0.119/M^{0.9}$	0.019	lb/ton
Dozer, all				
Coal	$78.4\ s^{1.2}/M^{1.3}$	$18.6\ s^{1.5}/M^{1.4}$	0.022	lb/in
Overburden	$5.7\ s^{1.2}/M^{1.3}$	$1.0\ s^{1.5}/M^{1.4}$	0.105	1b/h
Dragline	$0.0021\ d^{1.1}/M^{0.3}$	$0.0021\ d^{0.7}/M^{0.3}$	0.017	$1b/yd^3$
Scrapers	$(2.7x10^{-5})s^{1.3}W^{2.4}$	$(6.2x10^{-6})s^{1.4}W^{2.5}$	0.026	1b/VMT
Graders	$0.040\ S^{2.5}$	$0.051\ S^{2.0}$	0.031	1b/VMT
Light- and medium-duty vehicles	$5.79/M^{4.0}$	$3.72/M^{4.3}$	0. 040	lb/VMT
Haul trucks	$0.0067\ w^{3.4}L^{0.2}$	$0.0051\ w^{3.5}$	0.017	1b/VMT

a Test method allowed for measurement of TSP only.

s = silt content, %
A = area blasted, ft^2
D = depth of holes, ft
M = moisture content, %
d = drop distance, ft
W = vehicle weight, tons
S = vehicle speed, mph
w = number of wheels
L = silt loading, g/m^2

TABLE 13-9. TYPICAL VALUES FOR CORRECTION FACTORS

Source	Correction Factor	GM[a]	Range[b] Min.	Max.	Units
Blasting	Moisture	17.2	7.2	38	Percent
	Depth	25.9	20	135	Ft
	Area	18,885	1076	103,334	Ft^2
Coal loading	Moisture	17.8	6.6	38	Percent
Dozers, coal	Moisture	10.4	4.0	22.0	Percent
	Silt	8.6	6.0	11. 3	Percent
ovb.	Moisture	7.9	2.2	16.8	Percent
	Silt	6.9	3.8	15.1	Percent
Draglines	Drop distance	28.1	5	100	Ft
	Moisture	3.2	0.2	16.3	Percent
Scrapers	Silt	16.4	7.2	25.2	Percent
	Weight	53.8	36	70	Tons
Graders	Speed	7.1	5.0	11. 8	mph
Light- and medium-duty vehicles	Moisture	1.2	0.9	1.7	Percent
Haul trucks	Wheels	8.1	6.1	10.0	Number
	Silt loading	40.8	3.8	254.0	g/m^2

[a] GM = antilog,$\{\overline{\text{ln (correction factor)}}\}$that is, the antilog of the average of the in of the correction factors.
[b] Range is defined by minimum (Min.) and maximum (Max.) values of observed correction factors.

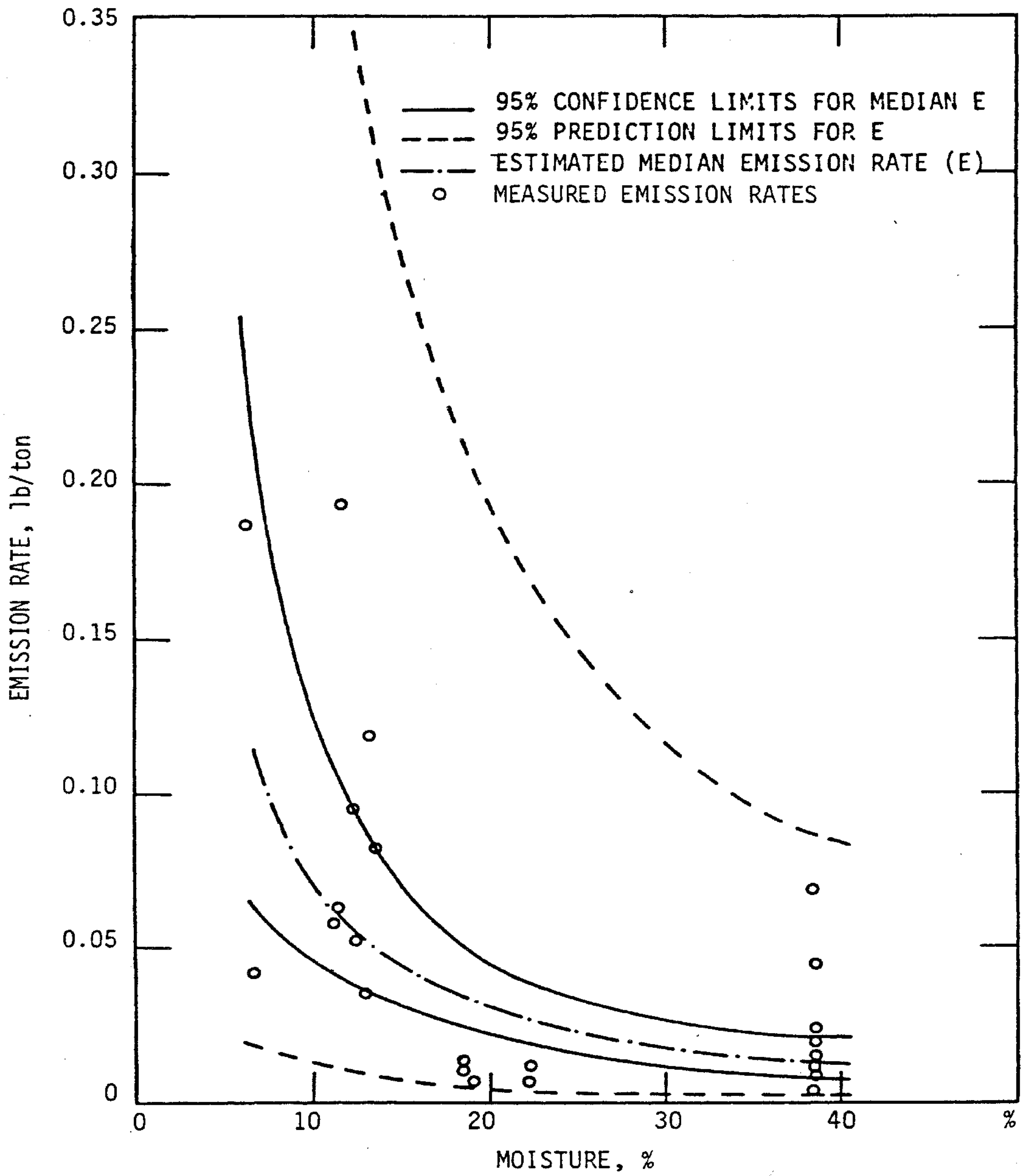


Figure 13-1. Confidence and prediction intervals for emission factors for coal loading.

TABLE 13-10. EMISSION FACTORS, CONFIDENCE AND PREDICTION INTERVALS

Source	TSP/IP	Emission factor,[a] median value	Units	95% Confidence Internal for Median		95% Prediction Interval for Emission Factor	
				LCL[b]	UCL[b]	LPL	UPL
Drills	TSP	1.3	lb/hole	0.8	2.0	0.1	12.7
Blasting, all	TSP	35.4	1b/b1ast	22.7	55.3	5.1	245.8
	IP	13.2		8.5	20.7	2.0	87.9
Coal loading, all	TSP	0.034	lb/ton	0.023	0.049	0.005	0.215
	IP	0.008		0.005	0.013	0.001	0.071
Dozers, all	TSP	46.0	lb/h	35.5	59.6	18.1	117.0
coal	IP	20.0		13.2	30.4	4.5	90.2
ovb.	TSP	3.7	1b/h	2.6	5.3	0.91	15.1
	IP	0.88		0.59	1.3	0.21	3.7
Draglines	TSP	0.059	lb/yd^3	0.046	0.075	0.020	0.170
	IP	0.013		0.009	0.020	0.002	0.085
Lt.- and med-duty vehicles	TSP	2.9	lb/VMT	2.3	3.9	1.35	6.4
	IP	1.8		1.6	2.0	0.64	5.0
Graders	TSP	5.7	lb/VMT	3.2	9.9	1.14	28.0
	IP	2.7		1.4	5.3	0.39	18.5
Scrapers	TSP	13.2	lb/VMT	10.0	17.7	5.2	33.1
	IP	6.0		4.3	8.9	1.8	20.2
Haul trucks	TSP	17.4	1b/VMT	12.8	23.4	4.3	68.2
	IP	8.2		5.7	11.0	1.8	33.7

[a] These exact values from the MLR output are slightly different than can be obtained from the equations in Table 13-8 and the correction factor values in Table 13-9 due to the rounding of the exponents to one decimal place.

[b] LCL denotes lower confidence limit. UCL denotes upper confidence limit.

TABLE 13-11. CALCULATED EROSION POTENTIAL VERSUS WIND SPEED

			SP Erosion Potential, lb/acre				
Surface	**Mine**	**Test Series**	**26 mph**	**29 mph**	**32 mph**	**35 mph**	**38 mph**
Coal							
Area surrounding pile	1	J-26	> 140[b]			470[b]	
		J-26 and 27					
On pile, uncrusted	2	K-45 and 46		230			
		K-40 and 41			480		550[b]
		K-39					370
		K-42 and 43					
On pile, lightly crusted tracks[c]	3	P-20	68[b]				
		P-31 and 32	30	140	260		
		P-20 to 22			130[b]		
		P-20 to 24					
		P-31 to 35					
On pile furrow	3	P-27 and 28				70	
		P-27 to 30					90
Overburden	2	K-35 and 36				90	
		K-37				40[b]	
Scoria (roadbed material)	2	K-49 and 50				100	

[a]Wind speed measured at a height of 15 cm above the eroding surface.
[b]Estimated value.
[c]Erosion loss may have occurred prior to testing.

TABLE 13-12. SURFACE AND EMISSION CHARACTERISTICS

Surface	Mine	Roughness height, cm	Threshold speed, mph	IP/SP Ratio
Coal				
Area surrounding pile	1	0.01	21	0.62
On pile, uncrusted	2	0.3	25	0.68
On pile, lightly crusted tracks	3	0.06	20	0.55
On pile furrow	3	0.05	33	0.60
Overburden	2	0.3	23	0.68
Scoria	2	0.3	30	0.75

TABLE 13-13. HYPOTHETICAL MONTHLY WIND DATA PRESENTED IN LCD FORMAT

	Wind					
	Resultant		Avg. Speed, mph	Fastest Mile		
Month	**Direction**	**Speed, mph**		**Speed, mph**	**Direction**	**Date**
January	21	0.5	7.8	32	NW	17
February	27	2.2	9.2	34	NW	23
March	27	1.9	10.9	47	N	11
April	04	0.3	8.7	38	S	10
May	17	3.9	10.8	37	SW	18
June	16	2.3	8.9	35	N	26
July	16	1.0	7.9	35	SW	9
August	13	1.4	7.5	31	W	30
September	20	1.9	9.0	45	NW	23
October	17	1.1	7.5	37	NW	7
November	22	0.7	9.2	34	W	26
December	28	2.4	9.1	41	W	24

APPENDIX A

STEPWISE MULTIPLE LINEAR REGRESSION

Multiple linear regression (MLR) is a statistical technique for estimating expected values of a dependent variable, in this case particulate emission rates, in terms of corresponding values of two or more other (independent) variables. MLR uses the method of least squares to determine a linear prediction equation from a set of simultaneously-obtained data points for all the variables. The equation is of the form:

$$\text{Emission rate } B_1x_1 + B_2x_2 + B_nx_n + \ldots + B_nx_n + \text{constant}$$

where x_1 to x_n = concurrent quantitative values for each of the independent variables

B_1 to B_n = corresponding coefficients

The coefficients are estimates of the rate of change in emission rates produced by each variable. They can be determined easily by use of an MLR computer program or with a programmed calculator. Other outputs of the MLR program are:

1. A correlation matrix. It gives the simple correlation coefficients of all of the variables (dependent and independent) with one another. It is useful for identifying two interdependent (highly correlated—either positive or negative) variables (two variables that produce the same effect on emission rates), one of which should be eliminated from the analysis.
2. The multiple correlation coefficient (after addition of each independent variable to the equation). The square of the multiple correlation coefficient is the fraction of total variance in emission rates that is accounted for by the variables in the equation at that point.
3. Residual coefficient of variability. This is the standard deviation of the emission rates predicted by the equation (with the sample data set) divided by the mean of the predicted emission rates, expressed as a percent. If a variable eliminates some sample variance, it will reduce the standard deviation and hence the relative coefficient of variability.
4. Significance of regression as a whole. This value is calculated from an F test by comparing the variance accounted for by the regression equation to the residual variance. A 0.05 significance level is a 1 in 20 chance of the correlation being due to random occurrence.
5. Significance of each variable. This is a measure of whether the coefficient (B) is different than 0, or that the relationship with the dependent variable is due to random occurrence. Variables that do not meet a prespecified significance level may be eliminated from the equation.

6. Constant in the equation.

The multiple correlation coefficient, unlike the simple correlation coefficient, is always positive and varies from 0 to 1.0. A value of zero indicates no correlation and 1.0 means that all sample points lie precisely on the regression plane. Because of random fluctuations in field data and inability to identify all the factors affecting emission rates, the multiple coefficient is almost never zero even when there is no real correlation and never 1.0 even when concentrations track known variables very closely. Therefore, it is important to test for statistical significance .

The form of MLR in the program used in this study was stepwise MLR. Variables were added to the equation in order of greatest increase in the multiple correlation coefficient, with concentrations then adjusted for that variable and regressed against the remaining variables again. The procedure can be ended by specifying a maximum number of variables or a minimum F value in the significance test. In subsequent runs, the order of entry of variables was sometimes altered by specifying that a certain variable be entered first or last.

In order to satisfy the requirement that the variables be quantitative, some were input as dummy variables with only two possible values. For example, in an MLR run of all blasts, one variable had a value of 0 for all coal blasts and 1 for all overburden blasts. The significance of this variable determined whether there was a significant difference between coal and overburden blast emission rates, and the B value was a direct measure of the difference between the two average emission rates after adjustment for other variables in the MLR equation.

A statistically significant regression relationship between independent variables and particulate emission rates is no indication that the independent variables cause the observed changes in emission rate, as both may be caused by a neglected third variable.

APPENDIX B

CALCULATIONS FOR CONFIDENCE AND PREDICTION INTERVALS

The computational procedures for confidence and prediction intervals for emission rates are illustrated in this appendix using TSP emission rates for coal loading as a function of moisture content (M). The data are tabulated in Table B-1 for convenience, that is, the moisture, %, and the observed emission rate, lb/ton, for each of the 24 tests. The arithmetic average ($\bar{x}$), standard deviation (s), and geometric mean (GM) are given at the bottom of the table.

Confidence Interval

The computational procedure for confidence intervals is as follows:

1. The first step in the analysis is to perform a linear regression analysis. In this example, the dependent variable is the logarithm of the emission rate (ln E) and the independent variable is the logarithm of moisture (ln M). (Natural logarithms, i.e., to base e are used throughout this discussion).
2. The prediction equation for the mean of ln E is given by:

$$\ln^{\wedge}E = b_o + b_1 (\ln M - \overline{\ln M}) \qquad \text{(B-1)}$$

where:

$\ln^{\wedge}E$ is the predicted mean for ln E as a function of M

b_o, b_1 are the regression coefficients estimated from the data

ln M is the ln of moisture content

$\overline{\ln M}$ is the arithmetic average of ln M

($\overline{\ln M}$ = 2.882 for this example)

3. The following results are obtained from the MLR (multiple linear regression) computer printout for subsequent use in computation.

   The prediction equation is:

$$\ln^{\wedge}E - 3.385 - 1.227 (\ln M - 2.882)$$

Note: Almost all computer printouts give the prediction equation in the form:

$$\hat{\ln E} - 0.152 - 1.227 \ln M \qquad \text{(B-2)}$$

that is, the constants are combined into one term (0.152 = -3.385 + 1.227 x 2.882). The form provided above in Equation B-1 is simpler for the computation of the confidence and prediction intervals. In the above form b_o is the average of the ln E (ln E), which is available in the printout.

In addition, one obtains:

$r^2 = 0.451$ (the square of the correlation coefficient)

$s^2 = 0.764$, $s = 0.874$ (the standard deviation of the logarithm of the observed emission rates about the corresponding predicted ln values).

The variances of the estimated regressions coefficients are read or computed from data listed in the computer printout:

$$s_o^2 = \text{estimated variance of } b_o = \frac{s^2}{n}$$

$$s_o^2 = \frac{0.764}{24} = 0.0318$$

$$s_1^2 = \text{estimated variance of } b_1$$

$$= (0.2523)^2 = 0.0637$$

The value of s_1^2 can be computed by formulas given in Hald.[1] In this case $s_1 = 0.2523$ is given in the computer printout for the purpose of testing the significance of the estimated coefficient b_1.

4. The standard deviation of ln E is:

$$s\,(\hat{\ln E}) = [s_o^2 + s_1^2\,(\ln M - \ln M)^2]^{1/2} \qquad \text{(B-4)}$$

$$= [0.0318 + 0.0637\,(\ln M - 2.882)^2]^{1/2} \qquad \text{(B-5)}$$

5. The geometric mean of the emission factor E is given by:

$$\exp\,\{\hat{\ln E}\} \qquad \text{(B-6)}$$

and this estimates the median value of E as a function of M. It should be noted that the mean value of E is estimated by:

$$\exp\,\{\hat{\ln E} + \tfrac{1}{2}\,s^2\} \qquad \text{(B-7)}$$

Throughout the remainder of this discussion the GM values are used as estimates of the corresponding median emission value.

6. The confidence interval for the median value of E as a function of M is obtained by:

$$\exp\ \{\ln\hat{E} \pm t\ s(\ln\hat{E})\} \qquad \text{(B-8)}$$

where $\ln\hat{E}$ and $s(\ln\hat{E})$ are obtained from Equations B-2 and B-4, respectively, and t is read for the desired confidence level from a standard t table available in almost any statistical test (e.g., Hald's tables[2]). Substituting values of M in Equation (B-8) (and B-2 and B-4) yields the results plotted in Figure 13-1 and repeated here for convenience as Figure B-1. One must not go beyond the limits for observed M because there are no data or theory to support the extrapolation.

The 95 percent confidence limits for the median E at the GM of M (i.e., exp {2.882} = 17.85%) are:

$$\exp\ \{\ln\hat{E} \pm 2.074\ s(\ln\hat{E})\} \qquad \text{(B-8)}$$

where

$$\ln\hat{E} = -3.385$$

$$s(\ln\hat{E}) = [0.0318 + 0.0637(0)]^{1/2} = 0.178$$

and the upper (UCL) and lower (LCL) 95 percent confidence limits are:

$$95\%\ \text{Limits}\begin{cases}\text{UCL} = 0.049\ \text{lb/ton}\\ \text{LCL} = 0.023\ \text{lb/ton}\end{cases}$$

Similarly, the 80 percent confidence limits are given by:

$$\exp\ \{\ln\hat{E} \pm 1.321\ s(\ln\hat{E})\}$$

or

$$80\%\ \text{Limits}\begin{cases}\text{UCL} = 0.043\ \text{lb/ton}\\ \text{LCL} = 0.027\ \text{lb/ton}\end{cases}$$

The median value is:

$$\exp\ \{\ln\hat{E}\} = 0.0339$$

The above confidence limits are also expressed below as percentages of the predicted median, 0.0339.

$$95\%\ \text{Limits}\begin{cases}\text{UCL} = 1.45 \times \text{predicated median} \\ \text{LCL} = 0.68 \times \text{predicted median}\end{cases}$$

$$80\%\ \text{Limits}\begin{cases}\text{UCL} = 1.27 \times \text{predicted median} \\ \text{LCL} = 0.80 \times \text{predicted median}\end{cases}$$

These limits are a measure of the quality of the prediction of the median emission E for given M on the basis of the data from the three mines. The widths of these confidence intervals are consistent with data typically reported by EPA as stated in Section 15.

One application of these limits would be to estimate the median annual emissions based on a large number of tons of coal loaded at the mine with GM moisture content of 17.85 percent. If the moisture content deviates from this value (17.85%), it is necessary to calculate the interval at the appropriate value of M using Equation (B-8) .

Because of the complication in presenting the complete results for all sources and pollutants as in Figure B-1, the confidence intervals are presented only for the correction factors (M in this example) at their GM value. Table 13-10 contains these data for all sources and pollutants.

<u>Prediction Interval</u>

The confidence interval previously described gives a measure of the quality of the data and of the predicted median which is applicable only for a large number of operations relative to the emission factor of interest. In the example in this appendix, this would imply a large number of coal loading operations (or tonnage of coal loaded). There will be applications in which the number of operations is not large and a prediction interval is desired which is expressed as a function of the number of operations. The calculation of this interval follows the first three steps of that for the confidence interval; the subsequent steps, starting with Step 4, are as follows:

4. The standard deviation of an individual predicted In emission factor is:

$$s\ (\ln\ E) = [s^2(\ln \hat{E}) + s^2]^{1/2}$$

$$= [\frac{s^2}{n} + s_1^2\ (\ln\ M - \overline{\ln\ M})^2 + s^2]^{1/2} \qquad \text{(B-9)}$$

For the coal loading data,

$$s\ (\ln E) = [0.0318 + 0.0637\ (\ln M - 2.882)^2 + 0.764]^{1/2} \qquad \text{(B-10)}$$

5. The prediction interval for an emission factor E is

$$\exp\ \{\ln^{\wedge}E \pm t\ s(\ln E)\}$$

For the coal loading data, this interval is given by:

$$\exp\ \{\ln^{\wedge}E \pm t[0.0318 + 0.0637\ (\ln M - 2.882)^2 + 0.764]^{1/2}\} \qquad \text{(B-11)}$$

The results are plotted in Figure B-1 as a function of M. For the GM of M (i.e., ln M = 2.882), the prediction limits are:

$$95\%\ \text{Limits}\{\begin{matrix}\text{UPL} = 0.215\ \text{lb/ton} \\ \text{LPL} = 0.005\ \text{lb/ton}\end{matrix}$$

$$80\%\ \text{Limits}\{\begin{matrix}\text{UPL} = 0.110\ \text{lb/ton} \\ \text{LPL} = 0.010\ \text{lb/ton}\end{matrix}$$

6. The prediction interval for an individual value is obviously much wider than the corresponding confidence interval for a median value. If it is desired to predict the emissions based on a number of operations, say N (e.g., N tons of coal), the confidence interval is given by

$$\exp\{\ln^{\wedge}E \pm t\ [s^2\ (\ln E) + \frac{s^2}{N}]^{1/2}\} \qquad \text{(B-12)}$$

that is, the last term in Equation B-9 is divided by N instead of 1. Note that as N becomes large this result simplifies to that of Equation (B-8).

Test for Normality

One of the major assumptions in the calculations of the confidence and prediction intervals is that the ln residuals (deviations of the ln E from ln E) are normally distributed, hence the lognormality assumption for the original (and transformed data). A check for normality was performed on the ln residuals for six data sets with the largest number of data values. In two of the six cases the data deviated from normality (these two cases were TSP and IP emissions for Blasting). Based on these results, the lognormal assumption was made because of both computational convenience and adequate approximation for most of the data.

REFERENCES

1. Hald, A. Statistical Theory with Engineering Applications. John Wiley and Sons, Inc. New York. 1952.

2. Hald, A. Statistical Tables and Formulas. John Wiley and Sons, Inc. New York. 1952.

TABLE B-1. TSP EMISSION RATES FOR COAL LOADING, LB/TON

Test Number	Moisture, %	Observed Emission, lb/ton
1	22	0.0069
2	22	0.0100
3	38	0.0440
4	38	0.0680
5	38	0.0147
6	38	0.0134
7	38	0.0099
8	38	0.0228
9	38	0.0206
10	38	0.0065
11	11.9	0.1200
12	11.9	0 0820
13	11.9	0.0510
14	18	0.0105
15	18	0.0087
16	18	0.0140
17	12.2	0.0350
18	11.1	0.0620
19	11.1	0.0580
20	11.1	0.1930
21	11.1	0.0950
22	6.6	0.0420
23	6.6	0.3580
24	6.6	0.1880
$\bar{x}$	21.42	0.0639
s	12.64	0.0819
GM	17.85	0.0337

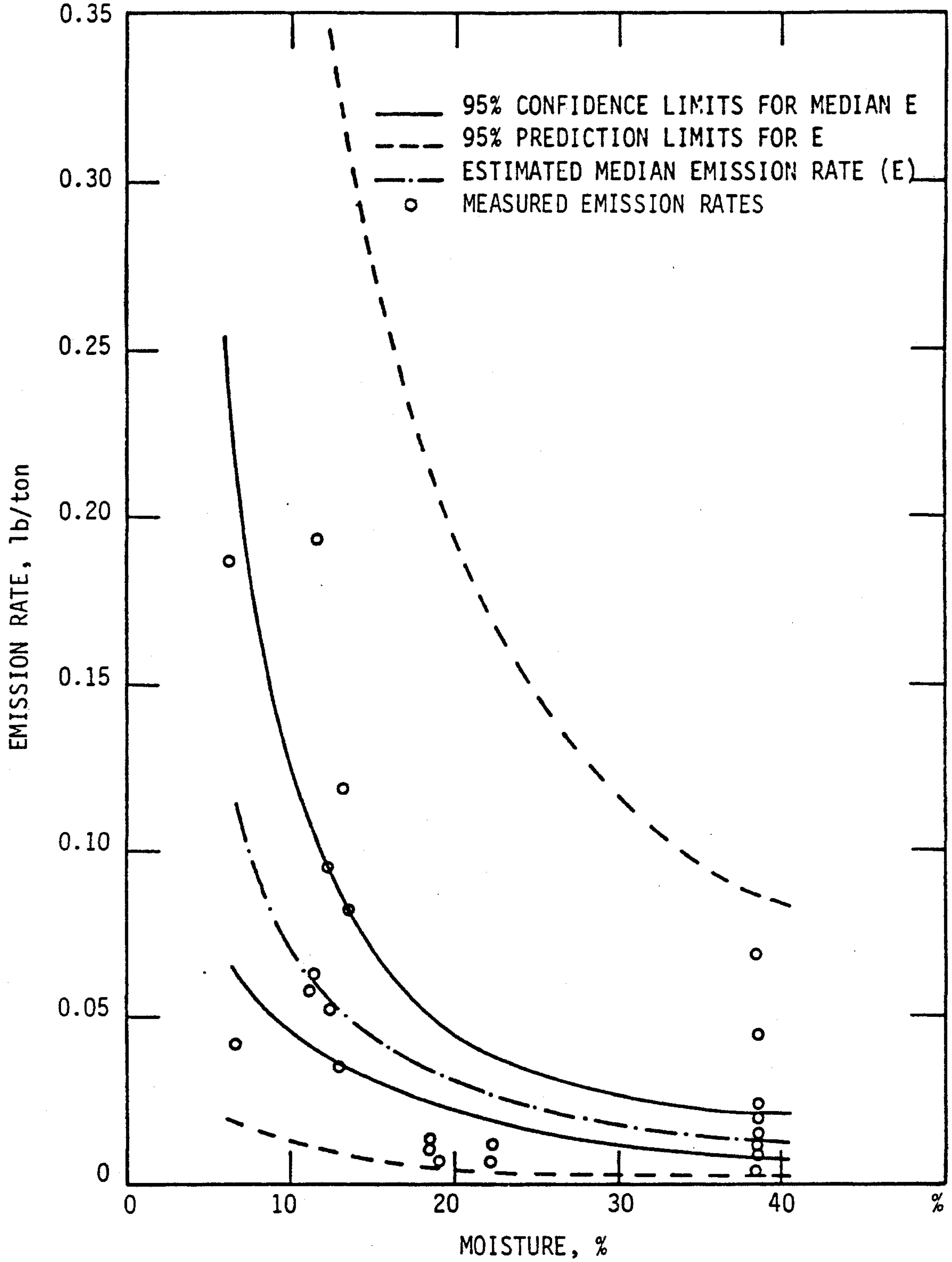


Figure B-1. Confidence and prediction intervals for emission factors for coal loading.